Scenario study for Flood Hazard Assessment in the lower Bicol Floodplain Philippine using A 2D Flood model

Based on the 1988 flood event caused by typhoon Yonning

A case study for flood hazard assessment WP 4500 SLARIM an ITC research project in Strengthening local authority in risk management.

Student Jennifer Adhiambo Otieno
March 2004

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By

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

NATURAL HAZARDS

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Abstract

In the frameworks of the ITC Projects (SLARIM) Strengthening Local Authorities in Risk Management, a case study was carried out on hazard assessment on Lower Bicol floodplain. The floodplain is located in four provinces in the Philippines. It is an area frequented by Typhoons accompanied with floods. This study was carried out in collaboration with Naga City Municipality, the Philippines, In order to assist the Local authorities in the flood management. 2D flood model Delft-FLS was used to reconstruct one of the flood events caused by the Typhoon Yonning. The Model parameters were the DEM of the floodplain, the DEM of the riverbed, the floodplain and riverbed roughness, and the artificial structures. The model hydrological boundaries were the discharges at the upstream and the tidal fluctuations at the Bay. The model results were compared with water depth information, obtained from the local people, during the fieldwork that was carried out in September 2003 and previous Reports. Then several Scenarios were constructed to simulate other flood events. A methodology was then developed to transform the modelled results into hazard indicators. It was finally concluded the 2D modelling approach is useful for reconstruction of past events. The model results suggest that the flood parameters water depth and flow velocity are not very sensitive to variations in surface roughness. However physical barriers, like embankments so affect flooding significantly.

Acknowledgments

The research related to this thesis and the writing process benefited from many people around the globe. Although words are not enough they appear weak and insufficient considering the contributions and strong support, nevertheless, I would like to express my sincere gratitude. First and fore most I thank the SLARIM ITC project (Strengthening Local Authorities in Risk Management), under the co-ordination of Dr. van Westen for giving me the chance to carry out my research in the Philippines the support he gave ensuring the fieldwork was done at the appropriate time and making all the right connections in Philippines for the fieldwork contributed a lot in making the whole fieldwork successful.

I thank my supervisors Drs D. Alkema and Drs N. C. Kingma, who patiently and tirelessly worked with me through out the challenging moments of the thesis, Mr. Gabriel Parodi for his guidance during the tiring hours of fieldwork his able knowledge in data collection went along way in helping build the gaps in data collection in the field. Their wisdom has been a constant challenge to my work, and their positive view when encountering problems gave me confidence and their being at my side at all times has encouraged me and made the work a success.

I thank the Government of Kenya for awarding me the scholarship to undertake this programme and ITC for giving me a chance in the EREG programme and Maseno University Geography department for giving me study leave.

Furthermore I thank the programme Director Dr. Paul van Dijk and the rest of the EREG staff for their encouragement and support whenever the outside pressure was high and there was so much to be done in such little time.

Data availability has been a key issue in this research. Thanks to the generous offers of transport from the office of the Mayor Naga city, the Mayor Mr. J. Robredo's personal attention was most welcome Mr. Ernesto Elcamel who was available most time to visit the offices with us, arrange for the necessary transport, his personal participation is most appreciated. Mrs Arlene Dayao gave her time and all the necessary support I needed during fieldwork especially in getting data from various ministries in Legapi thank you. Mr. Racadag for being my help in the field without whom the data collection on flooding would not have succeeded his knowledge of the local language made the interviews more complete.

Finally I thank my colleagues EREG 2002/2004, the colleagues in the field Vajira, Tennakon and Cruz whom many times were an encouragement during the many hours we spent together, the ITC Christian fellowships who prayed together with me and encouraged me, the Kenya community at ITC 2002-2004, 2004-2005 thank you very much.

To my family, Jacob, Lydia, Stella, Esther, Carry and Mercy My mother Margaret, brothers and sisters God bless you all.

THE LORD GOD ALMIGHTY WHO HAS SO FAITHFULLY BEEN MY SHEPHERD AND LIGHT

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Abbreviations

AIT:	Asia Institute of Technology
BRBFCIDP:	Bicol River Basin Flood Control Irrigation and Development Project
BRBIDP	Bicol River Irrigation Development Project
DEM:	Digital elevation model
FCIDP:	Flood control and Irrigation Development Project
Hec-RAS:	Hydrologic Engineering Centre –River analysis systems
IDNDR:	International decade for Natural Disaster Reduction
NCDP:	Naga City Development project
NEDA:	National Economic and Development authority
NIA:	National Irrigation Administration
NAMRIA:	National Mapping and Resource Information Authority
PAGASA:	Philippine Atmospheric Geophysics and astronomical services
RBMP:	River Basin Management Planning
SLRATP:	Soils and Land Resources Appraisal and Training Project
	Tippets-Abbet-MacCarthy-Stratton

Chapter 1

Introduction

1.1. Introduction

Humanity has interacted with the natural environment for as long as he has occupied the planet Earth. The environments dynamic nature cannot be ignored and the necessity of the natural resources cannot be over-emphasized. It is important to share space. As this interaction between humanity and the environment has increased so has the susceptibility to the hazards. Neither hazards nor resources are absolute they result from a relationship.
Natural hazards have been viewed as the detrimental consequences of peoples' use of their environment; beneficial outcomes of environmental use are labelled natural resources (Penning-Rowsell et.al 1996). It occurs that sometimes in the effort of the human to take full advantage of benefits and opportunities, the hazard is intensified. Hazard is an ever-present feature of everyday life requiring adaptive responses from individuals and society. Therefore it is of utmost importance to understand these adaptive responses, as the mismanagement of hazards would lead to serious accidents and disasters. It is important to interact and also to derive means and ways of limiting it effects.
The year 1990 was declared the International Decade for Natural Disaster Reduction (IDNDR). Several work groups were developed and special attention given to promoting worldwide initiatives in natural disaster mitigation and hence reduction. Despite the decade-long efforts of United Nations towards natural disaster reduction through its program, no reduction in losses from these hazards has been realized. This is mainly due to the facts that with the increase of population and urbanization, natural hazards are becoming increasingly catastrophic. Therefore there is a need to understand and assess the hazards and to develop means of hazard and disaster management

1.1.1. The Philippines and the Natural hazards

Hazards and disasters are a frequent occurrence in the Philippines. Its physical environment makes it vulnerable to typhoons, storm surges, floods, draughts earthquakes, tsunamis, volcanic eruptions and landslides. The major causes of disasters are typhoons and floods because of their frequency and the magnitude of their impact on society and the national economy. They seriously disrupt the agriculture – based economy (Brown et al, 1991). This area experiences the world's highest frequencies of tropical cyclones averaging 20 per year. 13% of these visit the Bicol region where the study area is located (AIT, 1975). The cyclones move at high wind speeds between 17m/s when it is a tropical depression and greater than 32m/s when it is a typhoon the highest speed ever recorded in Philippines was 77.2m/s (278km/hr) which occurred during the typhoon Senning October 13 – 14 1970 (BRBFCIDP) these winds are the main causes of enormous looses to life and heavy damage to property due to flooding.

1.1.2. Flooding

Flooding is becoming increasingly a major contributor to personal and to property damage worldwide and in many places strikes without warning. Increasing population pressure and economic activities has led to the development of extensive infrastructures near the rivers. These economic activities and changing land use increase the risk of future inundations (NCDP, 2002). The changing climate behaviour of extreme rainfall, typhoon and hurricane contribute extensively to this problem. Problems related to flooding have greatly increased and there is need for effective modelling and understanding of the problem to help mitigate the worst effects of flood disasters and the need for development of a system to understand the threatened areas. The understanding of flooding will help in flood hazard assessment and in giving insights to various ways of dealing with the hazard and disaster problems.

1.2. Definition

1.2.1. Hazard

Hazard refers to the probability of a potentially dangerous phenomenon occurring in a given location within a specified period of time (Alexander, 1993). Hazards include geophysical events, hydro meteorological phenomena, and technological circumstances that relate to accidents or failures in industrial, military and energy generation activities. While some hazards can be considered to be exclusively natural in origin, the spatial and temporal patterns of hazard occurrence are increasingly correlated with patterns of human behaviour and relationship with their natural environment. Human practices such as the alteration of natural drainage, the creation of landfills, or the destruction of the natural environments and increased groundwater extraction may radically alter the pattern of the hazard behaviour (IDNDR, 1997). Results of human habitation such as unplanned rapid urban development, uncontrolled logging of the natural forests or major changes in land use can influence the spatial and temporal pattern of the hazards.

1.2.2. Flood hazard assessment

Once a potential hazard has been identified, it is important to know its characteristics. The assessment of these characteristics requires a lot of historic data and in most rivers sufficient observations are not available. Therefore to determine these values recourse must be made to some sort of predictive model. The reliable prediction of the hydrodynamics of flooding events forms an indispensable basis to fulfil this (Stelling et al, 1998). Models are required where the characteristics and accuracy of the boundary conditions and the input data determine the outcome of the computations. Such models show the effects of different boundary conditions or input data on the results. Hence in flood hazard by looking at different inputs we can determine the behaviour of the hazard at given instances of a period of time. These results lead into better decision making in the management of the hazards and disasters.

1.2.3. Flood hazard Mitigation

Mitigation is the process under which different bodies try to reduce the current and the future vulnerability of our communities to natural hazards. Mitigation measures can be structural where the hazard is modified for example dam and reservoir construction, channel improvements, by-pass channels and artificial levees. Non-structural where the flood damage and disruption is modified for example setting up flood plain management regulations such as zoning, building codes and measures where both the methods are applied. The promotion of mitigation planning where a community or a country capitalizes on the opportunities available to ensure a safe and responsible development and the integration of mitigation principles into decision making processes of local governments is important

1.3. Study area

1.3.1. Bicol flood plain

The Bicol river flood plain is located along the eastern hemisphere typhoon belt. Its location causes it to experience several typhoons some accompanied by heavy rainfall and floods. The population has been increasing rapidly, causing a rapid urban growth and drastically changing the physical landscape. The reduction of the natural watershed due to logging has resulted in unimpeded down flow of water. The denudation of Mt. Isarog, the current incapacity of Bicol River to efficiently absorb storms and the blocking of the natural waterways and creeks due to silting have greatly contributed to the major problem of flooding in the Bicol floodplain.

1.3.2. Location of the study area

The flood basin lies in the provinces of Camarines Sur, Camarines Norte, the upper part of Albany and the whole of Catanduanes. It consists of 1 major river basin 10 minor river basins, covering an area of approximately 3,155.7 square kilometres as determined from the digitized delineation of he Bicol river basin from 1:50 000m scale. NAMRIA maps from River Basin and water management program (RBMP). The basin has an influence area of 10,058 square kilometres including the watersheds. It lies between 13°0 to 14°0N and 123°0 and 124°0 E. It is extensively a coastal flood plain.

The Bicol River starts from Lake Bato flowing through the alluvial plains to the coastal plain. The river starts at a height of 6m with a total length of 94 kilometres and a slope of 0.006% (SLRATP, 1976)

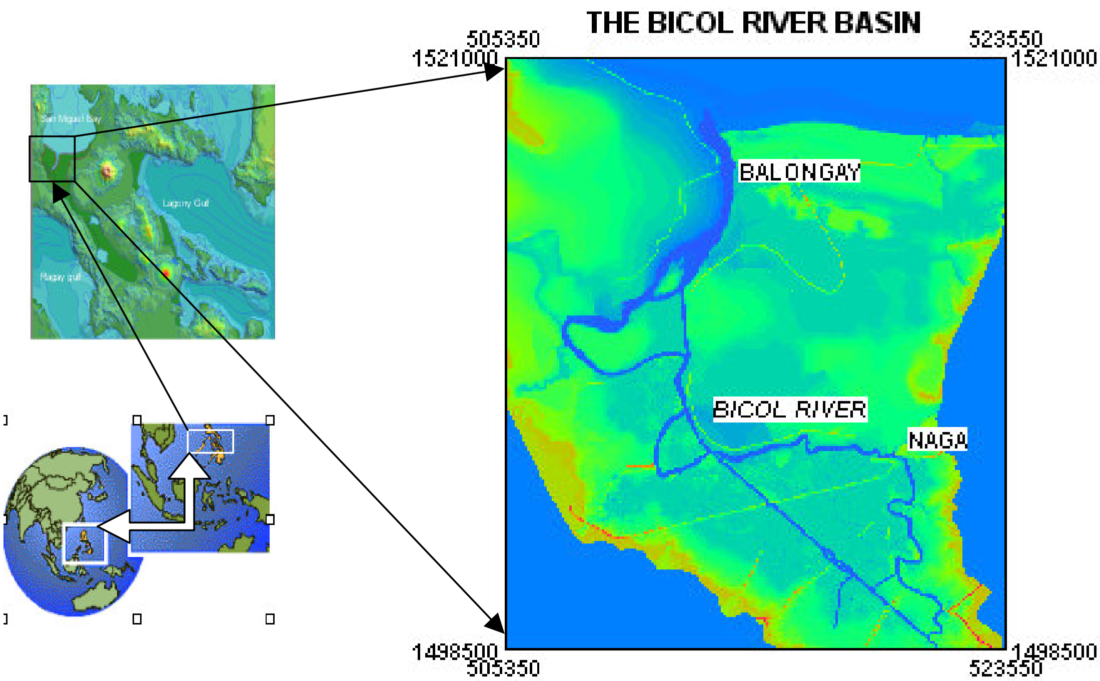

Figure.1 - 1 Location of the Lower Bicol River flood Plain

1.4. Description of the Problem

The flood plain has been experiencing increasing frequency in flooding, increase in extent of the Inundated area and increase in the duration of inundation (NCDMP, 2000) since 1950 to date several projects have been (AIT, 1975; TAMS, 1976; BRBFCIDP, 1991) undertaken to try and alleviate flooding situation without much success. Several mitigation measures have been put in place, measures like constructing three cut-off channels along the Bicol to reduce the river meandering, the setting up of embankments along the flood susceptible areas like the Naga-Calabanga embankment and the Cabusao area embankment and gates and sluices set up at strategic places along the channels to try and address the problem. All this effort has not relieved the area instead flooding has continued to cause continuous large economical looses and damage to infrastructure, residential and agriculture. It is therefore necessary to have a clearer understanding of its behaviour to be able to effectively develop methods and ways of addressing disaster and hazard management. Finally urbanization has taken its toll as more and more people move into this area rapid population growths increase the risk of future inundations.

1.5. Justification

Flood hazard assessment in the Bicol floodplain has been carried out in several different ways (BRFCIDP, 1991), this has not controlled the hazard instead it has increased. The need for a better understanding of the characteristics of the flooding is of utmost requirement. The increasing population and the fast disappearing forest in the upper catchments (NCDP, 2002) calls for the local authorities in the basin, to address the problem differently. 2D modelling as a new technique used in understanding the problems has a great potential in contributing toward the solution of this hazard, its spatial capabilities and the easy of its application in using raster format can enhance the capability of these local authorities in understanding and dealing the problem

1.6. Hypothesis

The failure to minimise the flooding occurrence in the Bicol floodplain has caused the application of different methods in approaching the problem. The detailed understanding of the behaviour of water over the surface is vital. To improve the understanding the use 2D models that require the reconstruction of the topography and the riverbed in detail elaborately give information about the water movement on the surface and the riverbed. The capability of

using scenarios in these models improves the understanding and addressing of the problem. The impacts of clearing of the natural land cover and over logging are areas that need re-addressing, the use of the roughness coefficient in 2D modelling increases the capability of these models in hadling such parameters. Delft –FLS 2D model with the video capability of interactively viewing the scenarios enables the Naga city and the outlying towns who are constantly under the threat of flooding to share the impact of setting up structures and depleting of the forest to flooding. The capabilities will allow the approach to be used in flood hazard assessment and sound disasters management

1.7. Research Questions

1. Can 2D model be used for flood hazard assessment?
2. Can 2D mode be used to accurately reproduce the observed historic floods?
3. To what extent does the assumed land cove roughness value affect the model prediction?
4. Which areas are likely to be inundated, at what depth and when?

1.8. Objectives

1.8.1. To assess flood hazard using a 2D flood propagation Model for some historic floods

1.8.2. Specific Objectives

- To develop a detailed digital elevation model of the lower Bicol flood plain;
- To derive a land-use map from remote sensing interpretation and fieldwork;
- To define surface roughness of the map using Manning's co-efficient values;
- To define flood hazard in terms of spatial extent, flood-depth, flow velocity and propagation of flood in time;
- To compare the model results with existing historic flood information.

1.9. Methodology

The characterization of floods in flood hazard assessment creates a clear understanding of the flood plain, and gives the understanding of the hazard behaviour. During characterization the hazard is not only described by its extent but by the depth of the water that has flooded the area, the depth of the water indicates the features in the topography that can be affected. The speed at which this water is moving over the surface is an important indicator of how fast this water reaches various destinations, if we can determine when the water will be at a given
location within the area then we are able to make better judgements on how to deal with the hazard when it strikes. By understanding the depth of the water and the speed under which it is moving we can easily determine the energy this water has, this energy indicates how much destruction it can do.

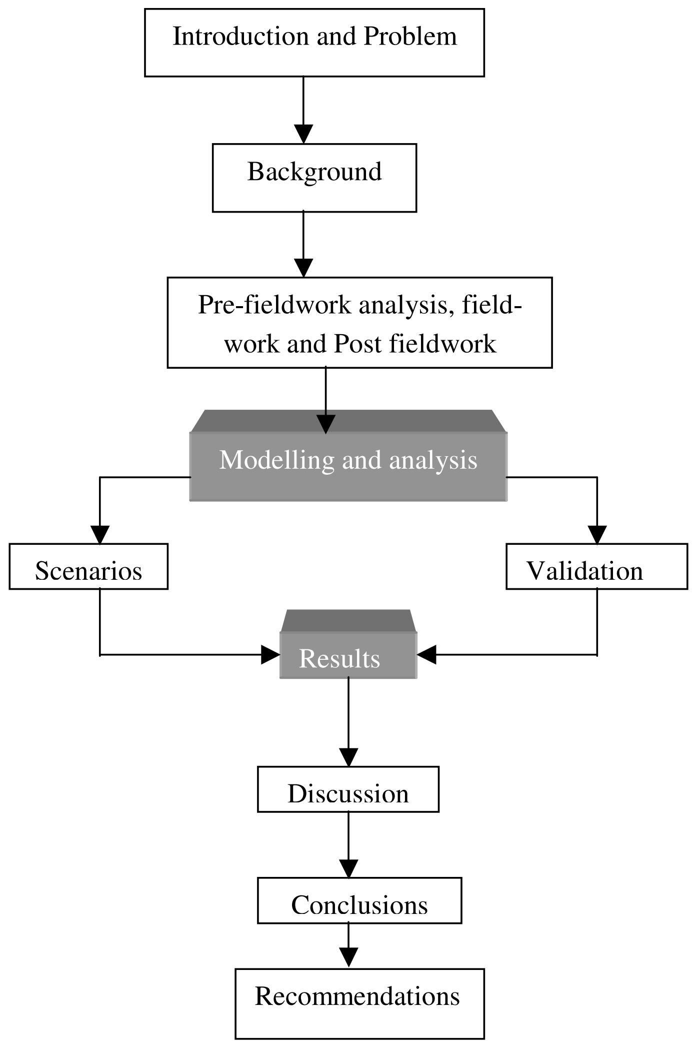

Figure: 1.2 Flow chart of the methodology

1.10. Limitations of the study

- Due to security reasons during the fieldwork the area covering cabusao was not visited and hence ground truthing was not done and the flood levels from the people could not be obtained. The only impression of the area was from the opposite side of the Bicol River and interviews with people on the other side who came from this area;

- The data collected for digitial elevation model (DEM) construction was not of the same accuracy as some areas the topographical maps obtained were at 1:4000 and others 1:50 000

- The data on tides was not complete so the creation of the harmonic behavior of the tide had to be done with data that was available and not very accurate.

Chapter 2

2. Background

2.1. Introduction

Several contributing factors to flooding problem have been identified (AIT, 1975), (TAMS/TAE, 1976), (BRBDP, 1983), (FCIDP, 1992), ranging from the topography, the geo-morphology, the morphology, sediment-load of the river, the tidal fluctuations, irrigation and drainage, flood alleviation and engineering structures, and climate. These factors affect the behaviour of water; and the understanding of their role and contribution helps in the hazard assessment

2.2. Geology and geomorphology

The Bicol River is bounded on the northeast by the Bicol Cordillera, which consists of a chain of volcanic mountains including Iriaga, Isarog, Malinao, Masaraga and Mayon. On the south-western side lie the Ragay Hills, which consist of folded and faulted sedimentary formations including limestones, siltstones, conglomerates, and shales. In between these higher areas lies the Bicol plain where the study area is located comprising of thick alluvial deposits consisting of sand silt and clay.

The main geo-morphological features found in the area include the estuarine plain, the river flood plain the piedmont plain and the valleys of incised creeks. The estuarine plain is level to nearly level and consists of fine fluvial-marine deposits over sandy layers with marine shells. The fluvial marine deposits are usually saline at depths of approximately 1 meter and includes depressed areas along the Bicol River. The river floodplain is made up of mixed alluvium is the focus of the study area and the piedmont plain on the fringe of the Ragay hills consists of fine alluvium clay and reworked colluviums.

2.3. Climate

This climate is influenced by Northeast Monsoon winds and the Pacific trade winds. These Monsoon winds create the low-pressure area in the pacific resulting in tropical cyclones that affects the area in November and December (SLREP, 1987; RBMP, 2003)

Rainfall occurs throughout the year with low rainfall between January to May and high rainfall between June and December. In the lower basin mean annual rainfall ranges between 1850-2300mm. The main factors influencing rainfall are the air streams, the inter-tropical convergence zone and the topography. Rainfall intensity is influenced by duration (RIDF, 1992; FCID, 2003).

The mean temperatures are high through out the year with the daily mean temperatures in the range of 24.1℃ to 28.1℃ and an annual mean of 27ºC (RBMP, 2003).
The average diurnal temperature range is about 7.5º0c the hottest months are between May and June. January and December experience highest mean annual relative humidly of 80%-90%. The annual potential evaporation observed is 1226 mm, the lowest being 75mm Observed in the month of November and the highest of 135mm in the month of April.

2.4. Wind Speeds

Wind speeds are generally high during typhoons, for example in the year 1985 to 1993 the lowest speed during the typhoons was 18kmph typhoon Ditang and the highest 173kph typhoon Monang. The maximum wind speed during typhoon Yoninig in 1988 that was reconstructed in the study was 158Kph, which was comparatively high. It is important to note that winds do affect storm surges causing an increase in flooding (GHA, 2002)

2.5 Typhoon recurrence

In the tropical typhoon recurrence interval study carried out the result shows that one particular cyclone does not have one specific recurrence interval; the recurrence intervals are unique at specific locations along the rivers The knowledge of the recurrence interval is important in flood hazard assessment as the difference of the return period are influenced by the distribution of rainfall over the basin during the cyclone and by the wind speeds. It is important to note that this gives the basis of comparison of the behaviour of the floods at every return period (BRBFCIDP, 1991).

2.6 River flows

River flow data gives the basic parameters in any flooding study showing how much water is discharged at given points along the river. In October 1988 the year of the flood Yonning the mean peak discharges on Bicol River at Nabua the closest station to the upper boundary in the basin was123m^3/sec and 205m^3/s in November showing an increase of 85m^3/s. This Discharge is high as the monthly average discharges at this station at the normal time is below 50 cm^3 which indicates a large influx into the river giving a clear indication of a flooding condition.

2.7 Land use

The assessment of flood hazard for management must look into how land-cover/land-use has been altered, as the impacts of these alterations, will be seen in the behaviour of water. The land cover is generally agricultural with paddy rice. Most of the rice is under irrigation. Pockets of coconut plantations exit at the peripheries of the rice fields. These rice fields are continuously under water, making the area to be saturated even before the on set of floods. The farming practices of canals in the field and poor drainage systems due to low relief encourages flooding. From the field observation there is indiscriminate development of urban centres and roads changing the previous land coves of grass into networks of paved roads, which enhance the movement of water into the lower areas.

2.8 Tides

In an area bordering open sea the understanding of the tidal behaviour is important. Bicol river drains into San Miguel bay and the tides influence the behaviour of floods. Tides influence flood by the varying nature. If a flood sets when the tides are high the levels raise much faster. Storms land falling during peak astronomical tides have higher surge heights and more extensive flood inundation than when the land falling is in the low tides. In this area Tidal variations exited between observed and predicted values due to the influence of wind stress, and the tidal statistics for at the San Miguel bay where Balongay is located did not show considerable variance from year to year (BRBFCIDP, 1991).

Chapter 3

3. Data

The research was accomplished in three faces

- Pre-Fieldwork
- Field work
- Post Fieldwork

3.1 Pre-Fieldwork

3.1.1. Data Available Before fieldwork

	DATA	Source	Year
1	Topographical map 1:50 000 Libmanan sheet and Naga city sheet	Naga city office of the Mayor	-
2	Report on Naga city	ITC	-
3	Report	ITC	-
4	Landsat image spatial resolution 30m	ITC	09/2001 10/2001
5	Aster image15m spatial resolution	ITC	
6	KVR image 1m spatial resolution Russian satellite	Naga city office of the mayor	

3.1.2. Data Available After fieldwork

	Data	Source	Year
1	Topographical maps at 1:4000	National Economic and development Authority (NEDA);	
2	River cross-sections at 1:2000 channels (Bicol river from San Miguel to Bato, cutoff channel 1, 2 and 3, and libmannan rive, and sipocot river)	NEDA	
3	Geological map	Philippine Atmospheric, Geophysical and Astronomical Services Administra-tion (PAGASA);	
4	Land use Map	National mapping and Resource Infor-mation Authority (NAMRIA)	
5	Reports Bicol River Basin flood control and irrigation development	NEDA	
6	Reports rainfall	PAGASA	
7	Reports land management	NAMRIA	
8	Reports Typhoons	PAGASA	
9	Reports geology of the area		
10	Roads and Embankments	Public works	

3.1.3. Literature review

At the onset of the fieldwork the literature that was available on the study area were few reports on the flood situation and the measures that have been taken to try and alleviate the problem. Due to limited information at the beginning it was decided to try and model the area as a data scarce environment. After the fieldwork this changed as there was substantial work carried out in the area and the literature was available for reference.

3.1.4. Preliminary analysis of existing data

The data that was used during the preliminary analysis was 1:50,000 map (Libmana sheet, and Naga sheet) covering the whole flood plain this was used to identify and delineate the boundary of the study area and for preliminary understanding of the topography of the area and some of drainage features. The initial 1m interval contours were digitised from this map; this was later changed, as the data from the field was at larger scale of 1:4000 more accurate.

3.1.5. Preliminary interpretation of land cover

The preliminary land cover interpretation was done using the acquired remote sensing images. The TM image and Aster were fused to form one image a sample set made and the classified. The land covers classification done according to Corrine land cover classification. It was printed out at a large-scale ready for field verification. The KVR image which was at a higher spatial resolution was geo-referenced and printed at 1:10 000 scale with grid values to be used with the fused Aster and TM image for field reference

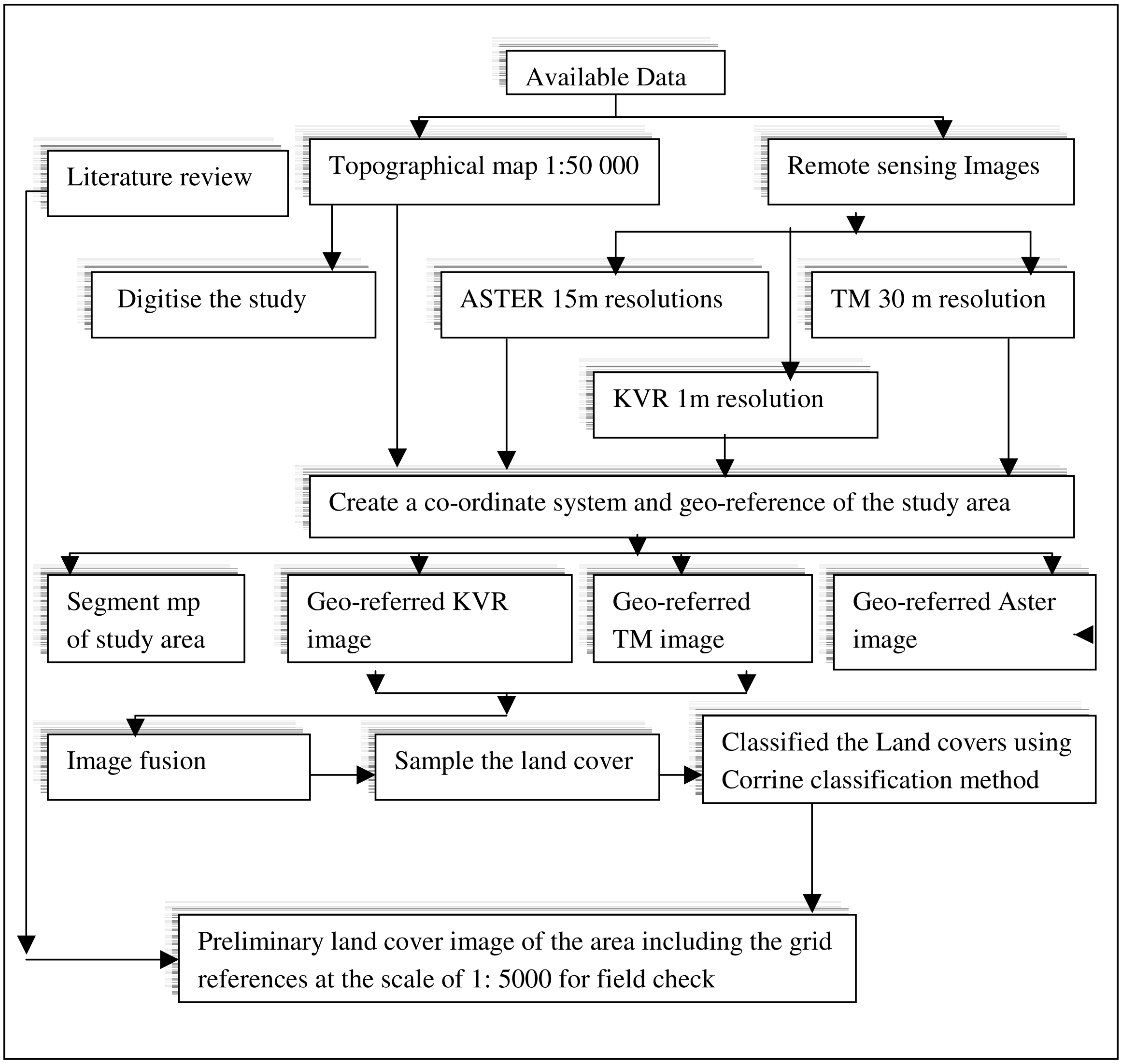

Figure: 3.1 Flow Diagram of the Pre-field preliminary interpretation of land cover

After the preliminary analysis of the available data and the identification of the data gaps the fieldwork was divided into three sections.

The collection of data for the construction of the DEM which included locating topographical maps at larger scales of than 1:50 000 map with detailed contour intervals

The collection of hydrological data with information on Q/h relation (discharge in relation to water level), typhoons, rainfall, river cross-sections, water levels available

Verifying the of information on land cover from the analysis carried out and field observations and collection of information on the past floods

3.2 Field work (22/08/03-15/09/03)

3.2.1 Data for DEM construction

Detailed Topographical maps made in 1991 by a consultant at 1:4000 with detailed information on contours (contours at 0.25m interval) were collected from NEDA and NAMRIA. And information on the river cross sections were also available at 1:2000

3.2.2 Hydrological data

The data on water stage, water level and discharge relation (Q/H) were more difficult to come by, as most of the available data was not continuous. Information on the water level in the main rivers, creeks and canals was measured using a tape and the height of the topography was also approximated these measurements were taken at points along the main roads since most of the fields were not very accessible due to the rice fields. These were then entered in a table to be used during analysis. See appendix-1 1for the full *table*

3.2.3 Historic flood data

The data on historic floods was collected by interviewing people at different towns in the study area; the people were interviewed using stand question format on the last major flood he/she remembered the name of that particular flood, the height of the water during that flood and the year that flood occurred. Mostly the elderly were approached as they had a better memory of the past floods. The information was entered in a table. See appendix-2

3.2.4 Field verification of the land cover (ground truthing)

Using the remote sensing image, with the preliminary analysis of the different land covers, digital camera and GPS the various land cover were verified. The identification of the point on the map was done with help of the GPS and map co-ordinates. Those that had not been correctly identified were changed; the digital camera was used to take photographs to use for further identification and analysis. The information and the location where the photographs were taken were entered in table

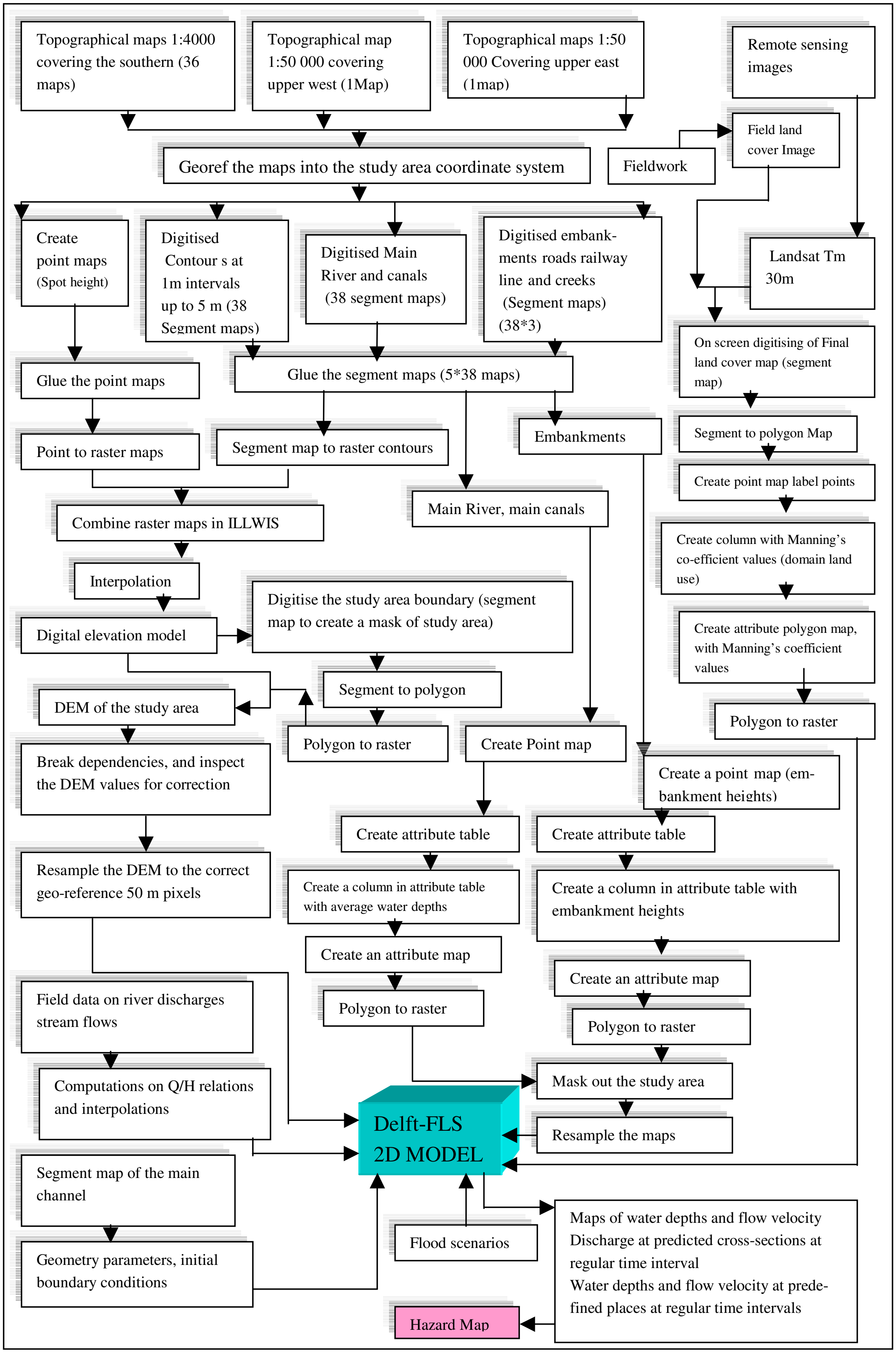

Figure 3.2:Flow diagram of the methodology of the post fieldwork

3.3 Post fieldwork

3.3.1 Construction of the DEM of the flood plain

The data used for the construction of the DEM was 1:4000 topographical maps with contours at 0.25m interval and 1:50 000m topographical maps with contours at 1m interval. The lack of data covering the whole area made the use of maps at 1:50 000m inevitable. The DEM was constructed by digitising contour lines at 1meter interval from 1m to 5m, which was the focus and extent of the study area. The scanned topographical maps were geo-referred and the contours digitised from 38 scanned topographical maps; these segment maps were then glued together. To improve the accuracy of fitting the segment maps the root mean error was kept to less than 0.9. This was not possible with the fitting of the 1:50 000 maps and a lot of adjustments had to be done to accurately fit the maps.

To improve the accuracy of the DEM a point map was created, from 1:4000 topographical maps and 1:50 000 maps as the maps had spot heights that had been accurately surveyed. The point map and the segment map were combined and interpolated in ILWIS to create the DEM of the flood plain.

3.3.2 Construction of the DEM of the river bed

The data used for the construction of the riverbed DEM were scanned 1: 4000 and 1:50 000 topographical maps with the river cross-sections 1:2000. The riverbed (Bicol) and all the other main water features (cut-off channel 1, cut-off channel 2 and cut-off channel 3) were digitised from the geo-referenced scanned topographical maps created during DEM of the floodplain construction see section 3.3.1. The digitised segment maps were glued together; the segment map was transformed to polygon, using the label points created. An attribute table was created and linked to the polygon map in the attribute table a column was created with average depths of the riverbed and the main channel beds, an attribute map created using a column created in the attribute table, which had average depths of the riverbeds. The map was transformed from polygon to raster.

3.3.3 Digitising the embankments

The embankments were identified and digitised as they appeared on the 1:4000 and 1:50 000 scanned topographical maps the segment maps were then glued together, and a point map created with a unique identifier. An attribute table was created linked to the segment map. A column showing the actual height of the embankment at different distances was created in the table. Using the column showing the embankment heights an attribute map was generated. The new map was then changed from polygon to raster. The information on embankment heights was from a report on flood alleviation and river engineering volume five from the BRBFCDP project, which carried actual measurements of the embankments and gave a report on their status. See appendix 14 for the embankment heights.

3.3.4 Construction of the final DEM

The DEM of the flood plain, the DEM of the riverbed and the embankments were all combined in ILWIS using the IFF command. First the flood plain DEM was combined with the riverbed; the values were the inspected to see if there were any irregular values that needed adjustment, especially checking if any values created unnecessary high area that would prevent water flow, these values were adjusted. The embankments were added to the DEM and the values inspected for any irregular values and the alignment of the pixels were inspected for gaps and misrepresentation. The values were manually adjusted. The alignment of the pixels in the channel and the embankments were carefully inspected. The study area was then masked out from the combined DEM re-sampled to the 50m pixels for the model input.

3.3.5 Development of the land cover map

The land cover map was developed TM image with 30m resolutions of September 2001 was used to make the final map; the classification was done by visual interpretation of the image, using ground truth information, obtained during fieldwork. Units of uniform land-cover were digitised onscreen and classified according to the Corrine classification method.
(See figure 3.3)

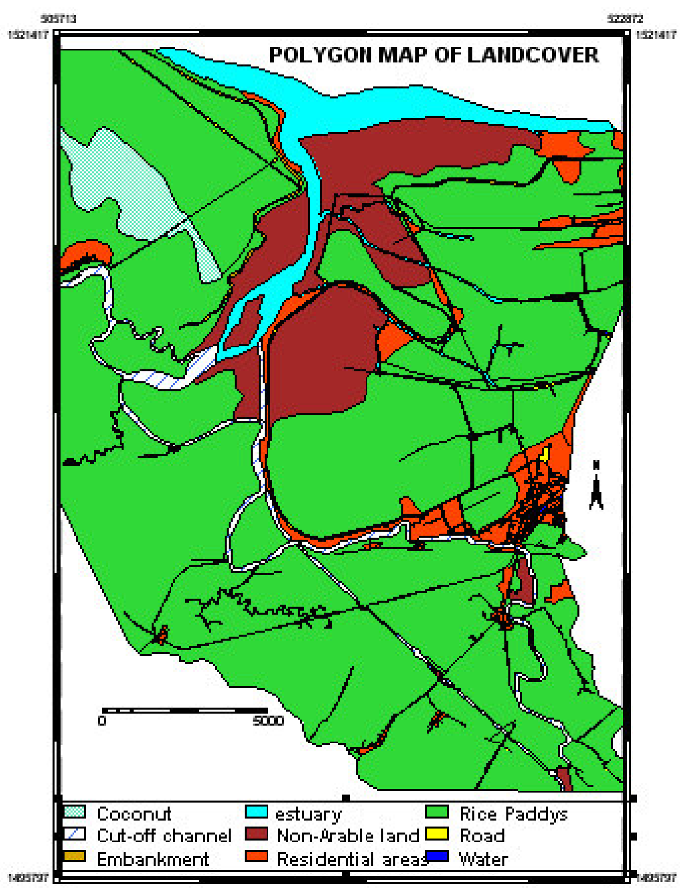

Figure 3.3 Land cover according to Corrine classification

3.4 Hydrological Data

The data that was used for the hydrological analysis was derived from pervious studies in the region and from data from the meteorological stations. Two types of data were derived.
One data set was of the input hydrograph discharge on the upstream boundary and the other was on the tidal fluctuations down stream

3.4.1 Model boundaries

The river discharge values for the typhoon Yoning were used. This typhoon started from Typhoon Usang on 21^{st} to 26^{th} of October 1998 and continued to Typoon Yoning from 5^{th} to 9th of November. The discharges were calculated by using the rating curves that were developed for Ombao, see figure 3.4 (BRBFCIDP, 1991). The hydrograph showed both the water levels and the discharges during the two typhoons. The actual water levels during the typhoons were also available from PAGASA. The hourly calculations for the discharges during typhoon Yonning were done using the rating curve with the water levels observed during the typhoons at Ombao station. The rating curve used was
Q=7.536*(H-0.50)^2.491

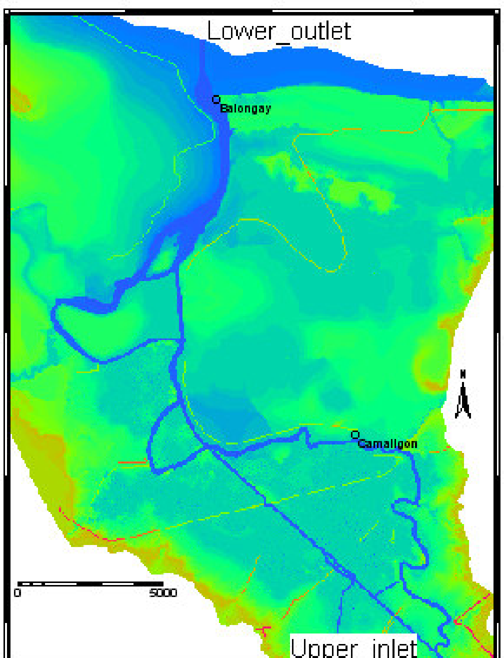

Figure 3.4: The boundaries used in the flood plain
See Appendix 11 for the calculation of the water levels from the rating curve formulae at ombao

3.5 Definition of the grid size and computer run time

The grid size for the DEM was decided at 50m-pixel size because of the size of the study area. The area has 130081 active pixels and 34981 inactive considering the computer run time this takes approximately 5days for 1000hrs. The computational time step was set by the model and was (±10 – 25sec) model was 6hourly

Chapter 4

4. Modelling and Analysis

4.1. Introduction

Modelling in the flood basin has been done to try and alleviate the flooding problem by identify the causes and contributing to the possible management tools. In 1975 AIT used node and branch method, with the Manning's coefficients between 0.0195 and 0.035. In 1976 TAMS-TAE, used Latis a mathematical model to try and improve the results by AIT by using the Manning's coefficient values from 0.037 to 0.028. In 1991 The BRBFCIDP using Mike-11 model used Manning's coefficient values between 0.025 to 0.040 for the main channel and 0.2 for the flood plain. In all these modelling only the BRBFCIDP 1991 produced a flood hazard map of the flood plain showing the return periods extents of 1.25 years, 5year 10 and 25 years. These models offered some solutions in identifying some of the causes of the problems. This created a need to try and look further into different types of applications that could approach the problem differently and create tools that could be used for further management. Models with capabilities of reconstructing flooding situations have been used to approach such problems (Alkema, 2002)

The reliable reconstruction of the past floods and the assessment of the hazard using modelling is a process that depends on the model capabilities. Models that simulate hydrological fluxes in lowland river catchments can be vital tools for hazard assessment and disaster management if they can be used for the characterization of hazard and in understanding of the catchments. The spatial variability of flooding needs a model that can give results that are accurate and replicable (Alkema, 2003). The ability to use raster format is necessary as most of the data is worked in raster formart. 2D models have the capability of giving replicable results and use raster format (Horritt et al, 2002). Models such as MIKE 21; Telemac-2D,
LISFLOOD-FP, SOBEK, Delft-FLS etc. are available and can be used but Delft-Fls was selected because its development was focused on research, its capability to tackle flow over initially dry land and complex topography is very important as the area of study is in the flood plain where the topography with little variation needs special attention. Its special design in simulating riverine floods will contribute in helping analyse this area as it within a river basin. Its capability to accurately describe the basin fill will help in describing the water propagation within the river and the flood plain. Its capability to compute on rectangular grids and to describe input data such as dykes, roads, railroads and water in different ways enabling them to be included in the analysis, is useful in the analysis of the influences of flood propagation due to the location of the structures (Alkema, 2003).

4.1.1. Flood hazard assessment in Bicol

Modelling one of the past severe floods Yoning and Usang that occurred between October 21st 1988 and November 9th 1988 continuously (the sooner the first flood stopped then the next flood began) was done over lowland flood plain topography with man-made obstacles of the Bicol river basin and was used to simulate the characteristics of the influence of structures and roughness of the terrain on floods. The changes in the landscape were then used to determine the flood hazard behaviour. A systematic scenario was modelled of these two floods over a period of 1000 hrs. The first 642 hrs was the actual time the flood lasted then allowed to recede in the last 350 hrs to its original level. The model then generated at regular intervals maps of water height, flow velocity maximum water level; maximum flow velocity. These were then transformed to indicator maps of, maximum impulse (amount of flowing water) maximum speed of the rising water level and the arrival time of the first floodwaters. These indicator maps were used to describe the various characteristics of the flood event.

4.2. Model requirements

4.2.1. Model input data

Detailed digital terrain model (DTM);
Inflow discharge hydrograph;
Initial estimate of the channel flow depth;
Channel and flood plain friction;

4.2.2. Model output

Maps of water depths and flow velocity at regular time intervals;
Discharge through predefined cross-sections at regular time intervals;
Water depth and flow velocity at predefined stations at regular time intervals;
A video show to visualize the flooding;

4.3. Data used in the Model for Bicol Basin

Data requirement	Source	Value
Raster digital elevation model	Topographical maps 1:4000 and 1:50 000	50m pixel size developed in ILWIS with active cells=130081 and inactive =34981
Inflow discharge hydrograph	Derived from BRFCIDP1991results	29 days flood event with peak discharge of approximately 990m³
Channel slope	Constructed DEM	
Channel width	Constructed DEM	
Bank-full depth	Constructed DEM	
Initial channel flow depth	Constructed DEM	
Channel and flood plain friction	Adapted from BRFCIDP	

Table 4.1: Data sources and parameters used in the application of Delft-FLS on Bicol flood plain analysis

4.4. Digital Elevation Model (DEM) of the Floodplain

The DEM was developed from 50m-pixel size; the computer run time was 5 days (1000hr). Due to the size of the basin and the available time it was not possible to try other pixel, sizes. The flood plain was constructed from digitising contours at 1m intervals from scanned topographical maps at 1:4000 scale covering the southern part of the map see figure: 4.1 and 1:50 000 scale covering the northern see figure: 4.2 part of the map. The accuracy of the DEM was improved by further by digitising 4347 spot heights covering the whole area and combining with the contours to create the final DEM for the floodplain. (Figure 4.3)

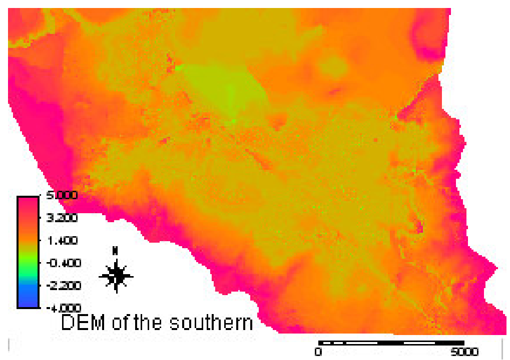

Figure: 4.1 DEM of the southern part of the flood plain

This Dem covered the southern part that had more accurate data with very good geo-referencing error of less than 0.7 of a pixel.

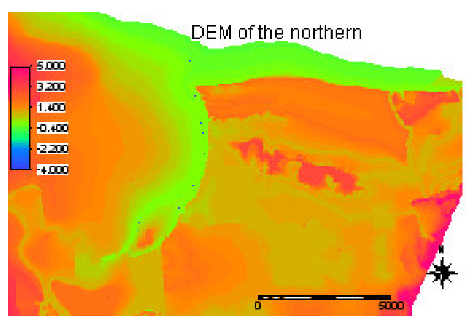

Figure: 4.2 DEM of the Northern part of the floodplain

This part of the DEM covers the southern part that had less detailed data and the geo-referencing error of more than 2 pixels.

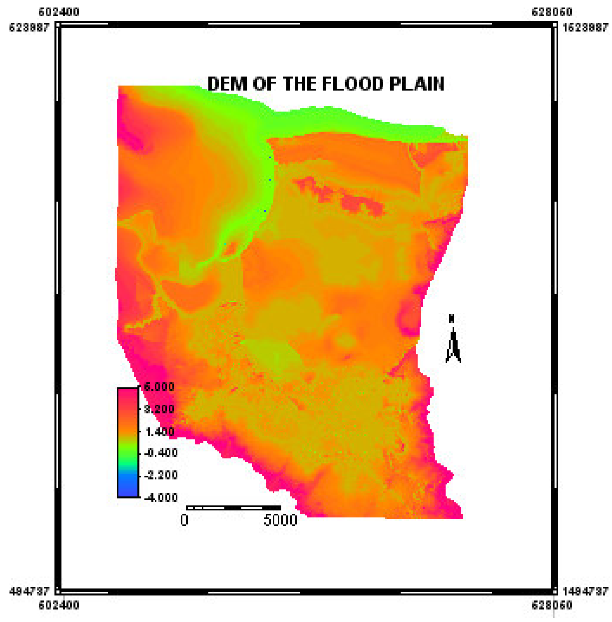

Figure 4.3 :The DEM of the floodplain

The DEM of the total floodplain had the errors reduced due to the final model pixel size of 50m reducing the error in the northern part that had an error of two pixels considering that the error of 2pixels would be accommodated in the 50m pixel size.

4.5. The DEM of the riverbed (The hydrological networks)

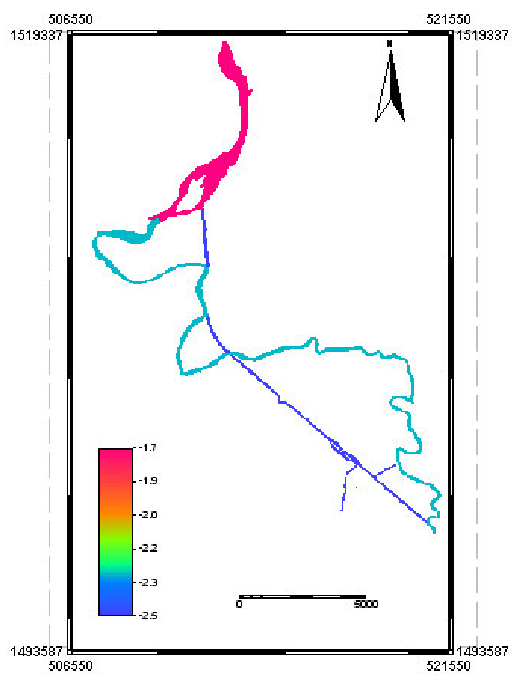

Figure 4.4: The DEM of the riverbed

The DEM was constructed using average depths though the actual detailed depths are available this was due to the time constraint. The river channels were located at the correct in the locations

4.5.1. The pixel alignment in hydrological networks

In Delft –FLS the river channels should be defined Cleary for the model to be able to be able to identify the flood plain from the other features, as the alignment of the cells plays an important role in the flow of water from cell to cell. These features are divided in two types the barriers and the hydrological network. The hydrological networks are features where water flows through such features as the main river channels and the cut-off channels. Their alignment in the model is different in that the pixels that define water channels should be aligned as in figure (Figure.4.5a) where they are side by side, and not as in figure 4.5b where there is a gap giving no continuity to the water flow.

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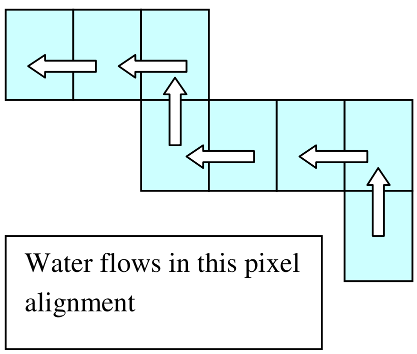


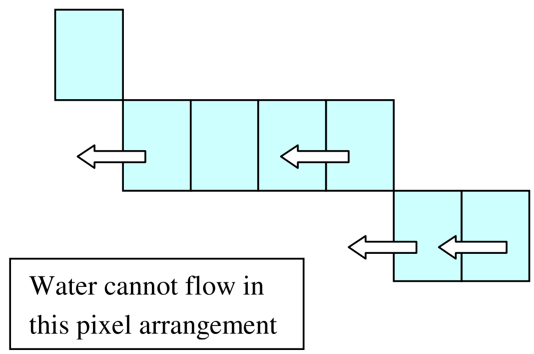


Figure 4.5a: Pixel alignment in hydrologic networks Figure 4.5b Wrong pixel alignment

4.6. Embankments and other structures (barriers)

In Delft –FLS The barriers should be defined differently from the other features for the model to be able to identify them in the DEM. the other features like the hydrological networks, the pixel alignment is side by side while in the barriers alignment of the cells need not to be side by side but can also be joined at the corners they only need to form a block which does not allow water flow to through. See figure 4.5a and 4.5b for the comparison of the water alignment and the barriers alignment

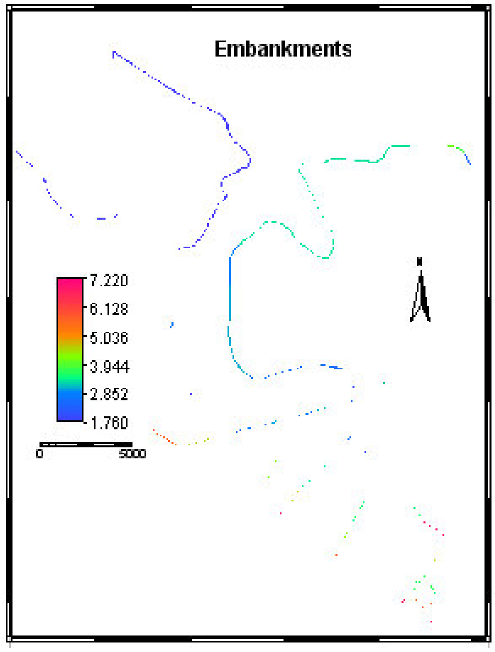
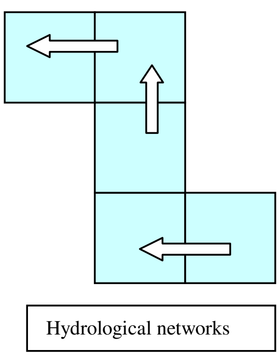


Figure 4.6: The embankments

4.6.1. The pixel alignment in structures (barriers)

The embankments accurately fitted since they were only fitted at three locations with the northern map



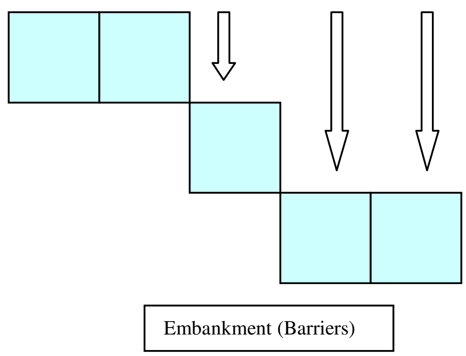


Figure: 4.7a: Pixel alignment in channels Figure 4.7b: Pixel alignment in barriers

The arrows show how the water moves in the Hydrological networks figure 4.7a and when it comes across the barriers in the floodplain figure 4.7b. Note the alignment of pixels in the barriers can be either side by side or joined at the edges, unlike water (hydrological networks) where they have to be side by side

4.7. DEM Final

The combined DEM of the embankments and the main river channels was created at 50m pixel size; the fitting of the features was accurate considering the pixel size and the features. The values on the DEM were inspected and locally adjusted to express the features accurately. The river channels were inspected for the pixel alignment and for channel values that showed values that would cause obstructions to ensure water flow. The embankments were inspected to adjust the pixels that did not have the correct alignment for a barrier. The values in the flood plain were inspected to eliminate any inconsistency in values See figure 4.8 for the final DEM

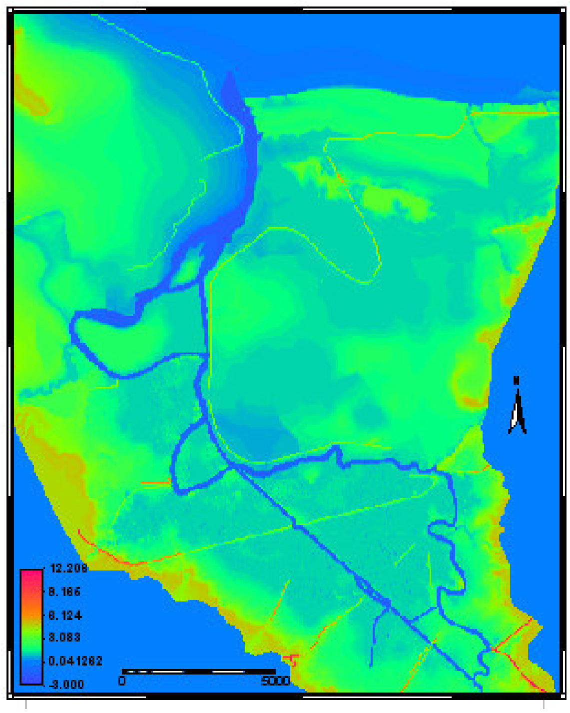


Figure 4.8: DEM Final

4.8. Hydrological data

River Bicol starts from lake Bato and ends at San Miguel bay, tidal effects from the bay due to storm surges influence the river flow. These surges have an impact on the river fluxes. The modelling of the hydrological fluxes was done using two boundaries in the flood plain. The upper (upper inlet) and the lower boundary (lower inlet in the figure) figure 4.9

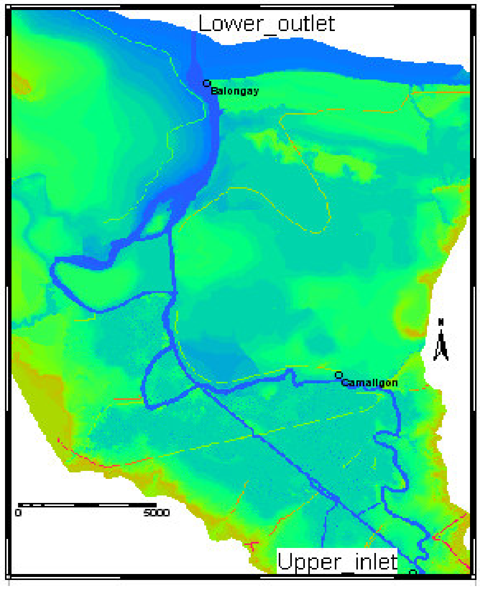


Figure 4.9: The location of the model boundaries in the floodplain

4.9. Upper boundary input hydrograph

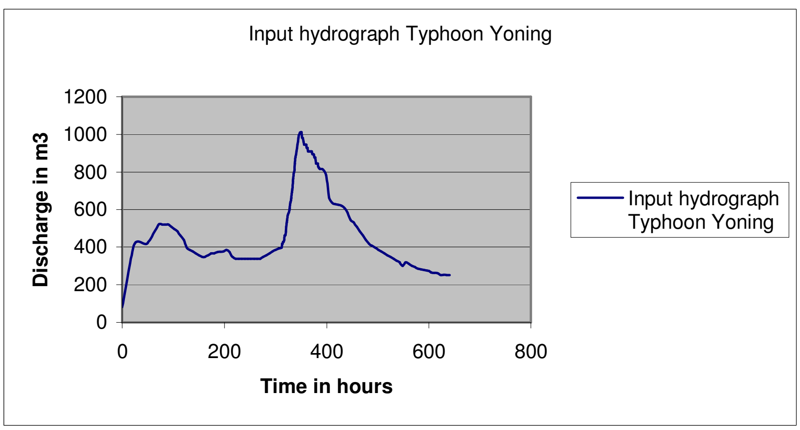


Figure: 4.10: The input hydrograph at the upper boundary

4.9.1. Lower boundary at San Miguel Bay tidal fluctuations

The boundary at san Miguel that has high tidal influence was located as in (figure: 4.3) Lower boundary outlet. The tidal fluctuation in the lower boundary condition as in (figure: 4.11)

The input tidal fluctuation was adapted from BRBFCIDP (See appendix for the values used)

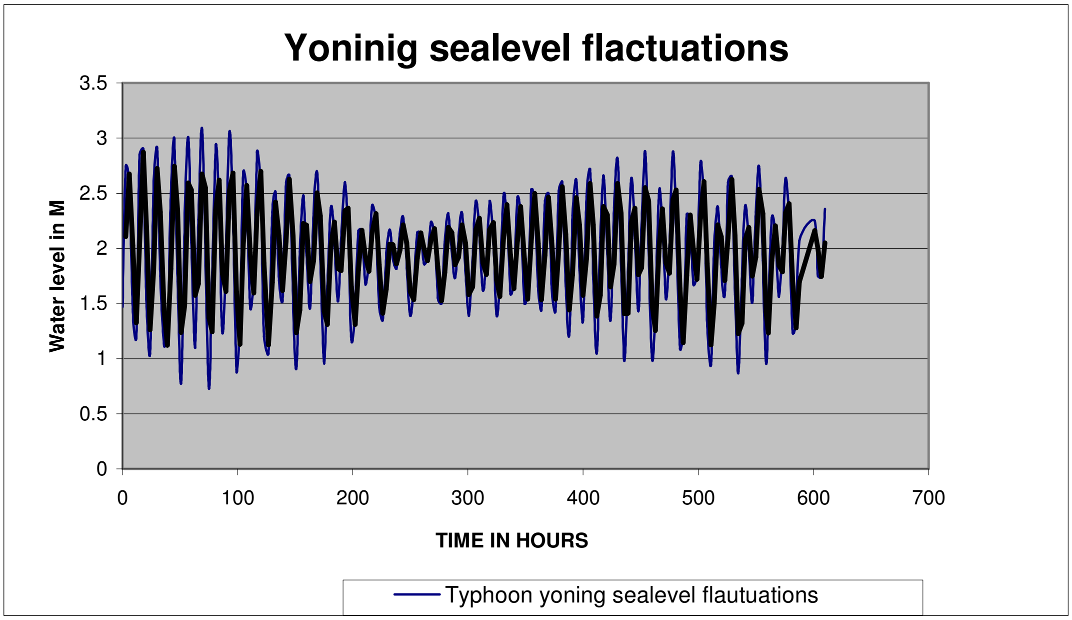


Figure 4.11: The input hydrograph at the lower boundary at San Miguel Bay

4.10. Land cover Using Manning's coefficient

For flood modelling the resistance of the ground force to flow is required and therefore the land cover see figure 3.3 was transformed to a map that displays the spatial distribution of Manning's coefficient See figure 4.12. The values for the Manning's coefficient were adopted from previous detailed surveys, which were carried out in the area (AIT, 1976; BRBFCDP, 1991) their results were almost similar values for the riverbed and the flood plain coefficient. The values form the latest survey which is the BRBFCIDP were closely adapted, though other values had to be derived from comparisons with the ground situations since all the Models were 1D and developed only one value for the flood plain. Table: 4.2

	Mannings
Coconut	0.200
Cut-off channel	0.080
Embankment	0.200
estuary	0.025
Non-Arable land	0.001
Residential are	0.200
Rice Paddys	0.100
Road	0.100
Water	0.025

Table: 4.2 The Manning's coefficient values used for the flood plain as adapted from BRBFCIDP, 1991

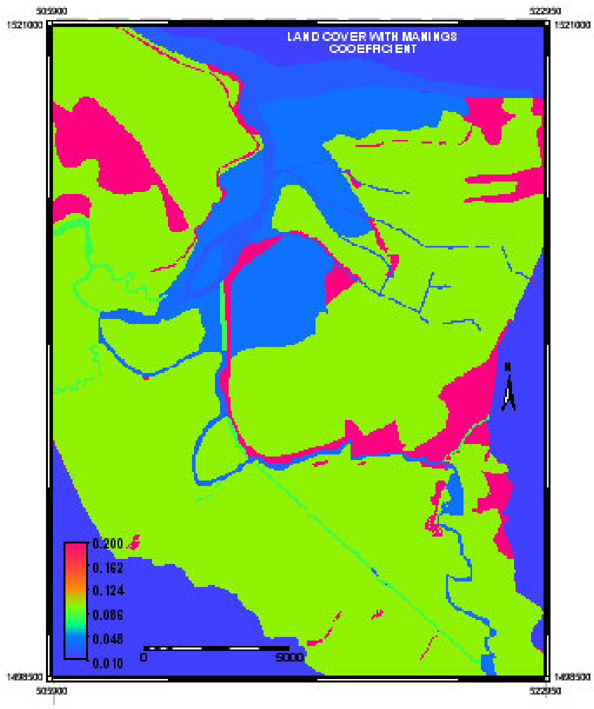


Figure 4.12: The land cover with the Manning's coefficient values

The values developed in the floodplain were compared with the existing ground situations. There was very little variation in Manning's coefficient values as the pixel size of the final input map was 50m-pixel size and lot of generalization was done in the original land cover map.

Chapter 5

5. Validation

5.1. Model validation

5.1.1. Comparing the Flood extent maps of Mike-11 and Delft-FLS for the10-year return period

The model was validated against one of the out puts of the BRFCIDP, 1991 which modelled the extent of the 1.25, 5, 10 and 25 year of the flood return period in the flood plain using Mike -11. (Figure: 5.1). The flood Yonning was comparable to a ten-year flood return period in the floodplain. The model results of Delft-fLS is indicated in figure 5.1 and Mike-11 is indicated in figure 5.2

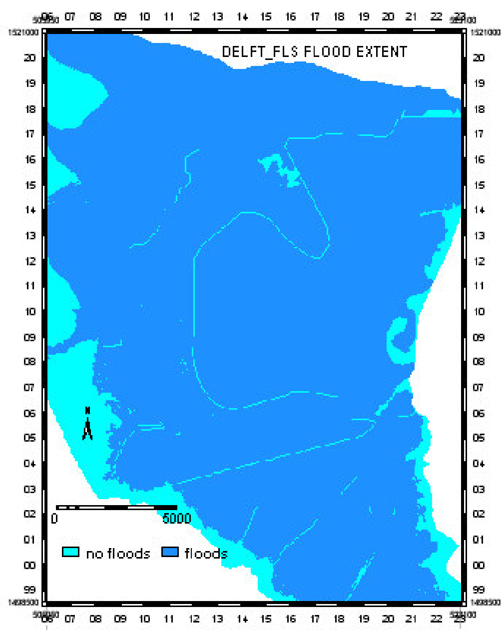


Figure 5.1: Flood extent as predicted by Delft-FLS

Table 5.1 indicates the area identified as flooded in Delft-FLS and table 5.2 indicates the area identified by Mike-11 as flooded

	npix	npixpct	pctnotund	Area
no floods	18059	10.94	13.88	45147500
floods	112022	67.86	86.12	280055000

Table 5.1: Flood extent using Delft-FLS

In the table 5.1 Delft-FLS shows that 67 percent covering an area of 280sq² as flooded and 10% covering an area of 45.15km² as not flooded the rest of the remainig 30% of the pixels are undefined.

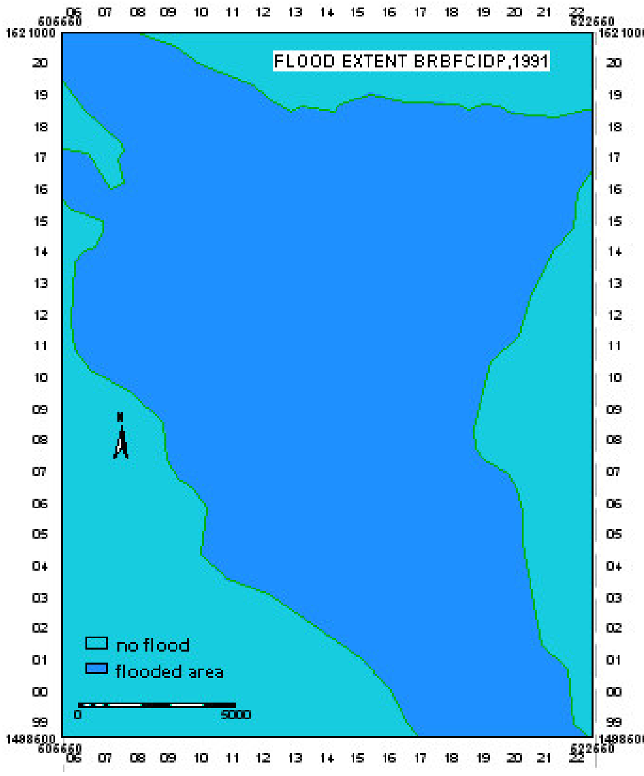


Figure 5.2: Flood extent as predicted by Mike -11 (BRBFCIDP, 1991)

	npix	npixpct	Area
no flood	68345	41.40	170862500
flooded area	96721	58.60	241802500

Table 5.2: Flood extent using Mike - 11

In the table 5.2 Mike-11 indicates that 58% is flooded covering an area of 241sq² as flooded and 41percent covering an area of 170km² as not flooded.

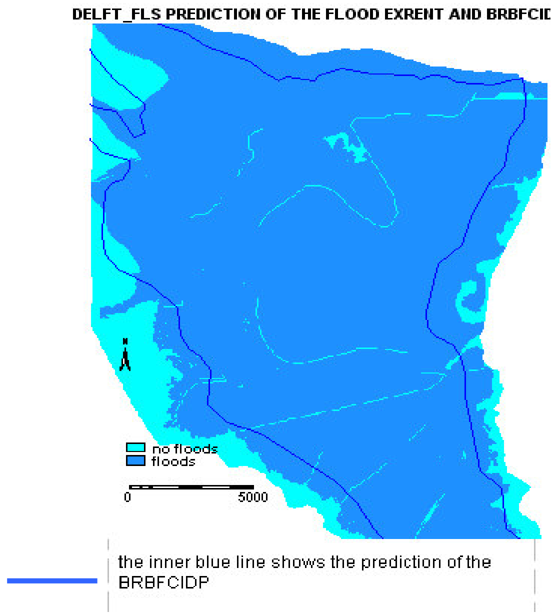


Figure 5.3: Flood extent of results of Delft-FLS and Mike – 11 (BRBFCIDP)

The areas modelled as flooded in both Delft-FLS and Mike – 11 show very little difference, where the blue line represents Mike-11 and the blue extent represent Delft-FLS

5.1.2. The analysis of flood extent as modelled by Delft-FLS and Mike-11

	hmax_flooded	flooded_new	NPix	Area
no floods * 10year	no floods	10year	4625	11562500
floods * 10year	floods	10year	92033	230082500

Table 5.3: The areas covered by floods in the Delft-FLS and Mike-11 results (two maps are crossed)

The table 5.3: Area results of both the models indicated as flooded is 230sq² km

Comparison of modelled Delft-FLS extent and Mike - 11	
	Modelled extent in ILWIS in meters squared
Mike - 11	241802500
Delft-FLS	280055000
Difference	38252500

Table 5.4: the comparison of the total areas covered by floods in Delft _FLS and Mike - 11

The analyses show that 82 % of the results on flood extent agree as flooded 18% do not agree.

5.2. Comparisons of Water depth values of Delft-FLS and field interviews

The field observation and Delft-FLS values were compared to determine the reliability of the Delft-FLS prediction. See appendix-5 for water depth values

The field interviews results were compared with the results from Delft-FLS model. The interviews carried out by structured questions in the field at various locations. The area which was not visited values were used from a previous field survey by GHA 2002

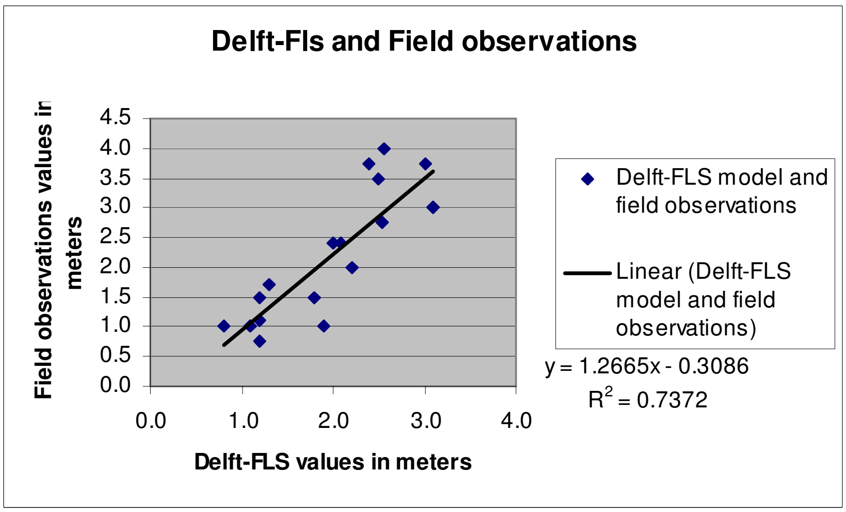


Figure 5.4: Delft-FLS and field observation water depth values compared

The values show 85 percent correlation in the results of water depths at different location in the floodplain figure 5.4 the confidence of prediction is 26 percent

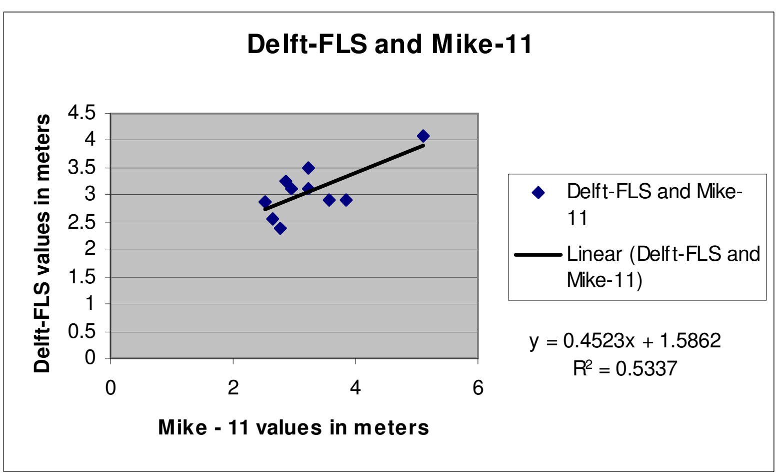


Figure 5.5: Delft-FLS and Mike-11 (BRBFCIDP, 1991) water depths values

The values of Delft-FLS and Mike-11 showed 73 percent correlation at different locations in the floodplain figure 5.5. The confidence of prediction 45percent reliability

The comparison of water depths at different locations in the floodplain, by field observations, Mike-11 (BRBFCIDP, 1991) and Delft-FLS showed results that were seventy three percent correlated in values

Chapter 6

6. Scenarios

6.1. Introduction

For the assessment of flood hazard several flood scenarios were developed to simulate conditions that could arise in the flood plain and to test the model sensitivity to different parameters. Different conditions that could influence flooding were developed and scenarios used to view the propagation of water over the floodplain. The ability to view how water propagates enhances the understanding of flood behaviour.

6.1.1. Flow chart of the scenarios

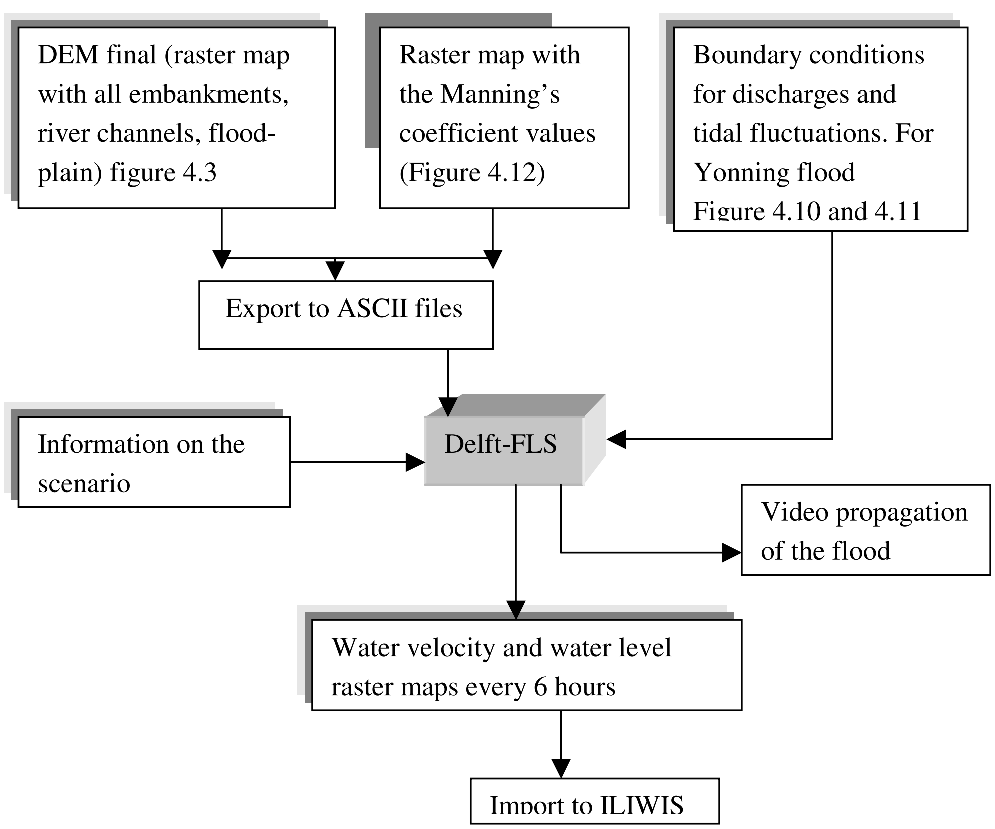


Figure 6.1: Flow chart of the scenarios

Flood hazard assessment was accomplished. The inputs for Delft-FLS were the DEM Final of the floodplain figure 4.8, the input hydrograph figure 4.10 in the lower boundary and the sea level fluctuations in upper boundary at San Miguel Bay figure 4.11 and Land cover showing the Manning's coefficient used in defining the roughness of the floodplain figure 4.12 Maps were generated in ILWIS and exported to ASCII files/arc info for the Delft-FLS model. The boundary condition files were created in excel copied to notepad and imported into the model

6.2. Scenario 1 Typhoon Yonning 80 hours

In the first run to balance the flow a discharge of 80m³ was used. The model was then checked to verify the water flow. For the 80 hours scenario the boundary conditions used was the water discharges calculated for the upper boundary and the tidal fluctuations developed during the typhoon Yonning that started on 5th and ended on 9th November 1988. The model generated 24 maps of (12water velocity and 12water level) raster maps. These model generated maps after every 6hours

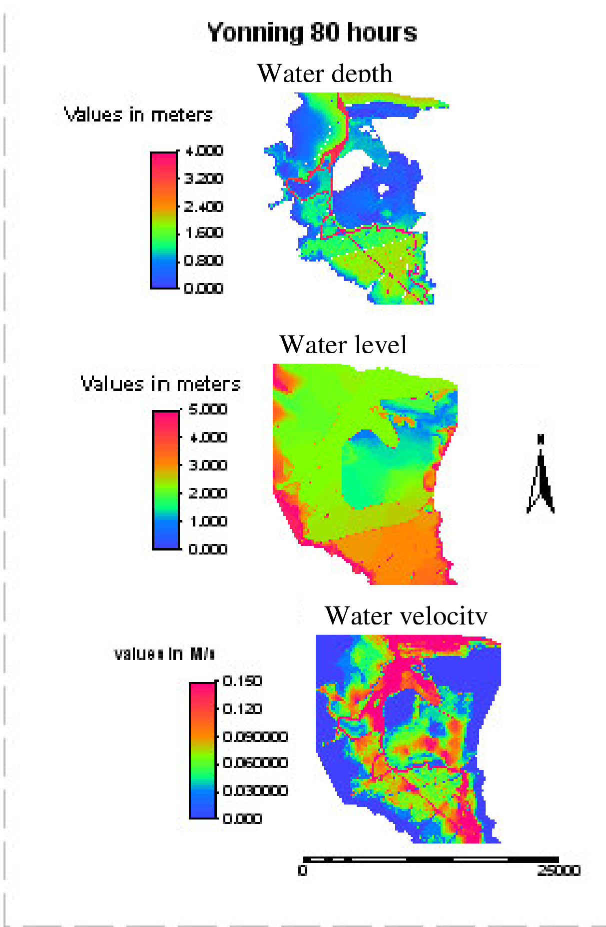


Figure 6.2: Yonning (80 hours) water level, water depth and speed after 72 hours

The water level map in figure: 6.2 show certain locations in the flood plain where water did not reach and a number of places remained undefined. From these results no accurate analysis could carry out. Therefore another run with longer period of 1000 hours was set up to try and express the flood propagation more accurately. It is important to note that model run time should be long enough for proper simulations.

6.3. Scenario 2 Typhoon Yoning (1000) hours

The upper boundary conditions calculated from the 23 of October 1988 to the 18 of November 1988 figure 4.10 and the lower boundary figure 4.11 was calculated for the same period of time for typhoon Yonning was used. The model was set for 1000 hours. 332 (velocity and water level) raster maps, two maps showing the maximum flood level and the maximum velocity (see figure 6. 2) and a video of the flood were generated.

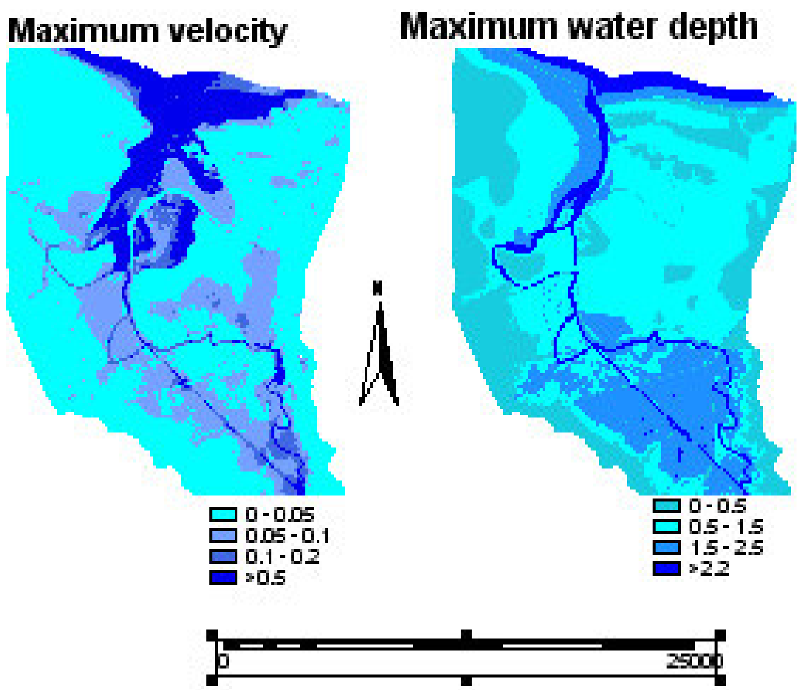


Figure 6.3:Maximum water level and maximum flow velocity

This scenario depicted the flood propagation during the typhoon Yonning. The models response during the simulation was more complete than when it was when modelled for only 80 hours see figure 6.2. This simulation was used to further determine the models response in the predicted water level, water speed and flood depth at various locations in the flood plain. See figure 5.4 for comparison of water depth and actual observed depths

The Maximum water level was calculated by adding the digital terrain model to the to the maximum water depth map to get the actual level related to the reference level (sea-level) see figure 6.3

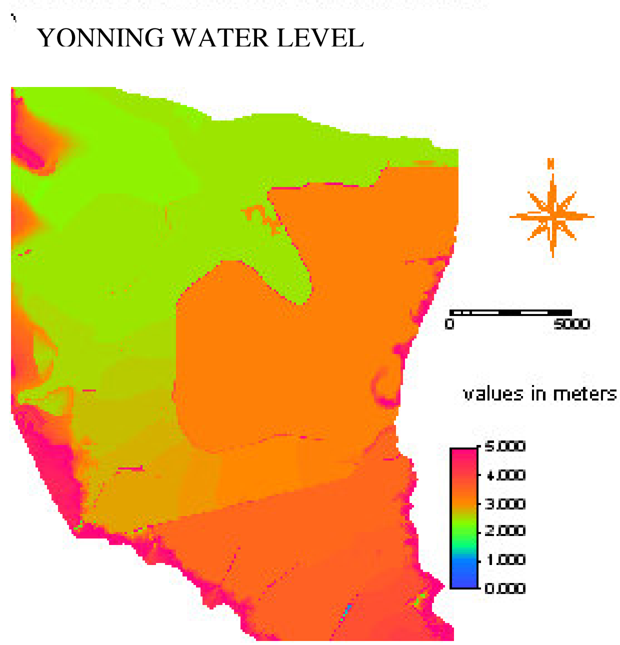


Figure 6.4: Maximum water level in the floodplain during typhoon Yonning

6.4. Scenario 3 and 4 different Manning's coefficient value

In this scenario different Manning's coefficient values were used for the determination of the models sensitivity to their changes. Table 6.1 shows the columns of the different Manning's used.

	Mannings	mannings_2	Mannings_3
Coconut	0.200	0.200	0.200
Cut-off channel	0.080	0.035	0.030
Embankment	0.200	0.300	0.200
estuary	0.025	0.050	0.025
Non-Arable land	0.001	0.004	0.001
Residential are	0.200	0.200	0.200
Rice Paddys	0.100	0.150	0.150
Road	0.100	0.100	0.100
Water	0.033	0.050	0.033

Table: 6.1 The Land cover Manning's coefficient values used in the model

In the table 6.1 Manning's values in the first column Manning's show the values that were originally developed for the model during the simulation of Yonning flood at 1000 hours. Columns, showing Manning's *2* and Manning's_3 are the new introduced values. The values were tested if resistance would significantly change the model results.

6.4.1. Pair wise comparison of water depth levels

The same boundary conditions were used as typhoon Yonning (1000hours) see figure: 4.10 and 4.11with changed Manning's coefficient values See table 6.1 column on Manning's coefficient_2 Manning's coefficient_3. Table 6.1

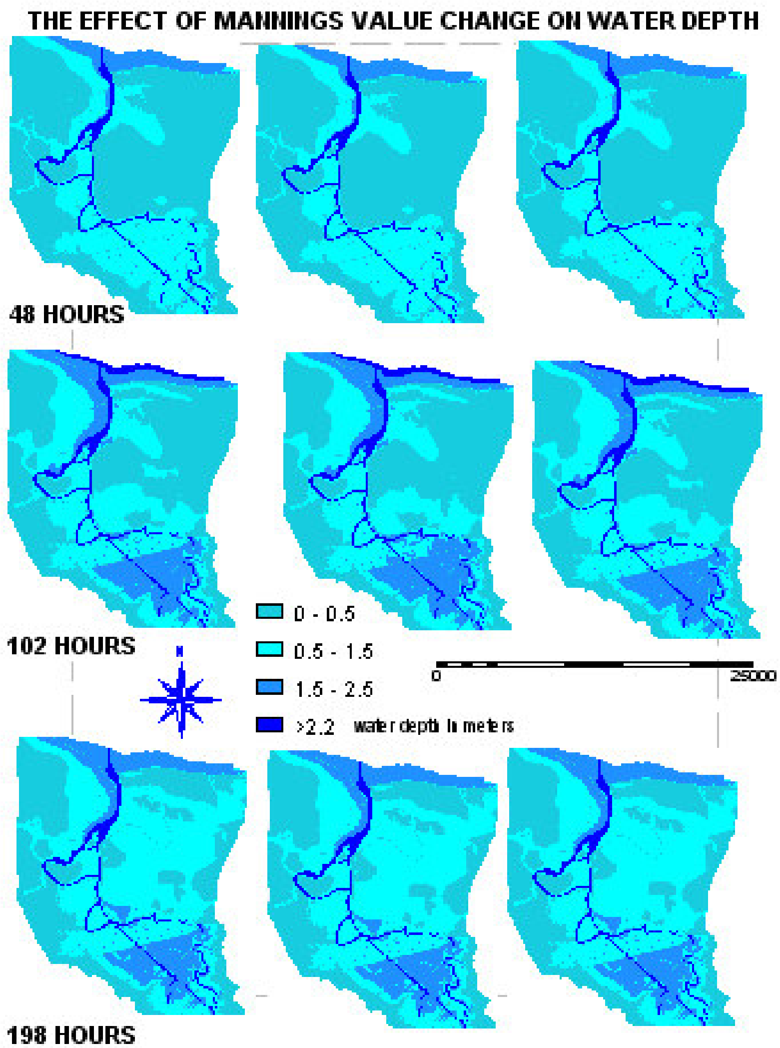


Figure 6.5: The effect of the application of Manning's, Manning's_2 and Manning's_3 to the water depth values in the floodplain

Figure 6.5: The three maps in a row use different Manning's coefficient values at different time steps. The first maps on each row used Manning's, the second map used manning's_2 and the third maps used manning's_3 see table 6.1.

An analysis were carried out to determine the difference in water depth after the application of the Manning's coefficient values figure 6.6 shows the results of this analysis.

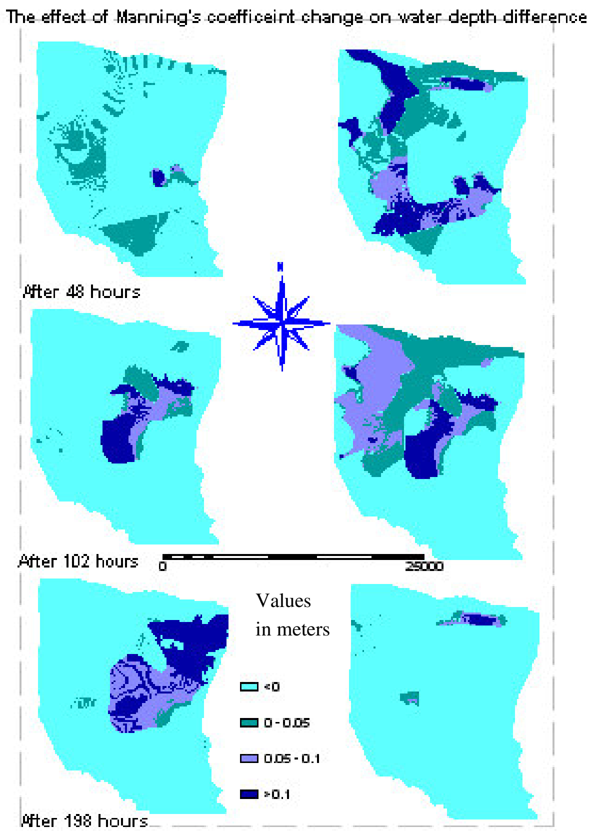


Figure 6.6: The difference in water depths after the application of Manning's_2 and Manning's_3 coefficient values

Figure 6.6 shows the difference in water depths after different time steps

The analysis of the model results figure 6.6 of water depths after the application of manning_2 and Manning's_3 coefficient in the floodplain. The values were pair wise compared. This is displayed graphically in figure 6.8 to 6.10. The analysis of model results for the comparison of the Manning's values with Manning's_ 3 were graphically displayed in figures 6.11 to 6.13. The difference was calculated by using the raster maps where the maps generated after the application of Mannings_2 and Manning_3 were subtracted from the raster maps generated from the original Manning's at different time steps. The maps were then sliced into classes for further analysis in percentages.

The results of the comparisons for Manning's and Manning's_2 are in table 6.2

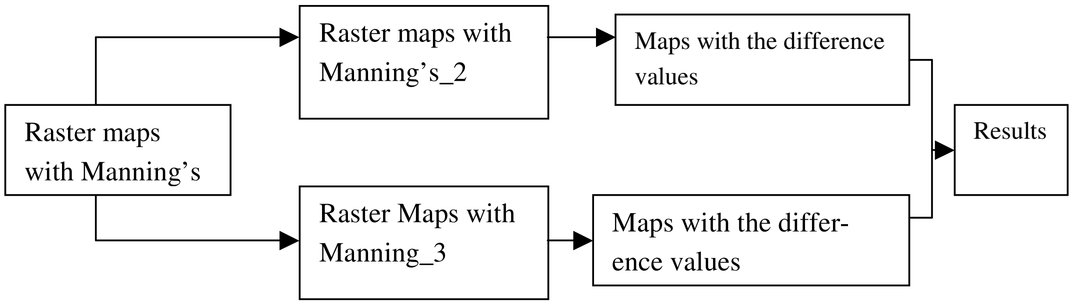


Figure 6.7: The analysis of the difference in water depth after the application of Manning's_2 and Manning's_3

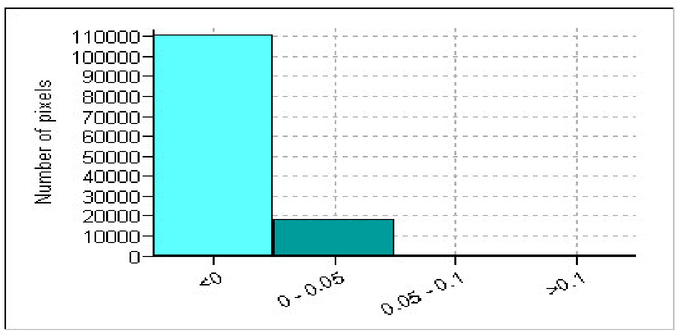


Figure 6.8: The water depth difference between Manning's and Manning's_2 values after 48 hours

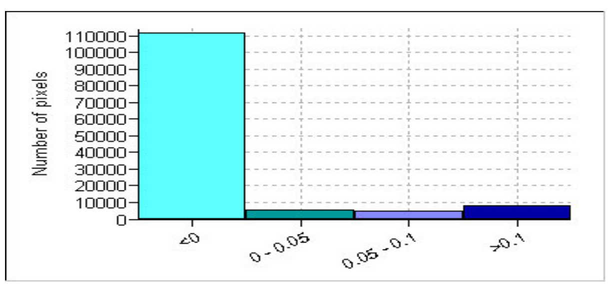


Figure 6.9: The water depth difference between Manning's and Manning's_2 values after 102 hours

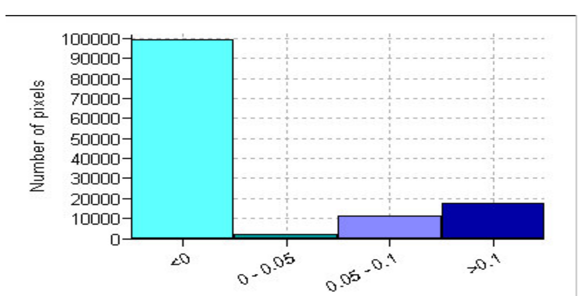


Figure 6.10: The water depth difference between Manning's and Manning's_2 values after 198 hours

Level in meters	048hours Manning's-2	102hours Manning's-2	198 hours Manning's-2
<0	85%	85%	76%
0- 0.05	14%	4%	1%
0.05 - 0 .1	0%	3%	8%
>0.1	0%	6%	13%

Table 6.2: The difference in water depth values after the application of Manning's_2 at different time steps.

Table 6.2 analysis: After the application of Manning's_2 in the first 48 hours 14 percent of the area had a difference in water depth of 0 - 0.05m. After 102 hours 4 percent of the areas had a difference of 0–0.05m, 3 percent 0.05 – 0.1 and 6 percent more than 0. 1m. After 198 hours 1percent had a water depth difference of 0 – 0.05m, 8 percent 0.05 – 0.1m l and 13 percent more than 0.1m.

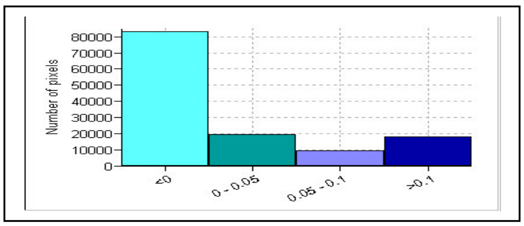


Figure 6.11: The water depth difference between Manning's and Manning's_3 values after 48 hours

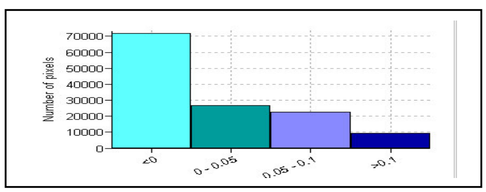


Figure 6.12: The water depth difference between Manning's and Manning's_3 values after 102 hours

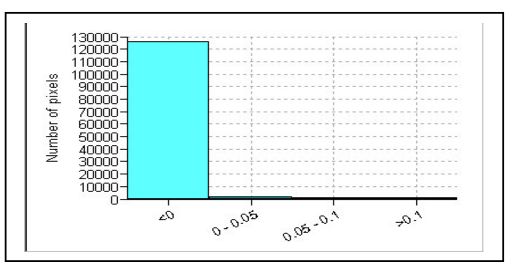


Figure 6.13: The water depth difference between Manning's and Manning's_3 values after 198 hours

Level in meters	O48hours Manning's-3	102hours Manning's-3	198 hours Manning's-3
<0	67%	55%	97%
0- 0.05	10	20%	1%
0.05 - 0 .1		17%	0%
>0.1		7%	0%

Table 6.3 :The comparison of the difference of water depth values after the application of manning's_3

Table 6.3 analysis after the application of Manning's_3 in the first 48 hours 10 percent of the area had a difference in water depth of 0 - 0.05m. After 102 hours 20 percent of the areas had a difference of 0–0.05m, 17 percent 0.05 – 0.1 and 7 percent more than 0. 1m. After 198 hours 97percent of the area had a water depth difference of 0 – 0.05m, 1 percent 0.05 – 0.1m.

The analysis of the sensitivity to Manning's was further carried out by correlating the values graphically. The model results at various locations were also pair wise compared. This is displayed in figures 6.13 to 6.15 for various time steps. The underlying fact is if the plotted points will lie on the line x=y (a straight line of 45º) then it would imply that the points have no difference. Any deviation would then imply that the change is due to the friction (Manning's) coefficient

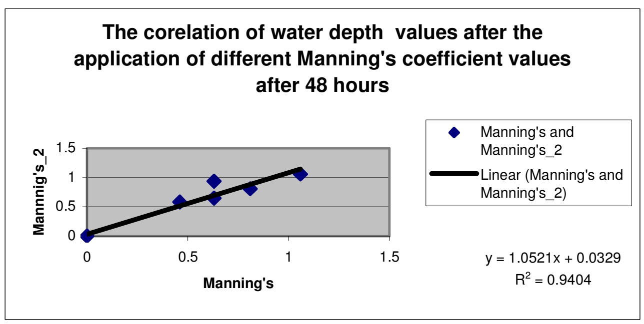


Figure 6.14: The correlation of water depth values after applying different Manning's coefficient values after 48 hours

The figure shows ninety six percent correlation and Delft-FLS predicted values at 198

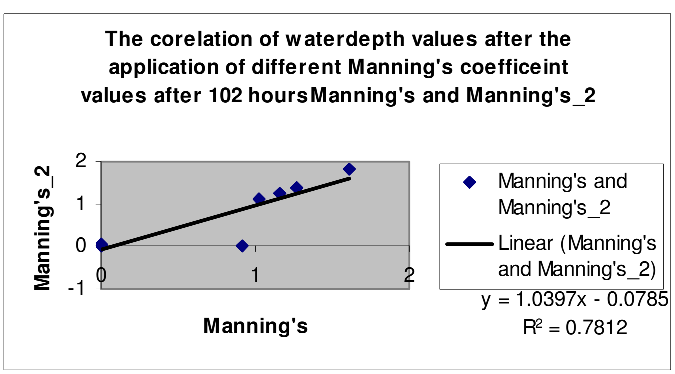


Figure 6.15: The correlation of water level values after applying different Manning's Coefficient values after 102 hours

The figure shows eighty eight percent correlation in the Delft-FLS predicted values at 198

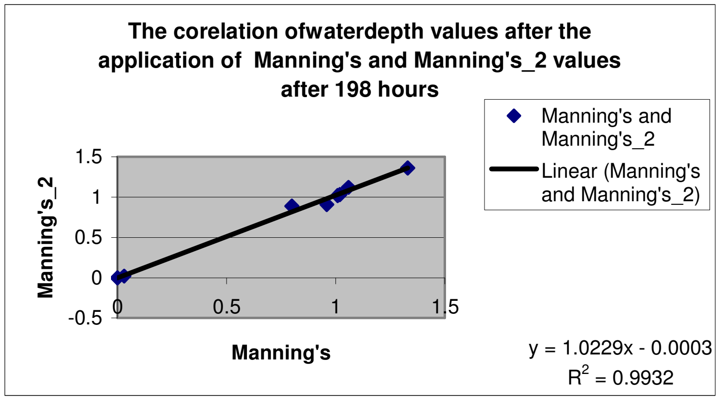


Figure 6.16: The correlation of water level values after applying different Manning's coefficient values after 198 hours

The figure shows ninety nine percent correlation in the Delft-FLS predicted values at 198

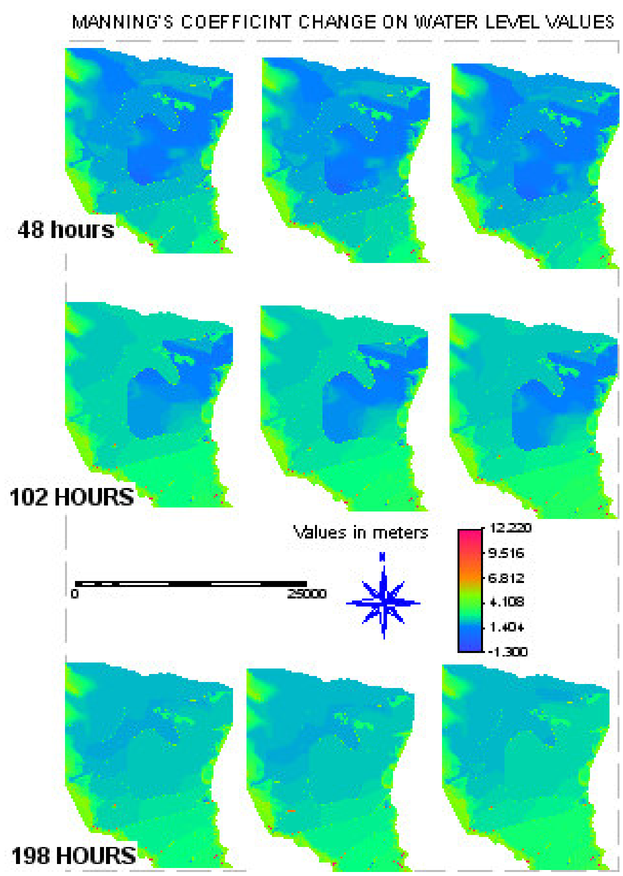


Figure 6.17: The effect of the application of Manning's, Manning's_2 and Manning's_3 to the water level values in the floodplain

The analysis for the model results for water levels figure 6.11 at various locations was pair wise compared. The analysis will be dependent on the line where y=x at 45º line when the values are perfect they will lie along this line if there is any deviation away from this line it will be attributed to the changes in the Manning's coefficient values. This is displayed graphically in figure 6.18 to 6.20

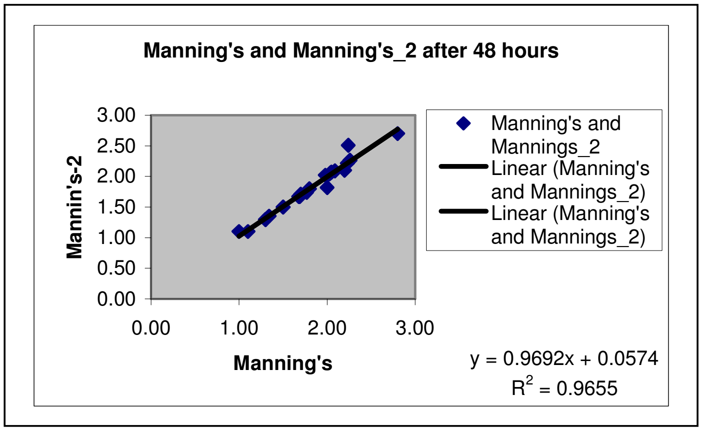


Figure 6.18: The correlation of delft-FLS water level values at Specific locations in the floodplain after the application of Manning's and Manning's_2

The Figure shows a ninety eight per-cent correlation of in the Delft-FLS predicted values after 48

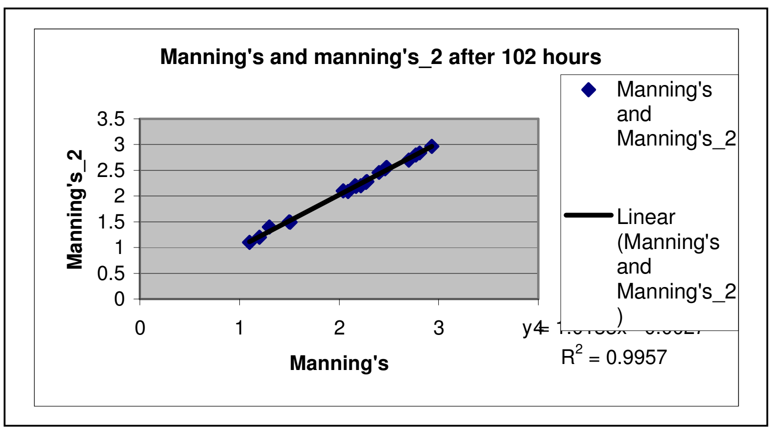


Figure 6.19: The correlation of Delft-FLS water level values at specific locations in the floodplain after the application of Manning's and Manning's_2 values

The table shows a ninety eight percent correlation in the Delft-FLS predicted values at 102 hours.

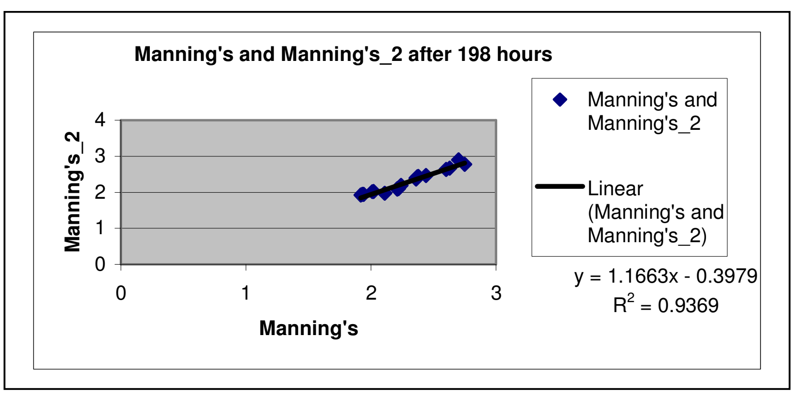


Figure 6.20: The correlation of Delft-FLS water level values at specific locations in the floodplain after the application of Manning's and Manning's_ 2 values

The table shows ninety seven percent correlation in the Delft-FLS predicted values at 198 hours

The analysis of the sensitivity to Manning's was further analysed by correlating water speed-values at specific locations in the floodplain to compare if there were any differences. The values were pair wise compared. The results are displayed in figures displayed in figures 6.21 to 6.26 for various time steps. The underlying fact is if the plotted points will lie on the line x=y (a straight line of 45º) then it would imply that the points have no difference. Any deviation would then imply that the change is due to the friction (Manning's coefficient

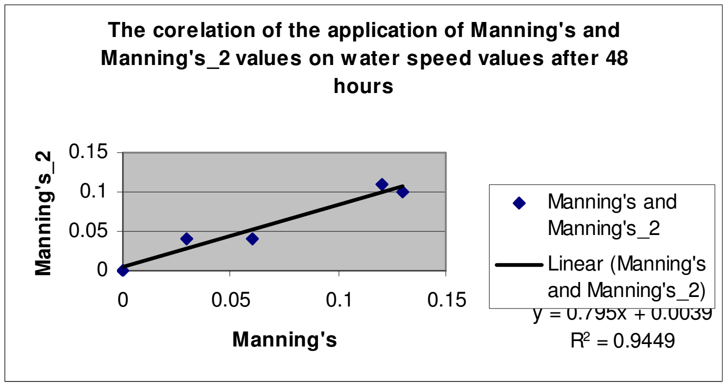


Figure 6.21: The correlation of water speed values after applying different Manning's coefficient values after 48 hours

The figure shows ninety eight percent correlation in the Delft-FLS predicted values at 198

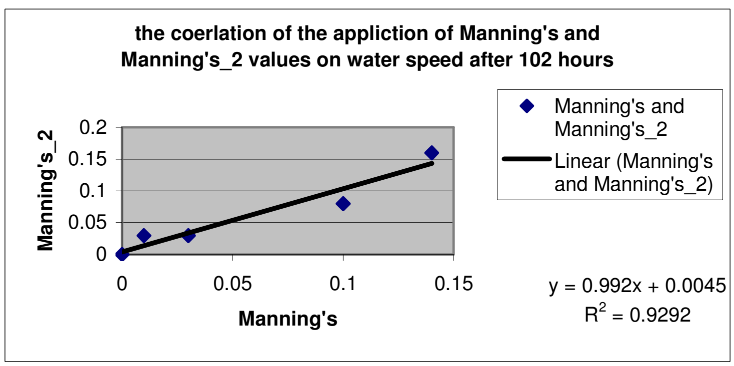


Figure 6.22: The correlation of water speed values after applying different Manning's coefficient values after 102 hours

The figure shows ninety six percent correlation in the Delft-FLS predicted values at 198

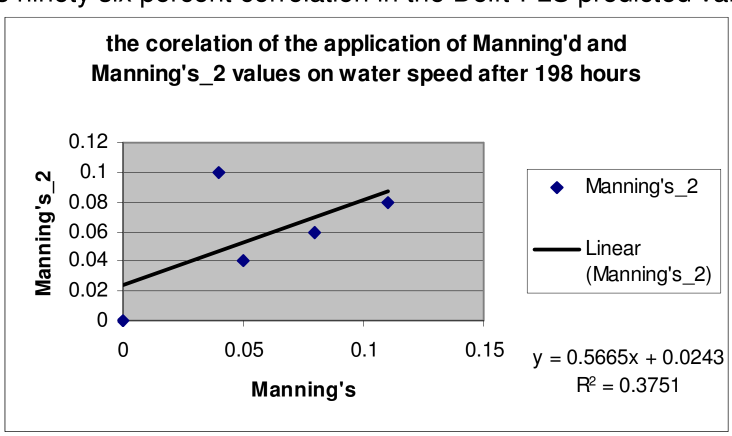


Figure 6.23: The correlation of water speed values after applying different Manning's

coefficient values after 198 hours

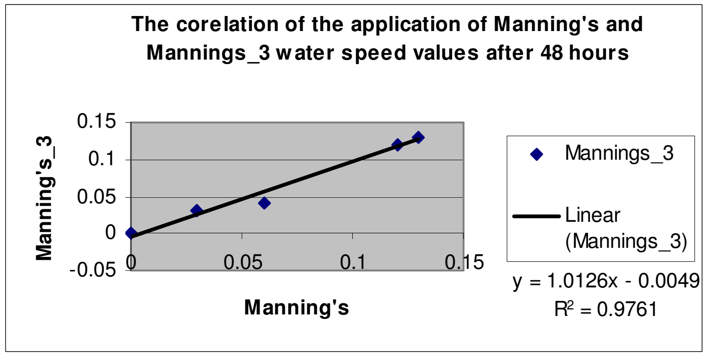


Figure 6.24: The correlation of water speed values after applying different Manning's coefficient values after 198 hours

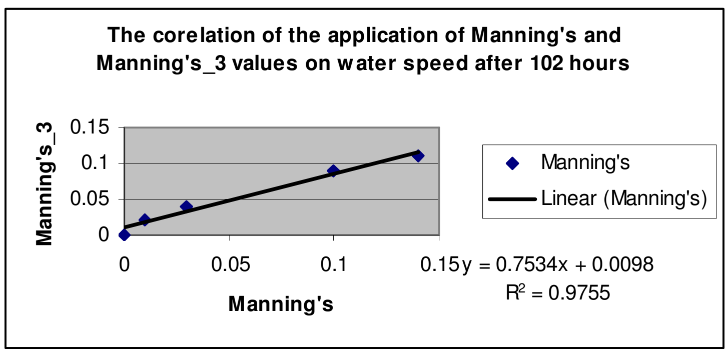


Figure 6.25: The correlation of water speed values after applying different Manning's coefficient values after 198 hours

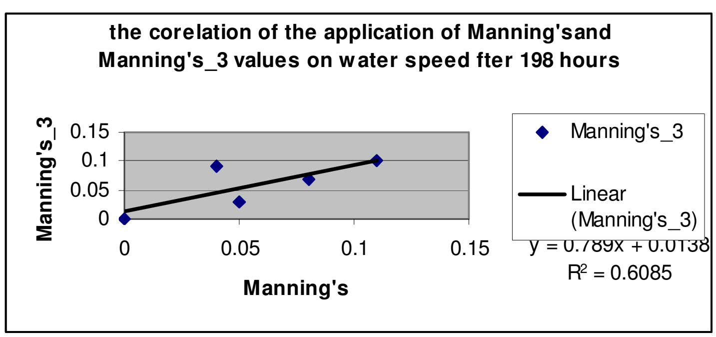


Figure 6.26: The correlation of water speed values after applying different Manning's coefficient values after 198 hours

6.5. Scenario 5 (Moved embankment)

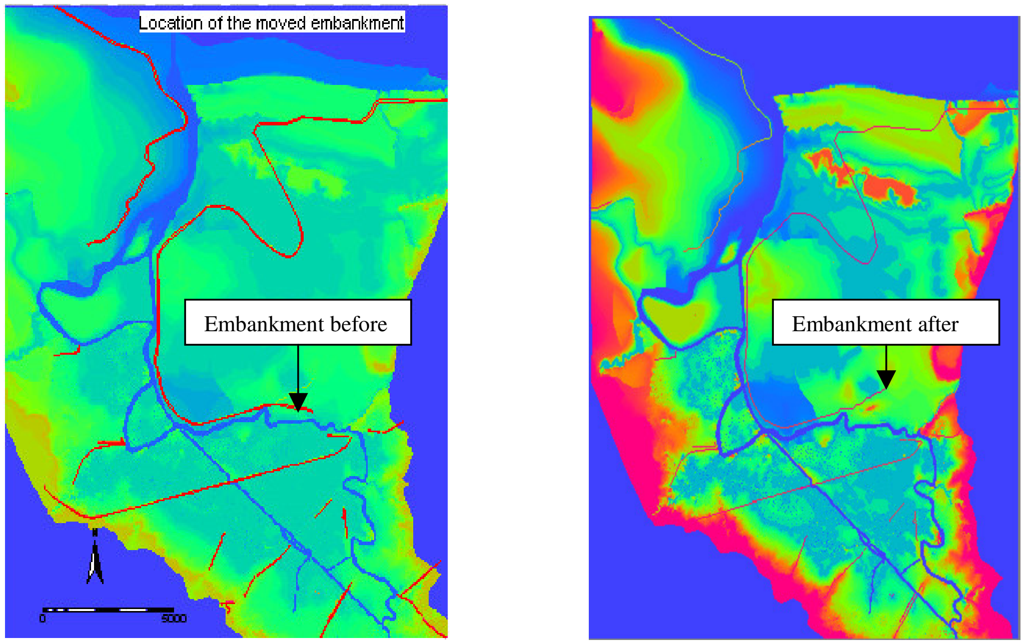


Figure 6.27: Location of the Moved embankment

The same boundary conditions were used but with the embankment that was partly moved from stopping in the lower area to stop at a in the higher ground where water was not moving to, the figure 6.27 indicates the position of the embankment before and after

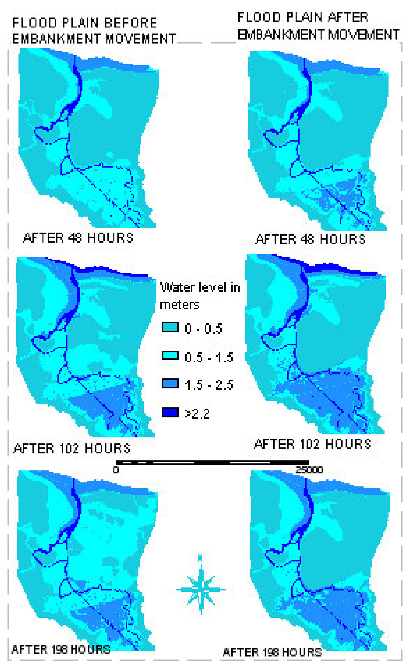


Figure 6.28: The effect of the embankment movement on water depth classes

The analysis was further carried out to determine the difference in water depth at different time steps after the embankment movement. The same method was applied as in figure 6.7

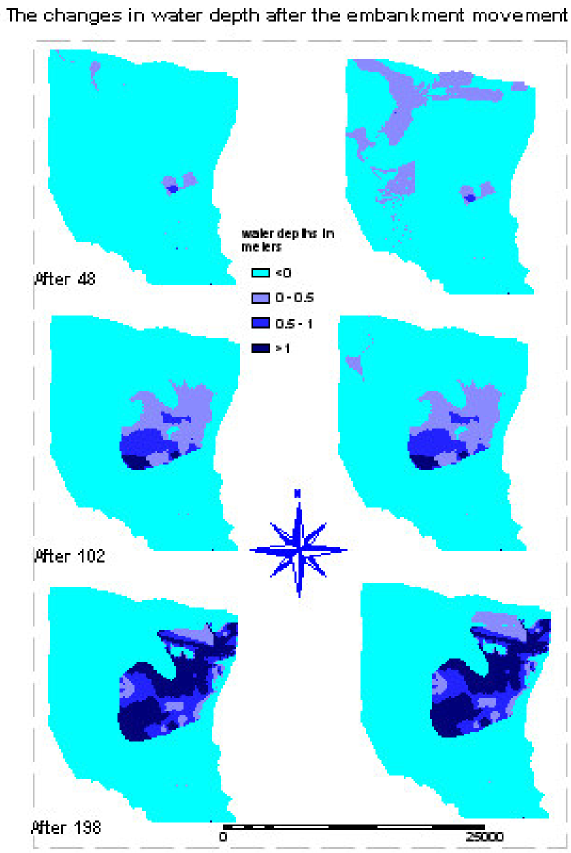


Figure 6.29: the difference in water depth after the embankment movement at different time steps

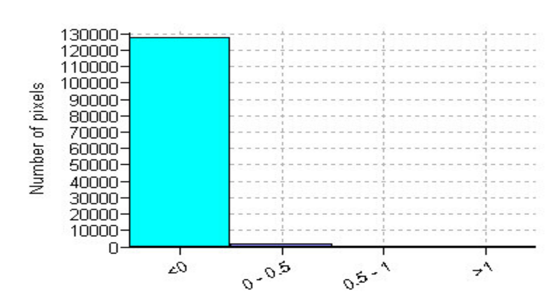


Figure 6.30: The difference in water depth values after the embankment movement after 48 hours

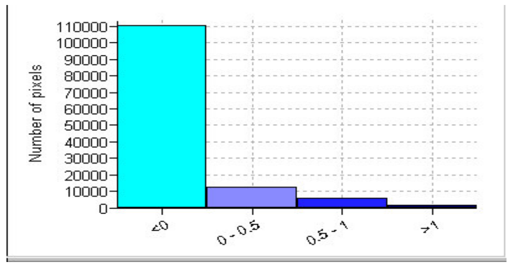
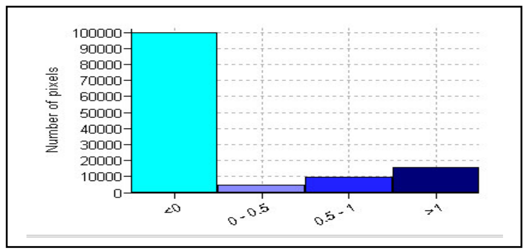


Figure 6.31: The difference in water depth values after the embankment movement after 102 hours



F Figure 6.32: The difference in water depth values after the embankment movement after 198 hours

Level in meters	048hours	102hours	198 hours
<0	98%	85%	76%
0- 0.05	1%	9%	3%
0. 5 - 1	0	4%	7%
>1	0	0%	12%

Table 6:4 the analysis for embankment movement and changed Manning's coefficient values

Table 6.4 analyses: After the embankment movement in the first 48 hours there was a 1 percent of the area had between 0 - 0.05m difference in water depths approximately 5cm of water depth. After 102 hours, 9 percent of the area had a difference in water depth of 0–0.05m and 4 percent of 0.05 – 0.1m. After 198 hours 3percent of the area had a water depth difference of 0 – 0.05m level 7 percent of 0.05 – 0.1m level and 12 percent of more than 0.1m

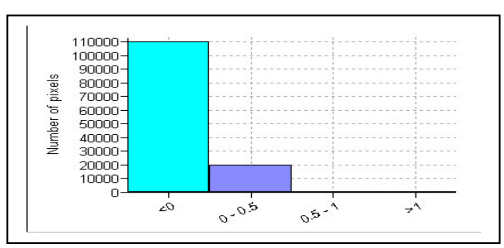


Figure 6.33: The water depth values after the embankment movement and applying different Manning's after 48 hours

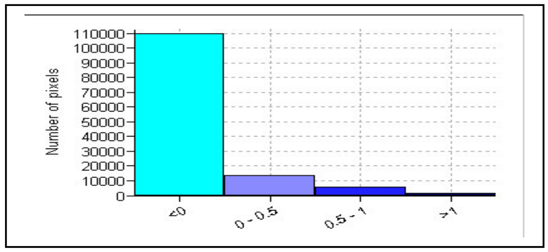


Figure 6.34: The water depth values after the embankment movement and applying different Manning's after 102 hours

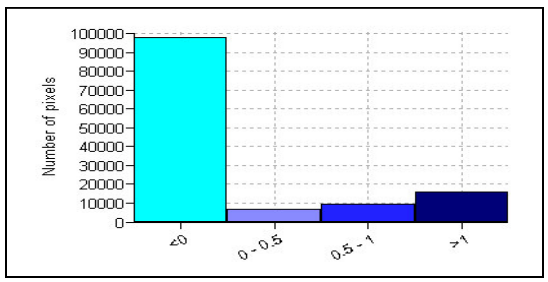


Figure 6.35: The water depth values after the embankment movement and applying different Manning's after 198 hours

Level in meters	048hours	102hours	198 hours
<0	85%	84%	75%
0- 0.05	15%	10%	5%
0. 5 - 1	0	4%	7%
>1	0	1%	12%

Table 6:5 the analysis of embankment movement and changed Manning's coefficient values

Table 6.5 analyses: After the embankment movement in the first 48 hours there was a 15 percent of the area had between 0 - 0.05m difference in water depths approximately 5cm of water depth. After 102 hours, 10 percent of the area had a difference in water depth of 0–0.05m and 4 percent of 0.05 – 0.1m and 1 percent a water depth difference of more than 1m. After 198 hours 5 percent of the area had a water depth difference of 0 – 0.05m level 7 percent of 0.05 – 0.1m level and 12 percent of more than 0.1m

6.6. Scenario 6 (Moved embankment and changed Manning's coefficient values)

The same model parameters were used but an embankment that was partly closed was moved to closure and different Manning's coefficient values were use

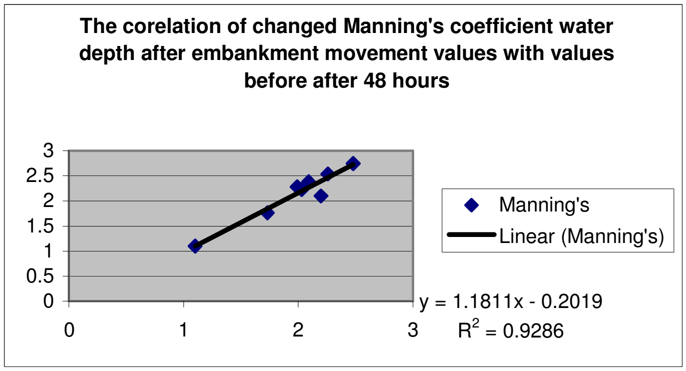


Figure 6.36: The correlation of water depth values after applying different Manning's coefficient values After embankment move after 48 hours

The figure shows ninety six percent correlation in the Delft-FLS predicted values at 198

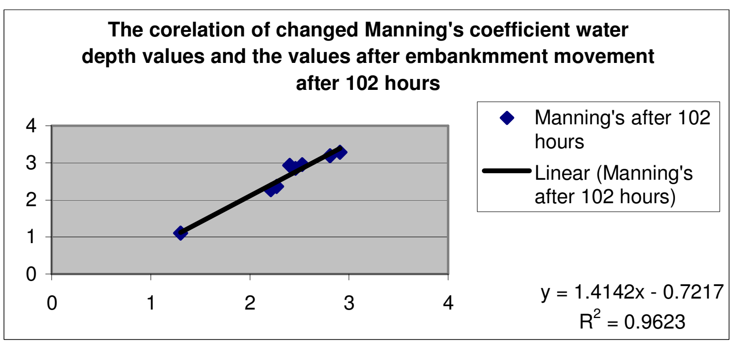


Figure 6.37: The correlation of water depth values after applying different Manning's coefficient values After embankment move after 102 hours

The figure shows ninety eight percent correlation in the Delft-FLS predicted values at 198

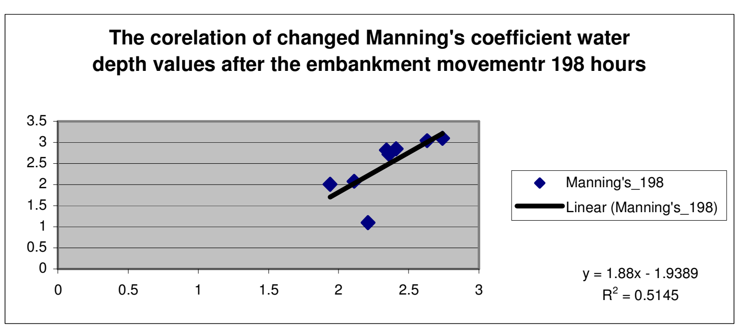


Figure 6.38: The correlation of water depth values after applying different Manning's coefficient values After embankment move after 198 hours

The figure shows seventy two percent correlation in the Delft-FLS predicted values at 198

6.7. Scenario 7(The embankment break at Sabang)

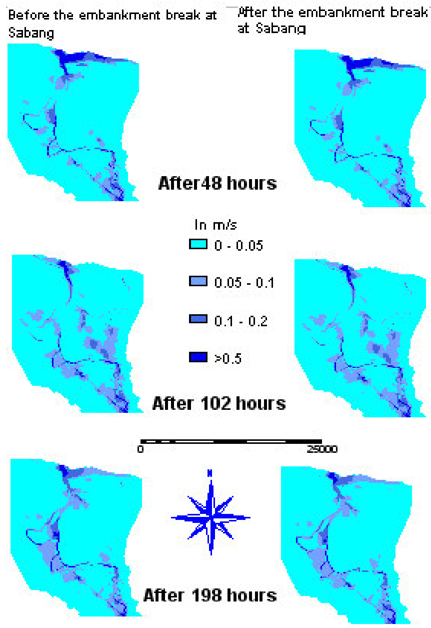


Figure 6.39: The impact of the embankment break at sabang

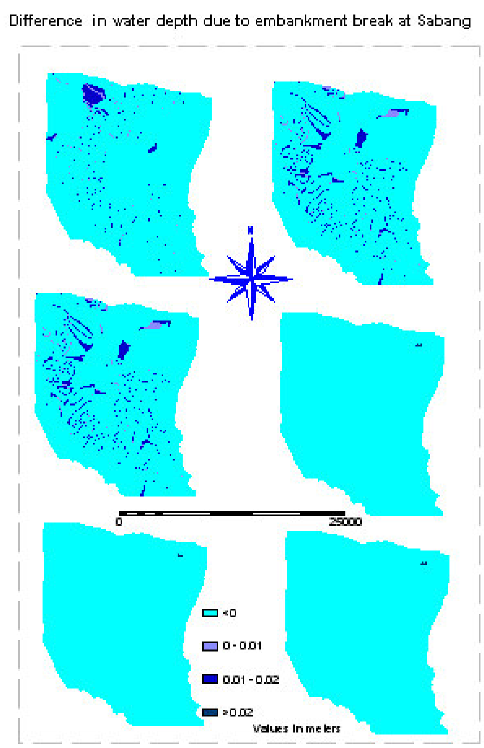


Figure 6.40 The difference in water depth after the embankment break at Sabang

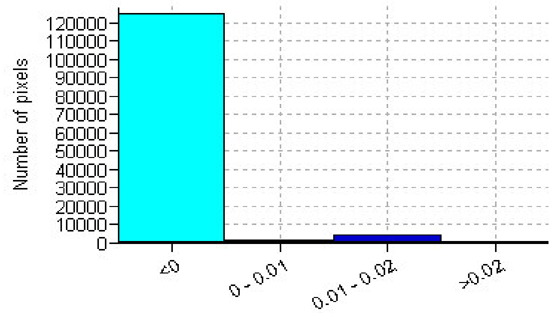


Figure 6.41: The difference in water depth after the embankment break at Sabang after 48 hours

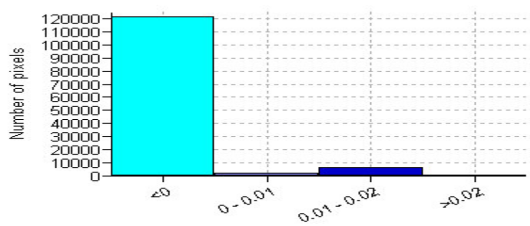


Figure 6.42: The difference in water depth after the embankment break at Sabang after 102 hours

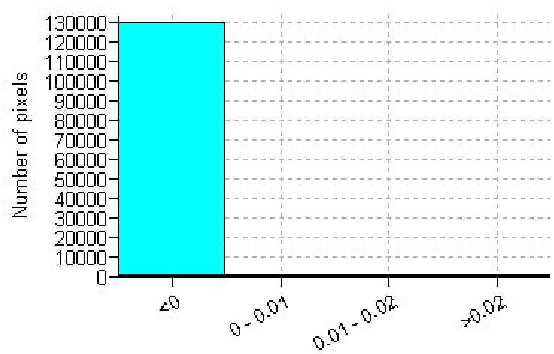


Figure 6.43: The difference in water depth after the embankment break at Sabang after 198 hours

Level in meters	048hours	102hours	198 hours
<0	85	85	76
0- 0.05	14	4	1
0. 5 - 1	0	3	8
>1	0	6	13

Table 6.6 The analysis for embankment break at Sabang

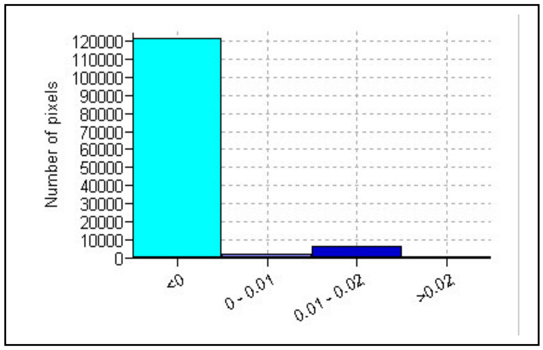


Figure 6.44: The difference in water depth after the embankment break widened at Sabang after 48 hours

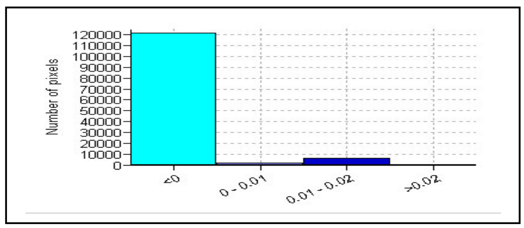


Figure 6.45: The difference in water depth after the embankment break widened at Sabang after 102 hours

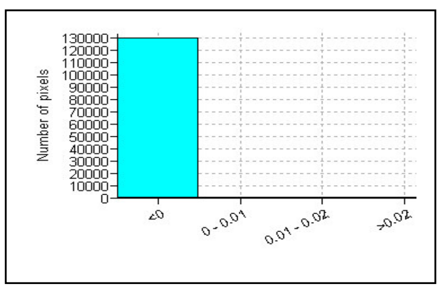


Figure 6.46: The difference in water depth after the embankment break widened at Sabang after 198 hours

Level in meters	048hours	102hours	198 hours
<0	85	85	76
0- 0.05	14	4	1
0. 5 - 1	0	3	8
>1	0	6	13

Table 6.7 The analysis for embankment break at Sabang

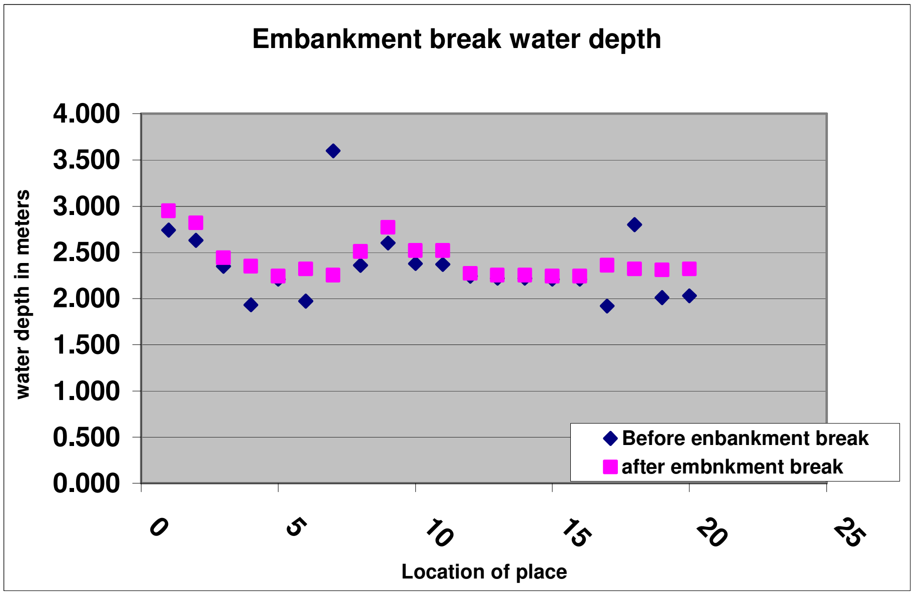


Figure 6.47: The comparison of the predicted water depth values before and after the Embankment break at Sabang

6.8. Scenario results for flood hazard assessment

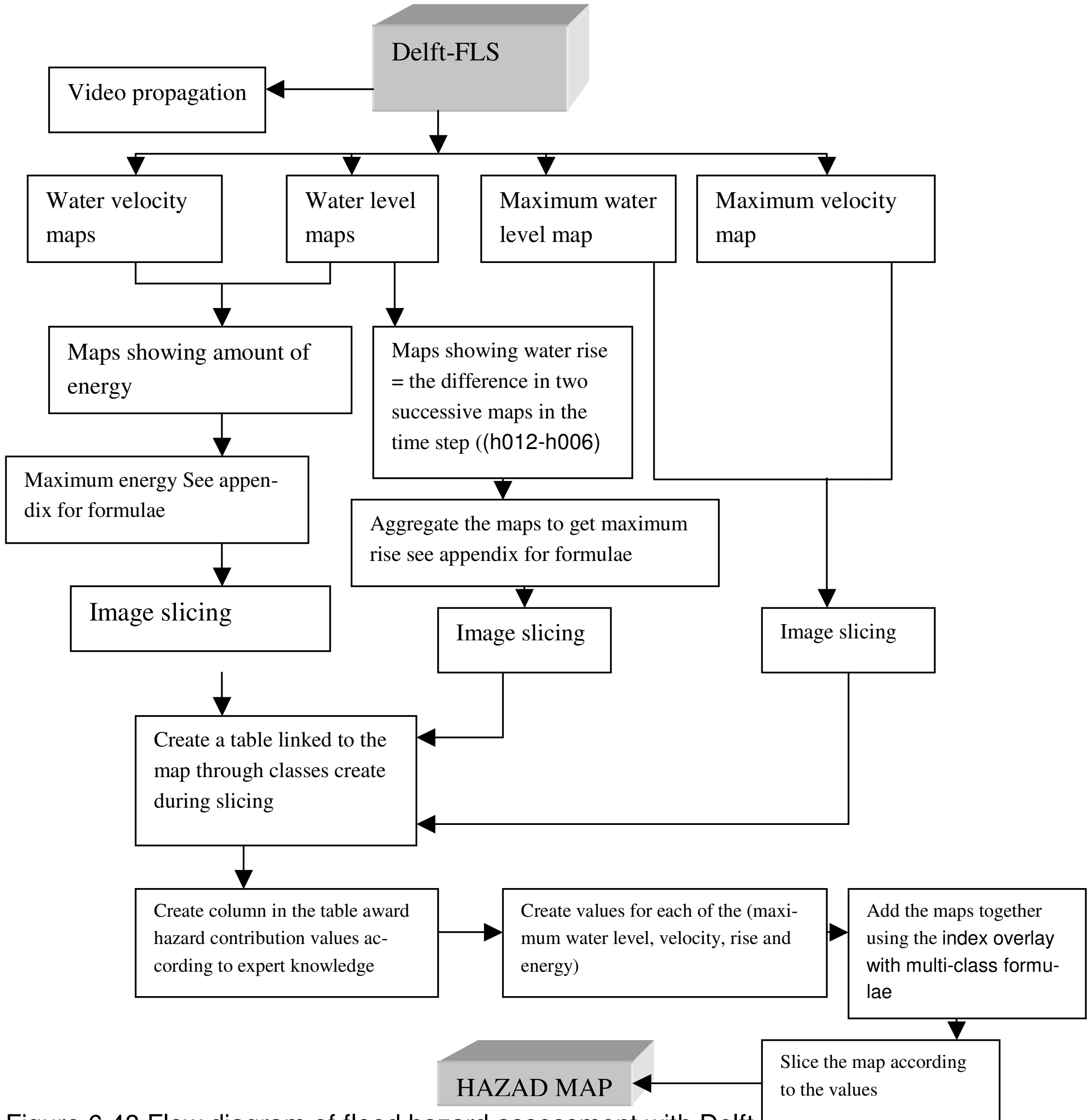


Figure 6.48 Flow diagram of flood hazard assessment with Delft-FLS

Using the model results from the 1000hrs yoning scenario 2(6.2) where maps were generated at an interval of every six (6) hours showing the velocity and the water level a total 332 maps generated for flood hazard assessment. Apart from the 336 maps the model generated one map showing the maximum water level during the flood and a maximum speed map. All these maps are imported into ILWIS for further analysis.

6.9. Parameterisation

6.9.1. Maximum water level and Maximum Velocity

These two maps were generated in section 6.3 Scenario2 and figure 6.3

6.9.2. Maximum water energy

The maps showing speed of water and level of water were multiplied and aggregated to get the maximum water energy. The formulae applied was based on energy is mass *velocity^2 over a given period of time. A of total of 166 maps were generated with one map which was aggregated to show the maximum energy. See appendix 13

6.9.3. Maximum water level rise

The water level rise was calculated by getting the difference of the water level map (h) between to successive maps (h012-h006); that is if h012 is the map that is created after h006 considering the 6-hour difference. The maps were aggregated to derive the maximum water rise. To calculate the maps and aggregate a script was written and run in ILWIS

6.10. Flood hazard Map

The maps created for the maximum flow velocity figure 6.3, maximum water depth figure 6.3, maximum energy and maximum water rise figure 6.49 were used to create the flood hazard map in. Using the histogram to decide on the class limits these maps were sliced to various classes table 6.8 – 6.11. Four maps were generated 6.51. Linked to each map an attribute table was generated with the domain of the classes in the maps 6.8 – 6.11. Using the index overlay with multi-class method a column was created in the table and each class weighted according to its contribution to the hazard, the maps were also individually weighted according to the maps contribution to the hazard. These maps were then added together to get one map that was sliced to get the final hazard map.

area.

	hmax
0 - 0.5	2.0
0.5 - 1.5	3.0
1.5 - 2.5	4.0
>2.2	5.0

Table: 6.8 Maximum water depth classes

	cmax
0 - 0.05	2.0
0.05 - 0.1	3.0
0.1 - 0.2	4.0
>0.5	5.0

Table 6.9: Maximum Speed

	implusemax
0 - 0.05	2.0
0.05 - 0.2	3.0
0.2 - 0.5	4.0
>0.5	5.0

Table 6.10: Maximum water energy

	risingmax
0 - 0.1	2.0
0.1- 0.5	3.0
0.5 - 1	4.0
>1	5.0

Table 6.11: Maximum rising

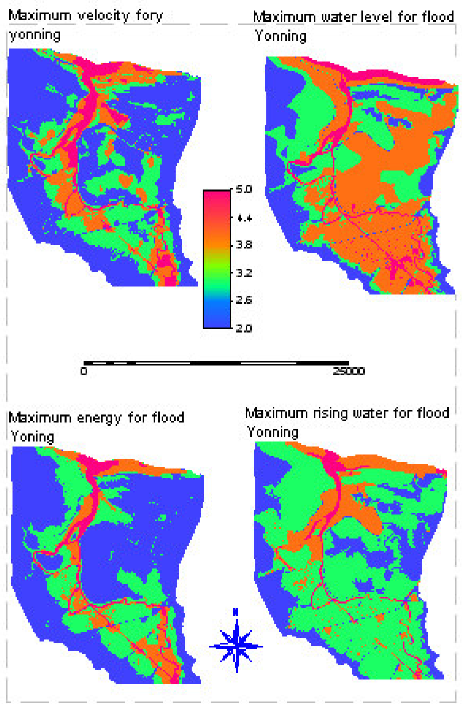


Figure 6.49 The aggregated map of the hazard in the floodplain

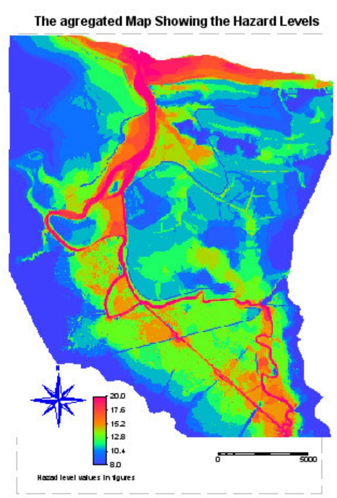


Figure 6.50: The aggregated values for flood Yonning from expert knowledge

The maps for the generation of the hazard map were aggregated from expert knowledge and reference to literature. Figure shows the representation of each of the hazard parameters after the expert knowledge input. These maps were added together and sliced to get the final Hazard map figure. The values of these maps determined the final hazard level of the

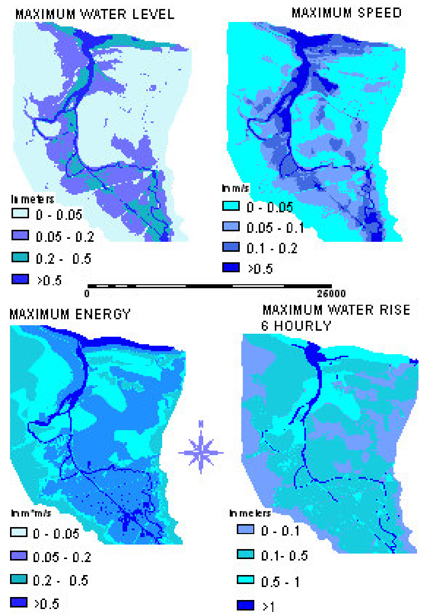


Figure 6.51: The classes of the flood hazard Maps

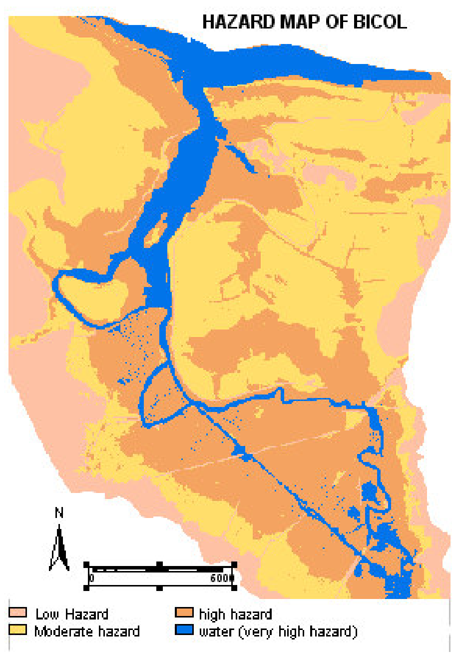


Figure 6.52: Hazard Map of Bicol floodplain

In figure 6.52the low hazard indicated a low input values from the original maps created from expert knowledge figure 6.37 and high hazard indicated a high input values.

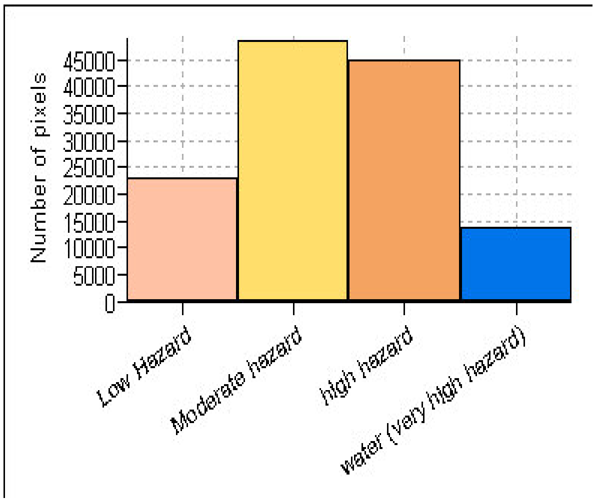


Figure 6.53 the hazard levels in the Bicol flood plain

6.11. Flood hazard Management

6.11.1. Delft-FLS model outputs (Velocity and Water level)

The water depth and velocity maps were used to identify the areas where the water depth was and speed high, the extent of the flood was also determined from these maps. The identified areas were to be prioritised for flood alleviation and further assessment.

6.12. The model scenarios for hazard management

The scenarios where an embankment was introduced to examine the contribution of the structures to the propagation of water over the flood plain. These scenarios in water depth and flow velocity compared with the scenarios without embankment. The difference
Are attributed to the presence of the structures that are on the flood plain. Using the method described in 6.8 a hazard assessment can be made for the new situation, where the hazard has decreased, then the structure was beneficial, but in those areas where the flood hazard has increased, then the structure has enhanced the effects of the flood, this information is useful in the evaluation of the construction of structures on the floodplain

6.13. Disaster management

The water arrival time maps were used to look into the possibilities of managing flood disaster. These arrival time maps when overlaid with an infrastructures map with roads and location of towns, by looking at the location of the roads and the towns the most accessible roads that could be used during the disaster could be easily identified and the areas where people could be moved were possibly identified the amount of time the management had to move the people was also possibly determined. The main use of disaster management in Delft-FLS is the capability of simulating a future flood and preparing for such an occurrence looking at the possibility and the availability of the infrastructure, and also for preparedness during a disaster

The water arrival time at different areas in the flood plain was derived by picking maps at different time steps from the velocity maps; the maps picked were at every 24 hours. A script in ILWIS was used to pick out the areas that had water above zero at the particular time steps. By developing another command script in ILWIS the areas that were newly flooded were identified. These were then used to determine how fast a flood hazard would set at different locations.

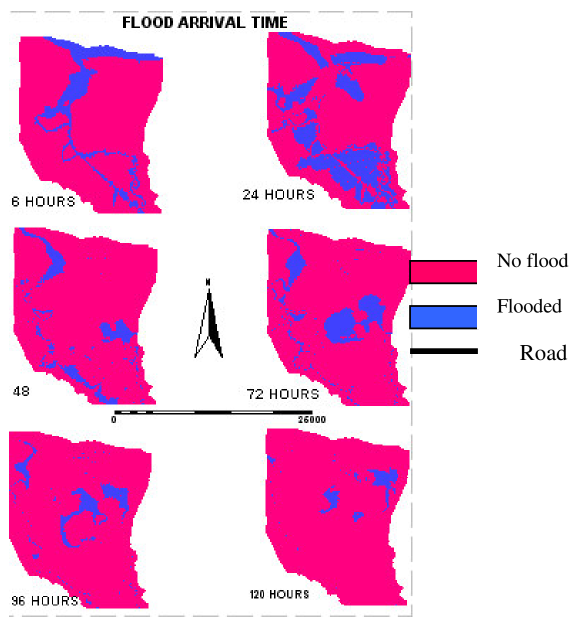


Figure 6.54: Flood arrival time at different location after every 24 hours

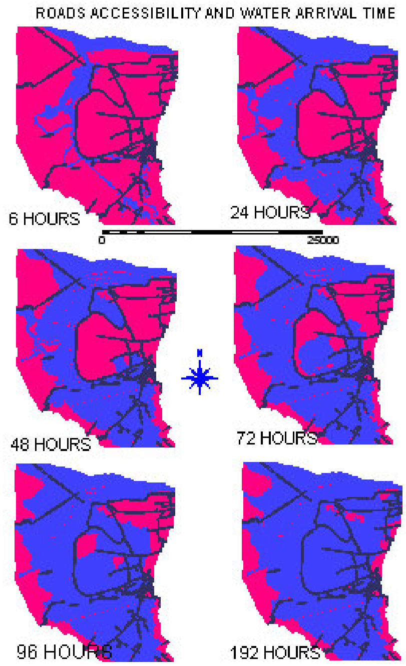


Figure 6.55: The road accessibility and flood arrival time for hazard management

Chapter 7

7. Results

7.1. The DEM (digital elevation model) of the floodplain

The root mean error on the upper (northern) figure 4.2 was greater then two the for Three maps covering that area and the root mean error on the lower (southern) figure 4.1 was less than 0.7 for all the 36 maps covering the area. 4387spot heights were used for the DEM 2/3 of these spot heights were used for the lower (southern) while only 1/3 was for the upper (northern) part. The errors were locally adjusted for the final DEM.

7.2. The DEM of the riverbed

	water_height
Bicol estuary	-1.7
Bicol river	-2.3
Channel	-2.5

Table 7.1: The average water heights of the main water channels

The roots mean error of the DEM of the riverbed figure 4.4 was less than 0.7 of a pixel for the entire segment maps glued together. The errors as a result of poor fitting were locally adjusted with reference to the river cross sections. The values used for the DEM Construction table 6.1 were averages calculated from the cross-sections of the river

7.3. The embankments.

The values used for embankments heights were actual heights from field observations as included in the report, they compared well with the field observation results.
See appendix for embankment heights as used in the model (figure 6.4)

7.4. DEM final

The values of the final results of the Dem of the flood plain fitted for the model input. The result DEM final figure 4.8 included (DEM floodplain figure 4.3, DEM of the riverbed figure 4.4, and the embankments figure 4.6)

7.5. Roughening the river channel and the floodplain

	Mannings
Coconut	0.200
Cut-off channel	0.080
Embankment	0.200
estuary	0.025
Non-Arable land	0.001
Residential area	0.200
Rice Paddys	0.100
Road	0.100
Water	0.025

Table 7.2: The Manning's coefficient values for the land cover classes

The results for the Manning's coefficient showed that the variability of the Manning's coefficient was small within the floodplain and ranged from 0.001 to 0.2 and 0.025 to 0.08 in the river channels table 7.2. The classes of the land cover divided up to level two in the Corrine method of land classification figure 3.3. The Manning's coefficient values were adapted to the present situation on he ground

7.6. Model Validation

7.6.1. Model extent

The predicted flood extent of Delft-FLS and Mike-11 agreed eighty five percent though it should be noted that Mike-11 is 1D model and Delft-FLS is a 2D model. Figure 5.1 to 5.5 and table 5.3

7.6.2. Water depth

The water depth values as predicted by Delft-FLS at different locations in the floodplain had an 80 percent correlation with the field observation values and seventy five percent correlation with Mike-11 predicted values at the same locations.

These compared values suggest that Delft-FLS model is possibly predicting with some percentage of accuracy.

7.7. Model Sensitivity

7.7.1. Manning's Coefficient values on water depth (roughness of the flood-plain)

In the water depth analysis the difference of the water depths and the correlation of the values at various locations were observed.

Water depth difference with Manning's_2: figure 6.8 – 6.10 and table 6.2

After forty eight hours fourteen percent of the area had experienced water depth change between 0 – 0.5m

After one hundred and two hours four percent of the area had experienced a change of 0 – 0.05m, three percent had experienced 0.05 – 0.1m and six percent had experienced more than 0.1m

After one hundred and ninety eight hours one percent had experienced 0 – 0.5m, eight percent had experienced 0.05 - 0.1m and thirteen percent more than 0.1m.

Water depth difference with Manning's_3: figure 6.11 – 6.13 and table 6.3

In the water depth analysis the difference of the water depths and the correlation of the values at various locations were observed.

Water depth difference with Manning's_2: figure 6.8 – 6.10 and table 6.2

After forty eight hours ten percent of the area had experienced water depth change between 0 – 0.5m

After one hundred and two hours twenty percent of the area had experienced a change of 0 –0.05m, seventeen percent had experienced 0.05 – 0.1m and seven percent had experienced more than 0.1m

After one hundred and ninety eight hours one percent had experienced 0 – 0.5m

Water levels in relation to Manning's see figures 6.17 – 6.22

After 48 hours the values were correlation had a 96 percent correlated with a prediction confidence of 96 percent

After 102 hours the values were 98 percent correlated with a prediction confidence of 1percent

After 198 hours the values had a 97 percent correlation with a prediction confidence of 16 percent

Water speed in relation to Manning's see figures 6.21 – 6.26

After 48 hours the values were correlation had a 96 percent correlated with a prediction confidence of 98percent

After 102 hours the values were 96 percent correlated with a prediction confidence of 99percent

After 198 hours the values had a 61 percent correlation with a prediction confidence of 66 percent

Water depths in relation to embankment movement at see figure 6.27 to 6.32 and table 6.5

After forty eight hours one percent of the area had experienced water depth change between 0 – 0.5m

After one hundred and two hours nine percent of the area had experienced a change of 0 – 0.05m and four percent had experienced 0.05 – 0.1m

After one hundred and ninety eight hours three percent had experienced 0 – 0.5m, seven percent had experienced 0.05 - 0.1m and twelve percent more than 0.1m.

Water depth in relation to embankment movement and changed Manning's coefficient see figure 6.27 to 6.32 and table 6.5

After forty eight hours fifteen percent of the area had experienced water depth change between 0 – 0.5m

After one hundred and two hours ten percent of the area had experienced a change of 0 – 0.05m, four percent had experienced 0.05 – 0.1m and one percent more than 0.1

After one hundred and ninety eight hours five percent had experienced 0 – 0.5m, seven percent had experienced 0.05 - 0.1m and twelve percent more than 0.1m.

Water depth in relation to embankment Break at Sabang see appendix for location map see figure 6.40 to 6.43 for analysis

After forty eight hours fourteen percent of the area had experienced water depth change between 0 – 0.5m

After one hundred and two hours four percent of the area had experienced a change of 0 –0.05m, three r percent had experienced 0.05 – 0.1m and six percent more than 0.1

After one hundred and ninety eight hours one percent had experienced 0 – 0.5m, eight percent had experienced 0.05 - 0.1m and thirteen percent more than 0.1m.

Water depth in relation to embankment break widened to 500m at see figure 6.44-6.46

After forty-eight hours fourteen percent of the area had experienced water depth change Between 0 – 0.5m

After one hundred and two hours four percent of the area had experienced a change of 0 – 0.05m, three percent had experienced 0.05 – 0.1m and six percent more than 0.1

After one hundred and ninety eight hours one percent had experienced 0 – 0.5m, eight percent had experienced 0.05 - 0.1m and thirteen percent more than 0.1m.

From the analysis the results suggest that the change of Manning's coefficient values does not create significant change in the model prediction of values as the results show that the percentage of the affected area is less than twenty percent and the values are between 5cm to 10 cm at any one level. However it is good to not that the speed of the flood does get influenced by the changes as the confidence of prediction stays high

The embankment movement does cause change in the water depth in the flood plain as more areas is inundated

The embankment break has an impact on the model water depth prediction

7.8. Flood hazard assessment

The maximum water level and the velocity could be used to generate maps that could enhance the understanding of the hazard characteristics and hence hazard assessment.

Chapter 8

8. Discussions

8.1. Dem of the flood plain

8.1.1. Data for the DEM construction

The data for the DEM construction lays the foundation for all the modelling and should be as accurate as possible. The data that was used for the modelling was from various sources with varying accuracy. Seventy five percent of the data was very accurate at the scale of 1:4000 and the rest was at the scale of 1:50 000. The variation of the accuracy of the data can limit the accuracy of the final DEM and hence introduce error in the results of the model. The data that was used was carefully adjusted and the results achieved compared with the previous results on the flood plain showed the location of the features correct within the flood plain

In Delft-FLS model the DEM is used to identify features on the topography such as valley Bottoms, channels, sizes, lengths and slopes the accuracy of the representation of these features depends on the resolution of the Dem and the DEM processing algorithms (Maidment, et al 2000). During the DEM construction for flood plain the upper part of the DEM was not as explicitly represented as the lower part, due to the difference in scale of the available data. The area that was represented with maps of 1:4000 was more accurate than the one represented by 1:50 000 maps, because 1cm on the map at 1:4000 represented 4000cm on the ground, which is 4000*4000 cm^2 =40m*40m=1600m^2 on the ground While the area which is represented by the 1:50 000, 1cm on the map represented 50 000 cm which is 50 000*50 000cm =500m*500m=250000m^2 on the ground. The amount of detail available in the 1:50 000 map is much less than the one in the 1:4000 map because in both cases only 1cm space is available on the map so one map must be more generalised than the other hence reducing the accuracy under which it can represent information. This information is further compromised by the size of pixel that has been used for the DEM construction where each pixel on the DEM is 50*50 that is 2500 m^2. Therefore the accuracy of information representation has been compromised and could lead to errors during interpolation and errors in the final model results.

8.1.2. Construction of the DEM riverbed

The river channel size and width compared to the (BRBFCIDP, 1991) was correct but the values used in the interpolation of the depth of the river were the average depths of each channel (Bicol, Cut-off channel 1, cut-off channel 2, cut-off channel 3) this could lead to accumulated errors as one of the basic requirement in Delft-FLS is the development of an accurate DEM of the river channel and all the important water features that influence water flow over the topography should be explicitly described for more accurate analysis (Stelling, et al). This could compromise the results of the model prediction.

The gluing together of map segments at specific points with different scales had to be adjusted due to poor fitting, the adjustment was locally carried out, this could easily introduce errors into the channel width and contribute to errors in the final results in the model

8.1.3. The Embankments

The constructed embankments are the indication of the measures that are already in place for hazard management. Their contribution to flood propagation as reported by the previous researchers (BRBFCIDP, 1991) reports. The placement of the structures within the flood floodplain should be as accurately replicated as possible in the model because of their significant influence on floodwater. The model results have appeared to be very sensitive to the presence and dimensions of obstructing elements in inundation simulation (Hesselink, et al, 2000). Their contribution to the results is significant in flood hazard and disaster management, it is important to take note that the results in the embankment placement could be compromised from having to use two types of information in their construction though the errors would minimal as the areas that were put together were at specific points.

8.1.4. Hydrological data

The availability of the hydrological data is the backbone of the success of the simulations. The data used in the simulation for the typhoon Yonning was derived form the actual observations for detail, the derived data when compared with the results used showed agreement with the observed by (BRBFCIDP, 1991). The availability of longer period of data during the typhoon yonning improved its predicting capability as when it was modelled for 80hours covering the actual time that the flood was at its peak the results showed incomplete results.

8.2. Model Validation

8.2.1. Flood Extent

The validation of model results gives reliability to the outputs of the model, and the closer the results are to the reality the more reliable the model. In modelling uncertainties result from various error sources, in the model, in the parameterisation, in the data and calibration

(Hesselink, et al). In the comparison of model result with other results flood extents was used to calibrate and validate the extent (Hesselink et al, Bates et al, 1998, de Roo, 2000). The model results compared to the previously modelled extent by (BRBFCIDP, 1991) the results are not compatible; at all places and approximately 12% of the area modelled was over estimated by Delft-FLS. This result showed good success in the performance of the model in handling the data, though it should be noted that this was note expected, as part of the data that was used was not at the required accuracy and needs further redefining.

The model over prediction can be attributed partly to the DEM construction method as the resolution of the DEM was 50m pixel size implying that 2500 sq m was represented in as one pixel, considering that this is a flood plain where even small differences in the topography can make a lot of difference especially in calculation a lot of detail must have been compromised.

In the model water movement is very important and this expressed by the difference in elevation if the difference in elevation was less than a whole digit and during construction this was lost because of the resolution of the DEM this movement could easily be expressed as same level creating no water movement and having water paddle. This could have easily contributed to the errors in the model results.

The expression of the water channels were very coarsely represented because of the DEM pixel size, if the pixel sizes were more refined and the available data more accurate the fitting of the segment would be more accurate and the expression precise expresses this would definitely have contribute to the over estimation of the flood extent during this typhoon.

8.2.2. Observed values

The values that are observed during the actual event show the true representation of the real world event, but even these values have limitation. Evaluation of each model is based on the comparison between the observed and the predicted (Romanowicz et al, 1998). In many cases we find that it is difficult to get the information at the actual time the event is taking place, as there is always danger or impossibilities, and this can in given circumstances compromise the observed values. Accuracy in the validation and calibration of the model depends on the availability of such data. In Bicol floodplain this data was used and the comparison of the observed and the Delft-FLS showed good consistency though the model gave results that were higher than the actual observations that could be attributed to other sources.

8.2.2.1. Wind speed

Wind is the main source of storm surges in this region and if not all most of the floods have wind speed contribution. During the analysis wind speed was not included, this would have probably contribute to the discrepancies in the water level results.

8.2.2.2. Reading

Errors in reading occurs in relation to the human judgment and due to the instrument

8.2.2.3. Fluxes

The fluxes within the flood plain can, can influence the final results in model prediction (Maidment, et al 2000). The contribution of the other fluxes such as rain, infiltration, and evaporation, were not considered hence their contribution could have contribute to the difference in the model results

8.3. Flood Hazard assessment

The flood hazard assessment in 2D Delft-FLS gives the understanding of its characteristics in several parameters enabling it to contribute more precisely to decision-making as it not only depends on one parameter but several contributing factors. The parameters can further be aggregated to give more insight into the behaviour of the hazard. The results from the analysis showed there is a positive correlation between the hazard parameters and the areas where they occur indicating an underlying common factor to the hazard. The assessment using these parameters The analysis set out as the beginning of many analysis have a potential of giving excellent guide lines into ways of determining the destructive force of water at given areas in the floodplain.

Parameters (speed, water levels, rising water and water energy)

During the typhoon Yonning More than 21 percent of the floodplain experienced high water speeds of more than 0.1m/s, fifty percent experienced high water levels of more than one and a half meter, 20 percent had water rising at a half meter and fifteen percent experienced water energy of more than 0.2m*m/s.

The hazard

During this flooding more than fifty percent of the flood plain suffered from severe flooding And the rest suffered from low to moderate flooding see figure:

Chapter 9

9. Conclusion

1 In the observations and the results 2d modelling with Delft-FLS was used to reproduce the observed historic flood Yonning with enough accuracy, the results that were achieved were generally comparable to the observed results that had been achieved during the (BRBFCIDP, 1991) and field observations but like any other software the Delft-FLS too has limitations which need further tuning before can be further applied

2 The model tested for the effect of the changes in Manning's coefficient changes showed very little significance to the values. This indicates that the changes in Manning's coefficient values do not create a significant difference in the model prediction. Therefore the roughness of the terrain does not influence the model prediction very much

3 The structural changes like the movement of the embankment to closure showed very significant changes in the models prediction of the water levels and velocity. Hence the changes in structures within a flood plain can cause a large difference in the predicted values. This proved to be more localised and affected especially the areas near where the structures was moved, this was not the case in the whole flood plain, as in some areas there was little difference in the water level and velocity prediction. the areas the upper catchment's experienced much more change that the area towards the lower catchments

4 2d modelling can be successfully used for hazard assessment as the water deth gives the indication where the depthl of water is the highest. The water depth combined with the DTM gives the level of water at every given location in the flood plain the higher the water depth the more damage it can do, depending on what is on the surface

5 The velocity at which the water is moving shows how much momentum it has the higher the momentum the more sweeping away that can be done, especially on the soils and loose particles

6 The combination of the water depth plus the speed shows the amount of force the water is carrying, the higher the value the more the energy it has and this can give the force at which this water can do distraction.

7 The water depth is used to determine the rising of water at given time steps in the flood plain the faster the rising the higher the hazard, this gives the indication of the likely flood arrival time, the faster the arrival time the less the time for warning the more the danger.

8 The embankment break at sabang has cause the area to be more inundated compared to before the embankment break

9 2D models can be used for hazard management. This is fulfilled by its capability to be sensitive to structures like the embankments. The developing of scenarios and different positions for the structures within the flood plain can contribute in hazard management. This capability can enable the simulation of future flood conditions and test the structures on the ground to help in the hazard management. As observed in the embankment move in the model the areas where the embankment was moved became very safe. The local authority can also use the model to determine the contribution of the structures on the ground for flood control where some structures moved can reduce flood susceptibility of one area to completely safe and increase the susceptibility of the other area to 100 percent so it can be used successfully to determine the safety of the construction in the plain to avoid flood.

10 2D modelling can help the local authority in disaster management. The disasters which can occur can be simulated as the past typhoon Yonning was simulated and characteristics of future floods used to see the capability of features like roads and open higher ground which can be used for temporary evacuation this can be simulated by laying the roads and the flood arrival at various points in the flood plains and view the areas which are likely to inundated first, and the depths at which they are inundated this will contribute in the planning and the management of the disasters

11 The capability of the 2d models in producing flood hazard map from the assessment parameters makes it a tool that can be used in quick assessment of the hazard in the flood plain and for management and integrated understanding of the flood behaviour in the area it enhances clear understanding of the reasons why the hazards are more severe at one locations than the other. The management can interactively view the decisions on the planning of the areas, which are more vulnerable hazards

12 The video capability of the Delft-FLS 2d model enables across- board the local authority to communicate the flood problem interactively with the stake holders the management of flooding in the area

13 The embankment break causes the area around Naga calabanga to surfer more flood inundation that would otherwise be. This also shows the capability of Delft-FLS model in being able to allow for the prediction of water depths at different places in the flood plain.

Chapter 10

10.Recommendations

- There is need for further refining of the data for model input for area on the upper part of the flood plain where the data was not as accurate as the lower part and using finer contour intervals than the 1m interval used since the maps are at 0.25m contour interval.
- The riverbed should be reconstructed using the actual data not the average for more accuracy on the DEM of the riverbed and the
- DEM should be tried at more refined pixel size for more accurate results.
- The model needs to be tried with more typhoons to clearly define it prediction capabilities Because using only one typhoon can give bias in the results for comparison and further calibration.
- The model needs more data on the floods for comparison with model especially the area that was note visited
- The data on the embankment break at sabang needs to be more detailed as to the time of the embanment break and the size of the break, this data was not collected
- The setting up and using of delft-FLS depends on data availability and the accuracy of the available data, for good and reliable results, this requires the local government to set up a data base where the information can be stored and retrieved for updating and for use.
- The model requires training and manpower development, there is a need for in-house training,where the majority will train on basic GIS data capture manipulation analysis and management and a few will be given longer training on the management and manipulation of this data in the model and the general

- The all round management of the hazard is important where all stake holders can have a session in training with the video shows from the model and see the impacts of the flood, At the present condition and in the future, the simulation of The analysis using the flood model Delft-fls for the bicol flood plain indicates very positively

- Computer infrastructure is important for the simulations and the running of the model
    - that the model can be used by this local government to manage flood in this city. Naga city does not have an infrastructure and enough capacity to Manpower

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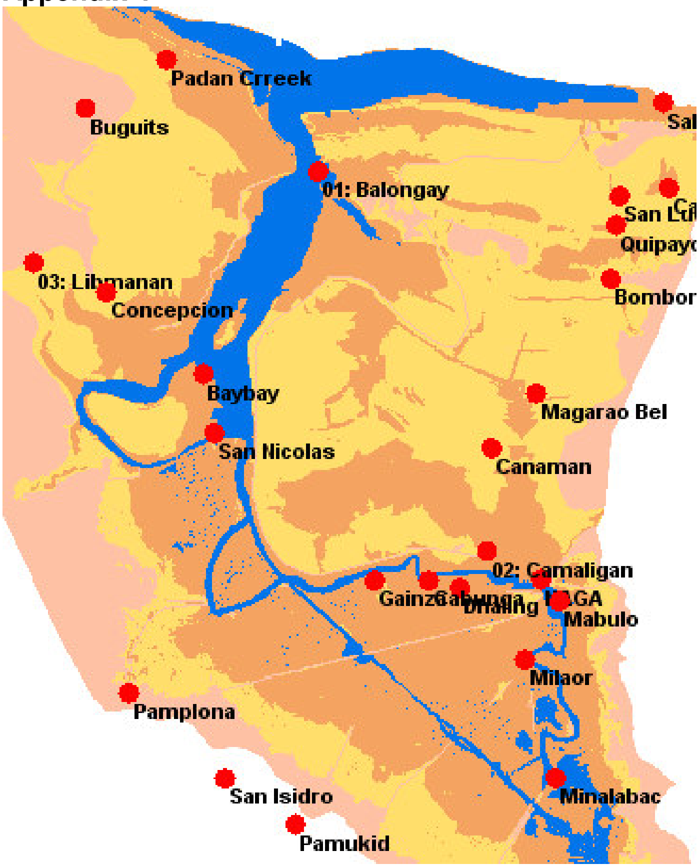
Appendix-1



Field work locations.

Appedix-2 Field work data

	Station	Y-Axis	X-Axis	Landcover	Water level	Heieght of the area	Flood	Flood height
1	Bridge	1501178	509328	Trees upto 2km away from the road with rice paddys in the background	5.3m	-	-	-
2	Bridge	1501101	509859	Trees upto 2km away from the road with rice paddys in the background	5.2m	-	-	-
3	Naga Bridge	1505757	519652	Continuous housing in the road sides	6.2m	-	loleng	2.0m
4	Canal	1503843	519058	Continuous housing in the road sides	1.4m	-	-	-
5	Bridge	1503610	518885	Continuous housing in the road sides	3.0m	-	-	-
6	Bridge/ Canal	1501844	517204	Trees upto 2km away from the road with rice paddys in the background	5.5m	-	-	-
7	Bridge	1501448	516823	Trees upto 2km away from the road with rice paddys in the background	3.9m	-	-	-
8	Bridge	1500711	515854	Houses constructed into the bridge continuous type of housing, rice paddys in the background	3.7m	-	loleng	0.9m
9	Bridge	1499587	513074	Continuous housing in the road sides	5.9m	-	-	-
10	Bridge/ San Isioho	1499553	518055	Continuous housing in the road sides	5.5m	-	sisang	5.5m
11	Bridge/ San Isiohio	1499553	518055	Buildings besides the the roads rice fields about 2km from the road there is a running channel besides the	5.5	-	loleng	3.0m

				road the area is MAKARAO				
12	Bridge/ St.gabriel	1500816	510860	Buildings besides the the roads rice fields about 2km from the road there is a running channel besides the road the area is MAKARAO	5.0m	-	-	-
13	Bridge/ Pahoho	1500947	510356	Buildings besides the the roads rice fields about 2km from the road there is a running channel besides the road the area is MAKARAO	4.2m	-	-	-
14	Road	1505696	519255	Rice and coconut along the road and in the back farm areas	-	1.0m	sisang	1.0m
15	Bridge/ Tarusanam	1505712	518635	Rice and coconut along the road and in the back farm areas	3.1m	-	-	-
16	Bridge	1505770	517450	Continuouns building along thre roads and rice fields behind these houses	5.0m	?	?	1.0m
17	Canal	1505790	516540	Rice fields covering from the road on both sides with underlying water cover	2.0m	-	-	-
18	Bridge	1505788	516540	Rice fields on both sides of the road the bridge has stangnat water	1.0m	-	-	-
19	Bridge	1505765	514946	Rice fields on both sides of the bridge	3.0m	-	-	-
20	Creek/canal	1509127	519720	Built up areas around the roads and rice paddys in the back, mixed banana planttions also along the roads the area is in CANA-	1.1m	-	monang	1.2m

				MAN (BA-RASS)				
21	Road	1509760	519447	Vegetation cover and houses solid buildings rice paddys in the background the area is CANAMAN	-	2.5m	monang	2.5m
22	Canal	1509833	519442	Buildings be-sides the the roads rice fields about 2km from the road there is a running chan-nel besides the road the area is MAKARAO	1.3m	-	-	-
23	Canal	1510880	520508	Buildings along the roads rinning channel bes-dides the road MAGARAO AREA	2.2m	-	monang	2.5
24	Canal	1510963	520469	Buildings along the roads mixed with bananas and trees the paddy fields are in the background MAGARAO AREA	1.4m	-	all	0.5m
25	Road	1510988	520503	Rice paddys along the road MAKARAO	-	1.3m	no floods	-
26	Road	1510988	520503	Rice paddys	-	1.3m	-	-
27	Road	1511297	521647	Rice paddys	-	1.2m	-	-
28	Road	1512292	522127	Rice continu-ously on one-side of the road and di-contnuos ur-ban cover on the otherside	1.2m	1.2m	-	-
29	Bridge	1513557	521463	Rice fields BOMBON BRIDGE the bfloodds the remain in the bridge the contnuoson the road sides	2.6m	-	all floods	2.6m
30	Canal	1513631	521453	Rice fields and contnuous buildings along the road	2.1m	-	all floods	2.1m
31	Road	1513631	521454	Paddy fields	-	1.2m	-	-

				and scattered buildings				
32	Road	1515768	521921	Buildings on the road before discont-nuos rice paddys on the road sides no overflowing during floods		1.15	all floods	1.2m
33	Road	1516450	522996	Rice paddys discontinuous urban set up dye 0.8m		0.6m	all floods	0.6m
34	Canal	1516480	522989	Continuous Urban on both sides of the roads rice paddys at the back	0.8m	-	-	-
35	Road	1517687	522966	Rice fields surrounded by coconut trees mixed with homesteads area is SALVALION	-	1.2m	-	-
36	Sea side	1517387	522964	Sea on one side and continuous urban cover on the other side nipa palms found	10.0m	-	Rosing	5.0m
37	Road	1518311	522846	Sea on one side and continuous urban cover on the other side nipa palms found	-	1.3m	Rosing	5.4m
38	Canal/Bridge	1515743	521181	Continuous buildings on the roadside with rice paddy's in the background	2.5m	-	Rosing	1.8m
39	Road	1515674	519642	Rice and building along the roads during the floods warers drain into the paddy fields the area is SANTO DONINGO CALABANGA	-	0.4m	no floods	-
40	Road	1515675	519642	The rougness changes from this point and becomes more trees palms and rice paddys as fom the	-	1.2m	Rosing	0.5m

				covering od mixed housing and trees				
41	Bridge	1515675	518195	Bananas and trees along the road and rice paddys at the back the area is SANTO DOMINGO ZONE 6 DARWIS	-	1.0m	Rosing	0.5m
42	Bribdge /Canal	1516076	516456	All road sides covered with rice fields and low grasses surrounded in the outer areas with coconut trees the floods do not get to the houses	2.7m	-	Rosing	1.7m
43	Road	1516797	515690	Fish farming, coconut trees rice paddys and Palm trees. The land cover along the roads is discontuous with mixed vegetation. The nipa pams are dominant	-	0.8m	Rosing	1.5m
44	Bridge	1516991	515496	Bananas and coconut trees nipa palms DOMNIERO BRIDGE	1.3m	-	-	-
45	Bridge	1516888	515220	Nipa palms grass and trees BALON-GAI BRIDGE	3.7m	-	Rosing	1.7m
46	River side	1516602	513725	The land cover along the river are nipa palm trees and some continu-ous urban set up The area name is BA-LONGAI	2.0m	-	Rosing	1.0m
47	Road	1469265	572547	Rice fields and contnuous urban and mixed vegeta-tion CANA-MAN MAGA-RAO boundary	-	-	-	-
48	Road	1469265	572547	Contimuous urban set up	-	0.8m	all floods	1.0m

				along the road with rice paddys in the back area				
49	Bridge	1510769	519464	Continuouns urban set up with rice paddys in the background	2.2m	-	all floods	1.4m
50	Bridge	1510800	518923	Continuouns urban set up with rice paddys in the background SAN FRANCISCO MAGARAO	4.2m	1.2m	-	-
51	Road	1510690	518804	Continuous urban set up and rice paddys at the back MAGARAO	-	1.8m	all floods	1.1m
52	Bridge(under bridge with the canal	1510701	518776	Mixed vegetation and continuous urban set up the bridge and the canal cross BELL MAGARAO	0.9m	-	all floods	0.55m
53	Canal	1510701	518776	Mixed vegetation and continuous urban set up BEE MAGARAO	0.8m	-	all floods	0.4m
54	Canal	1510755	518539	Continuous urban set up rice paddys in the back TALIDTID	1.8m	-	all floods	0.8m
55	Bridge	1510821	517724	mixed landcover along the road the rice paddys in the back	1.3m	0.4m	all floods	-
56	Road	1510829	517717	Rice paddys on both sides of the road coconut trees enclosing the paddys	1.0m	0.3m	all floods	1.5m
57	Canal	1510868	517434	Mixed vegetation along the roads and rice paddys in the back	1.1m	-	all floods	0.4m
58	Canal	1510892	517295	Mixed vegetation with rice paddys in the back	1.1m	0.3m	all floods	0.9m
59	Canal	1510897	517233	Mixed vegeta-	1.3m	0.2m	-	1.3m

				tion with rice paddys in the back				
60	Canal	1510913	517088	Rice fields in all sides of the road	1.5m	0.2m	Rosing	0.4m
61	Canal	1510946	516866	Rice fields in all sides of the road and at all stages planting harvesting and planting	1.6m	0.1m	Rosing	0.5m
62	Canal	1511165	515416	Mixed vegeta-tion and con-tinuous urban cover	3.9m	2.0m	Rosing	2.2m
63	Road	1511163	515419	Mixed vegeta-tion and con-tinuous urban cover	1.0m	0.5m	Rosing	0.8m
64	Canal	1511198	515231	Rice paddys on both sides	1.5m	0.1m	Rosing	0.6m
65	Canal	1511354	514079	Discontinuous urban cover with rice pad-dys in the background	2.0m	0.1m	Rosing	0.4m
66	Bicol River	1511247	512091	Discontinuous urban cover with rice pad-dys in the background	1.3m	0.3m	Rosing	0.6m
67	Road junction	1511230	511948	Continuous urban cover with mixed vegetation	-	0.3m	-	-
68	Canal	1509698	519431	Mixed vegeta-tion and build-ings along the road	1.1m	0.1m	Sining	1.1m
69	Road	1509524	518846	Mixed vegeta-tion and build-ings along the road rice pad-dys in the background	-	0.1m	-	-
70	Bridge	1509331	518220	Mixed vegeta-tion and con-tinuous urban set up	1.9m	2.6m	Rosing	1.6m
71	Road	1509429	518214	Rice paddys on one side of the road and continuous urban cover on the tother side of the road	-	1.1m	Rosing	0.5m
72	Bridge	1509508	518194	Mixed vegeta-tion cover along the roads and continuous	3.1m	2.6m	all floods	0.8m

				urban cover				
73	Canal	1509726	518084	Rice paddys and mixed housing along the roads	0.6m	0.2m	Rosing	0.2m
74	Road	1510478	517813	Rice cover on all sides of the roads	-	1.0m	Sinning	1.0m
75	Canal	1509068	517091	mixed housing with rice pad-dys in the background	1.5m	0.7m	all floods	1.1m
76	Canal	1509066	517090	Rice paddys on both sides of the roads	1.5m	0.7m	all floods	0.8m
77	Canal	1508920	516680	Rice paddys on both sides of the roads	1.65m	0.2m	Rosing	0.2m
78	Canal	1508784	516421	Mixed coconut and contiuous urban set up	1.9m	0.8m	Rosing	1.2m
79	Cana-man river	1508369	515885	Rice paddys along cana-man river	0.7m	-	-	-
80	Creek(poro)	1508651	514668	Rice paddys and nipa land-covers	1.9m	1.0m	all floods	2.4m
81	Bridge	1508648	514670	Urban set up with scattered vegetation NAGA BRIDGE	5.0m	5.05m	-	-
82	Road near naga bridge	1505749	519652	Continuous buildings with mixed vegeta-tion	-	0.8m	Rosing	7.0m
83	Road	1505113	519612	Continuous building wih mixed vegeta-tion	-	0.9m	Rosing	7.0m
84	Road	1504897	519378	continuous urban setup MILAOR	-	0.5m	all floods	
85	Creek	1503545	519156	Continuous urban with rice paddys in the back the area is built along bicol river	1.7m	0.9m	all floods	
86	Creek	1503487	519180	Mixed vegeta-tion and rice paddys	0.6m	0.7m	all floods	-
87	Road	1503297	519199	Rice paddys with bananas along the road	-	0.9m	all floods	-
88	Creek to bicol	1500844	519897	mixed urban and rice pad-dys in the background	1.8m	0.5m	all floods	2.0m
89	Road	1500845	519896	River bicol on one side with a dyke and a	-	0.1m	all floods	-

				contuous urban set up on the opposite side of the road with mixed vegetation				
90	Creek	1503310	508778	houses,roads for two km and then rice fields	2.6m	-	-	-
91	Road	1503306	508780	houses and trees on both sides of the roads continusly built up area	-	1.0m	-	-
92	Road	1502062	507589	Trees on both sides of the road few km away from the road side	-	4.0m	-	-
93	Road	1501581	507006	The area is bare on one sided abandoned area	-	1m	-	0.9m
94	Road junction	1501351	507610	trees and rice two km away from the road	-	0.4m	-	-
95	Bridge	1501322	508477	trees and buildings and rice paddys in the background	4.6m	-	-	5.5m
96	Bridge on bicol	1500048	521118	Rice paddys on all the sides with mixed vegetation along the river	5.5m	-	-	3.0m
97	Creek to bicol	1500026	521254	There are rice paddys discontiuous urban setup and mixed vegetation along the creek side the creek is fron Isarog mountainThe area is MALIT BOG	2.2m	1.1	Rosing	-
98	Creek to bicol	1500066	521224	There are rice paddys discontiuous urban setup and mixed vegetation along the creek	1.2	1.1	Rosing	-
99	-?	-	-	-	-	-	-	1.0m

Appendix-3

Flood water depth comparisons		
Water depth in meters		
Location	Delft-FLS	Field Observations
Minalabac	2.6	4.0
Milaor	2.5	3.5
Camaligan	2.1	2.4
Gainza	3.0	3.8
Dahiling Gainza	2.2	2.0
Cabonga	1.2	1.5
Calabanga	3.1	3.0
Magrao	1.2	0.8
Libmanan	2.5	2.8
Balongai	2.4	3.8
Baybay	1.1	1.0
Bell Magaro	1.2	1.1
Canaman	1.3	1.7
Bombon	1.8	1.5
Quipayo	1.1	1.0
Concepcion,Libmanan	1.9	1.0
Padan creek	0.8	1.0
Buguits	3.1	3.0
Naga	2.0	2.4

Appendix-4

Table 5.5:The water depths from field observations, and Delft-FLS

Comparison of water depth before the embankment break at Sabang and after		
Location	Before	After
Minalaback	2.740	2.950
Milaor	2.630	2.820
camaligan	2.350	2.440
Balongai	1.930	2.350
Calabanga	2.210	2.240
Libmanan	1.970	2.320
Naga	3.600	2.250
Gainza	2.360	2.510
Mabulo	2.600	2.770
Dhaling	2.380	2.520
Cabunga	2.370	2.520
Canaman	2.240	2.270
Bell Magarao	2.220	2.250
Bombon	2.220	2.250
Quipayo	2.210	2.240
San lucas	2.210	2.240
Baybay	1.920	2.360
Bugutis	2.800	2.320
Padam creek	2.010	2.310
Concepcetion	2.030	2.320

Table: the values predicted after the embankment break is higher showing more inundation after the brea

Appendix-5

SPEED CHANGES				
48 HOURS				
Location	Mannings	Mannings_2	Mannings_3	Std.dev
Minalaback	0.130	0.100	0.130	0.017
Milaor	0.030	0.040	0.030	0.006
camaligan	0.060	0.040	0.040	0.012
Balongai	0.120	0.110	0.120	0.006
Calabanga	0.000	0.000	0.000	0.000
102 HOURS				
Location				
Minalaback	0.140	0.160	0.110	0.02517
Milaor	0.030	0.030	0.040	0.00577
camaligan	0.100	0.080	0.090	0.01000
Balongai	0.010	0.030	0.020	0.01000
Calabanga	0.000	0.000	0.000	0.00000
198 HOURS				
Location				
Minalaback	0.110	0.080	0.100	0.01528
Milaor	0.050	0.040	0.030	
camaligan	0.080	0.060	0.070	0.01000
Balongai	0.040	0.100	0.090	0.00707
Calabanga	0.000	0.000	0.000	0.00000

Table 6.6: The effect of the application of Different Manning's
Coefficient values on water velocity at different locations in floodplain.
Table: The effect of embankment movement on the water level at different location on the floodplain.

Appendix-6

The effect of the embankment movement and changed Manning's coefficient		
Water depths in meters		
48 hours		
Location	After with changed Manning's	After moving the embankment
Minalaback	2.960	2.750
Milaor	2.640	2.540
camaligan	2.190	2.280
Balongai	1.720	1.760
Calabanga	1.100	1.100
Libmanan	2.200	2.100
Naga	2.250	2.380
Gainza	2.210	2.230
102 hours		
Minalaback	3.560	3.290
Milaor	3.480	3.190
camaligan	3.150	2.930
Balongai	2.320	2.360
Calabanga	1.100	1.100
Libmanan	2.220	2.270
Naga	3.180	2.950
Gainza	3.060	2.850
198hours		
Minalaback	3.470	3.100
Milaor	3.410	3.040
camaligan	3.130	2.820
Balongai	2.070	2.010
Calabanga	1.100	1.100
Libmanan	2.170	2.080
Naga	3.160	2.850
Gainza	3.050	2.720

Table 6.8: The effect of the embankment movement on the water depth values

Appendix-7

The effect of the embankment movement in the flood plain		
Water depths in meters		
48 hours		
Location	Before moving the embankment	After moving the embankment
Minalaback	2.480	2.750
Milaor	2.260	2.540
camaligan	1.990	2.280
Balongai	1.730	1.760
Calabanga	1.100	1.100
Libmanan	2.200	2.100
Naga	2.090	2.380
Gainza	2.030	2.230
102 hours		
Minalaback	2.910	3.290
Milaor	2.810	3.190
camaligan	2.400	2.930
Balongai	2.270	2.360
Calabanga	1.300	1.100
Libmanan	2.210	2.270
Naga	2.530	2.950
Gainza	2.460	2.850
198hours		
Minalaback	2.740	3.100
Milaor	2.630	3.040
camaligan	2.340	2.820
Balongai	1.940	2.010
Calabanga	2.210	1.100
Libmanan	2.110	2.080
Naga	2.410	2.850
Gainza	2.360	2.720

Table 6.8: The effect of the embankment movement on the water depth values

Appendix-8

The effect of changing Manning's coefficient on water depth at different locations in the floodplain			
After 198 Hours	Manning's	Manning's_2	Manning's_3
Minalabac	2.75	2.77	3.08
Milaor	2.63	2.66	2.93
Camaligan	2.36	2.39	2.51
Gainza	2.36	2.36	2.53
Dahiling Gainza	2.38	2.44	2.55
Cabonga	2.37	2.43	2.55
Calabanga	2.21	2.09	2.24
Libmanan	2.11	1.97	2.2
Balongai	1.93	1.94	1.96
Baybay	1.92	1.92	1.96
Bell Magaro	2.22	2.12	2.27
Canaman	2.24	2.19	2.3
Bombon	2.22	2.1	2.25
Quipayo	2.21	2.09	2.24
Concepcion,Libmanan	2.11	1.97	2.2
Padan creek	2.01	2.01	2.04
Buguits	2.7	2.9	2.8
Naga	2.44	2.46	2.62
Sabang	1.94	1.94	1.95
San lucas	2.21	2.09	2.24
Mabulo	2.6	2.63	2.91
San Nicolas	2.02	2.02	1.97

Table 6.4: The effect of the application of Different Manning's coefficient values 0n Delft-FLS water values at specific locations in the floodplain after 198 hours

Appendix-9

The effect of changing Manning's coefficient on water depth in meters at different locations in the floodplain			
After 48 Hours	Manning’s	Manning’s_2	Manning’s_3
Minalabac	2.24	2.51	2.70
Milaor	2.26	2.26	2.31
Camaligan	1.98	2.02	1.94
Gainza	2.03	2.04	1.92
Dahiling Gainza	2.05	2.07	1.96
Cabonga	2.04	2.06	1.95
Calabanga	1.10	1.10	1.20
Libmanan	2.20	2.10	2.10
Balongai	1.70	1.71	1.70
Baybay	1.68	1.67	1.67
Bell Magaro	1.30	1.30	1.30
Canaman	1.80	1.80	1.70
Bombon	1.50	1.50	1.50
Quipayo	1.00	1.10	1.20
Concepcion,Libmanan	2.00	1.82	2.00
Padan creek	1.34	1.35	0.98
Buguits	2.80	2.70	2.80
Naga	2.09	2.09	2.06
Sabang	1.69	1.67	1.60
San lucas	1.30	1.30	1.20
Mabulo	2.23	2.22	2.28
San nicolas	1.77	1.74	1.67

Table: 6.2 the effect of changing Manning’s coefficient values on Delft-FLS
Water depth values at specific locations in the floodplain after 48 ho

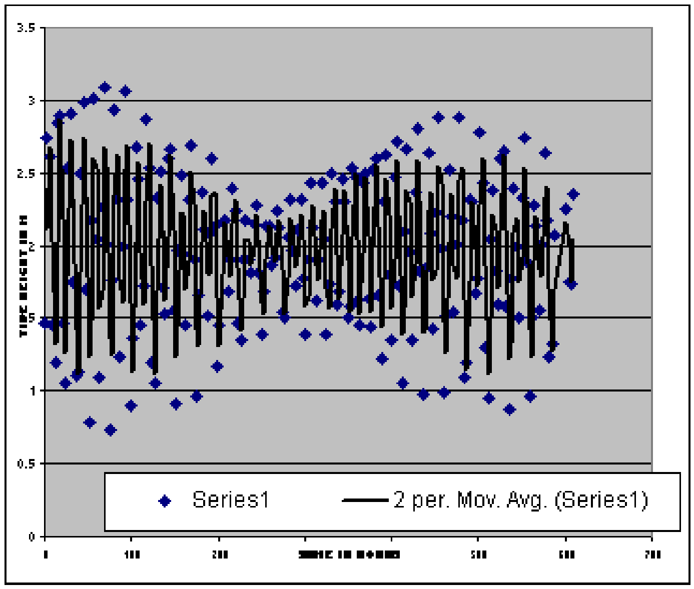
Appendix-10

The effect of changing Manning's coefficient on water depth in meters at different locations in the floodplain			
After 102 Hours	Manning's	Manning's_2	Manning's_3
Minalabac	2.93	2.97	3.24
Milaor	2.81	2.84	3.08
Camaligan	2.4	2.46	2.52
Gainza	2.46	2.53	2.58
Dahiling Gainza	2.48	2.56	2.6
Cabonga	2.47	2.55	2.59
Calabanga	1.2	1.2	1.1
Libmanan	2.16	2.2	2.11
Balongai	2.27	2.27	2.23
Baybay	2.27	2.27	2.23
Bell Magaro	1.51	1.49	1.54
Canaman	2.04	2.1	2.12
Bombon	1.5	1.5	1.5
Quipayo	1.1	1.1	1.1
Concepcion,Libmanan	2.17	2.19	2.11
Padan creek	2.22	2.2	2.14
Buguits	2.7	2.7	2.9
Naga	2.09	2.09	2.06
Sabang	2.27	2.27	2.23
San lucas	1.3	1.4	1.3
Mabulo	2.77	2.8	3.04
San Nicolas	2.28	2.28	2.23

Table 6.3: The effect of the application of Different Manning's coefficient values on Delft-FLS water depth values at specific locations in the floodplain after 102 hours.

Appendix: 11

Hours	Height(m)
0	1.47
3	2.74
6	2.61
9	1.45
12	1.2
15	2.85
18	2.9
21	1.47
24	1.05
27	2.54
30	2.91
33	1.75
36	1.113
39	1.13
42	2.5
45	2.99
48	1.7
51	0.78
54	2.18
57	3.01
60	2.05
63	1.1
66	2.26
69	3.09
72	2.01
75	0.73
78	1.76
81	2.93
84	2.31
87	1.23
90	1.99
93	3.06
96	2.31
99	0.9
102	1.36
105	2.68
108	2.46
111	1.46
114	1.73
117	2.87
120	2.53
123	1.2
127	1.05
130	2.33
133	2.51
136	1.71
139	1.53
142	2.6
145	2.66
148	1.56



151	0.91
154	1.97
157	2.48
160	1.94
163	1.46
166	2.32
169	2.69
172	1.9
175	0.96
178	1.66
181	2.37
184	2.11
187	1.52
190	2.08
193	2.6
196	2.13
199	1.17
202	1.45
205	2.16
208	2.17
211	1.68
214	1.9
217	2.39
220	2.24
223	1.47
226	1.35
229	1.91
232	2.17
235	1.9
238	1.82
241	2.15
244	2.28
247	1.82
250	1.39
253	1.68
256	2.14
259	2.14
262	1.86
265	1.92
268	2.24
271	2.12
274	1.55
277	1.5
280	2.06
283	2.32
286	1.97
289	1.73
292	2.11
295	2.32
298	1.77
301	1.39

304	1.91
307	2.43
310	2.12
313	1.62
316	1.91
319	2.43
322	2.04
325	1.39
328	1.74
331	2.49
334	2.3
337	1.59
340	1.68
343	2.46
346	2.3
349	1.5
352	1.58
355	2.53
358	2.47
361	1.62
364	1.45
367	2.43
370	2.5
373	1.64
376	1.44
379	2.52
382	2.6
385	1.66
388	1.22
391	2.3
394	2.62
397	1.8
400	1.35
403	2.47
406	2.71
409	1.72
412	1.05
415	2.1
418	2.66
421	1.95
424	1.35
427	2.37
430	2.81
433	1.83
436	0.98
439	1.84
442	2.64
445	2.09
448	1.43
451	2.22
454	2.88

457	1.98
460	0.99
463	1.52
466	2.52
469	2.2
472	1.54
475	2.01
478	2.88
481	2.18
484	1.09
487	1.2
490	2.31
493	2.3
496	1.67
499	1.77
502	2.78
505	2.43
508	1.3
511	0.95
514	2.05
517	2.38
520	1.83
523	1.59
526	2.6
529	2.65
532	1.58
535	0.87
538	1.77
541	2.39
544	1.99
547	1.51
550	2.33
553	2.74
556	1.89
559	0.96
561	1.5
564	2.28
567	2.13
570	1.56
573	2.01
576	2.64
579	2.17
582	1.24
585	1.32
588	2.07
601	2.25
604	1.75
607	1.74
610	2.36

Appendix 12

Hour	Discharge
0	80.15
24	417.8
48	417.8
72	522.43
78	520
84	520
90	520
96	507.98
102	496.13
108	484.44
114	461.57
120	439.35
126	396.87
132	386.65
138	376.59
144	366.69
150	356.95
156	347.36
162	347.36
168	356.95
174	366.69
180	366.69
186	372.61
192	374.6
198	376.59
204	386.65
210	372.61
216	347.36
222	337.93
228	337.93
234	337.93
240	337.93
246	337.93
252	337.93
258	337.93
264	337.93
270	337.93
276	347.36
282	356.95
288	366.69
294	376.59
300	386.65
306	392.76
312	396.87
313	417.79
314	417.79
315	428.49
316	428.49

317	439.35
318	461.57
319	461.57
320	484.44
321	507.98
322	532.19
323	544.55
324	569.78
326	582.66
327	595.7
328	608.92
329	635.88
330	649.62
331	663.54
332	691.91
333	706.36
334	750.8
335	765.97
336	796.87
337	812.59
338	844.59
339	877.32
340	893.97
341	910.81
342	927.84
343	945.05
344	962.46
345	980.05
346	997.84
347	1001.42
348	1008.6
349	1012.21
350	1012.21
351	1012.21
352	980.05
353	980.05
354	980.05
355	962.42
356	945.05
357	945.99
358	945.05
359	945.05
360	945.05
361	927.83
362	927.83
363	927.83
364	910.81
365	910.81
366	910.81
367	910.81
368	910.81
369	910.81

370	910.81
371	910.81
372	893.97
373	893.97
374	893.97
375	893.97
376	877.32
377	877.32
378	877.32
379	844.59
380	844.59
381	844.59
382	844.59
383	844.59
384	828.49
385	825.29
385	822.11
386	818.93
387	815.75
393	812.59
399	781.33
405	663.54
411	635.88
417	630.43
423	625.01
429	619.62
435	608.92
441	582.66
447	544.55
453	532.19
459	507.98
465	484.44
471	461.56
477	439.35
483	417.79
489	407.25
495	396.87
501	386.65
507	376.59
513	366.69
519	356.95
525	347.36
531	337.93
537	328.66
543	319.53
549	301.75
555	319.53
561	310.57
567	301.75
573	293.08
579	284.57
585	281.2

591	279.53
597	276.2
603	267.99
605	264.74
611	263.13
617	261.52
623	252
629	253.58
635	252
641	252

Appendix 13

```
impuls_006:=(h006_b07*c006_b07)
impuls_012:=(h012_b07*c012_b07)
impuls_018:=(h018_b07*c018_b07)
impuls_024:=(h024_b07*c024_b07)
impuls_030:=(h030_b07*c030_b07)
impuls_036:=(h036_b07*c036_b07)
impuls_042:=(h042_b07*c042_b07)
impuls_048:=(h048_b07*c048_b07)
impuls_054:=(h054_b07*c054_b07)
impuls_060:=(h060_b07*c060_b07)
impuls_066:=(h066_b07*c066_b07)
impuls_072:=(h072_b07*c072_b07)
impuls_078:=(h078_b07*c078_b07)
impuls_084:=(h084_b07*c084_b07)
impuls_090:=(h090_b07*c090_b07)
impuls_096:=(h096_b07*c096_b07)
impuls_102:=(h102_b07*c102_b07)
impuls_108:=(h108_b07*c108_b07)
impuls_114:=(h114_b07*c114_b07)
impuls_120:=(h120_b07*c120_b07)
impuls_126:=(h126_b07*c126_b07)
impuls_132:=(h132_b07*c132_b07)
impuls_138:=(h138_b07*c138_b07)
impuls_144:=(h144_b07*c144_b07)
impuls_150:=(h150_b07*c150_b07)
impuls_156:=(h156_b07*c156_b07)
impuls_162:=(h162_b07*c162_b07)
impuls_168:=(h168_b07*c168_b07)
impuls_174:=(h174_b07*c174_b07)
impuls_180:=(h180_b07*c180_b07)
impuls_186:=(h186_b07*c186_b07)
impuls_192:=(h192_b07*c192_b07)
impuls_198:=(h198_b07*c198_b07)
impuls_204:=(h204_b07*c204_b07)
impuls_210:=(h210_b07*c210_b07)
impuls_216:=(h216_b07*c216_b07)
impuls_222:=(h222_b07*c222_b07)
impuls_228:=(h228_b07*c228_b07)
impuls_234:=(h234_b07*c234_b07)
impuls_240:=(h240_b07*c240_b07)
impuls_246:=(h246_b07*c246_b07)
impuls_252:=(h252_b07*c252_b07)
impuls_258:=(h258_b07*c258_b07)
impuls_264:=(h264_b07*c264_b07)
impuls_270:=(h270_b07*c270_b07)
impuls_276:=(h276_b07*c276_b07)
impuls_282:=(h282_b07*c282_b07)
impuls_288:=(h288_b07*c288_b07)
impuls_294:=(h294_b07*c294_b07)
impuls_300:=(h300_b07*c300_b07)
impuls_306:=(h306_b07*c306_b07)
impuls_312:=(h312_b07*c312_b07)
impuls_318:=(h318_b07*c318_b07)
impuls_324:=(h324_b07*c324_b07)
impuls_330:=(h330_b07*c330_b07)
impuls_336:=(h336_b07*c336_b07)
impuls_342:=(h342_b07*c342_b07)
impuls_348:=(h348_b07*c348_b07)
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impuls_354:=(h354_b07*c354_b07)
impuls_360:=(h360_b07*c360_b07)
impuls_366:=(h366_b07*c366_b07)
impuls_372:=(h372_b07*c372_b07)
impuls_378:=(h378_b07*c378_b07)
impuls_384:=(h384_b07*c384_b07)
impuls_390:=(h390_b07*c390_b07)
impuls_396:=(h396_b07*c396_b07)
impuls_402:=(h402_b07*c402_b07)
impuls_408:=(h408_b07*c408_b07)
impuls_414:=(h414_b07*c414_b07)
impuls_420:=(h420_b07*c420_b07)
impuls_426:=(h426_b07*c426_b07)
impuls_432:=(h432_b07*c432_b07)
impuls_438:=(h438_b07*c438_b07)
impuls_444:=(h444_b07*c444_b07)
impuls_450:=(h450_b07*c450_b07)
impuls_456:=(h456_b07*c456_b07)
impuls_462:=(h462_b07*c462_b07)
impuls_468:=(h468_b07*c468_b07)
impuls_474:=(h474_b07*c474_b07)
impuls_480:=(h480_b07*c480_b07)
impuls_486:=(h486_b07*c486_b07)
impuls_492:=(h492_b07*c492_b07)
impuls_498:=(h498_b07*c498_b07)
impuls_504:=(h504_b07*c504_b07)
impuls_510:=(h510_b07*c510_b07)
impuls_516:=(h516_b07*c516_b07)
impuls_522:=(h522_b07*c522_b07)
impuls_528:=(h528_b07*c528_b07)
impuls_534:=(h534_b07*c534_b07)
impuls_540:=(h540_b07*c540_b07)
impuls_546:=(h546_b07*c546_b07)
impuls_552:=(h552_b07*c552_b07)
impuls_558:=(h558_b07*c558_b07)
impuls_564:=(h564_b07*c564_b07)
impuls_570:=(h570_b07*c570_b07)
impuls_576:=(h576_b07*c576_b07)
impuls_582:=(h582_b07*c582_b07)
impuls_588:=(h588_b07*c588_b07)
impuls_594:=(h594_b07*c594_b07)
impuls_600:=(h600_b07*c600_b07)
impuls_606:=(h606_b07*c606_b07)
impuls_612:=(h612_b07*c612_b07)
impuls_618:=(h618_b07*c618_b07)
impuls_624:=(h624_b07*c624_b07)
impuls_630:=(h630_b07*c630_b07)
impuls_636:=(h636_b07*c636_b07)
impuls_642:=(h642_b07*c642_b07)
impuls_648:=(h648_b07*c648_b07)
impuls_654:=(h654_b07*c654_b07)
impuls_660:=(h660_b07*c660_b07)
impuls_666:=(h666_b07*c666_b07)
impuls_672:=(h672_b07*c672_b07)
impuls_678:=(h678_b07*c678_b07)
impuls_684:=(h684_b07*c684_b07)
impuls_690:=(h690_b07*c690_b07)
impuls_696:=(h696_b07*c696_b07)
impuls_702:=(h702_b07*c702_b07)
impuls_708:=(h708_b07*c708_b07)
impuls_714:=(h714_b07*c714_b07)
impuls_720:=(h720_b07*c720_b07)
impuls_726:=(h726_b07*c726_b07)
impuls_732:=(h732_b07*c732_b07)
impuls_738:=(h738_b07*c738_b07)
impuls_744:=(h744_b07*c744_b07)
impuls_750:=(h750_b07*c750_b07)
impuls_756:=(h756_b07*c756_b07)
impuls_762:=(h762_b07*c762_b07)
impuls_768:=(h768_b07*c768_b07)
impuls_774:=(h774_b07*c774_b07)
impuls_780:=(h780_b07*c780_b07)
impuls_786:=(h786_b07*c786_b07)
impuls_792:=(h792_b07*c792_b07)
impuls_798:=(h798_b07*c798_b07)
```

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impuls_804:=(h804_b07*c804_b07)
impuls_810:=(h810_b07*c810_b07)
impuls_816:=(h816_b07*c816_b07)
impuls_822:=(h822_b07*c822_b07)
impuls_828:=(h828_b07*c828_b07)
impuls_834:=(h834_b07*c834_b07)
impuls_840:=(h840_b07*c840_b07)
impuls_846:=(h846_b07*c846_b07)
impuls_852:=(h852_b07*c852_b07)
impuls_858:=(h858_b07*c858_b07)
impuls_864:=(h864_b07*c864_b07)
impuls_870:=(h870_b07*c870_b07)
impuls_876:=(h876_b07*c876_b07)
impuls_882:=(h882_b07*c882_b07)
impuls_888:=(h888_b07*c888_b07)
impuls_894:=(h894_b07*c894_b07)
impuls_900:=(h768_b07*c900_b07)
impuls_906:=(h906_b07*c906_b07)
impuls_912:=(h912_b07*c912_b07)
impuls_918:=(h918_b07*c918_b07)
impuls_924:=(h924_b07*c924_b07)
impuls_930:=(h930_b07*c930_b07)
impuls_936:=(h936_b07*c936_b07)
impuls_942:=(h942_b07*c942_b07)
impuls_948:=(h948_b07*c948_b07)
impuls_954:=(h954_b07*c954_b07)
impuls_960:=(h960_b07*c960_b07)
impuls_966:=(h402_b07*c402_b07)
impuls_972:=(h972_b07*c972_b07)
impuls_978:=(h978_b07*c978_b07)
impuls_984:=(h984_b07*c984_b07)
impuls_990:=(h990_b07*c990_b07)
impuls_996:=(h996_b07*c996_b07)
```

Appendix -14

.clm Name embankment height

pnt 1	1.760
pnt 2	1.760
pnt 3	3.290
pnt 4	5.660
pnt 5	4.499
pnt 6	2.598
pnt 7	2.590
pnt 8	2.694
pnt 9	2.694
pnt 10	2.569
pnt 11	3.020
pnt 12	3.770
pnt 13	3.770
pnt 14	2.693
pnt 15	2.314
pnt 16	3.048
pnt 17	2.491
pnt 18	2.465
pnt 19	1.709
pnt 20	2.355
pnt 21	2.355
pnt 22	2.494
pnt 23	2.090
pnt 24	2.324
pnt 25	2.500
pnt 26	5.876
pnt 27	3.630
pnt 28	3.590
pnt 29	6.555
pnt 30	5.300
pnt 31	5.600
pnt 33	4.190
pnt 34	7.200
pnt 35	4.510
pnt 36	3.700
pnt 37	4.600
pnt 39	2.050
pnt 40	5.610
pnt 41	2.672
pnt 42	2.730
pnt 43	2.148
pnt 44	4.609
pnt 45	3.670
pnt 46	7.220
pnt 47	6.400
pnt 49	3.489
pnt 50	4.258
pnt 51	5.500
pnt 52	4.550
pnt 53	2.200
pnt 54	4.510
pnt 55	3.349
pnt 56	6.486
pnt 57	3.993
pnt 58	5.045
pnt 59	4.516
pnt 60	5.100
pnt 61	2.560
pnt 63	3.050
pnt 64	3.225
pnt 65	4.659
pnt 66	2.400
pnt 67	3.750
pnt 68	4.020
pnt 69	3.291
pnt 70	2.870
pnt 71	3.030
pnt 72	2.610
pnt 73	2.450
pnt 74	2.450

Appendix – 15

Sensitivity of Delt-fls to obstructions (structures)

The effect of the structural change in the flood plain		
Water Level in meters		
48 hours		
Location	Before moving the embankment	After moving the embankment
Minalaback	0.540	0.490
Milaor	1.060	1.260
camaligan	0.650	0.650
Balongai	0.810	0.700
Calabanga	0.000	0.000
Libmanan	0.600	0.700
Naga	0.000	0.000
Gainza	0.640	0.640
102 hours		
Minalaback	0.970	1.060
Milaor	1.540	1.840
camaligan	1.120	1.000
Balongai	1.270	1.270
Calabanga	0.000	0.000
Libmanan	1.070	1.170
Naga	0.000	0.000
Gainza	1.240	1.040
198hours		
Minalaback	0.770	0.860
Milaor	1.160	1.660
camaligan	1.020	0.910
Balongai	1.030	0.930
Calabanga	0.790	0.690
Libmanan	0.870	0.970
Naga	0.000	0.000
Gainza	1.120	1.020

Appendix-16

Comparison of water depth before the embankment break at Sabang and after		

Location	Before	After
Minalaback	2.740	2.950
Milaor	2.630	2.820
Camaligan	2.350	2.440
Balongai	1.930	2.350
Calabanga	2.210	2.240
Libmanan	1.970	2.320
Naga	3.600	2.250
Gainza	2.360	2.510
Mabulo	2.600	2.770
Dhaling	2.380	2.520
Cabunga	2.370	2.520
Canaman	2.240	2.270
Bell Magarao	2.220	2.250
Bombon	2.220	2.250
Quipayo	2.210	2.240
San lucas	2.210	2.240
Baybay	1.920	2.360
Bugutis	2.800	2.320
Padam creek	2.010	2.310
Concepcetion	2.030	2.320