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**Flood risk mapping and Vulnerability Analysis of Megech
River using 2D hydrodynamic flood modelling**

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Flood risk mapping and Vulnerability Analysis of Megech River using 2D hydrodynamic flood modelling

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DECLARATION

This document work undertaken as part of a programme of study at the Addis Ababa university institute of technology. All views and opinion expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

The consequences of flooding are complex and far-reaching. These consequences include direct damage to property and structures, as well as disruption of economic activity and displacement of affected population, with the attendant costs of evacuation and temporary accommodation. They include loss of agricultural productivity, including both opportunity as well as direct damage to crops in various stages of cultivation. They include direct damage to infrastructure, in addition to disruption of transportation and services, potentially affecting populations not directly touched by flood waters, and for extended periods of time, not limited to the period of inundation.

Flood is causing economical, social and environmental damage and lives loss in Ethiopia. In recent year, the August 2006, flooding is one of the worst flooding events. Understanding of flood risk is the first step for Flood risk management. Dembia floodplain is a frequently flooded catchment with Megech River. Flood risk management strategies have not been developed for this region and there is no spatial planning approach for regional development. This study focuses on studying the flooding characteristics in the flood plain of the catchment using two-dimensional (2D) hydrodynamic modelling.

Flood risk mapping is an important aid to a community to take action in the present for the reduction of future damages, to plan for flood preparedness and response, to develop infrastructure for reducing flood severity and flood damage, and to guiding development to avoid increased risk where hazard is frequent. An important aspect of this study is the development of models and procedures that could be used in generation of flood risk map.

This research was based on four major steps. The first step was to prepare input data for the modelling, such as topographic mesh, upstream boundary and surface roughness. Topographic mesh was generated using SMS11.0 based on 53238 x-y-z survey points. Upstream boundary condition was generated by flood frequency analysis methods.

The second step involves the calibration of the model based on field measured data. The calibration is performed by manually changing surface roughness coefficient until the good fit between simulated and measure surface water level is obtained.

The third steps concern simulation and mapping of flood hazard parameters based on model results respectively. The model results consist of flood depth, flow velocity and surface water elevation.

The final step is flood risk mapping. Flood risk map was generated by weighting flood depth, flow velocity and flood duration. Flood hazard and flood risk maps are important tools to communicate flood risk to different target groups.

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List of Figures

Figure 3-1 study area map.....	11
Figure 3-2 Monthly Variation in Temperature and Rainfall in the Study Area (1998-2007).....	12
Figure 3-3 Soil Properties of the Area	13
Figure 3-4: Land Cover of the Area.....	14
Figure 4-1: Mean Monthly Discharge of Megech River.....	15
Figure 4-2: Hydrograph of Megech River	16
Figure 4-3: Windows showing surface water system modelling (SMS).....	19
Figure 4-4: Mesh Representing the Area to Be Modelled	21
Figure 4-5: Schematic flow of the overall research process	23
Figure 5-1: Graphical User Interface of BASEMENT2.0	26
Figure 5-2: Command file editor of BASEMENT2.0.....	27
Figure 5-3: Nodes id for the STRING_DEF block for the inflow boundary	28
Figure 5-4: Nodes id for the STRING_DEF block for the inflow boundary	28
Figure 5-5: Stationary hydrograph file saved as inflow_stationary.txt.....	29
Figure 5-6: Spatial distribution of Manning's n.....	30
Figure 5-7: Comparison of simulated and observed surface water level	32
Figure 6-1: Flood water depth (10-year return period)	33
Figure 6-2: Flood water depth (25-year return period)	34
Figure 6-3: Flood water depth (50-year return period)	34
Figure 6-4: Flow velocity for 10-year return period	36
Figure 6-5: Flow velocity for 25-year return period	36
Figure 6-6: Flow velocity for 50-year return period	37
Figure 6-7: Flood duration for 10-year return period.....	38
Figure 6-8: Flood duration for 25-year return period.....	39
Figure 6-9: Flood duration for 50-year return period.....	39
Figure 6-10: Flood risk maps for different visions (25-year return period).....	42
Figure 7-1: Influence of mesh resolution to inundated area Flood risk mapping	44
Figure 7-2: Percentages of flood impact categories	45

List of tables

Table 4-1: Flood frequency by the Gumbel method	18
Table 4-2: Flood frequency by the Log Pearson III method.....	18
Table 4-3 Criteria and weightings for flood parameters.....	25
Table 4-4: Factors in percentage for different interest group	25
Table 5-1: Roughness Coefficient for Different Land Use Classes (Chow, 1988)	30
Table 5-2: RMS for all the calibration stations.....	32
Table 7-1: Characteristic of tested mesh	43
Table 7-2: Inundated percent for 25years return period	45
Table 7-3: Categorized Area for different scenarios.....	45

Contents

Abstract.....	i
Acknowledgements.....	iii
List of Figures	iv
List of tables	v
1. Introduction	1
1.1. General.....	1
1.2. Statement of the problem.....	2
1.3. Research objectives	3
1.3.1. General Objective.....	3
1.3.2. Specific objectives.....	3
1.4. Research Questions	3
2. Literature Review.....	4
2.1. Introduction.....	4
2.2. Hydrodynamic modeling.....	5
2.2.1. 1D hydrodynamic modeling	5
2.2.2. 2D hydrodynamic modeling	6
2.3. Flood Risk mapping.....	8
2.3.1. Flood Hazard Mapping.....	8
2.3.2. Flood Vulnerability Analysis	8
2.4. Tools for Floodplain Analysis and Flood risk Mapping	8
2.4.1. Surface water modelling system (SMS)	9
2.4.2. Basement Software	9
3. STUDY AREA	11
3.1. General Description.....	11
3.2. Topography.....	11
3.3. Climate of the study area.....	12

3.4.	Hydro Meteorology.....	12
3.5.	Soils.....	13
3.6.	Land Use.....	13
4.	Material and Methodology.....	15
4.1.	Data collection	15
4.1.1.	Data availability.....	15
4.1.2.	Topographic data.....	15
4.1.3.	Hydrological data.....	15
4.2.	Data Preparation preliminary processing	16
4.2.1.	Flood Frequency Analysis	16
4.2.2.	Mesh generation.....	18
4.3.	Methodology of the study.....	22
4.3.1.	Overall Methodology	22
4.3.2.	Hydrodynamic modeling simulation.....	24
4.3.3.	Flood Risk Mapping	24
5.	HYDRODYNAMIC FLOOD MODELLING.....	26
5.1.	Introduction.....	26
5.2.	Input Data.....	26
5.2.1.	Geometric Parameter	27
5.2.2.	Boundary Condition.....	28
5.2.3.	Initial Flow Condition.....	29
5.2.4.	Surface Roughness	29
5.3.	Model Calibration and Validation	30
5.4.	Flood Model Output.....	32
6.	Flood risk mapping.....	33
6.1.	Results of Hydrodynamic Modeling	33
6.2.	Scenario results.....	33

6.2.1. Flood depth	33
6.2.2. Flow velocity.....	35
6.2.3. Flood duration	38
6.3. Flood hazard mapping.....	40
6.4. Vulnerability analysis	41
6.5. Flood risk mapping.....	41
7. Discussion	43
7.1. Mesh sensitivity analysis.....	43
7.1.1. Influence on Inundated Area.....	43
8. Conclusion and Recommendations	46
8.1. Conclusion.....	46
8.2. Recommendations.....	47
Bibliography.....	48
APPENDIX.....	49

1. INTRODUCTION

1.1. General

A flood is a hydrological event which is characterized by high discharges and/or water levels that could lead to inundation of land adjacent to streams, rivers, lakes and other water bodies. Flood events could be caused by of long-lasting rainfall, failure of a dam or embankment system, earthquakes, landslides and by human activities, including the operation of flood control systems.

Most countries in the world experience floods and flooding. The risk flood causes is vast. This natural hazards cause damage to life, property and ecosystem. Flooding is one of the major natural hazards in Ethiopia, owing to a national topography of mountainous highlands and lowland plains, with natural drainage systems formed by the principal river basins.

Most flooding in the country is caused by river over flow, when prolonged rainfall causes rivers to overflow and inundate lowland plains. Among the major river flood-prone areas are parts of Oromia and Afar regions lying along the mid- and downstream plains of the Awash River; parts of Somali Region along the Wabishebele, Genale and Dawa rivers; lowlying areas of Gambella along the Baro, Gilo and Akobo rivers; downstream areas along the Omo River in SNNPR and the extensive floodplains surrounding Lake Tana in Amhara.

Throughout the world, structural and non-structural measures are taken to reduce flood damage. However, it is time-consuming and costly to thoroughly construct flood control facilities to lower the risk of flood damage. It is advisable to enhance local residents' awareness of the importance of flood protection efforts concurrently with the steady development of flood control facilities so that overall flood damage shall be mitigated. Flood risk Maps are essential in achieving this goal and assist local residents in becoming aware of the vulnerability of the area they live in, the important roles that they play in disaster prevention activities and proper evacuation in the event of floods.

Mitigating flood effects requires information on the flooding characteristics and how such characteristics propagate. Information about flood characteristics could be obtained through hydrodynamic models. Hydrodynamic models are able to simulate flood extents, depths, levels, velocities and timing over a distributed model domain and over the time dimension. Such a flood models solve governing flow equations that are based on the laws of mass, energy and momentum conservation. BASEMENT is one of such model approach and is

able to model flooding characteristics given that sufficient input data of good quality is available.

One of the data required in hydrodynamic flood modelling is topographic data. This topographic data is available as survey data of floodplain. Topographic survey data is used to generate unstructured mesh for floodplain using SMS 10.1. Meshed topographic data which represent floodplain and river topography are used as input for the model. Required quality of mesh generation is pre-requisite of hydrodynamic modelling.

Before generating the result, the model must be tested. To test the model results, field data on flood depth is required. Data can be available through observed time series data and/or through image data that provide complete coverage of the inundation area. In this thesis measured water surface level was used to calibrate.

1.2. Statement of the problem

Flooding, as a natural phenomenon, has been occurred in many part of Ethiopia. “By the end of August 2006, at least 75 woredas in eight regions had been affected by the flood according to report by Ethiopian government disaster prevention and preparedness agency, more than 500,000 people were vulnerable and about 200,000 people had been affected, with 639 deaths. Thousands of live stocks were killed, 228 tons of harvested crops were washed away, 147 tons of export coffee beans were lost (and machinery ruined), 42,229 ha of crop land were inundated.” (Semu moges, 2010)

The cause of this flood in Ethiopia is heavy rain and mountainous topography. Rivers overflow or burst their banks and inundate downstream plain lands. The heavy rains falling on the upstream highlands cause most rivers to swell and breach their courses, submerging the surrounding floodplains.

The downstream catchment of Megech River is known as one of the flood prone areas in dembia floodplain. By flooding in 2006, 9200 people are affected and 4300 people are displaced in dembia woreda. (Agency(DPPA), APRIL, 2007)

Traditionally flood risk is analysed using flood extent parameter only. However, flood extent map does not provide flood risk extent, i.e. flood risk analysed by flood extent only under estimate flood risk level. With advancement in hydrodynamic flood modelling it is possible to model flood depth, velocity and duration. These results of hydrodynamic model are used in the analysis of flood risk.

1.3. Research objectives

1.3.1. General Objective

The main focus of the study was to develop flood risk maps by 2-Dimensional hydrodynamic model (BASEMENT) simulation of the Megech River in Dembia floodplain. It also aimed at investigating the possible consequences of hazard scenarios in the assessment of risk.

1.3.2. Specific objectives

- To generate the irregular mesh of the floodplain from survey data of the area.
- To simulate flood depth, flood velocity and flood level using 2D hydrodynamic model
- To produce the flood risk map of Dembia floodplain.
- To analyses flood risk level for flood affected categories

1.4. Research Questions

The following questions are formulated based on the above research objective

- What are the significant elements that should be taken into account in the generation of the mesh?
- How to assess the flood characteristics for different return periods?
- What are the flood risk parameters and how to generate these parameters?
- What is the level of vulnerability as a function of the flood characteristics?
- How to analyses flood risk using flood risk map for different return periods?

2. LITERATURE REVIEW

2.1. Introduction

River flood is defined as a high flow that exceeds or over-tops the capacity either the natural or the artificial banks of a stream (Ghosh, 1997). Flooding results from excessive rain on the land or streams overflowing channels. Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow, and duration of the rainfall event (Keith Smith, 2009). The most common types are: river floods, flash floods, coastal floods and urban floods. In general, Factors causing flood in many parts of the world are climatologically, changes in land-use and increasing population and land subsidence (Keith Smith, 2009).

There is a relationship between a human interactions and hydrological characteristics, such as decrease of infiltration, increase of overland flow, increase in frequency and height of flood peak, increase in range of discharge (variability) and decrease lag time. The dangers of floodwaters are associated with a number of different characteristics of the flood such as depth of water, duration, velocity, sediment load, rate of rise and frequency of occurrence.

Flood Risk

Risk also can be defined as the probability of harmful consequences or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced (technology, industrial process or an agent like chemical, physical, etc.) hazards and vulnerable conditions. With regard to natural disasters, risk is more specifically described as the probability that natural events of a given magnitude and a given loss will occur. Therefore, risk encompasses two aspects: hazard and vulnerability. Risk and hazard is sometimes taken as synonymous but risk has additional implication of the chance and probability a particular hazard actually occurring. Hazard is defined as threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area, while risk is expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. (Selina Begum, 2007)

2.2. Hydrodynamic modeling

Development of flood model comes with the development of efficient computational tools. In addition Improvements in numerical modelling have provided engineers and hydrologists the ability to simulate hydrodynamics model with the aid of their desktop computers. Hydrodynamic models predict outputs, such as velocities vector and water surface elevations, given specific inputs, such as stream flows. In flood models, hydrologic and hydraulic processes in the river channel and flood plain are represented by the models.

Today, hydrodynamic model can simulate in-stream velocities in the longitudinal (x-direction), lateral (y-direction), and vertical (z-direction) directions. 3-dimensional model is used rarely; because, data requirements for a 3-dimensional model are extensive, the time and money required to setup, calibrate, and validate a 3-dimensional model are greater than those necessary for 2- and 1-dimensional models.

2.2.1. 1D hydrodynamic modeling

One-dimensional hydrodynamic models simulate flood in the longitudinal direction or along the length of the flow Canal. They typically require less time and resources to set up, calibrate, and validate than equivalent 2- or 3-dimensional models. Due to their longitudinal environment, one- dimensional models are best suited for hydraulic structures that are long, narrow, and shallow in nature.

It is assumed that the density of water remains constant, the bottom slope is small, The water-lengths are large as compared to water-depths. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e., vertical accelerations can be neglected and a hydrostatic pressure variation along the vertical can be assumed. Therefore, the conservation of mass equation simplifies to the continuity equation.



Where

A = Flow area (m²)

R * =Resistance radius (m)

C =Chezy's Resistance coefficient (m^{1/2}/ s)

g = Acceleration due to gravity (m/ s²)

h = Stage above horizontal reference level (m)

Q = discharge (m³/ s)

A = momentum distribution coefficient

q = Lateral inflow (m² / s)

2.2.2. 2D hydrodynamic modeling

Two-dimensional hydrodynamic models provide users the capability of simulating hydrodynamics in the longitudinal direction as well as the lateral direction or vertical direction. Depth averaged two-dimensional models (simulation in the longitudinal and lateral directions) are employed when changes in the vertical direction are negligible. They are typically applied to rivers, lakes, reservoirs, and estuaries that are long, wide, and relatively shallow. Additionally, two -dimensional hydrodynamic models typically require more time and resources to setup, calibrate, and validate than one-dimensional models. However, modelling in two-dimensions provides the ability to observe changes in either the lateral or vertical direction that would not be available with a one-dimensional model. Therefore, the results obtained from the two-dimensional hydrodynamic model may be more important than one-dimensional, in certain situations, the time, effort, and resources required for model setup and calibration.

2.2.2.1. Governing equation

The following basic equations for the conservation of mass and momentum are used to describe the flow and water level variations in two-dimensional models:

2.3. Flood Risk mapping

Flood risk map is prepared from flood hazard map and flood vulnerability analysis as flood risk comprises hazard and vulnerability.

2.3.1. Flood Hazard Mapping

Flood Hazard Mapping is flood map illustrating the flood hazard, i.e. the intensity of flood situations and their associated exceedance probability. Usually, flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth and distribution of flow velocity. (Selina Begum, 2007) The hazard aspect of the flood risk is related to the hydraulic and the hydrological parameters. Hazard level may be defined by the parameters like flood depth and flood velocity and flood duration. For this the weighted coexistence model facilitates the analysis by ranking the hazard level.

2.3.2. Flood Vulnerability Analysis

Flood hazard map alone cannot completely fulfil the information requirement I flood risk analysis. There is a need to combine flood hazard with other parameter, flood vulnerability, to develop more useful information. Vulnerability generally refers to that characteristic of society which specifies the potential for the damage to occur as a result of different types of hazards. Vulnerability can be defined as the degree to which people, property, environment, social and economical activities are subjected to harm or being exposed to any destructive factors or cause. Flood vulnerability describes the damage or exposure to damage due to flood.

The flood vulnerability is affected by the land use characteristics of the areas under the influence of flood i.e., a flood of same exceedance probability will have different levels of vulnerability according to the land use characteristics and potential for damage. The vulnerability analysis, therefore, consists of identifying the land use areas under the potential influence of a flood of particular return period.

2.4. Tools for Floodplain Analysis and Flood risk Mapping

There are a number of commercial and non-commercial software tools available for hydrodynamic modelling. The models can be further divided into one-dimensional and two-

dimensional model based on information on the lateral distribution of flow across a cross section. Descriptions of the software tools used in this thesis are presented below.

2.4.1. Surface water modelling system (SMS)

To describe a topographic surface, the terrain data is often triangulated to allow a perspective representation of the topography. In numerical simulation, two types of mesh are used: structured and unstructured grids. Structured grids are simpler to use, but need an interpolation of the data to determine the values at the desired vertex position if the input is irregular point cloud. In addition, they are not sufficiently flexible to fit complex geometries.

This triangulated mesh is generated using Surface-water Modelling System (SMS) software package. SMS is a pre and post-processor for surface water modelling developed by the Environmental Modelling Research Laboratory (EMRL). The EMRL is part of the Civil and Environmental Engineering Department at Brigham Young University (BYU). (University, 2006)

2.4.2. Basement Software

BASEMENT- BASic Simulation EnvironMENT for Computation of Environmental Flow and Natural Hazard simulation was developed by Swiss Federal Office for the Environment (FOEN). This software package is intended for simulation of water flow, sediment and pollutant transport and according to interaction in consideration of movable boundaries and morphological changes (ETH Zoric, VAW, 2010). The BASEMENT software uses the shallow water equations to compute water surface profiles given topographic data, roughness coefficients, and boundary condition.

In addition, the program has a number of special capabilities related to simulation of flow behaviour of channel and its transition under steady and unsteady conditions; simulation of sediment transport and erosion. The procedure to simulate a concrete problem setup is not unique. BASEMENT is coded using an object-oriented design which allows for flexibility and interchangeability concerning different application problems.

The model required a topographic data set as a mesh. Usually, the raw topography data needs a lot of treatments (manual correction, interpolation, adjustment of single elements, etc.) until a suitable computational mesh can be generated. Programs for grid generation like SMS provide some powerful tools to manipulate mesh.

The software system consists of the numerical subsystems and the different interfaces to the infrastructural software, such as pre- and post processors. The core of BASEMENT consists of the numerical solution algorithms comprised in the appropriate modules. Pre- and post-processing can be performed with independent products using as well defined common interface.

The core of the BASEMENT software system consists of numerical subsystems, which actually are:

BASEchain-The one dimensional numerical tool named BASEchain enables the simulation of river reaches (based on cross sections) with respect to sediment transport. A coupling with the 2-D tool is foreseen.

BASEplane-The two dimensional numerical tool named BASEplane enables the simulation of river reaches as well as flood plains (bases on a digital terrain model) with respect to sediment transport.

BASEspace(planned)-The three dimensional numerical tool named BASEspace is meant for the simulation of local flow fields (based on spatial geometry) with respect to sediment transport. A coupling with the 2-D tools is foreseen.

For this particular thesis the problem is simulated using two dimensional numerical tools, BASEplane.

3. STUDY AREA

3.1. General Description

Dembia floodplain is found in the North Gondar Zone of the Amharic region. This catchment is located about 727km from Addis Ababa. The Megech River originates in the North-Gondor in Gondor administrative zone and flows south to Lake-Tana through dembia flood plain. Megech River is one of the four perennial rivers (Gilgil Abbay, Megech, Ribb, and Gumera) which fed Lake Tana. The total population of dembia woreda according to Central Statistical Authority is 268,582 in 2005 (Dembia, 2005), with an average density of 260 inhabitant per km².

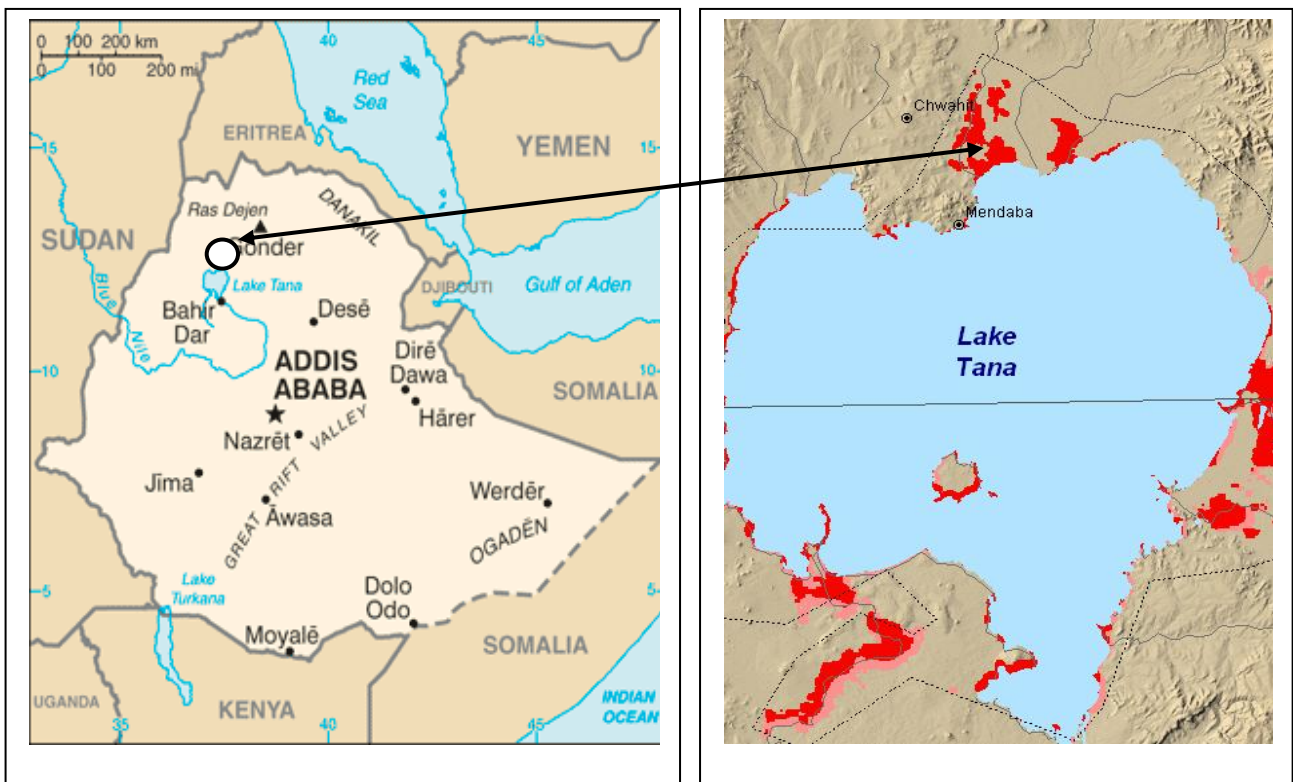


Figure 3-1 study area map

3.2. Topography

Geographically it lies between UTM coordinates of 12015'30'' – 12018'00'' N latitude and 37020'30'' – 37029'00'' E longitude. Topographically the study area lies in the vicinity of Lake Tana with altitude ranging from 1700 to 2500m above sea level. Dembia is characterized by large plains.

3.3. Climate of the study area

The sources of moisture for almost all rains in Ethiopia are the Indian and Atlantic Oceans. (Degefu, 1987). Based on the general classification of Agro- climate zone (on the bases of annual rainfall, temperature, length of growing period and plant types), the year is divided into two seasons: a rainy season mainly is on the months of June to September, and a dry season is from October to March. The amount of rainfall in Ethiopia is influenced by the location of the place relative to the source of moisture, the direction of winds and topographical relief. The mean annual rainfall at azezo meteorological station is 1450mm. The mean monthly temperature minima ranges' between 5.90c and 11.80c, and that of maximum temperature between 7.20c and 27.40c. The minimum temperature is 5.90c, registered in December and the maximum temperature 27.40c, registered in February (SOCIET, October 2007).

3.4. Hydro Meteorology

Hydrologic data has been collected from Azezo meteorological stations located within the vicinity of the study area. Azezo is standard metrological station which records temperature, precipitation, evaporation, relative humidity, wind speed and sunshine. The most important data was megech river flow data used to determine probable maximum flood for the required return period.

The study area is characterized by unimodal rain fall pattern with peak rainfall season starts at the mid of May and ends at the end of the September. The highest peak recorded in July at Azezo metrological station and the mean annual rainfall is 1225.83mm. (SOCIET, October 2007).

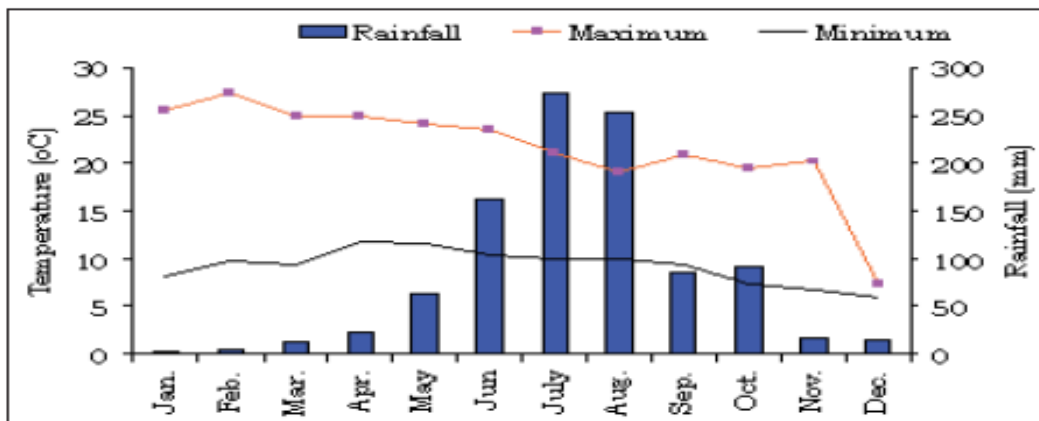


Figure 3-2 Monthly Variation in Temperature and Rainfall in the Study Area (1998-2007)

3.5. Soils

Dembia floodplain is mainly formed from clay and clay-loam soil type, but the riverbed has loam and sandy-loam type of soil (Dembia, 2005). As part of upper Blue Nile basin, Dembia floodplain soil is also more of clay and clay-loam type which is mainly belongs to the basaltic trap series of Tertiary volcanic eruptions. The soils have developed from a volcanic basement and reworked materials of Tertiary volcanic eruptions, and rarely from sedimentation processes. Fertile clay and clay loam soils present the basis for good harvests of barley, rice, finger millet, maize, teff, chickpea and vetch, whilst there is widespread rice production by smallholders on irrigated land – a highly unusual crop for Ethiopia, introduced in the zone by schemes in recent decades.

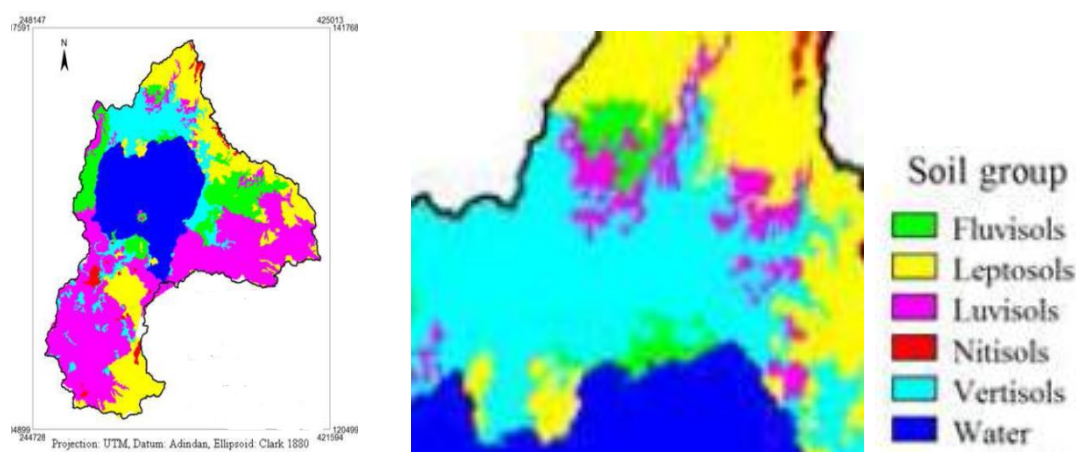


Figure 3-3 Soil Properties of the Area

Source: (Hydrological Balance of Lake Tana Upper Blue Nile Basin, Ethiopia)

3.6. Land Use

A survey of the land in Dembia woreda shows that 64% is arable or cultivable and another 25% under irrigation, 6% pasture, 4% forest or shrubland, and the remaining 1% is considered degraded or other. Agriculture is highly practiced in the wetland except at the modified habitats.)

Fertile clay and clay loam soils present the basis for good harvests of barley, rice, finger millet, maize, teff, chickpea and vetch, whilst there is widespread rice production by smallholders on irrigated land – a highly unusual crop for Ethiopia, introduced in the zone by schemes in recent decades. Maize, barley and millet are the main food crops, while rice, vetch and chickpea are the main cash crops. (Dembia, 2005)

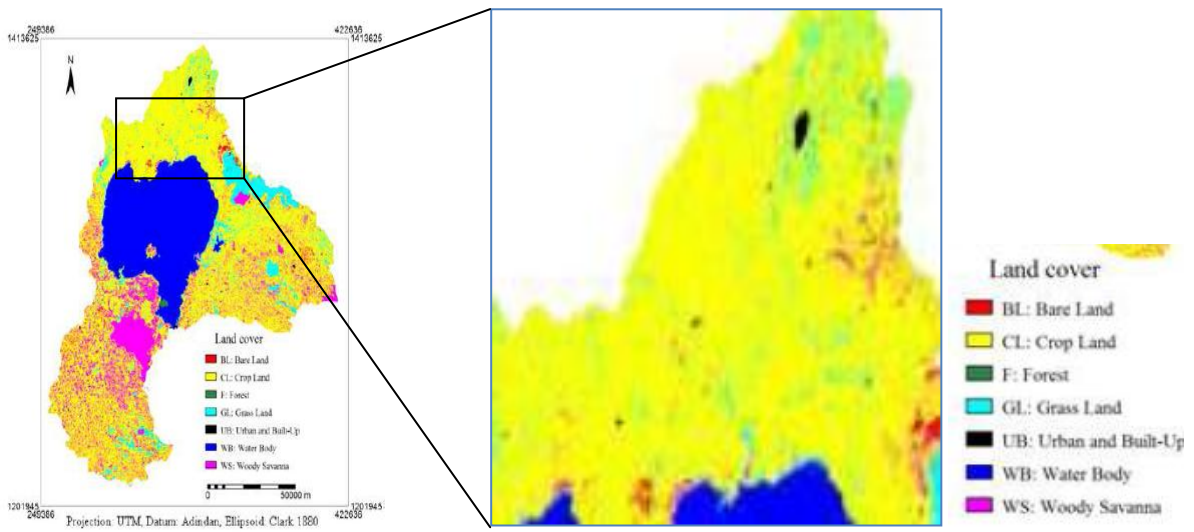


Figure 3-4: Land Cover of the Area

Source: (Hydrological Balance of Lake Tana Upper Blue Nile Basin, Ethiopia)

4. MATERIAL AND METHODOLOGY

4.1. Data collection

4.1.1. Data availability

In two-dimensional flood model there are two types of modelling, hydrodynamic model and terrain model. Each model requires data to be processed. The data required for both the hydrodynamic model and the terrain models are collected from Ethiopian National Meteorological Agency (ENMA), Ministry of Water and Energy and field measured data. The major data collected are the hydrological data and topographical data. Hydrological data are the daily discharge records of the gauged rivers while the topographical data are topographic survey data of the area.

4.1.2. Topographic data

A significant input for hydrodynamic modelling is the correct representation of terrain on which the model will work on. Accurate representation of the channel bed and other floodplain features are very essential in determining the quality of outcome of two dimensional hydrodynamic models. Detailed river and floodplain topography for this site in the form of xyz coordinates survey data and raster data which show area map was collected from ministry of water resource. A total of 2048 point elevations were collected over the entire reach.

4.1.3. Hydrological data

Daily series of discharge data of the Megech River were collected from the ministry of water resources of Ethiopia (MoWR) during the field work. The river discharge of Megech is measured per day near azezo gauging station. The available discharge data is in the unit of m^3s^{-1} . The data covers a time period of 27 years which is from the period 1980 to 2006. The minimum discharge lies between 0-1.997m³/s, while the maximum discharge is between 41.195-317.967m³/s. a time series plot of the river discharge data is shown in Figure 4.2.

year 1980- 2008	average discharge in m ³ /s											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
discharge	1.2	1	1	1.2	1.6	4.4	15	32	13	4.3	2.2	1.6

Figure 4-1: Mean Monthly Discharge of Megech River

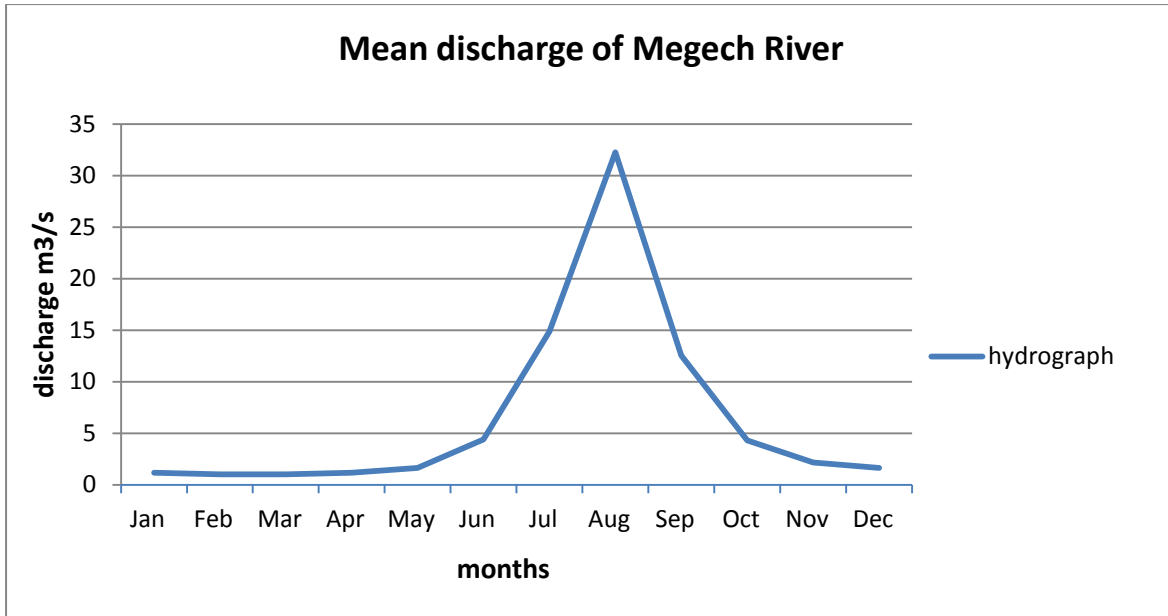


Figure 4-2: Hydrograph of Megech River

4.2. Data Preparation preliminary processing

4.2.1. Flood Frequency Analysis

Flood frequency analysis is essential in the estimation of the flood risk as it is one of the important studies of river hydrology. To determine and quantify the flood frequency and flow variation within a given area the statistic approach tool is widely used. Flood frequency analysis begins with the calculation of the statistical parameters required for a proposed probability distribution by the method of moments from the given data. Gumbel’s method and Log Pearson Type III method are used to build the relationship between the probability of the occurrence of a certain event, its return period and its magnitude.

4.2.1.1. The Gumbel’s Method

The Gumbel’s method (Gumbel Distribution) is the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks and maximum rainfalls (Chow, 1988). Gumbel’s method can be applied for flood frequency analysis if (a) peak flow data are homogeneous and independent hence lack long-term trends; (b) the river is less regulated, hence is not significantly affected by reservoir operations, diversions or urbanization; and (c) flow data cover a relatively long record (more than 10 years). (Mujere)

In this method the variable X (flood peak discharge) with a recurrence interval T is given by

Where X_T = flood peak discharge
 α and u is given by _____ ,

For a given return period T , _____

4.2.1.2. The Log Pearson Type III Method

In this method the variable is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. If X is the variable of a random hydrologic series, then the series of Z variable are first obtained.

From this z series, for any recurrence interval, T

Where Z_{ave} = arithmetic mean of Z values K_z is a frequency factor which is a function of recurrence interval T and the coefficient of skew C_s , For N = number of sample = n number of years of record.

s_z = Standard deviation of Z variable sample= _____

C_s = coefficient of skew of variable _____

Corresponding value of X = antilog (ZT)

4.2.1.3. Results of Flood Frequency Analysis

The result of 10,25, 50, 100 and 200-years Return Period Flood Frequency Analysis based on daily Maximum flow recorded at Azezo Station from year 1980 - 2008 using Gumbel's and Log Pearson Type III (LP III) are summarized below in Table 4-1 and Table 4-2 respectively. It is observed that flood frequency analysis by Gumbel's showed discharges of

266, 334, 384, 434 and 483 m³/sec for 10-years, 25-years, 50-years, 100-years and 200- years return periods respectively, which were slightly higher as compared to the results obtained by Log Pearson Type III. Result obtained Gumbel’s method is used in the model as upstream boundary for steady flow simulation

Return period T (yr)	Flood discharge Q (m ³ /s)
10	266
25	334
50	384
100	434
200	483

Table 4-1: Flood frequency by the Gumbel method

Return period T (yr)	Flood discharge Q (m ³ /s)
10	254
25	318
50	366
100	412
200	459

Table 4-2: Flood frequency by the Log Pearson III method

4.2.2. Mesh generation

Computational mesh is the fundamental basis of the simulation with basement. It represents the topography of the area and determines where exactly the solution of the flow variables is calculated. In this section, preliminary steps of the computational mesh generation are outlined.

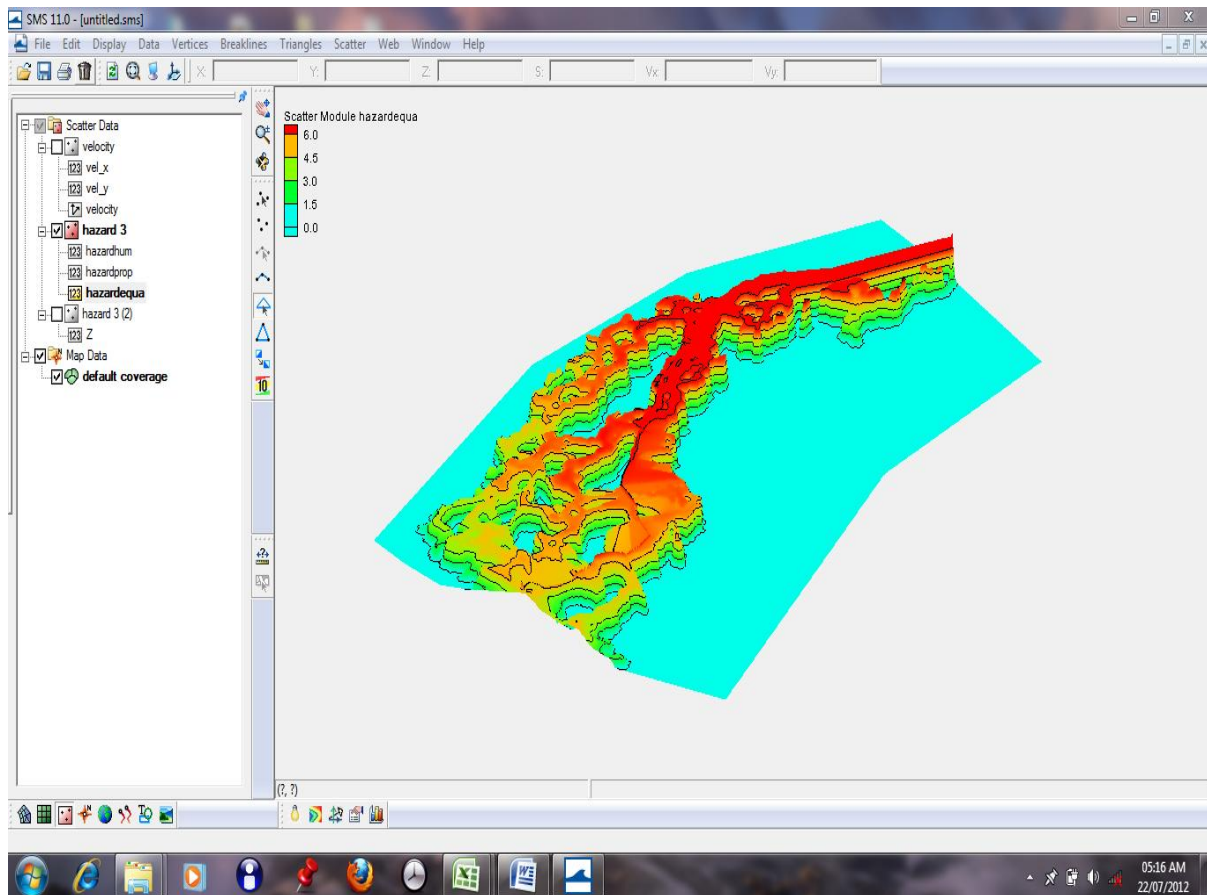


Figure 4-3: Windows showing surface water system modelling (SMS)

4.2.2.1. Study area boundary

Boundary of the area, which is intended to be modelled, has to be well defined. For this reason, a polygon shape file is created enclosing the model domain. The model domain has been confined in Dembiya flood plain.

4.2.2.2. Mesh triangulation

The computational mesh used for the simulation with BASEMENT is created with the software program surface water modelling system (SMS) by aquaveo LLC. Besides other features, the application is capable of importing topographic as well as other geo-referenced data that is used to generate a computational mesh for several numerical models, e.g. BASEMENT. SMS also contains a module which allows the user to visualise the simulation results on the mesh.

In order to generate mesh, geo-referenced data, DEM raster format, necessary for the mesh generation needs was converted in to an XYZ table using GIS 9.2, i.e. a delimited list of

single points described by their XY-coordinate and their elevation, and the polygon. The table serves as the scatter set out of which the elevation of mesh node is interpolated.

The polygon, representing the study area, confines the model domain to its extent. The break lines act as patch boundaries which are considered during the triangulation process. The land use layer is needed to directly assign the material properties of the terrain to the mesh elements. The coded values for the land used can be linked to roughness coefficients in the BASEMENT input file afterwards, so their absolute values can easily be changed independently of the mesh (for calibration purposes).

SMS allows the user to redistribute the vertices along a closed polyline. This is in order to increase regularity of the resulting mesh from the automatic triangulation and thus the performance, the boundary conditions for the triangulation.

The next step is that the break lines and the model domain layer can next be merged and polygons be built. This step allows the program to start the triangulation of the mesh as soon as the triangulation strategy is set. The strategy paving has been chosen with which the polygon boundary is paved inward until the interior is filled. The mesh triangles created from this method are thus aligned to their boundary i.e. model domain and break lines. Such a raw mesh is subsequently optimized by removing aspect ratio or duplicate nodes tolerance distance. The land use layer can now be mapped with the optimised mesh ensuring the material properties are set to every element.

As a last step, the NODESTRINGS, nodes at which the inflow and outflow will take place, need to be chosen. The ID's of these nodes need to be defined later in the input file for BASEMENT. The mesh is finally saved as a generic 2D mesh which is the format compatible (file extension .2dm). Survey data and shape file of the study area were used to generate the triangulated mesh of the study area. From constructed mesh, it was observed that node spacing is 10m for river section and 30m for floodplain. Figure 4-4 shows the mesh as it had been used for all main simulation runs. As shown from observation of the Generated mesh, it has 53238 vertexes and xx elements.

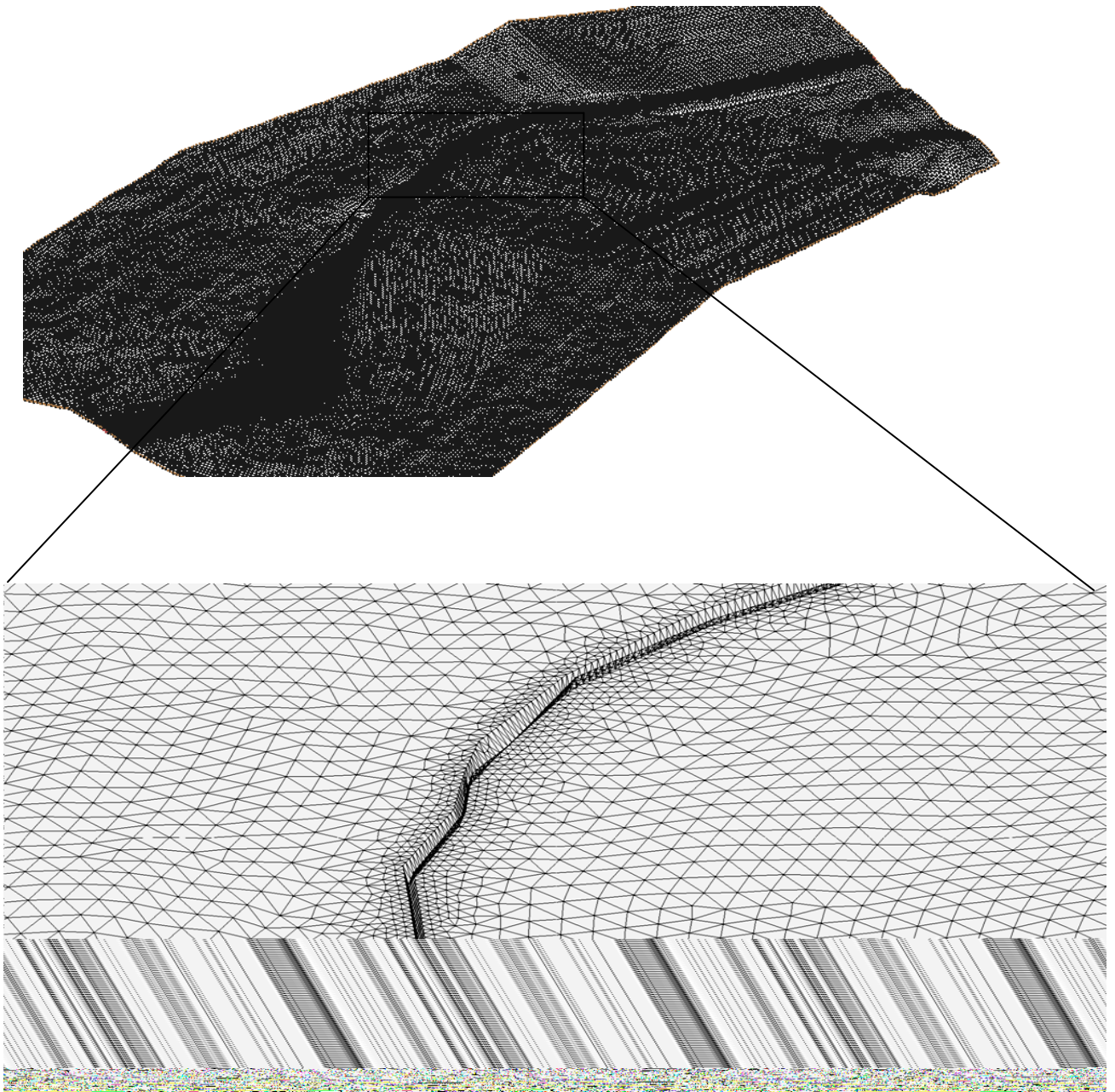
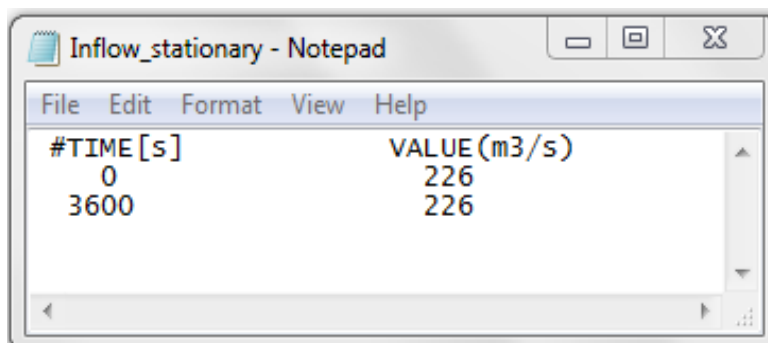


Figure 4-4: Mesh Representing the Area to Be Modelled

predefined string outflow. The normal slope was used in order to calculate the normal flow depths and the normal flow velocities at the boundary.



#TIME [s]	VALUE (m3/s)
0	226
3600	226

Figure 5-5: Stationary hydrograph file saved as inflow_stationary.txt.

5.2.3. Initial Flow Condition

In basement there is the initial block which defines the flow variables at the beginning of the simulation. In this block there are two options: “wet” and “dry” start. In a very first step the simulation is started with a dry initial condition. Then the program starts to run and fill the river with the flow and run until the flow reach outlet. This simulation generate “initial_condition.cgns” file which is automatically generated at the end of each successful model run. This file provides the initial flow to start the computation again.

For the next simulation, initial condition was set to be continue and the simulation start from the time given by restart time

5.2.4. Surface Roughness

Land use of the area significantly determines its roughness. Surface roughness values as required by the model have been derived from the land use map of the floodplain and from the properties of river bed materials. The land use type which is dominant is cultivated area and the river bed material is dominantly clay. The numerical model has implemented different flow resistance laws, here we used Manning’s coefficient. To setup the model a manning roughness coefficient values of 0.03 for flood plain and 0.02 for the river has been used. Figure 5-8 shows the distributed of surface roughness coefficients as used to set up the model.

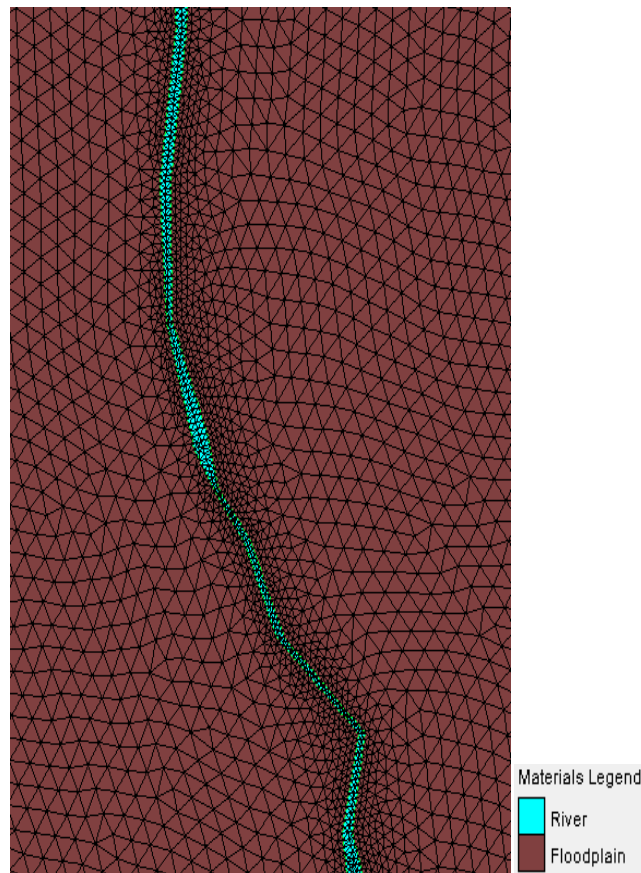


Figure 5-6: Spatial distribution of Manning’s n

Land cover types	Manning’s coefficients
Low vegetated area	0.025
Dry land agriculture	0.035
Grass land	0.035
Water course	0.010

Table 5-1: Roughness Coefficient for Different Land Use Classes (Chow, 1988)

5.3. Model Calibration and Validation

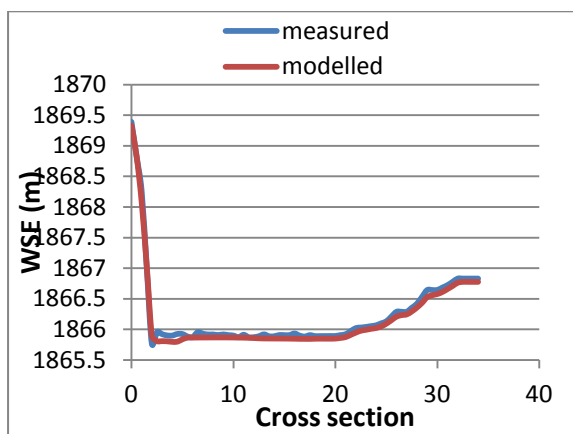
One of the most important variables for predicting the impact of a flood is the water depth. For these reasons, the calibration of the river hydrodynamic model focussed on predicting water depth and correctly representing the propagation of flood through the main river system. Both, the measured and observed water surface elevation, were used in the

calibration. Measured water surface elevation was calculated from measured flood depth and river bed elevation.

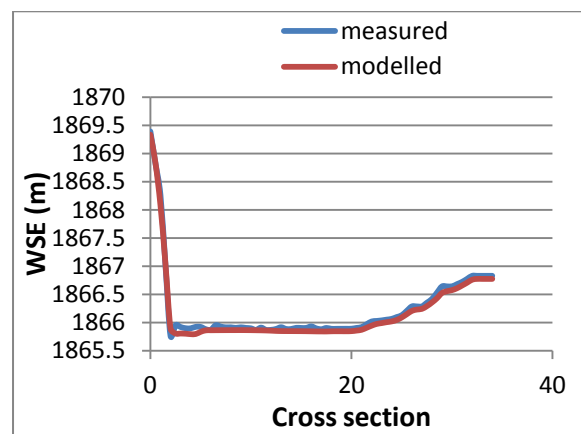
In this study, calibration of the hydrodynamic model was performed in two steps. Initially A calibration was made through a direct comparison between simulated and observed water surface elevation for the 4 stations. By changing Manning’s roughness coefficient, the model was re-run in order to optimise the adjustment between the results. Hence surface roughness coefficients of river and floodplain were adjusted iteratively until the best agreement between simulated and observed water levels on the river was obtained. Figure 5-9 shows the best results for 4 of these stations.

After obtaining the best adjustment, the next step is the quantification of the model accuracy. With this purpose it was performed a quantitative comparison, through the determination of the deviations between the model results and the observations. This was computed using the root-mean square (RMS). The RMS of the difference between the observed and predicted surface elevation is also used by numerous authors to evaluate models accuracy. (Dias, 2007)

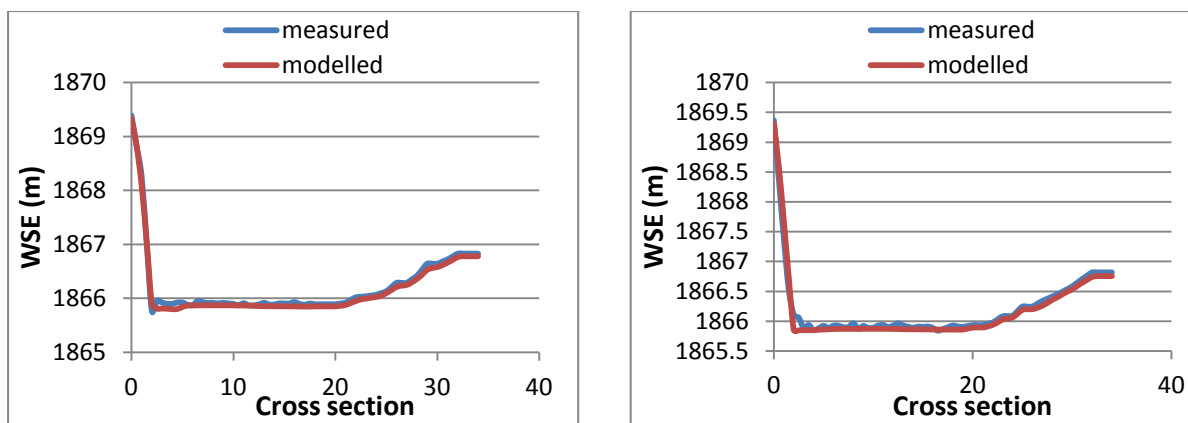
Where WSE_{obs} and WSE_{sim} are the observed and the simulated WSE, respectively, and N is the number of measurements in the time series.



a) Station A



b) Station B



c) Station C

d) Station D

Figure 5-7: Comparison of simulated and observed surface water level

In general there is a good agreement between the predicted and the observed WSE for all the stations (Figure 5-9 and Table 5-3), revealing the model’s ability to reproduce good result. The RMS values are acceptable for all the stations, ranging from 0% to a maximum of 14% of the local amplitude.

station	RMS
A	0.125148
B	0.066979
C	0.066979
D	0.082572

Table 5-2: RMS for all the calibration stations

5.4. Flood Model Output

There are three basic output information produces at the end of each successful computation. They are:

- ASCII raster map files indicating spatial distribution of pre selected parameters (i.e. water surface elevations, water depths, velocities) at specified time step.
- Historical plots, graphics of selected parameters vs. time at pre selected stations.
- Animations using incremental water depth or velocity map files.

6. FLOOD RISK MAPPING

6.1. Results of Hydrodynamic Modeling

The results of hydrodynamic model simulation from different flooding scenarios with different return periods will be further analyzed in this chapter to determine their effects on floods and, thereafter for flood risk analysis.

6.2. Scenario results

6.2.1. Flood depth

Flood depth information usually presented as maximum depth for each cell within simulation period. This way, the presence of flood hazard is clearly explained in both aspects; the size and the severity of the flood. Flood depth is described as distance between water level and bed level. Output files generated by BASEMENT can be reclassified into flood depth classes for further analysis of the results. The following figures show the inundation depth levels.

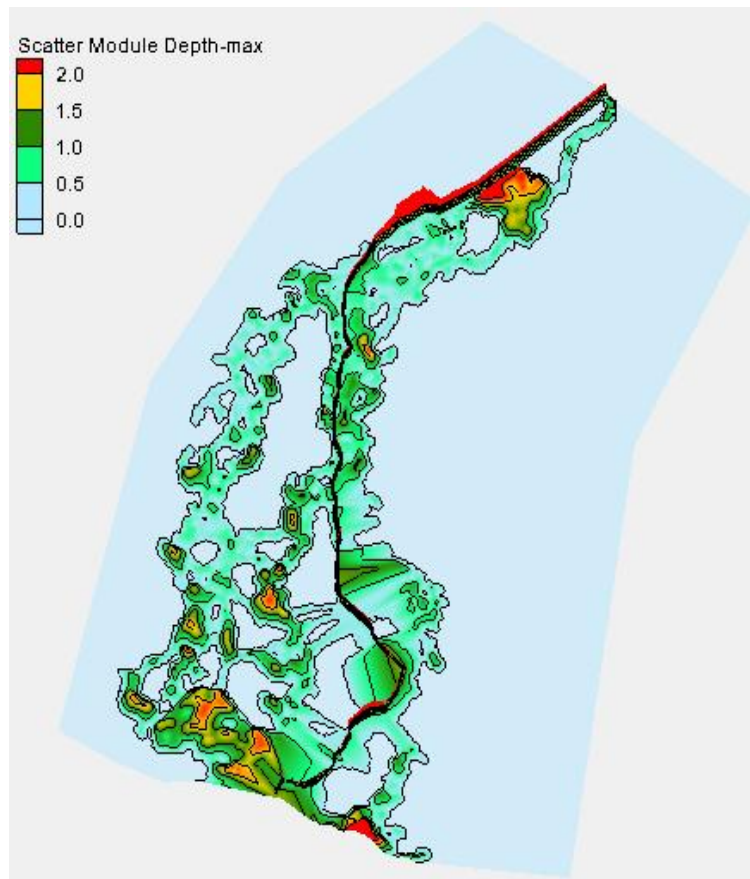


Figure 6-1: Flood water depth (10-year return period)

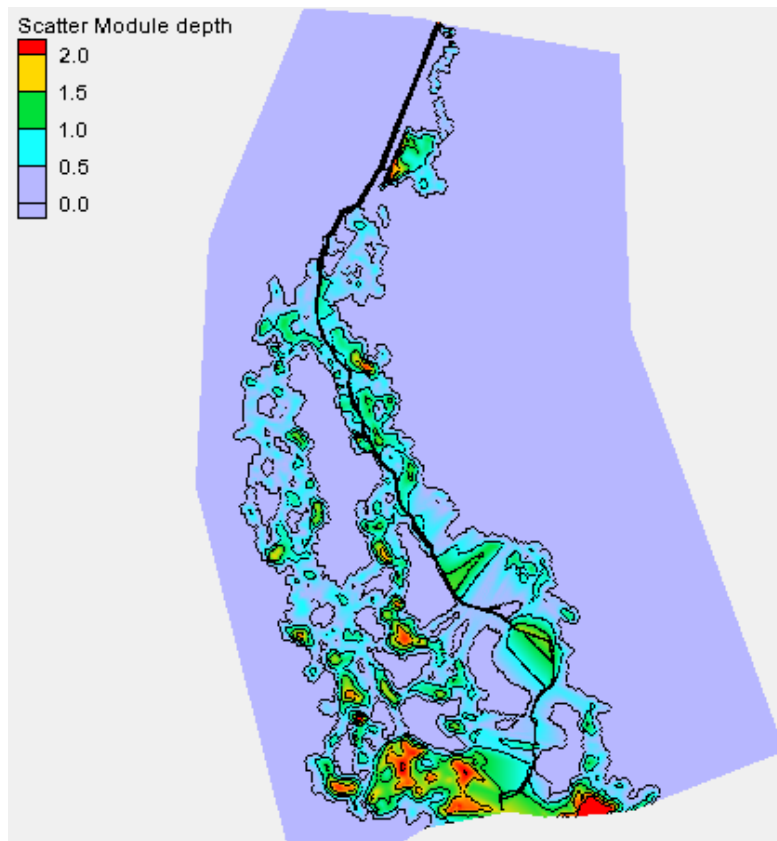


Figure 6-2: Flood water depth (25-year return period)

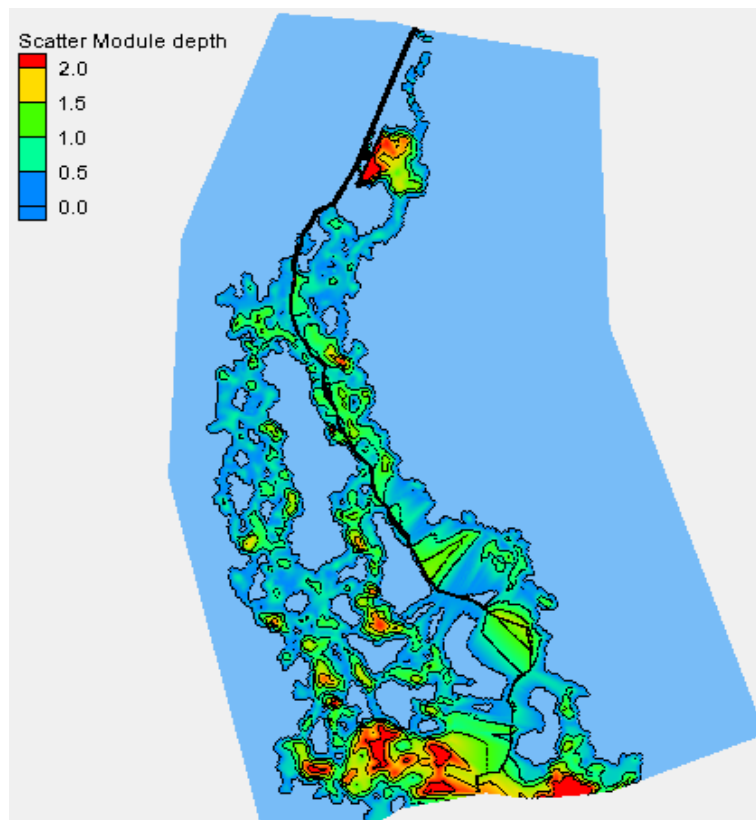
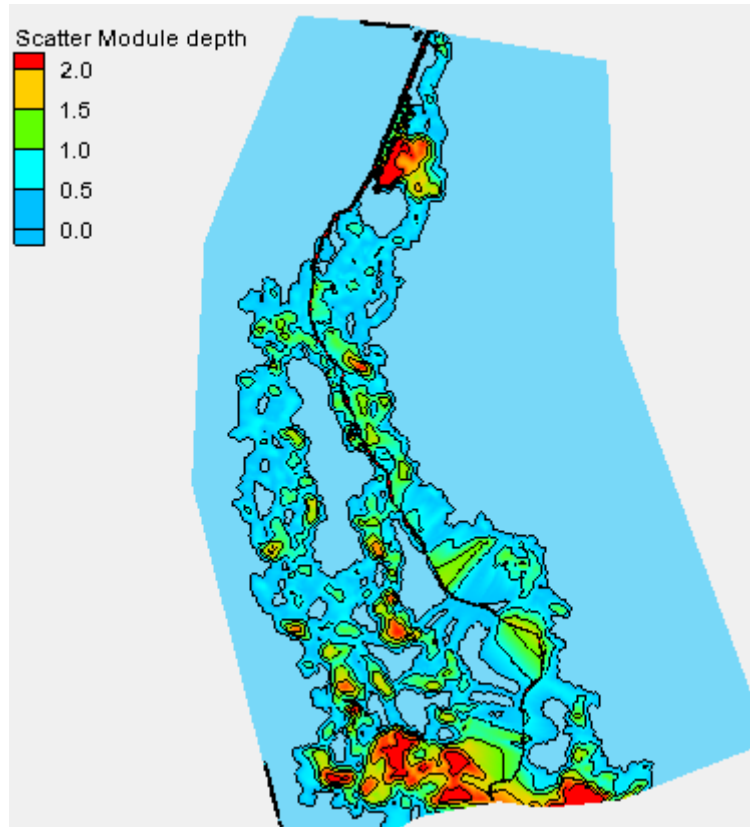


Figure 6-3: Flood water depth (50-year return period)



Flood water depth (50-year return period)

In this study inundation depth classes are considered defined as shown in table 4-3. The cut-off level for defining the hazard classes are subjected to several aspects including end requirements of the maps, study area as well as individual perspectives

6.2.2. Flow velocity

The following graphs from dynamic simulations indicate the spatial variability of water velocity in the river channel and the floodplain. For better comparison and visualization, the flow velocity of each scenario result was classified to 5 classes, In general, the high flow velocity in each scenario was observed in the narrow part of the main channel, where the highest value was, for example 6.69 m/s, in the 25-year return period scenario. For the overland flow on the flat plain, maximum water velocity is smaller than flow in the river, mainly under 2 m/s.

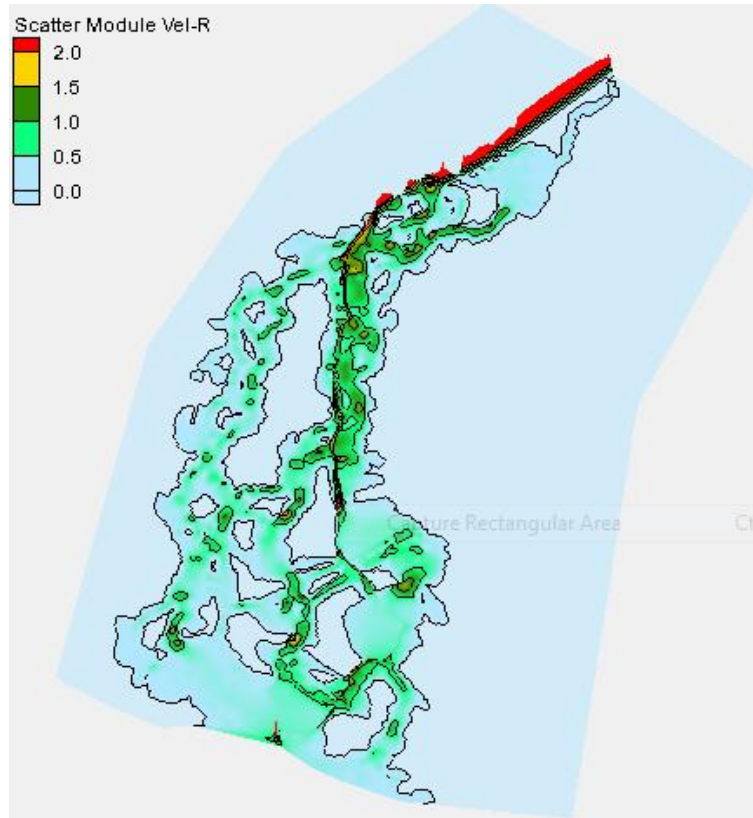


Figure 6-4: Flow velocity for 10-year return period

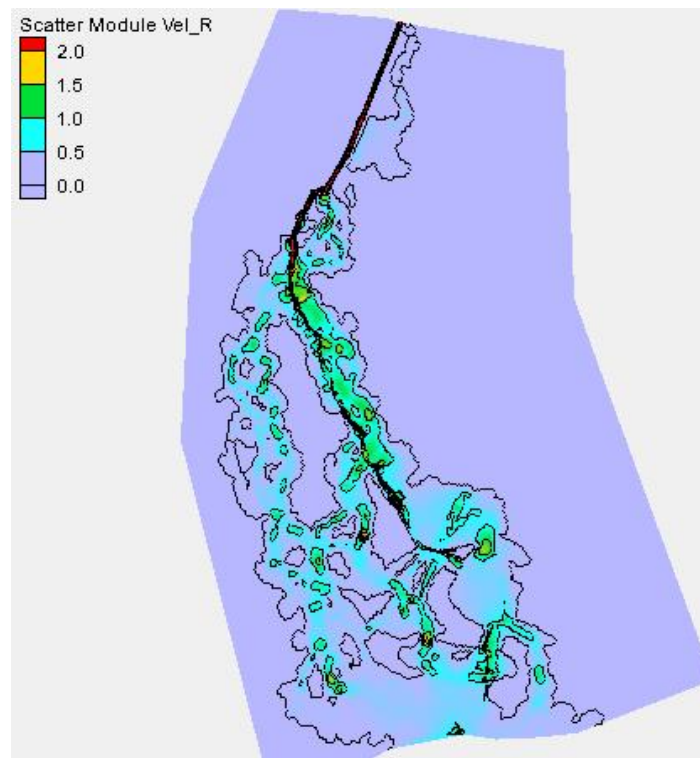


Figure 6-5: Flow velocity for 25-year return period

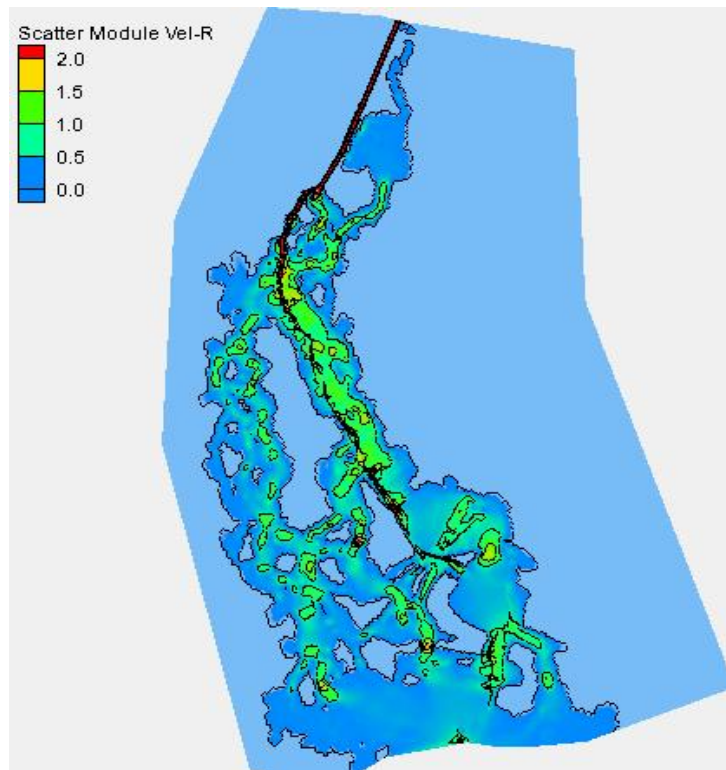
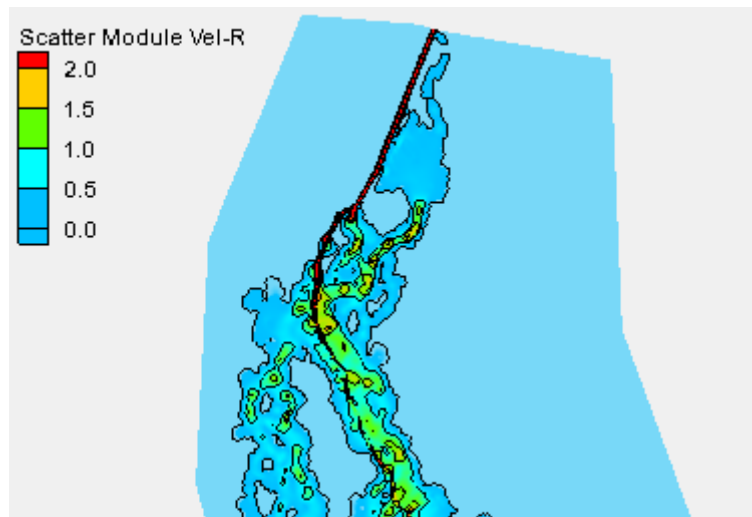


Figure 6-6: Flow velocity for 50-year return period



Flow velocity for 100-year return period

APPENDIX

year	maximum discharge
1980	199.297
1981	317.967
1982	41.195
1983	142.389
1984	160.708
1985	186.201
1986	143.544
1987	57.739
1988	72.487
1989	47.642
1990	65.939
1991	135.775
1992	96.695
1993	130.124
1994	136.884
1995	274.802
1996	89.792
1997	100.05
1998	190.848
1999	242.301
2000	83.946
2001	261.069
2002	137.881
2003	214.65
2004	263.668
2005	238.387
2006	186.04
2007	169.665
2008	214.65

Basement command files

The command file is generally structured as follows:

PROJECT

DOMAIN

PARALLEL

PHYSICAL_PROPERTIES

BASEPLANE_2D

region_name =

GEOMETRY

HYDRAULICS

OUTPUT

In the following, the blocks enclosed in the input file are introduced.

PROJECT: In the PROJECT block, the name of the project, the author and a date reference can be set.

PROJECT

title

author

date

DOMAIN: the domain block includes all blocks necessary for a simulation, including number of parallel threads and physical properties which act as global constants.

DOMAIN

PARALLEL

number threads

PHYSICAL_PROPERTIES

gravity

viscosity

rho_fluid

BASEPLANE_2D

BASEPLANE_2D: this block is enclosed in the DOMAIN block and contains all information regarding the two dimensional simulation which is structured in sub blocks named GEOMETRY, HYDRAULICS and OUTPUT.

BASEPLANE_2D

region_name

GEOMETRY

HYDRAULICS

OUTPUT

GEOMETRY: the calculation mesh file is linked in the GEOMETRY block and the inflow and outflow elements are listed.

GEOMETRY

type

File

STRINGDEF

name = inflow

node_ids

STRINGDEF

name = out flow

node_ids

HYDRAULICS: the HYDRAULICS block defines the hydraulic boundary condition e.g. the inflow hydrograph (block BOUNDARY), initial conditions (block INITIAL), the roughness coefficients (block FRICTION) and several computational parameters controlling the numerical simulation (block PARAMETER).

HYDRAULICS

BOUNDARY

Type
String_name
File
Slope

BOUNDARy

Type
String_name
File
Slope

INITIAL

Type

FRICTION

Type
Default_friction
Input_type
Index
Friction
Wall_friction

PARAMETER

Simulation_scheme
Cfl
Total_run_time
Minimum_water_depth
Initial_time_step
Minimum_time_step

OUTPUT: in this section, the output of the simulation result can be defined. Different output formats are available and the output frequency can be customised. For this project, the node-centred solution is put out in a file format ready to import into SMS for visualisation purposes.

OUTPUT

Output_time_step =

Console_time_step =

SPECIAL_OUTPUT

Type =

Format =

Values =

Output_time_step =

SPECIAL_OUTPUT

Type

Output_time_step

Balance_values

SPECIAL_OUTPUT

Type

boundary_values

history_one_file

Output_time_step