ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

FLOOD MODELLING USING 2D HYDRODYNAMIC MODEL IN THE FOGERA FLOOD PLAIN

BY

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Flood Modelling Using 2D Hydrodynamic Model

In the Fogera Flood plain

Wondwosen Dejenne

Thesis Assessment Board	Siginiture
1. Dr. (Chairman)	______________________________
2. Dr. (External examiner)	______________________________

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work. Signed … … … … … … … … .

Disclaimer

This document describes work undertaken as part of a programme of study at Addis Ababa institut of Technology in civil engineering Departement . All views and opinions expressed there in remain the sole responsibility of the author, and do not necessarily represent those of the institute.

This thesis is dedicated to all those people in the world who are facing Flood disaster . May there be a day when no one suffers from such disaster anymore.................

Acknowledgement

The achievement of this paper has come through the overwhelming help of many people. I wish to express my sincere gratitude to all those who offered their kind corporation and guidance throughout my project period.

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List of Acronyms

CSA.. Central Statistics Agency
DEM .... Digital Elevation Model
CCHE2D .... Computational Hydrodynamic 2 Dimensional Models
WM S .... Surface Water modeling systems
ESRI .... Environmental System Research Institute
MoWR .... Ministry of Water Resource
NMA .... National Meteorological Agency
EMA .... Ethiopia Mapping Agency
UNOCHA .... United Nation Office for the Coordination of Humanitarian Affaires
UNEP .... *United Nations Environment Programme*
DPPA .... Disaster Prevention and Preparedness Agency
2D .... Two Dimensions
1D .... One Dimensions

HEC .... Hydrological Engineering Center

Abstract

Flood occurs repeatedly in Ethiopia and cause tremendous losses in terms of property and life, particularly in the lowland areas. The majority of flood disasters' victims are poor people living in nearby stretch of floodplain. Therefore, the study was carried out to perform floodplain analysis and risk assessment of Fogera and near by areas.

This research involves application of 2D Hydrodynamic Modeling System with Geographic Information Systems (GIS) to develop a regional model for floodplain determination and representation.

The study describes the Velocity mangitude ,innudation depth in the area for different flow conditions derived from the historical flow data of the Gumera River. Flood frequency analysis is used for prediction of peak flow for daily time series data and Gumbel and Log pearson Type III is used and Gumbel Distrubution is adopted with(R^2 =0.994) and peak flow of the River for return periods of 2,5, 10, 25,50 and 100 years. boundary condition for upstream and downstream were defined. Similarly, flood discharges for different return periods were also inputted as inlet boundary and steady flow analysis was done for the results.
The result of Gumbel Distrubution shows a flow value of 233m^3/s,281 m^3/s,312m^3/s,352m^3/s,382 m^3/s,and 411 m^3/s for return periods of 2,5, 10,25, 50 and 100yr respectively.

Detailed topographic maps collected from various utility organizations and CCHE2D hydrodynamic models were used for simulations. Model results were evaluated for six different scenarios varying return period 2,5, 10,25,50 and 100yr. Finally, flood map was created.
Based on the study the following conclusions were drawn: to represent river flood modelling , we need Good mesh generated based on bathzemeteric data high resolution inculding both river geometry as well as flood plain is very important to get meanigful innduation depth and velocity mangitude map on flood plain.

Key words: CCHE2D, GIS, DEM, Flood Map

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1.Introduction

1.1 Research Background

Topographically, Ethiopia is both a highland/mountainous and lowland country. It is composed of nine major river basins, the drainage systems of which originate from the centrally situated highlands and make their way down to the peripheral or outlying lowlands. Especially during the rainy season (June-September), the major perennial rivers as well as their numerous tributaries forming the country's drainage systems carry their peak discharges.

The country experiences two types of floods: flash floods and river floods. Flash floods are the ones formed from excess rains falling on upstream watersheds and gush downstream with massive concentration, speed and force. Often, they are sudden and appear unnoticed. Therefore, such floods often result in a considerable toll; and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration. The recent incident that the Dire Dawa City experienced is typical of flash flood. On the other hand, much of the flood disasters in Ethiopia are attributed to rivers that overflow or burst their banks and inundate downstream plain lands. The flood that has recently assaulted Southern Omo Zone and South Gondar (mainly Fogera Woreda) Zone is a typical manifestation of river floods .Therefore, owing to its topographic and altitudinal characteristics, flooding, as a natural phenomenon, is not new to Ethiopia. Some parts of the country do face major flooding. Most prominent ones include: extensive plain fields surrounding Lake Tana and Gumara and Rib Rivers in Amhara Regional State; areas in Oromia and Afar Regional States that constitute the mid and downstream plains of the Awash River; places in Somali Regional State that fall mainly along downstream of the Wabishebelle, Genalle and Dawa Rivers; low-lying areas falling along Baro, Gilo and Akobo Rivers in Gambella Regional State; downstream areas of Omo River in the Southern Nations, Nationalities and Peoples Regional State (DPPA, 2006).

Fogera flood plain, which is located between $11^{0}57'$ and $12^{0}30'$ North latitude & $37^{0}35'$ and $37^{0}58'$ East longitude, is traditionally identified as one of flood prone areas of Ethiopia. This is particularly found in the downstream part of the above mentioned catchment. Fogera Flood plain has elevation ranges from 1780 m to 2510 m and it has
an average elevation of 1937 meter above mean sea level. Area is drained by two major rivers, namely Ribb and Gumara. It totally lays in Ribb-Gumara Catchment, which is part of the Blue NileBasin. This Catchment encloses big flat to gently sloping plains located in the administrative Zone of South Gondar, east side of Lake Tana, Fogera Woreda.

1.2 Problem of statement

The rainy season in Ethiopia is concentrated in four months from June to September. Large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands causes flooding of settlements close to any stretch of river courses.

Flood is probably the most devastating, widespread and frequent natural hazard of the world.This problem is more acute in highland areas like Ethiopia under strong environmental degradation due to population pressure. According to UNEP (2002), the major environmental disasters in Africa are recurrent droughts and floods.

The lower part of the Gumera catchment is known as one of the flood prone areas by the annual flooding in the Fogera floodplain. In 2006, extreme flooding affected 43,140 and displaced 8730 peoples respectively in the region (UNOCHA, 2006).

Even though flooding is frequently observed in the Fogera floodplain, the flood management strategy has not gone beyond strengthening rescue and relief arrangements and other post flood measures which are totally devoid of any pre-flood management and planning strategy to minimize loss of life, property and environment.

Information regarding the flooding characteristics and its effect are essential for flood management bodies for decision making in flood management strategies such as construction of flood protection structures (engineering structures), to develop flood emergency plan and human settlement planning.

With the advancement of new technology on flood modeling such as the Hydrodynamic modeling (CCHE2D) and GIS these days, it is possible to model flood extent, depth, velocity magintude etc. in the temporal and spatial dimensions. Past flood study in the area however ignores these applications.

Another major necessity to conduct this research work is frequent happening of floods in the area. As the region is known as crop productive area of the country, most of the crops may be suffered. Lack of flood resistant engineering structures is another case for the necessity of the research to conduct.

1.3 Objective

1.3.1 General Objective

This thesis research is mainly aimed at assessing the flooding on Fogera flood plain using 2D Hydrodynamic Model.

1.3.2 Specific Objectives

- Comparing Flood Frequency analysis output using daily time series data and selecting best method.
- Mapping of the floodplain and the Gumera River
- Developing flood map for different flow conditions for return period 2, 5,10,25,50,100 year.

1.4 Research Questions

- How does flood frequency Analysis is used for flood modelling ?
- How to apply Flood propagation model for Flood modelling?

1.5 Hydrodynamic Modelling

As with the development of remote sensing technology, near real-time flood monitoring becomes more and more popular and practical. Nevertheless, for the preventive purpose, hydrodynamic modeling has the advantage in the prediction of flood events which did not occur in the history, for example, 100-year or 200-year return period magnitude floods. From the perspective of prevention and mitigation, hydrodynamic modeling is of more importance in the planning phase.

Quite a number of researches have been carried or carrying out, trying to forecast flooding, giving advices on land-use planning and flood defending projects (Alkema*etal*, 2001). Zerger and Wealands (2004) pointed out that the importance of spatially explicit hydrodynamic flood models in flood risk reduction and their suitability to provide inundation information, such as time, location and severity of anticipative flooding.

The overall flooding study could be divided into three steps:

- To construct hydrologic models, DEM, land cover/use map and hydro meteorological information of the study area are needed as input data.
- Generation of flooding information, including possible inundation areas, water depth, flow velocity, flood extent.
- Relevant mitigation measures are proposed according to the results from previous step.

In the last few decades, 1 Dimensional (1D) hydrodynamic modeling has been well developed. It is mainly used for the modeling of rivers, streams and canals. For example, the HEC series are the well known and widely used "one-dimensional movable boundary open channel flow numerical model" which is initiated by US Army Corps of Engineers (Dodson & Associaties Inc., 2005). Though 1D modeling has the advantages, the major limitation of 1D model is that it considers the water flows along the main direction of river (Tennakoon, 2004). This gives 1D model limited capability to represent flooding in the complex terrain, due to the artificial constructions change water flow, depth etc.

1.3 Outline of Upcoming Chapters

Literature review and a general description of the study area is presented in the next two chapter and the fourth chapter is material and method used , model schematation, are presented. In the next two chapter follows a description of CCHE2D models used. Result and model caliberation is presented in chapter 6, and short conclusion and Recommendation is made at the end of the last chapters.

2. Literature Review

2.1 Historical Background of Flood Risk in Ethiopia

Risk assessment of the flood prone areas in Ethiopia is not an easy task. There is a big shortage of adequate and reliable water and soil data. More over, the absence of stream flow data and the secrecy about survey reports of some major rivers, classified as "International Rivers", effectively block any thorough study of the topic. However, there are some studies, particularly done by the then DPPC (now DPPA) and also by some other organizations and individuals, on flood risk in Ethiopia. In the past, there have been floods which have taken both human lives and destroyed properties. According to DPPC, 1978, the following areas have been recognized as flood-prone areas.

In Gondar Administrative Region immediately east of Lake Tana where River Gumara enter the Lake. In Hararghe Administrative Region on the Wabe Shebele River from Imi to Mustahil. the Baro In Illubabor Administrative Region on River from the town of Gambela to the border town of Jakao. In Wollo Administrative Region on the Awash River around Assayita. In Shewa Administrative Region around Tefki in the Teji Depression.

Maps that show geographical distribution of these areas, and other relevant information on flood occurrence years and flood risk are incorporated on the above mentioned document. However, the study is to general to show flood hazard and risks at a lower grass-root kebele
level. Another study conducted again by DPPC, 1996, showed areas that suffer from flood risk at a national scale.

Table-1 **Summary of Causes of Flooding, Flood Risk, and duration by Region**

Regions	Cause of flooding	Flood Risk			Dura
		No of affected population	No of affected livestock	Property damage in Birr	
Tigray	Flash flood	112	15	13835	1987
Afar	River flood	445700	_	_	1985
Amhara	river&flash flood	165363	2693	1504745	1985
Ormia	river&flash flood	63359	359	9882811	1985
SNNPR	flash&river flood	252713	79781	4708683	1981

(Source: Compiled from DPPC, 1996)

The rains have caused most rivers to swell and overflow or breach their courses, submerging the surrounding 'flat' fields or floodplains, which are mostly located in the outlying pastoralist regions of the country.

As a result of the extended and widespread heavy rainfall as of the beginning of 2006 main rainy season, many areas have already experienced devastating damage. According to DPPA, 2006, altogether some 635 people have died (364 in South Omo, 256 in Dire Dawa and 19 in various other parts of the country). Thousands have lost their property and means of livelihood. The soil in most areas is saturated and rivers are full.

In this summer (2006), a total of some 524,400 people were vulnerable to flood disaster through out the country. Out of this population, 199,900 people are actually affected by flood disaster in various areas (Table 2).

Table 2: Areas and Population Affected/under Threat by Flood Disaster in the 2006 main Rainy Season

No	Region	Vulnerable	Affected*
1	Afar	28000	4600
2	SNNP	106300	44000
3	Amhara	47100	47100
4	Oromia	61300	21900
5	Tigray	122300	2600
6	Diredawa	10400	10400
7	Somalia	87000	43200
8	Gambela	62000	26100
	Total	524400	199900

*The affected number of population includes 15 % contingency
Source: DPPA, 2006

2.2 River Flood

Water is a basic requirement for sustaining life and development of society. Proper management, protection and development of the water resources are challenges imposed by population growth, increasing pressure on the water and land resources by competing usage, and degradation of scarce water resources in many parts of the world. 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 (Hoyt and Langbein, 1958; Walesh, 1989; Knight and Shiono, 1996; Omen, et. al. 1997; Smith and Ward, 1998).

Flooding results from excessive rain on the land, streams overflowing channels or unusual high tides or waves in coastal areas. 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 (Smith, 1996). Most floods are caused by intense precipitation combined with other factors such as: snow melt, inadequate drainage, water-saturated ground or unusually high tides or waves. Floods are the most damaging phenomena that effect to the social and economic of the population (Smith and Ward, 1998). There are many different types of flooding. The most common types are: river floods, flash floods, coastal floods, urban floods and ice jams.

2.3 Floodplain Modelling

For an appropriate model selection, it is important to understand the purpose of the model and the applications it is selected for. Models come in different types and were developed for different purposes. Approaches used for specific hydrologic problems are categorized into five basic components; system characteristics, input, the governing equations, initial and boundary conditions and output (Singh, 1995).

Most hydrologic and hydraulic models employ mathematical equations to simplify real world processes. The input and output of the models generalizes the behavior of the system model that must reflect the real world system behavior. Model can be further to describe the processes in the system, in this study, flow in river systems, overland and floodplain interaction.

2.3.1 System Characteristics

For floodplain modeling, one must have a-priori understanding on the heterogeneity exists on the floodplain. The characteristics of a floodplain comprise both natural and man-made features. Examples of natural features include the weather, climate, topography, soils and land cover. The basis for how the flood water would propagate on the floodplain is governed by combination of these features such as the amount of precipitation or water fallen within the system, the topography of the study area, which influence the flow rate as well as direction of the flow, the soils holding capacity and resistance caused by the land cover. The man-made features are urbanization, channelization, and change in land use and water storage among many other features.

2.3.2 System Processes.

Hydrological processes are spatially homogeneous though heterogeneity does exist in the real world. To incorporate all heterogeneity of a catchment in a model, some kind of assumptions and transformation on those data and processes must be introduced commonly so-called "effective" values. Arising from here it must be decided what scale will be suitable to meet the applications and thus the purpose of the study.

This might requires some of the hydrologic responses treated as homogeneous. In this respect, Singh, (1995) describing that the scale should not be too small to be dominated by local features nor too large to ignore significant hydrologic heterogeneity and spatial variability of the catchment. For the purpose of floodplain modeling, data needed are hydrologic data such rainfall, water level, discharge, information on the land use, geomorphologic data such as the river networks, drainage areas and most important of all is the digital elevation model. One major difficulty encountered for any modeling particularly in flood modeling is lack of adequate flood data and observations during the flooding events (Bates and De Roo, 2000).

2.4 Two Dimensional Model Descriptions

The methods for mapping flood extent are ranging from simple such as by intersecting a planar observed water level surface with a digital elevation model of certain resolution and assigned to as flooded area (Preinstall et al., 2000) to highly sophisticate such as hydrodynamic modeling the Hydraulic flows models come in variety of forms have been employed to quantify flood magnitude and floodplain inundation (Bates et al. 1992, 1996, Marks and Bates, 2000, Alemseged, 2005, Abdul Rahman, 2006).

2D models are capable of providing information not only regarding the inundation depth and its spatial distribution but also the variation of flood extent and flow velocities over a user-defined time frame. Thus, 2D models are becoming more and more popular among the modeling community nowadays. In 2D modeling fluid is divided into fluid columns, and in these cells each variable is assumed to be constant (depth-averaged values) "(Borsányi, 1998). Cells in this approach are represented as 2D finite elements. All the input and output hydrological and hydraulic parameters are assumed to be uniform within a cell. In 2D models there are two approaches to model the flood plain. It could be as a rectangular grids format or a triangular mesh structure.

2.4.1 Triangular mesh approach

In the triangular mesh each cell is built out of triangles having different sizes. Therefore in this approach the higher the concentration of triangles, the more accurate the resulting representation.More concentrated mesh representation always guarantees better accuracy of the modeling effort and also accurate representation of features like rivers, estuaries, bays, wetland areas or coastal regions is feasible using 2D finite-element meshes rather than the rectangular mesh. For example 2D model offers two methods to generate the mesh structure. That is direct approach or conceptual approach. In the direct approach it allows to build the mesh structure first and model parameters can incorporate later with the mesh.

In the second approach a conceptual model is created first using GIS objects including points, arcs and polygons. The conceptual model is constructed independently of the mesh. In this level description of the site including geometric features such as channels and banks, the boundary of the study area, flow rates and water surface elevations of boundary conditions and roughness coefficients such as Manning's n value. Once the conceptual model is complete, a mesh network is automatically constructed to fit the conceptual model.

2.4.2 Raster grid approach

In raster based approach cells are identical all over the model. Data input to a raster-based model is fairly simple if the input data are manipulated through a raster based GIS system. Also it has the advantage of utilizing the recent high-resolution remotely sensed topographic data and the capability of exporting model results in to various GIS systems for presentation purposes.

As a result the raster based 2D modeling systems are quite popular nowadays in risk assessment, planning, environmental impact assessment and studies related to dike breach or dam failure. Some of the distinctive advantages in 2D hydrodynamic modeling between Triangular and Rectangular mesh are outlined below.

Table-3 triangular mesh and rater grid

	Triangular mesh	Raster grid
Easy mesh generation		Yes
Faster calculation time	yes	
Allow accurate result at critical point	yes	
Easy integration with RS data		Yes

2.5 Boundary Condition

In floodplain modeling, it is crucial to properly describe the boundary condition. Boundary condition plays a role as a connecting node that defines flux relationship between the model domains area. Boundary condition plays a role as a connecting node that defines flux relationship between the model domains area and its surrounding area. Boundary condition needs to be defined at the upper and lower boundary of the model domain area can be represented by either series of constant discharge, Q or series of water level, H (as a function of time). A wrong choice for boundary conditions may generate a misleading water balance of the system and consequently resulted in serious propagation of errors throughout the simulation, thus giving ambiguous results.

In hydraulic and hydrologic modeling, in general there are three types of mathematical boundary conditions namely:

1. Dirichlet condition - specified head boundary,
2. Neumann - specified flow boundary and
3. Cauchy condition - head dependent flow boundary.

In dirichlet boundary condition, the hydrological state of a specified hydraulic head is described as $h_{(x, y, z)} = ho$ with $h_{(x, y, z)}$ is the constant head boundary at location x, y and z and h_o is the specified head value defined as a function of time. In hydrologic modeling, Neumann boundary condition gives:

$$q_x = \partial h/\partial x \quad \text{.......} 1$$

The specified flow boundaries are constant across the boundary. The examples of specified flow boundaries in hydrology are the flow to surface water bodies, the natural groundwater recharge and infiltration to unsaturated zone.

Neumann boundary condition is applied to zero flux boundaries such as at water divide of a catchment, impermeable fault zone, sharp boundary between fresh and salt water in a coastal aquifer and streamlines on a cross section perpendicular to the contour lines of the hydraulic heads. Cauchy boundary condition is dependent upon the difference occurred between the specified head outside the model boundary and the calculated head inside the model boundary.

2.6 Surface Roughness

For the purpose of flood modeling, roughness coefficients need to be defined for natural rivers and floodplains. Usually, the roughness coefficients (Stricker Manning, ks) cannot be measured directly and therefore needs to be estimated. As an empirical parameter, the roughness depends on several factors such as small scale topographic heterogeneity, vegetation characteristics and channel geomorphology. Usually, the value of roughness parameters is estimated through a trial and error model calibration procedure that is based on visual comparison of simulated and observed values. This approach is subject to uncertainty and also time consuming. Reviewed few approaches to measurevegetation height data and transformed this information into roughness coefficients over the floodplain.

2.7 Model Calibration

Calibration is a process of fine tuning a model by optimizing the model parameters by modifying the model structures, boundary conditions and improving the hydro meteorological forcing input. Extensive calibration in this study was not undertaken because due to time constraints. Optimization of the parameter value is done manually and checked qualitatively such as by plotting of observed and simulated water level outputs.

Performance measures are quantitative indicators of how well or poorly an alternative meets a specific objective. Feature of good performance measures are:

- Quantifiable
- Have a specific target
- Indicate when the target has been reached or
- Measure the degree of improvement towards the target when it has not been reached.

1. The Root Mean Squared Error (RMSE)

The RMSE is the standard deviation between the measured and calculated head water and is represented with the following equation: Root Mean Square Error (RMSE) in flood modeling indicates the accuracy of flood extent as flood water propagates. This measures the discrepancy between the modeled and observed values on an individual basis and indicates the overall predictive accuracy weight is given to larger discrepancies. With this measure, smaller values indicate better model performance.

$$RMS = \frac{1}{n}\left[\sum_{i=1}^{n}\left(h_{measured} - h_{observed}\right)_i^2\right]^{0.5i} \quad \text{------------------------2}$$

2. Nash Sutcliffe

$$NS = 1 - \frac{\frac{1}{n}\sum_{i=1}^{n}\left(O_{simulated} - O_{observed}\right)^2}{\frac{1}{n}\sum_{i}^{n}\left(O_{observed} - \overline{O_{observed}}\right)^2} \quad \text{---------------------3}$$

With this coefficient, values equal to 1 indicate perfect fit between observed and predicted data, and values equal to 0 indicate that the model is predicting no better than using the average of the observed data. Therefore, positive value above 0 suggests that the model has some utility, with higher values indicating better model performance.

3. Description of the Study Area and Flood Related Facts

3.1 Gumara Catchment Overview

Gumara Catchment, drained by Gumara Rivers, is located between $11^0$53'N Latitude and $37^0$54' E Longitude. This catchment is part of the Nile Basin and more particularly part of that of Tana Basin located on the North Eastern side of Lake Tana. It has an areal extent of about 3320 km^2. Fogera Woreda, which has an area of 1110 km^2 totally lies in this Catchment. This Woreda is found in the down stream part of the Catchment where Gumara Rivers join to Lake Tana.

Overflow of this rivers and back flow of Lake Tana frequently flooded this Woreda than other woredas in the Catchment, and therefore selected for detailed flood risk study. Gumara River, which is found at 13 km from Woreta Town (headquarter of Fogera Woreda), has its source in Mogishe Kidane Mihiret kebele, Farta Woreda.

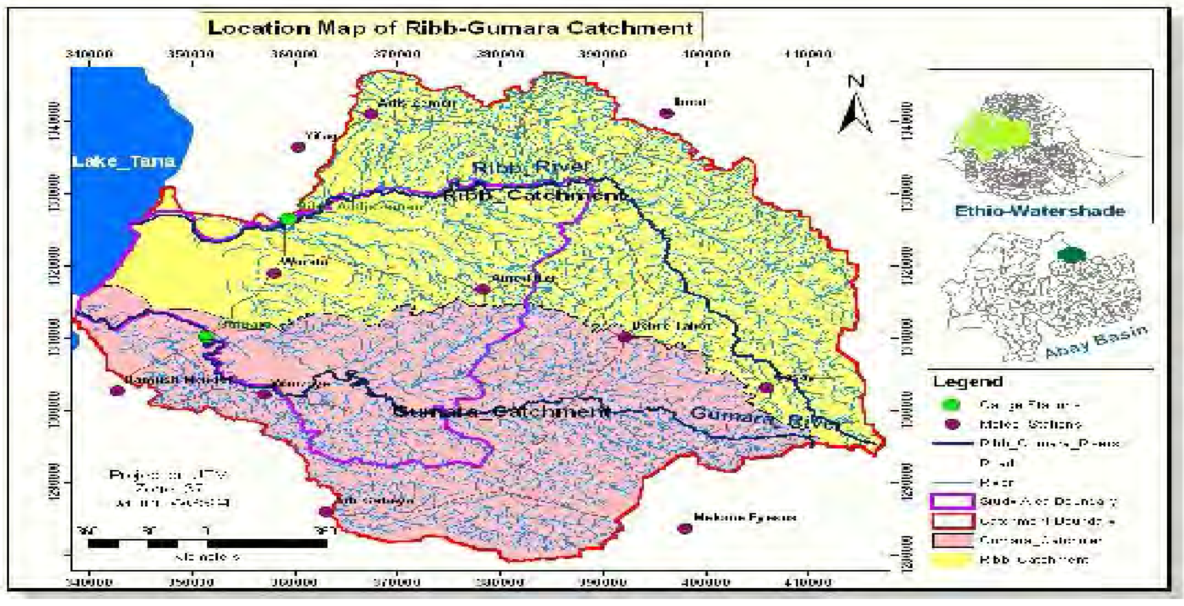


Figure -1 : loacation map of Rib-gumera catchement

3.2 Description of the Study area

3.2.1 Location

Fogera Woreda lies to the south-eastern shore of Lake Tana on the road from Bahir Dar to Gondar, 625 km from Addis Ababa and 55 km north of the Regional capital of Bahir Dar.

It is one of the 105 woredas in the Amhara National Regional State of Ethiopia and located at its center. Part of the Debub Gondar Zone, Fogera is bordered to the south by Dera Woreda, to the west by Lake Tana, to the north by Libo Kemkem Woreda, and to the east by Farata Woreda.

The major towns in Fogera Woreda are Woreta and Amed Ber, the former being the head quarter of the head quarter of the Woreda and it has twenty-five Peasant Associations (PAs) or kebeles and 2 urban Kebeles (figure 2). The area is located between 11° 57' and 12030’ N latitude and 37° 35’ E and 37058’ E longitude.

3.2.2 Topography

The study area has a very flat land, which is known by the Fogera plane, adjacent to the eastern coast of Lake Tana. However, proceeding to eastward there is a rugged topography as shown in figure 3. Altitude ranges from 1780m to 2510 m.   The Woreda consists mainly of flat land (76%), while the mountain slopes and valley bottoms account for 24%.

3.2.3 Climate

Rainfall

The study area has a diverse altitudinal difference which ranges from 1780 to 2510 masl. The agro climatic zone of the Fogera Woreda based on the agro climatic classification method (altitude and rainfall) is classified as Moist Dega (2300-3200masl) and Weyna-Dega (1500-2300m). Total annual rainfall ranges from about 1100 mm to 1530 mm/year. The spatial distribution of rainfall (Fig. 5) showed that Eastern and Central part of the Woreda receive highest rainfall while the northern portion receives the lowest.

The seasonal rainfall has a Unimodal distribution with peak in July. This is the 'Meher' season and it receives about 70% of the annual rainfall. The mean annual rainfall is 1430 mm and mean monthly values varies between 0.6 mm (January) and 415.8 mm (July), which indicate poor temporal distribution of rainfall.

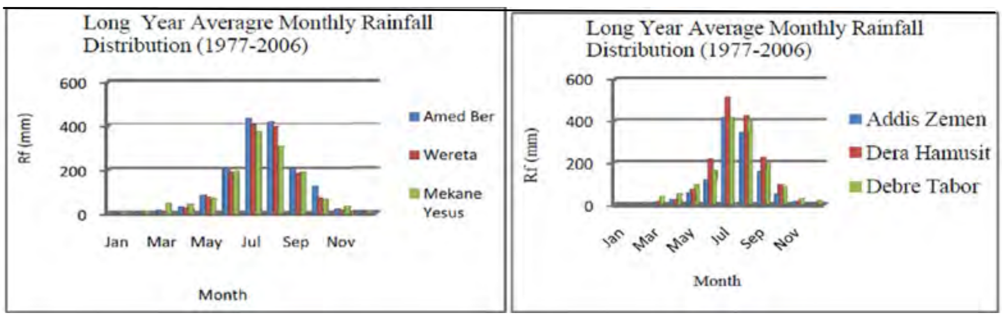


Figure -2: Yearly Average Monthly rainfall distrubition (1977-2006)

Temperature

Mean monthly temperature of the area is $19\ ^{0}{}_{C}$, the monthly mean maximum Temperature is about 230^{c}, and the mean monthly minumum temperature is 11.50^{c}. Dinural Range of temperature is higher (16.70^{c}) in woreta compared to that of Amed ber (14.90^{c}).

3.2.4 Soils

The major soil types in Fogera Woreda exhibit a general relationship with altitude and slopes. Vertisols and Fluvisols are generally dominating the Woreda and particularly the lowland flat plains, valley bottoms and river terraces (Fig. 3). Texturally these soils are sandy clay and sandy loam respectively. Shallow Leptisols are the dominant soil types found in the mountain and hills of the study area. Luvisols dominate the southern and central part of the Woreda.

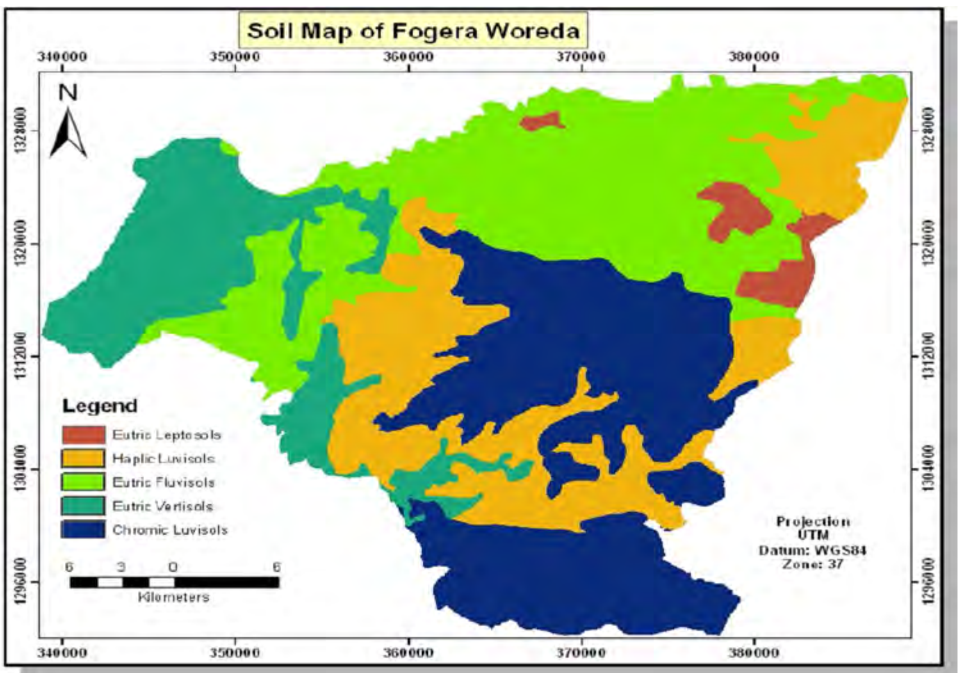


Figure -3 : soil map of fogera woreda

3.2.5 Drainage System

Fogera flood pain mainly consists of a flat, open plain across which the Rib River flows into Lake Tana . It passes through Wetemb, Addis Betekerstian, Reb Gebriel, Debasi ,Fatra, Abua Thua, Shaga, Naber and Shina PAs. The Gumara River forms the southern boundary of the study area and it passes through Fuafuat Gajera, Kinti Merewa, Abagunde Sendega, Aba Kiros, Bebeks, Quahr Michiel, Shena Kidist Hanna, Wagatera and Guramba PAs.

The perennial Gumara River also overflows its banks as it approaches the lake and floods up to 1.5 km inland during the rainy season (Shiferaw and Wondafrash, 2006).

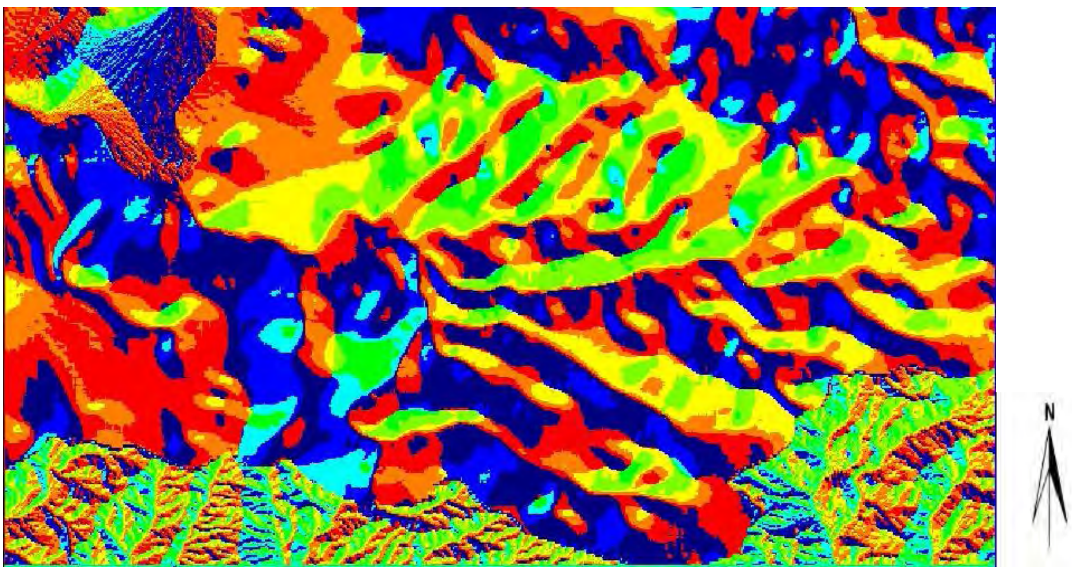


Figure-4 Drainage Direction of gumera watershed by Mohid GIS

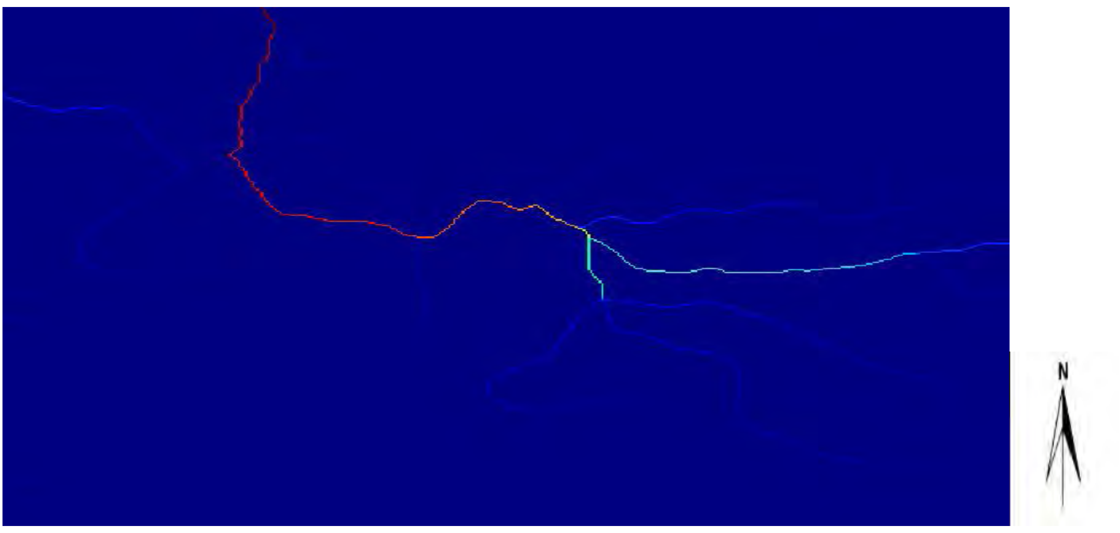


Figure-5 Drainage Network of study area

3.2.7 Vegetation

The shoreline of Lake Tana supports well-established papyrus beds 4 m tall. Further inland the vegetation is dominated by sedges, reed grasses and bulrushes, along with swamp grasses such as Echinochloa spp. And Cynodon aethiopicus that make very good grazing in the dry season. Patches of mixed small- and broadleaved trees and bushes are found around churches on small, rocky hills near the lake shore. These patches contain trees such as Albizia spp.,

3.2.8 Land Use/Land Cover

There are eight different types of land use/cover types in Fogeraflood plain , namely agricultural land, shrub land, grassland, swampy area, plantation forest, wood land, Urban, and Water body. Form these land use/land cover classes the dominant one is agricultural land. It covers about 78.7 % of the total land area (Fig. 6).

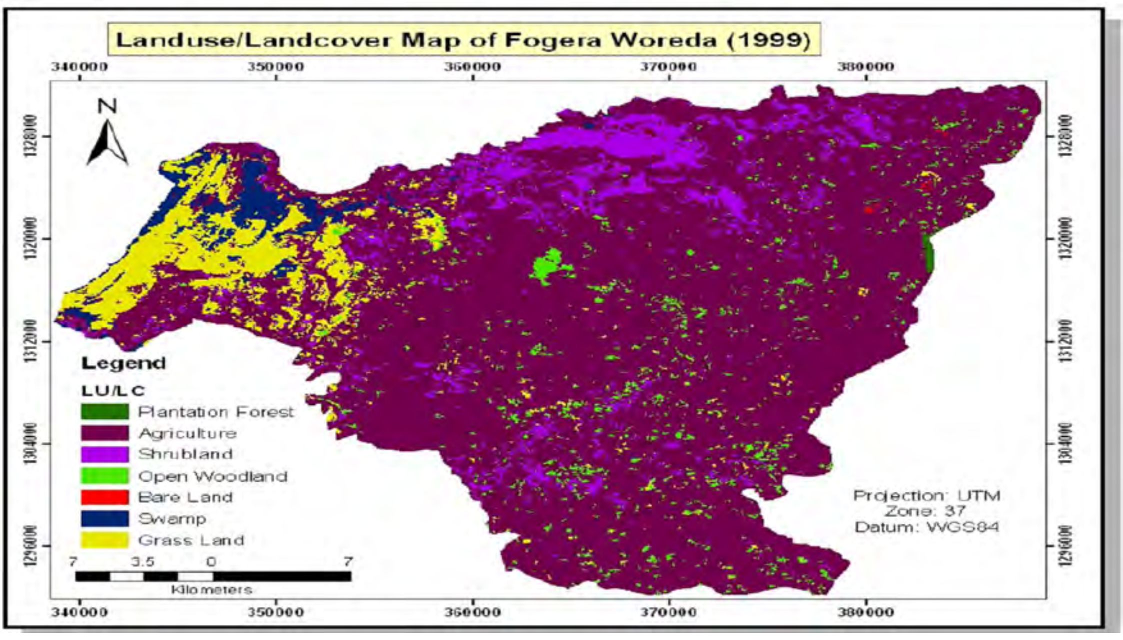


Figure -6: Land Use/Land Cover Map of the Study Area (1999)

3.3 Flood Related Facts in Fogera Flood plain

3.3.1 The Situation of Flooding in the Study Area

There have been many destructive floods in Fogera flood pain , including very severe floods of 1996, 1998, 1999, 2000, 2001, 2003 and 2006 (Shiferaw and Wondafrash, 2006). The 1996 flood set a new record for flooded area, while 2006 flood was unprecedented with its long duration and damage. In 1996, the total area inundated was over 5000 ha. In addition, about 2500-2600 ha area of land was inundated at the eastern shore of Lake Tana as the level of the Lake rose. The 1996 flood affected eight PAs, namely, Wagtera, Nabega, kidiste Hana, Shaga, Shina, Woreta Zuria, Kuhar Michael and Abatihua (Shiferaw and Wondafrash, 2006).

3.3.2 The 2006 Flood Event

The 2006 flood affected over 7473 households compared to that of the 1996 flood which affected about 6206 households (Shiferaw and Wondafrash, 2006). This year flood was the most sever of all the flood events experienced in the area so far. Due to the flood, 43,127 people (12% of the Woreda population) were affected (UNOCHA, 2006). This figure accounts 50% of the affected population in Amhara Administrative Regional State (UNOCHA, 2006). The following plates show the devastating 2006 flood events from its occurrence to the month when it gradually dries up.

Figure 7 : The 2006 Flood in Woreta Zuuzia PA Figure 8: Gummara Bridge (AAlong Bahir to woreta)

Figure 9: Evacuation from Flooding Figure 10 Journey to the Temporary Shelter

Figure 11.: Flood Damage around Woreta Zuria PA Figure 12: Displaced people in the Temporary Shelter

The flood has created a Post-traumatic stress disorder, including anxiety, depression, and psychosocial problems on the community (Shiferaw and Wondafrash, 2006). Direct health effects (heart attacks and injuries) occurred during the flood occurrence and indirect health effects like diarrhea were also happened later on. Large number of people is expected victims of malaria since the flood will be a good ground for mosquito breeding. This may indirectly affect the hospital treatment cost, the labor force, productivity and so on.

Figure 13 Innudating area by flooding Figure 14 Affected cattle by the flood

Besides such bad events and expected effects, the flood has killed 9 cows and 1 sheep. Moreover, 322 bee hives were also destroyed. Most of the hats have been drowned by the flood. Cattle have been evacuated from the area. As a result environmental degradation because of overgrazing occurred in areas where the animals concentrated. Grains, which have been inside traditional containers, were spoiled by the flood. As a result of this, people from the impact areas are forced to depend on food aid. In which, the food aid might bring long term impacts on our working power, creativity potential, culture and on agricultural development activity.

The flood has frequently devastated agricultural crops. A total of 6673ha of land, which were covered by different types of agricultural crops were drowned by the flood in the year 2006 . The expected crop productions, which lost was 148005 quintals. The reduction in agricultural production because of flooding may elevate prices in agricultural crops in the coming year, which in turn may lead to poverty that forces people into a vulnerable position causing great loss of life and damage. From 1988-1997, in different years time, the country has lost 69929760 Birr due to loss of agricultural crops caused by flooding in Fogera flood plain.

Figure 15 : Complete crop damage by Flooding

4.0 Materials and Methods

4.1 Introduction

This chapter focuses on the assessment of the data that was available and had been collected.
A brief description of the available data had been included and the final available data used for the study had been described. The work outlined in the preceding pages had been made possible using various datasets to analyze, compare and validate the results. It was also necessary to investigate the gaps in the existing data and gather the required information during the collection phase .Furthermore the methodologies adopted for achieving the final objective are described in this chapter.

4.2 Overall Methodology

The methodology of the study is divided into four major stages. The first stage was scanning through the available database and identification of the required data or gaps within the data. A detailed investigation through the available database was done in order to identify what was already available and what was required for the analysis.

The second stage dealt with the data collection and then preparation of the data for modeling and analysis purposes. The data collection was done for validation of the existing database and measurements were taken to acquire what was absent in the database. The elements at risk, the physical factors and the man made terrains were identified in the field for further analysis of the results from the model.

The third stage entailed modeling of the flood event for different scenarios and validating the result using ground truthing and historical data. For modeling, calibration and validation was done. The modeling of the flood provided the extension, depth and duration for the different return periods and scenarios were generated for them. This assisted in the hazard assessment.

4.3. Available Dataset

The available data sets were divided into the following sections depending up on their contents. They are listed in Table 4.

Table-4. Shows the data used in the research

S. No	Type of Data	Source
1	DEM	EMA
2	Land cover maps	EMA
3	Meteorological Data	NMA
4	Discharge data	MoWR
5	Hydrologic Data Gauge level Daily Max	MoWR
6	cross section Data of river Gumera	MoWR
7	Landuse/Landcover	EMA

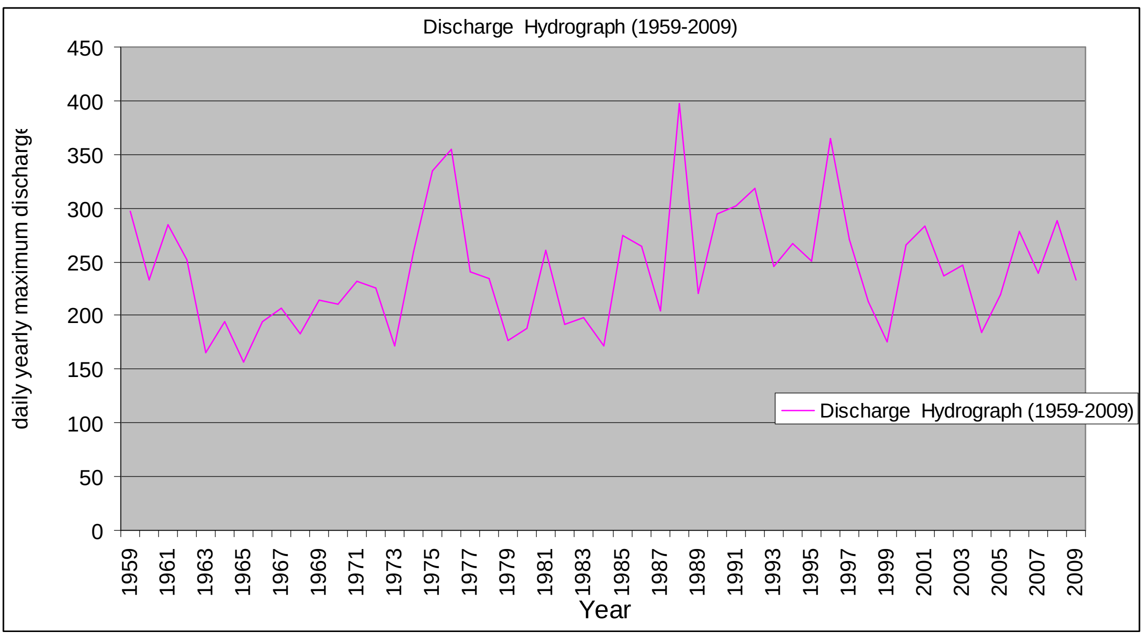
4.4. Methodology: Data Preparation

The available data were organized and processed for the analysis. The quality of the data was analyzed to identify any kind of abnormalities. The goodness of fit of data was evaluated with several statistical models and at the end Gumbel's max statistical model was selected for further analysis. Descriptive statistical analysis was conducted to see the distribution of the data. Topographic maps were geo-referenced and estimations were performed in metric projection system. All methodelogy and procedure are presented on the appendix page

4.5 Discharge data

The daily discharge of the study area is collected from the Ministry of Water and Energy. Unlike the daily precipitation, the daily discharge has full data composition for the considered stations to represent the study area.

Discharge data available at Gumera river outlet gauge stations, which was located at 11^0 50' 00'' N and 37^0 38' 00'' E. The daily yearly maximum data covered from 1959 to 2009 below on the figure 16.



Figur-16 :Yearly daily Maximum flow at gumera gauge station (1959-2009)

4.6 Meteorological data

During the Rainy season, precipitation is an important meteorological factor because the excessive rainfall is likely to coincide with the discharge peak in the river from upper basin, which will increase the probability of floods.

4.7 River crossection and Flood plain data

Cross section data represent the geometric boundary of the stream. Cross sections are located at relatively short intervals along the stream to characterize the flow carrying capacity of the stream and its adjacent floodplain. Even though it is not a must, it is advisable to take cross section at constant interval.

Cross sections are required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, roughness; at locations where levees begin and end; and at hydraulic structures (bridges, culverts, and weirs).

The required information for a cross section consists of: the river, reach and river station identifiers; a description; X & Y coordinates (station and elevation points); downstream reach lengths; Manning's roughness coefficients; main channel bank stations; and contraction and expansion coefficients. Points which are used to represent cross section in any floodplain modeling are:

For River flood modelling detailed river gemeotry and flood plain data is very important to get meanigifull innudation depth and flow velocity scenior in the study area. In the figure below detailed river gemotry and flood plain for study area

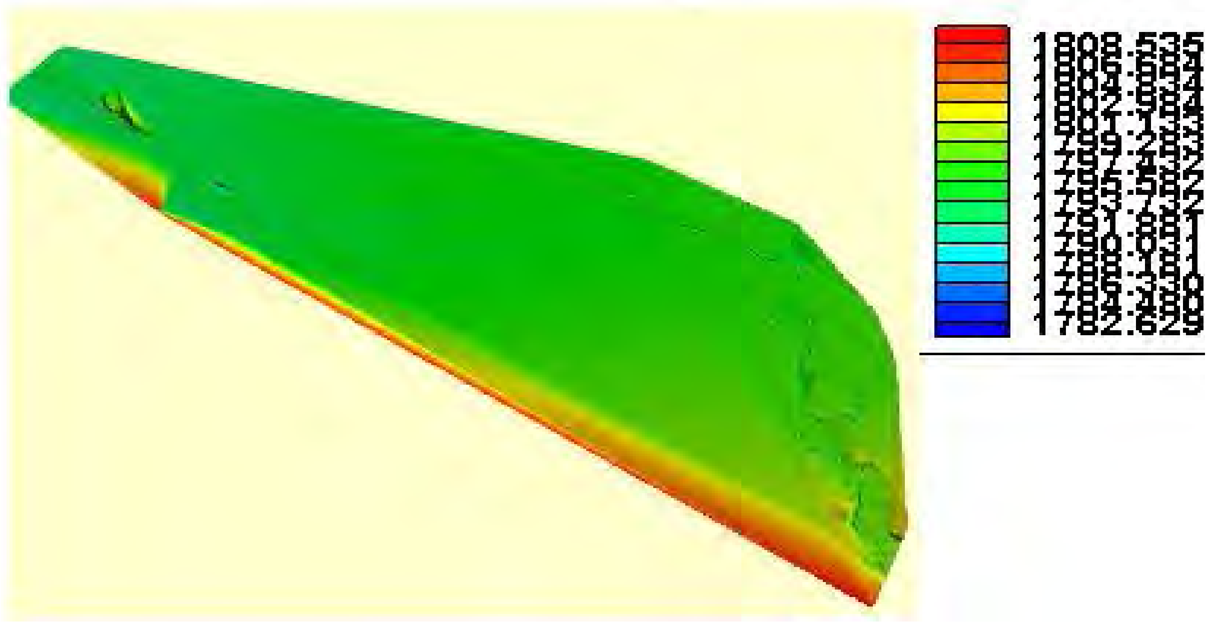


Figure-17: Detailed river gemotry and flood plain for study are

4.8. Flood Frequency Analysis

Statistical methods should be applied to conclude for flood probability analysis. This can be established from parameters such as Discharge or water height used. It was therefore necessary to evaluate the distribution of the available data and the probability of the occurrence of flood events (Calver et al., 2009). For this, a Gumbel plot is one of the most widely used statistical measures (Robson, 1999) for such kind of calculation and it was applied to get the probability values of the occurrence of extreme events. This also calculates the different return periods for flood modeling. Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedence probability. Flood frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. The common forms are and each distribution can be used to predict design floods.

- Gumbel Distribution
- Log-Pearson Type III Distribution

Table-5. Stastical Descripition of Discharge Sample data for Study area

Statistic	Value
Sample Size	51
Range	240.97
Mean	242.61
Variance	2890.3
Std. Deviation	53.762
Coef. of Variation	0.2216
Std. Error	7.5281
Skew ness	0.72815
Excess Kurtosis	0.44017

4.8.1 Flood Analysis For Gumble Distrubution

The Gumbel distribution is a statistical technique for fitting frequency distribution data to predict the peak flood for a river at some site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. In the Figure below describes observed discharge data with simulated by Gumble Distrubution.

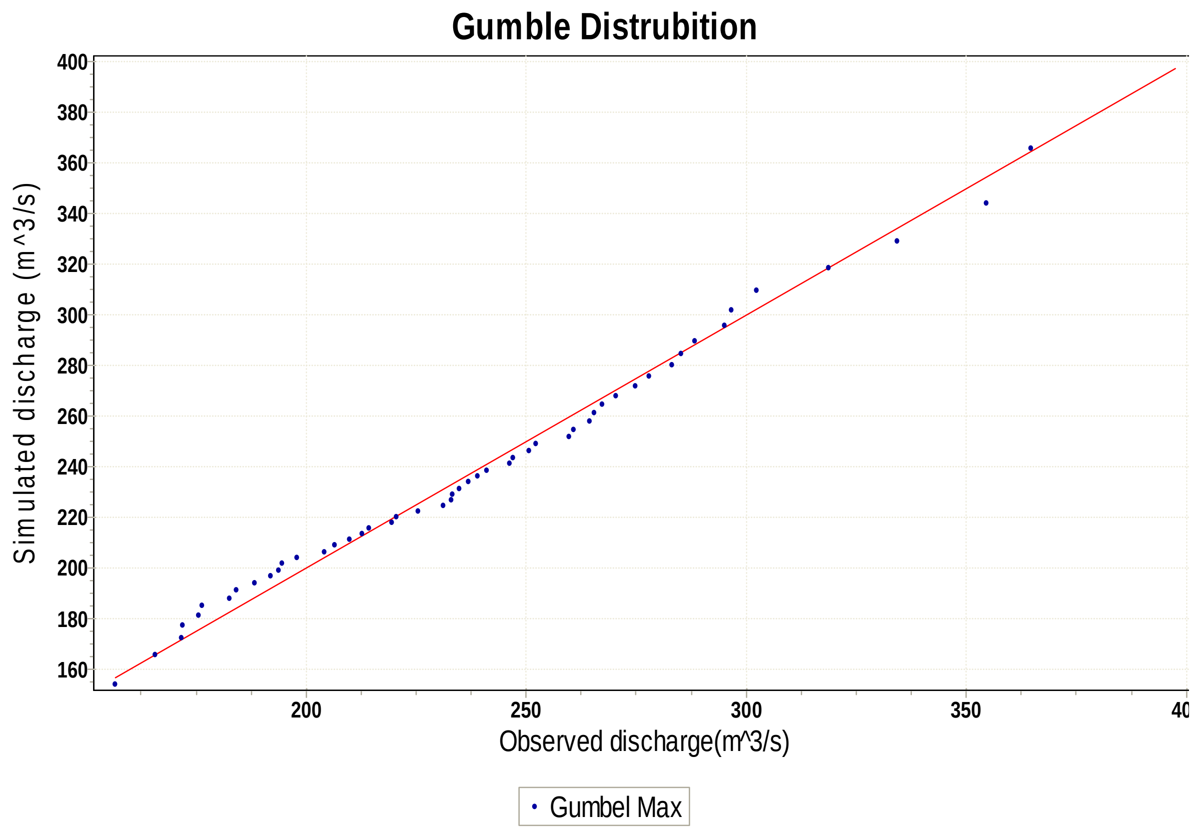


Figure-18: Observed vs simulated by Gumble Distrubution (R^2 =0.994)

How is it calculated?

The Gumbel distribution is calculated using the general equation:

$$X_T = \bar{X} + K\sigma \text{ ------------------------------------1}$$

Where X is the flood discharge value of some specified probability, $\bar{X}$ is the average of the X discharge values, K is a frequency factor, and σ is the standard deviation of the X values. The frequency factor K is a function of the skewness coefficient and return period and can be found using the frequency factor table. The flood magnitudes for the various return periods are found by solving the general equation.

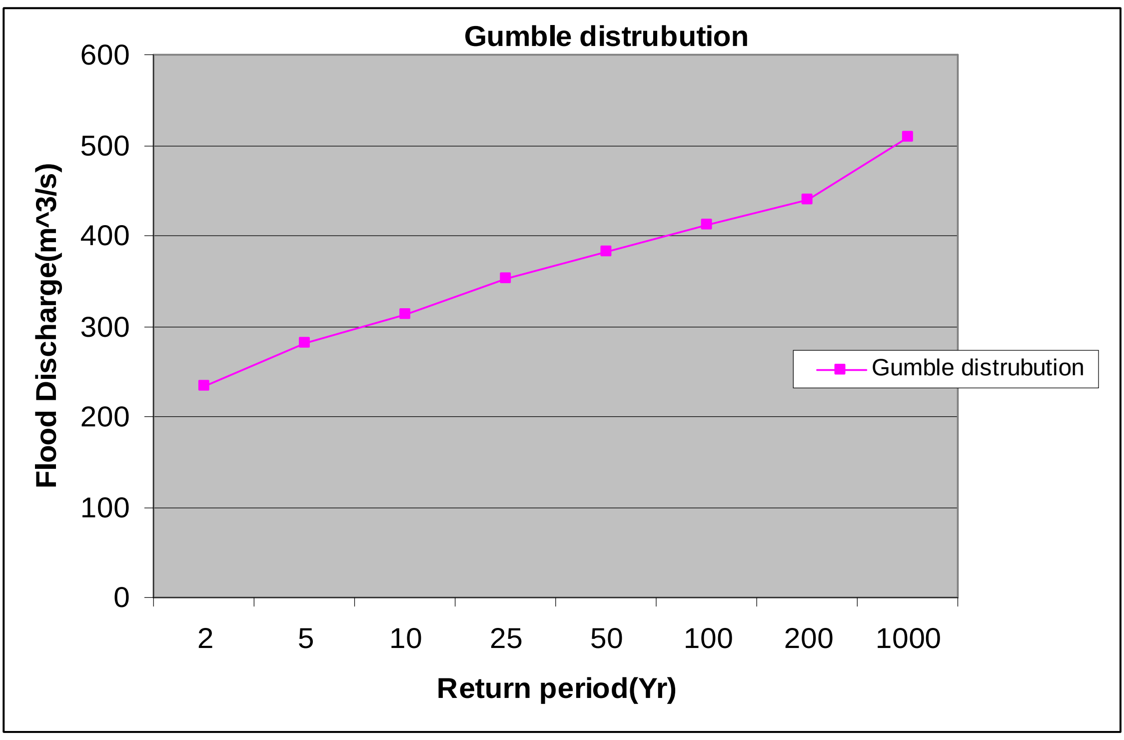


Figure-19: Gumble Flood hydrograph for Different Return period

4.8.2 Flood Analysis For Log-Pearson Type III Distribution)

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the peak flood for a river at some site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events.

The Log-Pearson Type III distribution tells you the likely values of discharges to expect in the river at various recurrence intervals based on the available historical record. This is helpful flood modeling and also helpful when designing structures to protect against the largest expected event. For this reason, it is customary to perform the flood frequency analysis using peak discharge data. However, the Log-Pearson Type III distribution can be constructed using the maximum values for mean daily discharge data.

How is it calculated?

The Log-Pearson Type III distribution is calculated using the general equation:

$$LogX_T = \overline{LogX} + K\sigma \text{ --4}$$

where X is the flood discharge value of some specified probability, $\overline{Logx}$ is the average of the LogX discharge values, K is a frequency factor, and σ is the standard deviation of the log x values. The frequency factor K is a function of the skewness coefficient and return period and can be found using the frequency factor table.

Table-6: Statistical Description Log discharge data

Statistic	Value
Sample Size	51
Range	0.40465
Mean	2.3749
Variance	0.00879
Std. Deviation	0.09376
Coef. of Variation	0.03948
Std. Error	0.01313
Skewness	0.20187
Excess Kurtosis	-0.38768

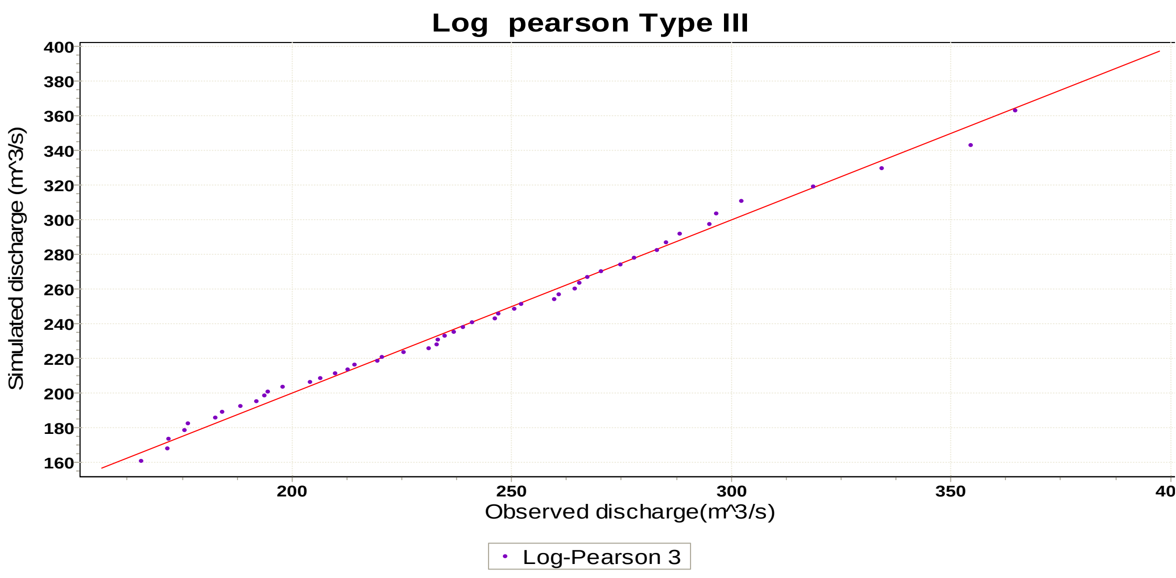


Figure-20:Observed vs simulated by Log pearson Type III (R^2 =0.980)

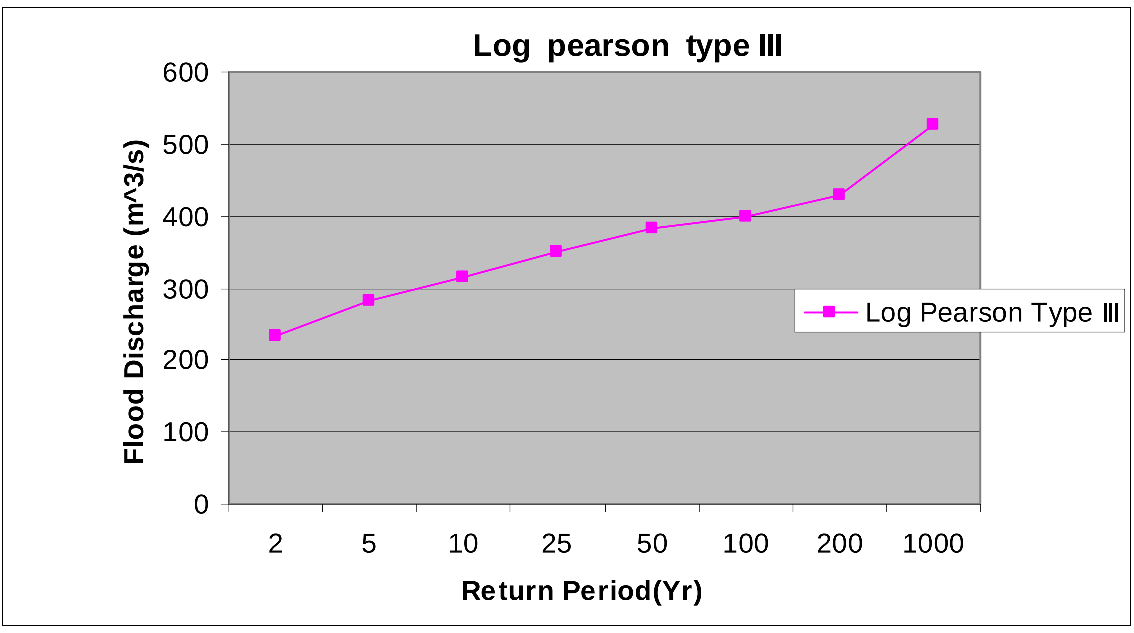


Figure-21: Log Pearson III Flood hydrograph for Different Return period

4.9. Flood Modeling

For comprehensive flood modeling the estimation of inundation depth and extent as well as velocity magnitude are essential. The selection is mostly made on need based and/or data based. For modeling the river flood CCHE2D model was selected which allows the computation of two dimensional river flood modeling.

4.9.1. Model Building: Schematization

The model 2D CCHE was schematized to get appropriate outputs for flood modelling assessment. The initial values for the event were used in the settings such as Discharge , initial water level , initial bed elevation and bed roughness with which the output maps will be generated. The combined channel flow module of the CCHE2D was used with a selection of steady calculation boundary nodes.

4.9.2. Generation of parameter maps

The result from the model was in the form of flood characteristics maps and additional information about the flow characteristics of the river were obtained from these maps.Major output of CCHE2D model for river flood analysis include:-

1. Water depth (unit in m): This flood characteristic map indicated the depth of water which occurred during an event. This map is very important for identifying potential areas which were affected by highest depth of water and influence the elements at risk in the area. It clearly denoted the amount of potential damage for a given area for a particular return period.
2. Velocity maps (unit m/sec): These parameter maps indicated the velocity of the flood water per unit of time. This component of flood characteristics is essential for hazard identification since it is an essential parameter for identifying degree of damage. It is interesting to note that sometimes large amount of water with lower velocity causes much less damage than a smaller amount of water with higher velocity.

5. CCHE2D Flood Modelling Simulation

5.1 Introduction

This chapter explains the data input for CCHE2D models and describe techiques needed to simulate river flood . CCHE2D model is depth –integerated pen channel flow simulation and sediment transport model and also it is used for flood propagation create flow depth and velocity magintude.

A cross-section geometry and morphology of natural river channels are complicated and change along the channel course resulting in a complex flow field characterized by turbulence, secondary currents and vortices. Successful flow simulation in a natural river channel requires numerical methods to be capable of taking into account sharp bends, irregular channel topography, bed roughness in different scales, vegetation on the flood plains.

CCHE2D model is a depth-integrated two-dimensional numerical model, which can be used to simulate steady and unsteady flow in natural river channels with complicated arbitrary cross sections. This paper presents a validation of CCHE2D model for flood modelling on fogera flood plain due to gumera river. Realistic simulation of over bank flow is an important task for flood control and river management in in the study area,since overbank flow frequently occurs in this reach and this numerical model, CCHE2D, is a useful tool to simulate steady and unsteady flows in natural river channels with very complicated geometry.Steady depth-integrated equations and continuity equation are solved in CCHE2D model using mixed finite element and finite volume method. Three turbulence closure schemes, the depth integrated parabolic eddy viscosity, the depth integrated mixing length eddy viscosity and the k-£ model, are available for computing Reynold’s stress.

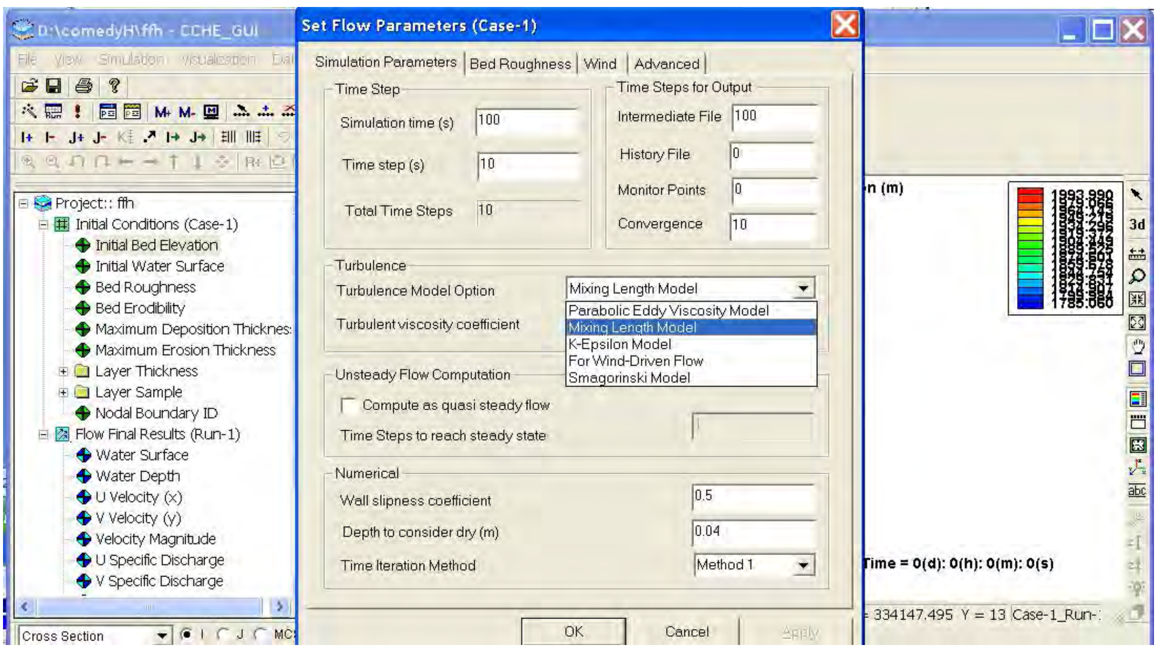


Figure 22 : Graphical User Interface (CCHE2D-GUI)

A detail description of the model CCHE2D is beyond the scope of this paper, it can be found in the publications Jia and Wang [1,3].CCHE2D model is an integrated package for two-dimensional Simulation and analysis of free surface flows, sediment transport and morphological processes. The package comprises of the numerical models, a mesh generator (CCHE2D Mesh Generator) and a Graphical User Interface (CCHE2D-GUI) as illustrated in Figure 23.

CCHE2D Mesh Generator helps in creation of complex structured mesh system for CCHE2D model system. It is acomprehensive and user-friendly mesh generator for generating structured mesh on the background of bedtopography and the bed elevation data.The processes involves to generating the mesh for study inculude .

a. Defining block boundaries.

b. Generate algebraic mesh.

c. Generate numerical mesh (to improve and smoothing the mesh).

d. Interpolate bed elevation.

e. Save mesh into geo file, to be used for simulation using CCHE2D.

CCHE2D-GUI is a graphical users environment for the CCHE2D model with four main functions: preparation of initial conditions and boundary conditions, preparation of modelparameters, run numerical solutions, andvisualization of modelling result. The CCHE-2D is adepth-averaged two dimensional numerical model for simulating unsteady,turbulent, free-surface flow in open channels with loose bed. It has been developed for simulating the sediment transport, soilerosion and morphological changes of a variety of shallow water bodies with special emphasis on natural streams an drivers (Jia and Wang, 1998) and this study only utilise the hydraulics capability of CCHE2D.

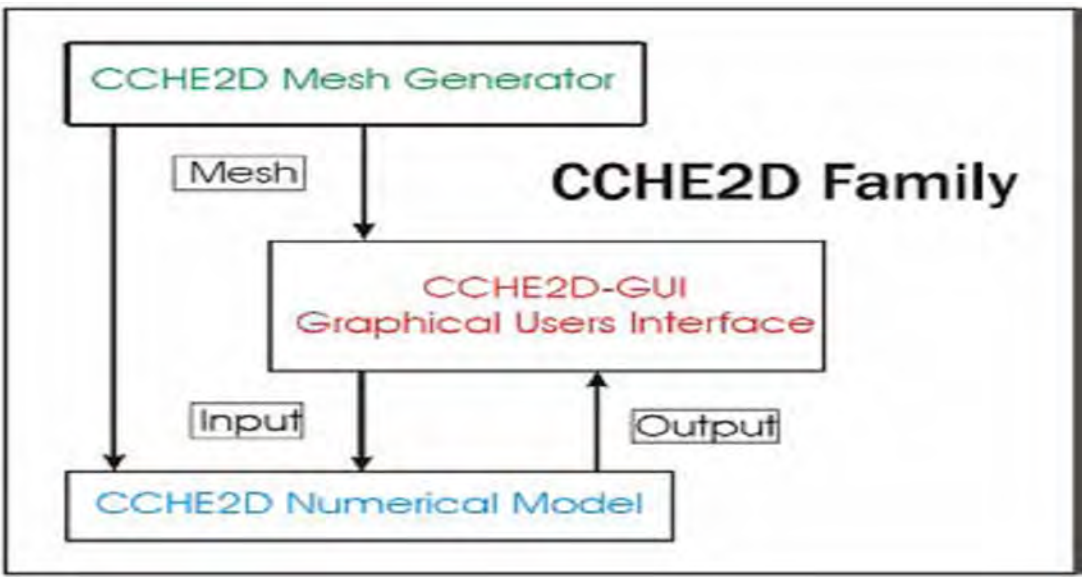


Figure- 23: CCHE2D MODEL FRAME WORK

5.2 General Equations

The momentum and continuity equations (shallow water approach) in Cartesian coordinates are:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+fu=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\varepsilon_H\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_H\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\varepsilon_V\frac{\partial v}{\partial z}\right) \quad \text{------------------------} \quad 5$$

$$\frac{\partial p}{\partial z}=-\rho g \quad \ldots\ldots 6$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad \ldots\ldots 7$$

where t is time, u, v, w are the velocity components in the x, y, z directions, f is the Coriolis parameter, p is pressure, ρ is the water density, g is the acceleration of gravity, and ε_H and ε_V are the horizontal and vertical turbulent viscosities.

5.3 Generating the Mesh and Running the Model

Computational fluid dynamics (CFD) is based on solving a set of highly non-linear partial differential equations (P.D.E) on a physical domain, which is usually discretized and represented by a computational mesh. Despite the numerical method used, the success of solving these P.D.Es depends largely on the mesh quality.

As the general academic criteria, the orthogonality and smoothness are often used to evaluate the mesh quality quantitatively. The adaptivity, referring to the control of the mesh density distribution according to the physics of a particular problem, is often required to evaluate the mesh quality. Basically, there are two types of meshes used in CFD: the structured and the unstructured. The structured meshes consist of families of mesh lines with the property that members of a single family do not cross each other and cross each member of the other families only once, while the unstructured mesh does not have such a restriction.

The advantage of the structured mesh is that any mesh node is uniquely identified by a set of two (2D mesh) or three indices (3D mesh) and thus is easy to access. In the unstructured meshes, a connection table is required to identify the relationship of the mesh nodes. Usually, the structured mesh is used for the Finite Difference Method (FDM) and the Finite Volume Method (FVM), while the Finite Element Method (FEM) often uses the unstructured mesh.

The CCHE-MESH Mesh Generator is developed to generate the structured meshes and the mesh was generated with the help of the CCHE2D Mesh Generator on the basis of bathymetry data.

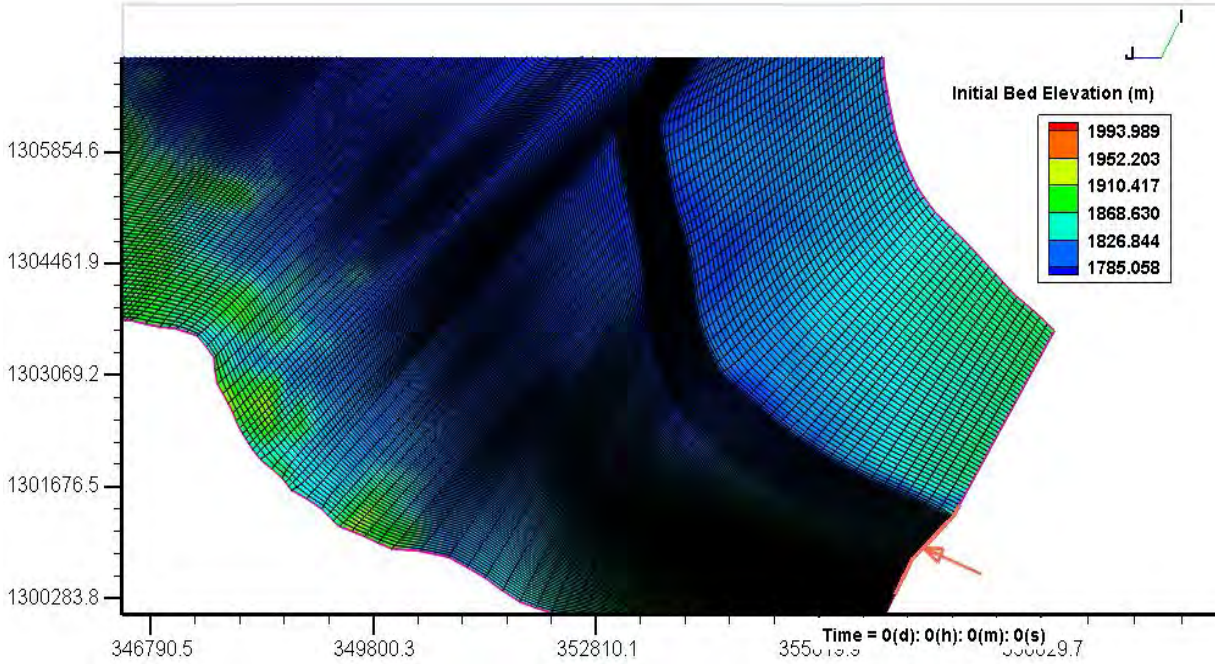


Figure -24 : Generated mesh for study Area (Imax=50 *300=Jmax)

5.4 Initial Flow Conditions

In CCHE2D model there are two basic techniques available to initialise the water level in the model and start the simulation. These are known as cold and hot start. Cold start specifies zero initial velocity and constant water level at specific grid points. The program also allows entering global initial value for whole system or local values in the domain.

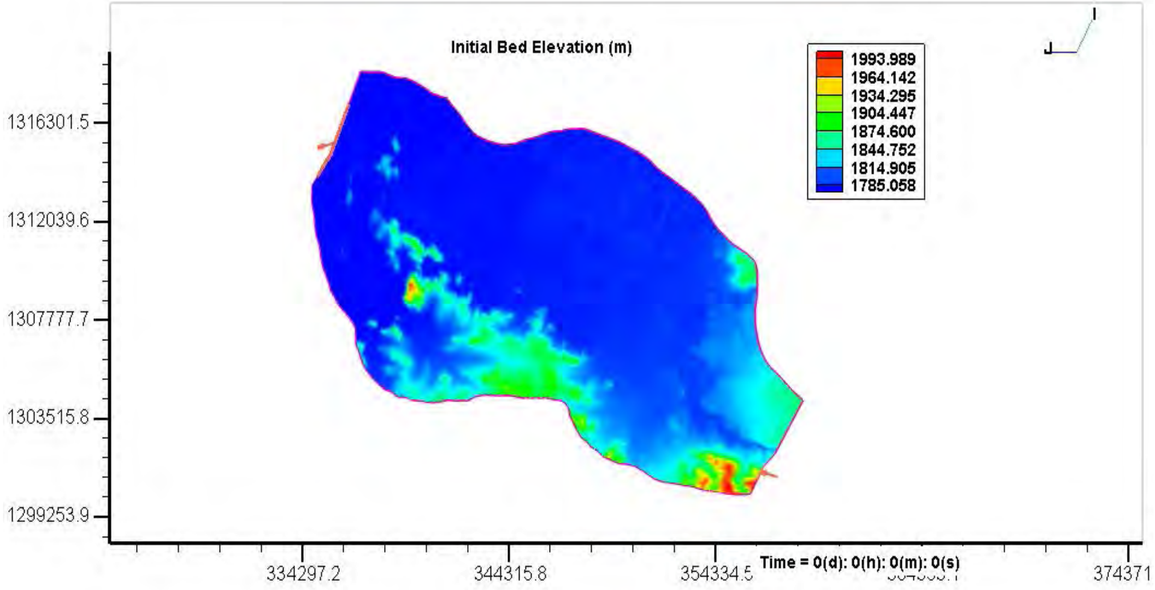


Figure-25: Initial bed elevation

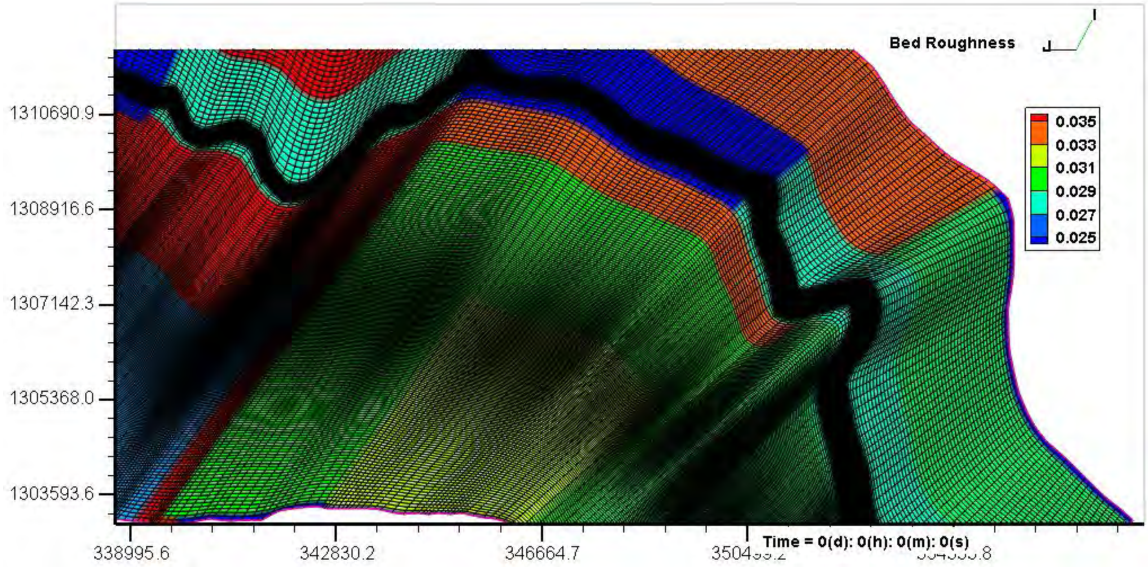


Figure-26:Bed rougheness value for study area

5.5 Boundary Conditions

There are two primary boundaries in the model, upstream and downstream of the Gumera River. For the upstream boundary, a discharge input node was selected and the downstream boundary represented the water levels. Total discharges of upstream boundary for return period 2, 5, 10, 25, 50 and 100 years are predicted using Flood frequency analysis. The secondary boundary nodes is downstream of the river in study domain indicate the water level at gauge station is determine using stage- discharge relationship at gauge station

Table-7: Flood Hydrograph for Different Return Period (Inlet boundary Condition)

Return period	QT(m3/s
2	233
5	281
10	312
25	352
50	382
100	411

Table-8: Gauge level (outlet boundary condition)

Return period(Yr)	Water depth(m)	Water level(m)
2	5.9	1790.9
5	6.616	1791.616
10	7.091	1792.091
25	7.685	1792.685
50	8.147	1793.147
100	8.582	1793.582

5.6 Surface roughness

The surface roughness (Manning's coefficient n) on four land use types in the study area was derived from previous studies. The spatial distribution of Manning's n for different land use is shown in the figure below.

Table-9: Spatial distribution of Manning's n for different land use(Tennakoon,2004).

Land use	**Manning's n**
Water	0.03
Vegetated area	0.04
Low vegetated area	0.025
Crops (rice, wheat...)	0.035

5.7 Model calibration and validation

Historically, model application should be carried out sequentially in four stages: Instantiation, calibration, validation and exploitation (Cunge, 2003). For Gumera catchment study,model simulation has been evaluated using efficiency critera such as coefficient of determination (RMSE) and (Nash and Sutcliff)

R^2 coefficient and E_{NS} simulation efficiency measures how well trends in the measured data are reproduce by simulated result over specified time period and for a specified time step .The statistical index of modeling efficiency NS values ranges from 1.0(best) to 0.

For research study Calibration done based on initial manning's ranges from 0.025 -0.035 for different land use by comparing Water surface Elevation result of CCHE2D model with HEC-RAS result output for 100-yr return period with efficiency criteria NS has a value of 0.78 is adopted for bedrougheness value on figure -26 and detailed procedure described in thefigure-46andTable10.

6. Results and Discussion of CCHE2D Hydrodynamic Modeling

CCHE2D model generate different flooding scenarios (inundation depth, Velocity magnitude) for return periods 2, 5,10,25,50 and 100 on the study area.

6.1 Scenario results

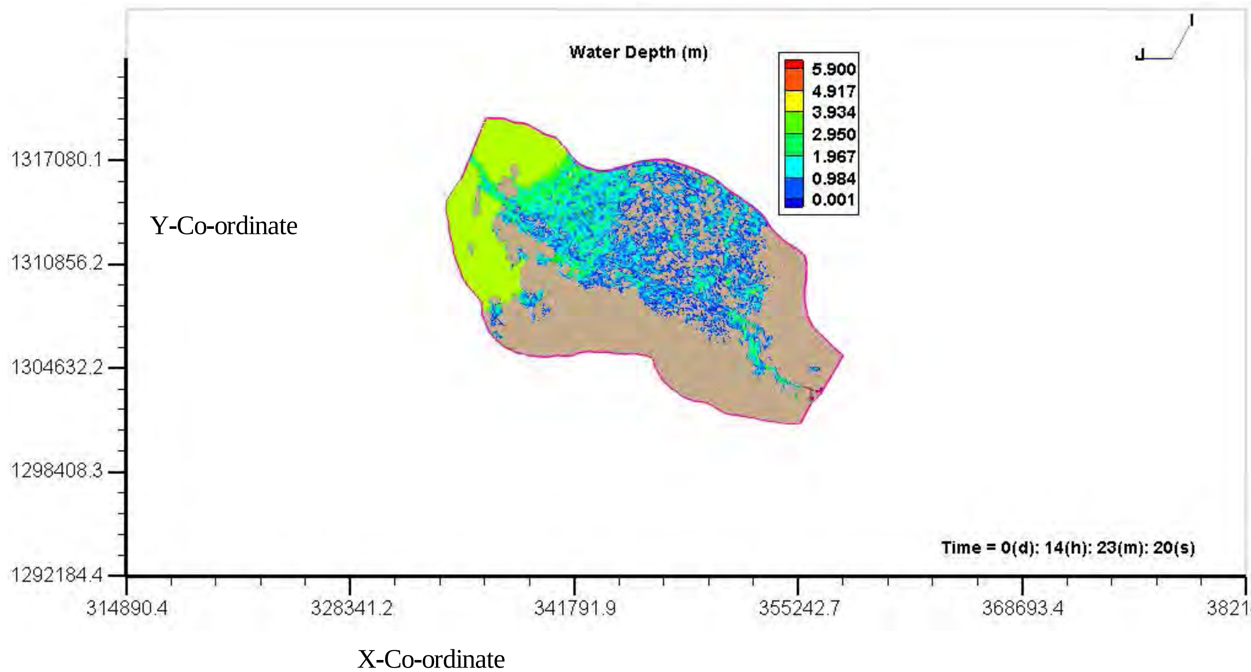


Figure-27: Flood extent and water depth (2-year return period)

From the above figure for 2- year storm event, it can be seen that the depth of the flood ranges from 0m-5.90m.

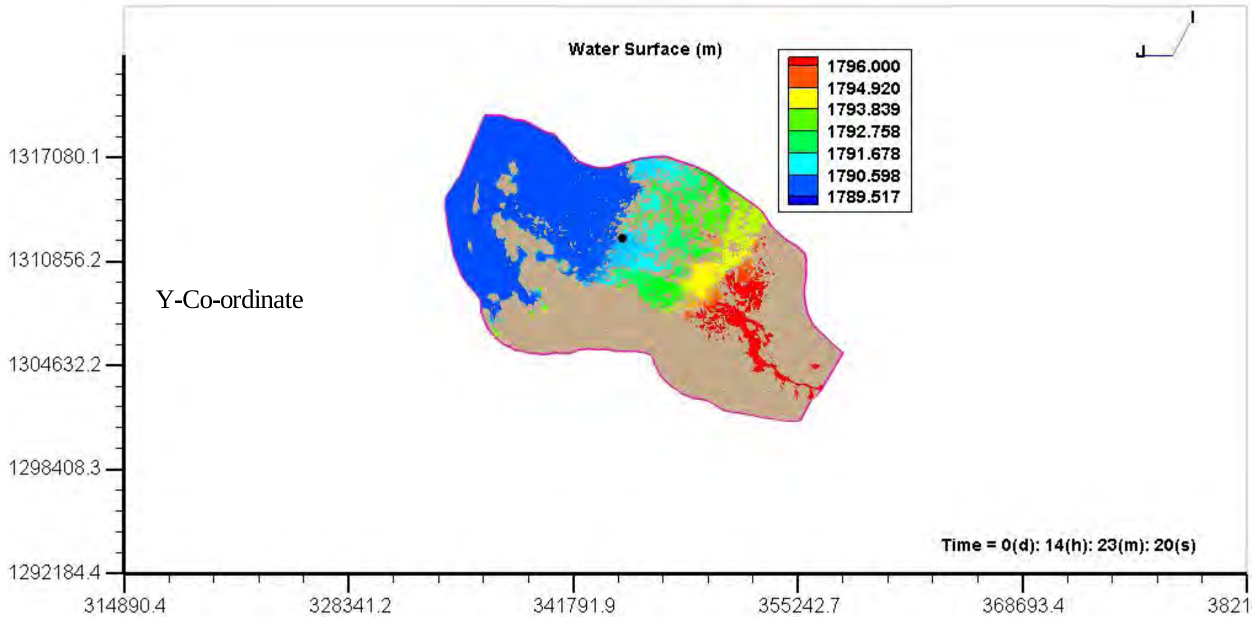


Figure-28 :Water Surface Elevation at Study area X-Co-ordinate

From the above figure for 2- year storm event, it can be seen that the water surface of the flood ranges from 1796-1789m.

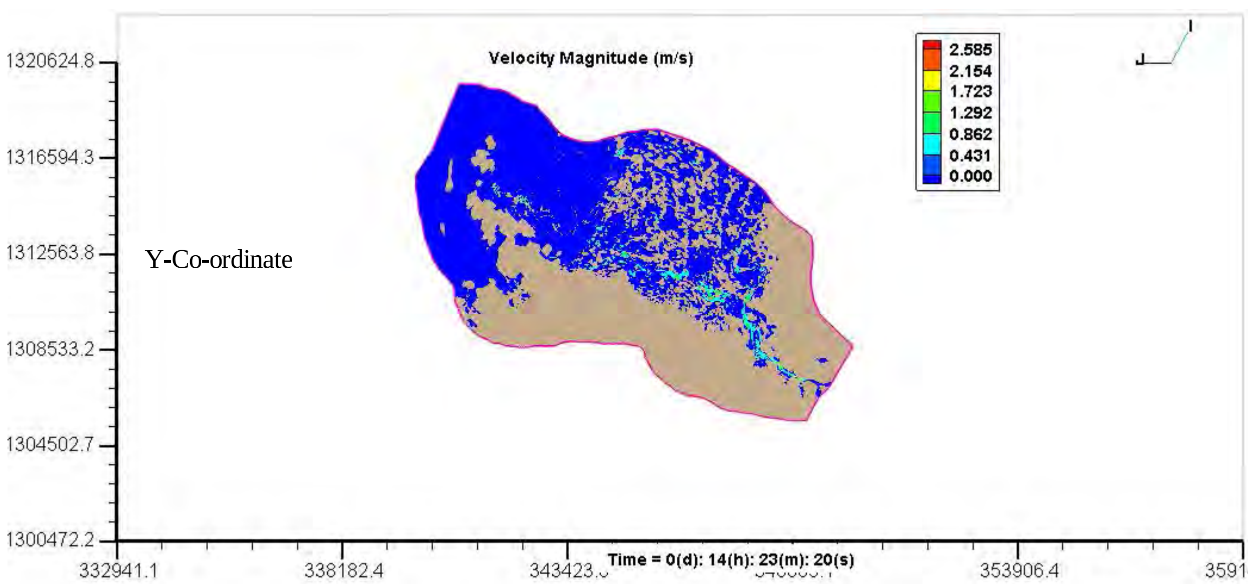


Figure-29: Velocity Magnitude of Study area

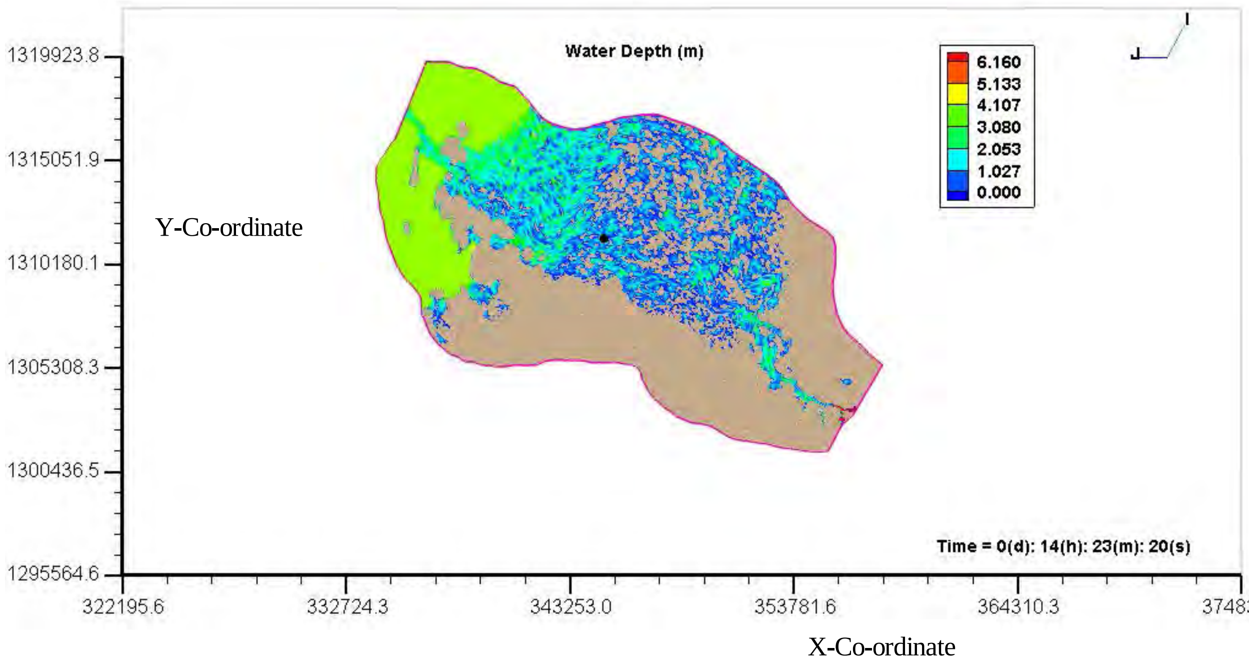


Figure-30: Flood extent and water depth (5-year return period)

From the above figure for 5- year storm event, it can be seen that the depth of the flood ranges from 0m-6.16m.

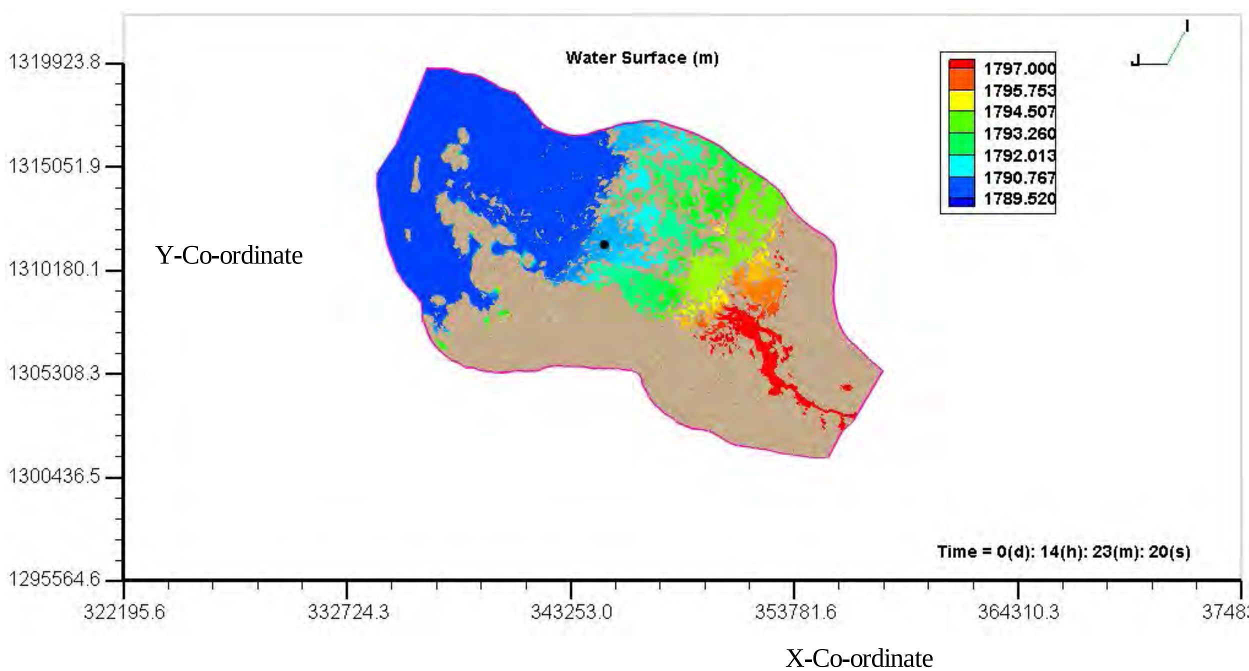


Figure-31b: Water Surface Elevation (5-year return period)

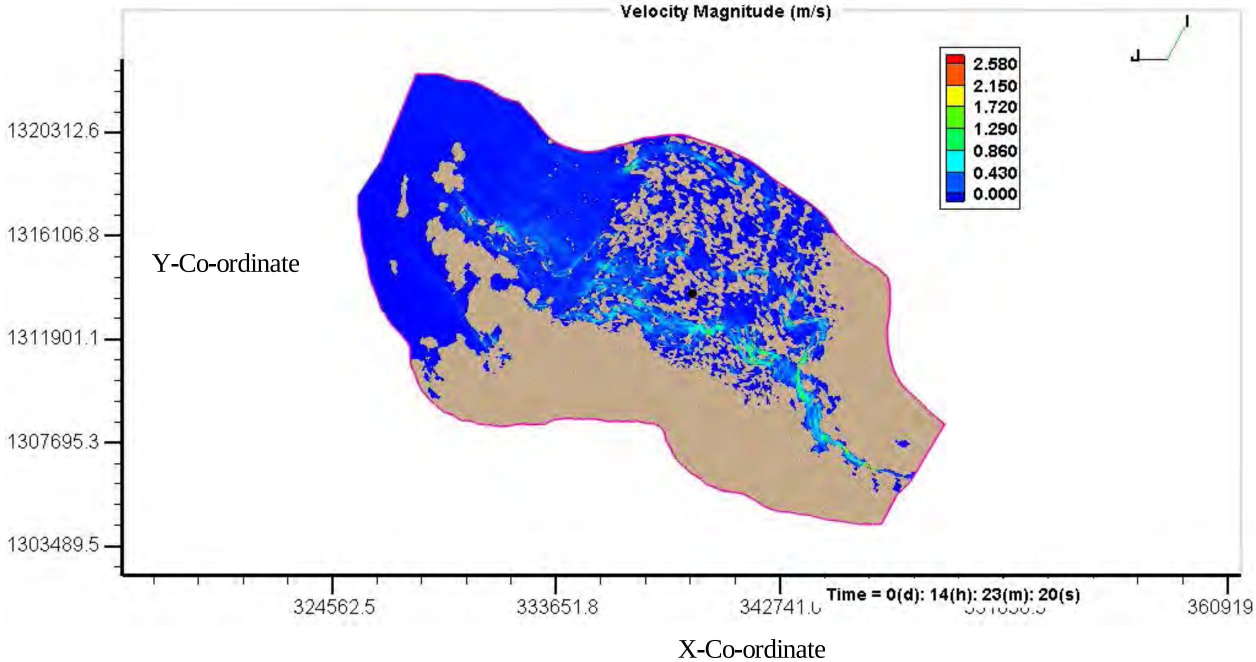


Figure-31: Velocity Magnitude (5-year return period)

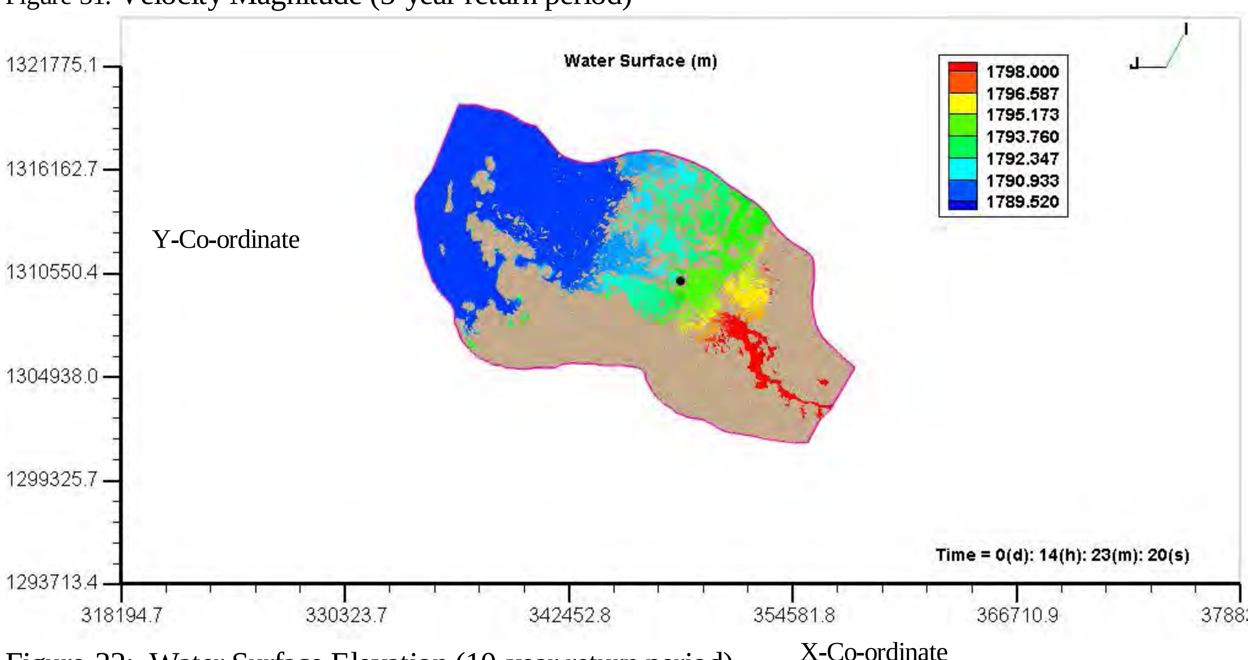


Figure-32: Water Surface Elevation (10-year return period)

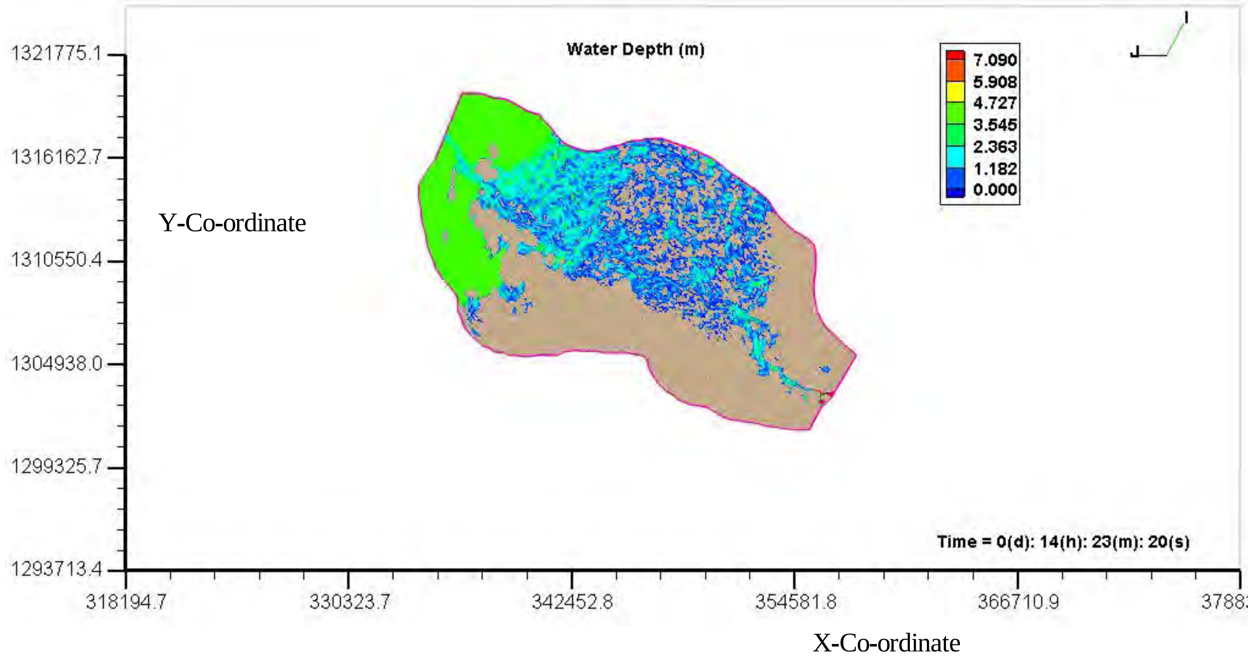


Figure-33: Flood extent and water depth (10-year return period)

From the above figure for 10- year storm event, it can be seen that the depth of the flood ranges from 0m-7.09m.

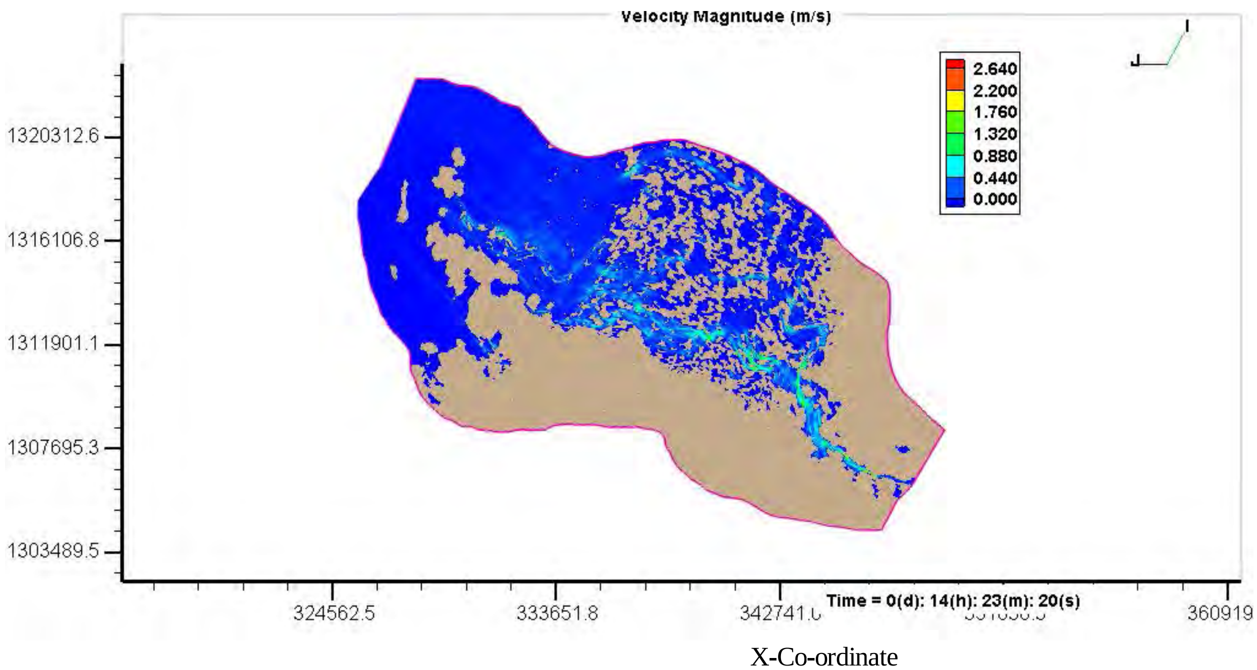


Figure-34: Velocity Magnitude (10-year return period)

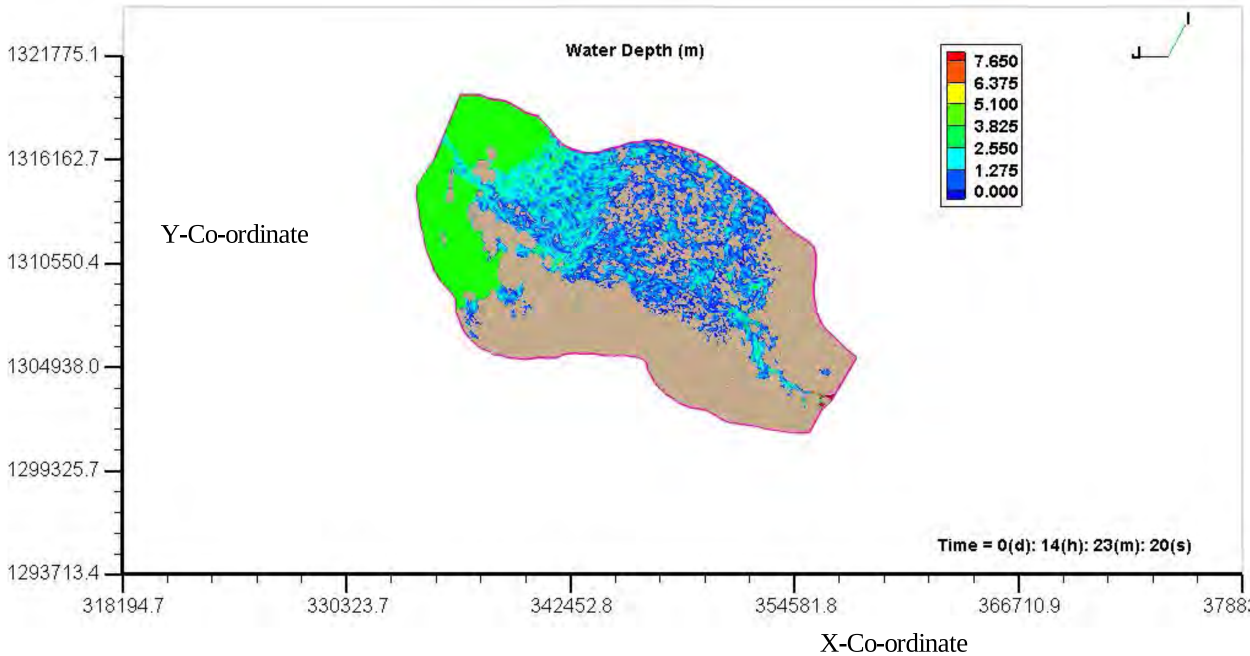


Figure-35: Flood extent and water depth (25-year return period)

From the above figure for 25- year storm event, it can be seen that the depth of the flood ranges from 0m-7.65m.

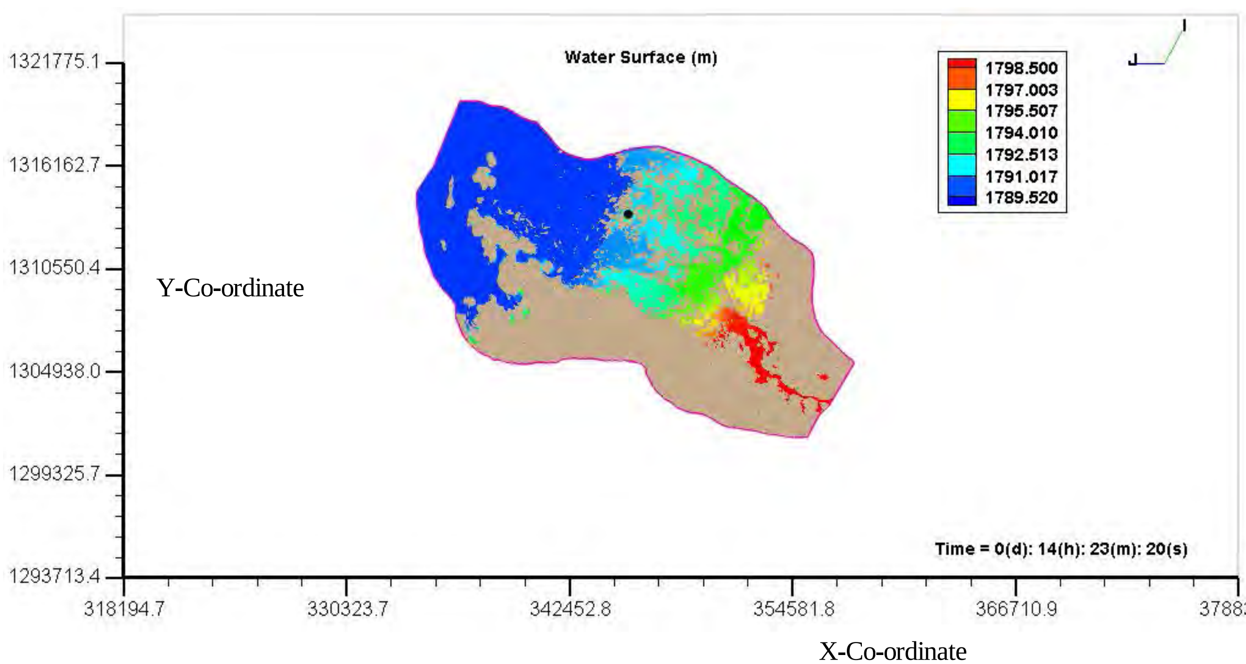


Figure-36: Water surface Elevation (25-year return period)

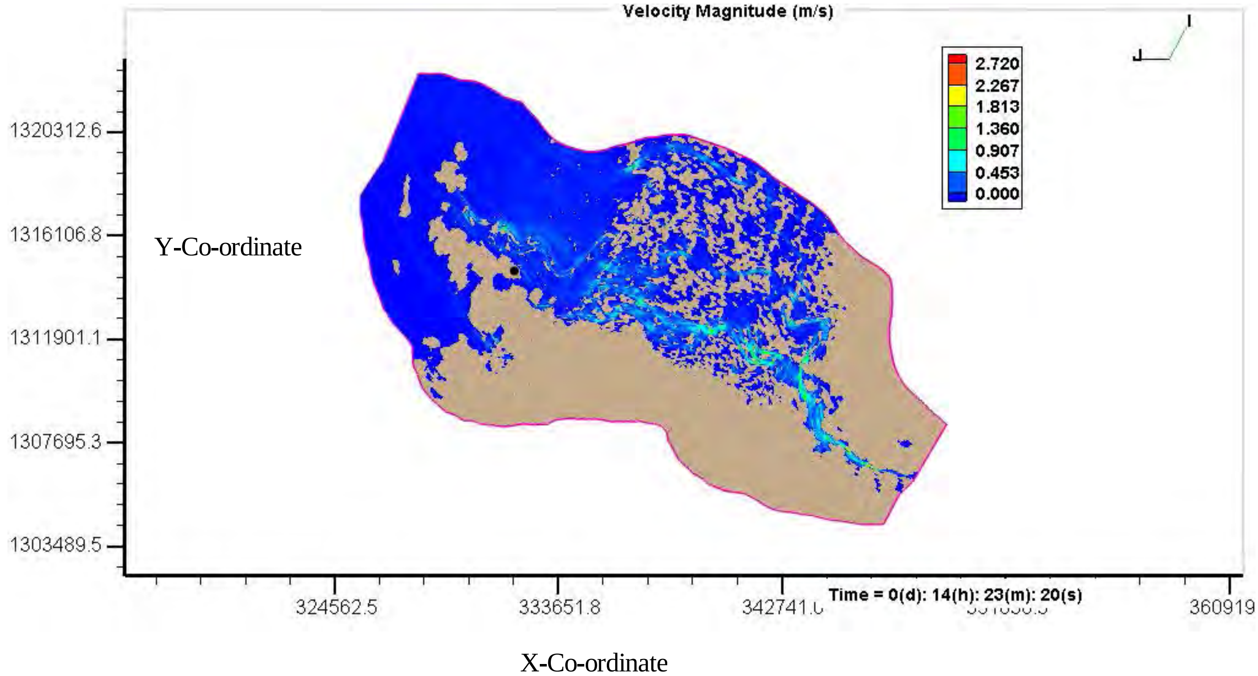


Figure -37: Flow velocity for 25-year return period

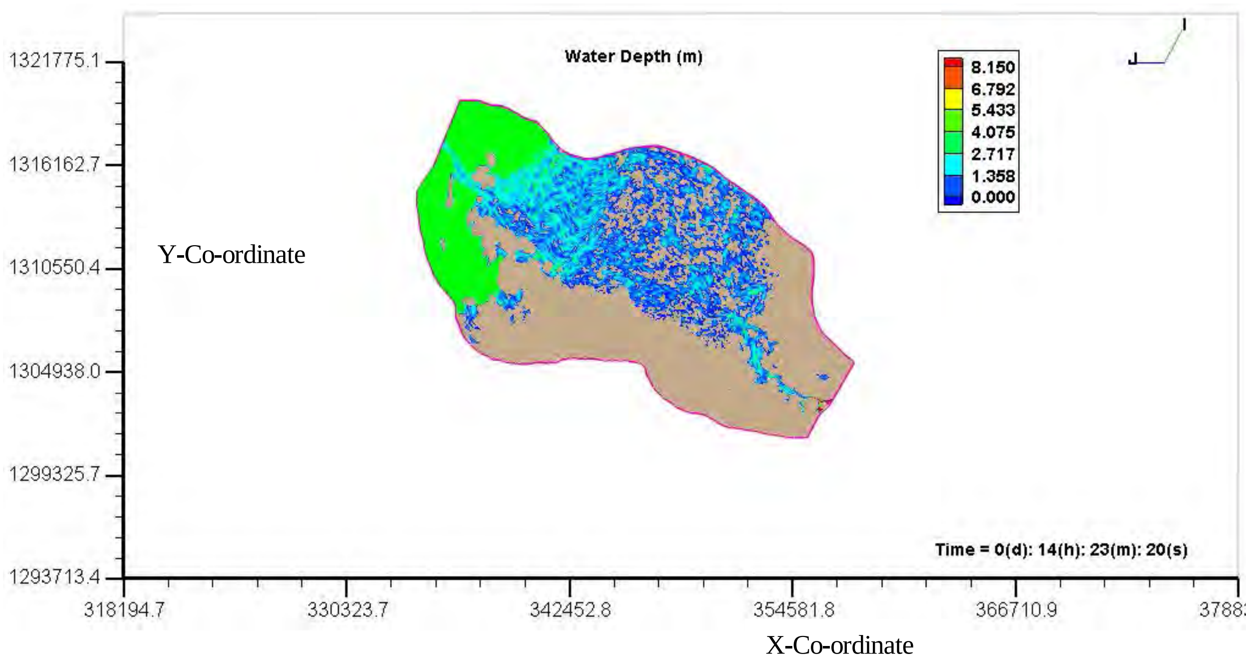


Figure-38: Flood extent and water depth (50-year return period)

From the above figure for 50- year storm event, it can be seen that the depth of the flood ranges from 0m-8.15m.

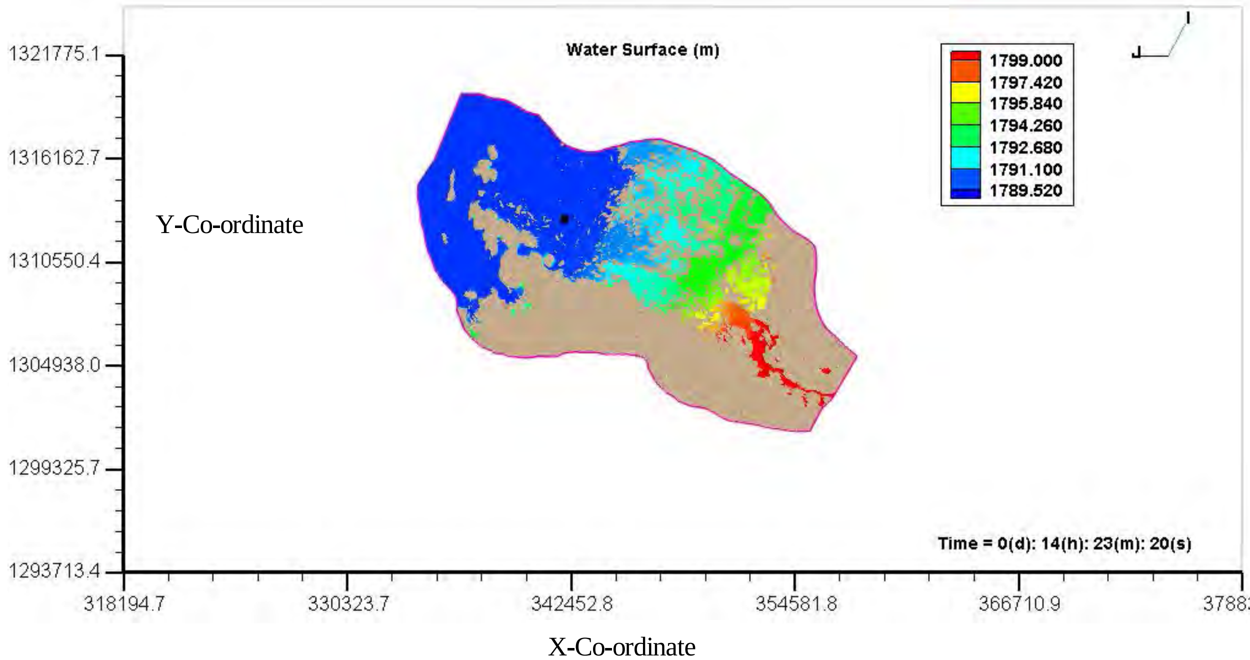


Figure-39: Water Surface Elevation (50-year return period)

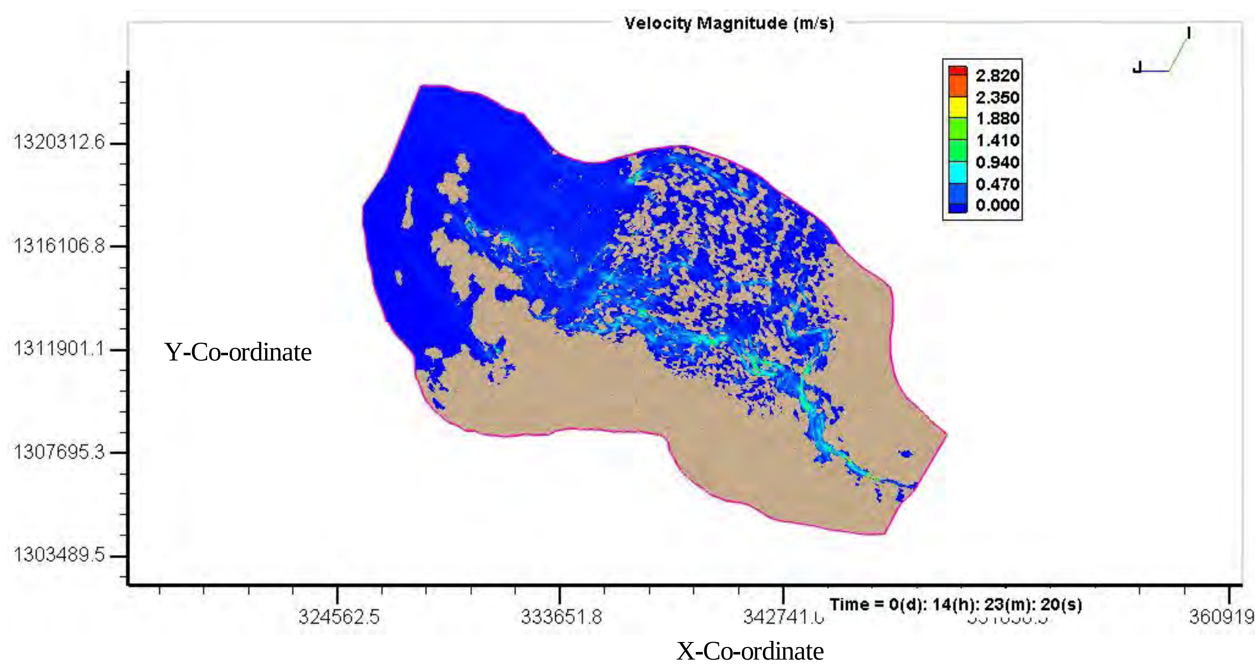


Figure -40: Flow velocity for 50-year return period

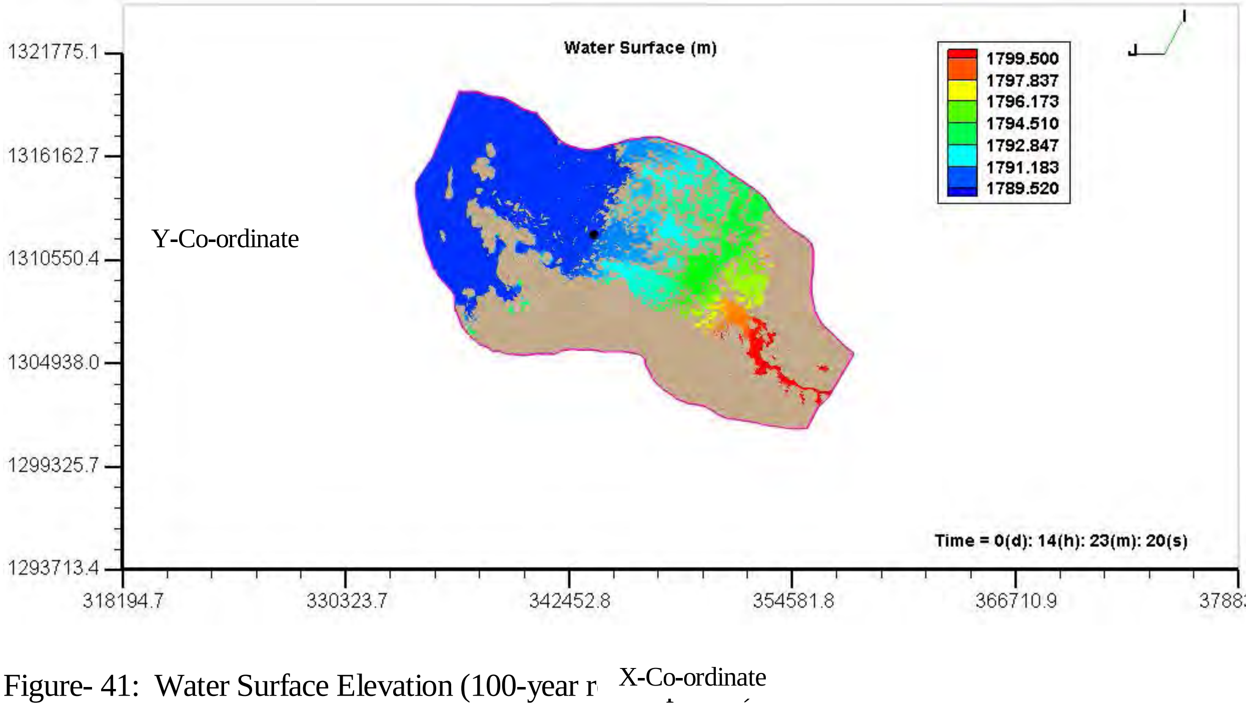


Figure- 41: Water Surface Elevation (100-year r

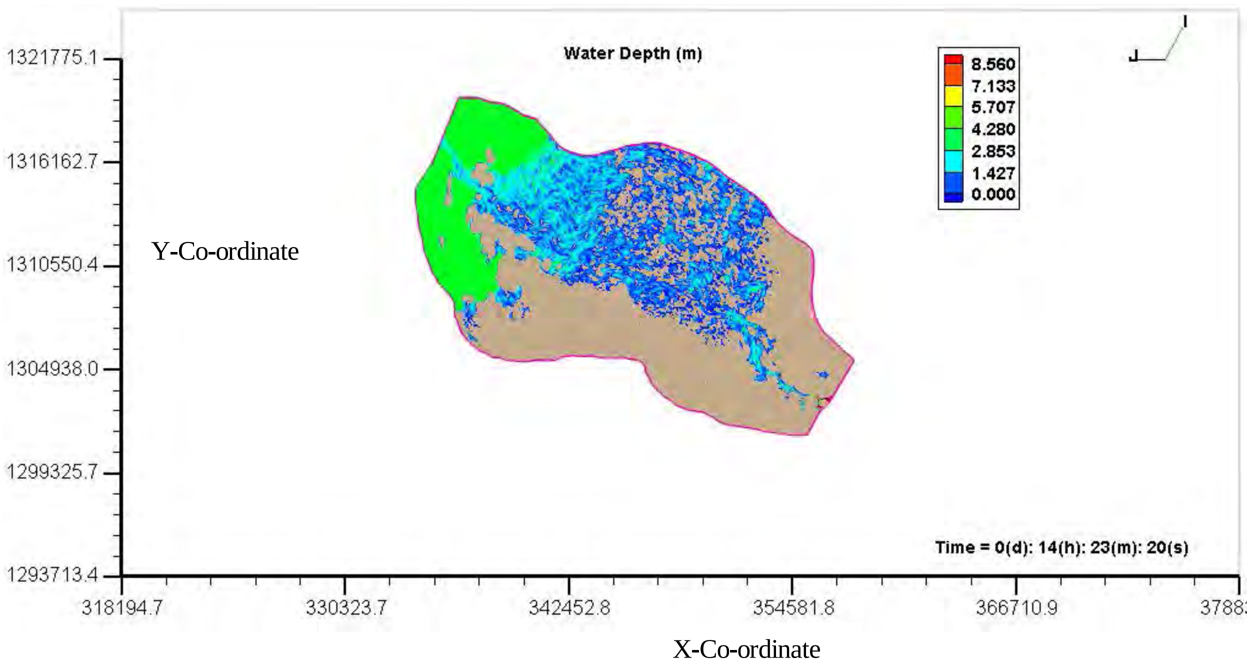


Figure- 42: Flood extent and water depth (100-year return period)

From the above figure for 100- year storm event, it can be seen that the depth of the flood ranges from 0m-5.8.56m.

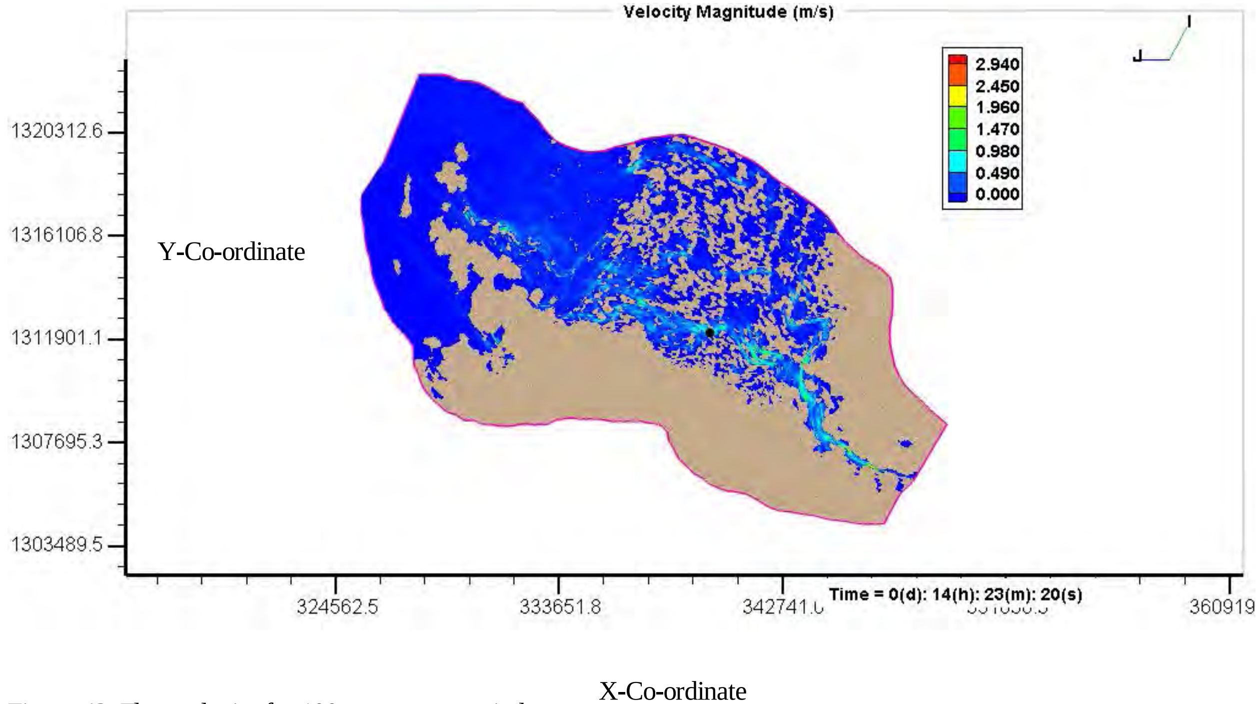


Figure-43: Flow velocity for 100-year return period

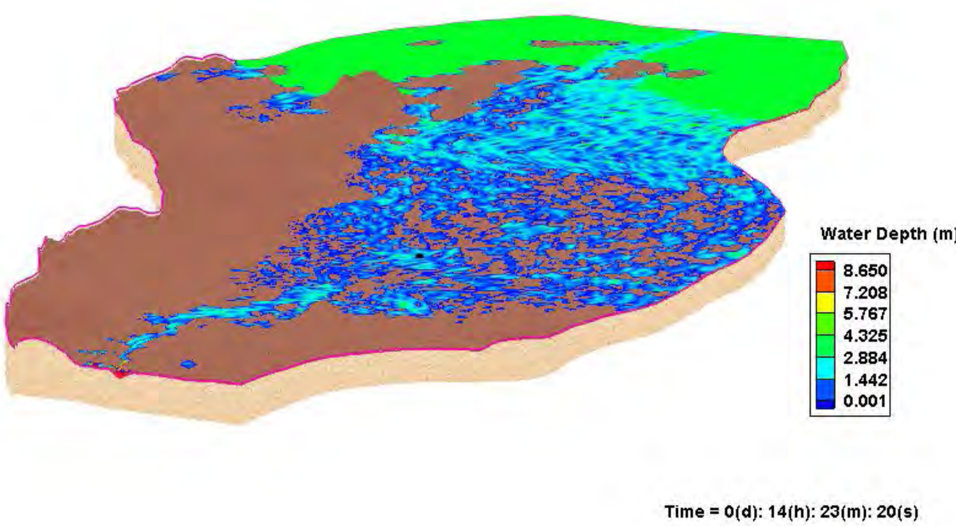


Figure-44:-100 year 3D Flood inundation depth of gumera river on study area

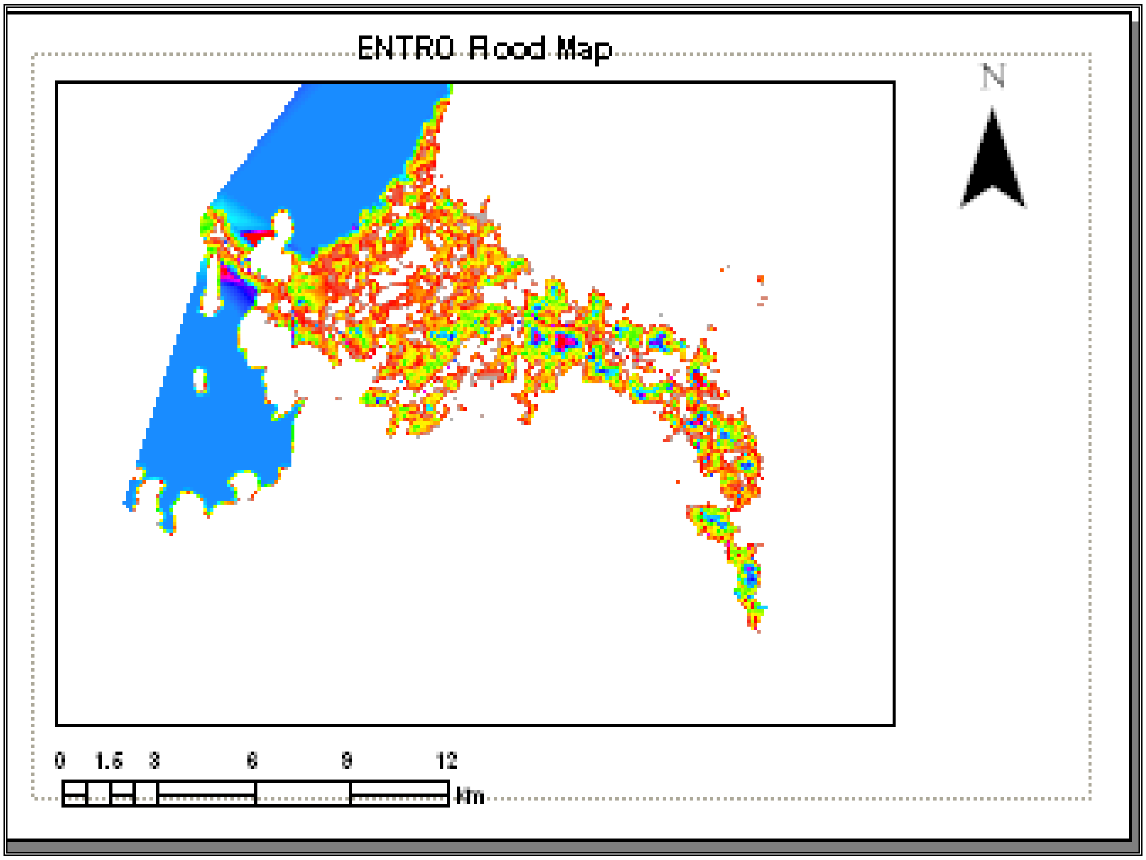


Figure- 45: ENTRO Flood Map for 100 Year Flood

6.2 Disccussion

The applications of CCHE2Dmodel and GIS for floodplain mapping have been limited in countries like Ethiopia, where the availability of the river geometric, topographic and hydrological data are also very limited. The situation of river flooding in Ethiopia is also completely different, as there is much higher variation in the river flows and rivers are completely unregulated.

There are very few flood control structures dykes at river banks and boundary lines which are not clearly defined.Hence, the floodplain analysis and modeling are subject to number of new sets of constraints. This study presents an approach of conducting a similar study, within these constraints.

- CCHE2D and ArcGIS were the primary software packages used for this analysis.

- The flood discharge of different return period is derived by different method. In this paper the result derived from Gumbel method of flood frequency analysis is considered representative of the right flow value.
- According to the model results, there is considerable flooding in the area even at flood discharge of 2-year frequency storm. This implies that the channel capacity is small to carry the flood water discharge.
- The flood maps prepared indicate a high risk to the agricultural, agro-pastoral land and river with considerable water depth. These areas are the most flood prone areas in the river floodplains and need further considerations for flood protection.

6.3 Model Calibration

Calibration is a process of fine tuning a model by optimizing the model parameters by modifying the model structures, boundary conditions and improving the hydro meteorological forcing input. Extensive calibration in this study was not undertaken because due to time constraints. Optimization of the parameter value(manning roughnness) is done manually and checked qualitatively such as by plotting of CCHE2D model and HEC-RAS model water level outputs and using Root Mean Squared Error (RMSE) between CCHE2D outuput with HEC-RAS output for 100-yr (RMSE=0.207)and (NS=0.78)

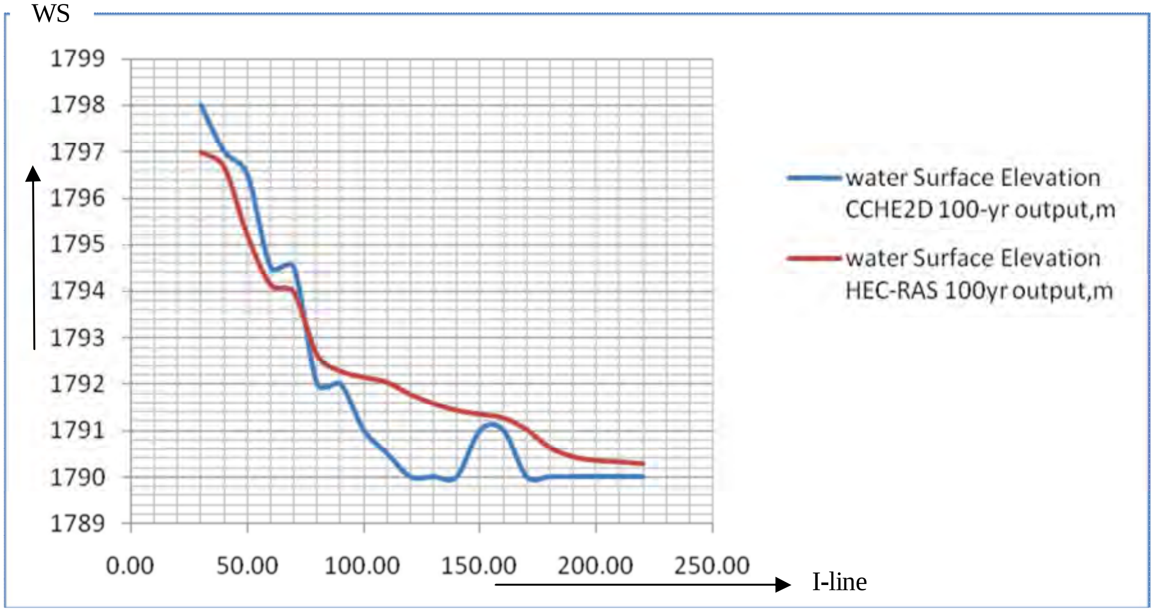


Figure- 46: Model Caliberation

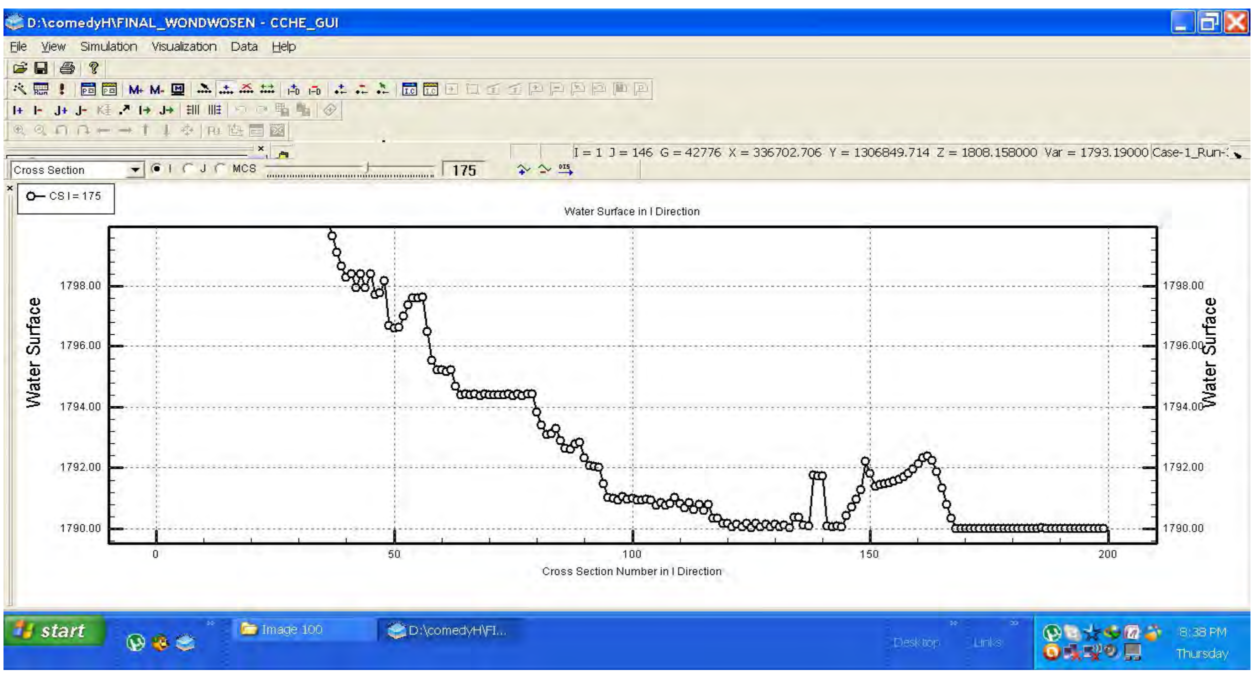


Figure-46: Water surface Elevation for 100-yr Flood in I-175

Table-7: Model Calibration between CCHE2D and HEC-RAS Model output I=175

J	X	Y	CCHE2DWS(simulated)	HEC-RAS output(observedWS)	(Ob-Si)	(Ob-Si)^2		
30	353020	1304442	1798	1797	1	1	5.68	21.9024
40	352360	1305457	1797	1796.68	0.32	0.1024	4.68	19.0096
50	352124	1306566	1796.5	1795.2	1.3	1.69	4.18	8.2944
60	352076	1307109	1794.5	1794.15	0.35	0.1225	2.18	3.3489
70	3512036	1307864	1794.5	1793.98	0.52	0.2704	2.18	2.7556
80	352407	1308454	1792	1792.63	-0.63	0.3969	-0.32	0.0961
90	352312	1309587	1792	1792.28	-0.28	0.0784	-0.32	0.0016
100	351463	1310082	1791	1792.15	-1.15	1.3225	-1.32	0.0289
110	350896	1311734	1790.5	1792.04	-1.54	2.3716	-1.82	0.0784
120	349633	1312324	1790	1791.78	-1.78	3.1684	-2.32	0.2916
130	348348	1312962	1790	1791.58	-1.58	2.4964	-2.32	0.5476
140	346625	1313575	1790	1791.43	-1.43	2.0449	-2.32	0.7921
150	344336	1313103	1791	1791.35	-0.35	0.1225	-1.32	0.9409
160	342967	1311852	1791	1791.27	-0.27	0.0729	-1.32	1.1025
170	341008	1312678	1790	1791.02	-1.02	1.0404	-2.32	1.69
180	340206	1313221	1790	1790.63	-0.63	0.3969	-2.32	2.8561
190	338483	1314142	1790	1790.43	-0.43	0.1849	-2.32	3.5721
200	337303	1315227	1790	1790.35	-0.35	0.1225	-2.32	3.8809
210	335722	1316077	1790	1790.32	-0.32	0.1024	-2.32	4
220	335250	1315794	1790	1790.28	-0.28	0.0784	-2.32	4.1616
			Oaverg	1792.33				79.3513
			RMS =	0.21		17.1853	4.145516	0.859265
			NS=	0.78				3.967565
								0.216572

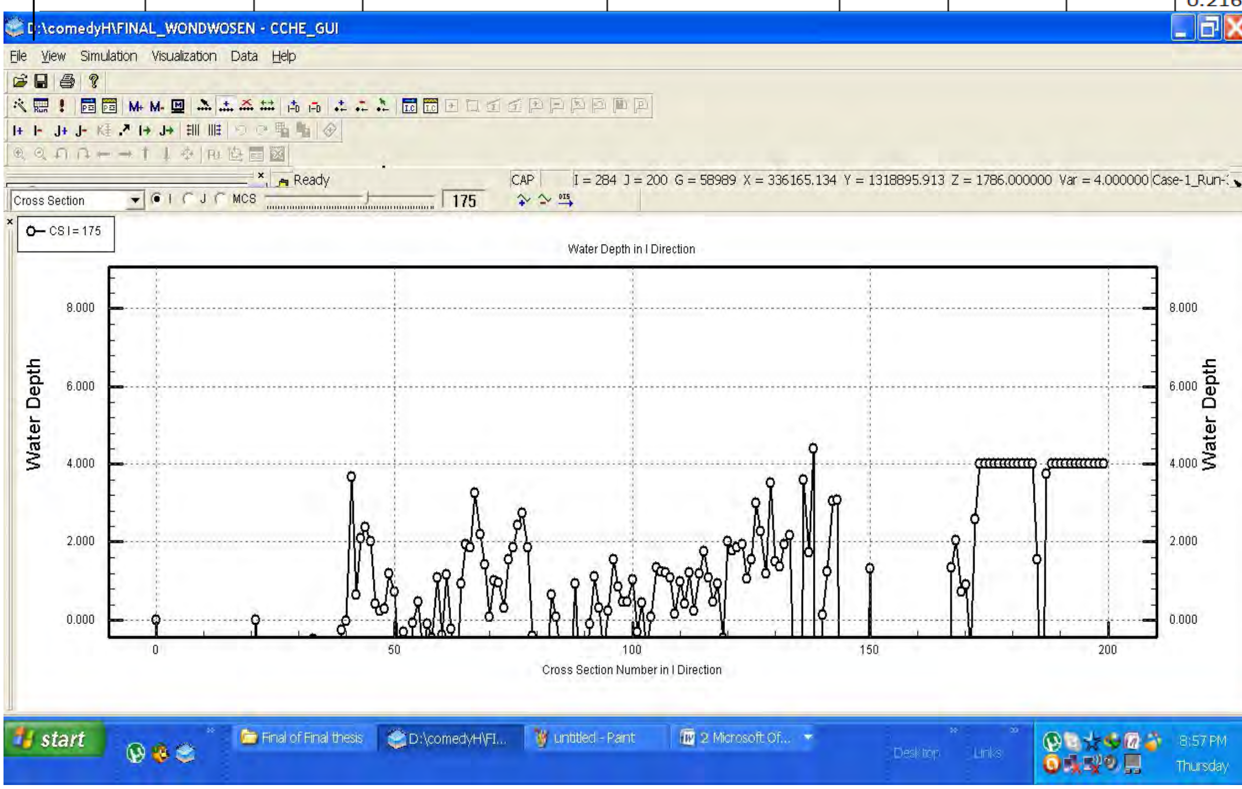


Figure-47 :Water Depth for 100-yr Flood in I-175

7. Conclusion and Recommendations

7.1. Conclusion

Flooding around Fogera Woreda causes a considerable damage to life and property. Large coverage of the area with cultivated land makes the problem hard. Past flood forecasting of the area lack the use of modern software.

This study presents a systematic approach in the preparation of flood map with the application of steady flow 2D Hydrodynamic models and GIS. The major tools/models used in this method is 2D-dimensional numerical model CCHE2D Model and ArcGIS.

The automated floodplain mapping and analysis using these tools provide more efficient, effective and standardized results and saves time and resources.

- The study also made the assessment of flood with relation to the return period of floods and their water depth. The relationship between the flood area and discharge indicates that there is a medium rate of increase of the flood area with the increase in discharge.
- Flooding in Fogera Woreda is devastating even with a 2 year storm. This shows the necessity of construction of engineering structures such as dykes and levees along the river channel and lower part of the flood plain.
- Topographic analysis using GIS and field survey data has a greater efficiency to represent terrain nature exactly. The higher the DEM resolution and enough topographic data, the more accurate the flood map is.
- Hydrologic data are central to flood plain analysis. Availability of day time series data increases the model reliability.
- Additional cross sections are used in the areas where the river makes meandering in order to avoid errors during interpolation.

- This study shows the applicability of CCHE2D hydrodynamic modeling, especially 2D modeling in flood modeling assessment. Furthermore, flood modeling methodology was proposed and examined. The objectives of the study were achieved and several maps were derived to indicate the different characteristics of floods at different return periods.

7.2. Limitation of study

Although modeling always requires simplification of reality, the more quality and quantity of data are, the greater the potential reliability of the model. The limitations of this study could be concluded as follows:

The study was handicapped by the unsatisfying resolution of DEM and image used have important influence on the flooding characteristics. Therefore, a better representation of the study area is very important to achieve the goal. However, this kind of source is rarely available in the less developed countries due to the financial constraints.

7.3. Recommendations

2D hydrodynamic modeling widens the possibility for effective flood management. In addition, the effective flood assessment proposed could offer more help in information delivery and indicating hazard zone. For future studies in this research area, the following recommendations should be considered:
Higher resolution DEM is suggested in the future study. The finer resolution not only gives better visualization for results, but also improves the reliability.

Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in the study area

Now days, most flood prone areas in Fogera flood plain have been changed in to rice cultivation fields. Strengthening this practice in these areas to the safe ground would be better to reduce the frequently recurring flood risks

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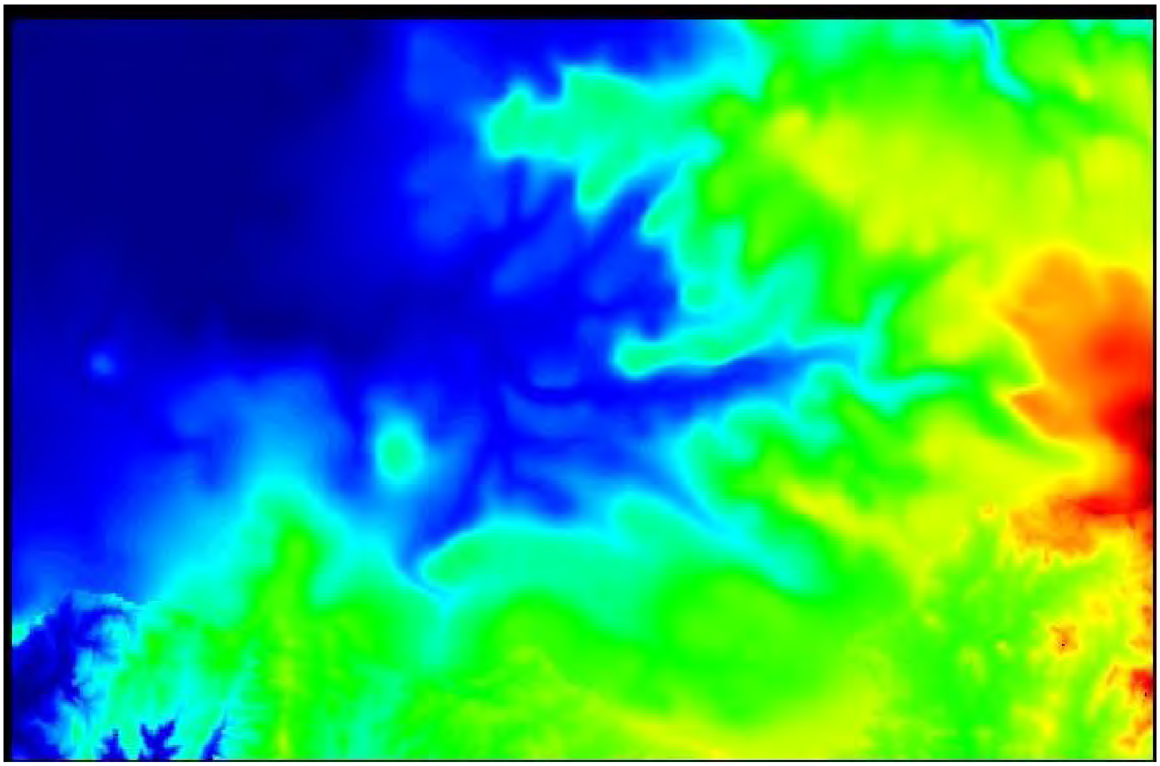
Appendix 1: Annual daily maximum discharge of Gumera River.

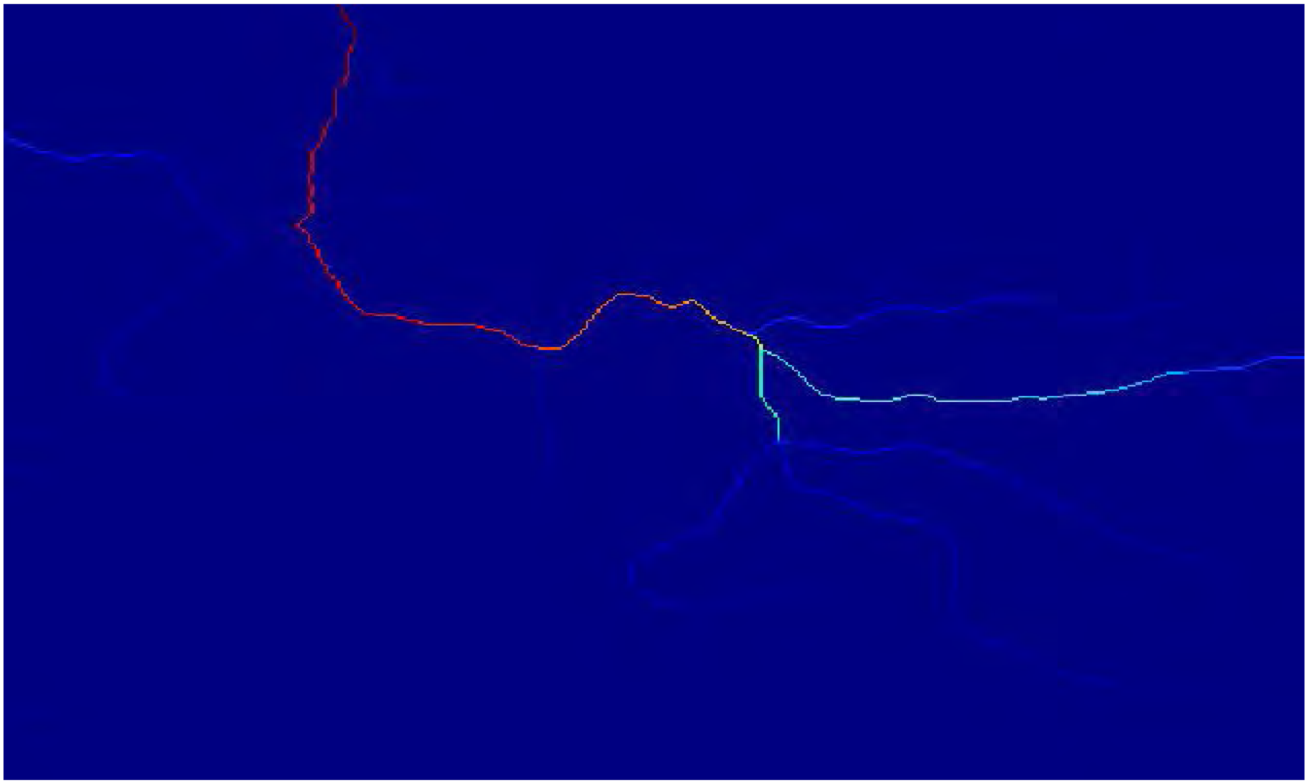
year	Annual daily maximum flow
1959	296.684
1960	233.05
1961	285.132
1962	252.275
1963	165.8708596
1964	194.6616148
1965	156.579
1966	193.841
1967	206.595
1968	182.593
1969	214.396
1970	210.013754
1971	231.354
1972	225.596
1973	171.727
1974	259.816
1975	334.303
1976	354.509
1977	240.991
1978	234.883
1979	176.378
1980	188.438
1981	260.709

1982	192.044
1983	197.969
1984	171.969
1985	274.857
1986	264.514
1987	204.161
1988	397.545
1989	220.511
1990	295.003
1991	302.501
1992	318.697
1993	246.225
1994	267.309
1995	250.649
1996	364.798
1997	270.484
1998	212.749
1999	175.681
2000	265.61
2001	283.066
2002	236.987
2003	246.94
2004	184.239
2005	219.584
2006	277.899
2007	239.031
2008	288.244
2009	233.416

Appendix 2: DEM of Study Area (DTM generated by MOHID GIS)

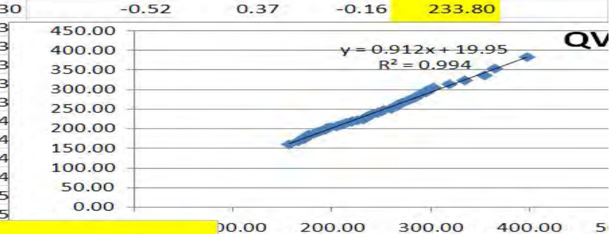


Appendix 3: Drainage Network of Study Area.



Appendix- 4: Gumbel distribution Method Stastical analysis for flood frequency

		P= (m/N+1)				T=1/P		K = (YT-.577)/(1.282
yrear max	Rank	probability	Return period	LOG(Tr/(Tr-1)		YT	K	XT
397.55	1.00	0.02	52.00	0.01	-2.07	3.94	2.62	383.69
364.80	2.00	0.04	26.00	0.02	-1.77	3.24	2.08	354.21
354.51	3.00	0.06	17.33	0.03	-1.59	2.82	1.75	336.79
334.30	4.00	0.08	13.00	0.03	-1.46	2.53	1.52	324.30
318.70	5.00	0.10	10.40	0.04	-1.36	2.29	1.34	314.51
302.50	6.00	0.12	8.67	0.05	-1.27	2.10	1.19	306.43
296.68	7.00	0.13	7.43	0.06	-1.20	1.93	1.06	299.51
295.00	8.00	0.15	6.50	0.07	-1.14	1.79	0.95	293.46
288.24	9.00	0.17	5.78	0.08	-1.08	1.66	0.85	288.05
285.13	10.00	0.19	5.20	0.09	-1.03	1.54	0.75	283.16
283.07	11.00	0.21	4.73	0.10	-0.99	1.44	0.67	278.67
277.90	12.00	0.23	4.33	0.11	-0.94	1.34	0.59	274.53
274.86	13.00	0.25	4.00	0.12	-0.90	1.25	0.52	270.67
270.48	14.00	0.27	3.71	0.14	-0.87	1.16	0.45	267.04
267.31	15.00	0.29	3.47	0.15	-0.83	1.08	0.39	263.62
265.61	16.00	0.31	3.25	0.16	-0.80	1.00	0.33	260.37
264.51	17.00	0.33	3.06	0.17	-0.76	0.93	0.27	257.28
260.71	18.00	0.35	2.89	0.18	-0.73	0.86	0.22	254.32
259.82	19.00	0.37	2.74	0.20	-0.70	0.79	0.16	251.47
252.28	20.00	0.38	2.60	0.21	-0.68	0.72	0.11	248.72
250.65	21.00	0.40	2.48	0.22	-0.65	0.66	0.06	246.07
246.94	22.00	0.42	2.36	0.24	-0.62	0.60	0.02	243.49
246.23	23.00	0.44	2.26	0.25	-0.60	0.54	-0.03	240.98
240.99	24.00	0.46	2.17	0.27	-0.57	0.48	-0.08	238.54
239.03	25.00	0.48	2.08	0.28	-0.55	0.42	-0.12	236.14
236.99	26.00	0.50	2.00	0.30	-0.52	0.37	-0.16	233.80
234.88	27.00	0.52	1.93	0.3				
233.42	28.00	0.54	1.86	0.3				
233.05	29.00	0.56	1.79	0.3				
231.35	30.00	0.58	1.73	0.3				
225.60	31.00	0.60	1.68	0.3				
220.51	32.00	0.62	1.63	0.4				
219.58	33.00	0.63	1.58	0.4				
214.40	34.00	0.65	1.53	0.4				
212.75	35.00	0.67	1.49	0.4				
210.01	36.00	0.69	1.44	0.5				
206.60	37.00	0.71	1.41	0.5				
204.16	38.00	0.73	1.					
197.97	39.00	0.75	1.					
194.66	40.00	0.77	1.					
193.84	41.00	0.79	1.					
192.04	42.00	0.81	1.24	0.72	-0.15	-0.50	-0.84	197.47
188.44	43.00	0.83	1.21	0.76	-0.12	-0.56	-0.89	194.87
184.24	44.00	0.85	1.18	0.81	-0.09	-0.63	-0.94	192.15
182.59	45.00	0.87	1.16	0.87	-0.06	-0.70	-0.99	189.26
176.38	46.00	0.88	1.13	0.94	-0.03	-0.77	-1.05	186.15
175.68	47.00	0.90	1.11	1.02	0.01	-0.85	-1.11	182.75
171.97	48.00	0.92	1.08	1.11	0.05	-0.94	-1.18	178.94
171.73	49.00	0.94	1.06	1.24	0.09	-1.05	-1.27	174.48
165.87	50.00	0.96	1.04	1.41	0.15	-1.18	-1.37	168.91
156.58	51.00	0.98	1.02	1.72	0.23	-1.37	-1.52	160.82

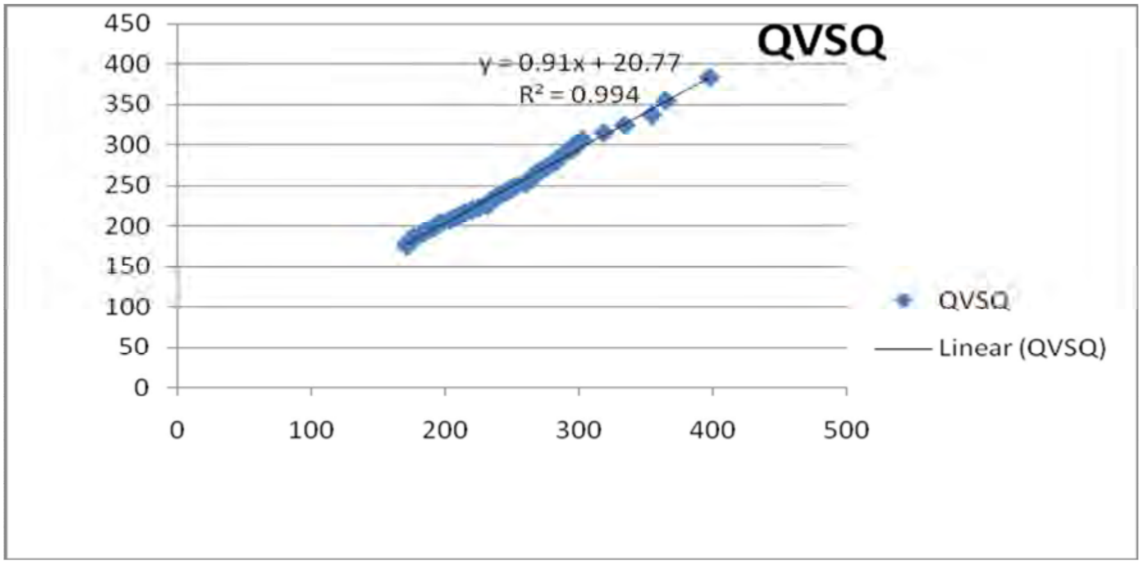


BEST FITTED METHOD

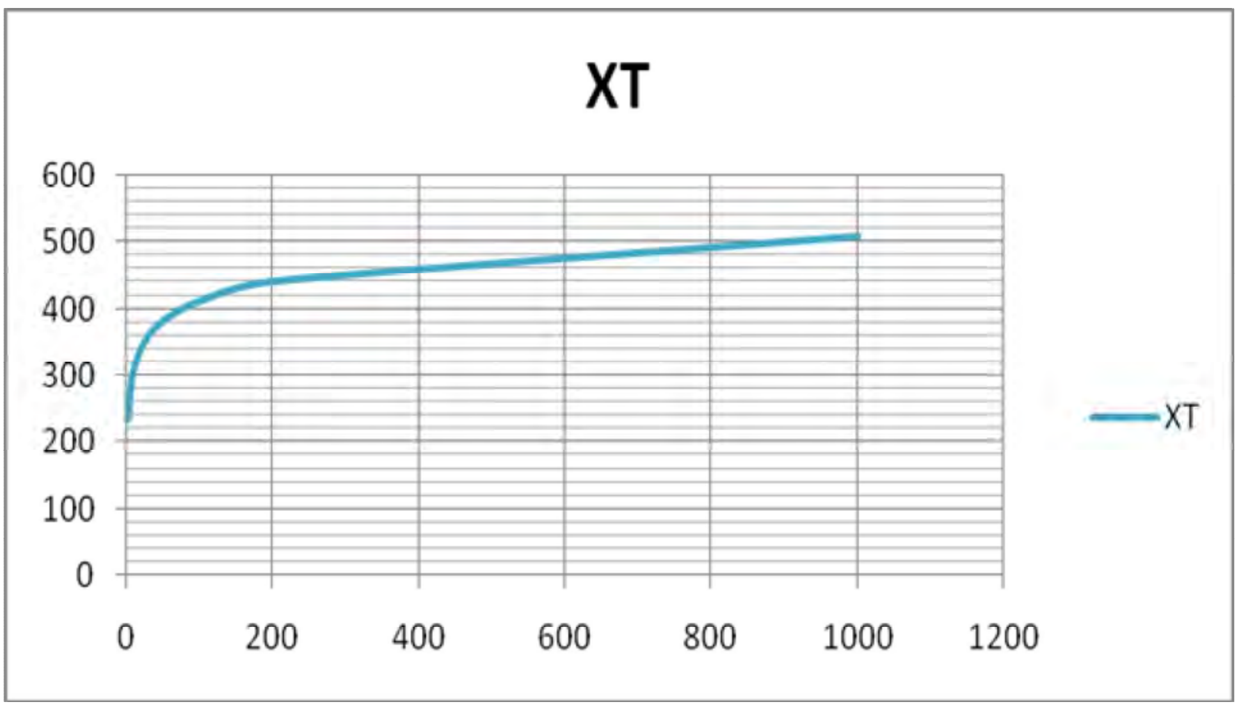
Appendix-5: simulated result table using Gumbel

Return period	U	Log U	YT	k	XT
2	0.301029996	-0.52139023	0.366761694	-0.16393	233.7962
5	0.096910013	-1.01363135	1.500392995	0.719995	281.3174
10	0.045757491	-1.3395378	2.250955556	1.305229	312.7805
25	0.017728767	-1.75132147	3.199293342	2.044673	352.5343
50	0.008773924	-2.05680612	3.902824486	2.593235	382.0259
100	0.004364805	-2.36003511	4.601160867	3.137747	411.2997
200	0.002176919	-2.66215768	5.296949136	3.680272	440.4667
1000	0.000434512	-3.36199845	6.908682432	4.936984	508.0296

Appendix 6: observed vs simulated comparssion using Gumbel



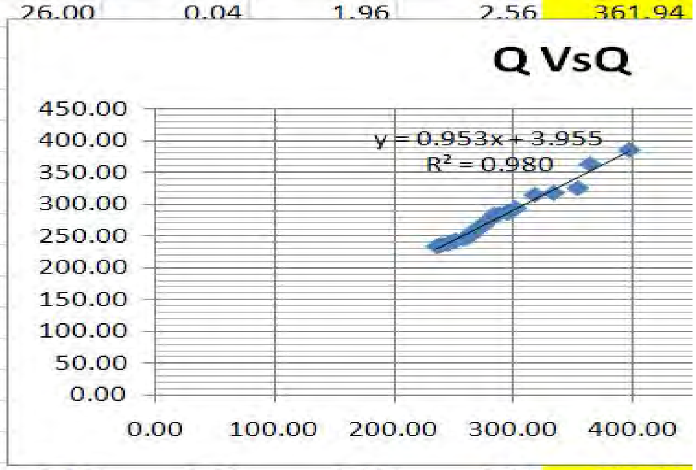
Appendix- 7: Flood discharge of gumera river using Gumble distrubution



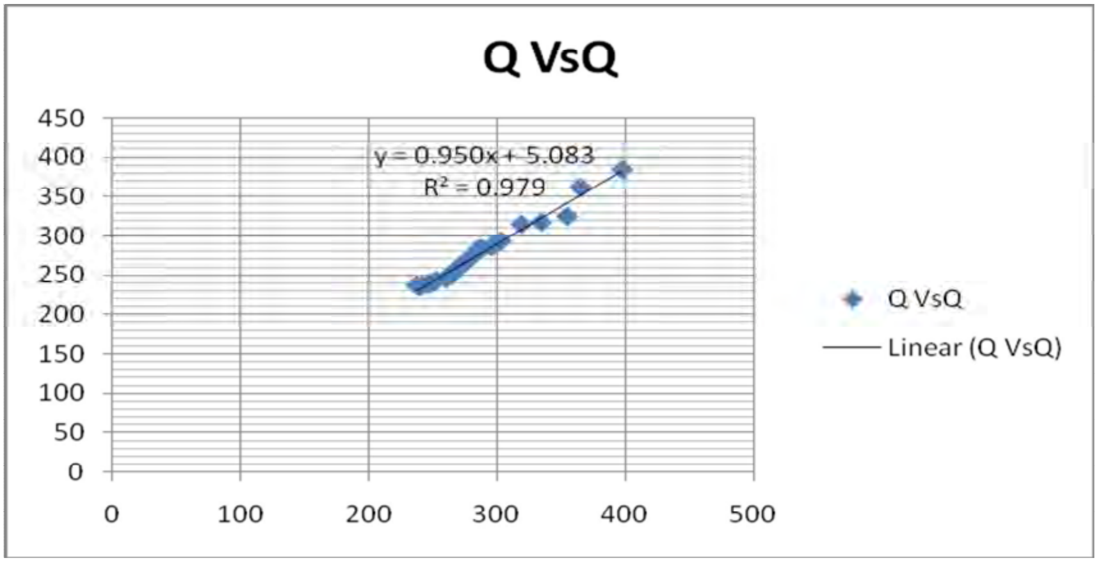
Appendix- 8: Log Pearson Type III distribution Method   Stastical analysis

OBSERVED VALUE

Q	rank	logQ	return period	P	K	LOgQ	Q
397.55	1.00	2.60	52.00	0.02	2.24	2.58	384.50
364.80	2.00	2.56	26.00	0.04	1.96	2.56	361.94
354.51	3.00	2.55					
334.30	4.00	2.52					
318.70	5.00	2.50					
302.50	6.00	2.48					
296.68	7.00	2.47					
295.00	8.00	2.47					
288.24	9.00	2.46					
285.13	10.00	2.46					
283.07	11.00	2.45					
277.90	12.00	2.44					
274.86	13.00	2.44					
270.48	14.00	2.43					
267.31	15.00	2.43					
265.61	16.00	2.42					
264.51	17.00	2.42	3.06	0.33	0.25	2.40	250.29
260.71	18.00	2.42	2.89	0.35	0.20	2.39	247.58
259.82	19.00	2.41	2.74	0.37	0.16	2.39	245.18
252.28	20.00	2.40	2.60	0.38	0.12	2.39	243.03
250.65	21.00	2.40	2.48	0.40	0.08	2.38	241.11
246.94	22.00	2.39	2.36	0.42	0.05	2.38	239.38
246.23	23.00	2.39	2.26	0.44	0.01	2.38	237.81
240.99	24.00	2.38	2.17	0.46	-0.01	2.37	236.37
239.03	25.00	2.38	2.08	0.48	-0.04	2.37	235.06
236.99	26.00	2.37	2.00	0.50	-0.06	2.37	233.86



Appendix- 9: Obseved Vs simulated discharge Comparssion graph using Log Pearson III



Appendix- 10: Flood discharge of gumera river using Log pearson III distrubution

Tr	K	LOgQ	Q
2	-0.063	2.368957	233.8605
5	0.828	2.452501	283.4657
10	1.303	2.497038	314.0787
25	1.825	2.545983	351.5469
50	2.21	2.582082	382.0168
100	2.42	2.601773	399.7356
200	2.756	2.633278	429.8111
1000	3.695	2.721322	526.4074

Appendix-11: Output Table of HEC-RAS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top W.
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)
new	21829.36	2 year	233	1790.6	1797.38		1797.6	0.0004	0.89	227.3	605.8
new	21829.36	10 year	312	1790.6	1796.77		1796.8	0.0004	0.94	566.5	1278
new	21829.36	50 year	382	1790.6	1795.9		1795.9	0.0003	0.94	767.6	1620
new	21829.36	100 year	411	1790.6	1794.96		1794.5	0.0003	0.94	866.1	1788
new	21180.82	2 year	233	1790.5	1794.11		1794.8	0.0005	0.95	198.1	379.5
new	21180.82	10 year	312	1790.5	1794.48		1794.6	0.0006	1.09	391.5	827.6
new	21180.82	50 year	382	1790.5	1794.62		1794.9	0.0006	1.15	521.1	1075
new	21180.82	100 year	411	1790.5	1793.68		1793.8	0.0006	1.17	586.2	1157
new	20897.08	2 year	233	1789.7	1792.24	1791.94	1792.7	0.0067	3.12	29.45	17.71
new	20897.08	10 year	312	1789.7	1792.92	1792.92	1793.2	0.0038	2.76	143.8	269.5
new	20897.08	50 year	382	1789.7	1793.12		1793.3	0.0033	2.65	212	434.3
new	20897.08	100 year	411	1789.7	1793.2		1793.4	0.0031	2.63	247.9	521.3
new	20436.15	2 year	233	1790.5	1792.54		1792.5	3E-05	0.2	562.5	534.3

new	20436.15	10 year	312	1790.5	1792.94		1792.9	8E-05	0.38	825.9	952.3
new	20436.15	50 year	382	1790.5	1793.09		1793.1	0.0001	0.48	987.4	1109
new	20436.15	100 year	411	1790.5	1793.15		1793.2	0.0001	0.5	1050	1136
new	19862.43	2 year	233	1789	1792.47		1792.5	0.0003	0.87	204.9	531.8
new	19862.43	10 year	312	1789	1792.82		1792.9	0.0004	1.1	463.3	971.5
new	19862.43	50 year	382	1789	1792.94		1793	0.0005	1.24	587.9	1171
new	19862.43	100 year	411	1789	1792.98		1793	0.0005	1.3	643	1265
new	19660.96	2 year	233	1790	1791.8	1791.8	1792.3	0.0125	3.09	29.75	30.7
new	19660.96	10 year	312	1790	1792.5	1792.5	1792.7	0.0038	2.21	192.8	638.4
new	19660.96	50yr	382	1790	1792.58	1792.58	1792.7	0.0043	2.42	243.7	752
new	19660.96	100 year	411	1790	1792.63	1792.63	1792.8	0.004	2.38	290.4	911.5
new	19160.75	2 year	233	1788.7	1791.71		1791.7	8E-05	0.32	465	684
new	19160.75	10 year	312	1788.7	1792.05		1792.1	0.0001	0.43	720.4	797
new	19160.75	50 year	382	1788.7	1792.22		1792.2	0.0002	0.48	857.6	878
new	19160.75	100 year	411	1788.7	1792.28		1792.3	0.0002	0.51	915	930.1
new	18515.08	2 year	233	1789.4	1791.63		1791.6	0.0002	0.49	369.5	783.6
new	18515.08	10 year	312	1789.4	1791.95		1792	0.0002	0.57	678.8	1216
new	18515.08	50 year	382	1789.4	1792.09		1792.1	0.0003	0.65	884.1	1502
new	18515.08	100 year	411	1789.4	1792.15		1792.2	0.0003	0.65	976.1	1541
new	17866.96	2 year	233	1788.1	1791.53		1791.5	0.0001	0.43	507.1	1173
new	17866.96	10 year	312	1788.1	1791.85		1791.9	0.0001	0.46	953.2	1559
new	17866.96	50 year	382	1788.1	1791.98		1792	0.0001	0.48	1177	1680
new	17866.96	100 year	411	1788.1	1792.04		1792.1	0.0001	0.49	1278	1733

new	17427.57	2 year	233	1789.8	1791.46		1791.5	0.0002	0.39	466.8	1389
new	17427.57	10 year	312	1789.8	1791.79		1791.8	0.0001	0.33	1002	1822
new	17427.57	50 year	382	1789.8	1791.93		1791.9	0.0001	0.33	1267	1990
new	17427.57	100 year	411	1789.8	1791.99		1792	0.0001	0.33	1388	2058
new	17186.57	2 year	233	1789.8	1791.41		1791.4	0.0002	0.37	410.9	981.9
new	17186.57	10 year	312	1789.8	1791.76		1791.8	0.0002	0.36	810.6	1302
new	17186.57	50 year	382	1789.8	1791.9		1791.9	0.0002	0.39	1007	1511
new	17186.57	100 year	411	1789.8	1791.96		1792	0.0002	0.4	1099	1577
new	16834.67	2 year	233	1790.1	1791.37		1791.4	6E-05	0.21	631.6	1138
new	16834.67	10 year	312	1790.1	1791.73		1791.8	7E-05	0.27	1086	1424
new	16834.67	50 yr	382	1790.1	1791.86		1791.9	9E-05	0.31	1284	1503
new	16834.67	100 year	411	1790.1	1791.92		1791.9	9E-05	0.33	1374	1567
new	16482.41	2 year	233	1790.3	1791.36		1791.4	3E-05	0.1	940.7	1605
new	16482.41	10 year	312	1790.3	1791.71		1791.7	3E-05	0.14	1561	1940
new	16482.41	50 year	382	1790.3	1791.84		1791.8	4E-05	0.17	1823	2037
new	16482.41	100 year	411	1790.3	1791.9		1791.9	4E-05	0.18	1944	2137
new	16324.36	2 year	233	1790.3	1791.36		1791.4	2E-05	0.09	977.5	1480
new	16324.36	10 year	312	1790.3	1791.7		1791.7	3E-05	0.12	1543	1842
new	16324.36	50 year	382	1790.3	1791.84		1791.8	4E-05	0.14	1794	1973
new	16324.36	100 year	411	1790.3	1791.89		1791.9	4E-05	0.15	1909	2098
new	16105.07	2 year	233	1790.2	1791.35		1791.4	7E-06	0.05	1593	2050
new	16105.07	10 year	312	1790.2	1791.7		1791.7	1E-05	0.08	2405	2564
new	16105.07	50 year	382	1790.2	1791.83		1791.8	1E-05	0.09	2752	2764
new	16105.07	100 year	411	1790.2	1791.89		1791.9	2E-05	0.1	2911	2830

new	15715.24	2 year	233	1790.7	1791.5		1791.6	1E-05	0.05	1177	1443
new	15715.24	10 year	312	1790.7	1791.7		1791.7	2E-05	0.08	1725	1864
new	15715.24	50 year	382	1790.7	1791.82		1791.8	3E-05	0.1	1978	2131
new	15715.24	100 year	411	1790.7	1791.88		1791.9	3E-05	0.12	2099	2214
new	15352.89	2 year	233	1790.8	1791.34		1791.3	4E-05	0.07	919.6	1808
new	15352.89	10 year	312	1790.8	1791.69		1791.7	4E-05	0.1	1597	2085
new	15352.89	50 year	382	1790.8	1791.81		1791.8	4E-05	0.11	1866	2155
new	15352.89	100 year	411	1790.8	1791.87		1791.9	4E-05	0.12	1981	2185
new	15119.36	2 year	233	1790.4	1791.34		1791.35	5E-06	0.05	1389	1411
new	15119.36	10 year	312	1790.4	1791.68		1791.7	2E-05	0.09	1988	2120
new	15119.36	50 yr	382	1790.4	1791.81		1791.8	2E-05	0.12	2272	2372
new	15119.36	100 year	411	1790.4	1791.86		1791.9	2E-05	0.13	2399	2429
new	14842.13	2 year	233	1790.8	1791.34		1791.3	2E-05	0.06	732	744.1
new	14842.13	10 year	312	1790.8	1791.67		1791.7	5E-05	0.12	1021	1003
new	14842.13	50 year	382	1790.8	1791.79		1791.8	6E-05	0.13	1149	1106
new	14842.13	100 year	411	1790.8	1791.85		1791.9	7E-05	0.12	1208	1187
new	14516.11	2 year	233	1790.9	1791.31		1791.3	0.0005	0.27	242.8	502.6
new	14516.11	10 year	312	1790.9	1791.62		1791.6	0.0006	0.45	461.4	890.4
new	14516.11	50 year	382	1790.9	1791.73		1791.8	0.0007	0.52	570	1107
new	14516.11	100 year	411	1790.9	1791.78		1791.8	0.0007	0.55	621.6	1177
new	14167.52	2 year	233	1790.9	1791.15		1791.2	0.0004	0.16	281.4	699.5
new	14167.52	10 year	312	1790.9	1791.43		1791.4	0.0006	0.33	577.2	1508
new	14167.52	50 year	382	1790.9	1791.54		1791.5	0.0005	0.35	752.6	1662
new	14167.52	100	411	1790.9	1791.58		1791.6	0.0005	0.37	827.6	1716

		year									
new	13803.91	2 year	233	1790.7	1791.03		1791	0.0003	0.17	396.3	990.9
new	13803.91	10 year	312	1790.7	1791.28		1791.3	0.0003	0.28	682.5	1340
new	13803.91	50 year	382	1790.7	1791.39		1791.4	0.0003	0.32	851.4	1586
new	13803.91	100 year	411	1790.7	1791.43		1791.4	0.0003	0.34	920.2	1624
new	13512.28	2 year	233	1790.4	1790.97		1791	0.0002	0.18	458.3	987.2
new	13512.28	10 year	312	1790.4	1791.2		1791.2	0.0002	0.26	776.6	1597
new	13512.28	50 year	382	1790.4	1791.31		1791.3	0.0002	0.3	973.5	1977
new	13512.28	100 year	411	1790.4	1791.35		1791.4	0.0002	0.32	1054	2074
new	13288.03	2 year	233	1790	1790.9		1790.9	0.0008	0.48	284.7	995
new	13288.03	10 year	312	1790	1791.12		1791.1	0.0007	0.56	562.4	1511
new	13288.03	50 yr	382	1790	1791.7		1791.8	0.0006	0.59	761.9	1937
new	13288.03	100 year	411	1790	1791.86		1791.9	0.0006	0.6	836.4	1974
new	12896.89	2 year	233	1790.4	1791.34		1791.7	0.0006	0.19	286.1	824.7
new	12896.89	10 year	312	1790.4	1791.67		1791.9	0.0007	0.29	496.1	1152
new	12896.89	50 year	382	1790.4	1791.79		1791	0.0007	0.34	651.3	1425
new	12896.89	100 year	411	1790.4	1791.85		1791	0.0007	0.36	705.1	1470
new	12528.02	2 year	233	1790.1	1791.31		1790.3	0.002	0.25	195.7	733.5
new	12528.02	10 year	312	1790.1	1791.62		1790.5	0.0016	0.4	363.7	969.4
new	12528.02	50 year	382	1790.1	1791.73		1790.6	0.0017	0.46	472.7	1139
new	12528.02	100 year	411	1790.1	1791.78		1790.7	0.0016	0.47	522.3	1166
new	12110.01	2 year	233	1789.8	1791.15		1790	0.0003	0.15	424.1	1353
new	12110.01	10 year	312	1789.8	1791.43		1790.3	0.0003	0.25	805.8	1708
new	12110.01	50 year	382	1789.8	1791.54		1790.4	0.0003	0.29	997.9	1786

new	12110.01	100 year	411	1789.8	1791.58		1790.4	0.0003	0.3	1086	1851
new	11797.6	2 year	233	1789.5	1791.03		1791.7	0.0004	0.22	372.5	1158
new	11797.6	10 year	312	1789.5	1791.28		1791.9	0.0003	0.28	788.9	1866
new	11797.6	50 year	382	1789.5	1791.39		1791	0.0003	0.31	1017	2104
new	11797.6	100 year	411	1789.5	1791.43		1791	0.0003	0.33	1124	2290
new	11505.25	2 year	233	1789.7	1790.97		1790.3	3E-05	0.03	931.6	1622
new	11505.25	10 year	312	1789.7	1791.2		1790.5	5E-05	0.09	1432	2226
new	11505.25	50 year	382	1789.7	1791.3		1790.6	6E-05	0.12	1700	2552
new	11505.25	100 year	411	1789.7	1791.3		1790.7	6E-05	0.13	1825	2696
new	11067.91	2 year	233	1789.8	1790.9		1790	0.0001	0.04	589.9	1544
new	11067.91	10 year	312	1789.8	1791.1		1790.3	0.0001	0.1	1062	2131
new	11067.91	50 yr	382	1789.8	1790.5		1790.4	0.0001	0.13	1310	2420
new	11067.91	100 year	411	1789.8	1791.86		1790.4	0.0001	0.14	1422	2519
							1791.7				
new	10591.12	2 year	233	1789.5	1791.34		1791.9	0.0024	0.45	194.6	939.8
new	10591.12	10 year	312	1789.5	1791.67		1791	0.0011	0.47	491.7	1458
new	10591.12	50 year	382	1789.5	1791.79		1791	0.0009	0.31	677.5	1999
new	10591.12	100 year	411	1789.5	1791.85			0.0008	0.29	781.3	2230
							1790.3				
new	9932.791	2 year	233	1789.2	1791.31		1790.5	0.0001	0.13	484.6	1196
new	9932.791	10 year	312	1789.2	1791.62		1790.6	0.0002	0.12	817.1	1488
new	9932.791	50 year	382	1789.2	1791.73		1790.7	0.0002	0.17	979.6	1574
new	9932.791	100 year	411	1789.2	1791.78		1791.7	0.0002	0.19	1054	1638
							1791.9				
new	9318.204	2 year	233	1788.5	1791.15		1791	0.0009	0.44	270.6	931.6
new	9318.204	10 year	312	1788.5	1791.43		1791	0.0007	0.53	514.3	1340
new	9318.204	50	382	1788.5	1791.54			0.0007	0.57	645.6	1397

		year									
new	9318.204	100 year	411	1788.5	1791.58		1790.3	0.0007	0.6	698.6	1422
							1790.5				
new	8898.782	2 year	233	1788.6	1791.03		1790.6	0.0009	0.37	243.2	718.2
new	8898.782	10 year	312	1788.6	1791.28		1790.7	0.0011	0.56	450.1	1240
new	8898.782	50 year	382	1788.6	1791.39			0.001	0.62	601.4	1569
new	8898.782	100 year	411	1788.6	1791.43		1790	0.001	0.64	660.6	1623
							1790.3				
new	8620.744	2 year	233	1788.3	1790.97		1790.4	0.0008	0.41	256.8	923
new	8620.744	10 year	312	1788.3	1791.2		1790.4	0.0006	0.48	566.5	1626
new	8620.744	50 year	382	1788.3	1791.31		1791.7	0.0006	0.53	759.4	1921
new	8620.744	100 year	411	1788.3	1791.35		1791.9	0.0006	0.54	850.7	2040
							1791				
new	8305.458	2 year	233	1788.1	1790.9		1791	4E-05	0.08	940.9	1828
new	8305.458	10 year	312	1788.1	1791.12			6E-05	0.14	1413	2297
new	8305.458	50 yr	382	1788.1	1791.81		1790.3	7E-05	0.16	1661	2421
new	8305.458	100 year	411	1788.1	1791.86		1790.5	7E-05	0.18	1769	2467
							1790.6				
new	7960.104	2 year	233	1787.8	1791.34		1790.7	0.0003	0.42	344.4	942.8
new	7960.104	10 year	312	1787.8	1791.67			0.0004	0.57	581.5	1220
new	7960.104	50 year	382	1787.8	1791.79		1790	0.0004	0.63	705.2	1302
new	7960.104	100 year	411	1787.8	1791.85		1790.3	0.0005	0.65	759	1346
new	7498.107	2 year	233	1787.8	1791.31		1791.7	0.0002	0.24	506.3	1568
new	7498.107	10 year	312	1787.8	1791.62		1791.9	0.0003	0.33	811.2	1693
new	7498.107	50 year	382	1787.8	1791.73		1791	0.0003	0.37	967.2	1715
new	7498.107	100 year	411	1787.8	1791.78		1791	0.0003	0.39	1025	1720
new	6930.722	2 year	233	1787.2	1791.15	1790.17	1790.3	0.0156	2.12	88.28	517.9
new	6930.722	10 year	312	1787.2	1791.43	1790.28	1790.5	0.0163	2.41	156.1	728.1

new	6930.722	50 year	382	1787.2	1791.54	1790.32	1790.6	0.0183	2.65	190.1	870.6
new	6930.722	100 year	411	1787.2	1791.58	1790.37	1790.7	0.0161	2.61	241.8	1256
new	6631.115	2 year	233	1787.3	1791.03		1790	4E-05	0.09	657.5	913.3
new	6631.115	10 year	312	1787.3	1791.28		1790.3	1E-04	0.18	879	1078
new	6631.115	50 year	382	1787.3	1791.39		1790.4	0.0001	0.23	981.4	1184
new	6631.115	100 year	411	1787.3	1791.43		1790.4	0.0001	0.25	1040	1253
							1791.7				
new	6321.055	2 year	233	1787.3	1790.97	1790.45	1791.9	0.0004	0.3	361.1	1016
new	6321.055	10 year	312	1787.3	1791.2		1791	0.0005	0.4	580.3	1161
new	6321.055	50 year	382	1787.3	1791.31		1791	0.0006	0.46	664	1201
new	6321.055	100 year	411	1787.3	1791.35			0.0006	0.48	714	1293
							1790.3				
new	6029.344	2 year	233	1787	1790.9	1790.4	1790.5	0.0261	1.96	71.76	427.2
new	6029.344	10 year	312	1787	1791.12	1790.53	1790.6	0.0162	1.78	157.8	836.6
new	6029.344	50 yr	382	1787	1791.81		1790.7	0.0039	1.11	350.9	1075
new	6029.344	100 year	411	1787	1791.86			0.0026	0.96	435.5	1149
							1790				
new	5710.898	2 year	233	1786.3	1791.34		1790.3	6E-06	0.05	1445	1669
new	5710.898	10 year	312	1786.3	1791.67		1791.7	1E-05	0.09	2104	2004
new	5710.898	50 year	382	1786.3	1791.79		1791.9	1E-05	0.11	2419	2071
new	5710.898	100 year	411	1786.3	1791.85		1791	2E-05	0.12	2569	2141
							1791				
new	5365.28	2 year	233	1786.2	1791.31			2E-06	0.03	1628	1223
new	5365.28	10 year	312	1786.2	1791.62		1790.3	6E-06	0.07	2100	1488
new	5365.28	50 year	382	1786.2	1791.73		1790.5	9E-06	0.09	2343	1672
new	5365.28	100 year	411	1786.2	1791.78		1790.6	1E-05	0.1	2464	1738
							1790.7				
new	5013.05	2 year	233	1786.7	1791.15			4E-05	0.11	534.3	635.5
new	5013.05	10	312	1786.7	1791.43		1790	9E-05	0.23	886.8	1339

		year									
new	5013.05	50 year	382	1786.7	1791.54		1790.3	0.0001	0.3	1112	1633
new	5013.05	100 year	411	1786.7	1791.58		1790.4	0.0001	0.34	1230	1715
							1790.4				
new	4750.999	2 year	233	1786.5	1791.03		1791.7	0.0075	1.57	105.2	439
new	4750.999	10 year	312	1786.5	1791.28		1791.9	0.0022	1.19	294.9	724.2
new	4750.999	50 year	382	1786.5	1791.39		1791	0.0019	1.23	415	980.9
new	4750.999	100 year	411	1786.5	1791.43		1791	0.0017	1.2	476.9	1039
new	4357.081	2 year	233	1785.6	1790.97		1790.3	1E-05	0.1	972.8	1159
new	4357.081	10 year	312	1785.6	1791.2		1790.5	3E-05	0.17	1359	1340
new	4357.081	50 year	382	1785.6	1791.31		1790.6	4E-05	0.21	1553	1577
new	4357.081	100 year	411	1785.6	1791.35		1790.7	4E-05	0.22	1646	1678
new	4046.409	2 year	233	1785.4	1790.9		1790	0.0012	1.15	175.7	543.5
new	4046.409	10 year	312	1785.4	1791.12		1790.3	0.0008	1.11	403.7	922.8
new	4046.409	50 yr	382	1785.4	1791.81		1790.4	0.0008	1.12	537.1	1115
new	4046.409	100 year	411	1785.4	1791.86		1791.7	0.0007	1.12	600.7	1178
							1791.9				
new	3764.391	2 year	233	1785.3	1791.34		1791	0.0005	0.64	241.6	466.7
new	3764.391	10 year	312	1785.3	1791.67		1791	0.0006	0.79	443.2	883
new	3764.391	50 year	382	1785.3	1791.79			0.0005	0.81	605.1	1261
new	3764.391	100 year	411	1785.3	1791.85		1790.3	0.0005	0.81	687.1	1336
							1790.5				
new	3490.179	2 year	233	1784.7	1791.31		1790.6	0.0005	0.88	235.3	503.2
new	3490.179	10 year	312	1784.7	1791.62		1790.7	0.0006	1.03	404.9	610.3
new	3490.179	50 year	382	1784.7	1791.73			0.0006	1.07	500.3	649.5
new	3490.179	100 year	411	1784.7	1791.78		1790	0.0006	1.1	542.8	655.5
			233				1790.3				
new	3267.181	2 year	312	1784.5	1791.15		1790.4	0.0006	0.92	200.9	410

new	3267.181	10 year	382	1784.5	1791.43		1790.4	0.0008	1.19	315.4	420.7
new	3267.181	50 year	411	1784.5	1791.54		1791.7	0.0009	1.3	376	426.2
new	3267.181	100 year	233	1784.5	1791.58		1791.9	0.0009	1.35	401.6	428.5
			312				1791				
new	2991.166	2 year	382	1784.2	1791.03		1791	0.0037	1.79	79.82	326.4
new	2991.166	10 year	411	1784.2	1791.28			0.0016	1.42	269	530.8
new	2991.166	50 year	233	1784.2	1791.39		1790.3	0.0014	1.41	363.2	758.6
new	2991.166	100 year	312	1784.2	1791.43		1791.5	0.0013	1.42	413.3	855.8
new	2559.985	2 year	233	1784	1790.7		1790.8	0.0002	0.53	314.6	618.6
new	2559.985	10 year	312	1784	1791.2			0.0002	0.61	622.1	932
new	2559.985	50 year	382	1784	1790.9		1791	0.0003	0.68	771.6	1125
new	2559.985	100 year	411	1784	1790.35		1790.45	0.0003	0.71	837.4	1154
new	2097.512	2 year	233	1781.5	1790.9		1791.7	0.0005	1.12	153.4	282.8
new	2097.512	10 year	312	1781.5	1791.12		1791.9	0.0008	1.53	309.7	577.9
new	2097.512	50 yr	382	1781.5	1790.81		1791	0.001	1.75	373.4	670.1
new	2097.512	100 year	411	1781.5	1790.86		1791	0.0011	1.85	400.4	694
new	1361.816	2 year	233	1782.4	1790.34	1790.99	1790.3	0.0035	2.08	92.51	396.1
new	1361.816	10 year	312	1782.4	1790.4		1790.5	0.0023	1.81	288.9	1031
new	1361.816	50 year	382	1782.4	1790.5		1790.6	0.0016	1.57	467.4	1390
new	1361.816	100 year	411	1782.4	1790.6		1790.7	0.0014	1.49	540.1	1460
new	855.9996	2 year	233	1778.8	1790.31		1790.45	0.0006	1.22	150.2	275.8
new	855.9996	10 year	312	1778.8	1790.4		1790.5	0.0011	1.69	245.8	335
new	855.9996	50 year	382	1778.8	1790.73		1790.8	0.0013	1.89	298.7	376.6
new	855.9996	100 year	411	1778.8	1790.26		1790.4	0.0014	1.97	323	392.5

new	540.4757	2 year	233	1780	1790.15		1791.9	0.0001	0.48	427.3	719.8
new	540.4757	10 year	312	1780	1790.43		1791	0.0002	0.64	641	804.7
new	540.4757	50 year	382	1780	1791.54		1791	0.0002	0.72	750.6	844.7
new	540.4757	100 year	411	1780	1790.58			0.0002	0.75	797.5	864
							1790.3				
new	157.6032	2 year	233	1781.7	1791.03	1790.9	1790.5	0.0051	2.13	96.71	348.6
new	157.6032	10 year	312	1781.7	1790.28	1790.06	1790.6	0.0077	2.73	160.1	439.3
new	157.6032	50 year	382	1781.7	1790.39	1790.11	1790.7	0.0098	3.12	183.3	454.6
new	157.6032	100 year	411	1781.7	1790	1790.15	1790.5	0.0097	3.14	201.2	465.6