

**Hydraulic Modeling and Flood Mapping Of Fogera Flood Plain:**

**A Case Study of Gumera River**

**School of Graduate Study ,Civil Engineering  
Department,Hydropower Engineering Stream**



**A Thesis Submitted to the School of Graduate Study of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydropower Engineering stream.**

**By Brhane Hagos**

**MARCH 2011**

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**CERTIFICATION**

I, the undersigned, certify that I read and hereby recommend for the acceptance by the Addis Ababa University a dissertation entitled: Hydraulic Modeling and Flood Mapping Of Fogera Flood Plain in partial fulfillment of a degree of Masters of Science in Hydropower Engineering Stream.

.....  
Dr .Yilma Sileshi

(Advisor)

Date: -----

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Date of Defense:

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### ABSTRACT

Nowadays, extraordinary floods are common many parts of Ethiopia causing a lot of losses to human lives as well as damage to property. Historically, Fogera/Dera flood plain has been vulnerable to flash flooding from rainfall, in particular of the Gumera catchment which passes in between the Fogera -Dera weredas. The tributary rivers are originating from the southern highlands of Debretabor with a steep slope. The Fogera –Dera flood plain is located east of Lake Tana in North West Ethiopia about 625 km from the capital city Addis Ababa and the terrain is fairly flat. The Gumara catchment drained by Gumara River is part of Nile basin The over flow of the river affects part of the Fogera /Dera flood plain but mainly the Fogera part at lower reach near to Lake Tana.

Hence, this thesis is to identify peak flood and delineate and produce flood inundation mapping areas that can be affected by extraordinary floods and to recommend mitigation measures.

This thesis tries to consider more options and fills the gaps not covered by others, adopting more than seven application soft wares like Arc GIS, Global Mapper, HEC-HMS, HEC-DSS, HEC-GeoHMS, HEC-RAS and HEC-GeoRAS. 30m\*30m resolution DEM for the catchment and 2m contour interval for Fogera flood plain are used to analyze terrain information.

For precipitation modeling, the daily rain fall basis is used for HEC\_HMS calibration and ERA Intensity-frequency-duration curve is used for frequency storm analysis. The hydrologic frequency model is used for determining the peak flow discharge for return periods of 2, 5, 10, 50 and 100 years and the result is found to be 197.7m<sup>3</sup>/s, 246.8 m<sup>3</sup>/s, 265.4m<sup>3</sup>/s, and 306.0m<sup>3</sup>/s and 319.60m<sup>3</sup>/s respectively. For the 100 year flood frequency the maximum depth of flood is 7.94m and this depth of flood is extended to the flood plain up to 10km of the flood area which affects mainly the Wageta, Kidist Hana, Shina, Quhar Michael and Bebeks Tana mistily and Jigna Weredas .The total area affected by this flood is 31.36 km<sup>2</sup> and the area affected by the 2year flood inundation of 7.36m is 22.27 Km<sup>2</sup>.

Key Words: HEC-GEORAS, HEC-HMS, HEC-RAS, TIN, DEM, Flood Map HEC-DSS

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## 1 INTRODUCTION

### 1.1 Back Ground

Flood is defined as a great flow of water, especially, a body of water, rising, swelling and overflowing over land surface. Flood control implies all measures taken to reduce the detrimental effect of flood. Flooding over the world is one of the worse natural disaster, in terms of economic losses and number of water born deaths. Accurate and current floodplain maps can be the most valuable tools for avoiding severe social and economic losses from floods. This updated floodplain maps also improve public safety and property. Early identification of flood-prone properties during emergencies allows public safety organizations to establish warning and evacuation priorities. Flooding occurs due to too high stages in the river, which can be caused by the following reasons that are: too high discharges, backing up of the water and increase in bed levels, human intervention in the highlands areas at an ever increasing scale.

Floods interfere with efficient drainage and economic use of lands for agricultural or industrial purposes. Floods also damages drainage channel, bridges, sewer outfalls and other structures. Human influence is an important factor that many artificial changes in the river system may induce morphological changes and subsequent rising of the water or bed level.

For minimizing the losses due to floods, various flood control measures are adopted. The flood control measures -which should more correctly be termed as “Flood Management” can be planned either through structural engineering measures or non-structural measures. Wise application of engineering science has afforded ways of mitigating the ravages due to floods and providing reasonable measure of protection to life and property.

As floods are among the major hazards in Ethiopia, It is important to implement interventions that reduce the vulnerability of people living in flood-prone areas. Providing rain forecasts and building capacity of people living in flood-prone areas need to be considered. Developing preparedness plan that can be implemented by the communities themselves, with or without the support of other actors, should be a priority. The purpose of a flood warning system is to

‘empower individuals and communities to respond to floods appropriately in order to reduce the risk of death, injury, property loss .

### 1.2 Description of the Study Area

Gumara river catchment is one of the largest sub-basin of Lake Tana located in between  $11^{\circ}30'$  to  $37^{\circ}38'$ N and  $37^{\circ}30'$  to  $37^{\circ}$ E. Gumara Rivers is the major tributary river in Lake Tana sub-basin that flow from a mountainous area to the flat fields of Fogera flood plain in to the Lake Tana. This flood plain is taken for researching the flood problem in Lake Tana Sub-basin due to the flood drained from the Gumara catchment.

The Fogera –Dera flood plain is located east of Lake Tana in North West Ethiopia about 625 km from the capital Addis Ababa and the terrain is fairly flat. The Gumara catchment drained to Gumara river is part of Nile basin ,located north west of Ethiopia, Eastern part of lake Tana at an altitude ranging 1787.01m to 3686.29m ,which originates in near to mountain Guna and ends in lake Tana and it covers a total catchment area of 1385.390404Km<sup>2</sup>.The over flow of the river affects part of the Fogera \_Dera flood plain but mainly the Fogera part at downstream side. A number of tributary rivers draining the highlands west wards can increase the water level of the the Gumera river in a short period of time and cause flooding in the low-lying alluvial plains along the river course. Tributaries of Gumera river from Guna high lands contributes to the lowland flooding in Fogera\_Dera flood plain. The catchment is characterized by its opened river system, which means it does have outlet to the lake tana .The Location of the three watersheds is presented in in the figure1.1 below.

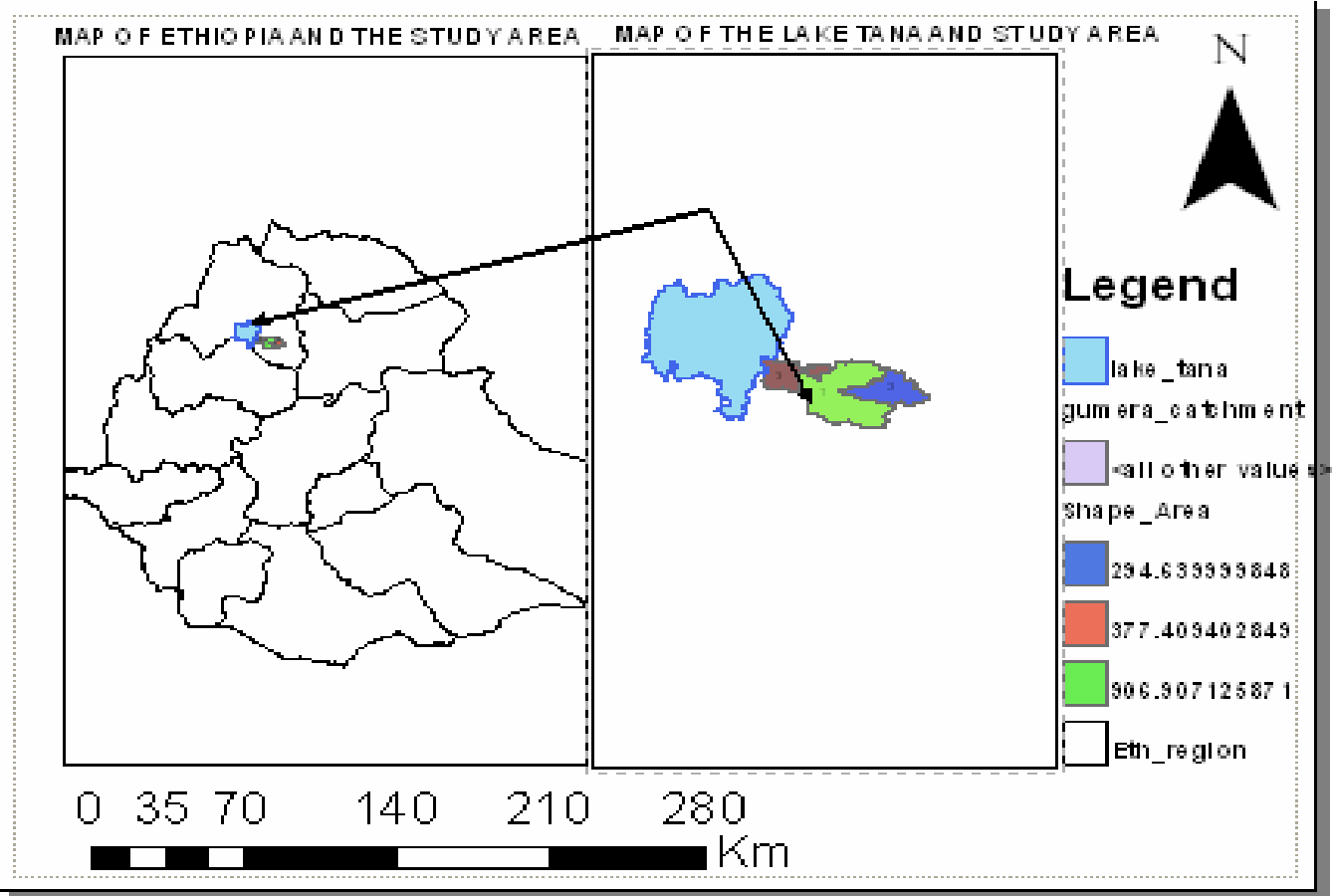


Fig 1.1 Location of the Study Area

The Gumera catchment has many small tributaries drained in to the the main river Gumera and this main river passes through the Fogera -Dera flood plain and is joined into the lake Tana . The catchmet is divided in the three sub catchment using Hec-GeoHMS and shown in the figure 1.2 below.

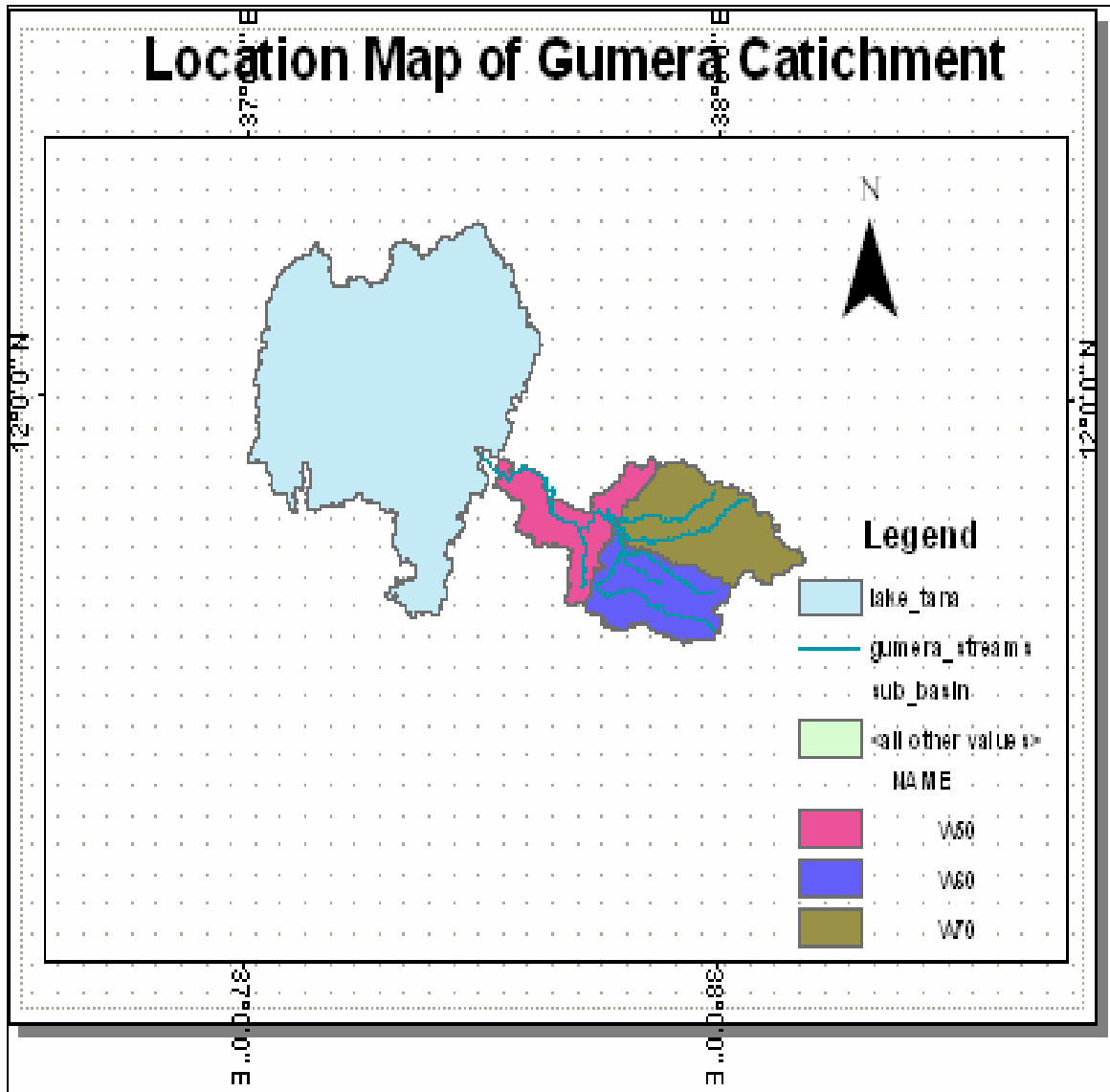


Fig:1.2 Turributaries of Gumera River Drained in to the Lake Tana

The Gumera River catchment DEM is clipped using Arc Tool from the the Ethiopian DEM and is presented below.

### 1.3 Previous Studies of the area

In the past, flood studies for Fogera Flood plain have been done by different organizations and researchers before and after the most severe flood event occurred on 2006..

Even though investigations were made in the past in the area related to this topic, due to considerable progress and invention of new approach including data type and application softwares flood studies still will continue in many aspects.

Some organizations have tried to estimate the amount of flood using different methods and recommended the mitigation measures. Among them the recent study was conducted by ENTRO under the title Flood Risk Mapping and Consultancy for Pilot Areas in Ethiopia.

This study was conducted after the most severe flood event. According to my assessment, The following major points are put not clear in the report and alternative is approach is put.

- While using HEC-HMS the basin loss parameters were not fixed but here before determining the flood peak flow ,the basin loss parameters are fixed using the daily flow basis.
- Calibration and validation of the model is not clearly put in the final report
- Inundation depth of the flood in each frequency flood is not indicated on the final report
- Total inundated area of the flood plain was not put clearly

Thus taking this in to consideration the thesis tried to develop the preveios studies and consider additional tasks not included in the preveios study. For the HEC-HMS model ,the previous approach is different from this work. For Comparson of the flood map ,the previous flood map is annexed in D ,Fig D7.

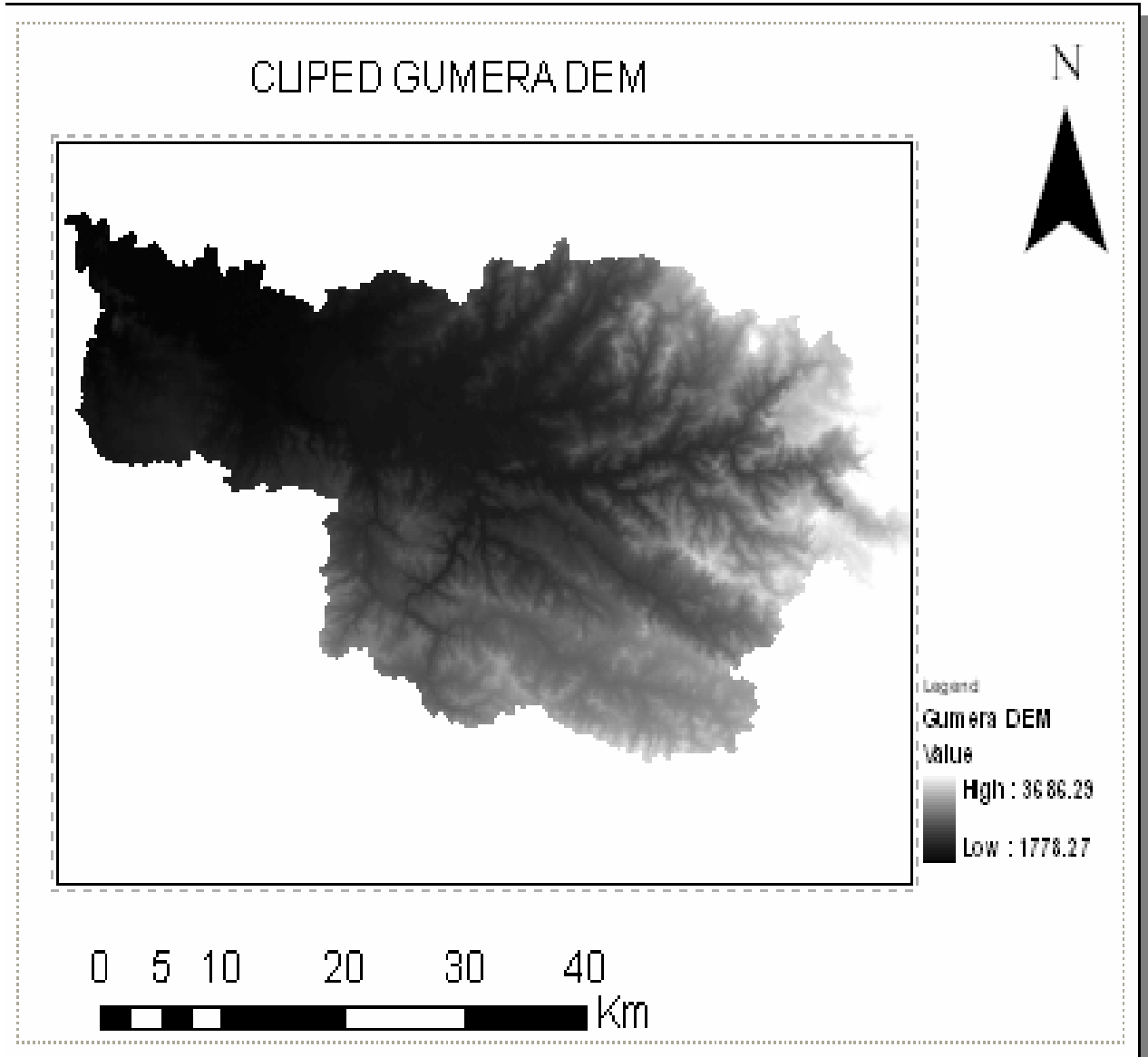


Fig 1.3 Clipped Gumera River Catchmet DEM

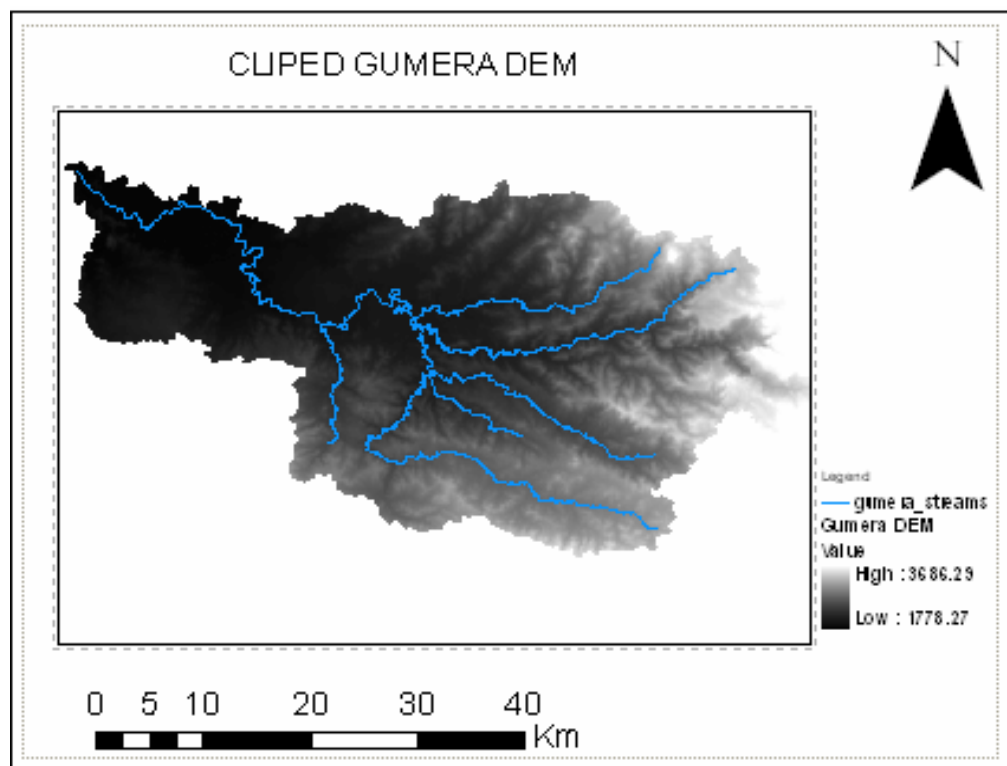


Fig 1.4 Gamera Catchment Streams

### 1.4 Topography of the Study Area

The topography of the study area was discussed above, but here the land use, land cover and soil characteristic of the study area will be discussed as shown below.

#### 1.4.1 Gamera Catchment Land Cover

The land cover of the study area can be classified as A, C1, C2, U, C2 which stands for alpine, dominantly cultivated, grass land and moderately cultivated. The feature of the land cover is shown below in figure 1.5

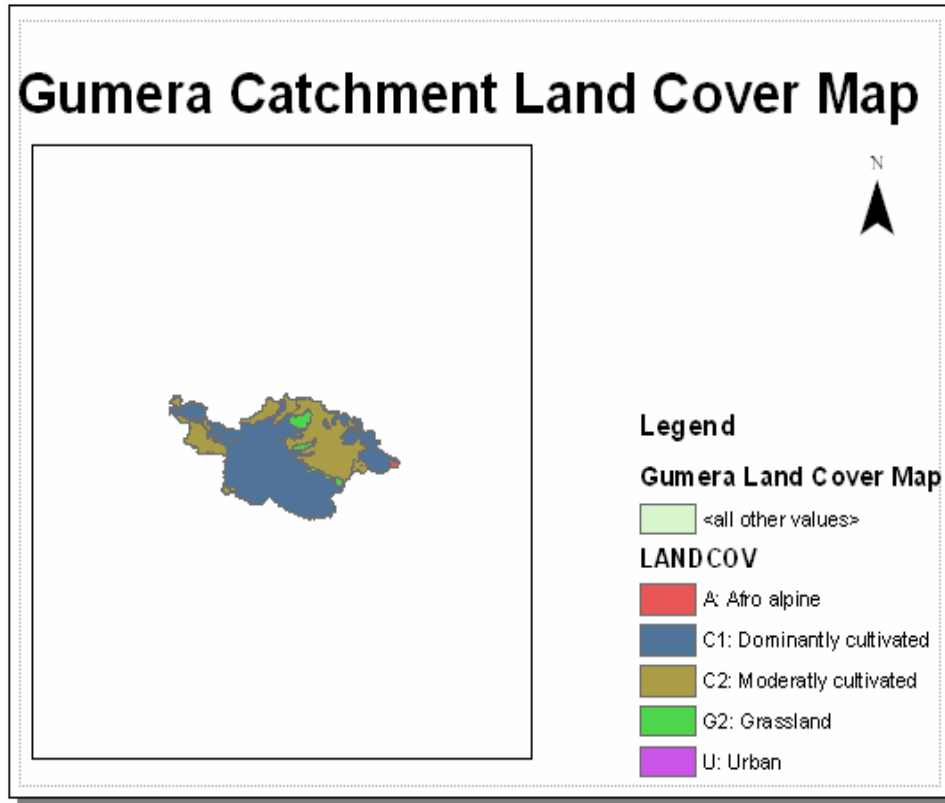


Fig 1.5 Land Cover of the Study Area

#### 1.4.2 Catchment Land Use

The land use of the study catchment is classified as that shown in the figure above mainly as agricultural, agro-pastoral, pastoral and urban. The large portion is covered by the agricultural and the small portion is pastoral.

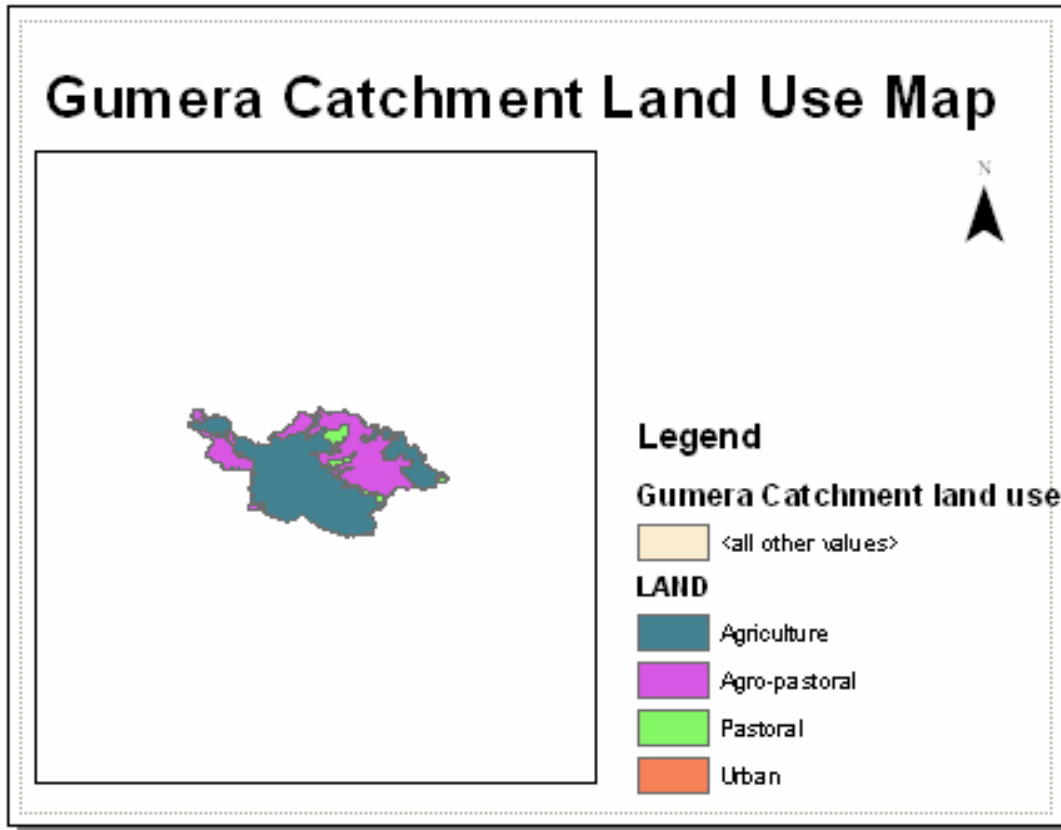


Fig 1.6 Land Use of the Study Area

### 1.4.3 Catchment Soil Group

The soil map of the study area is classified according to the curve number of the soils within the catchment. As it is shown from the soil map below.

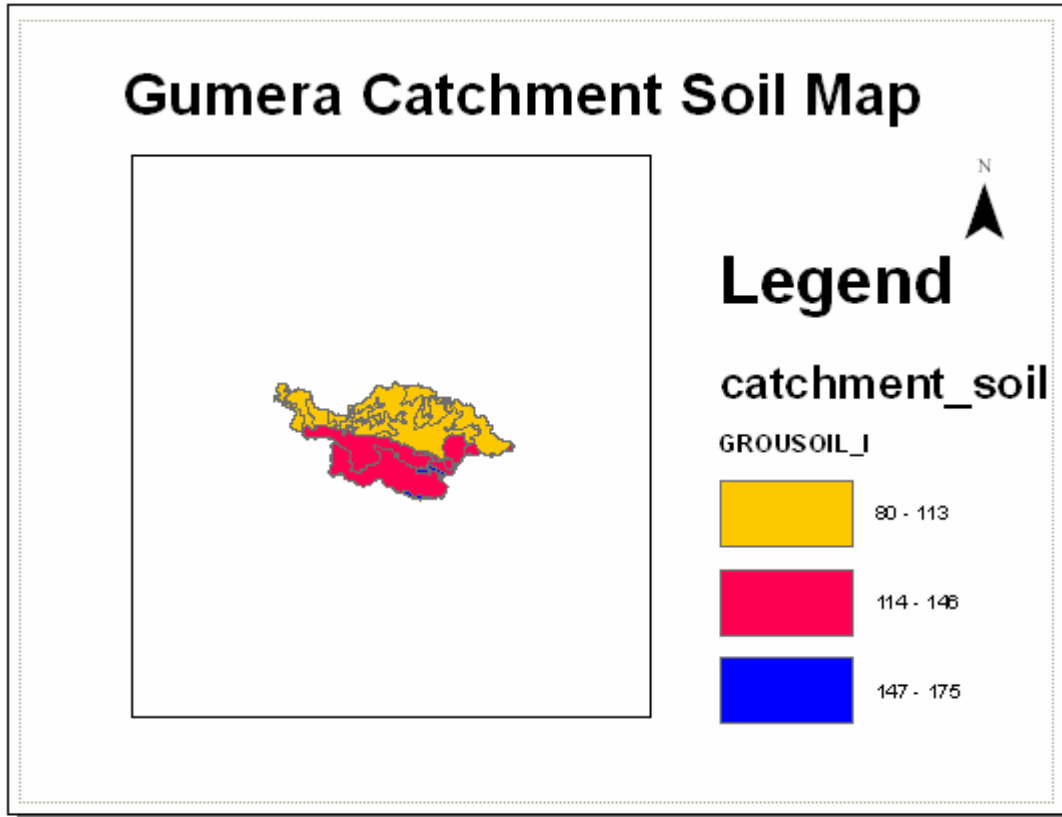


Fig 1.7 Soil map of the Study Area

### 1.5 Rain Fall

Ethiopia is generally characterized as residing in a tropical to sub-tropical climate, with the primary rain fall season typically occurring between the months of June to September. A secondary rain fall season usually occurs from February to May. The remaining months (October to January) tend to be the driest period. In general, the annual rain fall amount decreases as one moves to the northeast region of the country. The rain fall pattern over Ethiopia is driven by synoptic climatic mechanisms which tend to have predictability over homogeneous regions. The main synoptic influence on the hydrometeorology in Ethiopia includes the monsoon effects from the Indian and Atlantic oceans, the impacts of the inter-tropical convergence zones seasonal movements (to the north during the summer months), and the influence of the low-level jet stream. During the main rainy season, precipitation amounts are strongly influenced by the surface temperature, sea surface, and the active jet stream movement northward (WWDSE2007).

The project region around lake Tana tends to be hydrometeorologically homogeneous with minor geographic impacts on precipitation evident near Debre Tabor. A study by the Ethiopian Road Authority (ERA2002) characterizes the entire project region by a single set of intensity duration frequency (IDF) curves

There are four important rainfall recording stations in the catchment area, Bahiridar, Woreta, Debre Tabor and Nifas Mewcha. The most important rainfall station for the study area is the three stations named as Woreta, Debre Tabor and Bahiridar found on the upper side of the catchment.

Rainfall data analysed for the two stations covers 52 years record but for this research the recent 15 years period daily record from 1992 to 2006 is considered.

### 1.6 Problem of the Research Area

Flooding, as a natural phenomenon is not new to Ethiopia. It has been occurring at different places and times with varying magnitude. Much of these flood disasters are attributed to rivers that overflow or burst their banks and inundate downstream plain lands. The torrential rains falling for long days on the upstream highlands cause most rivers to swell and overflow or breach their courses, submerging the surrounding floodplains, which are mostly located in the outlying pastoralist regions of the country. Gumara River is one of the rivers which cause flooding at Fogera-Dera flood plain. The river builds up from continuous rainfall on the catchments and local rainfall on the flood plain to result in flooding problems. Areas in Fogera flood plain that are most at risk from flooding are located at lower level in the river. During high floods, people have to live in chest-high water levels. The Fogera flood plain is frequently

affected by floods. There have been floods recorded in the years of 1996, 1998, 1999, 2000,

2001, 2003 and 2006. The 1996 flood set a new record for flooded area, while 2006 flood was recorded with its long duration and damage. In the year 2006, the heavy rain, caused rising of the Lake level, overtopping of Ribb and Gumara rivers and high volume of water flow in the smaller catchments making thousands of people homeless, caused death of thousands cattle and led to

large crop losses (H. A. R. De Bruin<sup>1</sup>, I. F. Trigo<sup>2,6</sup>, M. A. Jitan<sup>3</sup>, N. Temesgen Enku<sup>4</sup>, C. Van der Tol<sup>5</sup>, and A. S. M. Gieske July 2010). In spite of the recurrent flood problem however the existing disaster management mechanism is primarily geared towards strengthening rescue and relief arrangements during and after major flood disasters with no systems to minimize the incidence and extent of flood damage. Part of Fogera plain is affected by flood that drained from the Gumara River catchment. This necessitates the development of hydraulic modeling and flood mapping of the study area in order to take mitigation measures to avoid the risk. Thus the specific problem for this thesis paper is the problem of flooding part of Fogera-Dera flood plain from the Gumara River due to over toping of the river banks.



Fig 1.8 Flooding Of The Study Area (Woubet G 2006)

### 1.7 Objectives of the Study

The main purpose of this research is to enhance and developing existing flood forecasting modeling through actual data sets and the specific objective includes

- ✚ Calibration of HEC- HMS,HEC-RAS
- ✚ To estimate peak flood discharge as a result of precipitation
- ✚ To delineate flood inundation areas, and

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

- ✚ Hydraulic modeling and flood mapping of the part of the Fogera \_Dera flood plain due to Gumera river and Producing flood plain mapping for different floods

### 1.8 Lower Reach Of The Gumera River

The Fogera flood plain is ranging for elevation of from 1800m to 1785m. The lower reach of the Gumera catchment has a length of 37660.36 m passing through the Fogera \_Dera flood plain with a slope of 0.0398% . The river at this stretch has a very flat slope tending to change its course with rising of its bed with silt deposition. As a result the river branches out into different reducing flows in the original river and denying supply to existing farms downstream.

Considering the loss of lives and property from any natural disaster, people benefit from mapping and protecting flood prone areas from any huge infrastructure in the flood plain areas.

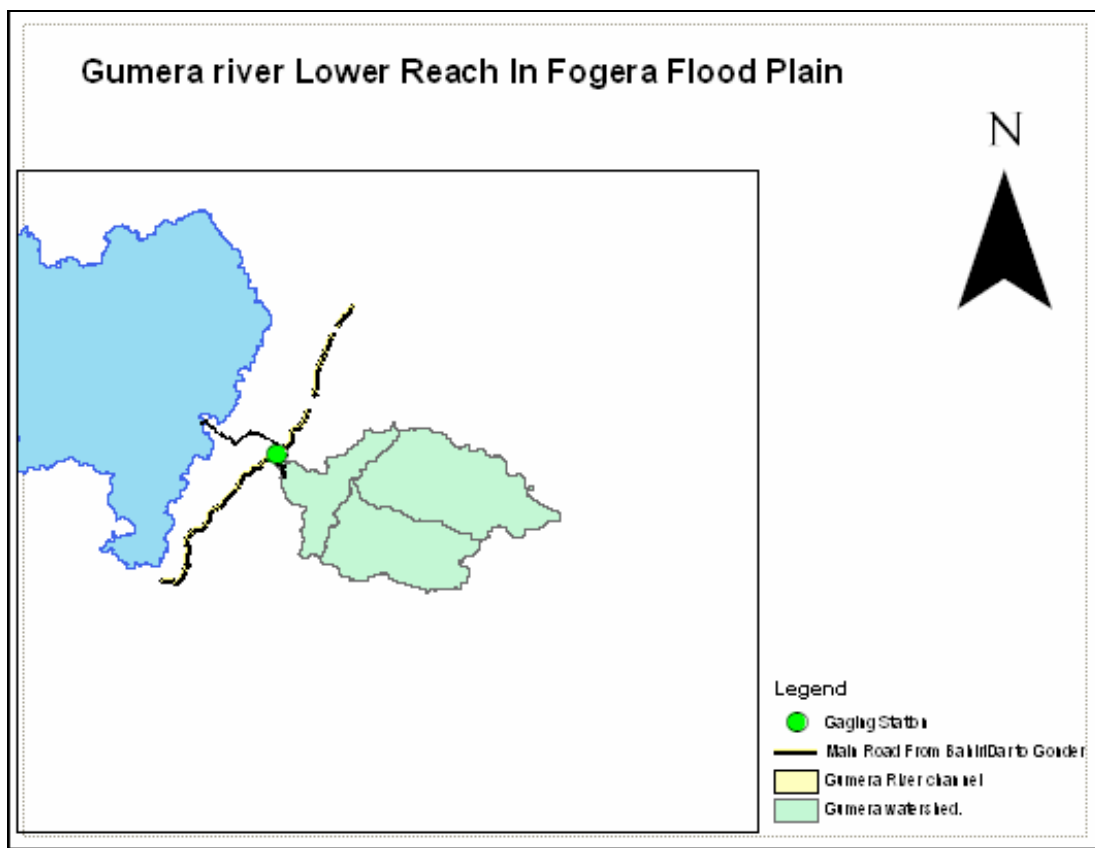


Fig 1.9 Lower Reach Of Gumera River For Hydraulic Modelling

### 1.9 Outline Structure of the Dissertation

This thesis is divided into seven chapters. Chapter 1 provides brief introduction and detail background of the study area. Chapter 2 presents the literature review. The Literature review part is compiled and presented in main topics (Rainfall Runoff Modeling, Basic Concepts HEC-HMS in Interconnected SubBasins HEC-GeoHMS, TerrainModel Pre-Processing Hydrologic processing Hydraulic Modeling Delineation of Flood Prone Area Preras (HEC-GeoRas) processing Creating RAS Themes Attributing Ras Theme ,Generating the RAS GIS Import File). Chapter 3 deals with methodology and software application used .Chapter 4 deals with the sources and analysis of the data, presents the spatial data analysis and model set up and model calibration and validation. Chapter 5 presents HEC-HMS modeling results and discussions. Chapter 6 presents out put of HEC-RAS and Hec-Georas and chapter 7 presents conclusion and recommendations. In addition to this Appendixes are attached at the end.

## 2. LITERATURE REVIEW

### 2.1 Flood Estimation

#### 2.1.1 Rainfall Runoff Modeling

The use of rainfall-runoff models inevitably extends the lead time. These models relate current rainfall in a catchment to river flows or reservoir inflows. For the forecasting chain starting from the measured rainfall and using it as input to a rainfall-runoff model, forecasting lead time becomes a function of delays, mostly due to the filling of the soil storage and surface waters travel time. Rainfall-runoff models may be either lumped (i.e. using a single rainfall input spatially averaged across the catchment) or distributed (i.e. accounting to some extent for the distribution of rainfall). River flows may be forecast at specific points along a river to provide warnings at these points, or used as input to flood routing models to provide warnings further downstream. The following are some of the rainfall-runoff models.

- Rational method
- SCS and unit hydrograph method
- Analysis of stream gage data
- Suitable computer programs
- Hydrologic modeling(HEC-HMS)

#### 2.1.2 Basic Concepts of HEC-HMS In Interconnected Sub Basins

HEC-HMS conceptually represents watershed behavior as different components of runoff processes. It has an appropriate representation of the hydrological system, and its specification depends upon the information needs of the hydrological study. For flood hydraulic modeling and flood inundation mapping, the main objective is to accurately predict catchment outflows from upstream sub catchments and flood wave propagation along the drainage network. As concluded by (Butts, Overgaard et al. 2006) .

Factor that limits the level of distributed data needed to make sufficiently accurate flood forecasts is data availability. Therefore the following basic concepts of a typical HEC-HMS

application shown in figure 2.1 were used in this study. As illustrated in Figure 2.1, only those components necessary to predict runoff are represented in detail, and the other components are omitted or lumped. For example, in a common application, HEC-HMS omits any detailed accounting of movement of water within the soil. In this mode, HEC-HMS includes models of infiltration at the land surface, but it doesn't model storage and movement of water vertically within the soil layer. It implicitly combines the near surface flow and overland flow and models this as direct runoff. Likewise, it does not include a detailed model of interflow or flow in the groundwater aquifer. Instead it represents only the combined outflow as base flow. A description on HEC-HMS model components used in this study and additional HEC functionalities are discussed in chapter 3.

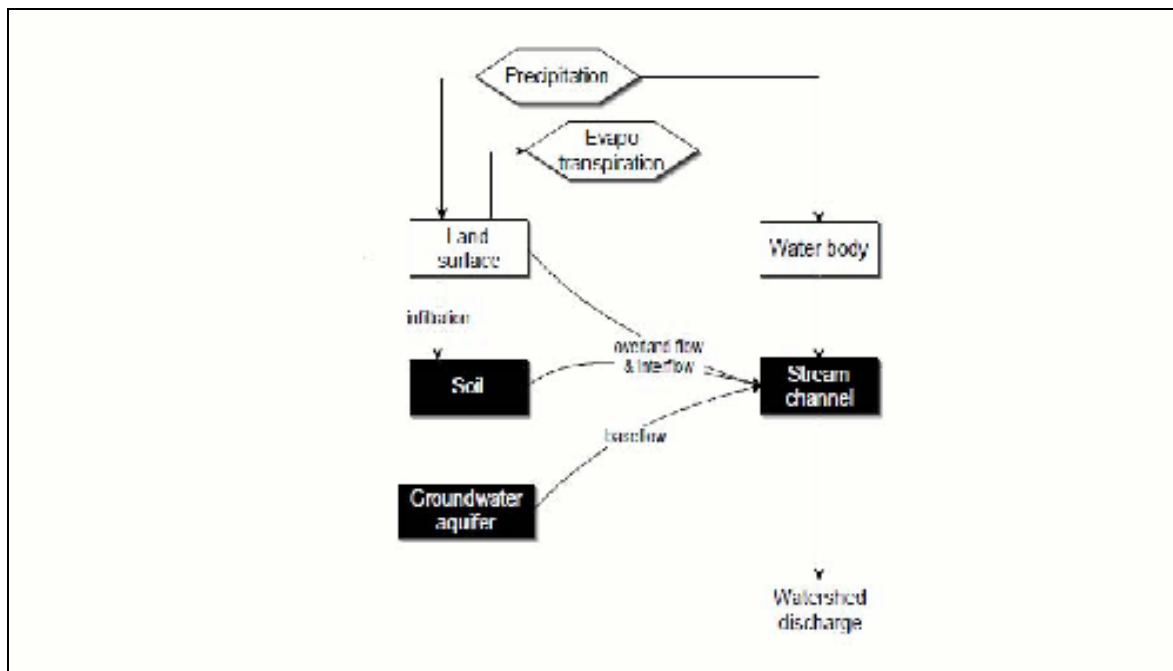


Fig 2.1 Typical Water Shed Representation Of HEC-HMS Run off (USACE 2000)

### 2.2 HEC-GeoHMS

HEC-GeoHMS has been developed as a geospatial hydrology tool kit for engineers and hydrologist. The program is an extension of Arc GIS and allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation. Eight

data sets can be derived from DEM that collectively describe the drainage patterns of the watershed.

HEC-GeoHMS provides the connection for translating GIS spatial information into hydrologic models. The end result of the GIS processing is a spatial hydrology database that consists of the digital elevation model (DEM), soil types, land use information, rainfall, etc. HEC-GeoHMS operates on the DEM to derive sub-basin delineation and to prepare a number of hydrologic inputs. 30m resolution DEM is used for this case. HEC-HMS accepts the hydrologic inputs as a starting point for hydrologic modelling.

The relation between GIS, HEC-GeoHMS, and HEC-HMS is illustrated in Figure below.

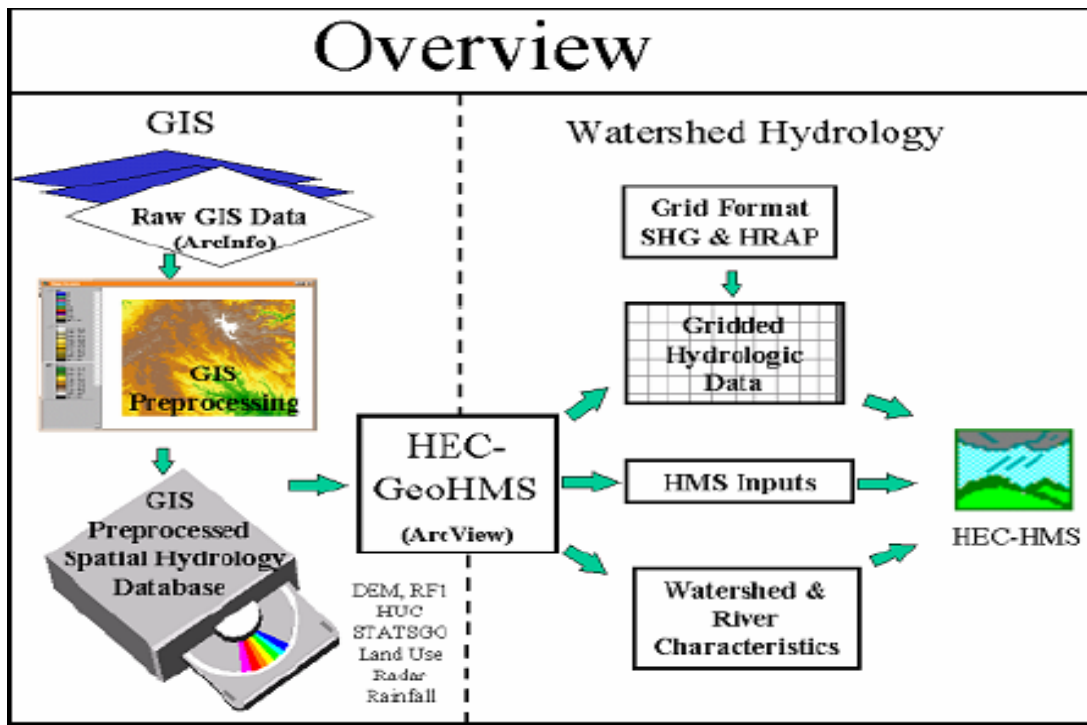


Fig.2.2 Overview of GIS, HEC-GeoHMS and HEC-HMS(HEC-GeoHMS user's manual 2009)

The following procedures describe the major steps in starting a project and taking it through the GeoHMS development of a hydrologic model using DEM. These are:

- i. Terrain Model Preprocessing
- ii. Hydrologic Processing

- Basin Processing
- Stream and Watershed Characteristics
- HMS Model Files

iii. Hydrologic Parameters and HEC-HMS

### 2.2.1 Terrain Model Pre-Processing

The steps consist of computing the fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, watershed delineation, watershed polygon processing, stream segmentation and watershed aggregation. These steps can be done step by step or in a batch manner. Watershed and stream delineation developed in this step is preliminary and they are used in later steps for sub-basin and stream delineation. Terrain pre-processing is performed in the Main View document of ArcGIS version 9.3

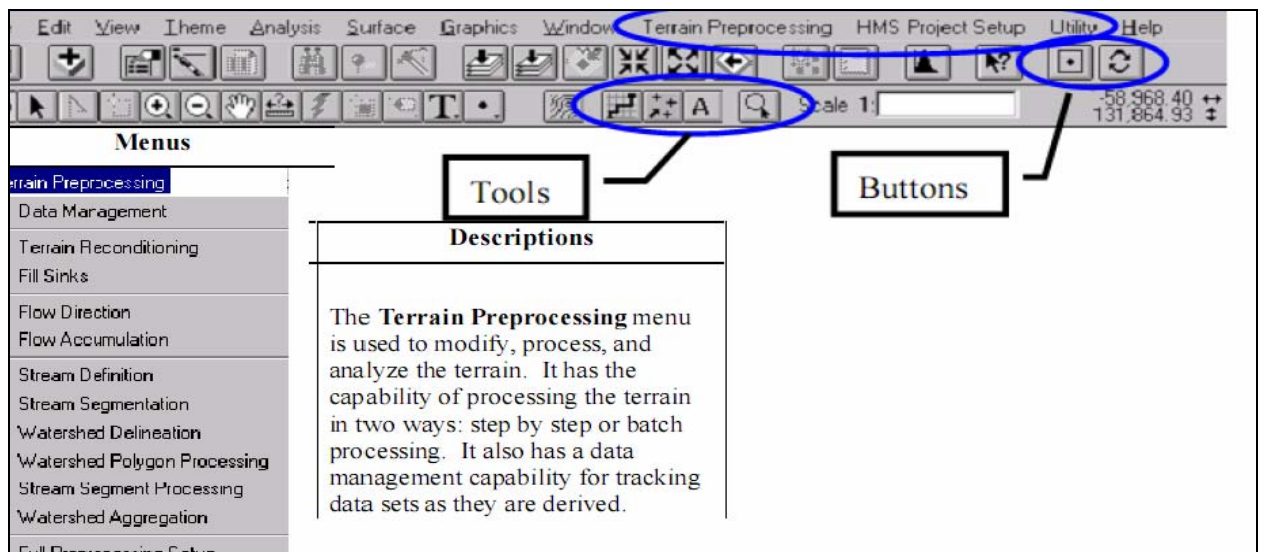


Fig 2.3 over view of Tools ,Buttons in Terrain preprocessing

### 2.2.2 Hydrologic Processing

The steps consist of computing basin processing, stream and watershed characteristics and HMS Model Files, is performed in the ProjectView document of Arc GIS GUI.

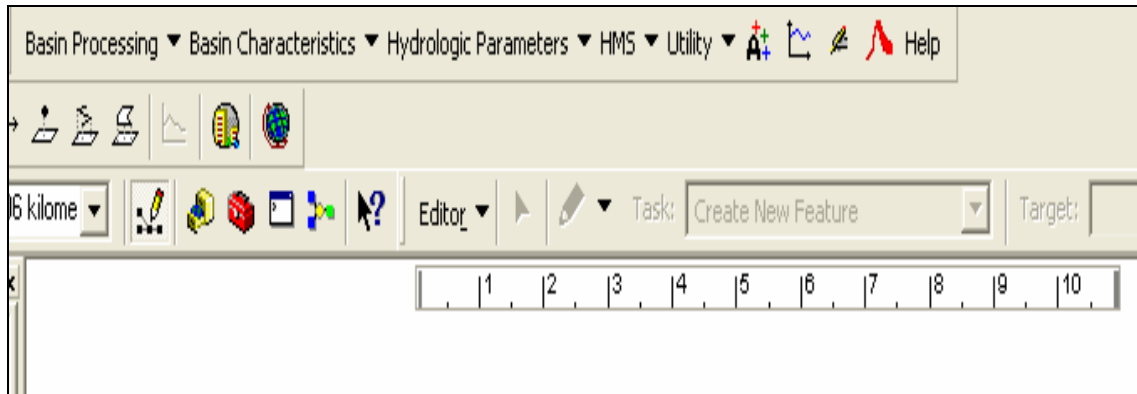


Fig 2.4 over view of hydrologic processing tools

### 2.2.3 Hydraulic Modeling Delineation of Flood Prone Area

The Flood Inundation map shows the area extent to be delineated as buffer zone. Two models HEC\_GeoRAS and HEC\_RAS are used one after another (i.e first HEC\_GeoRAS then HEC\_RAS then back to HEC\_GeoRAS) to accomplish the task.

HEC-GeoRAS is a set of procedures, tools, and utilities for processing geographic information systems (GIS) data in Arc GIS version 9.3, using a graphical user interface (GUI). The interface allows preparation of geometric data for import into HEC-RAS and generation of GIS data from exported HEC-RAS simulation results. Automated GIS processing procedures in HEC-GeoRAS provides a valuable and expeditious method for repetitive hydraulic model development during floodplain analysis. HEC-GeoRAS Version 9.3 is used to extract cross-sectional station-elevation data from a digital elevation model (DTM) represented by a triangulated irregular network (TIN). Downstream reach lengths and bank station locations were determined for each cross section. The automated procedures for extracting geometric data proved consistent and efficient for the development of floodplain models. The geometric data was imported into HEC-RAS Version 4.1 using a data exchange format developed by HEC-GeoRAS. The resultant water surface elevations exported from HEC-RAS simulations were processed by HEC-GeoRAS for floodplain delineation and water depth calculations. Analysis of cross-sectional velocities exported from HEC-RAS was also performed using HEC-GeoRAS.

GeoRAS allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS with an existing 2m contour interval of stream cross section in TIN format and 30m resolution digital terrain model (DTM) of the river system.

The user creates a series of line themes pertinent to developing geometric data for HEC-RAS. The themes created are the Stream Centerline, Flow Path Centerlines (optional), Main Channel Banks (optional), and Cross Section Cut Lines referred to as the RAS Themes.

Additional RAS Themes may be created/used to extract additional geometric data for import in HEC-RAS. These themes include Land Use, Levee Alignment, Ineffective Flow Areas, and Storage Areas.

HEC-GeoRAS is an Arc GIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into HEC-RAS, and generation of GIS data from RAS output.

### **Procedures followed:-**

The flood plain contour interval map is changed to Terrain TIN (a triangulated irregular network) using Arc GIS extension HEC-GeoRAS. Then the following main procedures are applied.

#### **2.2.4 Preras (HEC-Georas) Processing**

The goal of this section is to develop the spatial data required to generate a HEC-RAS import file with a 3-D stream network and 3-D cross sections defined. The process is divided in three steps:

- Preparation of 3-D polyline themes defining stream centerline, cross-sections, stream banks, and flow path lines.
- Use of the HEC-GeoRAS **preRAS** menu functions to extract 3-D spatial data from the TIN to develop 3-D polylineZ themes of the previously defined stream centerline, cross-sections, stream banks, and flow path lines.
- Generation of the HEC-RAS Import File.

#### **2.2.5 Creating RAS Themes**

The RAS Themes are the basis for the geometric data extracted in the GIS for hydraulic analysis in HEC-RAS. These Themes include: Stream Centreline, Banks, Flow Paths Centrelines, Cross-Sectional Cut Lines, Land Use, Levee Alignments, Ineffective Flow Areas, and Storage Areas.

### 2.2.6 Attributing Ras Theme

Once the RAS Themes have been created, the geometric data extraction process began. The Stream Centreline Theme completed and the cross-section attributes (geometric data for each cross section) calculated. Stream Centreline Theme created before completing the Cross-Section Cut Line Theme and the Cross-Sectional Cut Lines Theme completed.

### 2.2.7 Generating the RAS GIS Import File

To generate the RAS GIS Import File, the 3D stream Centreline and Cross Section Surface Line (3D) shape file created from the RAS Theme. Geometric data from the two 2D (stream Centreline and Cross Section Surface Line) shape files is written to the RAS GIS Export File. The geometric data includes: river, reach, and station identifiers; cross-section cut lines; cross-section surface lines; main channel bank stations; downstream reach lengths for the left overbank, main channel; and overbank.

HEC-GeoRas is an Arc GIS extension specifically designed to process geospatial data for use with the Hydrologic Engineering Center's River Analysis System (HEC\_RAS). This extension allows us to;

- Create an HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DEM) and complementary data sets.
- Process results exported from HEC-RAS.

It creates an import file, referred as the RAS GIS Import File, containing river, reach and station identifier; cross-sectional cut lines; cross-sectional surface lines; cross-sectional bank stations; downstream reach lengths for the left overbank, main channel, and right over bank; and cross-sectional roughness coefficients.

HEC\_GeoRAS also enables viewing of exported results from RAS. The import file is created from data extracted from data sets (ArcGIS shape files) and from a Digital Terrain Model (DTM) represented by a triangulated irregular network (TIN).

Prior to performing hydraulic computations in HEC-RAS, the geometric data must be imported and completed and flow data must be entered. Once the hydraulic computations are performed, exported water surface and velocity results from HEC-RAS may be imported back to the GIS

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

using HEC-GeoRAS for spatial analysis. GIS data is transferred between HEC-RAS and Arc GIS main view using a specifically formatted GIS data exchange file.

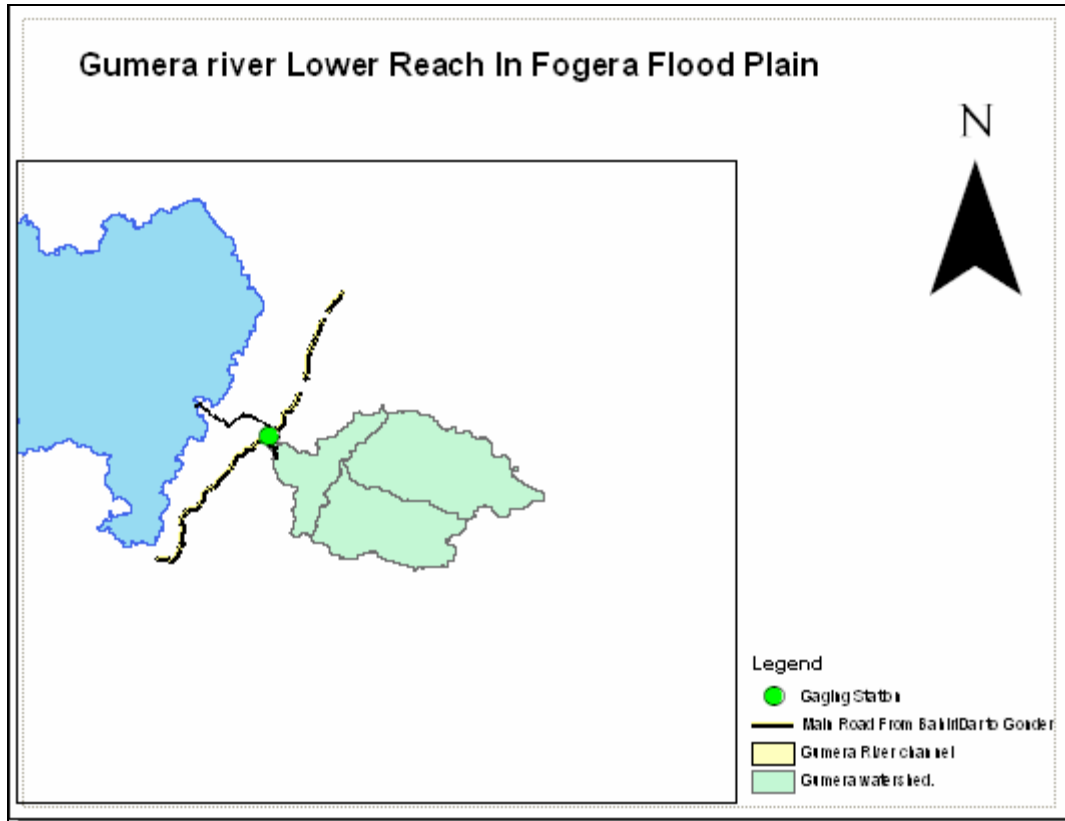


Fig 2.5 Catchment Lower Reach To Be Modeling

The fogera flood plain is ranging from an altitude of 1785 to 1800m. The lower reach of the Gamera catchment has a length of 37660.36 m passing through the Fogera \_dera flood plain with a slope of 0.0398%. The river at this stretch has a very flat slope tending to change its course with rising of its bed with silt deposition. As a result the river branches out into different reducing flows in the original river and denying supply to existing farms downstream.

Considering the loss of lives and property from any natural disaster, people benefit from mapping and protecting flood prone areas from any huge infrastructure in the flood plain areas.

### 3.0 Methodology

#### 3.1 Details of Selected Models

The methodology of for this is based on the application of the models used and problem of the statement required to be rectified.

##### 3.1.1 HEC-HMS Hydrological Model

HEC-HMS (The Hydrologic Engineering Center's Hydrological Modeling System) is the United States Army Corps of Engineers' hydrologic system computer program developed by the Hydrological Engineering Center (HEC) (USACE, 2000) .HEC-HMS consists of separate models of the major hydrological processes and transports. It consists of runoff volume models, models of direct runoff (overland flow and interflow), base flow models, channel flow models. HEC-HMS gives flexibility to the user by providing each component with suit of models. The model HEC-HMS is used for estimation of peak discharges and runoff hydrographs for different return periods at different location of the water shed out let.

HEC-HMS computes runoff volume by computing the volume of water that is intercepted infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception, infiltration, storage, evaporation, and transpiration collectively are referred to in the HEC-HMS program and documentation as losses. HEC-HMS considers that all land and water in a watershed can be categorized as either directly-connected impervious surface, or pervious surface. Directly connected impervious surface in a watershed is that portion of the watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses. Precipitation on the pervious surfaces is subject to losses.

### 3.3 Hydraulic Flood Modeling

#### 3.3.1 General

Flood models are the representation of the hydrologic and hydraulic processes in the water shed, river channel and floodplain. Accurate representation of the actual process is of paramount significance in predicting flood extent and depth. Determining the variation of flow characteristics in spatial and temporal resolution enables to design flood evacuation plan quite efficiently.

### 3.3.2 Development of DTM

The key data element that GeorAS uses to develop the input data is terrain data, commonly referred to as a Triangular Irregular Network (TIN). One source of data used to develop TIN is a Digital Elevation Model (DEM). The TIN of the study area is developed from the contour which is developed from DEM of the study data using the 3D-special analysis extension in the Arc GIS or survey data of the study area and is clipped using the Arc Tool Special Analysis .

DEM exist in grid (raster cell) format which can be displayed within ArcGIS, if the proper extensions are installed. The quality of this data is based on its resolution, or cell size.

The smaller the cell is, the greater the resolution and accuracy. However, the smaller the cell size, the greater the memory and computation requirements. The usefulness of DEM for developing terrain models should be determined based on the cell size and the level of hydraulic analysis to be performed. The more approximate the analysis is to be, the greater the cell size that may be used. This can best be represented by TIN of the study area.

The TIN is generated from the spot heights acquired from different sources in ArcGIS which included:

- 1) GPS surveyed data collected along the two river banks, with good accuracy.
- 2) The spot heights of the flood plains taken from the surveyed data which extend approximately far from both the left and right bank stations and cover the floodplain if topography permits.
- 3) River bed cross section elevation data.

### 3.3.3 TIN of the Study Area

In hydraulic modeling the topography of the river and flood plain are represented as continuous surface. The representation of the river and floodplain is by the use of the TIN generated from the intersection of actual field data and the existing DEM of the study area. The TIN for this research is done with high precision due to the availability of the field surveys on the Gumera channel which covers almost the entire reach.

The surveyed data contains information about the river layers (center line, right bank and left bank). The spot elevations are processed in ArcGIS to form shape files for the layers. When creating these shape files, there are meandering points which are lack of data for further processing. The points are then filled with successive interpolation and with additional field surveys.

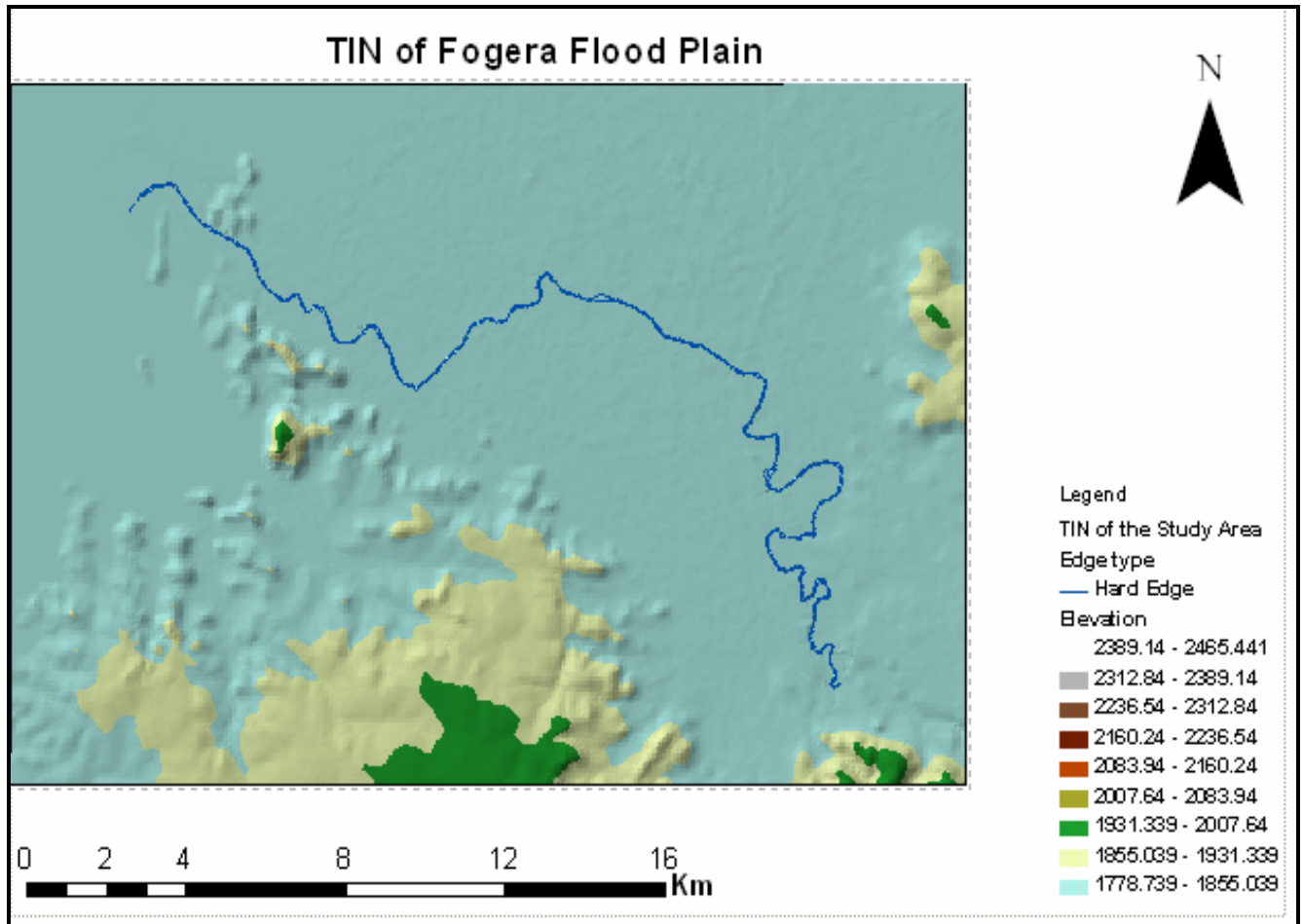


Fig 3.1 TIN Fogera Flood Plain

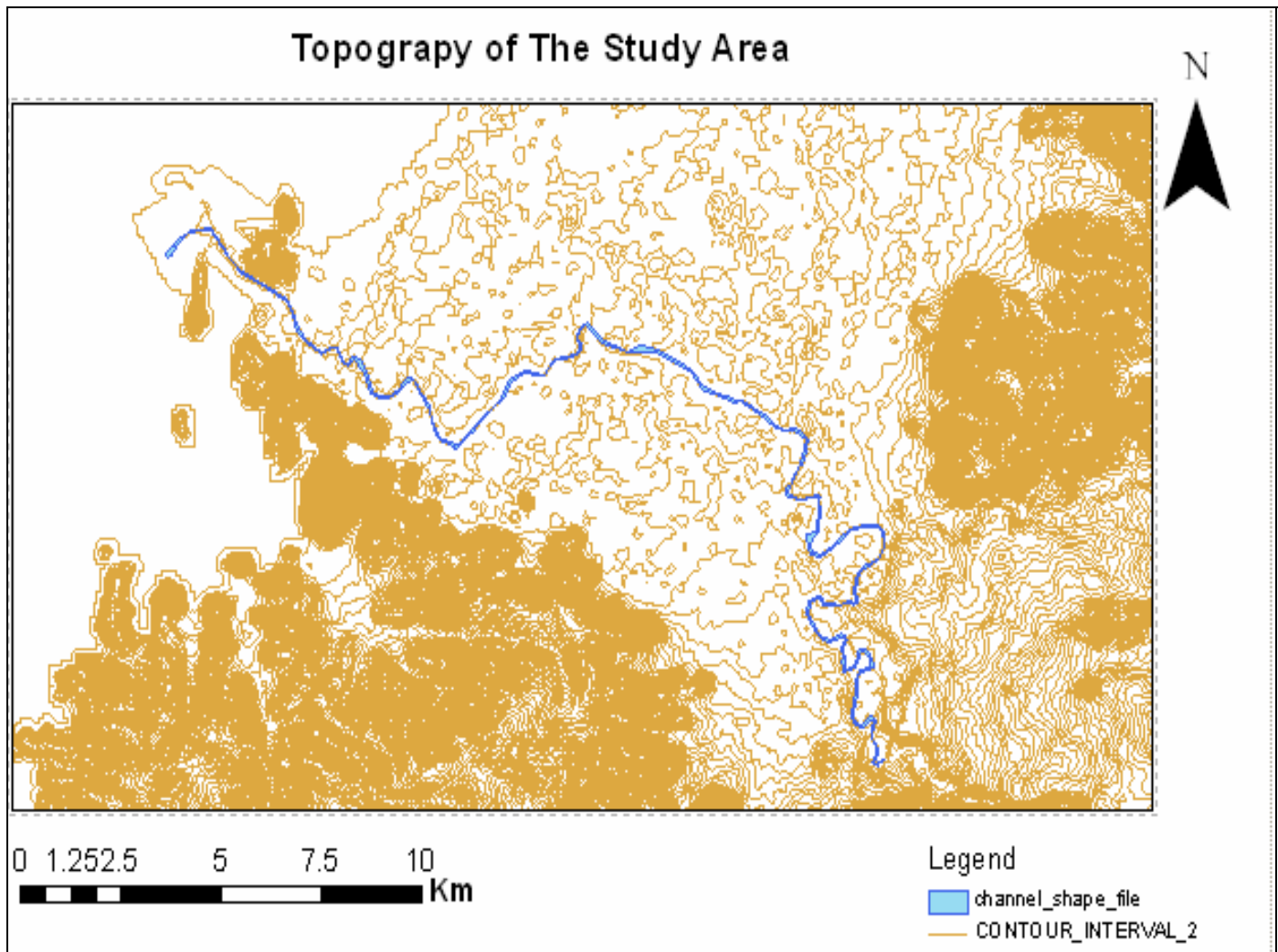


Fig 3.2 Topography of Gumera River in Fogera Flood Plain

### 3.3.4 Lower Reach of Gumera River (Fogera Flood Plain)

While a reach element conceptually represents a segment of stream or river, the actual calculations are performed by a routing method contained within the reach. Flow routing is a procedure to determine the time and magnitude of flow (i.e., the flow hydrograph) at a point on a watercourse from known or assumed hydrographs at one or more points upstream of the reach and out let for the catchment. In broad sense, flow routing may be considered as an analysis to trace the flow through a hydrologic system, given the input.

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

Muskingum-Cunge routing model is selected due to its preference on the manual (shown below) .when there is no gauged data and if the flood will go out of bank, into floodplain which is similar to Fogera –Dera Flood plaine.

This routing method is based on the combination of the conservation of mass and the diffusion representation of the conservation of momentum. It is sometimes referred to as a variable coefficient method because the routing parameters are recalculated every time step based on channel properties and the flow depth.

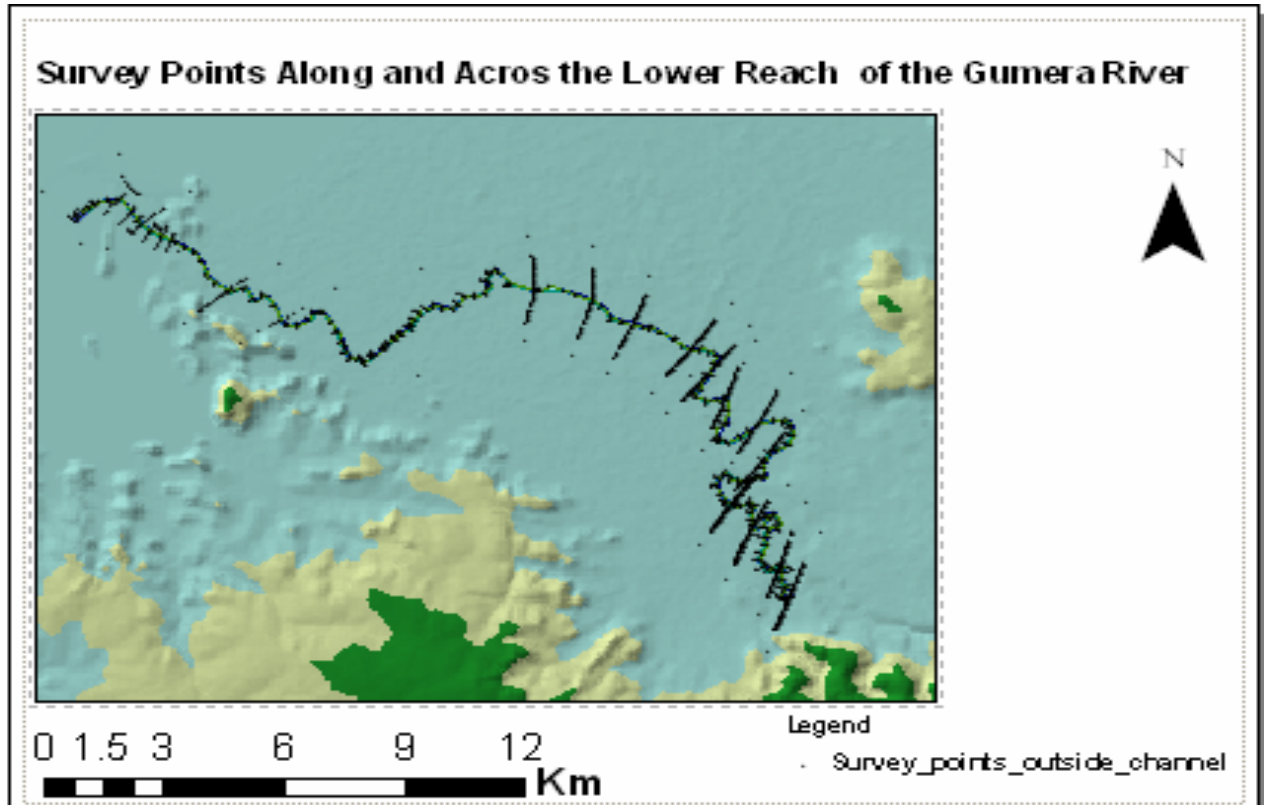


Fig 3.3 Field Survey Points Along the Stream Processed in Arc GIS

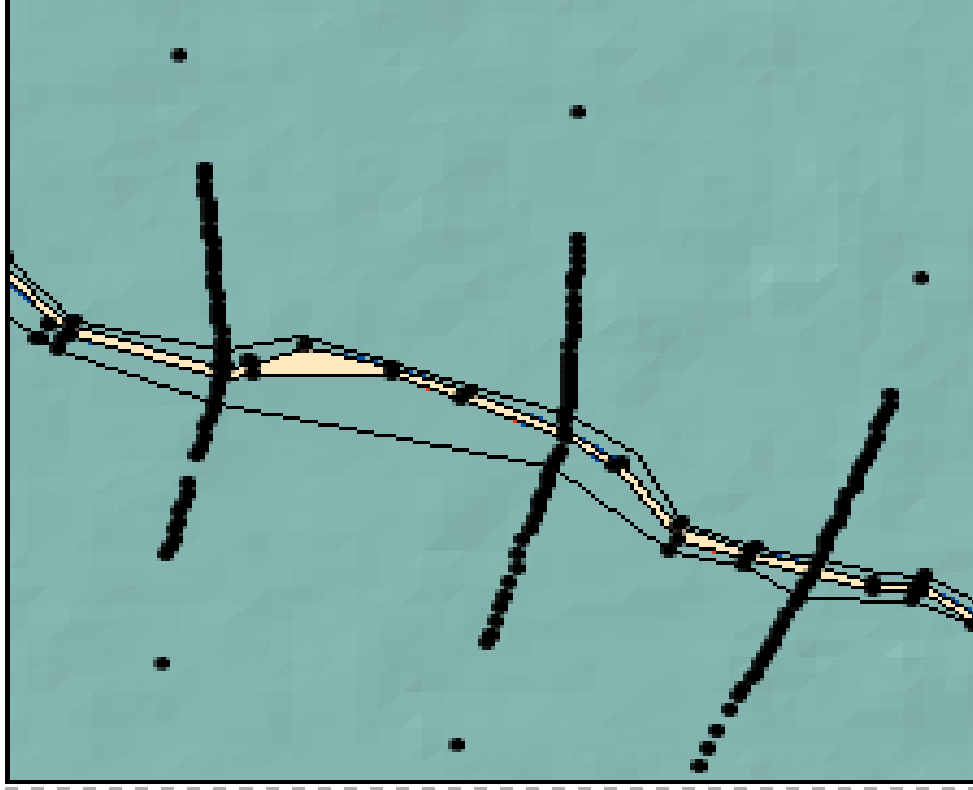


Fig 3.4 Survey Points On The Study Area With Closed View For Full Extent

With the field survey processed in ArcGIS, shape file of the stream centerline and bank lines are created. For high accuracy of stream and flood plain representation, a high resolution DEM is required.

The TIN processed is assumed to represent the entire floodplain. From the approach the elevation values derived from the DEM is used to represent flood plain where as the values from actual field survey to river channel. This is because of the fact that there may be water flowing during the DEM processing.

### 3.3.5 Topographic Survey Methodology

#### 3.3.5.1 Background

During the studies for the Tana Beles Project, in the late 1980's, a considerable amount of map production was undertaken. These maps were produced from aerial photographs (scales 1:50,000 and 1:20,000) and from ground surveys. Those maps, relevant to the present study are the 1: 50,000 maps of Ethiopian Mapping Agency (EMA). The specific quad sheets for Gumera rivers are 1237-D4 and 1137-B2. These maps shall be made available by the Ministry of Water Resources. The availability of these maps shall greatly

reduce the extent of additional mapping required to support the present study. In addition to these maps, The availability of recent (2008) topographic map (with 0.5m vertical interval) produced through the World Bank supported irrigation project which covers part of the Fogera and De mbia plain adjacent to Lake Tana and the WWDSE topographic survey for the upper Megech irrigation area shall be assessed. The above maps are all hard copies, but the availability of other maps (30m x 30m) and (90m x 90 m) resolutions digital elevation Models (DEM) will be used to cut cross-sections that extend to the flood plains. Cross-sections can be extracted using HEC-GEORAS by overlaying the stream lines (hopefully there is some kind of shapefiles) on the DEM. The cross-sections that are obtained from these data would have less detailed channel characteristics and also would not have the channel bottom elevations. (shebelle consulting PLC)

### 3.3.5.2 Objectives

The main objective of this survey is to supplement the river cross-section data by obtaining detailed survey at selected points along the rivers which coincide with the automatically derived cross-section cuts. The river cross-sections that are generated from this survey project are critical components of the hydrodynamic modeling as well as flood inundation mapping of the study area.

### 3.3.5.3 Survey Methods

Controls, vertical and horizontal references Control surveys shall be carried out as required at the sites by closed loop theodolite traversing. Semi-permanent stations shall be established at key locations around the sites. These stations shall comprise a mark painted on rock or a steel reinforcing bar driven into the ground and then surrounded with concrete. Horizontal and vertical control will be established to a local grid system by incorporating the stations in a closed 3D traverse. The horizontal angle, vertical angle and slope distance between adjacent stations will be measured by the electronic total station. To ensure accuracy, each angle will be measured twice on each theodolite face and the mean result used in calculation. Slope distances will be measured both ways. Any angular closing errors will be distributed equally among the measured angles prior to calculation of co-ordinates. Small level misclosures shall be distributed between survey stations in proportion to the lengths of the measured distances. In no case shall the

angular misclosure be greater than 20" or the vertical misclosure greater than 50 mm. From each of the traverse stations, local topographical features will be surveyed by bearing and distance to provide x, y, z co-ordinates for each point surveyed.

Local bench mark for Gumara River shall be taken on the bridge guide rail. Later that elevation will be connected to the National grid/ Chara Chara weir elevation. Horizontal control shall be established approximately using a hand-held GPS instrument to estimate the local UTM co-ordinates of a station.

### 3.3.5.4 What to Survey and Document

In addition to compliance to the control standards described above, the survey project shall gather and document data as specified in the following 10 points

1. Cross-section survey shall be carried out at 1 kilometre interval except in cases described in #2. The sections shall be proposed on 1:50,000 topographic maps. The Universal Transverse Mercator (UTM) coordinates for the intersection between the cross-sections lines and the river centre line shall be prepared by measuring from the maps, this will be useful to locate the axis vector on the ground to conduct the surveying. The sections shall be taken perpendicular to the flow direction.
2. The 1km spacing is quite sufficient, however take additional surveys at
  - a. hydraulic structure ( for example, bridges, dikes)
  - b. sites that are easily accessible such as pedestrian road crossing the river. This helps to identify future addition of observation sites.
  - c. at current observation sites (gauging sites).
3. The cross-section survey shall be taken in 1m horizontal interval across the main channel and 5-50 m horizontal interval (depending on variation in elevation and also limited to accessibility) outside the riverbanks. The survey shall extend to about 1km to the flood plain from both left and right river banks. Unique topographic features such as abrupt change of elevation shall be recorded regardless of the distances set in between two consecutive target points.

4. Digital photos of the cross-sections shall be taken using a high resolution camera for the purpose of judging the roughness coefficient for both the main channel and the flood plain. USGS Water Supply Paper 1849 shall be used as a plausible reference for estimating the roughness coefficients. Each photo shall be related to the site by having consecutive pictures of cross-section as survey proceeds from downstream to upstream. Setting up the time correctly and noting the date and time on survey recorded can help to relate cross-section pictures to surveyed data.
5. Naming of cross-sections (River Stations). River stations shall be named with using the first letter of the name of the river and the river distance from the most downstream point.
6. For each cross-section, survey and record coordinates shall be made from left bank to right bank. Left and Right bank are designated by looking towards flow direction.
7. In each cross-section, the left and right river bank limits shall be indicated as LB and RB, respectively. These are the approximate limits of the bankfull flow.
8. The water surface elevation during the survey period shall be recorded.
9. For each cross-section, high water marks related to historical floods could be noted, if there is any information available from any marks on structures or from locals.
10. At each river station, two additional current water level elevations shall be measured: one at 200 m upstream and another at 200 m downstream from the station.
11. In addition to detailed cross-section survey to be taken at 1km interval, (approximately centre line of the river bed), left and right end of the river bed, left and right overbank top elevations (in total 5 points across a river), with spacing of 200 m shall be surveyed. (shebelle consulting PLC ,2009)

### 3.4 HEC-RAS Hydraulic Model

HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. The model is used for determination of water surface profiles for different flow scenarios. The peak discharge generated by the HEC-HMS model is used to determine the flow profiles and flood plain profiles for the selected flood return periods. HEC-

RAS is intended for steady flow water surface profile computations and unsteady flow simulation. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendrite system, or a single river reach. The key datas used in this model are field observation, cross sectional survey works and the peak flow resulted from simulation of the HEC\_HMS model.

The HEC-RAS program, like the other softwares, it can be downloaded free of charge from the Hydrologic Engineering Center's. Hydrologic Engineering Center's River Analysis System (HEC-RAS) is the software predominately used in the field of hydraulic analysis for floodplain delineation.

HEC-RAS, combined with Hydrologic Engineering Center's Geographical River Analysis System (HEC-GeoRAS), offers engineers a powerful tool in the process of hydraulic modeling and analysis.

For each HEC-RAS project, there are three required components:the Geometry data, Flow data, and Plan data. The Geometry data, for instance, consists of a description of the size, shape, and connectivity of stream cross-sections. Likewise, the Flow data contains discharge rates. Finally, Plan data contains information pertinent to the run specifications of the model, including a description of the flow regime. Each of these components is explored below individually.

### **3.4.1 Importing and Editing Geometric Data**

The first of the components is the channel geometry. To analyze stream flow, HEC-RAS represents a stream channel and floodplain as a series of cross-sections along the channel. To create our geometric model, we need to import the geometry file that just exported from ARCGIS. This HEC-RAS geometry file contains physical parameters describing cross-sections.

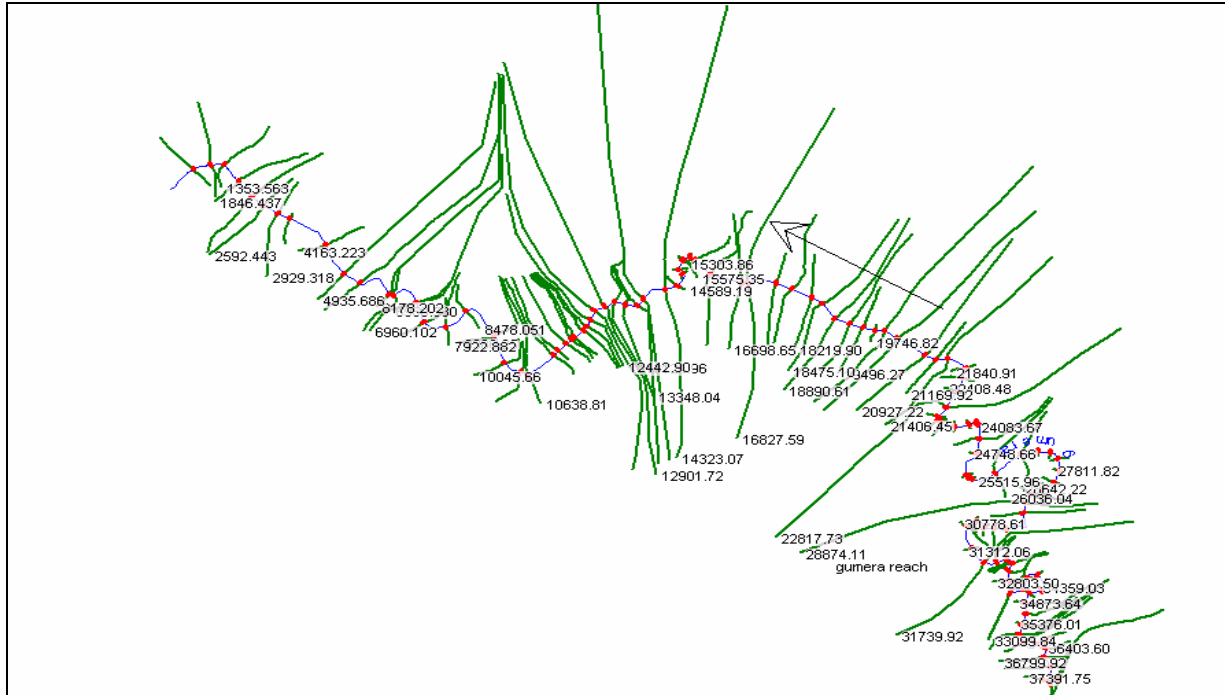


Fig 3.5 Geometry Data of the Flood Plain

### 3.4.2 Flow Data

The flow data has been extracted from a HEC-HMS hydrologic model. steady flow condition is adopted even though it is rare to find the steady flow condition in the natural channel flow condition. This component of the HEC-RAS modelling system is capable of simulating one dimensional steady flow through a full network of open channels. For the case of Gumera flood plain the peak flows estimated by HEC-HMS for 2,5,10,5,100 years return period is used at the out let of the catchment.

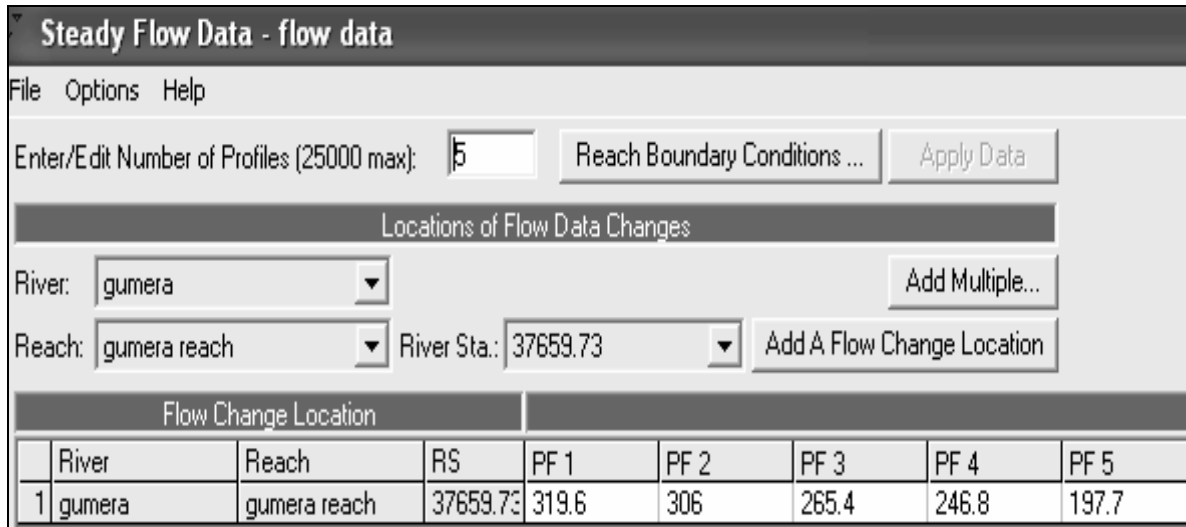


Fig 3.6 Steady Flow Condition of The Gumera River Using Five Flow Profiles

### 3.4.3 PostRAS (HEC-GeoRAS)

With the development of a GIS Import File from HEC-RAS, we can now begin the last portion of the model application. Post-processing using GeoRAS incorporates the water surface profiles derived from the HEC-RAS model into the spatial environment of GIS. The water surface profile data is used to develop a water surface TIN, and the intersection of the water surface TIN with the terrain model TIN provides flood visualization. The results can be shown in 2-D or 3-D views.

### 3.4.4 Roughness Coefficient Determination of the River and Flood Plain

Manning’s *n* values were used in the model to define roughness for each cross section. The “*n*” values were assigned in two steps: The first step involved defining land-use characteristics for common areas throughout the watershed and flood plain. Each land-use characteristic was given *n*-value based on published values for similar conditions (Chow, 1959; Barnes, 1967) and on engineering judgment and experience. Once the land-use was defined for the entire watershed, the representative *n*-values were assigned to the portion of each cross section that intersects the respective land-use area. These *n*-values were then exported to the HEC-RAS model using HEC-GeoRAS. For the study area the typical manning’s coefficient is determined by using field survey photos and compared it with the standard “*n*” values of different land use (ENTRO)

Table 3.1 Manning's Values For Different Land Uses

Types of channel and Description	Manning's Roughness (n) Values		
	Minimum	Normal	Maximum
<b>Natural Streams</b>			
1. Main channels			
1.1. Clean ,straight ,full ,no rifts or deep pools	0.025	0.030	0.033
1.2. Same as above ,but more stones and weeds	0.030	0.035	0.040
1.3. Clean ,winding ,some pools and shoals	0.033	0.040	0.045
1.4. Same as above ,but some weeds and stones	0.035	0.045	0.050
1.5. Same as above ,lower stage ,more ineffective slopes and sections	0.040	0.048	0.055
1.6. Same as “d” but more stones	0.045	0.050	0.060
1.7. Sluggish reaches ,weedy ,deep pools	0.050	0.070	0.080
1.8. Very weedy reaches ,deep pools or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. Flood plains			
2.1. Pasture no brush			
2.1.1. Short grass	0.025	0.030	0.035
2.1.2. High grass	0.030	0.035	0.050
2.2. Cultivated areas			
2.2.1. No crop	0.020	0.030	0.040
2.2.2. Mature row crops	0.025	0.035	0.045
2.2.3. Mature field crops	0.030	0.040	0.050
2.3. Brush			

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

2.3.1. Scattered brush ,heavy weeds	0.035	0.050	0.070
2.3.2. Light brush and trees ,in winter	0.035	0.050	0.060
2.3.3. Light brush and trees ,in summer	0.040	0.060	0.080
2.3.4. Medium to dense brush, in winter	0.045	0.070	0.110
2.3.5. Medium to dense brush, in summer	0.070	0.100	0.160
2.4. Trees			
2.4.1. Cleared land with tree stumps ,no sprouts	0.030	0.040	0.050
2.4.2. Same as above ,but heavy sprouts	0.050	0.060	0.080
2.4.3. Heavy stands of timber ,few down trees ,little under growth ,flow below branches	0.080	0.100	0.120
2.4.4. Same as above , but with flow into branches	0.100	0.120	0.160
2.4.5. Dense willows, ,straight ,straight	0.110	0.150	0.200
3. Mountain streams ,no vegetation in channel banks usually steep ,with trees and brush on banks submerged			
3.1. Bottom : gravels ,cobbles ,and few boulders	0.030	0.040	0.050
3.2. Bottom : cobbles with large boulders	0.040	0.050	0.070

### 3.5 HEC-GEORAS

Hec-Geo RAS is an Arc GIS extension specifically designed to process geo-spatial data for use with the Hydrologic Engineering Center River's Analysis System (HEC-RAS).The extension allows users to create Ras layers an HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DTM) and complementary data sets. Water surface profile results may also be processed to visualize inundation depths and boundaries. HEC-Geo RAS extension for Arc GIS used an interface method to provide a direct link to transfer

information between the Arc GIS and the HEC-RAS. The model uses the geometric attribute data from an existing digital terrain model (DEM) in TIN format and exported results from HEC-RAS model.

### 3.6 Source and Availability of Data

The data available for the study comprises time series data, and spatial data which were collected from the Ministry of water resources, hydrology and GIS department, and the Ethiopian National Metrological Agency and Ethiopian Road Authority.

### 3.7 Materials Used

The materials used for this thesis work include the following, but not limited to:

- ArcGIS, Arc hydro and HEC-GeoHMS tools
- HEC-DSS and HEC-HMS hydrological models
- HEC-RAS and HEC-GEORAS (pre and post processing).
- Global mapper 12
- Spatial data
- Hydrological and meteorological data
- Actual field survey data and clipped shape files from ENTRO

### 3.8 Time Series Data

Two types of time series data were collected for the purpose of this study

#### 3.8.1 Hydrological Data

The watershed has one main river flowing into lake tana by passing through the Fogera flood plain across the main road Bahiridar to Gonder. The stream flow data were available for Gumera gauging stations for eight years (1960-2006) with enormous data gaps and with few data gaps from 1992-2006.

Table 3.2 Gumera River Gaging Record

Station Name	River Name	Station Code	Discharge Record Period	Gaging location	Area
Gumera Near Bahiridar	Gumera River	111006	1960-2006	11:50:00N And 37:38:00E	1394 Km <sup>2</sup>

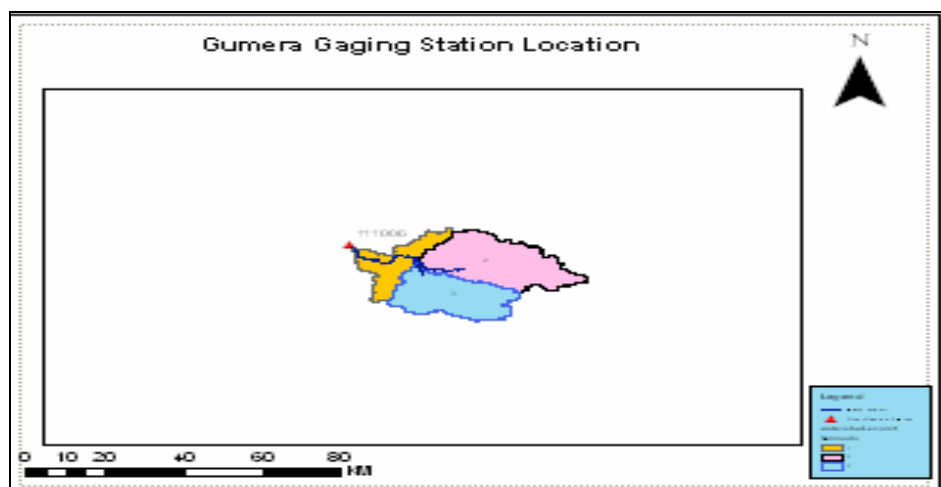


Fig 3.7 Gumera Gaging Station

### 3.8.2 Meteorological Data

- ☒ Daily rainfall within the water shed and of near by statins
- ☒ Daily te mperature (minimum and maximum)

The Meteorological data were obtained from the National Meteorological Agency (NMA) of Ethiopia. Data of daily rainfall, maximum and minimum temperature were collected from the same Agency from stations within and around the watershed.

Table 3.4 Loctaion of Meteorological Stations Within and Around the Water Shed

S.No	Station name	Elevation(m) m.a.s.l	Latitude	longitude
1	Bahiridar	1780	11.6	37.42
2	Woreta	1980	11.92	37.68
3	Debretabor	2690	11.88	38.03
4	Nefas Mewcha	3000	11.75	48.45

A Digital Elevation Model (DEM) covering the entire country is available from ministry of water and energy and is masked for the study area using Arc Tool Arc GIS is shown below

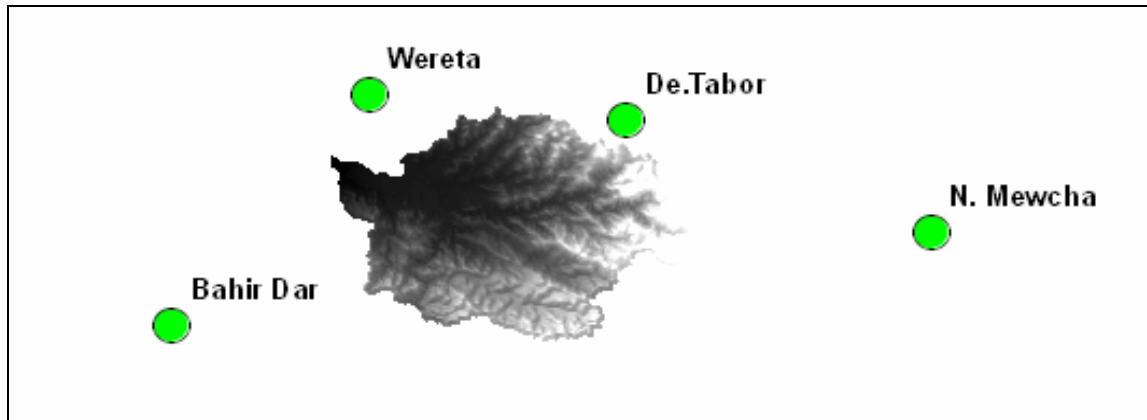


Fig 3.8 Meteorological Station Within And Around Water Shed And DEM of the Study Area

### 4 DATA ANALYSIS

#### 4.1 Filling Missing Rainfall Data

Rainfall data play a central role in developing rainfall – runoff models .Measured precipitation data are important to many problems in hydrologic analysis and design. For gages that require periodic observation, the failure of the observer to make the necessary visit to the gage may result in missing data. Vandalism of recording gages is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data.

The two procedures for estimating daily totals rely on the data from any adjacent stations. The locations of the adjacent stations are such that they are close to and approximately evenly spaced around the site with the missing data. When the average annual precipitation at each of the adjacent stations differs from the average at the missing data station by less than 10%, the following formula can be used to estimate the missing daily data.

$$P_x = \frac{N_x}{3} \left[ \frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \right]$$

Where  $P_x$  = is the precipitation for the station with missing records

$P_1, P_2$  and  $P_3$  are the adjacent stations' precipitation values

N1, N2, N3 are the long-term mean annual precipitation values at the respective stations and '3' is the number of stations surrounding the station X. When the difference between the average annual rainfall at any of the adjacent stations and the missing data station is greater than 10% a normal ratio method is normally used.

### 4.2 Checking of Consistency of Rainfall Data

A consistent record is one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result from any one of a number of events; specifically, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gage, changes in land use that make it impractical to maintain the gage at the old location, and where vandalism frequently occurs.

The checking for inconsistency of the record is done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique is used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge. If significant change in the regime of the curve is observed, it should be corrected.

$$P_{cx} = P_x + \frac{M_c}{M_a}$$

Where:  $P_{cx}$  = corrected precipitation at any time period  $T_1$  at station x

$P_x$  = original recorded precipitation at time period  $T_1$  at station x

$M_c$  = Corrected slope of the double mass curve

$M_a$  = Original slope of the double mass curve

There are four rainfall stations within and around the Gumera water shed and as it can be seen from the double mass curve the rain fall is consistent

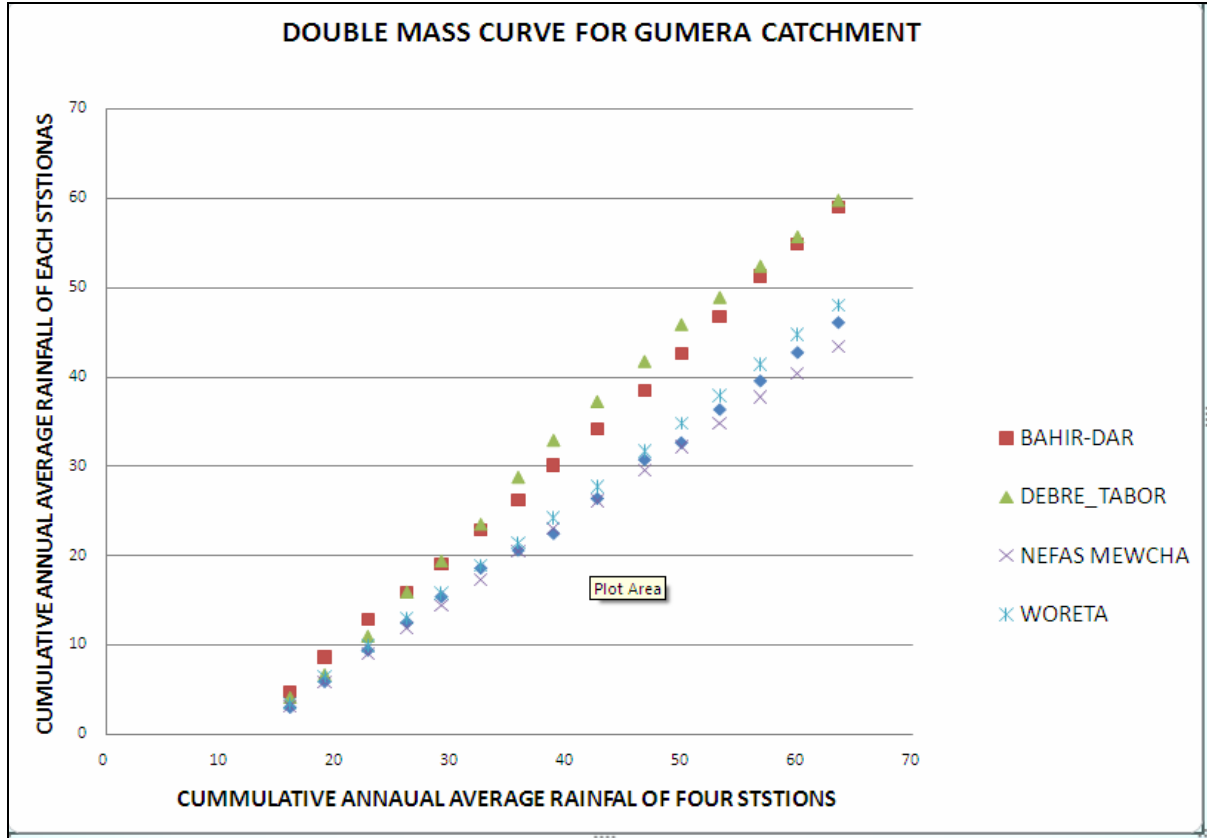


Fig 4.1 Consistency Checking of the Four Rain Fall Stations Within and Around the Catchment

### 4.3 Determination of Areal Rainfall

Rain gauges represent only point sampling of the areal distribution of a storm .In practice, however, hydrological analysis requires knowledge of the rainfall over an area .The following methods are in use to convert the point rainfall values at various stations into an average value over a catchment:

These methods are the Arithmetic mean, the Thiessen polygon and the Isohyetal method etc. However, the Thiessen polygon was used for this study for its sound theoretical basis and availability of computational tools. But the method is dependent on a good network of representative rain gauges.

#### Assumption

There is a linear variation in the precipitation between two gauge stations. The According to Thiessen, the average rainfall,  $R_{areal}$  over the area can be computed from:

$$R_{areal} = \sum_{i=1}^n \frac{R_i A_i}{A_t}$$

Where,  $R_i$  is the rainfall at station  $i$ ,  $A_i$  is the polygon area of station  $i$ ,  $A_t$  is total catchment area, and  $n$  is the number of stations.

The area functions  $A_i/A_t$  are known as the Thiessen coefficients and once they are determined for a given stable station network, the areal rainfall can be computed for the set of rainfall measurements. The four near by location of the rain fall stations are as shown below

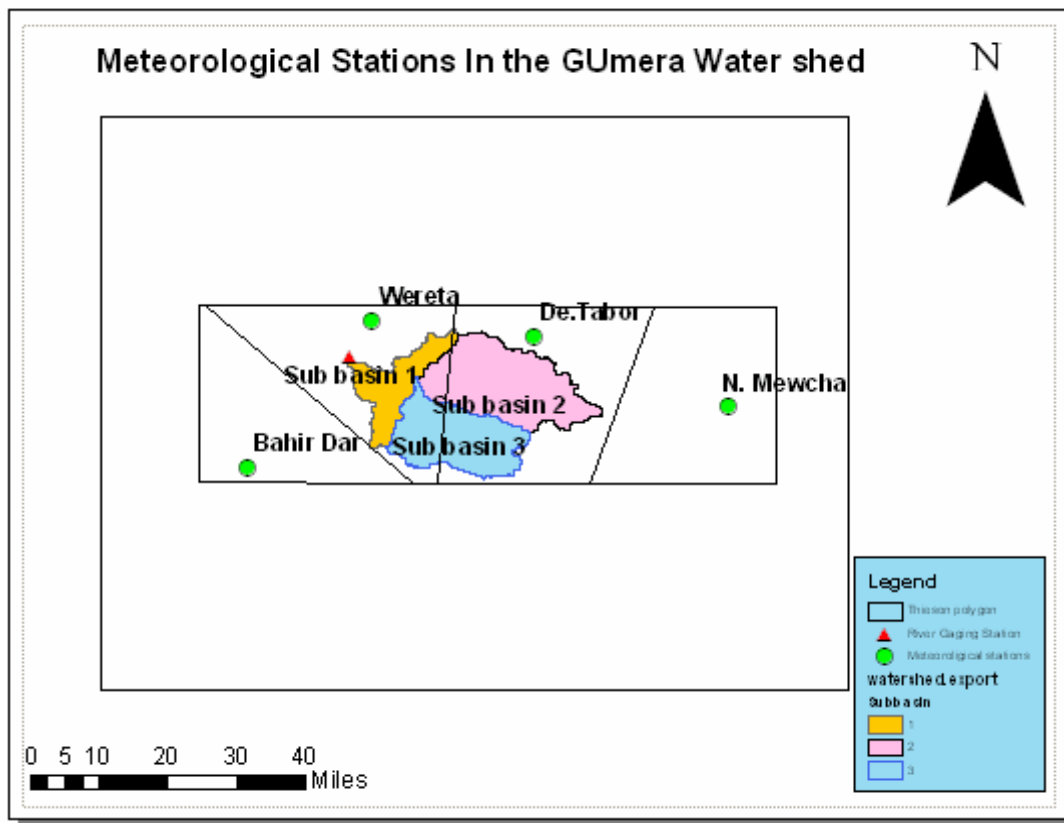


Fig 4.2 Thiessen Polygon Created From Stations Near To Gumera

#### 4.4 Flow 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. The discharge gage is located at out let of Gumera River down side of the main road from Bahiridar to Gonder where the downstream end is considered flood prone area.

**4.4.1 Data Filling and Consistency**

Missing flow data records for the sub basin is filled by developing correlation between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods. Consistency and extension of flow data is analyzed by regression technique. The correlation equations used for Gumera gauging station in terms of Rib gauging station, which shows good correlation is expressed below.

	<b>GA</b>	<b>Gumera</b>	<b>Koga</b>	<b>Megech</b>	<b>Rib</b>
<b>GA</b>	1	0.69	0.66	0.3	0.72
<b>Gumera</b>	0.69	1	0.59	0.33	0.74
<b>Koga</b>	0.66	0.59	1	0.25	0.64
<b>Megech</b>	0.3	0.33	0.25	1	0.34
<b>Rib</b>	0.72	<b>0.74</b>	0.64	0.34	1
	Rib	Gumera			
<b>Rib</b>	1	Y=0.3203X+2.1373			
<b>Gumera</b>	2.3099X+3.7835	1			

The Equation relating the Gumera flows with the Ribb River flow is,

$$G=2.3099R+3.7835, \text{Where } G= \text{ missed flow value at Gumera gage}, R= \text{ flow value at Rib gage}$$

**4.5 HEC-GeoHMS Data Processing**

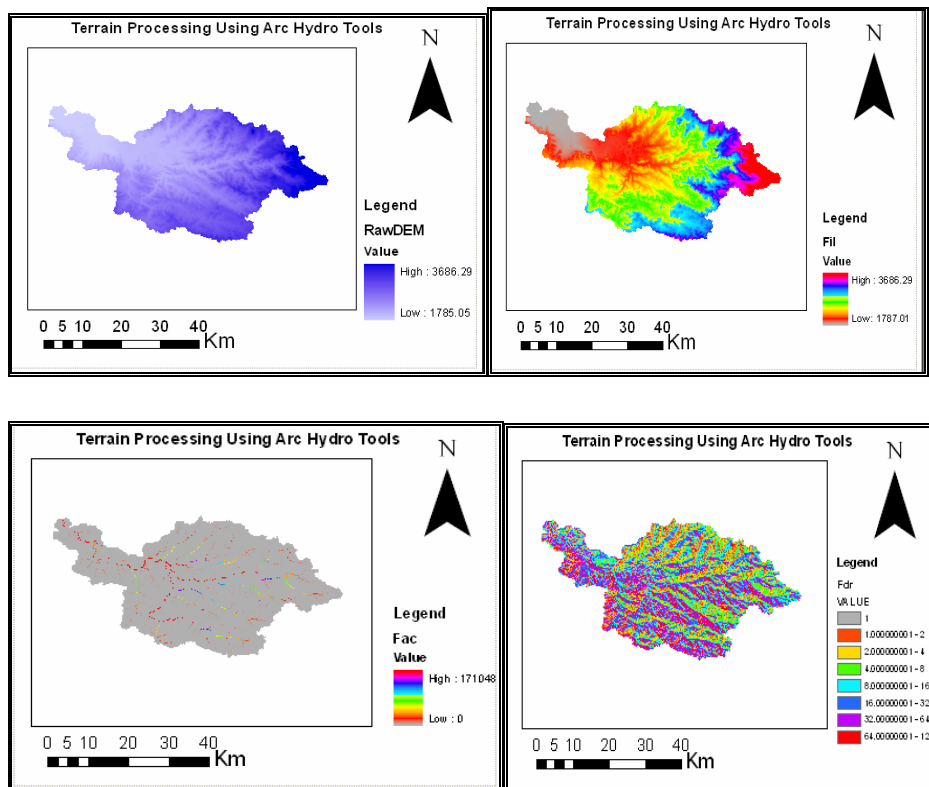
The point of the extensive data preprocessing using Arc-Hydro was to create input files for the GeoHMS tools. GeoHMS uses the output files from Arc Hydro and automatically create sub basins, longest and centroidal flow paths, basin centroid and other watershed properties. Additionally, parameters such as slope and length are assigned to flow lines and basins. In general, GeoHMS uses spatial analyst tools to convert geographic information into parameters for each of the basins and flow lines. These parameters are used to create a HEC-HMS model that can be used within the HEC-HMS program. The physical characteristics extracted for the Sub basins and streams for Gumera catchment using GeoHMS are put in table 4.2 and table 4.3 respectively.

## 4.6 Spatial Data Analysis

Hydrologic inputs that are used directly in HMS are prepared by making use of a geospatial hydrology toolkit called HEC-GeoHMS. The tool kit helps to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub basins and streams, and construct inputs to hydrologic models. Details are referred to User's Geospatial Hydrological Modeling Extension HEC-GeoHMS users manual. (USACE 2003) Digital elevation models (DEM) for Ethiopia were masked from the entire globe. The masked DEM, to the area of interest, was processed in sequential steps.

## 4.7 Terrain Pre-processing

Arc hydro tools allow performing terrain processing in either a step-by-step fashion or batch mode. The step-by-step process is good in that the output can be examined to correct the data set when necessary.



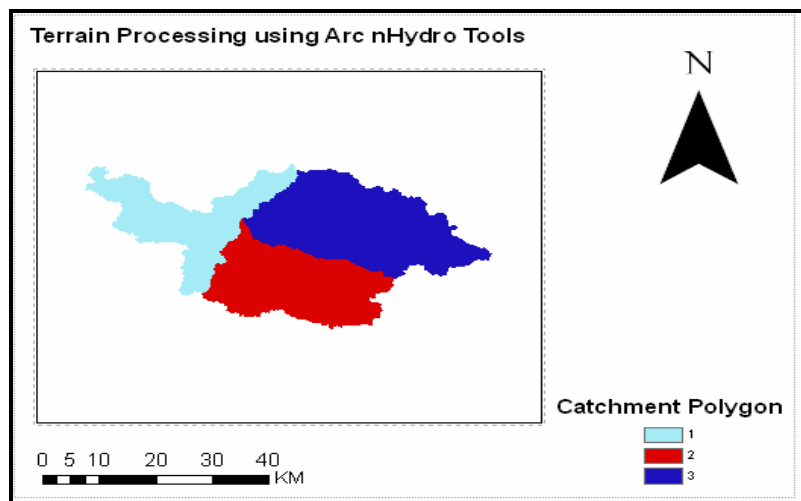


Fig 4.3 Terrain Preprocessing for Gamera Catchment  
Using the hecgeomhs model ,the basin characteritcs extracted paramenters are shown below in the table

Table 4.2 Gamera Catchment Basin Characteristics

Sub Basin Name	Basin Shape Length	Basin Shape Area(Km <sup>2</sup> )	Basin CN	Area-HMS	Longest FL(Km)
Sub basin 1	199.97	363.451	81.9	363.451	61.14
Sub basin 2	147.774	434.65	82	434.65	57.81
Sub basin3	164.334	587.29	78.3	587.29	56.29

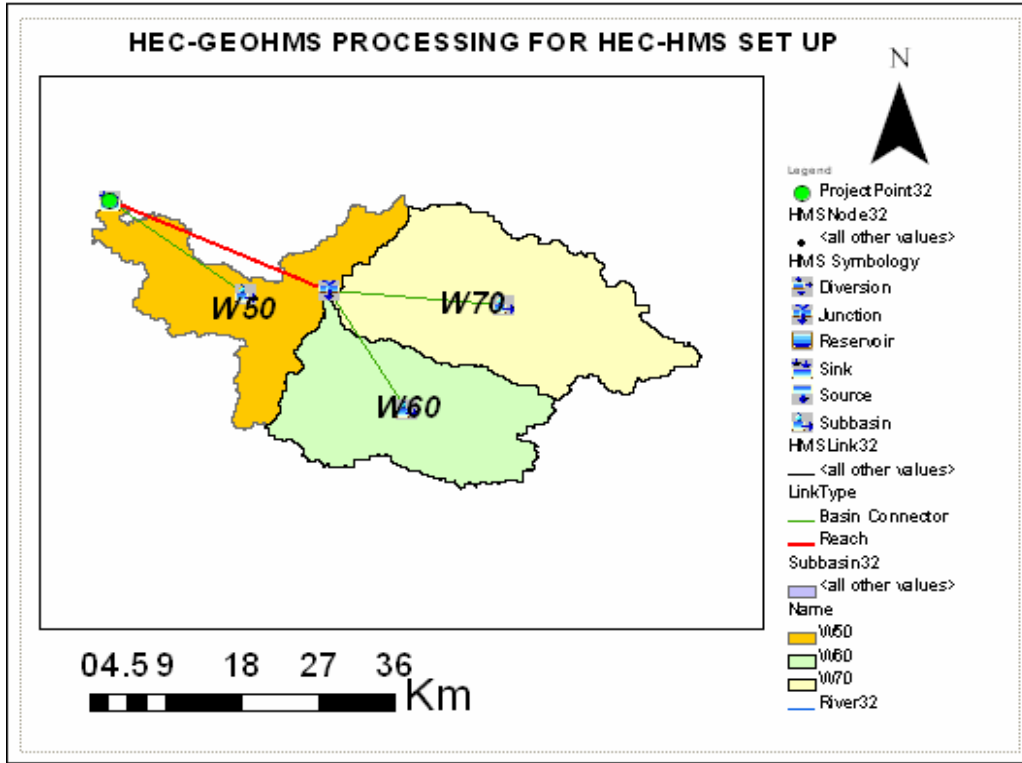


Fig4.4 HEC-HMS Representation Drived From HEC-GEOHMS

#### 4.7.1 Chanel Routing

The Muskingum-Cunge method was used for channel routing. The parameters used were determined from a combination of arc GIS processing and is presented below in the table

Table 4.3 Gumera River Tributaries Physical Characteristics

River Reach	Shape Length	Slope	Ele.Upstream	Ele Down Sream	River Length
1	45475.35	0.0021	1885.82	1787.82	45.48
2	23493.7	.0049	2001.41	1885.82	23.49
3	17001.17	0.0086	2033.14	1885.8	17

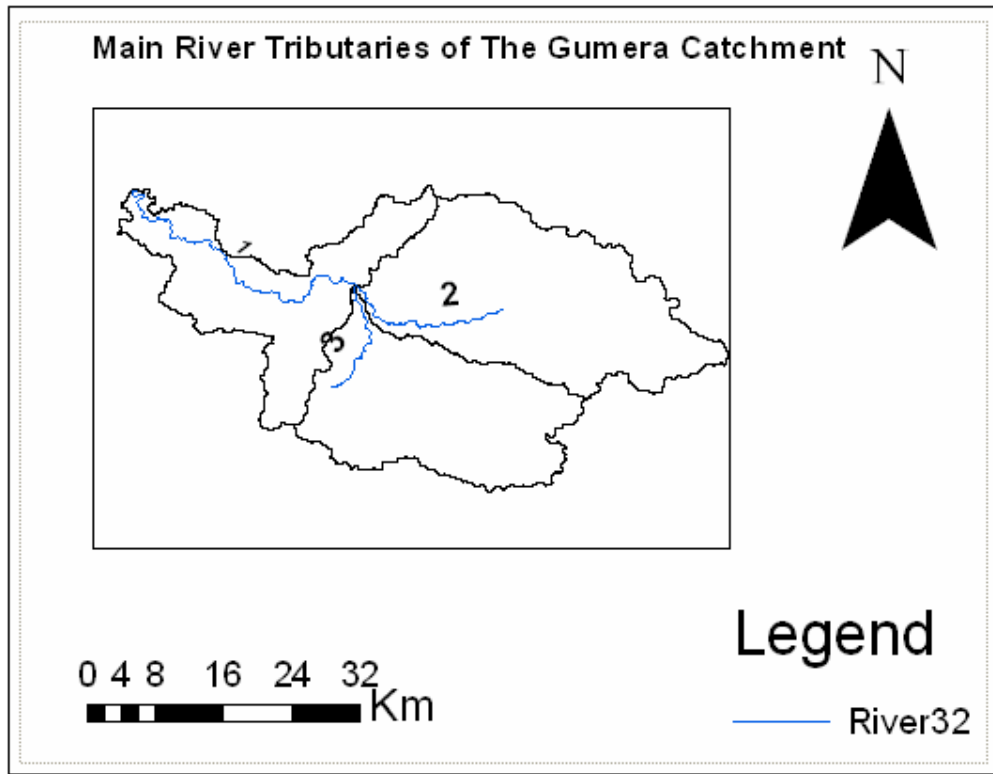


Fig 4.5 River Tributaries Of The Catchment

### 4.8 HEC-HMS Model

This subsection discusses the spatial data analysis and preparation of the hydro-metrological data for setting up HEC-HMS model in the catchment. The model components, data requirements for each the model types used in this study and calibration and validation results along with error measures are presented subsequently.

#### 4.8.1 Model Setup

In HEC-HMS, various models are provided to simulate each of the different hydrological processes. The selection of a particular method for a certain process depends on knowledge of the watershed, the goal of the hydrologic study, and data availability. Basin model, Metrologic model and control specification are the three broad classes for providing model input in HEC-HMS; and are discussed below along with the models used for each of the rainfall-runoff components.

##### 4.8.1.1 Basin Model

Basin models are one of the main components in HEC-HMS project set up. These models contain elements of the basin and their connectivity. The Basin model principally serves to

convert atmospheric conditions into stream flow at specific locations in the watershed. HEC-HMS treats the different phases of rainfall-runoff processes with separate mathematical models. All components of the loss models, direct runoff models, base flow and routing models are accessed from the basin model component of HEC-HMS.

### 4.8.1.2 Runoff-Volume Models

HEC-HMS computes runoff volume by computing the volume of water that is intercepted infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception, infiltration, storage, evaporation, and transpiration collectively are referred to in the HEC-HMS as losses. HEC-HMS considers that all land and water in a watershed can be categorized as either:

- Directly-connected impervious surface; or
- Pervious surface.

A directly connected impervious surface in a watershed is that portion of the watershed for which all contributing rainfall becomes direct runoff. Rainfall on the pervious surfaces is subject to losses. HEC-HMS includes the following alternative models to account for the cumulative losses:

- The initial and constant-rate loss model;
- The deficit and constant-rate model;

### 4.8.1.3 The Initial And Constant-Rate Loss Model (Transformation Model)

A HEC-HMS model of Gumera water shed was developed using the initial and constant loss rate method, the Clark Unit Hydrograph transform and Muskingum-Cunge channel routing.

To use this model in HEC-HMS, the initial loss and constant rate plus the recovery rate must be specified. Then HEC-HMS continuously tracks the moisture deficit, computing it as the initial abstraction volume less precipitation volume plus recovery volume during precipitation-free periods. The recovery rate could be estimated as the sum of the evaporation rate and percolation rate. This study makes use of the initial and constant-rate model because it is designed to simulate the long-term relationship between rainfall, runoff, storage, Evapotranspiration, and soil losses.

The direct runoff models describe the rain that has not infiltrated or been stored on the surface. This direct runoff process from effective precipitation on the catchment is referred in HEC-HMS

as transformation of precipitation excess into point runoff. The model includes two options for the direct runoff computations, the Empirical and the Conceptual model.

In this study the use of the conceptual models (a kinematic-wave model of overland flow) is difficult due to lack of cross section and other morphological data. Instead a Clark unit hydrograph method that requires only two input data, time of concentration and storage coefficient is employed.

### 4.8.1.4 Meteorological Model

Meteorological models are the other main components in the project screen. Meteorological boundary conditions for sub-basins and area contributions of each of the rainfall gauging stations for the sub-basins are the two key purposes of the Meteorologic model. The areal rainfall is estimated by making use of Thiessen polygon method in all the cases as it is described in section 3.2.3.

### 4.8.1.5 Control Specifications

The other major component in HEC-HMS project is Control specifications model input. Though, unlike the other two components, this one does not contain much parameter data, it contains the key step of controlling the time when simulations start and end. In this study the starting date, 01Jan1992 and ending date, 01Jan2001 with a time interval of 1day for calibration and 01Jan2002 and ending date, 01Jan2007 of the same time interval for validation has been used to model the Gumera water shed.

## 4.9 Modeling Base Flow with HEC-HMS

The Base flow models simulate the slow subsurface drainage of water. This base flow is the sustained runoff from precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from the current storm. The base flow is added to the direct runoff (obtained with the transformation model) to obtain the total flow, which is routed through the stream reach to the outlet. To model the base flow, HEC-HMS offers alternative models, which can be combined with other loss, and direct runoff models. These are:

- ✚ The Constant Monthly Varying Base Flow Method,
- ✚ The Exponential Recession Model And
- ✚ The Linear Reservoir Model

In this study, the mean monthly constant which is the minimum monthly flow is adapted for base flow calculation methods.

### 4.10 Routing Models

The routing models, also known as channel flow, is used in the simulation processes to predict the temporal and spatial variations of a flow or the flood hydrograph as it moves downstream of a river reach. The Routing models included in HEC-HMS are Lag; Muskingum; Modified Pul's (storage routing), Kinematic-wave; and Muskingum Cunge but Muskingum method is used in this study because of data limitation to employ the conceptual kinematic wave model.

### 4.11 Model calibration and validation

Model calibration is the process of adjusting selected model parameters values and other variables in the model in order to match the model outputs with the observed values. The calibration procedure involves a combination of both manual and automated calibrations.

The manual calibration proceeds the automate optimization to ensure a physically meaningful set of initial parameters. 10 years data (1992-2001) are used for calibration.

Model Validation is the process of testing the model ability to simulate observed data, Other than those used for the calibration, within acceptable accuracy. During this process, calibrated model parameter values are kept constant. The quantitative measure of the match is again the degree of variation between computed and observed hydrographs. The models are validated for a period of five years (2002-2007)

#### 4.11.1 Objective Function

The quantitative measure of the match is described by the objective function that measures the degree of variation between computed and observed hydrographs. Seven objective functions are available in HEC optimization manager and five of them are described below:

1. Peak-weighted root mean square error (PWRMSE). This function gives more weight to large errors than small errors and it gives a greater overall weight to errors near the peak discharge:
2. Sum of squared residuals (SSR). The SSR measure gives a greater weight to large errors and lesser weight to small errors and uses the squared differences as the Measure of fit

3. Sum of absolute residuals (SAR). The SAR function gives equal weight to both small and large errors:
4. Percent error in peak flow (PEPF) :The PEPF measure only considers the magnitude of computed peak flow and does not account for total volume or timing of peak
5. Percent error in volume (PEV):The PEV function only considers the computed Volume and doesn't account for the magnitude or timing of the peak flow Detailed reference on the formulas and descriptions can be referred to the HEC-HMS user's manual (USACE, 2003) In this thesis work, the peak-weighted root mean square was used to get the finally optimized parameter values.

### 4.11.2 Search Algorithms

**Two search methods are available in HEC-HMS model for minimizing the objective functions.**

- i. The Univariate gradient search Algorithm method (UG). The UG method is based on Newton's method and uses Taylor's series to approximate the objective function. This method evaluates and adjusts one parameter at a time while holding other parameters constant.
- ii. The Simplex method: In this method of direct search technique for optimization, suggested originally by Spendley et al. (1962), and subsequently improved by Nelder and Mead (1965), the parameter space is searched using a geometric figure called 'simplex' having number of vertices one greater than the number of spatial coordinates or the parameters. In this thesis work the Univariate gradient Evolution search method was adopted as it resulted in better results.

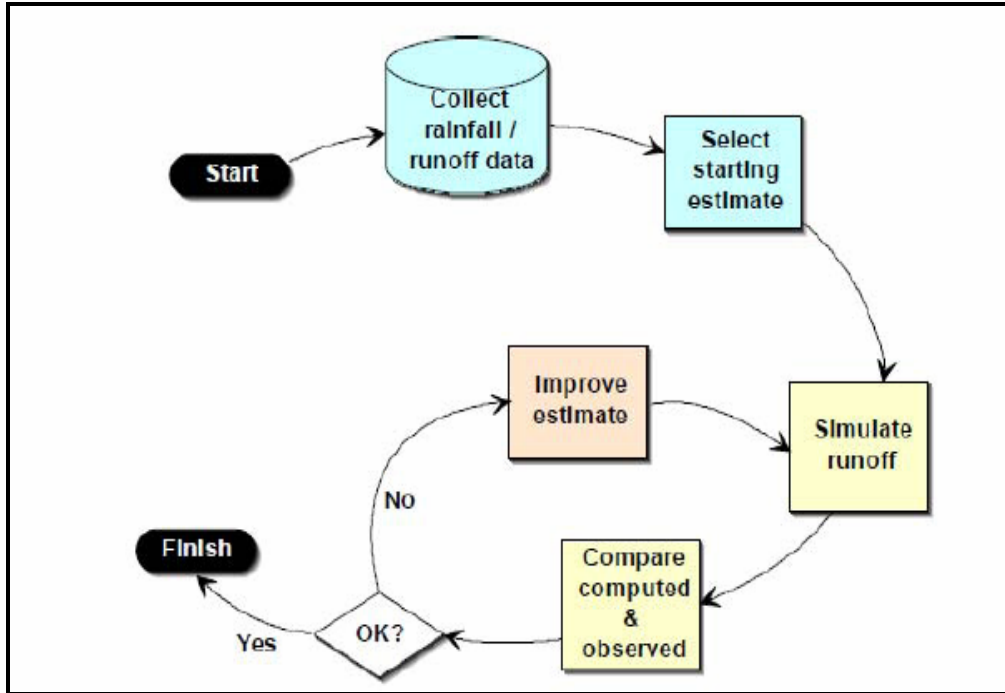


Fig 4.6 Schematic of HEC-HMS Calibration Procedure(USACE,2000)

Most efficiency criteria have their own limitation to be absolute objective functions. Collective use of two efficiency criteria is considered in this study.

#### 4.11.3 Coefficient Of Efficiency (Nash Sutcliffe Efficiency)

This coefficient is widely used in hydrology. In this case it represents the efficiency of the model in a scale, which goes from minus infinite to 1 (best fit). As proposed by (Nash and J.V. Sutcliffe 1970). An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model. The disadvantage of this efficiency criterion is an overestimation of the model performance during peak flows and an underestimation during low flow conditions.

$$E_{NS} = 1 - \frac{\sum_{i=1}^n (q_{oi} - q_{si})^2}{\sum_{i=1}^n (q_{oi} - \bar{q}_o)^2}$$

Where  $q_{o, i}$  =observed value at the  $i$  th time interval,  $q_{s, i}$  =simulated value at the  $i$  time interval ,  $Q_{o, av}$  = average value of the observed discharge

#### 4.11.4 Coefficient Of Determination- $R^2$

This measure estimates how well the dispersion of the measured data is predicted by the model. Its value ranges between 0 and 1, with the zero being no correlation at all and value one perfect atch. In all the formulae, the variables are:

$$R^2 = \frac{\left[ \sum_{i=1}^n (q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o) \right]^2}{\sum_{i=1}^n (q_{si} - \bar{q}_s)^2 \sum_{i=1}^n (q_{oi} - \bar{q}_o)^2}$$

Where  $q_{o, i}$  = observed value at the  $i$  th time interval

$q_{s, i}$  = simulated value at the  $i$  time interval

$q_{o, av}$  = average value of the observed discharge

$Q_{s,av}$  , average value of the simulated discharge

$n$  =Number of sample data

Both efficiency evaluation criteria parameters must resemble each other. For the Gumera HEC\_HMS modeling case the  $E_{NS}$  has a value of **0.71** and  $R^2=0.0.758$  and for validation simulation the result is 0.744 and is acceptable value.

#### 4.12 Modeling by Frequency Storm Method

To be more accurate for flooding and flood mapping problems the hourly time series datas are required to estimate the peak flow from the catchment and for this thesis work the hourly data in put is used for estimating the flood instead of the daily case and the daily data series of the gaging station is used for catchment parameter estimation using the opetimaization of the model.

### 4.13 Return Period

A return period shall be selected to match the mitigation measure cost, potential flood hazard to property, expected level of service, political considerations, and budgetary constraints, considering the magnitude and risk associated with damages from larger flood events.

The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. If a flood has a 20% chance of being equaled or exceeded each year, over a long period of time, the flood will be equaled or exceeded on an average of once every five years. This is called the return period or recurrence interval (RI). Thus the exceedence probability equals  $100/RI$ . The 5-year flood is not one that will necessarily be equaled or exceeded every 5 years. There is a 20% chance that the flood will be equaled or exceeded in any year; therefore the

5-year flood could conceivably occur in several consecutive years. The same reasoning applies to floods with other return periods.

## 5.0 HEC-HMS RESULTS AND DISCUSSIONS

### 5.1 HEC-HMS Calibration Results And Discussions For Gumera Catchment

HEC-HMS calibration was performed for a period of ten years (1992 to 2001) Gumera Watershed of the area using daily flows basis. As discussed previously in chapter 4 the flow was calibrated automatically using the observed flow at the outlet of Gumera watershed. Optimization of the parameter values was carried out within the allowable ranges recommended by the US Army corps of Engineers Hydrologic Engineering Center (Technical Reference Manual March 2000).

The model results as obtained from the final automatic calibration using the peak weighted root mean square error objective function showed that there was a good agreement between the simulated and observed gumera catchments. This was demonstrated by the correlation coefficient and the Nash-Sutcliffe (1970) efficiency values for catchments. The daily calibration results are presented in table5.1

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

Table 5.1 Optimized Parameters of HEC-HMS For Gumera Catchment, Daily Basis

Optimized Parameter Results for Trial "Trial 14"					
			Project: Gumera HMS simulation		Optimization Trial: Trial 14
		Start of Trial:	01Jan1992, 00:00	Basin Model:	Basin model
		End of Trial:	01Jan2001, 00:00	Meteorologic Model:	Gumera met
		Compute Time:	29Aug2011, 19:12:01	Control Specifications:	Control 1(simulation-calbrat
Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
Reach-1	Muskingum K	HR	21.375	21.695	-0.02
Reach-1	Muskingum X		0.0984211	0.0926332	0.00
Reach-2	Muskingum K	HR	34.006	34.517	-0.02
Reach-2	Muskingum X		0.0999677	0.0940888	0.01
Reach-3	Muskingum K	HR	46.206	46.896	-0.03
Reach-3	Muskingum X		0.14228	0.13391	0.00
Subbasin-1	Clark Storage Coeffic...	HR	22.144	22.144	-0.00
Subbasin-1	Clark Time of Concen...	HR	21.739	21.739	0.00
Subbasin-1	Constant Loss Rate	MM/HR	0.35521	0.36009	-0.03
Subbasin-1	Initial Loss	MM	0.25	0.25000	0.00
Subbasin-2	Clark Storage Coeffic...	HR	11	11.000	0.00
Subbasin-2	Clark Time of Concen...	HR	16.873	16.873	0.00
Subbasin-2	Constant Loss Rate	MM/HR	0.35521	0.36045	-0.16
Subbasin-2	Initial Loss	MM	0.25	0.25000	0.00
Subbasin-3	Clark Storage Coeffic...	HR	23.418	23.649	-0.01
Subbasin-3	Clark Time of Concen...	HR	40.764	41.159	-0.01
Subbasin-3	Constant Loss Rate	MM/HR	0.35513	0.35863	-0.11
Subbasin-3	Initial Loss	MM	0.25	0.25000	0.00

Flow hydrographs for the observed and simulated flows at Gumera gaging station is presented in the graph below

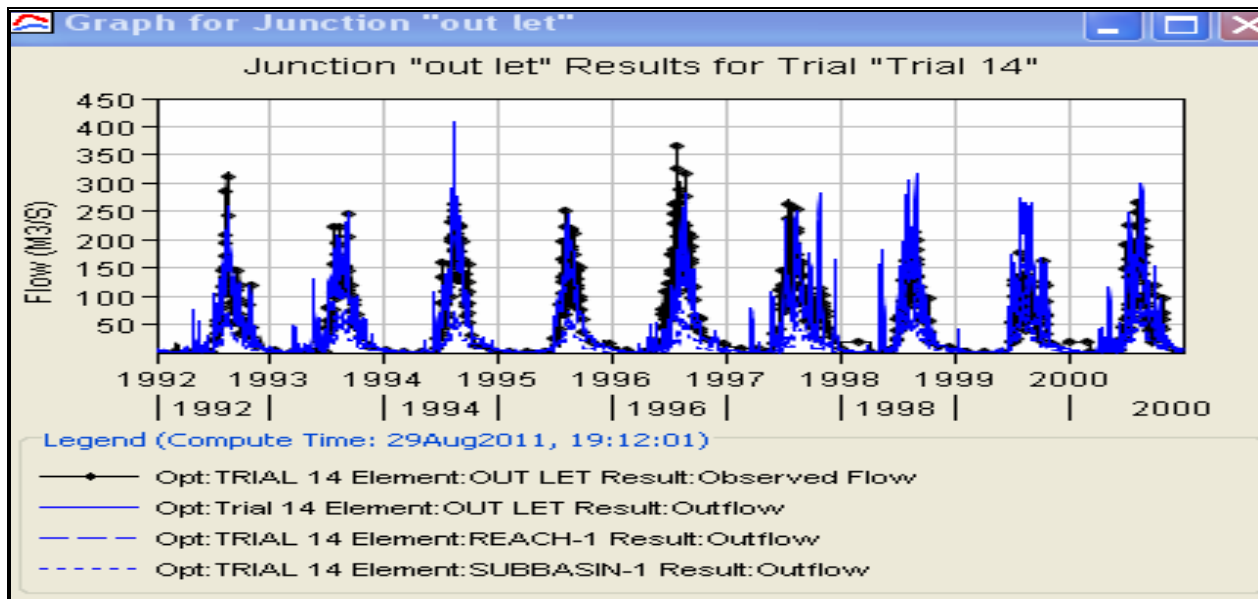


Fig 5.2 Calibration of HEC-HMS Observed and Simulated Daily Flow Hydrographs

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

The results of calibration of the model is presented in the table 5.2.

Table 5.2 Calibration Performance of HEC-HMS for Gumera Catchment

Catchment	Gumera
Coefficient of determination( $R^2$ )	0.758
Nash-Sutcliffe( $E_{ns}$ )	0.71
Period of calibration (daily)	From 1992 to 2001

The objective function results gumra catchment are presented in Table 4.2. The simulation is event based in all cases.

Table 5.3 Gumera Objective Function Result

Objective Function Results for Trial "Trial 14"				
Project: Gumera HMS simulation		Optimization Trial: Trial 14		
Start of Trial:	01Jan1992, 00:00	Basin Model:	Basin model	
End of Trial:	01Jan2001, 00:00	Meteorologic Model:	Gumera met	
Compute Time:	29Aug2011, 19:12:01	Control Specifications:	Control 1(simulation-calbrat	
Objective Function at Basin Element "out let"				
Start of Function :	01Jan1992, 00:00	Type :	Peak-Weighted RMS Error	
End of Function :	01Jan2001, 00:00	Value :	54.7	
Volume Units: <input checked="" type="radio"/> MM <input type="radio"/> 1000 M3				
Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	10853.94	8510.41	2343.53	27.54
Peak Flow (M3/5)	408.9	364.8	44.1	12.1
Time of Peak	09Aug1996, 10:53:34	26Jul1996, 00:00		
Time of Center of Mass	26Oct1996, 06:26	13Sep1996, 03:52		

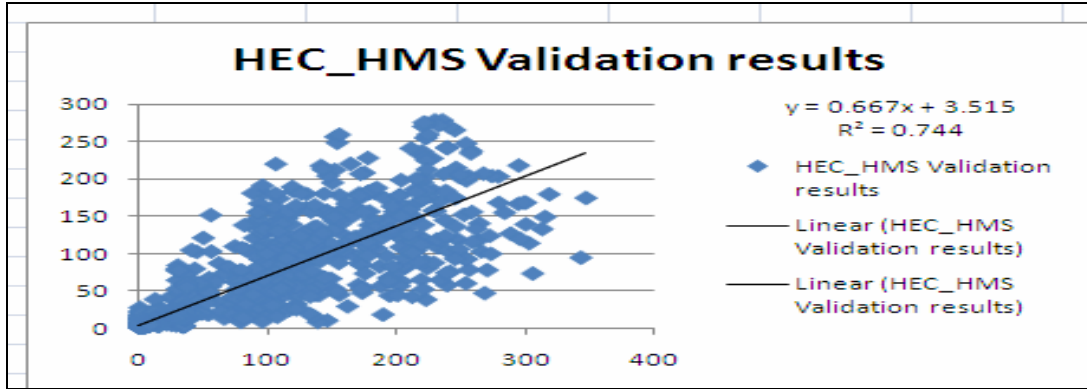


Fig 5.3 HEC-HMS Validation Results

From the validation result of the model we can conclude that the model is valid for simulation of the rain fall ruoff transformation method to generate the peak discharge.

## 5.2 Modeling By Frequency Storm Method

### 5.2.1 Using ERA Intensity -Duration-Frequency Curve

ERA has developed rainfall intensity-duration curves by dividing the country into different hydrological regions as shown below.

Table 5.4 ERA Hydrological Regions

Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	18	B	Bedele	19
	Mekele	35		Gore	45
	Maychew	24		Nekempte	27
A2	Gondar	40		Jima	45
	Debre Tabor	22		Arba Minch	11
	Bahir Dar	35		Sodo	28
	Debre Markos	44		Awasa	26
	Fitche	25	C	Kombolcha	46
	Addis Ababa	33		Woldiya	23
	Nazareth	40		Sirinka	17
A3	Kulumsa	31	D1	Gode	29*
	Robe/Bale	19		Kebri Dihar	38
A4	Metehara	28	D2	Kibre Mengist	24
	Dire Dawa	46		Negele	45
	Mieso	35		Moyale	18
* max 24 hour rainfall not given				Yabelo	34

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

After the model is calibrating using the daily data series and the loss parameters are fixed, the HEC- HMS model is simulated for rainfall intensity of 2, 10, 50, and 100 year return periods. The frequency intensity values are taken from the Ethiopian Roads Authority drainage manual (ERA, 2002). Thus as the study area is found in A2 meteorological region the values for the return period are tabulated as shown in the model below.

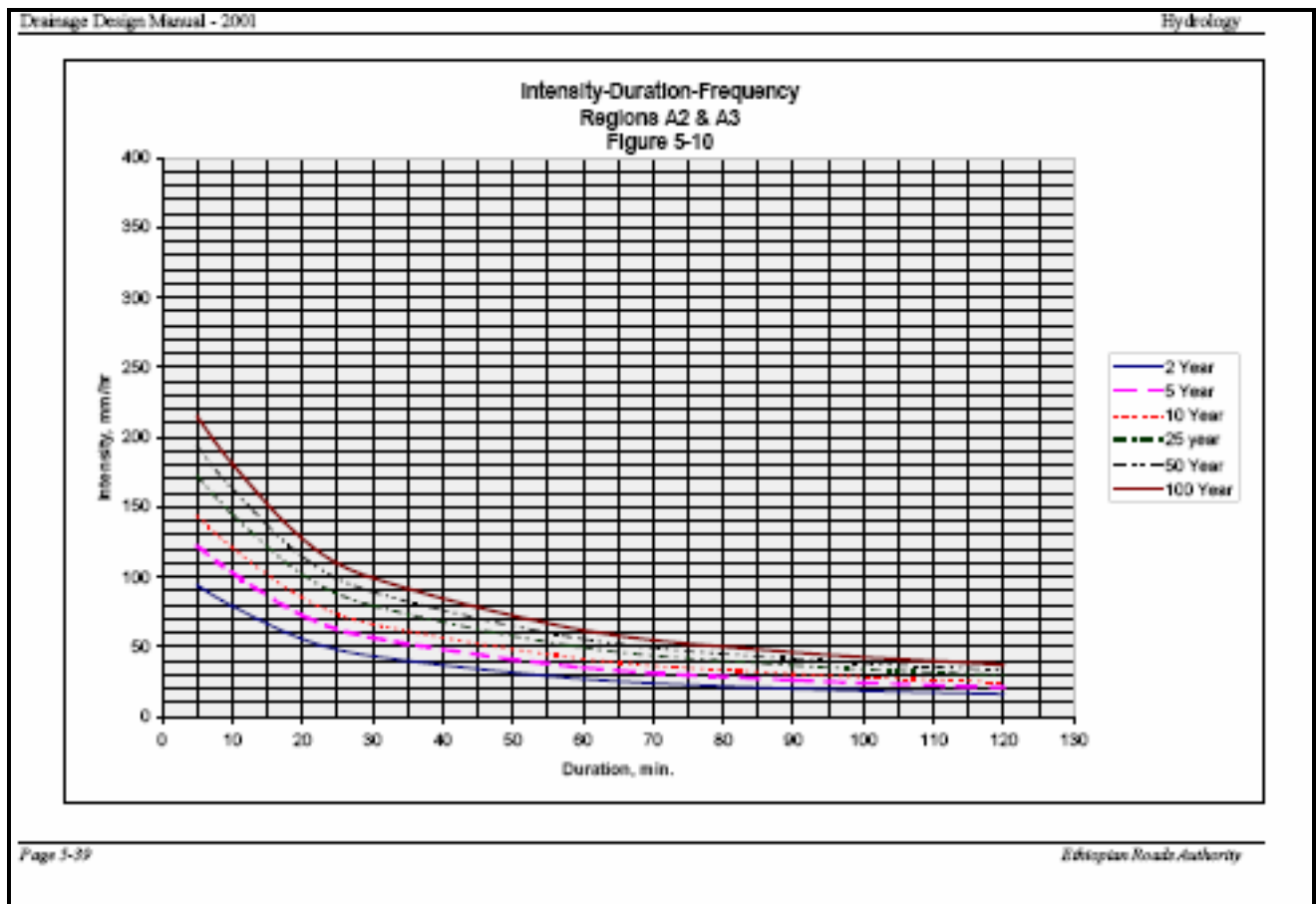


Fig 5.4 ERA Drainage Manual Rainfall Intensity-Duration Curves

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

Table 5.5 IDF Table For The Gumera Catchment (ERA Drainage Design Manual, 2002)

Intensity duration in (hr)	RF depth with return period				
	<b>2</b>	<b>5</b>	<b>10</b>	<b>50</b>	<b>100</b>
1	26.5	<b>34.00</b>	41	57	63
2	31.5	42	48	67	75
3	37	47	57	72	82
6	44	56	65	79	91
12	49	64	70	84	93
24(one day)	51.5	68	73	89	93

### 5.2.2 Output Of HEC-HMS By Frequency Storm

Using the parameters obtained from the daily basis the model results peak flows for the following return periods 2,5,10,50,100 years and the flow values are found accordingly.

Table 5.5 Determination of Peak Discharge Using HEC-HMS Frequency Method

S.NO	Return period(years)	Peak flow(m <sup>3</sup> /sec)
1	2	197.7
2	5	246.8
3	10	265.4
4	50	306.0
5	100	319.6

From the result table minimum peak flow for the Gumera River is occurred for 2 year return period for 24 hour storm duration and the maximum obtained with 100 year frequency storm for the same duration. The value being 197.7 m<sup>3</sup>/s and 319.7M<sup>3</sup>/s for 2 year and 100 year frequency respectively.

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

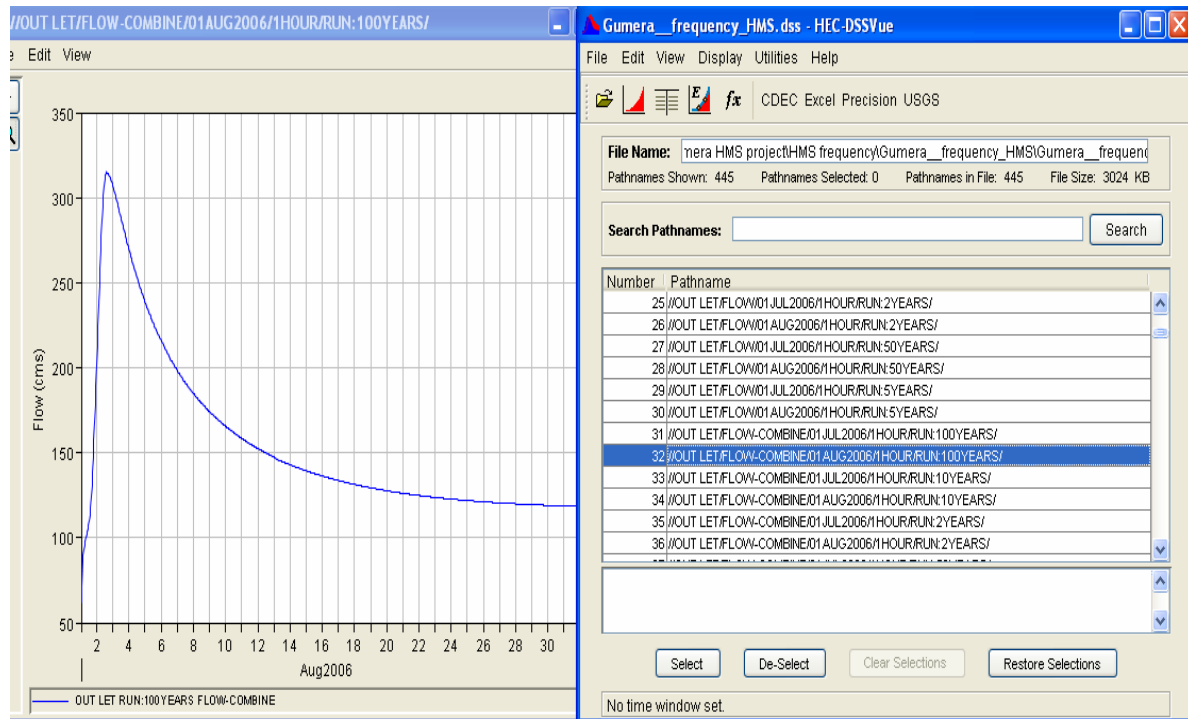


Fig 5.5 HEC-HMS Frequency Results of Gumera River For 100year Return Period(HEC-DSS)

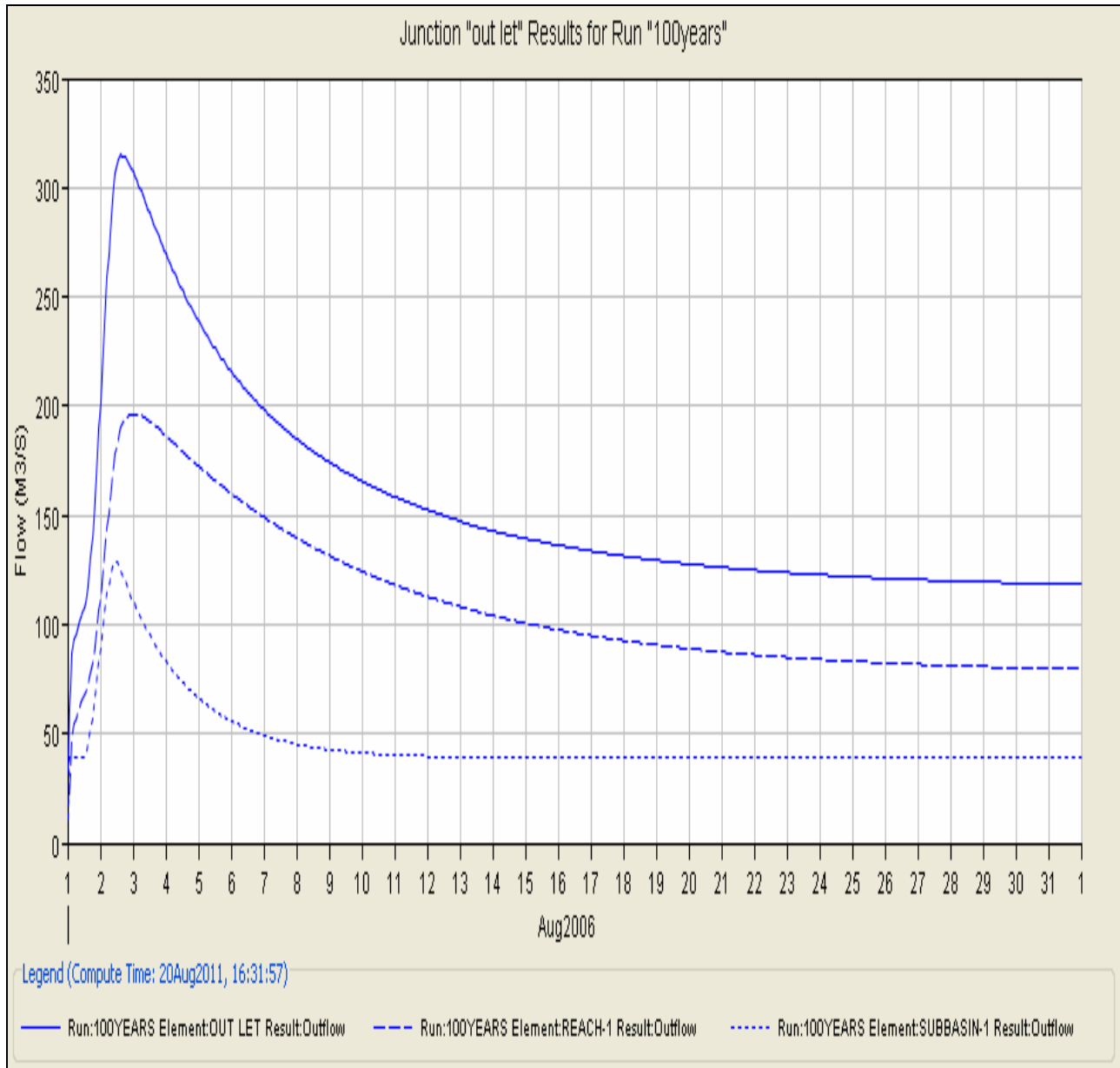


Fig 5.6 100year Hec-Hms Frequency Stream Flow Of Gamera River At Out Let

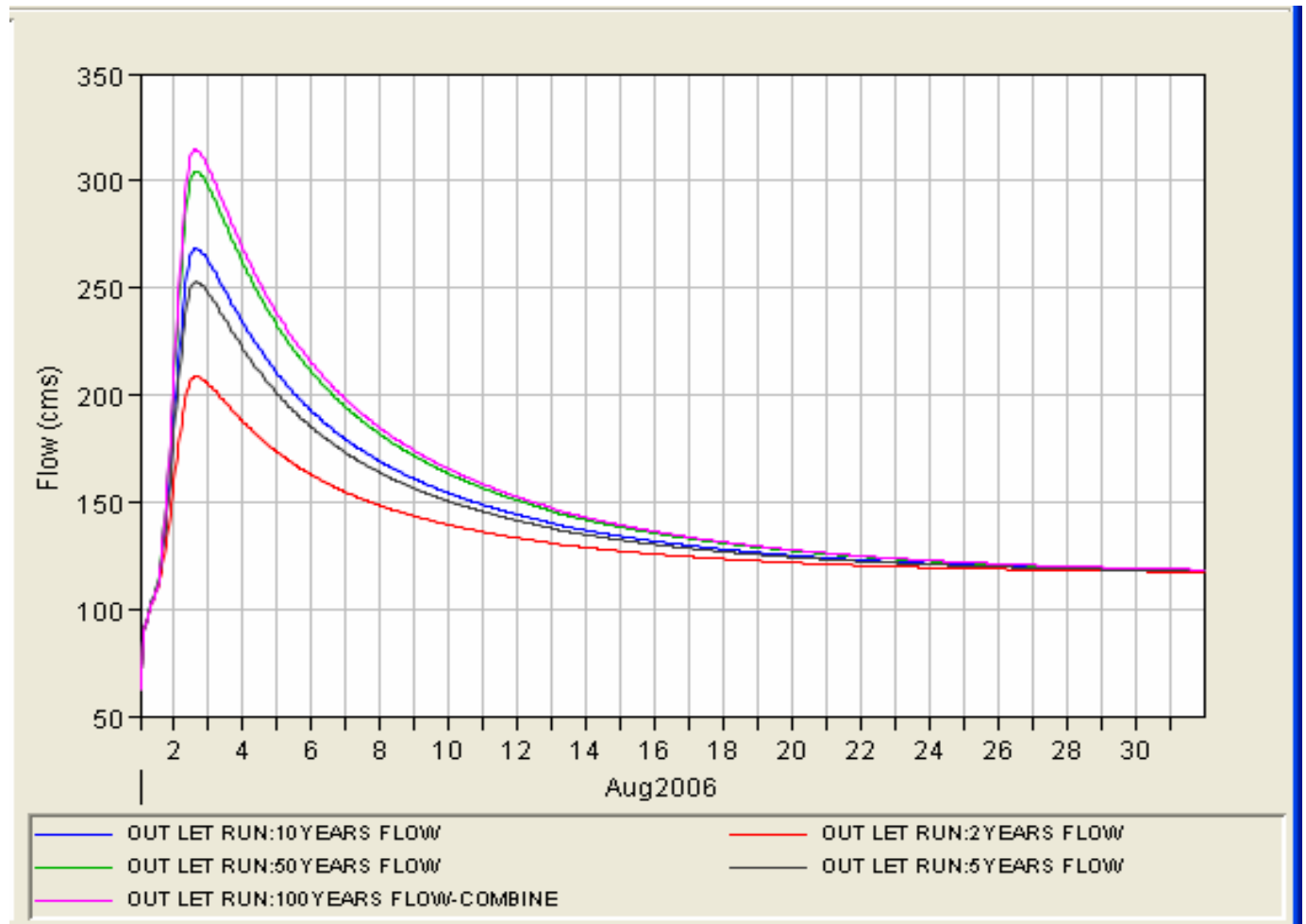


Fig 5.7 Frequency Flow Values Of The Gamera River For 2, 5, 10, 50 And 100 Year Storms In the figure all the frequency values of the five return periods are generated using the HEC-HMS frequency method at out let of the river(Gaging station).

### 6.0 OUT PUT OF THE MODELS HEC RAS AND HEC-GEORAS (Prea And Post Processing )

#### 6.1 Hydraulic Modeling with HEC-RAS

The objective of the hydraulic modeling process was to convert the flow values calculated into water surface elevations along the stream reach. Hydraulic Modeling using HEC-RAS computer programme is done for Gunera river which is the main river where over topping of riverbank is prevailed in in the fogera flod plain. One of the function of this model is to determine the water surface profile within the chanel. The inputs used for this model are the flow data (assumed steady flow condition ) and geometry data which is imported from Arc GIS with supported format and is georefernced.

The in put data for HEC-RAS is prepared using HEC-GeoRas Arc GIS extension. in the Hec-GeoRas pre processing the preparation of RAS(geospatial) layers which are stream center line and crossection cutlines ,flow bath line ,bank line and other optional layers are created. The contur line generated from TIN of the study area and the shape files collected from ENTRO is used to digitalize these layers .Ones the 2D feature class is created with all geospatial information the next step is creation of 3D feature of crossection cutlines by intersecting the 2D feature class and with the TIN of the area.

The 3D spatial data generation involved creation of 3D stream centerlines and 3D cross-sections, with Z values to define elevations. The Z values were extracted from the TIN.

Once generated, the 3D features identified the stream network and the HEC-RAS model layout. The generated cross section is then changed to polyline Z. The 2D point data is changed to the 3D polyline due to the extraction of elevation from the TIN.

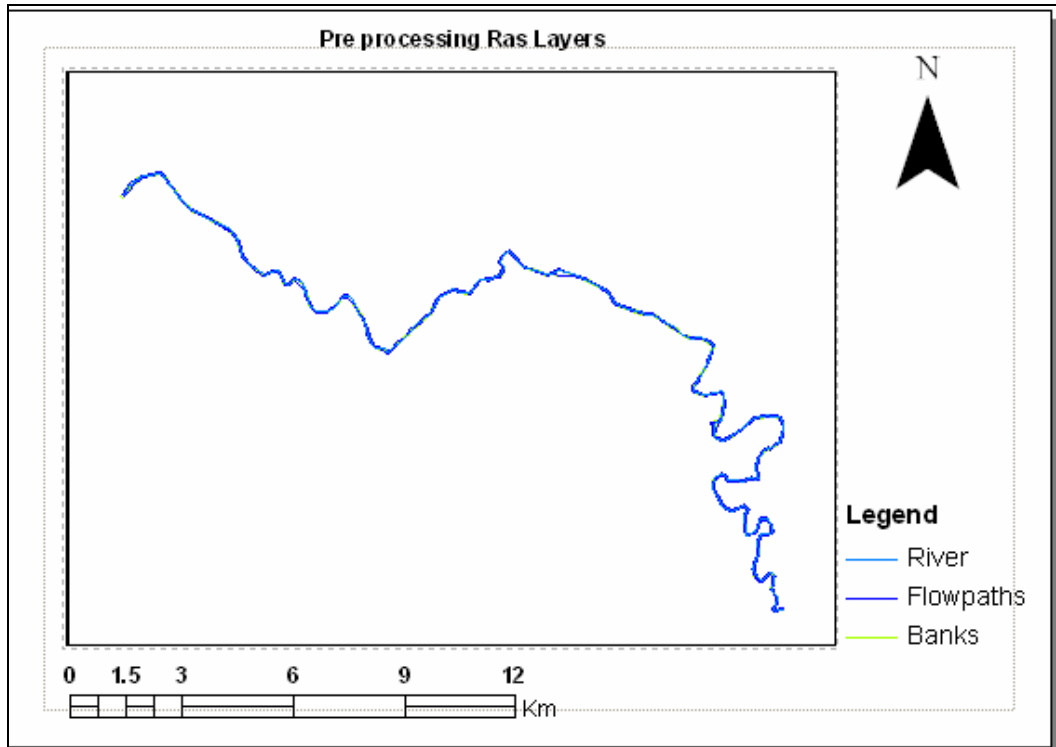


Fig 6.1 Digitalize Gumera Three River Ras Layers

In this figure we can see that the pre processing of ras layers created using the ArcGIS ,Hec-Georas extension for creating and digitizing the layers.

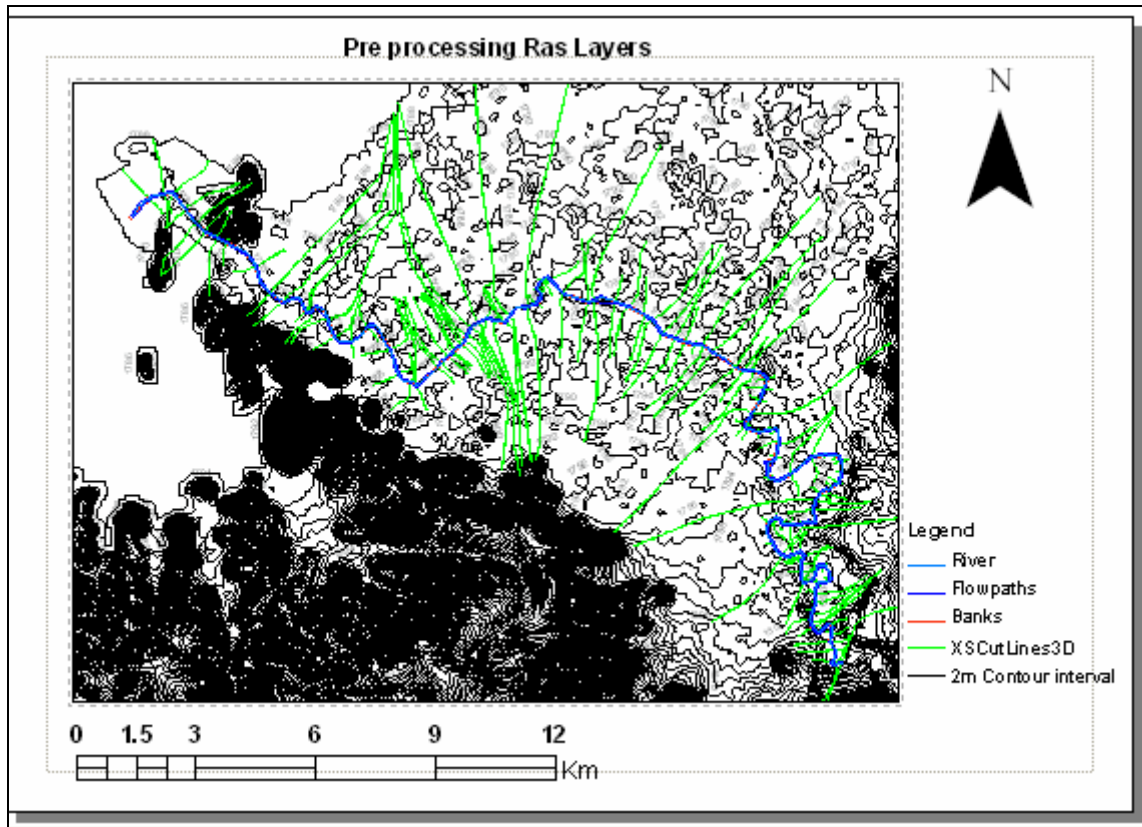


Fig 6.2 3D Cross Sectional Cut Line Created From Hec-Georas

For creating the cross section cut lines across the flood plain first the contour lines of 2m interval is generating from TIN and then these lines are using for guiding to digitalized the cross lines. From the figure above on left side of the river viewing downstream the south east of the study area it is all most surrounding by hill side with higher elevation and it will not have a problem of flooding.

### 6.1.1 Exporting GIS Dat To HEC RAS

Once the HEC-GEORAS layers are created, it is very important to edit and geo-reference all necessary layers used in GIS. The cross section is editing based on the center traverse data survey point in the HEC-RAS window interference. After all layers are edited in GIS and cross section survey points in HEC-RAS, post-ras process which is flood mapping and inundation is the next step. The following geometric data imported from the Arc GIS using the Hec-Georas extension tool bar.

- ✚ River System Schematic

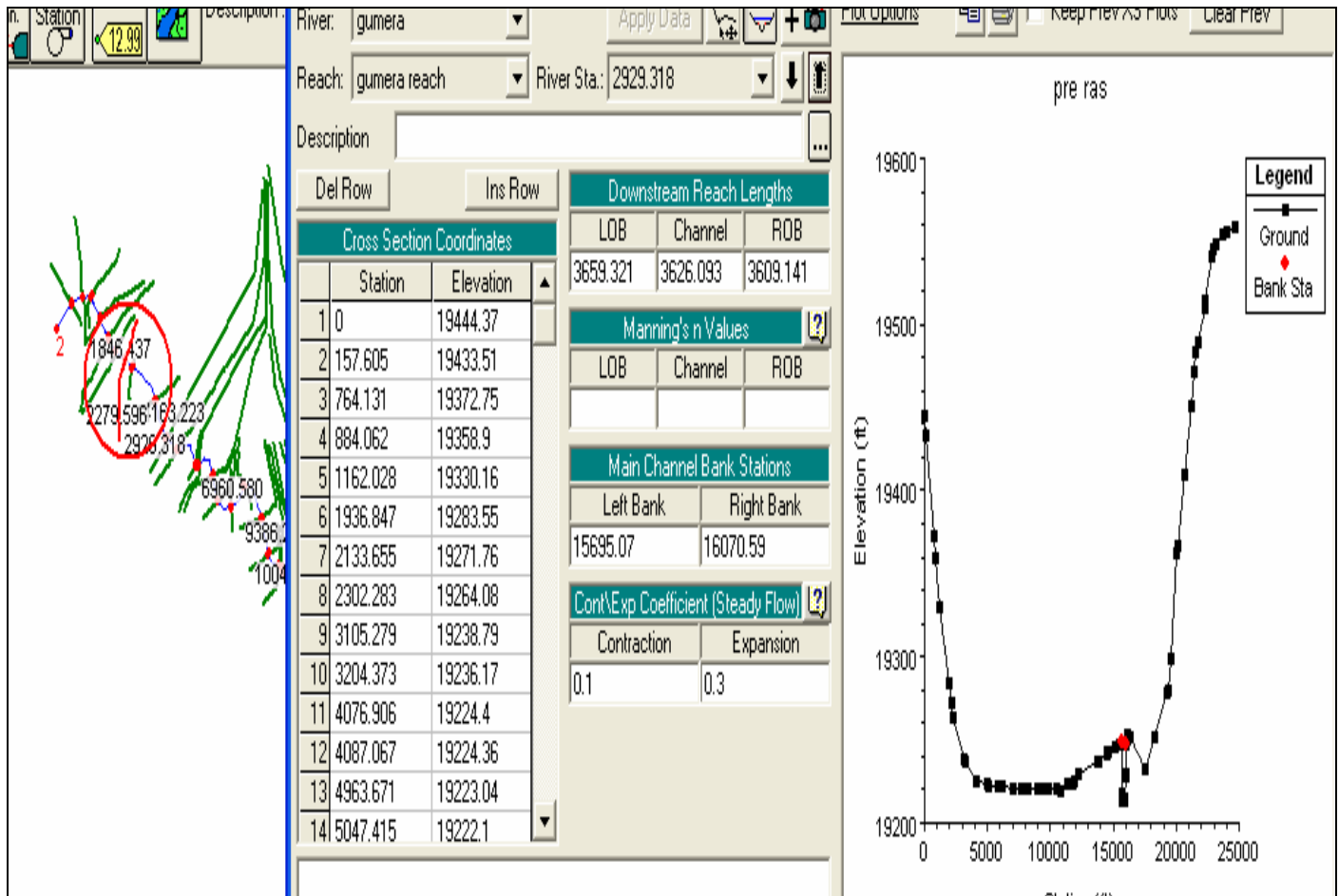
- ✚ Cross section Data

- Cross section surface line
- Cross section main channel bank stations
- River, Reach, and River Station identifiers
- Downstream reach lengths for the left overbank, main channel, and right over bank.
- Cross Section Cut Lines (X and Y coordinates of the plan-view line that represents the cross section).

Although the HEC-RAS has an editing interface for the exported value, the GIS is a better way to reduce the error during post-RAS process (flood mapping and delineation). There are different options to leave or export RAS layers depending on their use and necessity. There may be errors during pre-RAS processes.

- ✚ The bank stations which are made fit with the cross section points in GIS may not match when exported to HEC-RAS. In this case manual edition should be applied.
- ✚ The exported cross section may not also be readable by the HEC-RAS. The problem may emerge from the unit system between the HEC-RAS and that used in GIS. The GIS unit system must be re-projected according to the RAS unit.

Since most GIS inputs such as DEM, TIN and field cross sections are in metric unit .It must be projected to the same unit. In the figure below the last two cross sections bank points are away from the channel bank line, so that they require manual edition.



**Fig 6.3 Good Coss Section View**

The cross-section shown above represents a station of 2929.318 and extends for about 2.5 km from left to right. It has enough station points across the flood plain and it represents a good look in cross-sectional point of view, which is a U-shaped cross-section. Thus, it does not need any correction on the survey points.

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

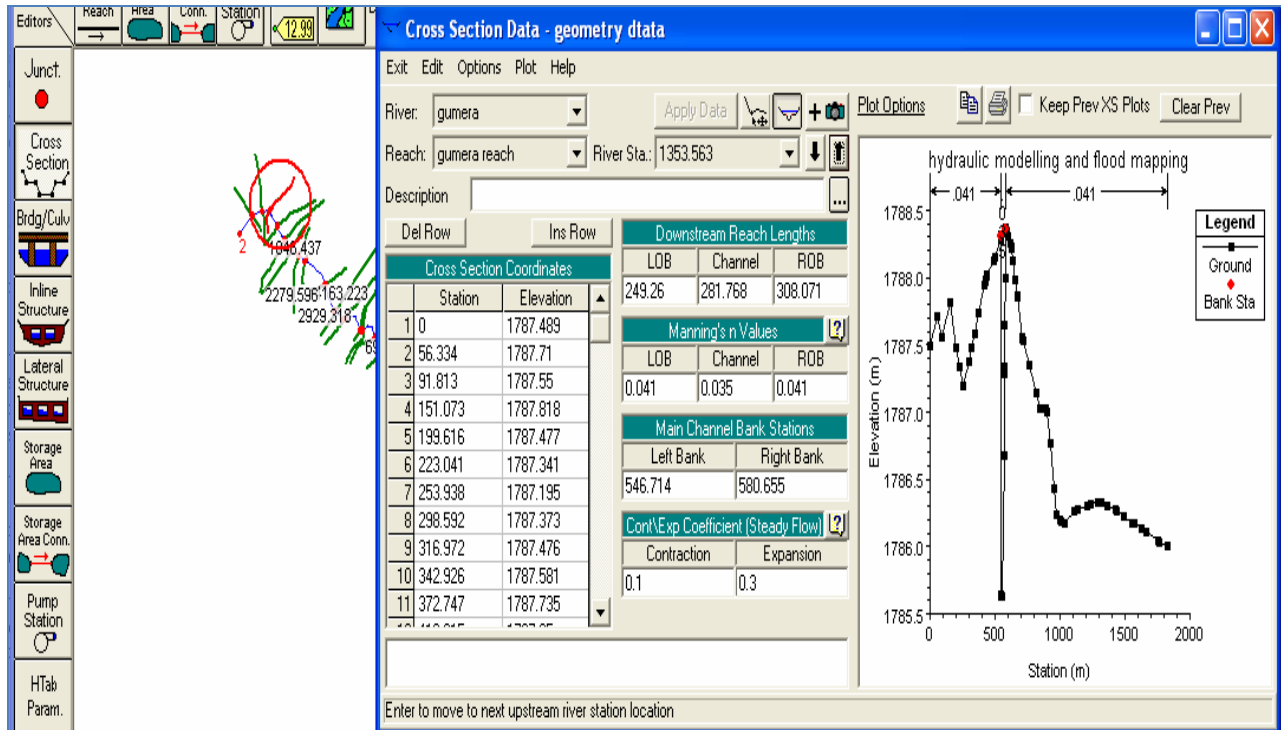


Fig 6.4 Bad Crossection View

Comparing the two crosssections at station 2929.318 and 1353.563 ,the latter crosssection has aproblem of taking survey points across the flood plain.Thus it needs editing befor a hydraulic analysis is performed .The edition procedure of the cross section is held on the ARC GIS and after editing is completed it again inported to HEC RAS.This procedure of correcting the geometry data of the crosssection on the ARC GIS and editing its travers profile based on the actual data field is called calibration of the hydraulic model.

Finally the output table for the model is given for each station consisting of different parameters. The parameters can be changed during calibration. The model is calibrated for the cross section parameters. The calibration was performed based on the actual survey field survey collected and the 2m contour interval generated from the TIN of the flood plain.Thus the HEC-RAS is calibrated for the field survey data but for the flow data its already calibrated and verified on the HEC-HMS and no need to calibrate here further.Based on the traverse data calibration of the model is field data for the center of the river and the 2m contour interval is used to extend the crosssectional length across the flood plain and to maintain the shape of the crosssection.

### 6.1.2 Roughness Coefficients

The selection of Manning values involves judgment, skill, and subjectivity. Roughness characteristics of natural channels are given by Barnes (1967). Barnes presents photographs and cross sections of typical rivers and creeks and their respective  $n$  values. Therefore, the roughness value for Gumera river and fogera flood plain was determined by comparing the Barnes standard photos with that of gumera river main channel and found to be between 0.035 and 0.041 (ENTRO)

### 6.1.3 HEC-RAS output

The model HEC RAS needs survey crosssectional data and flow data which is determined using the hourly data frequency method using HEC-HMS which is determined in chapter four. Inserting the flow data and importing the survey data from ARC GIS using the Hec Georas post processing, by running the model for the five flow condition profiles to determine the water surface profile of the reach. The simulation is made for steady flow condition. Simulated water surface profiles for flood of 100 year return period at selected cross sections where there is over breaching of riverbank are presented here.

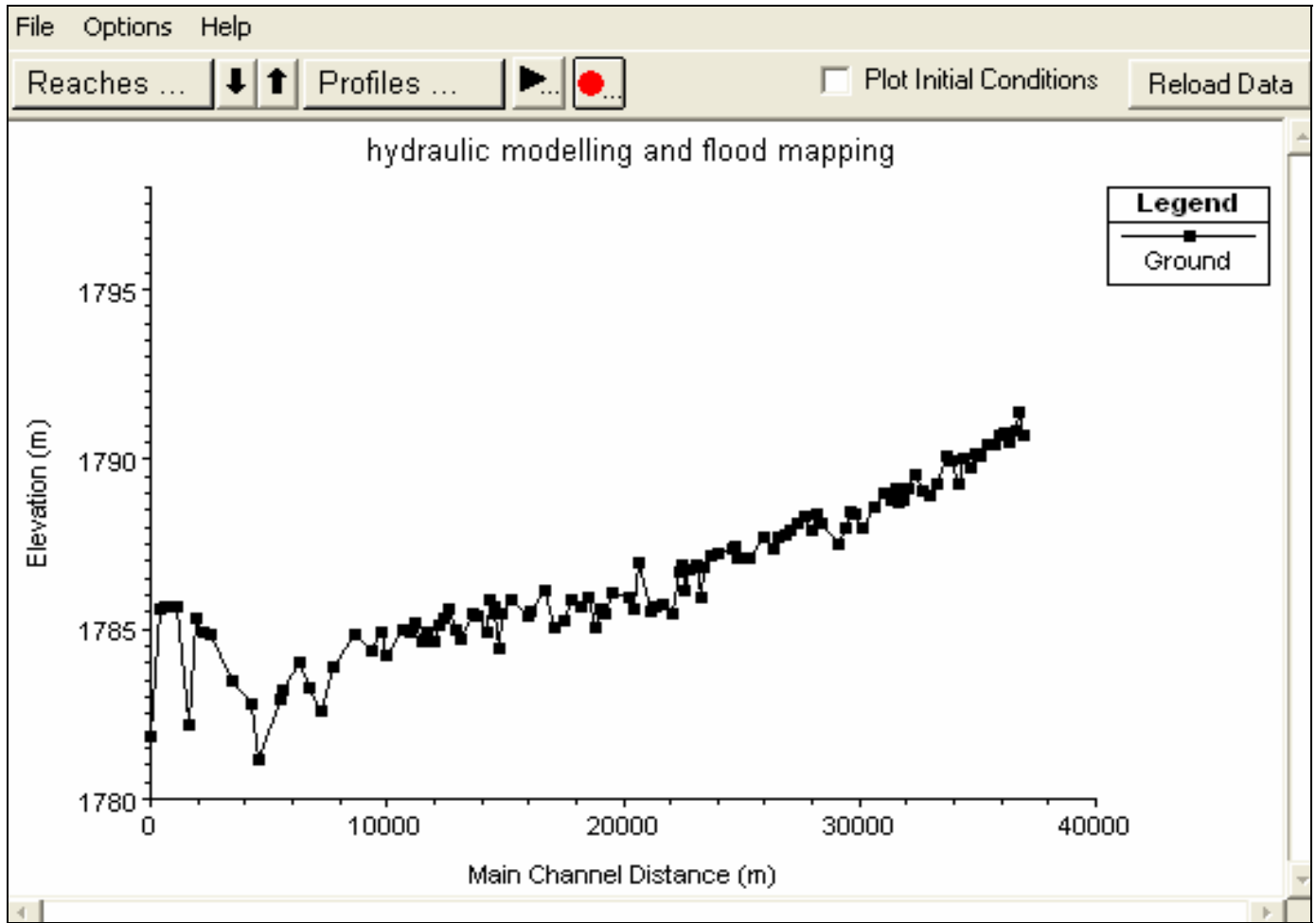


Fig 6.5 Profile of the Reach

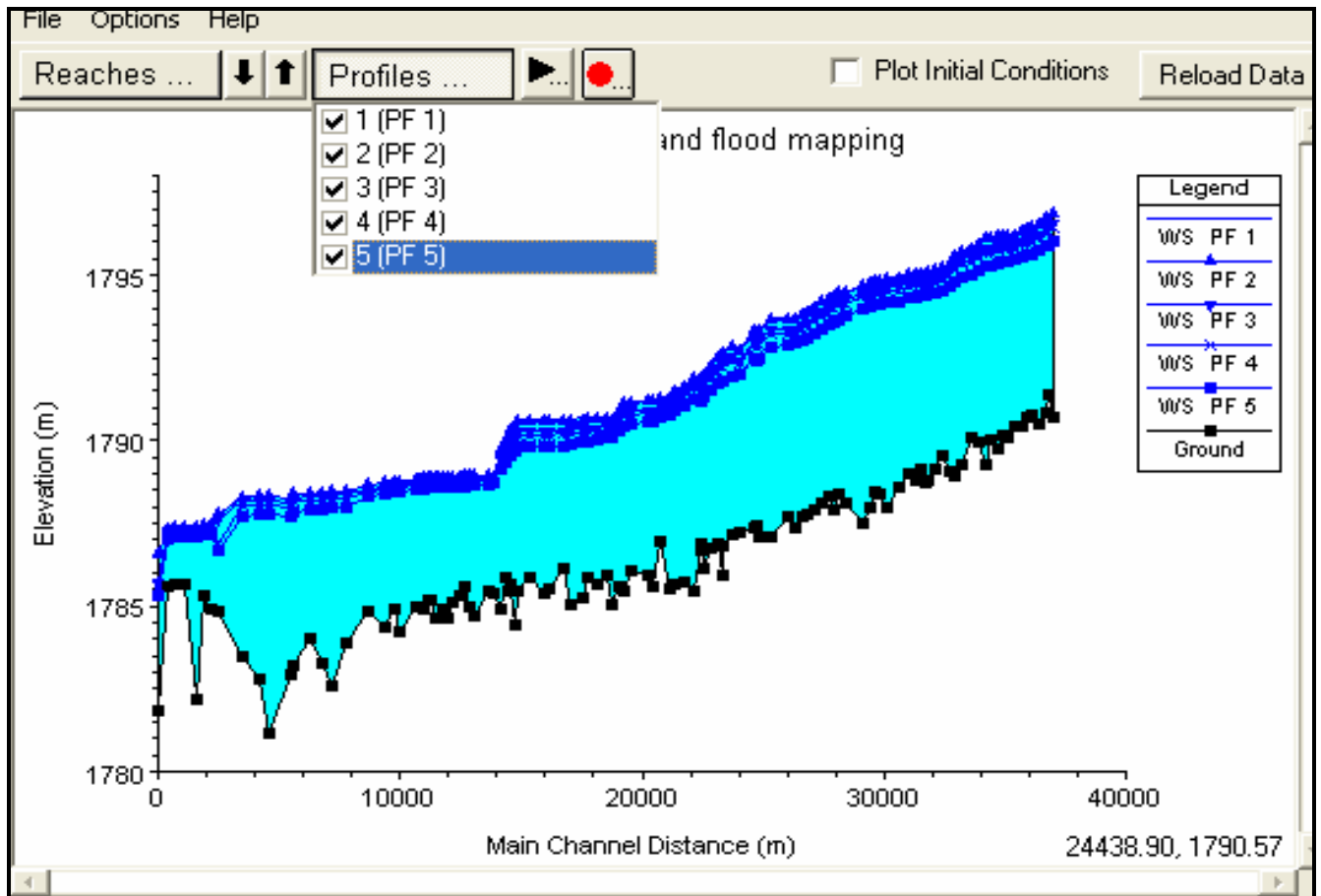


Fig 6.6 Water Surface Profile For All Return Periods

We can see from the figure above that the water surface profile along the reach for the five flow conditions. The flow conditions are labeled as PF1, PF2, PF3, PF4 and PF5 which represent 100, 50, 10, 5 and 2 years respectively.

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

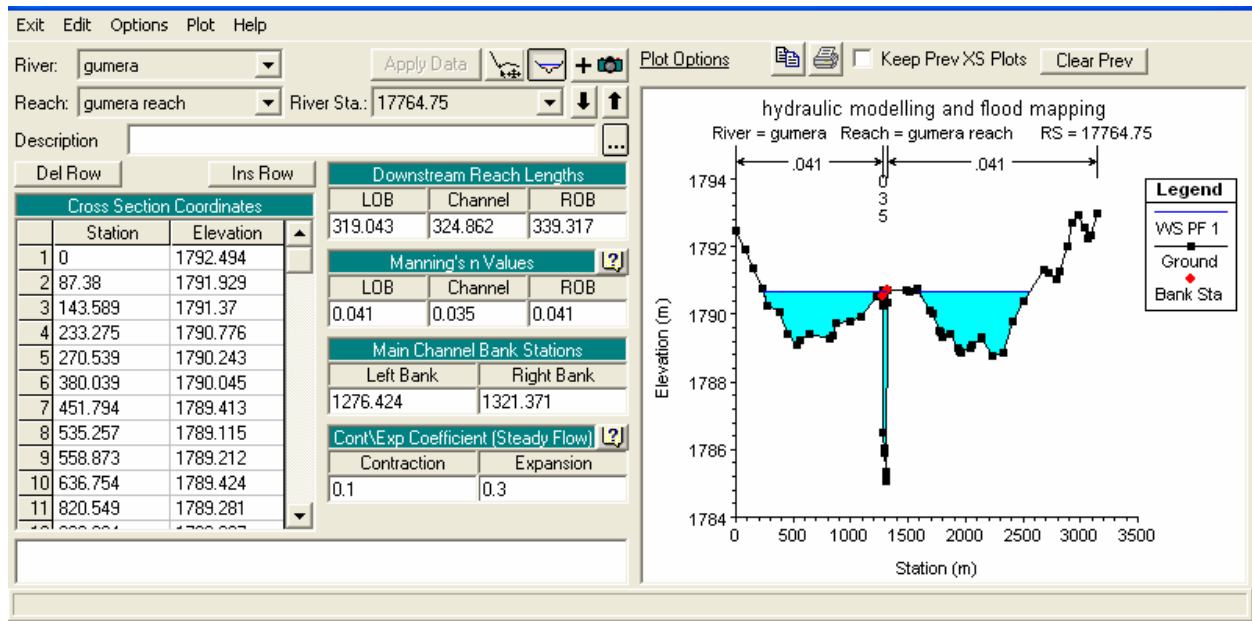


Fig 6.7 Cross section view at River station 21829.36 for profile1 (100year return period)

From the above figure of cross-sectional view we can see the water level profile for the 100 years flow condition and it is observed that the cross-section is made for length of 3.5km across the flood plain and it is long enough to see the water surface profile for water level on the left of the cross section. we can see that the survey data that is station number, elevation of each station, downstream reach length and Manning's values of the cross-section at a point.

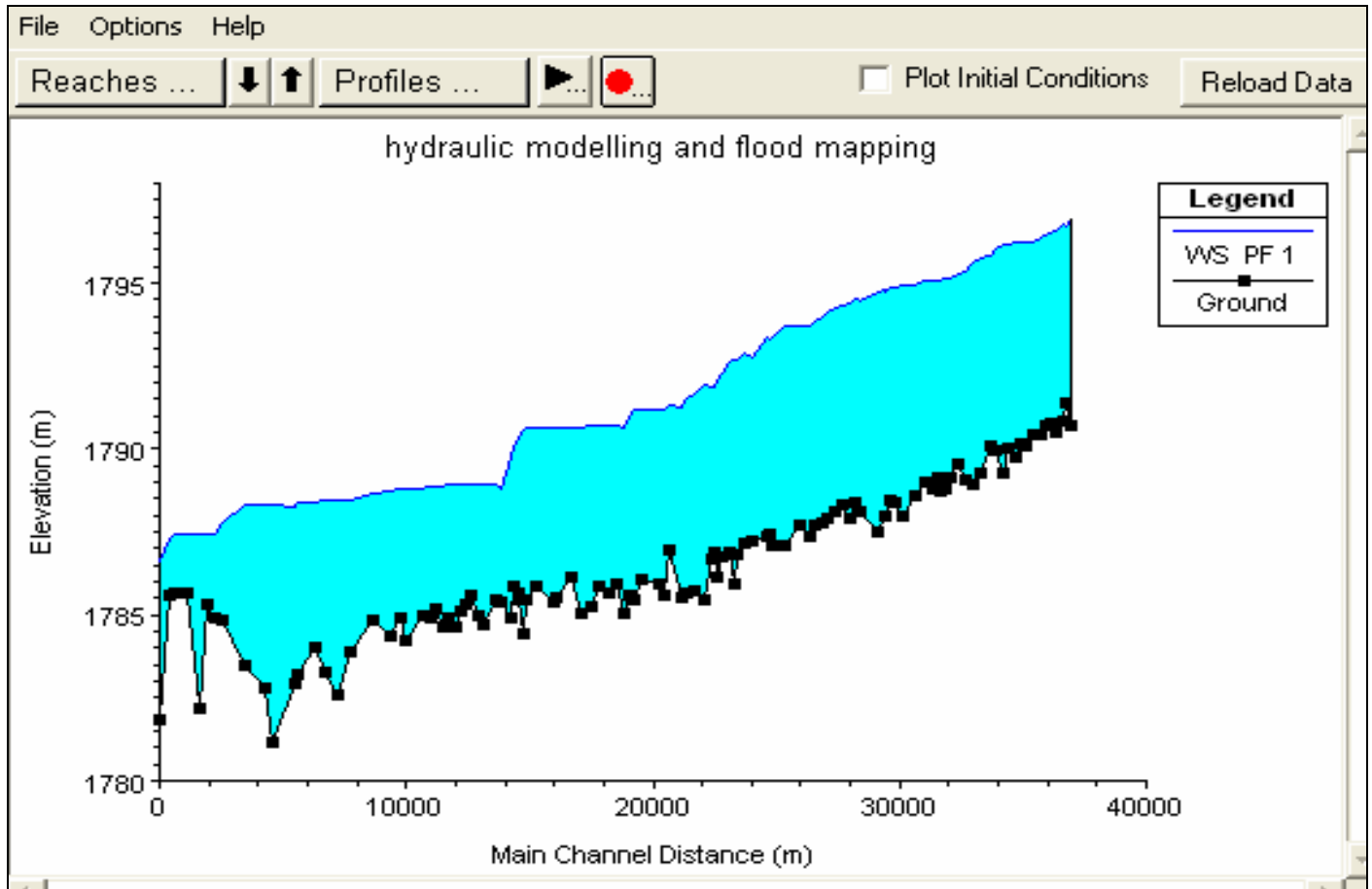


Fig 6.8 Water Surface Profile Plot of the Reach for 100 Year Storm

Other application of HEC-RAS is providing the 2D river water profile to ArcGIS to display the flood plain in 3D. The flood plain mapping and finally delineated output is the one which uses the RAS output in the form of the river profile.

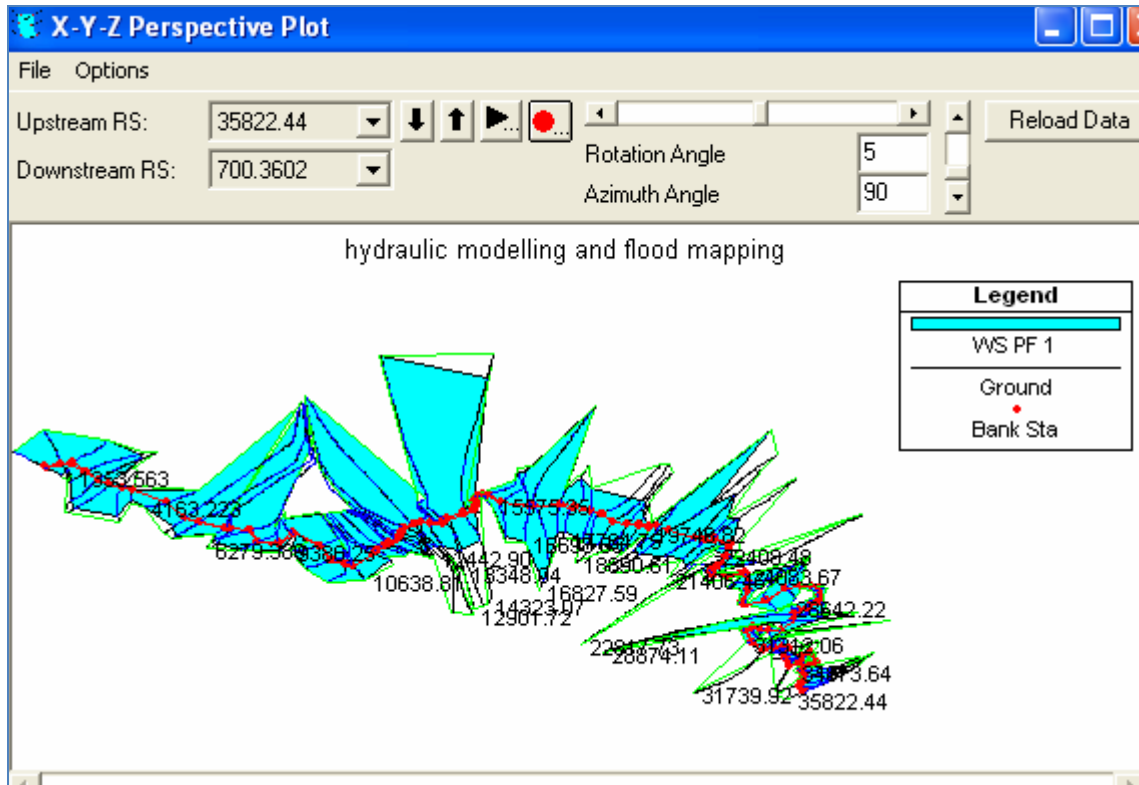


Fig 6.9 3D Perspective View of the Flood Plain and the Channel In HEC-RAS (100 Year Storm

### 6.1.4 Mapping Flood plains Using GIS

The flood plain mapping is completed in two steps with generation of water surface TIN from cross-section water surface elevations and water surface Tin is intersected with the digital terrain model to create flood plain polygons for flow scenario. Using the Hec-Georas post processing exporting the hec-ras outputs in .sdf format to Arc GIS the flood plain inundation mapping and delineation is done using the arc gis tool bars.

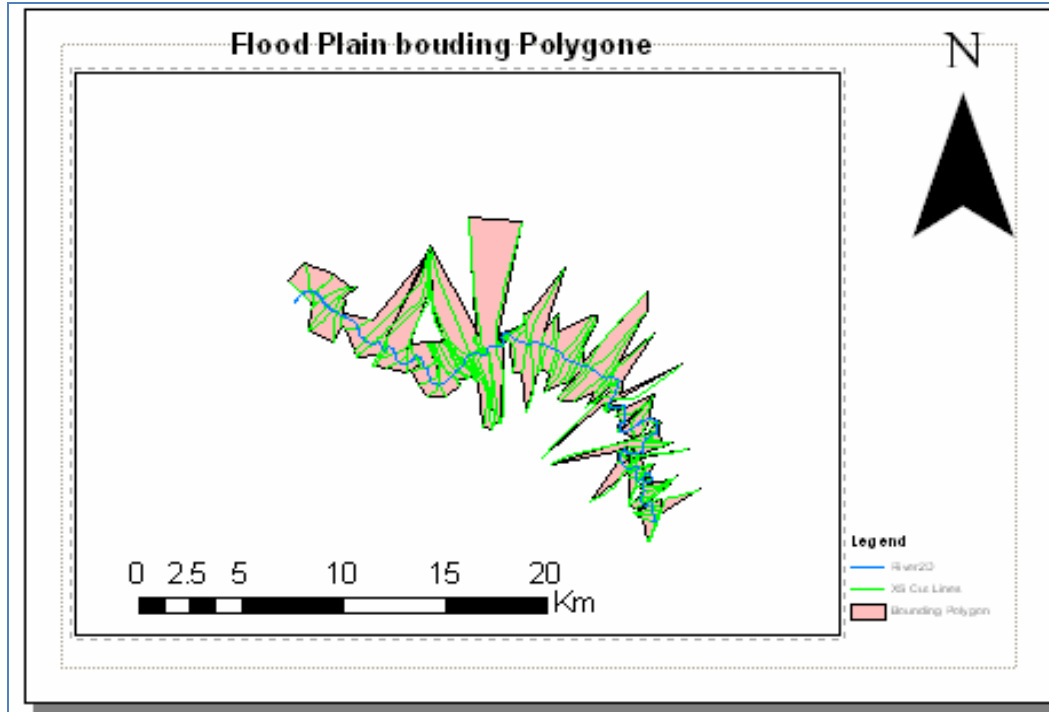


Fig 6.10 Bounding Polygon For The Water Surface TIN Generation

### 6.1.5 Flood Inundation Mapping and Delineation

In this part the flooding map shows the area extent that can be delineated as buffer zone. The two models hec-georas and hec-ras are used one after the another. Areas inundated by flooding occur wherever the elevation of the floodwater exceeds that of the land. To delineate these areas, we will create surface models of the floodwater and land surface, and then compare the elevations. HEC-RAS represents the floodplain as a computed water surface elevation at each cross-section. During the data import step, these elevations were brought into ArcGIS, along with the distance from the stream centerline to the left and right floodplain boundaries. Hence, two things are known about the floodplain at each cross-section: water surface elevation and width on each side of the centerline.

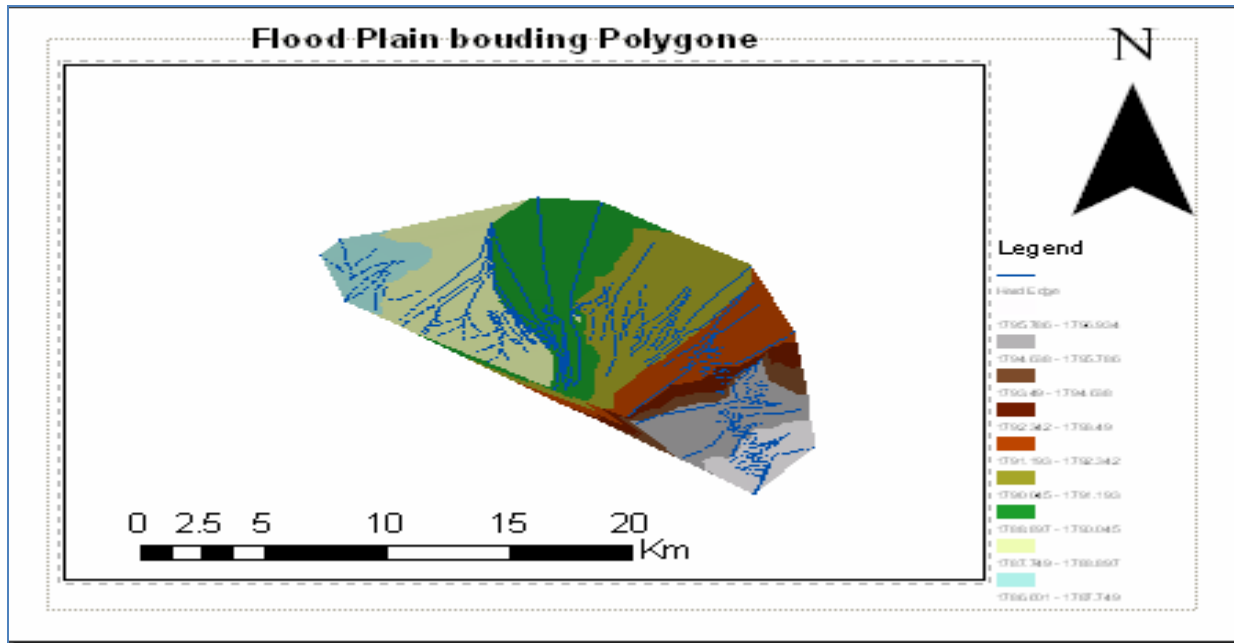


Fig 6.11 Water Surface TIN Generated From Bounding Polygon ArcGIS with an extension of HEC-GeoRAS delineates flood plain for different flow conditions. In this 2, 5,10, 50 and 100 year storm considered .In the figure below the flood inundation of 100year and 2 year storm is considering for mpping and other flow storms are considered in APPENDIX D.

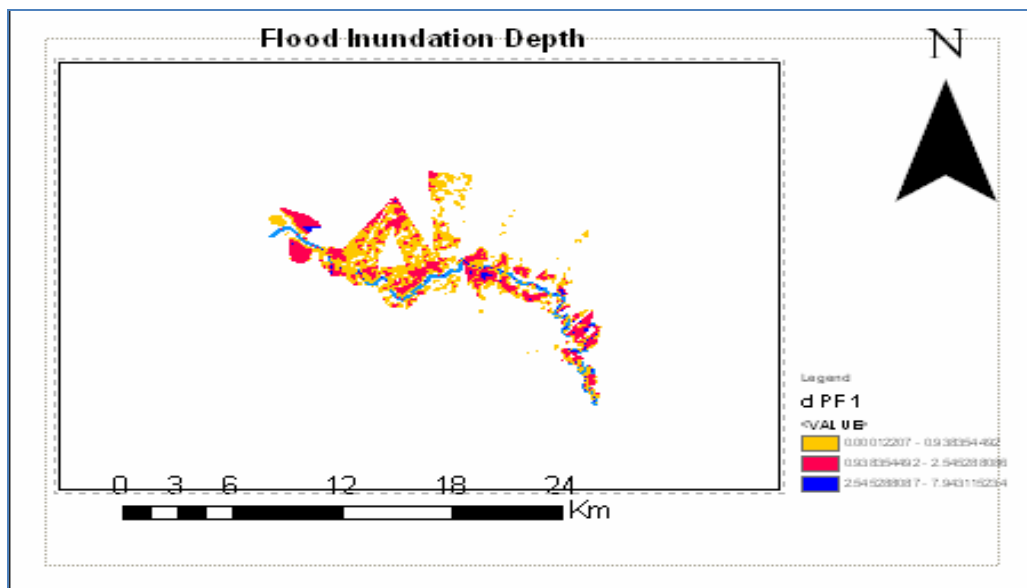


Fig 6.12 Flood Plain Inudtion Depth For 100years Storm

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

The above figure shows flood inundation of flood plain for the flow condition of 100 year return period and it can be seen that the depth of the flood ranges from 0m to 7.943m. The flood extent also stretches to about 6km having an increase at the downstream of the reach which is out let to the lake Tana.

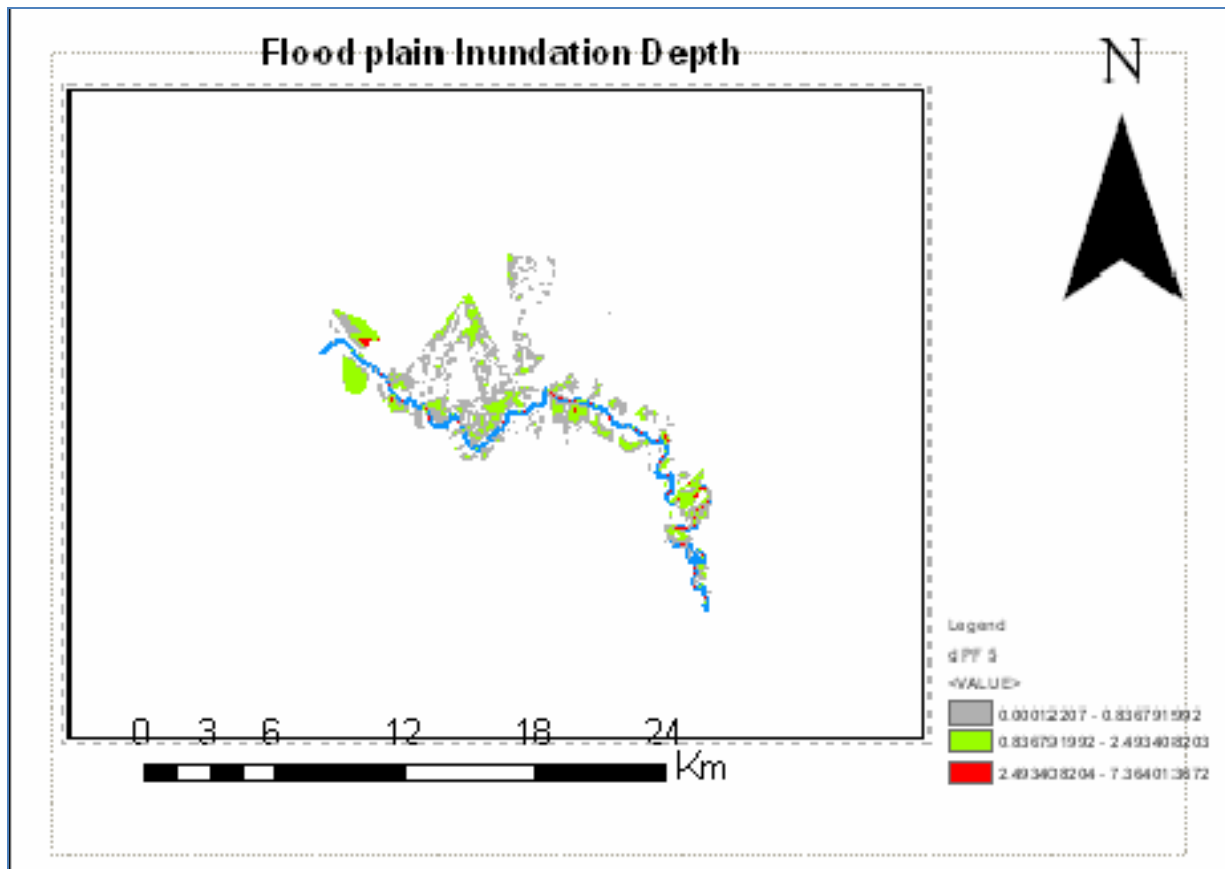


Fig 6.13 Flood Plain Inundation Depth For 2 Years Storm

In the figure above for the 2-year flood inundation map the maximum depth of inundation is 7.36m and is increased its extent at the downstream of the river as it emerges to the lake Tana. The maximum area inundated is occurred from station 14589.192 to downstream station at the out let 1071.796 which is near to lake tana. Most flooding extents are occurred for the flow conditions of 100 year and 50 year due to the maximum flow conditions at this period.

6.2 Result And Discussion

After the hec-georas post processing is completed, the flooded areas are identified in the figure below. For the 100 year flood frequency the maximum depth of flood is 7.94m and this depth of flood is extended to the areas named as Wageta, Kidist Hana, Shina, Quhar Michael and Bebeks from the Fogera flood plain and Tana Mistily And Jigna from the Debra wereda. Most of the area is affected from the flood in fogera flood plain and a small portion is affected from the Dera werda. This is due to the topography of the flood plain between the two weredas as it is showed in Fig 3.2. As we can see from the figure below all most fully the keble wageta is affected by the flood near to the mouth of lake tana.

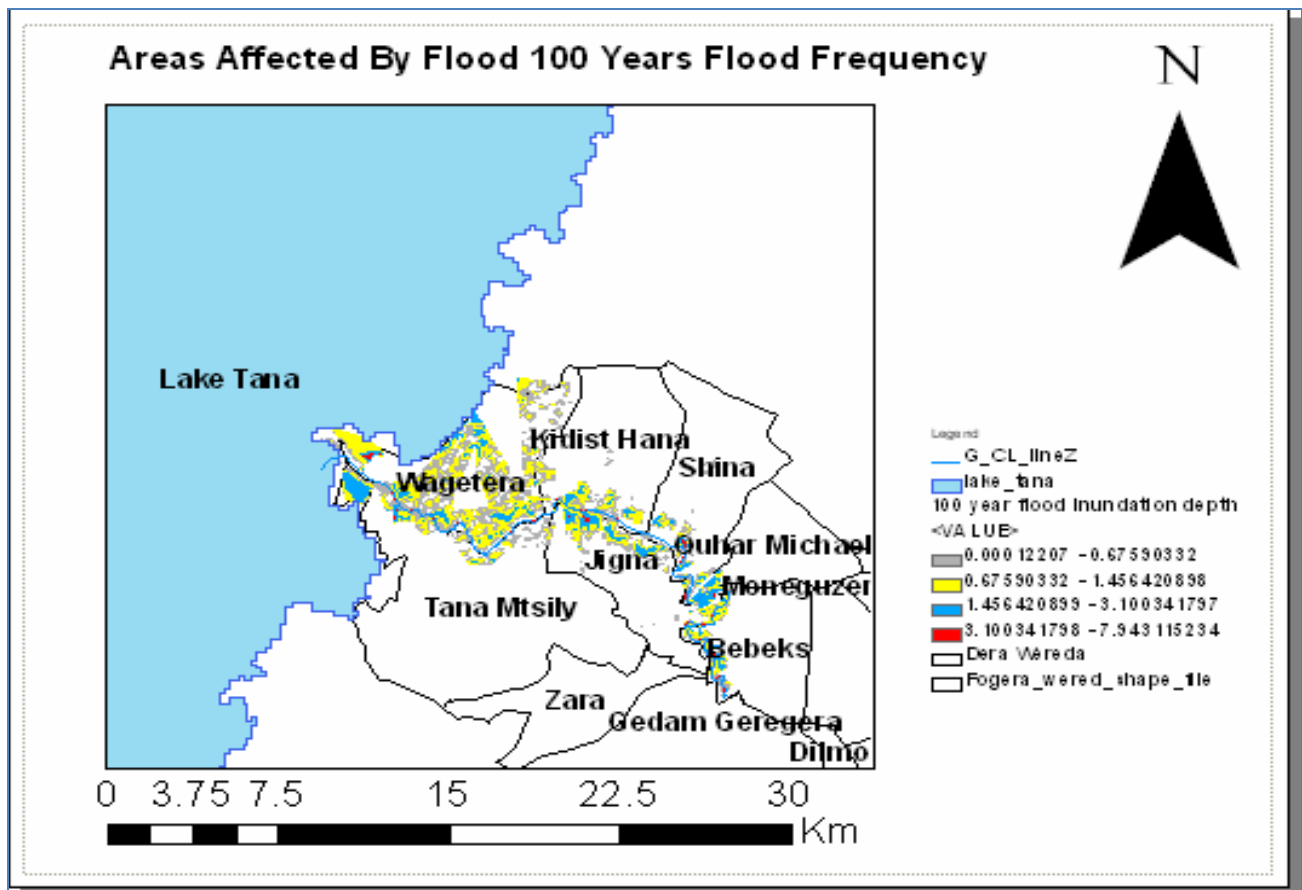


Fig 6.14 Areas Affected By 100 Years Flood Frequency In The Fogera-Dera Flood Plain

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

Similarly the area affected by the 2year flood frequency is shown below. The maximum flood inundation is 7.36m. The flooded kebles of the area from the two side of the flood plains are similar to the 100 year flood frequency but with different magnituded . The flood inundation map and areas affected by the flood is show below in the figure 7.2

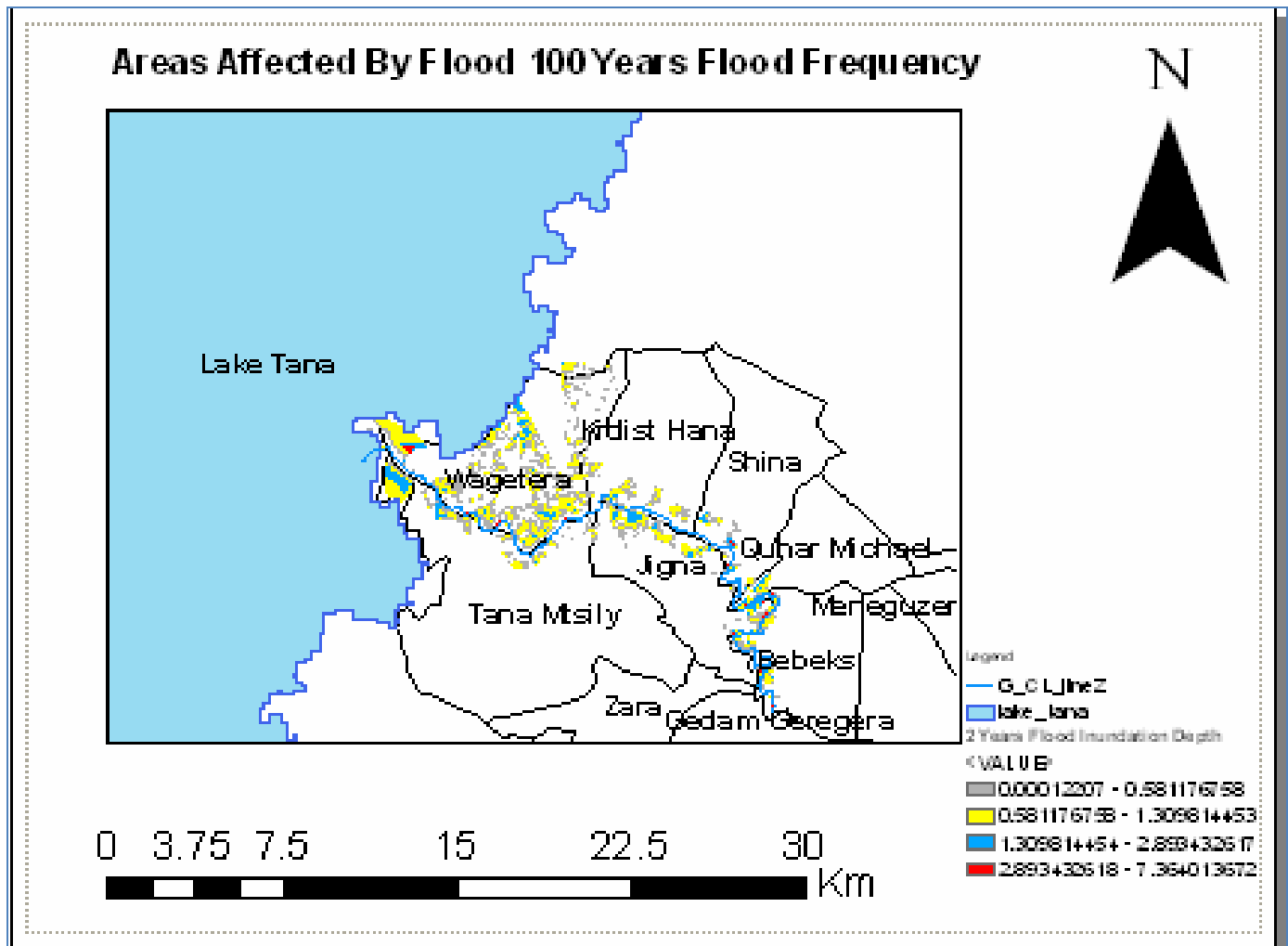


Fig 6.15 Areas Affected By 100 Years Flood Frequency In The Fogera-Dera Flood Plain

### 7 RECOMMENDETION AND CONCLUSION

#### 7.1 Recommendation

As it can be understand from the model results discussed in chapter six all most large portion of the lower reach of the river is flooded with high inundation depth and decreasing as we go from the downstream to up stream of the the river. The inundation depth is large in depth up to 7.94 m and within this depth of flood the effect of flood on life and property is very high. Thus depending on this understanding it is recommended that the area is to be free of any agricultural activities and residence of people in order to avoide the risk of flooding in the area. Especially the lower kebel's of the Fogera weredas (Wageta ,Kidist Hana And Shina) which are affected maily from the flood should be avoided from any infrastructure development and investment. Acording to the result of this flood inundation mapping the area could be free from any of activites.

For the other portion of the flood plain a river training activities is recommended because of its low flood inundation .The river training could be construction of dykes and other structures to avoide the over bursting of the flood from the river banks and avoiding silting problems deposited within the the river course also one mechanism to avoide flooding .Thus this part of the flood plain could be used for agricultural activities and development of any other infrstructure.

But for further recommendation and select the best smethods , it is required risk analysis of the flooding in the flood plain .Thus this is out of this thesis work

#### 7.2 Conclusion

The main source of flooding in Fogera-Dera flood plain is a result of flash flood originating from rainfall on the upper catchment of the Gumera River catchment from Debretabor high lands to the lower reach of the Fogera flood plain . It is formed as a result of intensive showers, and steep slope of the area.

100 years return period peak flood discharge estimated using Computer Programs HEC-GeoHMS and HEC-HMS found to be 319.0 m<sup>3</sup>/sec and ERA IDF curves is used for flood analysis in plain..

As explained above in chapter six , the 100 years and 2years flood frequency values are used for the flood mapping.

Flood affected areas are delineated for 100 years and 2 years return period peak flood discharge using two models HEC\_GeoRAS and HEC\_RAS one after another (i.e first

HEC\_GeoRAS then HEC\_RAS then back to HEC\_GeoRAS) and wageta, kidist Hana, Shina, Quhar Michael and Bebeks, Tana Mistily and Jigna are found to be mainly affected areas. The left and right sides distance range of Gumera River which are affected by the 100yrs return period peak flood varies from place to place. The result is shown on sub chapter 6.2. The total area affected by this flood is 31.36 km<sup>2</sup> and the area affected by the 2year flood inundation of 7.36m is 22.27 Km<sup>2</sup>.

Finally, to select the type of mitigation measure it is recommended to undertake further flood risk analysis study instead of the traditional way of design to protect the area from flood.

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- ✚ USACE (November 2008). Flood Damage Analysis user's manual.

**ANNEXES**

**APPENDIXA :DMC Meteorological stations of the study Area**

Table A1: Annual Precipitation Of Each Station

<b>Annual Precipitation Of Each Station</b>				
year	Debretabor	woreta	Bahir dar	Average
1992	3.71	3.1	3.9	3.57
1993	4.31	3.9	4.52	4.24333
1994	4.92	3.6	4.06	4.19333
1995	4.3	3.6	4.06	3.98667
1996	4	3.57	4.04	3.87
1997	5.5	2.5	3.31	3.77
1998	4.17	4.17	3.89	4.07667
1999	4.55	4.22	4.04	4.27
2000	4.61	3.9	4.29	4.26667
2001	3.7	3.1	4.27	3.69
2002	4.13	3.1	4.1	3.77667
2003	4.2	3.46	4.51	4.05667
2004	4.13	3.35	3.64	3.70667
2005	4.3	3.8	4.11	4.07
2006	4.3	4.15	4.06	4.17

Table A2: cummulative of each station

<b>cummulative of each station</b>			
Debretabor	woreta	Bahir dar	cummmlative average
3.71	3.10	3.90	3.57
8.02	7.00	8.42	7.81
12.94	10.60	12.48	12.01
17.24	14.20	16.54	15.99
21.24	17.77	20.58	19.86
26.74	20.27	23.89	23.63

<b>cummulative of each station</b>			
<b>Debretabor</b>	<b>woreta</b>	<b>Bahir dar</b>	<b>cummmlative average</b>
30.91	24.44	27.78	27.71
35.46	28.66	31.82	31.98
40.07	32.56	36.11	36.25
43.77	35.66	40.38	39.94
47.90	38.76	44.48	43.71
52.10	42.22	48.99	47.77
56.23	45.57	52.63	51.48
60.53	49.37	56.74	55.55
64.83	53.52	60.80	59.72

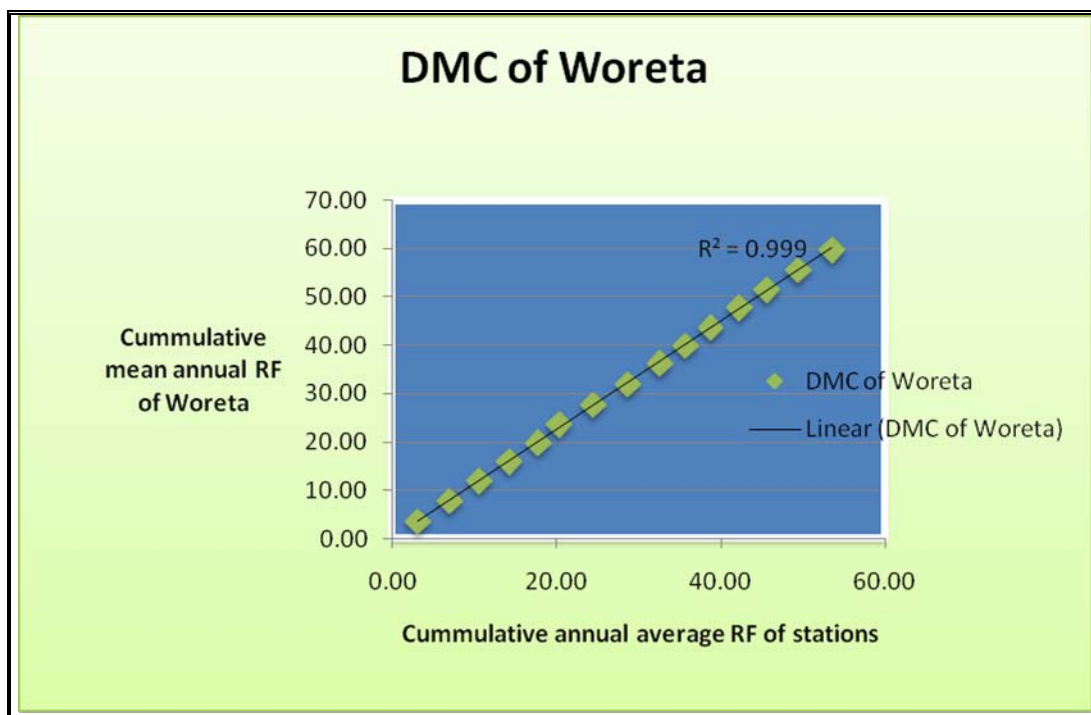


Fig A1:DMC Of Woreta Rain Fall Station

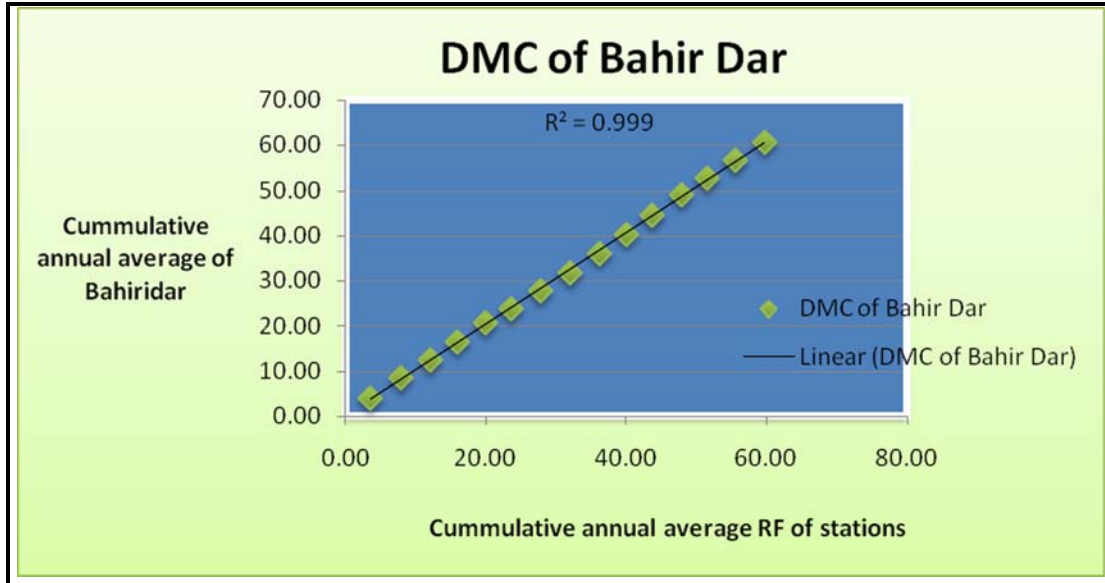


Fig A2:DMC Of Bahiridar Rain Fall Station

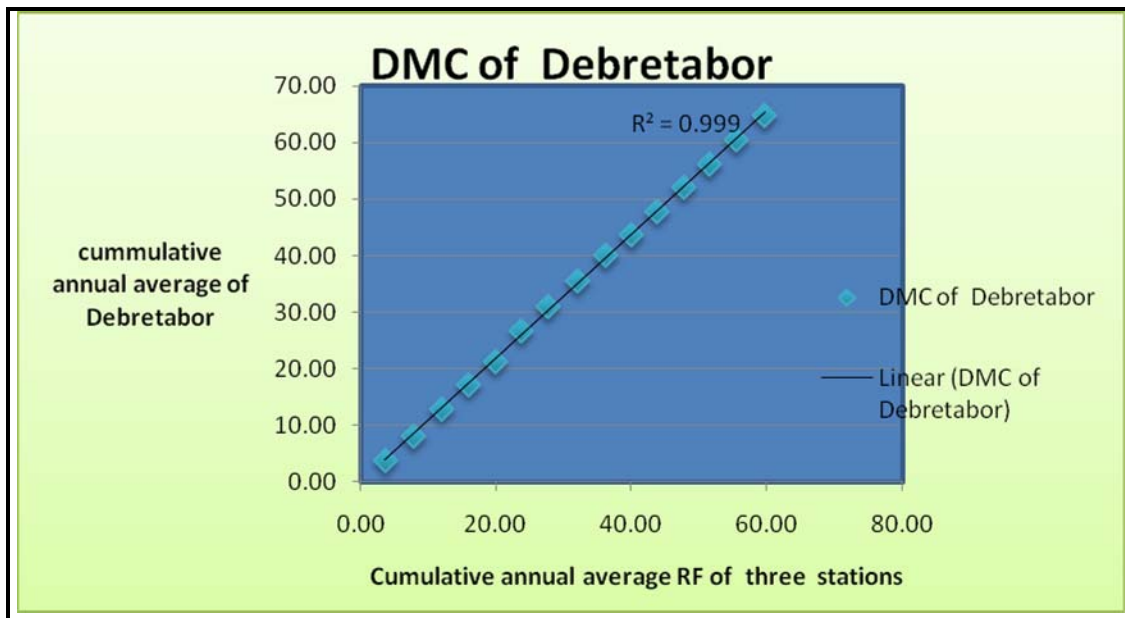


Fig A2:DMC Of Debrotabor Rain Fall Station

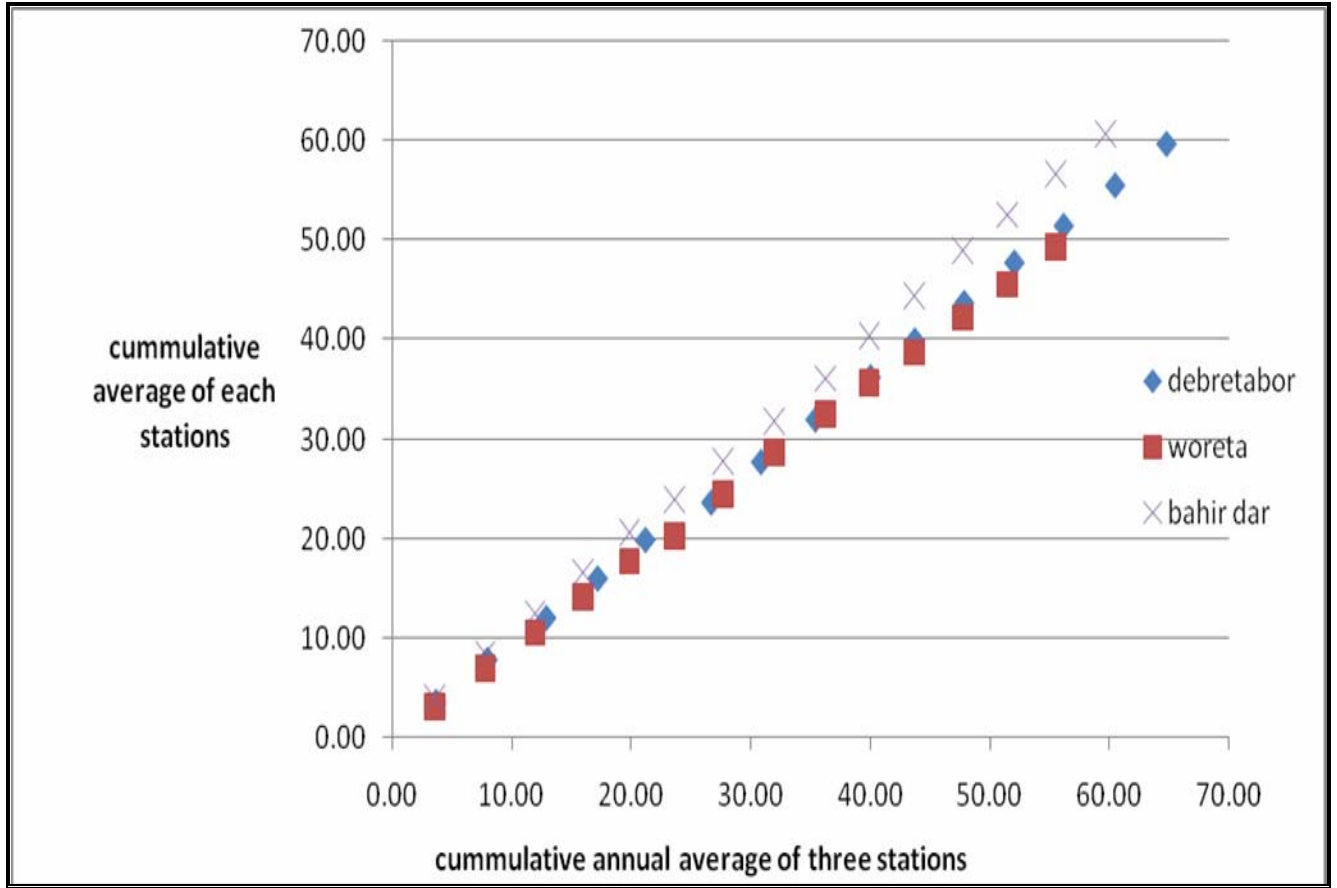


Fig A3:Consistency Checking For The Three Rain Fall Stations

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

### APPENDIX B: HEC- HMS Out Puts At The Gaging Stations

Table B1: Optimized Parameter For HEC- HMS Daily Annalysis

Optimized Parameter Results for Trial "Trial 18"						
Project: Gumera HMS simulation      Optimization Trial: Trial 18						
Start of Trial: 01Jan1992, 00:00      Basin Model: Basin model End of Trial: 01Jan2001, 00:00      Meteorologic Model: Gumera met Compute Time: 29Aug2011, 23:57:42      Control Specifications: Control 1(simulation-calbrat)						
Element	Parameter	Units	Initial Value	Optimized Value	Objective Function	Sensitivity
Reach-1	Muskingum K	HR	21.13	21.440		0.00
Reach-1	Muskingum X		0.18464	0.17378		0.00
Reach-2	Muskingum K	HR	28.8	97.200		-0.02
Reach-2	Muskingum X		0.18464	0.17378		0.00
Reach-3	Muskingum K	HR	6.9638	6.5543		0.00
Reach-3	Muskingum X		0.13618	0.12817		0.00
Subbasin-1	Clark Storage Coeffic...	HR	9.3639	9.3639		0.00
Subbasin-1	Clark Time of Concen...	HR	29.244	29.661		-0.01
Subbasin-1	Constant Loss Rate	MM/HR	0.10796	0.10958		-0.04
Subbasin-1	Initial Loss	MM	0.5	0.50000		0.00
Subbasin-2	Clark Storage Coeffic...	HR	256.03	387.14		-0.03
Subbasin-2	Clark Time of Concen...	HR	24	24.000		0.00
Subbasin-2	Constant Loss Rate	MM/HR	0.52447	0.53201		-0.22
Subbasin-2	Initial Loss	MM	0.5	0.50000		0.00
Subbasin-3	Clark Storage Coeffic...	HR	93.364	89.667		0.01
Subbasin-3	Clark Time of Concen...	HR	24	24.000		0.00
Subbasin-3	Constant Loss Rate	MM/HR	0.10250	0.10351		-0.07
Subbasin-3	Initial Loss	MM	0.5	0.50000		0.00

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

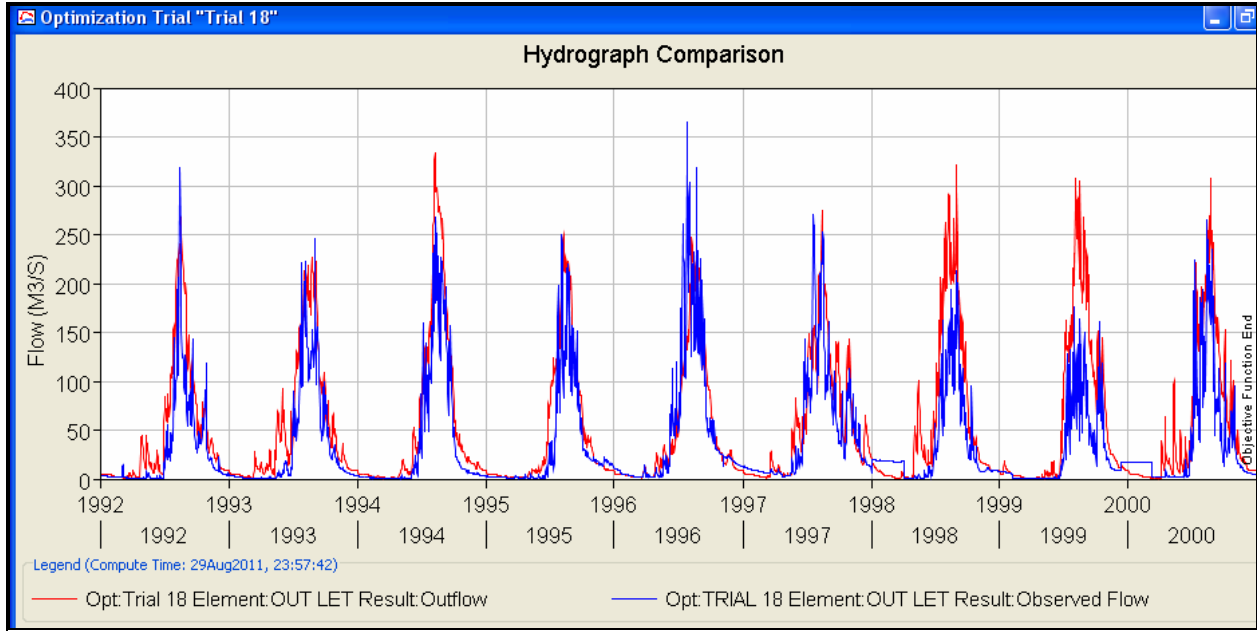


Fig B1: Daily Hydrograph Comparison Between Resulted HEC- HMS Out Flow Virus Observed Flow

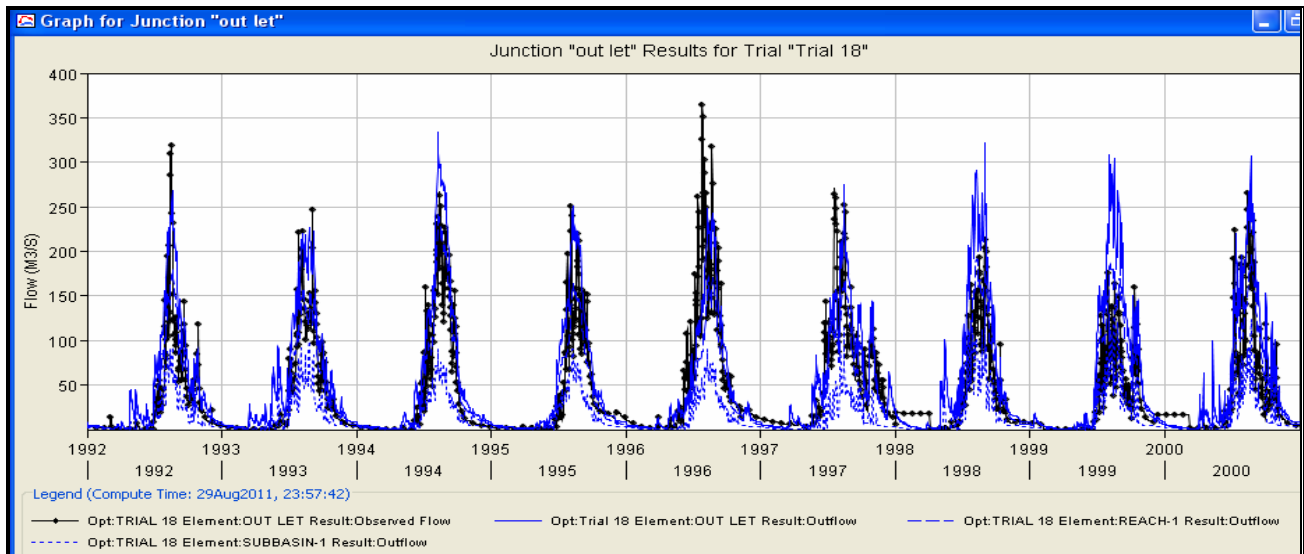


Fig B2: Daily Hydrograph Results Of HEC- HMS Out Flow Virus Observed Flow

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

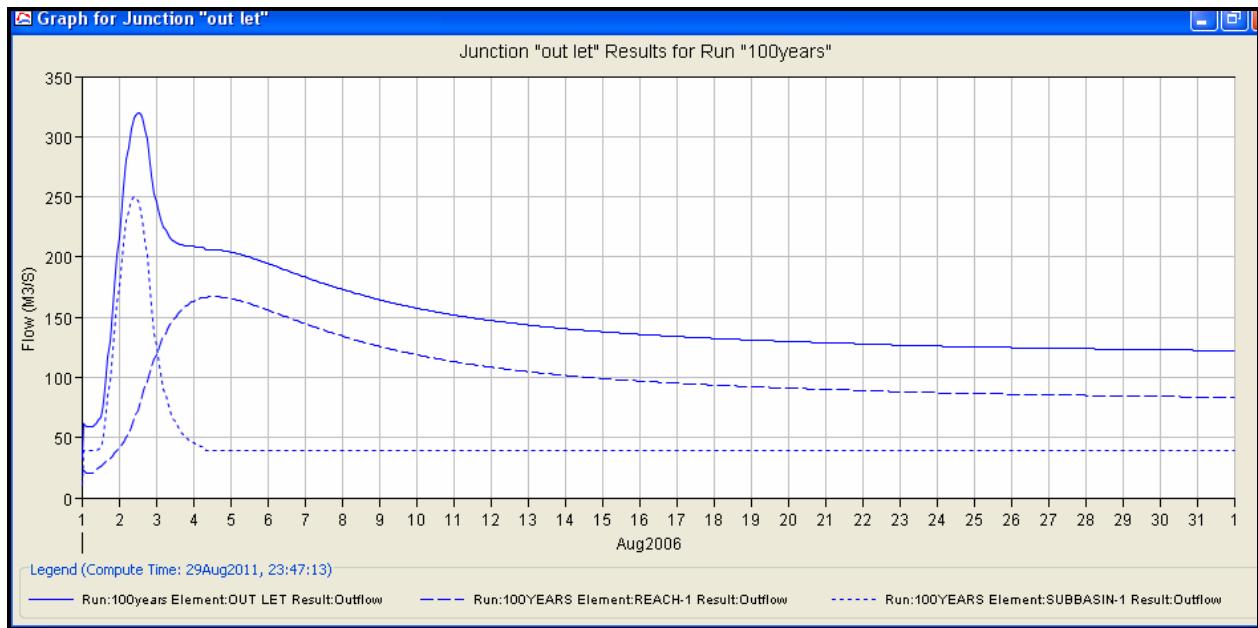


Fig B3: HEC- HMS Frequency Hydrograph For 100years Return Period

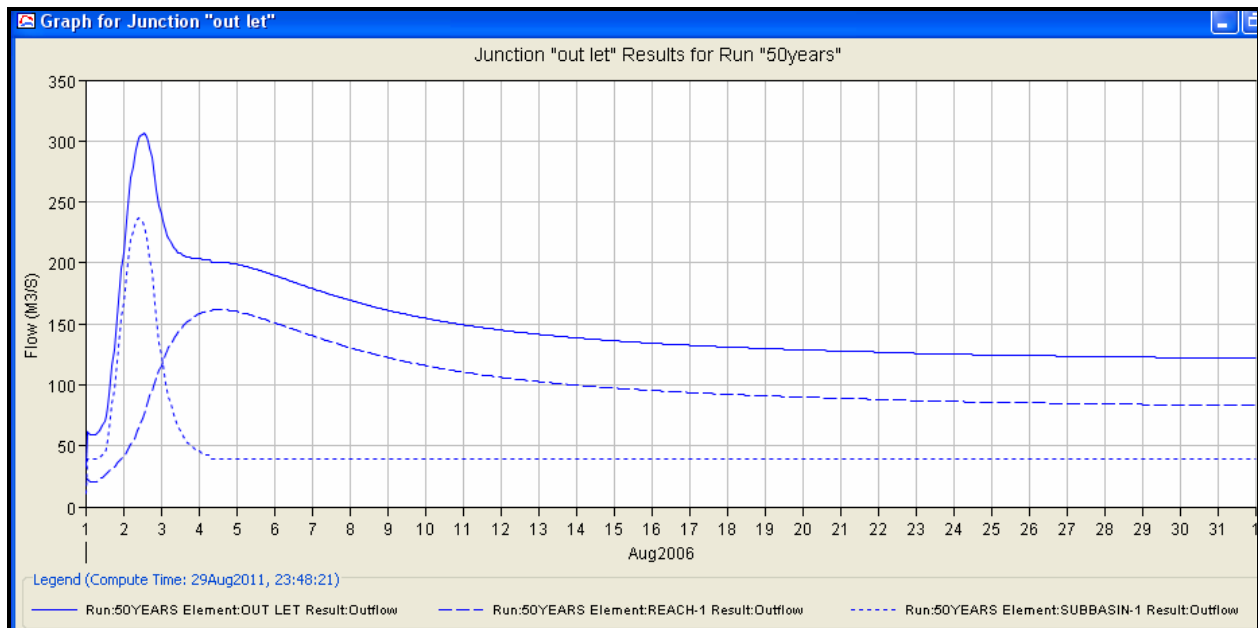


Fig B4: HEC- HMS Frequency Hydrograph For 50years Return Period

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

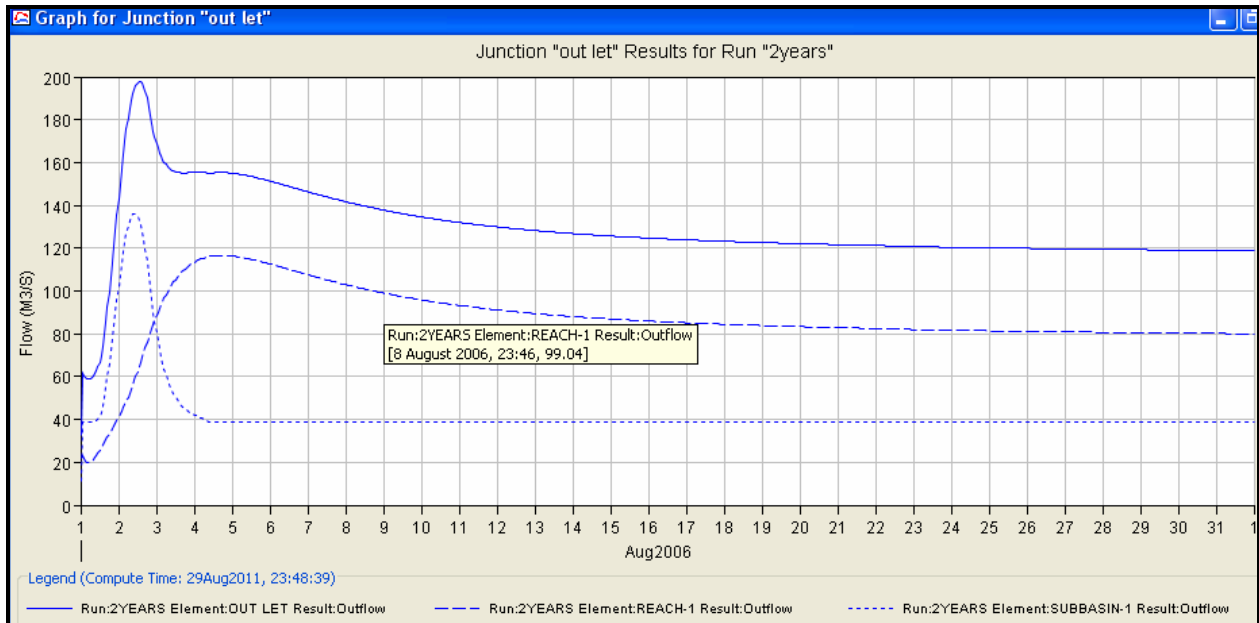


Fig B5: HEC- HMS Frequency Hydrograph For 2years Return Period

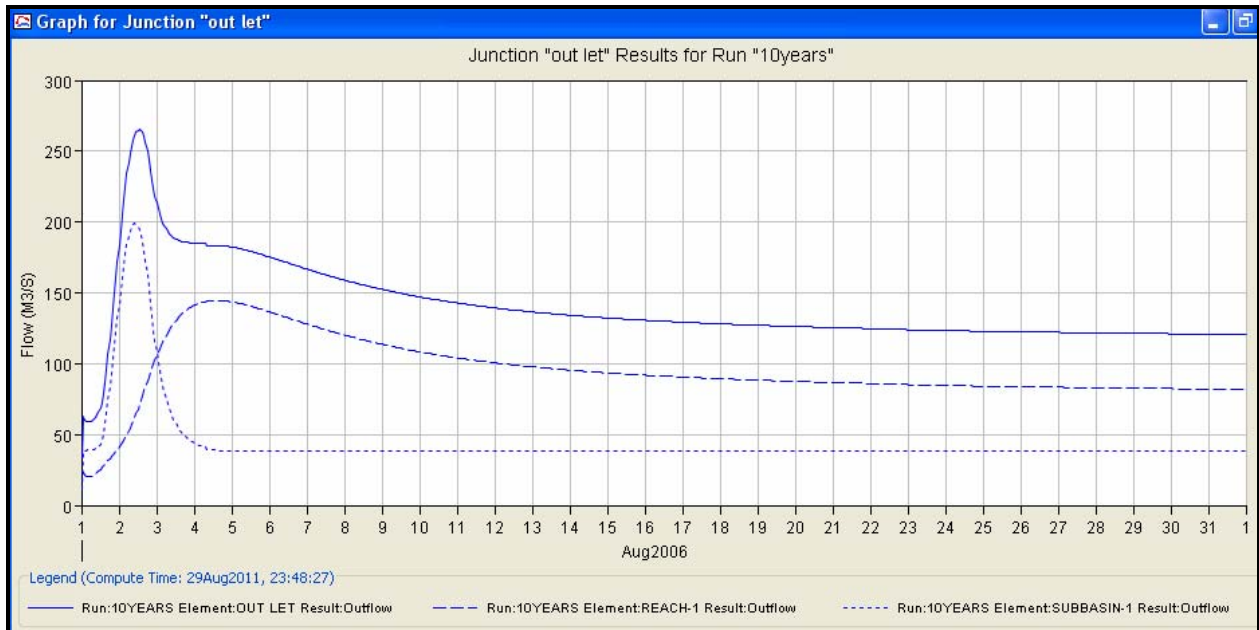


Fig B6: HEC- HMS Frequency Hydrograph For 10years Return Period

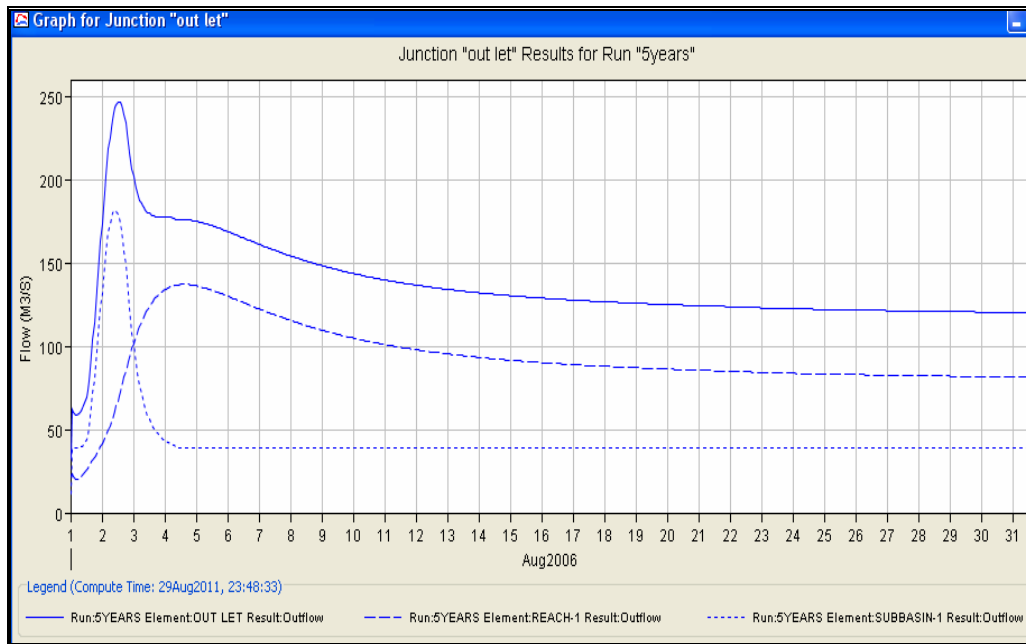


Fig B7: HEC- HMS Frequency Hydrograph For 5years Return Period

## APPENDIX C : HEC RAS MODEL OUT PUTS

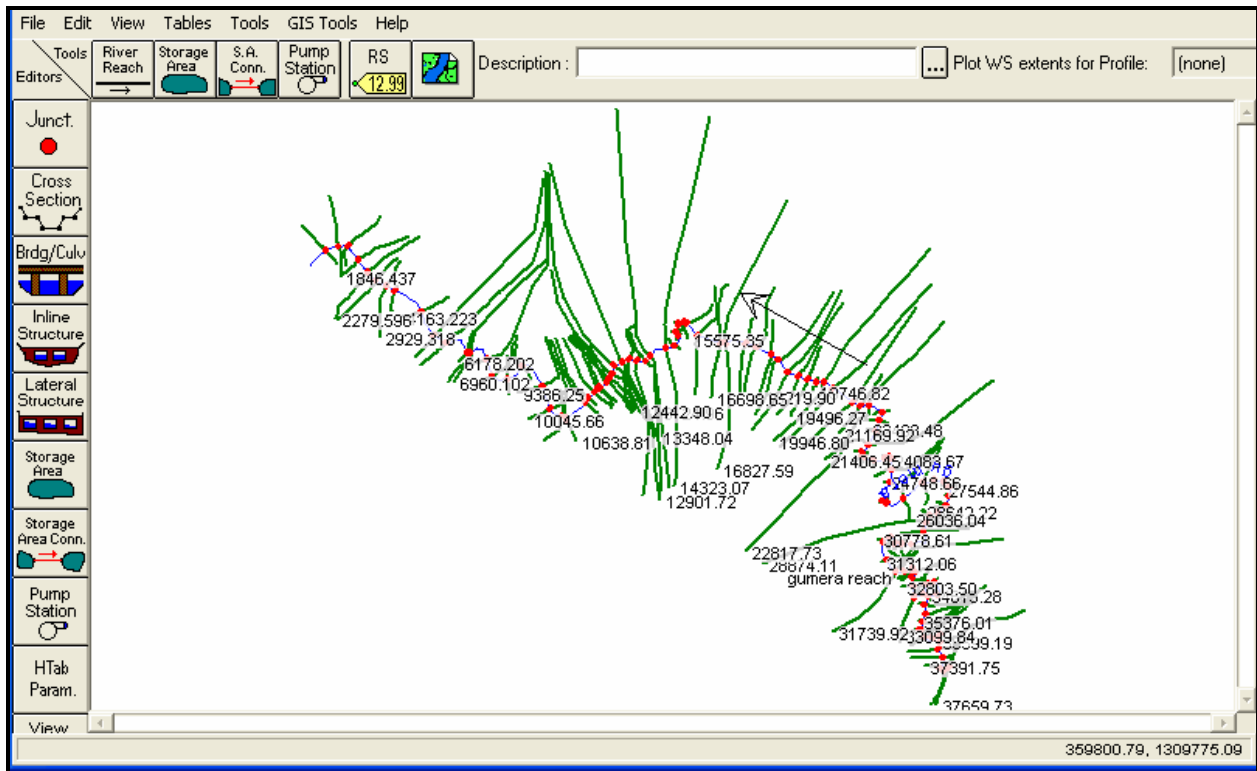


Fig C1 :Schematic Lay Out Of The Lower Reach In Hec-Ras Model

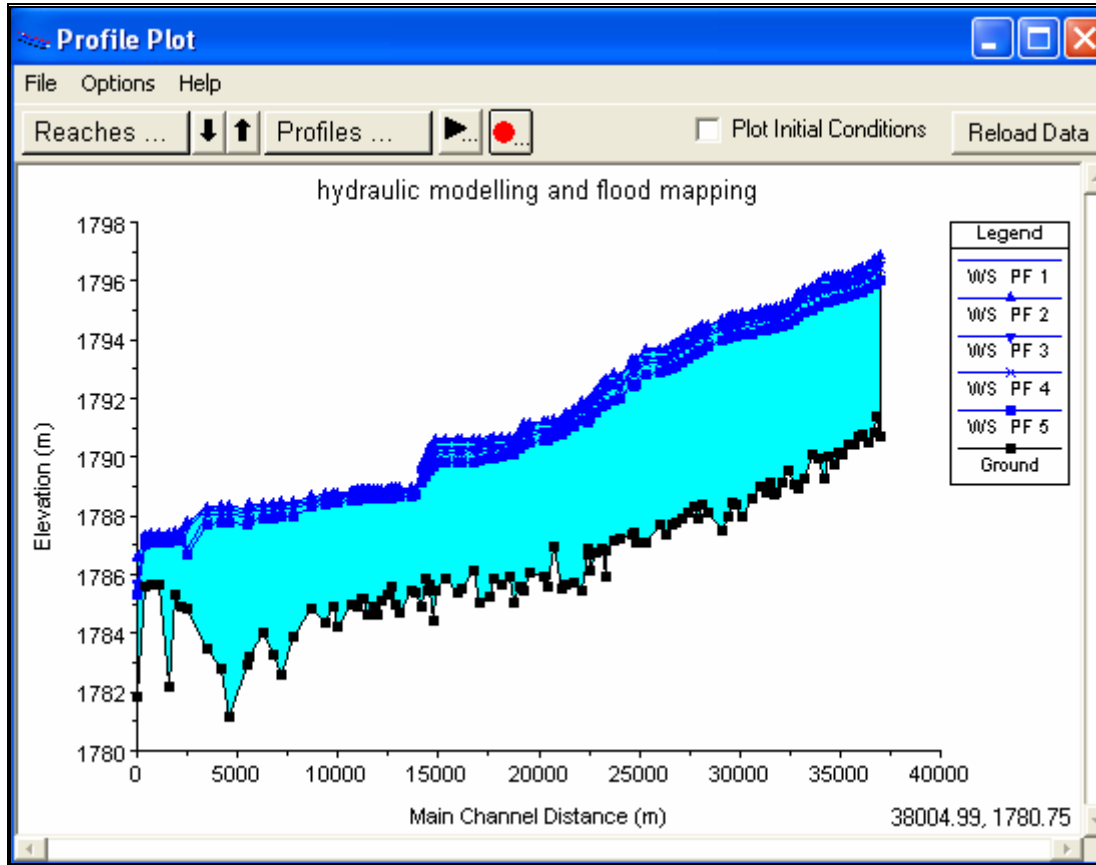


Fig C2 :Flood Profiles For The Five Flood Return Periods

## Hydraulic Modeling and Flood Mapping of Fogera Flood Plain

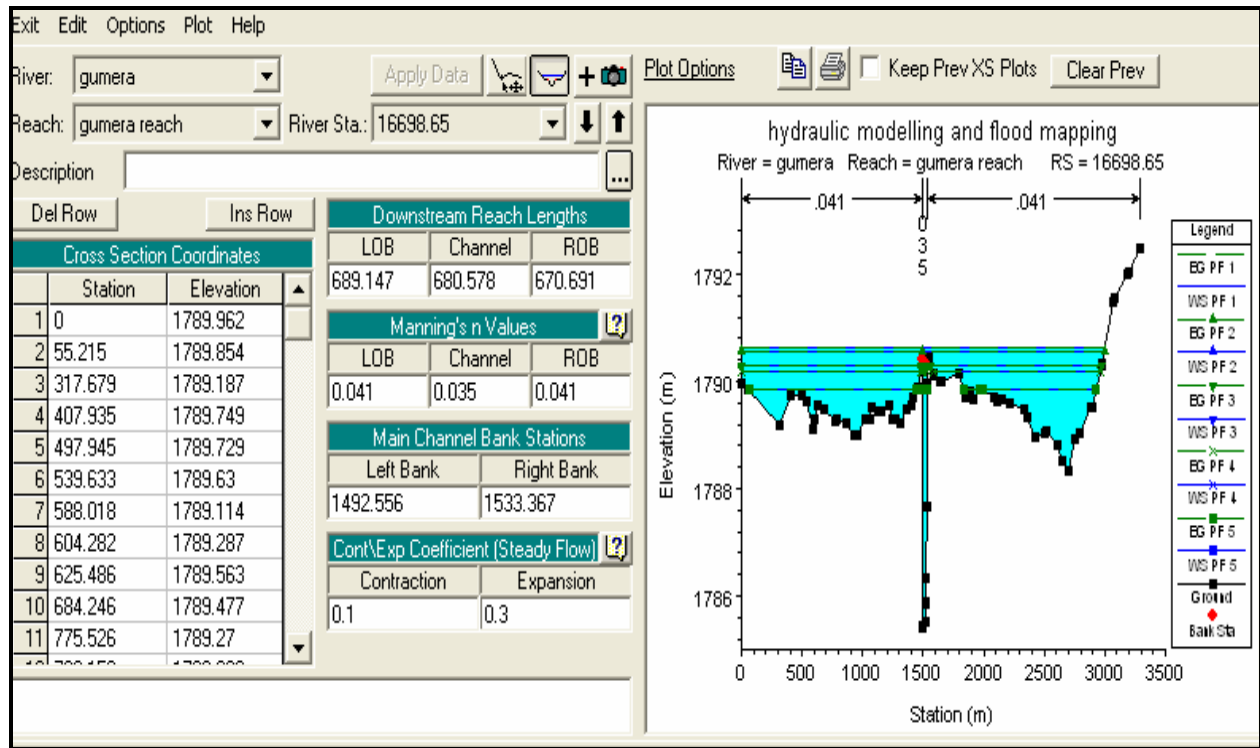


Fig C3 :Crosssectional Flood View For The Station 16698.65

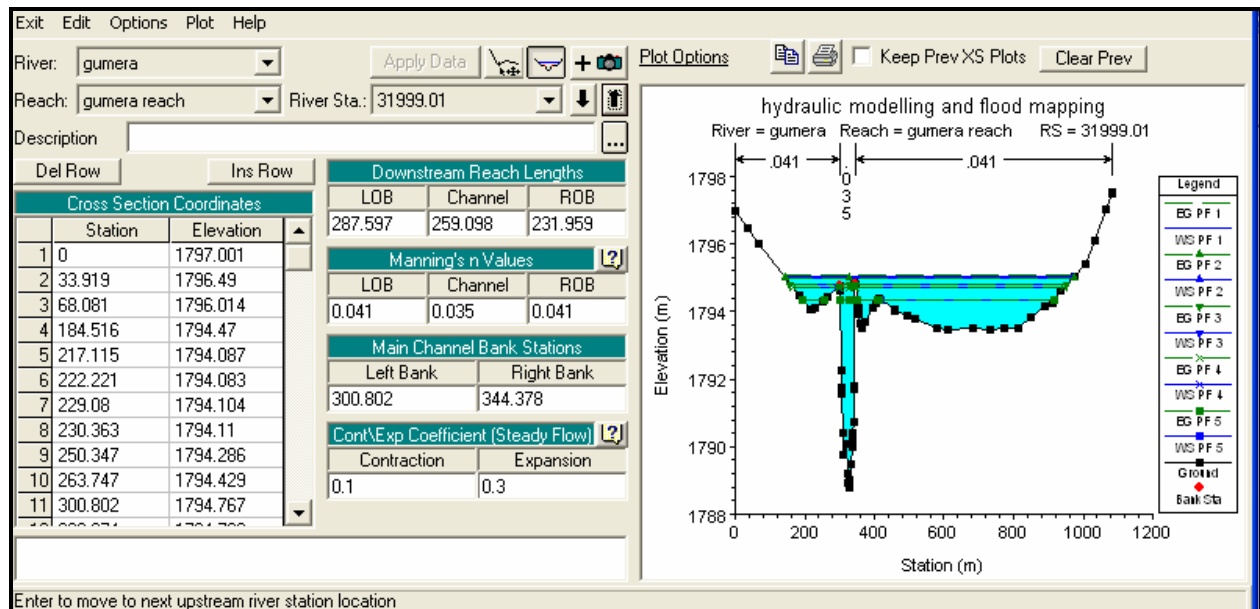


Fig C4 :Crosssectional Flood View For The Station 31999.01

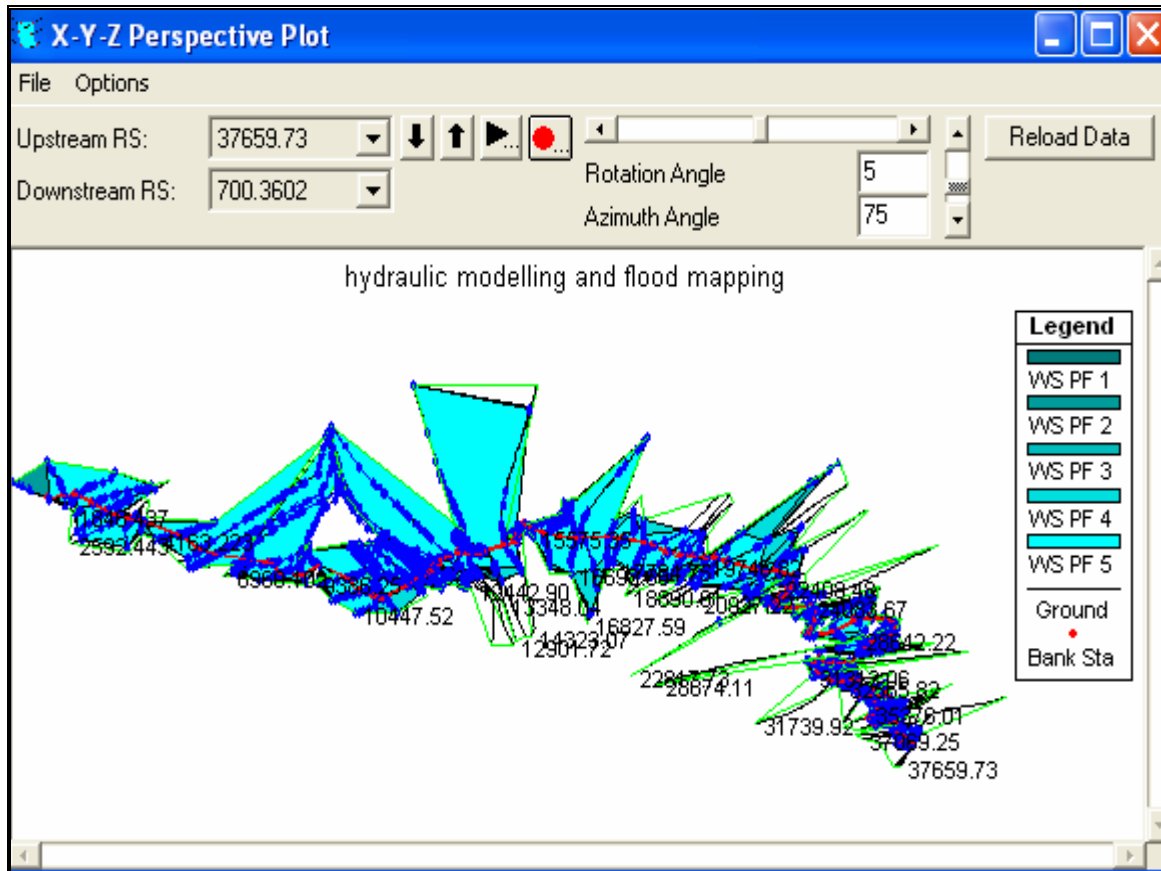


Fig C5 :3D Perspective View Of The Flood Plain And The Channel In HEC-RAS Five Return Periods

APPENDIX D :Flood Mapping Of The Flood Plain

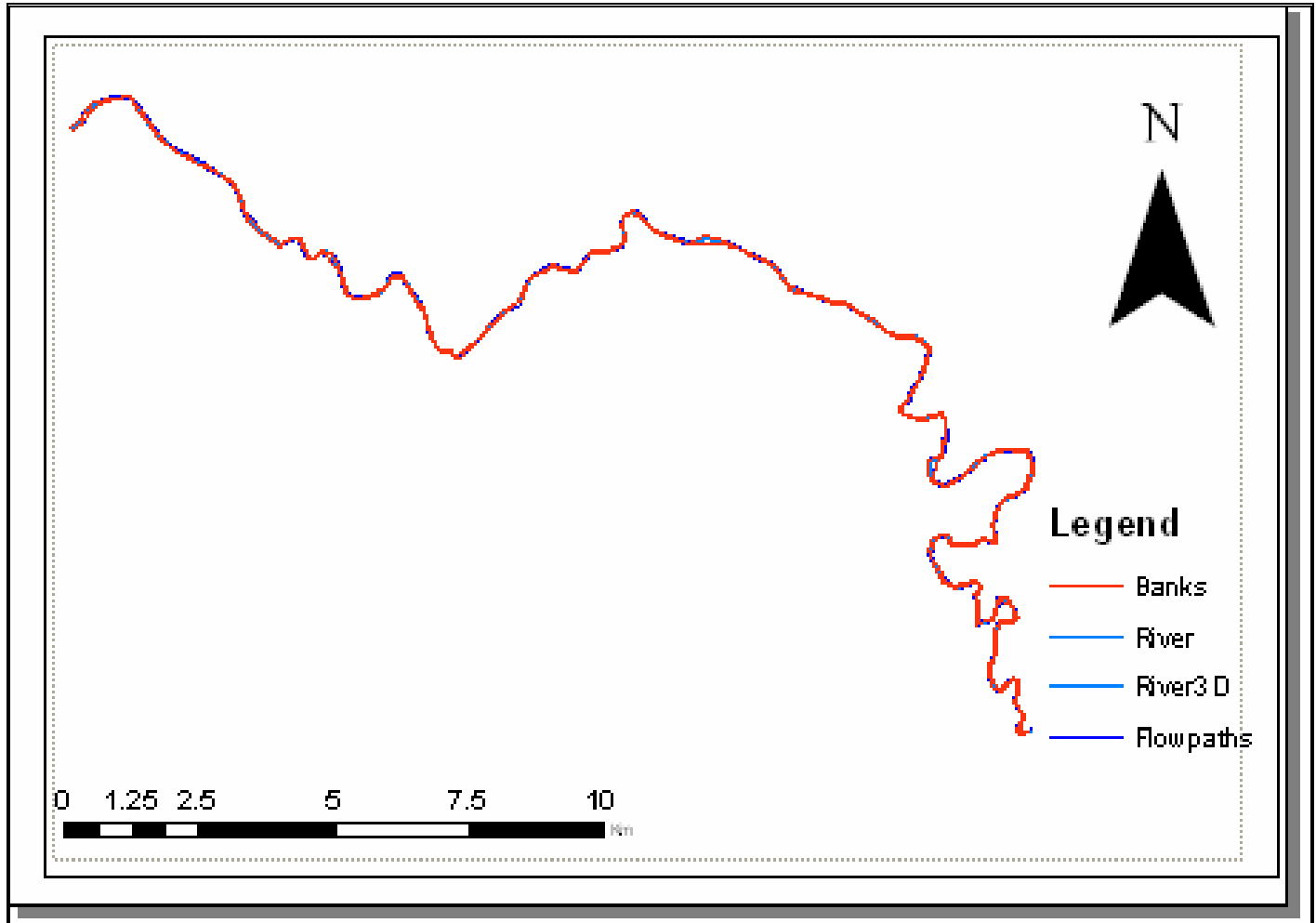


Fig D1:HEC-GeoRas Layer Created

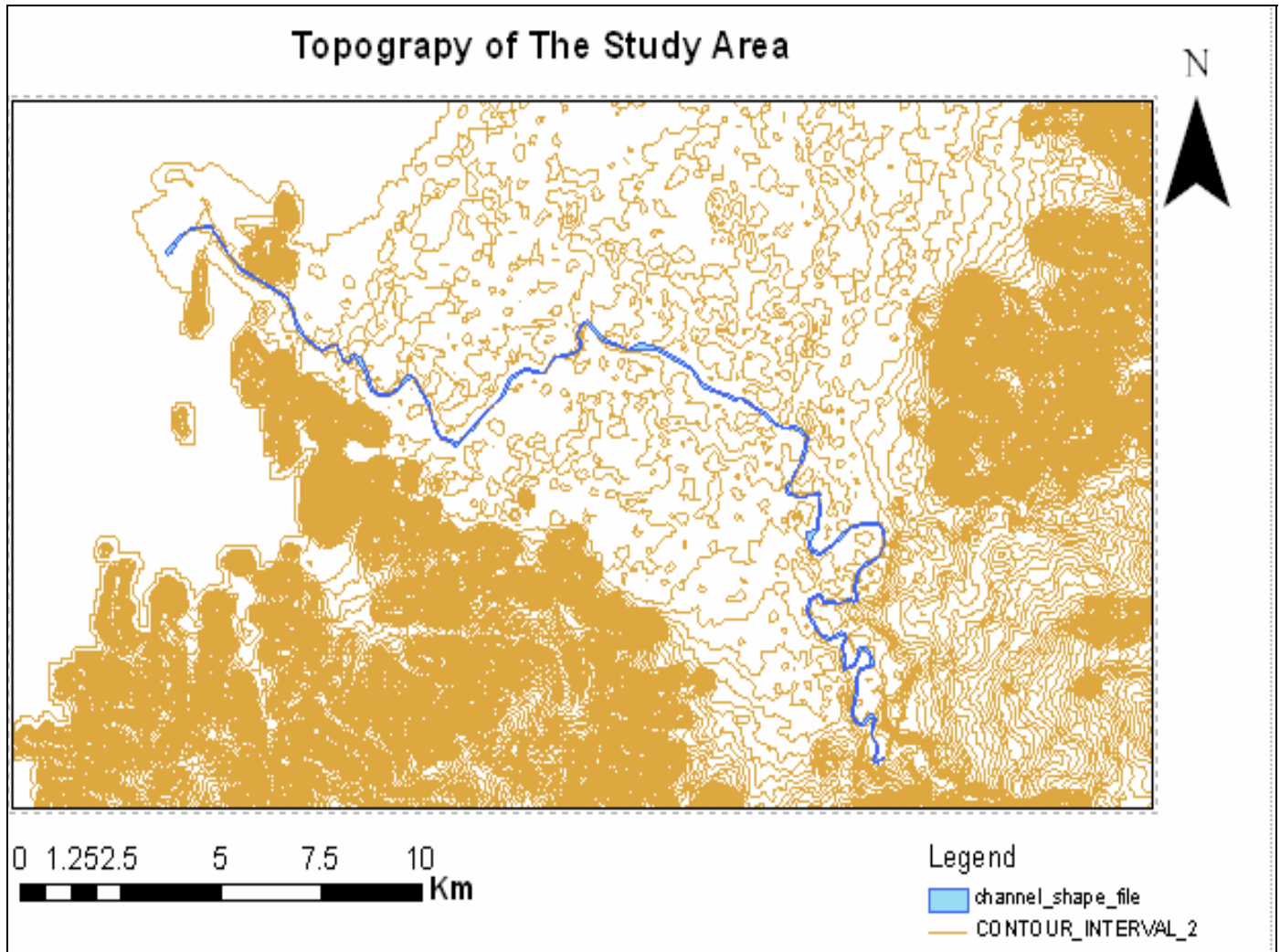


Fig D2: Topography Map For Contour Interval Created For The Flood Plain

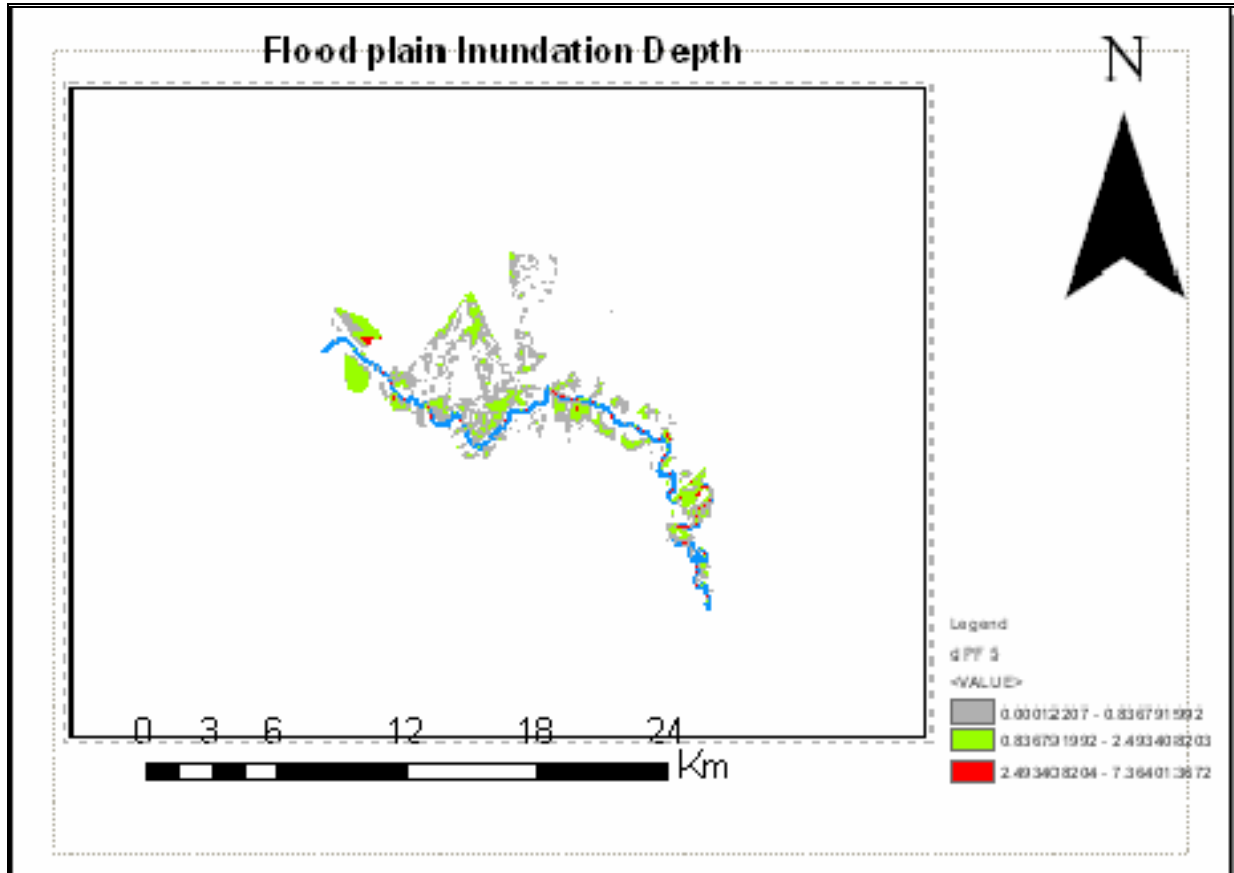


Fig D3: Flood Plain Inundation Depth For 2 Years Storm

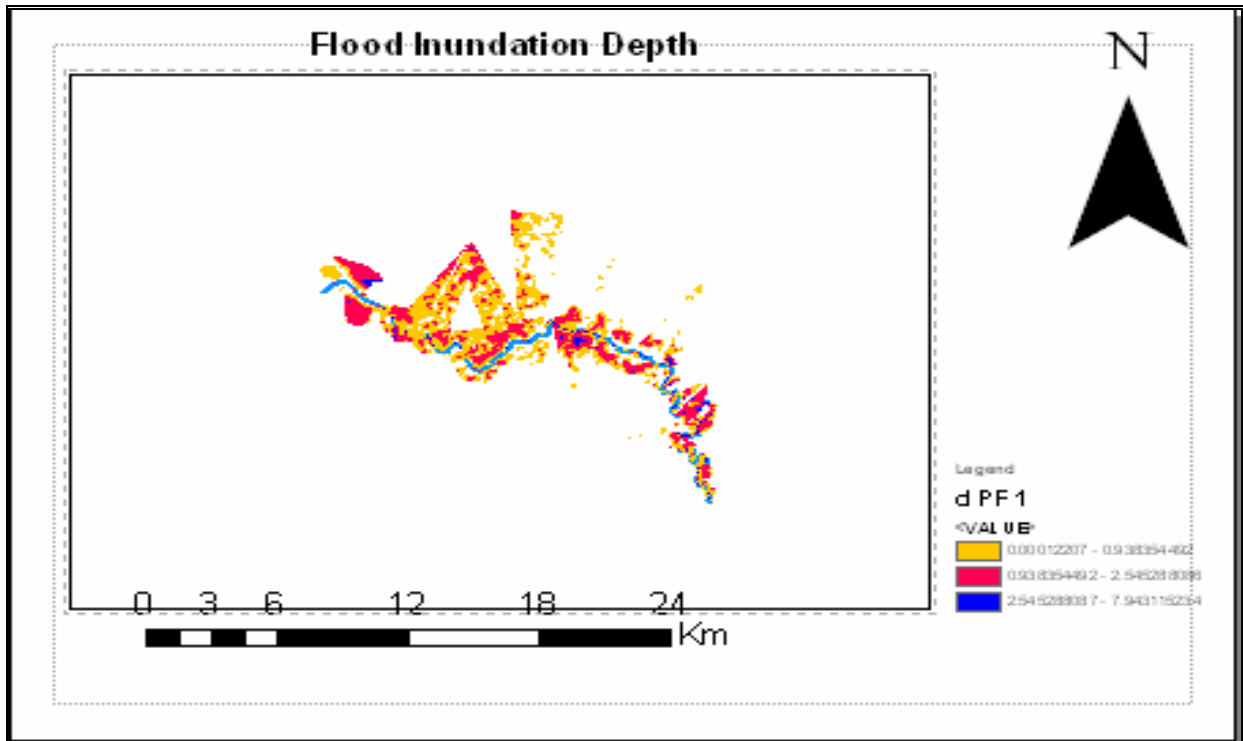


Fig D4: Flood Plain Inudtion Depth For 2 Years Storm

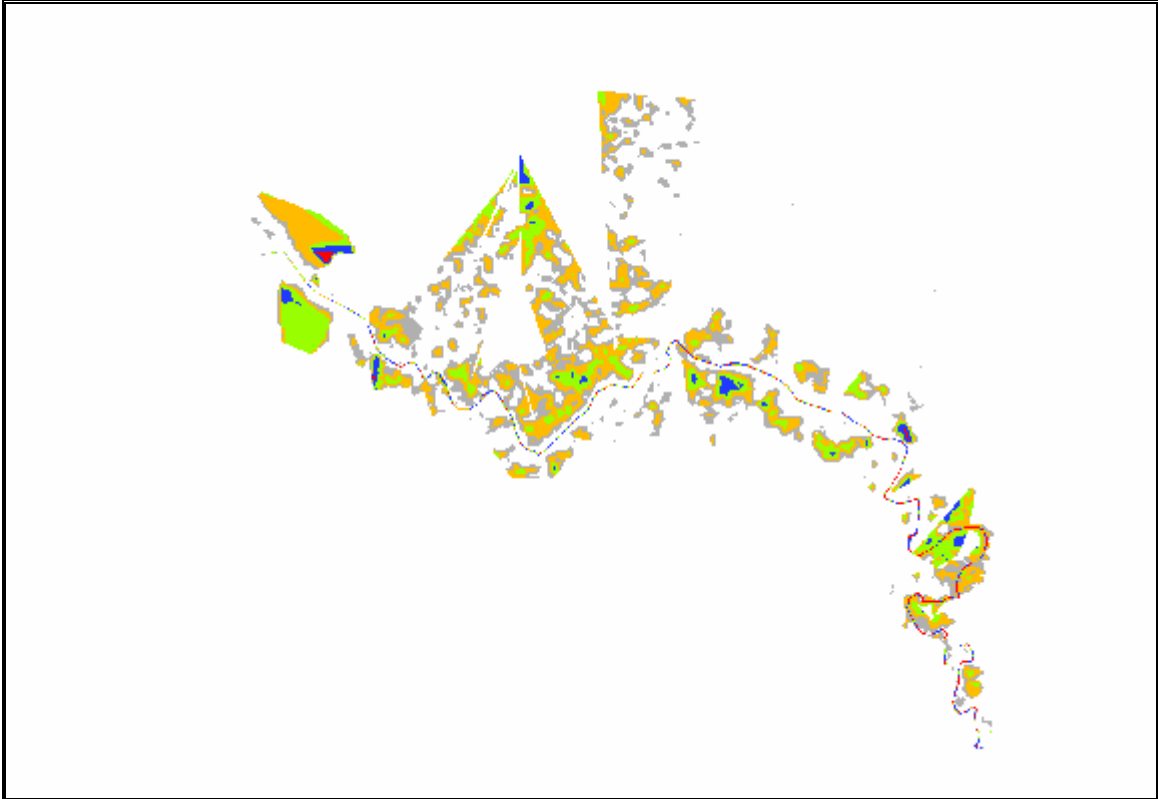


Fig D5: Flood Plain Inundation Depth For 50Years Storm

Table D1: Values Of Peak Discharge And Inundation Areas For The 2,5,10,50 And 100 Return Periods

Return Period(years)	Peak Discharge (m <sup>3</sup> /s)	Total Area Inundation In Km <sup>2</sup>
<b>100</b>	319.6	31.36
<b>50</b>	306	30.45
<b>10</b>	265.4	27.32
<b>5</b>	246.8	25.96
<b>2</b>	197.7	22.271

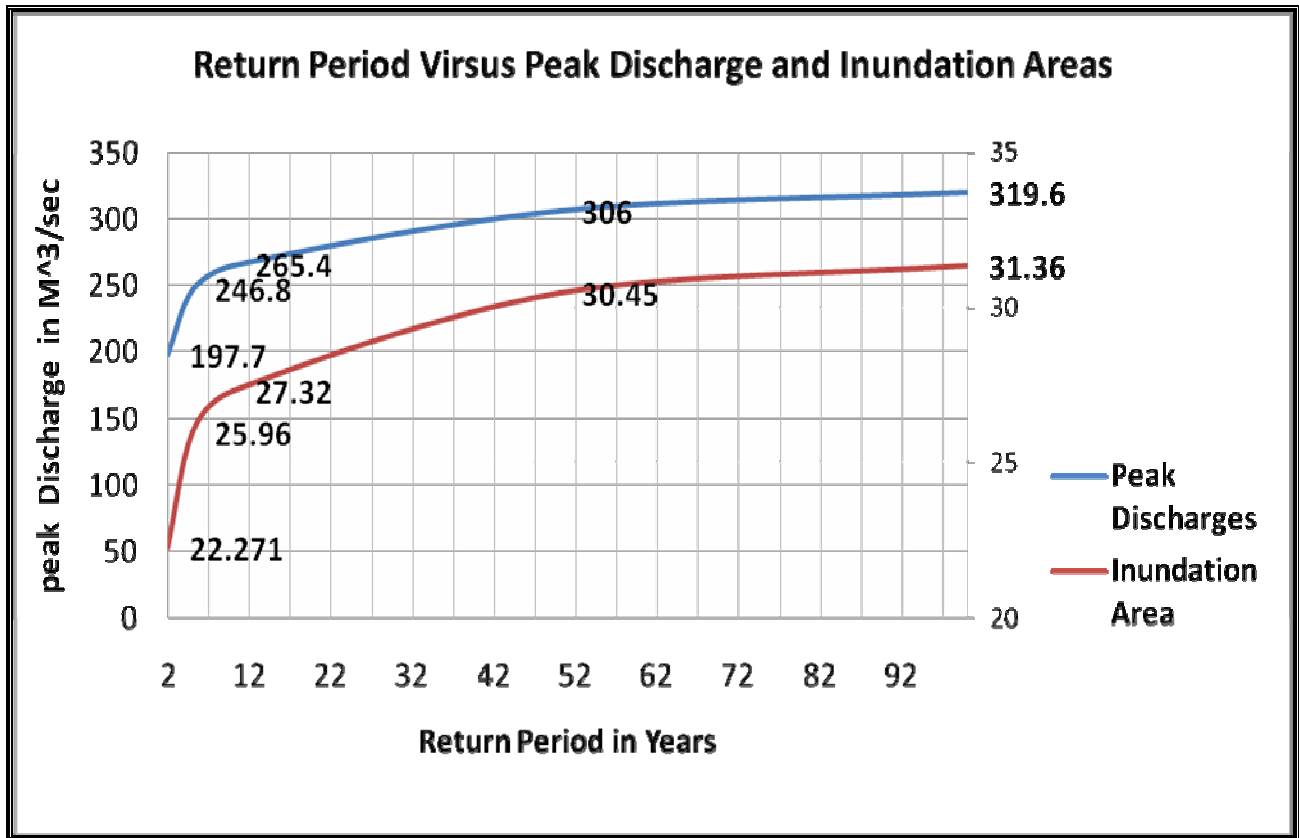


Fig D6: Peak Discharge And Inundation Areas

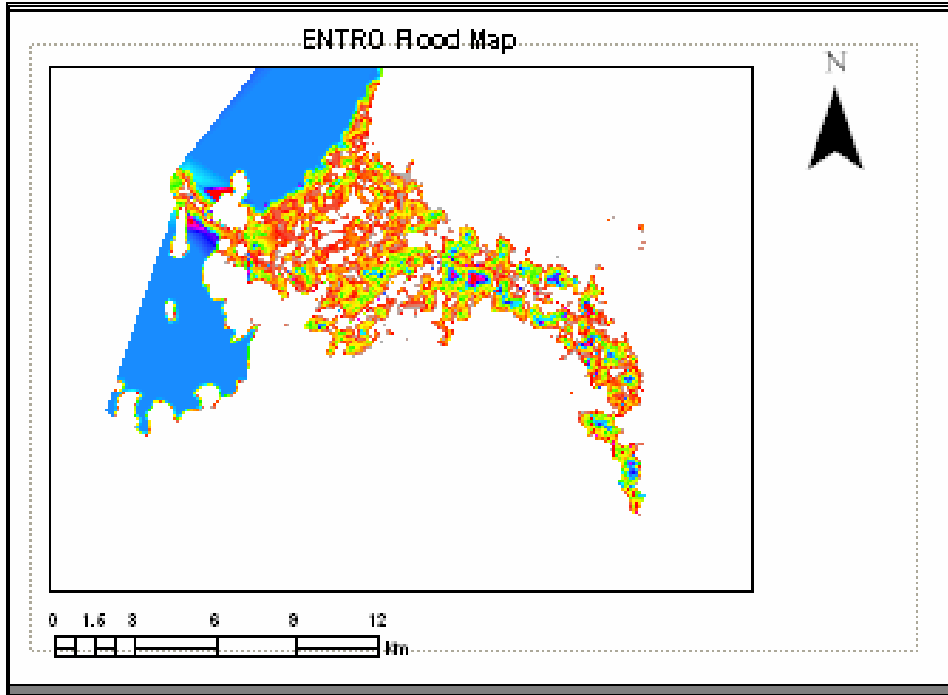


Fig D7: ENTRO Flood Mapp