ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF CIVIL ENGINEERING
HYDRAULICS ENGINEERING STREAM

Prediction and Flood Modeling For Kello Town

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Hydraulics Engineering

By Admasu Bereded

Submission Date March 2017

CERTIFICATION

I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a dissertation entitled: **Prediction and Flood Modeling for Kello Town** and here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements of the degree of Masters of Science in Hydropower Engineering.

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Dr. Dereje Hailu (Supervisor)

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Date

DECLARATION AND COPY RIGHT

I, Admasu Bereded Teklegiorgis, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

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Date_______________________________

Thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering under Hydraulics Engineering Stream.

Prepared by Admasu Bereded

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Acknowledgement

I would like to express my deep gratitude to my advisor, Dr Dereje Hailu, for his priceless support in supervising and advising my thesis work. My sincere appreciation goes to all staff members of Ministry of Water Resources particularly Hydrology and GIS department, Metrology Agency for their appreciable support in providing me hydrological, metrological and other data. The Ethiopian Mapping Authority also gratefully acknowledged since they helped me in providing 1:50000 scale maps of the target area.

Mahiber Kidusan is deserved my acknowledgement for its cooperation in giving us GIS training by assigning a GIS trainer. My acknowledgment is also goes to Haile who is a GIS trainer assigned by Mahiber Kidusan. My sincere appreciation goes to all staff members of Kemissie Agricultural and Disaster Prevention offices.

Finally, I wish to extend my gratitude to all staff members of Technology Department and others who helped me in one way another to carry out my research through remarkable encouragement, advice, material support and collaboration in every aspect.

Abstract

Nowadays, extraordinary floods are common to many parts of Ethiopia causing a lot of losses to human lives as well as damage to property. Though, Kello town is been one among such places that has affected by flash flooding from rainfall, in particular of the ungauged Kello River which passes through the center of the town. This thesis is aimed to identify flood causative factors, peak flood estimation, delineate flood risk areas that can be affected by extraordinary floods and to recommend mitigation measures. This is accomplished by adopting application software's like Arc View GIS, HEC-HMS and HEC-RAS and related software's. The data usage for this thesis is (DEM and contour), (soil, land use and 1:50,000 scale topo map) and text (rainfall and discharge) type. For precipitation modeling, ERA Intensity-frequency-duration curve is used for frequency storm. For geographic and terrain data, 30m resolution DEM for catchment, 4m contour interval for the town part and Kello Stream cross section are used. In this thesis, the flood magnitude is estimated for 2, 5, 10, 25, 50 and 100years return period peak flood discharge using Computer Programs HECGeo-HMS and HEC-HMS. And the corresponding results are estimated as 38.05, 47.38, 67.28, 81.87, 92.66 and 103.33m^3/sec. 50 and 100years peak discharge is used for further analysis which is flood mapping. Based on the result full of the town, the right and left side of the cultivated land and left and right sides of Kello Stream are found to be the vulnerable areas. According to the flood delineation an area of 92.7 and 95.5ha of land will be inundated by 50 and 100 year and this flood has an inundation depth of 4.7806m at the downstream of the catchment and decreases to the upstream of the catchment. Besides this mitigation measures considering different alternative measures levee construction is found to be best fitted for the study area along the selected reach of the Kello stream and Kello Town and the agricultural area.

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ABBREVIATIONS

ADPC .... Agricultural Development Planning Center
CN .... Curve Number
DAs .... Developmental Agencies
DEM .... Digital Elevation Model
DTM .... Digital Terrain Model
E .... East
EM-DAT …………………… Emergency Events Database, the International Disaster Database
EQN .... Equation
ERA .... Ethiopian Roads Authority
FUPI .... Federal Urban Planning Institute
GDP .... Gross Domestic Product
Geo .... Geographical
GIS .... Geographical Information System
GPS .... Global Positioning System
GUI .... Graphical User Interface
ha .... Hectare
HEC .... Hydrologic Engineering Center
HMS .... Hydrologic Modeling System
ICSU .... International Council for Science
IPCC .... Intergovernmental Panel on Climate Change
Km .... Kilo-meter
MK …………………… Mahiber Kidusan
m .... Meter
M .... Million
masl .... Meter above sea level
mm .... milli-meter
MoWR .... Ministry of Water Resources
N .... North
OFDA/CRED...................... Office of Foreign Disaster Assistance/ Centre for the Epidemiology of Disasters
RAS .... River Analysis System
SCS .... Soil Conservation Service
Sec .... Second
TIN .... Triangular Irregular Network
U.S. .... United States
UH .... Unit Hydrograph
UN .... United Nation
USD .... United States Dollar
WWDSE........................... Water works Design and supervision Enterprise
Yr .... Year

1. INTRODUCTION

1.1 Background

According to (Daniel, 2009) natural disasters are common in today's world. They are the result of sudden changes in the state of natural elements due to natural forces and triggering or accelerating anthropogenic activities. Most of the natural disasters are beyond control of human beings and cannot be predicted accurately when they occur. Major natural disasters like floods, earthquakes, landslides and droughts result in a threat to human life, loss of property, and negatively affect infrastructure, agriculture and environment but impact of disaster vary according to its intensity and areal coverage.

Rapid growth of the world's population has scaled both the frequency and severity of natural disasters. Flood disaster has a very special place in natural hazards. Floods are the costliest natural hazard in the world and account for 31 percent of economic loss resulting from natural catastrophes (Munich Re 1977). EM-DAT data show that flooding caused the majority of disasters between 1994 and 2013, accounting for 43 percent of all recorded events (The Human cost of Natural Disaster 2015)

Over the past decades, the pattern of floods across all continents has been changing, becoming more frequent, intense and unpredictable for local communities, particularly as issues of development and poverty have led more people to live in areas vulnerable to flooding. The (Fourth Assessment Report 2007) of the Intergovernmental Panel on Climate Change (IPCC) predicts that 'heavy precipitation events, which are very likely to increase in frequency, will augment flood risk'. These floods will affect life and livelihoods in human settlements in all areas, like, coastal zones, river deltas and mountains.

Flooding in urban areas, causing severe problems, especially people living in large port cities are exposed to frequent coastal flooding. Across all cities, about 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population in the cities) are exposed to a 1 in 100 year coastal flood event. The total value of assets exposed in 2005 due to coastal flooding is estimated to be US$3,000 billion; corresponding to around 5% of global GDP in 2005 (Susan Hanson et.al) both measured in international USD.

By the 2070s, total population exposed could grow more than threefold to around 150 mill people due to the combined effects of climate change (sea-level rise and increased storminess), subsidence, population growth and urbanization (Susan Hanson et.al). The total asset exposure could grow even more dramatically, reaching US$35,000 billion by the 2070s; more than ten times current levels and rising to roughly 9% of projected annual GDP in this period (Susan Hanson et.al).

In Ethiopia, from 1980 to 2010, 86 natural disasters were recorded and they result in a loss of 313,486 human lives and 57,382,354 people were affected and result in an economic loss of US$31.7million. Among the natural hazard drought and flood were rank the first and the second respectively (OFDA/CRED, 2002).

Floods have been occurring more frequently and affecting the country almost every year 1993 to 2013. Basing on limited available data between1980 to 2010 an estimated 45 flooding events had happened in different parts of the country. The main types of floods in Ethiopia are flash and riverine (Luche Tadesse et.al). The most serious flood hazards occurred are in May 1968, August 1994, and May 2005, August 2006 (is the most catastrophic flood which affected many regions of Ethiopia and an estimate of over 600 people were killed and more than 500,000 people affected (Luche Tadesse et.al)) causing damage estimated at US$0.9, 3.5, 6.2, and 3.2 million, (OFDA/CRED, 2002), respectively.

1.2 Statement of the problem

Floods are among the most devastating natural hazards in Africa, whereas flash floods are among the greatest hazards arising from tropical cyclones and severe storms. Floods and flash floods cause loss of life, damage to property, and promote the spread of diseases such as malaria, dengue fever, cholera, and chikungunya. From 1900 to 2006, floods in Africa killed nearly 20,000 people and affected nearly 40 million more, and caused damage estimated at US$4 billion (ICSU Africa, 2007). Water related disasters increased more than four folds in Africa (Adikari et al., 2008). According to World Bank (2003), in most developing countries flood disasters still claim tens of thousands of lives each year and destroy livelihoods in an instant.

In the last decade the frequency of flash floods has markedly increased all over Ethiopia. They have caused a number of fatalities and a large amount of property damage. The occurrence of such flash floods is recorded mainly in semi-arid areas with the monsoon-like rain distribution typical of Ethiopia and an annual rainfall around 500-700 mm. The whole country is potentially prone to flash flood hazard. The shortest return intervals (less than 10 years) were found in semiarid areas and at rain gauges located near the main rifting escarpments, i.e. where commonly the headwater of the most of the river catchment is located. The highest rainfall intensities may occur in every month, though they are more common in July and August and, subordinately in March and April. The increased frequency of flash floods in a few areas of Ethiopia cannot be accounted for by any significant change in rainfall intensity. (Paolo Billi et.al, 2013)

Floods in the Horn of Africa normally follow the June–September rainy season. According to the UN, the 2006 floods, which followed droughts in 2005, affected 1.8 million people and were the worst in the region for 50 years. In August 2006, overflow of the Dechatu River killed more than 300 people in Dire Dawa (a town in southeastern Ethiopia), displaced thousands more, and caused extensive damage to homes and markets (ICSU Regional Office for Africa Science Plan).

Kello is one of the towns facing such problem. The flood at Kello is as a result of flash flood from rainfall on the eastern highlands. Historically Kello has been vulnerable to flash flooding particularly the Kello River which passes at the center of the town. The flood in Kello is impacting many properties and human lives as well. The flood which occurred in April 2012 is resulted in a loss of an estimated of above 5million Ethiopian birr. And the blockage of the main road from Addis to Dessie by a big stone creates a great delay on the passengers until the Kemissie town administrative council clears the road by excavator.

The flood that occurred in August 2013 on Friday night at 7:00 O'clock is the most destructive one and resulted to a loss of an expected of above 10 million Ethiopian birr and to a loss of 31 human life's among these 15 were children and the remaining were mostly females and this make the problem very serious and to a total damage of 29 houses and to partial damage of 154 houses as a result 2575 people were remain homeless. Besides this, silt up the cultivable area is also seen as the main problem of the catchment. Consequently, the community left; didn't stabilize their living standard and couldn't able to satisfy their food security.

Figure 1-1: Pictures showing small part of the night of 10 August 2013 damages.

1.2 Research Questions

The research aims to answer the questions of what are the causative factors for Kello town flooding. Which part and how much of the town and the cultivable area is vulnerable by the flood hazard and what measures to be taken to alleviate the problem?

1.3 Objectives of the Study

1.4.1. General Objective

The main objective of this study is to contribute towards a study of Prediction and flood modeling of Kello town.

1.4.2. Specific Objective

The specific objective includes estimation of peak discharge of the stream, delineation of flood risk areas of Kello town and recommend for flood mitigation measures.

1.4 Significance of the Study

This study is expected to be helpful for the planners, decision makers and any concerned bodies to understand the consequences of flood on hydrological variables and the impacts these have on Kello town water resource planning management and accordingly device decision and management support tools and be an input for those who are interested to further research in related field and area of study.

1.5 Scope and limitation of the study

This study investigates the flood problems which have been occurred in the study area. Based on the available data a possible flood mitigation alternative measure is worked out. This study is limited to selected areas in Kello district. So, the conclusions and recommendations were also made accordingly.

2. Literature Review

2.1 Flood Magnitude Estimation

Many hydrologic methods are available to estimate peak flood. If possible, the method shall be calibrated to local conditions and tested for accuracy and reliability. The choice of these methods depends on data available and the practical existing situations. Among the many hydrologic methods, some are explained below.

2.1.1 Rational Method

A rational approach is to obtain the yield of a catchment by assuming a suitable runoff coefficient. It estimates the peak runoff at any location in catchment area as a function of the area, runoff coefficient, and rainfall intensity for duration equal to the time of concentration. It is best suited to urban storm drain systems and rural ditches. It shall be used with caution if the time of concentration exceeds 30 minutes. This method is used for catchment areas less than 50 hectares ($0.5km^2$) and expressed as below.

$Q = 0.00278CIA$

Where: Q = maximum rate of runoff, m^3/sec.

C = runoff coefficient representing a ratio of runoff to rainfall

I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/h

A = catchment area tributary to the design location, ha

2.1.2 SCS and other Unit Hydrograph Methods

The U.S. Soil Conservation Service has developed a synthetic unit hydrograph procedure that has been used widely for developing rural and urban hydrographs. The unit hydrograph used by the SCS method is based upon an analysis of a large number of natural unit hydrographs from a broad cross section of geographic locations and hydrologic regions. This method can be used for catchment areas greater than 50 hectares (0.5km2).

This technique requires the same basic data as the Rational Method: catchment area, a runoff factor, time of concentration and rainfall. The SCS approach, however, is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. With

SCS method, the direct runoff can be calculated for any storm either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions. Data for land-treatment measures, such as contouring and terracing, from experimental catchment areas were included. The equation was developed mainly for small catchment areas for which daily rainfall and catchment area data are ordinarily available. It was developed from recorded storm data that included total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hours or 1-day storm rainfall.

The equation is: $P_e = \frac{(p - I_a)^2}{P - I_a + S}$

Where, P_e = accumulated precipitation excess at time t, mm

P = accumulated rainfall depth (potential maximum runoff) at time t, mm

I_a = the initial abstraction (initial loss) including surface storage, interception, and infiltration prior to runoff, mm

S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation.

Analysis of results from many small experimental watersheds, the SCS developed an empirical relationship of Ia and S:

Ia = 0.2S, Therefore, the cumulative excess at time *t* is: $P_e = \frac{(p - 0.2S)^2}{P + 0.8S}$

The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (CN) as: $S = \frac{25400}{CN} - 254$

2.1.3 Regional Regression Analysis

Peak flow can be calculated by using regression equations developed for specific geographic regions. In the equations the dependent variable would be the peak flow, and the independent variables may be area, slope, channel geometry, rainfall and other meteorological, physical or site specific data. This method shall be used for all routine designs at sites where applicable. Regression Equations are a commonly accepted method for estimating peak flows at unguaged sites or sites with insufficient data. Also, they have been shown to be accurate, reliable, and easy to use as well as providing consistent findings. Regression equations are one of the preferred methods for estimating peak flows for larger catchment areas. A regional approach to estimating floods at ungauged sites can be adopted using this regression model to predict flood.

2.1.4 Analysis of Stream Gauge Data

If a project is located near one of gauged station and the gauging record is of sufficient length, flood estimation may be made. The most important aspect of applicable station records is the series of annual peak discharges.

These methods shall preferably be used for all routine designs provided there is continuous or synthesized recorded discharge data. Example at least 10 years of continuous or synthesized record for 10 years of discharge estimates and 25 years for 100-year discharge estimates. With at least 25 years of continuous or synthesized stream gage data the log Pearson III is considered to be the most reliable method for estimating flood frequency relationships and shall be used for all designs (ERA Drainage Manual, 2001).

2.1.5 Suitable Computer Programs

Suitable Computer Programs such as HYDRAIN's HYDRO, HEC-1, HEC-HMS and others may be used to facilitate tedious hydrologic calculations.

2.2 Previous Study of the Area

There is one study which has been conducted by the zone water experts in collaboration with the zone Agricultural experts that tries to estimate the peak discharge for Kello town after the most severe flood event occurred on the tenth day of August 2013.

This study is entitled with "Flood Design Report" and is based on the Rational Method of flood magnitude estimation according to the report the peak discharge is 166.82m^3/s and the report mainly focuses on indicating ways of alleviating the flood hazard especially on watershed management of the catchment. According to the standard the catchment peak discharge should not be calculated by rational method, since the area is much greater than 0.5Km^2.

3. Materials and Methods

3.1 Study Area Description

Kello is located in Oromia Zone Amhara national regional state, to the Southern of kemisie town. It is found on the main road 320 Kilometer from the way Addis Ababa to Dessie and 560Kilo meter from Bahir Dar, the capital of Amhara regional state. One of the main features of the area is the presence of Kello River which flows from the neighboring upper catchment down to Kello town then to Borkena River. The area is with relatively flat terrain and surrounded with a number of scattered small hills.

3.1.1 Geographic Location

The watershed is geographically located at different GPS Location including 597839.853-603440.737E and 1180855.811-1187468.974N and an altitudinal range is from 1431-2368m above sea level.

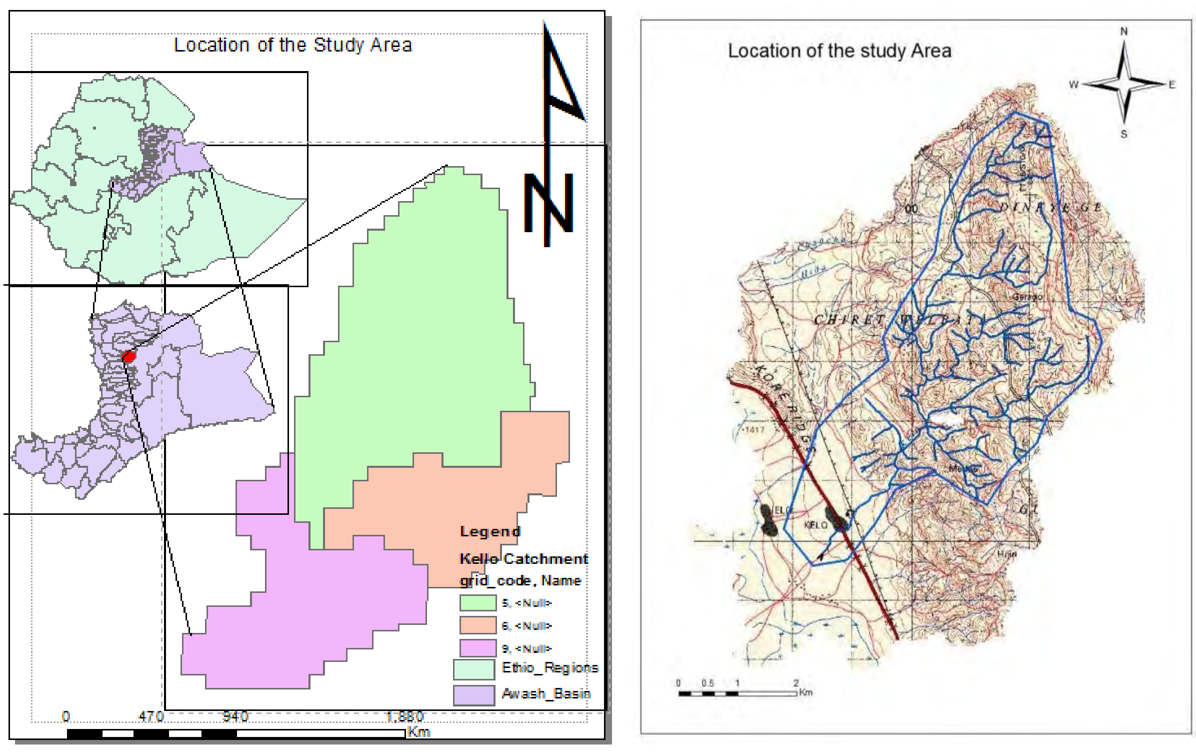


Figure 3-1: Location of the Study Area

3.1.2. Topographic feature of the catchment

The Watershed has marked topographic variation. All types of slopes are present. The dominant slope class is 15-30% which covers 60% of the total area followed by 6-15% which is 30%. Flat and almost rolling slopping accounts 3% and 7% percent respectively, very steep slopes also cover about 4.26% of the total area.

3.1.3. Land use Land cover of the Catchment

The land use of the study catchment is mainly covered by agricultural land.

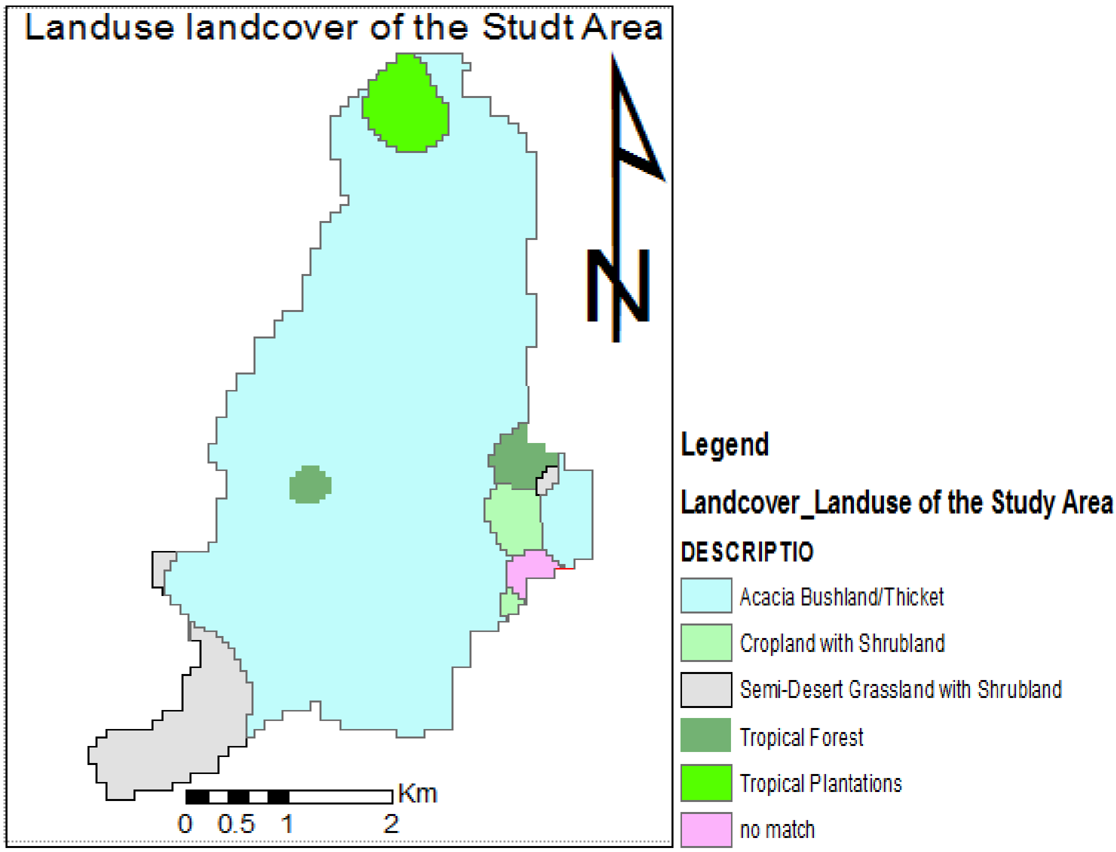


Figure 3-2: Land use Land cover of the study Area

As can be seen on the figure the catchment has covered by six land cover types. These are Acacia bush land (thicket), cropland with shrub land, semi desert grassland with shrub land, tropical forest, and tropical plantation. Most of the catchment area is covered by Acacia bush land and by semi desert grassland with shrub land.

3.1.4. Soil Type of the catchment

The soil type of the study area is mainly classified as Chromic vertisols, Eutric cabisols, Eutric regosols, Haptic xerosols and leptosoils are the main classes. As it is shown from the soil map below

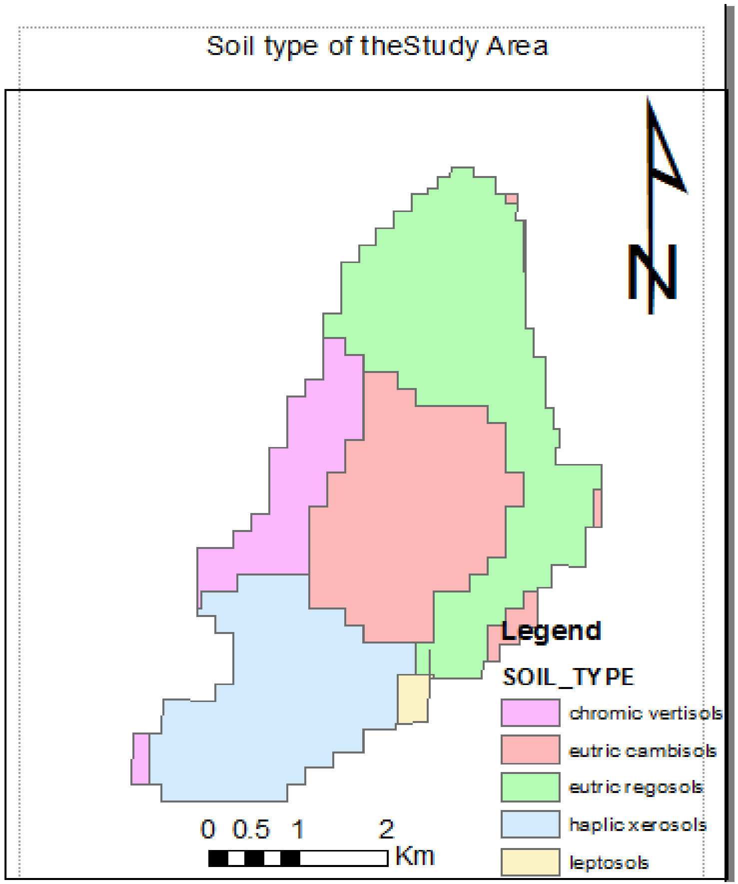


Figure 3-3: Soil Type of the study Area

As can be seen on the figure the catchment has covered by five soil types. Among them Eutric regosol and eutric cambisols are the dominant then haplic xerosols and chromic vertisols follows.

3.1.5. Rainfall

Ethiopia is generally characterized as residing in a tropical to sub-tropical climate, with the primary rainfall season typically occurring between the months of June to September. A secondary rainfall season usually occurs from February to May. The remaining months (October to January) tend to be the driest period. In general, the annual rainfall amount decreases as one move to the northeast region of the country. The rainfall pattern over Ethiopia is driven by synoptic climatic mechanisms which tend to have predictably over homogeneous regions. The main synoptic influence on the hydrometeorology in Ethiopia include the monsoon effects from 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 rainfall of the study area is also a bi-modal type the heights rainfall season being from June to September and the lower one is from February to May and the rainfall of the study area is low, erratic and exhibits spatial and temporal variability.

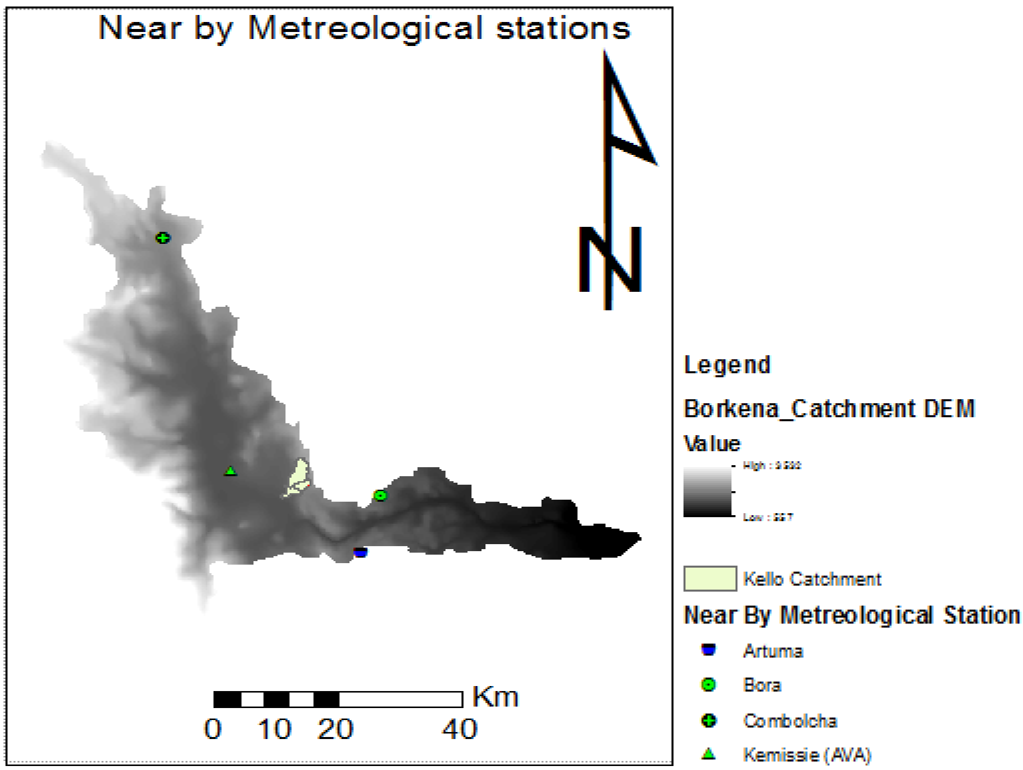


Figure 3-4: Nearby Meteorological Stations

3.1.6. Climate

The climate is warm and dry with relative low precipitation. Mean annual temperature ranges from 24^0c to 31^0c as a result potential evapotranspiration is relatively high at 3,255mm on average. The relative humidity Weather condition of the area is 84% arid, 15% semi-arid, and 1% cool environment.

3.2 Methodology

Generally, the method for this thesis work has two main parts which are site work and homework. The site work part includes inspection of the site, taking flood mark records of the site, surveying of the site (collecting elevation data of the site) using GPS (global positioning system) and collecting the necessity data's from different institutions. The homework include task include the rest part of the work which are analyzing precipitation and discharge data using suitable procedures and running with suitable programs. These steps are generally stated as:

- Data collection and analysis,
- Peak discharge estimation, and
- Flood vulnerable area delineation

3.2. 1 Materials used

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

- ArcGIS, Arc hydro and HEC-GEOHMS tools
- HEC-HMS hydrological model
- 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

3.2. 2 Data Collection and Analysis

- Primary data from field visit and secondary data from different organizations are collected.
- The following table describes the data type and its purpose.

Table 3-1: Data Type, purpose and Source

Data Type	Purpose	Source
Awash basin 30m Resolution DEM	Generating Catchment geo-spatial data using HEC-GeoHMS	MoWR
Maximum daily rainfall for the stations Dawa cheffa, Kemissie, Combolcha ,Artuma and Bora	To compute Hydrograph using HEC-HMS	Meteorology Agency
ERA Intensity-frequency duration curve for the region	To compute Hydrograph using HEC-HMS	ERA drainage manual
Soil type and land-use for Kello Catchment	For curve number computation	MoWR

3.2.3 Peak Discharge Estimation

3.2.3.1 Selection of Method

Flash floods develop in hilly and mountainous terrains where the slope of the river is rather steep. The rapid development of the flood is due to the extremely short concentration time of the drainage catchment. This means that precipitation falling on a point in the catchment farthest from the river takes only a short time to reach the river channel and become part of stream flow. Thus, the amount of stream flow rapidly increases and, consequently, the rise in water level. When the flow capacity of the stream is exceeded, the channel overflows and the result is a flash flood.

Flash flood is a surface flow of short duration with a relatively high peak discharge. It is a typical example of unsteady non-uniform flow. This flash flood is common feature in the Kello region during the rainy season.

Many hydrologic methods are available to estimate peak flood as discussed in chapter two. However, some of them are applicable for this case due to the reasoning explained below. Rational method is used for catchment areas less than 50 hectares ($0.5km^2$). Kello catchment area is much greater than $0.5km^2$ which is $21km^2$.

No peak flood discharge regression equation developed for the catchment. The development of regression analysis by itself can be a separate study and is not part of this thesis. In order for regression equations to be useful for Ethiopia, extensive study of drainage basins and hydrologic regions for the country is required. Also analysis of stream gauge data is not possible, since the catchment is not gauged. Hence, the preferred methodology for this study is suitable Computer Programs HEC-GeoHMS and HEC-HMS used to facilitate the SCS hydrologic calculations as well described in next chapter.

For this selected methodology, the following steps are followed:

i. Chufa Dawa 30m resolution DEM was cut for Kello using Grid Machine (ArcViewextension)
ii. HEC-GeoHMS processed as it is a geospatial hydrology toolkit
iii. Using HEC-HMS modeled and simulated for hydrologic response

The ERA drainage Design hydrologic analysis procedure flowchart shows the steps for the hydrologic analysis and the designs that will use the hydrologic estimates. With modification for flood and the updated technology since the manual prepared, the procedure is presented below.

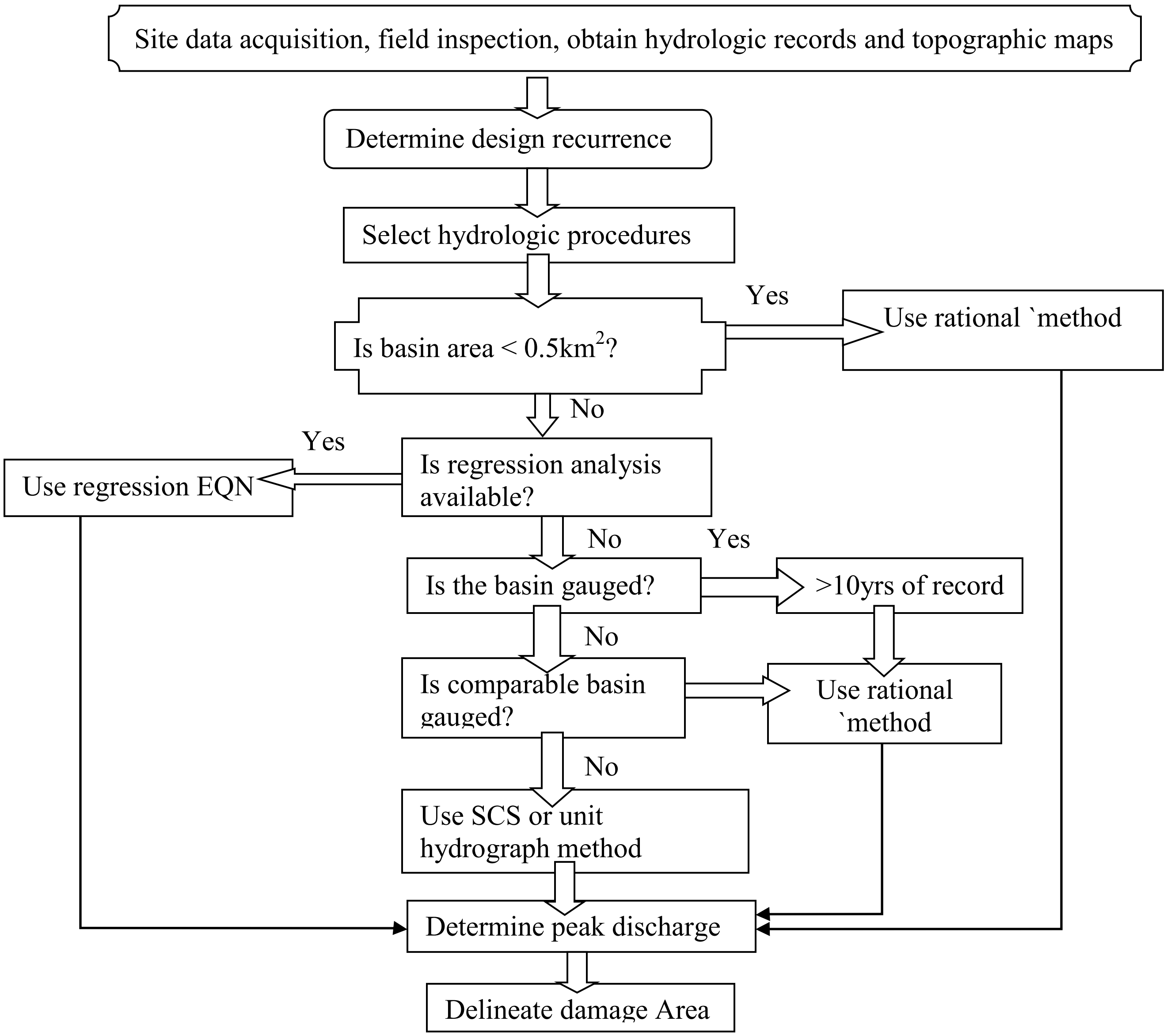


Figure 3-5: Hydrologic estimates procedure flowchart

3.2.4 DETAILS OF SELECTED MODELS

3.2.4.1 HEC-GeoHMS

HEC-GeoHMS is a set of ArcGIS tools specifically designed to process geospatial data and create input files for the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-

HMS). It includes integrated data management and a graphical user interface (GUI). Through the GUI, which consists of menus, tools, and buttons, the user can analyze the terrain information, delineate sub-basins and streams, and prepare hydrologic inputs.

The relationship between GIS, HEC-GeoHMS, and HEC-HMS is illustrated in Figure 3.2, with the vertical dashed line separating the roles of GIS and watershed hydrology. HEC-GeoHMS provides the connection for translating GIS spatial information into model files for HEC-HMS. The GIS capability is used for data formatting, processing, and coordinate transformation. 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.

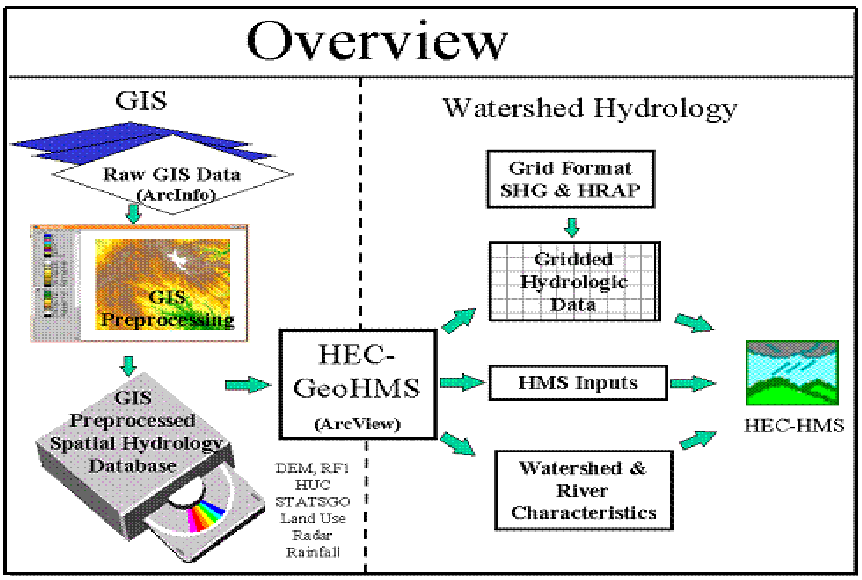


Figure 3-6: Overview of GIS, HEC-GeoHMS and HEC-HMS (HEC-GeoHMS user's manual 2010)

HEC-GeoHMS operates on the DEM to derive sub-basin delineation and to prepare a number of hydrologic inputs. HEC-HMS accepts these hydrologic inputs as a starting point for hydrologic modeling. The following steps describe the major steps in starting a project and taking it through the HEC-GeoHMS process.

i. Terrain Preprocessing

ii. Hydrologic processing

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

iii. Hydrologic Parameters

3.2.4.1.1 Terrain Preprocessing

Using the terrain data as input, terrain preprocessing is a series of steps to drive the drainage network. The steps consist of computing the flow sink, flow direction, flow accumulation, stream definition, and watershed delineation. These steps can be done step by step or in a batch manner. Once these datasets are developed, they are used in the later steps for sub-basin and stream delineation. It is important to recognize that the watershed and stream delineation in the terrain preprocessing steps is preliminary. Tools are available on the basin processing menu that gives the user the capability to delineate and edit basins in accordance with project specifications.
The terrain data is processed and analyzed using the eight-pour point approach to determine flow paths. This approach uses the steepest slope to define the direction that water flows from one grid cell to one of its eight neighbors. Terrain analysis is computer intensive and some steps may require several hours, depending on the amount of data and computer resources. After terrain preprocessing is completed, the resulting datasets serve as a spatial database for the study. With the information centralized in the spatial database, pertinent datasets can be extracted for subsequent work to build the hydrologic models. Preliminary watershed and stream delineation provides results that can be verified with published information to detect possible errors in the terrain data. If errors are detected, the DEM should be edited.

3.2.4.1.2 Basin Processing

After the terrain preprocessing is completed and a new project has been created, the basin processing menu can be used to revise the delineations. Customized sub-basin and routing reach delineations. Customized sub-basin and routing reach delineations should include points where information is needed, i.e., stream flow gauge locations flood damage centers, and hydrologic and hydraulic controls. The tools described in this chapter will allow the user to interactively combine or sub-basins to a set of points.

3.2.5 HEC-HMS MODEL

The Hydrologic System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It supersedes HEC-1 and provides a similar variety of options but represents a significant advancement in terms of both computer science and hydrologic engineering. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear quasi-distributed runoff transform (ModClark) for use with gridded precipitation, continuous simulation with either a one layer or more complex five-layer soil moisture method, and a versatile parameter estimation option.

The program feature a completely integrated work environment including a data base, data entry utilities computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the program. Simulation results are stored in the Data Storage System (HEC-DSS) and can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation.

The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment.

3.2.5.1 HEC-HMS Model Components

HEC-HMS model Components are used to simulate the hydrologic response in a watershed. HMS Model Components includes basin models, meteorologic models, control specifications, and input data. A simulation calculates the precipitation-runoff response in the model given the input from the meteorologic model. The control specifications define the time period and time step of the simulation run. Input data Components such as time-series data, paired data and gridded data are often required as parameter or boundary conditions in basin and meteorologic models.

3.2.5.1.1 Basin model Components

The basin model represents the physical watershed. The user develops a basin model by adding and connecting hydrologic elements. Hydrologic elements use mathematical models to describe physical processes in the watershed.

3.2.5.1.2 Meteorologic Model Component

The meteorologic model calculates the precipitation input required by a sub-basin element. The meteorologic model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapotranspiration. The newly added snowmelt method uses a temperature index algorithm to calculate the accumulation and melt of the snow pack. The evapotranspiration methods include the monthly average method and the new priestly Taylor and gridded priestly Taylor methods. An evapotranspiration method is only required when simulating the continuous or long term hydrologic response in a watershed.

3.2.5.1.3 User Interface

The user interface consists of a menu bar, tool bar, and four main panes. Starting from the upper left pane in figure 1 and moving counter-clockwise, these panes will be referred to as the watershed Explorer, the component Editor, the Message Log, and the Desktop.

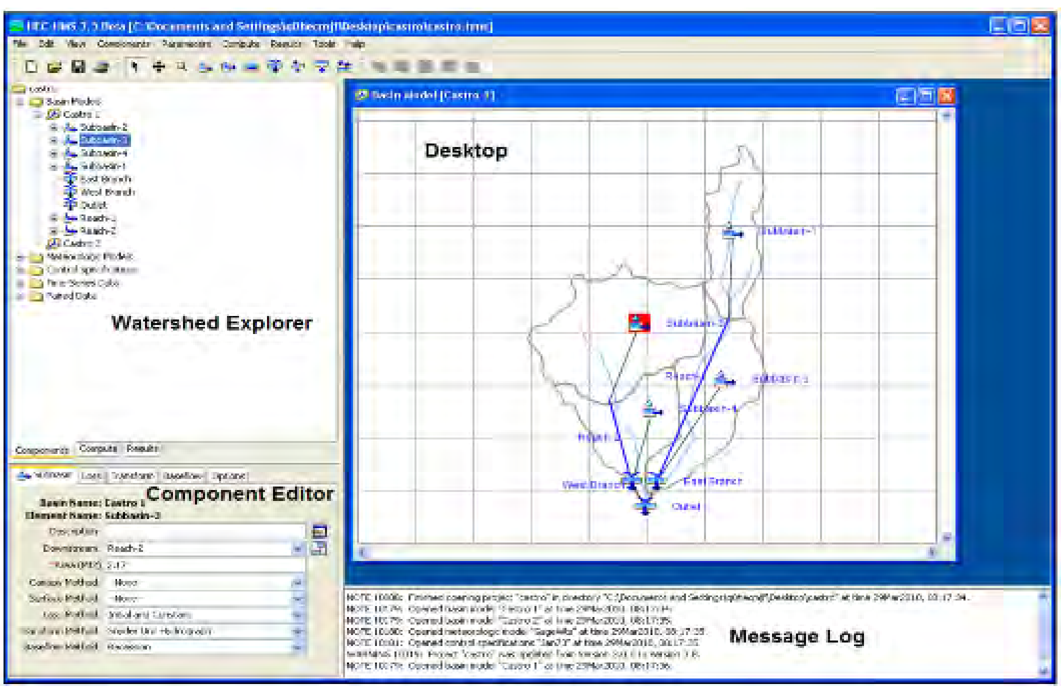


Figure 3-7: HEC-HMS GUI

3.2.5.1.4 Watershed Explorer

The Watershed Explorer was developed to provide quick access to all components in a HEC-HMS project. For example, the user can easily navigate from a basin model to a precipitation gage and then to a meteorologic model without using menu options or opening additional windows. The Watershed Explorer is divided into three parts; Components, Compute, and Results. The hierarchal structure of model components, such as basin models, meteorologic models, etc, is available from the "components" tab of the Watershed Explorer. The Watershed Explorer organizes model components into individual folders. When a component is selected, the Watershed Explorer expands to show sub-components.

3.2.6 Delineation and Identification of Flood risk 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 ArcView GIS, 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 10.0 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 to evaluate wetland scenarios (http://cedb.asce.org/cgi/WWWdisplay.cgi). The geometric data was imported into HEC-RAS Version 4.0 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 4m 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 (for Manning's n values), Levee Alignment, Ineffective Flow Areas, and Storage Areas, Blocked Obstacles, Bridges/culverts, Inline structures, Lateral structures and storage areas. HEC-GeoRAS 10 is an extension for use with ArcGIS (Environmental Systems Research Institute,2000) that provides the user with a set of procedures ,tools ,and utilities for the preparation of GIS data for import into RAS and generation of GIS data from RAS output.

Procedure 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.

3.2.6.1 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 polyline themes defining stream centerline, stream banks, flow path lines and cross- sections.
- ❖ 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, stream banks, flow path lines and cross-sections.
- ❖ Generation of the HEC-RAS Import File.

3.2.6.2 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 Centerline, Banks, Flow Paths Centerlines, Cross-Sectional Cut Lines, Land Use, Levee Alignments, Ineffective Flow Areas, and Storage Areas.

3.2.6.3 Attributing RAS Theme

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

3.2.6.4 Generating the RAS GIS Import File

To generate the RAS GIS Import File, the 3D stream Centerline and Cross Section Surface Line (3D) shape file created from the RAS Theme. Geometric data from the two 2D (stream Centerline 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 and 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.

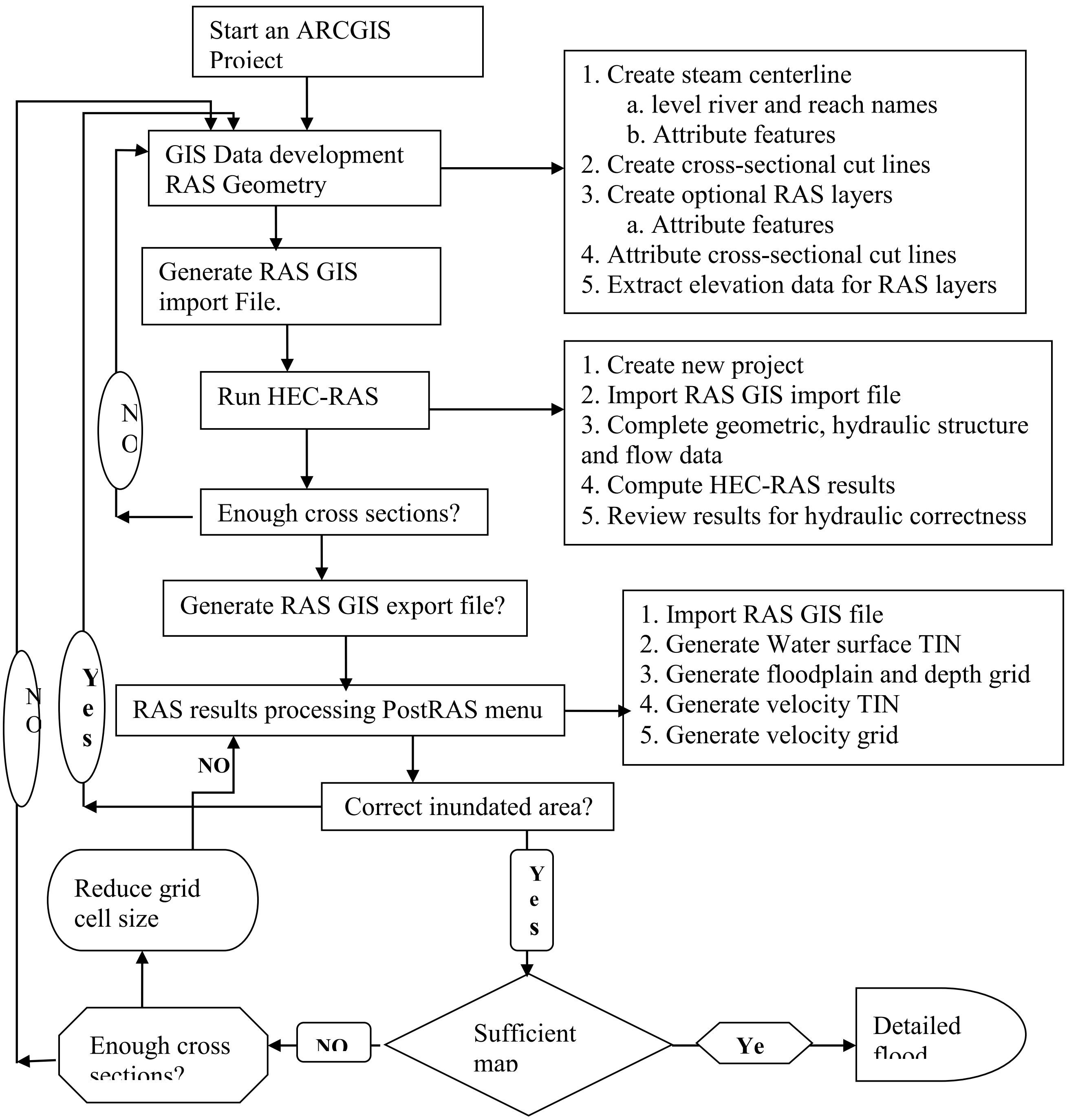


Figure 3-8: Process flow diagram for HEC-GeoRAS

3.2.7 HEC-RAS

The Hydraulic Engineering Center River Analysis System (HEC-RAS) developed by the Hydraulic Engineering center of U.S. Army corps of Engineers. The software allows performing one dimensional steady flow, unsteady flow calculations, sediment transport/mobile bed computations and water temperature modeling. The system is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities.

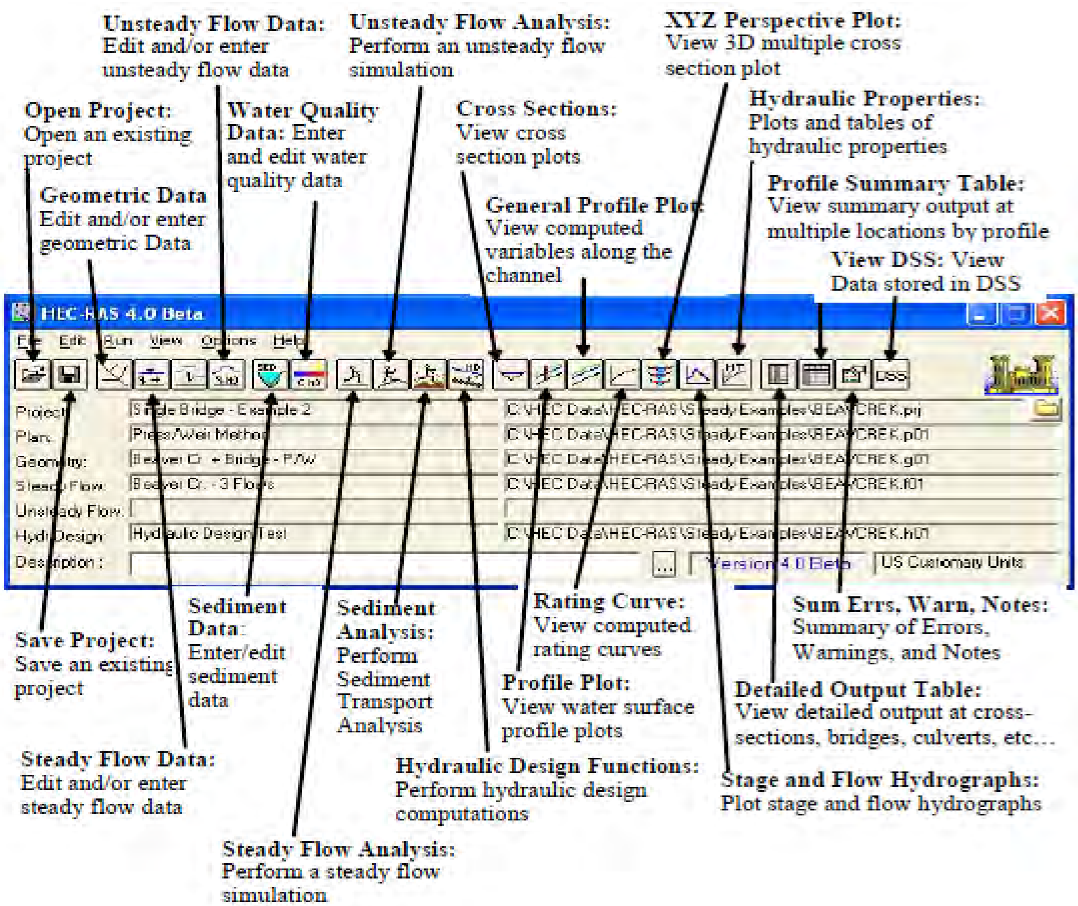


Figure 3-9: HEC-RAS GUI

The goal of this section is to develop the HEC-RAS model for the study area, using the geometric data extracted from the TIN using GeoRAS and to develop the model's geometry data and unsteady flow data. The unsteady flow file was extracted from a HEC HMS hydrologic model.

The process is divided into two steps. These are opening the geometry and unsteady flow data by opening the HEC-RAS project file and Run unsteady flow simulation and export the results of the simulation into Arcview.

For each HEC-RAS project, there are three required components:

- ✓ 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.

3.2.7.1 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 the geometric model, importing the geometry file is needed that is just exported here. This HEC-RAS geometry file contains physical parameters describing cross-sections.

3.2.7. 2 Flow Data

The flow data has been extracted from HEC-HMS hydrologic model. Unsteady flow condition is adopted since it is rare to find the steady flow in the natural channel flow condition. This component of the HEC-RAS modeling system is capable of simulating one dimensional unsteady flow through a full network of open channels.

3.2.7. 3 Development of TIN

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. 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.

3.2.7.4 TIN of the Study Area

In flood 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 existing DEM of the study area.

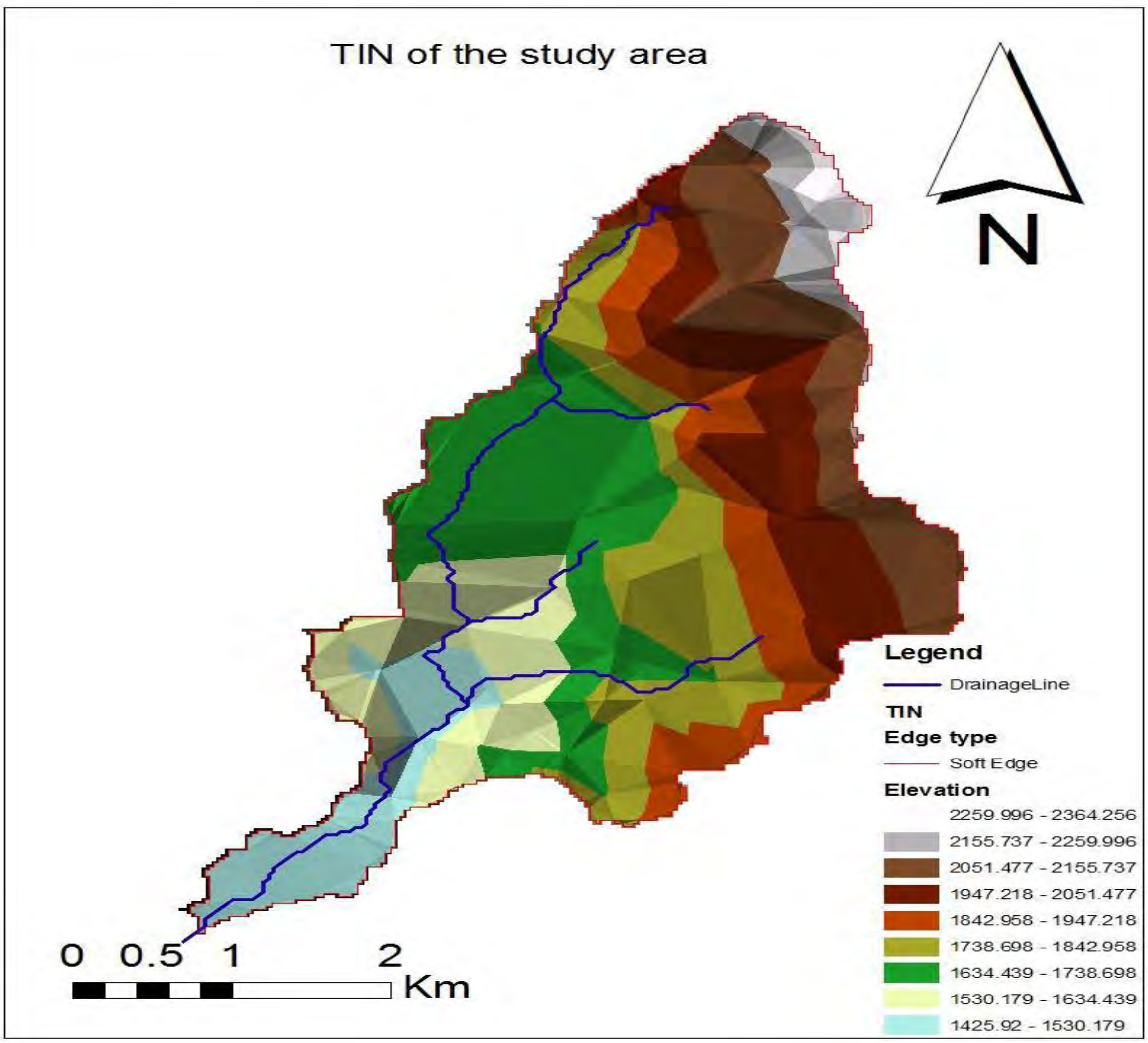


Figure 3-10: TIN of the study Area

4 DATA ANALYSIS

4.1 Filling Missing Rainfall Data

Precipitation is that part of atmospheric moisture, which reaches the earth's surface in different forms. Hydrologists start working when the precipitation reaches the ground. This connects hydrology with meteorology. Rainfall data plays a central role in developing rainfall – runoff models. Measured precipitation data are important for many problems in hydrologic analysis and design purposes. The main problem in hydrologic analysis is that these data's are not fully available as expected. The reason behind for the shortage of these data is either of the malfunctioning of the gauge or may be due to absence of an observer to make the necessary visit to the gauge. These gaps in rainfall record data's can be filled with several approaches. But the result from these data may not be as accurate as the original data. The commonly approaches are:

- Station Average Method
- Normal Ratio Method
- Regression Method
- Inverse Distance Weighting Method

4.1.1 Station Average Method,

The missing record is computed as the simple average of the values at the nearby gauges. Mc Cuen (1998) recommends using this method only when the annual precipitation value at each of the neighboring gauges differs by less than 10% from that for the gauge with missing data.

$$P_x = \frac{1}{M}\left[P_1 + P_2 + \ldots + P_n\right]$$

Where: Px = The missing precipitation record

P1, P2, …., Pm = Precipitation records at the neighboring stations

M = Number of neighboring stations

4.1.2 Normal Ratio Method

If the annual precipitations vary considerably by more than 10 %, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighboring stations by the ratios of normal annual precipitations.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots \frac{P_m}{N_m}\right]$$

Where:

N_x = Annual-average precipitation at the gage with missing values

N_1, N_2, …, N_m = Annual average precipitation at neighboring gauges

4.1.3 Regression Method

A multiple linear regression of the form

$$p_x = a_0 + a_1 p_1 + a_2 p_2 + \dots + a_n p_n$$

May be established and the coefficients a_0, a_1, a_2, ..., a_n can be calculated by least square method. The equation can be used to compute rainfall P_x of the missing station. Use of this method is advantageous over the previous two and can be effectively used when a digital computer is available at a site. A random error component **e × Syx** may be added to equation above if large amount of missing data is to be estimated, where EI is the normal random number with zero mean and unit standard deviation. It can be selected from random number tables given in any standard mathematical book. *S* is the standard error of estimate. The standard error of estimate can be estimated from the equation

$$S_{y_x} = \sqrt{\sum_{i=1}^{n} (y_i - y_{ei})^2}$$

4.1.4 Inverse Distance Method weights

The annual average values only by their distances, dm, from the gauge with the missing data and so does not require information about average annual precipitation at the gauges.

The Inverse Distance Method weights the annual average values only by their distances, d_m, from the gauge with the missing data and so does not require information about average annual precipitation at the gauges.

$$D = \sum_{m=1} d_m^{-b}$$

The missing value is estimated as:

The value of b can be 1 if the weights are inversely proportional to distance or 2, if the weights are proportional to distance squared.

If relatively few values are missing at the gauge of interest, it is possible to estimate the missing value by regression method.

Due to compatibility of the method the Normal Ratio Method is used for filling the missing rainfall data.

4.2 Checking the Consistency of Rainfall Data

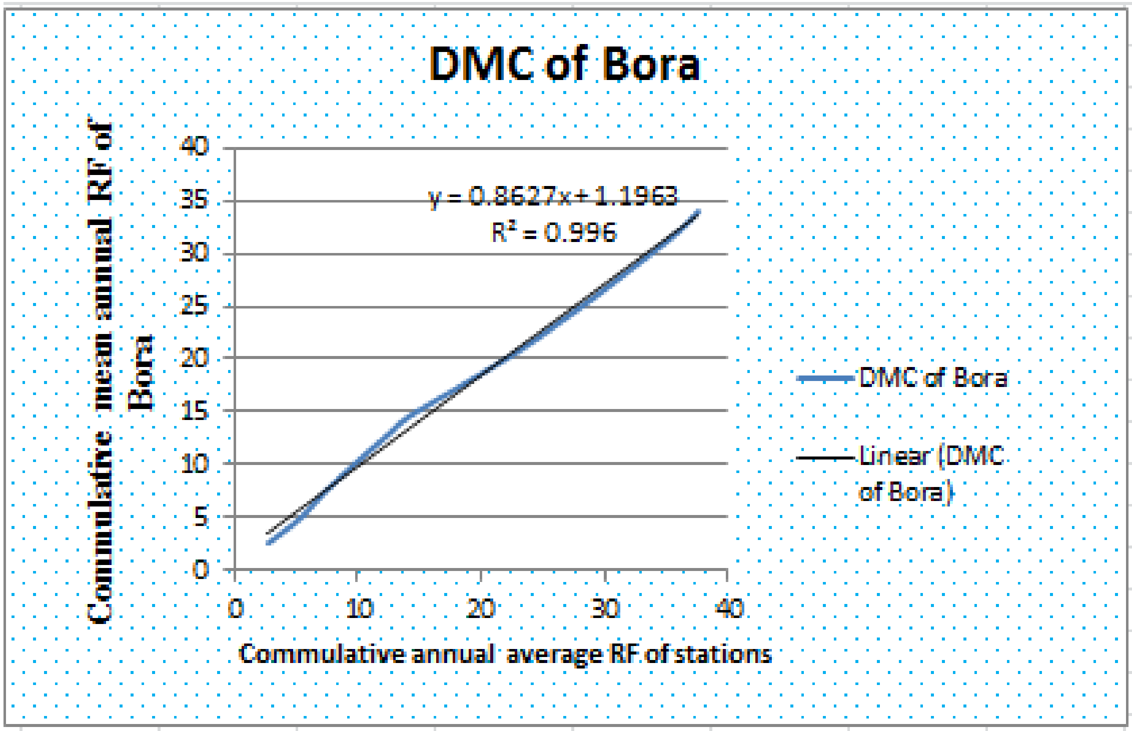
Consistency is to mean when someone behaves or performs in a similar way or when something always happens in a similar way. If the conditions relevant to the recording of rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. Some of the common causes for inconsistency of record are:

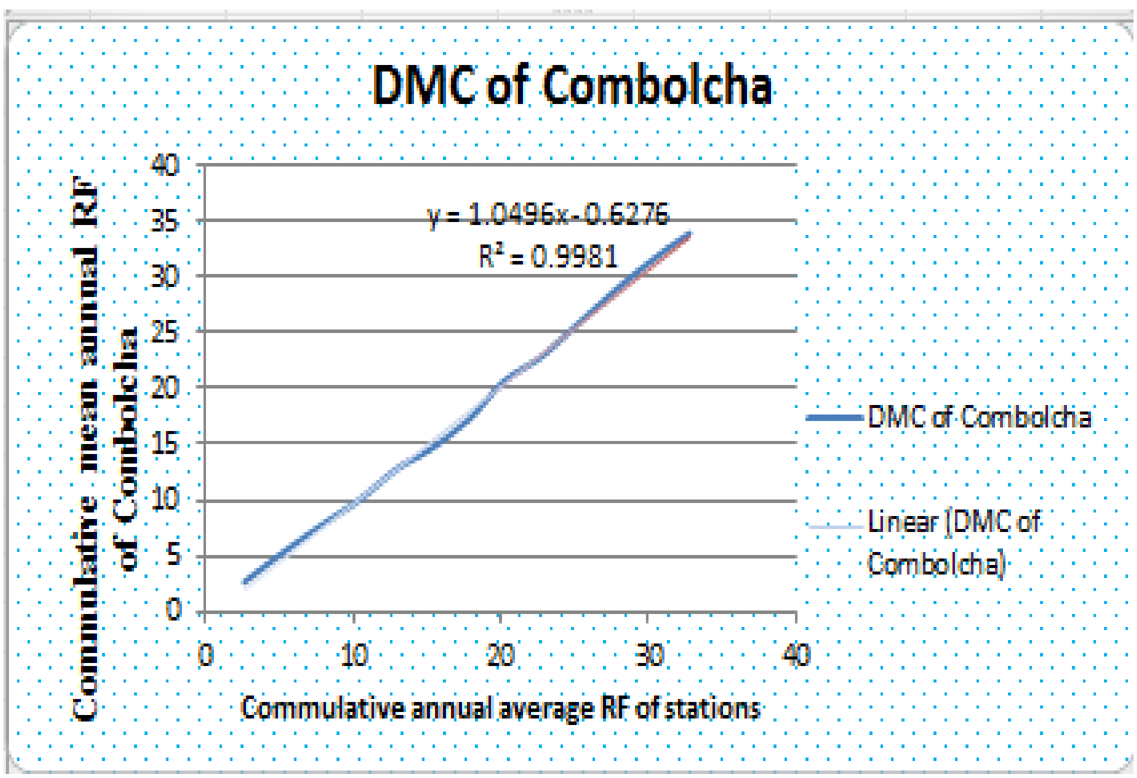
- Shifting of a rain gauge station to a new location
- The neighborhood of the station may have undergoing a marked change
- Change in the immediate environment due to damage due to deforestation, obstruction, etc.
- Occurrence of observational error from a certain date both personal and instrumental

The most common method of checking for inconsistency of a record is the Double-Mass Curve analysis (DMC). The curve is a plot on arithmetic graph paper, of cumulative precipitation collected at a gauge where measurement conditions may have changed significantly against the average of the cumulative precipitation for the same period of record collected at several gauges in the same region. The data is arranged in the reverse order, i.e., the latest record as the first entry and the oldest record as the last entry in the list. A change in proportionality between the measurements at the suspect station and those in the region is reflected in a change in the slope of the trend of the plotted points.

If a Double Mass Curve reveals a change in slope that is significant and is due to changed measurement conditions at a particular station, the values of the earlier period of the record should be adjusted to be consistent with latter period records before computation of areal averages. The adjustment is done by applying a correction factor K, on the records before the slope change given by the following relationship.

$$K = \frac{Slope\ for\ period\ after\ slope\ change}{Slope\ for\ peroid\ before\ slope\ change}$$





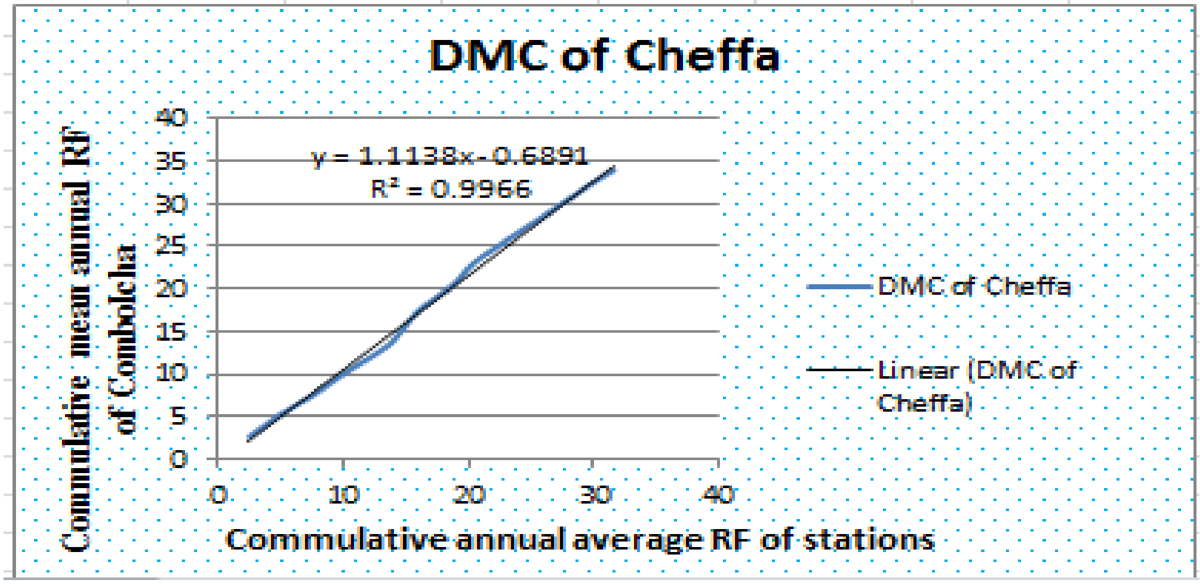


Figure 4-1: Consistency checking of the three Meteorological Stations within and around the study area

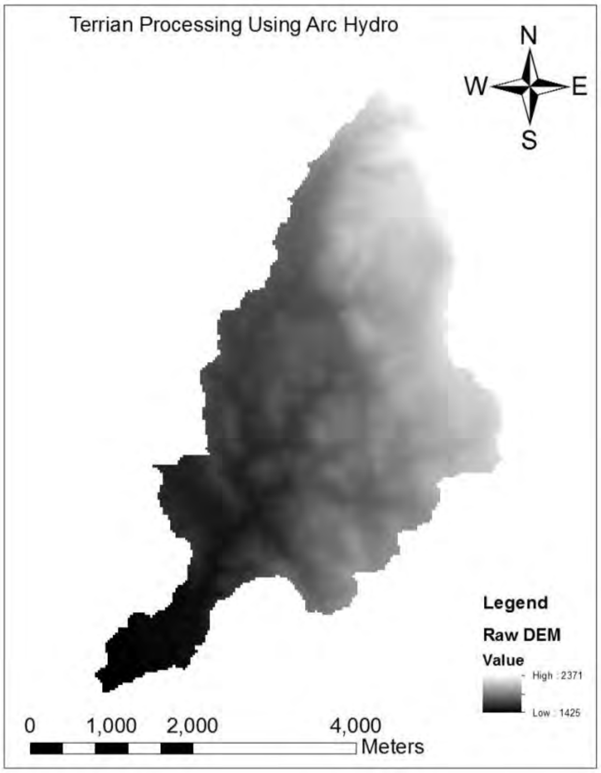
It can be concluded from the above graph that the data is consistent.

4.3 HEC-GeoHMS Data Processing

The point of the extensive data preprocessing using Arc-Hydro was to create input files for the HEC- GEOHMS tools. HEC-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.

4.4 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.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Low : 1425
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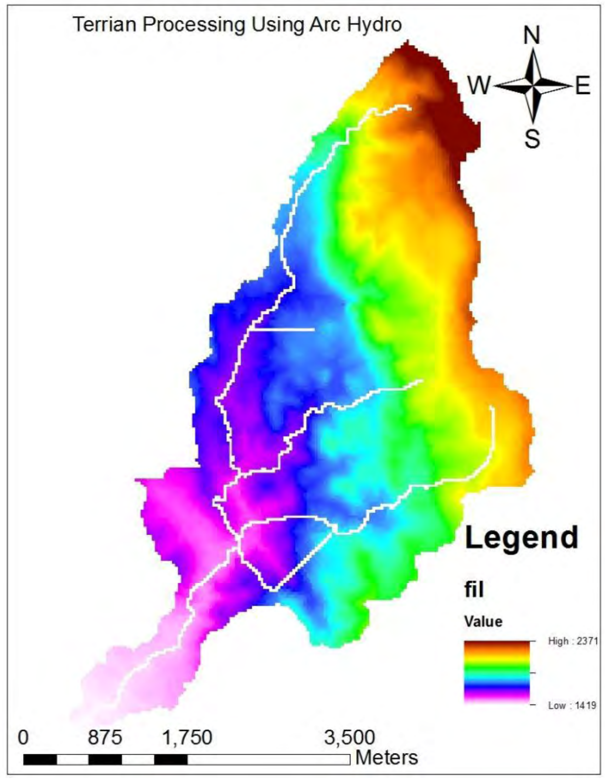
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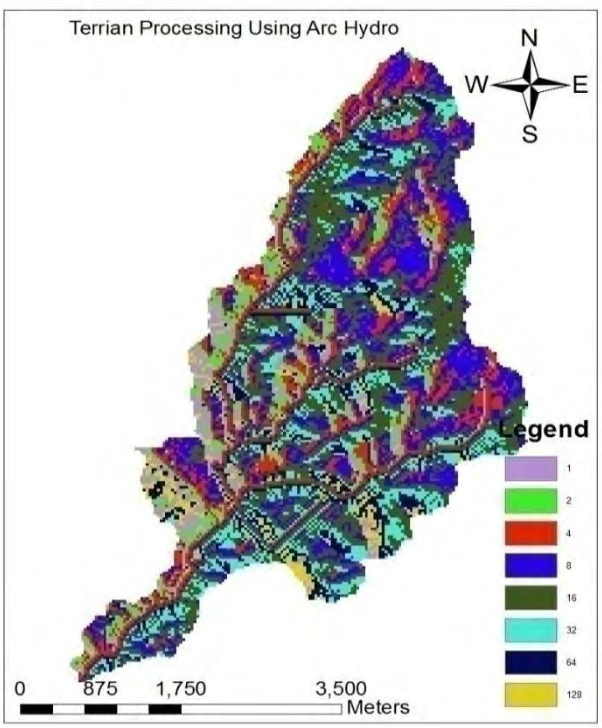
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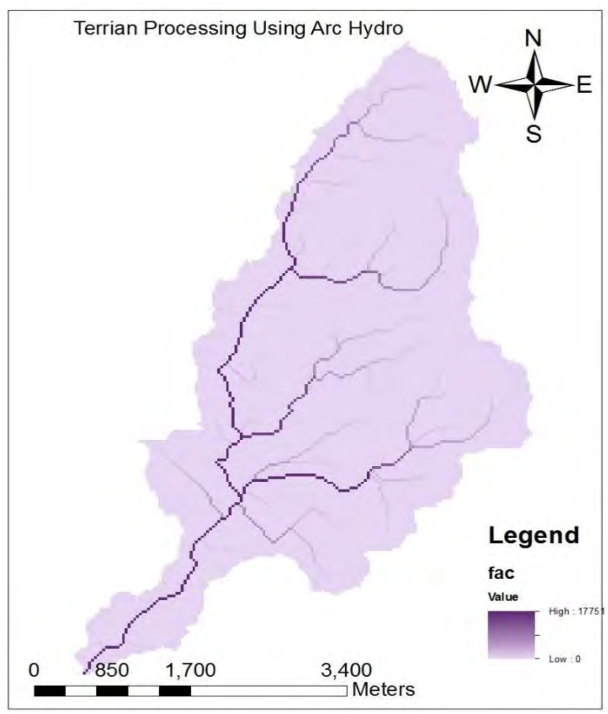
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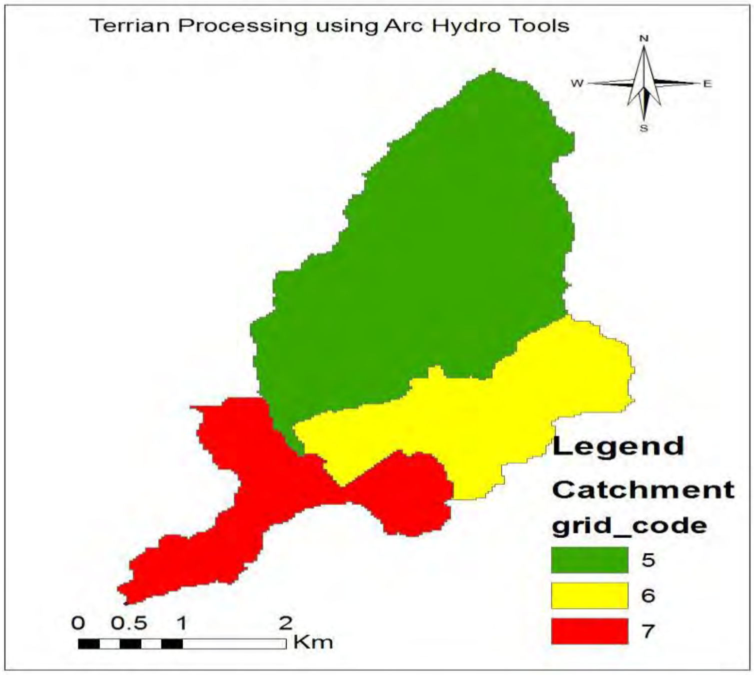


Figure 4-2: Terrain Preprocessing for Kelo Catchment

Using the HEC- GEOHMS model, the basin characteristics extracted parameters are shown below in the table.

Table 4-1: Kelo Catchment Basin Characteristics

Sub Basin Name	Basin shape Length	Basin shape Area (Km^2)	Basin CN	Longest FL(Km)
W250	19.5	9.43	62.027	7.392
W270	13.96	3.91	58.845	4.294
W340	16.8	3.349	70.63	5.211

4.5 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 4-2: Kelo River Tributaries Physical Characteristics

River Reach	Shape Length	Slope	Ele. U.S	Ele. D.S	River Length (m)
R120	6035.751	0.0833	2014	1511	6035.751
R130	2553.607	0.134	1854	1511	2553.607
R170	3471.004	0.0265	1511	1419	3471.004

4.6 Basin Model

Basin model is 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.

The basin model is responsible for describing the physical properties of the watershed and the topology of the stream network. This portion describes how watershed information is entered into the program using HEC-GeoHMS and HEC-HMS basin model. It contains the modeling components that describe catchment data, infiltration, surface runoff and channel routing. Outflow is computed from meteorological data by subtracting losses of basin and transforming excess precipitation through the basin. Sub-basins are used to model the catchment. A sub-basin is an element that usually has no inflow and only one outflow.

4.6.1 Physical Description of Sub-basin (HEC-GeoHMS)

Hydrologic elements are used to break the sub-basin into manageable pieces. They are connected together in a dendritic (branched extension or shape of a tree branch) network to form a representation of the stream system. The physical parameter analysis is done using HEC-GeoHMS.

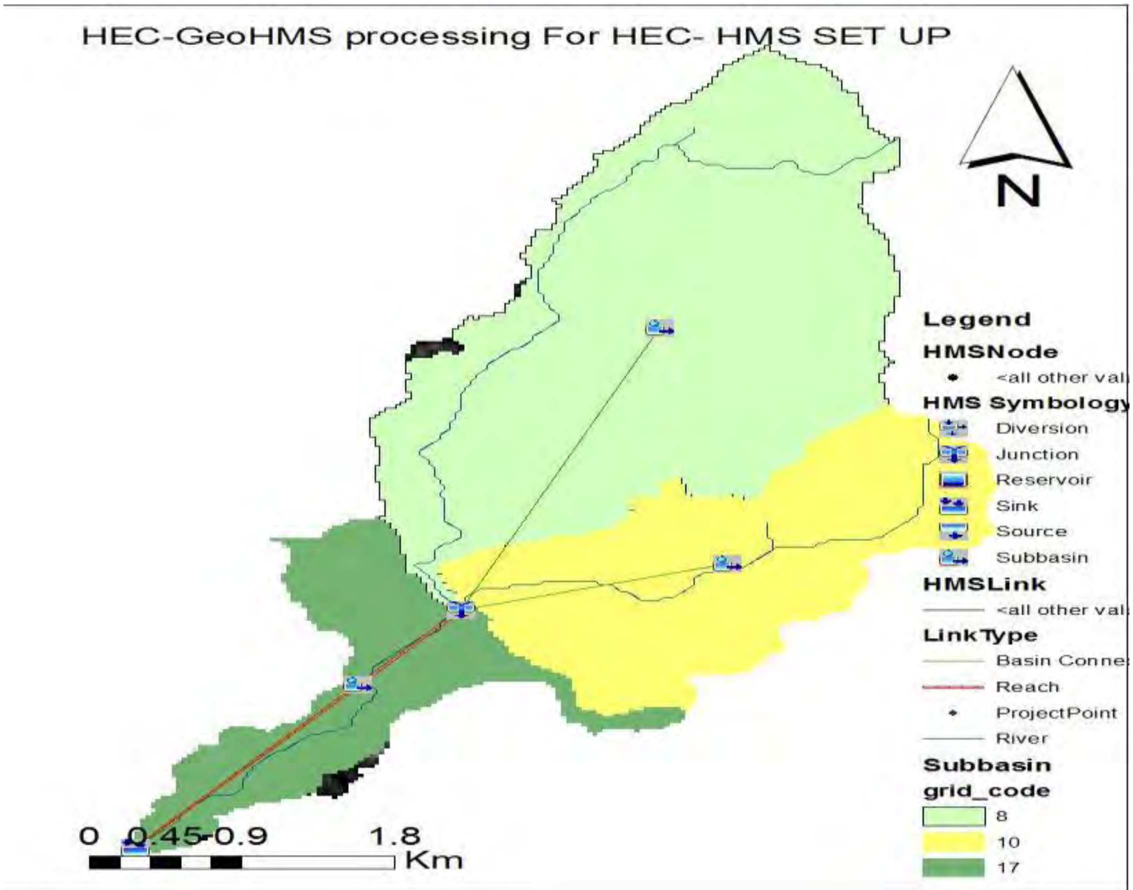


Figure 4-3: HEC-HMS Representation Derived From HEC-GEOHMS

For a watershed that consists of more than one soil types and land uses, a composite CN is calculated as:

$$CN_{composite} = \frac{\sum A_i \, CN_i}{\sum A_i}$$

Where, CNcomposite = the composite CN used for runoff volume computations;

CN_i = an index of watersheds subdivisions of uniform land use and soil type

A_i = the CN for subdivision i; and

i = the drainage area of subdivision i

Using GIS intersection of watershed map and soil, the following table is summarized.

Table 4-3: Kello sub-basins the corresponding soil-type, hydrologic soil group, land use

Sub-Basin Name	Soil Type	Hydrologic Soil Group	Area (km^2)	Sub-Basin Name	Land use	Area (km2)
Sub Basin 1	Eutric regosols	A	6.476	Sub Basin 1	Accacia bushland	10.95
	Eutric cambisol	B	0.453		Tropical plantation	0.61
	Chromic Vertisol	D	1.628		Tropical Forest	0.3
	Haplic xerosol	B	0.134			
Sub Basin 2	Eutric regosols	A	2.936	Sub Basin 2	Accacia bushland	3.13
	Eutric cambisol	B	2.31		Tropical Forest	0.102
					Cropland with shrubland	0.377
					Semi desert Glwshl	1.46
					No much	0.163
Sub Basin 3	Eutric regosols	A	0.222	Sub Basin 3	Accacia bushland	2.575
	Chromic Vertisol	D	0.106		Semi desert Grassland with shurbland	1.44
	Haplic xerosol	B	3.343			
	Leptosol	D	0.34			

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control And Watershed Management Study project, January 2006)

Table 4-4: Composite curve number

Sub-Basin Name	Soil Type	Soil Group	Land use	CN	Area (km^2)	Area (km^2)	CN composite
Sub Basin 1	Eutric regosols	A	Tropical plantation	67	0.614		
			Accacia bushland	48	5.735		
			Tropical Forest	57	0.127		
	Eutric cambisol	B	Accacia bushland	71	3.45		
			Tropical Forest	73	0.172		
	Chromic Vertisol	D	Accacia bushland	89	1.628		
	Haplic xerosol	B	Accacia bushland	71	0.134	11.861	62.02
Sub Basin 2	Eutric regosols	A	Accacia bushland	48	0.877		
			Tropical Forest	57	0.102		
			Cropland with shrubland	74	0.333		
			Semi desert Glwshl	49	1.462		
			No much		0.16		
	Eutric cambisol	B	Cropland with shrubland	83	0.044		
			No much	73	0.0022		
			Accacia bushland	71	2.254	5.24	58.85
Sub Basin 3	Eutric regosols	A	Accacia bushland	48	0.222		
	Leptosol	D	Accacia bushland	89	0.339		
	Haplic xerosol	B	Accacia bushland	71	1.955		
	Haplic xerosol	B	Semi desert Glwshl	68	1.387		
	Chromic Vertisol	D	Semi desert Glwshl	84	0.048		
	Chromic Vertisol	D	Accacia bushland	89	0.058	4.01	70.63

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

Initial Abstraction, Ia

From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship of Ia and S:

I = 0.2S, the maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (CN) as:

$$S = \frac{25400}{CN} - 254$$

Table 4-5: Maximum retention (S) and Initial abstraction (Ia)

Sub-Basin Name	Soil Type	Soil Group	Land use	Area ΣAi (Km2)	CN composite	Maximum Retention S	Initial Abstraction Ia
Sub Basin 1	Eutric regosols	A	Tropical plantation				
			Accacia bushland				
			Tropical Forest				
	Eutric cambisol	B	Accacia bushland				
			Tropical Forest				
	Chromic Vertisol	D	Accacia bushland				
	Haplic xerosol	B	Accacia bushland	11.861	62.022	155.53	31.106
Sub Basin 2	Eutric regosols	A	Accacia bushland				
			Tropical Forest				
			Cropland with shrubland				
			Semi desert Glwshl				
			No much				
	Eutric cambisol	B	Cropland with shrubland				
			No much				
			Accacia bushland	5.24	58.845	177.64	35.52
Sub Basin 3	Leptosol	D	Accacia bushland				
	Haplic xerosol	B	Accacia bushland				
	Haplic xerosol	B	Semi desert grassland with shurbland				
	Chromic Vertisol	D	Semi desert grassland with shurbland				
	Chromic Vertisol	D	Accacia bushland	4.01	70.63	105.62	21.12

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control And Watershed Management Study project, January 2006)

After insertion of these three data, the Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation.

The HEC-HMS program computes incremental precipitation during a storm by recalculating the infiltration volume at the end of each time interval. Infiltration during each time interval is the difference in volume at the end of two adjacent time intervals.

$$P_e = \frac{(p - Ia)^2}{p - Ia + S}$$

The precipitation excess, and hence the runoff will be zero until the accumulated rainfall exceeds the initial abstraction.

Therefore, the cumulative excess at time **t** is: $P_e = \frac{(p - 0.2S)^2}{p - 0.8S}$

4.6.2 Transformation Model

A HEC-HMS model of Kelo watershed was developed using the SCS curve number method, the SCS Unit Hydrograph transform and Muskingum-Cunge channel routing.

The SCS (now known as NRCS) peak flow method calculates peak flow as a function of drainage basin area, potential watershed storage, and the time of concentration.

Research by the SCS suggests that the UH peak and time of UH peak are related by:

$$U_p = \frac{CA}{T_p}$$

Where, A = watershed area;

C = conversion constant (2.08 in SI system).

The time of peak (also known as the time of rise) is related to the duration of the unit of excess precipitation as:

$$T_e = \frac{\Delta t}{2} + t_{lag}$$

In which Δt the excess precipitation duration (which is also the computational interval in the run) and

tlag = the basin lag , defined as the time difference between the center of mass of rainfall excess and the peak of the UH.

When the lag time is specified, the program solves the above equations to find the time of UH peak and the UH peak. With Up and Tp known, the UH can be found from the dimensionless form, which is built into the program, by multiplication.

For ungauged watersheds, the SCS suggests that the UH lag time may be related to time of concentration, t_c, as:

$t_{lag} = 0.6\, t_c$

Where t_c =Time of concentration can be estimated as:

$t_c = t_{sheet} + t_{shallow} + t_{channel}$

Where, tsheet = sum of travel time in sheet flow segments over the watershed land surface;

$t_{shallow}$ = sum of travel time in shallow flow segments, down streets, in gutters, or in shallow rills and rivulets; and

tchannel = sum of travel time in channel segments.

i. Sheet Flow

Sheet flow is flow over the watershed plane surface, before water reaches a channel.

Distances are short on the order of 10-100 meters (30-300 feet). For sheet flow of less than 100 meters, use Manning's kinematic solution (Overton and Meadows, 1976) to compute t_{sheet}

$$t_{sheet} = \frac{0.091(NL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

Where:

t_{sheet} = travel time, hr; N = an overland-flow roughness coefficient;

L = flow length, m; P_2 = 2-year, 24-hour rainfall depth, mm; and

S = slope of hydraulic grade line, which may be approximated by the land slope.

The topography of our catchment is mountainous. Hence, the sheet flow is negligible since rills and rivulets are the dominant ones in mountainous topography; which are considered in the next section (shallow flow).

ii. Shallow Concentrated Flow velocity

After short distances of at most 90m (300ft) Sheet flow usually turns to shallow concentrate in rills and then gullies of increasing proportions. Such flow is usually referred to as shallow flow. The average velocity m/sec for shallow concentrated flow can be estimated as:

$V = 16.1345\sqrt{S}$ For unpaved surface

$V = 20.3282\sqrt{S}$ For paved surface

Table 4-6: Time of concentration and basin lag

River/ Basin	Sub-basin	U/S ELV (m)	D/S ELV (m)	Longest Length (m)	$t_{shallow}$				Basin Lag(t_{lag}) (min.)
					Slope	V (m/s)	$t_{shallow}$ (Sec.)	$t_{shallow}$ (min.)	
Kelo	W140R120	2014	1511	7377.25	0.116	5.495	1342.538	22.376	13.43
	W150R130	1854	1511	4311.97	0.146	6.165	699.427	11.657	6.994
	W180R170	1511	1419	5376.23	0.0878	4.781	1124.5	18.74	11.244

iii. Channel Flow and pipe flow velocity

Flow in gullies empties in to channels or pipes. Open channel flow is assumed to begin where the stream follows and defined path and becomes visible/ significant. Manning's equation can be used to estimate average flow velocities in pipe and open channels

. $$V = \frac{1}{n} R^{2/3} S^{1/2}$$

R = the hydraulic radius (defined as the ratio of channel cross-section area to wetted perimeter);

S = slope of the energy grade line (often approximated as channel bed slope); and

n = Manning's roughness coefficient, can be estimated from textbook tables.

Once velocity is estimated, channel travel time is computed as:

$$t_{channel} = \frac{V}{L}$$

Where, L = channel length for these channels,

V = average velocity

Since there is no separate channel segments in which flow takes place, travel time in channel segments ($\mathbf{t}_{channel}$) is not applicable for this case.

4.6.3 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 averages of minimum monthly flow is adapted for base flow calculation methods.

4.2.1 Routing Models

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. In broad sense, flow routing may be considered as an analysis to trace the flow through a hydrologic system, given the input.

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 Kelo case.

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.

No observed hydrograph data available for calibrationSignificant backwater will influence discharge hydrograph	Kinematic wave; Muskingum-cunge, Modified puls
Flood wave will go out of banks, into floodplain	Modified puls, Muskingum-Cunge with 8-point cross section
Channel slope >0.002 and $\frac{TS_oU_o}{d_a} \geq \lvert 7 \rvert$	Any
Channel slope >0.002 to 0.0004 and $\frac{TS_oU_o}{d_a} \geq \lvert 7 \rvert$	Muskingum-Cunge, modified Puls, Muskingum
Channel Slope <0.0004 and $TS_o\left(\frac{g}{d_o}\right)^{1/2} \geq 30$	Muskingum-Cunge
Channel Slope <0.0004 and $TS_o\left(\frac{g}{d_o}\right)^{1/2} \angle 30$	None

(USACE April 1975)

The length is the total length of the reach element. The slope is the average slope for the whole reach. These values are measured from the 30m resolution DEM using HEC-GeoHMS.

The Manning's n, roughness coefficient, is the average value for the whole reach. This value is estimated from Ven Te Chow, David R. Maidment, Larry W. Mays. APPLIED HYDROLOGY.

4.8 Meteorological Model

Meteorological model is one of the main components in a project. There are seven different precipitation methods. Some precipitation methods require parameter data for each sub-basin. Other methods use the same data for all sub-basins. For this thesis work Frequency storm method is adopted.

4.8.1 Frequency Analysis

The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions.

Rainfall frequency analysis was used as a key input to the calculation of flood frequency and magnitude. Certain hydrologic procedures use rainfall and rainfall frequency as the basic input rather than flood frequency. It is commonly assumed that the 10-year rainfall will produce the 10-year flood. Depending on antecedent soil moisture conditions, and other hydrologic parameters, there may not be a direct relationship between rainfall and flood frequency (ERA Drainage Design Manual, 2002). The rainfall frequency analysis was carried out using the available 24 hour annual maximum rainfall data for the rain gauge stations situated in the nearby areas. It was necessary to combine data from different stations in order to arrive at an acceptable representative record.

4.9 Runoff Data

No runoff data are available for Kelo catchment. The Kelo River has no gauging station.
No discharge measurements have been carried out. Therefore, gauged catchment nearby and hydrologically similar to Kello catchment named Borkena catchment is used for the Calibration which is discussed on the next table.

Figure 4-4: comparision of the two catchments

Comparision of the two catchments			
No	Parameters	Kello Catchment	Borkena Catchment
1	Mean annual maximum Temprature	37.5	37.5
2	Mean annual minimum Temprature	5	6.75
3	Weather condition	warm	warm
4	Soil type	53.67%, 15.4%, 9.7% and 19.4% of the area is covered by eutric regosols, eutric cambisols,chromic vertisols and haplic xerosols respectively	36.96%, 25.6%, 14.87%, 7.53 and 5.57% of the area is covered by Eutric Cambisols, Eutric regosols, Leptosols,Chromic vertisols and Haplic xerosols respectively
5	Land cover	78.9% and 13.7% of the area is mainly covered by Acacia bushland and semi deserted grass land respectively	37.5%, 32%, 14.33%, 5.9% and 5.4% of the area is covered by Cropland with shrubland and Acacia bushland, sparsely vegetated, semi deserted grass land and herbaceous wetland respectively.
6	Maximum annual rainfall	124	154
7	Minimum annual rainfall	0	0
8	Land slope	0.0265 to 0.134	0.0182 to 0.672
9	High elevation	2368	3037
10	Low elevation	1431	537

As seen from the table by all the comparison parameters it is clear that the two catchments are hydrologically exactly similar catchments.

5. Model Calibration and Validation

Calibration is the process of adjusting selected model parameter 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. 7 years data (2003-2009) are used for calibration. Each model that is included in HEC-HMS has parameters. The value of each parameter must be specified to use the model for estimating runoff or routing hydrographs.

Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search is often referred to as optimization.

Given initial estimates of the parameters, the models included in the program can be used with the observed boundary conditions (rainfall or upstream flow) to compute the output, either the watershed runoff hydrograph or a channel outflow hydrograph. At this point, the program compares the computed hydrograph to the observed hydrograph. The goal of this comparison is to judge how well the model "fits" the real hydrologic system.

If the fit is not satisfactory, the program systematically adjusts the parameters and reiterates.
When the fit is satisfactory, the program will report the optimal parameter values. The presumption is that these parameter values then can be used for runoff or routing computations that are the goal of the flood runoff analyses.

A process called optimization is used that begins from initial parameter estimates and adjusts them so that the simulated results match the observed stream flow as closely as possible. Two different search algorithms are provided that move from the initial estimates to the final best estimates. A variety of objective functions are provided to measure the goodness of fit between the simulated and observed stream flow in different ways. While parameter estimation using optimization does not produce perfect results, it can be a valuable aid when calibrating models.

Borkena hydro meteorological station is used for the calibration due to the hydrological similarity of the catchments assigned by the Ministry of Water Resources. Then the parameters are transferred to Kelo catchment.

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 four years (2012-2015)

5.1 Watershed Physical Description

The Kelo catchment is not only located in Awash basin but also with in the Borkena catchment. Geographically the Borkena hydro meteorological station is 638'N and 2396'E.

The elevation of Borkena Catchment Varies from 576m to 3037m amsl. Slopes range from almost 0.0182 to 0.672(i.e. 1.82 to 67.2%). Whereas the elevation of Kello Catchment varies from about 1431m in the town of Kello and 2368m in the escarpment of the eastern edge of the Kello highlands. Catchment slopes range from 0.06 to 0.3 (i.e. 6 to 30%).

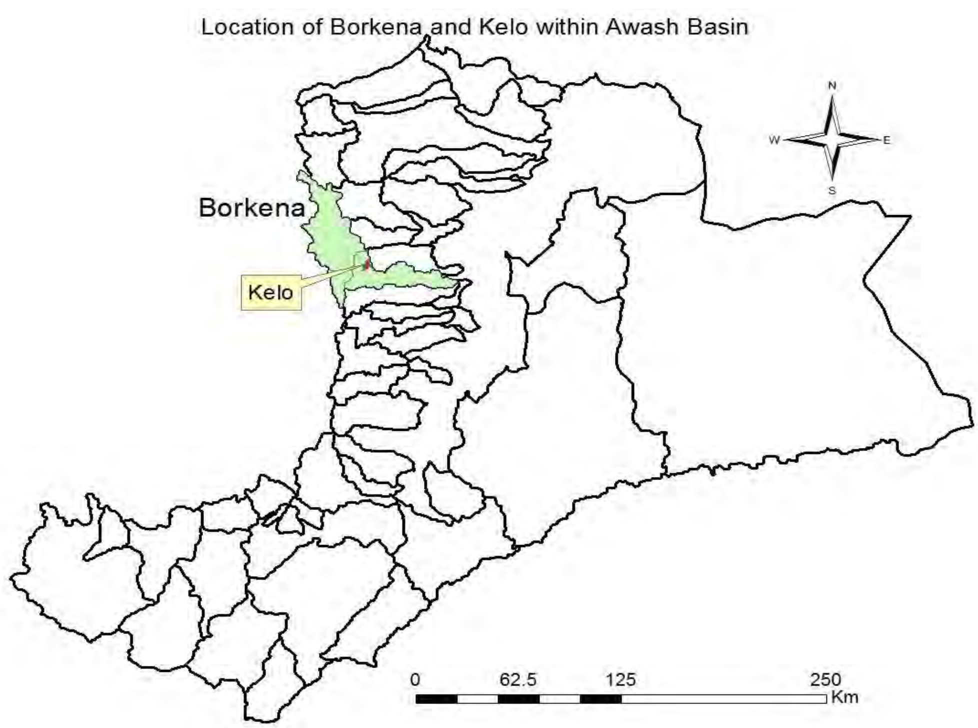


Figure 5-1: Location of Borkena and Kelo within Awash basin

5.2 Sub-Basins Modeling for Borkena Catchment

To consider the spatial analysis in the catchment, it is divided into three sub-basins as shown below.

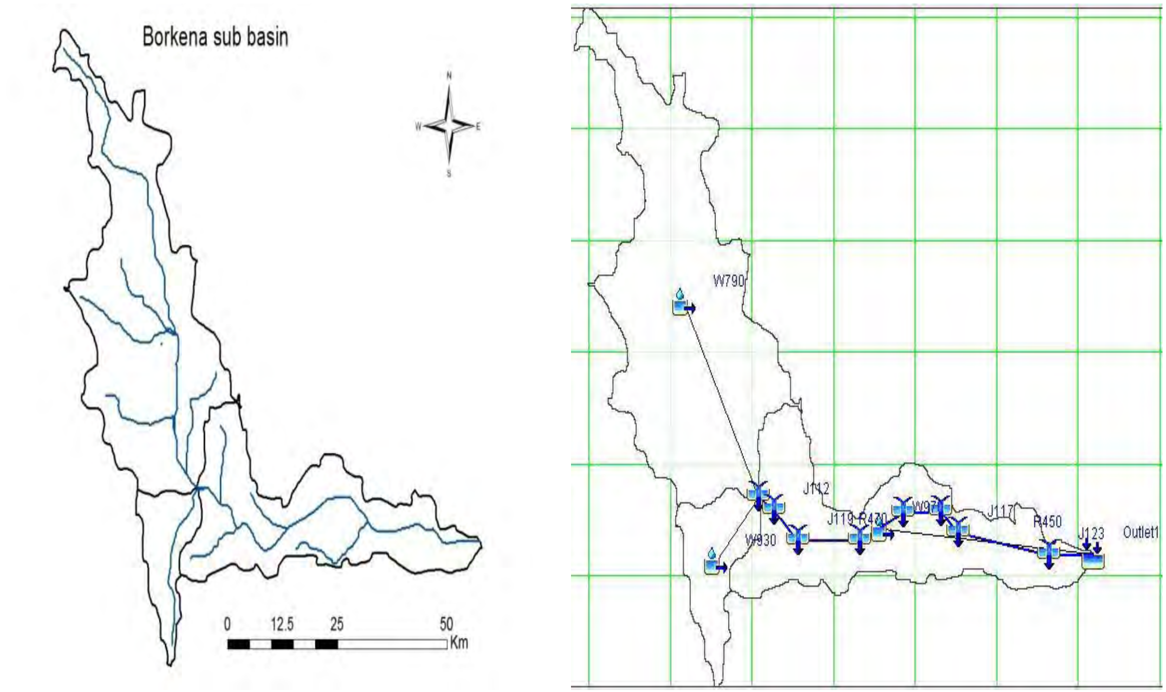


Figure 5-2: Borkena Catchment with its sub-basins

5.3 Loss

Since it is for calibration purpose, the loss method should be similar to the target area method which is SCS Curve Number Loss method.

Table 5-1: Sub-Basin Catchment Areas of Borkena Basin

Name of Sub basin	Area (km^2)
Sub basin 1	1245.72
Sub basin 2	210.84
Sub basin 3	780.36

The three parameters to compute the loss required are shown below.

- Curve Number
- Initial Abstraction
- Impervious (%)

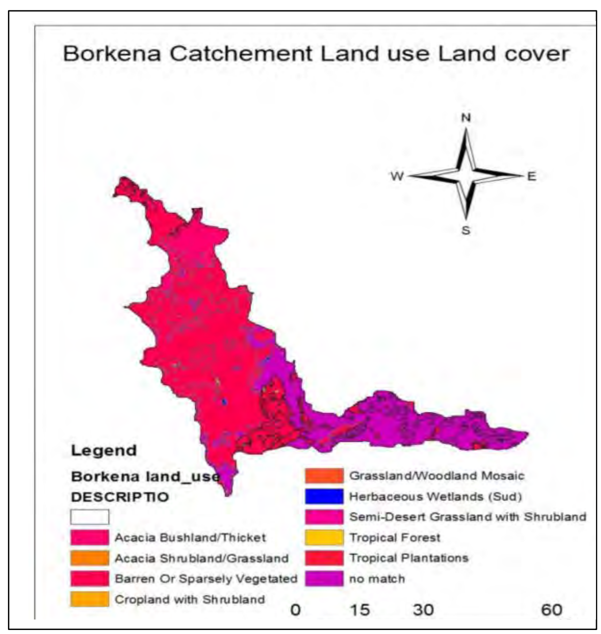


Figure 5-3: Borkena Land use land cover map

Table 5-2: Borkena Land use table

Name	Land use	Area (Km^2)
Sub_ Basin 1	Acacia bushland	201.932
	Cropland with shrubland	632.051
	Tropical Forest	18.83
	Barren/Sparsely vegetated	146.189
	Herbaceous wetland	48.565
	Tropical plantation	46.853
	semi desert grass land	76.392
	No match	69.875
Sub Basin 2	Acacia bushland	30.923
	Cropland with shrubland	79.283
	Barren/Sparsely vegetated	69.023
	Herbaceous wetland	9.236
	No match	3.908
Sub Basin 3	Acacia bushland	416.342
	Cropland with shrubland	46.084
	Tropical Forest	31.55
	Barren/Sparsely vegetated	75.04
	Herbaceous wetland	51.372
	Tropical plantation	2.129
	semi desert grass land	42.878
	Grassland/woodland	0.286
	No match	122.478

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

5.3.1 *Curve Number*

To compute the Curve Number (CN), soil and land use are required which are shown below.

Table 5-3: Borkena Soil Data in the Required Sub Catchment Range

Name	Soil type	Hydrologic Soil Group	Area (km2)
Sub Basin 1	Eutric Cambisols	B	677.242
	Eutric regosols	A	323.696
	Leptosols	D	52.699
	Chromic vertisols	D	78.96
Sub Basin 2	Eutric Cambisols	B	38.238
	Eutric regosols	A	67.672
	Leptosols	D	108.823
	Chromic vertisols	D	13.635
Sub Basin 3	Eutric Cambisols	B	46.217
	Eutric regosols	A	133.977
	Leptosols	D	144.853
	Chromic vertisols	D	62.671
	Eutric fluvisols	B	61
	Orthic Solonchaks	B	88.604
	Haplic xerosols	B	114.853
	Chromic cambisols	B	5.444
	Vertic Cambisols	B	41.99

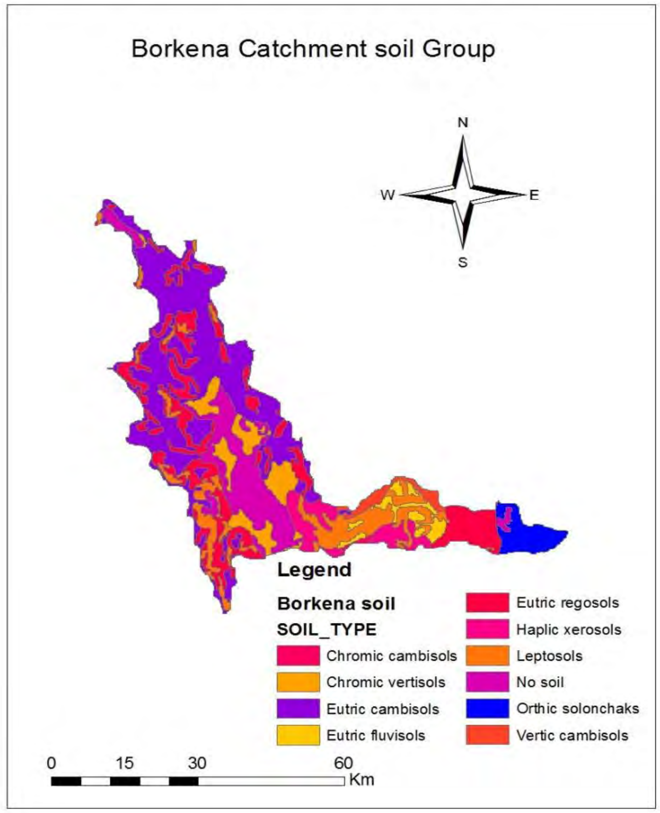


Figure 5-4 Borkena catchment Soil map

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

Name	Soil_type	Land use	Area (Km2)
Sub Basin 1	Eutric cambisol	Acacia bushland	123.989
		Cropland with shrubland	387.388
		Tropical Forest	12.439
		Barren/Sparsely vegetated	38.856
		Herbaceous wetland	4.157
		Tropical plantation	18.512
		Semi desert grass land	49.576
		No match	46.693
	Eutric regosolsol	Acacia bushland	81.334
		Cropland with shrubland	85.185
		Tropical Forest	5.546
		Barren/Sparsely vegetated	35.853
		Herbaceous wetland	0.979
		Tropical plantation	10.032
		Semi desert grass land	4.713
		No match	22.354
	Leptosols	Acacia bushland	8.107
		Cropland with shrubland	8.892
		Barren/Sparsely vegetated	29.408
		Herbaceous wetland	0.478
		Tropical plantation	3.075
		Semi desert grass land	0.0148
		No match	2.513
	chromic Vertisols	Acacia bushland	0.472
		Cropland with shrubland	63.594
		Tropical Forest	0.0072
		Barren/Sparsely vegetated	0.0185
		Herbaceous wetland	4.503
		Semi desert grass land	6.663
		No match	3.282
Sub Basin 2	Eutric Cambisols	No match	2.9
		Acacia bush land	8.82
		Cropland with shrub land	17.38
		Barren/ sparsely vegetated	8.6
	Eutric regosols	No match	0.85
		Acacia bush land	17.103
		Cropland with shrub land	20.82
		Barren/ sparsely vegetated	25.67
		Herbaceous wetland	2.71
	Leptosols	No match	0.25
		Acacia bush land	4.7
		Cropland with shrub land	13
		Barren/ sparsely vegetated	27.69
		Herbaceous wetland	0.92
	Chromic vertisols	Acacia bush land	1.17
		Cropland with shrub land	12.33
		Barren/ sparsely vegetated	0.03
		Herbaceous wetland	0.105

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

Name	Soil_type	Land use	Area (Km2)
SUB BASIN 3	Eutric Cambisols	Acacia bush land	36.67
		Cropland with shrub land	5.1
		Barren/ sparsely vegetated	0.18
		Herbaceous wetland	0.07
		Semi desert grass land	0.23
		Tropical plantation	0.43
		Tropical Forest	0.57
	Eutric regosols	No match	4.93
		Cropland with shrub land	14.3
		Herbaceous wetland	0.17
		Semi desert grass land	1.2
		Tropical plantation	1.07
		Tropical Forest	2.2
	Leptosols	No match	20.74
		Acacia bush land	105.38
		Barren/ sparsely vegetated	1.82
		Semi desert grass land	3.08
		Tropical Forest	16.92
	Chromic vertisols	So match	1.71
		Acacia bush land	9.83
		Cropland with shrub land	13
		Herbaceous wetland	6.69
		Semi desert grass land	11.12
		Tropical plantation	0.37
		Tropical Forest	0.07
	Chromic cambisols	No match	0.32
		Acacia bush land	4.93
		Herbaceous wetland	2.47
		Semi desert grass land	0.14
	Vertic Cambisols	No match	2.47
		Acacia bush land	33.44
		Cropland with shrub land	5.6
		Barren/ sparsely vegetated	0.44
		Tropical Forest	0.61
	Eutric Fluvisols	No match	12.23
		Acacia bush land	42.94
		Cropland with shrub land	0.2
		Semi desert grass land	1.2
		Tropical Forest	2.3
	Haplic Xerosols	No match	5.65
		Acacia bush land	85.37
		Barren/ sparsely vegetated	1.13
		Semi desert grass land	11.57
		Tropical Forest	6.44
	Orthic Solonchaks	No match	41.74
		Acacia bush land	14.52
		Barren/ sparsely vegetated	32.62
		Semi desert grass land	0.37

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

5.3.2 *Maximum Retention, S*

As discussed above, $S = \dfrac{25400}{CN} - 254$

When the CN is specified, the program solves the above equations to find Ia.

Table 5-4: Weighted Curve Number

Name	Soil Type	Soil Group	Land Use	CNi	Area $\sum A$ (Km^2)	CN_c
Sub Basin 1	Eutric cambisol	B	Acacia bush land	67	634.92	66.9
			Cropland with shrub land	73		
			Tropical Forest	65		
			Barren/Sparsely vegetated	86		
			Herbaceous wetland	100		
			Tropical plantation	59		
			semi desert grass land	69		
	Eutric regosolsol	A	Acacia bush land	48	223.642	
			Cropland with shrub land	63		
			Tropical Forest	43		
			Barren/Sparsely vegetated	77		
			Herbaceous wetland	100		
			Tropical plantation	35		
			semi desert grass land	49		
	Leptosols	D	Acacia bushland	83	49.975	
			Cropland with shrubland	83		
			Barren/Sparsely vegetated	94		
			Herbaceous wetland	100		
			Tropical plantation	79		
			semi desert grass land	84		
	chromic Vertisols	D	Acacia bushland	83	78.539	
			Cropland with shrubland	83		
			Tropical Forest	82		
			Barren/Sparsely vegetated	94		
			Herbaceous wetland	100		
			Semi desert grass land	84		
Sub Basin 2	Eutric Cambisols	B	Acacia bush land	67	34.8	91.8
			Cropland with shrub land	73		
			Barren/ sparsely vegetated	86		
	Eutric regosols	A	Acacia bush land	48	66.303	
			Cropland with shrub land	63		
			Barren/ sparsely vegetated	77		
			Herbaceous wetland	100		
	Leptosols	D	Acacia bush land	83	46.31	
			Cropland with shrub land	83		
			Barren/ sparsely vegetated	94		
			Herbaceous wetland	100		
	Chromic vertisols	D	Acacia bush land	83	13.635	
			Cropland with shrub land	83		
			Barren/ sparsely vegetated	94		
			Herbaceous wetland	100		

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

Name	Soil Type	Soil Group	Land Use	CNi	Area∑A (Km^2)	CN_c
Sub Basin 3	Eutric cambisols	B	Acacia bush land	67	43.3	66.922
			Cropland with shrub land	73		
			Barren/ sparsely vegetated	86		
			Herbaceous wetland	100		
			Semi desert grass land	69		
			Tropical plantation	59		
			Tropical Forest	65		
	Eutric regosols	A	Acacia bush land	63	106	
			Cropland with shrub land	43		
			Herbaceous wetland	77		
			Semi desert grass land	100		
			Tropical plantation	35		
			Tropical Forest	49		
	Leptosols	D	Acacia bush land	83	127	
			Barren/ sparsely vegetated	94		
			Semi desert grass land	84		
			Tropical Forest	81		
	Chromic vertisols	D	Acacia bush land	83	41.08	
			Cropland with shrub land	83		
			Herbaceous wetland	100		
			Semi desert grass land	84		
			Tropical plantation	80		
			Tropical Forest	82		
	Chromic cambisols	B	Acacia bush land	67	7.54	
			Herbaceous wetland	100		
			Semi desert grass land	69		
	Vertic Cambisols	B	Acacia bush land	67	40.09	
			Cropland with shrub land	73		
			Barren/ sparsely vegetated	86		
			Tropical Forest	65		
	Eutric Fluvisols	B	Acacia bush land	67	46.64	
			Cropland with shrub land	73		
			Semi desert grass land	69		
			Tropical Forest	65		
	Haplic Xerosols	B	Acacia bush land	67	105.21	
			Cropland with shrub land	73		
			Barren/ sparsely vegetated	86		
			Semi desert grass land	69		
			Tropical Forest	65		
	Orthic Solonchaks	B	Acacia bush land	67	47.51	
			Barren/ sparsely vegetated	86		
			Semi desert grass land	69		

Source: Ministry of water, Irrigation & Energy (Awash River Basin Flood Control and Watershed Management Study project, January 2006)

5.3.3 Transformation

Table 5-5: Time of concentration and Basin lag

River/ Basin	U/S EI (m)	D/S EI (m)	Length (m)	tshallow			Basin Lag (tlag) min
				S	V (m/s)	tshallow(min)	
	3037	1400	90106.305	0.0182	2.177	689.835	413.901
	2221	576	81295.036	0.0202	2.29	591.667	355.00
	3433	1400	99580.317	0.0672	4.182	396.86	238.116

5.8.1 Base Flow

For the calibration area, constant monthly method is adopted. Base flow is nicely approximated by a constant flow for each month and for this thesis work the average of the minimum of the respective months are adopted for 7 years of data are used(2003 to 2009).

For the calibration, Borkena station Seven years (2003 to 2009) daily rainfall data is adopted for Gage weights precipitation modeling.

5.5 Runoff Data

Borkena station seven years (2003to 2009) daily recorded data are used for the calibration. However, the hydrological data taken from the Ministry of Water Resources does not resemble the actual condition at site. As per the hydrologist assigned for this catchment, the actual values are highly greater than these values. Since the gauge station is not automatic, there is clearly personal error while recording.

5.6 Simulation Run and Search Method

Two search methods are available for minimizing the objective function and finding optimal parameter values. The univariate gradient method evaluates and adjusts one parameter at a time while holding other parameters constant. The Nelder and Mead method uses a downhill simplex to evaluate all parameters simultaneously and determine which parameter to adjust. For this thesis work the univariate gradient Evolution search method was adopted as it resulted in a better result.

5.7 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 a 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 considers only 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 referenced 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 values.

5.6.2 Coefficient of Efficiency (Nash Sutcliffe Efficiency)

The coefficient is widely used in hydrology. In this case it represents the efficiency of the model in scale, which goes from minus 1 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 predicator 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.

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

Where, q_{oi} = observed value at the ith time interval

q_{si} = simulated value at the ith time interval

q_{oa} = average value of observed discharge

5.6.3 Coefficient of determination

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 attach. In all the formula, the variables are:

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(q_{si} - q_{sa}\right)\left(q_{oi} - q_{oa}\right)\right]^2}{\sum_{i=1}^{n}\left(q_{si} - q_{sa}\right)^2 \sum_{i=1}^{n}\left(q_{oi} - q_{oa}\right)^2}$$

Where, q_{oi} = observed value at the ith time interval

q_{si} = simulated value at the ith time interval

q_{oa} = average value of observed discharge

qsa = average value of simulated discharge

n = number of sample data

Both efficiency evalution criteria parameters must resemble each other.

6. Results and Discussion

6.1 HEC-HMS Calibration Results and Duiscussion for Kelo Town

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 Borkena catchment. This is demonstrated by correlation coefficient and the Nash- Sutcliffe (1970) efficiency values catchments. The daily calibration results are presented in table 6.1.

Table 6-1Optimized Parameters of HEC-HMS for Borkena Catchment on Daily Basis

Optimized Parameter Results for Trial "Trial 1"

Project:Borkena Catchment Cal Optimization Trial:Trial 1

Start of Trial: 01Jan2003, 00:00 Basin Model: Bcatchment1
End of Trial: 31Dec2009, 00:00 Meteorologic Model:Met 1
Compute Time:17Feb2017, 10:26:50

Element	Parameter	Units	Initial Value	Optimized Value	Objective Func... Sensitivity
W1060	SCS Curve Number...		69.244	62.320	0.20

Flow hydrographs for the observed and simulated flows at Combolcha gauging station is presented in the graph below.

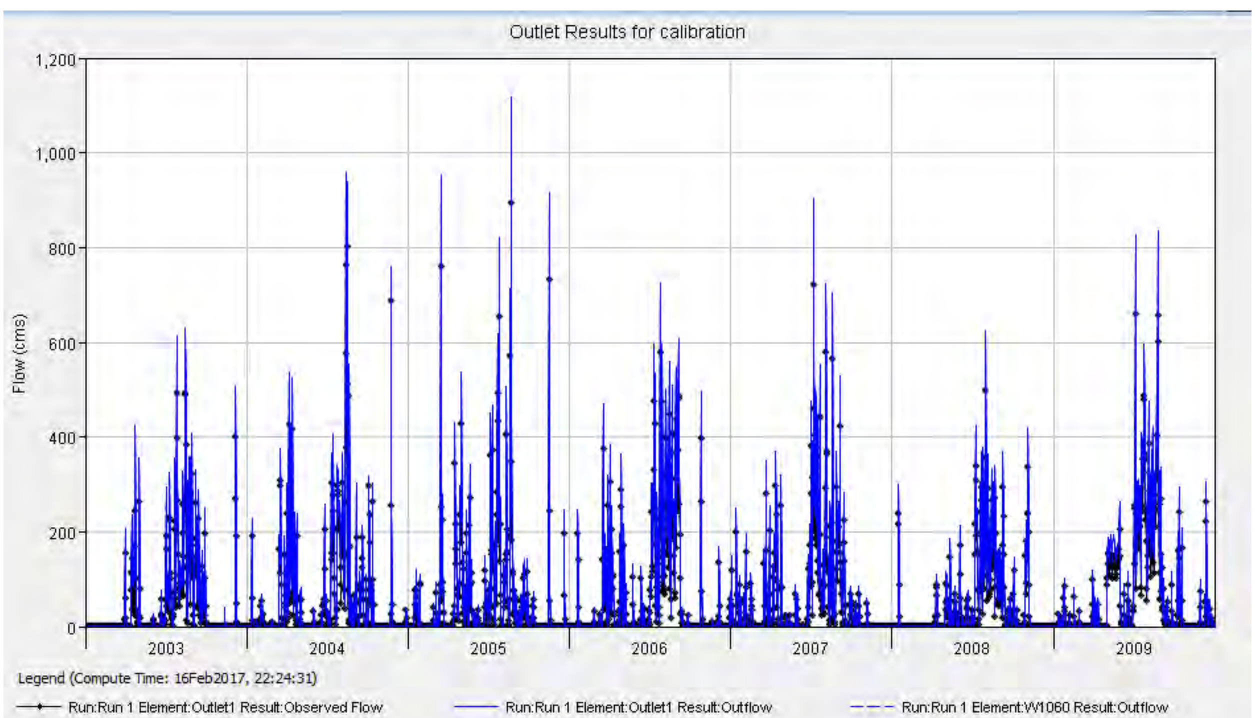
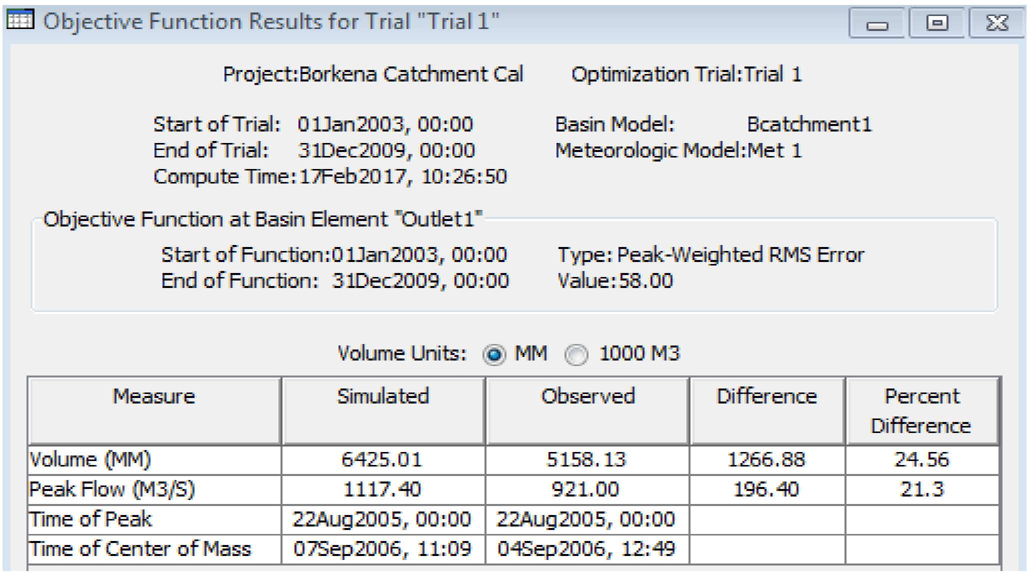


Figure 6-1 Calibration of HEC-HMS Observed and Simulated Daily Flow Hydrographs

Table 6-2 Calibration Performance of HEC-HMS for Borkena Catchment

Catchment	Borkena
Coefficient of determination(R^2)	0.75
Nash-Sutcliffe(Ens)	0.73
Period of calibration (daily)	From 2003 to 2009

Table 6-3 Borkena Catchment Objective Function Result


Objective Function Results for Trial "Trial 1"

Project:Borkena Catchment Cal   Optimization Trial:Trial 1

Start of Trial: 01Jan2003, 00:00   Basin Model: Bcatchment1
End of Trial: 31Dec2009, 00:00   Meteorologic Model:Met 1
Compute Time:17Feb2017, 10:26:50

Objective Function at Basin Element "Outlet1"

Start of Function:01Jan2003, 00:00   Type: Peak-Weighted RMS Error
End of Function: 31Dec2009, 00:00   Value:58.00

Volume Units: MM 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	6425.01	5158.13	1266.88	24.56
Peak Flow (M3/S)	1117.40	921.00	196.40	21.3
Time of Peak	22Aug2005, 00:00	22Aug2005, 00:00		
Time of Center of Mass	07Sep2006, 11:09	04Sep2006, 12:49		

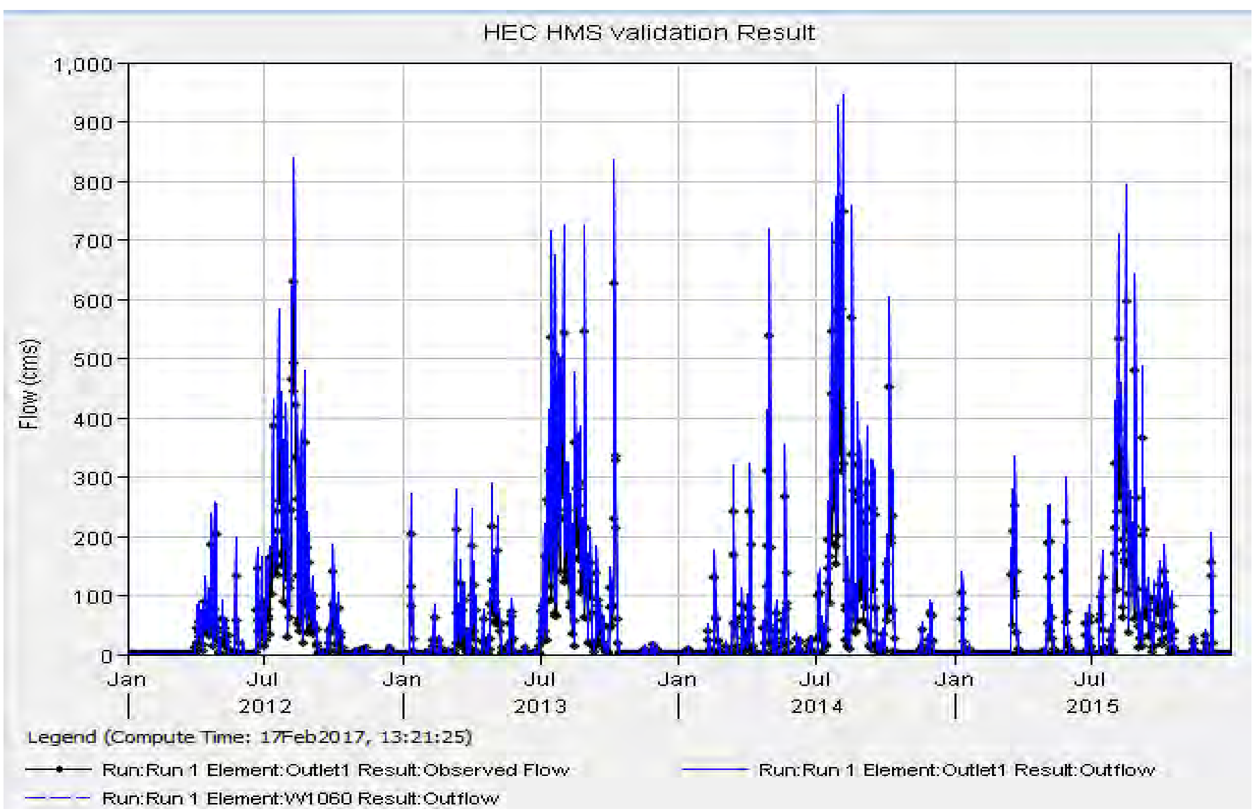
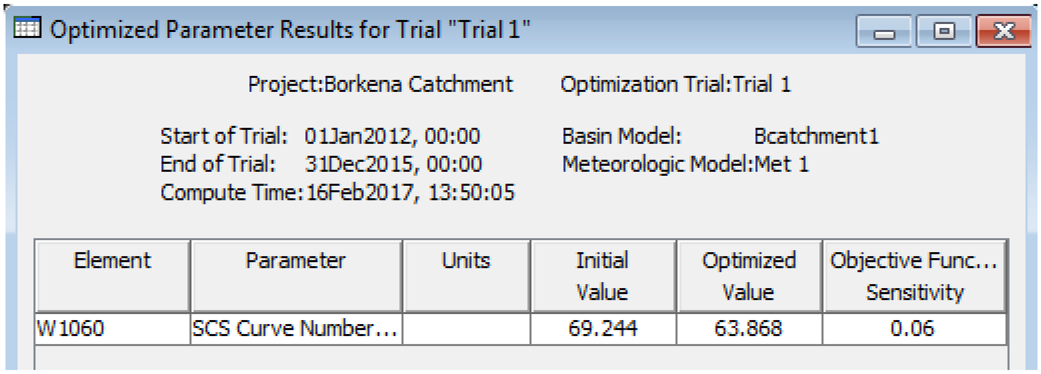


Figure 6-2 HEC-HMS Validation Results

Table 6-4 Optimized Parameters of HEC-HMS for Borkena Catchment for Validation on Daily Basis

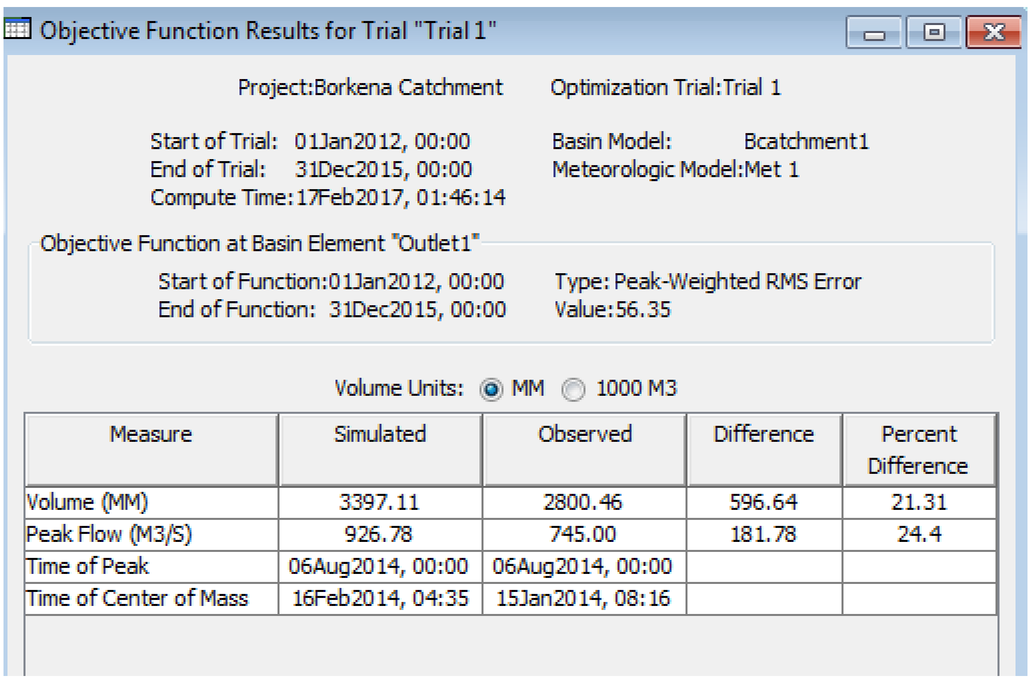

Optimized Parameter Results for Trial "Trial 1"

Project:Borkena Catchment   Optimization Trial:Trial 1

Start of Trial: 01Jan2012, 00:00   Basin Model: Bcatchment1
End of Trial: 31Dec2015, 00:00   Meteorologic Model:Met 1
Compute Time: 16Feb2017, 13:50:05

Element	Parameter	Units	Initial Value	Optimized Value	Objective Func... Sensitivity
W1060	SCS Curve Number...		69.244	63.868	0.06

Table 6-5 Borkena Catchment Objective Function Validation Result


Objective Function Results for Trial "Trial 1"

Project:Borkena Catchment   Optimization Trial:Trial 1

Start of Trial: 01Jan2012, 00:00   Basin Model: Bcatchment1
End of Trial: 31Dec2015, 00:00   Meteorologic Model:Met 1
Compute Time: 17Feb2017, 01:46:14

Objective Function at Basin Element "Outlet1"

Start of Function: 01Jan2012, 00:00   Type: Peak-Weighted RMS Error
End of Function: 31Dec2015, 00:00   Value: 56.35

Volume Units: MM 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	3397.11	2800.46	596.64	21.31
Peak Flow (M3/S)	926.78	745.00	181.78	24.4
Time of Peak	06Aug2014, 00:00	06Aug2014, 00:00		
Time of Center of Mass	16Feb2014, 04:35	15Jan2014, 08:16		

Table 6-6Validation Performance of HEC-HMS for Borkena Catchment

Catchment	Borkena
Coefficient of determination(R^2)	0.77
Nash-Sutcliffe(Ens)	0.75
Period of calibration (daily)	From 2012 to 2015

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

As can be seen from the above table and the hydrograph, the optimization result shows computed and observed stream flow best fits at CN value equal to 62.32. Hence, with the absence of gauged data for the study area we can use HEC-HMS for flood estimation for kello catchment by adjusting CN value with a ratio of: 69.224/62.32 = 1.11

6.2 Meteorological Model

Meteorological model is one of the main components in a project. There are seven different precipitation methods. Some precipitation methods require parameter data for each sub-basin. Other methods use the same data for all sub-basins.

Two methods are adopted as an option for precipitation modeling since the concern is flood that uses more than one nearby metrological stations. These are frequency storm and gage weights. Easy Fit is used for the analysis allowing fitting probability distributions.

6.2.1 Flood Frequency Analysis

Rainfall frequency analysis was used as a key input to the calculation of flood frequency and magnitude. Certain hydrologic procedures use rainfall and rainfall frequency as the basic input rather than flood frequency. It is commonly assumed that the 10-year rainfall will produce the 10-year flood. Depending on antecedent soil moisture conditions, and other hydrologic parameters, there may not be a direct relationship between rainfall and flood frequency (ERA Drainage Design Manual, 2002). The flood frequency analysis was carried out using the available 24 hour annual maximum flood data for the rain gauge stations situated in the nearby areas. It was necessary to combine data from different stations in order to arrive at an acceptable representative record.

Table 6-7: Kello goodness of fit

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.49481	8	8.7992	8	53.766	8
2	Exponential (2P)	0.16422	7	2.4811	7	2.583	7
3	Log-Pearson 3	0.09532	3	0.28136	1	0.42189	4
4	Lognormal	0.09927	4	0.30636	2	0.05614	2
5	Lognormal (3P)	0.10152	6	0.30905	3	0.06111	3
6	Normal	0.09295	1	0.3828	4	0.74164	5
7	Weibull	0.09425	2	0.54663	6	1.4505	6
8	Weibull (3P)	0.09939	5	0.42078	5	0.0514	1

#	Distribution	Parameters
1	Exponential	λ=0.01215
2	Exponential (2P)	λ=0.03832 γ=56.18
3	Log-Pearson 3	α=37458.0 β=-0.00114 γ=47.036
4	Lognormal	σ=0.21678 μ=4.3867
5	Lognormal (3P)	σ=0.2686 μ=4.1715 γ=15.112
6	Normal	σ=18.076 μ=82.275
7	Weibull	α=5.199 β=87.94
8	Weibull (3P)	α=1.6019 β=32.333 γ=53.15

Using the average of the test ranking methods, the Kello discharge data fits both the lognormal and Log-pearson 3 parameter distribution. But for this work the lognormal one is selected.

Table 6-8: Kello river T year's extreme discharge magnitude (XT)

Return Period T(years)	XT (Using log-normal distribution)
2	80.35
5	89.33
10	106.58
25	118.18
50	126.34
100	134.15
500	147.87
1000	158.74

6.3 Modeling by gauge weight storm method

6.3.1 Output of HEC-HMS by frequency Storm

Table 6-9: peak discharge output of HEC- HMS using gauge weight method

S.No	Return period (years)	peak flow (m3/s)
1	2	38.05
2	5	47.38
3	10	67.28
4	25	81.87
5	50	92.66
6	100	103.33

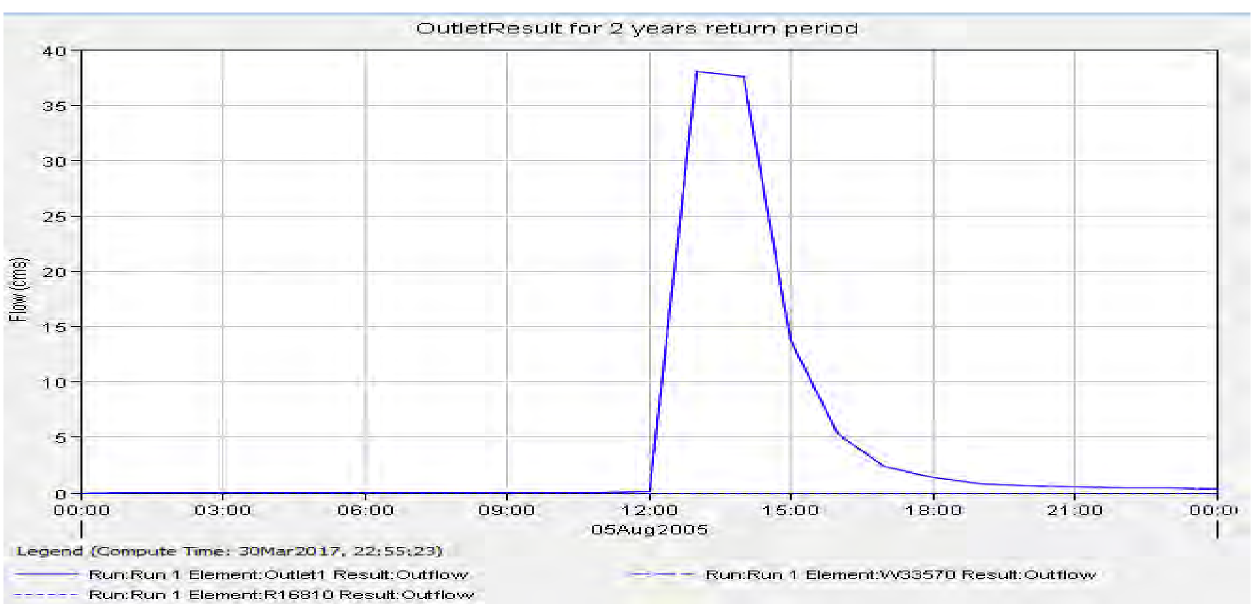


Figure 6-3 HEC-HMS Frequency Resuts of Kello River for 2 years return Period

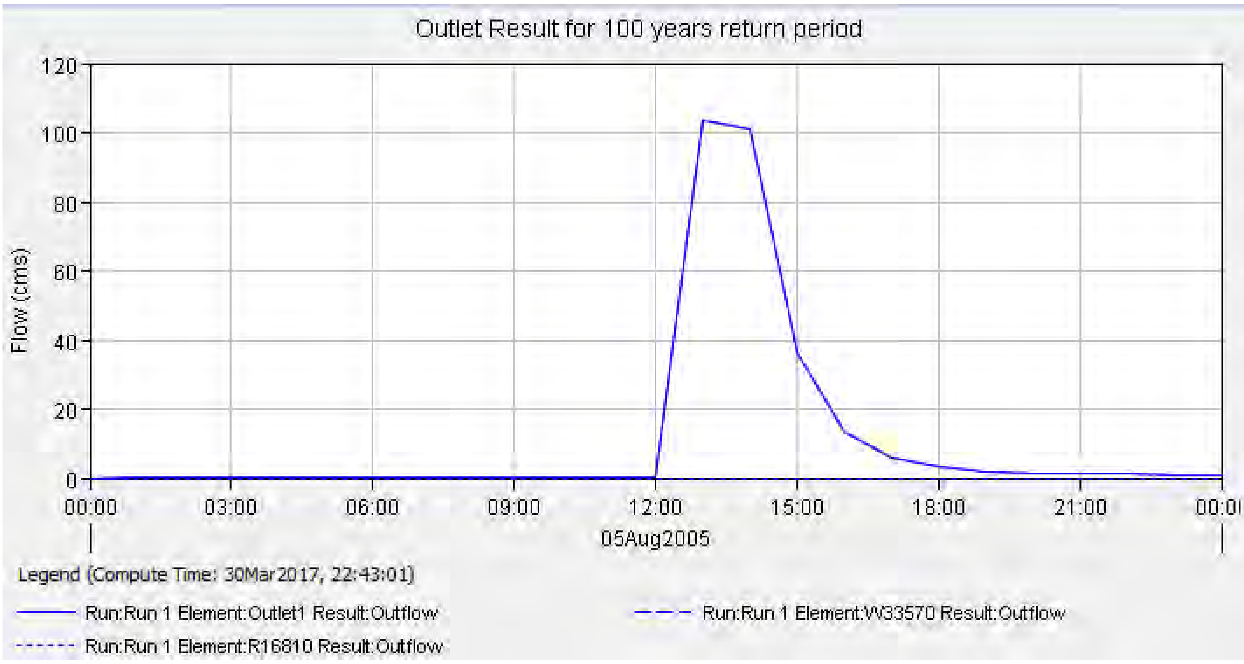


Figure 6-4 HEC-HMS Frequency Resuts of Kello River for 100 year return Period

From the result table minimum peak flow for the Kello 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 18.41m^3/s and 119.63M^3/s for 2 year and 100 year frequency respectively.

6.3 FLOOD INUNDATION MAP

(The models HEC-RAS and HEC-GEORAS (Pre and post processing) results)

The flood Inundation map shows the area extent that can 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. 4m contour interval is developed from 30m DEM of the study area. Then in combination with the DEM and 4m contour interval is converted to TIN data format used to proceed with the HEC-GeoRAS.

6.3.1 Pre-RAS (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 polyline themes defining stream centerline, stream banks, flow path lines and cross- sections.

- ❖ 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, stream banks, flow path lines and cross-sections.
- ❖ Generation of the HEC-RAS Import File.

6. 3.1.1 *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 Centerline, Banks, and Flow Paths Centerlines and Cross-Sectional Cut Lines.

6.3.1.2 *Attributing RAS Theme*

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

6. 3.1.3 *Generating the RAS GIS Import File*

To generate the RAS GIS Import File, the 3D stream Centerline and Cross Section Surface Line (3D) shape file created from the RAS Theme. Geometric data from the two 3D (Stream Centerline 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.

6.4 HEC-RAS Results

6. 4.1 *Geometric Data*

HEC-RAS has the ability to import three-dimensional (3D) river schematic cross section data created in a GIS /ArcView HEC-GeoRAS/ While the HEC-RAS utilizes two dimensional data. During the computations, the three-dimensional information is used in the program for display purpose. Surface profiles exported back to the GIS /ArcView HEC-GeoRAS/ system for development and display of a flood inundation map.

The following geometric data imported using HEC-RAS:-

- 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).

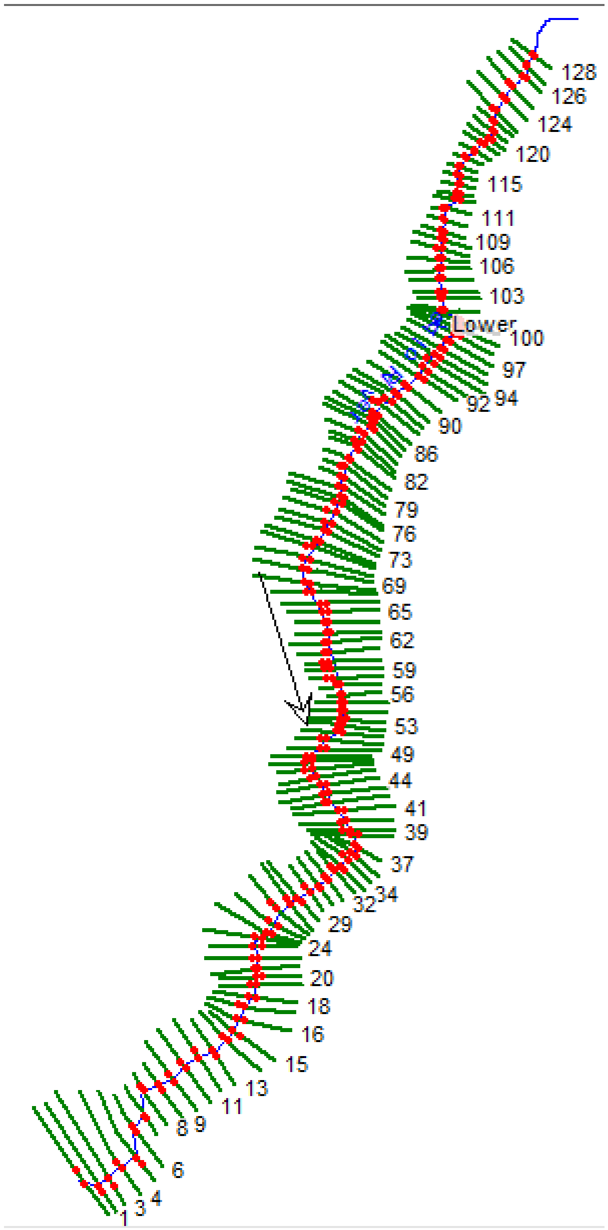


Figure 6-5 Geometric Schematic data imported to HEC-RAS Cross-Section:-

Cross sections are taken perpendicular to the stream and extended to achieve the maximum watershed elevation so as to identify areas where flood overtops.

Station 73 Station 123

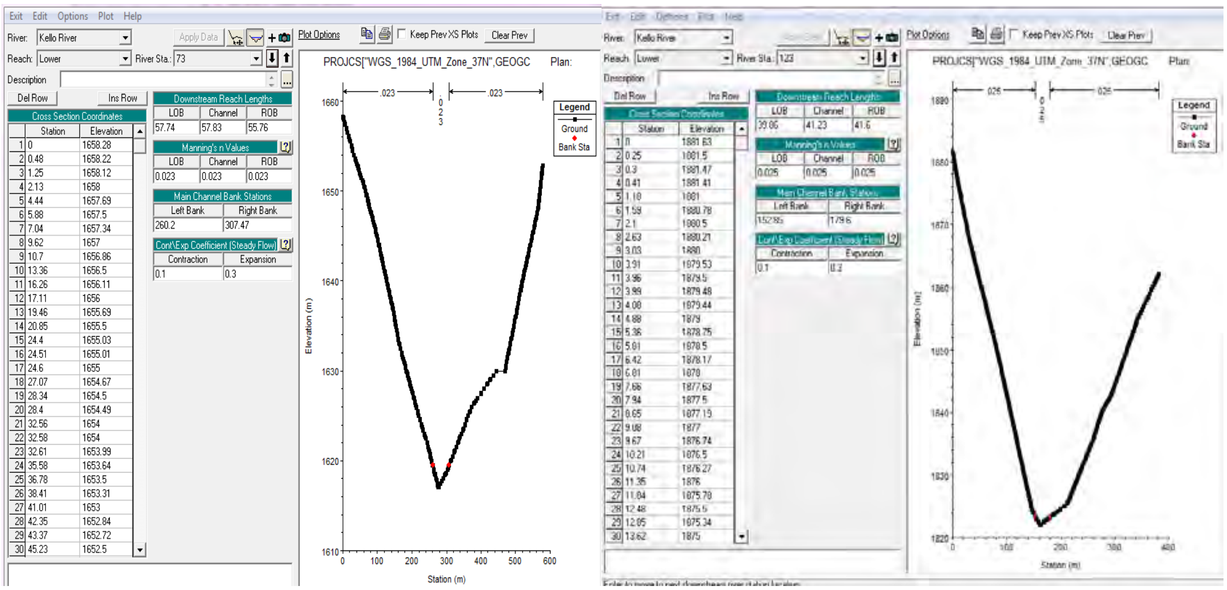


Figure 6-6 Sample Cross-Sections data imported to HEC-RAS

Station-7 Station 56

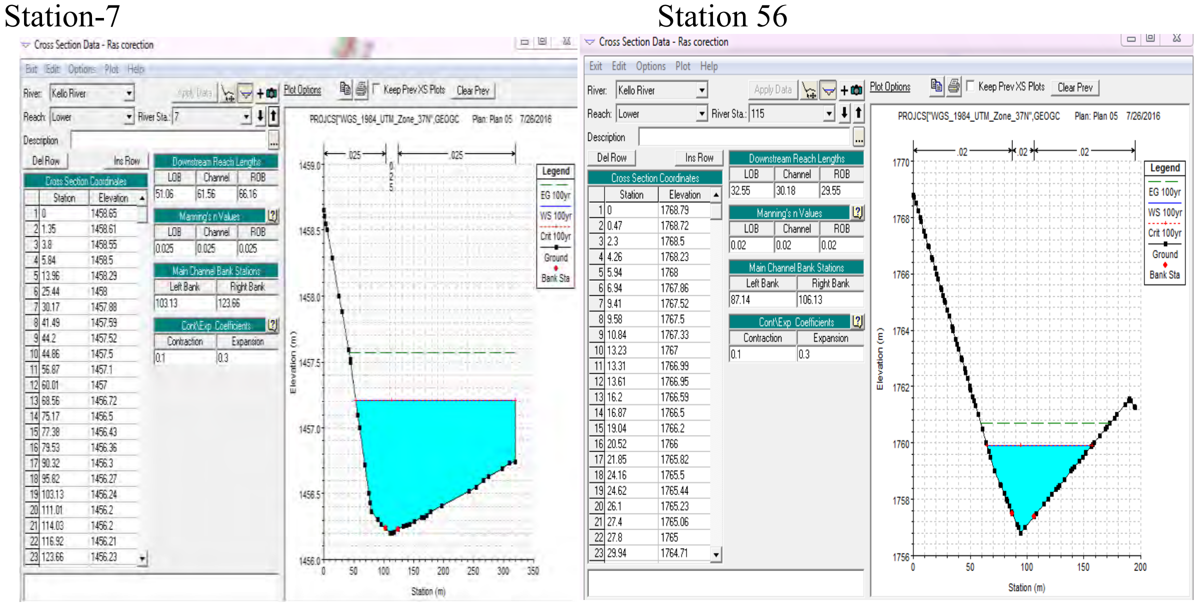


Figure 6-7 Sample Cross-Sections at station 7 and 56 profile for 100 years return period

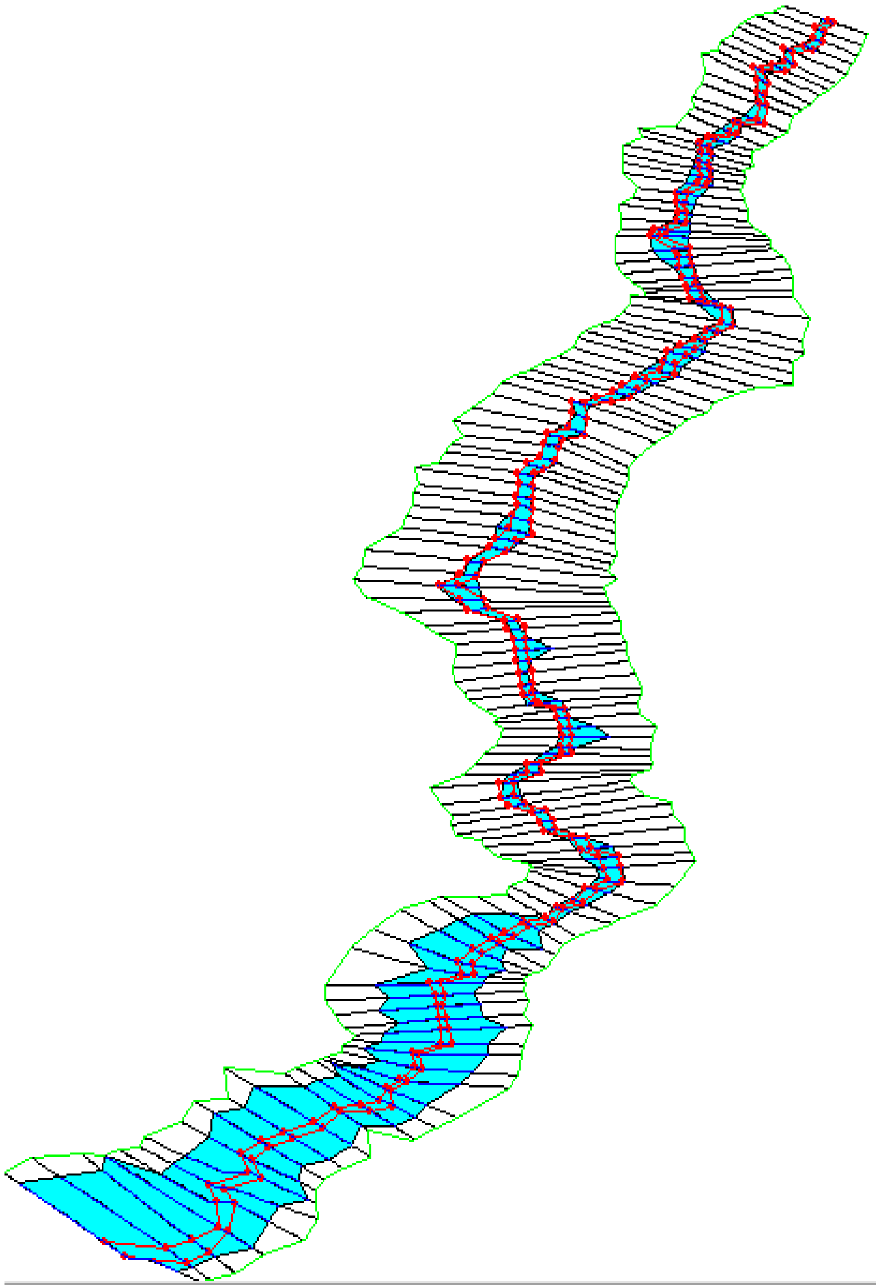


Figure 6-8 3D Perspective View of the Flood Plain and the Channel in HEC-RAS (100 Year Storm

6.5 Flood Plain Delineation- HEC-GeoRAS -Post RAS

Flood plain delineation is performed using HEC-RAS Post processing and the result is shown below.

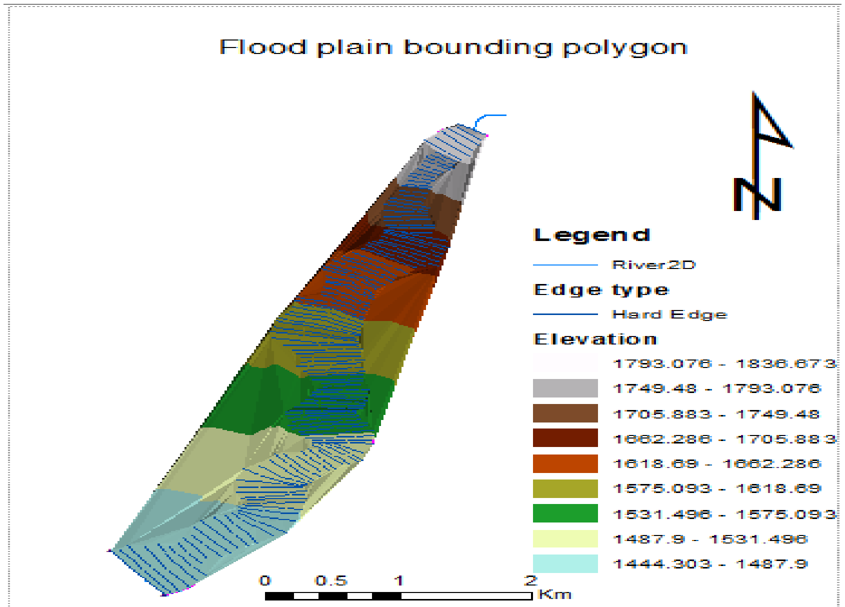


Figure 6-9 Water Surface TIN Generated From Bounding Polygon

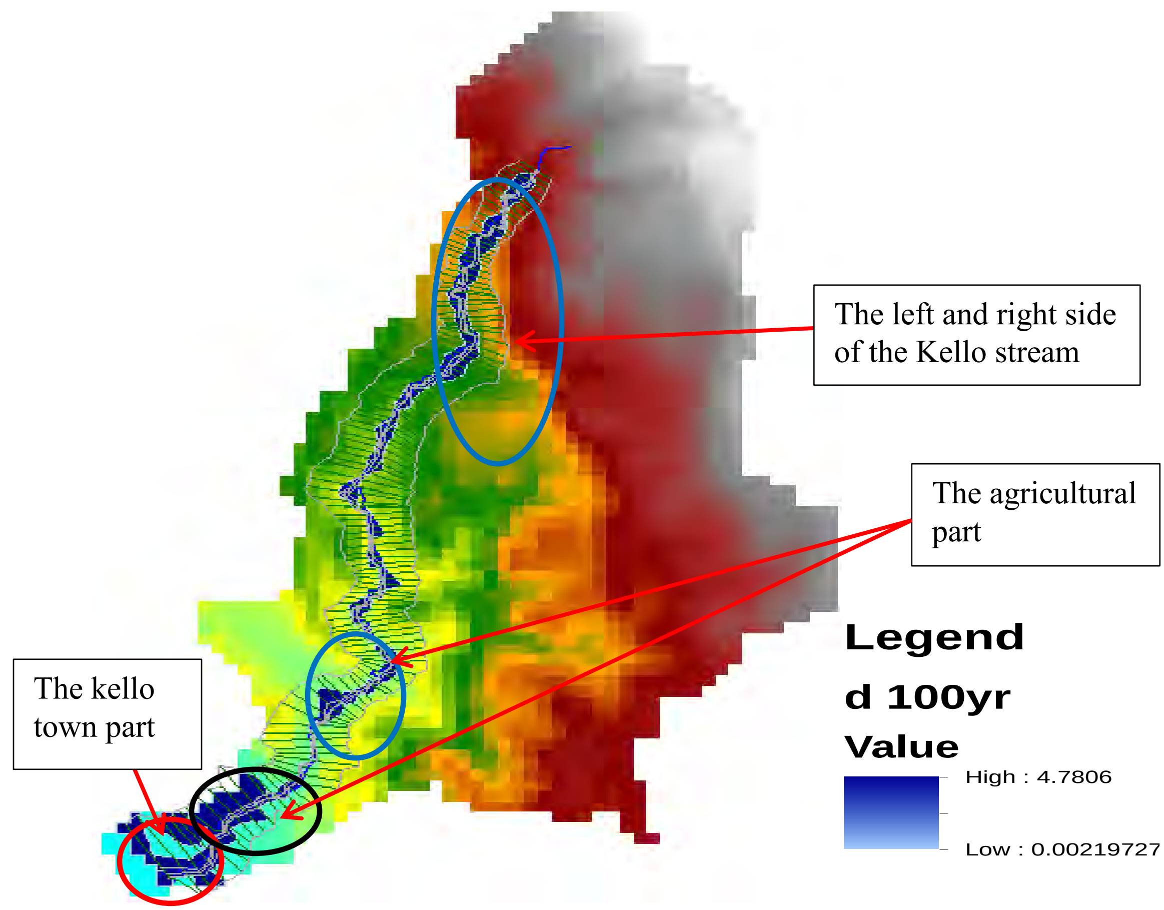


Figure 6-10: Delineated flood plain for 100 year Storm

As seen from the delineation result almost the full part of the town and the cultivated land and also the left and right side of the Kello stream was found to be flood vulnerable areas by the 100 year flood especially the lower right side of both the town part and the cultivated area is highly susceptible areas by the 100 year flood and part of and the left and right side of the Kello stream which are affected by 100 varies from place to place and the inundation depth of the 100 year flood ranges from 0.5 - 4.78m depth at the upstream of the catchment and at the downstream of the catchment.

6. 6 Flood mitigation alternatives

The effects of various river training measures can be analyzed based on the performance of the hydraulic parameters of flood risk and environmental impacts. For this study, three flood mitigation alternatives, including levee construction and different scale of channel modification along with dredging river channel of debris and sediments are proposed in order to reduce flood hazards in residential area and its surrounding agricultural flood plain, as described latter.

Channel modification for flood control was based upon the idea of widening and deepening of the channel by sediment removal will provide a substantially larger channel capacity to allow a greater volume of water to flow downstream without causing an impact on the adjacent flood plain (Tefera B., 2015). In proposed alternatives no channel straightening was considered in order to prevent any negative erosion effects on downstream as there is a natural bend in the river reach that was thought to be more effective in decreasing the energy and velocity of flow, and there by prevent any further erosion (Tefera B., 2015). Removing the natural bend of a river usually leads to stream bank erosion and often requires costly protection measures. No water detention basins or flood diversion structures were considered in the study area because of limited land availability.

Alternative1: A levee is an earthen embankment supported by Gabion-type revetments (riprap) and was constructed on the left and right side of the river bank adjacent to the residential and agricultural area, with the capability of widening a 100-year flood. Levees were chosen for this reach because they seem to be an effective solution for reducing flood damage and were practical because of the availability of materials. Dimensions of the levee considered had an average elevation of 2m and length of 2690m at the left side and a length of 2680m at the right side. Riprap revetment with an additional 1-m foundation form a steep slope in the riverside to prevent any limitation in the cross sectional area of the river channel.

Alternative 2: In this alternative, river bed elevation is set at 1442.4 with a slope of 0.0265. River width was widened with an average of 45m in the main channel using channel excavation and dredging.

Alternative3: in this alternative channel modification was conducted by deepening with an elevation of 1441.58m with a slope of 0.0265 and 70m width using machinery based channel excavation.

The selected flood mitigation alternatives could be positioned at appropriate locations along the selected reach of Kello River for HEC-RAS model runs to extract model results for comparison. Flood level, flow velocity and inundation area at various locations along the river and flood plain were predicted based on proper flood plain inundation analysis in the 50- and 100- year flood associated with the four proposed alternatives, including current condition (baseline).

Implementation of river training practices would likely alter flow characteristics along the river system including flood level and flow velocity (Tefera B., 2015). Therefore, changes in flow characteristics were adopted as decision criteria along the selected reach for selecting a reliable and environmentally sound flood control alternative.

Two specific control cross sections were considered at appropriate locations on the downstream of the river for comparison purposes. The outside of the river bend adjacent to the residential area was considered as the first control point, which is important in terms of higher risk of erosion and over topping of flood hazard. The upstream of the residential area (Kello) before the river bend was also considered as second control point.

6.7 Flood Inundation Analysis

The result of flood frequency analysis showing the magnitude of 50 and 100 years flows were used as a base to run for different alternatives after the model calibration done at base line condition. These magnitudes were used as a base to run the model for different flood mitigation alternatives. In fact all flood alternatives were computed on similar model setting. The flood mitigation alternatives were positioned at appropriate locations along the selected reach of lower Kello River in HEC-RAS model runs. Delineation of extents and depths within flood plain of Lower Kello river with different return periods based on the integration of hydraulic simulations on GIS analysis using HEC-GeoRAS. Flood inundation extents, including different model outputs in all cross sections were extracted after running the model for each alternative.

Figures 6.11 and 6.12 shows subsequent maps of predicted 50 and 100 years flood inundation extents and depths for all proposed flood mitigation alternatives.The flood boundary was delineated in blue. The rainbow colour in the backgraund represents the TIN of the study area where cross secctions are generated. As can be seen in fig 6.12 flood affected area for 100 year flood event were of larger extent than the 50 year flood (fig 6.11).

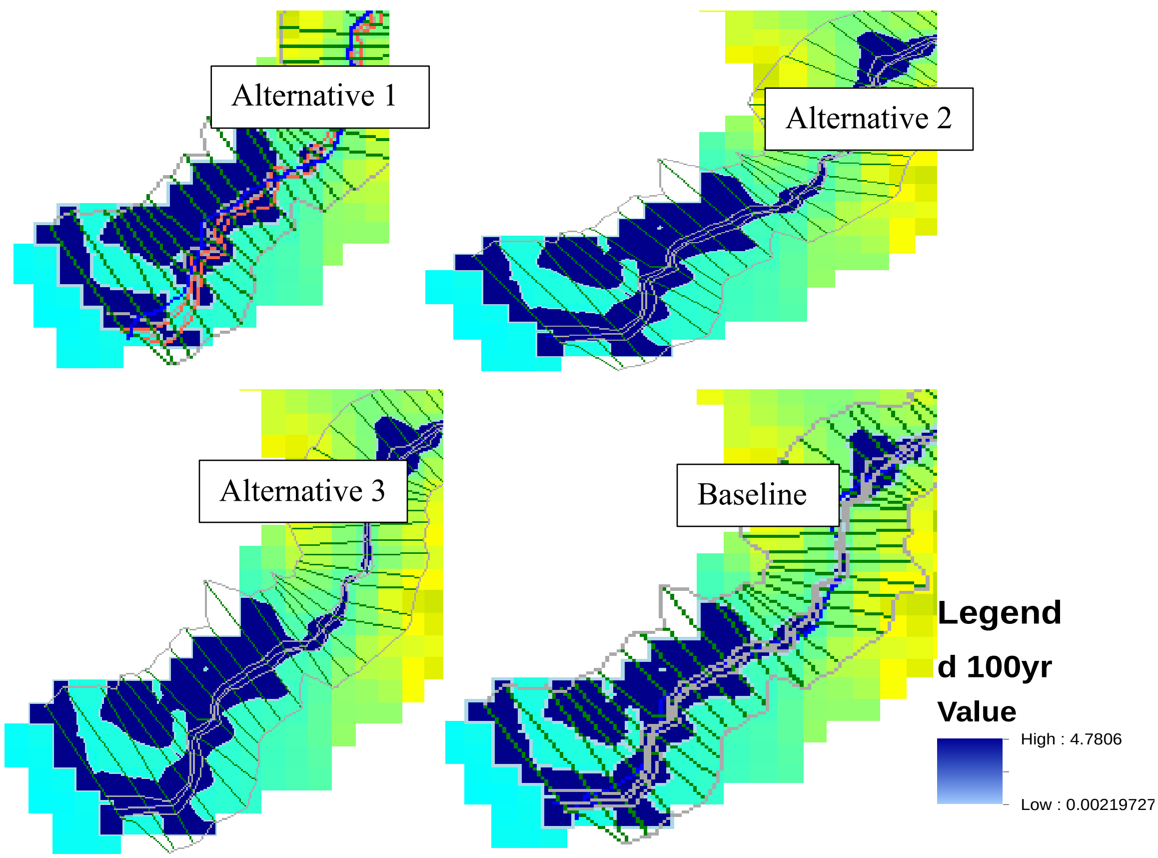


Figure 6-11: Flood inundation area and depths for 50 year flood mitigation alternatives

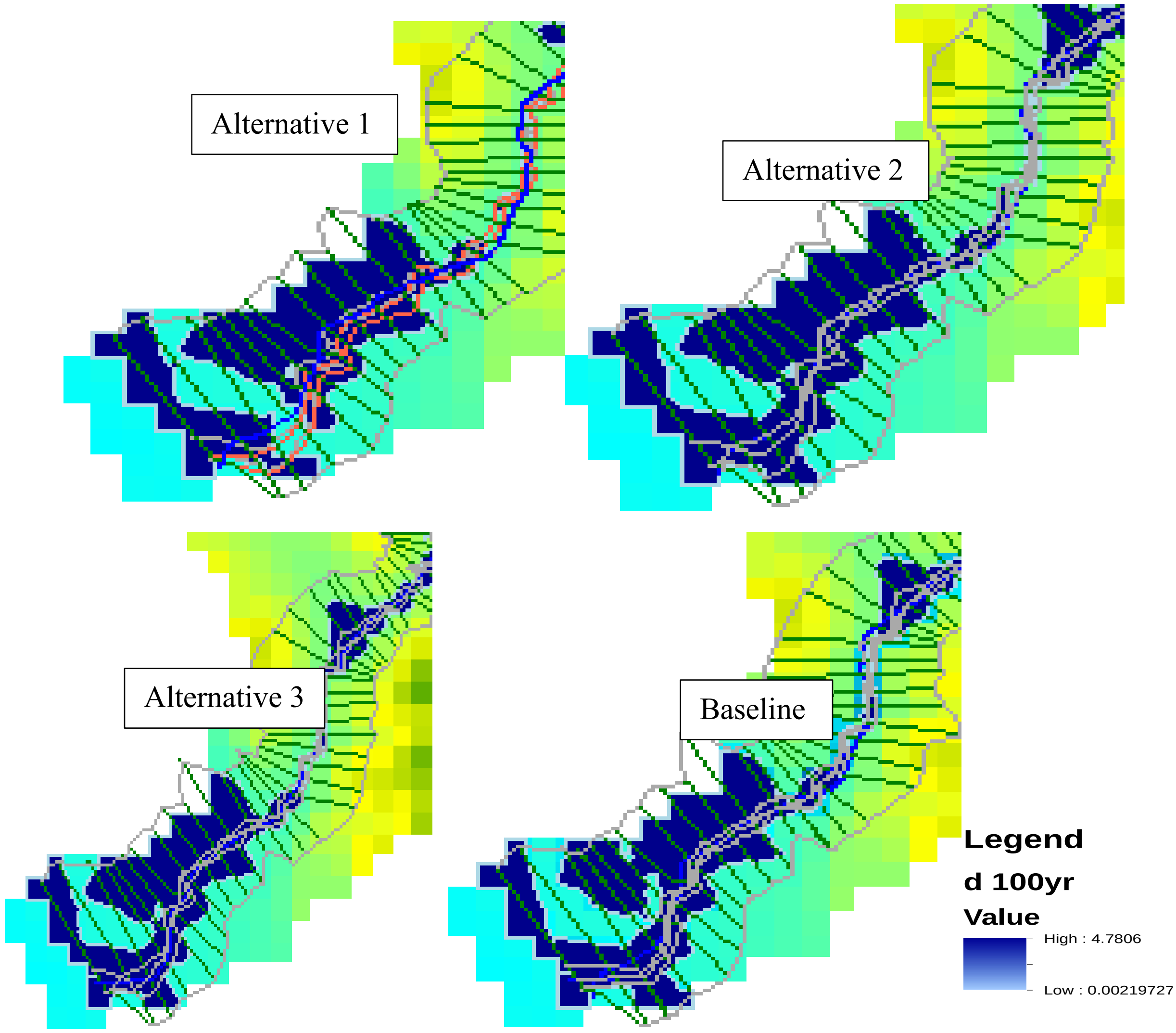


Figure 6-12: Flood inundation area and depths for 100 year flood mitigation alternatives

6.8 Comparission of flood mitigation alternatives

All proposed flood mitigation alternatives had different flood extents. The evaluted results for all measures could be sumurazed as follows.

Flood inundation area, flood level and flow velocity at two control points along the Kello River system were extracted based on flood plain inundation analysis for 50 and 100 years associated with the three proposed alternatives with the HEC-RAS simulation combined with GIS (figure 6.11 and 6.12). Table 6.10 was determined based upon flood inundation layers in GIS depicted in figures 6.11 and 6.12. Table 6.10 shows a simple comparision of inundation area (ha) and flood depths (m) for each alternative under 2,5 10, 50 and 100 year floods.

Without any flood mitigation measure (baseline), the inundation areas were 92.7 and 95.5ha under the 50 and 100 year floods, respectively, with an inundation depth over 4.78m for the measures of alternatives 1 the total inundation areas were 76.2 and 81.2ha for 50-year and 100-year flood respectively which were less than those of the other alternatives including baseline. As a result it could be found that alternative 1 was superior to the other two measures in terms of flooded area protection.

Table 6-10: comparison of inundation areas (ha) for proposed flood mitigation alternatives based on flood depth in 2,5,10,50 and 100 year floods.

Return period (years)	Flood mitigation alternatives			
	Alternative1	Alternative 2	Altetrnative3	Baseline
100	81.2	90.42	87.77	95.5
50	76.2	84.63	82.65	92.7
10	68.4	78.45	75.75	88.59
5	58.60	67.25	68.22	84.9
2	50.5	59.11	65.87	79.3

Where Alternative 1, levee construction

Alternative 2, channel excavation and dredging

Alternative 3, compound channel (widening and deepening)

Table 6.11 compares Hydraulics parameters in baseline conditions with those reconstructed from flood mitigation alternatives under 50 - and 100- year floods at two specific control sections. The effects on flood level reduction by the different alternatives were presented in Table 6.11. Alternatives 3 had better performance in terms of flood level reduction than the other alternative baseline in selected cross sections. There was no major improvement in flood level reduction in using construction of a levee may not decrease a river flood stage, it could decrease the risk of an overbank flooding disaster in residential areas.

Comparison between all alternatives in terms of changes in flow velocity under 50- and 100-year floods were presented in table 6.11 at two selected control points. There was a variation of flow velocity among the alternatives, depending on the local river geometry and hydraulic conditions of river flow. As shown in table 6.11, alternative 1 causes a significant increase in flow velocity on downstream cross section in comparison with the baseline.

Generally, construction of a levee had a negative impact on flow velocity on the downstream (Table 6.11) and was superior to other alternatives for erosion control and river bank protection. Alternative 2 performs better than other options in terms of flow velocity. Alternative 3 had the lowest flow velocity at the river bend control point, which could cause a minimum progressive river bank cut and erosion towards the land adjoining the river sides.

Table 6-11: comparisons of Hydraulics parameters for proposed flood mitigation alternatives based on 50- and 100-year flood at some selected control cross sections.

Hydraulics parameters	Return period (years)	control cross sections	Flood mitigation alternatives			
			Alternative 1	Alternative 2	Alternative 3	Baseline
Flood Level(m)	50	1	1505.39	1504.41	1504.0	1504.85
		2	1496.13	1495.65	1595.16	1495.96
	100	1	1505.46	1504.36	1504.23	1504.90
		2	1496.65	1496.44	1495.42	1496.20
Flow velocity (m/s)	50	1	2.73	1.43	1.25	1.66
		2	2.87	1.45	1.30	1.80
	100	1	2.95	1.47	1.37	1.83
		2	3.06	1.46	1.40	1.95

*[1] on the upper side of the river bend; [2] on the lower of the river bend

From the above alternative mitigation measures and parameters it can be concluded that alternative 1 which is construction of a levee best performs in terms of flood inundation area that is the flood inundation area both at 50 and 100 years was the smallest than the rest of alternatives and the inundation area of the baseline (with the original river channel without the provision of any channel modification) both at 50 and 100 years is the highest than the other alternatives (Table 6.10).

Likewise, flow velocity of alternative 1 (construction of a levee) is the highest than the other alternatives. But in terms of flood level alternative 3 best performs than the other alternative both at 50 and 100 year floods and alternative 1 is the highest by flood level both at 50 and 100 year floods than the other alternatives (Table 6.11).

Finally for this thesis work alternative 1 is selected as best practice since it fits two of the criteria's which were considered even though the economy matters weather the construction of levee or compound channel (widening and deepening) which is listed as on the recommendation part and is not part of this thesis work .

7. CONCLUSION AND RECOMMENDETION

7.1 CONCLUSION

This thesis work mainly aims at investigating causative factors that contributes towards flooding of kello town and delineation of the flood risk areas and then suggesting of flood mitigation measures actually the flood mitigation measures were suggested by considering some comparative criteria's as like flow velocity, flood level and the flood inundation area between the selected flood mitigation alternatives as construction of a levee, channel excavation and dredging, compound channel (widening and deepening) and the baseline (which is without any channel modification simply the natural channel) .

As a result the principal source of flooding for Kello town is a result of flash flood originating from rainfall on the easthern highlands of catchments. It is formed as a result of intensive showers, sparse vegetation cover and steep slope of the area.

Concerning the flood mitigation measures alternative one (construction of levee) best performs by the given criteria's than the other alternatives. And for this thesis work construction of a levee is forwarded for flood mitigation measure along the selected reach of the Kello River and Kello Town and agricultural area was to construct a levee as a structural measure. Other proposed structures such as channel modification with different dimensions, failed to be optimal options in the study area. As a result this study shows, channel modification activities change the upstream and downstream velocity and this brought a great possibility of channel degradation. So this condition leads to the selection of construction of a levee.

7.2 Recommendations

For solving the flood hazard of the study area the structural measures as the main strategy and the non-structural measures such as flood retarding basin, land use planning, and an integrated water shade management also adopted as supplements to strengthen flood hazard mitigations.

For further studies in the study area the following points should be considered.

- Higher resolution DEM than 30m*30m resolution is suggested which gives better visualization and reliability.

- Traditional flood design methods should be supplemented or replaced by risk- oriented methods which are based on compressive risk analysis.
- Economic oriented criteria will be suggested.
- The reliability of the result mainly depends on the input data. There is a much data variation of the study area, this affects the result. So the concerned body should pay great attention on the quality of data.

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APPENDIX: HEC- HMS Out Puts at the Gaging Stations

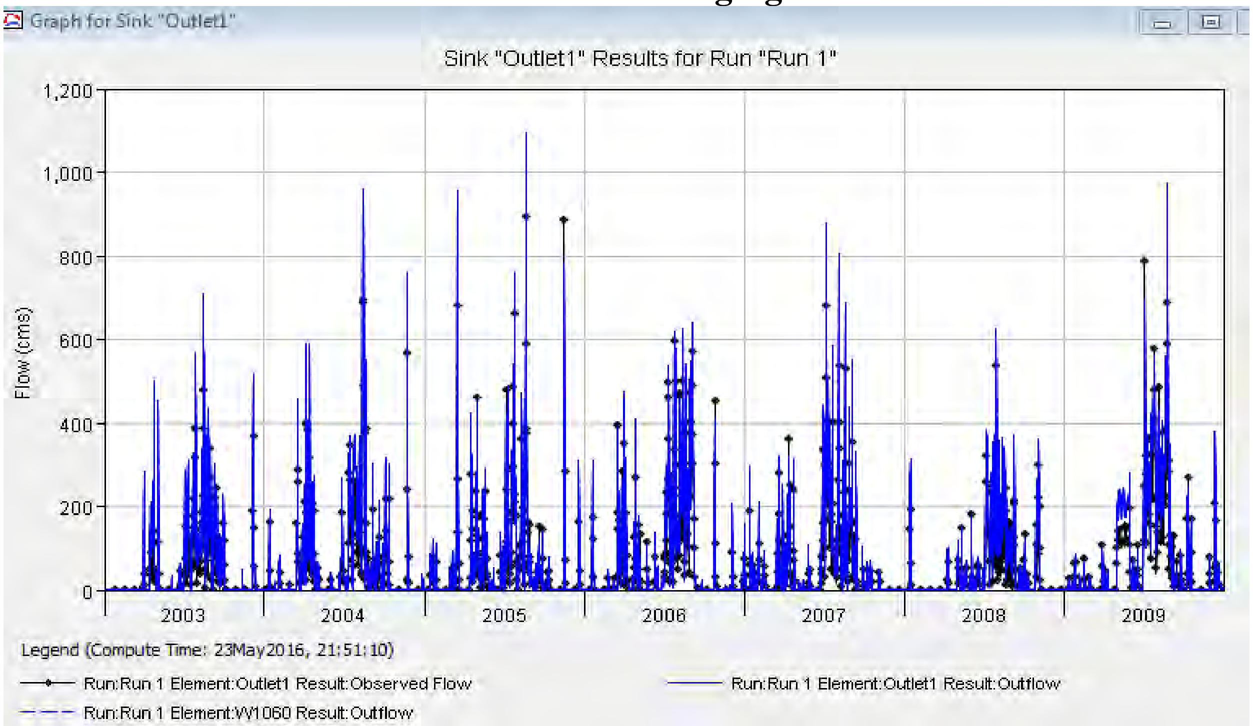

Figure 0-1 Daily Hydrograph Comparison between simulated HEC- HMS Out Flow Virus Observed Flow

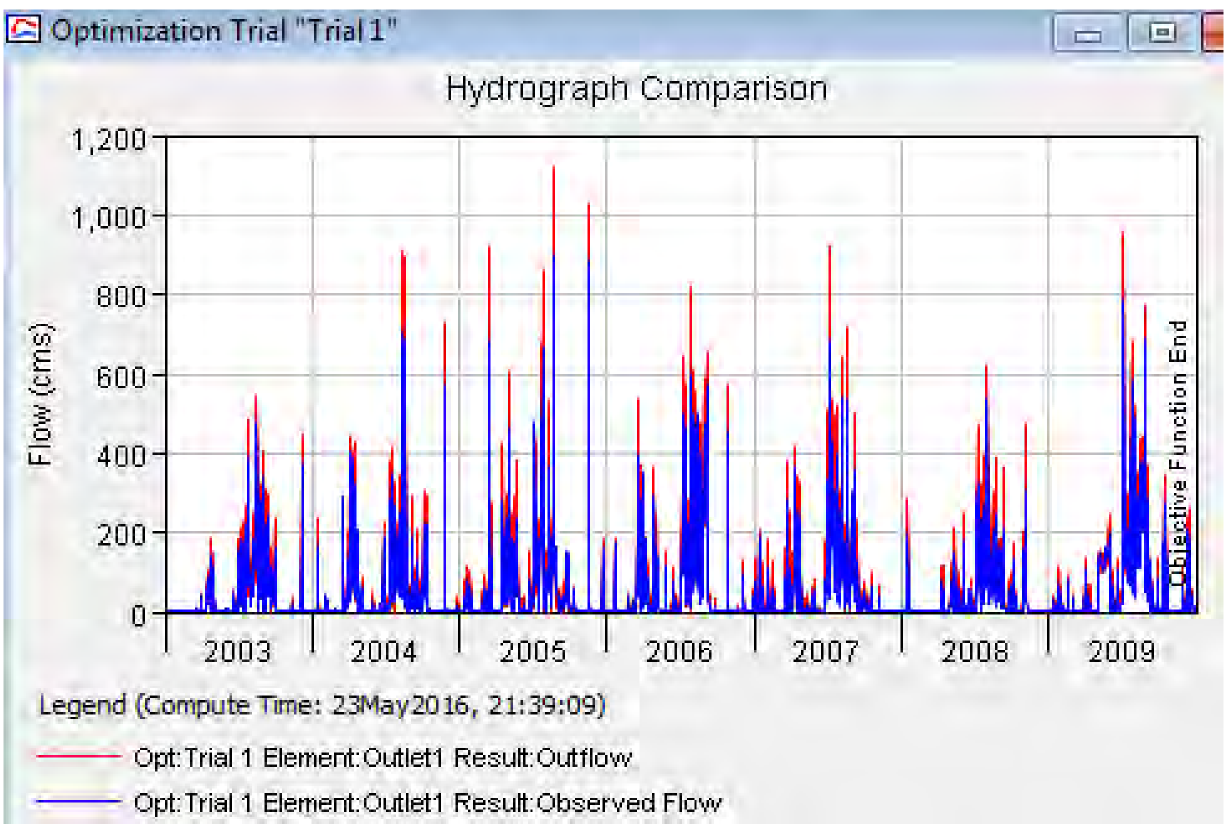

Figure 0-2 Daily Hydrograph Comparison between simulated HEC- HMS Out Flow Virus Observed Flow

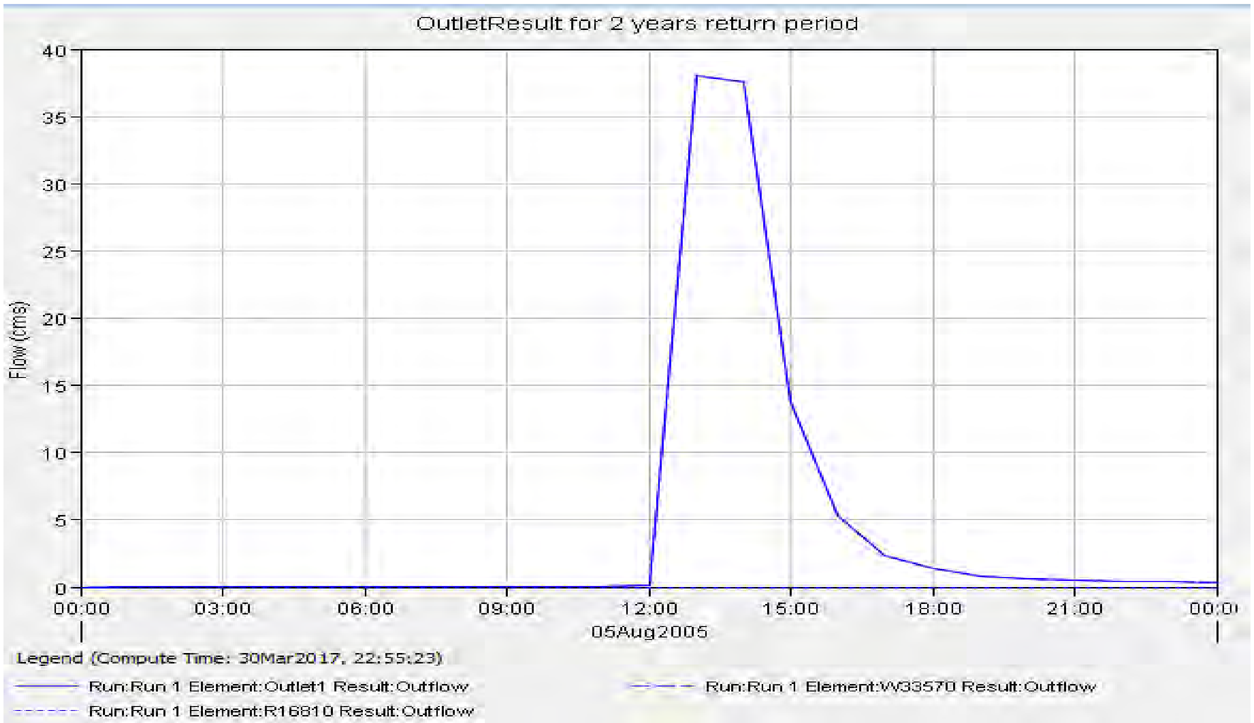

Figure 0-3 HEC- HMS Frequency Hydrograph for 2years Return Period

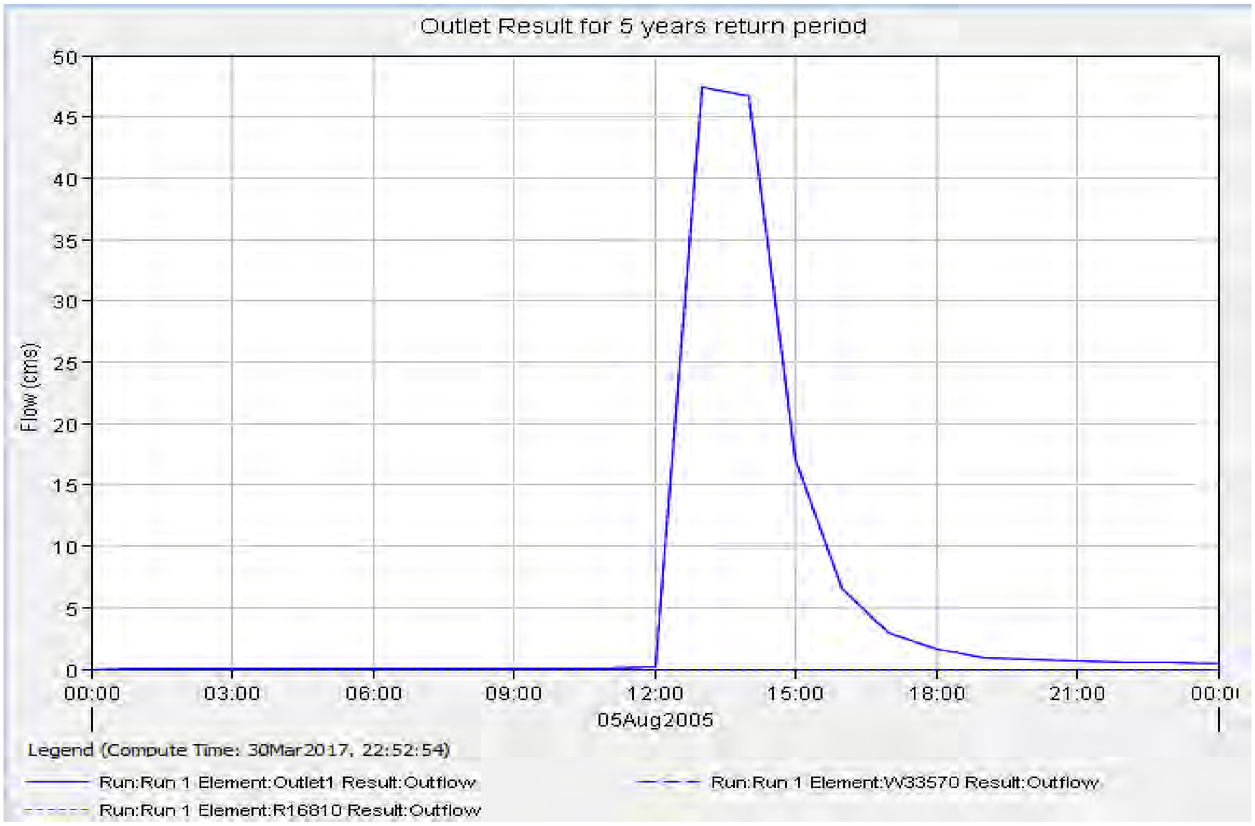

Figure 0-4HEC- HMS Frequency Hydrograph for 5years Return Period

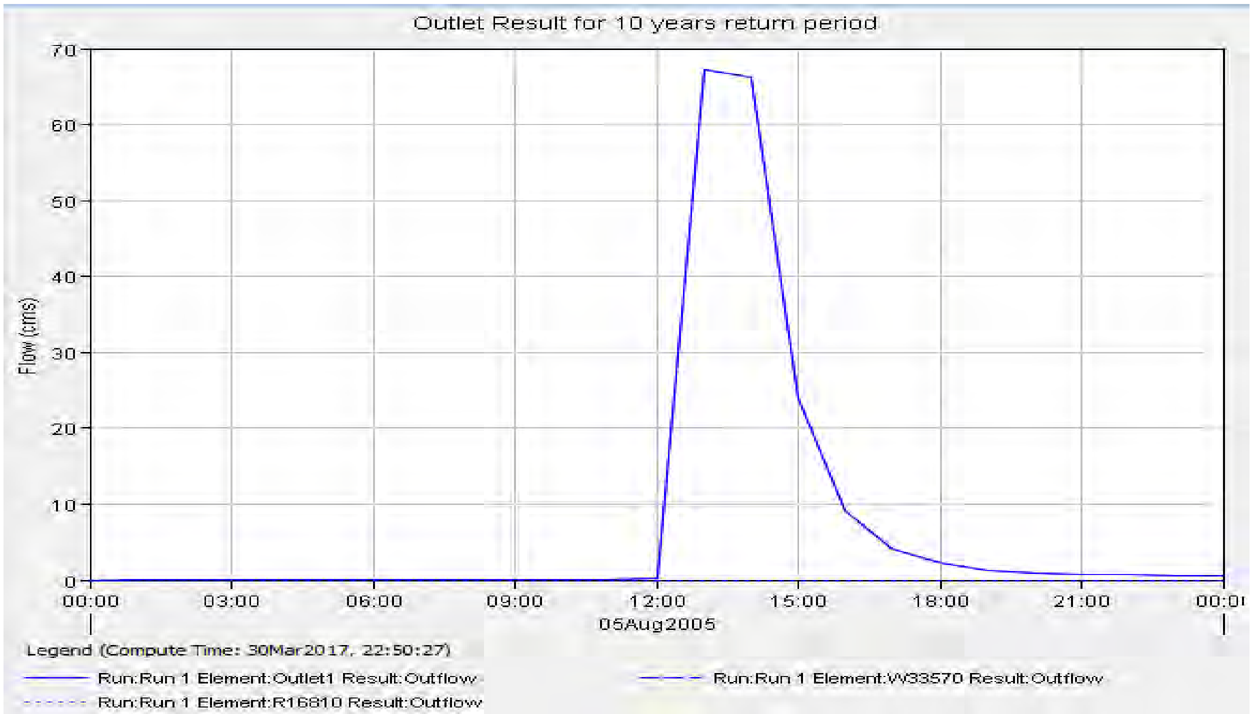

Figure 0-5 HEC- HMS Frequency Hydrograph For 10years Return Period

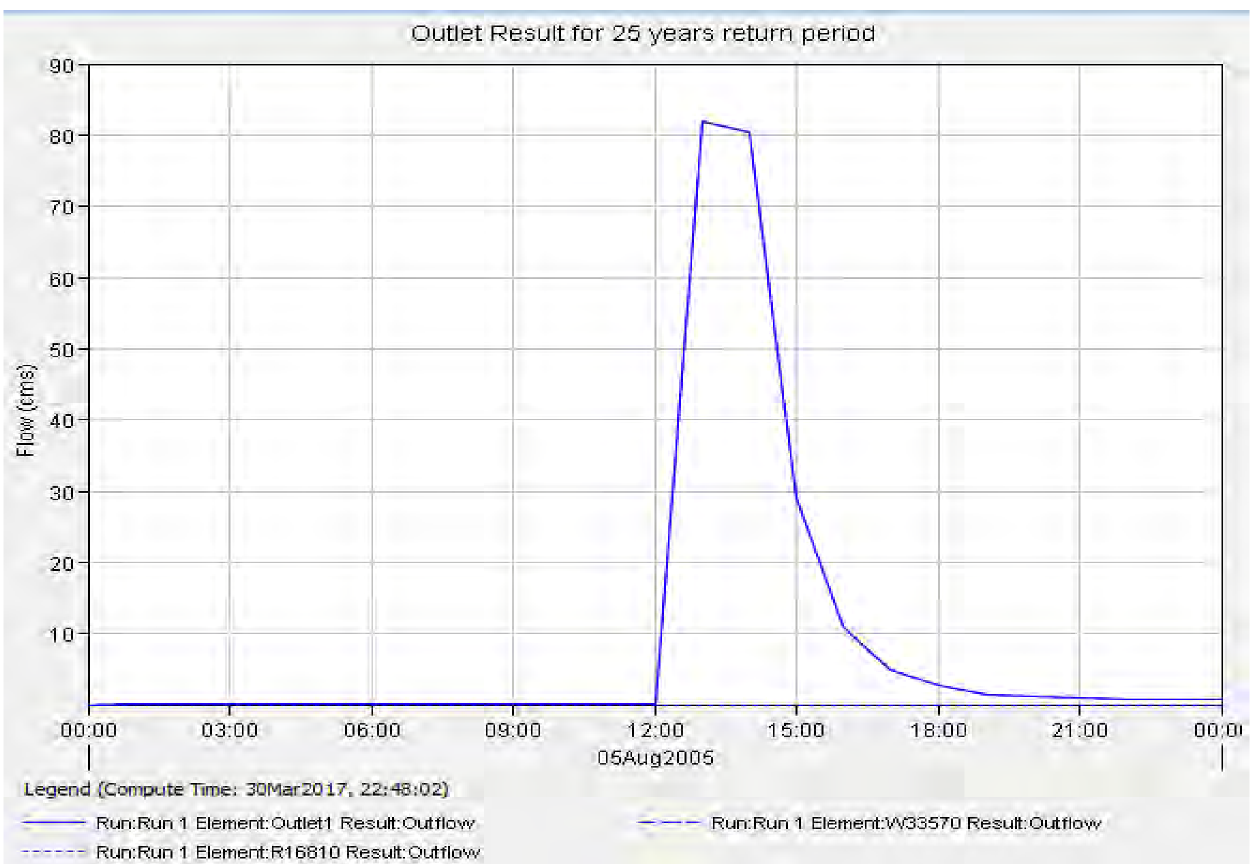

Figure 0-6 HEC- HMS Frequency Hydrograph for 25years Return Period

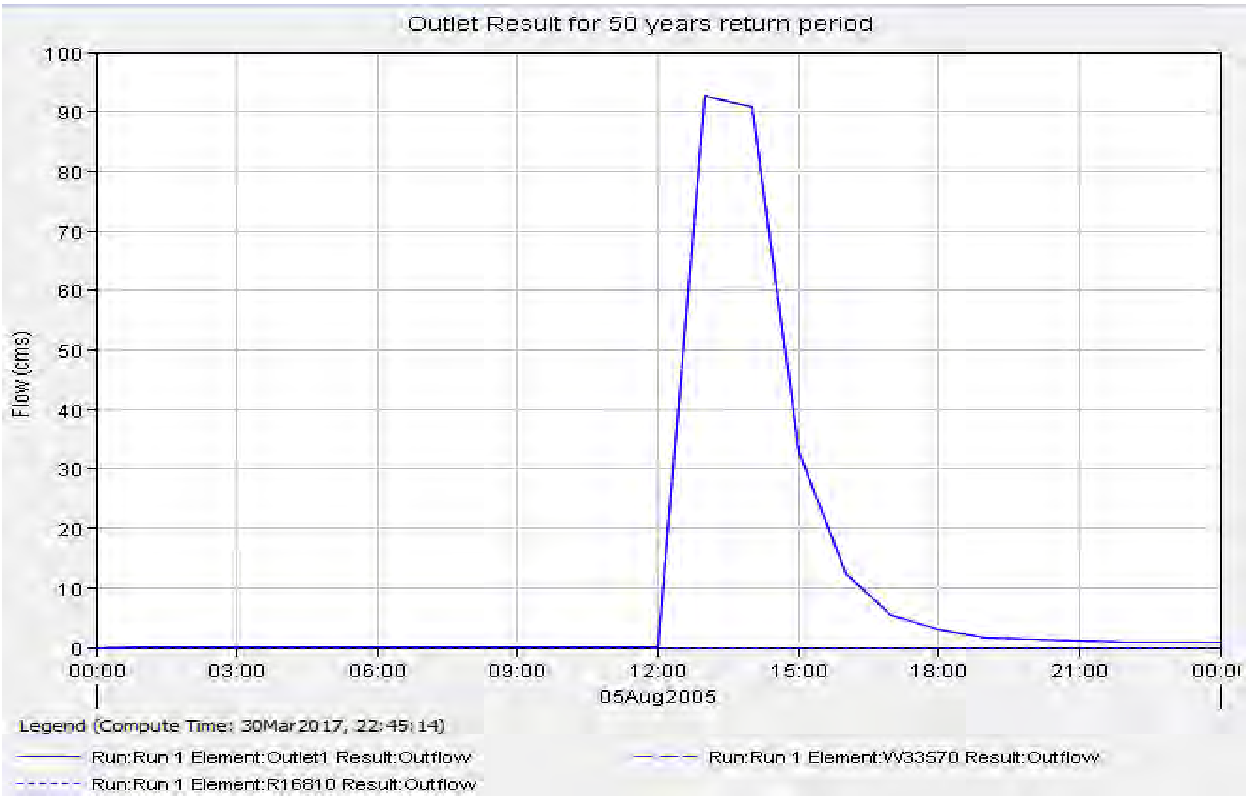

Figure 0-7 HEC- HMS Frequency Hydrograph For 100 years Return Period

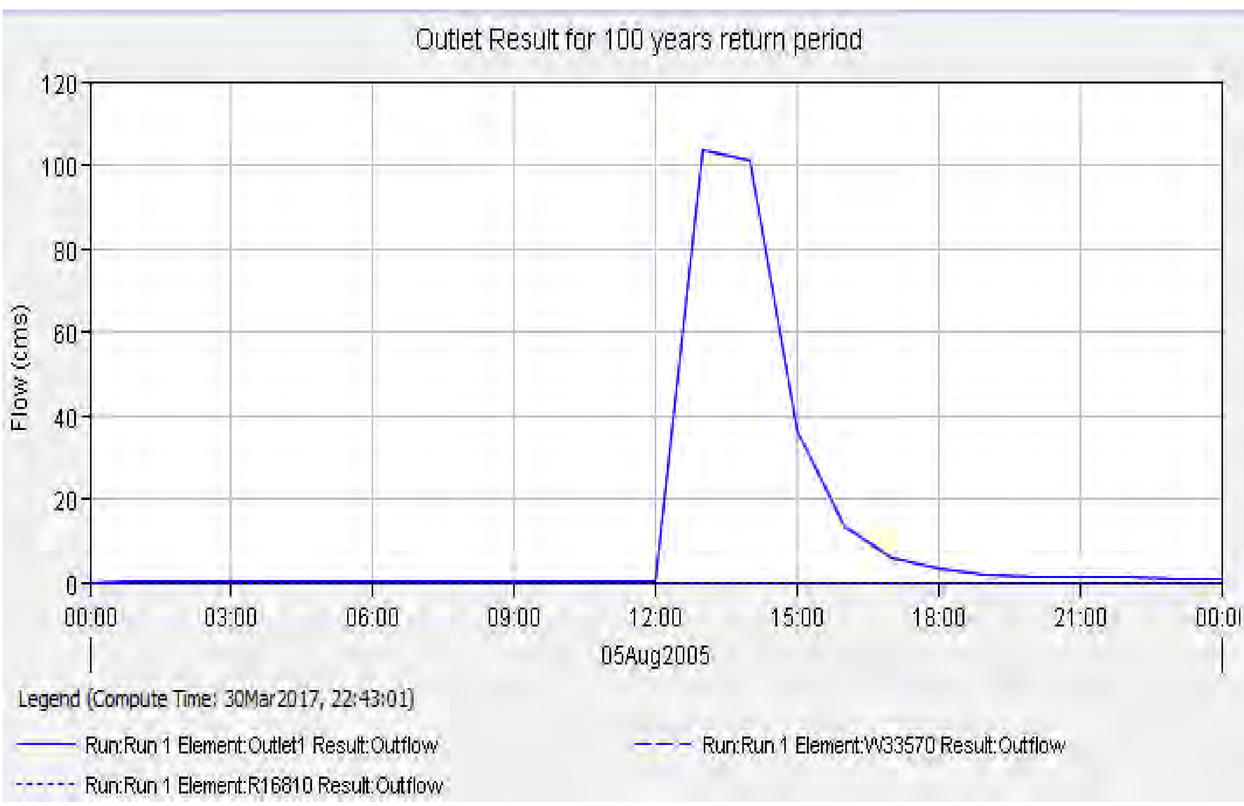

Figure 0-8 HEC- HMS Frequency Hydrograph For 100 years Return Period