

ADDIS ABABA UNIVERSITY  
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FLOOD MAPPING

Case study: on Bantyeketu River in Addis Ababa

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APRIL, 2015

**CERTIFICATION**

I, the undersigned, certify that I read and hereby recommend for the acceptance by the Addis Ababa University a dissertation entitled: Flood Mapping Case study on Bantyeketu River in partial fulfillment of a degree of Masters of Science in Hydraulic Engineering.

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

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## ABSTRACT

Floods represent a natural risk with a very high frequency, which yearly produce important material and human losses. Therefore, developing some detailed maps regarding flood imposes for the accuracy of representation, these must be done at high scales. This study assesses the potential impact of flood on extreme hydrological events in Bantyeketu River in Addis Ababa.

ARC-GIS 10 modeling software is used to delineate catchment for different river system in Akaki catchment and helps to obtain hydrological and physical parameters and spatial information of the Akaki catchment. Road Networks, houses and buildings as well as vegetation cover of Akaki catchment is digitized and corresponding areas is calculated.

A hydrological model, HEC-HMS was utilized to simulate Runoff in Akaki Catchment. The performance of the model was assessed through calibration process and resulted  $R^2=0.7$ . Optimal calibration parameters were developed for Akaki Catchment and these parameters was used as an input for HEC-HMS for estimation of peak discharge in the study. The peak discharge for Bantyeketu River for the coming ten years, Twenty five years and fifty years was found to be  $13.1 \text{ m}^3/\text{s}$ ,  $14.7 \text{ m}^3/\text{s}$  and  $16 \text{ m}^3/\text{s}$  respectively.

Bantyeketu river carrying capacity was estimated using river cross section and HEC-RAS hydrological modeling software. Major problematic areas due to flooding were identified. The cross section around the distance of 1.2 km, 1.5 km, 2.8 km and 3.5 km from Finfina Bridge show low carrying capacity less than  $13.1 \text{ m}^3/\text{s}$  or 10 years estimated probable flood.

50 years return period flood of Bantyeketu River is used for the design of flood protection structure and river bed improvement work. Different flood protection structures and river bed improvement works were recommended depending on the flood depth and condition of river bank. Masonry flood wall and dyke were recommended and designed for areas around ECA ,Hay hulet , and up stream of Bantyeketu confluence with Kebena River. River bed improvement works were also recommended for Bambisse Area

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## ABBREVIATIONS

AAU	Addis Ababa University
AAWSA	Addis Ababa water Sewerage Authority
+masl	Meter Above mean Sea Level
DEM	Digital Elevation Model
GIS	Geographical Information System
HEC	Hydrological engineering center
HEC HMS	Hydrological Engineering Center hydrological Modeling system
LU/LC	Land use and Land cover
HEC-DSSVue	Hydrologic Engineering Center Data Storage System Visual Utility Engine
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
IDF	Intensity duration frequency
JICA	Japan International Cooperation Agency
NMSA	National Meteorological Service Agency
SI	International Unit system
MoWE	Ministry of Water and Energy

## **CHAPTER ONE**

### **1 INTRODUCTION**

#### **1.1 Back Ground**

Natural disasters are happened every year and their impact and frequency seem to have greatly increased in recent decades, mostly because of environmental degradation, such as deforestation, intensified land use, and increasing population. Floods are among the most frequent and costly natural disasters in terms of human and economic loss.

Human activities such as unplanned rapid settlement development, uncontrolled construction of buildings in general and major land use changes can influence the spatial and temporal pattern of hazards. There are several factors that contribute to the flooding problem ranging from topography, geomorphology, drainage, engineering structures, climate, poor drainage and other local factors can be mentioned. Most floods are caused by storms in which a lot of precipitation falls in a short period of time. Intensity and duration of the rain are the most influencing factors for flood hazards. The approach of developing proper flood mapping system is to know the extent of the flooding of river so as to redirect the flows to the nearest receiving watercourse as efficiently as possible or constructing flood protection structures to protect areas susceptible to flooding.

The need to study the cause and effect of flooding has begun since flooding has become a problem to society when people and their valuables become affected. Historically many solutions have been proposed to mitigate the effects of flooding but knowledge on the actual cause effect relation is lacking. With the advent of digital computers, much emphasis has been on simulating and modeling of flood events and related characteristics and such is the main concern of this paper. The challenge here is to develop a reliable flood model to simulate flood events for Bantyeketu River in Addis Ababa. Causes of flooding may be either natural or human induced. Natural causes may be high and long lasting precipitation or extreme events such as earth quick and tsunamis. Man induced causes include failure of dam or levee. Mitigating in flood effects requires information on the flooding characteristics and how such characteristics propagate. Problems related to flooding have greatly increased, and there is a need for

an effective modeling to understand the problem and mitigate its disastrous effects. In hydraulic flood modeling, availability of data in the required spatial and temporal resolution is vital. Topographic data is one of such data used as input in hydraulic flood modeling. Digital Elevation Model (DEM) is major source of topographic data.

In this paper, (Arc GIS), (HEC-HMS) & (HEC-RAS) computer modeling software along with hydrological, metrological and other data will be used to delineate the flood susceptibility mapping for Bantyeketu River in Addis Ababa. Node take map of Addis Ababa is used to develop river cross section, DEM, slope, flow direction, flow accumulation, soil characteristics, land cover, and precipitation information is used to enable the quantification of flood associated attributes.

## 1.2 Statement of problem

According to JICA and Region 14 Administration report (1998), the city has flood prone riparian area especially Kebena, Bantyeketu, Kurtume, Big Akaki and Little Akaki rivers. These areas suffered from serious floods in the year 1978, 1994 and 1995 causing damages to houses, various infrastructures. Even, it led to loss of human lives and paralyze of socio economic activities resulting serious social disturbance.

This report also claims that there are potential risks increased by urban growth in several parts of the Addis Ababa city. The city has also steep slopes from North end to the Akaki plateau. This elevation ranges between 2800 m (at the northern part) and 2200 m (at the southern part). This high elevation difference could favor run off with higher speed and flow.

Hydrological condition of the area enables us to estimate the possible flood risks through future development progress. Therefore, the need for a scientific research is unquestionable.

### 1.3 General objective

Model the hydraulic nature of Bantyeketu River using HEC-RAS and HEC-HMS Modeling software's and develop proper flood map for the area.

Specific Objectives includes:-

- Delineate and map areas located on both sides of the river that will be potentially affected by flooding.
- Determine flood levels and magnitude for Bantyeketu River by routing flow data from Akakai Gaging Station.
- Evaluate the response of a hydrologic model of the study area catchment to the carrying capacity of Bantyeketu River and recommend appropriate flood protection structure and measures.

### 1.4 Framework of the study

The method to determine flood, on hydrological regimes can be achieved through Integrating GIS, and hydrological models. Satellite image have great contribution for preparation of flood mapping of the area. LU/LC information is of critical importance in hydrologic modeling, as it helps determine model variables that account for the volume, timing, and quality of runoff. HEC-HMS and HEC-RAS Computer modeling is used for determination of river characteristics as well as delineation of flood affected areas.

### 1.5 Limitation of the study

In this study the peak flood at the down stream out let is used for the design of flood protection structure. Besides Bantyeketu River bottom channel was assumed to be flat for area calculation. However the channel is not flat in actual term.

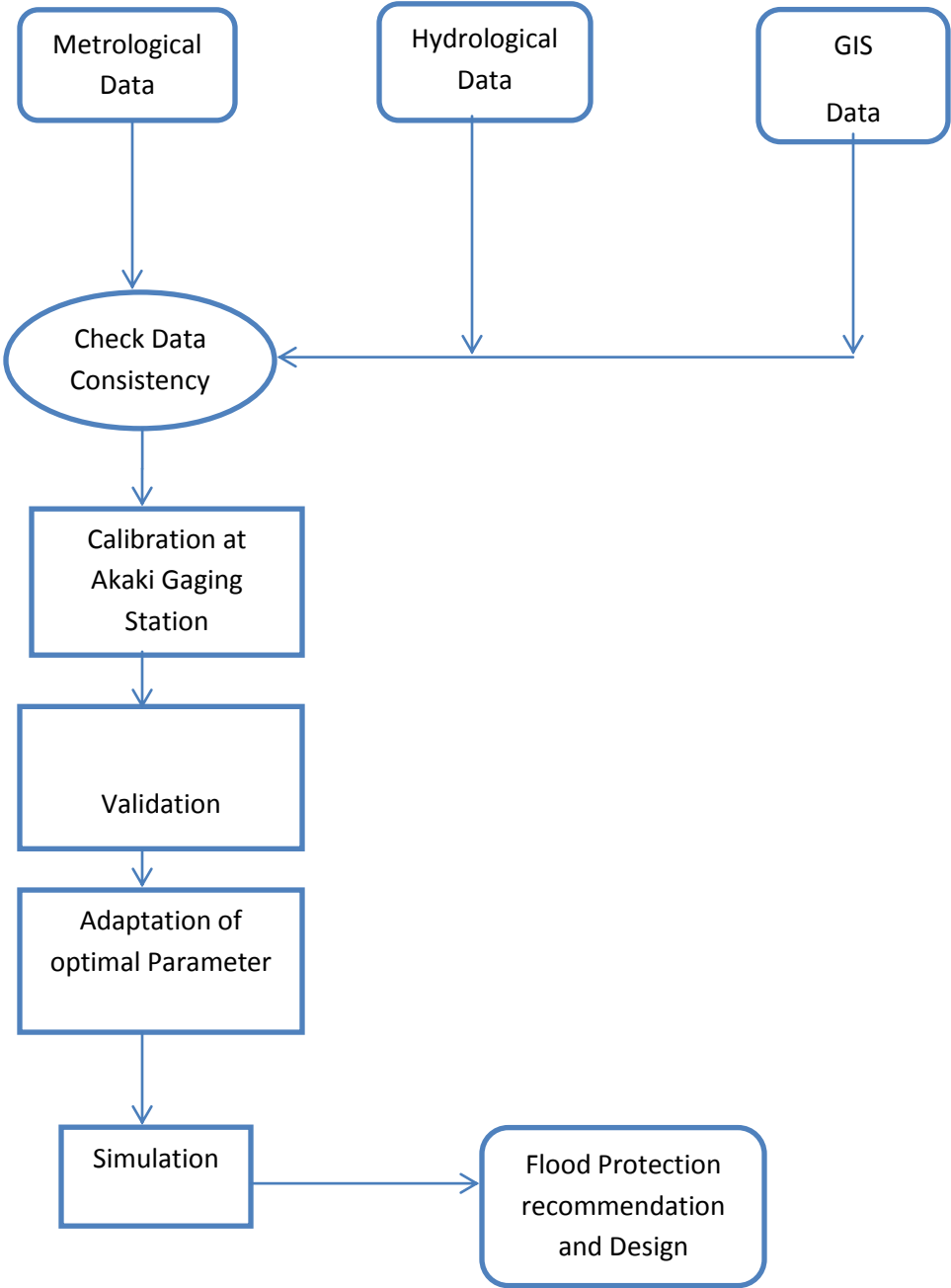


Figure 1-1: Frame work of the study

## 1.6 Study area

The project area is located in the upper most catchment area of the Awash River basin. Having a total area of 28 km<sup>2</sup> In addition the study area has three river systems namely, Kechene , Kurtum and Bantyeketu.

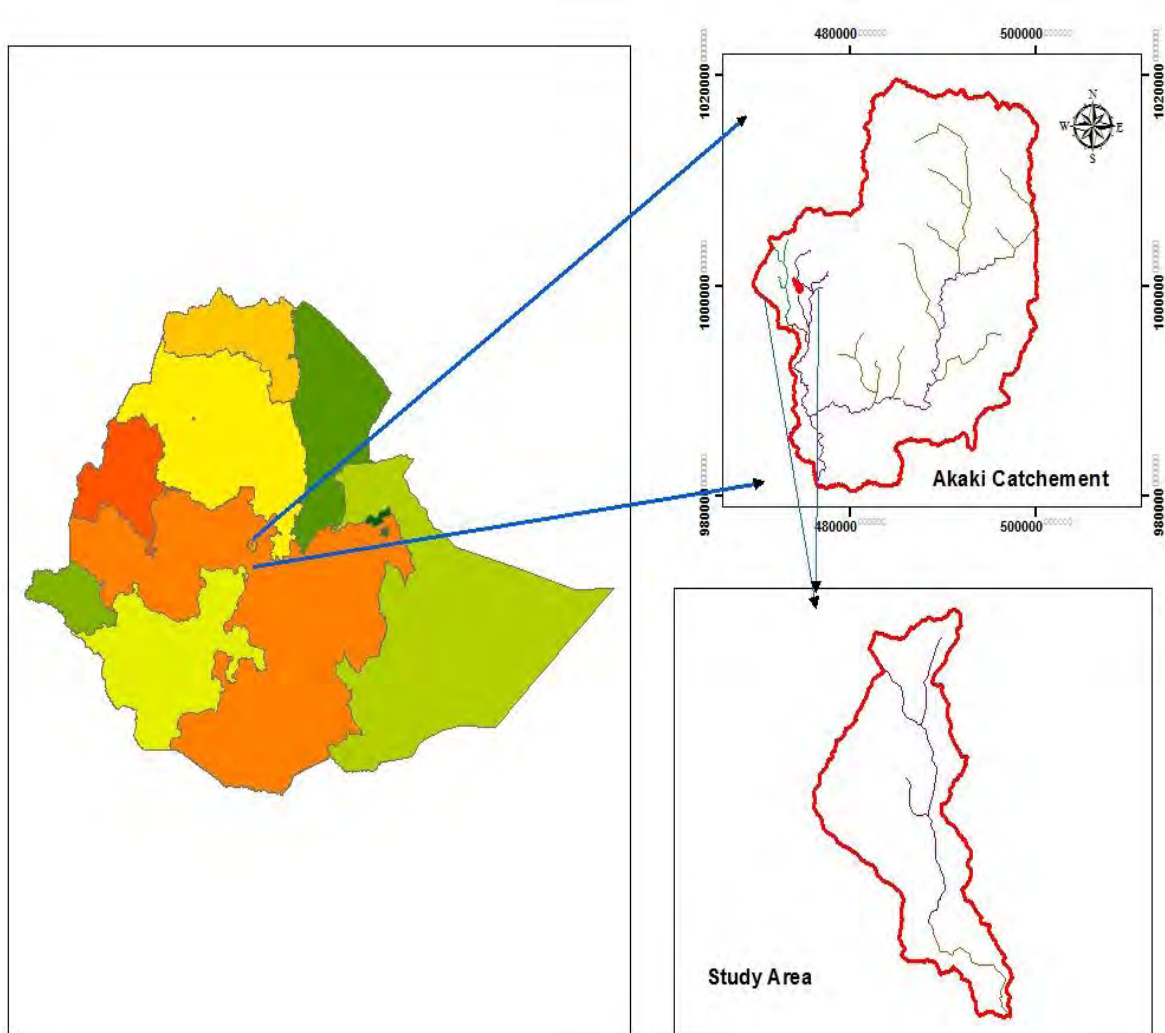


Figure 1-2: Study Area Location Map

## 1.7 Hydrology

Daily runoff is gauged on the big Akaki River at Akaki with a catchment area of 884 km<sup>2</sup>. This gaging station is located about 12 km downstream from the boundary of the study area. The average runoff at Akaki is 8.8 m<sup>3</sup> /s. Bantyeketu River has two tributary Kechene and Kurtume . Kechene is the main tributary of the Bantyeketu Kechene and Kurtume join at the Felewaha Bridge and the river is called Bantyeketu River in the lower reaches. Bantyeketu River takes its route south-eastward for a distance of 4.1 km towards the confluence with the Kebena River.

### 1.7.1 Bantyeketu River

Bantyeketu River runs in the central area of Addis Ababa and reaches a natural retarding basin located at the confluence with the Kebena River. The channel width in the upper and middle reaches is narrow, having a width of around 6 meters. The riverine areas have habitually suffered from recurrent flooding.

### 1.7.2 Kechene River

Kechene River originates at the Intoto mountain slop and flows down southward, the river upstream of the Kechene bridge flows in an incised, wide and deep valley after flowing down in the valley for further 1km ,the Kechene River is joined by the Kostre. Then, the Kechene River flows down for 3.5km towards the confluence with the Bantyeketu. Some sites of this reach are constricted by private houses and buildings. The river bank areas have been densely covered by houses subjected to flooding. Therefor, area along this reach has habitually suffered from flooding .Especially; the lower reach has been vulnerable to flooding.

### 1.7.3 Kurtume River

The Kurtume River originates on the southern slope of the Intoto ridge. Five major drainage canals joins together in the upstream of the Habte Giyorgis bridge .Then ,the Kurtume river flows south-eastward in the very urbanized area for about 2 km down to the Churchill avenue which is one of the main streets in Addis Ababa.

## 1.8 Vegetation

The land coverage of the study area is characterized with the significant urban area of Addis Ababa,

## 1.9 Climate

The Climate in the study area is subjected to low pressure called as Inter Tropical Convergence Zone (ITCZ) moving across the equator seasonally northward and southward on the African Continent. The Average annual rainfall in Addis Ababa amounts to 1178 mm. The main wet season generally takes place from June to September, causing about 70% of annual rainfall. The highest peak of monthly rainfall occurs in August. Another small peak of monthly rainfall is observed in April. Seasonal variation of air temperature is less through a year .the average maximum temperature ranges from 24.3° C in May to 20.3 ° C in August, while the average minimum temperature varies from 11.8° C in May to 7.7° C in December.

## 1.10 Water Reservoirs

In the outskirts of the city four water reservoirs were built for two main purposes. Gefersa, Legadadi, and Dire dam were built for public water supply, while Abba Samuel dam was built for hydroelectric power generation. As a consequence, Lake Gefersa in the northwest, Lake Dire and Legedadi in the northeast and Lake Abba Samuel in the southern outskirts of the city were formed at different times. Gefersa was the first dam built in 1944 about 18 kms west of Addis Ababa. At present the dam has a reservoir capacity of 6.5 million cubic meters and the maximum capacity of the treatment plant is 30,000 m<sup>3</sup> of water per day. Due to rapid growth of the population and expansion of the city from year to year, there is a serious shortage of water indifferent parts of Addis Ababa. To alleviate the problem Legedadi and Dire dams were built in 1970 and 1999 at about 33 kms east of Addis Ababa. In 1940 Abba Samuel dam was built on the Akaki River, 30 kms south of Addis Ababa. The dam has a storage capacity of 65 million cubic meters and an annual output of 23 million kilowatt- hr. (Berhane, 1982). However, due to siltation and pollution it is not functional at present.

## Flood Mapping Case Study on Bantayeketu River in Addis Ababa

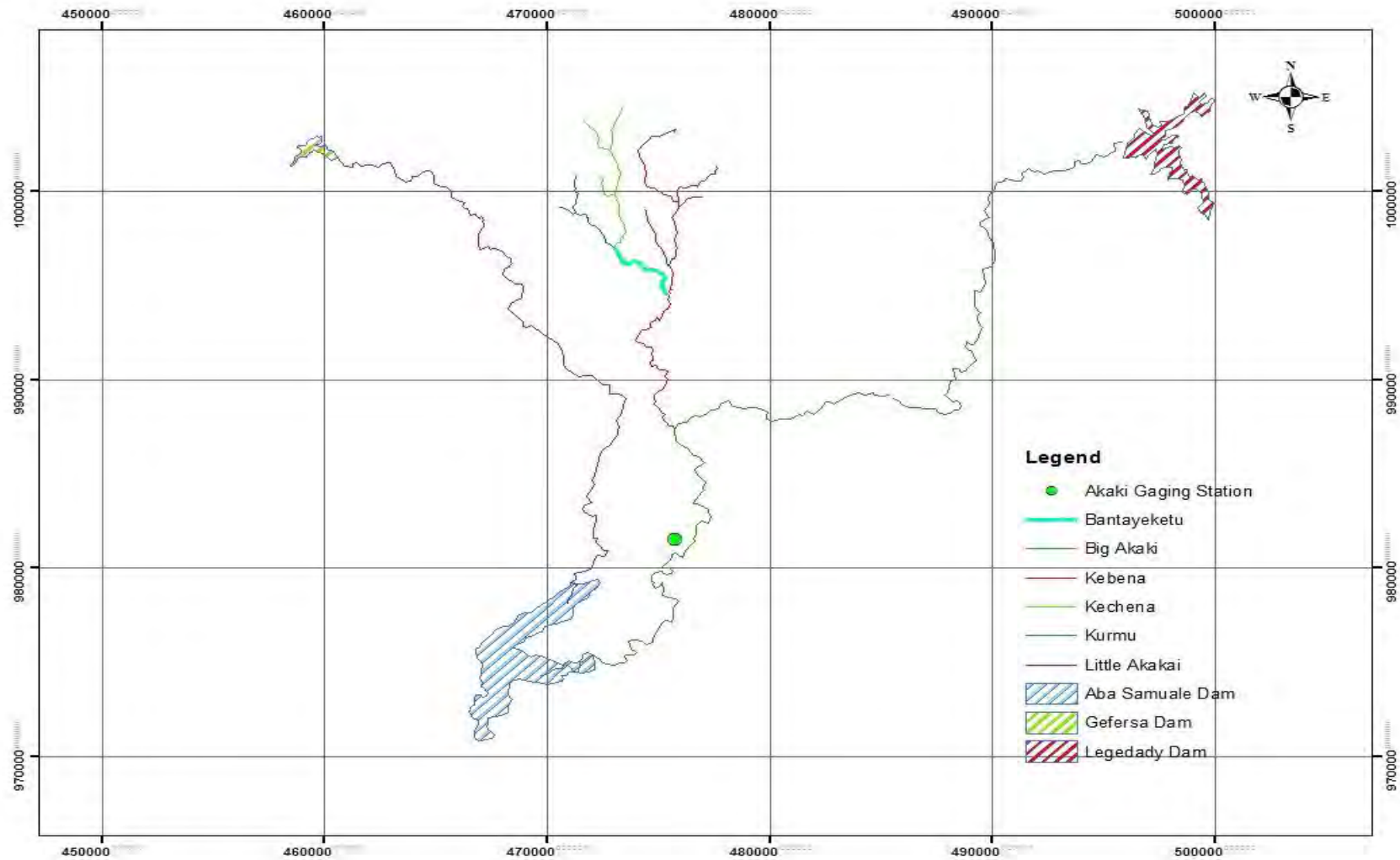


Figure 1-3: Akaki Catchment River System

## **CHAPTER TWO**

### **2 Review of Literature**

#### **2.1 Storm Water**

Storm water, defined as runoff caused by rain and snowmelt in urban areas, and domestic wastewater are the main flows that are handled by the urban drainage system. Urban drainage systems should be designed to handle wastewater and storm water with the aim of minimizing the problems caused to humans and the environment. The available choices for handling the quantity and quality aspects of storm water will be different depending on if the actual sewer System is of combined or separate type.

The hydrologic conditions, i.e. the natural cycle of water, are disrupted and altered when natural land is developed. Rainfall that once seeped into the ground now runs off the surface. The addition of buildings, streets and roads, parking lots and other surfaces that are impervious further reduces infiltration and increases runoff.

Depending on the magnitude of changes to the land surface, the total runoff volume can increase considerably. These changes not only increase the total volume of runoff, but also increase the rate at which runoff flows across the land.

Development and urbanization affect not only the quantity of storm water runoff, but also its quality. Development increases both the concentration and types of pollutants carried by runoff. As it runs over rooftops and lawns, parking lots and industrial sites, storm water picks up and transports a variety of contaminants and pollutants to downstream water bodies. In cities with separate sewer systems, storm water runoff is recognized as the primary source of stream pollution.

Bantyeketu River around ambassador area in Addis Ababa has a record of flooding recently on August, 2012 and residential and commercial areas have been affected during the time, under capacity culvert and cross drainage structures were the main reason for the flooding.

## 2.2 Impact of Climate Change on Availability of Water

Findings of the IPCC 2014, suggests that water resource respond to global warning in ways that will negatively impacted the water availability and water supplies. The climate change has also the potential to deteriorate the surface water quality due to increased evapotranspiration, lower flows and rivers becoming warmer, making the management of water treatment works (and subsequent compliance with the drinking water quality regulations) more challenging. The reduction in the runoff volume will lead to the decrease in the inflow to the reservoirs consequently; longer period might be required to fill the reservoir. As result of the increase in temperature the rate of evaporation from the reservoir open water surface may increase and this may create the reservoir to fail to supply at least the required amount of demand because of its depletion or decrease in the active storage volume.

## 2.3 Flooding

Urban areas always present some risk of flooding when rainfall occurs. Buildings, roads, infrastructure and other paved areas prevent rainfall from infiltrating into the soil and so produce more runoff. Heavy and/or prolonged rainfall produces very large volumes of surface water in any city, which can easily over flow drainage systems. Floods are already having very large impacts on cities and smaller urban centers in many African nations for instance the floods in Mozambique in 2000 which included heavy floods in Maputo, the floods in Algiers in 2001(with around 900 people killed, and 45,000 affected); heavy rains in East Africa in 2002 that brought floods and mudslides forcing tens of thousands to leave their homes in Rwanda and the very serious floods in Port Harcourt and in Addis Ababa in 2006 (UN- Habitat 2007, Douglas etal., 2008). The flood problems are common in most parts of the country. Large scale flooding is rare and limited to the lowland areas where major rivers cross to neighboring countries. However, intense rainfall in the highlands causes flooding of settlements close to any stretch of river courses. The most serious flood problems are found in the abovementioned Awash River basin. Irrigation development in this basin is quite advanced and is located in the flood plains on either side of the river, with close to 70% of the country`s large-scale irrigated agriculture; thus, high economic damage occurs

during flooding. It is estimated that in the Awash Valley almost all of the area delineated for irrigation development is subject to floods; this amounts to an inundated surface of some 200,000-250,000 ha during high flows. The other rivers where significant floods occur are the Wabi-Shebelle River in southeastern Ethiopia near the Somali border and Baro-Akobo/Sobat River in western Ethiopia, near the Sudanese border. In the Baro-Akobo Plain an area of about 300,000-350,000 ha is prone to annual flooding and in the Wabi-Shebelle Basin some 100,000 ha may be inundated. Flooding in urban settlements, especially in Addis Ababa, annually causes damages to property along streams coming down from the near by hills (Kefyalew, 2001).

## 2.4 Hydrological model

Models are a simplified representation of the real world .What features of the actual system are represented in a model, and what features are not, will depend in part on what the modeler thinks is important with respect to the issues being discussed or the questions being asked. How well this is done will depend on the skill of the modeler, the time and money available, and, perhaps most importantly, the modeler's understanding of the real system and decision-making process (Louks etal 2005).

Hydrological models, which are simplified representation of complex hydrological system, can be: (a) physical, such as a scaled-down reproduction of a full-scale prototype built in a laboratory to assume dynamic similarity between model and real world; (b) abstract, in which the behavior of the system is represented by a set of equations, together with logical statements, expressing relationships between variables and parameters This variable may be functions of space and time, and they may also be probabilistic or random variables which do not have a fixed value at a particular point in space and time instead are described by probability distribution (Chow, 1998).

A model which does not consider randomness and for given input always produces the same output such model is called a deterministic model on the other hand a model output at least partially random called stochastic model.

Hydrologic models can be either lumped or spatially distributed. Lumped models do not take into account spatial heterogeneity across the modeling domain. Rather, they simulate a spatially averaged hydrologic system Spatially distributed models however

allow for spatially varying precipitation, temperature, and other climatic variables, and the spatial occurrence of watershed characteristics such as soils, slope, and land cover types (Chow et al., 1988).

Therefore, spatially distributed models are the best way towards understanding the impacts of land use/land cover changes rather than the lumped ones. Hence, the following spatially distributed models are fall in to consideration during model selection period.

### **2.5 HEC-GEO RAS (Hydrologic modeling System)**

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

HEC-GeoHMS provides the connection for translating GIS spatial information into hydrologic models. The end result of the GIS processing is a spatial hydrology database that consists, soil types, land use information, rainfall, etc. HEC-GeoHMS use river cross section which is developed by surveying data.

### **2.6 HEC-RAS (Hydrological modeling System)**

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.

### **2.7 Model selection**

The selection of a particular model is a key issue to get satisfactory answers to a given problem. Currently, there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. Although there are no clear criteria for

making a choice between models, some simple guidelines can be stated (Cunderlik, 2003).

These criteria are always project-dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-dependent (and therefore subjective), such as the personal preference for graphical user interface, computer operation system (OS), input-output (I/O) management and structure, or user's add-on expansibility.

Among the various project-dependent selection criteria, there are four common and fundamental ones that must be always answered:

- ✓ Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long-term sequence of flows...),
- ✓ Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating flood mapping, regulated reservoir operation, snow accumulation and melt, single-event or continuous processes...),
- ✓ Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),
- ✓ Price (Does the investment appear to be worthwhile for the objectives of the project?) (Cunderlik, 2003).

This study aims to evaluate the capacity of existing culverts, delineate proper flood mapping and finally recommend flood protection structures for flood prone areas in the study area, and hence the hydrologic model for this study needs to have the capability to:

- Simulate different components of the stream flow including surface runoff, lateral flow and base flow
- Route hydrographs through different stream reaches, and identify principal runoff source areas at selected points-of interest.
- Compute sub-area release rates, or provide travel time and peak flow information from which these release rates may be developed.
- To be applied over a range of catchment sizes from small to large catchments

- Simulate continuous and long term impact
- Freely available

For this study, HEC-HMS and HEC-RAS modeling software are selected for catchment characteristic determination and delineation of flood mapping respectively to meet the simulation requirements set above using available soil, topography, hydrology, metrology, and weather data.

## CHAPTER THREE

### 3 Material and Analysis

#### 3.1 Meteorological Data

Before beginning any hydrological analysis it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers, (Vedula, 2005). Generally, data should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques. Basically a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. For this particular research work Meteorological, Hydrological, and Digital Elevation Model (DEM) data setting was undertaken.

Daily data for five stations was collected from National Meteorological Agency (NMA). Data like daily precipitation were collected in a soft copy the location of meteorological stations and Average monthly precipitation is available in Appendix A & B.

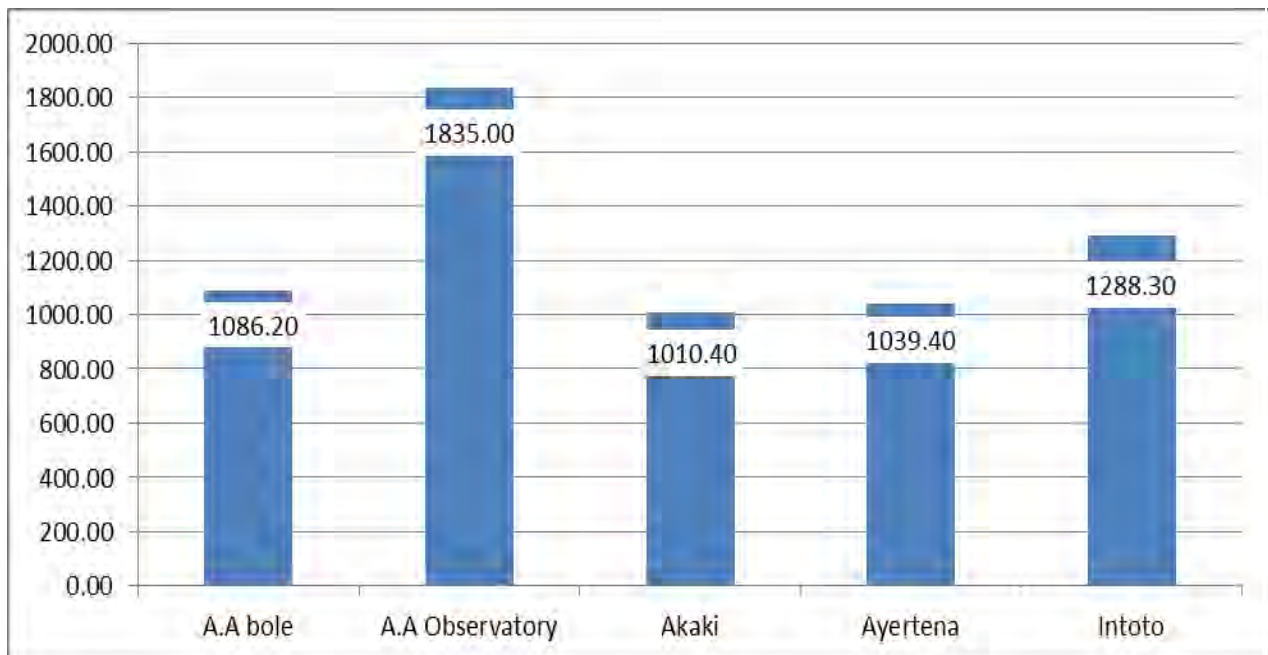


Figure 3-1: Rainfall Data

### 3.2 Filling Missing Precipitation

A number of methods have been proposed for estimating missing precipitation. The station average method is the simplest one. The normal ratio and quadrant method provide a weighted mean, with the former biasing the weights on mean annual precipitation at each gauge and the later having weights that depend on the distance between gauges where recorded data are available and the point where the value is required. The isohyetal method is the fourth alternative. Normal ratio method is used in this research paper. The method is used when the normal annual precipitation of the index stations differ by more than 10% of the missing stations (K.Subramanya). This is the case for the stations near the study area. The general formula for computing missing precipitation by this method is:

$$P_x = N_x / 3 [ P_1/1 + P_2/2 + P_3/3 ]$$

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

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

$N_1$ ,  $N_2$ ,  $N_3$  are the long-term mean annual precipitation values at the respective stations and '3' is the number of stations surrounding the station X.

### 3.3 Checking the Consistency of Data

Sometimes a significant change may occur in and around a particular rain gage station. Such a change occurring in a particular year, will start affecting the rain gauge data, being reported from that particular station. After a number of years it may be felt that the data of station is not giving consistent rainfall values. In order to detect any such inconsistency, and to correct and adjust the reported rainfall values a technique, called double mass curve method is generally a doubted.

The curve is a plot of rainfall record of a station and cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region. The data is arranged in the reverse order that is the latest record as the first entry and the oldest record as the last entry in the list. A change in the

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.

The data series, which is inconsistent, adjusted to consistent values by proportionality. Double mass curve plot made for all five stations. Figure 3-2 shows only Addis Ababa Bole metrological station for the rest station available in Appendix A. From the double mass curve figures the stations are consistent each other.

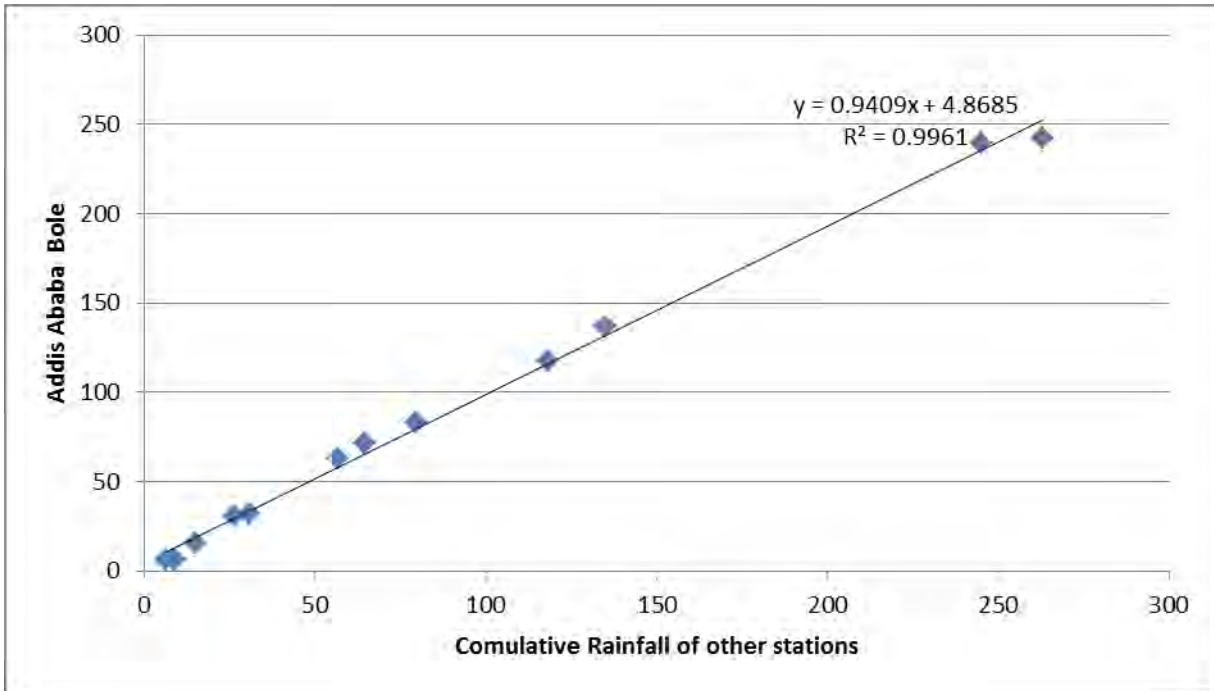


Figure 3-2: Double mass curve for Addis Ababa Bole Meteorological stations

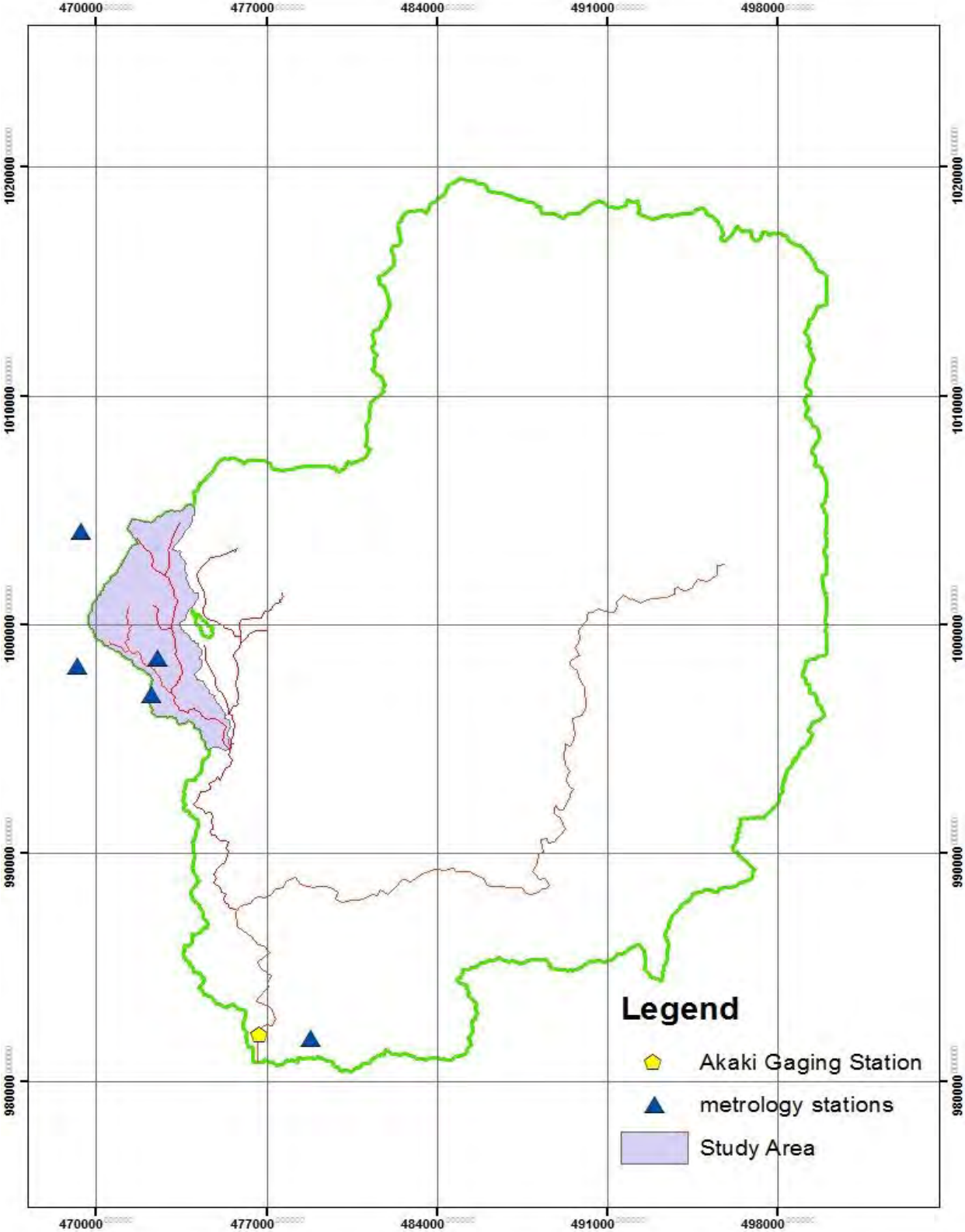


Figure 3-3: Distribution of Meteorological and gauging station

### 3.4 Hydrological data availability

The study area is not gauged but the river system is gaged downstream at big Akaki gaging station. The hydrological data for Big Akaki was collected from the Ethiopian MoWE (Ministry of Water and Energy), is used for calibration of the model. Hence, daily flow data from 2003-2007 was used for model calibration. The mean monthly discharges of Big Akaki river at Akaki gauging station is shown in the figure below.

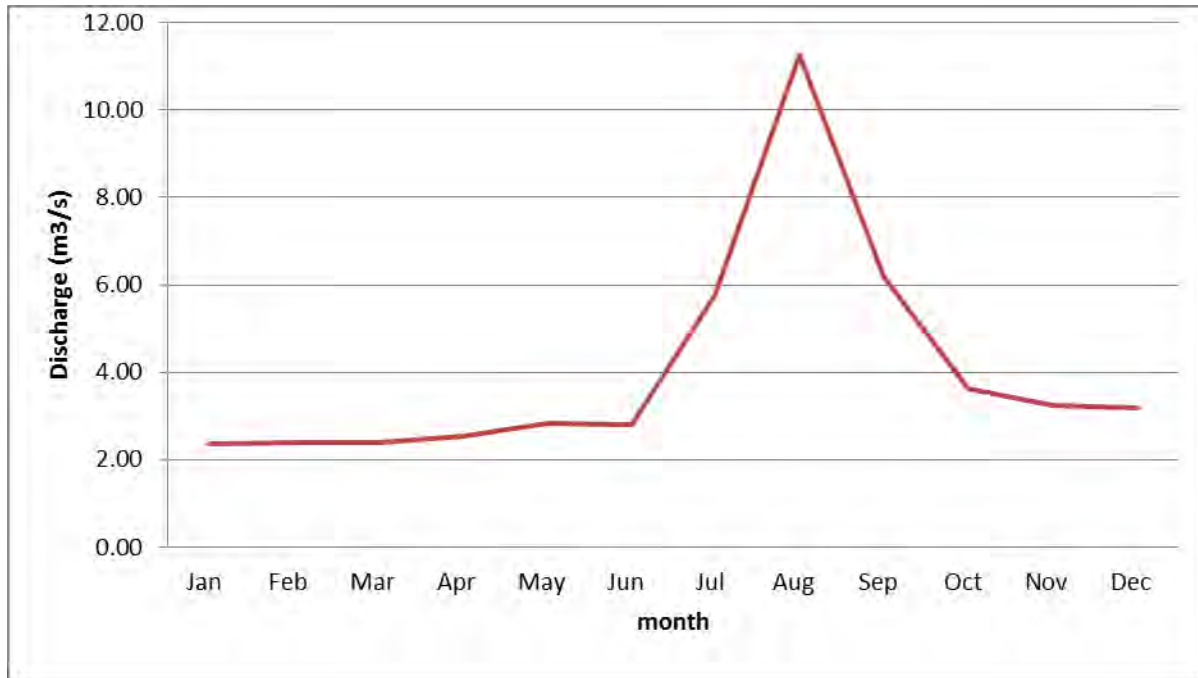


Figure 3-4: Mean monthly flow at Big Akaki for a period of (2003-2007)

### 3.5 Digital elevation model (DEM)

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution. DEM is used to analyze the drainage pattern of the watershed, slope, stream length, width of channel within the watershed. The digital elevation model used in this study was obtained from the Ministry of Water Resource with a resolution of 30m×30m.

### 3.6 Hydrological Model

A number of hydrologic models have been developed which estimate the peak discharges and the runoff hydrograph for a given rainfall distribution. The applicability and performance of these hydrological models depends on factors such as

mathematical representation of processes occurring, structural complexity of the model, and reliability of the model predictions for the available data, geographic location, climatic conditions, and area of interest, physiographic characteristics, computational skill level, Cost and others. These hydrological Models with different approaches are used nowadays for different water resource development works.

The choice of methods of estimation of peak discharge clearly depends on the data requirements and data availability. Among the different approaches, GIS based hydrological model systems are increasingly becoming major hydrological modeling tools because of its capability to handle the spatial variation of hydrological and physiographic inputs of the watershed (HEC-HMS User Manual). Several models, which either are embedded in the GIS environment or have capability of importing the GIS derived spatial and temporal attributes, have been developed. One of which is the United States Army Corps of Engineers HEC-HMS (the Hydrologic Engineering centers Hydrological Modeling System).The program simulates precipitation-runoff and routing processes, both natural and controlled (USACE, 2000). This study currently focused on application of watershed model (HEC-HMS) for Bantyeketu river (Ambassador area) to establish rainfall-runoff modeling for the determination of important hydrologic parameter runoff volume and peak value in order to use them for delineation of proper flood mapping and for further water resource development works.

# Flood Mapping Case Study on Bantyeketu River in Addis Ababa

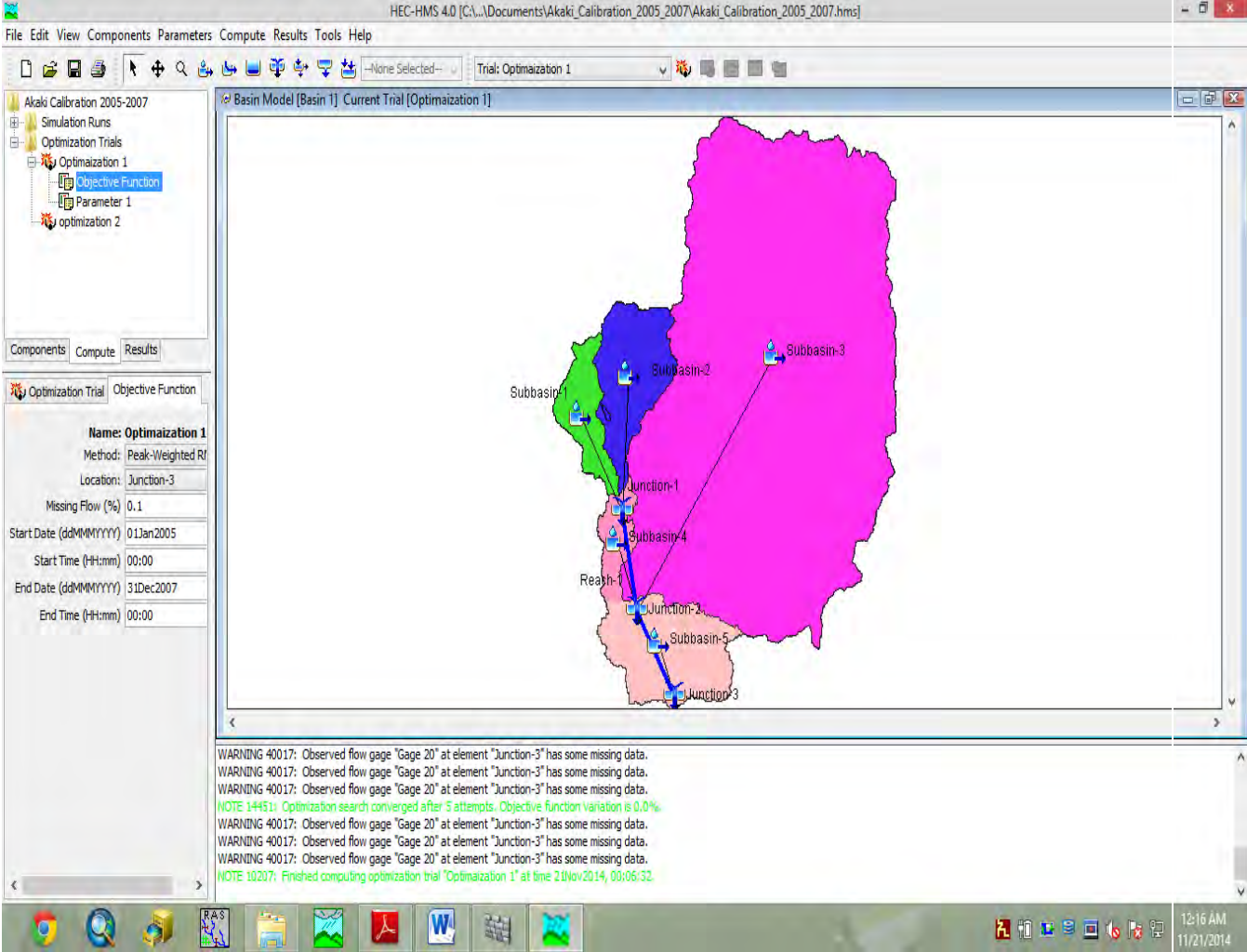


Figure 3-5: HEC-HMS Hydraulic model of Akaki Catchment

## **CHAPTER FOUR**

### **4 Methodology**

#### **4.1 General**

The main objective of the study is to carry out the rainfall runoff generating for Akaki catchments to evaluate the effect of flood from Bantyeketu River for different scenarios. The methods used include desk study of the previous study on different basins, data collection from institutions such as Ministry of water resource, national meteorological agency and etc. After collecting the necessary data for the research delineation of the study areas, determination of basin characteristics, and analysis of rainfall and stream flow data have been made. The basin data is pre-processed by ARC-GIS, and exported to HEC-HMS for generation of rainfall-runoff model finally the peak discharge generated from HEC-HMS is used as an input for HEC-RAS for determination of flood.

The materials used for this research are:-

- ARC-GIS to obtain hydrological and physical parameters and spatial information of Akaki catchments as well as the study area.
- DEM data is used as an input data for ARC-GIS software for catchment delineation and estimation of catchment characteristic. Hydrological data and meteorological data and etc.
- HEC-HMS is used to estimate peak discharge of the study area and determine basin characteristics for calibration.
- HEC-RAS is used to delineate flood in the study area.

#### **4.2 River Cross section**

Bantyeketu river cross section data is collected 30 to 50 m along the longitudinal direction of the river for about 4.1 km length from the node take map of Addis Ababa. And extend to about 200 m to the flood plain from both left and right river banks of Bantyeketu. Unique topographic features such as abrupt change of elevation were recorded regardless of the distances set in between two consecutive target points. The collected data helps to develop river cross section, which clearly show Bantyeketu river

channel. The river cross-section later used as an input for HEC-RAS computer modeling so as to develop the river catchment characteristics.

### **4.3 Hydrological modeling**

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

### **4.4 HEC-HMS hydrological model**

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

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

### **4.5 HEC-RAS Hydrological model**

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

selected flood return periods. HEC-RAS is intended for steady flow water surface profile computations and unsteady flow simulation. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, or a single river reach. The key data's used in this model are field observation, cross sectional survey works and the peak flow resulted from simulation of the HEC\_HMS model. The HEC-RAS program, like the other software's, it can be downloaded free of charge from the Hydrologic Engineering Center's. Hydrologic Engineering Center's River Analysis System (HEC-RAS) is the software predominately used in the field of hydraulic analysis for floodplain delineation. HEC-RAS, combined with Hydrologic Engineering Center's Geographical River Analysis System (HEC-RAS), offers engineers a powerful tool in the process of hydraulic modeling and analysis. For each HEC-RAS project, there are three required components: the Geometry data, Flow data and Plan data. The Geometry data, for instance, consists of a description of the size, shape, and connectivity of stream cross-sections. Likewise, the Flow data contains discharge rates. Finally, Plan data contains information pertinent to the run specifications of the model, including a description of the flow regime. Each of these components is explored below individually.

### **HEC-RAS Parameters**

HEC-RAS uses a number of input parameters for hydraulic analysis of the stream channel geometry and water flow. These parameters are used to establish a series of cross-sections along the stream. In each cross-section, the locations of the stream banks are identified and used to divide into segments of left floodway (overbank), main channel, and right floodway. HEC-RAS subdivides the cross sections in this manner, because of differences in hydraulic parameters. For example, the wetted perimeter in the floodway is much higher than in the main channel. Thus, friction forces between the water and channel bed have a greater influence in flow resistance in the floodway, leading to lower values of the Manning coefficient.

As a result, the flow velocity and conveyance are substantially higher in the main channel than in the floodway showing higher values of manning's resistance coefficient.

At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream:

- ❖ River station (cross-section) number
- ❖ Lateral and elevation coordinates for each (dry, un flooded) terrain point
- ❖ Left and right bank station locations
- ❖ Reach lengths between the left floodway, stream centerline, and right floodway of adjacent cross-sections (The three reach lengths represent the average flow path through each segment of the cross-section pair. As such, the three reach lengths between adjacent cross-sections may differ in magnitude due to bends in the stream.)
- ❖ Manning's roughness coefficients (may vary horizontally or vertically)
- ❖ Channel contraction and expansion coefficients
- ❖ Geometric description of any hydraulic structures, such as bridges, culverts, and weirs

Data requirements for the HEC-RAS model:

a) Geometry Data

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

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

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

➤ **Flow Data**

Once the geometric data is entered, the necessary flow data can be entered. Steady Flow Data consist of: the number of profiles to be computed; the flow data; and the river system boundary conditions. At least one flow must be entered for every reach within the system. Additionally, flow can be changed at any location within the river system. Flow values must be entered for all profiles. Flow values can be imported directly from the HEC-HMS run for different hypothetical design storms or entered manually from the model run results.

➤ **Plan Data**

Usually the first step in performing a simulation is to put together a Plan. The Plan defines which geometry and flow data are to be used, as well as provide a description and short identifier for the run. If the geometry and flow data do not exist, then this action is performed after their creation. Also included in the plan information are the selected flow regime and the simulation options.

**4.5.1 Deficit and Constant**

The deficit and constant rate loss method uses a single soil layer to account for continuous changes in moisture content. The maximum storage specifies the amount of water the soil layer can hold, specified as a depth. An upper bound would be the depth of the active soil layer multiplied by the porosity. However, in most cases such an estimate will have to be reduced by the permanent wilting point and for other conditions that reduce the holding capacity of the soil. The constant rate defines the infiltration rate when the soil layer is saturated. A good approximation is to use the saturated hydraulic conductivity. The percentage of the sub-basin which is directly connected to impervious area can be specified. No loss calculations are carried out on the impervious area; all precipitation on that portion of the sub basin becomes excess precipitation and subject to direct runoff. This study makes use of the deficit and constant loss rate model because it is designed to simulate the long-term relationship between rainfall, runoff, storage, Evapotranspiration, and soil losses.

#### 4.5.2 Clark unit hydrograph transform

Clark unit hydrograph technique was used to transform the excess rainfall to direct runoff. In this method, the processes of translation and attenuation of excess rainfall dominate the movement of flow through a watershed. Translation is the movement of flow down gradient through the watershed in response to gravity whereas attenuation is a reduction of the magnitude of the discharge as the excess is stored throughout the watershed. The time area curve built in the model develops the translation hydrograph resulting from a burst of precipitation, and the resulting translation hydrograph is routed through a linear reservoir for accounting storage attenuation affects across the sub basins. Time of concentration and storage coefficient are the two important parameters in Clark unit hydrograph transforming excess rainfall in to runoff. The time of concentration is used in the development of the translation hydrograph where as storage coefficient is used in the linear reservoir that accounts for storage changes. In this study due to lack of cross section and other morphological data to use other transformation model the Clark unit hydrograph method that requires only two input data, time of concentration and storage coefficient is employed.

#### 4.5.3 Lag Model

The Lag routing method only represents the transformation of flood waves. It is best suited to short stream segment with predictable travel time that doesn't vary with depth of flow. The parameter is the lag time in minutes. Inflow to the reach is delayed in time by an amount equal to the specified lag, and then becomes outflow .The lag time for flood transformation in stream need to be determined through calibration. The routing models included in HEC-HMS are: Lag; Muskingum; Modified Puls (storage routing), Kinematic-wave; and Muskingham Cunge. Lag method is used in this study because of data limitation.

### 4.6 Modeling base flow with HEC-HMS

The Base flow models simulate the slow subsurface drainage of water. This base flow is the 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 is adapted for base flow calculation methods.

#### **4.7 HEC-HMS model setup**

HEC-HMS has four main model components: basin model, meteorological model, control specifications and input data (time series, paired data and gridded data). The Basin Model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, river reach connectivity, or reservoir data. Likewise, the Meteorological Model holds rainfall data. The Control Specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval is to be used in the model, etc. Finally, the input data component stores parameters and boundary conditions for basin and meteorological models (HEC, 2006b). Each of the sections is explored below individually.

#### **4.8 Basin model**

The Basin model contains the hydrologic element and their connectivity that represents the movement of water through the drainage system. Its main purpose is to convert the atmospheric conditions in to stream flow at specific locations in the watershed (HEC, 2006b). HECGeoHMS, an Arc view extension developed by the U.S. Army Corps of Engineers (USACE) was employed to create the basin model background map file and to delineate the sub catchments from the Digital Elevation Model (DEM). The background maps provide a spatial context for the hydrologic elements composing basin model. The maps are not actually used in the computational process, but they can be very helpful in showing the spatial relationship between the elements. They are commonly used for showing the boundaries of a watershed or the location of streams. Terrain preprocessing, Basin processing and HMS model support are the main functionalities of HEC-GeoHMS. In the terrain preprocessing DEM is used as input and a series of steps consisting of computing the flow direction, flow accumulation, stream definition, stream delineation, watershed delineation, and watershed aggregation were

performed step by step to derive the drainage networks. The basin processing step gives capability of merging, editing and subdividing of basins and rivers whereas the HMS model support produces a number of hydrologic inputs that are used directly in HMS. With this the basin model and background map files are included and imported in to HMS the setup is then completed with meteorological and control specification.

#### **4.9 Meteorological model**

The meteorological component is the first computational element by means of which precipitation input is spatially and temporally distributed over the river basin. The spatial-temporal precipitation distribution of daily rain fall data of different gaging station is accomplished in to point peak rainfall by the gauge weight method. The Thiessen's polygon technique was used to determine the gauge weights.

#### **4.10 Control specification**

Control specifications are one of the main components of a project, and principally used to control simulation runs. They control when a simulation starts and stops, and what time interval is used in the simulation. A simulation run is created by combining a basin model, meteorological model, and control specifications. The data input to HEC-HMS is possible through two ways. The first and simplest method is manual data input. Here the time series data is copied from Excel or any compatible format and pasted in HEC-HMS time series table for any time series data (either precipitation or discharge).The second and relatively complex is saving the data in HEC-DSS and retrieving from it during analysis. For this study manual data input method is used because this method is simple one.

#### **4.11 Arc GIS**

A GIS integrated with enterprise database management systems could manage large volumes of geospatial data to provide spatially distributed parameters for modeling However, use of GIS for modeling data management and integration is generally hampered by the differences in scale, precision, data structure, data meaning, representation of the reality, and others, between a GIS and a simulation model .

A hydraulic model, like any other model, is intended to be a realistic representation of the physical processes over time in a river channel or flood plain and gives decision makers an indication of the outcome for different options (Pullar & Springer, 2000).

The hydraulic model usually has the capacity to analyze, to predict and to solve engineering problems without taking into consideration the geographical perspective (McKiney & Cai, 2002). Under these circumstances, GIS becomes a valuable tool (Pullar & Springer, 2000) notes that there are strong grounds for believing that GIS has an important function to play because natural hazards are multidimensional phenomena which has a spatial component. Many GIS integrated modeling applications have capitalized on using the GIS as a database manager and visualization tools. Data requirements, search method, governing algorithms, flood inundation extent and depth are the main area where these procedures might need to be modified and differ from the manual flood hazard map delineation processes (Norman et al., 2001). These enabling techniques which depend on the spatial capabilities of GIS, produce consistent modeling inputs as well as continual quality control (before, during and after the modeling process) where the benefits are nearly impossible to be obtained using the spreadsheets or other non-graphic methods of data organization.

Moreover, once data is available in the GIS, they can be extracted, combined with other data, reformatted as needed for various modeling processes and even used to generate other inputs needed by the models. Some of the common modeling issues that need to be tackled as described by Norman et al. (2001) are:

- a) Data structure of the Digital Terrain Model (DTM)
- b) Hydraulic model integration
- c) Flood plain delineation
- d) Accuracy of inundation maps

#### 4.12 Calibration

HEC-HMS has the capabilities to process automated calibration in order to minimize a specific objective function, such as sum of the absolute error, sum of the squared error, percent error in peak, and peak-weighted root mean square error. However in this case, the resulted automated parameters are not reasonable and practical. Therefore manual calibration method was adopted to determine a practical range of the parameter values preserving the hydrograph shape, minimum error in peak discharges and volumes. To compare a computed hydrograph to an observed hydrograph, the program computes an index of the goodness-of-fit. Algorithms included in program search for the model parameters that yield best value of an index, also known as objective function.

Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data. The quantitative measure of the match is described by the objective function. In the precipitation-runoff models, this function measures the degree of variation between the observed and the computed hydrographs. The calibration process finds the optimal parameter values that minimize the Objective function. Further, the calibration estimates some model parameters that cannot be estimated by observation or measurement, or have no direct physical meaning. Calibration can be either manual or automated (optimization). Manual calibration relies on user's knowledge of basin physical properties and expertise in hydrologic modeling. In the automated calibration model parameters are iteratively adjusted until the value of the selected objective function is minimized (CFCAS, 2004). The latest version of HEC-HMS model includes optimization manager that allows automated model calibration.

#### 4.13 Model Validation

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data is commonly referred to as model validation. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenario.

For this research work the measured stream flow data of Big Akaki were validate from a period of 1995-1999 were used to validate the model.

#### 4.14 Model Evaluation

The performance of HEC-HMS was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination ( $R^2$ ) and Nash-Sutcliffe simulation efficiency (ENS) were the goodness of fit measures used to evaluate model prediction. The  $R^2$  value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (ENS) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, ENS is 1. If the ENS is between 0 and 1, it indicates deviations between measured and predicted values. If ENS is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). The  $R^2$  and ENS values are explained in equations below.

$$r2 = \frac{\sum_{i=1}^n (qsi - qs)(qoi - qo)^2}{\sum_{i=1}^n (qsi - qs)^2 \sum_{i=1}^n (qoi - qo)^2} \quad \text{----- (Eq).4.1}$$

Where:

qsi :- is the simulated value , qoi :- is the measured values, qs:- is the average simulated value and qo:- is the average measured value

The ENS simulation efficiency for n time steps is calculated as:

$$\sum ENS = 1 - \frac{\sum_{i=1}^n (qoi - qsi)^2}{\sum_{i=1}^n (qoi - qo)^2} \quad \text{----- (Eq)4.2}$$

Where: qsi is the simulated value and qoi is the measured value

The percent difference for a quantity (D) over a specified period with total days is calculated from measured and simulated values of the quantity in each model time step as:

$$D = 100 * \left| \frac{\sum_{i=1}^n qoi - \sum_{i=1}^n qsi}{\sum_{i=1}^n qoi} \right| \quad \text{----- (Eq). 4.3}$$

Where: qsi is the simulated value and qoi is the measured value

A value close to 0% is best for D. A negative value indicates model over estimation and a positive value indicate model under estimation.

Observation standard deviation ratio (RSR) is also another performance rating which standardizes Root mean square error (RMSE) using the observations standard deviation and it combines both an error index (McCabe 1999, Cited in D.N Moriasi, 2007). RSR is calculated as the ratio of the RMSE and standard deviation of measured data, as shown in equation below:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{[\sum_{i=1}^n (q_{obs} - Q_{sim})^2]^{0.5}}{[\sum_{i=1}^n (q_{obs} - q_{Nobs})^2]^{0.5}} \dots\dots\dots (Eq). 4.4$$

Where: Qobs is the observed flow, Q sim is the simulated flow and Q”obs is means observed flow.

RSR incorporates the benefits of error index statistics and includes a scaling / normalization factor, so that the resulting statistic and reported values can apply to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. Note: NSE= 1- (RSR) 2

**Table 4-1: General Performance ratings for recommended Statics values**

	RSR	NSE	%D
Very Good	0.0<=RSR<=0.5	0.75<NSE<=1	D <=±10
Good	0.5<RSR<=0.6	0.65<NSE<=0.75	±10 <=D < ±15
Satisfactory	0.6<RSR<=0.7	0.5<NSE<=0.65	±15<=D<± 25
Unsatisfactory	RSR>=0.7	NSE<=0.5	D >= ± 25

#### 4.15 Frequency of point rainfall

In many hydraulic engineering application such as those concerned with floods probability of occurrence of a particular extreme 24h maximum rainfall, will be of importance. Such information is obtained by the frequency analyses of the point rainfall data. The rainfall at place is a random hydrologic Process and the rainfall data at a place when arranged in chronological order constitute a time series. One of the commonly used data series is the annual series composed of annual values such as annual rainfall. If the extreme values of a specified event occurring in each year are listed, it also constitutes an annual series. One may list the maximum 24 h rainfall occurring in a year at a station to prepare an annual series of 24 hr. maximum rainfall values. The probability of occurrence of an event in this series is studied by frequency analysis of this annual data series (k.subramanya). Some of the commonly used frequency distribution functions for the prediction of maximum rainfall are Gumball's extreme –value distribution, log-Pearson type III distribution and log normal distribution. The rainfall depth for the study area is estimated for different return periods using two metrological stations Ababa Bole and Addis Ababa observatory rain fall data. Using Gumball's extreme –value distribution (Attached as Annex D & E) Since it is one of the most widely used probability –distribution function for extreme values in hydrologic and Metrologic studies for prediction of flood peaks ,maximum rainfall ,maximum wind speed.

**Table 4-2: Rain fall depth for different return periods**

Rain fall Depth (mm)	Return Period		
	10 years	25 years	50 years
	80.7 mm	90.6 mm	98.0 mm

## CHAPTER FIVE

### 5 Result and Discussion

#### 5.1 ARC-GIS model result

ARC-GIS 10 modeling software is used to delineate catchment for different river system in Akaki catchment and helps to obtain hydrological and physical parameters and spatial information of the Akaki catchment. Road Networks, houses and buildings as well as vegetation cover of Akaki catchment is digitized and corresponding areas is calculated.

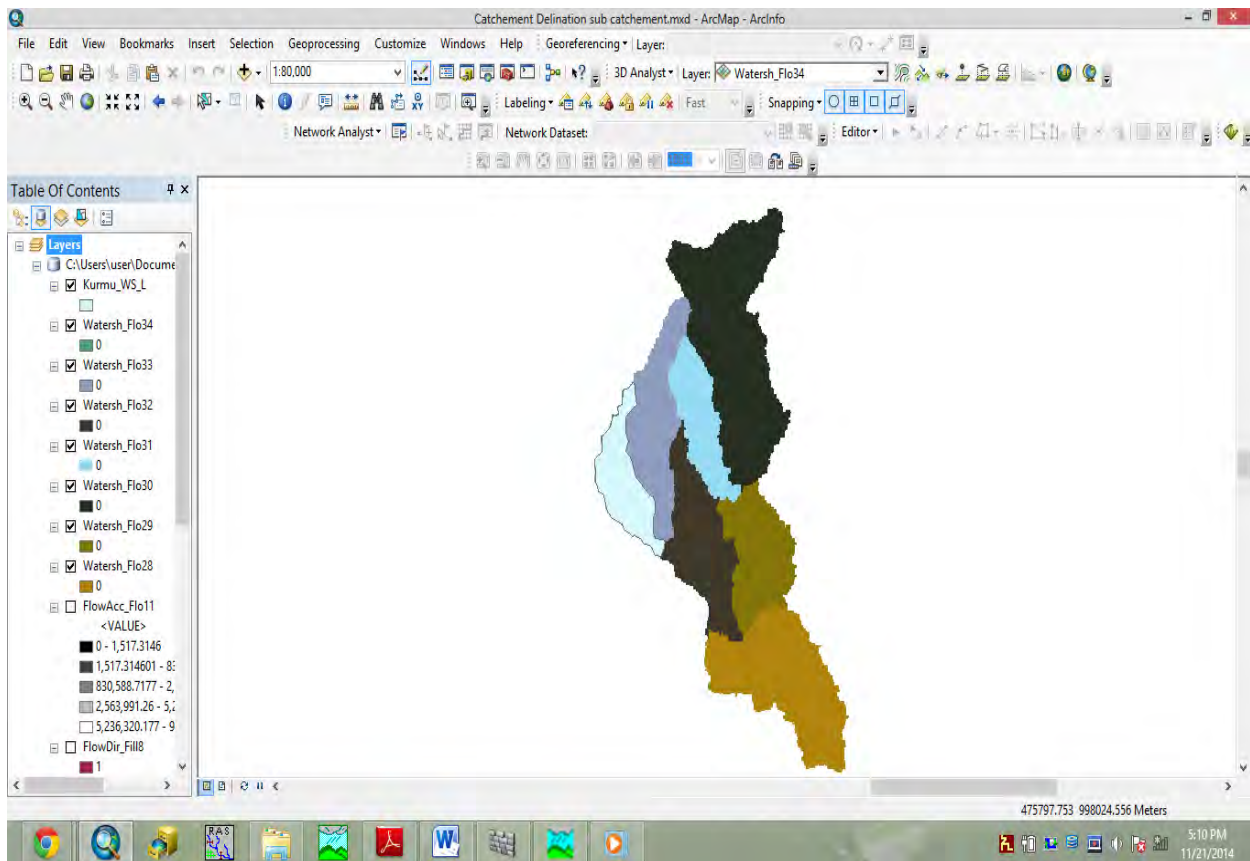


Figure 5-1: Study Area catchment delineation

S.no	Name of River Catchment	Area (ha)
1	Kechena	13
2	Kurmu	9
3	Bantyeketu	6
Total		28

## 5.2 HEC-HMS hydrological modeling results

### 5.2.1 Calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The calibration of HEC-HMS for this particular study area was carried out using Three years from 2005 to 2007 daily rainfall and daily stream flow data of Big Akaki River. Table 5-1 shows the optimal parameters found in calibration. The coefficient of determination ( $R^2$ ) during calibration was found to be 0.7(Figure 5-2). The stochastic nature of precipitation effect on the simulated hydrograph was handled by stochastic calibration. In the stochastic calibration observed and simulated discharge time series were arranged in descending order and the objective function,  $\Sigma(Q_{ob}-Q_{sim})^2$  was minimized by observing the plot of observed and simulated discharge. As it can be seen in (Figure 5-3) the observed and simulated hydrograph coincides for peak discharge for calibration. The optimal parameter found in calibration at big Akaki River is used as an input for estimation of flood peak for different return period for the study area.

**Table 5-1: Optimal model calibration parameters**

<b>Parameter</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Optimal Parameter</b>
<b>Loss</b>			
Constant Rate (mm/hr.)	0.001	500	<b>10</b>
Initial Deficit (mm)	0.001	500	<b>5</b>
Maximum Deficit	0.001	500	<b>15</b>
<b>Transform</b>			
Storage Coefficient (hr.)	0.01	1000	<b>20</b>
Time Concentration (hr.)	1	1000	<b>30</b>
Lag Time (min)	0	1000	<b>30</b>

Source: HEC-HMS Technical Manual

Deficit and constant loss method is adopted together with constant base flow and Clark unit Hydrograph transformation. The parameters needed for each adopted methods were taken into consideration in this simulation. The above Table indicates parameters used with their minimum and maximum limits. Time of concentration, Clark storage component as well as base flow parameters had significant influence on the simulated flow discharges. The remaining parameters were adjusted to match the simulated and observed peak flows, volumes and hydrograph shape. Optimized parameters are also shown in this Table 5-1. As it can be seen in the figure 5-3 the observed and simulated hydrograph coincides very well.

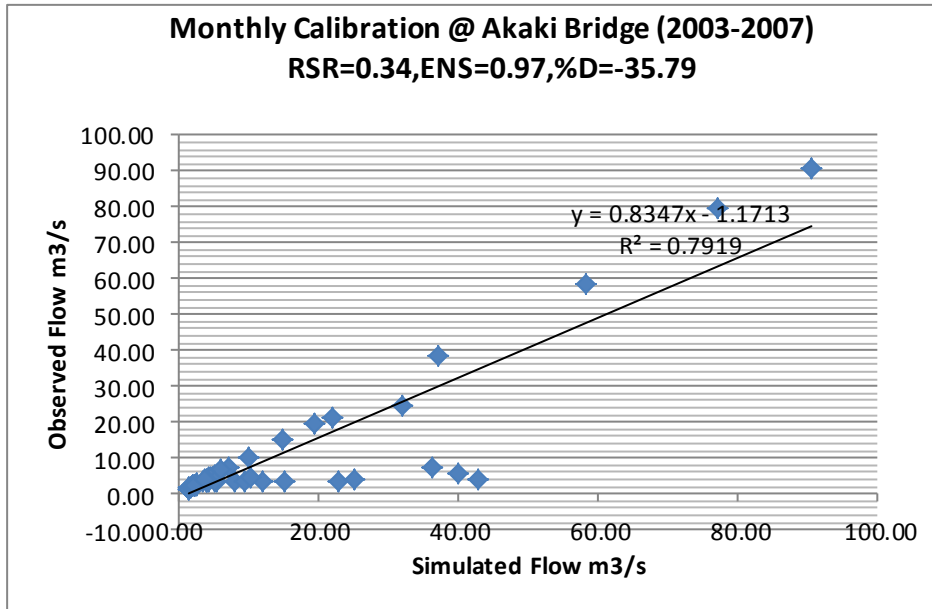


Figure 5-2: Simulated vs. Observed (Calibration)

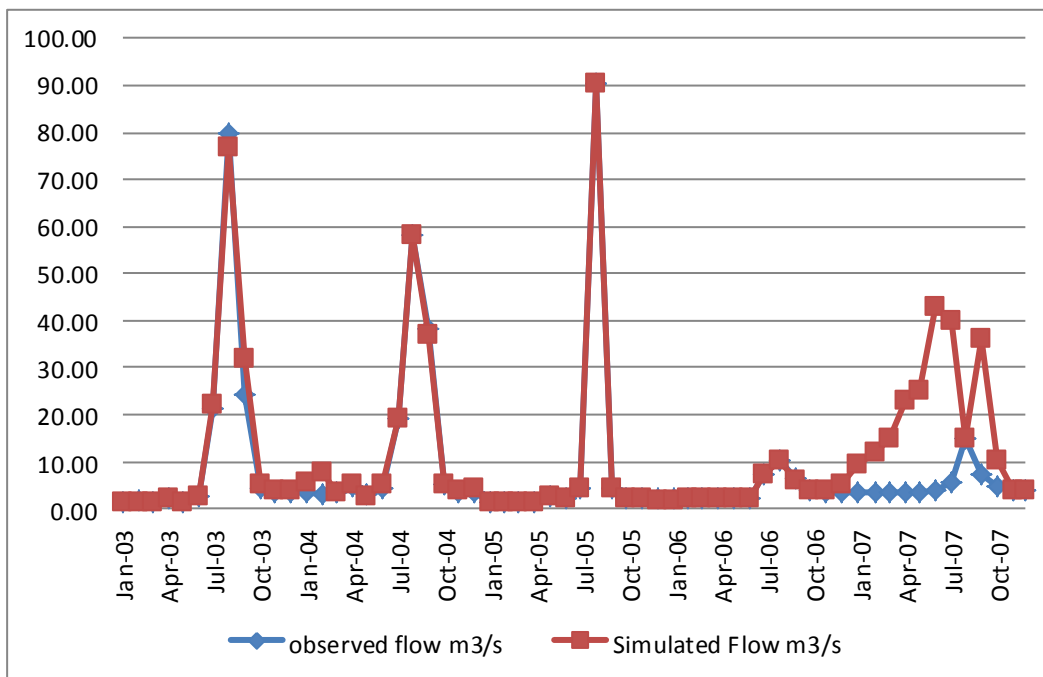


Figure 5-2: Simulated and Observed flow Hydrograph (Calibration)

Model validation was carried out over the period of 1995-1999. As it can be seen in (Figure ) the model performance is improved, the coefficient of determination in this case is found

to be 0.806 (Figure 5.12). The observed and simulated flow hydrograph show well agreement **except in peak flow in year 1999**. In general the model performed reasonably in simulating flow for periods outside of the calibration period, based on adjusted parameters during calibration.

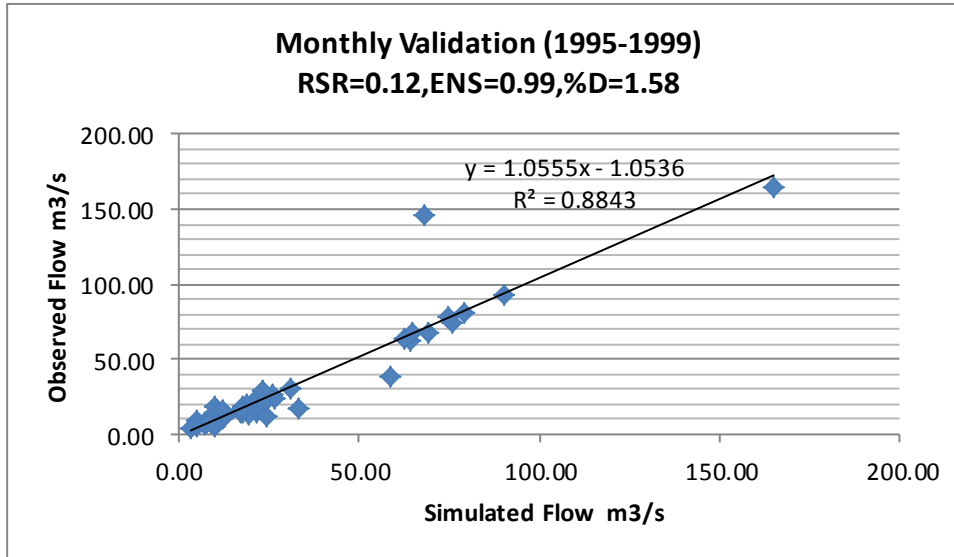


Figure 5-2: Simulated vs. Observed (Validation)

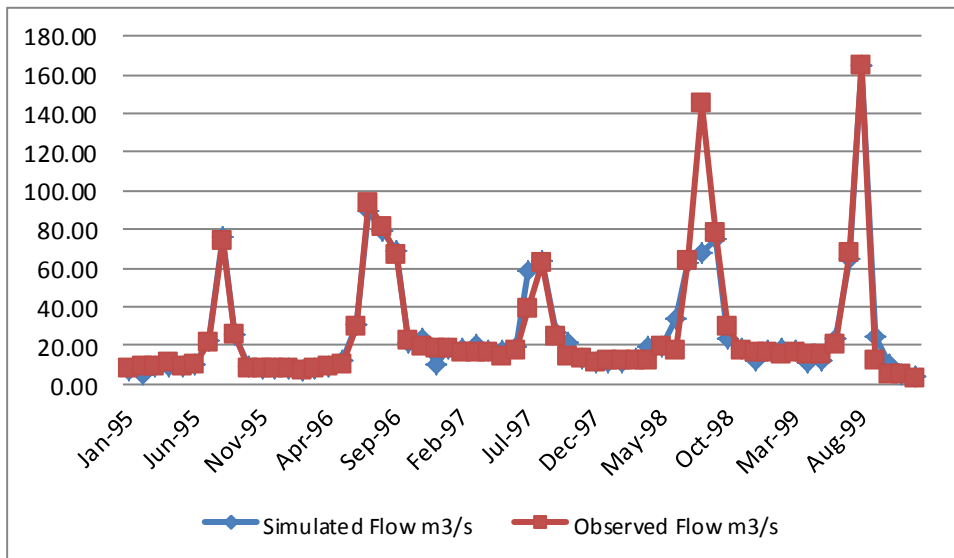


Figure 5-3: Simulated and Observed flow Hydrograph (Validation)

### 5.2.2 Peak Flood

Bantyeketu River is evaluated by HEC-HMS Hydraulic modeling software and the Peak flood for different return periods is identified using the rain fall depth determined in chapter four Table 4-1 And the result of the peak floods is shown in the table below.

**Table 5-2: Peak flood**

Estimated Peak Flood	Return Period		
	10 Years	25 Years	50 Years
Peak Flood (m <sup>3</sup> /s)	13.1	14.7	16

### 5.3 HEC-RAS hydrological modeling result

The central urban area along both right and left bank of Bantyeketu River suffer by flood almost every time when heavy rainfall occurs. The present carrying capacity of Bantyeketu River is evaluated by HEC-RAS Hydraulic modeling software using river cross section and the results are compiled in to longitudinal profile, River width diagram and carrying capacity diagram.

**Table 5-3 Bantyeketu River Characteristics**

River	Average Slop	Channel Width (m)		Carrying Capacity( m <sup>3</sup> /s)
		Minimum	Maximum	
Bantyeketu	1/120	6	16	5-109

Table 5-4: Bantyeketu River carrying capacity

Channage (m)	Channel top width (m)	Channel Height (m)	Channel bed Width (m)	Area (m2)	Average velocity from 50 years return period HEC-RAS	Carring Capacity (m3/s)	MAX Carring Capacity (m3/s)
0.00	10.00	3.00	5.00	22.50	2.60	58.50	109.60
99.70	11.00	4.40	5.00	35.20	1.61	56.67	
199.70	10.00	3.00	3.00	19.50	1.17	22.82	
299.20	11.00	2.50	3.00	17.50	2.64	46.20	
399.40	13.00	1.50	5.00	13.50	1.00	13.50	
499.40	16.00	1.50	5.00	15.75	2.23	35.12	
599.40	13.00	4.50	4.00	38.25	1.00	38.25	
699.40	9.00	2.50	3.00	15.00	2.59	38.85	
798.90	12.00	4.50	10.00	49.50	0.76	37.62	
899.20	13.00	4.00	4.00	34.00	1.13	38.42	
988.20	11.00	5.00	5.00	40.00	2.74	109.60	
1088.20	10.00	7.00	3.00	45.50	1.23	55.97	
1142.20	11.00	5.00	3.00	35.00	2.72	95.20	
1241.60	10.00	1.00	3.00	6.50	1.29	8.39	
1341.60	10.00	1.50	2.00	9.00	0.80	7.20	
1441.60	10.50	2.00	3.00	13.50	1.71	23.09	
1543.60	9.00	1.80	3.00	10.80	0.80	8.64	
1643.60	8.00	0.70	3.00	3.85	1.50	5.78	
1743.60	9.00	0.50	5.00	3.50	1.43	5.01	
1760.60	10.00	1.00	4.00	7.00	1.79	12.53	
1822.60	9.00	3.00	2.00	16.50	2.18	35.97	
1921.80	8.50	3.00	3.00	17.25	1.12	19.32	
2022.80	7.00	1.00	5.00	6.00	2.27	13.62	
2122.80	10.50	2.00	5.00	15.50	0.90	13.95	
2222.80	10.00	3.00	4.00	21.00	2.53	53.13	
2322.80	11.00	2.00	3.00	14.00	2.43	34.02	
2423.80	9.00	3.00	3.00	18.00	1.26	22.68	
2521.80	11.00	1.00	6.00	8.50	2.31	19.64	
2621.80	10.00	2.00	2.00	12.00	1.20	14.40	
2721.80	9.00	2.80	3.00	16.80	1.27	21.34	
2821.80	8.00	2.50	3.00	13.75	0.83	11.41	
2919.80	7.00	2.50	2.00	11.25	2.58	29.03	
3019.80	9.50	1.50	4.00	10.13	2.37	24.00	
3119.20	11.00	2.50	4.00	18.75	1.86	34.88	
3219.20	6.00	3.30	2.00	13.20	1.39	18.35	
3319.20	9.00	2.50	2.00	13.75	1.85	25.44	
3419.20	15.00	3.00	2.00	25.50	1.14	29.07	
3519.20	11.00	1.50	2.00	9.75	0.76	7.41	
3619.20	9.50	0.70	3.00	4.38	1.30	5.69	
3718.70	10.00	1.50	2.00	9.00	1.20	10.80	
3818.70	9.80	1.00	4.00	6.90	2.11	14.56	
3918.50	9.00	3.00	2.00	16.50	2.63	43.40	
4018.50	12.00	1.50	3.00	11.25	2.44	27.45	
4118.50	11.50	5.00	3.00	36.25	1.80	65.25	
4188.50	14.00	6.00	5.00	50.00	1.90	95.00	

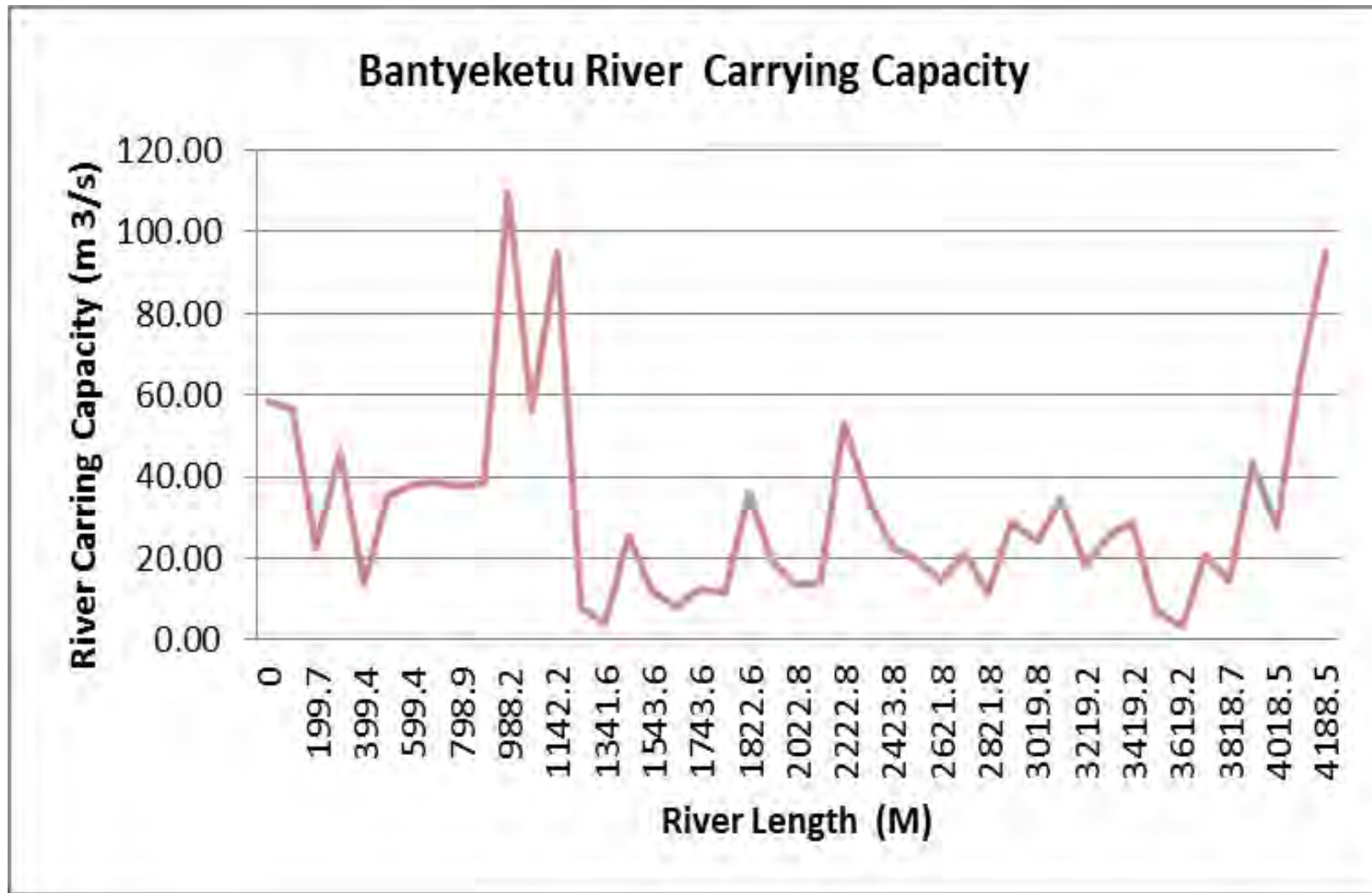


Figure 5-4: Bantyeketu river carrying capacity

5.3.1 Flooding Areas

Potential flooding area due to probable flood of different return period was identified.

**Table 5-5: Flooding area (10 years return period)**

	Area Description	Flooding Area (ha)
10 Years Return Period	ECA	0.69
	Haya Hulete Bridge	1.98
	Up stream of Bantyeketu River Confluence with Kebena River around Bole Bridge	0.47
	<b>Total Area (ha)</b>	<b>3.14</b>

**Table 5-6: Flooding area (25 years return period)**

	Area Description	Flooding Area (ha)
25 Years Return Period	Sides of ECA compound	0.7
	Haya Hulete Bridge	2.5
	Up stream of Bantyeketu River Confluence with Kebena River around Bole Bridge	0.73
	<b>Total Area (ha)</b>	<b>3.93</b>

**Table 5-7: Flooding area (50 years return period)**

	Area Description	Flooding Area (ha)
50 Years Return Period	Sides of ECA compound	0.71
	Haya Hulete Bridge	2.79
	Up stream of Bantyeketu River Confluence with Kebena River around Bole Bridge	0.97
	Total Area (ha)	<b>4.47</b>

## CHAPTER SIX

### 6 Conclusion and Recommendation

#### 6.1 Design Background

Designing of small Flood Protection structures mainly depends on the Flood depth and its magnitude. There are a number of points to be followed during the design of these structures (JICA V.III 1998) among this:-

- The height should include the site flood depth including sufficient free board.
- Side slopes not steeper than 1.5:1.0
- Crest width adequate for person's movement and not less than 0.5 m in width.
- Proper stripping of foundation to below depth of weathering.
- Bed width should be  $1\text{ m} < B_2 < 2\text{ m}$

The out put from HEC-RAS Computer modeling shows River Bantyeketu is flooded at about four different places. This area is at ECA ,Hayahulet bridge ,Bambisse, and Up stream of Bantyeketu River confluence with Kebena. Different flood protection structures are recommended based on river bank condition and design discharge.

This paper mainly Proposes Masonry flood wall, Masonry Dyke and River bed excavation for flood affected areas for Bantyeketu River.

#### 6.2 Other flood Protection Measures

For urban flood protection apart form the above mentioned Structures and Measures there are also other ways. Balancing pond is one of the other flood protection measures for urban areas. The Balancing pond can also be used as a recreational center besides balancing flood for some areas.

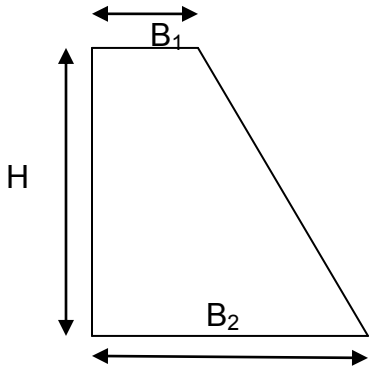
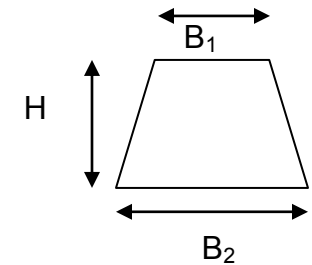
Sand filled bags are also used as Temporary flood protection in urban areas until permanent flood protection structures built in the area.

Knowing the flood corridor in the urban areas and evacuating the corridor from people and Animals is also another option.

### 6.3 Hydraulic Modeling of Bantyeketu River Channel

The findings of Hydraulic modeling of Bantyeketu river channel characteristics indicate the channel have the manning’s coefficient (n) between 0.04 and 0.1 and the channel have an Average slope of 1/120.

**Table 6-1: Design Background for Flood Protection Structures (Flood Wall and Masonry Dyke).**

	Design Parameters		
<p><b>Masonry Flood Wall</b></p> 	Height (H)	Crest Width (B <sub>1</sub> )	Bed Width (B <sub>2</sub> )
	Depends on the Water Level + free board	Not less than 0.5 m	It should be 1 m < B <sub>2</sub> < 2 m
<p><b>Masonry Dyke</b></p> 	Depends on the Water Level + free board	Not less than 0.5 m	It should be 1 m < B <sub>2</sub> < 2 m

### 6.4 Carrying Capacity

From the carrying capacity diagram of River Bantyeketu , major problematic areas due to flooding were identified the cross section around the distance of 1.2 km, 1.5 km, 2.8 km and 3.5 km from Finfina Bridge show low carrying capacity less than 13.1 m<sup>3</sup>/s or 10 years estimated probable flood. This area are located at ECA,Haya hulet,Bambisse and up stream of Bantyeketu River confluence with Kebena River.

## 6.5 Structural Measures

### 6.5.1 Masonry Flood wall

Masonry flood Wall is recommended for about seven different sections of the river the height of the flood wall varies from 1.8 m to 1.2 m including 0.2 m free board and the base width varies from 1.9 m to 1.3 m and the total length is about 0.8 km. Table 6-1 Show Detail of recommended structure and locations.

### 6.5.2 Masonry dyke

Masonry dyke is recommended for one location. The height of the dyke is about 1.2 m including 0.2 m free board and the total length of the dyke is about 1 km. Table 6-1 Show Detail of recommended structure and locations.

### 6.5.3 River bed excavation

River bed excavation is recommended in the case of smaller flood depth and when the bank of the river is not allowing constructing Masonry dyke or Flood wall. River bed excavation is recommended for three locations having excavation depth of 0.6 to 0.5 m and the total length is 2.98 km

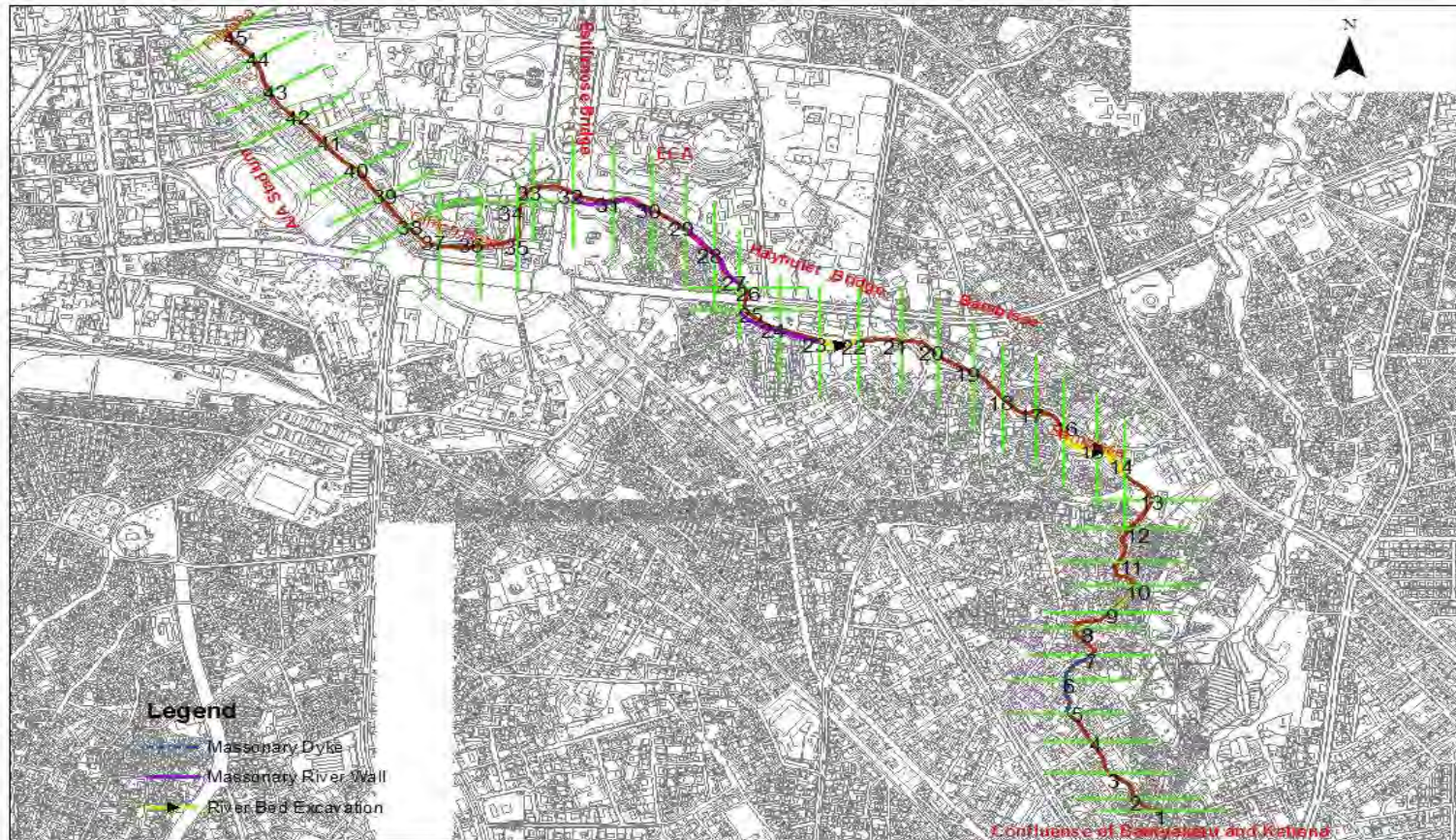
**Table 6-2: Recommended Flood Protection Structures**

Cross Section	Area Name	Recommended Type				
		Recommended Structure	Height (m)	Top Width (m)	Bed Width (m)	Length (m)
32-31	ECA	Flood Wall (R)	1.4	0.5	1.5	100
31-30	ECA	Flood Wall (R)	1.4	0.5	1.5	100
30-29	ECA	Flood Wall (R &L)	1.7	0.5	1.8	204
29-28	Haya Hulet Bridge	Flood Wall (L)	1.2	0.5	1.3	100

Cross Section	Area Name	Recommended Type				
		Recommended Structure	Height (m)	Top Width (m)	Bed Width (m)	Length (m)
28-27	Haya Hulet Bridge	Flood Wall (L)	1.2	0.5	1.3	100
25-24	Bambisse	Flood Wall (R)	1.8	0.5	1.9	99.2
24-23	Bambisse	Flood Wall (R & L)	1.2	0.5	1.3	101
8-7	Up stream of Bantyeketu River Confluence with Kebena River	Masonry Dyke (R)	1.2	0.5	1.3	99.5

**Table 6-3:** Recommended Flood Protection (River bed Excavation

Cross Section	Area Name	Recommended Type			
		Recommended Structure	Excavation Depth (m)	River Bed Width (m)	Length (m)
23-22	Bambisse	River bed Excavation	0.6	9	100
16-15	Bambisse	River Bed Excavation	0.5	9	100
15-14	Bambisse	River Bed Excavation	0.5	7.5	98



Recommended Flood Protection Structure and locations

Figure 6-1: Lay out map of Bantyeketu River

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## 7 Annexes

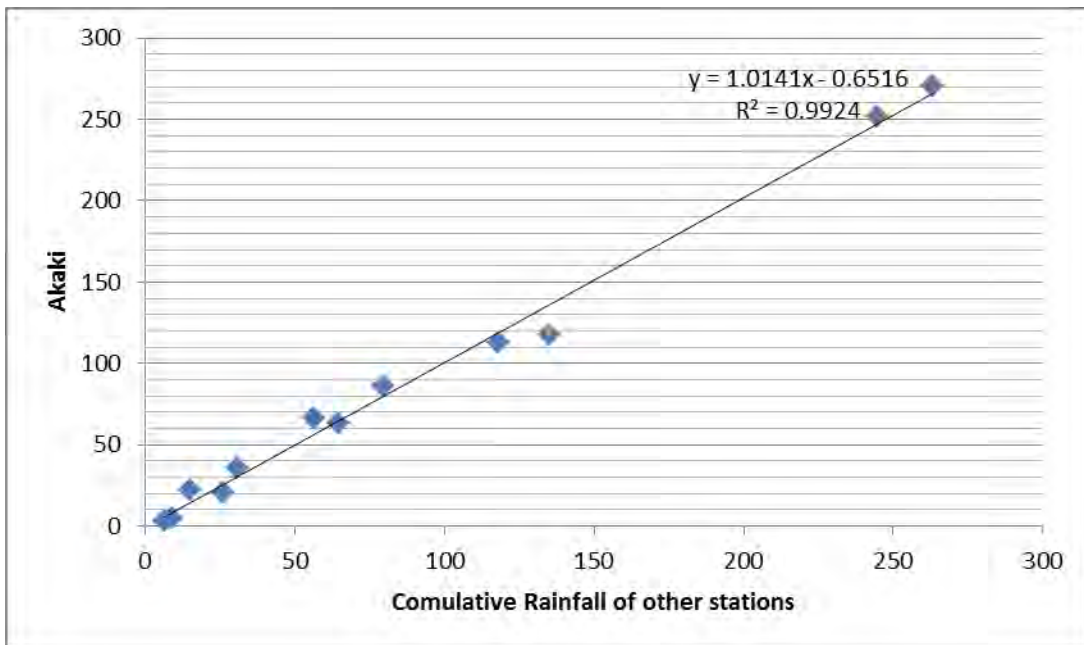
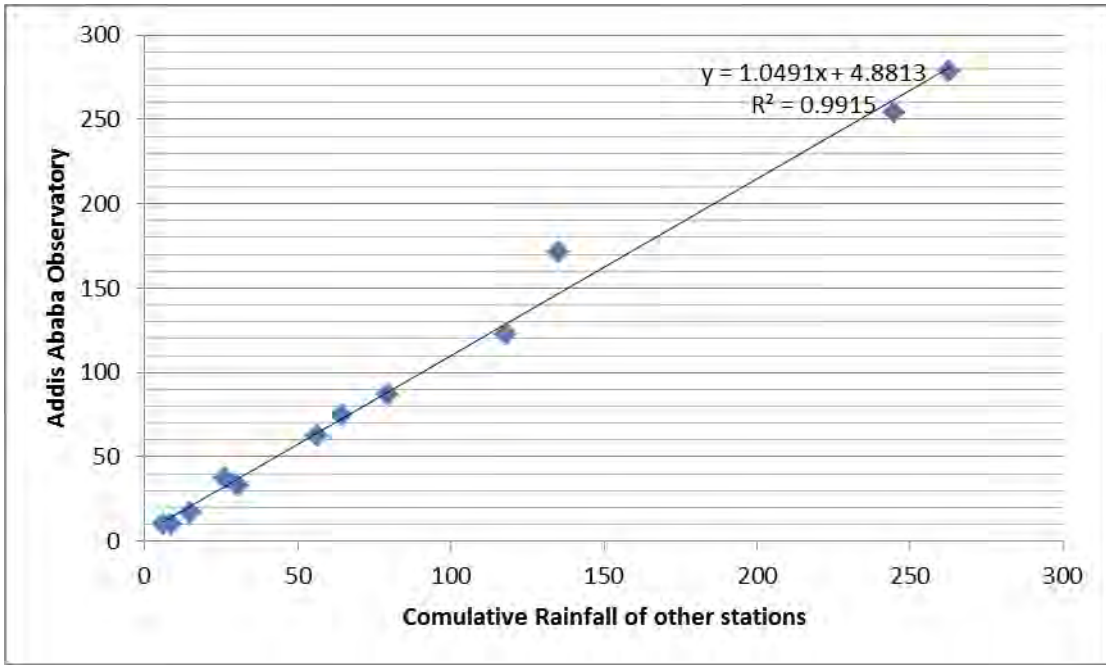
### Annex A: Location of Metrological Stations

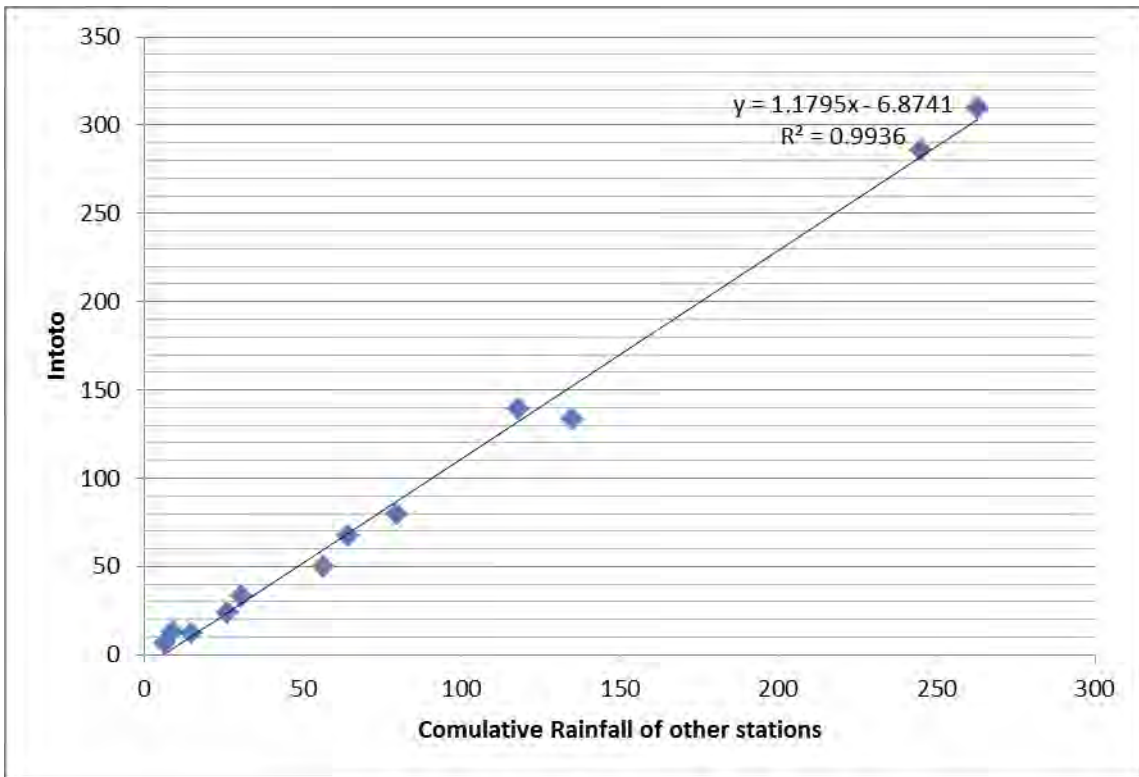
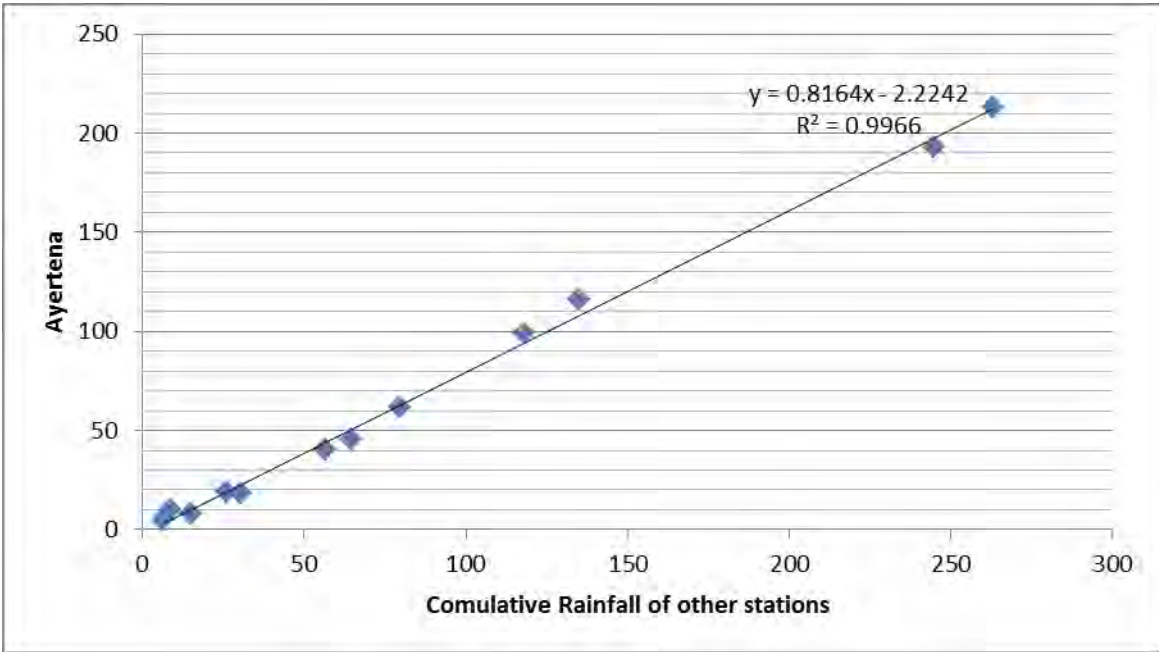
Station	X-coordinate	Y-coordinate	Elevation (m)
Addis Ababa Bole	472518	998493	2324
Addis Ababa Observatory	472268	996844	2225
Akaki	478738	981460	2075
Ayertena	469070	998244	2125
Intoto	469370	1004190	2205

**Annex B: Monthly Average Precipitation for all five Stations**

Addis Ababa Bole (1954-2014)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15.6	32.0	63.2	83.3	71.7	117.1	239.4	242.3	136.7	30.5	6.4	6.3
Addis Ababa Observatory (1951-2014)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16.8	33.0	62.8	86.9	75.0	122.5	254.0	278.5	171.3	37.3	9.7	10.2
Akaki (1954- 2014)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
21.8	35.7	66.3	86.0	62.9	112.8	251.9	270.6	117.8	20.6	5.1	3.5
Ayertena (1998 -2014)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8.2	18.7	40.2	61.9	45.4	98.9	193.1	213.2	115.8	18.8	10.0	4.7
Intoto (1988-2014)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12.3	33.2	49.9	79.6	67.1	139.0	286.1	310.1	133.2	23.9	12.8	6.5

Annex C: Double mass curve Plots

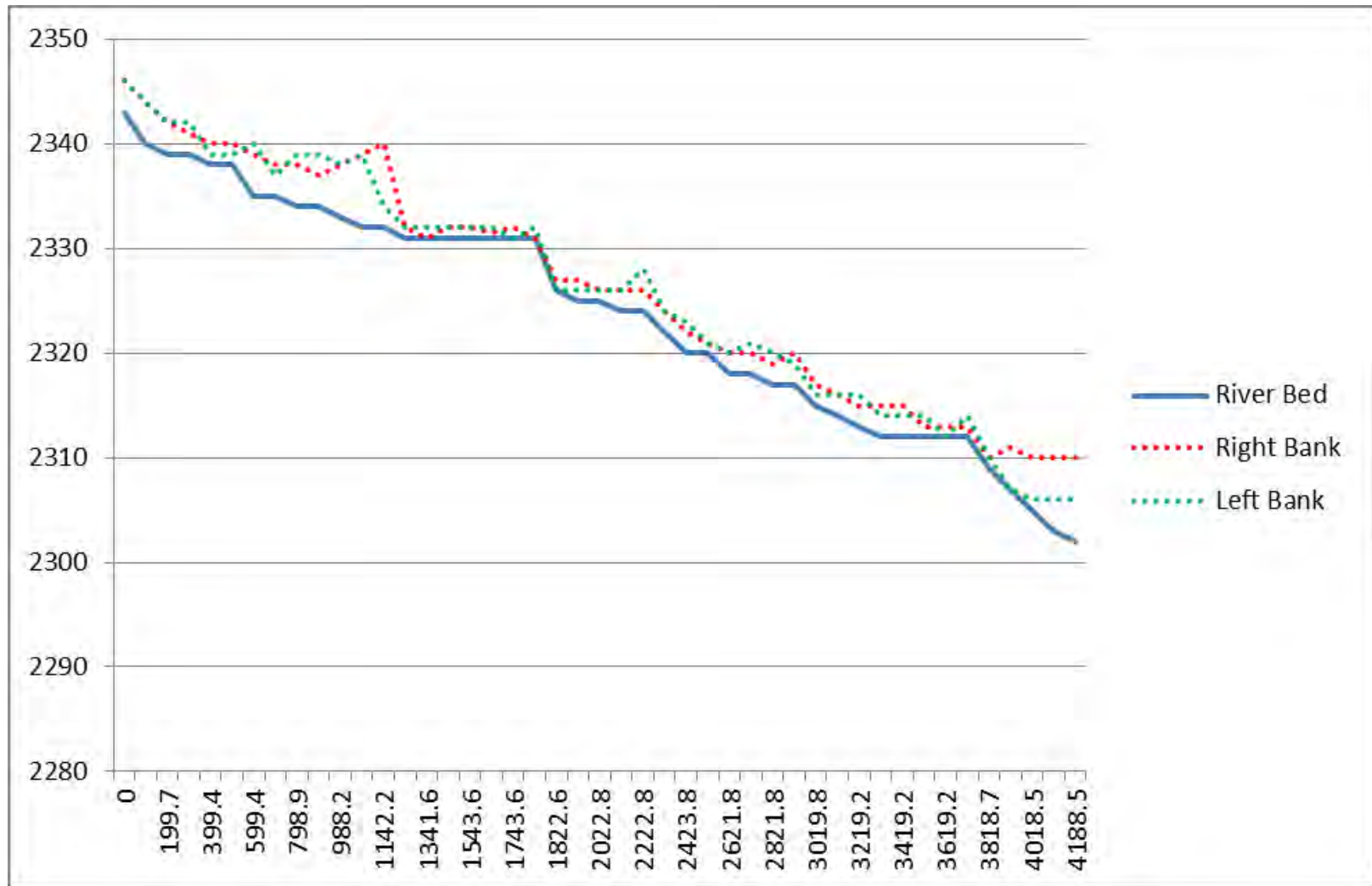




**Annex D: Bantyeketu River Profile**

Change (m)	Left Bank (Elv)	River Center (Elv)	Right Bank (Elv)
0	2346	2343	2346
99.7	2344	2340	2344
199.7	2342	2339	2342
299.2	2342	2339	2341
399.4	2339	2338	2340
499.4	2339	2338	2340
599.4	2340	2335	2339
699.4	2337	2335	2338
798.9	2339	2334	2338
899.2	2339	2334	2337
988.2	2338	2333	2338
1088.2	2339	2332	2339
1142.2	2334	2332	2340
1241.6	2332	2331	2332
1341.6	2332	2331	2331
1441.6	2332	2331	2332
1543.6	2332	2331	2332
1643.6	2332	2331	2332
1743.6	2331	2331	2332
1760.6	2332	2331	2331
1822.6	2326	2326	2327
1921.8	2326	2325	2327
2022.8	2326	2325	2326
2122.8	2326	2324	2326
2222.8	2328	2324	2326
2322.8	2324	2322	2324
2423.8	2323	2320	2322
2521.8	2321	2320	2321
2621.8	2320	2318	2320
2721.8	2321	2318	2320
2821.8	2320	2317	2319
2919.8	2319	2317	2320
3019.8	2316	2315	2317
3119.2	2316	2314	2316
3219.2	2316	2313	2315
3319.2	2314	2312	2315
3419.2	2314	2312	2315
3519.2	2314	2312	2313
3619.2	2312	2312	2313
3718.7	2314	2312	2313
3818.7	2310	2309	2310
3918.5	2307	2307	2311
4018.5	2306	2305	2310
4118.5	2306	2303	2310
4188.5	2306	2302	2310

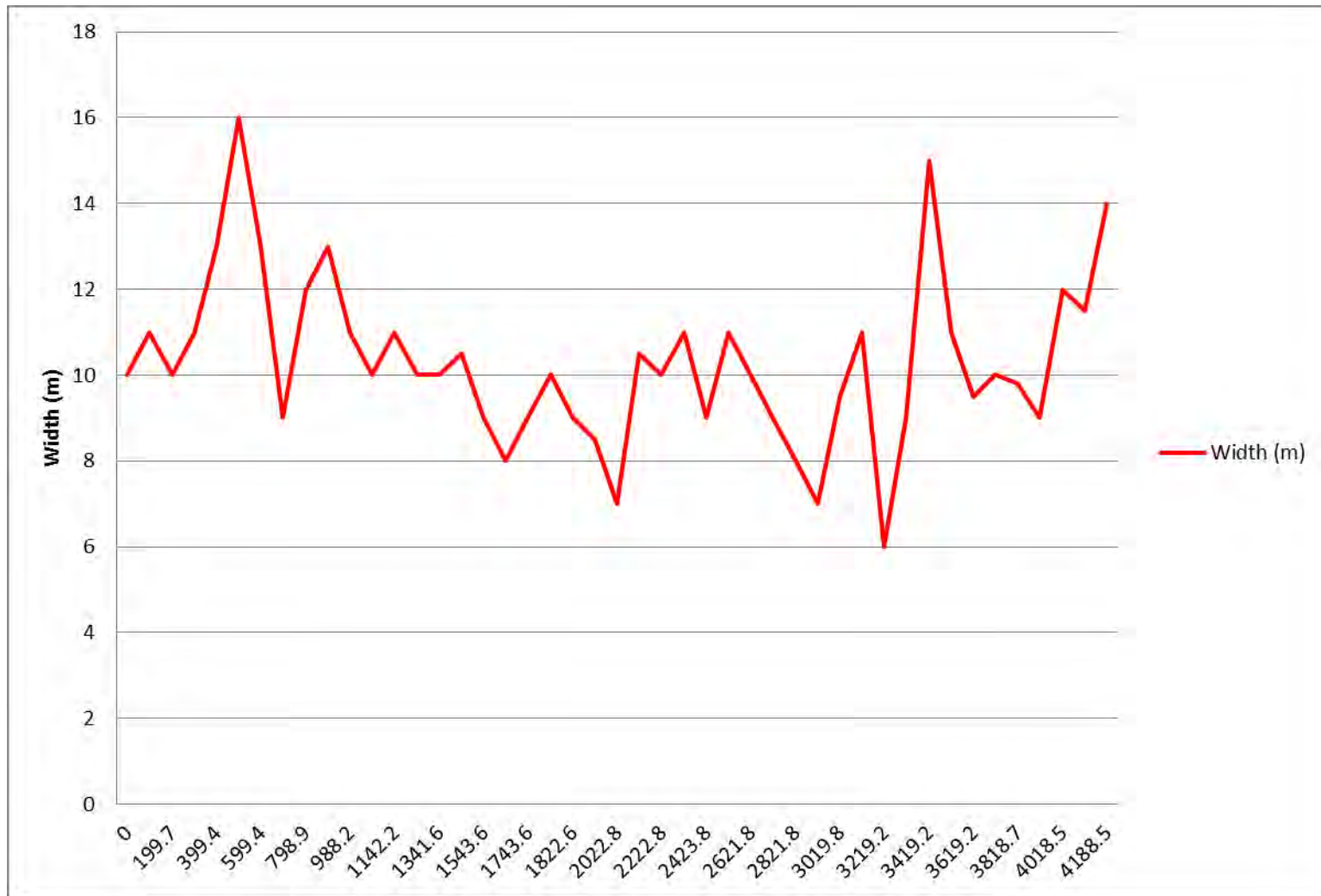
Annex E: Longitudinal Profile, River Bed and River Banks of Bantyeketu River



**Annex F: Bantyeketu River width Profile**

Channage (m)	Average Width (m)	Max Width (m)	Min Width (m)
0	10.0		
99.7	11.0		
199.7	10.0		
299.2	11.0		
399.4	13.0		
499.4	16.0		
599.4	13.0		
699.4	9.0		
798.9	12.0		
899.2	13.0		
988.2	11.0		
1088.2	10.0		
1142.2	11.0		
1241.6	10.0		
1341.6	10.0		
1441.6	10.5		
1543.6	9.0		
1643.6	8.0		
1743.6	9.0		
1760.6	10.0		
1822.6	9.0		
1921.8	8.5		
2022.8	7.0	16.0	6.0
2122.8	10.5		
2222.8	10.0		
2322.8	11.0		
2423.8	9.0		
2521.8	11.0		
2621.8	10.0		
2721.8	9.0		
2821.8	8.0		
2919.8	7.0		
3019.8	9.5		
3119.2	11.0		
3219.2	6.0		
3319.2	9.0		
3419.2	15.0		
3519.2	11.0		
3619.2	9.5		
3718.7	10.0		
3818.7	9.8		
3918.5	9.0		
4018.5	12.0		
4118.5	11.5		
4188.5	14.0		

**Annex G:- Longitudinal Profile of Bantyeketu River Width**



**Annex H:-Monthly Rain fall Data of five Stations (2005-2007) for Calibration**

Station	Year	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Addis Ababa Bole	2005	55.40	14.10	41.80	116.20	164.60	159.10	174.30	248.00	77.60	25.80	7.20	0.00
Addis Ababa Bole	2006	2.00	36.60	107.80	93.90	37.80	115.10	313.20	331.10	132.50	35.90	0.00	0.00
Addis Ababa Bole	2007	9.90	21.30	61.10	86.80	134.00	157.60	191.30	305.40	130.90	37.20	0.10	0.00
SUM		67.30	72.00	210.70	296.90	336.40	431.80	678.80	884.50	341.00	98.90	7.30	0.00
Average		22.43	24.00	70.23	98.97	112.13	143.93	226.27	294.83	113.67	32.97	2.43	0.00
Addis Ababa Obs	2005	45.90	51.60	83.20	160.90	133.70	179.80	246.00	315.20	162.50	28.50	4.40	0.00
Addis Ababa Obs	2006	0.70	11.20	56.40	78.90	74.60	150.10	356.30	243.60	239.10	54.00	0.30	8.00
Addis Ababa Obs	2007	51.30	19.10	59.80	73.80	120.10		261.80	381.20	147.60	24.80	0.00	0.00
SUM		97.90	81.90	199.40	313.60	328.40	329.90	864.10	940.00	549.20	107.30	4.70	8.00
Average		32.63	27.30	66.47	104.53	109.47	109.97	288.03	313.33	183.07	35.77	1.57	2.67
Akaki	2005	28.80	7.30	47.90	112.20	140.70	139.90	218.70	231.40	152.70	9.10	15.20	0.00
Akaki	2006	2.60	44.20	56.30	79.70	22.00	84.30	276.40	262.60	148.10	38.00	0.00	3.20
Akaki	2007	34.20	24.70	25.60	96.80	64.60	132.70	254.20	221.80	148.50	14.30	1.30	0.00
SUM		65.60	76.20	129.80	288.70	227.30	356.90	749.30	715.80	449.30	61.40	16.50	3.20
Average		21.87	25.40	43.27	96.23	75.77	118.97	249.77	238.60	149.77	20.47	5.50	1.07
Ayertena	2005	7.40	11.50	34.10	54.10	94.80	129.00	257.80	245.60	162.50	18.80	14.50	0.00
Ayertena	2006	1.80	39.20	60.90	81.20	101.20	173.80	375.40	258.90	272.00	70.60	1.80	5.50
Ayertena	2007	51.30	35.40	95.00	108.60	100.50	162.80	314.60	342.70	155.80	26.70	1.30	0.00
SUM		60.50	86.10	190.00	243.90	296.50	465.60	947.80	847.20	590.30	116.10	17.60	5.50
Average		20.17	28.70	63.33	81.30	98.83	155.20	315.93	282.40	196.77	38.70	5.87	1.83
Intoto	2005	8.30	11.40	42.80	98.60	143.90	106.40	241.80	339.30	134.40	19.60	8.20	0.00
Intoto	2006	0.90	19.10	93.80	66.50	79.10	131.50	371.10	311.50	128.70	36.10	0.60	15.50
Intoto	2007	38.60	16.20	36.40	52.10	106.40	246.70	272.10	322.60	87.00	16.40	0.00	0.00
SUM		47.80	46.70	173.00	217.20	329.40	484.60	885.00	973.40	350.10	72.10	8.80	15.50
Average		15.93	15.57	57.67	72.40	109.80	161.53	295.00	324.47	116.70	24.03	2.93	5.50

**Annex I:- Annual daily peak rain fall data of two stations for frequency Analysis**

years	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Addis Ababa Bole	37.0	59.6	44.3	40.6	38.2	64.7	52.0	37.3	60.1	37.8	47.0	32.4	28.6	34.6	29.0	44.5	61.7	71.2	37.2	51.2	54.4	36.9	64.7	42.6	27.2
Addis Ababa Obs	39.6	47.3	51.4	53.5	57.0	85.3	67.0	46.3	78.3	37.4	37.1	96.3	29.5	54.9	44.2	58.6	70.9	64.0	53.3	54.7	44.6	55.8	36.4	47.2	
Max Annual daily peak	71.2																								
Mean of peak	49.9																								
Standard Deviation	16.67																								

**Annex J:- Rain fall depth for different Return period ( Gambele `s Extreme value distribution)**

<b>10 Years</b>				
Yt	Yn	Sn	k	Xt
2.25037	0.495	0.95	1.848	<b>80.7</b>

<b>25 years</b>				
Yt	Yn	Sn	K	Xt
3.19853	0.531	1.092	2.444	<b>90.63</b>

<b>50 years</b>				
Yt	Yn	Sn	K	Xt
3.90194	0.549	1.161	2.889	<b>98.05</b>

**Annex K:-10 Years Return Period Flooding Area Calculation**

Channage (m)	Flood Width (m)	Flooding Area
0.00	0.00	0.00
99.70	0.00	0.00
199.70	0.00	0.00
299.20	0.00	0.00
399.40	0.00	0.00
499.40	0.00	0.00
599.40	0.00	0.00
699.40	0.00	0.00
798.90	0.00	0.00
899.20	0.00	0.00
988.20	0.00	0.00
1088.20	0.00	0.00
1142.20	0.00	0.00
1241.60	0.00	0.00
1341.60	50.00	2500.00
1441.60	38.00	4400.00
1543.60	40.00	3978.00
1643.60	48.00	4400.00
1743.60	0.00	2400.00
1760.60	0.00	0.00
1822.60	0.00	0.00
1921.80	60.00	2976.00
2022.80	30.00	4545.00
2122.80	0.00	1500.00
2222.80	0.00	0.00
2322.80	0.00	0.00
2423.80	0.00	0.00
2521.80	0.00	0.00
2621.80	0.00	0.00
2721.80	0.00	0.00
2821.80	5.00	250.00
2919.80	0.00	245.00
3019.80	0.00	0.00
3119.20	0.00	0.00
3219.20	0.00	0.00
3319.20	0.00	0.00
3419.20	0.00	0.00
3519.20	26.00	1300.00
3619.20	21.00	2350.00
3718.70	0.00	1044.75
3818.70	0.00	0.00
3918.50	0.00	0.00
4018.50	0.00	0.00
4118.50	0.00	0.00
4188.50	0.00	0.00
Total Area (m2 )		31888.75
Total Area( ha )		3.19

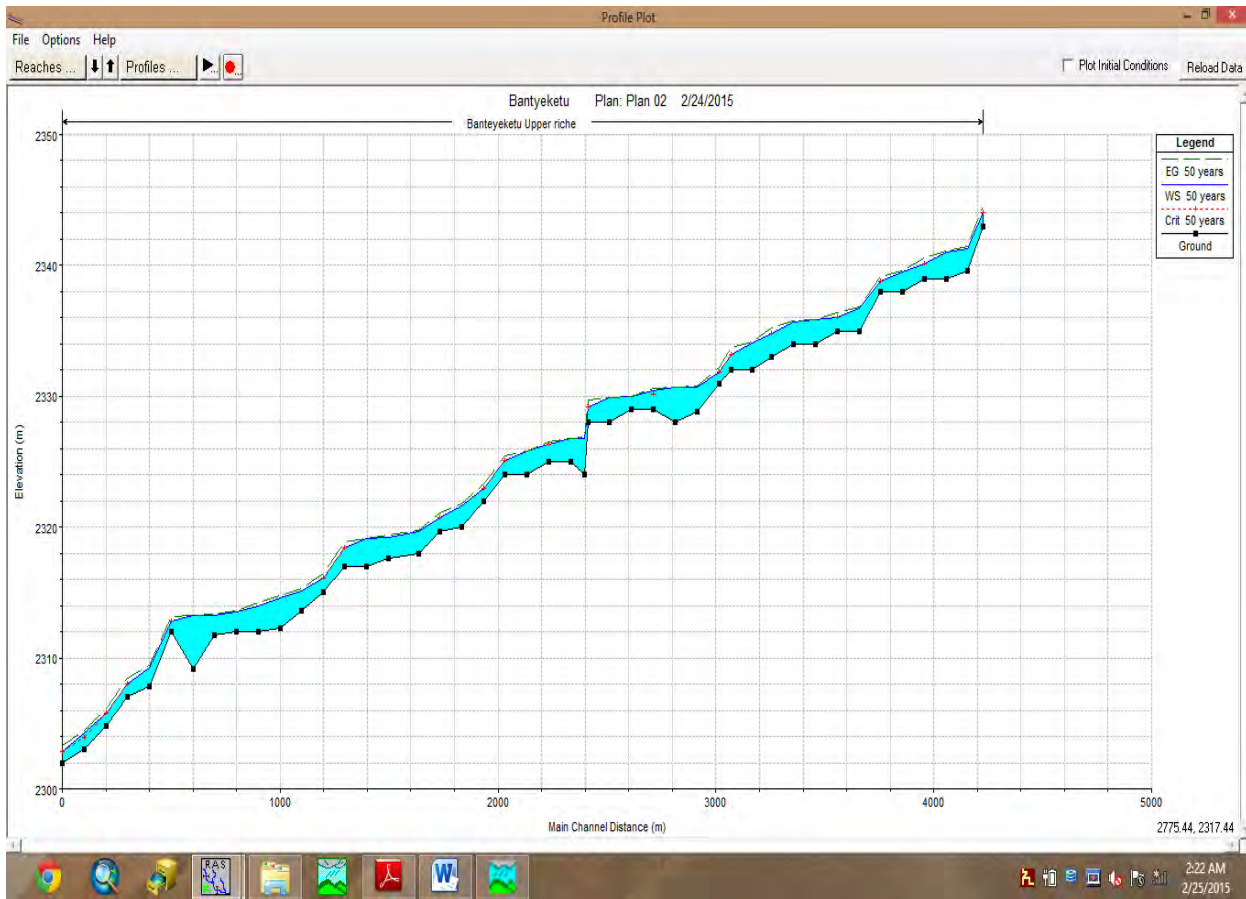
**Annex L:- 25 Years Return Period Flooding Area Calculation**

Channage (m)	Flood Width (m)	Flooding Area
0.00	0.00	0.00
99.70	0.00	0.00
199.70	0.00	0.00
299.20	0.00	0.00
399.40	0.00	0.00
499.40	0.00	0.00
599.40	0.00	0.00
699.40	0.00	0.00
798.90	0.00	0.00
899.20	0.00	0.00
988.20	0.00	0.00
1088.20	0.00	0.00
1142.20	0.00	0.00
1241.60	0.00	0.00
1341.60	50.00	2500.00
1441.60	40.00	4500.00
1543.60	41.00	4131.00
1643.60	52.00	4650.00
1743.60	60.00	5600.00
1760.60	0.00	510.00
1822.60	0.00	0.00
1921.80	60.00	2976.00
2022.80	41.00	5100.50
2122.80	0.00	2050.00
2222.80	0.00	0.00
2322.80	0.00	0.00
2423.80	0.00	0.00
2521.80	0.00	0.00
2621.80	0.00	0.00
2721.80	0.00	0.00
2821.80	7.00	350.00
2919.80	0.00	343.00
3019.80	0.00	0.00
3119.20	0.00	0.00
3219.20	0.00	0.00
3319.20	0.00	0.00
3419.20	0.00	0.00
3519.20	42.00	2100.00
3619.20	31.00	3650.00
3718.70	0.00	1542.25
3818.70	0.00	0.00
3918.50	0.00	0.00
4018.50	0.00	0.00
4118.50	0.00	0.00
4188.50	0.00	0.00
Total Area (m2)		39309.75
Total Area (ha)		3.93

**Annex M:- 50 Years Return Period Flooding Area Calculation**

Channage (m)	Flood Width (m)	Flooding Area (m2)
0	0	0.0
99.7	0	0.0
199.7	0	0.0
299.2	0	0.0
399.4	0	0.0
499.4	0	0.0
599.4	0	0.0
699.4	0	0.0
798.9	0	0.0
899.2	0	0.0
988.2	0	0.0
1088.2	0	0.0
1142.2	0	0.0
1241.6	0	0.0
1341.6	50	2500.0
1441.6	42	4600.0
1543.6	45	4437.0
1643.6	58	5150.0
1743.6	68	6300.0
1760.6	0	578.0
1822.6	0	0.0
1921.8	62	3075.2
2022.8	52	5757.0
2122.8	0	2600.0
2222.8	0	0.0
2322.8	0	0.0
2423.8	0	0.0
2521.8	0	0.0
2621.8	0	0.0
2721.8	0	0.0
2821.8	0	0.0
2919.8	0	0.0
3019.8	0	0.0
3119.2	0	0.0
3219.2	0	0.0
3319.2	0	0.0
3419.2	0	0.0
3519.2	52	2600.0
3619.2	45	4850.0
3718.7	0	2238.8
3818.7	0	0.0
3918.5	0	0.0
4018.5	0	0.0
4118.5	0	0.0
4188.5	0	0.0
Total Area (m2)		<b>44686.0</b>
Total Area (ha)		<b>4.47</b>

**AnneN:- Profile and 3D view of HEC-RAS outputs**



**Figure 7-1: Water surface Profile 50 years**

# Flood Mapping Case Study on Bantyeketu River in Addis Ababa

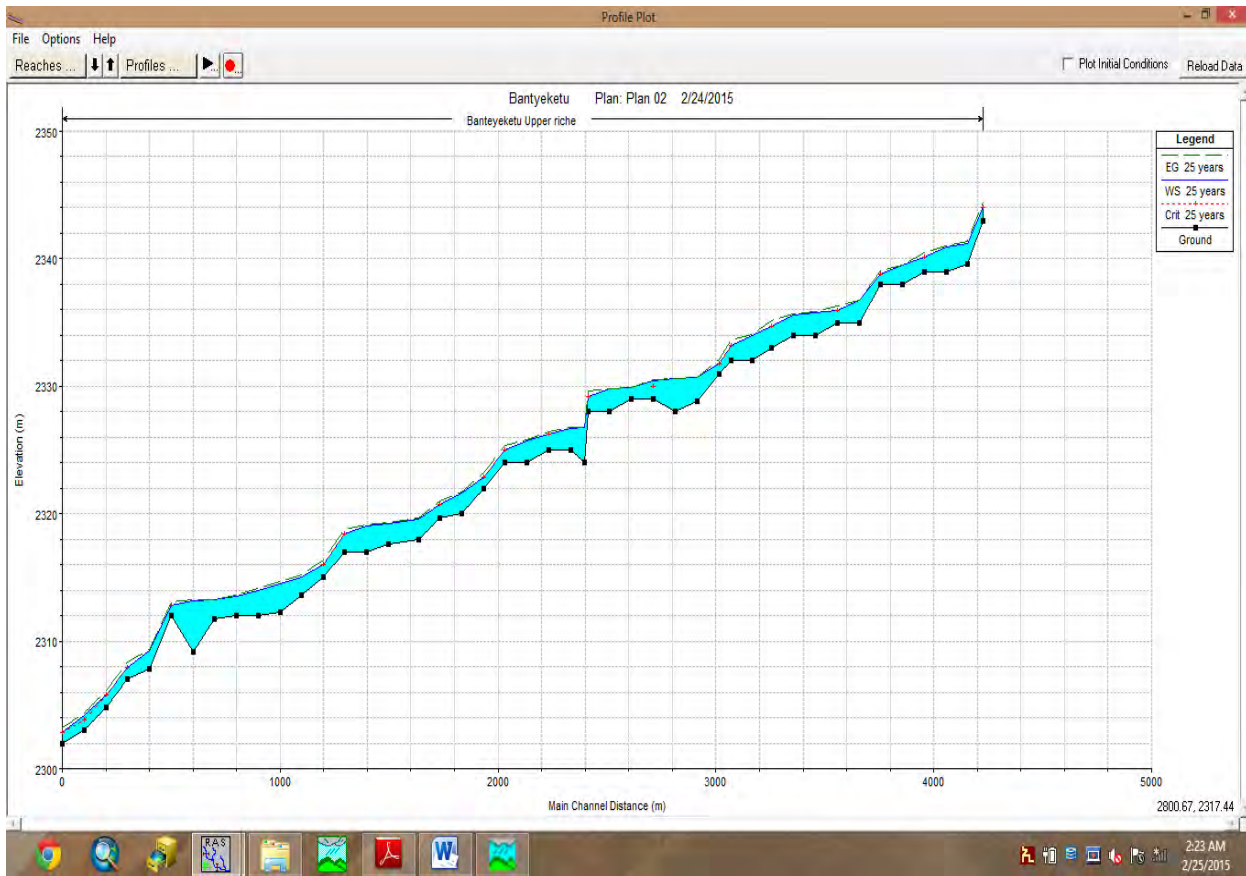


Figure 7-2: Water surface Profile 25 years

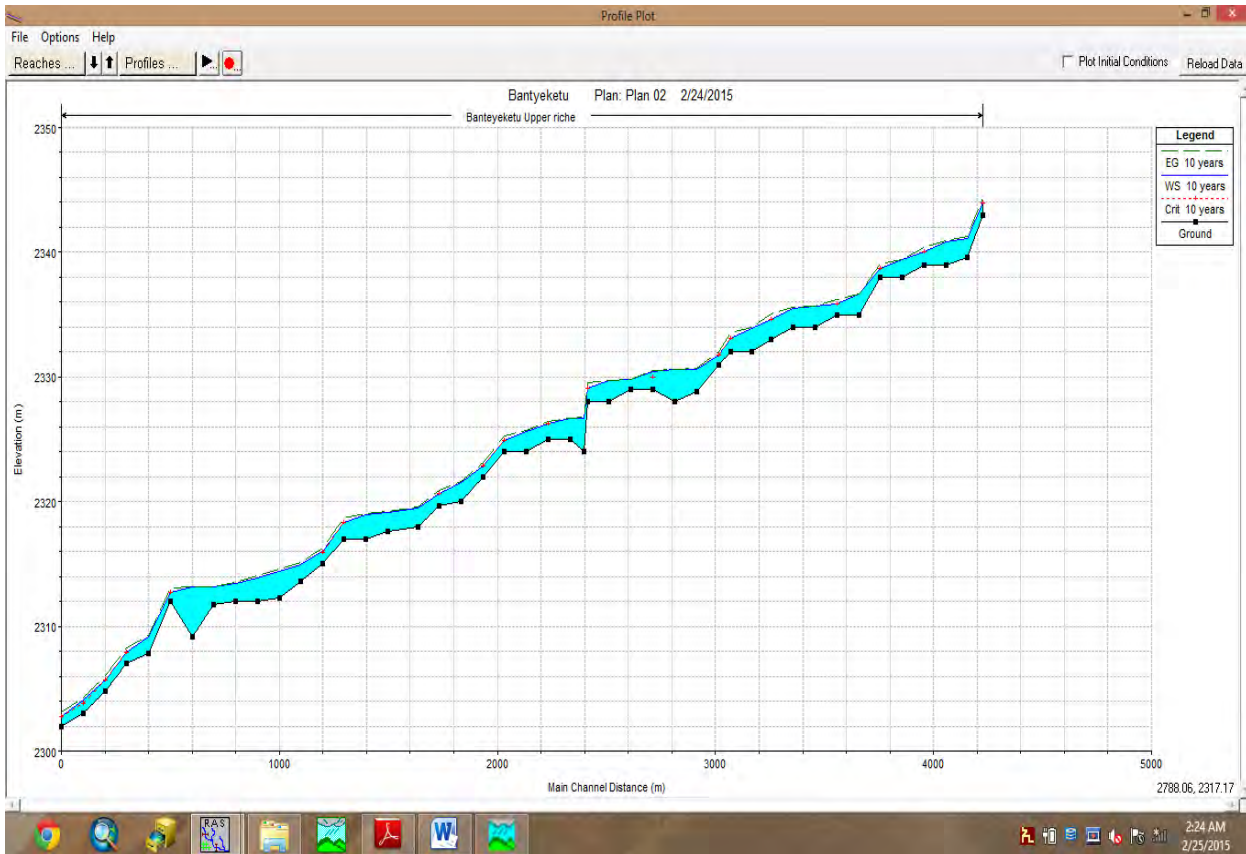


Figure 7-3: Water surface Profile 10 years

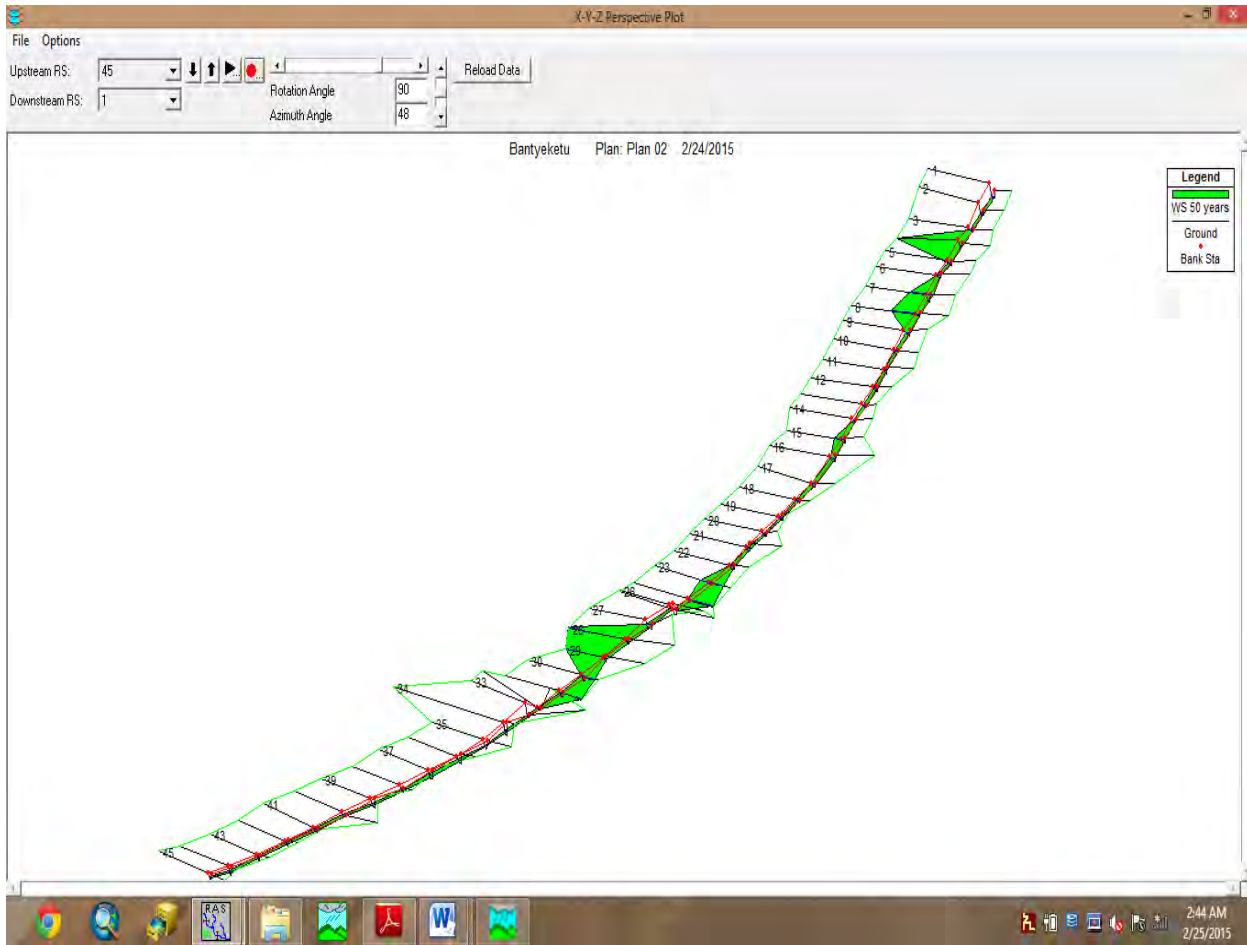


Figure 7-4: 3D View of 50 years flood

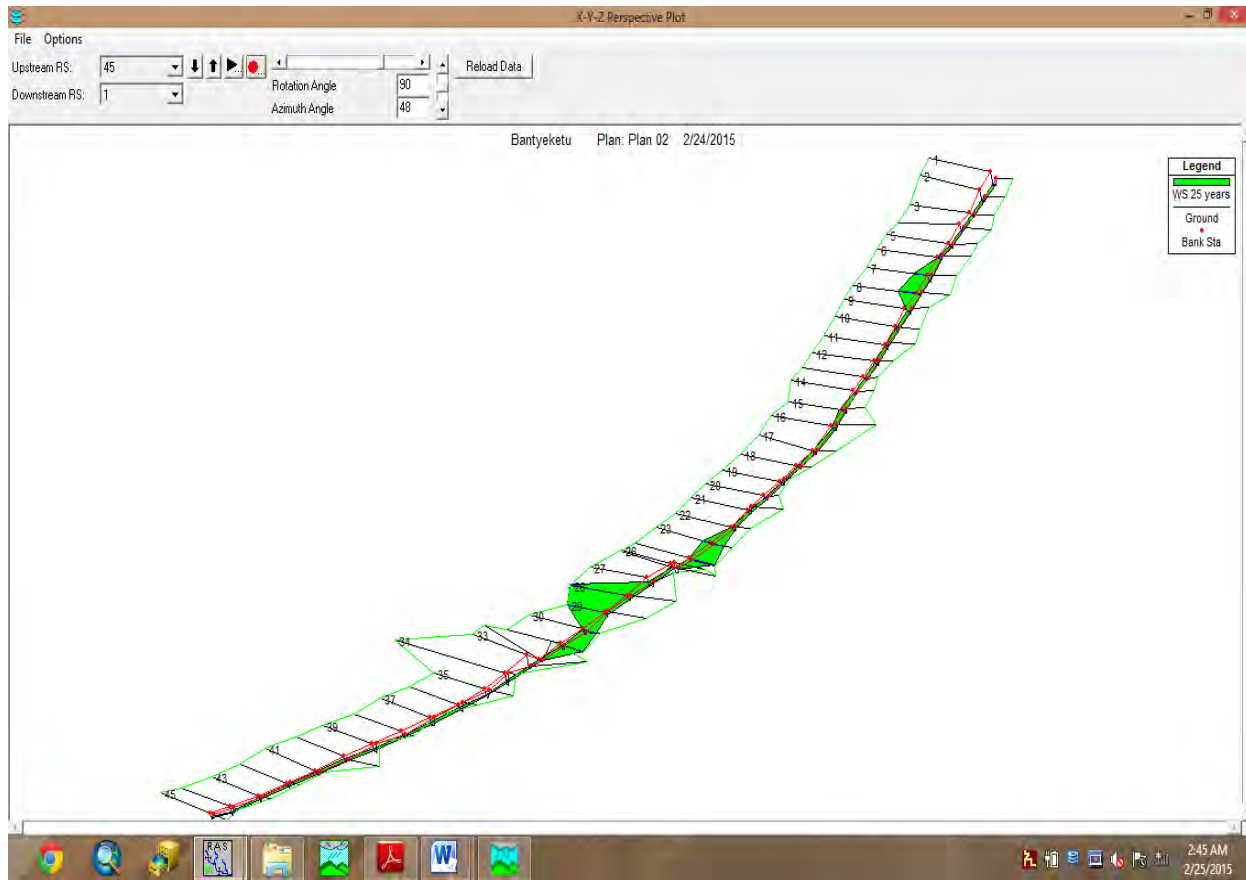


Figure 7-5: 3D View of 25 years flood

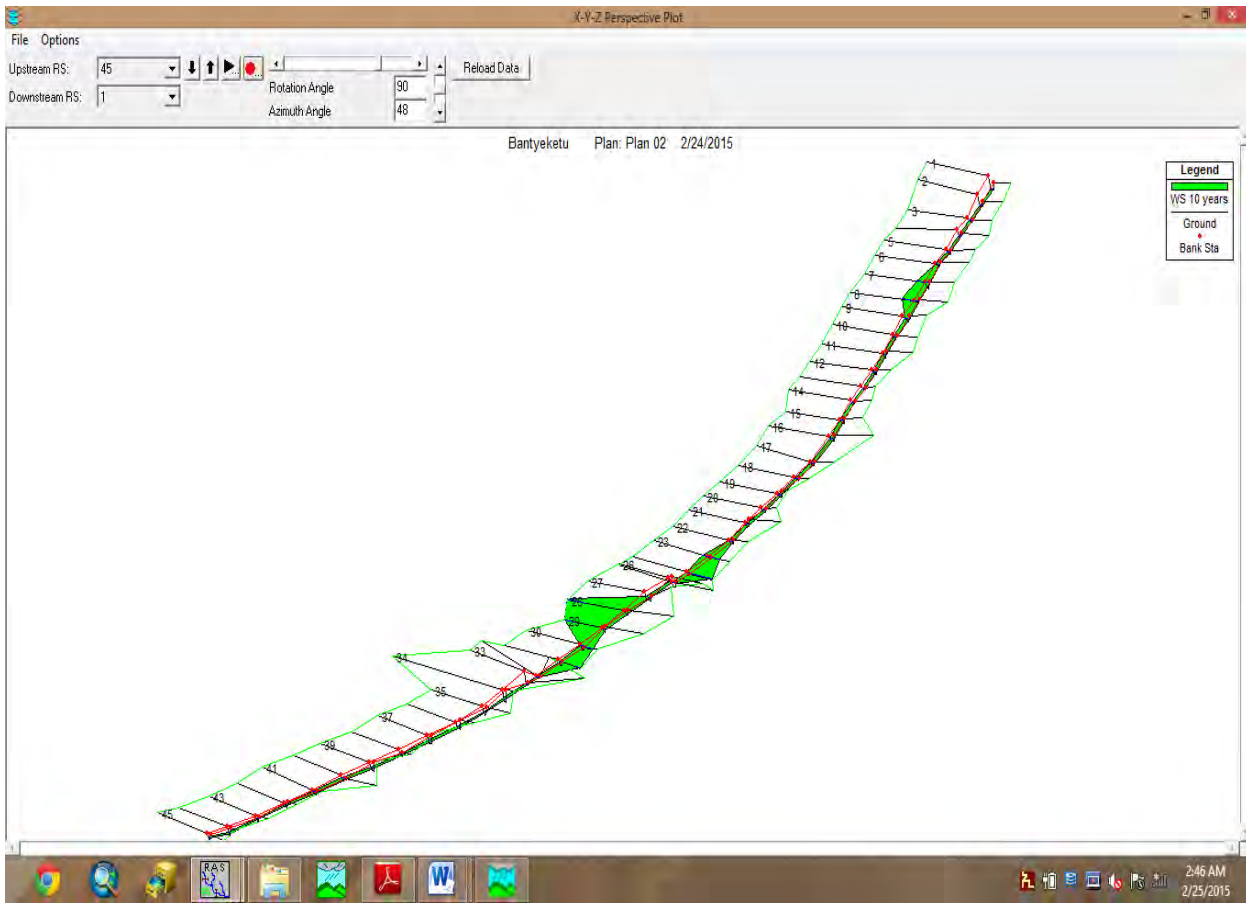


Figure 7-6: 3D View of 10 years flood

**Annex O:- Table out Put HEC-RAS**

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyeketu	45	50	16	2343	2344.07	2344.07	2344.51	0.020499	2.96	5.41	6.13
Bantyeketu	45	25	14.7	2343	2344.02	2344.02	2344.44	0.020571	2.89	5.09	6.03
Bantyeketu	45	10	13.1	2343	2343.95	2343.95	2344.35	0.020851	2.8	4.67	5.89
Bantyeketu											
Bantyeketu	44	50	16	2339.6	2341.31		2341.46	0.00487	1.75	9.15	7.35
Bantyeketu	44	25	14.7	2339.6	2341.23		2341.38	0.004938	1.71	8.58	7.21
Bantyeketu	44	10	13.1	2339.6	2341.13		2341.27	0.005056	1.67	7.84	7.04
Bantyeketu											
Bantyeketu	43	50	16	2339	2341.03		2341.12	0.002336	1.35	11.81	7.96
Bantyeketu	43	25	14.7	2339	2340.95		2341.04	0.00227	1.31	11.22	7.8
Bantyeketu	43	10	13.1	2339	2340.85		2340.93	0.00218	1.25	10.46	7.59
Bantyeketu											
Bantyeketu	42	50	16	2339	2340.14	2340.14	2340.57	0.01988	2.89	5.54	6.59
Bantyeketu	42	25	14.7	2339	2340.09	2340.09	2340.5	0.020023	2.83	5.19	6.43
Bantyeketu	42	10	13.1	2339	2340.02	2340.02	2340.41	0.020217	2.75	4.76	6.22
Bantyeketu											
Bantyeketu	41	50	16	2338	2339.52		2339.58	0.001775	1.11	14.47	12.29
Bantyeketu	41	25	14.7	2338	2339.46		2339.52	0.001717	1.07	13.79	12.09
Bantyeketu	41	10	13.1	2338	2339.39		2339.44	0.001642	1.01	12.91	11.83
Bantyeketu											

Flood Mapping Case Study on Bantyekeku River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyekeku	40	50	16	2338	2338.82	2338.82	2339.13	0.019618	2.46	6.49	10.66
Bantyekeku	40	25	14.7	2338	2338.79	2338.79	2339.08	0.019645	2.4	6.13	10.5
Bantyekeku	40	10	13.1	2338	2338.74	2338.74	2339.02	0.020363	2.34	5.6	10.26
Bantyekeku											
Bantyekeku	39	50	16	2335	2336.78		2336.85	0.001689	1.16	13.74	9.47
Bantyekeku	39	25	14.7	2335	2336.7		2336.77	0.001647	1.13	13.06	9.32
Bantyekeku	39	10	13.1	2335	2336.61		2336.67	0.001586	1.07	12.2	9.14
Bantyekeku											
Bantyekeku	38	50	16	2335	2335.99	2335.99	2336.41	0.019879	2.86	5.6	6.81
Bantyekeku	38	25	14.7	2335	2335.94	2335.94	2336.34	0.019963	2.79	5.27	6.7
Bantyekeku	38	10	13.1	2335	2335.88	2335.88	2336.25	0.020452	2.71	4.83	6.54
Bantyekeku											
Bantyekeku	37	50	16	2334	2335.85		2335.89	0.000877	0.88	18.11	11.64
Bantyekeku	37	25	14.7	2334	2335.78		2335.81	0.000855	0.85	17.22	11.49
Bantyekeku	37	10	13.1	2334	2335.67		2335.71	0.000831	0.82	16.05	11.28
Bantyekeku											
Bantyekeku	36	50	16	2334	2335.67		2335.76	0.002261	1.28	12.5	9.46
Bantyekeku	36	25	14.7	2334	2335.6		2335.68	0.002227	1.24	11.83	9.29
Bantyekeku	36	10	13.1	2334	2335.5		2335.58	0.002207	1.2	10.94	9.06
Bantyekeku											
Bantyekeku	35	50	16	2333	2334.77	2334.77	2335.21	0.020113	2.95	5.42	6.14
Bantyekeku	35	25	14.7	2333	2334.7	2334.7	2335.14	0.020715	2.92	5.03	5.9

Flood Mapping Case Study on Bantyeketu River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
											1
Bantyeketu	35	10	13.1	2333	2334.63	2334.63	2335.04	0.020626	2.83	4.63	5.67
Bantyeketu											
Bantyeketu	34	50	16	2332	2334.09		2334.18	0.001967	1.3	12.34	6.79
Bantyeketu	34	25	14.7	2332	2334.01		2334.09	0.001889	1.25	11.78	6.72
Bantyeketu	34	10	13.1	2332	2333.9		2333.97	0.001791	1.19	11.05	6.63
Bantyeketu											
Bantyeketu	33	50	16	2332	2333.22	2333.22	2333.68	0.020589	3	5.33	5.86
Bantyeketu	33	25	14.7	2332	2333.17	2333.17	2333.61	0.020925	2.94	5.01	5.78
Bantyeketu	33	10	13.1	2332	2333.1	2333.1	2333.51	0.021093	2.84	4.62	5.69
Bantyeketu											
Bantyeketu	32	50	16	2331	2331.85	2331.85	2332.17	0.020046	2.51	6.37	10.08
Bantyeketu	32	25	14.7	2331	2331.81	2331.81	2332.11	0.020311	2.46	5.97	9.83
Bantyeketu	32	10	13.1	2331	2331.75	2331.75	2332.05	0.020632	2.39	5.47	9.52
Bantyeketu											
Bantyeketu	31	50	16	2328.8	2330.71		2330.78	0.001883	1.22	17.31	22.61
Bantyeketu	31	25	14.7	2328.8	2330.67		2330.73	0.001757	1.16	16.34	21.66
Bantyeketu	31	10	13.1	2328.8	2330.61		2330.67	0.001587	1.09	15.18	20.46
Bantyeketu											
Bantyeketu	30	50	16	2328	2330.66		2330.69	0.000445	0.73	30.78	37.39
Bantyeketu	30	25	14.7	2328	2330.62		2330.65	0.000405	0.69	29.34	36.21
Bantyeketu	30	10	13.1	2328	2330.57		2330.59	0.000353	0.64	27.58	34.71

Flood Mapping Case Study on Bantyeketu River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyeketu											
Bantyeketu	29	50	16	2329	2330.45	2330.18	2330.57	0.005214	1.69	17.91	51.66
Bantyeketu	29	25	14.7	2329	2330.43	2330.02	2330.54	0.004805	1.61	16.79	49.41
Bantyeketu	29	10	13.1	2329	2330.4	2329.95	2330.5	0.004226	1.5	15.55	46.78
Bantyeketu											
Bantyeketu	28	50	16	2329	2329.97		2329.99	0.005469	1.17	31.04	53.09
Bantyeketu	28	25	14.7	2329	2329.89		2329.92	0.007204	1.27	26.23	58.07
Bantyeketu	28	10	13.1	2329	2329.79		2329.82	0.010848	1.42	20.61	51.6
Bantyeketu											
Bantyeketu	27	50	16	2328	2329.85		2329.88	0.000481	0.7	22.98	14.79
Bantyeketu	27	25	14.7	2328	2329.77		2329.8	0.000473	0.67	21.81	14.58
Bantyeketu	27	10	13.1	2328	2329.67		2329.69	0.000462	0.64	20.32	14.32
Bantyeketu											
Bantyeketu	26	50	16	2328	2329.22	2329.22	2329.69	0.020471	3.04	5.27	5.64
Bantyeketu	26	25	14.7	2328	2329.16	2329.16	2329.61	0.020695	2.98	4.94	5.51
Bantyeketu	26	10	13.1	2328	2329.08	2329.08	2329.51	0.021101	2.9	4.51	5.34
Bantyeketu											
Bantyeketu	25	50	16	2324	2326.81		2326.86	0.000892	0.96	16.61	8.64
Bantyeketu	25	25	14.7	2324	2326.77		2326.81	0.000793	0.9	16.3	8.58
Bantyeketu	25	10	13.1	2324	2326.72		2326.76	0.000675	0.82	15.88	8.49
Bantyeketu											
Bantyeketu	24	50	16	2325	2326.77		2326.79	0.000996	0.85	46.91	58.

## Flood Mapping Case Study on Bantyekeku River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
											6
Bantyekeku	24	25	14.7	2325	2326.74		2326.75	0.000971	0.83	44.45	68.54
Bantyekeku	24	10	13.1	2325	2326.69		2326.7	0.000943	0.81	41.18	68.45
Bantyekeku											
Bantyekeku	23	50	16	2325	2326.3	2326.3	2326.5	0.009711	2.11	14.45	60.03
Bantyekeku	23	25	14.7	2325	2326.27	2326.27	2326.47	0.010228	2.1	12.34	53.7
Bantyekeku	23	10	13.1	2325	2326.22	2326.22	2326.42	0.011005	2.08	9.85	45.07
Bantyekeku											
Bantyekeku	22	50	16	2324	2325.79		2325.84	0.001436	1.04	15.33	11.34
Bantyekeku	22	25	14.7	2324	2325.72		2325.77	0.001401	1.01	14.55	11.13
Bantyekeku	22	10	13.1	2324	2325.63		2325.68	0.001358	0.97	13.54	10.84
Bantyekeku											
Bantyekeku	21	50	16	2324	2325.05	2325.05	2325.45	0.020223	2.8	5.72	7.24
Bantyekeku	21	25	14.7	2324	2325	2325	2325.39	0.020458	2.74	5.37	7.12
Bantyekeku	21	10	13.1	2324	2324.94	2324.94	2325.3	0.020609	2.65	4.94	6.96
Bantyekeku											
Bantyekeku	20	50	16	2322	2322.94	2322.94	2323.31	0.01962	2.68	5.97	8.27
Bantyekeku	20	25	14.7	2322	2322.9	2322.9	2323.25	0.019871	2.62	5.61	8.11
Bantyekeku	20	10	13.1	2322	2322.84	2322.84	2323.17	0.020127	2.54	5.15	7.91
Bantyekeku											
Bantyekeku	19	50	16	2320	2321.64		2321.75	0.003365	1.46	10.94	9.4
Bantyekeku	19	25	14.7	2320	2321.59		2321.69	0.003272	1.41	10.4	9.23

## Flood Mapping Case Study on Bantyekeku River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyekeku	19	10	13.1	2320	2321.51		2321.6	0.003143	1.35	9.71	9
Bantyekeku											
Bantyekeku	18	50	16	2319.7	2320.73	2320.73	2321.05	0.020083	2.51	6.38	10.16
Bantyekeku	18	25	14.7	2319.7	2320.69	2320.69	2321	0.020185	2.45	5.99	9.89
Bantyekeku	18	10	13.1	2319.7	2320.64	2320.64	2320.93	0.020526	2.39	5.48	9.54
Bantyekeku											
Bantyekeku	17	50	16	2318	2319.66		2319.75	0.00266	1.34	11.91	9.88
Bantyekeku	17	25	14.7	2318	2319.59		2319.67	0.002638	1.31	11.23	9.66
Bantyekeku	17	10	13.1	2318	2319.5		2319.58	0.002612	1.26	10.37	9.36
Bantyekeku											
Bantyekeku	16	50	16	2317.6	2319.26		2319.35	0.00312	1.36	11.73	10.43
Bantyekeku	16	25	14.7	2317.6	2319.19		2319.28	0.00315	1.34	11	10.2
Bantyekeku	16	10	13.1	2317.6	2319.09		2319.18	0.003234	1.3	10.04	9.88
Bantyekeku											
Bantyekeku	15	50	16	2317	2319.12		2319.17	0.001047	0.97	17.44	26.33
Bantyekeku	15	25	14.7	2317	2319.05		2319.1	0.001028	0.93	15.92	17.45
Bantyekeku	15	10	13.1	2317	2318.96		2319	0.000993	0.89	14.74	10.54
Bantyekeku											
Bantyekeku	14	50	16	2317	2318.44	2318.44	2318.86	0.019535	2.86	5.59	6.84
Bantyekeku	14	25	14.7	2317	2318.39	2318.39	2318.79	0.019709	2.8	5.25	6.71
Bantyekeku	14	10	13.1	2317	2318.33	2318.33	2318.7	0.019792	2.71	4.84	6.54
Bantyekeku											

Flood Mapping Case Study on Bantyekeku River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyekeku	13	50	16	2315	2316.08	2316.08	2316.46	0.018724	2.75	5.86	8.5
Bantyekeku	13	25	14.7	2315	2316.03	2316.03	2316.4	0.019095	2.69	5.47	7.81
Bantyekeku	13	10	13.1	2315	2315.99	2315.97	2316.32	0.018403	2.56	5.12	7.3
Bantyekeku											
Bantyekeku	12	50	16	2313.6	2315.09		2315.28	0.007309	1.92	8.31	8.31
Bantyekeku	12	25	14.7	2313.6	2315.02		2315.2	0.007622	1.91	7.71	8.09
Bantyekeku	12	10	13.1	2313.6	2314.92		2315.1	0.008085	1.88	6.95	7.81
Bantyekeku											
Bantyekeku	11	50	16	2312.3	2314.62		2314.75	0.003854	1.6	10.02	7.35
Bantyekeku	11	25	14.7	2312.3	2314.55		2314.67	0.00376	1.55	9.5	7.18
Bantyekeku	11	10	13.1	2312.3	2314.45		2314.56	0.003626	1.48	8.84	6.96
Bantyekeku											
Bantyekeku	10	50	16	2312	2313.99		2314.2	0.007963	2.05	7.8	7.87
Bantyekeku	10	25	14.7	2312	2313.93		2314.13	0.007958	2.01	7.32	7.62
Bantyekeku	10	10	13.1	2312	2313.85		2314.04	0.007951	1.95	6.71	7.28
Bantyekeku											
Bantyekeku	9	50	16	2312	2313.53		2313.64	0.00376	1.48	10.83	10.13
Bantyekeku	9	25	14.7	2312	2313.48		2313.58	0.003641	1.43	10.3	9.92
Bantyekeku	9	10	13.1	2312	2313.41		2313.5	0.003497	1.36	9.6	9.63
Bantyekeku											
Bantyekeku	8	50	16	2311.7	2313.3		2313.35	0.001956	1.1	21.77	67.63
Bantyekeku	8	25	14.7	2311.7	2313.23		2313.29	0.002111	1.1	17.9	55.93

## Flood Mapping Case Study on Bantyeketu River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyeketu	8	10	13.1	2311.7	2313.15		2313.21	0.002303	1.09	13.97	40.73
Bantyeketu											
Bantyeketu	7	50	16	2309.2	2313.27		2313.29	0.000264	0.61	31.7	55.46
Bantyeketu	7	25	14.7	2309.2	2313.21		2313.23	0.000245	0.58	28.76	45.49
Bantyeketu	7	10	13.1	2309.2	2313.13		2313.15	0.000218	0.54	25.79	32.48
Bantyeketu											
Bantyeketu	6	50	16	2312	2312.84	2312.84	2313.17	0.020481	2.53	6.33	9.91
Bantyeketu	6	25	14.7	2312	2312.8	2312.8	2313.12	0.020689	2.47	5.94	9.68
Bantyeketu	6	10	13.1	2312	2312.75	2312.75	2313.05	0.020833	2.4	5.46	9.4
Bantyeketu											
Bantyeketu	5	50	16	2307.8	2309.28		2309.44	0.005786	1.78	8.97	8.7
Bantyeketu	5	25	14.7	2307.8	2309.22		2309.38	0.005733	1.74	8.47	8.51
Bantyeketu	5	10	13.1	2307.8	2309.14		2309.29	0.005747	1.68	7.79	8.25
Bantyeketu											
Bantyeketu	4	50	16	2307	2308.01	2308.01	2308.44	0.019838	2.91	5.51	6.9
Bantyeketu	4	25	14.7	2307	2307.95	2307.95	2308.37	0.020421	2.86	5.14	6.29
Bantyeketu	4	10	13.1	2307	2307.89	2307.89	2308.28	0.02042	2.76	4.75	6.17
Bantyeketu											
Bantyeketu	3	50	16	2304.8	2305.81	2305.81	2306.18	0.01949	2.68	5.97	8.28
Bantyeketu	3	25	14.7	2304.8	2305.77	2305.77	2306.12	0.019583	2.62	5.62	8.11
Bantyeketu	3	10	13.1	2304.8	2305.71	2305.71	2306.04	0.020096	2.55	5.14	7.88
Bantyeketu											

Flood Mapping Case Study on Bantyeketu River in Addis Ababa

Rich	Station	Profile	Q total (m <sup>3</sup> /s)	Min cha Elv	W.S Elv Cha	Cri w.s.(m)	E.G Elv m	E.G slop m/m	Vel Chal m/s	Flow Area m <sup>2</sup>	Top Width (m)
Bantyeketu	2	50	16	2303	2304.24	2303.92	2304.46	0.007532	2.05	7.81	7.07
Bantyeketu	2	25	14.7	2303	2304.18	2303.87	2304.38	0.007489	1.99	7.38	6.99
Bantyeketu	2	10	13.1	2303	2304.1	2303.8	2304.29	0.007424	1.91	6.84	6.89
Bantyeketu											
Bantyeketu	1	50	16	2302	2302.88	2302.87	2303.28	0.020022	2.81	5.7	6.99
Bantyeketu	1	25	14.7	2302	2302.83	2302.82	2303.21	0.020008	2.73	5.39	6.94
Bantyeketu	1	10	13.1	2302	2302.78	2302.77	2303.13	0.019998	2.62	5	6.87

