



Addis Ababa University Institute of Technology Civil  
Engineering Department

**Thesis Paper On**  
**Application of GIS in Cross Drainage Structure**  
*(Case study taken on major drainage structure on Goro-Akaki road)*

By: Melat Kaleab

June, 2015

# **Application of GIS in Cross Drainage Structure**

*(Case study taken on major drainage structure on Goro-Akaki road)*

**By**

**Melat Kaleab**

**A thesis      Submitted in partial fulfilment of the requirements  
for the Degree of Master of Science in civil  
engineering**

Board of Examiners:

Approved by:

Chairman \_\_\_\_\_

Advisor \_\_\_\_\_

Examiners  
\_\_\_\_\_  
\_\_\_\_\_

\_\_\_\_\_

## Certification

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa institute of Technology a Thesis entitled "Application of GIS in Cross Drainage Structure (*Case study taken on major drainage structure on Goro-Akaki road*)" in partial fulfilment of the requirements for the degree of Master of Science in Hydraulic Engineering.

---

Dr. Daneal Fekersillassie

(Supervisor)

## Declaration

I, Melat Kaleab, declare that this Thesis is my own original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

Signature: \_\_\_\_\_

This thesis is copyright material protected under the Berne convention, the copyright Act 1999 and other international and national enactments, in that behalf, on intellectual property. It may not be reproduced by any means, in full or in part, except for short extracts in fair dealing, for research or private study, critical scholarly review or discourse with an acknowledgment, without written permission of the Directorate of Postgraduate studies, on behalf of both the author and Addis Ababa University.

## **ACKNOWLEDGMENT**

I would like to express my gratitude to my advisor Dr Daneal Fekersillassie for his support and guidance throughout the course of this work. I wish to thank Ministry of water works GIS department for material and data support.

I am indebted to Ato Mohammed Esa, GIS expert for his unreserved support and guidance throughout the course of the study.

Last but not least, my everlasting gratitude goes to my loving family especially my Husband and my Mother for their invaluable encouragement and support. Above all I would like to thank God for his blessings.

## ABSTRACT

Cost of most highway projects can be attributed to the design and construction of drainage facilities such as bridges, culverts, storm drains etc. The design of these structures involves hydrologic analyses to determine the design discharge and hydraulic analyses to determine the conveyance capacity. Although most hydrologic and hydraulic calculation procedures are now available as computer programs, which can significantly reduce the mathematical effort involved, substantial effort is still necessary to manipulate the data required for input into these programs.

Traditionally the data generated to support these programs have been extracted manually from maps and cross-sections presented on paper drawings, however by building a digital spatial database of the hydrologic features, a GIS in conjunction with this database, the extraction of data and application of design procedures will become automated and more efficient.

In this research study a GIS support system has been developed to assist in the design of highway drainage facilities. The selected case study is on tributary of the main Akaki River which is located in Addis Ababa. By utilizing hydrologic spatial data to calculate the input parameters such as catchment area and flow direction for standard hydrologic software packages. This GIS support system reduces the analysis time and improves the analysis accuracy by integrating digital spatial data that describe the watershed of interest with hydrologic theory. This helps in selecting methods of hydrological analysis based on the existing situations.

Hydrology model is an essential tool for use in simulation, planning and management of rainfall and runoff processes. It is designed in a simplified way for quantitative and qualitative modelling at the hydrological processes. In this study, HEC-HMS version 3.2 is used to simulate stream flows for the tributary of Akaki river catchment which is located in Goro-Akaki road. Precipitation data used for calibration is collected from IDF curves of the region for 10, 25, 50 and 100 return periods the results obtained for return period of 100 is  $504.3\text{m}^3/\text{sec}$  and the high-water mark is 2164m which is lower than manually computed peak discharge and high water mark. The accuracy of simulation is highly dependable on the suitability of the parameters and accuracy of data used in the calibration and validation process. Results of simulation can be generated in hydrograph, summary table and time series table. The correlation coefficient ( $R^2$ ) and root mean square (RMSE) are used to evaluate the prediction of HEC-HMS model. Key words: GIS, hydrological analysis

## **LIST OF TABLES**

table 4.1 data collection.....	38
table 5.1 Spatial reference of the study area .....	46
table 5.2 Attribute table for AKAKI watershed.....	55
table 5.3 Attribute table for delineated Catchment area.....	59
table 5.4 Attribute table for longest flow paths.....	60
table 6.1Attribute table for the sub-basin with the calculated hydrologic parameters .....	68
table 6.2summary of computed peak discharge for return periods.....	69
table 6.3 Risk of exceedance in percent for different recurrence intervals and life times of a project.....	72

## **LIST OF FIGURES**

Fig 2.1 Flood unit hydrograph.....	7
Fig 2.2 Grid representation of Topography .....	18
Fig 2.3 Representation of a surface by a Tin in 2D (left) and 3D (right).....	19
Fig 2.4 Picture showing GIS representation of Streams in Akaki catchment. ....	22
Fig 3.1 Flow direction .....	27
Fig 3.2 Flow accumulation Grid .....	29
Fig 3.3 Stream definition grid.....	30
Fig 4.1 Location Map of study area.....	32
Fig 4.2 Elevation Surface Map of Akaki River Catchment .....	34
Fig 4.3 Profile showing Elevation drop along line A-B .....	34
Fig 4.4 Land Use/Cover Map of the Akaki River Catchment .....	36
Fig 5.1 Conceptual framework .....	39
Fig 5.2 Land use map of Awash basin .....	41
Fig 5.3 Clipped Land use map of the study area .....	42
Fig 5.4 Soil map of Awash basin.....	44
Fig 5.5 Clipped soil map of the study area .....	45
Fig 5.6 DEM coverage of Akaki catchment .....	48
Fig 5.7 Filling a sink in the DEM.....	49
Fig 5.8 Flow direction grid .....	51
Fig 5.9 Akaki flow accumulation grid .....	52
Fig 5.10 AKAKI watershed catchment polygons.....	54
Fig 5.11 Drainage lines on Akaki watershed .....	56
Fig 5.12 Drainage points on Akaki watershed .....	56
Fig 5.13 Adjoint catchment with drainage lines .....	57
Fig 5.14 Delineated catchment areas.....	59

Fig 5.15 Longest flow paths on the delineated catchment.....	60
Fig 6.1 longest flow path.....	63
Fig 6.2 HEC HMS schematic .....	64
Fig 6.3 Flow comparison of simulated and observed outlet flow for return periods, 10, 25, 50, 100 years .....	71
Fig 6.4 HEC RAS one dimensional stream schematic .....	74
Fig 6.5 HEC-RAS Cross-Section plot .....	74
Fig 6.6 Cross section of the road section at the bridge.....	75

## TABLE OF CONTENTS

CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1 Background .....	1
1.2 Problem Statement and Background .....	2
1.3. Objective and Scope of the Study.....	3
1.3.1 Specific Objectives.....	3
1.4 Significance of the Research Study .....	3
1.5 Outline and Scope of the Thesis .....	4
CHAPTER TWO .....	5
LITERATURE REVIEW.....	5
2.1 Flow Hydrographs and Peak Discharges .....	5
2.1.1 Unit Hydrograph .....	5
2.1.2 Rational Method.....	7
2.1.2.1 Runoff Coefficient & Frequency Factors .....	8
2.1.2.2 Frequency Factor .....	8
2.1.2.3 Time of Concentration .....	9
2.1.3 SCS Unit Hydrograph Method .....	12
2.1.3.1 The Curve Number .....	13
2.2 REGIONAL REGRESSION ANALYSIS .....	14
2.2.1 Analysis of Stream Gauge Data .....	14
2.3 GEOGRAPHIC INFORMATION SYSTEM.....	14
2.3.1 GIS data types.....	16
2.3.1.1 Topographic Data.....	16
2.3.1.2 Topologic Data.....	16
2.3.1.3 Raster or Grid-Based Data.....	17
2.3.1.4 Vector-Or Contour-Based Line Networks .....	19
2.3.2 Use of Remotely Sensed Data .....	20
2.3.3 Geographic Features .....	21
2.4 ARC HYDRO.....	22
2.4.1 Arc Hydro Modeling Procedure for Watershed Delineation.....	23
CAPTER THREE .....	25
USE OF GIS FOR HYDROLOGIC AND HYDRAULIC MODELLING.....	25
3.1 HYDROLOGIC CONCEPTS .....	25
3.2 DEM-BASED TERRAIN ANALYSIS .....	26
3.2.1 Digital Elevation Data.....	26

3.2.2 Flow Direction.....	27
3.2.3 Flow Accumulation.....	28
3.2.4 Stream Definition and Segmentation .....	29
3.2.5 Watersheds .....	30
CHAPTER FOUR .....	31
AN OVERVIEW OF THE STUDY AREA AND FIELD WORK ACTIVITIES ...	31
4.1 STUDY AREA .....	31
4.1.1 Climate .....	32
4.1.2 Topology.....	33
4.1.3 Land use / land cover .....	35
4.1.5 Drainage .....	37
4.2. ACTIVITIES PERFORMED .....	38
CHAPTER FIVE .....	39
RESEARCH METHODS .....	39
5.1 CONCEPTUAL FRAMEWORK.....	39
5.2 APPLICATION OF GIS.....	40
5.2.1 LAND USE MAP CLASSIFICATION .....	40
5.2.2 SOIL MAP CLASSIFICATION .....	43
5.2.3 DEM PROCESSING .....	46
5.2.3.1 Creating a Depression less DEM.....	49
5.3 RASTER-BASED SUB BASIN AND REACH NETWORK DELINEATION	50
5.3.1 Flow Direction of the study area .....	50
5.3.1.1 Terrain Pre-processing   Flow Direction.....	50
5.3.2 Flow Accumulation.....	51
5.3.3 Stream Definition .....	52
5.3.4 Stream Segmentation .....	53
5.3.4.1 Terrain Preprocessing   Stream Segmentation .....	53
5.3.5 Catchment Grid Delineation .....	53
5.3.5.1 Catchment Polygon Processing .....	53
5.3.5.2 Drainage Line Processing.....	55
5.3.5.3 Drainage Point Processing .....	56
5.3.6 Adjoint Catchment Processing .....	57
5.3.7 Locating Outlet Point.....	58
5.3.8 Longest Flow Path and Slope Determination .....	59
CHAPTER SIX .....	61
DATA PROCESSING AND ANALYSIS .....	61

6.1 PRE-PROCESS THE TERRAIN MODEL .....	62
6.1.1 Basin Processing .....	62
6.1.1.1 River characteristics .....	63
6.1.1.2 Basin Centroid .....	63
6.1.2 Developing the Hydrologic Parameters .....	64
6.1.3 Develop HEC HMS Input .....	64
6.1.3.1 HMS Schematic.....	64
6.2 BASIN MODEL ANALYSIS.....	65
6.3 COMPUTATION OF HYDROLOGIC PARAMETERS.....	68
6.4 MODEL CALIBRATION AND OPTIMIZATION .....	70
6.5 Hydraulics of Bridge.....	71
6.5.1 Water Surface Profile Determination Using HEC- RAS .....	73
6.6 Comparison with Manual Techniques.....	75
CHAPTERSEVEN.....	76
CONCLUSION AND RECOMMENDATION .....	76
7.1 CONCLUSION .....	76
7.2 RECOMMENDATION .....	76

## **APPENDIX**

ANNEX 1 IDF CURVE

ANNEX 2 SOIL CLASSIFICATION TABLE

ANNEX 3 DESIGN RETURN PERIOD FOR ROAD TYPES

ANNEX 4 RETURN PERIODS FOR DIFFERENT STRUCTURES

ANNEX 5 EQUATIONS FOR CALCULATING THE CULVERT CAPACITY

ANNEX 6 RIVER CROSSECTIONS OF THE BRIDGE

ANNEX 7 SIMULATED AND OBSERVED DISCHARGE

ANNEX 8 DISCHARGE AND STREAM FLOW DATA OF AKAKI RIVER

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

The first step in undertaking any kind of hydrologic modelling whether it is associated with storm water, sewer or combined systems involves delineating catchments and overland flow paths. In recent year's advances in terrain data collection techniques, most notable Light Detection and Ranging (LiDAR), computing power, and geographical information systems (GIS) have allowed many opportunities for enhancing hydrological parameter estimation for urban system.

Traditionally, drainage areas and overland flow paths have been delineated from topographic maps, where drainage divides and flow direction were located by analyzing contour lines, or by visually inspecting ground slopes in site.

In water resource projects DEMs (Digital elevation models) are used in order to identify features such as ridges, valley bottoms, channel networks, surface drainage patterns, and elevation differences of the catchment areas.

A significant portion of the cost of most highway projects can be attributed to the design and construction of drainage facilities, which includes bridges, highway culverts, storm drains, and water quality and quality control structures. At the minimum, the design of these facilities involves hydrological and hydraulic analysis to determine the design discharge and conveyance capacity of structures. Although most hydrologic and hydraulic calculation procedures are now available as computer programs, which can significantly reduce the mathematical effort involved, substantial effort is still necessary to establish and manipulate the data required for input into those programs. To simplify the process of determining the input data, several state departments of transportation have developed Geographic Information System (GIS) to calculate spatial hydrologic parameters that can then be used as input values to standard hydrologic software packages. (Francisco and Maidment, Oct 1999).

Catchment characterization and modelling activity is highly dependent on the existing digital elevation models with adequate spatial resolution and covering the whole area of interest is a basic requirement to achieve the goal of catchment characterization and modelling activity .The quality of DEM is very important and great attention is needed to avoid errors that are introduced by the terrain model itself. Since the propagation of errors play a significant role in GIS analysis it is important to have a clear understanding of how to minimize data errors.

Catchment models are in general designed to meet one of two primary objectives. The first is to gain a better understanding of the hydrologic behaviours of a catchment and of how changes in the catchment may affect these behaviours. The second objective of catchment modelling is the generation of synthetic hydrologic data for facility design like water resources planning, flood protection, mitigation of contamination, or licensing of abstraction or for forecasting. They are also providing valuable information for studying the potential impacts of changes in land use or climate.

Knowing how to analyze the DEM is not the only important procedure, the other important thing is knowing the flow directions especially in flat terrain. DEM inherent altitude errors and the difficulty to recognize the pathways of water in flat areas and also challenges in finding the source of the river channel.

The question of catchment characterization and classification involves a problem of scale and of data availability. Therefore it is very important to understand the most important parameters that characterize the landscape, the hydrological response and the environmental behaviour of a catchment at different scales.

## **1.2 Problem Statement and Background**

The process of determining the input data required for hydrological analysis of drainage structures needs mathematical effort in manipulating the necessary data's, which makes the process to be subjected to errors. The hydrologic parameters are extracted based on description of the watershed and/or the stream channel of interest. Traditionally, the data generated have been extracted manually from maps and cross-sections presents on paper drawings.

However, by building a digital spatial database of the hydrologic features on *Akaki River (crossing Goro-Akaki road)* and by using GIS, the extraction of data and application of the design procedures becomes automated and more efficient. In areas with no map this procedure can be applied and accurate result can be obtained.

### **1.3. Objective and Scope of the Study**

The general objective of this research paper is to develop rainfall runoff model for Akaki river catchment (which is on Goro-Akaki road) by extracting hydrological parameters using GIS and developing model and comparing the result with manual techniques.

#### **1.3.1 Specific Objectives**

- By using DEMs of the area to extract the hydrological parameters, such as; catchment area, land use, soil type and slope of the selected catchment.
- Integrating GIS with HEC-GEO-HMS exporting the basin and map files with catchment characteristics to HEC-HMS and HEC RAS and develop a model for the catchment and access the hydrological response of the catchment area due to flash flood event.
- Compare simulated and observed discharge with manually calculated design discharge and HWM.

### **1.4 Significance of the Research Study**

Extracting hydrological parameters is the basic step in calculating discharge of certain watershed. Basin characteristics include the Size (area) of drainage basin which is the area that contributes to flow at the site of drainage structure. Shape or outline formed by the basin boundaries is also characteristics of the basin. The shape of the basin affects the rate at which water is supplied to the main stream as it precedes along its course from the runoff source to the site of the drainage structures. Slope of a drainage basin is one of the major factors affecting the time of overland flow and concentration of rainfall. Changes in land use always cause increases in surface water runoff. The type of surface soil which is characteristics of an area is an important consideration for any hydrologic analysis. Rock formations underlying the surface soil and other

geophysical characteristics such as volcanic, glacial, and river deposits can have a significant effect on run-off. The mean elevation of a drainage basin and significant variations in elevation within a drainage basin may be important characteristics affecting run-off. These parameters are frequently determined from field surveys, topographic maps, or aerial photographs these paper addresses the method of extracting these hydrological parameters with the help of GIS. This helps to change the usual method to more developed and accurate method.

The other importance of these theses is can help to proposes methodologies to be followed for the design procedures of hydrologic analysis of crossing structures in road projects, as HEC-HMS and HEC-RAS models are used to compare the peak discharges and High water marks.

## **1.5 Outline and Scope of the Thesis**

The presentation of this report has been organized as follows;

**Chapter 1:** Introduction part is a brief summary of background of the project the purpose of the report and organization of the document.

**Chapter 2:** Literature review part is compiled and presented in two sections the first section deals with Rainfall-Runoff model analysis and the next section deals with introduction to Geographic information system (GIS) and its tool Arc Hydro.

**Chapter 3:** Presents the use of GIS for hydrologic and hydraulic modelling hydrologic concept and DEM based terrain analysis is discussed briefly.

**Chapter 4:** Presents General description of the study area. Mainly, hydrology, Climate, topography are summarized and presented.

**Chapter 5:** Presents digital spatial data of the project area with details on how to work with GIS and Arc Hydro in order to extract hydrological parameters, catchment area, slope land use and soil type.

**Chapter 6:** Presents data extraction using HEC-Geo-HMS in this section how the parameters are extracted and HEC-HMS models are created from HEC-Geo-HMS, this procedure is discussed briefly, finally HEC-RAS modelling is used for high water mark determination and the results are compared with results obtained manually.

**Chapter 7:** conclusion and recommendations are presented

## **CHAPTER TWO**

### **LITERATURE REVIEW**

The literature review has been divided into two sections: the first section deals with methods of peak discharge computation and the second section talks about the use of computer based hydrologic and hydraulic modelling analysis by using geographic information system (GIS) in collaboration with Arc Hydro to take into account the spatial variability of the terrain and Rainfall-Runoff models of hydrologic parameters.

#### **2.1 Flow Hydrographs and Peak Discharges**

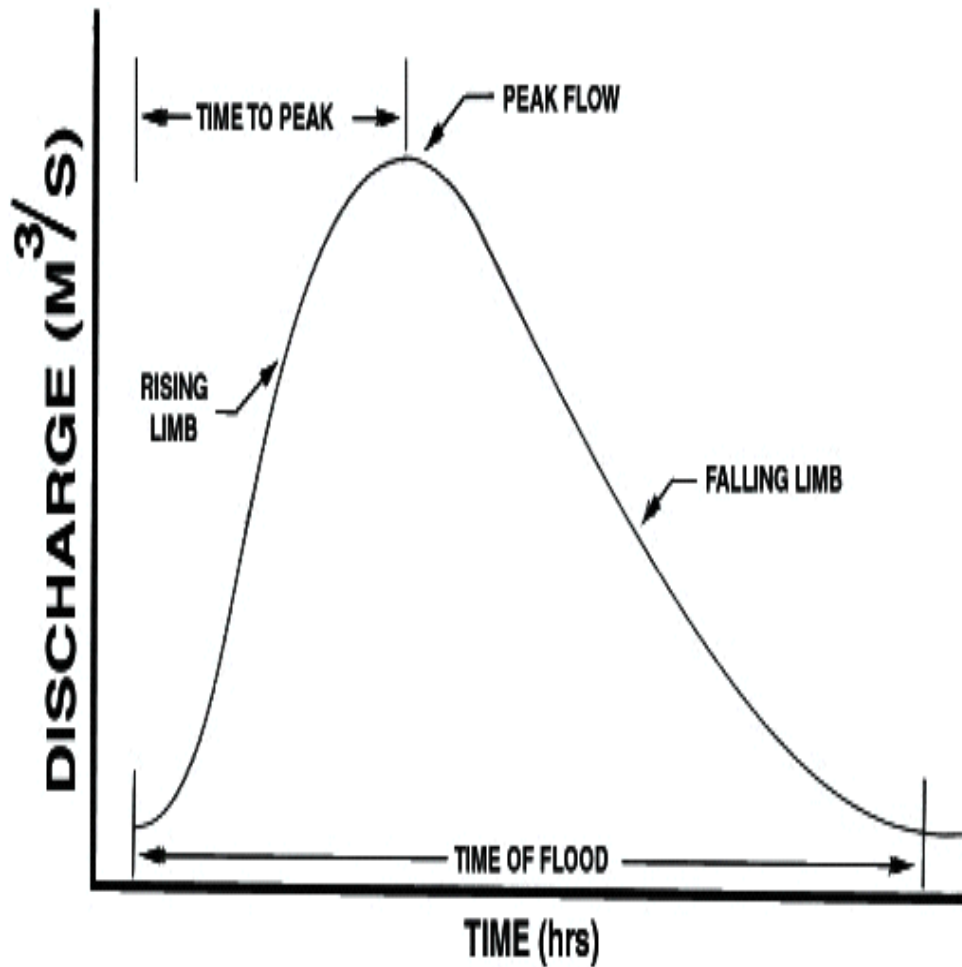
Because of the importance of estimating flow hydrographs and peak discharges for design purposes, discussions of the published work in this field has been included.

##### **2.1.1 Unit Hydrograph**

Unit hydrograph is a method for estimating storm runoff, first proposed by L.K. Sherman in 1932 (Chow et al., 1988), and since then has been used as a key concept. The unit hydrograph is defined as the watershed response to a unit depth of excess rainfall, uniformly distributed over the entire watershed, and applied at a constant rate for a given period. After studying watersheds in the Appalachian mountains of the United States Snyder proposes relationships between individual characteristics of the unit hydrographs, such as peak flow, lag time, base time, and width (in units of time) at 50% and 70% of the peak flow (Chow et al., 1988). Snyder's method was enhanced with the regionalization of the watershed parameters developed in 1977 by Espey, Altman, and Graves (Chow et al., 1988). Clark (1945) proposed that a unit hydrograph is the result of a combination of a pure translation routing process followed by a pure storage routing process. Although Clark does not develop a spatially distributed analysis, the translation component of the routing is based on the time-area diagram of the watershed (Francisco and Maidment, 1999). The storage component consists of routing the response of the translation through a single linear reservoir located at the watershed outlet.

The detention time of the reservoir is selected in order to reproduce the falling limb of observed hydrographs. Note that the actual travel time of a water particle, according to this approach, is the travel time given by the time-area diagram plus the detention time of the reservoir, which is somewhat inconsistent. Some years later, a unit hydrograph equation was proposed that is the response of a cascade of identical linear reservoirs to a unit impulse, i.e., a gamma distribution (Nash, 1957). It is important to notice that the method proposed by Nash does not model the watershed itself, but is just a fitting technique based on the first and second moments of the calculated and observed hydrographs. In 1972, the soil conservation service (SCS) of the United States department of Agriculture (USDA) proposed a unit hydrograph model based on a single parameter: the lag time between the centre of mass of the excess precipitation hyetograph and the peak of the unit hydrograph (Francisco and Maidment, 1999).

In response to a rainstorm the quantity of water flowing in a stream increases. The water level rises and may continue to do so after rainfall ceases. The response of an affected stream, during and after a storm event, can be pictured by plotting discharge against time to produce a flood hydrograph. The principal elements of a typical flood hydrograph are shown in fig 2.1 (Chow et al., 1988).



*Fig 2.1 Flood unit hydrograph*

### 2.1.2 Rational Method

Because the movement of water is so complex, numerous empirical methods have been used in hydrology. Empirical methods in hydrology have great usefulness to the highway engineer. Undoubtedly, the most popular and most often misused empirical hydrology method is the Rational Formula.

A Rational approach is used to obtain the yield of a catchment by assuming a suitable runoff coefficient. It estimates the peak runoff at any location in catchment area as a function of the area, runoff coefficient, and rainfall intensity for duration equal to the time of concentration. It is best suited to urban storm drain systems and rural ditches. This method is used for catchment areas less than 50 hectares (0.5km<sup>2</sup>) and expressed as below (Era drainage design manual 2001).

$$Q = 0.00278CIA$$

Where:

Q = maximum rate of runoff, m<sup>3</sup>/sec

C = runoff coefficient representing a ratio of runoff to rainfall

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

A = catchment area tributary to the design location, ha.

Rational methods are simple to use, and it is this simplicity that has made them so popular among highway drainage design engineers. Design discharge, as computed by these methods, has the same probability of occurrence as the frequency of the rainfall used.

An assumption that limits applicability is that the rainfall is of equal intensity over the entire watershed. Because of this, Rational Methods should be used only for estimating runoff from small watershed areas.

### **2.1.2.1 Runoff Coefficient & Frequency Factors**

The runoff coefficient "C" in the equation represents the percent of water which will run off the ground surface during the storm. The remaining amount of precipitation is lost to infiltration, transpiration, evaporation and depression storage.

Values of "C" are determined by considering relief, soil infiltration, vegetal cover, and surface storage.

### **2.1.2.2 Frequency Factor**

A design frequency shall be selected to match the structure's cost, amount of traffic, potential flood hazard to property, expected level of service, political considerations, and budgetary constraints, and magnitude and risk associated with damages from larger flood events. In case of long highway routes, having no practical detour, and where many sites are subject to independent flood events, it may be necessary to increase the design frequency at each site to avoid frequent route interruptions from floods. In selecting a design frequency, potential upstream land use that could reasonably occur over the anticipated

life of the drainage facility shall be considered. (ERA Drainage design manual 2001).

Hydrologic analysis should include the determination of several design flood frequencies for use in the hydraulic design. These frequencies are used to size different drainage structures to allow for an optimum design, that considers both risk of damage and construction cost. Consideration shall be given to what frequency flood was used to design other structures along a highway corridor.

Since it is not economically feasible to design a structure for the maximum runoff a catchment area is capable of producing, a design frequency must be established. The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equalled or exceeded in a given year. If a flood has a 20 percent chance of being equalled or exceeded each year, over a long period of time, the flood will be equalled or exceeded on an average of once every five years. This is called the **Return Period or Recurrence Interval** (RI). Thus the exceedence probability equals  $100/RI$ .

### **2.1.2.3 Time of Concentration**

Time of concentration is the time required for water to flow from hydraulically remote point of catchments area to the point under investigation. The most intense rainfall that contributes at drainage structures crossing will be that the duration equal to the time of concentration (Highway design manual, 2001).

The time of concentration is the sum of sheet flow travel time, shallow concentrated flow travel time and open channel flow travel time. Sheet flow occurs in the upper reaches of the watershed. Such flow occurs over short distance and at shallow depths prior to the point where topographic and surface characteristics cause the flow to concentrate in rills and swales. Concentrated flow is the runoff that occurs in rills and swales with depth on the order of 0.04m to 0.10m where as depth of sheet flow is 0.02 and 0.03m or less. Velocity in the open channels is usually determined assuming bank-full depth.

Sheet flow travel time is computed using Manning's kinematic equation (Era drainage design manual, 2001).

$$T_t = \frac{0.091 \times [nL]^{0.4}}{[P_2]^{0.5} \times s^{0.4}}$$

Where:

- T<sub>t</sub> = travel time, hr
- n = Manning's roughness coefficient
- L = flow length, m
- P<sub>2</sub> = 2-years, 24 hours rainfall, mm
- S = Land slope, m/m

**Travel time for shallow concentrated flow** is determined from average velocity computed in from the following expression

$$V = 4.9178(s)^{0.5} \quad \text{For unpaved channel}$$

$$V = 6.1961(s)^{0.5} \quad \text{For paved channel}$$

Where:

s is the slope in percent

The above equations is based on the solution Manning's equation with the following assumption

- n = 0.050 and r = 0.12 for unpaved area and
- n = 0.025 and r = 0.06 for paved area

Where:

r = Hydraulic radius, m (equal to A/P<sub>w</sub>)

n = Manning's roughness coefficient

Then the travel time of sheet flow is computed using

$$T_t = \frac{L}{V}$$

Where:-

T<sub>t</sub> = travel time of the sheet flow, second

L = flow length, meter

V = average velocity in m/s computed by the above equation

When cross sectional information of the open channel (stream cross section parameter for the entire reach) is acquired, the average velocity of the open channel flow can be calculated using Manning's equation.

$$V = \frac{1}{n} r^{2/3} s^{1/2}$$

Where

- V = Average velocity, m/s
- r = Hydraulic radius, m (equal to A/P<sub>w</sub>)
- A = Cross section area of the flow, m<sup>2</sup>
- P<sub>w</sub> = Wetted perimeter, m
- s = Slope of the hydraulic grade line, m/m
- n = Manning's roughness coefficient

The travel time can be computed for each stream segment from average velocity of flow computed using the above expression and reach length.

As it is known, the cross section of the stream varies and irregular along reach for large catchment area. Acquiring the cross sectional information of the stream along entire length is difficult (it varies). But Kirpich's equation for time of concentration computation in the open channel depends only on the stream length and stream slope.

Stream length and slope can be determined on the topographic map. Hence, Kirpich's equation was used for time of concentration computation in open channel with caution for large catchment (long stream length) in order not to under estimate the time of concentration. Depending on the slope of the river, the time of concentration is computed on reach bases.

$$T_c = \sum_{i=1}^{i=n} \frac{0.00032 L_i^{0.77}}{S_i^{0.385}}$$

Where:

T<sub>c</sub> = Time of concentration, in hr

L<sub>i</sub> = Length of stream segment, in m

S<sub>i</sub> = Slope equal to H/L, where H is the difference in elevation between the segment (reach), in m

For small catchments areas, where the maximum elevation difference of the watershed could not be determined on the available map scale the velocity method is adopted. It is based on the concept of travel time ( $T_v$ ) where a flow segment is a function of length of flow ( $L$ ) and the velocity. The following equations were used (Era drainage design manual, 2011).

$$T_c = \frac{L}{60 * V}$$

Where:

$T_c$  = Time of concentration [minutes]

$L$  = Distance from remote point to the point of crossing  
[m]

$V$  = Average velocity [m/sec]

### 2.1.3 SCS Unit Hydrograph Method

The SCS unit hydrograph method for calculating rates of runoff require the same basic data as Rational Method, that is Catchment area, a runoff factor, time of concentration and rainfall. The SCS approach, however, is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception, depression storage and infiltration rate that decreases during the course of storm. With the SCS method, the direct runoff can be calculated for any storm, either from real or fabricated by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

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

### 2.1.3.1 The Curve Number

The potential maximum soil water retention “s” is related to hydrologic soil properties, land cover and management conditions as well as the soil moisture status of the catchment prior to rainfall event and expressed by a dimensionless response index termed the catchment curve number (CN).

The CN and S are related as follows: (Highway design manual, 2001).

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

The CN number is selected according to soil type, moisture condition and land cover/use of the watershed area.

- Rainfall Runoff Equation

The direct runoff from 24-hour or 1-day storm rainfall using the expression below:

$$Q_u = \frac{(P - 0.2 S)^2}{P + 0.8 S}$$

Where

- Q<sub>u</sub> = Direct runoff (mm)
- P = Design rainfall (mm)
- S = Potential infiltration or potential maximum soil water retention

After determination of the various input parameters as discussed above, the peak unit discharge, q<sub>u</sub> can be read from a graph as function of ratio of I<sub>a</sub> & P and T<sub>c</sub>. I<sub>a</sub>= initial abstraction including surface storage, interception, and infiltration prior to runoff in mm and P is design point rainfall (ERA drainage design manual).

Then peak discharge is computed from the following expression:

$$Q_p = q_u A Q$$

**Where:**

- Q<sub>p</sub>= peak flow (m<sup>3</sup>/s)
- q<sub>u</sub> = unit peak flow (m<sup>3</sup>/s/km<sup>2</sup>/mm)
- A = drainage area (km<sup>2</sup>)
- Q = accumulated direct runoff (mm)

## **2.2 REGIONAL REGRESSION ANALYSIS**

Peak flow can be calculated by using regression equations developed for specific geographic regions (ERA Drainage manual, 2001). In the equations the dependent variable would be the peak flow, and the independent variables may be area, slope, channel geometry, rainfall and other meteorological, physical or site specific data. This method shall be used for all routine designs at sites where applicable. Regression Equations are a commonly accepted method for estimating peak flows at ungaged sites or sites with insufficient data. Also, they have been shown to be accurate, reliable, and easy to use as well as providing consistent findings. Regression equations are one of the preferred methods for estimating peak flows for larger catchment areas. A regional approach to estimating floods at ungauged sites can be adopted using this regression model to predict flood.

### **2.2.1 Analysis of Stream Gauge Data**

If a project is located near one of gauged station and the gauging record is of sufficient length, flood estimation may be made. The most important aspect of applicable station records is the series of annual peak discharges. These methods shall preferably be used for all routine designs provided there is continuous or synthesized recorded discharge data, that means: At least 10 years of continuous or synthesized record for 10 years discharge estimates and 25 years for 100-year discharge estimates. With at least 25 years of continuous or synthesized stream gage data the log Pearson III is considered to be the most reliable method for estimating flood frequency relationships and shall be used for all designs (ERA Drainage Manual, 2001).

## **2.3 GEOGRAPHIC INFORMATION SYSTEM**

Geographic Information Systems (GIS) link land cover data to topographic data and to other information concerning processes and properties related to geographic location. Non topographic information can include description of soils, land use, ground cover, and ground water condition, as well as man-made systems and their characteristics on or below the land surface.

While maps have been the most common historical form of representing topography, the advent of digital maps in GIS provides an alternative method of storing and retrieving this information. The amount of digital data required to accurately describe the topography of even small geographic regions make GIS a memory intensive and computationally complicated system.

The characteristic that differentiates a GIS from general computer mapping or drawing systems is the link to the information data base. Once the data base is constructed, correlations between different pieces of information can be examined easily through computer-generated overlay maps. For hydrologic modelling purposes, there is generally an extra step of generating hydrologic parameters that are dependent on data-base information. This hydrology GIS link is a significant complicating factor, because it involves complex empirical or physics-based relations (De Vantier, and D.Feldman, 1993).

DEMs can be derived from stereo-photos or from satellite imagery such as stereoscopic spot images, but are generally derived by interpolation of scattered point elevation data, of contour lines, or of Triangulated Irregular Networks (TIN).

In landscapes with varying complexity regular gridded DEMs appear with limitation as it cannot accurately describe the topographic errors which are introduced by the interpolation procedure which creates changes in regions with gentle slopes.

Scales and grid cell size influence the extraction of the channel network to a point where the same method produces different results for the same area.

In general the grid cell size dependency is introduced by the inability to accurately reproduce drainage features that are at the scale as the spatial resolution of the DEM. For meandering channels, this results in shorter channel and drainage area aggregation. In these situations, the number of channels, the size of direct drainage areas and the network pattern may depart considerably from the initial reference values (Wang and Yin.1998). Garbrecht and Martz (1994) presented a sensitivity analysis on drainage properties extracted from DEMs of increasing cell size and for several hypothetical network configurations. On the basis of these results they found that a DEM should

have a grid cell area of less than 5% of the network reference area in order to reproduce important drainage features with an accuracy of about 10%. The network reference area is the mean area draining directly into the channel links of the network.

The underlying data source used for deriving the DEM is a crucial factor. For this reason, the aggregation of an accurate DEM is considered better than using a DEM derived from maps at a lower scale (Thieken et al.,1999; Wolock and Price,1994,Walker and Wilgoose 1999).

Traditionally catchment boundaries have been manually derived from topographic maps, a labour-intensive activity after the introduction of digital Elevation Models (DEMs) Even though methods for delineating catchment boundaries and flow paths from contour lines (Moore and Grayson,1991) and triangulated irregular networks (Jones et al., 1990; Palacios-Velez and Cuevas-Renaud,1986) provide reliable results, they require extensive data storage and computation time. Grid cell elevation models have advantages for their computational efficiency and the availability of topographic databases (Sabbagn et al., 1994). Therefore, they have seen widespread application for analyzing hydrological problems.

### **2.3.1 GIS data types**

GIS is defined as “computer assisted systems for the capture, storage, retrieval, analysis and display of spatial data”

#### **2.3.1.1 Topographic Data**

One of the capabilities of GIS in the hydrological applications is the description of the topography of a region. Some spatial information is not directly described by elevation and can be described as topologic data. Topologic data define how the various pieces of the region are connected. Topology can be described as the spatial distribution of terrain attributes. A good example of topology is the collection of lines describing a stream network.

#### **2.3.1.2 Topologic Data**

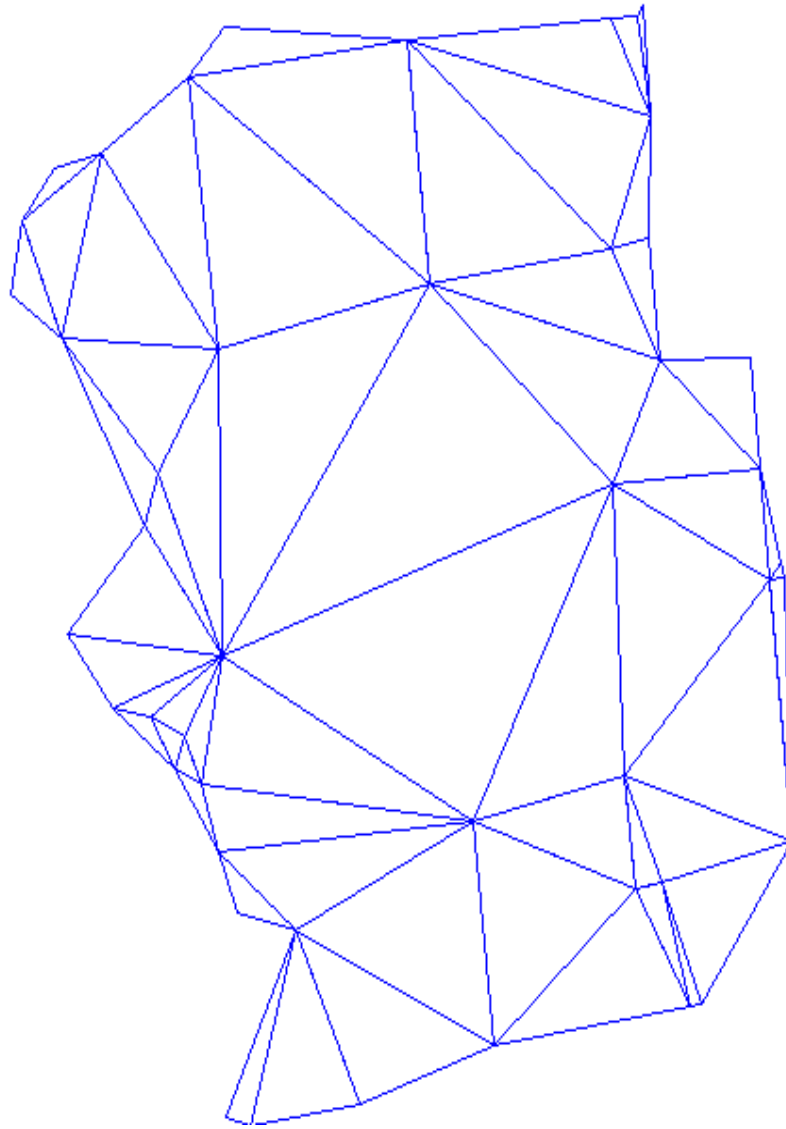
There are significant hydrological attributed which is not related to land surface elevation. The more obvious of these are catchment areas, flow lengths, land

slope, surface roughness, soil types, and land cover. These attributes help to describe the ability of a region to store and transmit water.

The most basic of which is the description of watershed boundary. Given a drainage point, the topography alone can be used to define those areas that should drain to the point. Average slope and drainage path networks are related and topographically derived topologic attributes which are useful in determining watershed parameters such as time of concentration, flow potential energies and flow attenuation. (Feldman, De Vantier,1993).

### **2.3.1.3 Raster or Grid-Based Data**

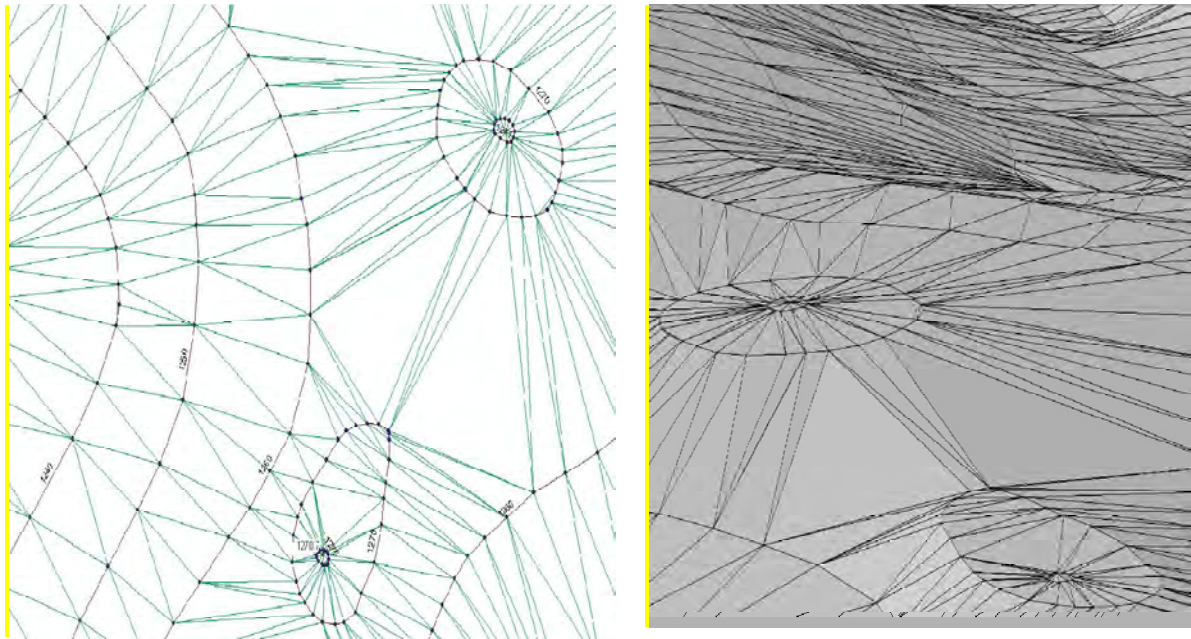
The first application of GIS in hydrological modelling utilized grid cell or raster storage of information. The grid is made up of regularly spaced lines, and the enclosed area of each rectangle is described in terms of its centre coordinates. There may be different grid scale for different attributes of the terrain, although following the scale of the available data is the obvious first choice. For attributes that are largely homogeneous, the use of the rigid resolution necessary for a DEM would require the storage of large amounts of redundant data. The grid resolution necessary to resolve the elevation of the most coarse terrain of a region dictates the scale (Feldman, De Vantier, 1993).



*Fig 2.2 Grid representation of Topography*

An alternate approach to producing DEM's relies upon determination of significant peaks and valley points into a collection of irregularly spaced points connected by lines as shown above in *Fig 2.2*. The lines produce a patchwork of triangles known as a Triangular Irregular Network (TIN). Most typically the triangles are treated as planar facets, but smoother interpolation is possible. The problem of depressions and interrupted drainage paths are partly avoided with a TIN as the path of water movement follows the slope of a plane or flows down the edge between two triangles as shown below in *fig 2.3*. Due to the fact that triangle networks from points are non unique, several algorithms have been developed to produce them from sets of points. The most widely used is

known as Delaunay triangulation (Lee and Schacter 1980) based on a principle of maximizing the minimum angle of all triangles produced by connector lines to nearest neighbor points. One of the main TIN systems available commercially is ARC/INFO (Feldman, De Vantier, 1993).



*Fig 2.3 Representation of a surface by a Tin in 2D (left) and 3D (right)*

As with raster methods, scales of representation for attributes other than elevation need not be the same as the TIN. In addition, the triangle-based representation can be a subset of a more general polygonal description of attribute regions. One of the most useful characteristics of a TIN for hydrologic system is the ability to define streams in terms of triangle boundary segments. This allows a more continuous description of stream paths and networks in conjunction with the topography. By comparison, grid data tend to produce zig-zag meandering paths for streams on upslope portions of a watershed.

#### **2.3.1.4 Vector-Or Contour-Based Line Networks**

The third major form of representing topography is contour line mapping. The contour can be represented digitally as a set of point-to-point paths (vectors) of a common elevation. Contour based methods require an order of magnitude more data storage, so that the transformation is typically from digital line graph

to other forms. Moore et al. (1988) have developed hydrologic applications using contour lines along with an orthogonal set of intersecting lines describing steepest descent to divide the mapped region into quadrilaterals. The chief advantage of the approach is that an important hydrologic attribute (steepest descent path) is inherent in the resulting data structure.

### **2.3.2 Use of Remotely Sensed Data**

Data for GIS can be collected from ground surveys, digitizing existing maps, digitally recorded aerial photography, satellite imaging data, or combinations of these. A problem of the scale of accuracy arises when these data are used in combination, so there is a disincentive to mix them. Aerial photography is the oldest of techniques for determining topology from a remote location. This has the ability to produce DEM data accurate to 0.03% of the altitude of photography (Kelly et al.1997). Satellites have been used for several decades for remote sensing, and the potential for applications in hydrology were quickly recognized. There are parameters which can be obtained through remote sensing such as land cover, vegetation properties, thermal and moisture indices, snow cover, and imperviousness. Most of these are obtained through satellites imagery however, not all information from satellites is imagery. Satellites are often used for communication of hydrologic data from land-based sensors to analysis centers.GPS allows accurate location of hydraulic control points such as curbs and valves and can greatly improve the ability of the GIS and hydrologic model in prediction of flow paths in an urban setting.(Feldman and De Vantier,1993).

There are four main components of a true GIS system (Marble, 1990).These are:

- Data input system: Collects and/or processes spatial data from existing sources, such as maps, remote sensing data, images, etc. Data can be "collected "through digitizing, scanning, interactive entry, etc.
- Data Storage and retrieval: Organizes spatial data and allows for quick retrieval and updates (i.e., editing).
- Data analysis and manipulation: allows for changing form of data, simulation modelling, spatial-temporal comparison, etc.

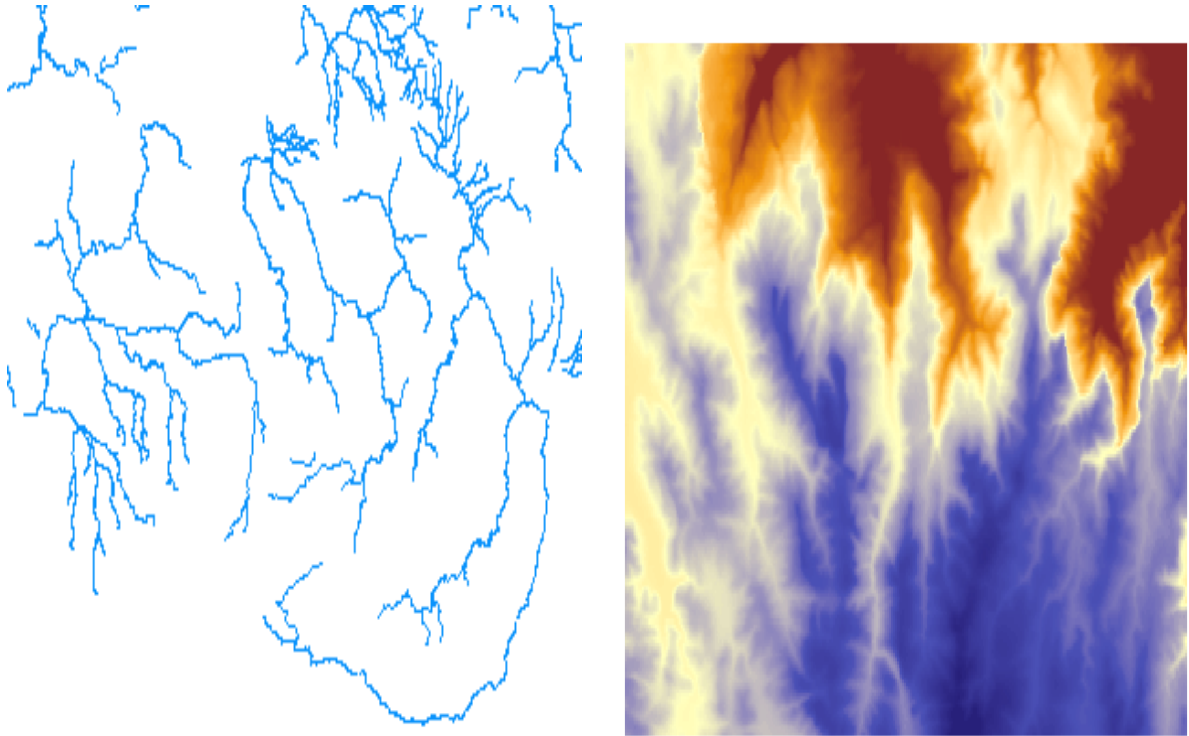
- Output: displays spatial database and analysis in graphic (i.e., map) or tabular form.

Many software programs can handle spatial data or display maps. GIS is separated from these programs in that it is capable of performing spatial analyses. In other words, GIS is able to readily solve spatial questions or problems by using geo referenced data (e.g. ., latitude, longitude). GIS allows for more efficient, and often more cost-effective ways of manipulating, analyzing and displaying spatial data (Applications of GIS Introduction – Page 12 Fall 2002).

### **2.3.3 Geographic Features**

It is important to recognize that a GIS is not a simple mapping tool, nor is it solely a fancy way to display images from aerial photos, land sat scenes etc. GIS contains databases where features are related to each other according to their spatial locations. Thus for each feature contained within the GIS database, information exists on: Its identity, location and the relationship to other features. (Applications of GIS Introduction – Page 12 Fall 2002).

A GIS map contains “Layers”, which can be combined to produce a map. It is important to remember that with GIS, you can “peel off” these layers one by one to examine them independently or in some combination. Which we cannot do this on paper maps. Layers can also be related to features that are best displayed at smaller or larger scales. For example, the map on the left below shows the location of rivers in Akaki catchment and at the right it shows the elevation.



*Fig 2.4 Picture showing GIS representation of Streams in Akaki catchment.*

## **2.4 ARC HYDRO**

Arc Hydro is a model developed for building hydrologic information systems to synthesize geospatial and temporal water resources data that support hydrologic modelling and analysis. The model is developed as an Add-on to Arc GIS software. It is used to extract topologic variables from a digital elevation model raster (DEM) for building geometric networks for hydrologic analysis. This geospatial and temporal model supports hydrologic simulation models categories to divide water resources elements, such as network, drainage, channel, hydrograph, and time series.

The Arc Hydro tools (part of the Arc Hydro Add on toolbar) generate several datasets that collectively describe the drainage pattern of a catchment. Most watershed managers use this facility more than other advanced hydrologic analysis for their watershed management requirement. At the outset, a raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and finally watershed delineation. Next,

these data are used to develop a vector representation of catchments and drainage lines and in the end to help in constructing a geometric network. Arc hydro tool is added to Arc Gis after installing it by adding it to the Arc toolbox.

#### **2.4.1 Arc Hydro Modeling Procedure for Watershed Delineation**

The procedure used for watershed delineation in Arc Hydro involves a sequence of steps accessed through the toolbar menus. The first of these was the reconditioning of the DEM data to reconcile with the stream layer using the AGREE method. AGREE is a surface reconditioning system for DEMs. With the application of the AGREE method, the system adjusts the surface elevation of the DEM to be consistent with vector coverage of a stream or ridgeline coverage. Arc Info's Arc Macro Language (AML) code is written for this AGREE tool's operation like other Arc Hydro tools.

Reconditioning was required to raise the base level of the DEM values to prevent negative values in the DEM because it would have created problems when filling sinks in the next step. Sinks are artefact features from DEM creation which are cells in which there is no adjacent downstream cell. Once sinks were filled, flow direction was calculated using the adjusted DEM values and steepest flow path algorithm and eight-direction pour path model. The next step was the calculation of flow accumulation, which was used when specifying the threshold by which streams are defined in the next step. The model designates stream path channels begin at the point at which the accumulation threshold was exceeded. The stream definition dialog sets the default threshold at ten percent of the total drainage area, which may be too detailed for small study areas or too general for large ones.

Processing large DEM files using small threshold values may require an extended processing period for completion. The stream layer output was in binary raster format; with cells occurring within stream features assigned a value of one.

The stream grid was segmented into sections representing headwater tributaries or segments between confluences, with each segment assigned a unique grid code identifier. The resulting link grid was used in the next step to generate a catchment grid based on the values held by each stream segment. The number

of catchments was equal to the number of stream segments defined in the previous step. These catchment grids were converted to polygon vector features in the next step, with single cell catchments automatically dissolved within the process topology. Additionally, the link grid from earlier processing was converted to a line feature corresponding to the catchment polygon in which it resides.

To facilitate the definition of entry and exit points, the next step generated aggregated adjoint catchments that represented the cumulative upstream area of each stream segment that was not a headwater segment. In the next step drainage points which are point features placed at the transfer points between adjacent catchments were generated. Each point was assigned a unique identifier based on the catchment it drains. For general watershed analysis, the adjoint catchments contain the watershed elements of the selected catchments and adjacent downstream catchments in the watershed, thus delineating the watershed boundary based on the selected catchment. Figure 2.5 below is a very comprehensive flow chart to show the entire process involved in the watershed delineation using ArcHydro extension toolbar in ArcGIS (Carol Kraemer and Sudhanshu S Panda 2009).

## CAPTER THREE

### USE OF GIS FOR HYDROLOGIC AND HYDRAULIC MODELLING

The shape of a surface determines how water will flow across it. The hydrologic modelling tools in the spatial analyst tools of arc view extension provide a method to describe the physical characteristics of a surface. Using a digital elevation model (DEM) as input, it is possible to delineate a drainage system and then quantify the characteristics of that system.

Watershed and stream networks, created from DEMs using the Spatial Analyst, are the primary inputs to most surface hydrologic models. An understanding of the shape of the Earth's surface is useful for many fields such as urban and regional planning, agriculture, and forestry. These fields require an understanding of how water flows across an area, and how changes in that area may affect that flow.

The source and ultimate destination of water must be determined before modelling the behaviour of water in a system. This section explains the concepts and key terms regarding drainage systems and surface processes, and how to use the tools in the Spatial Analyst to model the movement of water across a surface and to extract hydrologic information from DEM.

#### 3.1 HYDROLOGIC CONCEPTS

The area upon which waterfalls, and the network through which it travels to an outlet, is referred to as a *drainage system*. The flow of water through a drainage system is only a subset of what is commonly referred to as the *hydrologic cycle*, which also includes precipitation, evapotranspiration, and ground water flow. This paper focuses on the movement of water across a surface.

A *drainage basin* is an area that drains water and other substances to a common outlet as concentrated drainage. Other common terms for a drainage basin are: *watershed*, *basin catchment* or *contributing areas*. This area is normally defined as the total area flowing to a given outlet, or pour point. An *outlet*, or *pour point*, is the point at which water flows out of an area. This is the

lowest point along the boundary of the drainage basin. The boundary between two basins is referred to as a *drainage divide* or *watershed boundary*.

The physical characteristics of a surface determine the characteristics of flow across it, and the flow across that surface changes its physical characteristics. The direction of flow across a surface is determined by the slope direction at each location. Slope direction is the direction of the maximum rate of change in elevation from each cell. Slope is the maximum rate of change in elevation from each cell. A steeper slope results in greater energy. As the energy of a stream increases, its ability to transport more and larger particles also increases. Therefore, steeper slopes result in a greater potential for erosion. *Profile curvature* indicates where the surface is concave or convex, resulting in acceleration or deceleration of flow.

Where acceleration of flow occurs, the stream gains energy and its ability to transport particles increase. Therefore, areas of convex profile curvature indicate areas of erosion. Conversely, in areas of concave profile curvature, the flow rate decreases, the stream loses energy, and deposition occurs.

## **3.2 DEM-BASED TERRAIN ANALYSIS**

The most common digital data of the shape of the earth's surface are cell-based DEMs. These data are used as input to the raster tools to quantify the characteristics of the land surface.

### **3.2.1 Digital Elevation Data**

A DEM is a raster representation of a continuous surface, usually referring to the surface of the earth. The accuracy of this data is determined primarily by the resolution (distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface of the surface when creating the original DEM.


Errors in DEMs are usually classified as either sinks or peaks. A *sink* is an area surrounded by higher elevation values, and can be referred to as a depression or pit. A sink may be formed naturally but most of the time its imperfections in the DEM. A peak is an area surrounded by cells of lower value.

Flow across a surface will always be in the steepest down slope direction. Once the direction of flow out of each cell is known, it is possible to determine which and how many cells flow into any given cell. This information can be used to define watershed boundaries and stream networks. In order to have corrected DEM sinks should be filled first.

### 3.2.2 Flow Direction

One of the keys to deriving hydrologic characteristics about a surface is the ability to determine the direction of flow from every cell in the grid. Flow direction takes a surface as input and outputs a grid showing the direction of flow out of each cell. There are eight valid output directions, relating to the eight adjacent cells into which flow could travel. This model is known as the eight-direction pour point model (fig 3.1)

The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. This is calculated as the change in elevation by the distance. The distance is determined between cell centres. Therefore, if the cell size is 1, the distance between two orthogonal cells is 1 and the distance between two diagonal cells is the square root of 2.

32	64	128
16		1
8	4	2

*Fig 3.1 flow direction*

If all neighbours are higher than the processing cell, the processing cell is a sink, and has an undefined flow direction. If two cells flow to each other, they are sinks, and have an undefined flow direction. If a cell has the same change in Z value in multiple directions it is also a sink and has an undefined flow direction.

For cells that have an undefined flow direction, the value for that cell in the output flow direction grid will be the sum of those directions. For example, if the change in z value is the same both to the east or if flow direction is 1 and south flow direction is 4 the flow direction for that cell will be the sum which is 5. Cells with an undefined flow direction can be flagged as sinks using the sink command. To obtain an accurate representation of flow direction across a surface, the sinks should be filled.

### **3.2.3 Flow Accumulation**

Flow accumulation grid is extracted from the flow direction grid. The flow accumulation records the number of cells that drain into an individual cell in the grid as shown in fig 3.2, the flow accumulation grid is essentially the drainage area to a specific cell measured in grid units. The flow accumulation grid is the core grid used in stream delineation.

The flow accumulation presents an indirect way to determine the drainage paths based on a DEM. The accumulation in a cell is defined as the number of cells that drain through that cell. The result of running the flow accumulation tool is a raster with the accumulation value calculated as specified stored in each cell. The calculation of the discharge accumulated on different segments of the drainage paths and the determination of streams can be done using the flow accumulation function. The stream network and the potential drainage lines are extracted from the accumulation of the flow on the terrain. If some models need the catchment area contributing to each cell it can be obtained easily by multiplying the value of the flow accumulation with the area of a single cell. Some GIS products have a separate.

This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid. Flow accumulation shows by the intensity of the colour assigned.

0	0	0	0	0
0	1	1	2	1
0	3	8	5	2
0	1	1	20	0
0	0	0	1	24

*Fig 3.2 flow accumulation Grid*

Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges.

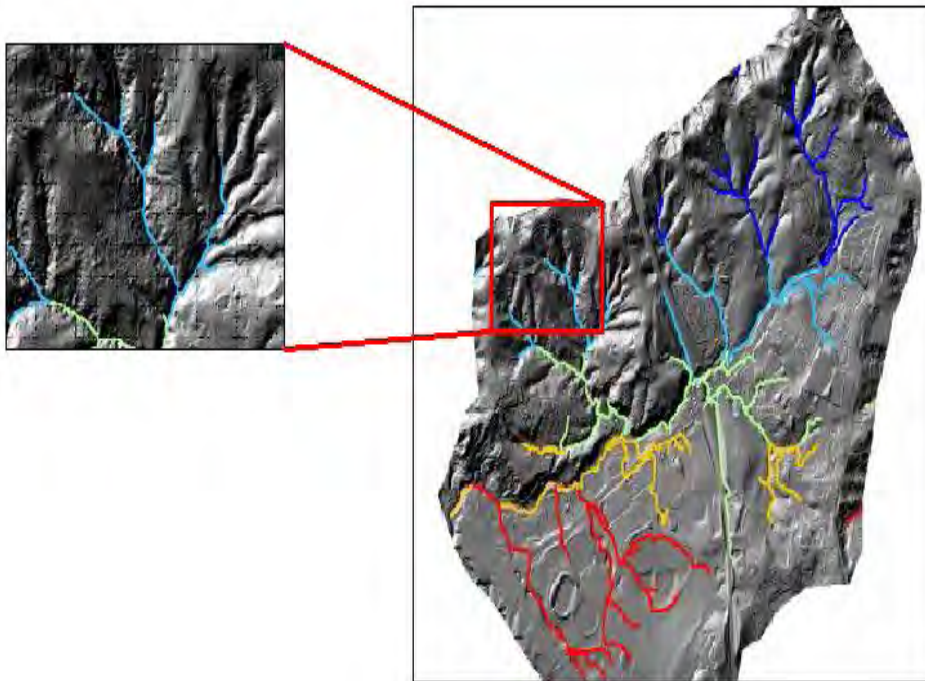
The output of FLOW ACCUMULATION would then represent the amount of rain that would flow into each cell, assuming that all rain became runoff and there was no interception, evapotranspiration, or loss to groundwater. This could also be viewed as the amount of rain that fell on the surface, upslope from each cell.

### **3.2.4 Stream Definition and Segmentation**

The definition of the streams can be done using the stream Definition tool. This tool considers every cell with a flow accumulation larger than a value, given by the user, as being a stream. The value has a great effect on the density of the streams obtained from the operation and different applications can use different values for this purpose.

Stream and watershed delineation is the process of identifying flow elements (streams) and drainage areas (watersheds) of a hydrologic system. In this application delineation is based on raster topographic data as shown in fig 3.3 stream grid shows streams.

Another function that splits the streams according to their structure is the Stream Segmentation. Using this function, each stream is split in segments. The first segment represents the first level in the graph assigned to the stream network (from the source until the first confluence) and each edge of this graph (between two confluences) becomes a segment. Each segment has a grid code for unique identification of the segment.



*Fig 3.3 Stream definition grid*

### **3.2.5 Watersheds**

A watershed is the upslope area contributing flow to a given location, and can also be referred to as a basin, catchment, sub-watershed, or contributing area. A sub-watershed is simply part of a hierarchy implying that a given watershed is part of a large watershed. Watershed can be delineated from a DEM using the output from the FLOW DIRECTION request as input to watershed.

Watershed boundaries are a key requirement for nearly all surface hydrologic modelling. These boundaries can then be combined with soil and land use information and discharge calculations can be done.

## CHAPTER FOUR

### AN OVERVIEW OF THE STUDY AREA AND FIELD WORK ACTIVITIES

#### 4.1 STUDY AREA

The study area covers a tributary river of the main Akaki River which crosses the Goro-Akaki road. The area is about 726.11 km<sup>2</sup>, almost a half of the overall upstream contributing area. The study area has catchment boundary length of 198.7km, and approximately bounded between the geographic coordinates of 80 45'20" to 90 13'17" N latitude and 380 34' 3"to 390 4'10" E longitude.

The Akaki River catchment is located in the Western Ethiopian highlands of the Shewan plateau, and partly in the western margin of the Ethiopian Rift valley. The capital city, Addis Ababa and other small towns such as Akaki, Sendafa, Burayu and smaller peasant association villages are found in this catchment.

The Intoto Mountain forms the northern drainage boundary of the Akaki River Catchment and other volcanic mountains bound it from the eastern, western and south-western boundaries; these are Mt. Yerer, Mt. Wechecha and Mt. Furi, respectively.

As Addis Ababa is found in the northern central heart of the catchment, the study area is accessed in every direction by highways from the capital that is, by the major roads stretching to Jimma, Wollega, Harar/Sidamo, Wallo and Gojjam. In fact, other minor roads are found in the catchment and these are used for traverses between villages and sites. The location map of the study area is shown in Fig 4.1

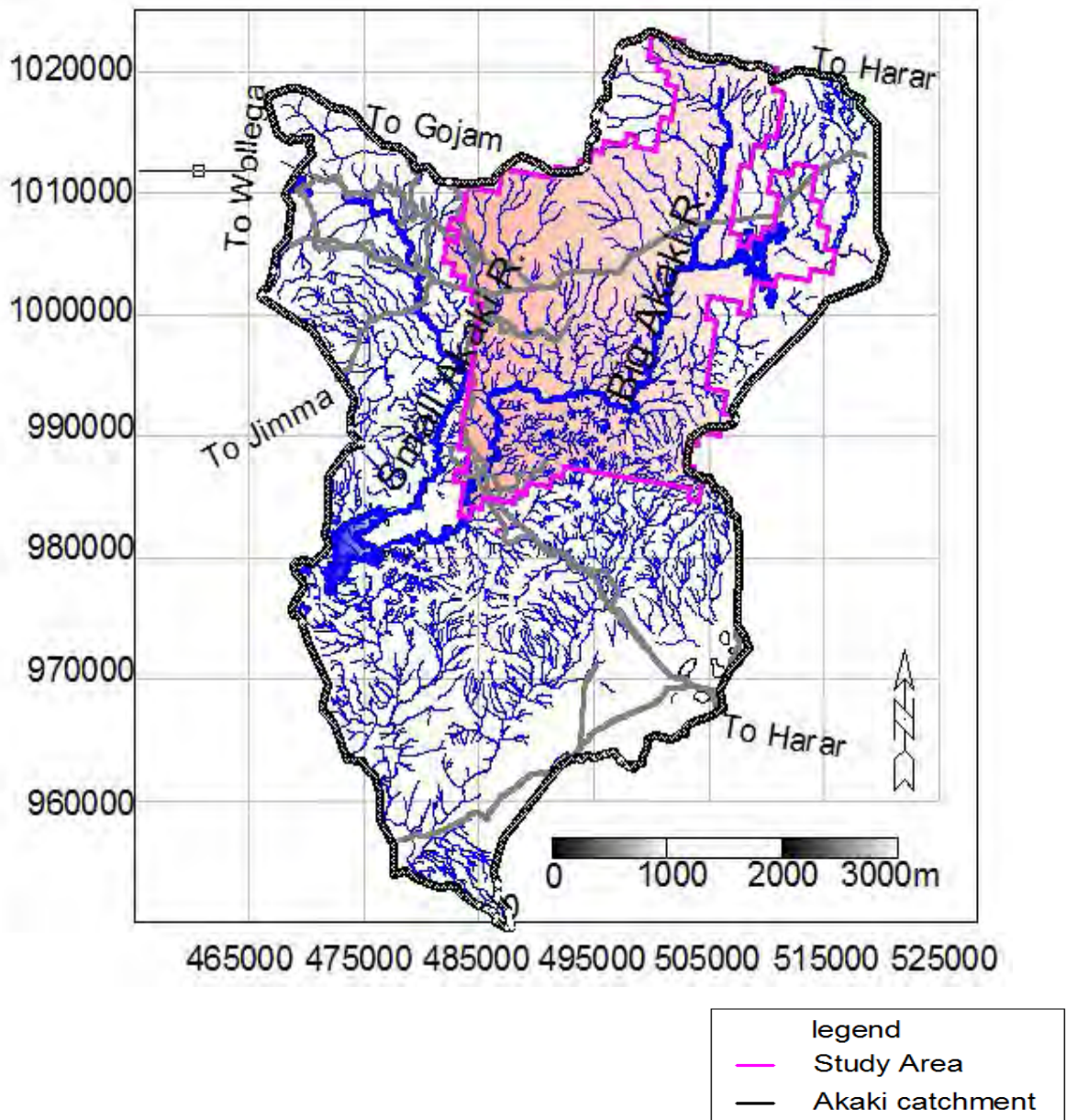


Fig 4.1 Location Map of study area

#### 4.1.1 Climate

Based on Rainfall, the climate of the area can be categorized in to two broad seasons: the dry season (winter) which covers the period from October to May and the Wet season extends from June to September, with slight rainfall during autumn and spring. This seasonal variation of rainfall distribution within the study area is due to the annual migration of the inter-tropical convergence zone, a low-pressure zone marking the convergence of dry tropical easterlies and moist equatorial westerlies across the catchment.

The highest and lowest mean maximum temperature over the record periods is 25°C in dry season (March) and 20°C in wet season (August), while the variation of mean monthly temperature values fall in the range of 7°C (December) to 12°C (March) throughout the year. From these values one can observe that daily variation in temperature in the area is more pronounced than the annual variation and the calculated mean annual temperature was around 16.32°C (Solomon Tale, 2000). In general, one can classify the climate in this area as warm temperate climate.

#### **4.1.2 Topology**

The Akaki River catchment is an extensive drainage system located at the eastern edge of the Western Ethiopian plateau that slowly descends to the Main Ethiopian Rift and has an elevation drop of about 1km in a space of about 30km towards the south (Figure 3.2). As it can be seen in this figure the topography close to the ridge in the north is sharp and tends to flatten towards south.

The present rugged landform of the area is due to volcano – tectonic activity that formed the plateau and rift followed by later erosion and river dissection. Akaki River catchment has an elevation range of 2040 to 3,200m above sea level (Topographic Map of Scale 1:50,000, EMA, 1973). Ridges/volcanic centers and mountain ranges bound the catchment.

The landform of the catchment is complex and changes within small distances; the central part resembles a wide caldera and is characterized by decreasing elevation in the direction of river flow. The south-eastern tip of this catchment is relatively flat with recent quaternary deposits and NE –SW aligned scoria cone hills standing above the ground surface. The north-eastern part of the catchment is also relatively flat. The northern part of the catchment has ragged topography & steep slopes, which in turn are characterized by rapids, and a high runoff coefficient compared to the southern part of the catchment.

Vernier et.al (1985) tried to characterize the Intoto mountain Range as a remnant edge of an old volcanic caldera, which has been collapsed southward

by means of a wide system of step faults. This also shows that the landscape is the result of complex geological structures, which has been modified by erosional processes.

Peak elevation is found at: Intoto mountain Range (pick elevation Mt. Intoto 3200m above sea level, Mt. Bereh 3,228m above sea level), Wechecha range (3,391m a.s.l), Mt. Furi (2839m a.s.l.) and Mt. Yerer (3100m a.s.l.) and the minimum elevation is found to the south of catchment (around Abba Samuel Lake (2060m a.s.l.)

Fig 4.2 Elevation Surface Map of Akaki River Catchment

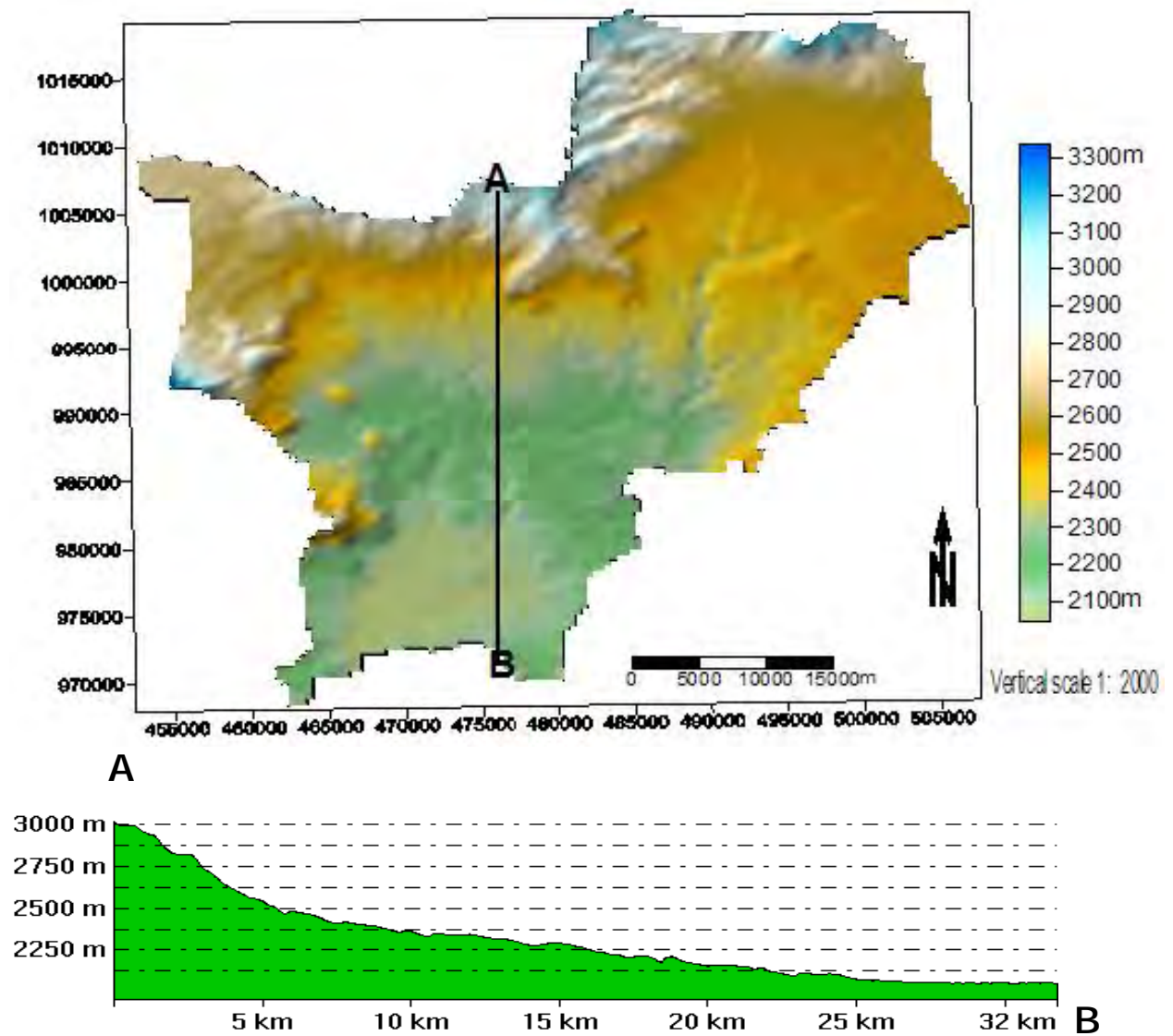


Fig 4.3 Profile showing Elevation drop along line A-B

### 4.1.3 Land use / land cover

Although very much diverse, the general land use/cover pattern of the catchment was broadly classified into four groups: Forest, Urban area, agricultural or open areas and water bodies, according to BCEOM- Seureca (2000).

In the northern part of the catchment on Intoto Mountains, the land is covered by forest, dominantly eucalyptus trees and the top of the mountain range is relatively flat that facilitates infiltration of precipitation into the ground. As the slope gets sharper towards the city a relatively higher runoff coefficient is expected.

Residential areas are found either as towns /city and villages or as sparse settlements of household. The Addis Ababa city is characterized by paved surfaces /built up areas, that cause very small infiltration of precipitation into the ground and most of the rainfall is converted into surface runoff that drains into networks of rivers.

The other residential towns /villages in the catchment include, Sendafa, Akaki, Burayu and other moderately populated rural settlement villages. Some garden areas and woodland covers also characterize urban areas.

Although elevation peaks (hills, ridges), that are not convenient for farming, are widely distributed in the catchment, agricultural or open areas cover a large part of the catchment in the east, south and southwest directions. Such areas are less subjected to human influence in terms of change in soil permeability and rainwater is assumed to infiltrate in this zone at a natural rate (BCEOM – Seureca, 2000).

There are about five man-made reservoirs /dams in the Akaki River catchment. These are: Gefersa I, II and III, Lega Dadi, Dire and Abba Samuel Lake. The first four are serving for drinking water supply except Gefersa III which serves as a sediment trap while the last one was constructed for electric power generation (Yewendson Mengistu and Dereje Nigussa, 2002).

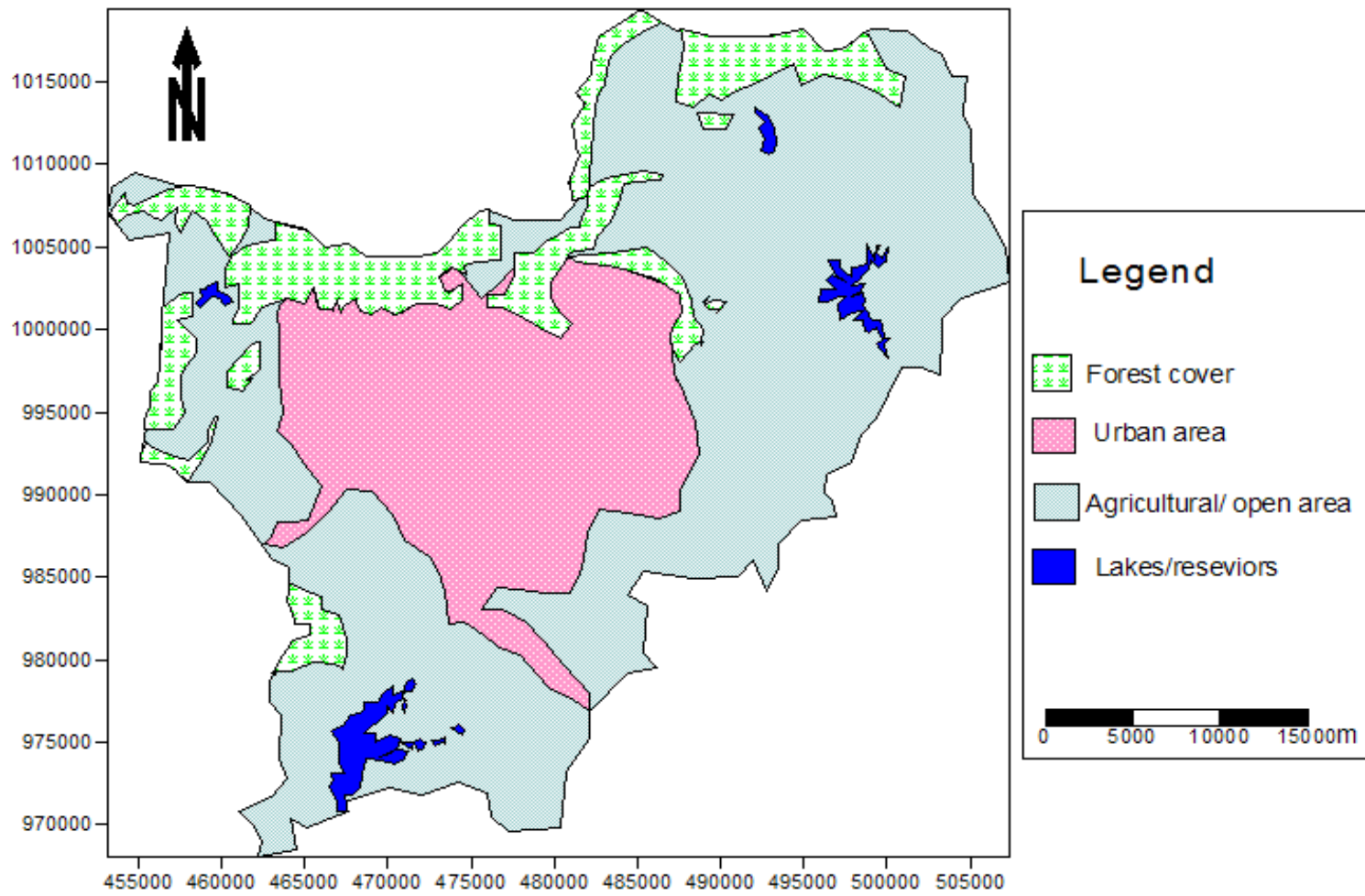


Fig 4.4 Land Use/Cover Map of the Akaki River Catchment

Accordingly, based on the distribution and areal coverage of each land use type in the catchment, the proportion of each was calculated as follows: forest covers about 15.45% of the total, agricultural/ open area 69.02%, urban areas 14.55% and water body/ wet lands covers about 1.5% of the catchment.

#### **4.1.5 Drainage**

The Akaki River catchment comprises of numerous small rivers. The dominant ones are the Big Akaki, which drains the eastern part of the catchment area, and the little Akaki that drains the western part of the catchment; and their respective tributaries. The two rivers form one of the biggest tributaries of the Awash River called Akaki River that enters Abba Samuel Lake, leaves the lake and passes through a gorge up to 100m deep which extends for about 8km before it joins the Awash River. Almost all the streams in the catchment originate from the northern part of the catchment. Refer figure 4.1

The Big Akaki suffers a total drop of about 600m in a river length of 95km from its origin to its confluence with the Awash River near Dodota, 1800m above sea level (AAWSA et al., 2000).

The Intoto Mountain range in the northern forms the surface water divide between the Blue Nile and Awash River basins. The drainage of an area is affected by numerous factors among which, rainfall, slope, vegetation, rock type and tectonic activity, infiltration capacity, soil types and thicknesses, are some. In the northern part of the catchment the drainage forms steep narrow gorges (facilitates runoff) which can be attributed to high rainfall, dense vegetation cover and high topographic elevation (>2800m). Where there are volcanic ridges /domes, drainage radiates in all directions forming radial or parallel drainage system. It is clear that areas with higher permeability have lower drainage density that in turn may decrease the surface runoff. These can be observed from the topographic map of the area in that areas with high elevation and that are not covered with vegetation have higher drainage density compared to flat lying areas and areas that are covered with vegetation (increases permeability). Generally the drainage in the catchment is oriented nearly from north to south following the regional slope.

## 4.2. ACTIVITIES PERFORMED

The activity performed is data collection which includes:

MAPS	<ul style="list-style-type: none"><li>• Geological, map of the area of 1:50,000 scale (from mapping agency)</li><li>• Geomorphologic map of the area of 1:50,000 scale (from mapping agency)</li> <li>• Soil map of the area of 1:50,000 scale (from mapping agency)</li></ul>
Measured Data	<ul style="list-style-type: none"><li>• Rainfall data of the area (from Metrology)</li><li>• Discharge data of the area (From Ministry of water and irrigation)</li></ul>
GIS Data	<ul style="list-style-type: none"><li>• Land cover shape file of Awash Basin (From Ministry of water, irrigation and energy)</li><li>• Soil type shape file of Awash Basin (From Ministry of water, irrigation and energy)</li><li>• DEM of the study area (From Ministry of water irrigation and energy)</li></ul>
Design Document	<ul style="list-style-type: none"><li>• Hydrologic and structural report of Goro-Akaki Road is collected from Consulting office</li></ul>

*table 4.1 data collection*

## CHAPTER FIVE RESEARCH METHODS

This chapter starts with a “conceptual frame work” which describes an overall methodology applied to carry out this research. It is followed by “GIS and RS application “including land use classification, rainfall data analysis and DEM processing.

### 5.1 Conceptual Framework

A conceptual framework serves to describe the overall research steps as shown in fig 5.1, Firstly, two main data types required as input includes rainfall and DEM. Other input data such as soil, land cover, land use are extracted using GIS. After having data, HEC HMS model is developed through model parameterization, and then these models are operated. The main output from these models is discharge at the outlet of the catchment. The output is compared with real discharge data (collected from MWIE) to calibrate the model. Model output is compared based on criteria to see if the model yields better result.

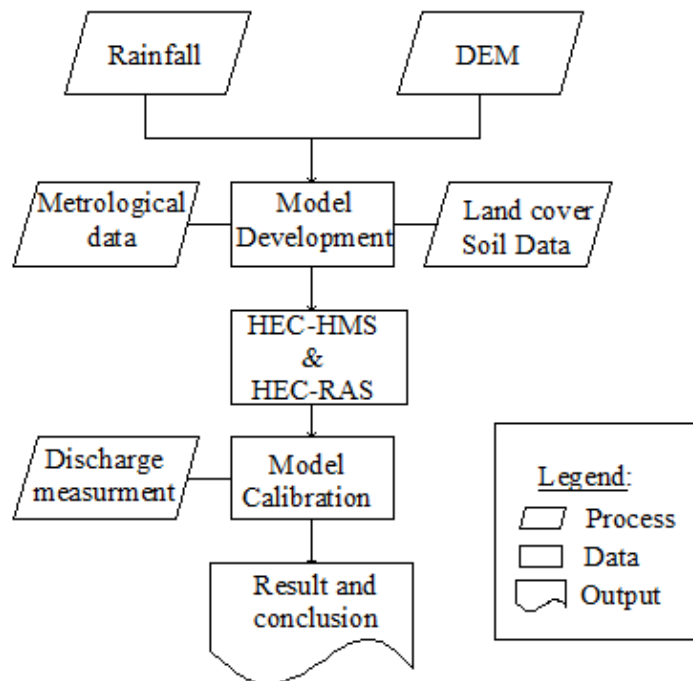


Fig 5.1 Conceptual framework

## 5.2 APPLICATION OF GIS

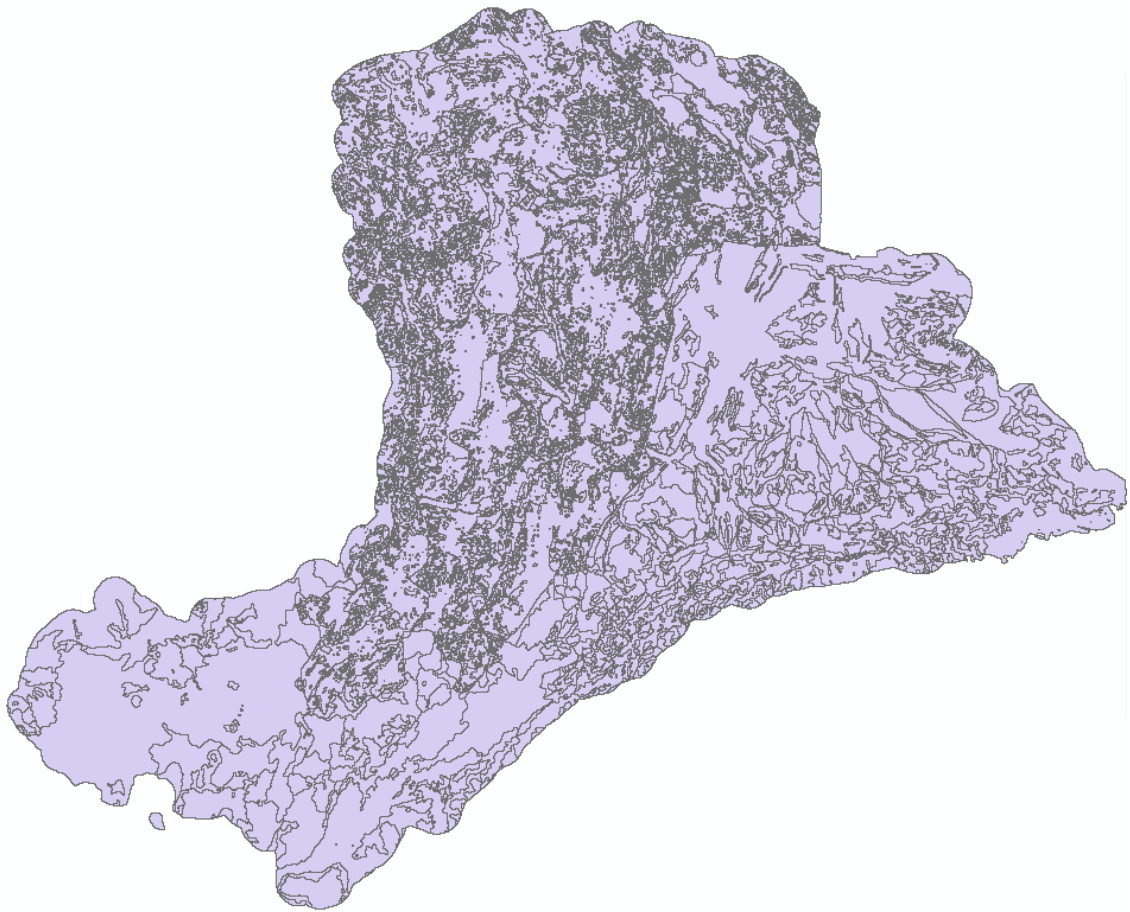
In this thesis, the application of GIS and techniques are explored. Three typical applications reported in this section include land use classification, soil type classification, and DEM processing.

### 5 .2.1 LAND USE MAP CLASSIFICATION

The Land Use and Land cover data files describe the vegetation, water, natural surface, and cultural features on the land surface.

Steps followed are explained as:

- Land use shape file of Awash basin (fig 5.1) was taken from ministry of water and irrigation office;
- The image was Georeferenced to the coordinate system of the study area (ADENDA, Projection: UTM, Zone 37);
- The catchment boundary is clipped to the study area shape file using GIS spatial analyst tool extract-Clip. The input feature class is Awash basin land use, the clip feature is the study area boundary the output is clipped land use map as shown in (fig 5.2).
- Land use pattern is analyzed and percentages are calculated as shown fig 5.2 the dominant soil type of the study area is crop land with grass land. Each land use area is linked to the land use interpretation record attribute database. This attribute database gives the proportionate extent of the component land use and their properties for each map unit.



Table

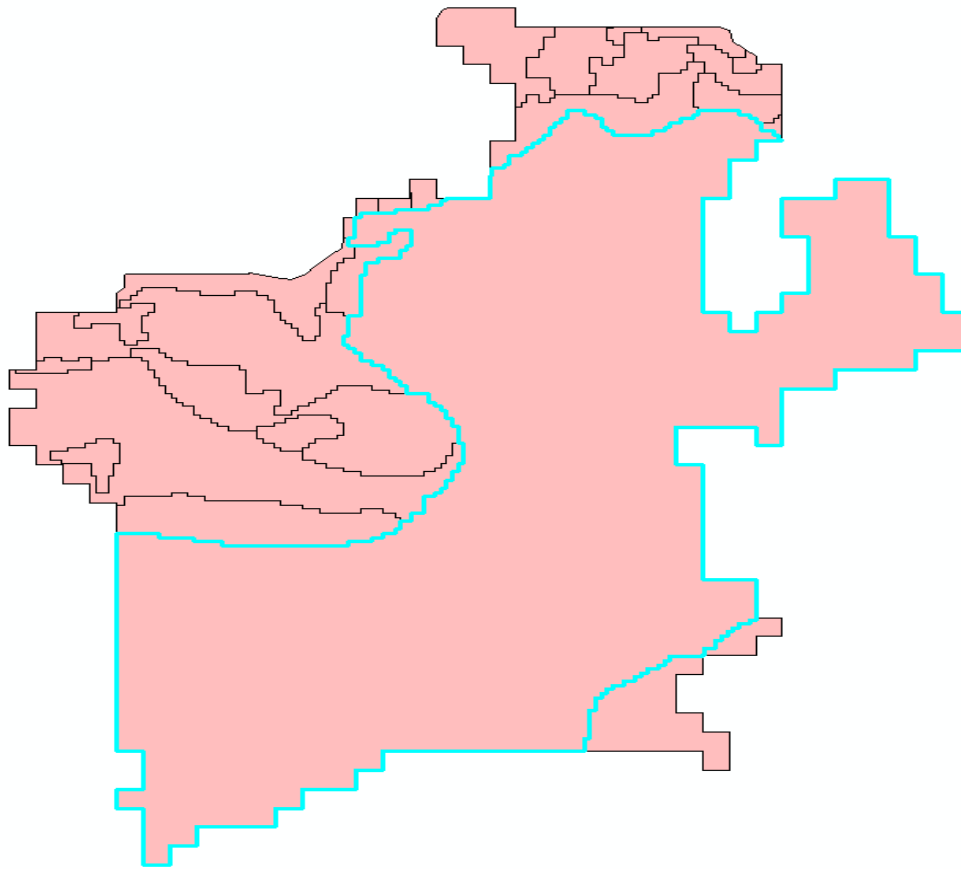
Landcover\_Landuse

FID	Shape	REC_NUM	DATA_VALUE	ALL AWASH	DESCRIPTIO
0	Polygon	1	1	AE	Grassland, Herbaceous Wetland
1	Polygon	2	2	AE/GB	Grassland, Herbaceous Wetland
2	Polygon	3	3	CI	Cropland (Sugar Cane And Other Crops)
3	Polygon	4	4	CI/CPEL	no match
4	Polygon	5	5	CI/FRD	no match
5	Polygon	6	6	CRCB	Cropland with Shrubland
6	Polygon	7	7	CRCB/CI	no match
7	Polygon	8	8	CRCB/GB	Cropland with Grassland Savanna
8	Polygon	9	9	CRCB/SHO	Cropland with Grassland Savanna
9	Polygon	10	10	CRCL	Cropland with Shrubland
10	Polygon	11	11	CRCL/GB	Cropland with Grassland Savanna
11	Polygon	12	12	CRCL/GL	Cropland with Grassland Savanna
12	Polygon	13	13	CRCL/GM	Cropland with Grassland Savanna
13	Polygon	14	14	CRCL/SHD	Cropland/Savanna/Bushland Mosaic
14	Polygon	15	15	CRCM	Cropland with Shrubland
15	Polygon	16	16	CRCM/FCO	Cropland/Tropical Forest
16	Polygon	17	17	CRCM/GM	Cropland with Grassland Savanna
17	Polygon	18	18	CRCM/SHD	Cropland/Savanna/Bushland Mosaic
18	Polygon	19	19	CRCM/SHO	Cropland/Savanna/Bushland Mosaic
19	Polygon	20	20	FBD/CRCL	Deardred Tropical Forest/Cropland

(0 out of 100 Selected)

Landcover\_Landuse

Fig 5.2 Land use map of Awash basin



Table

Landcover\_Landuse\_Clip

OBJ	Shape *	REC	DATA_V	ALL_AWAS	DESCRIPTIO	Shape_Length	Shape_Area
1	Polygon	10	10	CRCL	Cropland with Shrubland	270806.635526	586682500.760811
2	Polygon	11	11	CRCL/GB	Cropland with Grassland Savanna	183052.293828	644098827.476723
3	Polygon	15	15	CRCM	Cropland with Shrubland	198728.3504	726112973.912125
4	Polygon	21	21	FBO	Secondary Semi-deciduous Forest/Woodland	230243.435941	711658274.728774
5	Polygon	30	30	FPC	Tropical Plantations	249888.975211	693492245.311237
6	Polygon	37	37	GB	no match	218372.010573	420412678.969637
7	Polygon	44	44	GL	Semi-Desert Grassland with Shrubland	263416.524273	622155617.273827
8	Polygon	45	45	GL/CRCL	Grassland With Cropland	108163.613891	158235443.385075
9	Polygon	52	52	HH	Inland Water	168786.096074	374188774.731573
10	Polygon	54	54	HSS	Herbaceous Wetlands (Sud)	214165.308764	518549705.050729
11	Polygon	88	88	U	no match	163399.062195	450191439.174226
12	Polygon	92	92	WO	Montane Broadleaf Evergreen Woodland	21469.24654	14166915.24817

1 (1 out of 12 Selected)

Landcover\_Landuse\_Clip

Fig 5.3 Clipped Land use map of the study area

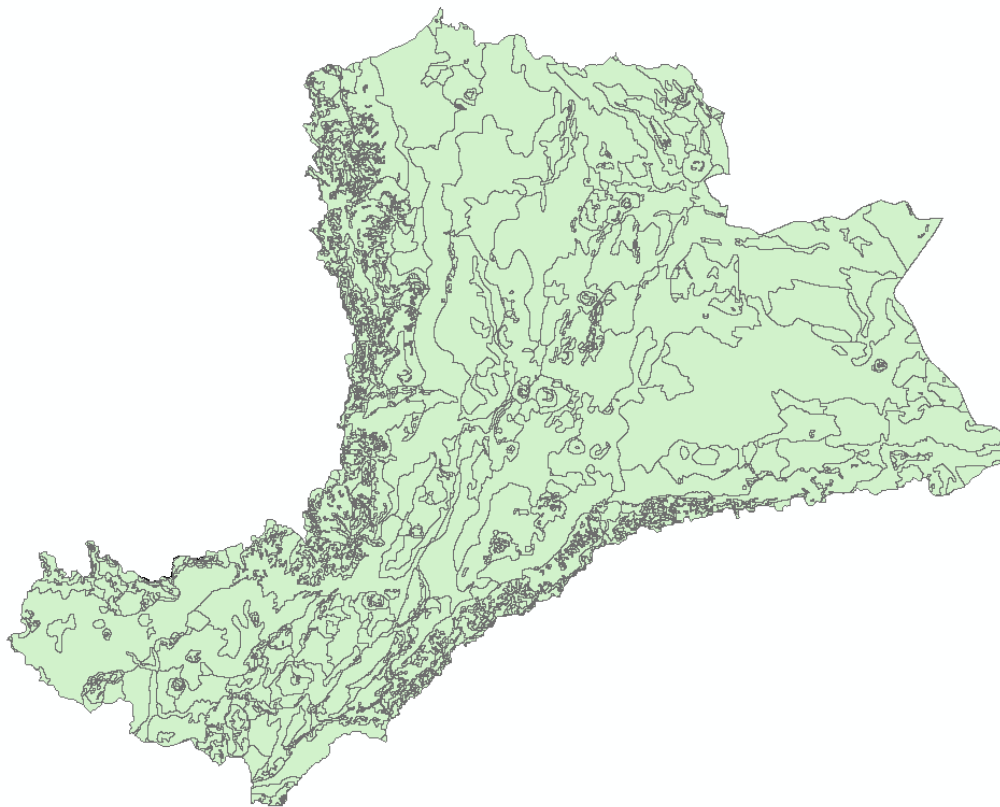
## 5 .2.2 SOIL MAP CLASSIFICATION

Soil maps for the study area are extracted from Awash basin soil map shape file which covers the whole basin. Each soil area is linked to a soil interpretations record attribute database. This attribute database gives the proportionate extent of the component soils and their properties for each map unit.

Steps followed are explained as:

- Soil map shape file of Awash basin (fig 5.3) was taken from ministry of water and irrigation office;
- The image was Georeferenced to the coordinate system of the study area (ADENDA, Projection: UTM, Zone 37);
- The catchment boundary is clipped to the study area shape file using GIS spatial analyst tool extract-Clip. The input feature class is Awash basin soil map, the clip feature is the study area boundary the output is clipped soil map as shown in (fig 5.3)
- Soil type is analyzed and percentages are calculated as shown fig 5.4 the dominant soil type of the study area is pelvic vertisoils.

Each Soil type is linked to the soil type interpretation record attribute database. This attribute database gives the proportionate extent of the component soil type and their properties for each map unit.



Table

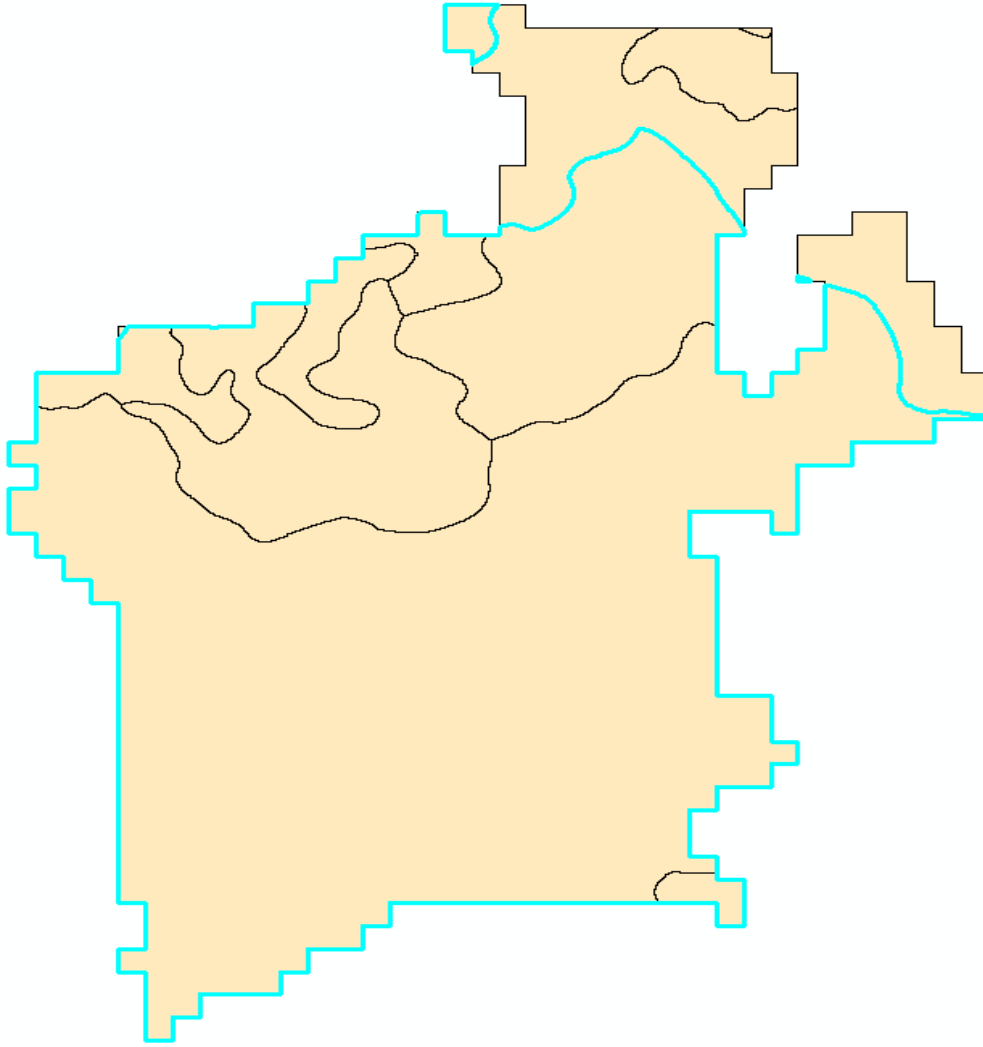
Soil

FID	Shape	AREA	PERIMETER	ETSOIL01CO	ETSOIL01_1	SOIL_CODE	GROUP	UNIT	SOIL_TYPE
0	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
1	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
2	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
3	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
4	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
5	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
6	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
7	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
8	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
9	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
10	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
11	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
12	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
13	Polygon	0	30675600	0	0	456	4	56	Eutric cambisols
14	Polygon	0	3353200	0	0	700	7	0	Leptosols
15	Polygon	0	3353200	0	0	700	7	0	Leptosols
16	Polygon	0	3353200	0	0	700	7	0	Leptosols
17	Polygon	0	3353200	0	0	700	7	0	Leptosols

(0 out of 1485 Selected)

Soil

Fig 5.4 Soil map of Awash basin



Table

Soil\_Clip

OBJECTID *	Shape *	AREA	PERIMETER	SOIL	GR	UNIT	SOIL_TYPE	Shape_Length	Shape_Area
4	Polygon	46160000	102000	1452	14	52	Calcic xerosols	4183.035794	769891.550261
5	Polygon	46160000	102000	1452	14	52	Calcic xerosols	4190.281	655140.5
6	Polygon	9400000	18400	1264	12	64	Orthic solonchaks	14990.281	7150281
7	Polygon	5560000	14400	1264	12	64	Orthic solonchaks	10099.63445	2491135.076679
8	Polygon	7640000	16400	1452	14	52	Calcic xerosols	16400	7640000
9	Polygon	6760000	20400	700	7	0	Leptosols	12306.4134	3948563.926441
10	Polygon	22880000	40000	1264	12	64	Orthic solonchaks	36102.5818	13906623.512469
11	Polygon	0	1585600	1565	15	65	Pellic vertisols	182562.8222	489249556.390599
12	Polygon	2280000	7600	1452	14	52	Calcic xerosols	4400	787359.974664
13	Polygon	0	458400	462	4	62	Vertic cambisols	9145.2296	2787465.242901
14	Polygon	22120000	33600	1264	12	64	Orthic solonchaks	28592.81528	10259666.291411

1 (1 out of 24 Selected)

Soil\_Clip

Fig 5.5 Clipped soil map of the study area

The land use/cover map was used for the estimation of the CN values used in the SCS curve number method. The hydrologic soil group of the study area is type D (annex 2) and the dominant soil type is Pelvic vertisoils the adapted CN value used is 80.

### 5.2.3 DEM PROCESSING

Owing to the increasing use of GIS, geographic information are available in digital format, For this paper, the interest is hydrologic spatial data related to the design of highway design structure located in Akaki river catchment.

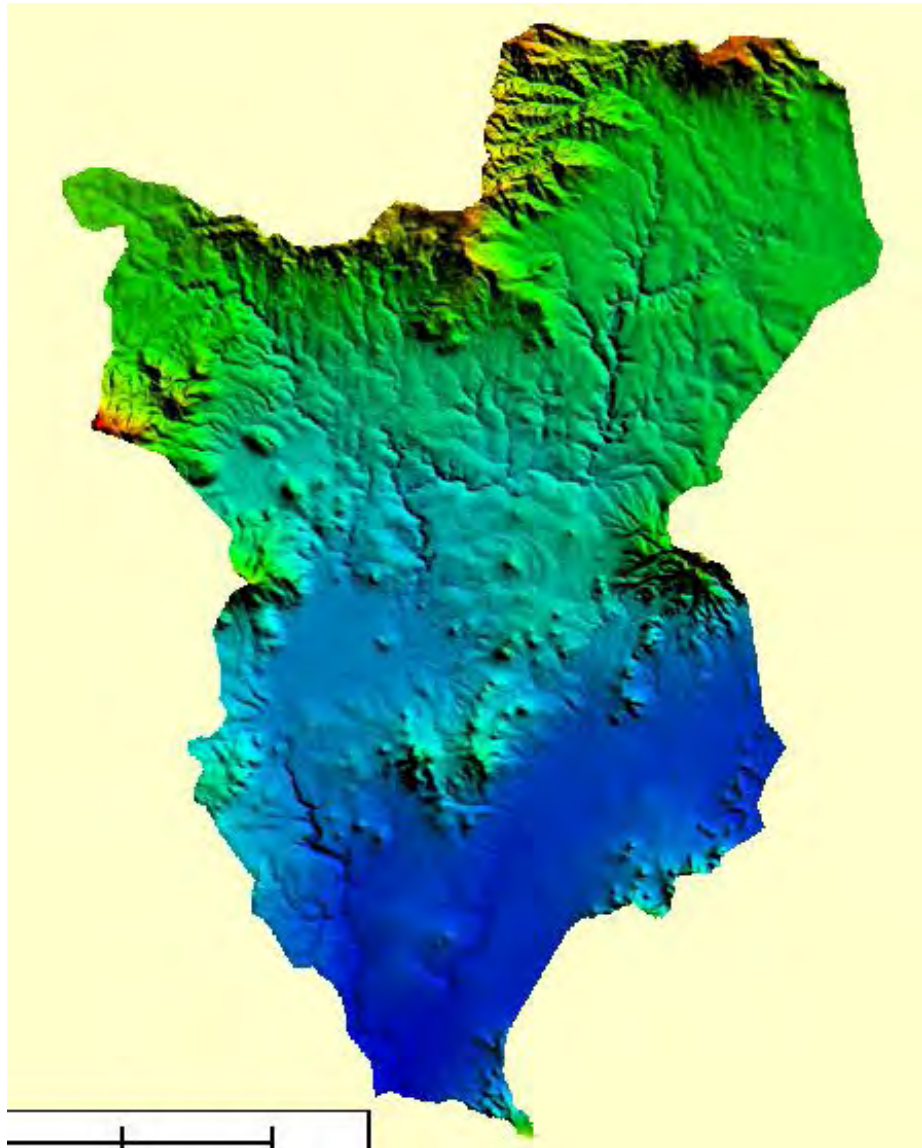
<b>SPATIAL REFERENCE</b>	
Linear Unit	Meter
Angular unit	Degree (0.017453292519943295)
False Easting	500000
False Northing	0
Central Meridian	39
Scale Factor	0.9996
Latitude of Origin	0
Datum	UTM
<b>Extent</b>	
Top	1020681.051923
Left	452340.757426
Right	508058.986306
Bottom	943604.168639

*table 5.1 Spatial reference of the study area*

A DEM is a sampled array of elevations for ground positions that are normally at regularly spaced intervals. The Defence Mapping Agency's has made available the entire world data that can be downloaded from Data Centre Internet site.

Shuttle Radar Topography Mission (SRTM) 90m resolution data for whole world is free available on <http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp> . It is in WGS 1984 projection system. DEMs are digital records of terrain elevations for ground positions at regularly spaced horizontal intervals. These grids are derived from standard topographic quadrangle maps through the use of hypsographic data and /or photogrammetric methods.

In this project, DEM is based on the 30m by 30m data spacing with the Universal Transverse Mercator (UTM) projection which is collected from ministry of water and irrigation GIS department as shown in fig 5.6. The DEM is clipped to the area of interest using Global mapper software and imported to GIS data base which is created for this purpose. The DEM is optimised through integration of the existing digitised drainage to obtain a final DEM. Most grids that can be derived from the DEM are flow direction (flow network), flow accumulation (drainage area), and flow length downstream and upstream.



*Fig 5.6 DEM coverage of Akaki catchment*

The GIS has been developed independently of specific spatial data sets, and can be applied to other region if the required spatial database is prepared. However, change in some of the scripts, associated with the horizontal and vertical units of the spatial data and with the cell size of the raster data, might be necessary for application with other data sets. The projection used is explained in table 5.1 below

### 5.2.3.1 Creating a Depression less DEM

DEM errors such as sinks and peaks should be removed before attempting to derive any surface information. In particular, sinks (defined as areas of internal drainage) may cause undesirable results when calculating flow direction.

The number of sinks in a given DEM is normally higher for coarser resolution DEMs. Another common cause of sinks results from storing the elevation data as an integer number; this can be particularly troublesome in areas of low vertical relief. It is common to find about 1% of the cells in a 30-meter-resolution DEM are sinks. This can jump sometimes as high as 5% for 3-arc-second DEMs. (Francisco Olivera and David Maidment, Oct 1999).

A DEM free of sinks, a *depression less DEM*, is the desired input to the FLOW DIRECTION Avenue request. The presence of sinks may result in an erroneous flow-direction grid. Since FLOW DIRECTION is the first step in deriving hydrologic information about a surface, its input should be as accurate as possible. When a sink is filled it is filled to its pour point, the minimum elevation along its watershed boundary (fig 5.2).

In some cases, there may be legitimate sinks in the data. It is important in this case to understand the morphology of the area to know what features may truly be sinks on the surface of the earth, and which are data errors.

Sinks can be filled using the tool fill sinks in arc hydro which is Terrain Processing- Dem Manipulation -Fill Sinks the input to fill sinks is the original DEM for this project and the filled DEM will be the output of the Fill Sinks. After filling the sinks the next step is determine flow direction.

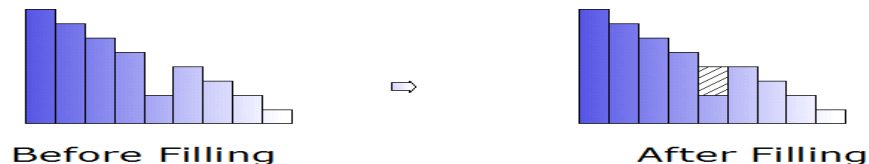


Fig 5.7 filling a sink in the DEM

## **5.3 RASTER-BASED SUB BASIN AND REACH NETWORK DELINEATION**

The DEM cells that form each reach are defined as the union of two sets of grid cells. Watershed areas will be determined by clicking on a certain point on the map in which stream crosses the road which results in an automatic selection of all the downstream cells. After the reach cells have been defined, a unique identification number, grid code, is assigned to each reach segment.

Sub-basin outlets are also defined as the union of two sets of grid cells. The first set, based on the reach network, consists of all cells located just upstream of the junctions. Consequently, at a junction, two outlet cells are identified, one for each of the upstream branches. The system outlet is also identified as a sub-basin outlet. Since these outlets are the most-downstream cells of the reach segments, their grid code is the same as their corresponding reach segment. The drainage point locations on the road segment are defined interactively by clicking on the cell of the reach network. Reach segments containing interactively-defined outlets are subdivided at the clicked cells, so that the new segments upstream of the new outlets are assigned the same grid code as their corresponding new outlet.

### **5.3.1 Flow Direction of the study area**

The flow direction of the study area is extracted from the raw Dem using the arc hydro tool. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. Accordingly water in a given cell can flow to one of its eight adjacent cells according to the slope along the direction of steepest descent.

#### **5.3.1.1 Terrain Pre-processing | Flow Direction.**

The flow direction grid was then derived from the fill grid and the premise that water flows downhill, and in so doing will follow the path of steepest descent. In a DEM grid structure, there exist at most eight cells adjacent to each individual grid cell as shown in fig 5.3 below. Accordingly water in a given cell can flow to one of its eight adjacent cells according to the slope along the direction of the steepest descent.

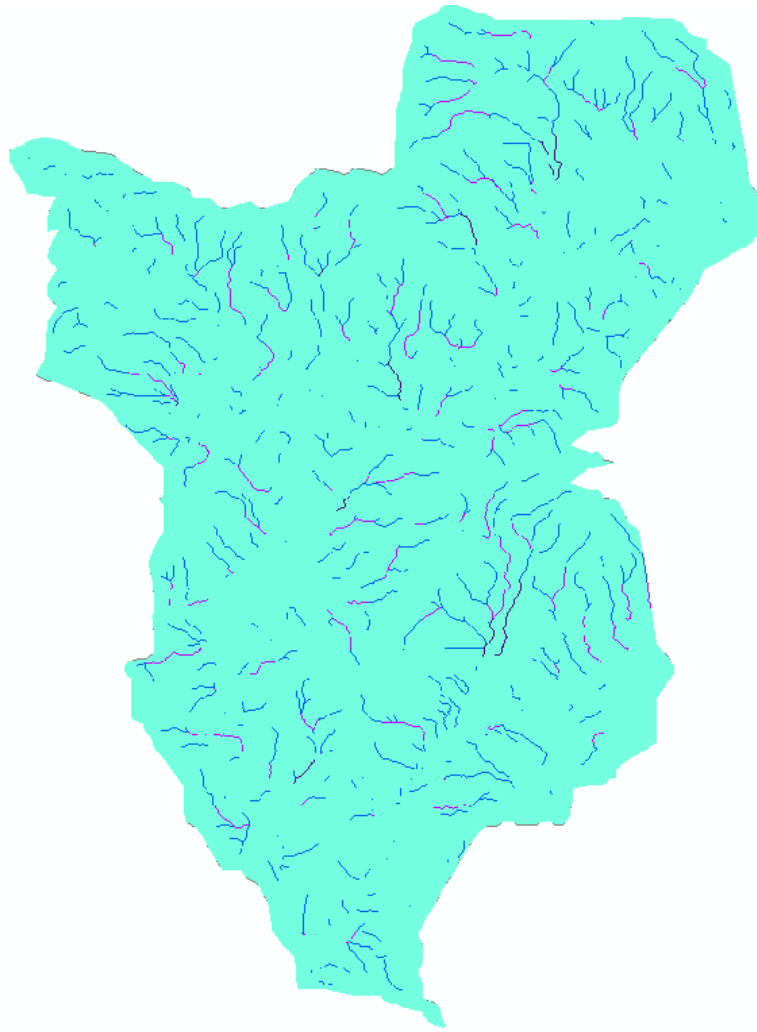


*Fig 5.8 Flow direction grid*

This function computes a stream grid which contains a value of "1" for all the cells in the input flow accumulation grid that have a value greater than the given threshold. All other cells in the Stream Grid contain no data.

### **5.3.2 Flow Accumulation**

Flow accumulation grid as in fig 5.9 was then extracted from the flow direction grid. The flow accumulation records the number of cells that drain into an individual cell in the grid. The flow accumulation grid is essentially the drainage area to a specific cell measured in grid units. The flow accumulation grid is the core grid used in stream delineation.



*Fig 5.9 Akaki flow accumulation grid*

### **5.3.3 Stream Definition**

Stream definition computes a stream grid based on a flow accumulation grid and a user defined threshold .The cells in the input flow accumulation grid that have a value greater than the threshold are assigned a value of 1 in the stream grid. All other cells in the Stream Grid contain no data.

The threshold value doesnot represent the existing streams. Smaller threshold will result in denser stream network and usually in a greater number of delineated catchments, which may hinder delineation performance.

### 5.3.4 Stream Segmentation

This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment.

#### 5.3.4.1 Terrain Preprocessing | Stream Segmentation

The stream segmentation function takes the flow direction grid and the output of stream definition grid which is extracted in the earlier steps as an input and stream link grid will be the output. The flow direction grid is *AKKAKIIfdr* and the stream grid is *AKAKIstr* the resulting stream link grid id *AKAKAIstrLnk*.

### 5.3.5 Catchment Grid Delineation

The catchment grid created is a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid.

#### 5.3.5.1 Catchment Polygon Processing

The catchment polygon is created by converting a catchment grid into a catchment polygon feature. This takes as input catchment grid which is *Akaki cat* and converts it into a catchment polygon feature class which is *Akaki watershed (fig 5.10)*. The adjacent cells in the grid that have the same grid code are combined into a single area, boundary is vectorized.



*Fig 5.10 AKAKI watershed catchment polygons*

The attribute table is stored under *AKAKI/watershed* (as shown in table 5.2 below) layer and shape length and shape area for specific location can be easily identified.

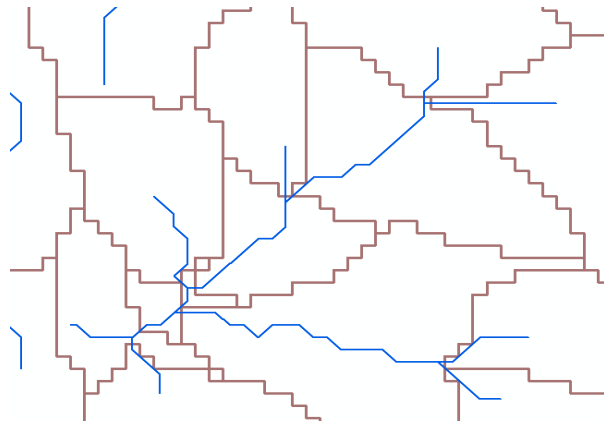
OBJECTID *	Shape *	Shape_Length	Shape_Area	Hydroid *	GridID *
1	Polygon	9537.530762	2203466.982972	1	1
2	Polygon	4768.765991	857838.272451	2	2
3	Polygon	7703.390259	1118553.710714	3	3
4	Polygon	2934.624268	159793.322475	4	4
5	Polygon	6236.078491	630763.339813	5	5
6	Polygon	5135.593628	950350.348591	6	6
7	Polygon	6052.663818	1118553.688324	7	7
8	Polygon	8620.46106	1993212.353521	8	8
9	Polygon	5685.835205	967170.562222	9	9
10	Polygon	14489.710449	5575948.647792	10	10
11	Polygon	10454.601685	3069715.356641	11	11
12	Polygon	3484.866821	302766.319374	12	12
13	Polygon	11921.913208	3431352.731575	13	13
14	Polygon	6602.906006	1404499.950794	14	14
15	Polygon	8253.632813	1152194.574568	15	15
16	Polygon	7703.390137	1825008.694739	16	16
17	Polygon	6786.319946	1850239.513349	17	17
18	Polygon	8437.046753	1597934.181902	18	18
19	Polygon	4585.351196	782146.611446	19	19
20	Polygon	5135.593628	647583.894881	20	20
21	Polygon	12472.155518	2136185.41199	21	21
22	Polygon	10271.187378	2581925.080895	22	22
23	Polygon	4952.179199	681224.271765	23	23
24	Polygon	6419.491211	1370859.030966	24	24
25	Polygon	2751.210449	210254.394362	25	25
26	Polygon	5869.249634	832607.772891	26	26
27	Polygon	6419.491577	1454960.989096	27	27
28	Polygon	4035.109253	765326.274674	28	28
29	Polygon	6969.734497	1370859.08694	29	29
30	Polygon	10454.601196	1724086.103177	30	30
31	Polygon	6786.319946	1101733.429915	31	31

table 5.2 Attribute table for AKAKI watershed

### 5.3.5.2 Drainage Line Processing

Drainage lines are feature classes which are extracted from the input stream grid and flow direction grids. The activity performed by this function is the identification of upstream-downstream relationship.

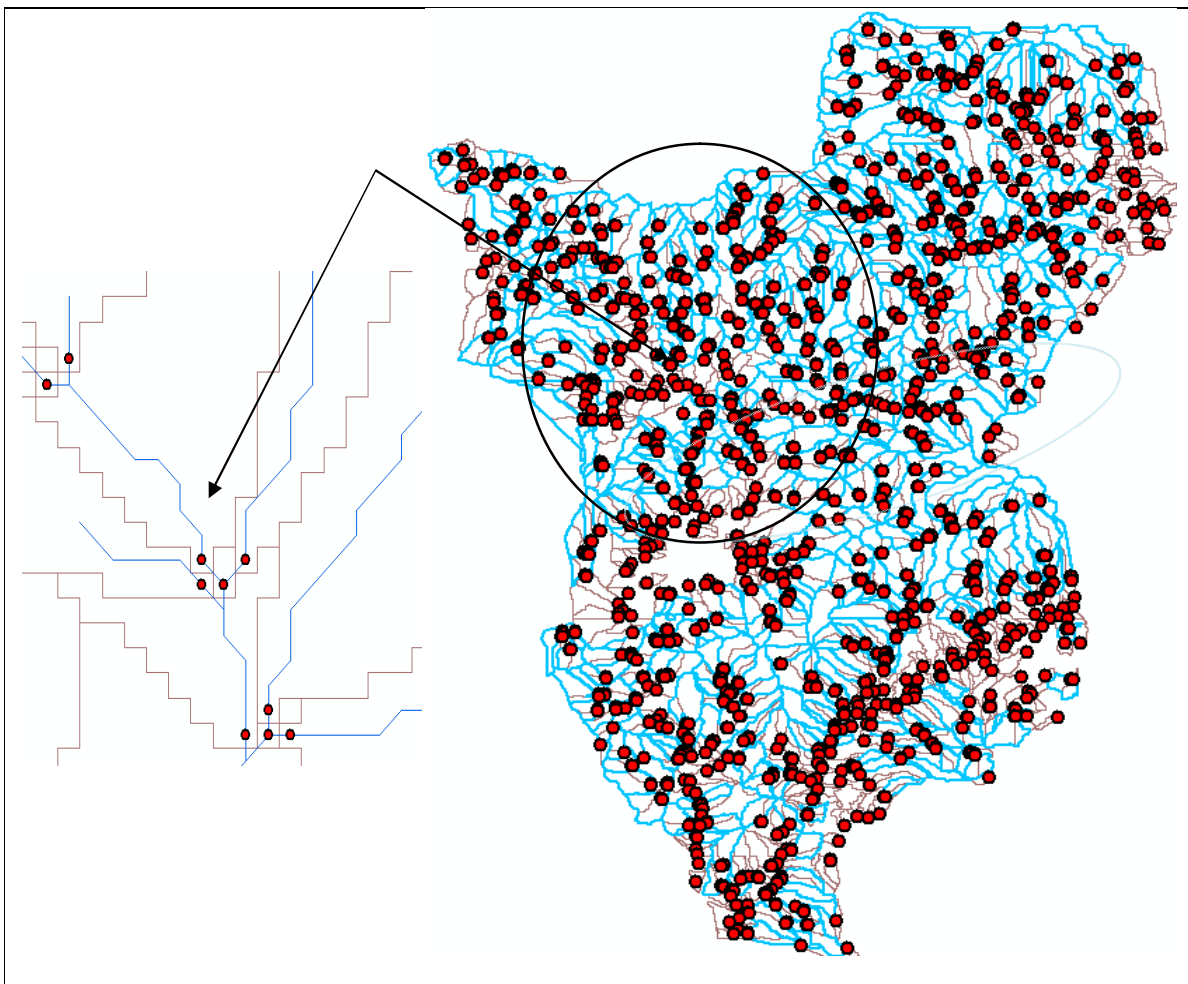
Drainage line processing takes *AKAKIstrLnk* and *AKAKIfdr* as stream link grid and flow direction grid respectively and *AKAKIDrainage Line*.The drainage lines is as shown in fig5.9.



*Fig 5.11 Drainage lines on Akaki watershed*

### 5.3.5.3 Drainage Point Processing

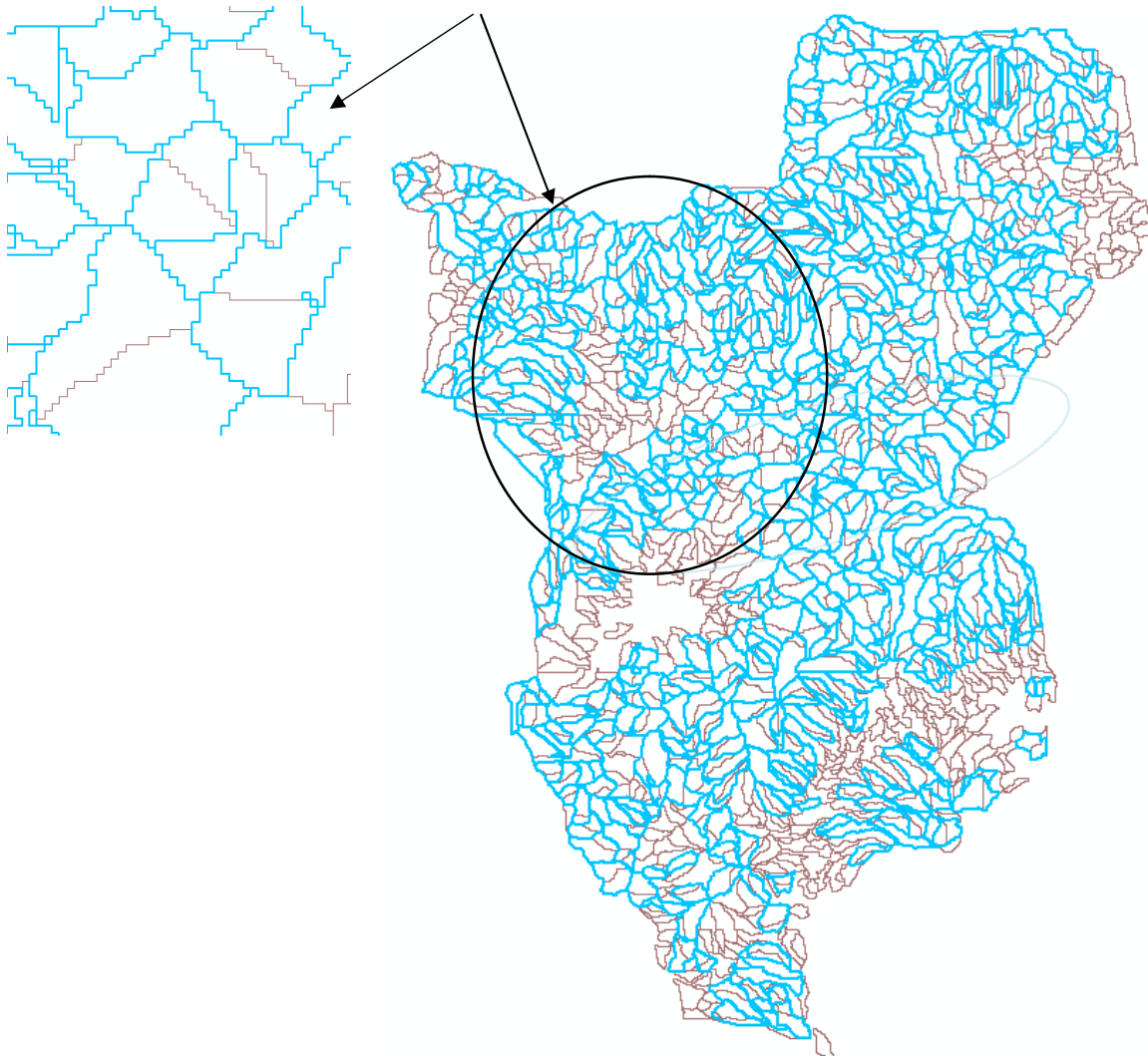
This function on terrain processing menu allows generation of drainage points associated to the catchments.



*Fig 5.12 Drainage points on Akaki watershed*

### 5.3.6 Adjoint Catchment Processing

This function generates the aggregated upstream catchments from the "Catchment" feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an "Adjoint Catchment" tag as in fig 5.11 below. This feature class is used to speed up the point delineation process.



*Fig 5.13 Adjoint catchment with drainage lines*

### 5.3.7 Locating Outlet Point

The next step is combining the road alignment which is the main road from Goro to AKAKI to the catchment grid by using the add data option on Arc Map window.

The road alignment is in *AUTOCAD* format which can easily be imported to the *GIS window*. By superimposing the drawing file over the drainage line the outlet point can easily be extracted the other approach is importing the coordinate of the outlet and adding it to the GIS database the catchment area of interest can be extracted.

The next procedure is selecting the outlet point, the outlet is selected which is on the Akaki river crossing the road alignment as shown in fig 5.14, since the aim of this paper is to extract hydrological parameters using GIS and estimating runoff using HEC HMS modelling the catchment selected has records of discharge data which helps for the calibration of the model.

On the catalog window of *ARC GIS* point feature is added with file name of *Outlet*. Using the editor tools of *ARC GIS* outlet is picked by zooming to exact locations in which the road alignment crosses the drainage lines.

The other option is picking the point by using point delineation icon from arc hydro menu. Both methods will give us the same result.

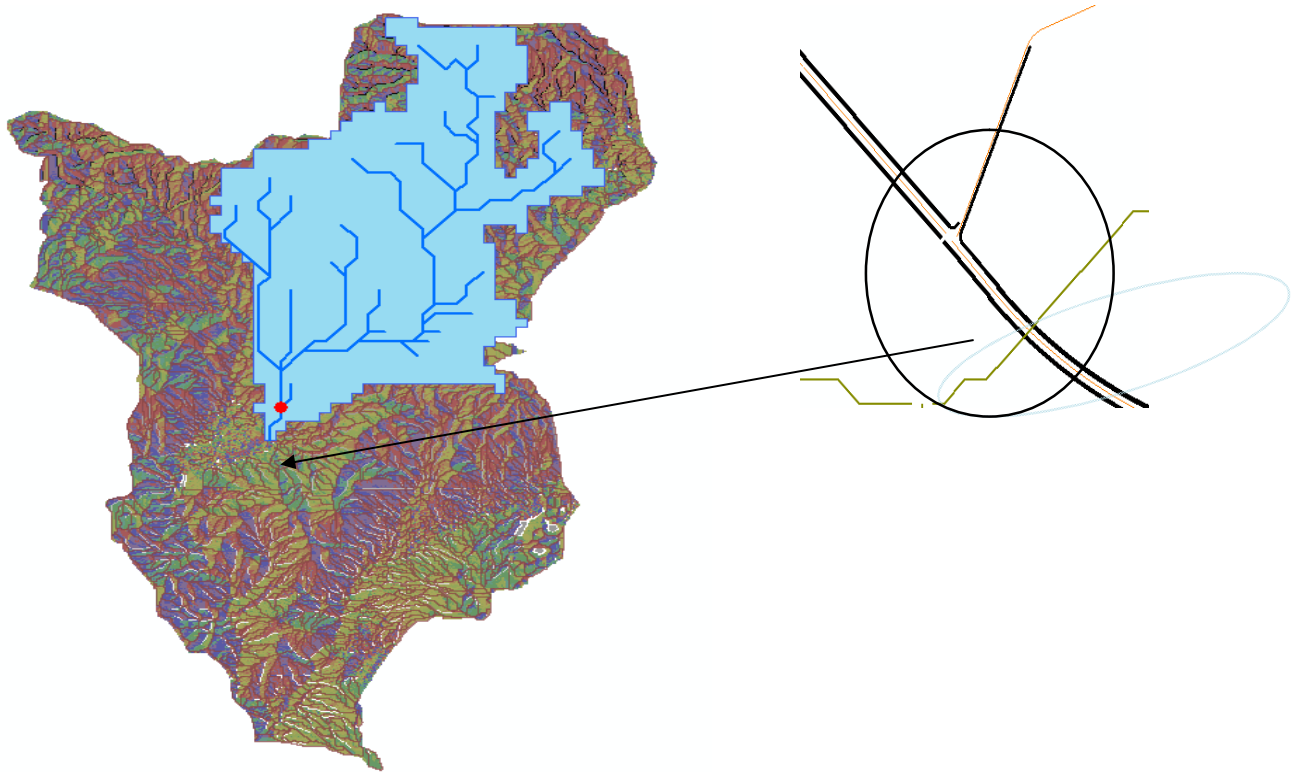


Fig 5.14 Delineated catchment areas

The watershed area will be saved under subbasin695 having its own attribute table consisting of shape length and shape area.

OBJECTID *	Shape *	grid_code	Shape_Length	Shape_Area	HydroID	DrainID
42	Polygon	42	198728.3504	726112973.912127	84	84

table 5.3 Attribute table for delineated Catchment area

### 5.3.8 Longest Flow Path and Slope Determination

Longest flow path generates the longest flow path for the selected watersheds. If no watershed has been selected this function processes all the records. This function relies on pre-processed data, and in particular the longest flow path adjoint catchment to speed up the computation of the longest flow paths.

To calculate the longest flow path on the catchment area watershed processing menu is used from *ARCHYDRO* menu. The inputs are *subbasin695* which is the catchment polygon and flow direction grid *Akakifdr* which are extracted earlier the output will be longest flow path catchment which is stored under *AkakiLongestFlowPathCat*.

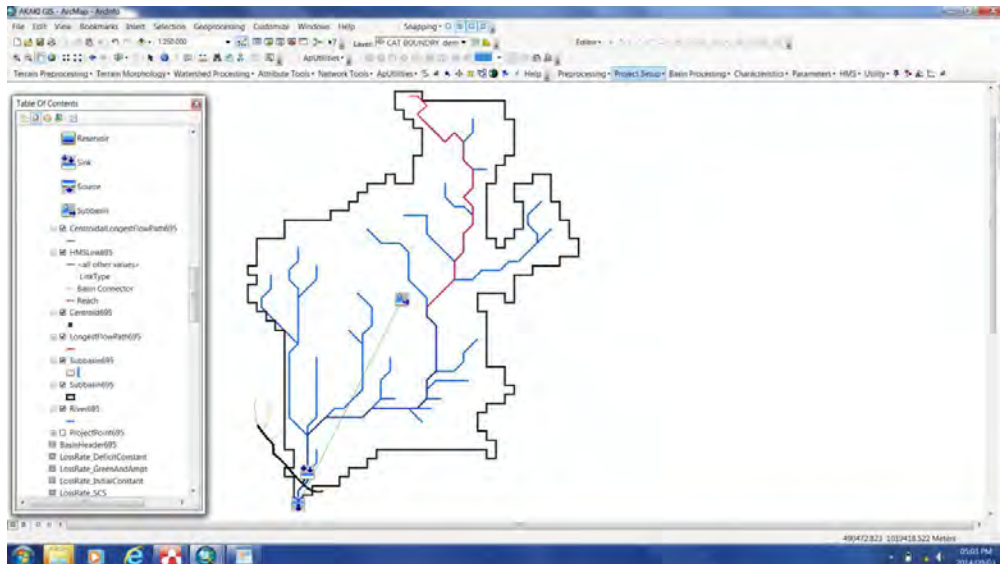


Fig 5.15 Longest flow paths on the delineated catchment

OBJECTID *	Shape *	Shape_Length	DrainID	Slp	ElevUP	ElevDS	Slp1085
1	Polyline	60466.070845	84	-0.001108	3	70	-0.001411

table 5.4 Attribute table for longest flow paths

After the longest flow path is extracted from watershed processing menu construct 3D line feature is used to convert the longest flow path line which is a 2D line to 3D line using the input as the 2Dline and Raw DEM, 3D line with its attribute table is extracted.

## **CHAPTER SIX**

### **DATA PROCESSING AND ANALYSIS**

From the above steps GIS data base has been developed to estimate watershed parameters which are catchment area, length of longest flow path, slope of longest flow path and average curve number. Peak discharges are calculated for return periods (5, 10, 25 and 50 years). HEC GEO HMS is used to extract the watershed models from the GIS.

As stream flow analysis is essential for stream flow predictions, flood control and an even use of water, Geographic Information Systems in combination with rainfall-runoff models have proven to be ideal for runoff estimations.

HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) rainfall-runoff model was chosen for the discharge calculations in the present study, a model developed by the US Army Corps of Engineers.

The HEC-HMS Rainfall-Runoff model was created for flow simulation on the basis of its three composing models: the basin model, the climatic model and the control indices. Among the many existing methods used for the generation of the hydrographs, the SCS (Soil conservation System) method is widely applied due to its accurate results (SCS,1972).

The HEC-Geo HMS (Geospatial Hydrologic Modelling Extension of US Army Corps Engineering) extension will use this pre-Processed data to extract model-Specific information from it. On the basis of elevation and geometric algorithms, the hydrologic parameters are computed, such as river length, river elevation, centroid, Longest flow path, Curve Number, CN lag time (which serve as input for the Rainfall-Runoff model in HEC-HMS).They are stored in the ARCGIS feature classes "River" and "Subbasin". After converting the Arc GIS model created with HEC-Geo HMS into an HEC-HMS model file, the initial parameters calculated in Arc GIS can be adjusted, updated or removed in HEC-HMS.

Essentially, the process of converting an ARCGIS model into an HEC-HMS project requires four steps:

- Assigning and converting ArcGIS data to a HEC-Geo HMS project (where the whole project is vectorized and concentrated on the basin of choice, with its subbasins);
- Adjusting the model where necessary and computing parameters used in HEC-HMS based on ARCGIS geographic data stored in the "River" and "Subbasin" feature classes.
- Converting the model in a HEC-HMS project where geographic data used in ArcGIS is discarded and the only left is the one computed by HEC-GeoHMS;
- Opening and working with the model in HEC-HMS.(HEC-Geo-HMS user manual)

The procedures followed in developing hydrologic model using HEC-Geo-HMS is explained below:-

The procedures followed involved three steps

- Pre-process the Terrain Model
- Basin Processing
- Hydrologic Modelling System

## **6.1 PRE-PROCESS THE TERRAIN MODEL**

The Terrain data which is used in the GIS analysis is loaded and the terrain pre-processing procedures are revised which includes filling the sinks, Flow direction determination, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing and adjoint catchment processing which are briefly discussed in the previous chapter.

The next procedure is defining a new project with a project name and description and adding the outlet for Akaki River using Add project point tool. The point created is saved under the name OUTLET 1 and project will be generated.

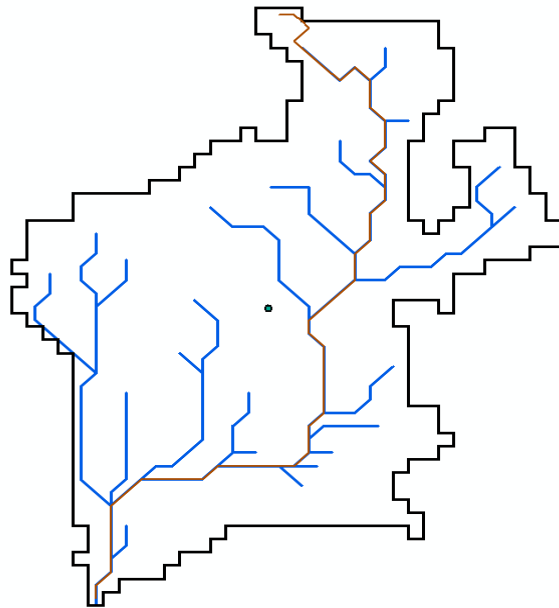
### **6.1.1 Basin Processing**

The basin processing option helps in order to merge basins and also subdivide a basin with different sub basins.

### 6.1.1.1 River characteristics

Information about the river such as river slope, river length, and longest flow path are extracted from the characteristics menu. The attribute table with all the details can be exported from HEC-Geo-HMS.

The longest flow path is also extracted from the characteristics menu as shown below.



*Fig 6.1 longest flow path*

The attribute table for the longest flow path in the catchment is extracted which includes elevations upstream and downstream and also slope of the catchment.

### 6.1.1.2 Basin Centroid

Centroid of the basin is extracted from characteristics menu by using center of gravity method the input subbasin should be the active subbasin.

Centroid elevation is also extracted from the basin centroid which is Characterstic-Center Elevation which is 2490.5m in this case.

From the attribute table for the longest flow path  $T_c$  (time of concentration) and lag time can be computed which are important parameters for the hydrologic modelling using SCS method.

## 6.1.2 Developing the Hydrologic Parameters

The next step is selecting methods of analysis by using HMS processes of the HEC Geo HMS menu the input subbasin should be the same as the subbasin we are using which is subbasin 695 and the input river should be river 695 subbasin loss method is SCS and the transform method applied is also SCS and none is selected for both subbasin-Baseflow and river route methods as shown below.

The river auto name and basin auto names are selected to make sure the same river name and basin names are used to export the data to HEC-HMS.

## 6.1.3 Develop HEC HMS Input

In this section all the required basin and map file data watershed will be exported to HEC HMS by using Map to HMS units. The results of the unit conversion are added to the attribute tables of the subbasins.

### 6.1.3.1 HMS Schematic

HMS schematic helps to display the links and symbols of HEC HMS model. The legend can also be highlighted and visualized in GIS window

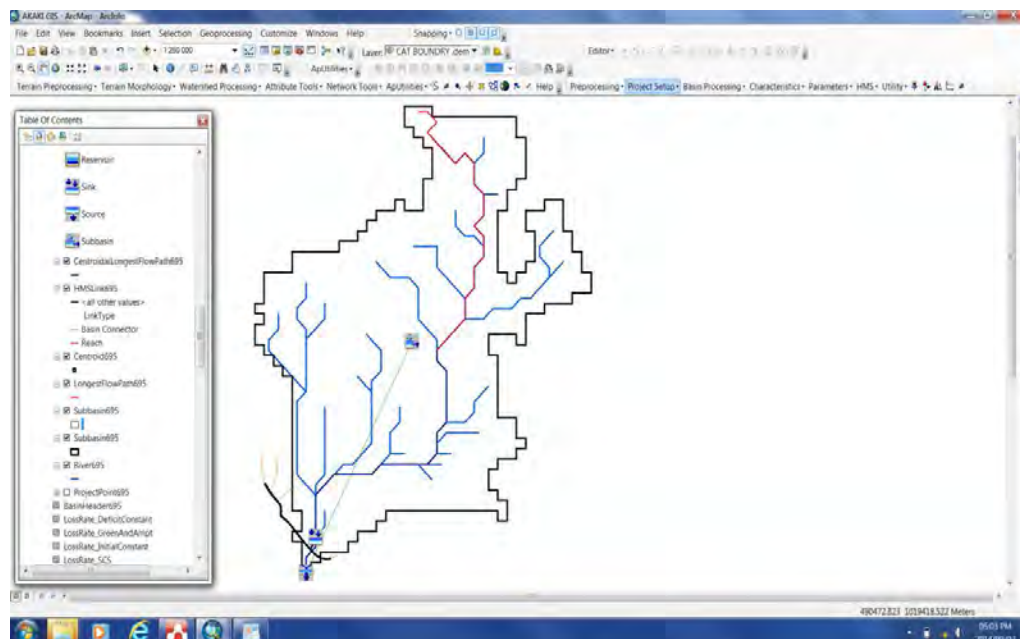


Fig 6.2 HEC HMS schematic

The basin data is ready to be exported using Basin model file and background shape file from HMS window.

## **6.2 BASIN MODEL ANALYSIS**

Rainfall runoff modelling and flood discharge estimation have always been important tasks in hydrologic sciences and engineering. Flood flow estimation, in particular, has been given special attention because of the impact that accurate forecasts have on the management of flood-related emergency programs.

For rainfall runoff modelling, HMS requires three input components:

- A basin component, which is a description of the different elements of the hydrologic system
- A precipitation component, which is a description- in space and time of the precipitation event to be modelled, and which consists of a time series of precipitation at specific points or areas and their relation to the hydrologic elements. Which also is used for calibration of the model?
- A control component, which defines the time window for the precipitation event and for the calculated flow hydrograph.

The first two components, basin and precipitation, depend strongly on spatial factors, so geographic information systems constitute a powerful tool to generate this type of input data.

HEC-HMS is a very flexible program that allows the user to choose among different loss rates, sub-basin routing scenarios, and base flow models for the sub-basin, as well as different routing methods for the reaches. However, for this research:-

- The SCS curve number method is used for loss method.
- The SCS unit hydrograph method is used for transform method for which the lag-time is calculated with the SCS lag-time formula.

SI units are required for all input data. Calculated parameters and HEC-HMS input files are also calculated in SI units. In terms of spatial data, this implies that horizontal and elevation units should be SI.

Establishing the topology of the hydrologic system consists of determining the element located downstream of each element, no ambiguity is introduced in this process. A background map file also readable by HEC-HMS is used to

graphically represent sub-basin and reaches, and ease the identification of hydrologic elements.

The basin file, when opened with HEC-HMS, generates a topologically correct schematic network of hydrologic elements and displays it in the HEC-HMS-Schematic window, together with the background map details of HEC-HMS schematic and the corresponding section of the basin file used to build it.

The SCS CN loss method, described by the soil conservation service, is based on an empirical equation that estimates effective precipitation according to the cumulative precipitation, land use and soil type. The SCS CN equation is the following:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (1)$$

Where:

Pe = effective precipitation (in) at time "t"

P = accumulated rainfall depth (in) at time t

Ia = the initial abstraction (in)

S = potential maximum retention (in)

Initial abstraction (*Ia*) is all losses before runoff begins. *Ia* is highly variable, but from data, from many small agricultural watersheds, it was approximated by the following empirical equation" (*Maidment, 1993*):

$$Ia = 0.2 \times S \quad (2)$$

The initial loss (*Ia*) was estimated to be 12.7(MM) from equation (2)

The potential maximum retention is calculated according to the Curve Number (CN).

$$S = (1000/CN) - 10 \quad (3)$$

The SCS Unit Hydrograph Method was developed and applied starting with the 1950s in the US, and due to its simplicity, its use has been adopted all around the world. The parameters needed for generating the Hydrograph are the lag time, *tL* and the watershed areas, both calculated with the help of HEC Geo HMS (On the basis of the lag time ("Basin Lag", in hours), the time of concentration, *Tc* (in hours) corresponding to the sub watersheds was also calculated

previously: The model analysis is computed for return periods 10, 25, 50 and 100.

The model approach used to determine the runoff volume was the SCS-CN method. With this method, the precipitation excess is a function of cumulative precipitation, soil type, land use/cover and antecedent moisture. Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth,  $P$ , and runoff depth,  $Q$  (USDA, 1986; Schulze et al., 1992):

$$Q = \frac{(P - 0.2 S)^2}{(P + 0.8 S)} \text{ for } P > 0.2 S; \text{ otherwise } Q = 0 \quad (1)$$

$$S = \frac{25400}{CN} - 254 \text{ (in mm)} \quad (2)$$

$$I_a = 0.2 S \quad (3)$$

Where:  $Q$  is surface runoff (mm),  $P$  is the precipitation (mm),  $S$  is the soil retention (mm),  $I_a$  is the initial loss (mm), and CN is the curve number.

To obtain volumes,  $P$  and  $Q$  must be multiplied by the basin area. The potential maximum retention ( $S$ ) represents an upper limit for the amount of water that can enter the basin through surface storage, infiltration, and other hydrologic losses. For convenience,  $S$  is expressed in terms of a CN, which is a dimensionless basin parameter ranging from 0 to 100. A CN of 100 represents a limit condition for a perfectly impermeable basin with zero retention, where all the rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the basin trapping all the rainfall with no runoff regardless of the rainfall amount. The basin parameter CN can be determined from empirical information. The SCS has developed tables of initial curve number (CNI) values as a function of the basin soil type and the land cover/use/condition. These are listed in Schulze et al. (1992). The hydrologic soil groups are defined in accordance to the standard SCS soil classification procedures, which establish a range from classification A for sand and aggregated silts with high infiltration

rates, to classification D for soils that swell significantly when wet and have low infiltration rates. On the basis of the soil information for the study area and the Visible ground coverage, a CN of 80 was chosen. A potential retention (S) of 63.5 mm was computed by applying Equation 2. The initial loss (Ia) was estimated to be 12.7 mm from Equation 3. These values were used in the model for the study area. To determine how the runoff is distributed over time we must introduce a time-dependent factor. The time-of concentration ( $t_c$ ) is used in the SCS methods. The  $t_c$  is most often defined as the time required for a particle of water to travel from the most hydrological remote point in the basin to the point of collection. There are several methods available for calculating  $t_c$ , one of them is the SCS Lag Method:

$$t_L = \frac{L^{0.8} [ (1000 / CN) - 9 ]^{0.7}}{1900S^{0.5}} \quad (4)$$

$$t_c = 1.67 t_L \quad (5)$$

Where  $t_c$  is the time of concentration (minutes);  $t_L$  is the watershed lag time (minutes);  $L$  is the length of longest watercourse (ft);  $S$  is the mean slope of the basin (%); and CN is the curve number.

Subbasin	Area (km <sup>2</sup> )	$t_c$ (min)	CN	Initial loss (mm)	$t_L$ (min)
Subbasin 1	725.98	1160.65	80	12.7	695

*table 6.1 Attribute table for the basin with the calculated hydrologic parameters*

### 6.3 COMPUTATION OF HYDROLOGIC PARAMETERS

The sub-basin parameters (area, lag-time and average curve number) were calculated. Other parameters, needed for estimating the lag-time, such as length and slope of the longest flow path, were also calculated and stored in the sub-basin attribute table. These files, when opened in HEC-HMS, automatically create topologically correct schematic network of sub-basins and reach with hydrologic parameters. Table 1 shows the attribute table for the sub-basins with

the calculated hydrologic parameters. The following procedure was adopted to construct the rainfall-runoff model for the catchment area. A schematic representation of the catchment was created by dragging and dropping icons that represent hydrological elements, and connections between them were established. The hydrologic parameters for each sub-basin were entered using HEC-HMS sub-basin editor; required data consist of sub-basin area, loss rate method (SCS-CN method was used), transform method (SCS Unit Hydrograph method was used), and base flow method (base flow was set to zero for Study area). Considering that the time span of the storm event was short, it was assumed that evapotranspiration was zero.

A precipitation model is the next component of the HEC-HMS model. The intensity of rainfall was obtained from the Intensity-Duration-Frequency (IDF) curve of the region rainfall station for the selected return periods: 5, 10, 25 years and 50 years (annex). For each time duration, the corresponding precipitation depth was computed as the product of intensity and duration. The precipitation data were used for each corresponding return periods. Finally, the control specifications for three-day simulation period were selected with 24 hour time interval.

Table below shows a summary of the computed direct runoff volume and peak discharge for each sub-basin in the simulated model. The peak discharge for the 3 day design storm with the corresponding return periods is as shown in table 6.2 below.

Hydrologic element				
Drainage area (Km <sup>2</sup> )	725.98			
IDF curve for return periods	10	25	50	100
Peak Discharge/m <sup>3</sup> /sec	216.5	326.1	416.4	504.3

*table 6.2summary of computed peak discharge for return periods*

## 6.4 MODEL CALIBRATION AND OPTIMIZATION

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations. Once a model was developed and simulated for the initial parameter estimates, it was calibrated against known discharge runoff rates measured at Akaki station for the year 2004. The model calibration was done by adjusting the curve number values until the results matched the field data. The process was done automatically by using the iterative calibration procedure called optimization. The process can also be completed manually by repeatedly adjusting the parameters, computing, and inspecting the goodness of fit between the computed and observed hydrographs.

The measure of the goodness of fit is the objective function to provide the best calibration results (HEC, 2005). The objective function measures the variation between computed and observed hydrographs, and is equal to zero when the hydrographs are identical. The automated calibration was used to adjust initial losses, curve number and lag time to optimize the objective function value and to find optimal parameters. When manual validation of the observed and simulated hydrograph was not acceptable, initial parameters were adjusted to provide a better optimization target value for the optimization process (USACE, 2000). The objective function used was the peak-weighted root mean square error (RMS). This objective function gave greater weight to large errors and lesser weight to small errors, in addition of giving greater overall weight to error near the peak discharge.

The optimization procedure required the use of a search method for minimizing an objective function and finding optimal parameters. The search method used for this calibration was the univariate gradient method. This method evaluated and adjusted one parameter at a time while holding all other parameters constant. The search method estimates the optimal parameters but do not indicates while parameters had the greatest impact on the solution (kathol et al., 2003). Besides evaluating the objective function for determining if the process produces an accurate calibration, graphical comparisons were made between the fit of the model and the actual measured data. Graphical comparisons of scatter plots and time series plots of residuals between computed and observed flow were used to visually inspect the results of the calibration (Kathol et al., 2003).

The storm event used to calibrate the model was chosen because of the goodness of fit for the basin. The function value for the peak RMS error was set at only 0.1 which is reasonable value (Hammouri and El-Naqa, 2007) The values for the basin model parameters indicate that the CN had low sensitivity to changes in the function value. Therefore, any change in the CN value will slightly affect the overall function if all other variables are held constant. The curve number was set to an optimized value of 74 this is a reasonable value, as it is in the range of 71 and 89 (Annex 2).

The results of the difference of peak runoff for the simulated model versus the observed models are included in table 6.4. The values for time of peak runoff and the time of center of mass for the simulated and observed results are also included in that table.

The flow comparison graph for the outlet of the catchment area indicates how well the calibrated model fits the observed runoff data fig 6.4 shows the plot between the observed and simulated outflows. Area conversion factor is applied as the measured catchment has larger area than the case study.

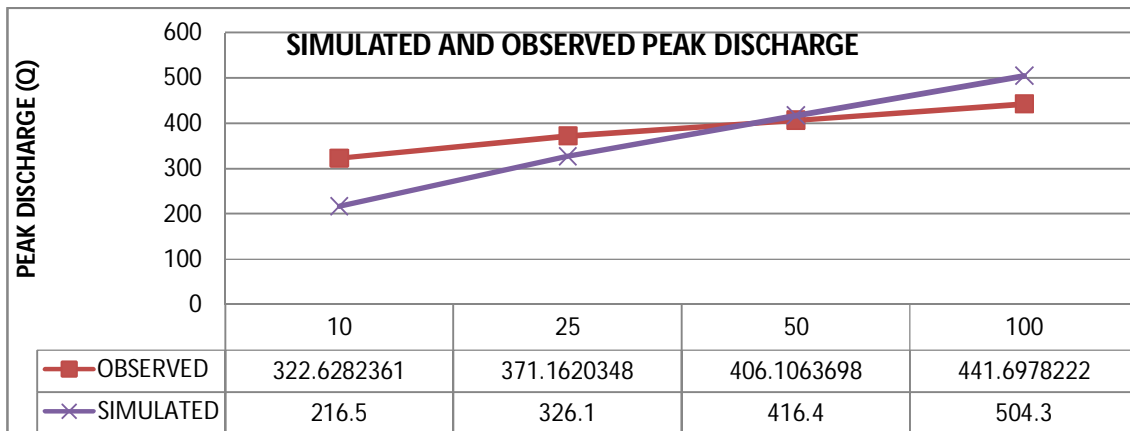


Fig 6.4 flow comparison of simulated and observed outlet flow for return periods, 10, 25, 50, 100 years

## 6.5 Hydraulics of Bridge

The main objective of hydraulic analysis is the determination of safest and economical cross sectional elements such as type, shape, depth, width, slope and others which can safely drain the design discharge without overtopping the structure and with none silting and scouring system.

The design discharge for the drainage structures depends on the selected flood frequency, termed the recurrence interval or return period. By selecting a larger recurrence interval the probability of the flood discharge exceeding the capacity of the structure is reduced, but the cost of the structure to accommodate such larger floods are increased.

Lifetime (years)	Recurrence Interval		
	10 years	25 years	50 years
10	65%	34%	18%
25	93%	64%	40%
50	99%	87%	64%

*table 6.3 Risk of exceedence in percent for different recurrence intervals and life times of a project*

The probability 'P' that an event with a return period 'T' occurs during a 'n' years period is given by:

$$P = 1 - (1 - 1/T)^n$$

Or P is chance of failure

T is flood recurrence interval and

n is design life of structure

Hence, according to this the probability that a 100 year flood will occur during a 25 year period is 22%.

The water way opening of a bridge must be large enough to pass the design flood without creating excessive backwater.

An analysis of the channel to determine the relationship between peak flow, water way opening, water-surface elevation at the structure and upstream from it, and flow velocity must then be made. A major factor is the degree of contraction of the flowing water in the approach channel.

When the downstream depth has no effect on the discharge due to the information of the "Standing Wave", the discharge 'Q' results from:

$$Q = 1.71 C_d L [Y_u + V_u^2/2g]^{3/2}$$

Where,  $C_d$  = Discharge coefficient.

$L$  = Effective opening width, m.

$Y_u$  = Upstream water depth, m.

$V_u$  = Upstream velocity, m/sec.

' $C_d$ ' accounts for frictional losses. The various values of ' $C_d$ ' for different types of openings are:

- for narrow bridge openings with or without lined/paved riverbed,  $C_d = 0.94$ ;
- for wide bridge openings with lined/paved riverbed,  $C_d = 0.96$ ;
- For wide bridge openings without lined/paved riverbed,  $C_d = 0.98$ .

For general purposes the allowable velocity can be taken as safe velocity and for most of the river beds it can be assumed that  $V_u = 1.2$  m/sec.

Though these methods are to be employed the simplified method relating height and width of the structures is adopted for the estimate of the flood carrying capacity as shown in **annex**

The capacity equations used are derived from the monographs assuming square edge with wing wall as entrance type.

### **6.5.1 Water Surface Profile Determination Using HEC- RAS**

HEC-RAS is a one-dimensional (1-D) model, intended for 1-D hydraulic analyses of river channels. In HEC-RAS, the stream morphology is represented by a series of cross section called river stations. Proceeding from downstream to upstream, the river station number increases. The distance between adjacent cross sections is termed the reach length.

The HEC-RAS model requires cross sections to be defined such that they are perpendicular to flow lines in the flood ways and main channel. Within relatively straight portions of the channel, this means straight cross sections.

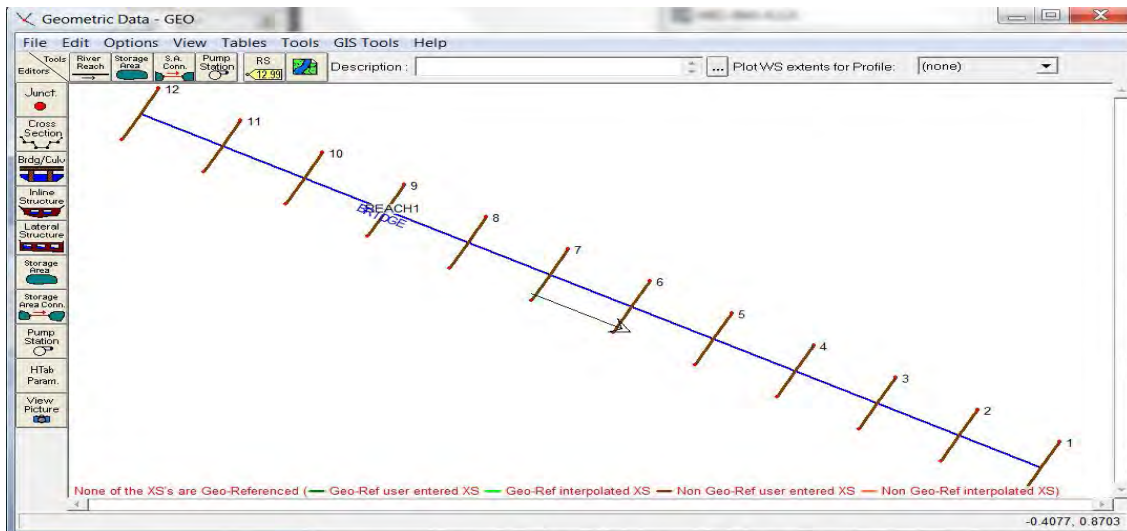


Fig 6.5 HEC RAS one dimensional stream schematic

In the HEC-RAS coordinate system, the coordinate of any given point is based on its river station along a one-dimensional stream centerline, its location along the cross-section line, and its elevation. Each cross section is defined by a series of lateral and elevation coordinated, which are typically obtained from land surveys. The numbering of the lateral coordinated begins at the left end of the cross section (looking down stream), and increases until reaching the right end. The value of the starting lateral coordinate is arbitrary; only the distance between points is important and steady flow is assumed throughout the length.

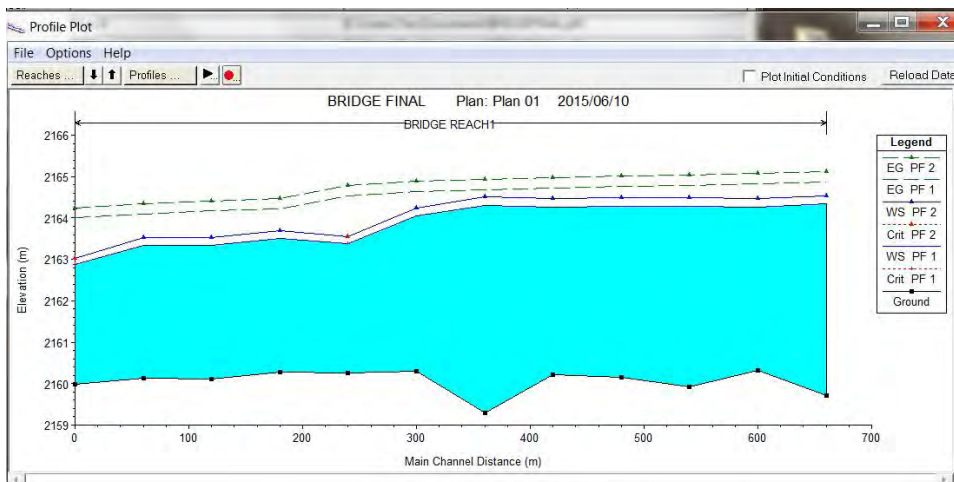


Fig 6.6 HEC-RAS Cross-Section plot

## 6.6 Comparison with Manual Techniques

The selected case study is previously designed with manual methods and the computed peak discharge for the return period of 100 was 560.21m<sup>3</sup>/sec and HWM is 2164.64m.

From the above result we can see that the HWM of the previous design is observed to be higher elevation which has an effect on the design of the road alignment as the profile of the road depends on the top of bridge elevation.

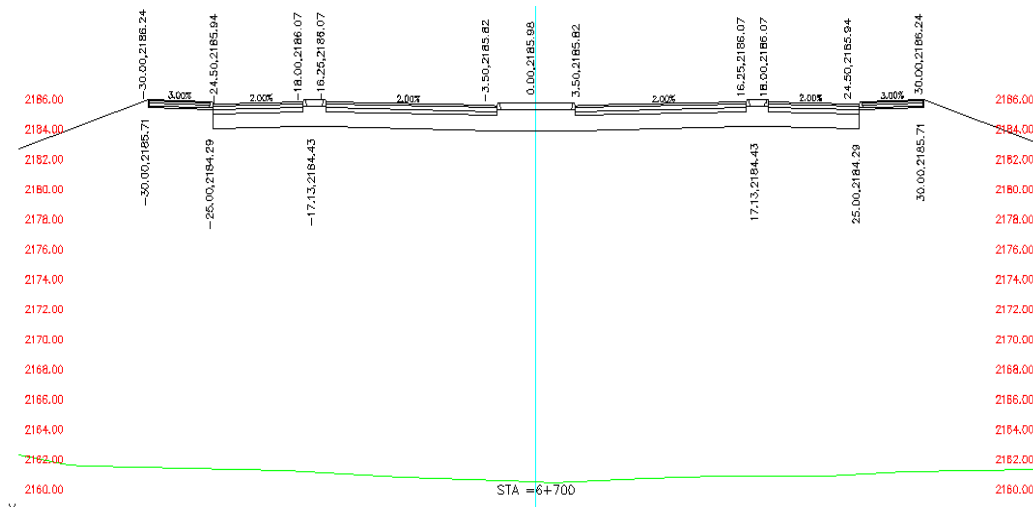


Fig 6.7 cross section of the road section at the bridge

## CHAPTER SEVEN

### CONCLUSION AND RECOMMENDATION

#### 7.1 CONCLUSION

It is observed that hydrologic parameters can be easily extracted from GIS using the Raw DEM of the area. The extracted parameters which are catchment area, longest flow path, slope; land use and soil types can be easily converted and adjusted to be in the HEC-HMS model format using HEC-Geo-HMS.

Accuracy of catchment delineation and overland flow path estimation plays a crucial role in the development and calibration of hydrologic and hydraulic models of urban and rural catchments.

- Delineating the catchment area by using a scanned map is observed to be tiresome and leads to personal errors.
- Using the spatial analysis and incorporating GIS with Arc hydro and HEC-Geo-HMS better result can be obtained.
- For places with no available Topo maps it's difficult to do the hydrological analysis and drainage structures design. Applying the GIS tools DEMs of the area can be obtained and the analysis can be done.
- IF there is a possibility to get DEM's with higher accuracy better result can be obtained.
- Proper determination of river profile and high water mark is essential for highway design of roads.

#### 7.2 RECOMMENDATION

- As GIS is contributing a lot to the road sector industry it's better to be familiar with it and adapt its uses.
- It is easier and better to upgrade the usual trend of hydrological analysis which is calculating the catchment areas and other hydrological parameters manually.

- Ethiopian roads Authority should further study the procedure and force the designers to use GIS for their analysis.
- DEM's can be produced using GIS raster techniques. Features like roads, buildings and stream banks have great effect on catchment dynamics and overland pathways and as such must be accounted for in the DEM set-up.
- Reconditioning the DEM to account for roads is required for catchment delineation.
- A successful GIS based automatic catchment delineation is dependent on the factors: the extent and accessibility of the data sources, the accuracy of the GIS base data, and the type of system being modelled.
- Manual "cleaning" of the automated techniques must be anticipated to obtain usable results. The level of cleaning is directly related to care taken with input parameters and the required accuracy for the project.
- The automated techniques discussed if used correctly can significantly expedite the model build process.

## REFERENCES

Applications of GIS Introduction (2002).

AAWSA, BCEOM, SEURECA and TROPICS (2000). Addis Ababa water supply project - stage III A groundwater - Phase II, modelling of Akaki well field, V1, Draft main report. Addis Ababa Water and Sewerage Authority, Addis Ababa, Ethiopia.

Arlen D.Feldman, Bruce A. De Vantier (1993). Review of GIS Applications in Hydrologic Modelling

ERA Drainage Design Manual (2001)

Francisco Olivera and David Maidment (Oct 1999), GIS-Based system of Hydrologic and Hydraulic Applications for Highway Engineering.

Garbrecht and Martz (1994): Grid size dependency of parameters extracted from digital elevation Models.

Highway design manual, (2001)

HEC-Geo-HMS user manual,(2013)

Moore,I.D.; Grayson,R. B. 1991: Terrain-based catchment portioning and runoff prediction using vector elevation data

*Maidment, 1993* Maidment, DR., 1991. GIS and hydrologic modelling.

Nezar Hammouri and Ali El-Naqa, Hydrological modelling of Ungauged wadis in arid environments using GIS, M.Sc.Thesis, Department of Earth and Environmental Sciences, Hashemite University, Jordan

SCS, 1972. National engineering handbook, sec. 4: hydrology, soil conservation service (SCS). USDA, Washington, D.C.

Solomon Tale, 2000 Solomon Tale (2000). The Extent of Surface and Groundwater Pollution in Addis Ababa. M.Sc. Thesis, Addis Ababa University, Addis Ababa.

Thielen , A.H.; Lucke, A.; Diekkruger, B.; Richter, O.(1999): Scaling input data by GIS for hydrological modeling

USACE, 2000 US Army Corps of Engineers, 1990. HEC-1, Flood Hydrograph package: User's manual version 4, 1990, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA.

Van Te Chow (1988), Applied Hydrology

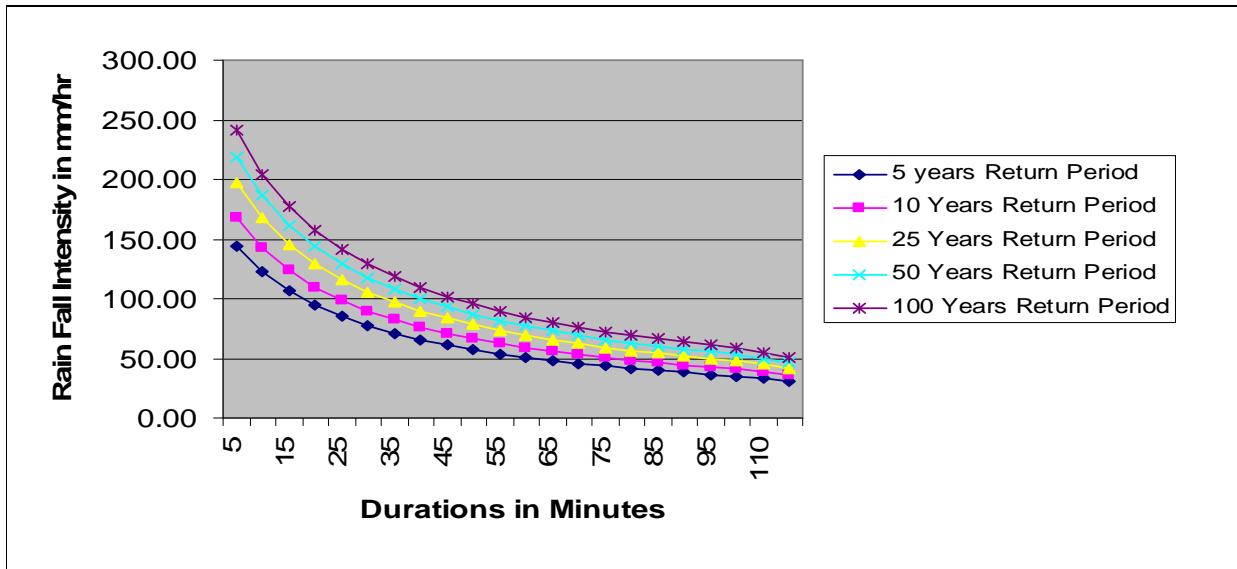
Wolock, D.M.; Price, C.V. (1994): Effects of digital elevation model map scale and data resolution on topography-based watershed model

Walker, J.P.; Wilgoose, G. R. (1999): On the effect of digital elevation model accuracy on hydrology and geomorphology

Yewondosen Mengistu and Dereje Nugussa (2002). Large Dams in Ethiopia.

## APPENDIX

### ANNEX 1 IDF CURVE



### ANNEX 2 SOIL CLASSIFICATION TABLE

Cover type	Hydrologic condition <sup>2</sup>	A <sup>3</sup>	B	C	D
Mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Mountain brush mixture of small trees and brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Small trees with grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Brush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub brush	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

<sup>1</sup> Average runoff condition, and  $I_a = 0.2S$

<sup>2</sup> Poor : < 30 % ground cover (litter, grass, and brush overstory)

Fair : 30 to 70 % ground cover    Good: > 70 % ground cover

<sup>3</sup> Curve numbers for Group A have been developed only for desert shrub

### ANNEX 3 DESIGN RETURN PERIOD FOR ROAD TYPES

Roadway Classification	Exceedance Probability	Return Period
Urban Principal Arterian Road	4% - 2%	25 – 50-year
Urban Minor Arterian Road	4%	25-year
Urban Collector Street System	10%	10-year
Urban Local Street System	20% - 10 %	5 – 10-year

Source: AACRA Drainage Design Manual (HDS2 1996)

### ANNEX 4 RETURN PERIODS FOR DIFFERENT STRUCTURES

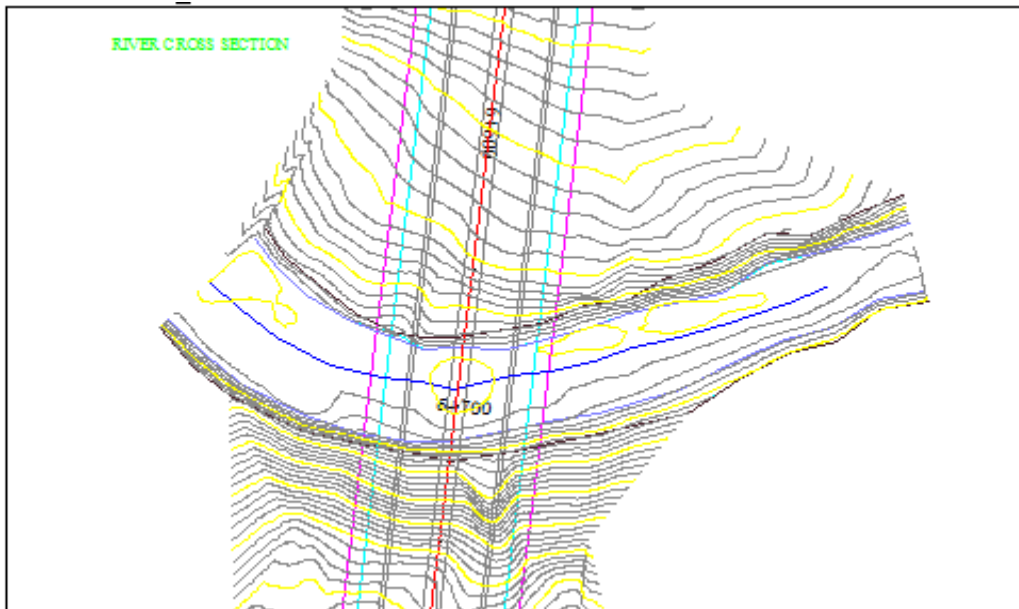
Structure Type	Return Period for DS 3 & DS 4
Bridges	
Span > 50m	100 Years
Span 6 – 50m	50 Years
Box and large slab culverts (2 – 6m span)	25 Years
Pipe and small slab/box culverts	10 Years

Source: ERA Drainage Design Manual – 2002

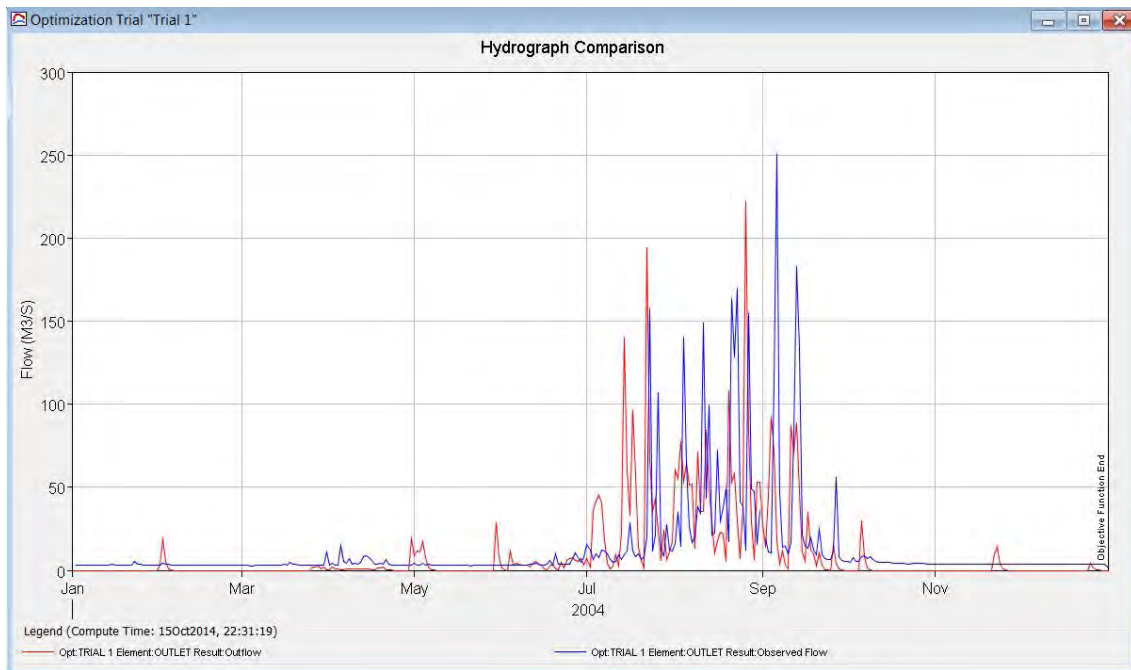
## ANNEX 5 EQUATIONS FOR CALCULATING THE CULVERT CAPACITY

Type of structures	Equations	Remarks
Bridges	$HW/h=1.0, Q= 1.4*bh^{1.5}$	
Box and arch structures, including slab culverts	$HW/h=1.0, Q= 1.4*bh^{1.5}$ $HW/h=1.2, Q= 1.76*bh^{1.5}$	Arch culverts will under inlet control in most cases operate as a box culvert
Pipe culverts	$HW/h=1.0, Q= 1.2*d^{2.5}$ $HW/h=1.2, Q= 1.55*d^{2.5}$	
Armco pipes	$HW/h=1.0 Q= 2.2*h^{2.5}$ $HW/h=1.2 Q= 2.7*h^{2.5}$	Valid for a span and rise ratio of approx. 1.6

## ANNEX 6 RIVER CROSSECTIONS OF THE BRIDGE



# ANNEX 7 SIMULATED AND OBSERVED DISCHARGE



## ANNEX 8 DISCHARGE AND RAINFALL DATA OF AKAKI RIVER

Station: AKAKI MISSION

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	Max daily
1975	0	0	3.8	107.2	58.5	175.2	347.2	308.3	281.6	19.9	0	0	1301	347.2
1976	0	17	19.5	92	93.8	195.3	282.4	325.3	83.6	7	46.6	0.5	1163	325.3
1977	80.5	29.9	80.8	67.4	108.2	158	289.7	329.4	108.4	225.7	5	0	1483	329.4
1978	2.4	84.4	607	50.4	39.7	153.8	150.6	328.2	194.6	45.5	0	0	1656	607
1979	106.4	28.2	107.6	57.6	122	75.9	243.2	241.4	96.5	13	0	4	1095	243.2
1980	28.5	36.8	54.7	55.8	56.8	111.8	381.5	364.4	64.4	13.1	0	0	1167	381.5
1981	0	13.3	179.8	143.9	1.3	46.2	402.6	186.5	219	5	0	0	1197	402.6
1982	12.1	35.4	39.5	94.6	75.2	63.5	199.6	275.1	124.2	25.8	11	8.1	964	275.1
1983	1.8	33.3	15	147.3	175	83	278	275	138.7	9.2	0	0	1156	278
1984	0	0	40.4	5.1	130	215.3	277.9	227.1	57.2	0	0	1.9	954	277.9
1985	3.6	0	32.4	71.8	96.6	96.5	294	324.1	164.3	1.6	0	0	1084	324.1
1986	0	95.4	66.9	148.7	68.2	143.4	189.4	216.5	86.1	9.4	0	0	1024	216.5
1987	0	65.6	181.9	80.7	187.7	69.3	202	246.9	81.7	4.4	0	0	1120	246.9
1988	0	44.5	0	96	23.8	124.6	255.9	278.1	254.2	35.4	0	0	1112	278.1
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301	170.9	37.9	0	0	1185	301
1990	7.7	120.6	48.4	129.4	37.8	78.9	280.7	222.9	117.3	5.8	1.2	0	1050	280.7
1991	0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.4	4.4	0	56.5	994	308.5
1992	34.7	24.2	30.5	15.5	25.6	100.4	218.4	276	86.7	43.3	0.2	0	855	276
1993	1.2	53.9	5.6	118.4	62.5	116.5	218	251.5	118.3	20.5	0	0	966	251.5
1994	0	0	62.7	72.2	20.2	125	251	168.9	106.8	x	11	0	817	251
1995	0	25.4	63.7	102.1	20.9	95.7	269.2	242.3	79.5	0	0	4.8	903	269.2
1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119	1.9	0	0	1112	292.5
1997	27.6	0	29.5	102.7	25.2	57	203.6	203.4	82.5	114.9	10.3	0	856	203.6
1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280	118.5	36	0	0	1070	280

1999	1.3	1.8	91.8	12.1	44.7	92.8	282.6	300.7	61.7	65	0	0	954	300.7
2000	0	0	29.1	93	64.9	100.1	188.9	210	124.1		23.4	3.8	837	210
2001	0	20.7	121.2	23.6	118	142.6	257.5	145	64.9	2.2	0	0	895	257.5
2002	31.1	10.5	87.1	82.4	76.6	108	167.3	187	52.4	0.6	0	17.7	820	187
2003	19.6	24.3	23.9	114	2.9	125.4	325.1	307.4	112.4	0	1.9	0	1056.9	325.1
2004	13.6	15.8	62.4	154.2	15.4	95.2	177.7	189.1	80.9	4.8	x	x	809	189.1
total	422.2	895.9	2301	2584.1	2054.6	3455.4	7662	7754.1	3563.8	752.3	105.6	96.8	31647.7	290.54
average	14.1	29.8	76.7	86.1	68.5	115.2	255.4	258.5	118.8	25.1	3.6	3.2	1055	78.83065