Limitations in the Process of Peak Discharge Estimation for Design of Major Road Crossing Drainage Structures

(*Based on Current Practices in Ethiopia*)

SCHOOL OF GRADUATE STUDIES
ADDIS ABABA UNIVERSITY

By

Mekari Zemedagegnehu

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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Thesis Advisor

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DECLARATION

I the undersigned, declare that, this Thesis is my work and all sources of materials used for this Thesis have been duly acknowledged.

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LIST OF ACRONYMS

Acronym	Description
A	Area
AACRA	Addis Ababa City Roads Authority
AACRADDM	AACRA Drainage Design Manual
AMC	Antecedent Moisture Content
C	Runoff Coefficient
CN	Runoff Curve Number
D	Unit Duration of Excess Rainfall
DDM	Drainage Design Manual
DEM	Digital Elevation Model
ERA	Ethiopian Roads Authority
ERADDM	ERA Drainage Design Manual
EV	Extreme Value
FHWA	Federal Highway Administration
H	Height
HDS	Hydraulic Design Series
HEC	Hydraulic Engineering Circular
HGS	Hydrologic Soils Groups
Hr.	Hour
I	Rainfall Intensity
km	Kilo Meter
L	Length
M	Meter
MSE	Mean-Square Error
N	Number
NMA	National Meteorological Agency
NMA	National Meteorological Agency
Nr.	Near
ODA	Overseas Development Administration
ORN	Overseas Road Note
PMF	Probable Maximum Flood
R	Roughness Coefficient
S	Slope
SCS	Soil Conservation Service
SDF	Standard Design Flood
SRTM	Shuttle Radar Topography Mission

Tc	Time of Concentration
TDOT	Tennessee Department of Transport
TDOTDDM	TDOT Drainage Design Manual
T_L	lag Time
T_P	Time to Peak
TR	Technical Report
TRL	Transport Research Laboratory
UH	Unit Hydrograph
USGS	United States Geological Survey
USGS	United States Geological Survey

ABSTRACT

Drainage structures of a road are one of the major components which contribute for proper function of the road system. Under designing might result in over flooding of the road surface which undermines the safety of the road as well as cause damage to the road pavement structure. Overdesigning will result in unnecessary expenditure of fund. There have been documented instances of occurrences these issues based on the current practice. One of the reasons for this problem is improper estimation of design discharges. This has been evident on many constructed roads throughout the country. Therefore it is apparent that identification as well as proposition of remedial measure of drawbacks during peak flood estimation for road drainage design is critical issue.

The main objective of the proposed research is to identify areas of limitations and drawbacks in the process of peak discharge estimation for design of major road crossing drainage structures and propose possible remedial solutions. The analysis is based on current practice in Ethiopia, i.e. basically ERADDM and AACRADDM procedures will be followed.

The methodology adopted to achieve this objective was taking sample rivers with sufficient and adequate gauge data, from different parts of the country, and performing detailed hydrological study based on the current practice in Ethiopia. This was done using two methodologies, i.e., by estimation of flood using rainfall-runoff relationships as dictated by the currently applied manuals in the country initially and later conducting flood estimation for the same catchments based on the historical gauged data using probabilistic methods, such as Log Normal Distribution or Gumbel EVI Distribution or Log Pearson Type III Distribution, which ever fits best.

The gauged rivers selected for further analysis were Akaki, Geba near Suppi, Gheba near Mekele, Weib near Agarfa and Weito. Based on the results obtained from the two methods (SCS and Statistical) it was concluded that the variation considerable, except that of Gheba nr Mekele and Weito. The variation of results obtained with the methods (SCS and Statistical) are considerably high in three cases out of five which is in the range of 83% to 142% while in the case of Gheba nr Mekele and Weito the variation is not significant (2% and 7% respectively). At this point it should be noted that the comparison is made just to show the magnitude of variation in estimated flood and there shouldn't be any implication that one estimation method is more accurate than another.

Some of the setbacks observed using the SCS method are unavailability of topographic, land use and soil maps of large scale, inaccuracy in determination of Time of Concentration and unavailability as well as insufficiency of rainfall data. Setbacks using statistical method are insufficiency and reliability of data and manual collection of data (not automatically) which results in human error and omission of peak floods.

ERADDM 2013 section 5.5 emphasizes that, "Regression equations and derivations from stream gauging (Gumbel, Log Pearson, General Extreme Value) are often preferred but rely on data not available. For this reason, only the Rational Method and the SCS method are given in this chapter." The result of the research reinforces this statement. Similarly it is recommended that to get a lasting solution the density and reliability of river gauge data should be sought after. This can be achieved by installing automatic gauging stations in new as well as already existing river locations to get sufficient and accurate data. This could be achieved for instance along existing or newly constructed roads. After some time elapses regional formulas can be developed using flood frequency analysis to get a reliable estimate of peak discharge.

1. INTRODUCTION

1.1. Background

One of the key components of a road is its drainage facility which includes its cross drainage structures such as bridges and culverts as well as its longitudinal structures such as side ditches and storm water drainage pipes. The sizing of these structures is dependent on the hydrological study undertaken to determine design discharges for a given set of return periods.

In undertaking flood estimation for road projects based on the current practice in Ethiopia, primarily Ethiopian Roads Authority Drainage Design Manual (ERADDM) and Addis Ababa City Roads Authority Drainage Design Manual (AACRADDM) procedures and methodologies are utilized. These methods include Rainfall-Runoff relationship such as Rational and SCS Method for un-gauged streams and Flood Frequency Analysis Methods for gauged streams.

During runoff estimation using Rainfall _ Runoff relationship such as Rational and SCS Method the following factors cause the prediction of the design flood subjective. These are:

Rainfall Prediction: The prediction of rainfall recurrence is dependent on probability analysis of gathered random rainfall events (cannot exactly be determined or very large unanticipated rainfall events can occur). Furthermore occurrence of antecedent rainfall events might incur large flood events than predicted. Consequently, according to ERA drainage design manual, usage of CN values for wet regions is to be applied for regions of B1 and in the vicinity of Bahir Dar. However an anticipated occurrence of antecedent of rainfall events might occur in other regions of the country as well warranting the use of wet CN values.

C values for Rational method and CN values for SCS Method determination: Selection of this values is dependent upon knowledge of catchment characteristics such as land use/cover, soil type and terrain slope. With the exception of terrain slope which can be determined from topographic maps, land use/cover as well as soil type of large catchments (with area of hundreds of kilometers) cannot be accurately determined. Usage of maps is the only liable option. These maps are subject to change through time due to natural or manmade reasons. It is a known fact that land use/cover of the country is changing continuously.

Additionally it should be noted that CN factor is a very sensitive parameter, i.e. small change of this value might result as high as 50% increase in computed discharge. For instance keeping all other parameters the same if CN dry value is changed to CN average or CN average value is changed to CN wet the resulting estimated flood increases by more than 60% in most cases.

Therefore the determined floods might not seem to fit the prevalent condition of the site under study. In most cases based on site observation adjustment/calibration of these parameters are made in order to obtain a more fitting result. The above reasoning can be attributed to the variation of the hydrological study results.

Moreover for gauged catchments Flood Frequency Analysis Methods such as Gumble and Log-Pearson Distribution are used. However the usually encountered problems while using these methods are inadequacy as well as inaccuracy of the available gauge data.

Therefore it is apparent that there are grey areas during flood estimation that should be investigated and remedied so as to get a better estimation. Better estimation implies safe as well as economical road system.

1.2. Statement of the Problem

As stated above drainage provisions of a road is one of the major components which contribute for proper function of the road system. Under designing might result in over flooding of the road surface which undermines the safety of the road as well as cause damage to the road pavement structure. Overdesigning will result in unnecessary expenditure of fund. However at the moment there are many instances and occurrences of under as well as over estimation of peak discharges based on the current practice. One of the reasons for this problem is improper estimation of design discharges. This has been evident on many constructed roads throughout the country. Therefore it is apparent that identification as well as proposition of remedial measure of drawbacks during peak flood estimation for road drainage design is critical issue. In this study emphasis is made on major crossing drainage structures.

With this regards, in worst cases, there have been instances where already constructed structures have been washed away and interruption of traffic flow occurred. Two of the cases are Dilbena river crossing (on Arbaminch – Konso Road) and Fafem river crossing (On Harar – Jijiga Road). Photographs of these structures are included in the literature review section below. Moreover in the less severe cases, there are many cases where the structures were not sufficient and overtopping of structures have been reported and evidences of debris accumulation observed on the road surfaces. Furthermore in mild cases, there are numerous cases where flow is constricted due to undersized structures designed based on underestimated discharges resulting in accumulation of water on the upstream side and erosion of river bed on the downstream side occurs.

1.3. Objective of the Study

The main objective of the proposed research is to identify areas of limitations and drawbacks in the process of peak discharge estimation for road drainage design and propose possible remedial solutions. The analysis is based on current practice in Ethiopia, i.e. basically ERADDM and AACRADDM procedures will be followed. It should be clear at this stage that the study will focus on the drawbacks during application of the flood estimation methodologies rather than scrutiny of the basic principles. This objective can be achieved by accomplishing the following specific tasks:

- Based on current practice in Ethiopia, i.e. using ERA and AACRA manual methodologies, determine peak discharges for a set of recurrence periods using both:
    - Rainfall _ Runoff models as well as
    - Statistical methods;
- Scrutinize each step so as to determine grey areas;
- Propose possible remedial measures.

1.4. Research Questions

1) What is the result of this undertaking, i.e. estimation of peak discharge for road drainage design based on rainfall – runoff relationship methods as well as statistical methods that are currently used in Ethiopia for the selected river locations? Or what is the magnitude of deviation of the results obtained using the two methods for the same river location?
2) What is the reason behind this deviation? Or what are the setbacks that incur inaccuracies during estimation of peak discharge for road drainage design based on rainfall – runoff relationship methods as well as statistical methods that are currently used in Ethiopia?
3) What are the practices of other countries with respect to estimation of flood for road drainage design?
4) What are the proposed long term solutions that minimize the setbacks of estimation of peak discharge in both methods? Or is there a better method other than those practiced in Ethiopia that would give a better estimation of peak discharge to get a lasting solution?

2. LITERATURE REVIEW

Since this research is based on the current practice in Ethiopia scrutinized review is done on the currently available design manuals in use. These are *Ethiopian Roads Authority and Addis Ababa City Roads Authority Drainage Design manuals*. Furthermore reference is made to other design manuals and publications and will be discussed in the main text of this thesis. In the process of preparation of this paper a new version of ERA Drainage Design Manual is released, i.e. the focus is changed to the updated manual rather than the previous one.

Hydrological analysis can be grouped into the two broad categories of deterministic and statistical methods. Deterministic methods is based on modeling the physical aspects of the rainfall-runoff process while statistical methods utilize measured data to fit functions that represent the process. For instance, unit hydrograph methods are deterministic whereas flood frequency analyses are examples of the statistical approach. (*HDS 2 2002*)

When considering the approaches of Hydrological Analysis, according to both *Ethiopian Roads Authority Drainage Design Manual (ERADDM)* as well as *Addis Ababa City Roads Drainage Design Manual (AACRADDM)*, the methods lie within the same broad categories as described below depending on the availability of river gauge data. For un-gauged locations deterministic methods based on rainfall-runoff relationship such as rational as well as SCS model are applied. Whereas for gauged streams statistical approach such as Gumbel and Log-pearson distributions are applied to forecast floods. The detailed description and analysis of these methodologies according to *ERA and AACRA DDM* as well as other renowned manuals such as *HEC (Hydraulic Engineering Circular) manuals of US Federal Highway Authority* are discussed as follows.

Before going through the discussion of the methodologies the following basic concepts of the runoff process and effect of basin characteristic should be reviewed. During this process reference has been done to *HEC 19 (1984), HDS 2 (2002), ERADDM (2013) and AACRADDM (2003).*

2.1. Effects of Basin Characteristics on Runoff

Factors that determine the hydraulic character of the natural drainage system are drainage area, slope, hydraulic roughness, natural and channel storage, drainage density, channel length, antecedent moisture conditions, urbanization, and other factors. The effect that each of these factors has on the important characteristics of runoff is often difficult to quantify. The following paragraphs discuss some of the factors that affect the hydraulic character of a given drainage system. (*HEC 19 1984 and HDS 2 2002)*

- Drainage Area

Drainage area is the most important watershed characteristic that affects runoff. The larger the contributing drainage area, the larger will be the flood runoff. Regardless of the method utilized to evaluate flood flows, peak flow is directly related to the drainage area.

- Slope

Slope is very important in how quickly a drainage channel will convey water and, therefore, it influences the sensitivity of a watershed to precipitation events of various time durations. Watersheds with steep slopes will rapidly convey incoming rainfall and, if the rainfall is convective (characterized by high intensity and relatively short duration), the watershed will respond very quickly with the peak flow occurring shortly after the onset of precipitation. If these convective storms occur with a given frequency, the resulting runoff can be expected to occur with a similar frequency. On the other hand, for a watershed with a flat slope, the response to the same storm will not be as rapid and, depending on a number of other factors, the frequency of the resulting discharge may be dissimilar to the storm frequency.

- Hydraulic Roughness

Hydraulic roughness has a marked effect on the characteristics of the runoff resulting from a given storm. The peak rate of discharge is usually inversely proportional to hydraulic roughness (i.e., the lower the roughness, the higher the peak discharge). Roughness affects the runoff hydrograph in a manner opposite of slope. The lower the roughness, the more peaked and shorter in time the resulting hydrograph will be for a given storm.

- Storage

It is common for a watershed to have natural or manmade storage that greatly affects the response to a given precipitation event. Common features that contribute to storage within a watershed are lakes, marshes, heavily vegetated overbank areas, natural or manmade constrictions in the drainage channel that cause backwater, and the storage in the floodplains of large, wide rivers. Storage can have a significant effect in reducing the peak rate of discharge, although this reduction is not necessarily universal.

The total volume of runoff is not directly influenced by the presence of storage. Storage will redistribute the volume over time, but will not directly change the volume. By redistributing the runoff over time, storage may allow other abstraction processes to decrease the runoff (as was the case with slope and roughness).

- Drainage Density

Drainage density can be defined as the ratio between the number of well-defined drainage channels and the total drainage area in a given watershed. Drainage density is usually assumed to equal the total length of continuously flowing streams divided by the drainage area. It is determined by the topography and the geography of the watershed.

Drainage density has a strong influence on both the spatial and temporal response of a watershed to a given precipitation event. If a watershed is well covered by a pattern of interconnected drainage channels, and the overland flow time is relatively short, the watershed will respond more rapidly than if it were sparsely drained and overland flow time was relatively long. The mean velocity of runoff is normally lower for overland flow than it is for flow in a well-defined natural channel. High drainage densities are associated with increased response of a watershed leading to higher peak discharges and shorter hydrographs for a given precipitation event.

Changes in drainage density such as with channel improvements in urbanizing watersheds can have an effect on the frequency of discharges of given magnitudes. By strongly influencing the response of a given watershed to any precipitation input, the drainage density determines in part the frequency of the response. The higher the drainage density, the more closely related the resultant runoff frequency would be to that of the corresponding precipitation event.

- Channel Length

Channel length is an important watershed characteristic. The longer the channel, the more time it takes for water to be conveyed from the headwaters of the watershed to the outlet. Consequently, if all other factors are the same, a watershed with a longer channel length will usually have a slower response to a given precipitation input than a watershed with a shorter channel length. As the hydrograph travels along a channel, it is attenuated and extended in time due to the effects of channel storage and hydraulic roughness. Longer channels result in lower peak discharges and longer hydrographs. The frequency of discharges of given magnitudes will also be influenced by channel length. As was the case for drainage density, channel length is an important parameter in determining the response time of a watershed to precipitation events of given frequency. However, channel length may not remain constant with discharges of various magnitudes. In the case of a wide floodplain where the main channel meanders appreciably, it is not unusual for the higher flood discharges to overtop the banks and essentially flow in a straight line in the floodplain, thus reducing the effective channel length.

- Antecedent Moisture Conditions

Antecedent moisture conditions, which are the soil moisture conditions of the watershed at the beginning of a storm, affect the volume of runoff generated by a particular storm event. Runoff volumes are related directly to antecedent moisture levels. The smaller the moisture in the ground at the beginning of precipitation, the lower will be the runoff. Conversely, the larger the moisture contents of the soil, the higher the runoff attributable to a particular storm.

- Urbanization

As a watershed undergoes urbanization, the peak discharge typically increases and the hydrograph becomes shorter and rises more quickly. This is due mostly to the improved hydraulic efficiency of an urbanized area. In its natural state, a watershed will have developed a natural system of conveyances consisting of gullies, streams, ponds, marshes, etc., all in equilibrium with the naturally existing vegetation and physical watershed characteristics. As an area develops, typical changes made to the watershed include: (l) removal of existing vegetation and replacement with impervious pavement or buildings, (2) improvement to natural watercourses by channelization, and (3) augmentation of the natural drainage system by storm sewers and open channels. These changes tend to decrease depression storage, infiltration rates, and travel time. Consequently, peak discharges increase, with the time base of hydrographs becoming shorter and the rising limb rising more quickly.

- Other Factors

There can be other factors within the watershed that determine the characteristics of runoff, including the extent and type of vegetation, the presence of channel modifications, and flood control structures. These factors modify the runoff by either augmenting or negating some of the basin characteristics described above. It is important to recognize that all of the factors discussed exist concurrently within a given watershed, and their combined effects are very difficult to model and quantify.

2.2. Hydrological Analysis Methods based on Manuals used in Ethiopia

As per *ERADDM (2013)* the methods to be used and the circumstances for their use are listed in Table 2.1.

Table 2.1: Hydrological Analysis Methods as per ERADDM (2013)

Method	Input data	Recommended maximum area (km^2)	Return period of flood that could be determined (years)
Rational Method	Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity	Less than 0.5	2 – 200, PMF
SCS Method	Catchment area, watercourse length, daily maximum rainfall, veg. type and soil cover	0.5 to 65	2 – 200, PMF
Synthetic Hydrograph Method	Catchment area, watercourse length, daily maximum rainfall, veg. type and soil cover and synthetic regional unit hydrograph	0.5 to 5000	2 -200
Empirical Methods	Catchment area, watercourse length, distance to catchment centroid (centre), mean annual rainfall	No limitation large areas	2 – 200, PMF
Statistical Method	Historical flood peak records	No limitation, large areas	2 – 200 (depending on the record length)

Similarly, the methodologies suggested by *AACRADDM (2003)* are the Rational Formula (limited to area less than $0.8km^2$), the SCS Graphical Peak Discharge Method and The SCS Unit Hydrograph Method for un-gauged catchments as well as statistical method for gauged catchments.

2.3. Rainfall-Runoff Flood Estimation Methods as per ERA and AACRA DDMs

As shown in section 2.3 the following methods have been recommended as per ERA and AACRA Drainage Design Manuals (DDMs) for un-gauged catchments to calculate the peak discharge depending on the size of the catchment area:

For catchment area between less than $0.5km^2$ → Rational Method
For catchment area between 0.5 to $65km^2$ → SCS Method
For catchment area between 0.5 to $5000km^2$ → Synthetic Hydrograph Method
No area limitations → Empirical Methods

2.3.1. The Rational Method

The Rational Method of estimating design flood on small watershed (less than 50ha.) is conceptually based on the criterion that storms of uniform intensity distributed evenly over the basin, maximum rate of runoff equal to a certain percentage of rainfall intensity occurs when the entire basin area is contributing at the outlet. This assumption limits the size of the drainage basin that can be evaluated by the Rational Method. For large catchment areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur and shorter more intense rainfalls can produce larger peak flows. (*ERADDM 2002*) This condition is met after the elapsed time, time of concentration (tc). The equation in the Rational Formula is function of catchment area, runoff coefficient, frequency factor and rainfall intensity.

The equation is expressed as:

$$Q_d = 0.00278\, C C_f\, I\, A \qquad (2.1)$$

Where:

- Q_d = Design Discharge (m^3/sec)
- C = Runoff Coefficient
- C_f = Frequency factor
- I = Rainfall Intensity [for duration equal to time of concentration] (mm/hr)
- A = Drainage area (ha.)

Table 2.2: Frequency Factors for Rational Formula C_f

Recurrence Interval (Years)	C_f
5	1
10	1
25	1.1
50	1.2
100	1.25

(*Source: ERADDM 2013*)

a) Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate in mm/hr for duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the catchment area, the rainfall intensity can be determined from Rainfall-Intensity-Duration curves. Rainfall-Intensity-Duration curves for use in Ethiopia are given in *ERA DDM*.

For drainage areas in Ethiopia, you may compute the rainfall intensity at any required time using the 24hr rainfall depth, using the rainfall ratio method. The Rainfall Ratio Method was used to estimate the rainfall depth to be distributed at required duration based on a 24 hour rainfall. For this the following the relationship can be applied. (*Fiddes et al. 1974 and ERADDM 2013*)

$$RR_t = \left(\frac{t}{24}\right) \left[\frac{(b + 24)^n}{(b + t)^n}\right] \quad (2.2)$$

Where:

RR_t: Rainfall ratio R_t: R_{24}

R_t: Rainfall in a given duration't' (hr)

R_{24}: Rainfall in 24 hours

n: constant

b: constant

t: time (hr)

Based on studies of a large number of rainfall gauges in East Africa, the average values of b and n are found to be 0.3 and 0.9 respectively with range of n is 0.78 to 1.09 *(Fiddes et al. 1974 and ERADDM 2013).*

b) Runoff Coefficient

The runoff coefficient (C) is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the designer. A typical coefficient represents the integrated effects of many drainage basin parameters. The following tables 2.3 and 2.4 of runoff coefficient are presented in *ERADDM.*

Table 2.3: Recommended Runoff Coefficients C for Rural Catchment

Factor	Description	Runoff Coefficient
C_S - Average Slope of Catchment	< 3.5% Flat	0.05
	3.5% - 10% Soft to moderate	0.1
	10% - 25% Rolling	0.15
	25% - 45% Hilly	0.2
	> 45% Mountainous	0.25
C_P - Permeability of soil	Well drained soil e.g. sand and gravel	0.05
	Fair drained soil e.g. sand and gravel with fines	0.1
	Poorly drained soil e.g. silt	0.15
	Impervious soil e.g. silts and clay clay, organic	0.25
	Water-logged black cotton soil	0.5
	Rock	0.4
C_V - Vegetation	Dense forest/thick bush	0.05
	Sparse forest/dense grass	0.1
	Grassland/scrub	0.15
	Cultivation	0.2

Factor	Description	Runoff Coefficient
	Space grassland	0.25
	Barren	0.3

(Source: ERADDM 2013)

Runoff coefficient, $C = C_T+C_S+C_V$

Table 2.4: Recommended Runoff Coefficient C for Various Land Uses

Description of Area	Runoff Coefficients
Business: Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential: Single-family areas	0.30-0.50
Residential: Multi units, detached	0.40-0.60
Residential: Multi units, attached	0.60-0.75
Suburban	0.25-0.40
Residential (0.5 hectare lots or more)	0.30-0.45
Apartment dwelling areas	0.50-0.70
Industrial: Light areas	0.50-0.80
Industrial: Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30

(Source: ERADDM 2013)

2.3.2. The United States Soil Conservation Service (SCS) Method

As per *ERADDM*, for catchment areas less than 65 km^2 with slopes of less than 30% and a time of concentration (Tc) less than 10 hours, the SCS method of estimation of peak floods is the most suitable. The primary input variables for the SCS methods are:

- Drainage area (km^2)
- Time of concentration, Tc (hr)
- Weighted runoff curve number (CN)
- Type of rainfall distribution
- Total design rainfall, P (mm)

The SCS methods produce the direct runoff for a storm by subtracting infiltration and other losses from the total rainfall. (*ERADDM 2013*) A rainfall-runoff relationship is used to separate total rainfall into direct runoff, retention and initial abstraction utilizing the following equations:

$$Q = \frac{[P - I_a]^2}{[P - I_a + S]} \qquad (2.3)$$

$$S = 25.4\left[\frac{1000}{CN} - 10\right] \qquad (2.4)$$

$$I_a = 0.2S \qquad (2.5)$$

From these, the following resulting equation is derived:

$$Q = \frac{[P - 0.2S]^2}{[P + 0.8S]} \qquad (2.6)$$

Where:
Q = accumulated direct runoff (mm)
P = accumulated rainfall (potential maximum runoff), (mm)
S = potential maximum retention (mm)
I_a = initial abstraction
CN = runoff curve number

Using the above procedure and after the determination of CN for each catchment, by plugging the appropriate P, the accumulated runoff Q is calculated. Peak discharge is then computed from:

$$Q_P = q_u A Q \qquad (2.7)$$

Where:
Q_p = peak flow (m^3/s)
q_u = unit peak flow (m^3/s/km^2/mm)
A = drainage area (km^2)
Q = accumulated direct runoff (mm)

The unit peak discharge, q_u is a function of t_c prepared for different types of rainfall. It can be determined from: (*ERADDM 2013*)

$$q_{u=}\ \alpha 10^{c_o + c_1 \log t_c + c_2 (\log t_c)^2} \qquad (2.8)$$

Where:

α = unit conversion factor equal to 0.000431 in SI unit

C_0, C_1 and C_2 = regression coefficients given in table 2.5 below for various Ia/p ratios

The SCS developed four dimensionless rainfall distributions using the Weather Bureau's Rainfall Frequency Atlases. The rainfall frequency data for areas less than 1050 km^2 for durations to 24 hours, and for frequencies from 1 to 100 years were used. Data analyses indicated four major regions, and the resulting rainfall distributions were labeled type I, IA, II, or III. (*HDS 2 2002)*

The Type II storm distribution is applicable for interior rather than the coastal regions and appropriate for Ethiopia. The Type II rainfall distribution will usually give a higher runoff than a Type I distribution. To use this distribution it is necessary for the user to obtain the total depth of a 24-hour duration storm, P, for the relevant frequency. (*ERADDM 2013)*

Table 2.5: Coefficients for SCS Peak Discharge Method

Rainfall Type	Ia/P	C_0	C_1	C_2
I	0.10	2.3055	-0.5143	-0.1175
	0.20	2.2354	-0.5039	-0.0893
	0.25	2.1822	-0.4849	-0.0659
	0.30	2.1062	-0.4570	-0.0284
	0.35	2.0030	-0.4077	0.0198
	0.40	1.8773	-0.3227	0.0575
	0.45	1.7631	-0.1564	0.0045
	0.50	1.6789	-0.0693	0.0000
IA	0.10	2.0325	-0.3158	-0.1375
	0.20	1.9198	-0.2822	-0.0702
	0.25	1.8384	-0.2554	-0.0260
	0.30	1.7266	-0.1983	0.0263
	0.50	1.6342	-0.0910	0.0000
II	0.10	2.5532	-0.6151	-0.1640
	0.30	2.4653	-0.6226	-0.1166
	0.35	2.4190	-0.6159	-0.0882
	0.40	2.3641	-0.5986	-0.0562
	0.45	2.2924	-0.5701	-0.0228
	0.50	2.2028	-0.5160	-0.0126

Rainfall Type	Ia/P	C_0	C_1	C_2
III	0.10	2.4732	-0.5185	-0.1708
	0.30	2.3963	-0.5120	-0.1325
	0.35	2.3548	-0.4974	-0.1199
	0.40	2.3073	-0.4654	-0.1109
	0.45	2.2488	-0.4131	-0.1151
	0.50	2.1777	-0.3680	-0.0953

(Source: ERADDM 2013)

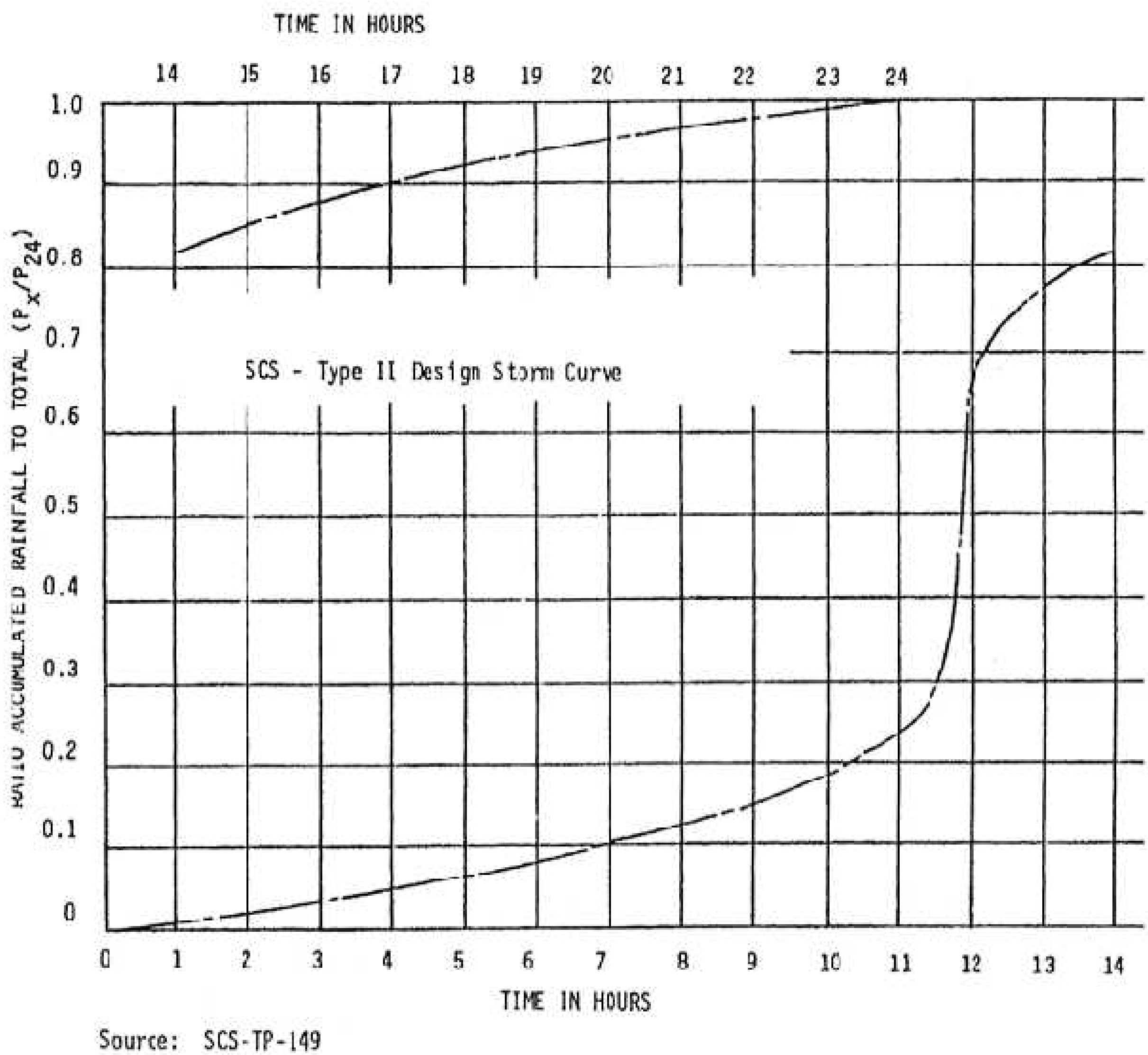

Figure 2.1: Type II Design Storm Curve ***(Source: ERADDM 2013)***

CN values will be taken from the tables 2.6 to 2.9 below by considering their respective soil group, land cover and hydrologic condition.

a) Hydrological Soil Groups

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration are the principal data required to classify soils into Hydrologic Soils Groups (HSG). (*HEC 19 1984*) Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:

Group A: Sand, loamy sand or sandy loam. Soils having a low runoff potential due to high infiltration rates. These soils primarily consist of deep, well-drained sands and gravels.

Group B: Silt loam, or loam. Soils having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Sandy clay loam. Soils having a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D: Clay loam, silty clay loam, sandy clay, silty clay or clay. Soils having a high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently-high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

b) Rainfall Regions of Ethiopia as per ERADDM

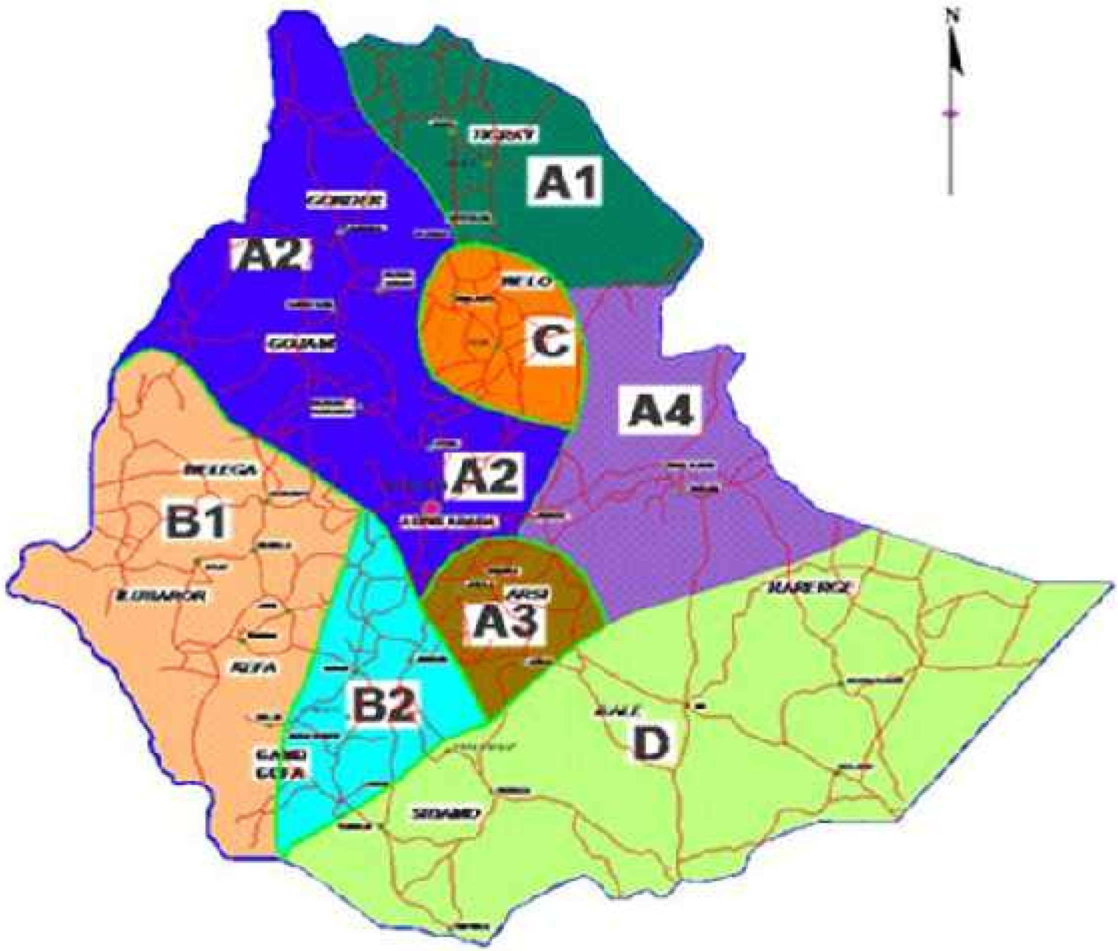

Figure 2.2: Rainfall Regions of Ethiopia ***(Source: ERADDM 2013)***

Note: Rainfall data used in the preparation of this figure have been collected from meteorological service agency meteorology stations. In the course of the preparation of this manual, they have been subjected to statistical techniques. The results indicate that the country can be divided into the above hydrological regions displaying similar rainfall patterns. The information is reviewed with the current available data up to 2010. (*ERADDM 2013*)

c) Antecedent Moisture Conditions

As per ERADDM, for antecedent moisture conditions (AMC) in Ethiopia, use dry for Region D1, wet for Region B1, and average AMC for all other regions. The portion of Region A2 in the vicinity of Bahir Dar should also be treated as wet. When wet AMC is used, it is unlikely that the vegetation density will also be poor to sparse.

Table 2.6: Runoff Curve Numbers- Urban Areas ***(Source: ERADDM 2013)***

Cover description	Curve numbers for hydrologic soil groups				
Cover type and Hydrologic condition	**Average % impervious area**[2]	**A**	**B**	**C**	**D**
Open space (lawns, parks, cemeteries, etc.)[3]	85	68	79	86	89
Poor condition (grass cover <50%)	72	49	69	79	84
Fair condition (grass cover 50 % to 75%)		39	61	74	80
Good condition (grass cover >75%)		98	98	98	98
Impervious areas:					
Paved parking lots, roofs, driveways, etc.		98	98	98	98
(excluding right-of-way)		83	89	92	93
Streets and roads:		76	85	89	91
Paved; curbs and storm drains (excluding right-of-way)		72	82	87	89
Paved; open ditches (including right-of-way)		63	77	85	88
Gravel (including right-of-way)					
Dirt (including right-of-way)		89	92	94	95
Desert urban areas:		81	88	91	93
Natural desert cover					
Urban districts: Commercial					
and business Industrial					
Residential districts by average lot size:					
0.05 hectare or less	65	77	85	90	92
0.1 hectare	38	61	75	83	87
0.135 hectare	30	57	72	81	86
0.2 hectare	25	54	70	80	85
0.4 hectare	20	51	68	79	84
0.8 hectare	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

[1] Average runoff condition, and $I_a = 0.2S$

[2] The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. If the impervious area is not connected, the SCS method has an adjustment to reduce the effect.

[3] CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

Table 2.7: Cultivated Agricultural Land ***(Source: ERADDM 2013)***

Cover description			Curve numbers for Hydrologic soil group			
Cover Type	**Treatment[2]**	**Hydrologic condition[3]**	**A**	**B**	**C**	**D**
Fallow	Bare soil	- Poor	77	86	91	94
	Crop residue cover (CR)	Poor Good	76 74	85 83	90 88	93 90
Row Crops	Straight row (SR)	Poor Good	72 67	81 78	88 85	91 89
	SR + CR	Poor Good	71 64	80 75	87 82	90 85
	Contoured (C)	Poor Good	70 65	79 75	84 82	88 86
	C + CR	Poor Good	69 64	78 74	83 81	87 85
	Contoured & terraced (C & T)	Poor Good	66 62	74 71	80 78	82 81
	C&T + CR	Poor Good	65 61	73 70	79 77	81 80
	Small grain SR	Poor Good	65 63	76 75	84 83	88 87
	SR + CR	Poor Good	64 60	75 72	83 80	86 84
	C	Poor Good	63 61	74 73	82 81	85 84
	C + CR	Poor Good	62 60	73 72	81 80	84 83
	C&T	Poor Good	61 59	72 70	79 78	82 81
	C&T + CR	Poor Good	60 58	71 69	78 77	81 80
	Close-seeded SR or broadcast	Poor Good	66 58	77 72	85 81	89 85
	Legumes or C Rotation	Poor Good	64 55	75 69	83 78	85 83
	Meadow C&T	Poor Good	63 51	73 67	80 76	83 80

[1] Average runoff condition, and $I_a = 0.2S$.
[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
[3] Hydrologic condition is based on a combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or closed-seeded legumes in rotations, (d) percent of residue cover on the land surface (good > 20%), and (e) degree of roughness.

Poor : Factors impair infiltration and tend to increase runoff.
Good : Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2.8: Other Agricultural Lands *(Source: ERADDM 2013)*

Cover description		Curve numbers for hydrologic soil group			
Cover type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range-continuous forage for grazing[2]	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow-continuous grass, protected from grazing	--	35	59	72	79
Brush-weed-grass mixture with brush the major element[3]	Poor Fair Good	48 35 30[4]	67 56 48	77 70 65	83 77 73
Woods-grass combination[5]	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods[6]	Poor Fair Good	45 36 30[4]	66 60 55	77 73 70	83 79 77
Farms—buildings, lanes, driveways, and surrounding lots	--	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$

[2] Poor: < 50% ground cover or heavily grazed with no mulch
Fair: 50 to 75% ground cover and not heavily grazed
Good: > 75% ground cover and lightly or only occasionally grazed

[3] Poor: < 50% ground cover
Fair: 50 to 75% ground cover
Good: > 75% ground cover

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CNs shown were computed for areas with 50% grass (pasture) cover. Other combinations of conditions may be computed from CNs for woods and pasture.

[6] Poor : Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning. Fair : Woods grazed but not burned, and some forest litter covers the soil.
Good : Woods protected from grazing, litter and brush adequately cover soil.

Table 2.9: Arid and Semi-arid Rangelands *(ERADDM 2013)*

Cover type	**Hydrologic condition[2]**	**A[3]**	**B**	**C**	**D**
Mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor Fair Good		80 71 62	87 81 74	93 89 85
Mountain brush mixture of small trees and brush	Poor Fair Good		66 48 30	74 57 41	79 63 48

Cover type	Hydrologic condition[2]	A[3]	B	C	D
Small trees with grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Brush with grass understory	Poor	63	67	80	85
	Fair	55	51	63	70
	Good	49	35	47	55
Desert shrub brush	Poor		77	85	88
	Fair		72	81	86
	Good		68	79	84

[1] Average runoff condition, and $I_a = 0.2S$
[2] Poor : < 30 % ground cover (litter, grass, and brush overstory)
Fair : 30 to 70 % ground cover Good: > 70 % ground cover
[3] Curve numbers for Group A have been developed only for desert shrub.

Table 2.10: Conversion from Average Antecedent Moisture Conditions to Dry and Wet Conditions

CN for Average Conditions	Corresponding CN for	
	Dry	Wet
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50
25	12	43
15	6	30
5	2	13

(Source: ERADDM 2013)

2.3.3. Synthetic Hydrograph Method

For large catchments (>65km^2 and <5000km^2) with time of concentration greater than 10hrs, the composite synthetic unit hydrograph is drawn to determine peak runoff. For this purpose, *as per ERADDM*, the SCS Unit Hydrograph is applied.

The *Soil Conservation Service Handbook* presents a synthetic unit hydrograph procedure that has been widely used in their conservation and flood control work. The unit hydrograph used by the SCS is based upon an analysis of a large number of natural unit hydrographs from a broad cross-section of geographic locations and hydrologic regions. This method is easy to apply. The input parameters are the peak discharge, the area of the watershed, and the time to peak. With these parameters, a standard unit hydrograph is constructed. (*HDS 2 2002*)

The SCS methods use dimensionless unit hydrographs that are based on an extensive analysis of measured data. Unit hydrographs were evaluated for a large number of actual watersheds and then made dimensionless by dividing all discharge ordinates by the peak discharge and the time ordinates by the time to peak. An average of these dimensionless unit hydrographs (UH) was computed. The time base of the dimensionless UH was approximately 5 times the time to peak, and approximately 3/8 of the total volume occurred before the time to peak; the inflection point on the recession limb occurs at approximately 1.7 times the time to peak, and the UH has a curvilinear shape. The dimensionless UH is shown in Figure 2.3 and the discharge ratios for selected values of the time ratios are given in Table 2.11. (*HDS 2 2002*)

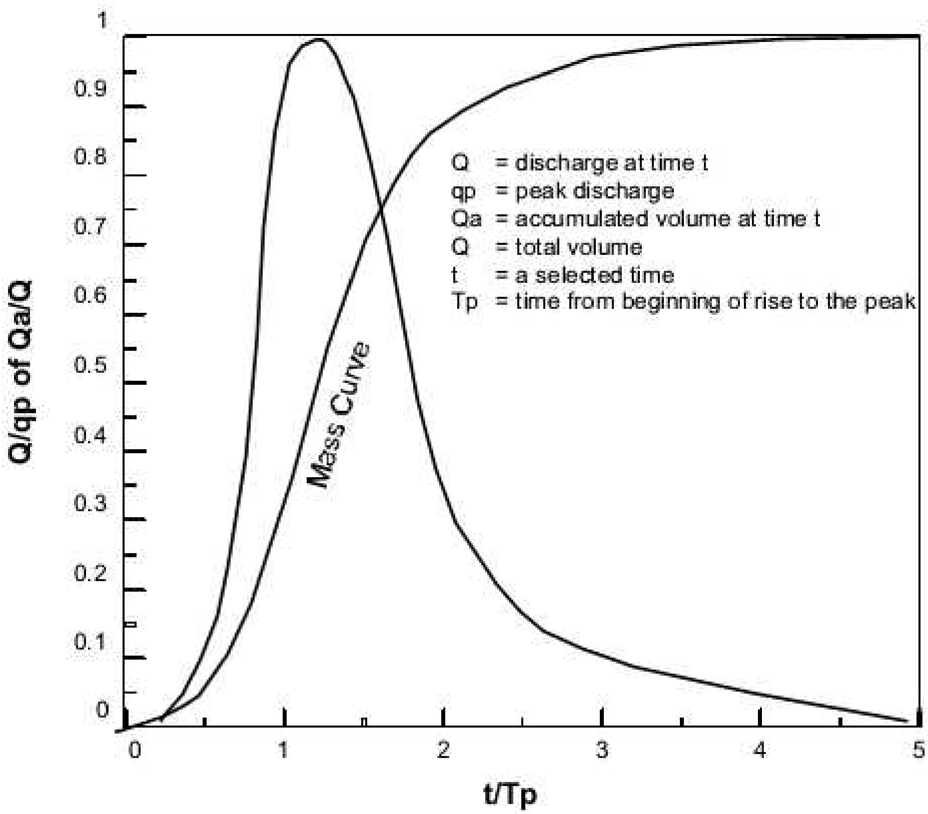

Figure 2.3: Dimensionless Unit Hydrograph and Mass Curve ***(Source: HEC19 1984)***

Table 2.11: Ratios for Dimensionless Unit Hydrograph and Mass Curve ***(Source: HEC19 1984)***

Time Ratios t/Tp	Discharge Ratios q/qp	Mass Curve Ratios Qa/Q
0.0	0.000	0.000
0.1	0.030	0.001
0.2	0.100	0.006
0.3	0.190	0.012
0.4	0.310	0.035
0.5	0.470	0.065
0.6	0.660	0.107
0.7	0.820	0.163
0.8	0.930	0.228
0.9	0.990	0.300
1.0	1.000	0.375
1.1	0.990	0.450
1.2	0.930	0.522
1.3	0.860	0.589
1.4	0.780	0.650
1.5	0.680	0.700
1.6	0.560	0.751
1.7	0.460	0.790
1.8	0.390	0.822
1.9	0.330	0.849
2.0	0.280	0.871
2.2	0.207	0.908
2.4	0.147	0.934
2.6	0.107	0.953
2.8	0.077	0.967
3.0	0.055	0.977
3.2	0.040	0.984
3.4	0.029	0.989
3.6	0.021	0.993
3.8	0.015	0.995
4.0	0.011	0.997
4.5	0.005	0.999
5.0	0.000	1.000

For purposes of comparison, the curvilinear unit hydrograph can be approximated by a triangular UH that has similar characteristics; Figure 2.4 shows a comparison of the two dimensionless unit hydrographs. It is important to recognize that the triangular UH is not a substitute for the curvilinear UH. The curvilinear UH is always used in hydrologic computations. The triangular unit hydrograph is only used to develop an expression for computing the peak discharge of the curvilinear unit hydrograph. While the time base of the triangular UH is only 8/3 of the time to peak (compared to 5 for the curvilinear UH), the areas under the rising limbs of the two UHs are the same (i.e., 37.5 percent). (*HDS 2 2002*)

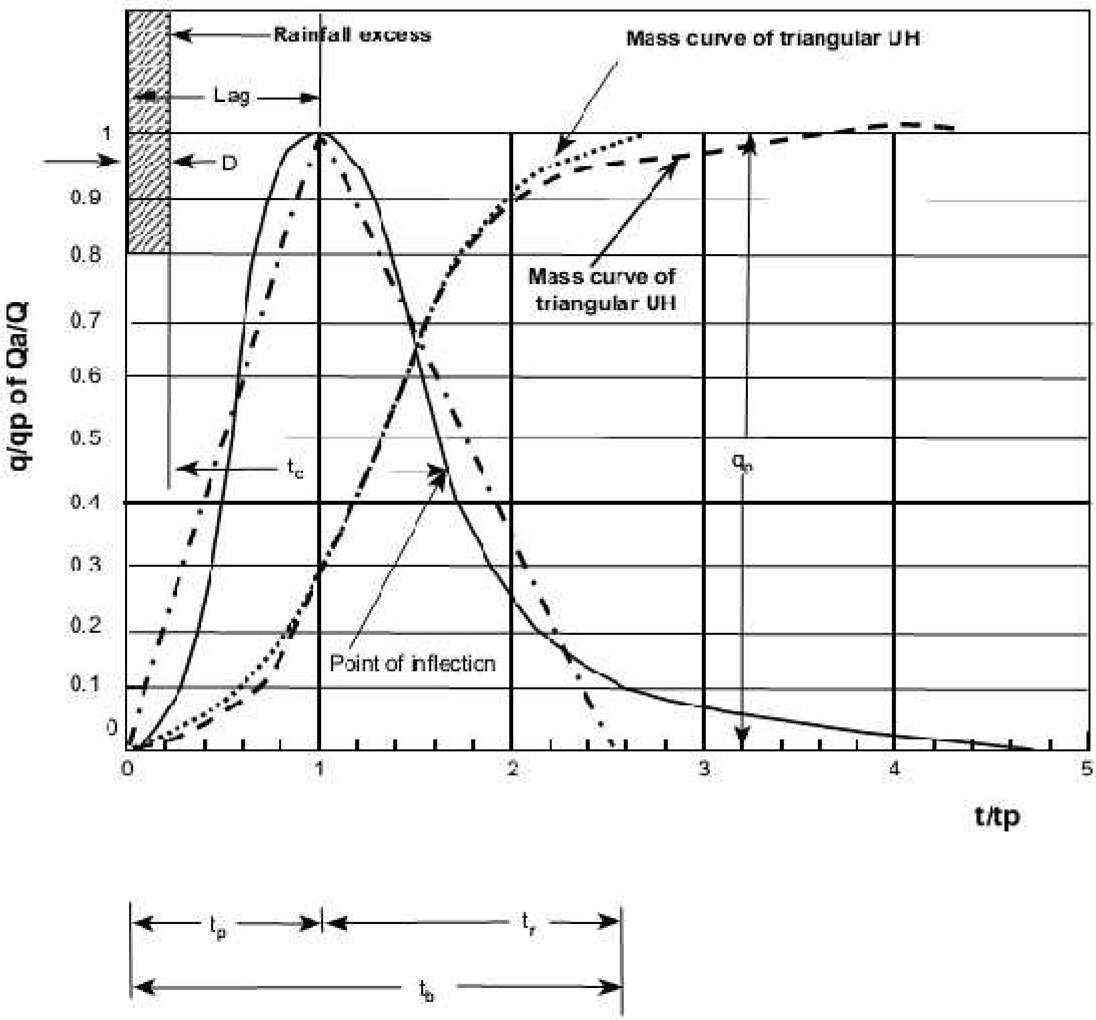

Figure 2.4: Dimensionless Curvilinear Unit Hydrograph and Equivalent Triangular Hydrograph *(Source: HEC19 1984)*

The area under a hydrograph equals the depth of direct runoff Q, which is 1 mm (1 in) for a unit hydrograph; based on geometry the runoff volume is related to the characteristics of the triangular unit hydrograph by:

$$AQ = \frac{1}{2} q_p (t_p + t_r) \qquad (2.9)$$

Where,

t_p = time to peak
t_r = recession time
A = watershed area
q_p = peak discharge

Solving the above equation for q_p and rearranging yields:

$$q_p = \frac{AQ}{t_p}\left[\frac{2}{1+\frac{t_r}{t_p}}\right] \qquad (2.10)$$

Letting K_p replace the contents within the brackets yields:

$$q_p = \frac{K_p AQ}{t_p} \qquad (2.11)$$

The above equation was developed using CU units of ft^3/s for discharge, mi^2 for area, in for runoff depth, and hours for t_p and setting t_r = 1.67tp. Therefore, K_p equals 484. A more general expression is:

$$q_p = \frac{\alpha K_p AQ}{t_p} \qquad (2.12)$$

Where,

q_p = peak discharge, m^3/s (ft^3/s)
A = watershed area, km^2 (mi^2)
Q = runoff depth, mm (in)
t_p = time to peak, h
K_p = peaking constant equal to 484, dimensionless
α = unit conversion constant equal to 0.00043 in SI units and 1 in CU units

For the SI units, taking the depth of direct runoff Q as 1 mm for a unit hydrograph, the following simplified equation is derived.

$$q_p = \frac{0.21A}{t_p} \qquad (2.13)$$

Figure 2.4 provides the following two relationships:

$$t_c + D = 1.7t_p \qquad (2.14)$$

And if the lag equals 0.6 t_c,

$t_l = 0.6t_c$ (2.15)

Then,

$0.5D + 0.6t_c = t_p$ (2.16)

Solving the above equations result as,

$D = 0.133t_c$ and (2.17)

$t_p = 0.667t_c$ (2.18)

Where:

t_l = the lag time
t_c = time of concentration
t_p = time to peak
D = unit duration of the rainfall excess

2.3.4. Time of Concentration

The Time of Concentration, T_c, is the time required for water to flow from the most remote point of the basin to the location being analyzed. A storm equal to this duration will permit direct runoff to arrive from all points in the watershed concentrating at the outlet. This time measure is taken to be the critical time by many flood-estimating approaches, in that it is assumed that the use of any other time would result in a lower flood estimate. A shorter time, although resulting in higher rainfall intensity, will not permit the entire basin to contribute flow simultaneously. A longer duration allows the entire basin to contribute, but with a lower intensity.

The time of concentration consists of an inlet time plus the time of flow in a defined water course, such as open channel or closed conduit. Inlet time is the time required for runoff to flow over the surface to the nearest inlet and is primarily a function of the length of overland flow, the slope of the drainage basin, and surface cover. Define watercourse flow time can be estimated from the hydraulic properties of the channel or conduit. The following are the methodologies stated to determine the overland flow and channel flow per *ERADDM (2013)*.

a) Calculation of the Time of Concentration for Overland Flow

Overland flow is the type of flow that occurs in small, flat or in upper reaches of catchments, where there is no clearly defined watercourse. Run-off, then, is in the form of thin layers of water flowing slowly over the fairly uneven ground surface. The kerby formula is recommended for the calculation of T_c in this case. It is only applicable to parts where the slope is fairly even.

$$T_c=0.604\left(\frac{rL}{S^{0.5}}\right)^{0.467} \quad (2.19)$$

Where:

T_c = time of concentration (hours)
r = roughness coefficient
L = hydraulic length of catchment, measured along flow path from the catchment boundary to the point where the flood needs to be determined (km)
S = Slope of the catchment (m/m)
H = height of most remote point above outlet of catchment (m)

b) Calculation of Time of Concentration for Defined Watercourses

In a defined watercourse, channel flow occurs. The recommended empirical formula for calculating the time of concentration in natural channels was developed by the US Soil Conservation Service.

$$T_c=\left(\frac{0.87L^2}{1000S_{av}}\right)^{0.385} \quad (2.20)$$

Where:

T_c = time of concentration (hours).
L = hydraulic length of catchments measured along flow path from the catchment boundary to the point where the flood needs to be determined (km).
S_{av} = average slope (m/m).

2.4. Hydrological Analysis via Probabilistic Methods for Gauged Streams

For gauged streams, the usual practice is to apply probabilistic methods such as Gumbel Extreme Value Distribution as well as Log-Pearson Type III Distribution to forecast peak floods for a certain recurrence interval. These distribution types give better fitting to hydrological phenomenon, i.e. are better suited for flood estimation based on historical stream gauge data. (*HEC 19 1984)*

2.4.1. Record Length Requirements

Analysis of gaged data permits an estimate of the peak discharge in terms of its probability or frequency of exceedence at a given site. This is done by statistical methods provided sufficient data are available at the site to permit a meaningful statistical analysis to be made. In general at least 10 years of record are necessary to warrant a statistical analysis by methods presented therein. (*ERADDM 2013*)

Table 2.12: Recommended Minimum Stream Gauge Record Lengths per *ERA's Drainage Design Manual 2013*

Design Frequency (Years)	Minimum Record Length (Years)
10	8
25	10
50	20
100	25

2.4.2. Standard Frequency Distributions

Several cumulative frequency distributions are commonly used in the analysis of hydrologic data and, as a result, they have been studied extensively and are now standardized. The frequency distributions that have been found most useful in hydrologic data analysis are the normal distribution, the log-normal distribution, the Gumbel extreme value distribution, and the log-Pearson Type III distribution. The characteristics and application of each of these distributions will be presented in the following sections. (*HDS 2 2002)*

a) Normal Distribution

The normal or Gaussian distribution is a classical mathematical distribution commonly used in the analysis of natural phenomena. The normal distribution has a symmetrical, unbounded, bell-shaped curve with the maximum value at the central point and extending from -∞ to + ∞.

For the normal distribution, the maximum value occurs at the mean. Because of symmetry, half of the flows will be below the mean and half are above. Another characteristic of the normal distribution curve is that 68.3 percent of the events fall between ±1 standard deviation (S), 95percent of the events fall within ±2S, and 99.7 percent fall within ±3S. In a sample of flows, these percentages will be approximated.

For the normal distribution, the coefficient of skew is zero. The function describing the normal distribution curve is:

$$f(X)=\frac{e^{-[\frac{(X-\bar{X})^2}{2S^2}]}}{S\sqrt{2\pi}} \qquad (2.22)$$

One disadvantage of the normal distribution is that it is unbounded in the negative direction whereas most hydrologic variables are bounded and can never be less than zero. For this reason and the fact that many hydrologic variables exhibit a pronounced skew, the normal distribution usually has limited applications. However, these problems can sometimes be overcome by performing a log transform on the data. Often the logarithms of hydrologic variables are normally distributed.

b) Log-Normal Distribution

The log-normal distribution has the same characteristics as the normal distribution except that the dependent variable, X, is replaced with its logarithm. The characteristics of the log-normal distribution are that it is bounded on the left by zero and it has a pronounced positive skew. These are both characteristics of many of the frequency distributions that result from an analysis of hydrologic data.

c) Gumbel Extreme Value Distribution

The Gumbel extreme value distribution, sometimes called the double-exponential distribution of extreme values, can also be used to describe the distribution of hydrologic variables, especially peak discharges. It is based upon the assumption that the cumulative frequency distribution of the largest values of samples drawn from a large population can be described by the following equation:

$$F(X)= e^{-e^{\alpha(x-\beta)}} \quad (2.23)$$

Where:

$$\alpha = \frac{1.281}{S}$$

$$\beta = \overline{X} - 0.450\ S$$

Characteristics of the Gumbel extreme-value distribution are that the mean flow, occurs at the return period of Tr = 2.33 years and that it has a positive skew (i.e., it is skewed toward the high flows or extreme values).

d) Log-Pearson Type III Distribution

Another distribution that has found wide application in hydrologic analysis is the log-Pearson Type III distribution. The log-Pearson Type III distribution is a three-parameter gamma distribution with a logarithmic transform of the variable. It is widely used for flood analyses because the data quite frequently fit the assumed population.

The log-Pearson Type III distribution differs from most of the distributions discussed above in that three parameters (mean, standard deviation and coefficient of skew) are necessary to describe the distribution. By judicious selection of these three parameters, it is possible to fit just about any shape of distribution.

2.4.3. Frequency Analysis Using Frequency Factor

Calculating the magnitudes of extreme events requires that the probability distribution function be invertible. Some probability distribution functions are not readily invertible, including the Normal and Pearson Type III distributions, and an alternative method of calculating the magnitudes of extreme events is required for these distributions. (*HDS 2 2002)*

The magnitude X_T of a hydrologic event may be represented as the mean X_M plus the departure ΔX_T of the variate from the mean.

$$X_T = X_M + \Delta X_T \quad (2.24)$$

The departure may be taken as equal to the product of the standard deviation S_X and a frequency factor K_T. Therefore:

$$X_T = X_M + KS_X \quad (2.25)$$

In the event that the variable analyzed is Y = log X, then the same method is applied to the statistics for the logarithms of the data. Therefore:

$$Y_T = Y_M + KS_Y \quad (2.26)$$

And the required value of X_T is found by taking the antilog of Y_T.

Where:

X = hydrological event (rainfall, flood,…)
T = return period
X_T = extreme hydrological event of return period T
X_M = mean of the hydrological event
ΔX_T = departure from the mean
S_X = Standard deviation of the hydrological events
K = frequency factor
Y_T = logarithms of extreme hydrological event of return period T
Y_M = mean of the logarithms of the hydrological event
S_Y = Standard deviation of the logarithm of the hydrological events

For a given distribution, a relationship can be determined between the frequency factor and the corresponding return period (and coefficient of skewness for log-Pearson Type III distribution). This relationship can be expressed in mathematical terms or can be acquired from tables.

Table 2.13: Frequency Factors (K) for the Gumbel Extreme

n (Sample Size)	Corresponding Return Period in Years						
	2	**5**	**10**	**25**	**50**	**100**	**500**
10	-0.1355	1.0581	1.8483	2.8468	3.5876	4.3228	6.0219
15	-0.1433	0.9672	1.7025	2.6315	3.3207	4.0048	5.5857
20	-0.1478	0.9186	1.6247	2.5169	3.1787	3.8357	5.3538
25	-0.1506	0.8879	1.5755	2.4442	3.0887	3.7285	5.2068
30	-0.1525	0.8664	1.541	2.3933	3.0257	3.6533	5.1038

n (Sample Size)	Corresponding Return Period in Years						
	2	5	10	25	50	100	500
35	-0.154	0.8504	1.5153	2.3555	2.9789	3.5976	5.0273
40	-0.1552	0.8379	1.4955	2.3262	2.9426	3.5543	4.968
45	-0.1561	0.828	1.4795	2.3027	2.9134	3.5196	4.9204
50	-0.1568	0.8197	1.4662	2.2831	2.8892	3.4907	4.8808
55	-0.1574	0.8128	1.4552	2.2668	2.869	3.4667	4.8478
60	-0.158	0.8069	1.4457	2.2529	2.8517	3.446	4.8195
65	-0.1584	0.8019	1.4377	2.241	2.8369	3.4285	4.7955
70	-0.1588	0.7973	1.4304	2.2302	2.8236	3.4126	4.7738
75	-0.1592	0.7934	1.4242	2.2211	2.8123	3.3991	4.7552
80	-0.1595	0.7899	1.4186	2.2128	2.802	3.3869	4.7384
85	-0.1598	0.7868	1.4135	2.2054	2.7928	3.3759	4.7234
90	-0.16	0.784	1.409	2.1987	2.7845	3.366	4.7098
95	-0.1602	0.7815	1.4049	2.1926	2.777	3.357	4.6974
100	-0.1604	0.7791	1.4011	2.1869	2.7699	3.3487	4.686

(Source: HEC19 1984)

Table 2.14: Frequency Factors (K) for the Log-Pearson Type III Distribution

Coef. of Skew	Corresponding Return Period in Years						
	2	5	10	25	50	100	500
3	-0.3955	0.4204	1.1801	2.2778	3.1519	4.0514	6.2051
2.8	-0.3835	0.4598	1.2101	2.2747	3.114	3.973	6.0186
2.6	-0.3685	0.4987	1.2377	2.2674	3.0712	3.8893	5.6282
2.4	-0.3506	0.5368	1.2624	2.2558	3.0233	3.8001	5.6282
2.2	-0.33	0.5738	1.2841	2.2397	2.9703	3.7054	5.4243
2	-0.3069	0.6094	1.3026	2.2189	2.912	3.6052	5.2146
1.8	-0.2815	0.6434	1.3176	2.1933	2.8485	3.4994	4.9994
1.6	-0.2542	0.6753	1.329	2.1629	2.7796	3.388	4.7788
1.4	-0.2254	0.7051	1.3367	2.1277	2.7056	3.2713	4.553
1.2	-0.1952	0.7326	1.3405	2.0876	2.6263	3.1494	4.3226
1	-0.164	0.7575	1.3404	2.0427	2.5421	3.0226	4.088
0.8	-0.132	0.7799	1.3364	1.9931	2.453	2.891	3.8498
0.6	-0.0995	0.7995	1.3285	1.939	2.3593	2.7551	3.6087
0.4	-0.0665	0.8164	1.3167	1.8804	2.2613	2.6154	3.3657
0.2	-0.0333	0.8304	1.3011	1.8176	2.1594	2.4723	3.1217
0	0	0.8416	1.2816	1.7507	2.0538	2.3264	2.8782
-0.2	0.0333	0.8499	1.2582	1.68	1.945	2.1784	2.6367
-0.4	0.0665	0.8551	1.2311	1.6057	1.8336	2.0293	2.3994
-0.6	0.0995	0.8572	1.2003	1.5283	1.7203	1.8803	2.1688
-0.8	0.132	0.8561	1.1657	1.4481	1.606	1.7327	1.9481
-1	0.164	0.8516	1.1276	1.3658	1.4919	1.5884	1.7406

Coef. of Skew	Corresponding Return Period in Years						
	2	5	10	25	50	100	500
-1.2	0.1952	0.8437	1.0861	1.2823	1.3793	1.4494	1.5502
-1.4	0.2254	0.8322	1.0414	1.1984	1.27	1.3182	1.3798
-1.6	0.2542	0.8172	0.9942	1.1157	1.1658	1.1968	1.2313
-1.8	0.2815	0.7986	0.945	1.0354	1.0686	1.0871	1.1047
-2	0.3069	0.7769	0.8946	0.9592	0.9798	0.99	0.998
-2.2	0.33	0.7521	0.8442	0.8881	0.9001	0.9052	0.9085
-2.4	0.3506	0.725	0.7947	0.8232	0.8296	0.832	0.8332
-2.6	0.3685	0.696	0.7471	0.7646	0.7678	0.7688	0.7692
-2.8	0.3835	0.666	0.7021	0.7123	0.7138	0.7142	0.7143
-3	0.3955	0.6357	0.6602	0.6659	0.6665	0.6667	0.6667

(Source: HEC19 1984)

2.4.4. Generalized and Weighted Skew

Three methods are available for representing the skew coefficient. These include the station skew, a generalized skew, and a weighted skew. Since the skew coefficient is very sensitive to extreme values, the station skew (i.e., the skew coefficient computed from the actual data) may not be accurate if the sample size is small. Generalized skew coefficients are determined from a map that shows isolines of generalized skew coefficients of the logarithms of annual maximum stream flows.

Often the station skew and generalized skew can be combined to provide a better estimate for a given sample of flood data. The mean-square error (MSE) of the weighted estimate is minimized by weighting the station and generalized skews in inverse proportion to their individual MSEs, which are defined as the sum of the squared differences between the true and estimated values of a quantity divided by the number of observations. Mean Square Error of Station Skew is a function of record length and the calculated station skew and can be obtained from tables of summary of Mean Square Error of station skew. Whereas Mean Square Error of Generalized Skew is a given for the map that provided the values of the skew coefficient. (*HDS 2 2002)* This concept is given by the equation:

$$G_W = \frac{MSE_{\bar{G}}(G) + MSE_G(\bar{G})}{MSE_{\bar{G}} + MSE_G} \qquad (2.27)$$

Where:

G_W = weighted skew
G = station skew
$\bar{G}$ = generalized skew
MSE_G, $MSE_{\bar{G}}$ = mean-square errors for the station and generalized skews, respectively.

2.4.5. Probability Plotting

As a check that a probability distribution fits a set of hydrologic data, the data may be plotted on specially designed probability paper, or using a plotting scale that linearizes the distribution function. The plotted data are then fitted with a straight line for interpolation and extrapolation purposes. (*HDS 2 2002)*

Plotting Position Formulas

When making a flood frequency analysis, it is common to plot both the assumed population and the peak discharges of the sample. To plot the sample values on frequency paper, it is necessary to assign an exceedence probability to each magnitude. A plotting position formula is used for this purpose.

A number of different formulas have been proposed for computing plotting position probabilities, with no unanimity on the preferred method. A general formula for computing plotting positions is:

$$P=\frac{i-a}{(n-a-b+1)} \qquad (2.28)$$

Where,

i = rank order of the ordered magnitudes, with the largest value having a rank of 1
n = record length
a, b = constants for a particular plotting position formula.

The Weibull, P_w (a = b = 0), Hazen, P_h (a = b = 0.5), and Cunnane, P_c (a = b = 0.4) are three possible plotting position formulas.

The data are plotted by placing a point for each value of the flood series at the intersection of the flood magnitude and the exceedence probability computed with the plotting position formula. The plotted data should approximate the population line if the assumed population model is a reasonable assumption.

The following steps are used to plot the data:

1. Rank the flood series in descending order, with the largest value having a rank of 1 and the smallest flood having a rank of n.
2. With a plotting position formula compute the plotting probabilities for each flood using the rank.
3. Plot the magnitude against the corresponding plotting probability on logarithmic scale.
4. For Gumbel distribution plot the magnitude against the corresponding reduced variate, which is determined from $y_i = -\ln(-\ln(1-Pi))$.

If the data falls on a straight line, the data comes from the particular distribution.

2.4.6. Outliers

Outliers, which may be found at either or both ends of a frequency distribution, are measured values that occur, but appear to be from a longer sample or different population. This is reflected when one or more data points do not follow the trend of the remaining data.

If the station skew is greater than 0.4, tests are applied for high outliers first, and, if less than -0.4, low outliers are considered first. If the station skew is between ± 0.4, both high and low outliers are tested before any data are eliminated. (*HDS 2 2002)* The detection of high and low outliers is obtained with the following equations, respectively:

$Y_H = Y_M + K_N S_Y$ (2.29)

$Y_L = Y_M - K_N S_Y$ (2.30)

$X_H = 10^{YH}$ (2.31)

$X_L = 10^{YL}$ (2.32)

Where,

Y_H, Y_L = log of the high or low outlier limit, respectively
X_H, X_L = high or low outlier limit, respectively
Y_M = mean of the log of the sample flows
S_Y = standard deviation of the sample
K_N = critical deviate (from Table 2.15)

If the sample is found to contain high outliers, the peak flows should be checked against other historical data sources and data from nearby stations. This check enables categorization of the flow observation as a potential anomaly or error in the sample. It is recommended that high outliers be adjusted for historical information or retained in the sample as a systematic peak. The high outlier should not be discarded unless the peak flow is shown to be seriously in error. If a high outlier is adjusted based on historical data, the mean and standard deviation of the log distribution should be recomputed for the adjusted data before testing for low outliers.

If any discharges in the flood series are less than X_L, then they are considered to be low outliers and should be deleted from the sample.

Table 2.15: Outlier Test Deviates (KN) at 10 Percent Significance Level

n (Sample Size)	K_N	n (Sample Size)	K_N	n (Sample Size)	K_N	n (Sample Size)	K_N
10	2.036	45	2.727	80	2.94	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.134	47	2.744	82	2.949	117	3.07
13	2.165	48	2.753	83	2.953	118	3.073
14	2.213	49	2.76	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.97	122	3.083
18	2.335	53	2.79	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.989	125	3.092

n (Sample Size)	K_N	n (Sample Size)	K_N	n (Sample Size)	K_N	n (Sample Size)	K_N
21	2.408	56	2.811	91	2.984	126	3.095
22	2.429	57	2.818	92	2.889	127	3.097
23	2.448	58	2.824	93	2.993	128	3.1
24	2.467	59	2.831	94	2.996	129	3.102
25	2.487	60	2.837	95	3	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.51	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.011	133	3.112
29	2.549	64	2.86	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.021	136	3.119
32	2.591	67	2.877	102	3.024	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3.03	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.65	72	2.903	107	3.04	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.14
41	2.692	76	2.922	111	3.052	146	3.142
42	2.7	77	2.927	112	3.055	147	3.144
43	2.71	78	2.931	113	3.058	148	3.146
44	2.72	79	2.935	114	3.061	149	3.148

(Source: HDS 2 2002)

2.4.7. Incomplete Records and Zero Flows

Stream flow records are often interrupted for a variety of reasons. Gages may be removed for some period of time, there may be periods of zero flow that are common in the arid regions and there may be periods when a gage is inoperative either because the flow is too low to record or it is too large and causes a gage malfunction.

If the break in the record is not flood related, such as the removal of a gage, no special adjustments are needed and the segments of the interrupted record can be combined together to produce a record equal to the sum of the length of the segments. When a gage malfunctions during a flood, it is usually possible to estimate the peak discharge from high-water marks or slope-area calculations. The estimate is made a part of the record, and a frequency analysis performed without further adjustment. (*HDS 2 2002)*

2.5. Hydrological Analysis Methods used in Other Countries

As per *South African National Roads Agency DDM (2007)*, the methods to be used and the circumstances for their use are listed below.

Table 2.16: Hydrological Analysis Methods as per South African National Roads DDM (2007)

Method*	Input Data	Recommended Maximum Area (km2)	Return Period of Floods that could be Determined
Statistical Method	Historical Flood Peak Records	No Limitation	2 - 200 PMF, depending on the record length
Rational Method	Catchment Area, Watercourse Length, Average slope, catchment characteristics and rainfall intensity	< 15	2 - 100 PMF
Alternative Rational Method**		No Limitation	2 - 200 PMF
Synthetic Hydrograph Method+	Catchment Area, Watercourse Length, length to catchment centroid, mean annual rainfall, veld type and synthetic regional unit hydrographs	15 to 5000	2 - 100 PMF
Standard Design Flood Method++	Catchment area, slope and SDF basin number	No Limitation	2 - 200 PMF
Empirical Methods+++	Catchment Area, Watercourse Length, distance to catchment centroid and mean annual rainfall	No Limitation	10 - 100 RMF

*Methods not included in this manual are SCS and Run Hydrograph Methods.
**The alternate method uses the modified recalibrated Hershfield equation for storm duration up to 6 hours and TR102 for duration from 1 to 7 days.
+The method is based on regional analysis of historical data.
++The method is based on a calibrated discharge coefficient for recurrence period of 2 and 100 years. Calibrated discharge parameters are based on historical data and were determined for 29 homogeneous basins in South Africa.
+++Requires a combination of experience, historical data and/or the results of other methods. Empirical methods are more suited to check the order of magnitude of the results obtained by means of other methods.
Source: South African National Roads Agency DDM (2007)

According to *Tennessee Department of Transportation (TDOT) Design Division DDM (2010)*, the rational method is the preferred method for all drainage areas less than 100 acres. The USGS regression equations for rural and urban areas are the preferred methods for drainage areas larger than 100 acres. These methods should be used for all projects unless they are not applicable due to the watershed conditions or the need for a runoff hydrograph.

The United States Geological Survey (USGS) published regression equations for rural areas of Tennessee in 2003. The rural regression equation development is described in Water-Resources Investigations Report 03-4176, "Flood-Frequency Prediction Methods for Unregulated Streams of Tennessee, 2000". The study was based on stream flow data gathered from 453 gauging stations located in rural and lightly developed areas of Tennessee and the adjacent states (except Arkansas). Of these, 297 gauges were located in Tennessee. All of the gauges had a minimum of 10 years of stream flow data. Stream gauges were not included in the analysis where historical discharge records had been significantly impacted by urbanization, dredging, or other man-made watershed changes. *(TDOTDDM 2010)*

According to *ORN 16 (1997)*, the following approaches are proposed with no recommended maximum area for usage. These are:

- Deterministic approach (*ORN 16*)
  - The Rational or Modified Rational Method
  - Parametric modeling of rainfall-runoff conversion based on catchment variables (such as land use, slope, permeability and catchment wetness
  - Usage of unit hydrographs within similar hydrological region

- Statistical approach (*ORN 16*)
  - If continuous gauging records are available develop unit hydrographs to be used for catchments within similar hydrological regions
  - Derive magnitude vs. frequency relationship for peak discharges from daily records
  - Prepare flood envelop curves of maximum peak discharge against catchment area for each gauging station in the same hydrological region and develop regional flood formula

2.6. Review of Similar Research Papers and Studies

Amiry et al. (2012) aimed to describe the most optimized model of instantaneous peak discharge estimation. To achieve this, four models including GIUH, SCS, Snyder and Triangular have been taken into account. The study area taken was Mehran drainage basin which is one of the sub basins of the Central Alborz basin. It is located in Tehran province and its Taleghan unit situated 50° 53' 24.0" to 50° 59' 19.0" East longitudinal and 34° 10' 48.0"to 36° 20' 21.0" North latitude and covers 99.71km2. In this basin, one rain gauge station: Joestan and also one hydrometric station named Mehran- Joestan were considered. The length of its main river is about 22km. The maximum and minimum elevations are 4390 and 1940 m respectively. Mehran drainage basin contains poor range lands and farming terrains and a small part of the watershed is garden. The total precipitation changes from 635 to 768 mm in different places of the watershed.

Flood discharge statistics and recorded rain in the station of local water institute of Tehran province and organization of water resources research was used. For Mehran drainage basin 15 coincidence events of rain and discharge were extracted 7 of which were recognized to be good. Supply digital topographic map was extracted from National Cartographic Center (N.C.C.). Stream map study drainage basin, mean slope of drainage basin area, mean weighted slope of main stream in outlet of drainage basin, main stream length from centroid to outlet of drainage basin were also extracted.

Table 2.17: Date of events and peak discharge estimation (m^3/s) - using models in Mehran drainage basin.

Events Date	Q_P (Obs.)	Q_P (Tri.)	Q_P (SCS)	Q_P (Sny.)	Q_P (GIUH)
20, 21 April 2003	55.46	48.483	47.893	21.39	18.73
29 May 2003	23.51	54.83	54.145	22.09	23.366
24, 25 April 2004	8.97	58.67	57.92	22.45	9.052
26, 27 April 2005	18.54	33.66	34.108	22.45	16.94
19, 20 May 2005	34.054	32.77	32.35	22.1	12.59
7, 8 November 2006	22.57	31.136	31.54	21.73	22.83
27, 28 April 2007	22.35	51.46	50.827	21.73	21.803

Based on the results obtained the GIUH model is the best model for the estimation of instantaneous peak discharge. Data obtained for each of the events in the Mehran drainage basin demonstrate that in one of the events in 20 and 21 April, 2003, the observed discharge (Qpo) was greater than the estimated discharge by model (Qpe). Sensitivity analysis of daily peak discharge model's factors in Mehran drainage basin demonstrates that the factors like flow velocity and discharge area have the major effects on model's sensitivity. So, accurate measurement of these parameters enhances the efficiency and will provide a more accurate model. For many drainage basin in the world, that do not have hydrometric station or have an incomplete data, it is recommended that if there is a gauge rain station, the Geomorphologic model for peak discharge estimation to be used. If it does not exist, the Snyder model is recommended. (*Amiry et al. 2012)*

Another paper by Koutroulis et al. (2010) aimed at comparison between a number of consolidated methods for estimating peak discharge under a stage gauge failure, or, in general, when limited information are available. The Giofiros basin (158 km^2) located in the central-nort part of the island of Crete was used as case study and, in particular, the flash flood occurred on 13th January 1994 was analyzed.

Giofiros basin is located in the central-north part of the island of Crete, Greece and has a drainage area of 186 km^2 at the outlet to the Aegean Sea, while the drainage area at the river gauge is 158 km^2 (about 6 km upstream). The southern upstream part of the basin is rugged mountainous terrain, whereas, the northern part has milder rolling hill slopes. Geologically, the basin is com-posed of extensive strata of marly limestone, flysch and sandstone, gypsum and alluvial deposits. The watershed has a Mediterranean climate, thus, the Giofiros basin has seasonal flow during the wet fall-winter period (typically from October to March), when the majority of the mean annual rainfall of 827 mm occurs (Ganoulis, 2003). Land use in Giofiros basin is mainly vineyards, olive trees and farmlands, which are also present along the stream banks. From the three rain-gauges of Giofiros basin, one has hourly records and two stations providing daily precipitation measurements.

Rainfall–run-off simulation of several events based on HEC-HMS were conducted for the area (158 km^2) upstream from the Finikia flow stage gauge. The extent of the hydraulic simulation of the 1994 flood event were downstream of the flow stage gauge to the outlet of the basin (a distance of about 6 km), where the most significant impacts of the flood were observed. The estimated total water volume was 5.20 Mm^3. The peak flow value was 296m^3/s. The maximum precipitation intensity as well as the center of mass of precipitation time series was observed at 20:00 of 13 January 1994, while the peak discharge based on the simulation was observed at 24:00.

Because there was no observed field flow data, the evaluation of the result was based on indirect method for estimation of peak flow from a specific cross-section for various flow levels up to 5.1m. The results of this analysis showed that Q varied from 220 m^3/s for manning coef. n_1= 0.04 and n_2= 0.08 to 350 m3/s for n_1= 0.03 and n_2= 0.04. Peak flow for 1994 flood was estimated at 292 m^3/s for n_1= 0.03 and n_2= 0.06, compares well with the simulation result based on hydrological model. Peak flow for the 1994 flash flood event based on the empirical method estimated to 287 m^3/s that compares very well with the rainfall–runoff simulation output.

The peak discharge for a flash flood case based on the empirical equation, is in agreement with the one calculated via the verified hydrological model and the one derived based on Manning's equation and post flood measurements of the control cross-section (e.g., all values were close to 290 m3/s for the 1994 flood on the Giofiros River). These methods can be applied to other poorly gauged basins facing common stage gauge failures or poorly defined rating curves during flash floods caused by severe convective rainstorms. The coefficients that represent the characteristic of the basin have to be developed for the individual basin. A severe storm that produces a flash flood can be approached with a variety of methods. Among others, meteorological analysis, hydrological modeling, hydraulic modeling and analysis, post event campaigns for data retrieving (flood marks, peak flow timing through interviews) can be used to provide additional information for reliable peak discharge estimations. This multilateral approach reduces uncertainty in the event interpretations. (Koutroulis et al. 2010)

Similarly Beza (2010) wrote his Master of Science thesis under the title "Investigation of cause of failures of Highway cross drainage Structures (Case study on Raya River Bridge)". The study area, Raya River Bridge, is located on Addis Ababa Arbaminch main road at 428 km from Addis Ababa. The Raya river originates in the mountains of Chencha at an elevation of 2650m a.m.s.l and drains to the eastern direction through Wajifo town after receiving flows from its tributaries and finally ends in Lake Abaya and the bridge located at the upstream of the lake around 3km. The Raya river catchment covers 91.253 km2 area at the bridge crossing location and its elevation varies from 2654 m at the highest point and 1217 m at the crossing location above mean sea level. More than 79% of the catchment is cultivated and the remaining 21% were covered by small trees, shrubs and scarcely distributed trees were found. Different types of soils are found chromic vertisols, dystric and orthic acrisoils are the dominant which covers more than 85% of the total soil coverage.

As per *Beza (2010)*, the failure of the Raya river bridge resulted from the change in the property of the flow of the river around the bridge crossing location. As the clear opening area of the bridge water way decreases the property of the flow changed from normal flow condition to pressurized flow as result the flood over floats one of the super structure of the bridge resulting collapse of the Raya river bridge. The specific failure causes are:

- Clear opening height reduction or flow area reduction at the bridge location due to long term river bed level rise or Aggradation due to sediment deposition which occurred due to deforestation of the catchment and resulted in the decrease of bridge opening.

- Sediment deposition at the bridge crossing location which is estimated about 24.4m^3 or 64.64 tons of sediment deposition per meter width in each year.
- The presence of weir or diversion structure at the upstream of the bridge location which aggravates the rate of sediment deposition at the bridge location and upstream of it.
- Reduction of the slope due to improper location of the bridge at the entrance to the Lake Abaya which increases the rate of sediment deposition around the bridge location.

The following recommendations were drawn from this study. *(Beza 2010)*

- To get accurate estimation of peak flood in the study area there is a need to meteorological and flow data around the bridge location.
- This study does not look to the dynamics of the morphology of the channel, future studies should focus to consider the channel as movable channel.
- Furthermore sediment concentration flow data collection is also required to estimate the exact amount of sediment deposition around the bridge.
- In our country lots of bridge failures were experienced and researchers have to do a lot of works in this topic.

2.7. Cases of Bridge Failure Due to Flooding

Figure 2.5: Failed Bridge Crossing of Dilbena River Crossing on Arbaminch – Konso road

This structure failed due to high flooding. The superstructure has been washed away and replaced by temporary bailey brdige structure.

Figure 2.6: Eroded Embankment on Konso side of Dilbena river crossing.

Figure 2.7: Eroded Embankment on Arbaminch side of Dilbena river crossing.

Figure 2.8: Failed Bridge Crossing of Fafem River Crossing on Harar – Jigjiga road

Figure 2.9: Part of the Failed Superstructure and View of Far Side of the Abutment of Fafem River Crossing

3. DATA AND MATERIALS

In order to accomplish the hydrological analysis, different data and materials have been collected from different sources, ERA, AACRA, Ethiopian Mapping Agency, National Meteorological Service Agency, Ministry of Water and Energy, Ministry of Agriculture and other relevant sources. The following are the data set obtained from these sources.

3.1. River Gauge Data

River gauge data was obtained from the Ministry of Water and Energy. The data obtained were from the different parts of the country as well as river basins. The following table 3.1 summarizes the data acquired.

Table 3.1: Summary of River Gauge (Daily Flow) Data

No.	Station	Basin	From	To
1	Agula	Tekeze	1992	2006
2	Akaki	Awash	1981	2008
3	Borkena nr Kombolcha	Awash	1976	2010
4	Dabus	Abay	1963	2010
5	Geba nr Suppi	Baro	1976	2010
6	Gheba nr. Mekele	Tekeze	1967	2004
7	Ghibe nr. Baco	Omo-Gibe	1979	2009
8	Hamessa nr. Humbo	Rift Valley	1985	2007
9	Kulfo nr. Arbaminch	Rift Valley	1976	2008
10	Mille	Awash	1987	2010
11	Weib nr. Sofumer	Genale Dawa	1990	2009
12	Weib nr. Agarfa	Wabi Shebele	1981	2009
13	Weito	Rift Valley	1980	2009
14	Wenchit	Abay	1997	2010

3.1.1. Data Adequacy

This data was investigated initially for adequacy so as to select appropriate samples. This was done based on the following criteria.

- Sufficiency of the data in terms of length of years recorded,
- Completeness of the recorded data (data during rainy seasons),
- Data discrepancy.

Based on the above criteria Agula Station has almost in all cases missing record in the main rainy season (in the months of June, July and August). Six locations have data less than 25years, which is minimum length of record required to estimate flood of 100years frequency per *ERADDM 2013*, Dabus 12, Mille 10, Gheba nr Mekele 14, Geba nr. Suppi 20, Borkena 15, Hammessa 21 and Weib at Sofomar 17.

Nevertheless considering the adequacy of the data and relative adequacy five stations were selected for further investigation as shown in the table 3.2 below.

The reason for selection of these data is considering their locations with respect to position in the country as well as river basin as indicated in the table 3.2 below. However as can be observed in the table there is no adequate data in the eastern part of the country. The reason for this is unavailability of data in this part of the country. There is only one location, Mille station, in this region with data available for 10years period. Even the available data exhibit unrealistic figure, i.e. most of the record is below $31m^3/s$ and one is $242m^3/s$ for catchment area of $206km^2$. This could be due to omission of peak flood due to recording since the nature of the flood is flashy (the peak flood occurs for a small duration) in this part of the country.

Table 3.2: Data Selected for Further Analysis

No.	Station	River Basin	Location	Length of Record* (Years)	Catchment Area (km^2)
1	Akaki River	Awash	Central	28	890.6
2	Geba River nr Suppi	Baro	West	20	3759.1
3	Gheba River nr Mekele	Tekeze	North	14	2392.4
4	Weib River nr Agarfa	Wabi Shebele	South	28	808.4
5	Weito River	Rift Valley	South West	27	4532.9

Data with records less than 25years had to be included due to unavailability of data in the respective parts of the country

Figure 3.1 below depicts the general locations of the catchments of the above selected stations.

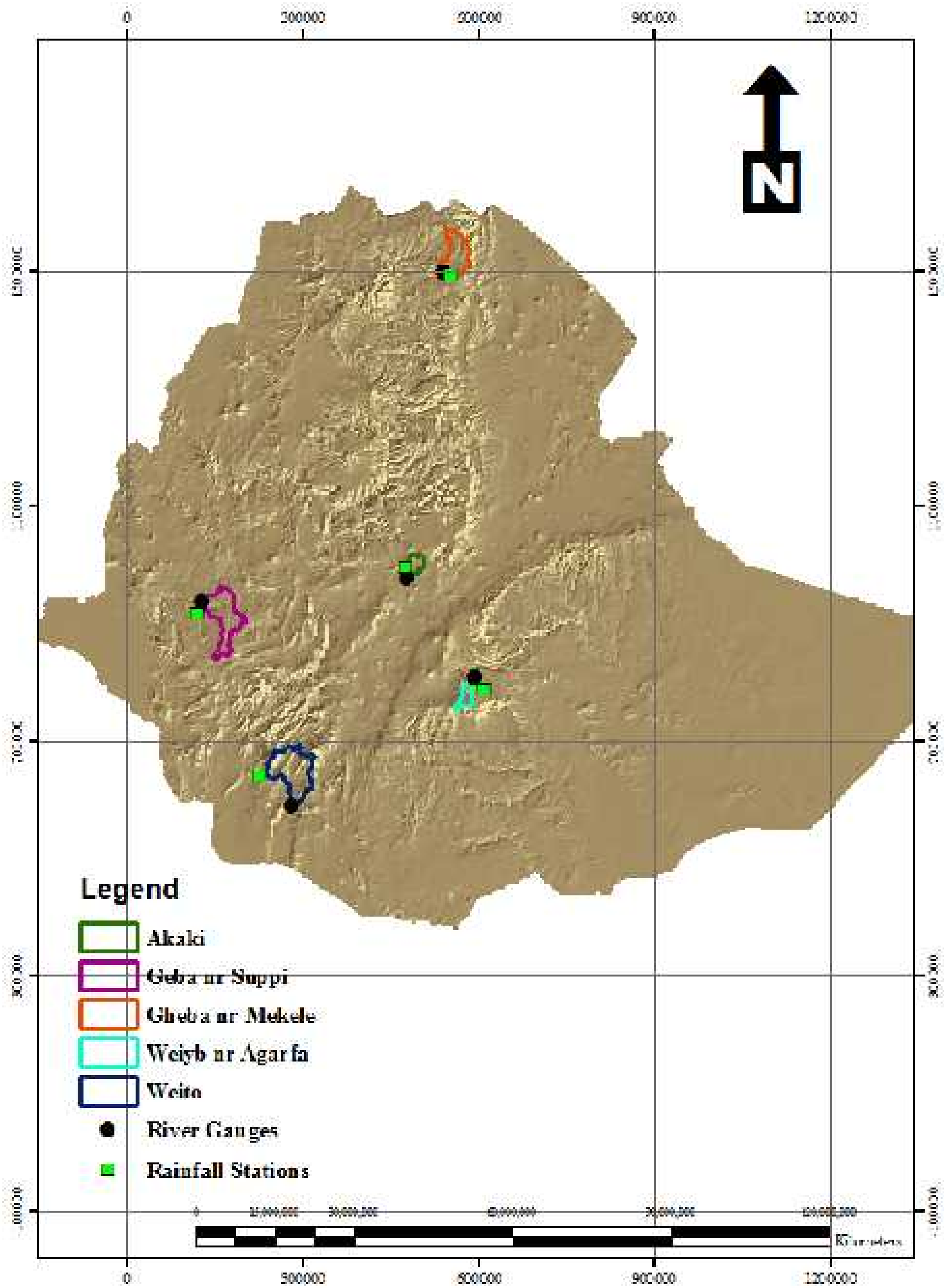

Figure 3.1: Location Map of the Selected Catchments with the respective River Gauge and Rainfall Stations

3.2. Description of Characteristics of the Selected Catchments

The following is the description of characteristics of each catchment selected for study:

Catchment Area	**Akaki River**
Drainage Area (km^2)	891.5
Soil Type	Approximately 74% Type D (high runoff potential due to very slow infiltration rates with majority clay type) and the remaining Type B (moderately low runoff potential due to moderate infiltration rates with majority silt loam type)
Land Use/Cover	Approximately 77% is Cultivated the remaining is a combination of Built-up area, Grass and Wood Land
Topography based on the Longest Water Course	Approximately 83% Flat and 15% Rolling
Length of the Longest Water Course (km)	63.2
Weighted Average Slope of the Longest Water Course (%)	1.7
Time of Concentration (hr.)	11.8

Catchment Area	**Geba River nr. Suppi**
Drainage Area (km^2)	3759
Soil Type	Approximately 24% Type D and the remaining Type B
Land Use/Cover	Approximately 30% is Cultivated the remaining is Wood Land
Topography based on the Longest Water Course	Mostly Flat
Length of the Longest Water Course (km)	169.1
Weighted Average Slope of the Longest Water Course (%)	0.8
Time of Concentration (hr.)	46.3

Catchment Area	**Gheba River nr Mekele**
Drainage Area (km^2)	2392.3
Soil Type	About 52% Type D and the remaining Type B
Land Use/Cover	Approximately 94% is Cultivated the remaining is a combination of Shrub Land and bare ground
Topography based on the Longest Water Course	Approximately 92% Flat and 8% Mountainous
Length of the Longest Water Course (km)	85.2

Weighted Average Slope of the Longest Water Course (%)	1.8
Time of Concentration (hr.)	18.4

Catchment Area	**Weyib River nr Agarfa**
Drainage Area (km^2)	808.4
Soil Type	Only Approximately 4% Type D and the remaining Type B
Land Use/Cover	Approximately 46% is Cultivated the remaining is a combination of Wood Land and Afro-alpine vegetation
Topography based on the Longest Water Course	Mostly Flat
Length of the Longest Water Course (km)	72.7
Weighted Average Slope of the Longest Water Course (%)	2
Time of Concentration (hr.)	14.3

Catchment Area	**Weito River**
Drainage Area (km^2)	4532.8
Soil Type	Only Approximately 8% Type D and the remaining Type B
Land Use/Cover	Approximately 17% is Cultivated the remaining is a combination of Wood and Grass Land
Topography based on the Longest Water Course	Approximately 90% Flat and 10% Rolling and Mountainous/Escarpment
Length of the Longest Water Course (km)	117.7
Weighted Average Slope of the Longest Water Course (%)	1.2
Time of Concentration (hr.)	30.4

3.3. Rainfall Data

Maximum daily rainfall data was obtained from National Meteorological Agency for the following stations which are within the influence of catchment areas selected for analysis. These are shown in Table 3.3.

Table 3.3: Rainfall Data Collected from NMA

No	Station	Type of data	Length of Record (Years)
1	Addis Ababa	Max. 24hr Rainfall	28
2	Arbaminch		16
3	Konso		13

No	Station	Type of data	Length of Record (Years)
4	Weito*		6
5	Jinka		28
6	Mekele		32
7	Wikro		25
8	Adigrat		17
9	Metu		27
10	Bedele		27
11	Bale Robe		30

*Weito rainfall record is too short, i.e. not used for further analysis.

The rainfall stations used the respective catchment areas are as shown below.

Catchment Area	Rainfall Stations
Akaki River	Addis Ababa
Geba River nr Suppi	Metu
Gheba River nr Mekele	Mekele
Weyib River nr Agarfa	Robe
Weito River	Jinka

3.4. Maps and Satellite Imagery

Topographic maps, geomorphology & soil maps, land use & land cover maps and satellite imagery data were collected.

- From Ethiopian Mapping Agency topographic maps 1:50,000 and 1:250000 scale of the catchment areas were acquired;
- Digital contour map with 20 meter interval extracted from the 30mx30m accuracy Digital Elevation Model (DEM) of the project area obtained from Shuttle Radar Topography Mission (SRTM);
- Google earth satellite imagery data was obtained;
- From Ministry of Agriculture, geomorphology/soil and land use/cover maps also available in shape files.

4. METHODOLOGY

As discussed in the previous section, five sample rivers with sufficient and adequate gauge data were chosen as samples from different parts of the country. In general for these locations detailed hydrological study based on the current practice in Ethiopia will be conducted. This will be done using two types of methodologies broadly deterministic and statistical approaches.

- The first approach is estimation of flood using rainfall-runoff relationships as dictated by the currently applied manuals in the country.
- The second approach is conducting flood estimation for the same catchments based on the historical gauged data using probabilistic methods, such as Log Normal Distribution or Gumbel EVI Distribution or Log Pearson Type III Distribution, which ever fits best.

The process of the two methods will be scrutinized for any setbacks or limitation. Also the results of each phase will be compared with each other also to determine the magnitude of their variation, if acceptable or not, and what the reason behind is. The reason could be with respect to sufficiency as well as reliability of rainfall data, adequacy of available maps, sufficiency as well as reliability of stream gauge data, availability of sufficient data during selection of runoff coefficients, etc.

In order to reinforce and draw conclusion of the above investigation, it is intended to conduct consultation with prominent road drainage design professionals with ample experience in the field so as to gain further insight. (refer to Annex 7) Furthermore design manuals of other countries will be investigated to get a better grasp of the issue.

Based on this information it is intended to form a comprehensive knowledge into the subject matter and propose possible remedial solutions. Figure 4.1 shows the general workflow of the study.

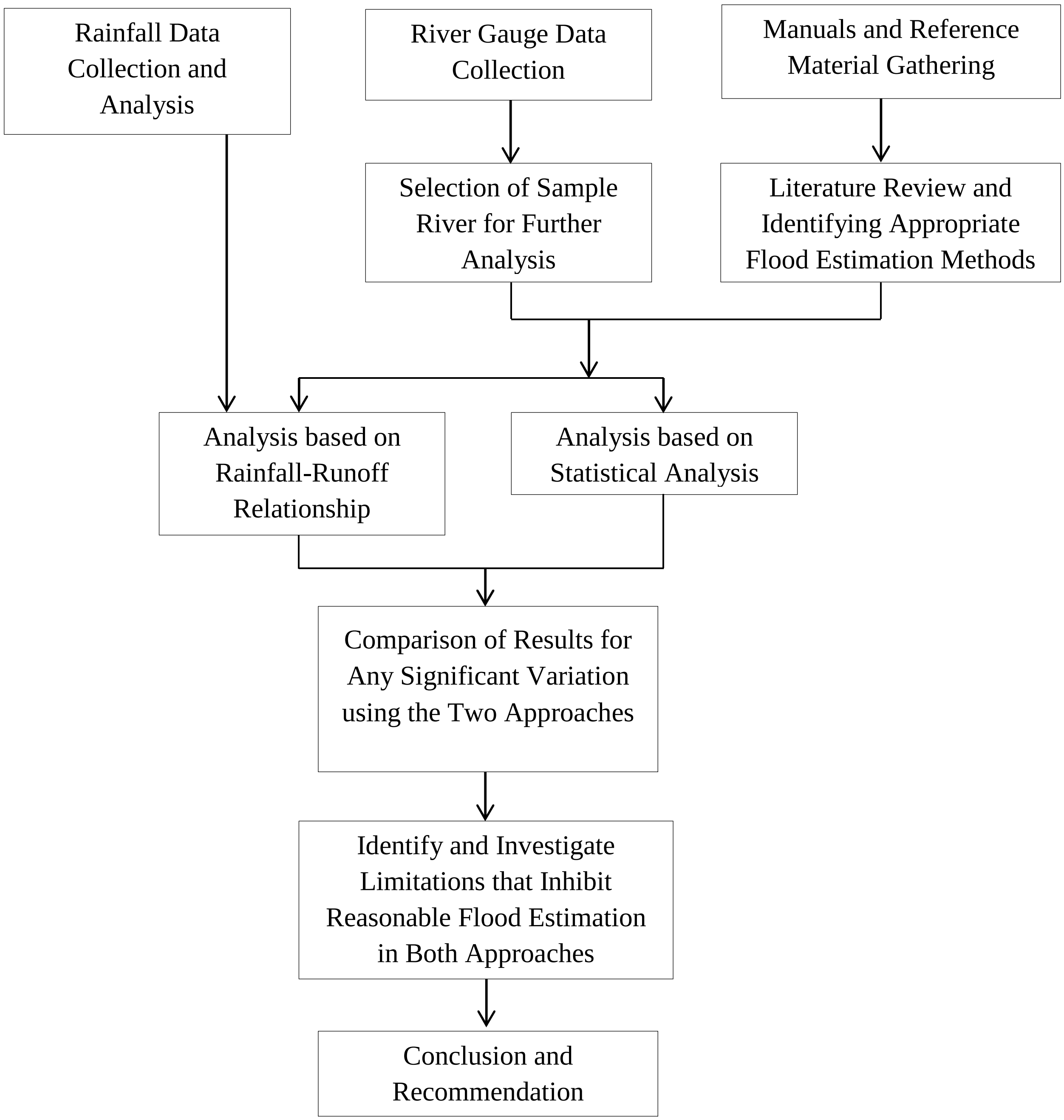

Figure 4.1: A General Workflow Showing the Main Tasks in the Study

4.1. Study of Watershed Characteristics

To obtain information and data on relief, geomorphology soil type, land cover and catchment parameter of the rivers, topographic maps, satellite images, DEM, land use and land cover maps as well as soil and geomorphology maps will be used.

a) Catchment Area Delineation and Watershed Parameters

Catchment areas were carefully delineated based on DEM extracted from the 30mx30m accuracy satellite image data applying WMS (Watershed Modeling System) software. Accurate area measurements of size as well as other catchment parameters such as stream slope, length of longest watercourse and elevation difference was obtained from the software as well as manipulating the output of the software by other applications such as AutoCAD software.

General drawing presentation of all catchment areas and details of these parameters are shown in Annex 1.

b) Hydrologic Soil Group

Hydrologic soil grouping for each catchment was identified using available soil maps of scale 1:1,000,000 (shape file format) by applying ArcGIS software. Drawing presentation and summary of hydrological soil grouping will be shown in Annex 2.

c) Land Use and Land Cover

Land use and land cover for each catchment was identified using available land use and land cover maps of scale 1:1,000,000 (shape file format) by applying ArcGIS software. List of the type of land cover encountered as well as drawing representation of each respective catchment area will be shown in Annex 3.

4.2. Rainfall Data Analysis

Annual series of daily maximum rainfall data that was available at all locations was analyzed using an extreme value frequency analysis and for which the Gumbel or Log-Normal or Log-Pearson III distributions. These distributions are discussed in detail in sections 4.4.2 and 4.4.3. Details of the analysis are shown in Annex 4.

4.3. Methods Viable for Application and Procedures of Analysis

As can be seen in table 3.2 all the selected areas have catchments with area greater than 65km^2, i.e. usage of synthetic hydrograph method or empirical formulas are the only viable methods. Furthermore, empirical methods is not presented in the manuals, i.e. this method is not subjected for investigation. Therefore the method used for rainfall – runoff analysis is synthetic hydrograph method (SCS Unit hydrograph method) as suggested in the manuals. For gauged catchments usage of statistical method are appropriate according to the DDMs.

a) SCS Unit Hydrograph Method

The steps to be followed in the course of application of SCS Unit Hydrograph Method are as follows. The process is based on the procedures and formulas stated in section 4.2.3..

- Estimate the Time of Concentration (T_C), the time required for water to flow from the most remote point of the basin to the location being analyzed; *(Eqn. 2.20)*
- Based on the T_C determine unit duration of the rainfall excess (D); *(Eqn. 2.17)*
- Calculate the ordinates of Unit Hydrograph, such as Time to Peak (T_P), Time Base of Hydrograph (T_B), Lag Time (T_L) and Peak Rate of Discharge (q_P); *(Eqn. 2.16, 2.15, 2.16 and Fig. 2.4)*
- Subdivide the 24h duration rainfall of required frequency based on Type II Design Storm Curve into blocks equal to the unit duration of excess rainfall; *(Fig. 2.1)*
- The effective rainfall (direct runoff) is calculated for each subdivision of the total rainfall based on the SCS method to be used as rectangular pulse to be applied to the ordinates of the unit hydrographs; *(Eqn. 2.6)*
- Apply the proportionality principle to scale the UH by the actual volume of the corresponding rectangular pulse. The resulting hydrographs are lagged so that their origins coincide with the time of occurrence of the corresponding rainfall pulse;
- Apply the superposition principle to obtain the Total Runoff Hydrographs by summing lagged hydrographs obtained after scaling the UHs.

b) Procedure of Statistical Method

For this analysis three distributions are applied. These are Gumbel (EVI), Log Normal and Log Pearson Distribution.

Based on the procedures stated in *Sec. 2.3.2.*, frequency analysis using frequency factor will be calculated for each distribution to determine the required extreme events. These will be done using annual flow data series after removal of outliers based on the procedure stated in *Sec. 2.4.6.*.

The probability plotting is done based on *Sec. 2.4.5.* as a check that a probability distribution fits a set of hydrologic data. These will determine the result to be used for further assessment.

5. ANALYSIS, RESULTS AND DISCUSSION

This chapter deals with the analysis and results of the undertaking. This includes study of watershed characteristics, rainfall data analysis and flood determination bases on the SCS approach and the statistical approach. Due to the bulky nature of these data only the analysis and results of Akaki catchment is presented here. The remaining are included in the Annex part. The results for all catchments are later summarized.

5.1. Calculation of Time of Concentration

Based on ERADDM the recommended empirical formula for calculating the time of concentration in natural channels was developed by the US Soil Conservation Service as presented in 2.3.4. equation 2.20. This was done by subdividing the longest water course into stretches with similar slope to avoid underestimation of Tc. The table 5.1 below presents the analysis. Topographic features for the calculation such as the length of the longest water course and elevations were obtained from topographic data obtained from satellite imagery.

Table 5.1: Calculation of Time of Concentration

Catchment Area	Tc Sum.	Elev. 1*	Elev. 2**	Elev. Dif.	Length	Slope	Tc***
	hr.	m	M	m	m	m/m	hr.
Akaki	11.79	2060	2260	200	26778	0.007	5.49
		2260	2460	200	15892	0.013	3.01
		2460	2600	140	10208	0.014	2.07
		2600	3160	560	10339	0.054	1.23
Geba nr Suppi	46.34	1180	1280	100	20960	0.005	5.40
		1280	1360	80	19230	0.004	5.33
		1360	1480	120	17236	0.007	4.02
		1480	2160	680	30583	0.022	4.00
		2160	2180	20	33160	0.001	17.05
		2180	2360	180	25895	0.007	5.50
		2360	2500	140	22083	0.006	5.04
Gheba nr Mekele	18.38	1740	1780	40	6507	0.006	1.99
		1780	1880	100	14037	0.007	3.40
		1880	1940	60	13558	0.004	3.98
		1940	1980	40	4156	0.010	1.19
		1980	2220	240	16917	0.014	3.01
		2220	2500	280	23733	0.012	4.20
		2500	3260	760	6332	0.120	0.62
Weib nr Agarfa	14.27	2370	2480	110	11526	0.010	2.61
		2480	2900	420	11275	0.037	1.52
		2900	3040	140	7678	0.018	1.49
		3040	3460	420	11134	0.038	1.50
		3460	3500	40	8527	0.005	2.72
		3500	3580	80	6072	0.013	1.41
		3580	3800	220	16495	0.013	3.02
Weito	30.39	600	640	40	14667	0.003	5.09

Catchment Area	Tc Sum.	Elev. 1*	Elev. 2**	Elev. Dif.	Length	Slope	Tc***
	hr.	m	M	m	m	m/m	hr.
		640	680	40	9558	0.004	3.10
		680	740	60	19451	0.003	6.03
		740	860	120	29740	0.004	7.54
		860	1080	220	15898	0.014	2.90
		1080	1180	100	16866	0.006	4.20
		1180	1560	380	9920	0.038	1.36
		1560	2020	460	1591	0.289	0.15

*Elevation at the lower end of the stream of the section

**Elevation at the higher end of the stream of the section

***Estimated time of concentration of the section

5.2. Catchment Area Delineation

Catchment areas were delineation based on DEM extracted from the 30mx30m accuracy satellite image data applying WMS (Watershed Modeling System) software. Catchment area was obtained from the software. General drawing presentation of Akaki River catchment is shown hereunder. The remaining catchment areas and details of these parameters are shown in Annex 1.

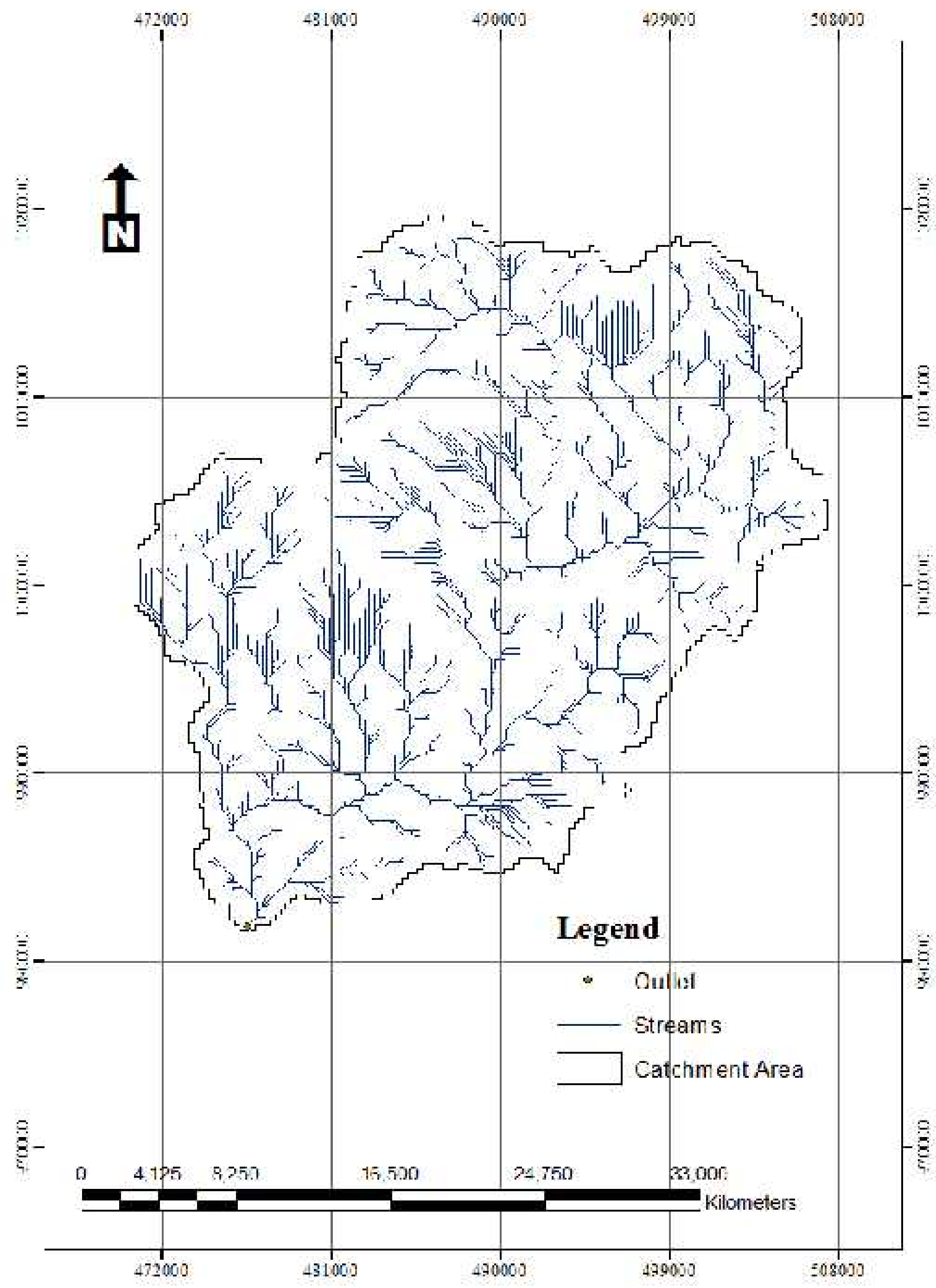

Figure 5.1: Catchment Area of Akaki River

5.3. Identification of Hydrologic Soil Groups

Hydrologic soil grouping for each catchment was identified using available soil maps of scale 1:1,000,000 (shape file format) by applying ArcGIS software. Soil group map and summary table from this analysis for Akaki river catchment is shown hereunder. These data for the remaining catchments are shown in Annex 2.

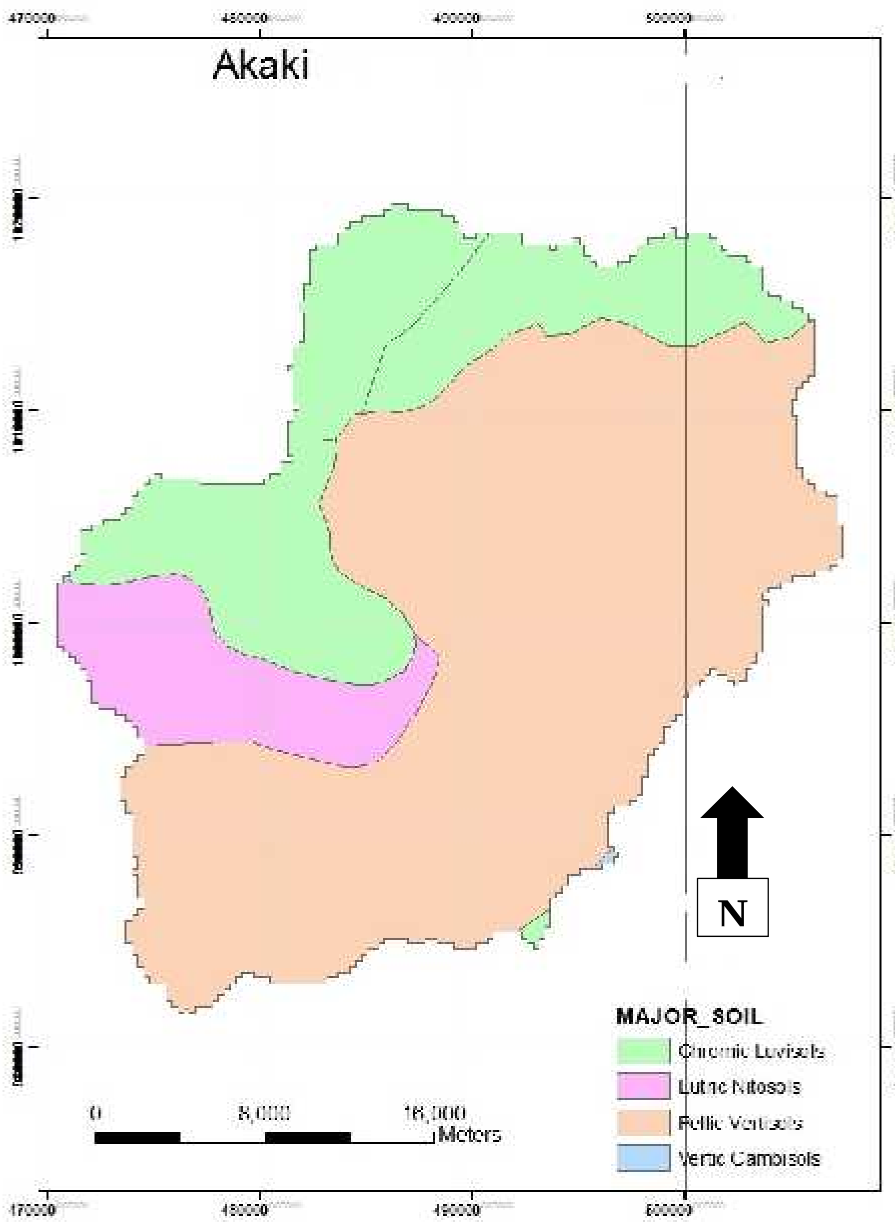

Figure 5.2: Soil Type Map for Catchment Area of Akaki River

Table 5.2: Soil Type of Akaki Catchment Area

Dominant Soil	Major Soil	Area (m^2)	Area (km^2)	B	D
Lc,s'	Chromic Luvisols	53532942.04	53.5	53.5	
Lc,s-Lv	Chromic Luvisols	79607300.45	79.6		79.6
Ne	Eutric Nitosols	85670663.11	85.7	85.7	
Vp	Pellic Vertisols	579210184.8	579.2		579.2
Lc,s-Lv	Chromic Luvisols	91728907.5	91.7	91.7	
Bv,r.s	Vertic Cambisols	460455.262	0.5	0.5	
Lc,s'	Chromic Luvisols	1336929.737	1.3	1.3	
		891547382.8780	**891.5**	**232.7**	**658.8**
				26%	**74%**

5.4. Determination of Land Use and Land Cover

Land use and land cover for each catchment was determined using available land use and land cover maps of scale 1:1,000,000 (shape file format) by applying ArcGIS software. Land use and land cover map for Akaki river catchment and summary table is shown hereunder. These data for the remaining catchments are shown in Annex 3.

Table 5.3: Land Use/Cover Type Map for Catchment Area of Akaki River

				CN	
Land Cover	**Area (m^2)**	**Area (km^2)**	**Proportion**	**B**	**D**
Intensively Cultivated	686553730.2	686.5537	77.0%	83	90
Open Shrub-land	42607985.52	42.6080	4.8%	67	83
Eucalyptus Woodland	56115181.3	56.1152	6.3%	60	79
Water Body	11475026.79	11.4750	1.3%		
Urban Or Built-Up Land	79040987.7	79.0410	8.9%	85	92
Open Grassland	15736071.9	15.7361	1.8%	79	89
Open Shrub-land	18399.476	0.0184	0.0%	67	83
	891547382.9	**891.5474**	100.0%	**79.8**	**88.0**
				26%	**74%**
				85.8	

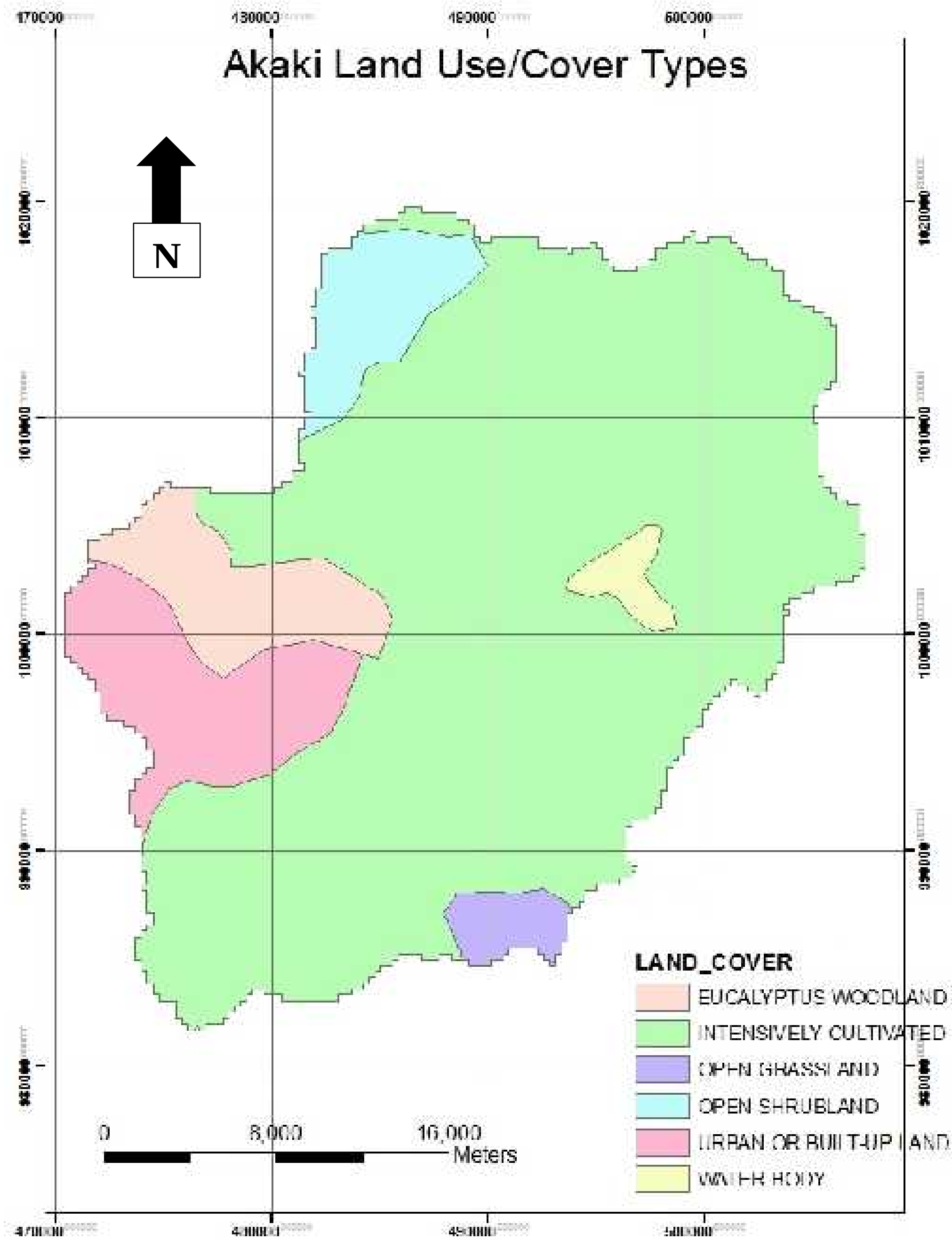

Figure 5.3: Land Use/Cover Type Map for Catchment Area of Akaki River

5.5. Rainfall Data Analysis

Annual series of daily maximum rainfall data that was available at all locations was analyzed using an extreme value frequency analysis and for which the Gumbel or Log-Normal or Log-Pearson III distributions. These distributions were discussed in detail in sections 2.4.2 and 2.4.3. The analysis for Addis Ababa rainfall station is shown hereunder. Details of the analysis for the remaining stations are shown in Annex 4.

Table 5.4: Addis Ababa Rainfall Station Rainfall Data Frequency Analysis Computation

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1987	53.00	71.20	1.85	1.00	0.03	3%	29.00	3.35
1988	35.80	64.70	1.81	2.00	0.07	7%	14.50	2.64
1989	48.40	64.70	1.81	2.00	0.07	7%	14.50	2.64
1990	37.00	61.70	1.79	4.00	0.14	14%	7.25	1.91
1991	59.60	60.10	1.78	5.00	0.17	17%	5.80	1.66
1992	44.30	59.60	1.78	6.00	0.21	21%	4.83	1.46
1993	40.60	54.40	1.74	7.00	0.24	24%	4.14	1.29
1994	38.20	53.00	1.72	8.00	0.28	28%	3.63	1.13
1995	64.70	52.00	1.72	9.00	0.31	31%	3.22	0.99
1996	52.00	51.20	1.71	10.00	0.34	34%	2.90	0.86
1997	37.30	48.40	1.68	11.00	0.38	38%	2.64	0.74
1998	60.10	47.00	1.67	12.00	0.41	41%	2.42	0.63
1999	37.80	44.50	1.65	13.00	0.45	45%	2.23	0.52
2000	47.00	44.30	1.65	14.00	0.48	48%	2.07	0.42
2001	32.40	42.60	1.63	15.00	0.52	52%	1.93	0.32
2002	28.60	40.60	1.61	16.00	0.55	55%	1.81	0.22
2003	34.60	38.20	1.58	17.00	0.59	59%	1.71	0.13
2004	29.00	37.80	1.58	18.00	0.62	62%	1.61	0.03
2005	44.50	37.30	1.57	19.00	0.66	66%	1.53	-0.06
2006	61.70	37.20	1.57	20.00	0.69	69%	1.45	-0.16
2007	71.20	37.00	1.57	21.00	0.72	72%	1.38	-0.25
2008	37.20	36.90	1.57	22.00	0.76	76%	1.32	-0.35
2009	51.20	35.80	1.55	23.00	0.79	79%	1.26	-0.45
2010	54.40	34.60	1.54	24.00	0.83	83%	1.21	-0.56
2011	36.90	32.40	1.51	25.00	0.86	86%	1.16	-0.68
2012	64.70	29.00	1.46	26.00	0.90	90%	1.12	-0.82
2013	42.60	28.60	1.46	27.00	0.93	93%	1.07	-0.98
2014	27.20	27.20	1.43	28.00	0.97	97%	1.04	-1.21

n	28		
Mean (Xm)	45.43	Mean (Ym)	1.64
Standard Deviation (Sx)	12.17	Standard Deviation (Sy)	0.12

K_N*	2.53
High Outlier Limit	86.40
Low Outlier Limit	22.30

*From Table 2.15

Table 5.5: Rainfall Data Frequency Analysis Computation using Gumbel Method for Addis Ababa Rainfall Station

$X_T = X_M + K_T S_X$ *(Eqn. 2.25)*

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Addis Ababa	2	-0.15	0.37	43.6
	5	0.88	1.50	56.1
	10	1.55	2.25	64.4
	25	2.41	3.20	74.8
	50	3.05	3.90	82.6
	100	3.68	4.60	90.3
	500	5.15	6.21	108.1

*Gumble Distribution Frequency Factor (from *Table 2.13*)

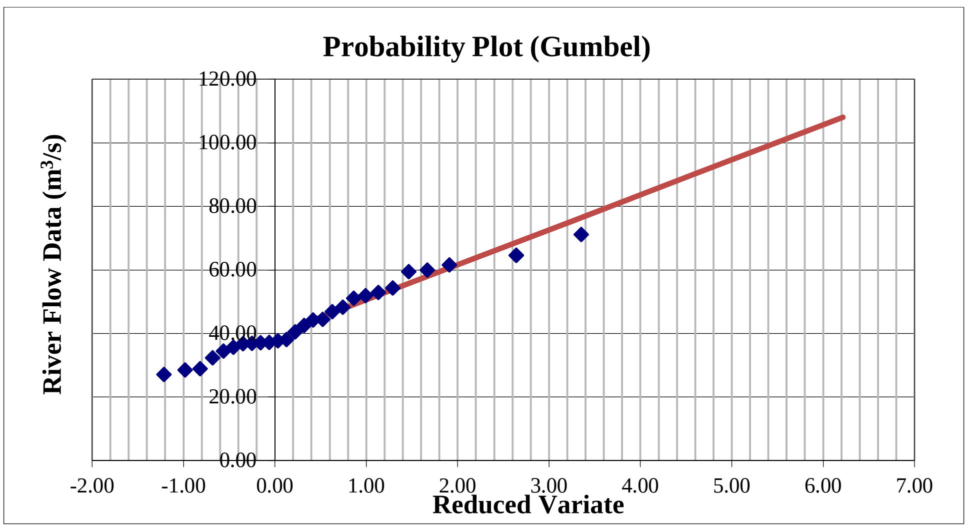

Figure 5.4: Probability Plot based on Gumbel Method for Addis Ababa Rainfall Station

Table 5.6: Rainfall Data Frequency Analysis Computation using Log Normal Method for Addis Ababa Rainfall Station

$$Y_T = Y_m + K_T S_y \qquad \textit{(Eqn. 2.26)}$$

Where:
$X_T = 10^{Y_T}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Addis Ababa	2	50.0%	0.00	0.00	1.64	43.89
	5	20.0%		0.84	1.74	54.96
	10	10.0%		1.28	1.79	61.82
	25	4.0%		1.75	1.85	70.08
	50	2.0%		2.05	1.88	75.99
	100	1.0%		2.33	1.91	81.74
	500	0.2%		2.88	1.98	94.72

* from standard distribution *Table 2.14*, f(Cs, T)

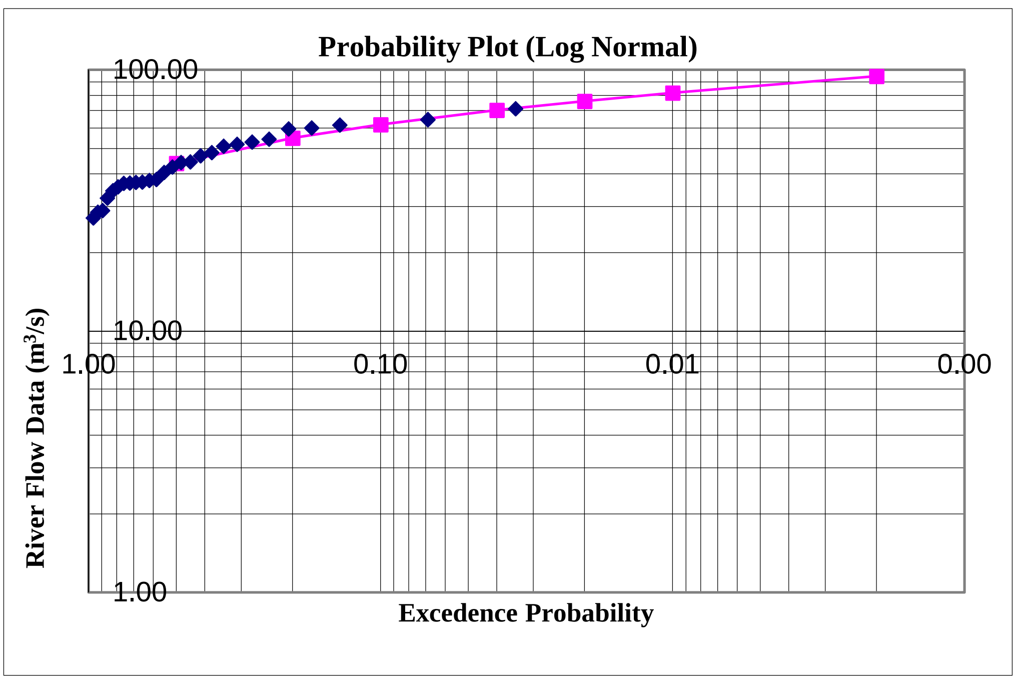

Figure 5.5: Probability Plot based on Log Normal Method for Addis Ababa Rainfall Station

Table 5.7: Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method for Addis Ababa Rainfall Station

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Addis Ababa	2	50.0%	0.04	-0.01	1.64	43.81
	5	20.0%		0.84	1.74	54.93
	10	10.0%		1.29	1.79	61.89
	25	4.0%		1.77	1.85	70.35
	50	2.0%		2.08	1.88	76.45
	100	1.0%		2.36	1.92	82.42
	500	0.2%		2.93	1.98	96.05

* from standard distribution Table 2.14, f(Cs, T)

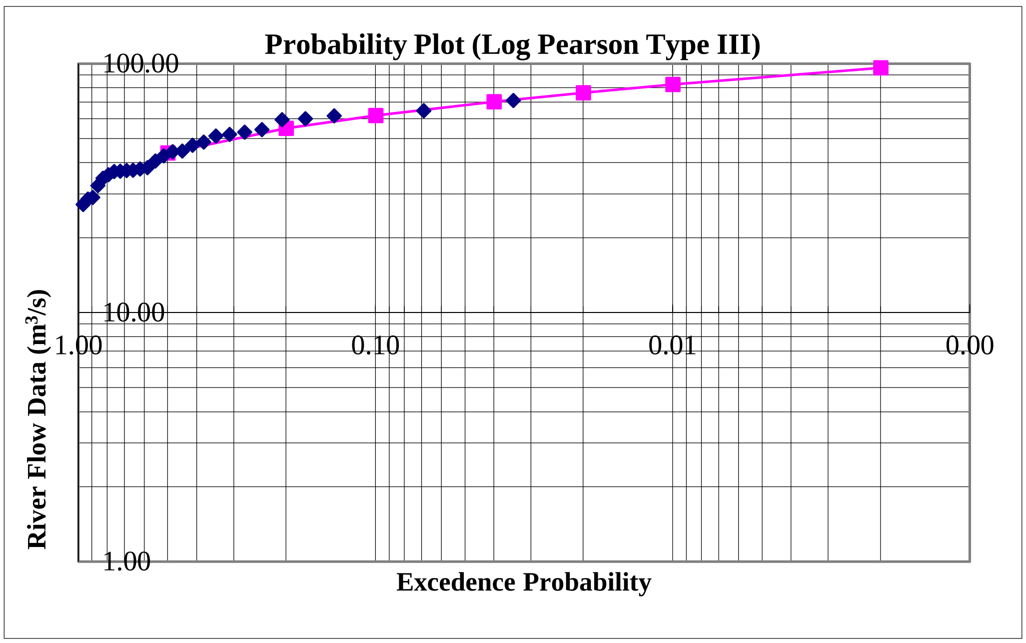

Figure 5.6: Probability Plot based on Log Pearson Type III Method for Addis Ababa Rainfall Station

5.6. Flood Estimation Using SCS Unit Hydrograph Method

Based on the procedure stated in the previous chapter flood estimation using SCS Unit Hydrograph method has been conducted for the selected five catchments. The analysis for Akaki catchment is shown hereunder. Details of the analysis for the remaining catchments are shown in Annex 5.

Table 5.8: Unit Peak Discharge Determination

Description	Formula	Unit	AKAKI
Area		km^2	891.50
Time of Conc.	Tc	hr.	11.79
Rainfall Excess Duration	D ~ Tc/6 if Tc < 3 hrs. D ~ 1 hr. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc	hr.	7.58
Time Base of Hydrograph	Tb = 2.67Tp	hr.	20.23
Lag Time	Tl = 0.6Tc	hr.	7.08
Peak Rate of Discharge	qp = (0.21A) / Tp	$m^3/s/mm$	24.71
Weighted CN Value			86
Maximum Potential Diff.	S=(25400/CN)-254		42.04

Table 5.9: Ordinates for Unit hydrograph Calculation

Duration (hrs.)		Rainfall 24hr Max.*	Rainfall Profile	Rainfall Profile	Times of Incremental Hydrograph			Direct Runoff	Incremental Runoff	Peak Runoff
Beginning	End	mm	%	mm	Begin	Peak	End	mm	mm	mm
0.00	1.00	90.26	1.08	0.97	0.00	7.58	20.23	0.00	0.00	0.00
1.00	2.00		2.23	2.01	1.00	8.58	21.23	0.00	0.00	0.00
2.00	3.00		3.47	3.13	2.00	9.58	22.23	0.00	0.00	0.00
3.00	4.00		4.83	4.36	3.00	10.58	23.23	0.00	0.00	0.00
4.00	5.00		6.32	5.70	4.00	11.58	24.23	0.00	0.00	0.00
5.00	6.00		7.97	7.19	5.00	12.58	25.23	0.00	0.00	0.00
6.00	7.00		9.84	8.88	6.00	13.58	26.23	0.01	0.01	0.13
7.00	8.00		12.03	10.86	7.00	14.58	27.23	0.14	0.13	3.21
8.00	9.00		14.67	13.24	8.00	15.58	28.23	0.50	0.36	8.98
9.00	10.00		18.08	16.32	9.00	16.58	29.23	1.25	0.75	18.65
10.00	11.00		23.51	21.22	10.00	17.58	30.23	2.99	1.74	43.00
11.00	12.00		66.32	59.86	11.00	18.58	31.23	28.32	25.32	625.84

*Rainfall station is located in Addis Ababa.

Table 5.10: Ordinates of Unit hydrographs

Time	Ordinates of Unit Hydrographs for AKAKI												Sum
0.00	0.00												0.00
1.00	0.00	0.00											0.00
2.00	0.00	0.00	0.00										0.00
3.00	0.00	0.00	0.00	0.00									0.00
4.00	0.00	0.00	0.00	0.00	0.00								0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00							0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						0.00
7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00					0.02
7.58	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.24					0.27
8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.42	0.00				0.46
8.58	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.67	0.68				1.39
9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.85	1.19	0.00			2.08
9.58	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.09	1.87	1.42			4.44
10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	1.27	2.37	2.46	0.00		6.17
10.58	0.00	0.00	0.00	0.00	0.00	0.00	0.08	1.51	3.05	3.88	3.27		11.79
11.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	1.69	3.56	4.92	5.68	0.00	15.94
11.58	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1.94	4.24	6.34	8.94	47.56	69.12
12.58	0.00	0.00	0.00	0.00	0.00	0.00	0.11	2.36	5.43	8.80	14.62	130.17	161.49
13.58	0.00	0.00	0.00	0.00	0.00	0.00	0.13	2.78	6.61	11.26	20.29	212.78	253.87
14.58	0.00	0.00	0.00	0.00	0.00	0.00	0.12	3.21	7.80	13.73	25.97	295.40	346.22
15.58	0.00	0.00	0.00	0.00	0.00	0.00	0.11	2.95	8.98	16.19	31.65	378.01	437.89
16.58	0.00	0.00	0.00	0.00	0.00	0.00	0.10	2.70	8.27	18.65	37.32	460.62	527.66
17.58	0.00	0.00	0.00	0.00	0.00	0.00	0.09	2.45	7.56	17.18	43.00	543.23	613.50
18.58	0.00	0.00	0.00	0.00	0.00	0.00	0.08	2.19	6.85	15.70	39.60	625.84	690.26
20.23	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.77	5.68	13.27	33.99	544.14	598.91
21.23		0.00	0.00	0.00	0.00	0.00	0.05	1.52	4.97	11.79	30.59	494.68	543.60
22.23			0.00	0.00	0.00	0.00	0.04	1.27	4.26	10.32	27.19	445.21	488.28
23.23				0.00	0.00	0.00	0.03	1.01	3.55	8.84	23.79	395.74	432.97
24.23					0.00	0.00	0.02	0.76	2.84	7.37	20.39	346.27	377.66
25.23						0.00	0.01	0.51	2.13	5.90	16.99	296.81	322.34
26.23							0.00	0.25	1.42	4.42	13.59	247.34	267.03
27.23								0.00	0.71	2.95	10.20	197.87	211.72
28.23									0.00	1.47	6.80	148.40	156.67
29.23										0.00	3.40	98.94	102.33
30.23											0.00	49.47	49.47
31.23												0.00	0.00

Area Reduction Factor (ARF)

The aerial reduction factor (ARF) in this study is given by an expression proposed for East Africa by Fiddes.

$ARF = 1 - 0.045\ A^{0.275}$ For catchments of area, $A > 30\ km^2$

$ARF = 1 - 0.020\ T^{-0.33}\ A^{0.50}$ Up to $30\ km^2$

Where:

ARF = Areal reduction factor

T = Duration, hr

A = Catchments area, km^2

ARF (%) =	71%
Q max (m^3/s) =	690.26
Q reduced (m^3/s) = Q max * ARF	489.12

Where

Q des = Design Discharge

Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph

ARF=Area Reduction Factor

5.7. Flood Estimation based on Statistical Methods

Annual series of river flow data that was available at all locations was analyzed using an extreme value frequency analysis and for which the Gumbel or Log-Normal or Log-Pearson III distributions. These distributions were discussed in detail in sections 2.4.2 and 2.4.3. The analysis for Akaki River Gauge station is shown hereunder. Details of the analysis for the remaining river gauge stations are shown in Annex 6.

Table 5.11: Akaki River Gauge Station Data Frequency Analysis Computation

Year	River Flow Data (m^3/s)	Descending Order River Flow Data (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1999	693.10	693.10	2.84	1.00	0.03	3%	29.00	3.35
1996	615.76	615.76	2.79	2.00	0.07	7%	14.50	2.64
1993	573.57	573.57	2.76	3.00	0.10	10%	9.67	2.21
2001	435.34	435.34	2.64	4.00	0.14	14%	7.25	1.91
1998	421.52	421.52	2.62	5.00	0.17	17%	5.80	1.66
2003	420.06	420.06	2.62	6.00	0.21	21%	4.83	1.46
1990	277.22	277.22	2.44	7.00	0.24	24%	4.14	1.29
1997	276.32	276.32	2.44	8.00	0.28	28%	3.63	1.13
1995	257.98	257.98	2.41	9.00	0.31	31%	3.22	0.99
2000	255.78	255.78	2.41	10.00	0.34	34%	2.90	0.86
2004	250.47	250.47	2.40	11.00	0.38	38%	2.64	0.74
1989	233.77	233.77	2.37	12.00	0.41	41%	2.42	0.63
2002	219.87	219.87	2.34	13.00	0.45	45%	2.23	0.52
1991	215.22	215.22	2.33	14.00	0.48	48%	2.07	0.42
1981	201.31	201.31	2.30	15.00	0.52	52%	1.93	0.32
1984	189.38	189.38	2.28	16.00	0.55	55%	1.81	0.22
1982	172.77	172.77	2.24	17.00	0.59	59%	1.71	0.13
1985	165.65	165.65	2.22	18.00	0.62	62%	1.61	0.03
1994	162.58	162.58	2.21	19.00	0.66	66%	1.53	-0.06
1992	153.07	153.07	2.18	20.00	0.69	69%	1.45	-0.16
1988	148.35	148.35	2.17	21.00	0.72	72%	1.38	-0.25
1983	138.72	138.72	2.14	22.00	0.76	76%	1.32	-0.35
1986	68.78	68.78	1.84	23.00	0.79	79%	1.26	-0.45
1987	36.55	36.55	1.56	24.00	0.83	83%	1.21	-0.56
2007	34.24	34.24	1.53	25.00	0.86	86%	1.16	-0.68
2008	32.41	32.41	1.51	26.00	0.90	90%	1.12	-0.82
2005	25.20	25.20	1.40	27.00	0.93	93%	1.07	-0.98
2006	22.17	22.17	1.35	28.00	0.97	97%	1.04	-1.21

n	28				K_N*	2.53
Mean (Xm)	239.18	Mean (Ym)	2.23		High Outlier Limit	1954.35
Standard Deviation (Sx)	178.65	Standard Deviation (Sy)	0.42		Low Outlier Limit	14.57

*From Table 2.15

Table 5.12: Akaki River Data Analysis using Gumbel Method

$X_T = X_M + K_T S_X$ *(Eqn. 2.25)*

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	Ext. Flow X_T [m3/s]
	2	-0.15	0.37	212.1
	5	0.88	1.50	395.5
	10	1.55	2.25	517.0
	25	2.41	3.20	670.4
	50	3.05	3.90	784.2
	100	3.68	4.60	897.2
	500	5.15	6.21	1158.4

*Gumble Distribution Frequency Factor (from *Table 2.11*)

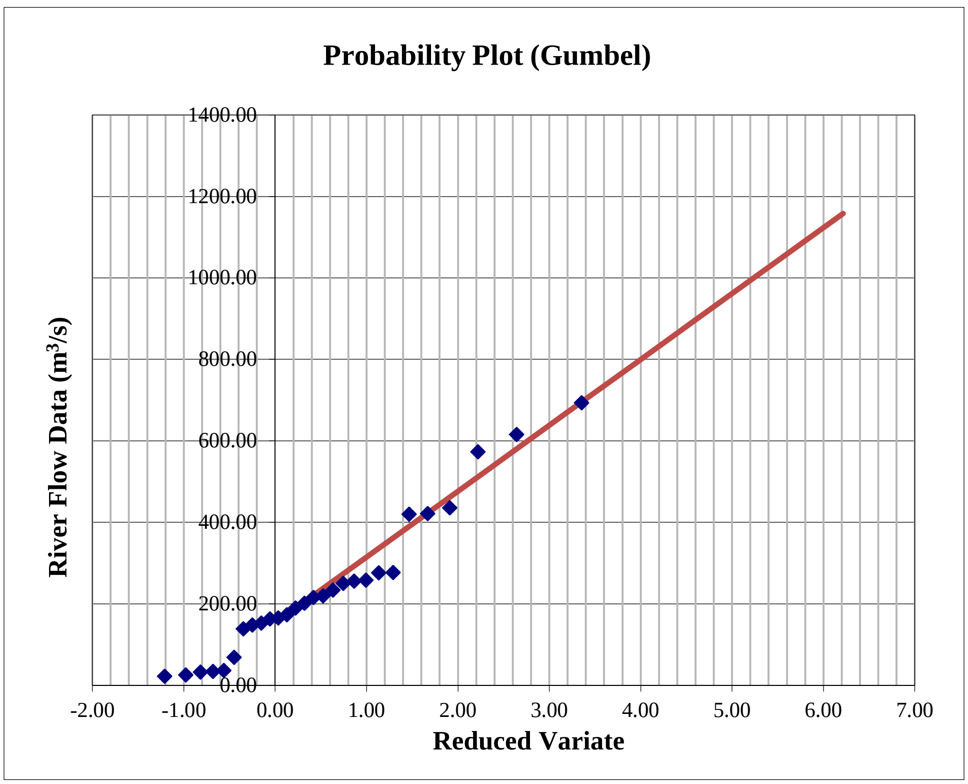

Figure 5.7: Probability Plot based on Gumbel Method for Akaki River Gauge Station

Table 5.13: Akaki River Data Analysis using Log Normal Method

$Y_T = Y_m + K_T S_y$ *(Eqn. 2.26)*

Where:
$X_T = 10^{Y_T}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	0.00	0.00	2.23	168.74
	5	20.0%		0.84	2.58	380.65
	10	10.0%		1.28	2.77	582.42
	25	4.0%		1.75	2.96	916.58
	50	2.0%		2.05	3.09	1228.61
	100	1.0%		2.33	3.20	1599.01
	500	0.2%		2.88	3.44	2725.84

* from standard distribution *Table 2.12*, f(Cs, T)

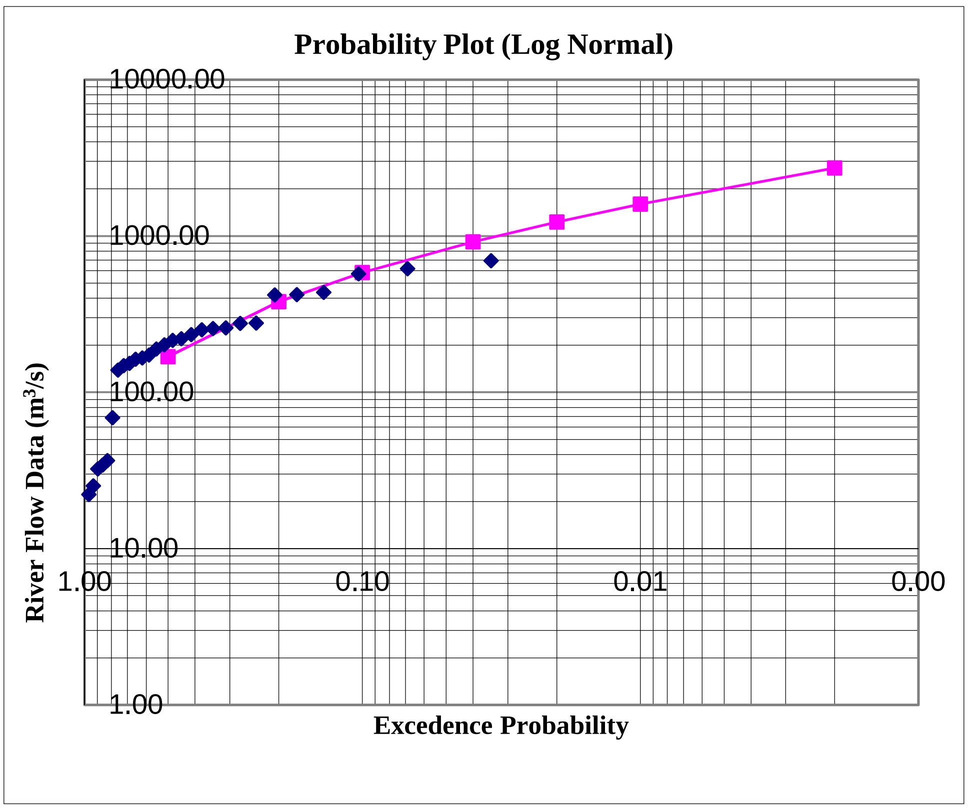

Figure 5.8: Probability Plot based on Log Normal Method for Akaki River Gauge Station

Table 5.14: Akaki River Data Analysis using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%		0.13	2.28	192.04
	5	20.0%		0.86	2.59	385.93
	10	10.0%		1.16	2.72	519.62
	25	4.0%	-0.81	1.44	2.83	681.08
	50	2.0%		1.60	2.90	792.02
	100	1.0%		1.72	2.95	893.74
	500	0.2%		1.94	3.04	1096.86

* from standard distribution Table 2.12, f(Cs, T)

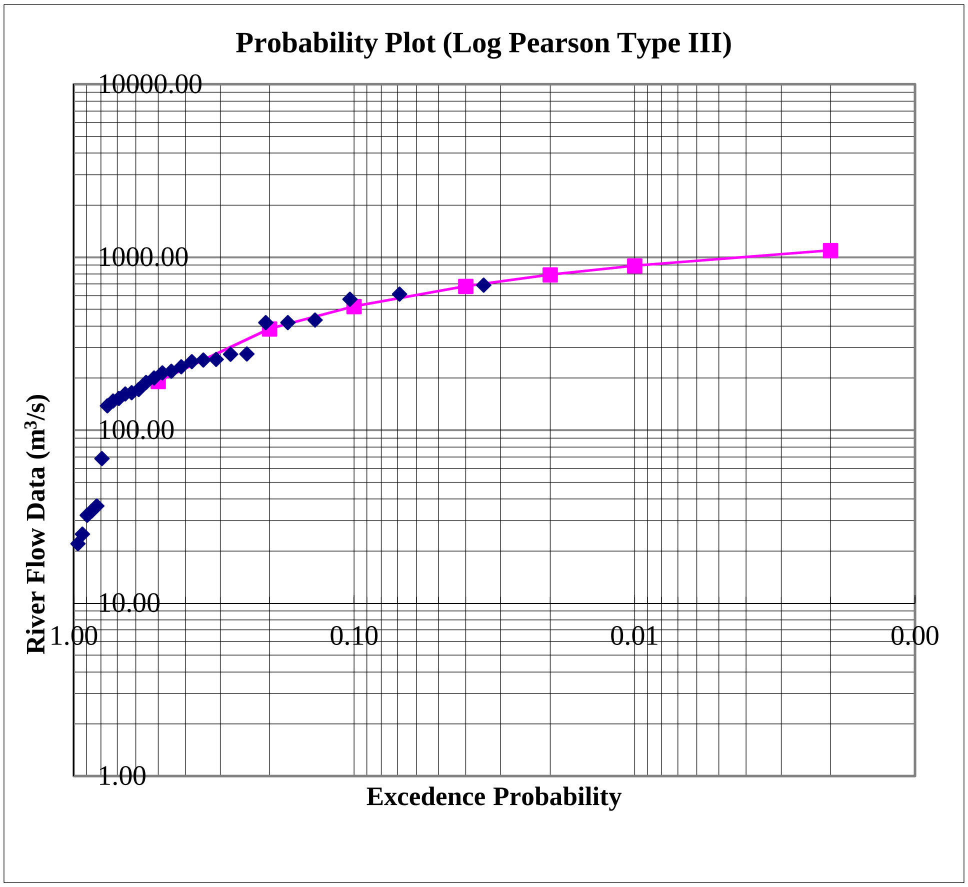

Figure 5.9: Probability Plot based on Log Pearson Type III Method for Akaki River Gauge Station

5.8. Summary of Estimated Floods

As described in the previous chapter flood estimation for the selected rivers have been carried out based on the currently practiced methodologies for road drainage design. These are the SCS Method and Statistical Methods such as Gumbel and Log Pearson. As an input for the SCS Method catchment delineation, catchment characteristics (land use/cover and soil type) determination, rainfall data analysis and time of concentration determination has been carried out. The details of these analysis is shown in the Annex part below. The following tables 5.15 and 5.16 give the summary of results obtained from the analysis for further examination and discussion.

Table 5.15: Summary of Estimated Flood based on SCS Method for Hundred Years Return Period

Name of River	Q – SCS Method (m^3/s)	
	Maximum	Reduced*
Akaki	690.26	489.12
Geba nr Suppi	1954.45	1108.42
Gheba nr Mekele	3083.55	1904.75
Weib nr Agarfa	704.13	504.39
Weito	1734.46	944

*The maximum estimated flood is reduced by area reduction factor as can be seen in Annex 6.

Table 5.16: Summary of Estimated Flood based on Statistical Methods using Gumbel (EVI), Log Normal and Log Pearson Distribution for Hundred Years Return Period

Name of River	Q - Estimation (m^3/s)		
	Gumbel	Log Normal	Log Pearson Type III
Akaki	897.2*	1599.01	893.74
Geba nr Suppi	457.3*	413.33	368.46
Gheba nr Mekele	1746.0	1869.63*	2844.20
Weib nr Agarfa	241.2*	288.28	235.79
Weito	1010.9*	1380.46	838.10

*These are the results having a better fitting of the Corresponding Statistical Method as can be seen from the graphs in Annex 7 therefore adopted for further analysis.

5.9. Discussion

Based on the results it can be concluded that the results obtained from the two methods (SCS and Statistical) vary considerably except in the case of Gheba nr Mekele and Weito. At this point it should be noted that the comparison is made just to show the magnitude of variation in estimated flood and there shouldn't be any implication that one estimation method is more accurate than another.

Based on this in the case of Akaki River the discharge estimated using the statistical method is higher by about 83%. In contrary to this in the cases of Geba nr Suppi and Weib nr Agarfa the discharge estimated using SCS Method is higher by about 142% and 109% respectively. The table 5.17 below exhibits the variation in terms of percentage.

Table 5.17: Comparison of Results

Name of River	Q – SCS* Method (m^3/s)	Q – Statistical** (m^3/s)	Variation (m^3/s) [* – **]	Variation (%) [* – **]/ [min. {* or **}]
Akaki	489.12	897.2	-408.1	-83%
Geba nr Suppi	1108.42	457.3	+651.1	+142%
Gheba nr Mekele	1904.75	1869.63	+35.1	+2%
Weib nr Agarfa	504.39	241.2	+263.1	-109%
Weito	944	1010.9	-66.9	-7%

These disparities could be due to many reasons. The following are the setbacks observed using the SCS method which might result in undermining or overestimation of the result.

Study of watershed characteristics such as size, Shape, soil type and land use/cover.

Size and shape can easily and to a reasonable accuracy be determined from catchment area delineation based on either topographic maps and/or satellite imagery for areas with rolling and mountainous topography. However for areas with flat topography considering the fact that the available topographic maps are not higher than scale of 1:50,000 and the satellite imagery DEM data is 30 x 30m accuracy it is difficult to accurately determine the size of the catchment area.

Determination of soil type and land use data which ultimately lead to the selection of CN factor are dependent on maps of scale 1:1,000,000, satellite images and observation. The maps are not entirely reliable due to the fact that they are of small scale and are not regularly updated to larger scale and accuracy. Also since observation couldn't be undertaken on the entire catchment area especially when the catchment area is very large this cannot also be totally dependable. Therefore since the determination of CN value is dependent on these parameters it cannot be accurately determined. To make matters worse this parameter is a very sensitive, i.e. a small change of this parameter would result in a considerable change of the end result (estimated flood). A good example for this is the estimation of flood undertaken for Geba (nr Suppi) River. Keeping all other parameters the same, the change of CN value from CN average (72) to CN wet (86) resulted in about 170% increase of flood.

The other crucial point to investigate is the determination of Time of Concentration (Tc). As mentioned before the Time of Concentration, Tc, is the time required for water to flow from the most remote point of the basin to the location being analyzed. A storm equal to this duration will permit direct runoff to arrive from all points in the watershed concentrating at the outlet. This time measure is taken to be the critical time by many flood-estimating approaches, in that it is assumed that the use of any other time would result in a lower flood estimate. A shorter time, although resulting in higher rainfall intensity, will not permit the entire basin to contribute flow simultaneously. A longer duration allows the entire basin to contribute, but with a lower intensity. Therefore miscalculation resulting in higher or lower time of concentration will result either in overestimation or underestimation.

An additional key point to consider is rainfall data. Rainfall Stations are not closely available throughout the country, i.e. for a very large catchment flood estimation might rely on 1 or 2 stations and in some cases may be none. This would hinder determination of areal distribution of rainfall. Moreover the data available in some cases have gaps in the rainy seasons as well as discontinuities. This would cause forecast unreliable. Furthermore in order to determine if an area is wet or average or dry as per the classification of the manual the continuity of the data is required. The region being wet rather than average or dry would cause a large difference of the estimated flood. This has been demonstrated above when considering the case of Geba (nr Suppi) River.

The above factors are the major setbacks in determination of flood using the SCS approach. However this shouldn't imply that the estimation made by the probabilistic methods is also accurate. During the preparation of this paper, setbacks using this method had been encountered. One of the key problems to consider is the insufficiency and reliability of data. The river gauge data collected were in some cases very short (less than 10years). In other cases the data had gaps as high as 10years and missed readings especially in rainy seasons. Also it is crucial to realize that all gauges are manual, i.e. data are gathered manually. Unavailability of automatic gauges makes readings subject to human error. The measurements are taken two times a day at best, i.e. could only give information of flood at the time of measurement. This could result in omission of peak floods during the day or night. These setbacks incur inaccurate estimation of peak discharges.

Therefore in the case of Akaki River, where the discharge estimated using the statistical method is higher by about 83%, the reason for the disparity could most probably be due to inaccuracy in determination of catchment property such as land use/cover and soil types in addition to inaccurate determination of time of concentration offsetting estimation using the SCS Method. However in the cases of Geba nr Suppi and Weib nr Agarfa, where the discharge estimated using SCS Method is higher by about 142% and 109% respectively, in addition to reasons stated for Akaki river above there could be inaccuracy in recording river gauge data (omission of peak floods) resulting in underestimation using statistical methods.

6. CONCLUSION AND RECOMMENDATION

In a nutshell the study carried out the following undertakings. These are:

- Selection of five sample rivers with sufficient river gauge data;
- Determination of peak discharges for these rivers based on currently used methodologies in Ethiopia, i.e. Rainfall – Runoff Procedures (SCS method) and statistical methods;
- Comparison of results were undertaken to determine if the results are compatible;
- Determine the setbacks in estimation of floods;
- Propose remedial solutions.

As summarized in the previous section the comparison of results obtained from the analysis based on the methods above indicated that except in the two cases (Gheba nr Mekele and Weito), the variation of obtained are considerably high which is in the range of 83% to 142%. This leads into an implication that the results obtained from either or both of the methods might have inaccuracy and leads to the inquiry of why the variation. Therefore further insight into the procedure should be sought after.

In the process of flood estimation the following major setbacks were observed. It is believed that these major problems are the contributing factors for the inaccuracies and subsequently the variations of the results. Since these factors are discussed in detail in the previous section only the summary of these setbacks are shown below.

- Difficulty in determination of watershed characteristics due to unavailability of up to date and accurate large scale maps;
- Inaccuracy in determination of Time of Concentration (T_C);
- Unavailability of sufficient and continuous hydrological data such as rainfall and river gauge data.

To further reinforce these claims other renowned Drainage Engineers working on road projects in Ethiopia were consulted. The points that were taken from the consultation have indeed reinforced the observed setbacks during the preparation of the paper. These information has been included in Annex 7.

Therefore, in general, it can be concluded that the areas mentioned above needs improvement in order to get a better estimation of peak flood using the methodologies suggested in the drainage design manuals of the country, i.e. rational, SCS methods as well as statistical methods.

At this point it is worth mentioning the statement in ERA Drainage Design Manual 2013 section 5.5, which is “Regression equations and derivations from stream gauging (Gumbel, Log Pearson, General Extreme Value) are often preferred but rely on data not available. For this reason, only the Rational Method and the SCS method are given in this chapter.”

As discussed in the Literature Review section the United States Geological Survey (USGS) published regression equations for rural areas of Tennessee. This study was based on stream flow data gathered from 453 gauging stations located in rural and lightly developed areas of Tennessee and the adjacent states (except Arkansas). Of these, 297 gauges were located in Tennessee. All of the gauges had a minimum of 10 years of stream flow data. Stream gauges were not included in the analysis where historical discharge records had been significantly impacted by urbanization, dredging, or other man-made watershed changes. *(TDOTDDM 2010)*

Regional methods, such as the method developed by the USGS, that are based on actual measured data produce better result than rainfall-runoff methods which depend on determination of vast catchment characteristics based on maps and other means. Therefore it can be recommended that, in the long run, to get a lasting solution, the density and reliability of river gauge data should be sought after. This can be achieved by installing automatic gauging stations in new as well as already existing river locations. This could be achieved for instance along existing or newly constructed roads. After some time elapses, when sufficient reliable data are obtained, regional formulas can be developed using regional flood frequency analysis and based on these data regional regression equations can be developed.

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ANNEX 1: GENERAL DRAWING PRESENTATIONS OF CATCHMENTS

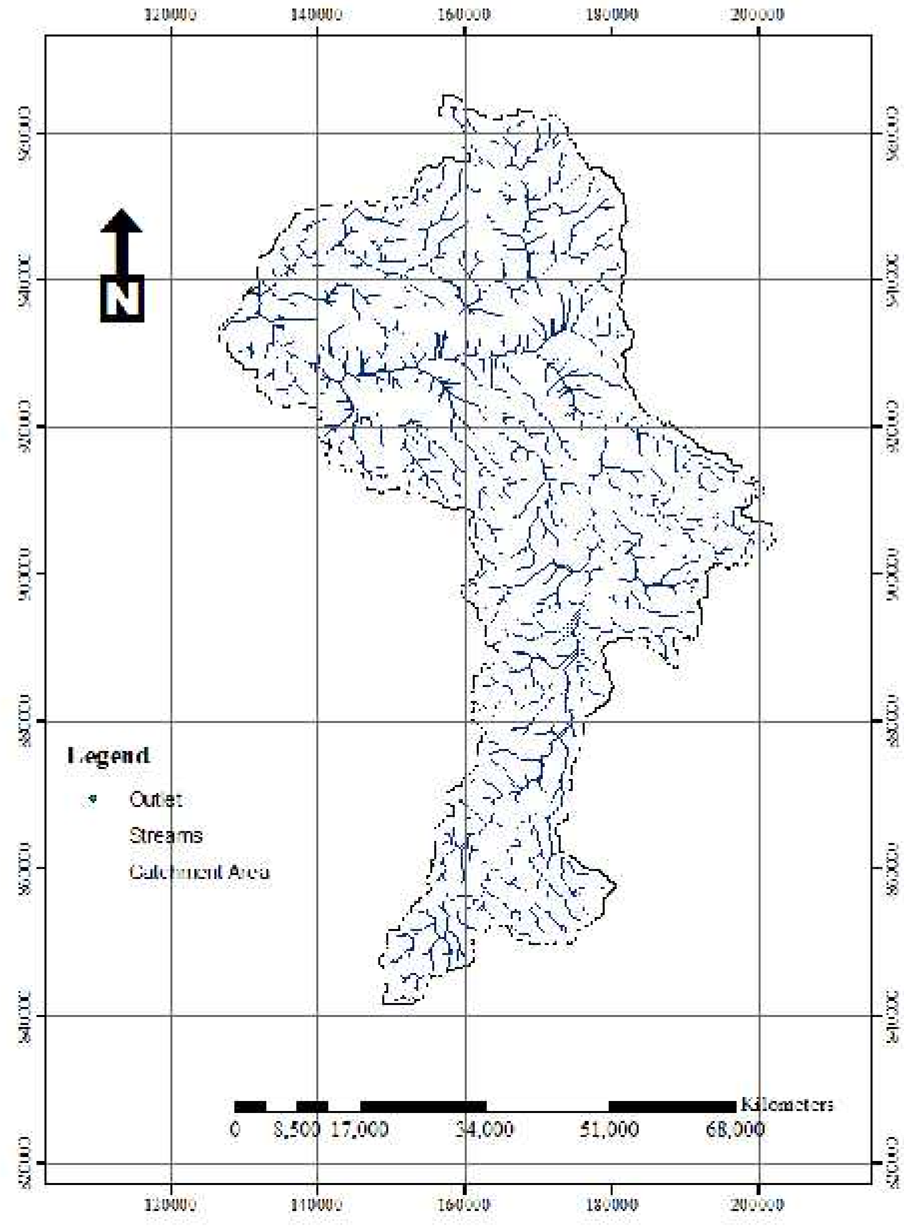


Figure A1.1: Catchment Area of Geba River nr. Suppi

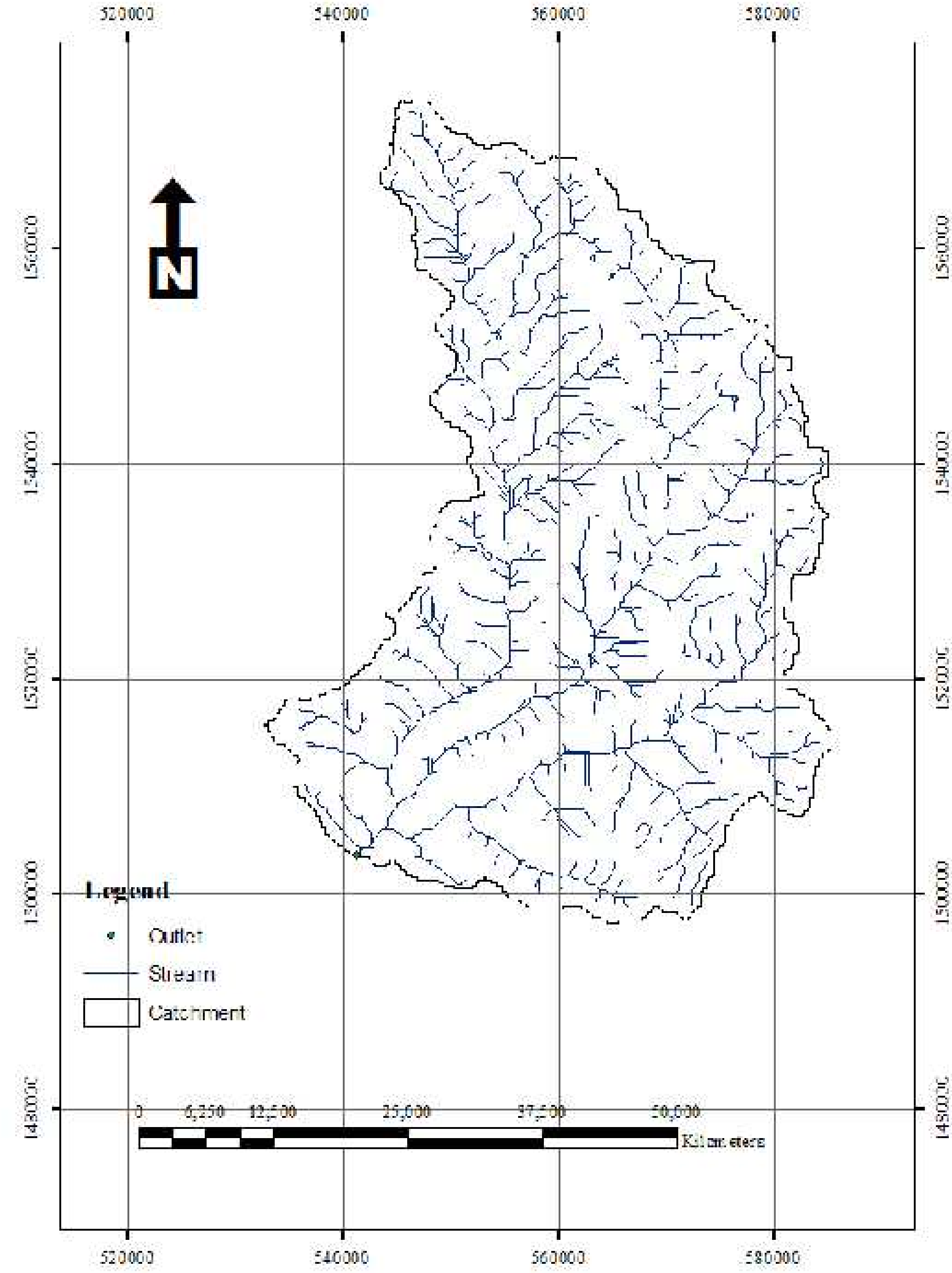


Figure A1.2: Catchment Area of Gheba River nr. Mekele

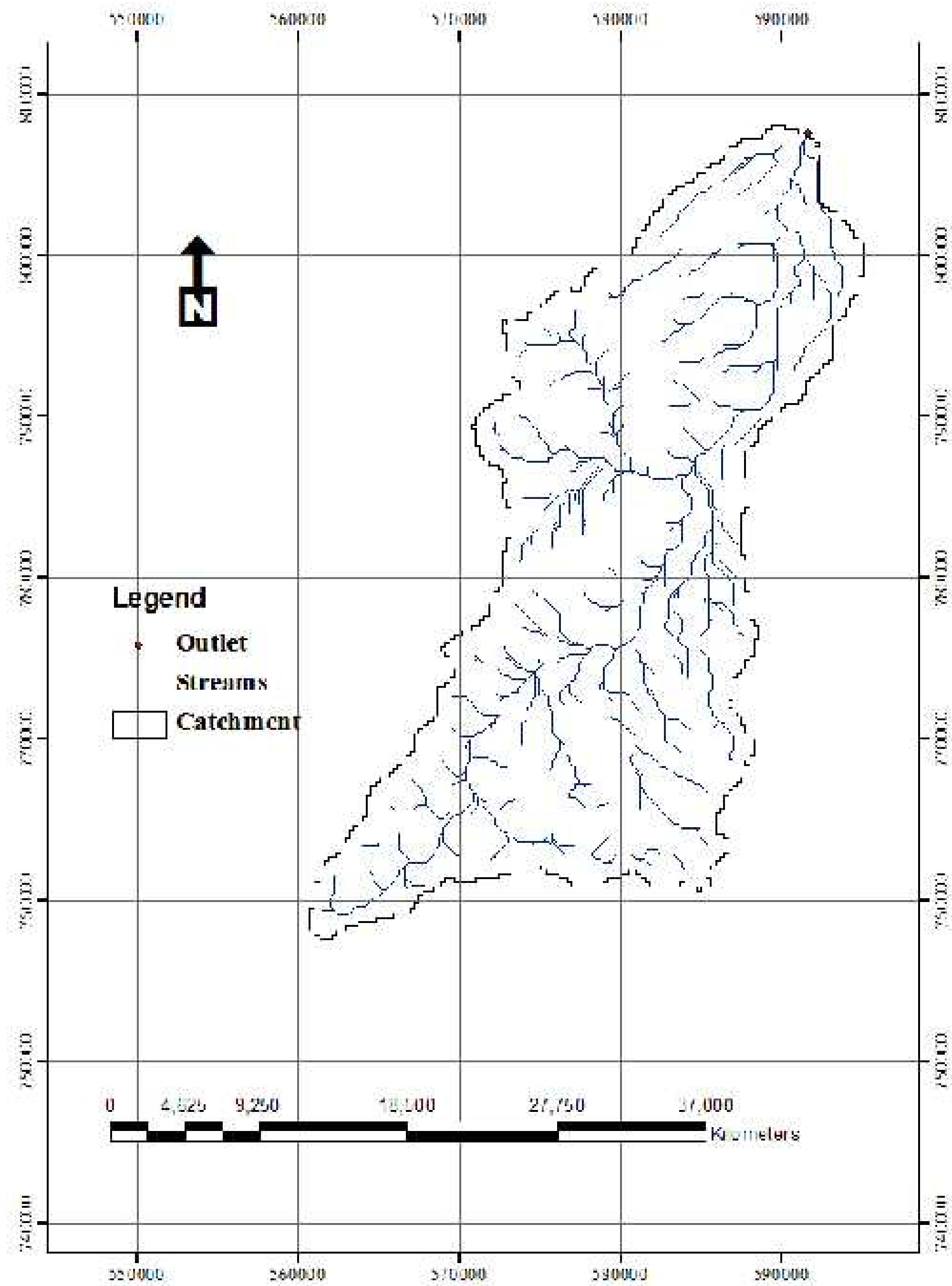


Figure A1.3: Catchment Area of Weib River nr. Agarfa

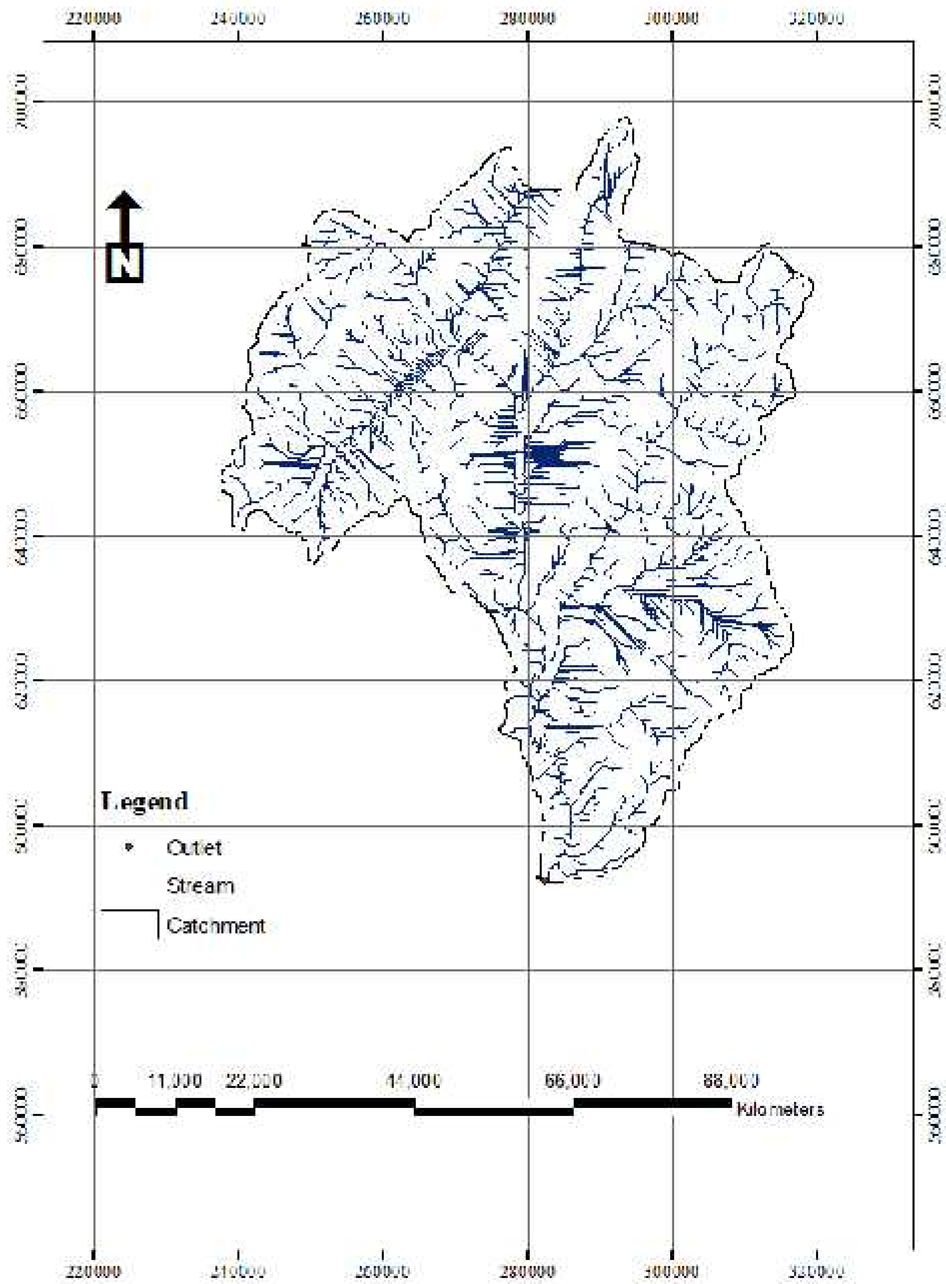


Figure A1.4: Catchment Area of Weito River

ANNEX 2: DRAWING PRESENTATION AND SUMMARY OF HYDROLOGICAL SOIL GROUPING OF THE CATCHMENTS

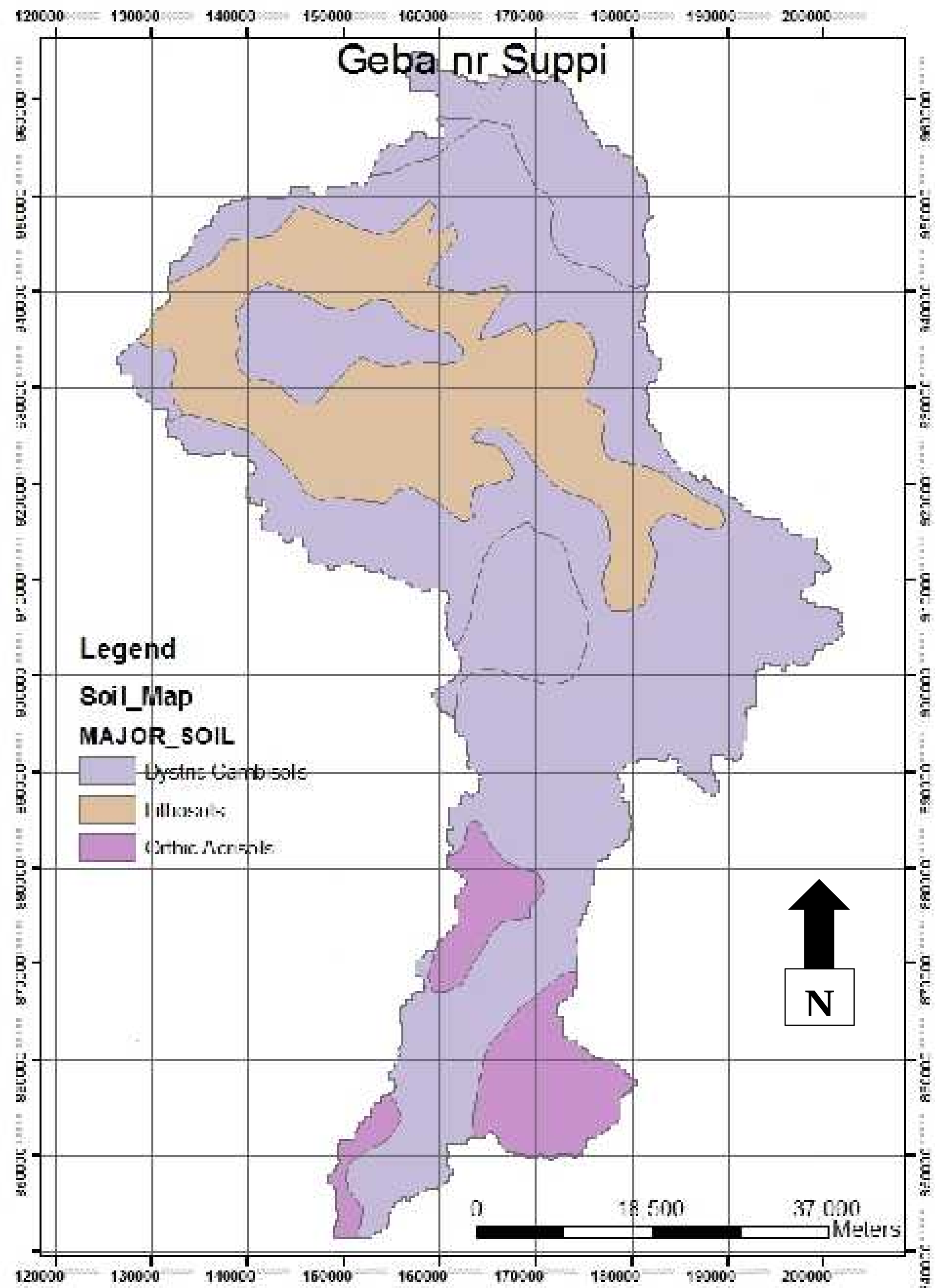


Figure A2.1: Soil Type Map for Catchment Area of Geba nr. Suppi River

Table A2.1: Soil Type of Geba nr Suppi Catchment Area

Dominant Soil	Major Soil	Area (m^2)	Area (km^2)	B	D
Nd-Ao	Dystric Cambisols	28525423.77	28.5	28.5	
Nd	Dystric Cambisols	1903461832	1903.5	1903.5	
Nd-Ao	Dystric Cambisols	231447401.7	231.4	231.4	
I-Be,S,L	Lithosols	912256421.9	912.3		912.3
Nd	Dystric Cambisols	163505510.4	163.5	163.5	
Nd-Ao	Dystric Cambisols	31064274.53	31.1	31.1	
Nd-Ao	Dystric Cambisols	171302283.4	171.3	171.3	
Ao,S-Nd	Orthic Acrisols	91342440.84	91.3	91.3	
Ao,S-Nd	Orthic Acrisols	188488242.6	188.5	188.5	
Ao,S-Nd	Orthic Acrisols	37635424.71	37.6	37.6	
		3759029256.2510	**3759.0**	**2846.8**	**912.3**
				76%	**24%**

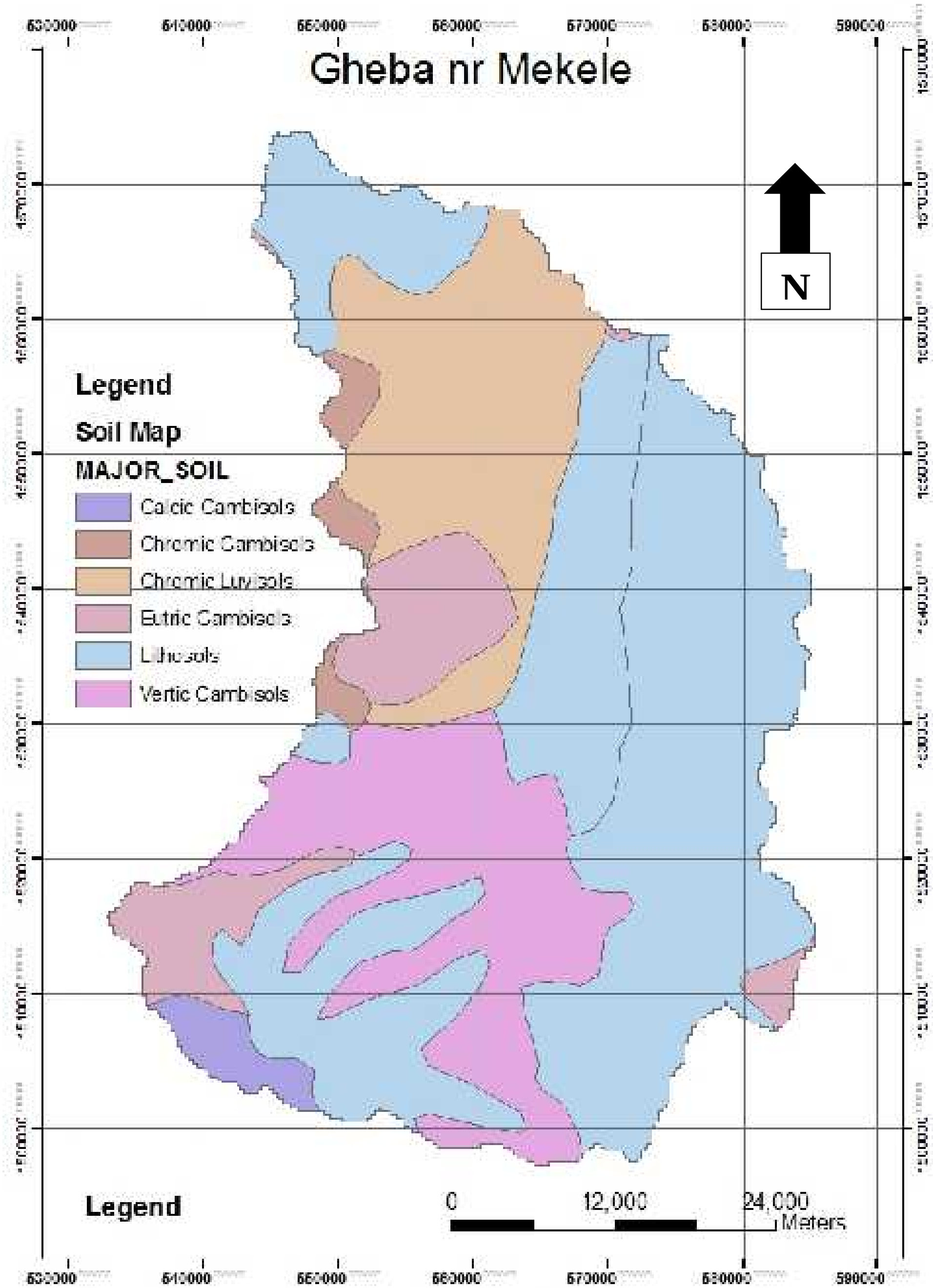


Figure A2.2: Soil Type Map for Catchment Area of Gheba River nr. Mekele

Table A2.2: Soil Type of Gheba nr Mekele Catchment Area

Dominant Soil	Major Soil	Area	Area (km^2)	B	D
I-Be,l	Lithosols	130723274.8	130.7		130.7
Lc-I	Chromic Luvisols	404374276.5	404.4	404.4	
Be,s-I	Eutric Cambisols	17250033.42	17.3	17.3	
Be,l	Eutric Cambisols	1356109.139	1.4	1.4	
I'-Bc,l	Lithosols	653650840.9	653.7		653.7
I-Be,l	Lithosols	225386596.6	225.4		225.4
Bc-Be,l	Chromic Cambisols	48296617.72	48.3	48.3	
Be,l	Eutric Cambisols	109853692	109.9	109.9	
I-Bk,l;Vc	Lithosols	11353806.5	11.4		11.4
Bv,s-Be,l	Vertic Cambisols	429048418.5	429.0	429.0	
Be,l	Eutric Cambisols	85261423.5	85.3	85.3	
I,r.s.	Lithosols	230361361.9	230.4		230.4
Bk,k'-Bv	Calcic Cambisols	45404667.23	45.4	45.4	
		2392321118.5820	**2392.3**	**1140.8**	**1251.5**
				48%	**52%**

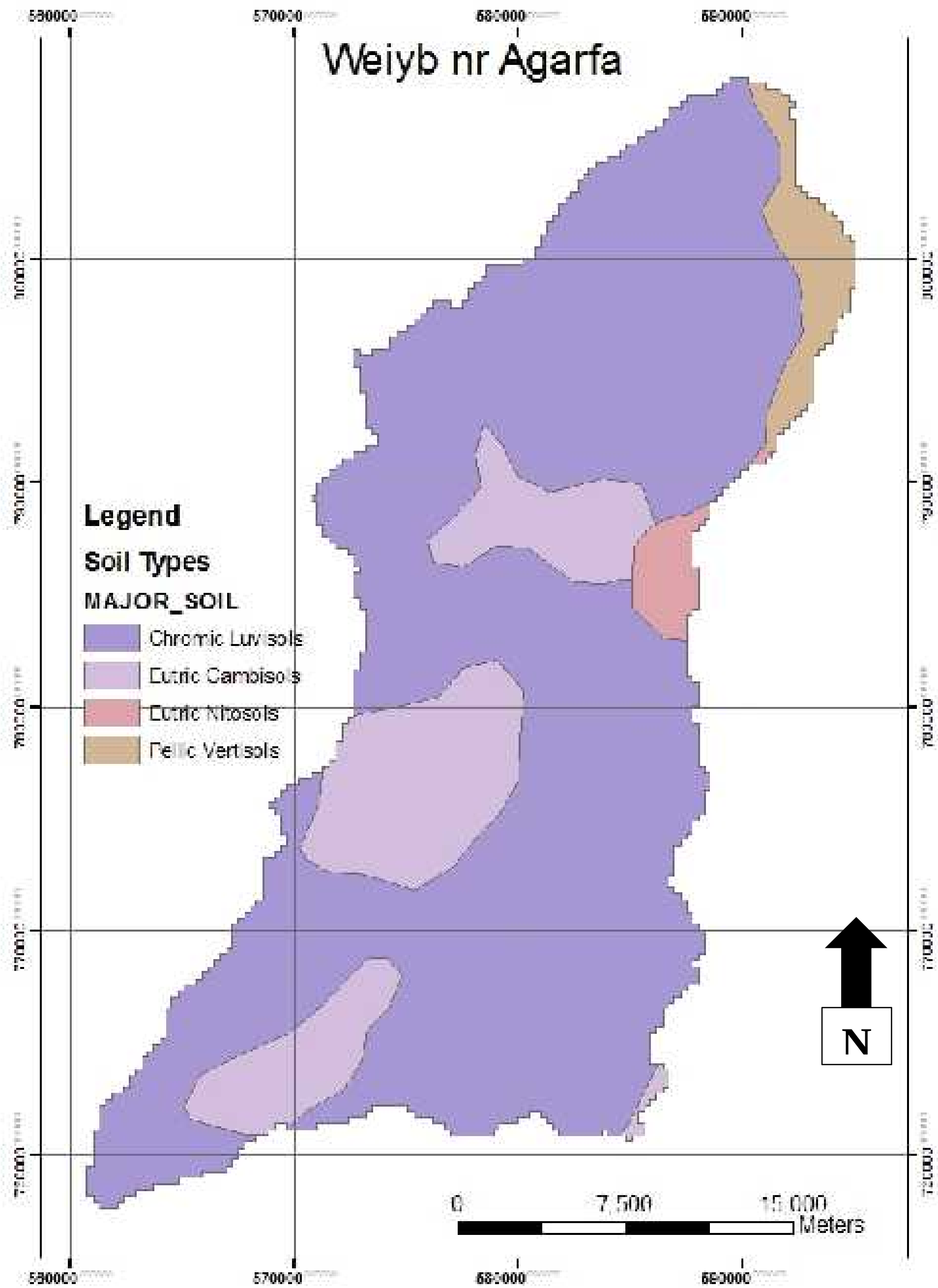


Figure A2.3: Soil Type Map for Catchment Area of Weiyb nr. Agarfa River

Table A2.3: Soil Type of Weiyb nr Agarfa Catchment Area

Dominant Soil	Major Soil	Area	Area (km^2)	B	D
Vp'	Pellic Vertisols	28316468.22	28.3		28.3
Lc,s-I	Chromic Luvisols	630692211.5	630.7	630.7	
Be	Eutric Cambisols	34833761.25	34.8	34.8	
Ne'-Vp	Eutric Nitosols	14085329.99	14.1	14.1	
Be	Eutric Cambisols	65762483.75	65.8	65.8	
Be	Eutric Cambisols	32727490.61	32.7	32.7	
Be	Eutric Cambisols	1949552.986	1.9	1.9	
		808367298.2684	**808.4**	**780.1**	**28.3**
				96%	**4%**

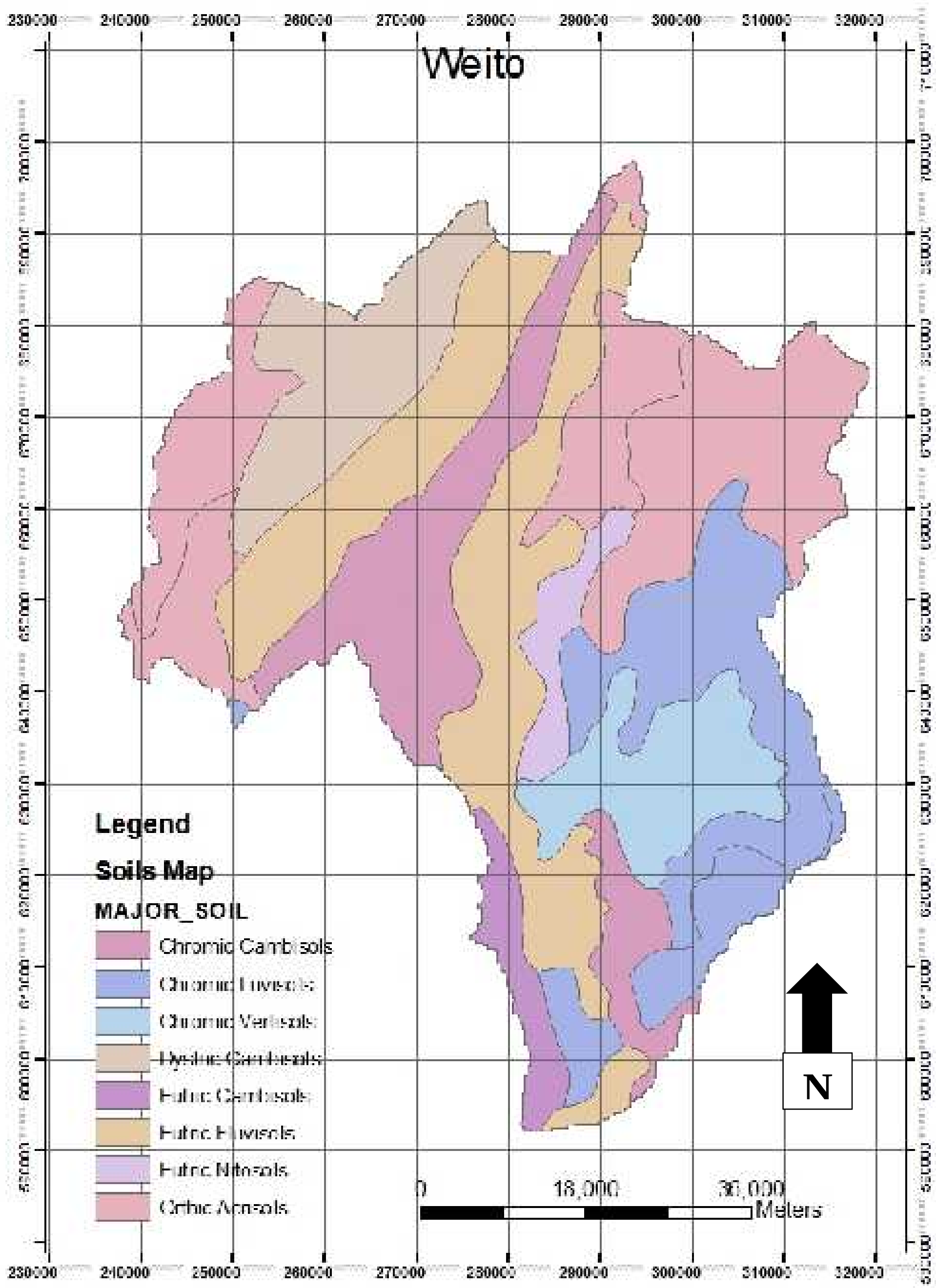


Figure A2.4: Soil Type Map for Catchment Area of Weito River

Table A2.4: Soil Type of Weito Catchment Area

Dominant Soil	Major Soil	Area	Area (km^2)	B	D
Ao,s-Nd	Orthic Acrisols	516529892.4	516.5	516.5	
Ao,s-Nd	Orthic Acrisols	228402824.3	228.4	228.4	
Bd,l-Nd	Dystric Cambisols	420441040.5	420.4	420.4	
Nd	Dystric Cambisols	137840.8625	0.1	0.1	
Je'	Eutric Fluvisols	425643853.1	425.6	425.6	
Ao,s-Nd	Orthic Acrisols	13400594.2	13.4	13.4	
Bc,l	Chromic Cambisols	504956978.1	505.0	505.0	
Je'	Eutric Fluvisols	580476863.8	580.5	580.5	
Ao-Nd	Orthic Acrisols	205614301.8	205.6	205.6	
Lc,s-Lv	Chromic Luvisols	502122874	502.1	502.1	
Ao-Nd	Orthic Acrisols	142507370.8	142.5	142.5	
Ne-Lc	Eutric Nitosols	117557319.2	117.6	117.6	
Vc	Chromic Vertisols	353715904.2	353.7		353.7
Lc,s'-Ne	Chromic Luvisols	4879125.253	4.9	4.9	
Lc,s'-Ne	Chromic Luvisols	142570448.8	142.6	142.6	
Be'-I;Bv	Eutric Cambisols	127731547.5	127.7	127.7	
Bc,l-Lc,s;Lv'	Chromic Cambisols	138548366.1	138.5	138.5	
Lc-Ne	Chromic Luvisols	65184491.96	65.2	65.2	
Je	Eutric Fluvisols	42408295.04	42.4	42.4	
		4532829931.9027	**4532.8**	**4179.1**	**353.7**
				92%	**8%**

ANNEX 3: DRAWING PRESENTATION AND SUMMARY OF THE LAND USE/COVER OF THE CATCHMENTS

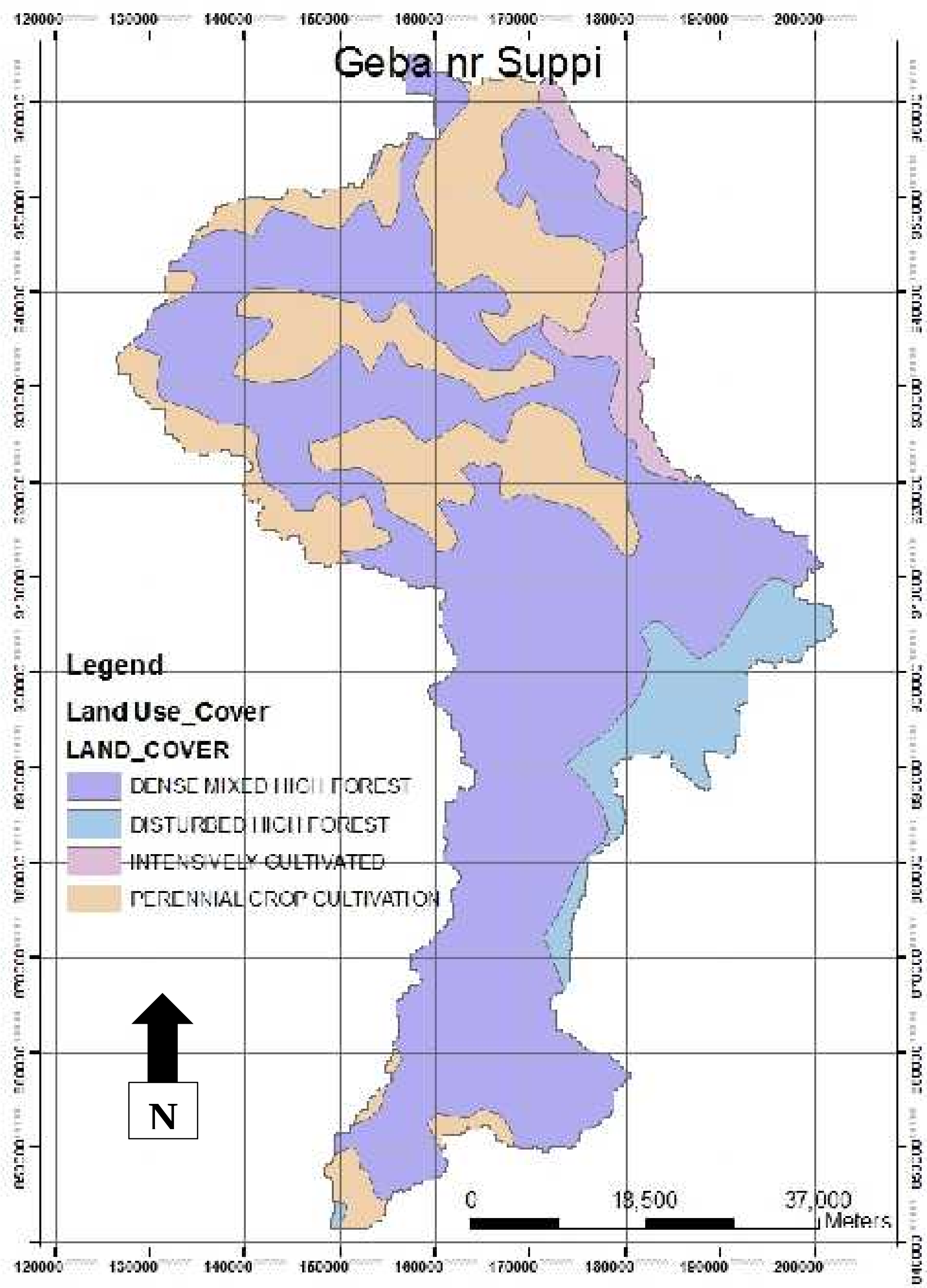


Figure A3.1: Land Use/Cover Type Map for Catchment Area of Geba River nr. Suppi

Table A3.1: Land Use/Cover Type Map for Catchment Area of Geba nr Suppi River

Land Cover	Area (m^2)	Area (km^2)	Proportion	CN B	CN D
Perennial Crop Cultivation	483936899.8	483.9369	12.9%	85	93
Intensively Cultivated	155262503	155.2625	4.1%	83	90
Dense Mixed High Forest	2266712150	2266.7122	60.3%	60	79
Dense Mixed High Forest	115823600.9	115.8236	3.1%	60	79
Perennial Crop Cultivation	164691370.1	164.6914	4.4%	85	93
Perennial Crop Cultivation	243045439.4	243.0454	6.5%	85	93
Disturbed High Forest	268189818	268.1898	7.1%	66	83
Disturbed High Forest	3210651.387	3.2107	0.1%	66	83
Perennial Crop Cultivation	58156821.92	58.1568	1.5%	85	93
	3759029255	**3759.0293**	100.0%	**67.7**	**83.3**
				76%	**24%**
				71.5	
			CN wet = 86.0		

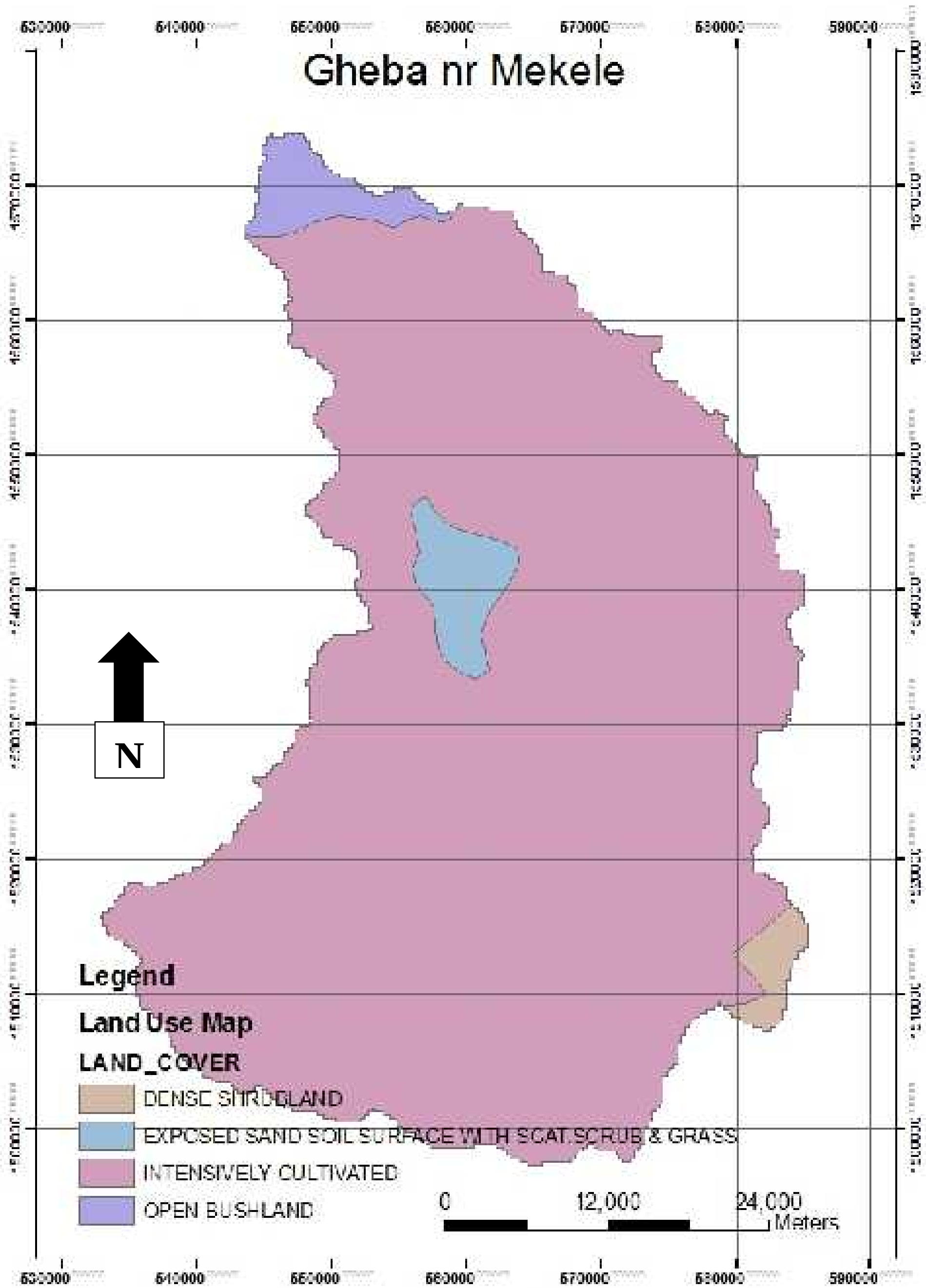


Figure A3.2: Land Use/Cover Type Map for Catchment Area of Gheba River nr. Mekele

Table A3.2: Land Use/Cover Type Map for Catchment Area of Gheba nr Mekele River

				CN	
Land Cover	**Area (m^2)**	**Area (km^2)**	**Proportion**	**B**	**D**
Open Bush-land	53841536.51	53.8415	2.3%	67	83
Exposed Sand Soil Surface With Scat. Scrub & Grass	59267729.96	59.2677	2.5%	67	83
Dense Shrub-land	28380476.19	28.3805	1.2%	56	77
Intensively Cultivated	2250831376	2250.8314	94.1%	83	90
	2392321119	**2392.3211**	100.0%	**81.9**	**89.5**
				48%	**52%**
				85.9	

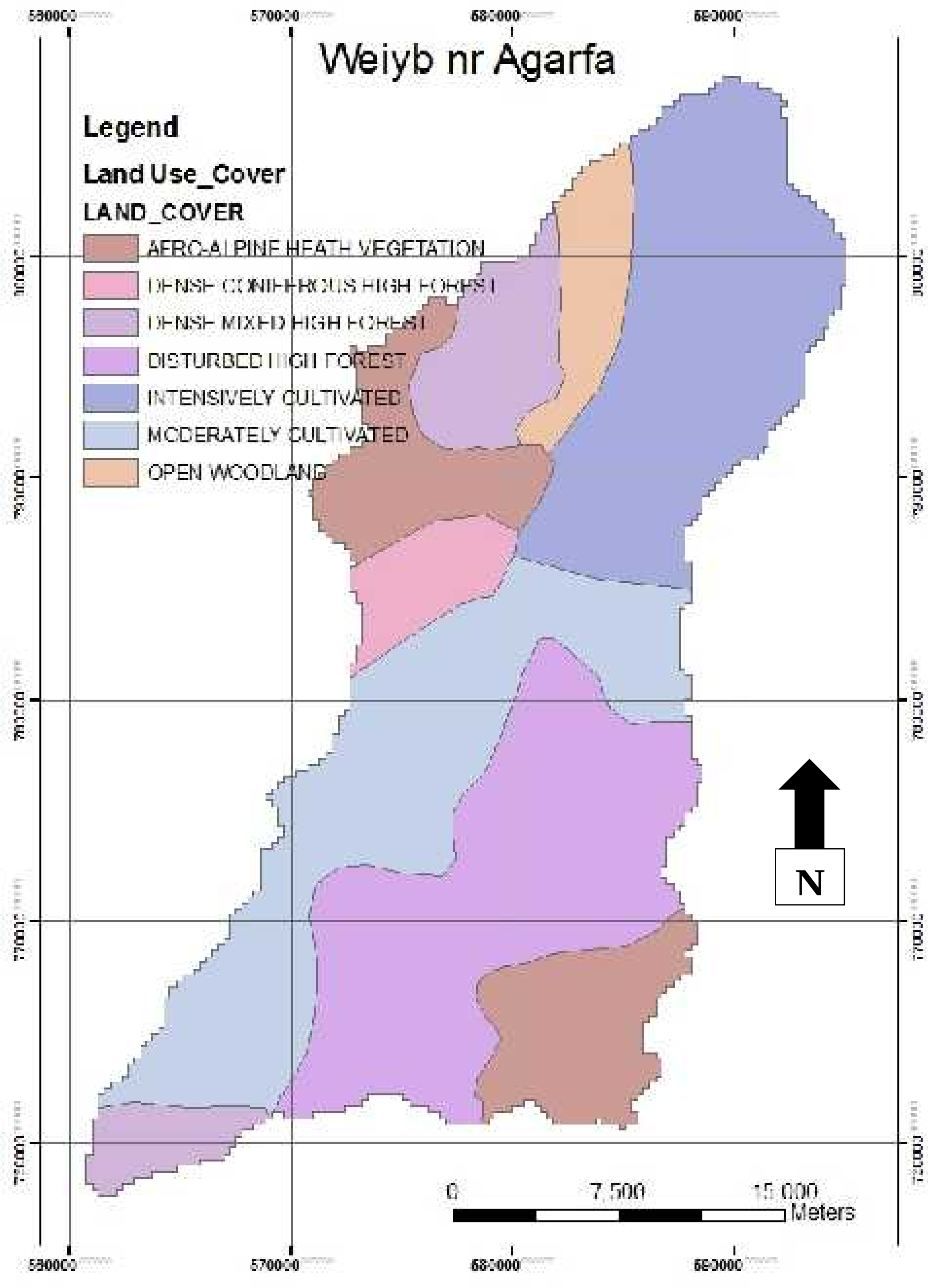


Figure A3.3: Land Use/Cover Type Map for Catchment Area of Weiyb River nr. Agarfa

Table A3.3: Land Use/Cover Type Map for Catchment Area of Weiyb nr Agarfa River

				CN	
Land Cover	**Area (m^2)**	**Area (km^2)**	**Proportion**	**B**	**D**
Intensively Cultivated	182135677	182.1357	23%	83	90
Open Woodland	35602408.93	35.6024	4%	66	83
Dense Coniferous High Forest	29328410.47	29.3284	4%	65	82
Dense Mixed High Forest	45184132.59	45.1841	6%	60	79
Afro-Alpine Heath Vegetation	54625580.26	54.6256	7%	67	83
Moderately Cultivated	186397100.5	186.3971	23%	85	93
Disturbed High Forest	193391319	193.3913	24%	66	83
Dense Mixed High Forest	21364434.5	21.3644	3%	60	79
Afro-Alpine Heath Vegetation	60338235.09	60.3382	7%	67	83
	808367298.3	**808.3673**	100%	**73.8**	**86.5**
				96%	**4%**
				74.3	

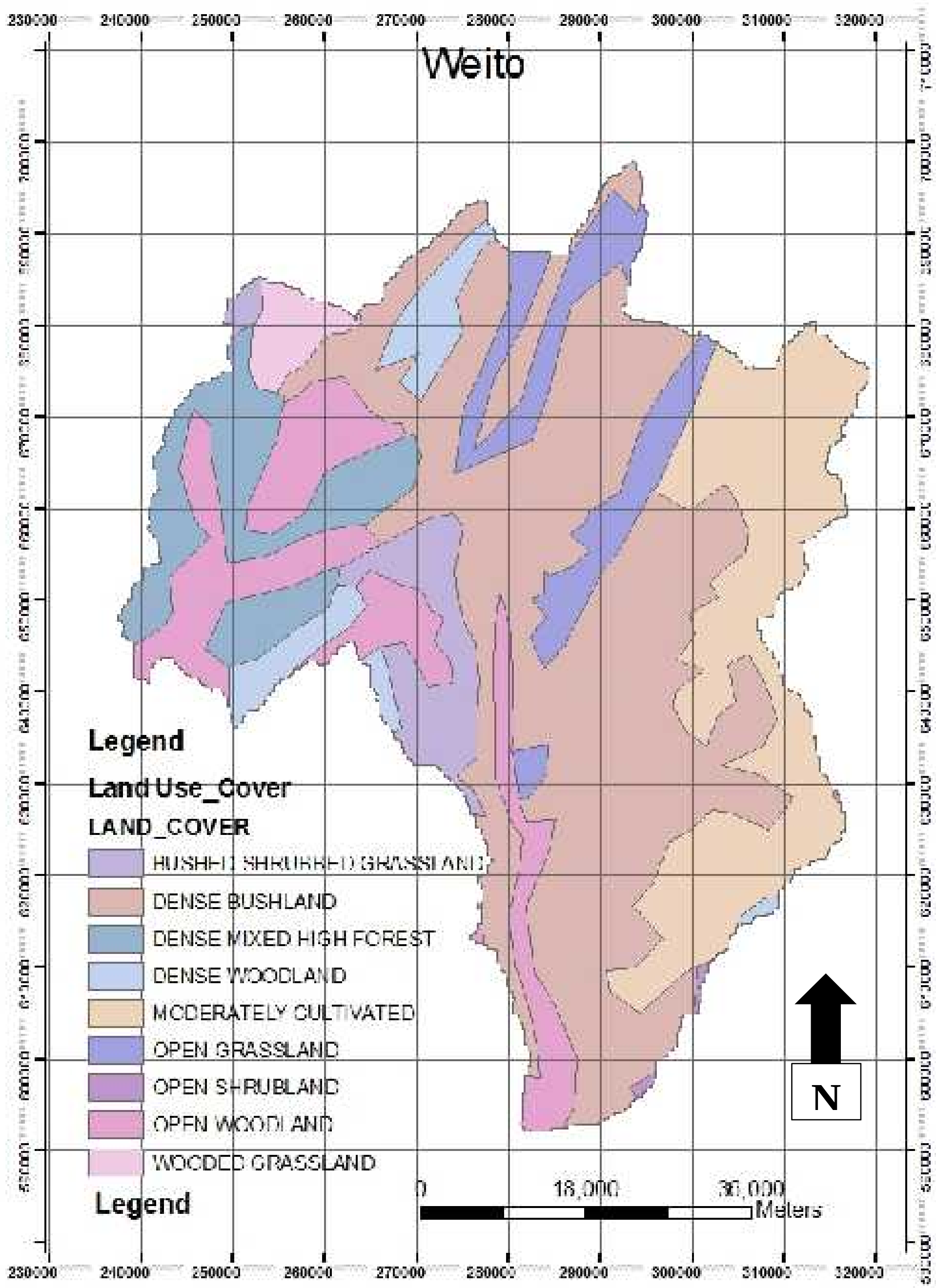


Figure A3.4: Land Use/Cover Type Map for Catchment Area of Weito River

Table A3.4: Land Use/Cover Type Map for Catchment Area of Weito River

				CN	
Land Cover	**Area (m^2)**	**Area (km^2)**	**Proportion**	**B**	**D**
Moderately Cultivated	803460406.8	803.4604	17.7%	85	93
Open Grassland	318828872.1	318.8289	7.0%	79	89
Bushed Shrub-bed Grassland	16798897.74	16.7989	0.4%	67	83
Dense Bush-land	1878995157	1878.9952	41.5%	68	84
Wooded Grassland	79258571.05	79.2586	1.7%	65	82
Dense Bush-land	70966080.49	70.9661	1.6%	56	77
Dense Woodland	87992918.22	87.9929	1.9%	55	77
Dense Mixed High Forest	309143503.5	309.1435	6.8%	60	79
Open Woodland	136295040.2	136.2950	3.0%	66	83
Open Woodland	201618131.1	201.6181	4.4%	66	83
Dense Woodland	84743060.73	84.7431	1.9%	55	77
Bushed Shrub-bed Grassland	199198656.1	199.1987	4.4%	67	83
Dense Mixed High Forest	75470525.16	75.4705	1.7%	60	79
Open Woodland	83533949.32	83.5339	1.8%	66	83
Open Woodland	155671685.4	155.6717	3.4%	66	83
Open Shrub-land	8617021.281	8.6170	0.2%	67	83
Open Grassland	16097456.31	16.0975	0.4%	79	89
Dense Woodland	6139999.432	6.1400	0.1%	55	77
	4532829932	**4532.8299**	100.0%	**70.1**	**84.9**
				92%	**8%**
				71.2	

ANNEX 4: RAINFALL DATA ANALYSIS

Adigrat **Rainfall Data Frequency Analysis Computation**

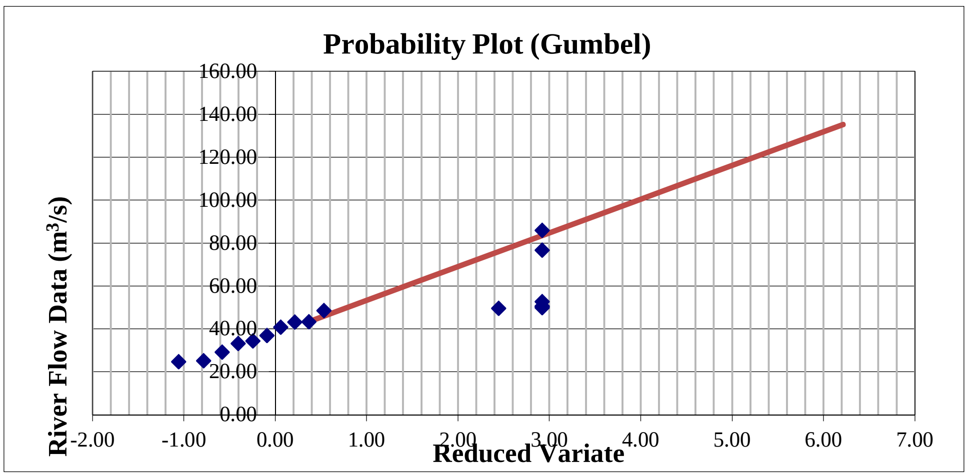
Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1997	43.30	86.00	1.93	1.00	0.05	5%	19.00	2.92
1998	50.00	76.80	1.93	1.00	0.05	5%	19.00	2.92
1999	25.30	52.90	1.93	1.00	0.05	5%	19.00	2.92
2001	50.60	50.70	1.93	1.00	0.05	5%	19.00	2.92
2002	49.70	50.60	1.93	1.00	0.05	5%	19.00	2.92
2003	29.30	50.00	1.93	1.00	0.05	5%	19.00	2.92
2004	33.30	49.70	1.93	1.00	0.08	8%	12.00	2.44
2005	50.70	48.60	1.69	8.00	0.44	44%	2.25	0.53
2006	52.90	43.40	1.64	9.00	0.50	50%	2.00	0.37
2007	48.60	43.30	1.64	10.00	0.56	56%	1.80	0.21
2008	76.80	40.90	1.61	11.00	0.61	61%	1.64	0.06
2009	40.90	37.00	1.57	12.00	0.67	67%	1.50	-0.09
2010	37.00	34.50	1.54	13.00	0.72	72%	1.38	-0.25
2011	86.00	33.30	1.52	14.00	0.78	78%	1.29	-0.41
2012	43.40	29.30	1.47	15.00	0.83	83%	1.20	-0.58
2013	34.50	25.30	1.40	16.00	0.89	89%	1.13	-0.79
2014	24.80	24.80	1.39	17.00	0.94	94%	1.06	-1.06
n	17				K_N	2.31		
Mean (Xm)	45.71	Mean (Ym)	1.71		High Outlier Limit	155.99		
Standard Deviation (Sx)	16.29	Standard Deviation (Sy)	0.21		Low Outlier Limit	16.58		

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Adigrat	2	-0.15	0.37	43.3
	5	0.95	1.50	61.2
	10	1.67	2.25	72.9
	25	2.59	3.20	87.8
	50	3.26	3.90	98.9
	100	3.94	4.60	109.8
	500	5.49	6.21	135.2

*Gumble Distribution Frequency Factor (from standard table)



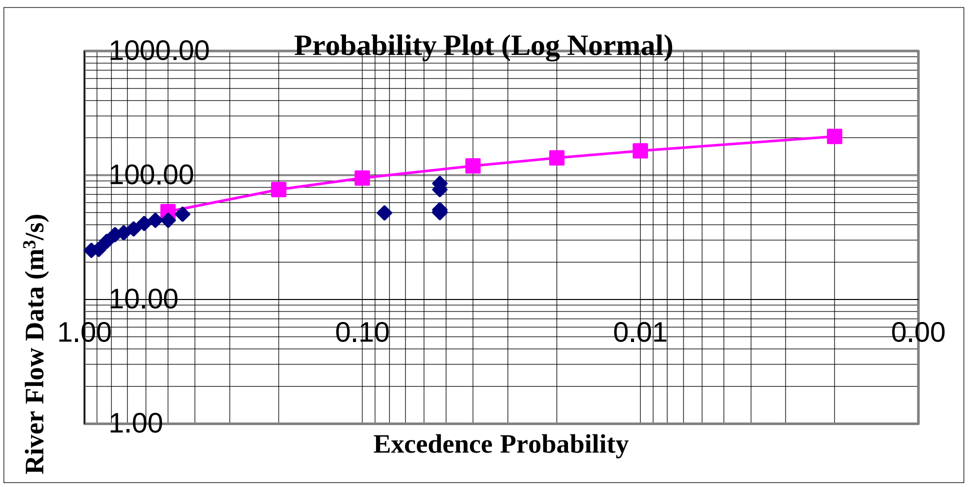
Rainfall Data Frequency Analysis Computation using Log Normal Method

$$Y_T=Y_m+K_TS_y$$

$$X_T=10^{YT}$$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Adigrat	2	50.0%	0.00	0.00	1.71	50.85
	5	20.0%		0.84	1.88	76.51
	10	10.0%		1.28	1.98	94.73
	25	4.0%		1.75	2.08	118.96
	50	2.0%		2.05	2.14	137.81
	100	1.0%		2.33	2.20	157.31
	500	0.2%		2.88	2.31	205.64

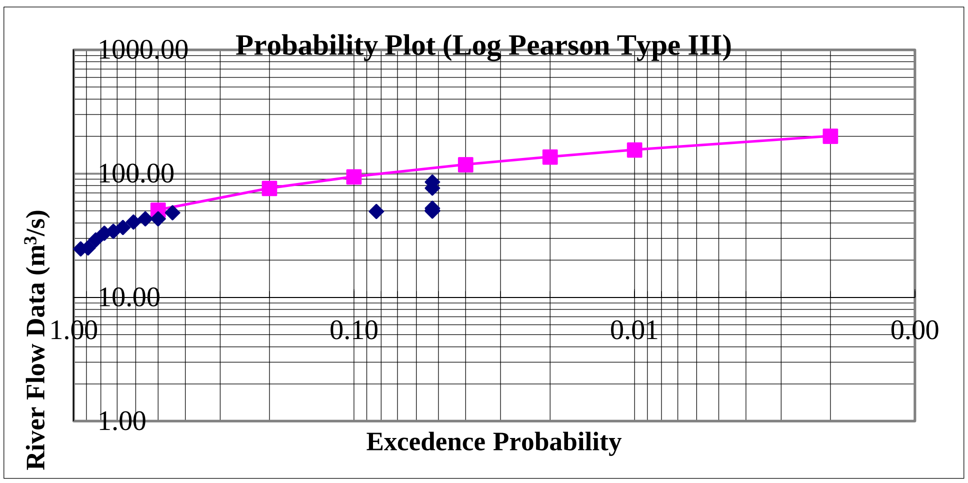
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Adigrat	2	50.0%	-0.03	0.00	1.71	50.97
	5	20.0%		0.84	1.88	76.55
	10	10.0%		1.28	1.98	94.57
	25	4.0%		1.74	2.07	118.36
	50	2.0%		2.04	2.14	136.76
	100	1.0%		2.30	2.19	155.68
	500	0.2%		2.84	2.31	202.17

* from standard distribution table, f(Cs, T)



Bedele **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1987	62.20	104.50	2.02	1.00	0.04	4%	28.00	3.31
1988	64.60	83.50	1.92	2.00	0.07	7%	14.00	2.60
1989	58.40	77.50	1.89	3.00	0.11	11%	9.33	2.18
1990	53.20	75.30	1.88	4.00	0.14	14%	7.00	1.87
1991	46.80	69.00	1.84	5.00	0.18	18%	5.60	1.63
1992	49.50	64.60	1.81	6.00	0.21	21%	4.67	1.42
1993	56.00	63.50	1.80	7.00	0.25	25%	4.00	1.25
1994	39.00	63.00	1.80	8.00	0.29	29%	3.50	1.09
1995	50.10	63.00	1.80	8.00	0.29	29%	3.50	1.09
1996	40.00	62.20	1.79	10.00	0.36	36%	2.80	0.82
1997	61.00	61.00	1.79	11.00	0.39	39%	2.55	0.70
1998	60.10	60.10	1.78	12.00	0.43	43%	2.33	0.58
1999	104.50	60.00	1.78	13.00	0.46	46%	2.15	0.47
2000	63.50	58.50	1.77	14.00	0.50	50%	2.00	0.37
2001	63.00	58.40	1.77	15.00	0.54	54%	1.87	0.26
2002	47.90	57.00	1.76	16.00	0.57	57%	1.75	0.17
2003	69.00	56.00	1.75	17.00	0.61	61%	1.65	0.07
2004	57.00	55.00	1.74	18.00	0.64	64%	1.56	-0.03
2005	55.00	53.20	1.73	19.00	0.68	68%	1.47	-0.13
2006	50.00	51.00	1.71	20.00	0.71	71%	1.40	-0.23
2007	83.50	50.10	1.70	21.00	0.75	75%	1.33	-0.33
2008	63.00	50.00	1.70	22.00	0.79	79%	1.27	-0.43
2009	58.50	49.50	1.69	23.00	0.82	82%	1.22	-0.54
2010	75.30	47.90	1.68	24.00	0.86	86%	1.17	-0.67
2012	60.00	46.80	1.67	25.00	0.89	89%	1.12	-0.80
2013	77.50	40.00	1.60	26.00	0.93	93%	1.08	-0.97
2014	51.00	39.00	1.59	27.00	0.96	96%	1.04	-1.20

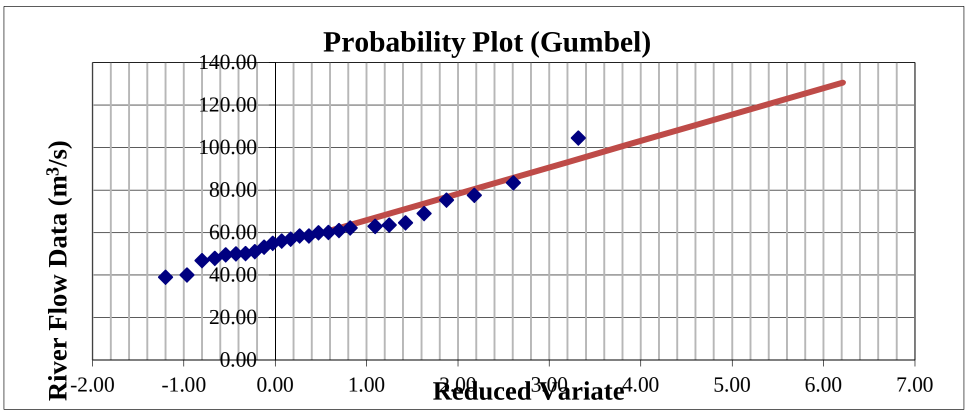
n	27				K_N	2.51
Mean (Xm)	59.99	Mean (Ym)	1.77		High Outlier Limit	100.04
Standard Deviation (Sx)	13.68	Standard Deviation (Sy)	0.09		Low Outlier Limit	34.38

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
	2	-0.15	0.37	57.9
	5	0.88	1.50	72.0
	10	1.56	2.25	81.3
Bedele	25	2.42	3.20	93.1
	50	3.06	3.90	101.9
	100	3.70	4.60	110.6
	500	5.17	6.21	130.6

*Gumble Distribution Frequency Factor (from standard table)



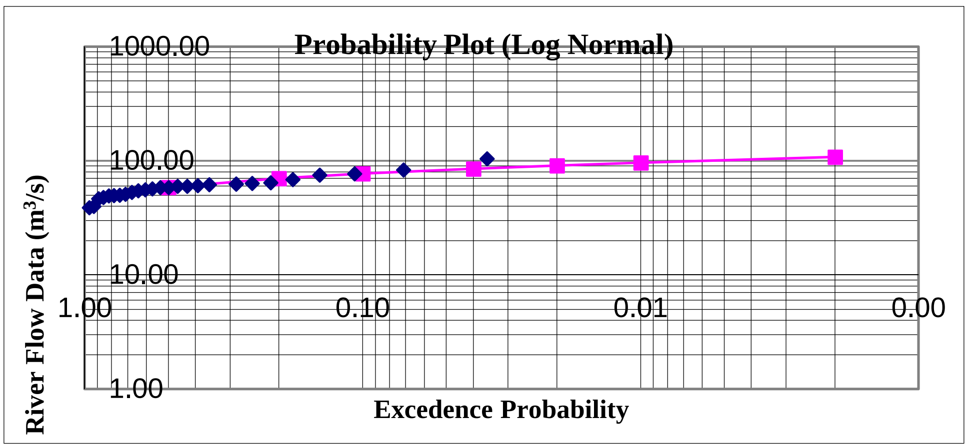
Rainfall Data Frequency Analysis Computation using Log Normal Method

$$Y_T = Y_m + K_T S_y$$

$$X_T = 10^{Y_T}$$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Bedele	2	50.0%	0.00	0.00	1.77	58.64
	5	20.0%		0.84	1.85	70.14
	10	10.0%		1.28	1.89	77.03
	25	4.0%		1.75	1.93	85.11
	50	2.0%		2.05	1.96	90.78
	100	1.0%		2.33	1.98	96.21
	500	0.2%		2.88	2.03	108.19

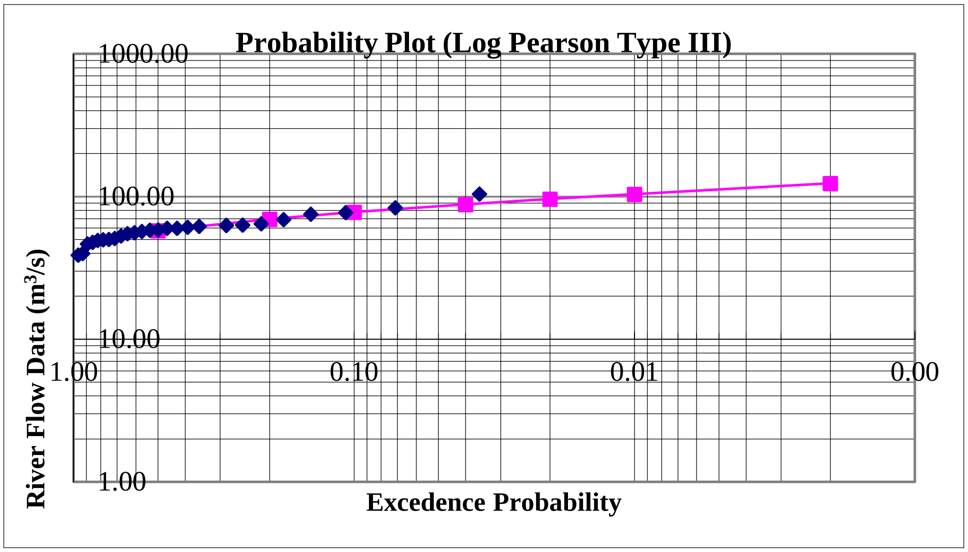
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Bedele	2	50.0%	0.52	-0.09	1.76	57.58
	5	20.0%		0.81	1.84	69.62
	10	10.0%		1.32	1.89	77.72
	25	4.0%		1.92	1.95	88.15
	50	2.0%		2.32	1.98	96.07
	100	1.0%		2.70	2.02	104.13
	500	0.2%		3.51	2.09	123.77

* from standard distribution table, f(Cs, T)



Arbaminch **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1987	39.00	75.30	1.88	1.00	0.06	6%	17.00	2.80
1988	46.90	72.10	1.86	2.00	0.12	12%	8.50	2.08
1989	72.10	71.20	1.85	3.00	0.18	18%	5.67	1.64
1991	54.00	70.10	1.85	4.00	0.24	24%	4.25	1.32
1992	71.20	68.20	1.83	5.00	0.29	29%	3.40	1.05
1993	70.10	66.80	1.82	6.00	0.35	35%	2.83	0.83
1994	38.00	54.00	1.73	7.00	0.41	41%	2.43	0.63
1995	40.70	46.90	1.67	8.00	0.47	47%	2.13	0.45
1996	66.80	46.80	1.67	9.00	0.53	53%	1.89	0.28
1997	68.20	46.60	1.67	10.00	0.59	59%	1.70	0.12
1998	46.60	45.70	1.66	11.00	0.65	65%	1.55	-0.04
1999	75.30	41.40	1.62	12.00	0.71	71%	1.42	-0.20
2000	45.70	40.70	1.61	13.00	0.76	76%	1.31	-0.37
2001	41.40	40.60	1.61	14.00	0.82	82%	1.21	-0.55
2002	40.60	39.00	1.59	15.00	0.88	88%	1.13	-0.76
2003	46.80	38.00	1.58	16.00	0.94	94%	1.06	-1.04

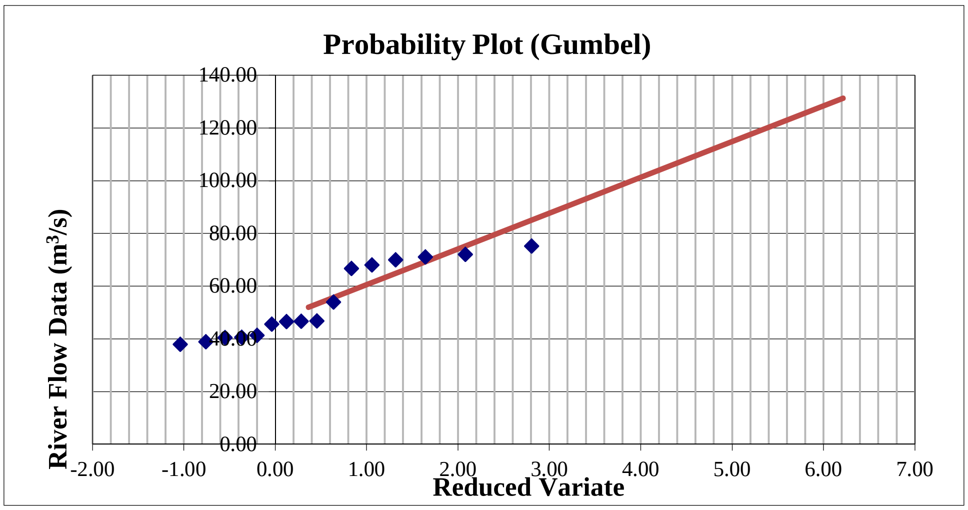
n	16				K_N	2.28
Mean (Xm)	53.96	Mean (Ym)	1.72		High Outlier Limit	93.52
Standard Deviation (Sx)	13.96	Standard Deviation (Sy)	0.11		Low Outlier Limit	29.28

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Arbaminch	2	-0.14	0.37	51.9
	5	0.96	1.50	67.3
	10	1.69	2.25	77.5
	25	2.61	3.20	90.4
	50	3.29	3.90	99.9
	100	3.97	4.60	109.4
	500	5.54	6.21	131.3

*Gumble Distribution Frequency Factor (from standard table)



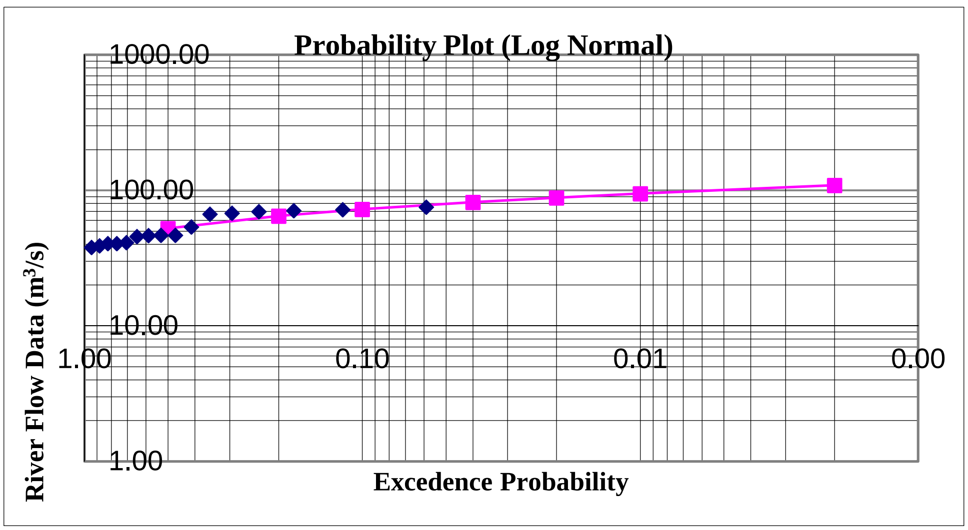
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{YT}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Arbaminch	2	50.0%	0.00	0.00	1.72	52.33
	5	20.0%		0.84	1.81	64.84
	10	10.0%		1.28	1.86	72.53
	25	4.0%		1.75	1.91	81.74
	50	2.0%		2.05	1.95	88.30
	100	1.0%		2.33	1.98	94.66
	500	0.2%		2.88	2.04	108.94

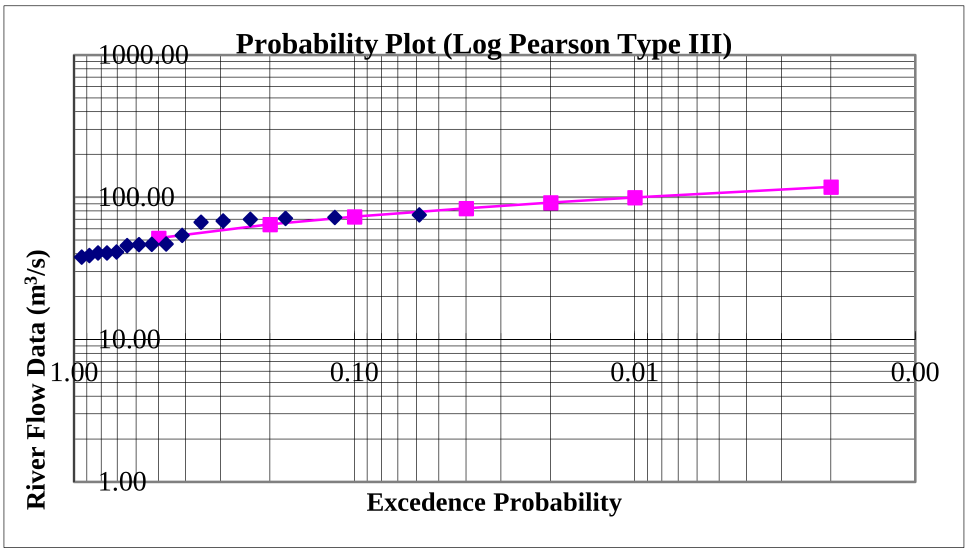
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Arbaminch	2	50.0%	0.27	-0.04	1.71	51.73
	5	20.0%		0.83	1.81	64.58
	10	10.0%		1.31	1.86	73.00
	25	4.0%		1.84	1.92	83.61
	50	2.0%		2.20	1.96	91.54
	100	1.0%		2.52	2.00	99.50
	500	0.2%		3.21	2.07	118.47

* from standard distribution table, f(Cs, T)



Jinka **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1987	56.80	80.90	1.91	1.00	0.03	3%	29.00	3.35
1988	70.00	79.90	1.90	2.00	0.07	7%	14.50	2.64
1989	79.90	75.40	1.88	3.00	0.10	10%	9.67	2.21
1990	63.40	75.40	1.88	3.00	0.10	10%	9.67	2.21
1991	80.90	74.70	1.87	5.00	0.17	17%	5.80	1.66
1992	47.60	73.40	1.87	6.00	0.21	21%	4.83	1.46
1993	42.30	70.40	1.85	7.00	0.24	24%	4.14	1.29
1994	75.40	70.00	1.85	8.00	0.28	28%	3.63	1.13
1995	48.30	68.90	1.84	9.00	0.31	31%	3.22	0.99
1996	68.70	68.70	1.84	10.00	0.34	34%	2.90	0.86
1997	47.60	68.40	1.84	11.00	0.38	38%	2.64	0.74
1998	74.70	65.00	1.81	12.00	0.41	41%	2.42	0.63
1999	52.60	64.20	1.81	13.00	0.45	45%	2.23	0.52
2000	61.50	63.40	1.80	14.00	0.48	48%	2.07	0.42
2001	39.40	61.50	1.79	15.00	0.52	52%	1.93	0.32
2002	64.20	60.40	1.78	16.00	0.55	55%	1.81	0.22
2003	73.40	60.20	1.78	17.00	0.59	59%	1.71	0.13
2004	46.40	56.80	1.75	18.00	0.62	62%	1.61	0.03
2005	60.40	52.90	1.72	19.00	0.66	66%	1.53	-0.06
2006	75.40	52.60	1.72	20.00	0.69	69%	1.45	-0.16
2007	60.20	49.70	1.70	21.00	0.72	72%	1.38	-0.25
2008	52.90	48.30	1.68	22.00	0.76	76%	1.32	-0.35
2009	68.40	47.60	1.68	23.00	0.79	79%	1.26	-0.45
2010	46.60	47.60	1.68	23.00	0.79	79%	1.26	-0.45
2011	49.70	46.60	1.67	25.00	0.86	86%	1.16	-0.68
2012	65.00	46.40	1.67	26.00	0.90	90%	1.12	-0.82
2013	68.90	42.30	1.63	27.00	0.93	93%	1.07	-0.98
2014	70.40	39.40	1.60	28.00	0.97	97%	1.04	-1.21

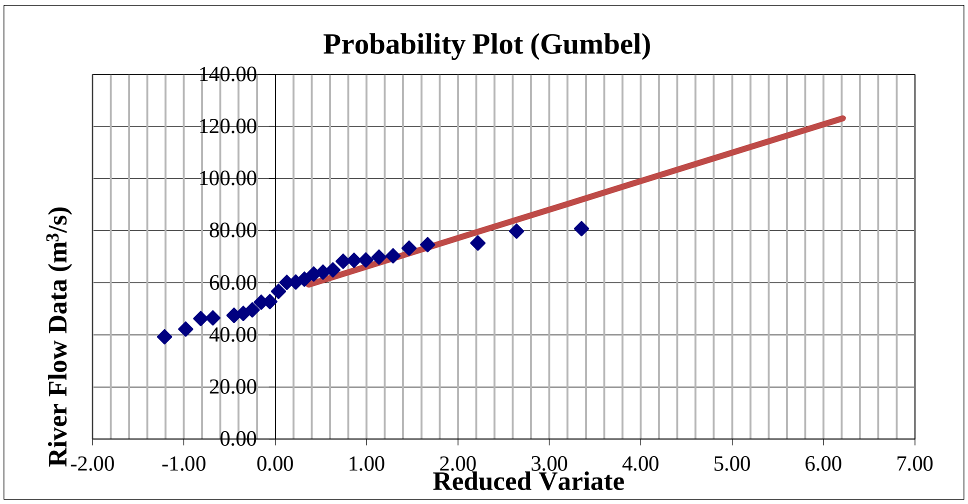
n	28			K_N	2.53
Mean (Xm)	61.11	Mean (Ym)	1.78	High Outlier Limit	100.79
Standard Deviation (Sx)	12.06	Standard Deviation (Sy)	0.09	Low Outlier Limit	35.61

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Jinka	2	-0.15	0.37	59.3
	5	0.88	1.50	71.7
	10	1.55	2.25	79.9
	25	2.41	3.20	90.2
	50	3.05	3.90	97.9
	100	3.68	4.60	105.5
	500	5.15	6.21	123.2

*Gumble Distribution Frequency Factor (from standard table)



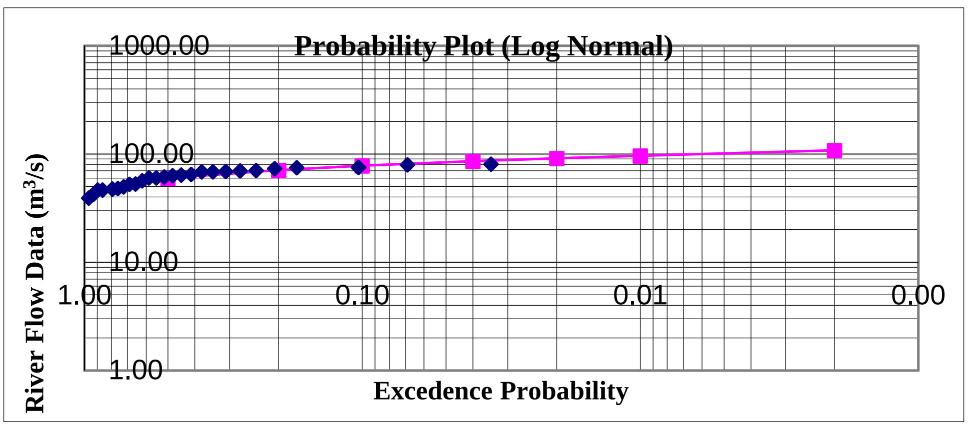
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{Y_T}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Jinka	2	50.0%	0.00	0.00	1.78	59.91
	5	20.0%		0.84	1.85	71.21
	10	10.0%		1.28	1.89	77.94
	25	4.0%		1.75	1.93	85.82
	50	2.0%		2.05	1.96	91.33
	100	1.0%		2.33	1.98	96.59
	500	0.2%		2.88	2.03	108.17

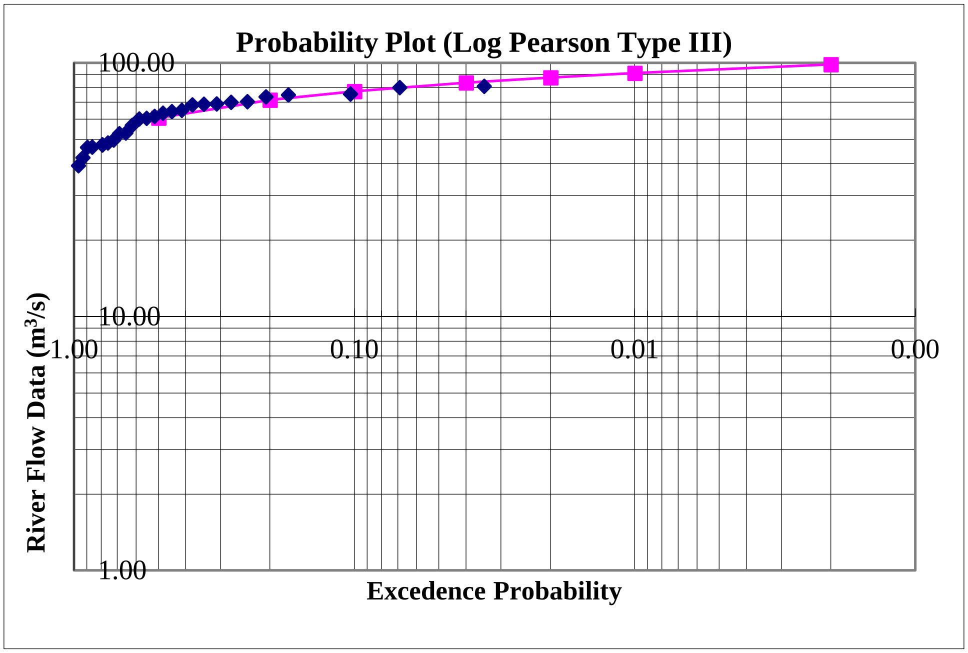
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Jinka	2	50.0%	-0.38	0.06	1.78	60.69
	5	20.0%		0.85	1.85	71.40
	10	10.0%		1.23	1.89	77.18
	25	4.0%		1.61	1.92	83.43
	50	2.0%		1.84	1.94	87.49
	100	1.0%		2.04	1.96	91.15
	500	0.2%		2.42	1.99	98.52

* from standard distribution table, f(Cs, T)



Konso **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1984	45.40	74.30	1.87	1.00	0.07	7%	14.00	2.60
1985	49.50	62.30	1.79	2.00	0.14	14%	7.00	1.87
1986	39.00	56.50	1.75	3.00	0.21	21%	4.67	1.42
1987	52.00	54.30	1.73	4.00	0.29	29%	3.50	1.09
1988	44.50	52.00	1.72	5.00	0.36	36%	2.80	0.82
1989	74.30	49.50	1.69	6.00	0.43	43%	2.33	0.58
1990	54.30	45.40	1.66	7.00	0.50	50%	2.00	0.37
1991	62.30	45.40	1.66	7.00	0.50	50%	2.00	0.37
1992	56.50	45.30	1.66	9.00	0.64	64%	1.56	-0.03
1993	45.40	44.50	1.65	10.00	0.71	71%	1.40	-0.23
1994	39.30	40.00	1.60	11.00	0.79	79%	1.27	-0.43
1995	45.30	39.30	1.59	12.00	0.86	86%	1.17	-0.67
1996	40.00	39.00	1.59	13.00	0.93	93%	1.08	-0.97

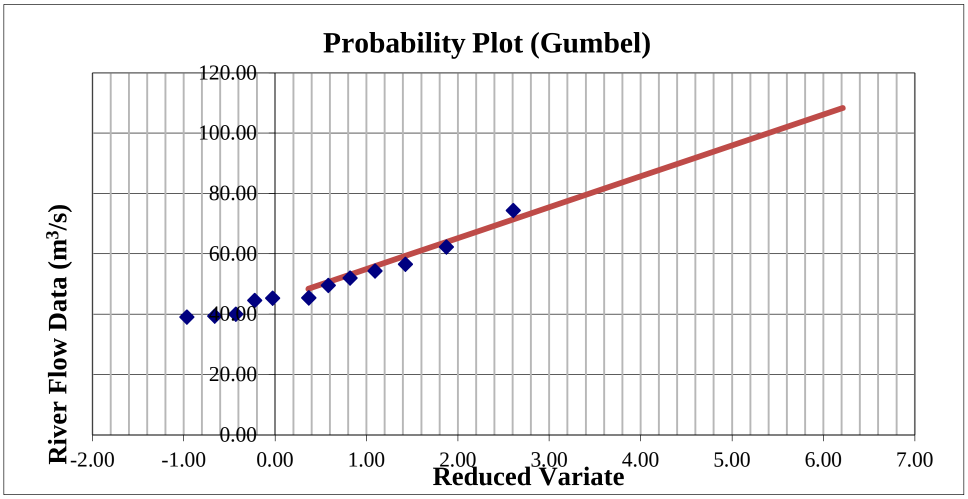
n	13				K_N	2.17
Mean (Xm)	49.83	Mean (Ym)	1.69		High Outlier Limit	73.93
Standard Deviation (Sx)	10.15	Standard Deviation (Sy)	0.08		Low Outlier Limit	32.44

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Konso	2	-0.14	0.37	48.4
	5	1.00	1.50	60.0
	10	1.76	2.25	67.7
	25	2.72	3.20	77.4
	50	3.43	3.90	84.6
	100	4.13	4.60	91.8
	500	5.76	6.21	108.3

*Gumble Distribution Frequency Factor (from standard table)



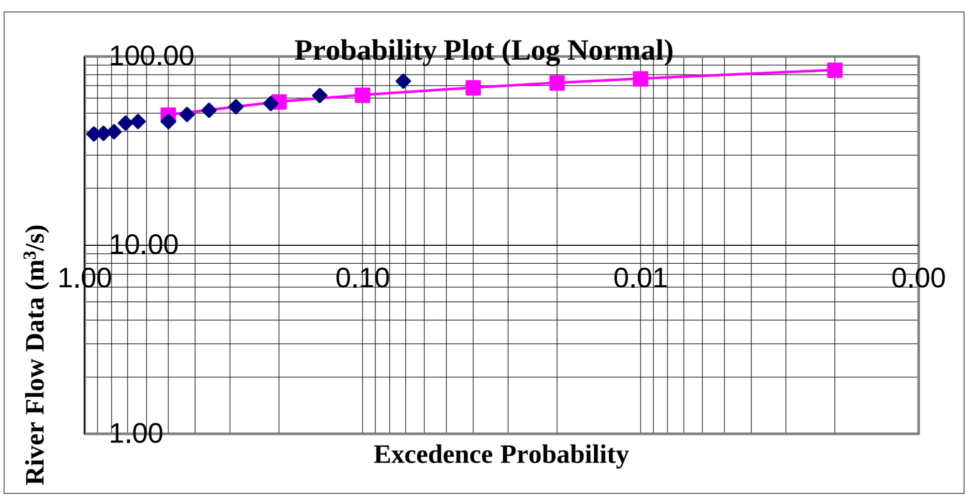
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{YT}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Konso	2	50.0%	0.00	0.00	1.69	48.97
	5	20.0%		0.84	1.76	57.47
	10	10.0%		1.28	1.80	62.49
	25	4.0%		1.75	1.83	68.33
	50	2.0%		2.05	1.86	72.38
	100	1.0%		2.33	1.88	76.24
	500	0.2%		2.88	1.93	84.68

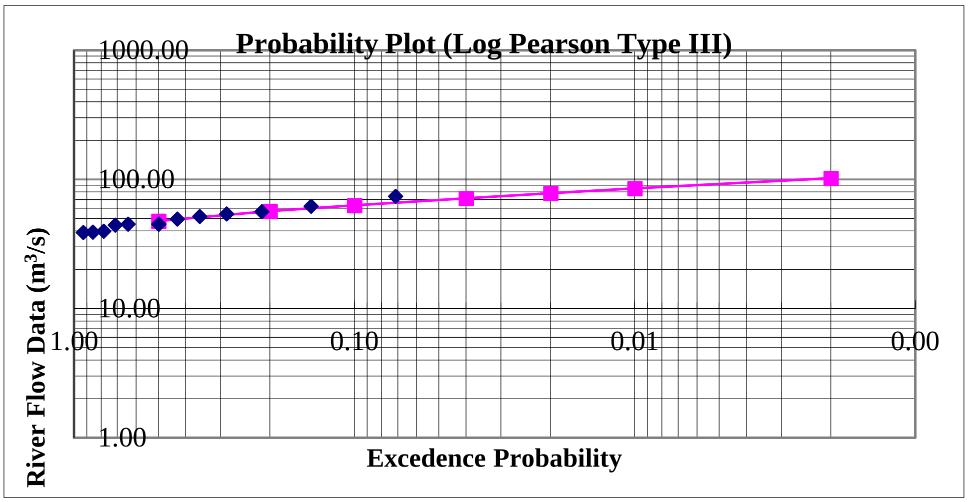
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Konso	2	50.0%	0.83	-0.14	1.68	47.72
	5	20.0%		0.78	1.75	56.77
	10	10.0%		1.34	1.80	63.15
	25	4.0%		2.00	1.86	71.64
	50	2.0%		2.46	1.89	78.26
	100	1.0%		2.91	1.93	85.15
	500	0.2%		3.88	2.01	102.46

* from standard distribution table, f(Cs, T)



Mekele **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1980	118.50	118.50	2.07	1.00	0.03	3%	33.00	3.48
1981	95.40	95.40	1.98	2.00	0.06	6%	16.50	2.77
1982	43.30	77.50	1.89	3.00	0.09	9%	11.00	2.35
1983	44.30	74.90	1.87	4.00	0.12	12%	8.25	2.05
1984	32.00	74.00	1.87	5.00	0.15	15%	6.60	1.81
1985	47.00	73.80	1.87	6.00	0.18	18%	5.50	1.61
1987	73.80	59.60	1.78	7.00	0.21	21%	4.71	1.43
1988	59.60	59.60	1.78	7.00	0.21	21%	4.71	1.43
1991	53.00	59.20	1.77	9.00	0.27	27%	3.67	1.14
1992	42.00	58.50	1.77	10.00	0.30	30%	3.30	1.02
1993	56.30	56.30	1.75	11.00	0.33	33%	3.00	0.90
1994	77.50	56.00	1.75	12.00	0.36	36%	2.75	0.79
1995	40.00	53.00	1.72	13.00	0.39	39%	2.54	0.69
1996	50.90	52.90	1.72	14.00	0.42	42%	2.36	0.59
1997	44.40	50.90	1.71	15.00	0.45	45%	2.20	0.50
1998	43.00	47.00	1.67	16.00	0.48	48%	2.06	0.41
1999	52.90	44.70	1.65	17.00	0.52	52%	1.94	0.32
2000	59.20	44.40	1.65	18.00	0.55	55%	1.83	0.24
2001	35.70	44.30	1.65	19.00	0.58	58%	1.74	0.15
2002	41.20	43.30	1.64	20.00	0.61	61%	1.65	0.07
2003	41.10	43.00	1.63	21.00	0.64	64%	1.57	-0.01
2004	39.80	42.00	1.62	22.00	0.67	67%	1.50	-0.09
2005	44.70	41.20	1.61	23.00	0.70	70%	1.43	-0.18
2006	74.90	41.10	1.61	24.00	0.73	73%	1.38	-0.26
2007	59.60	40.00	1.60	25.00	0.76	76%	1.32	-0.35
2008	23.00	39.80	1.60	26.00	0.79	79%	1.27	-0.44
2009	56.00	37.20	1.57	27.00	0.82	82%	1.22	-0.53
2010	37.20	35.70	1.55	28.00	0.85	85%	1.18	-0.64
2011	58.50	34.60	1.54	29.00	0.88	88%	1.14	-0.75
2012	34.60	32.00	1.51	30.00	0.91	91%	1.10	-0.87
2013	28.00	28.00	1.45	31.00	0.94	94%	1.06	-1.03
2014	74.00	23.00	1.36	32.00	0.97	97%	1.03	-1.25

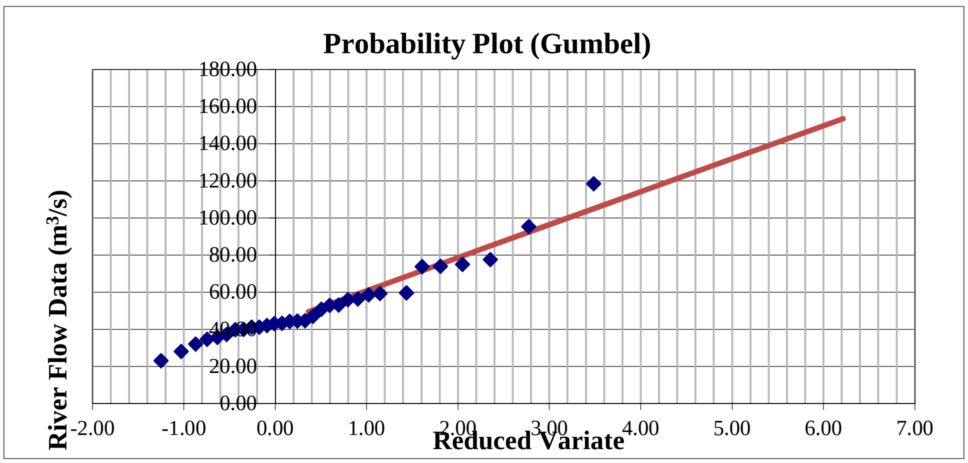
n	32			K_N	2.59
Mean (Xm)	52.54	Mean (Ym)	1.69	High Outlier Limit	121.61
Standard Deviation (Sx)	19.89	Standard Deviation (Sy)	0.15	Low Outlier Limit	20.11

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Mekele	2	-0.15	0.37	49.5
	5	0.86	1.50	69.6
	10	1.53	2.25	83.0
	25	2.38	3.20	99.8
	50	3.01	3.90	112.3
	100	3.63	4.60	124.8
	500	5.07	6.21	153.4

*Gumble Distribution Frequency Factor (from standard table)



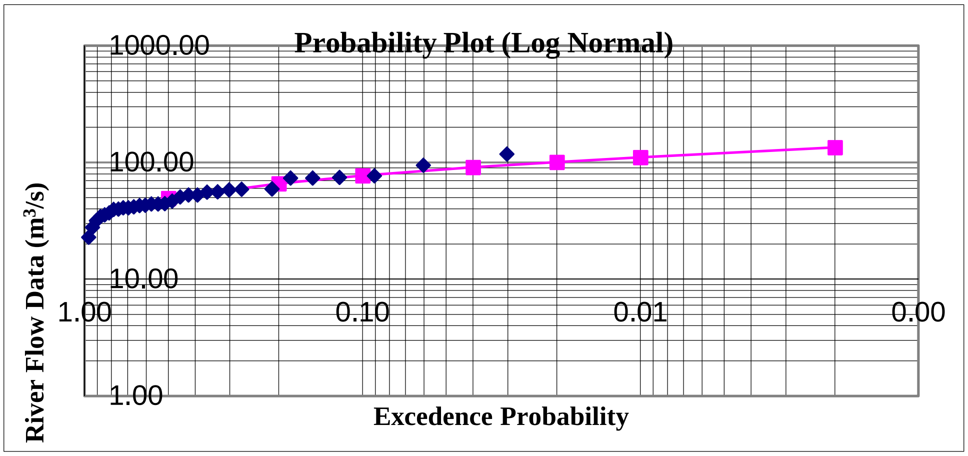
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{YT}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Mekele	2	50.0%	0.00	0.00	1.69	49.45
	5	20.0%		0.84	1.82	66.24
	10	10.0%		1.28	1.89	77.18
	25	4.0%		1.75	1.96	90.83
	50	2.0%		2.05	2.00	100.91
	100	1.0%		2.33	2.05	110.94
	500	0.2%		2.88	2.13	134.37

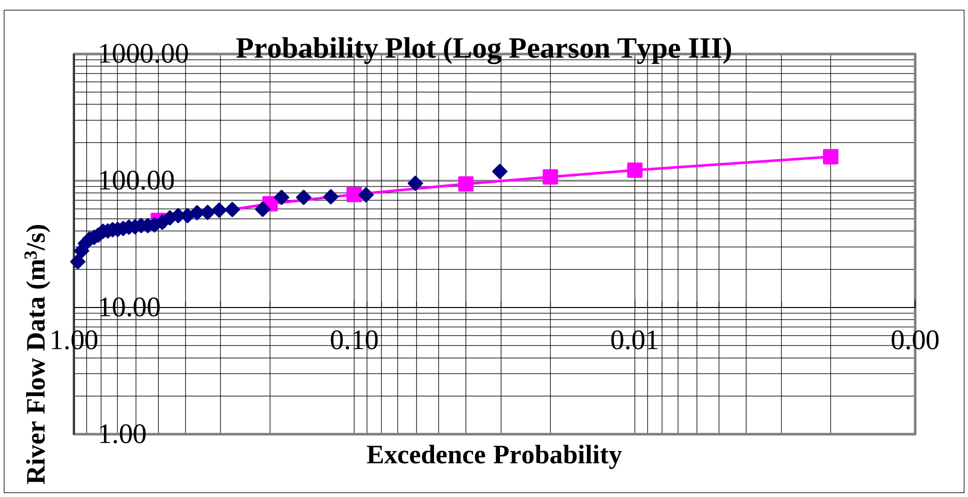
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Mekele	2	50.0%	0.33	-0.06	1.69	48.50
	5	20.0%		0.82	1.82	65.77
	10	10.0%		1.31	1.89	77.99
	25	4.0%		1.86	1.97	94.34
	50	2.0%		2.23	2.03	107.21
	100	1.0%		2.57	2.08	120.68
	500	0.2%		3.29	2.19	154.83

* from standard distribution table, f(Cs, T)



Metu **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1987	66.70	88.50	1.95	1.00	0.04	4%	28.00	3.31
1988	88.50	72.80	1.86	2.00	0.07	7%	14.00	2.60
1989	49.60	68.10	1.83	3.00	0.11	11%	9.33	2.18
1990	65.70	66.70	1.82	4.00	0.14	14%	7.00	1.87
1991	62.00	65.80	1.82	5.00	0.18	18%	5.60	1.63
1992	55.50	65.70	1.82	6.00	0.21	21%	4.67	1.42
1993	68.10	64.40	1.81	7.00	0.25	25%	4.00	1.25
1994	54.10	62.00	1.79	8.00	0.29	29%	3.50	1.09
1995	72.80	55.50	1.74	9.00	0.32	32%	3.11	0.95
1996	64.40	54.10	1.73	10.00	0.36	36%	2.80	0.82
1997	65.80	51.30	1.71	11.00	0.39	39%	2.55	0.70
1998	51.30	50.80	1.71	12.00	0.43	43%	2.33	0.58
1999	46.00	49.60	1.70	13.00	0.46	46%	2.15	0.47
2000	50.80	48.90	1.69	14.00	0.50	50%	2.00	0.37
2001	48.50	48.50	1.69	15.00	0.54	54%	1.87	0.26
2002	29.80	46.00	1.66	16.00	0.57	57%	1.75	0.17
2003	42.10	45.10	1.65	17.00	0.61	61%	1.65	0.07
2004	42.30	42.50	1.63	18.00	0.64	64%	1.56	-0.03
2005	39.00	42.30	1.63	19.00	0.68	68%	1.47	-0.13
2006	45.10	42.10	1.62	20.00	0.71	71%	1.40	-0.23
2007	48.90	42.00	1.62	21.00	0.75	75%	1.33	-0.33
2008	42.00	42.00	1.62	21.00	0.75	75%	1.33	-0.33
2009	42.50	39.00	1.59	23.00	0.82	82%	1.22	-0.54
2010	5.60	34.00	1.53	24.00	0.86	86%	1.17	-0.67
2012	42.00	29.80	1.47	25.00	0.89	89%	1.12	-0.80
2013	19.10	19.10	1.28	26.00	0.93	93%	1.08	-0.97
2014	34.00	5.60	0.75	27.00	0.96	96%	1.04	-1.20

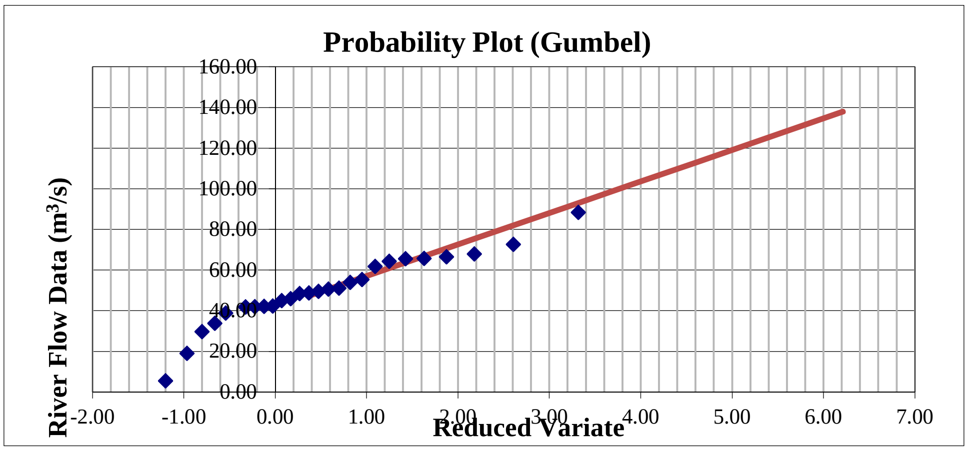
n	27			K_N	2.51
Mean (Xm)	49.71	Mean (Ym)	1.66	High Outlier Limit	167.40
Standard Deviation (Sx)	17.06	Standard Deviation (Sy)	0.23	Low Outlier Limit	12.30

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Metu	2	-0.15	0.37	47.1
	5	0.88	1.50	64.7
	10	1.56	2.25	76.3
	25	2.42	3.20	91.1
	50	3.06	3.90	102.0
	100	3.70	4.60	112.8
	500	5.17	6.21	137.8

*Gumble Distribution Frequency Factor (from standard table)



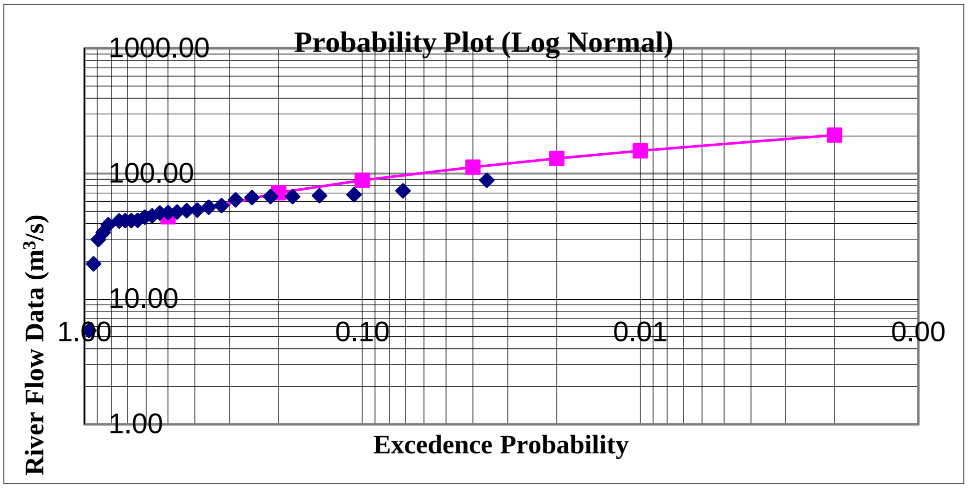
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{YT}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Metu	2	50.0%	0.00	0.00	1.66	45.38
	5	20.0%		0.84	1.85	70.30
	10	10.0%		1.28	1.95	88.38
	25	4.0%		1.75	2.05	112.79
	50	2.0%		2.05	2.12	132.05
	100	1.0%		2.33	2.18	152.16
	500	0.2%		2.88	2.31	202.73

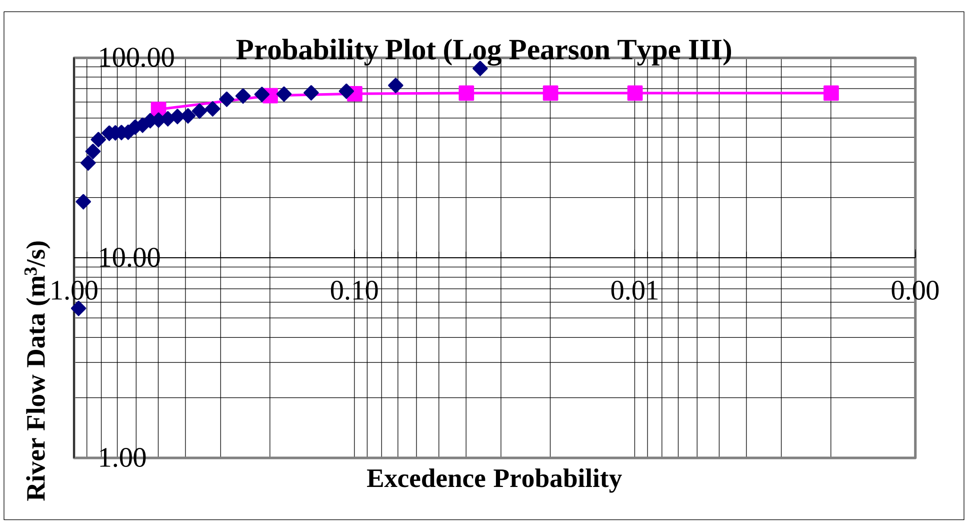
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Metu	2	50.0%	-2.71	0.38	1.74	55.21
	5	20.0%		0.68	1.81	64.59
	10	10.0%		0.72	1.82	66.04
	25	4.0%		0.73	1.82	66.50
	50	2.0%		0.74	1.82	66.57
	100	1.0%		0.74	1.82	66.60
	500	0.2%		0.74	1.82	66.60

* from standard distribution table, f(Cs, T)



Robe **Rainfall Data Frequency Analysis Computation**

Year	**Rainfall Data (mm)**	**Rainfall Data Descending Order (X)**	**Y = Log X**	**Rank**	**Plotting Positions**	**Probability, P [%]**	**Return Period, Tr [yr]**	**Reduced Variate, y**
1985	57.80	112.30	2.05	1.00	0.03	3%	31.00	3.42
1986	41.90	84.50	1.93	2.00	0.06	6%	15.50	2.71
1987	63.00	76.00	1.88	3.00	0.10	10%	10.33	2.28
1988	38.70	74.00	1.87	4.00	0.13	13%	7.75	1.98
1989	49.40	67.00	1.83	5.00	0.16	16%	6.20	1.74
1990	37.80	64.00	1.81	6.00	0.19	19%	5.17	1.54
1991	26.60	63.00	1.80	7.00	0.23	23%	4.43	1.36
1992	37.80	57.80	1.76	8.00	0.26	26%	3.88	1.21
1993	84.50	56.50	1.75	9.00	0.29	29%	3.44	1.07
1994	52.20	52.20	1.72	10.00	0.32	32%	3.10	0.94
1995	30.40	51.00	1.71	11.00	0.35	35%	2.82	0.82
1996	36.70	49.60	1.70	12.00	0.39	39%	2.58	0.71
1997	35.30	49.40	1.69	13.00	0.42	42%	2.38	0.61
1998	29.00	48.70	1.69	14.00	0.45	45%	2.21	0.51
1999	46.30	48.50	1.69	15.00	0.48	48%	2.07	0.41
2000	112.30	46.30	1.67	16.00	0.52	52%	1.94	0.32
2001	43.70	43.70	1.64	17.00	0.55	55%	1.82	0.23
2002	42.70	43.60	1.64	18.00	0.58	58%	1.72	0.14
2003	43.60	42.70	1.63	19.00	0.61	61%	1.63	0.05
2004	76.00	41.90	1.62	20.00	0.65	65%	1.55	-0.04
2005	49.60	41.00	1.61	21.00	0.68	68%	1.48	-0.12
2006	48.70	38.70	1.59	22.00	0.71	71%	1.41	-0.21
2007	48.50	37.80	1.58	23.00	0.74	74%	1.35	-0.30
2008	41.00	37.80	1.58	23.00	0.74	74%	1.35	-0.30
2009	34.40	36.70	1.56	25.00	0.81	81%	1.24	-0.50
2010	56.50	35.30	1.55	26.00	0.84	84%	1.19	-0.60
2011	64.00	34.40	1.54	27.00	0.87	87%	1.15	-0.72
2012	74.00	30.40	1.48	28.00	0.90	90%	1.11	-0.85
2013	51.00	29.00	1.46	29.00	0.94	94%	1.07	-1.01
2014	67.00	26.60	1.42	30.00	0.97	97%	1.03	-1.23

n	30		
Mean (Xm)	50.68	Mean (Ym)	1.68
Standard Deviation (Sx)	18.39	Standard Deviation (Sy)	0.14

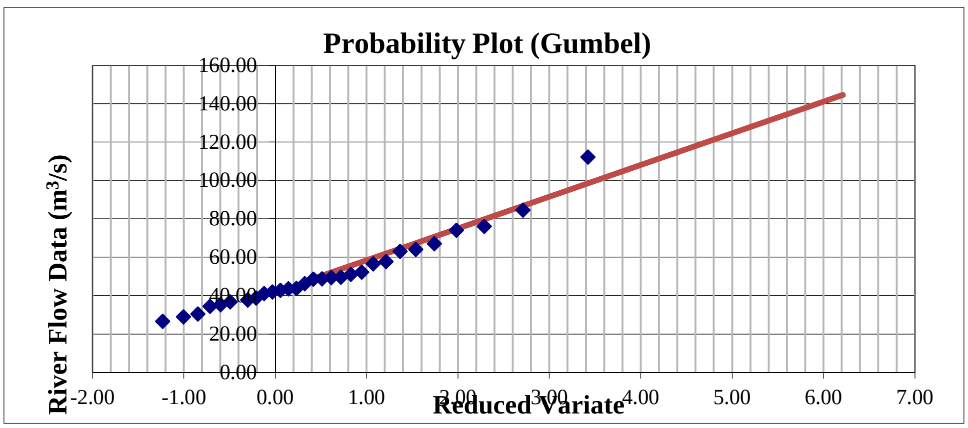
K_N	2.56
High Outlier Limit	111.05
Low Outlier Limit	20.74

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T=X_M+K_TS_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Robe	2	-0.15	0.37	47.9
	5	0.87	1.50	66.6
	10	1.54	2.25	79.0
	25	2.39	3.20	94.7
	50	3.03	3.90	106.3
	100	3.65	4.60	117.9
	500	5.10	6.21	144.5

*Gumble Distribution Frequency Factor (from standard table)



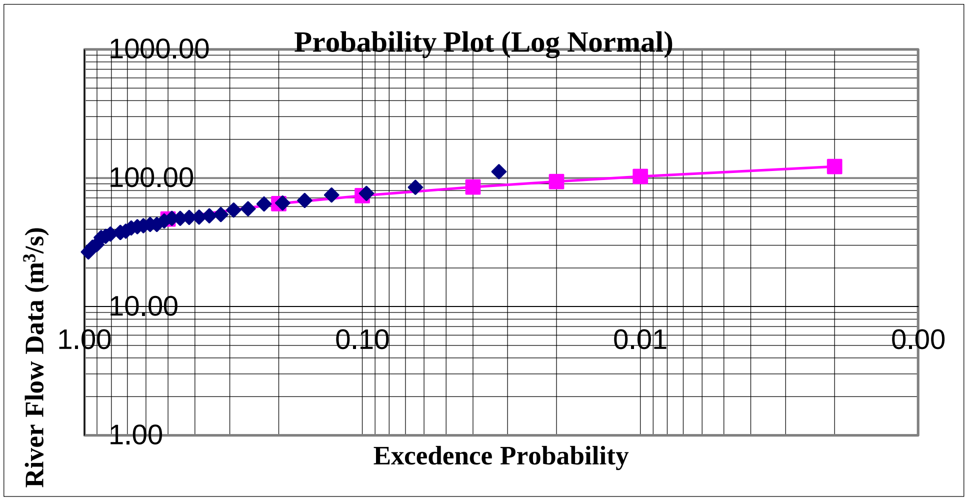
Rainfall Data Frequency Analysis Computation using Log Normal Method

$Y_T=Y_m+K_TS_y$

$X_T=10^{YT}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Robe	2	50.0%	0.00	0.00	1.68	47.99
	5	20.0%		0.84	1.80	63.21
	10	10.0%		1.28	1.86	73.00
	25	4.0%		1.75	1.93	85.12
	50	2.0%		2.05	1.97	94.00
	100	1.0%		2.33	2.01	102.77
	500	0.2%		2.88	2.09	123.12

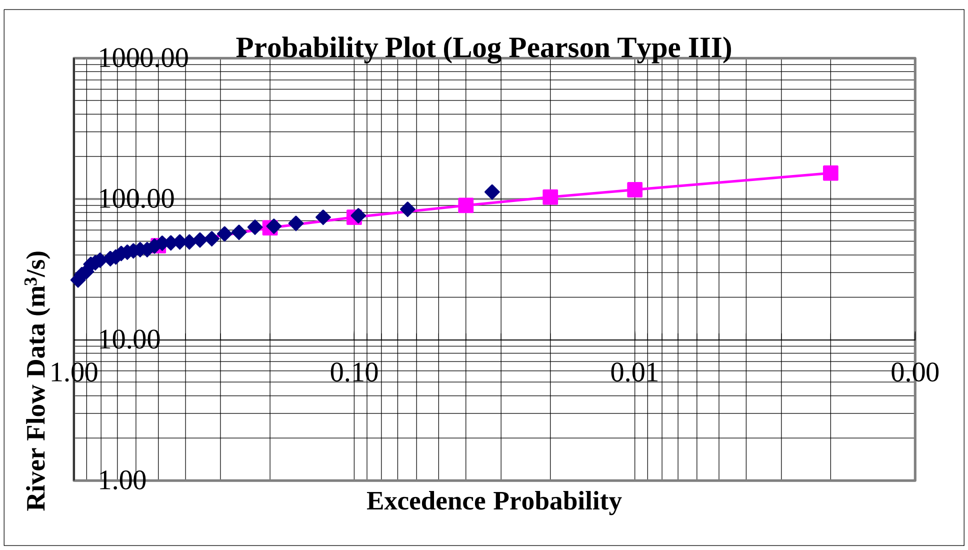
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Robe	2	50.0%	0.53	-0.09	1.67	46.61
	5	20.0%		0.81	1.80	62.46
	10	10.0%		1.32	1.87	74.04
	25	4.0%		1.92	1.95	89.96
	50	2.0%		2.33	2.01	102.79
	100	1.0%		2.71	2.07	116.49
	500	0.2%		3.53	2.18	152.33

* from standard distribution table, f(Cs, T)



Wukro **Rainfall Data Frequency Analysis Computation**

Year	Rainfall Data (mm)	Rainfall Data Descending Order (X)	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1975	62.70	128.00	2.11	1.00	0.04	4%	26.00	3.24
1976	53.70	100.50	2.00	2.00	0.08	8%	13.00	2.53
1992	33.40	89.20	1.95	3.00	0.12	12%	8.67	2.10
1993	37.50	86.50	1.94	4.00	0.15	15%	6.50	1.79
1994	89.20	75.00	1.88	5.00	0.19	19%	5.20	1.54
1995	39.30	73.40	1.87	6.00	0.23	23%	4.33	1.34
1996	64.30	64.30	1.81	7.00	0.27	27%	3.71	1.16
1997	21.20	62.70	1.80	8.00	0.31	31%	3.25	1.00
1998	53.00	61.40	1.79	9.00	0.35	35%	2.89	0.86
1999	41.30	56.00	1.75	10.00	0.38	38%	2.60	0.72
2000	100.50	53.70	1.73	11.00	0.42	42%	2.36	0.60
2001	128.00	53.00	1.72	12.00	0.46	46%	2.17	0.48
2002	86.50	52.00	1.72	13.00	0.50	50%	2.00	0.37
2003	50.00	50.60	1.70	14.00	0.54	54%	1.86	0.26
2004	50.00	50.40	1.70	15.00	0.58	58%	1.73	0.15
2005	50.60	50.00	1.70	16.00	0.62	62%	1.63	0.05
2006	61.40	50.00	1.70	16.00	0.62	62%	1.63	0.05
2007	73.40	45.00	1.65	18.00	0.69	69%	1.44	-0.16
2008	50.40	41.30	1.62	19.00	0.73	73%	1.37	-0.27
2009	45.00	41.00	1.61	20.00	0.77	77%	1.30	-0.38
2010	75.00	39.30	1.59	21.00	0.81	81%	1.24	-0.50
2011	52.00	37.50	1.57	22.00	0.85	85%	1.18	-0.63
2012	56.00	33.40	1.52	23.00	0.88	88%	1.13	-0.77
2013	41.00	29.00	1.46	24.00	0.92	92%	1.08	-0.94
2014	29.00	21.20	1.33	25.00	0.96	96%	1.04	-1.18

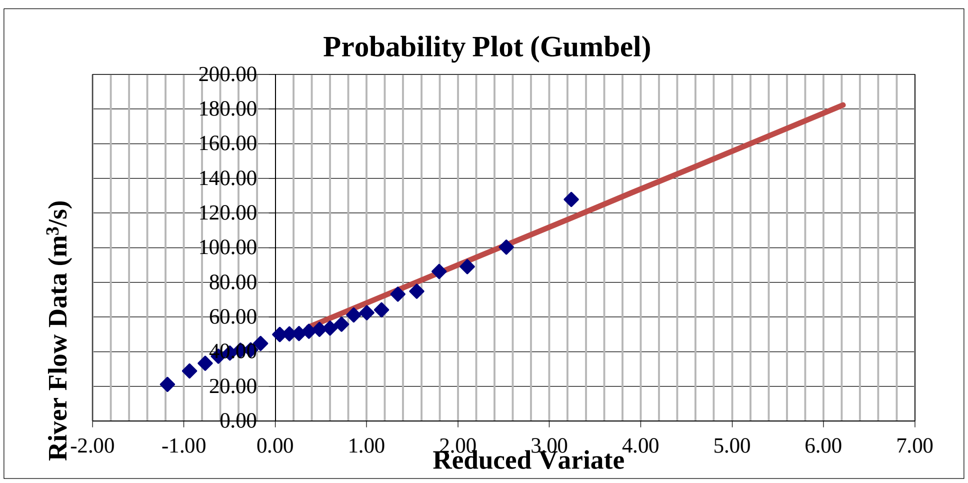
n	25			K_N	2.49
Mean (Xm)	57.78	Mean (Ym)	1.73	High Outlier Limit	144.12
Standard Deviation (Sx)	23.91	Standard Deviation (Sy)	0.17	Low Outlier Limit	19.89

Rainfall Data Frequency Analysis Computation using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	X_T [m3/s]
Wukro	2	-0.15	0.37	54.2
	5	0.89	1.50	79.0
	10	1.58	2.25	95.4
	25	2.44	3.20	116.2
	50	3.09	3.90	131.6
	100	3.73	4.60	146.9
	500	5.21	6.21	182.3

*Gumble Distribution Frequency Factor (from standard table)



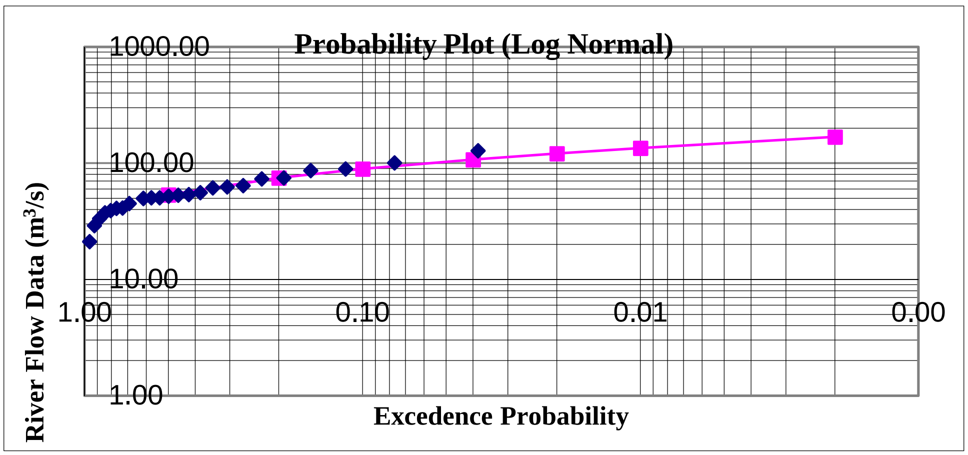
Rainfall Data Frequency Analysis Computation using Log Normal Method

$$Y_T = Y_m + K_T S_y$$

$$X_T = 10^{Y_T}$$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Wukro	2	50.0%	0.00	0.00	1.73	53.54
	5	20.0%		0.84	1.87	74.85
	10	10.0%		1.28	1.95	89.18
	25	4.0%		1.75	2.03	107.50
	50	2.0%		2.05	2.08	121.29
	100	1.0%		2.33	2.13	135.19
	500	0.2%		2.88	2.23	168.41

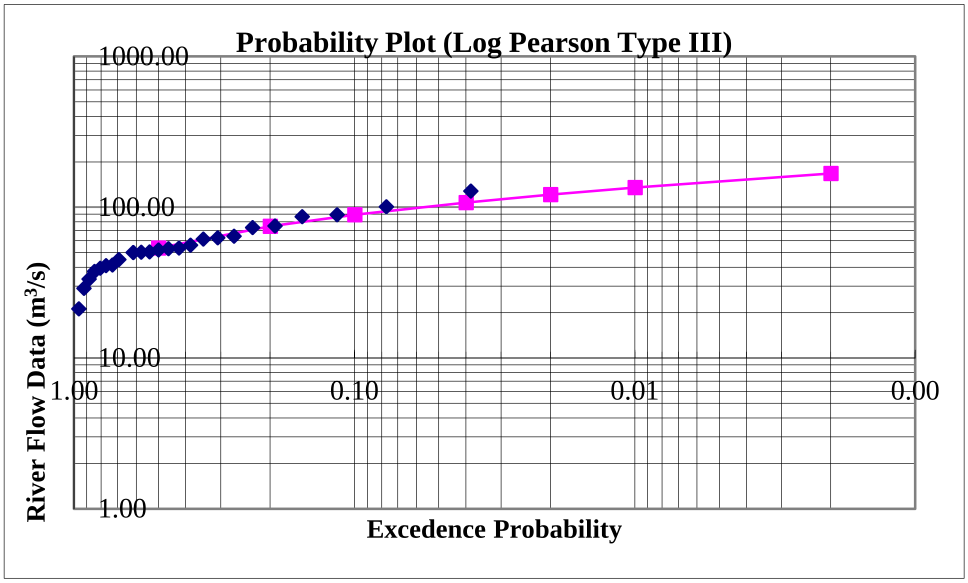
* from standard distribution table, f(Cs, T)



Rainfall Data Frequency Analysis Computation using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	X_T [m3/s]
Wukro	2	50.0%	-0.01	0.00	1.73	53.57
	5	20.0%		0.84	1.87	74.86
	10	10.0%		1.28	1.95	89.15
	25	4.0%		1.75	2.03	107.38
	50	2.0%		2.05	2.08	121.09
	100	1.0%		2.32	2.13	134.89
	500	0.2%		2.87	2.22	167.80

* from standard distribution table, f(Cs, T)



ANNEX 5: FLOOD ESTIMATION USING SCS UNIT HYDROGRAPH METHOD

GEBA nr SUPPI RIVER

SCS Synthetic Unit Hydrograph Method
Analysis based on *CN Average*

Unit Peak Discharge Determination

Description	Formula		Unit	Geba nr Supi
Area			km^2	3759.00
Time of Conc.	Tc		hr.	46.34
Rainfall Excess Duration	D ~ Tc/6 D ~ 1 hr.	if Tc < 3 hrs. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc		hr.	28.30
Time Base of Hydrograph	Tb = 2.67Tp		hr.	75.57
Lag Time	Tl = 0.6Tc		hr.	27.80
Peak Rate of Discharge	qp = (0.21A) / Tp		m^3/s/mm	27.89
Weighted CN Value				72
Maximum Potential Diff.	S=(25400/CN)-254			101.24

Ordinates for Unit hydrograph Calculation

Geba nr Supi										
Duration (hrs.)		Rainfall 24hr Max.*	Rainfall Profile	Rainfall Profile	Times of Incremental Hydrograph			Direct Runoff	Incremental Runoff	Peak Runoff
Beginning	End	mm	%	mm	Begin	Peak	End	mm	mm	mm
0.00	1.00	112.80	1.08	1.22	0.00	28.30	75.57	0.00	0.00	0.00
1.00	2.00		2.23	2.52	1.00	29.30	76.57	0.00	0.00	0.00
2.00	3.00		3.47	3.91	2.00	30.30	77.57	0.00	0.00	0.00
3.00	4.00		4.83	5.45	3.00	31.30	78.57	0.00	0.00	0.00
4.00	5.00		6.32	7.13	4.00	32.30	79.57	0.00	0.00	0.00
5.00	6.00		7.97	8.99	5.00	33.30	80.57	0.00	0.00	0.00
6.00	7.00		9.84	11.10	6.00	34.30	81.57	0.00	0.00	0.00
7.00	8.00		12.03	13.57	7.00	35.30	82.57	0.00	0.00	0.00
8.00	9.00		14.67	16.55	8.00	36.30	83.57	0.00	0.00	0.00
9.00	10.00		18.08	20.39	9.00	37.30	84.57	0.00	0.00	0.01
10.00	11.00		23.51	26.52	10.00	38.30	85.57	0.37	0.37	10.19
11.00	12.00		66.32	74.81	11.00	39.30	86.57	19.11	18.74	522.67
12.00	13.00		77.24	87.13	12.00	40.30	87.57	26.60	7.50	209.11
13.00	14.00		81.97	92.46	13.00	41.30	88.57	30.06	3.46	96.50
14.00	15.00		85.38	96.31	14.00	42.30	89.57	32.63	2.56	71.52
15.00	16.00		88.01	99.28	15.00	43.30	90.57	34.64	2.02	56.21
16.00	17.00		90.00	101.52	16.00	44.30	91.57	36.19	1.55	43.10
17.00	18.00		93.00	104.90	17.00	45.30	92.57	38.55	2.36	65.87
18.00	19.00		94.00	106.03	18.00	46.30	93.57	39.35	0.80	22.18
19.00	20.00		95.00	107.16	19.00	47.30	94.57	40.15	0.80	22.30
20.00	21.00		96.00	108.29	20.00	48.30	95.57	40.95	0.80	22.41
21.00	22.00		97.50	109.98	21.00	49.30	96.57	42.16	1.21	33.81
22.00	23.00		98.90	111.56	22.00	50.30	97.57	43.30	1.14	31.77
23.00	24.00		100.00	112.80	23.00	51.30	98.57	44.20	0.90	25.10

*Rainfall station is located inMetu.

Time	Ordinates of Unit Hydrographs for Geba nr Supi																							Sum
0.00	0.00																							0.00
1.00	0.00	0.00																						0.00
2.00	0.00	0.00	0.00																					0.00
3.00	0.00	0.00	0.00	0.00																				0.00
4.00	0.00	0.00	0.00	0.00	0.00																			0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00																		0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																	0.00
7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																0.00
8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00															0.00
9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00														0.00
10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00													0.00
11.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00												0.36
12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	18.47	0.00											19.19
13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.08	36.93	7.39	0.00										45.40
14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	55.40	14.78	3.41	0.00									75.03
15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.80	73.87	22.16	6.82	2.53	0.00								107.18
16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.16	92.33	29.55	10.23	5.05	1.99	0.00							141.31
17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.52	110.80	36.94	13.64	7.58	3.97	1.52	0.00						176.97
18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.88	129.26	44.33	17.05	10.11	5.96	3.05	2.33	0.00					214.96
19.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.24	147.73	51.72	20.46	12.63	7.94	4.57	4.65	0.78	0.00				253.73
20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	166.20	59.10	23.87	15.16	9.93	6.09	6.98	1.57	0.79	0.00			293.29
21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.96	184.66	66.49	27.28	17.69	11.91	7.61	9.31	2.35	1.58	0.79	0.00		333.64
22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.32	203.13	73.88	30.69	20.22	13.90	9.14	11.64	3.14	2.36	1.58	1.19	0.00	375.19
23.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.68	221.60	81.27	34.09	22.74	15.89	10.66	13.96	3.92	3.15	2.37	2.39	1.12	0.00	417.85
28.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.59	319.54	120.45	52.18	36.15	26.42	18.74	26.31	8.08	7.33	6.57	8.72	7.07	4.70	648.84
29.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.95	338.00	127.84	55.59	38.67	28.40	20.26	28.63	8.86	8.12	7.36	9.92	8.20	5.59	692.40
30.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.31	356.47	135.23	59.00	41.20	30.39	21.78	30.96	9.64	8.90	8.16	11.11	9.32	6.48	735.95
31.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.67	374.94	142.61	62.41	43.73	32.38	23.30	33.29	10.43	9.69	8.95	12.31	10.44	7.36	779.51
32.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.03	393.40	150.00	65.82	46.25	34.36	24.83	35.61	11.21	10.48	9.74	13.50	11.56	8.25	823.06
33.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.39	411.87	157.39	69.22	48.78	36.35	26.35	37.94	12.00	11.27	10.53	14.70	12.69	9.14	866.61
34.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	8.75	430.33	164.78	72.63	51.31	38.33	27.87	40.27	12.78	12.06	11.32	15.89	13.81	10.02	910.17
35.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.11	448.80	172.17	76.04	53.83	40.32	29.40	42.60	13.56	12.84	12.11	17.09	14.93	10.91	953.72
36.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.47	467.27	179.55	79.45	56.36	42.30	30.92	44.92	14.35	13.63	12.91	18.28	16.05	11.80	997.28

Time	Ordinates of Unit Hydrographs for Geba nr Supi																							Sum
37.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.83	485.73	186.94	82.86	58.89	44.29	32.44	47.25	15.13	14.42	13.70	19.47	17.18	12.68	1040.83
38.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	10.19	504.20	194.33	86.27	61.42	46.28	33.96	49.58	15.91	15.21	14.49	20.67	18.30	13.57	1084.38
39.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.98	522.67	201.72	89.68	63.94	48.26	35.49	51.90	16.70	15.99	15.28	21.86	19.42	14.46	1127.36
40.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.76	511.61	209.11	93.09	66.47	50.25	37.01	54.23	17.48	16.78	16.07	23.06	20.54	15.35	1140.81
41.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.55	500.55	204.68	96.50	69.00	52.23	38.53	56.56	18.27	17.57	16.86	24.25	21.67	16.23	1142.46
42.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.33	489.49	200.26	94.46	71.52	54.22	40.06	58.89	19.05	18.36	17.66	25.45	22.79	17.12	1138.65
43.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	9.12	478.44	195.83	92.42	70.01	56.21	41.58	61.21	19.83	19.15	18.45	26.64	23.91	18.01	1130.80
44.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.90	467.38	191.41	90.38	68.50	55.02	43.10	63.54	20.62	19.93	19.24	27.84	25.03	18.89	1119.77
45.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.68	456.32	186.99	88.33	66.98	53.83	42.19	65.87	21.40	20.72	20.03	29.03	26.16	19.78	1106.31
46.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.47	445.26	182.56	86.29	65.47	52.64	41.28	64.47	22.18	21.51	20.82	30.23	27.28	20.67	1089.13
47.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.25	434.20	178.14	84.25	63.96	51.45	40.37	63.08	21.72	22.30	21.61	31.42	28.40	21.55	1070.70
48.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.04	423.15	173.71	82.21	62.44	50.26	39.45	61.69	21.25	21.82	22.41	32.61	29.52	22.44	1051.01
49.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.82	412.09	169.29	80.17	60.93	49.07	38.54	60.29	20.78	21.35	21.93	33.81	30.64	23.33	1030.05
50.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.61	401.03	164.87	78.13	59.42	47.88	37.63	58.90	20.31	20.88	21.46	33.09	31.77	24.21	1007.18
51.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.39	389.97	160.44	76.08	57.90	46.69	36.72	57.51	19.84	20.41	20.98	32.38	31.09	25.10	982.52
75.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.16	121.64	53.09	26.54	21.18	17.84	14.59	23.69	8.45	8.96	9.48	15.02	14.79	12.21	349.63
76.57		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	110.58	48.66	24.50	19.67	16.65	13.68	22.30	7.98	8.49	9.01	14.31	14.11	11.68	323.55
77.57			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73	99.52	44.24	22.46	18.16	15.46	12.77	20.90	7.51	8.02	8.53	13.59	13.44	11.15	297.47
78.57				0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.51	88.46	39.82	20.42	16.64	14.27	11.85	19.51	7.04	7.55	8.06	12.87	12.77	10.62	271.39
79.57					0.00	0.00	0.00	0.00	0.00	0.00	1.29	77.40	35.39	18.37	15.13	13.08	10.94	18.12	6.57	7.08	7.58	12.16	12.10	10.09	245.31
80.57						0.00	0.00	0.00	0.00	0.00	1.08	66.35	30.97	16.33	13.62	11.89	10.03	16.72	6.10	6.60	7.11	11.44	11.43	9.56	219.23
81.57							0.00	0.00	0.00	0.00	0.86	55.29	26.54	14.29	12.11	10.70	9.12	15.33	5.63	6.13	6.64	10.73	10.75	9.03	193.15
82.57								0.00	0.00	0.00	0.65	44.23	22.12	12.25	10.59	9.51	8.21	13.94	5.16	5.66	6.16	10.01	10.08	8.50	167.07
83.57									0.00	0.00	0.43	33.17	17.70	10.21	9.08	8.32	7.29	12.54	4.69	5.19	5.69	9.30	9.41	7.97	140.99
84.57										0.00	0.22	22.12	13.27	8.17	7.57	7.13	6.38	11.15	4.22	4.72	5.21	8.58	8.74	7.43	114.91
85.57											0.00	11.06	8.85	6.12	6.05	5.95	5.47	9.75	3.75	4.25	4.74	7.87	8.06	6.90	88.83
86.57												0.00	4.42	4.08	4.54	4.76	4.56	8.36	3.29	3.77	4.27	7.15	7.39	6.37	62.97
87.57													0.00	2.04	3.03	3.57	3.65	6.97	2.82	3.30	3.79	6.44	6.72	5.84	48.16
88.57														0.00	1.51	2.38	2.74	5.57	2.35	2.83	3.32	5.72	6.05	5.31	37.78
89.57															0.00	1.19	1.82	4.18	1.88	2.36	2.84	5.01	5.38	4.78	29.44
90.57																0.00	0.91	2.79	1.41	1.89	2.37	4.29	4.70	4.25	22.61
91.57																	0.00	1.39	0.94	1.42	1.90	3.58	4.03	3.72	16.97
92.57																		0.00	0.47	0.94	1.42	2.86	3.36	3.19	12.24
93.57																			0.00	0.47	0.95	2.15	2.69	2.66	8.91
94.57																				0.00	0.47	1.43	2.02	2.12	6.04

Time	Ordinates of Unit Hydrographs for Geba nr Supi																							Sum
95.57																				0.00	0.72	1.34	1.59	3.65
96.57																					0.00	0.67	1.06	1.73
97.57																						0.00	0.53	0.53
98.57																							0.00	0.00

ARF (%) = 57%

Peak Discharge obtained Based on *CN Average*

Q max (m^3/s) = 1142.46

Q reduced (m^3/s) = Q max * ARF 647.92

Where

Q des = Design Discharge
Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph
ARF=Area Reduction Factor

GEBA nr SUPPI RIVER

SCS Synthetic Unit Hydrograph Method

Unit Peak Discharge Determination
Analysis based on *CN wet*

Description	Formula		Unit	Geba nr Supi
Area			km^2	3759.00
Time of Conc.	Tc		hr.	46.34
Rainfall Excess Duration	D ~ Tc/6 D ~ 1 hr.	if Tc < 3 hrs. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc		hr.	28.30
Time Base of Hydrograph	Tb = 2.67Tp		hr.	75.57
Lag Time	Tl = 0.6Tc		hr.	27.80
Peak Rate of Discharge	qp = (0.21A) / Tp		m^3/s/mm	27.89
Weighted CN Value				86
Maximum Potential Diff.	S=(25400/CN)-254			41.35

Ordinates for Unit hydrograph Calculation

Geba nr Supi										
Duration (hrs.)		**Rainfall 24hr Max.***	**Rainfall Profile**	**Rainfall Profile**	**Times of Increamental Hydrograph**			**Direct Runoff**	**Incremental Runoff**	**Peak Runoff**
Beginning	**End**	**mm**	**%**	**mm**	**Begin**	**Peak**	**End**	**mm**	**mm**	**mm**
0.00	1.00	112.80	1.08	1.22	0.00	28.30	75.57	0.00	0.00	0.00
1.00	2.00		2.23	2.52	1.00	29.30	76.57	0.00	0.00	0.00
2.00	3.00		3.47	3.91	2.00	30.30	77.57	0.00	0.00	0.00
3.00	4.00		4.83	5.45	3.00	31.30	78.57	0.00	0.00	0.00
4.00	5.00		6.32	7.13	4.00	32.30	79.57	0.00	0.00	0.00
5.00	6.00		7.97	8.99	5.00	33.30	80.57	0.01	0.01	0.34
6.00	7.00		9.84	11.10	6.00	34.30	81.57	0.18	0.17	4.71
7.00	8.00		12.03	13.57	7.00	35.30	82.57	0.60	0.42	11.74
8.00	9.00		14.67	16.55	8.00	36.30	83.57	1.38	0.78	21.72
9.00	10.00		18.08	20.39	9.00	37.30	84.57	2.75	1.37	38.16
10.00	11.00		23.51	26.52	10.00	38.30	85.57	5.59	2.84	79.18
11.00	12.00		66.32	74.81	11.00	39.30	86.57	41.04	35.45	988.69
12.00	13.00		77.24	87.13	12.00	40.30	87.57	51.73	10.69	298.25
13.00	14.00		81.97	92.46	13.00	41.30	88.57	56.46	4.73	131.95
14.00	15.00		85.38	96.31	14.00	42.30	89.57	59.90	3.44	95.99
15.00	16.00		88.01	99.28	15.00	43.30	90.57	62.57	2.67	74.48
16.00	17.00		90.00	101.52	16.00	44.30	91.57	64.60	2.03	56.60
17.00	18.00		93.00	104.90	17.00	45.30	92.57	67.68	3.07	85.69
18.00	19.00		94.00	106.03	18.00	46.30	93.57	68.70	1.03	28.66
19.00	20.00		95.00	107.16	19.00	47.30	94.57	69.73	1.03	28.70
20.00	21.00		96.00	108.29	20.00	48.30	95.57	70.76	1.03	28.75
21.00	22.00		97.50	109.98	21.00	49.30	96.57	72.31	1.55	43.20
22.00	23.00		98.90	111.56	22.00	50.30	97.57	73.76	1.45	40.40
23.00	24.00		100.00	112.80	23.00	51.30	98.57	74.90	1.14	31.80

*Rainfall station is located in Metu.

Time	**Ordinates of Unit Hydrographs for Geba nr Supi**																							**Sum**
0.00	0.00																							0.00
1.00	0.00	0.00																						0.00
2.00	0.00	0.00	0.00																					0.00
3.00	0.00	0.00	0.00	0.00																				0.00
4.00	0.00	0.00	0.00	0.00	0.00																			0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00																		0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00																	0.01
7.00	0.00	0.00	0.00	0.00	0.00	0.02	0.17	0.00																0.19
8.00	0.00	0.00	0.00	0.00	0.00	0.04	0.33	0.41	0.00															0.78
9.00	0.00	0.00	0.00	0.00	0.00	0.05	0.50	0.83	0.77	0.00														2.14
10.00	0.00	0.00	0.00	0.00	0.00	0.06	0.67	1.24	1.53	1.35	0.00													4.85
11.00	0.00	0.00	0.00	0.00	0.00	0.07	0.83	1.66	2.30	2.70	2.80	0.00												10.36
12.00	0.00	0.00	0.00	0.00	0.00	0.09	1.00	2.07	3.07	4.04	5.60	34.93	0.00											50.80
13.00	0.00	0.00	0.00	0.00	0.00	0.10	1.17	2.49	3.84	5.39	8.39	69.86	10.54	0.00										101.77
14.00	0.00	0.00	0.00	0.00	0.00	0.11	1.33	2.90	4.60	6.74	11.19	104.79	21.08	4.66	0.00									157.41
15.00	0.00	0.00	0.00	0.00	0.00	0.12	1.50	3.32	5.37	8.09	13.99	139.73	31.61	9.32	3.39	0.00								216.44
16.00	0.00	0.00	0.00	0.00	0.00	0.13	1.66	3.73	6.14	9.44	16.79	174.66	42.15	13.99	6.78	2.63	0.00							278.10
17.00	0.00	0.00	0.00	0.00	0.00	0.15	1.83	4.15	6.91	10.79	19.58	209.59	52.69	18.65	10.17	5.26	2.00	0.00						341.76
18.00	0.00	0.00	0.00	0.00	0.00	0.16	2.00	4.56	7.67	12.13	22.38	244.52	63.23	23.31	13.57	7.89	4.00	3.03	0.00					408.45
19.00	0.00	0.00	0.00	0.00	0.00	0.17	2.16	4.98	8.44	13.48	25.18	279.45	73.76	27.97	16.96	10.53	6.00	6.06	1.01	0.00				476.15
20.00	0.00	0.00	0.00	0.00	0.00	0.18	2.33	5.39	9.21	14.83	27.98	314.38	84.30	32.63	20.35	13.16	8.00	9.08	2.03	1.01	0.00			544.86
21.00	0.00	0.00	0.00	0.00	0.00	0.19	2.50	5.81	9.97	16.18	30.77	349.31	94.84	37.29	23.74	15.79	10.00	12.11	3.04	2.03	1.02	0.00		614.59
22.00	0.00	0.00	0.00	0.00	0.00	0.21	2.66	6.22	10.74	17.53	33.57	384.25	105.38	41.96	27.13	18.42	12.00	15.14	4.05	3.04	2.03	1.53	0.00	685.85
23.00	0.00	0.00	0.00	0.00	0.00	0.22	2.83	6.64	11.51	18.88	36.37	419.18	115.91	46.62	30.52	21.05	14.00	18.17	5.06	4.06	3.05	3.05	1.43	0.00	758.53
28.30	0.00	0.00	0.00	0.00	0.00	0.28	3.71	8.84	15.58	26.03	51.21	604.44	171.80	71.34	48.51	35.01	24.60	34.22	10.43	9.43	8.43	11.15	9.00	5.96	1149.98
29.30	0.00	0.00	0.00	0.00	0.00	0.30	3.88	9.25	16.35	27.38	54.00	639.37	182.34	76.00	51.90	37.64	26.60	37.25	11.45	10.45	9.45	12.67	10.43	7.08	1223.78
30.30	0.00	0.00	0.00	0.00	0.00	0.31	4.05	9.67	17.11	28.72	56.80	674.30	192.88	80.67	55.29	40.27	28.60	40.28	12.46	11.46	10.46	14.20	11.85	8.21	1297.59
31.30	0.00	0.00	0.00	0.00	0.00	0.32	4.21	10.08	17.88	30.07	59.60	709.24	203.41	85.33	58.68	42.90	30.60	43.31	13.47	12.48	11.48	15.73	13.28	9.33	1371.40
32.30	0.00	0.00	0.00	0.00	0.00	0.33	4.38	10.50	18.65	31.42	62.40	744.17	213.95	89.99	62.07	45.53	32.60	46.33	14.48	13.49	12.50	17.25	14.71	10.45	1445.20
33.30	0.00	0.00	0.00	0.00	0.00	0.34	4.54	10.91	19.41	32.77	65.19	779.10	224.49	94.65	65.46	48.16	34.60	49.36	15.50	14.51	13.51	18.78	16.14	11.58	1519.01
34.30	0.00	0.00	0.00	0.00	0.00	0.34	4.71	11.32	20.18	34.12	67.99	814.03	235.03	99.31	68.86	50.80	36.60	52.39	16.51	15.52	14.53	20.31	17.56	12.70	1592.80
35.30	0.00	0.00	0.00	0.00	0.00	0.33	4.61	11.74	20.95	35.46	70.79	848.96	245.56	103.98	72.25	53.43	38.60	55.42	17.52	16.53	15.54	21.83	18.99	13.82	1666.32
36.30	0.00	0.00	0.00	0.00	0.00	0.32	4.51	11.49	21.72	36.81	73.59	883.89	256.10	108.64	75.64	56.06	40.60	58.44	18.53	17.55	16.56	23.36	20.42	14.95	1739.18
37.30	0.00	0.00	0.00	0.00	0.00	0.31	4.41	11.24	21.26	38.16	76.38	918.82	266.64	113.30	79.03	58.69	42.60	61.47	19.55	18.56	17.57	24.88	21.85	16.07	1810.81
38.30	0.00	0.00	0.00	0.00	0.00	0.31	4.31	10.99	20.80	37.35	79.18	953.76	277.18	117.96	82.42	61.32	44.60	64.50	20.56	19.58	18.59	26.41	23.27	17.20	1880.29
39.30	0.00	0.00	0.00	0.00	0.00	0.30	4.21	10.75	20.34	36.55	77.51	988.69	287.71	122.62	85.81	63.95	46.60	67.53	21.57	20.59	19.61	27.94	24.70	18.32	1945.29
40.30	0.00	0.00	0.00	0.00	0.00	0.29	4.11	10.50	19.88	35.74	75.83	967.77	298.25	127.28	89.20	66.58	48.60	70.55	22.58	21.60	20.62	29.46	26.13	19.44	1954.45
41.30	0.00	0.00	0.00	0.00	0.00	0.29	4.01	10.25	19.42	34.93	74.16	946.85	291.94	131.95	92.60	69.22	50.60	73.58	23.60	22.62	21.64	30.99	27.56	20.57	1946.75
42.30	0.00	0.00	0.00	0.00	0.00	0.28	3.91	10.00	18.96	34.12	72.48	925.94	285.63	129.16	95.99	71.85	52.60	76.61	24.61	23.63	22.65	32.52	28.98	21.69	1931.61
43.30	0.00	0.00	0.00	0.00	0.00	0.27	3.81	9.75	18.50	33.32	70.81	905.02	279.32	126.36	93.96	74.48	54.60	79.64	25.62	24.65	23.67	34.04	30.41	22.81	1911.04
44.30	0.00	0.00	0.00	0.00	0.00	0.26	3.71	9.50	18.04	32.51	69.13	884.10	273.01	123.57	91.93	72.90	56.60	82.66	26.63	25.66	24.68	35.57	31.84	23.94	1886.26
45.30	0.00	0.00	0.00	0.00	0.00	0.26	3.61	9.26	17.58	31.70	67.46	863.18	266.70	120.78	89.89	71.33	55.40	85.69	27.65	26.67	25.70	37.10	33.27	25.06	1858.29
46.30	0.00	0.00	0.00	0.00	0.00	0.25	3.52	9.01	17.12	30.90	65.78	842.27	260.39	117.99	87.86	69.75	54.20	83.88	28.66	27.69	26.72	38.62	34.69	26.18	1825.48
47.30	0.00	0.00	0.00	0.00	0.00	0.24	3.42	8.76	16.66	30.09	64.10	821.35	254.08	115.20	85.83	68.18	53.00	82.07	28.05	28.70	27.73	40.15	36.12	27.31	1791.05
48.30	0.00	0.00	0.00	0.00	0.00	0.23	3.32	8.51	16.20	29.28	62.43	800.43	247.77	112.41	83.80	66.60	51.81	80.25	27.45	28.10	28.75	41.67	37.55	28.43	1754.99
49.30	0.00	0.00	0.00	0.00	0.00	0.23	3.22	8.26	15.74	28.47	60.75	779.52	241.46	109.61	81.77	65.02	50.61	78.44	26.84	27.49	28.14	43.20	38.98	29.55	1717.32
50.30	0.00	0.00	0.00	0.00	0.00	0.22	3.12	8.01	15.28	27.67	59.08	758.60	235.15	106.82	79.74	63.45	49.41	76.63	26.23	26.88	27.53	42.29	40.40	30.68	1677.20
51.30	0.00	0.00	0.00	0.00	0.00	0.21	3.02	7.77	14.82	26.86	57.40	737.68	228.84	104.03	77.71	61.87	48.22	74.81	25.63	26.27	26.92	41.37	39.55	31.80	1634.80

Time	**Ordinates of Unit Hydrographs for Geba nr Supi**																								**Sum**
75.57	0.00	0.00	0.00	0.00	0.00	0.04	0.60	1.74	3.68	7.27	16.75	230.09	75.72	36.29	28.43	23.64	19.16	30.82	10.91	11.54	12.16	19.19	18.81	15.47	562.30
76.57		0.00	0.00	0.00	0.00	0.03	0.50	1.49	3.22	6.46	15.08	209.17	69.41	33.50	26.40	22.06	17.96	29.01	10.31	10.93	11.56	18.28	17.95	14.80	518.10
77.57			0.00	0.00	0.00	0.02	0.40	1.24	2.76	5.65	13.40	188.25	63.10	30.71	24.37	20.48	16.76	27.19	9.70	10.32	10.95	17.37	17.10	14.13	473.90
78.57				0.00	0.00	0.01	0.30	0.99	2.30	4.84	11.73	167.34	56.79	27.92	22.34	18.91	15.57	25.38	9.09	9.72	10.34	16.45	16.24	13.46	429.71
79.57					0.00	0.01	0.20	0.75	1.84	4.04	10.05	146.42	50.48	25.12	20.31	17.33	14.37	23.57	8.49	9.11	9.73	15.54	15.39	12.78	385.51
80.57						0.00	0.10	0.50	1.38	3.23	8.38	125.50	44.17	22.33	18.28	15.76	13.17	21.76	7.88	8.50	9.12	14.62	14.53	12.11	341.32
81.57							0.00	0.25	0.92	2.42	6.70	104.59	37.86	19.54	16.25	14.18	11.97	19.94	7.28	7.89	8.51	13.71	13.68	11.44	297.13
82.57								0.00	0.46	1.61	5.03	83.67	31.55	16.75	14.22	12.61	10.78	18.13	6.67	7.29	7.91	12.80	12.82	10.76	253.04
83.57									0.00	0.81	3.35	62.75	25.24	13.96	12.18	11.03	9.58	16.32	6.06	6.68	7.30	11.88	11.97	10.09	209.20
84.57										0.00	1.68	41.83	18.93	11.17	10.15	9.45	8.38	14.50	5.46	6.07	6.69	10.97	11.11	9.42	165.82
85.57											0.00	20.92	12.62	8.37	8.12	7.88	7.18	12.69	4.85	5.47	6.08	10.05	10.26	8.75	123.24
86.57												0.00	6.31	5.58	6.09	6.30	5.99	10.88	4.24	4.86	5.47	9.14	9.40	8.07	82.34
87.57													0.00	2.79	4.06	4.73	4.79	9.06	3.64	4.25	4.87	8.23	8.55	7.40	62.36
88.57														0.00	2.03	3.15	3.59	7.25	3.03	3.64	4.26	7.31	7.69	6.73	48.69
89.57															0.00	1.58	2.39	5.44	2.43	3.04	3.65	6.40	6.84	6.06	37.81
90.57																0.00	1.20	3.63	1.82	2.43	3.04	5.48	5.98	5.38	28.96
91.57																	0.00	1.81	1.21	1.82	2.43	4.57	5.13	4.71	21.69
92.57																		0.00	0.61	1.21	1.82	3.66	4.27	4.04	15.61
93.57																			0.00	0.61	1.22	2.74	3.42	3.36	11.35
94.57																				0.00	0.61	1.83	2.56	2.69	7.69
95.57																					0.00	0.91	1.71	2.02	4.64
96.57																						0.00	0.85	1.35	2.20
97.57																							0.00	0.67	0.67
98.57																								0.00	0.00

ARF (%) = 57%

Peak Discharge obtained Based on ***CN wet***

Q max (m^3/s) = 1954.45

Q reduced (m^3/s) = Q max * ARF 1108.42

Where Q des = Design Discharge
Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph
ARF=Area Reduction Factor

GHEBA nr MEKELE RIVER

SCS Synthetic Unit Hydrograph Method

Unit Peak Discharge Determination

Description	Formula	Unit	Gheba nr Mekele
Area		km^2	2392.30
Time of Conc.	Tc	hr.	18.40
Rainfall Excess Duration	D ~ Tc/6 if Tc < 3 hrs. D ~ 1 hr. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc	hr.	11.54
Time Base of Hydrograph	Tb = 2.67Tp	hr.	30.81
Lag Time	Tl = 0.6Tc	hr.	11.04
Peak Rate of Discharge	qp = (0.21A) / Tp	$m^3/s/mm$	43.53
Weighted CN Value			86
Maximum Potential Diff.	S=(25400/CN)-254		41.69

Ordinates for Unit hydrograph Calculation

Gheba nr Mekele										
Duration (hrs.)		Rainfall 24hr Max.*	Rainfall Profile	Rainfall Profile	Times of Increamental Hydrograph			Direct Runoff	Incremental Runoff	Peak Runoff
Beginning	End	mm	%	mm	Begin	Peak	End	mm	mm	mm
0.00	1.00	124.80	1.08	1.35	0.00	11.54	30.81	0.00	0.00	0.00
1.00	2.00		2.23	2.78	1.00	12.54	31.81	0.00	0.00	0.00
2.00	3.00		3.47	4.33	2.00	13.54	32.81	0.00	0.00	0.00
3.00	4.00		4.83	6.03	3.00	14.54	33.81	0.00	0.00	0.00
4.00	5.00		6.32	7.89	4.00	15.54	34.81	0.00	0.00	0.00
5.00	6.00		7.97	9.95	5.00	16.54	35.81	0.06	0.06	2.60
6.00	7.00		9.84	12.28	6.00	17.54	36.81	0.34	0.28	12.22
7.00	8.00		12.03	15.01	7.00	18.54	37.81	0.92	0.58	25.28
8.00	9.00		14.67	18.31	8.00	19.54	38.81	1.92	1.00	43.65
9.00	10.00		18.08	22.56	9.00	20.54	39.81	3.62	1.69	73.79
10.00	11.00		23.51	29.34	10.00	21.54	40.81	7.04	3.42	148.74
11.00	12.00		66.32	82.77	11.00	22.54	41.81	47.71	40.67	1770.54
12.00	13.00		77.24	96.40	12.00	23.54	42.81	59.76	12.06	524.84
13.00	14.00		81.97	102.30	13.00	24.54	43.81	65.08	5.32	231.60
14.00	15.00		85.38	106.55	14.00	25.54	44.81	68.95	3.87	168.30
15.00	16.00		88.01	109.84	15.00	26.54	45.81	71.94	3.00	130.49
16.00	17.00		90.00	112.32	16.00	27.54	46.81	74.22	2.28	99.11
17.00	18.00		93.00	116.06	17.00	28.54	47.81	77.67	3.45	149.97
18.00	19.00		94.00	117.31	18.00	29.54	48.81	78.82	1.15	50.14

*Rainfall station is located in Mekele.

Time	Ordinates of Unit Hydrographs for Gheba nr Mekele																			Sum
0.00	0.00																			0.00
1.00	0.00	0.00																		0.00
2.00	0.00	0.00	0.00																	0.00
3.00	0.00	0.00	0.00	0.00																0.00
4.00	0.00	0.00	0.00	0.00	0.00															0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00														0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00													0.23
7.00	0.00	0.00	0.00	0.00	0.00	0.45	1.06	0.00												1.51
8.00	0.00	0.00	0.00	0.00	0.00	0.68	2.12	2.19	0.00											4.98
9.00	0.00	0.00	0.00	0.00	0.00	0.90	3.18	4.38	3.78	0.00										12.24
10.00	0.00	0.00	0.00	0.00	0.00	1.13	4.24	6.57	7.57	6.39	0.00									25.89
11.00	0.00	0.00	0.00	0.00	0.00	1.35	5.30	8.76	11.35	12.79	12.89	0.00								52.44
11.54	0.00	0.00	0.00	0.00	0.00	1.47	5.87	9.95	13.39	16.24	19.85	82.85								149.62
12.00	0.00	0.00	0.00	0.00	0.00	1.58	6.36	10.95	15.13	19.18	25.78	153.43	0.00							232.40
12.54	0.00	0.00	0.00	0.00	0.00	1.70	6.93	12.14	17.17	22.64	32.74	236.28	24.56							354.14
13.00	0.00	0.00	0.00	0.00	0.00	1.80	7.41	13.14	18.91	25.58	38.67	306.85	45.48	0.00						457.85
13.54	0.00	0.00	0.00	0.00	0.00	1.92	7.99	14.33	20.96	29.03	45.63	389.70	70.04	10.84						590.43
14.00	0.00	0.00	0.00	0.00	0.00	2.03	8.47	15.33	22.70	31.97	51.55	460.28	90.96	20.07	0.00					703.37
14.54	0.00	0.00	0.00	0.00	0.00	2.15	9.05	16.52	24.74	35.42	58.51	543.13	115.52	30.91	7.88					843.82
15.00	0.00	0.00	0.00	0.00	0.00	2.25	9.53	17.52	26.48	38.36	64.44	613.71	136.44	40.14	14.58	0.00				963.47
15.54	0.00	0.00	0.00	0.00	0.00	2.37	10.10	18.71	28.52	41.82	71.40	696.56	161.00	50.98	22.46	6.11				1110.03
16.00	0.00	0.00	0.00	0.00	0.00	2.48	10.59	19.72	30.26	44.76	77.33	767.13	181.92	60.21	29.17	11.31	0.00			1234.88
16.54	0.00	0.00	0.00	0.00	0.00	2.60	11.16	20.90	32.31	48.21	84.29	849.98	206.48	71.05	37.04	17.41	4.64			1386.07
17.00	0.00	0.00	0.00	0.00	0.00	2.54	11.65	21.91	34.05	51.15	90.22	920.56	227.40	80.28	43.75	22.62	8.59	0.00		1514.71
17.54	0.00	0.00	0.00	0.00	0.00	2.46	12.22	23.09	36.09	54.61	97.18	1003.41	251.96	91.12	51.63	28.72	13.23	7.02		1672.73
18.00	0.00	0.00	0.00	0.00	0.00	2.40	11.93	24.10	37.83	57.55	103.11	1073.98	272.88	100.35	58.34	33.92	17.18	13.00	0.00	1806.56
18.54	0.00	0.00	0.00	0.00	0.00	2.33	11.59	25.28	39.87	61.00	110.07	1156.83	297.44	111.19	66.21	40.03	21.81	20.01	2.35	1966.01
19.54	0.00	0.00	0.00	0.00	0.00	2.19	10.95	23.97	43.65	67.39	122.96	1310.26	342.92	131.26	80.79	51.34	30.40	33.01	6.69	2257.79
20.54	0.00	0.00	0.00	0.00	0.00	2.06	10.32	22.66	41.39	73.79	135.85	1463.69	388.40	151.32	95.38	62.64	38.99	46.01	11.03	2543.53
21.54	0.00	0.00	0.00	0.00	0.00	1.93	9.69	21.34	39.12	69.96	148.74	1617.11	433.88	171.39	109.96	73.95	47.58	59.00	15.38	2819.04
22.54	0.00	0.00	0.00	0.00	0.00	1.79	9.05	20.03	36.86	66.13	141.02	1770.54	479.36	191.46	124.55	85.26	56.17	72.00	19.72	3073.94
23.54	0.00	0.00	0.00	0.00	0.00	1.66	8.42	18.72	34.59	62.30	133.30	1678.67	524.84	211.53	139.13	96.57	64.76	84.99	24.07	3083.55
24.54	0.00	0.00	0.00	0.00	0.00	1.52	7.78	17.41	32.33	58.47	125.58	1586.80	497.61	231.60	153.71	107.88	73.34	97.99	28.41	3020.44
25.54	0.00	0.00	0.00	0.00	0.00	1.39	7.15	16.10	30.06	54.64	117.86	1494.92	470.37	219.59	168.30	119.18	81.93	110.99	32.76	2925.24
26.54	0.00	0.00	0.00	0.00	0.00	1.25	6.51	14.79	27.80	50.82	110.15	1403.05	443.14	207.57	159.57	130.49	90.52	123.98	37.10	2806.73
27.54	0.00	0.00	0.00	0.00	0.00	1.12	5.88	13.47	25.53	46.99	102.43	1311.18	415.91	195.55	150.83	123.72	99.11	136.98	41.45	2670.14
28.54	0.00	0.00	0.00	0.00	0.00	0.98	5.25	12.16	23.27	43.16	94.71	1219.31	388.67	183.53	142.10	116.95	93.97	149.97	45.79	2519.82
29.54	0.00	0.00	0.00	0.00	0.00	0.85	4.61	10.85	21.00	39.33	86.99	1127.44	361.44	171.51	133.37	110.18	88.82	142.19	50.14	2348.72
30.81	0.00	0.00	0.00	0.00	0.00	0.67	3.81	9.18	18.12	34.46	77.18	1010.59	326.80	156.23	122.26	101.57	82.28	132.30	46.83	2122.28
31.81		0.00	0.00	0.00	0.00	0.54	3.17	7.87	15.86	30.63	69.46	918.72	299.57	144.21	113.53	94.80	77.14	124.51	44.23	1944.23
32.81			0.00	0.00	0.00	0.40	2.54	6.56	13.59	26.80	61.74	826.85	272.34	132.20	104.79	88.02	72.00	116.73	41.62	1766.19
33.81				0.00	0.00	0.27	1.90	5.25	11.33	22.97	54.02	734.98	245.10	120.18	96.06	81.25	66.85	108.95	39.02	1588.14
34.81					0.00	0.13	1.27	3.94	9.06	19.14	46.31	643.10	217.87	108.16	87.33	74.48	61.71	101.17	36.42	1410.09
35.81						0.00	0.63	2.62	6.80	15.32	38.59	551.23	190.64	96.14	78.60	67.71	56.57	93.39	33.82	1232.05
36.81							0.00	1.31	4.53	11.49	30.87	459.36	163.40	84.12	69.86	60.94	51.43	85.60	31.22	1054.14
37.81								0.00	2.27	7.66	23.15	367.49	136.17	72.11	61.13	54.17	46.28	77.82	28.62	876.86
38.81									0.00	3.83	15.44	275.62	108.93	60.09	52.40	47.40	41.14	70.04	26.01	700.89
39.81										0.00	7.72	183.74	81.70	48.07	43.66	40.63	36.00	62.26	23.41	527.19

Time	**Ordinates of Unit Hydrographs for Gheba nr Mekele**																			**Sum**
40.81											0.00	91.87	54.47	36.05	34.93	33.86	30.86	54.47	20.81	357.32
41.81												0.00	27.23	24.04	26.20	27.08	25.71	46.69	18.21	195.17
42.81													0.00	12.02	17.47	20.31	20.57	38.91	15.61	124.89
43.81														0.00	8.73	13.54	15.43	31.13	13.01	81.84
44.81															0.00	6.77	10.29	23.35	10.41	50.81
45.81																0.00	5.14	15.56	7.80	28.51
46.81																	0.00	7.78	5.20	12.99
47.81																		0.00	2.60	2.60
48.81																			0.00	0.00

ARF (%) = 62%

Q max (m^3/s) = 3083.55

Q reduced (m^3/s) = Q max * ARF 1904.75

Where Q des = Design Discharge
Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph
ARF=Area Reduction Factor

WEYIB nr AGARFA RIVER

SCS Synthetic Unit Hydrograph Method

Unit Peak Discharge Determination

Description	Formula	Unit	WEYIB nr Agarfa
Area		km^2	808.40
Time of Conc.	Tc	hr.	14.27
Rainfall Excess Duration	D ~ Tc/6 if Tc < 3 hrs. D ~ 1 hr. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc	hr.	9.06
Time Base of Hydrograph	Tb = 2.67Tp	hr.	24.20
Lag Time	Tl = 0.6Tc	hr.	8.56
Peak Rate of Discharge	qp = (0.21A) / Tp	$m^3/s/mm$	18.73
Weighted CN Value			74
Maximum Potential Diff.	S=(25400/CN)-254		87.86

Ordinates for Unit hydrograph Calculation

WEYIB nr Agarfa										
Duration (hrs.)		Rainfall 24hr Max.*	Rainfall Profile	Rainfall Profile	Times of Increamental Hydrograph			Direct Runoff	Incremental Runoff	Peak Runoff
Beginning	End	mm	%	mm	Begin	Peak	End	mm	mm	mm
0.00	1.00	117.90	1.08	1.27	0.00	9.06	24.20	0.00	0.00	0.00
1.00	2.00		2.23	2.63	1.00	10.06	25.20	0.00	0.00	0.00
2.00	3.00		3.47	4.09	2.00	11.06	26.20	0.00	0.00	0.00
3.00	4.00		4.83	5.69	3.00	12.06	27.20	0.00	0.00	0.00
4.00	5.00		6.32	7.45	4.00	13.06	28.20	0.00	0.00	0.00
5.00	6.00		7.97	9.40	5.00	14.06	29.20	0.00	0.00	0.00
6.00	7.00		9.84	11.60	6.00	15.06	30.20	0.00	0.00	0.00
7.00	8.00		12.03	14.18	7.00	16.06	31.20	0.00	0.00	0.00
8.00	9.00		14.67	17.30	8.00	17.06	32.20	0.00	0.00	0.00
9.00	10.00		18.08	21.32	9.00	18.06	33.20	0.15	0.15	2.87
10.00	11.00		23.51	27.72	10.00	19.06	34.20	1.05	0.90	16.81
11.00	12.00		66.32	78.19	11.00	20.06	35.20	24.75	23.70	443.97
12.00	13.00		77.24	91.07	12.00	21.06	36.20	33.48	8.73	163.48
13.00	14.00		81.97	96.64	13.00	22.06	37.20	37.45	3.98	74.53
14.00	15.00		85.38	100.66	14.00	23.06	38.20	40.39	2.93	54.94

*Rainfall station is located in Robe.

Time	Ordinates of Unit Hydrographs for WEYIB nr Agarfa															Sum
0.00	0.00															0.00
1.00	0.00	0.00														0.00
2.00	0.00	0.00	0.00													0.00
3.00	0.00	0.00	0.00	0.00												0.00
4.00	0.00	0.00	0.00	0.00	0.00											0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00										0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00									0.00
7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00								0.00
8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							0.00
9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						0.00
9.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02						0.02
10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00					0.32
10.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.12					0.45
11.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	1.86	0.00				2.49
11.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	1.97	3.04				5.66
12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	3.71	48.99	0.00			53.65
12.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	3.83	52.03	1.12			57.94
13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	5.57	97.99	18.04	0.00		122.86
13.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.29	5.68	101.02	19.16	0.51		127.66
14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	7.42	146.98	36.08	8.22	0.00	200.29
14.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	7.54	150.02	37.20	8.73	0.38	205.46
15.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.92	9.39	199.01	55.24	16.96	6.44	288.95
16.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.24	11.25	248.00	73.28	25.18	12.50	372.45
17.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.55	13.10	296.99	91.32	33.41	18.57	455.94
18.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.87	14.96	345.99	109.36	41.63	24.63	539.43
19.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68	16.81	394.98	127.40	49.86	30.69	622.42
20.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.49	15.70	443.97	145.44	58.08	36.75	702.44
21.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30	14.59	414.63	163.48	66.31	42.82	704.13
22.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	13.48	385.30	152.68	74.53	48.88	676.97
23.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.92	12.37	355.96	141.87	69.61	54.94	636.67
24.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71	11.11	322.71	129.63	64.02	50.83	580.00
25.20		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.52	10.00	293.37	118.83	59.10	47.20	530.01
26.20			0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33	8.89	264.03	108.02	54.17	43.57	480.01
27.20				0.00	0.00	0.00	0.00	0.00	0.00	1.14	7.78	234.69	97.22	49.25	39.94	430.02
28.20					0.00	0.00	0.00	0.00	0.00	0.95	6.67	205.36	86.42	44.32	36.31	380.02
29.20						0.00	0.00	0.00	0.00	0.76	5.55	176.02	75.62	39.40	32.68	330.03
30.20							0.00	0.00	0.00	0.57	4.44	146.68	64.81	34.47	29.04	280.03
31.20								0.00	0.00	0.38	3.33	117.35	54.01	29.55	25.41	230.03
32.20									0.00	0.19	2.22	88.01	43.21	24.62	21.78	180.04
33.20										0.00	1.11	58.67	32.41	19.70	18.15	130.04
34.20											0.00	29.34	21.60	14.77	14.52	80.24
35.20												0.00	10.80	9.85	10.89	31.54
36.20													0.00	4.92	7.26	12.19
37.20														0.00	3.63	3.63
38.20															0.00	0.00

ARF (%) =	72%
Q max (m^3/s) =	704.13
Q reduced (m^3/s) = Q max * ARF	504.39

Where

Q des = Design Discharge
Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph
ARF=Area Reduction Factor

WEITO RIVER

SCS Synthetic Unit Hydrograph Method

Unit Peak Discharge Determination

Description	Formula	Unit	WEITO
Area		km^2	4532.80
Time of Conc.	Tc	hr.	30.39
Rainfall Excess Duration	D ~ Tc/6 if Tc < 3 hrs. D ~ 1 hr. if Tc > 3 hrs.	hr.	1.00
Time to Peak	Tp = 0.5D + 0.6Tc	hr.	18.73
Time Base of Hydrograph	Tb = 2.67Tp	hr.	50.02
Lag Time	Tl = 0.6Tc	hr.	18.23
Peak Rate of Discharge	qp = (0.21A) / Tp	$m^3/s/mm$	50.81
Weighted CN Value			71
Maximum Potential Diff.	S=(25400/CN)-254		102.74

Ordinates for Unit hydrograph Calculation

WEITO										
Duration (hrs.)		**Rainfall 24hr Max.***	**Rainfall Profile**	**Rainfall Profile**	**Times of Increamental Hydrograph**			**Direct Runoff**	**Incremental Runoff**	**Peak Runoff**
Beginning	**End**	**mm**	**%**	**mm**	**Begin**	**Peak**	**End**	**mm**	**mm**	**mm**
0.00	1.00	105.50	1.08	1.14	0.00	18.73	50.02	0.00	0.00	0.00
1.00	2.00		2.23	2.35	1.00	19.73	51.02	0.00	0.00	0.00
2.00	3.00		3.47	3.66	2.00	20.73	52.02	0.00	0.00	0.00
3.00	4.00		4.83	5.10	3.00	21.73	53.02	0.00	0.00	0.00
4.00	5.00		6.32	6.67	4.00	22.73	54.02	0.00	0.00	0.00
5.00	6.00		7.97	8.41	5.00	23.73	55.02	0.00	0.00	0.00
6.00	7.00		9.84	10.38	6.00	24.73	56.02	0.00	0.00	0.00
7.00	8.00		12.03	12.69	7.00	25.73	57.02	0.00	0.00	0.00
8.00	9.00		14.67	15.48	8.00	26.73	58.02	0.00	0.00	0.00
9.00	10.00		18.08	19.07	9.00	27.73	59.02	0.00	0.00	0.00
10.00	11.00		23.51	24.80	10.00	28.73	60.02	0.17	0.17	8.60
11.00	12.00		66.32	69.97	11.00	29.73	61.02	16.05	15.88	806.94
12.00	13.00		77.24	81.49	12.00	30.73	62.02	22.69	6.64	337.27
13.00	14.00		81.97	86.48	13.00	31.73	63.02	25.77	3.08	156.61
14.00	15.00		85.38	90.08	14.00	32.73	64.02	28.06	2.29	116.39
15.00	16.00		88.01	92.85	15.00	33.73	65.02	29.86	1.80	91.63
16.00	17.00		90.00	94.95	16.00	34.73	66.02	31.25	1.38	70.36
17.00	18.00		93.00	98.12	17.00	35.73	67.02	33.37	2.12	107.67
18.00	19.00		94.00	99.17	18.00	36.73	68.02	34.08	0.71	36.30
19.00	20.00		95.00	100.23	19.00	37.73	69.02	34.80	0.72	36.50
20.00	21.00		96.00	101.28	20.00	38.73	70.02	35.52	0.72	36.70
21.00	22.00		97.50	102.86	21.00	39.73	71.02	36.61	1.09	55.41
22.00	23.00		98.90	104.34	22.00	40.73	72.02	37.64	1.03	52.10
23.00	24.00		100.00	105.50	23.00	41.73	73.02	38.45	0.81	41.19

*Rainfall station is located in Jinka.

Time	**Ordinates of Unit Hydrographs for WEITO**																							**Sum**
0.00	0.00																							0.00
1.00	0.00	0.00																						0.00
2.00	0.00	0.00	0.00																					0.00
3.00	0.00	0.00	0.00	0.00																				0.00
4.00	0.00	0.00	0.00	0.00	0.00																			0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.00																		0.00
6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																	0.00
7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																0.00
8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00															0.00
9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00														0.00
10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00													0.00
11.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00												0.46
12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	43.07	0.00											43.99
13.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.38	86.15	18.00	0.00										105.53
14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.84	129.22	36.01	8.36	0.00									175.42
15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	172.29	54.01	16.72	6.21	0.00								251.53
16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	215.37	72.01	25.08	12.43	4.89	0.00							332.53
17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.21	258.44	90.02	33.44	18.64	9.78	3.76	0.00						417.29
18.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.67	301.52	108.02	41.80	24.85	14.67	7.51	5.75	0.00					507.79
18.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.01	333.13	121.23	47.93	29.41	18.26	10.27	9.97	1.42					575.64
19.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.13	344.59	126.02	50.16	31.06	19.56	11.27	11.49	1.94	0.00				600.23
19.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.47	376.21	139.24	56.29	35.62	23.15	14.02	15.71	3.36	1.43				669.51
20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.59	387.66	144.03	58.52	37.28	24.46	15.02	17.24	3.88	1.95	0.00			694.62
20.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.93	419.28	157.24	64.65	41.84	28.05	17.78	21.46	5.30	3.38	1.44			765.34
21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.05	430.74	162.03	66.88	43.49	29.35	18.78	22.99	5.81	3.90	1.96	0.00		790.96
21.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.38	462.35	175.24	73.01	48.05	32.94	21.54	27.21	7.24	5.33	3.40	2.17		863.85
22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.51	473.81	180.03	75.24	49.70	34.24	22.53	28.74	7.75	5.85	3.92	2.96	0.00	890.27
22.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.84	505.43	193.25	81.37	54.26	37.83	25.29	32.95	9.17	7.28	5.36	5.13	2.04	965.20
23.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.97	516.88	198.04	83.60	55.91	39.13	26.29	34.48	9.69	7.79	5.88	5.92	2.78	0.00	992.36
23.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	548.50	211.25	89.73	60.47	42.72	29.05	38.70	11.11	9.22	7.31	8.09	4.82	1.61	1068.90
24.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.76	591.57	229.25	98.09	66.69	47.61	32.80	44.45	13.05	11.17	9.27	11.04	7.60	3.81	1173.18
25.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.22	634.65	247.26	106.45	72.90	52.50	36.56	50.20	14.99	13.12	11.23	14.00	10.38	6.01	1277.47
26.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.68	677.72	265.26	114.81	79.11	57.39	40.31	55.94	16.92	15.07	13.19	16.96	13.16	8.21	1381.75
27.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.14	720.80	283.26	123.17	85.33	62.28	44.07	61.69	18.86	17.02	15.15	19.92	15.95	10.41	1486.04
28.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.60	763.87	301.27	131.53	91.54	67.17	47.83	67.44	20.80	18.97	17.11	22.87	18.73	12.61	1590.32
29.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.32	806.94	319.27	139.89	97.75	72.07	51.58	73.19	22.74	20.91	19.07	25.83	21.51	14.81	1693.87
30.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.05	781.15	337.27	148.25	103.96	76.96	55.34	78.93	24.68	22.86	21.03	28.79	24.29	17.00	1728.56
31.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.77	755.36	326.49	156.61	110.18	81.85	59.09	84.68	26.61	24.81	22.99	31.75	27.07	19.20	1734.46
32.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.50	729.57	315.71	151.60	116.39	86.74	62.85	90.43	28.55	26.76	24.95	34.71	29.85	21.40	1726.99

Time	Ordinates of Unit Hydrographs for WEITO																								Sum
33.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.22	703.77	304.93	146.60	112.67	91.63	66.60	96.17	30.49	28.71	26.90	37.66	32.63	23.60	1709.60
34.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.95	677.98	294.15	141.59	108.95	88.70	70.36	101.92	32.43	30.66	28.86	40.62	35.41	25.80	1684.38
35.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	652.19	283.37	136.59	105.23	85.77	68.11	107.67	34.36	32.61	30.82	43.58	38.19	28.00	1653.16
36.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.40	626.39	272.59	131.58	101.51	82.84	65.86	104.23	36.30	34.55	32.78	46.54	40.97	30.19	1612.75
37.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.12	600.60	261.81	126.57	97.79	79.92	63.61	100.79	35.14	36.50	34.74	49.49	43.76	32.39	1569.24
38.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.85	574.81	251.03	121.57	94.07	76.99	61.36	97.34	33.98	35.34	36.70	52.45	46.54	34.59	1522.61
39.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.57	549.02	240.25	116.56	90.35	74.06	59.12	93.90	32.82	34.17	35.53	55.41	49.32	36.79	1472.86
40.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.30	523.22	229.47	111.56	86.63	71.13	56.87	90.46	31.66	33.00	34.35	53.64	52.10	38.99	1418.37
41.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.02	497.43	218.69	106.55	82.91	68.20	54.62	87.02	30.50	31.84	33.18	51.87	50.43	41.19	1359.44
50.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	283.72	129.36	65.07	52.08	43.93	35.98	58.50	20.89	22.17	23.46	37.19	36.64	30.28	842.03
51.02		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.47	257.93	118.58	60.07	48.36	41.00	33.73	55.06	19.73	21.00	22.29	35.42	34.97	28.96	779.58
52.02			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	232.13	107.80	55.06	44.64	38.07	31.49	51.62	18.57	19.83	21.11	33.65	33.30	27.65	717.14
53.02				0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.92	206.34	97.02	50.06	40.92	35.15	29.24	48.18	17.40	18.67	19.94	31.88	31.64	26.33	654.69
54.02					0.00	0.00	0.00	0.00	0.00	0.00	1.65	180.55	86.24	45.05	37.20	32.22	26.99	44.74	16.24	17.50	18.77	30.11	29.97	25.01	592.25
55.02						0.00	0.00	0.00	0.00	0.00	1.37	154.76	75.46	40.05	33.48	29.29	24.74	41.30	15.08	16.33	17.60	28.34	28.31	23.70	529.80
56.02							0.00	0.00	0.00	0.00	1.10	128.96	64.68	35.04	29.76	26.36	22.49	37.86	13.92	15.17	16.42	26.57	26.64	22.38	467.36
57.02								0.00	0.00	0.00	0.82	103.17	53.90	30.03	26.04	23.43	20.24	34.41	12.76	14.00	15.25	24.79	24.98	21.06	404.91
58.02									0.00	0.00	0.55	77.38	43.12	25.03	22.32	20.50	17.99	30.97	11.60	12.83	14.08	23.02	23.31	19.75	342.46
59.02										0.00	0.27	51.59	32.34	20.02	18.60	17.57	15.74	27.53	10.44	11.67	12.90	21.25	21.65	18.43	280.02
60.02											0.00	25.79	21.56	15.02	14.88	14.64	13.49	24.09	9.28	10.50	11.73	19.48	19.98	17.11	217.57
61.02												0.00	10.78	10.01	11.16	11.72	11.24	20.65	8.12	9.33	10.56	17.71	18.32	15.80	155.40
62.02													0.00	5.01	7.44	8.79	9.00	17.21	6.96	8.17	9.38	15.94	16.65	14.48	119.02
63.02														0.00	3.72	5.86	6.75	13.77	5.80	7.00	8.21	14.17	14.99	13.16	93.42
64.02															0.00	2.93	4.50	10.32	4.64	5.83	7.04	12.40	13.32	11.85	72.83
65.02																0.00	2.25	6.88	3.48	4.67	5.87	10.63	11.66	10.53	55.96
66.02																	0.00	3.44	2.32	3.50	4.69	8.86	9.99	9.22	42.02
67.02																		0.00	1.16	2.33	3.52	7.08	8.33	7.90	30.32
68.02																			0.00	1.17	2.35	5.31	6.66	6.58	22.07
69.02																				0.00	1.17	3.54	5.00	5.27	14.98
70.02																					0.00	1.77	3.33	3.95	9.05
71.02																						0.00	1.67	2.63	4.30
72.02																							0.00	1.32	1.32
73.02																								0.00	0.00

ARF (%) =	54%
Q max (m^3/s) =	1734.46
Q reduced (m^3/s) = Q max * ARF	944.00

Where

Q des = Design Discharge
Q max = Maximum Discharge Obtained from the Sum of the Composite Hydrograph
ARF=Area Reduction Factor

Summary of Estimated Flood based on SCS Unit Hydrograph Method for Hundred Years Return Period

Name of River	Q max (m^3/s)	ARF	Q reduced (m^3/s)	Condition
Akaki	690.26	71%	489.12	CN average
Geba nr Suppi	1142.46	57%	647.92	CN average
	1954.45		1108.42	CN wet
Gheba nr Mekele	3083.55	62%	1904.75	CN average
Weib nr Agarfa	704.13	72%	504.39	CN average
Weito	1734.46	54%	944	CN average

ANNEX 6: FLOOD ESTIMATION BASED ON STATISTICAL METHODS USING GUMBEL (EVI), LOG NORMAL AND LOG PEARSON DISTRIBUTION

Geba nr Suppi River Flow Data Frequency Analysis Computations

Year	River Flow Data (m^3/s)	Descending Order	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1976	268.52	370.21	2.57	1.00	0.05	5%	21.00	3.02
1979	163.07	351.83	2.55	2.00	0.10	10%	10.50	2.30
1980	253.52	351.83	2.55	2.00	0.10	10%	10.50	2.30
1981	218.34	308.42	2.49	4.00	0.19	19%	5.25	1.55
1986	257.96	305.10	2.48	5.00	0.24	24%	4.20	1.30
1987	268.52	268.52	2.43	6.00	0.29	29%	3.50	1.09
1988	260.95	268.52	2.43	6.00	0.29	29%	3.50	1.09
1989	305.10	268.52	2.43	6.00	0.29	29%	3.50	1.09
1990	370.21	268.52	2.43	6.00	0.29	29%	3.50	1.09
1995	268.52	268.52	2.43	6.00	0.29	29%	3.50	1.09
1996	268.52	268.52	2.43	6.00	0.29	29%	3.50	1.09
1997	268.52	268.52	2.43	6.00	0.29	29%	3.50	1.09
1998	268.52	268.52	2.43	6.00	0.29	29%	3.50	1.09
1999	268.52	260.95	2.42	14.00	0.67	67%	1.50	-0.09
2000	268.52	260.95	2.42	14.00	0.67	67%	1.50	-0.09
2002	260.95	257.96	2.41	16.00	0.76	76%	1.31	-0.36
2003	351.83	253.52	2.40	17.00	0.81	81%	1.24	-0.51
2004	308.42	218.34	2.34	18.00	0.86	86%	1.17	-0.67
2005	351.83	163.07	2.21	19.00	0.90	90%	1.11	-0.86
1994	37.04	37.04	1.57	23.00	0.79	79%	1.26	-0.45

n	20		
Mean (Xm)	276.33	Mean (Ym)	2.44
Standard Deviation (Sx)	47.19	Standard Deviation (Sy)	0.08

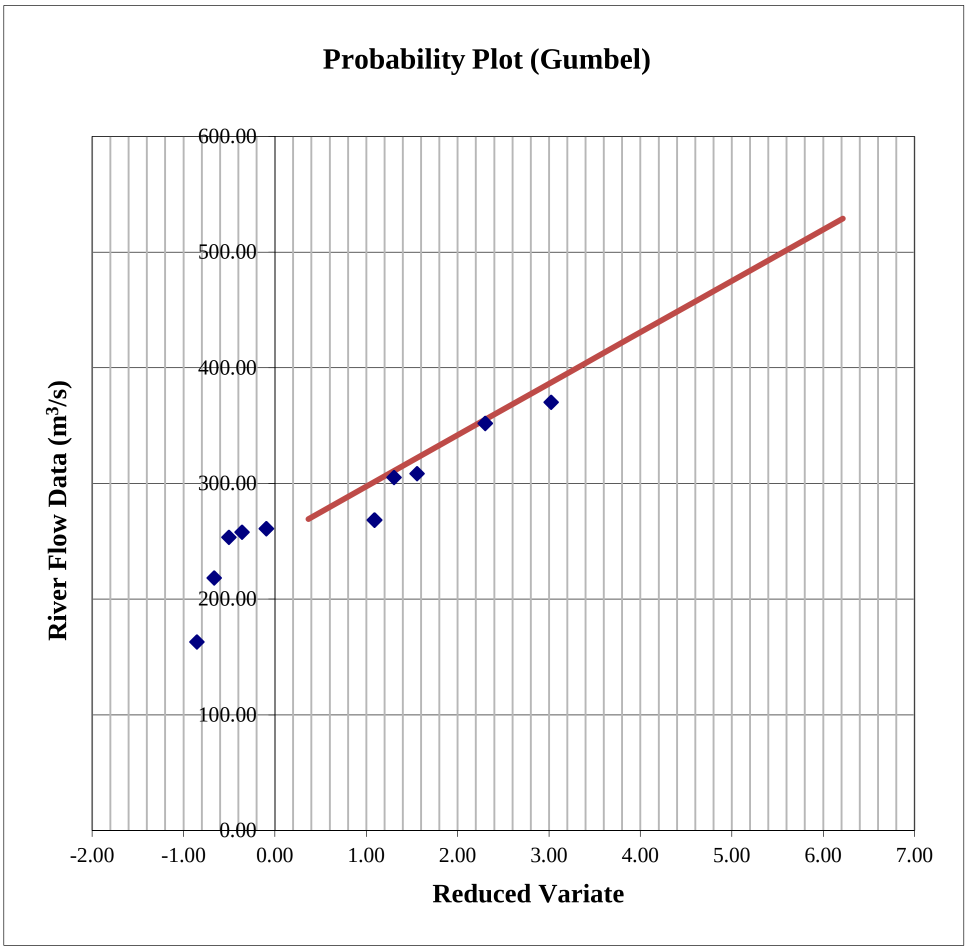
K_N	2.39
High Outlier Limit	417.69
Low Outlier Limit	177.55

River Data Analysis using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	Ext. Flow X_T [m3/s]
	2	-0.15	0.37	269.4
	5	0.92	1.50	319.7
	10	1.62	2.25	353.0
	25	2.52	3.20	395.1
	50	3.18	3.90	426.3
	100	3.84	4.60	457.3
	500	5.35	6.21	529.0

*Gumble Distribution Frequency Factor (from standard table)



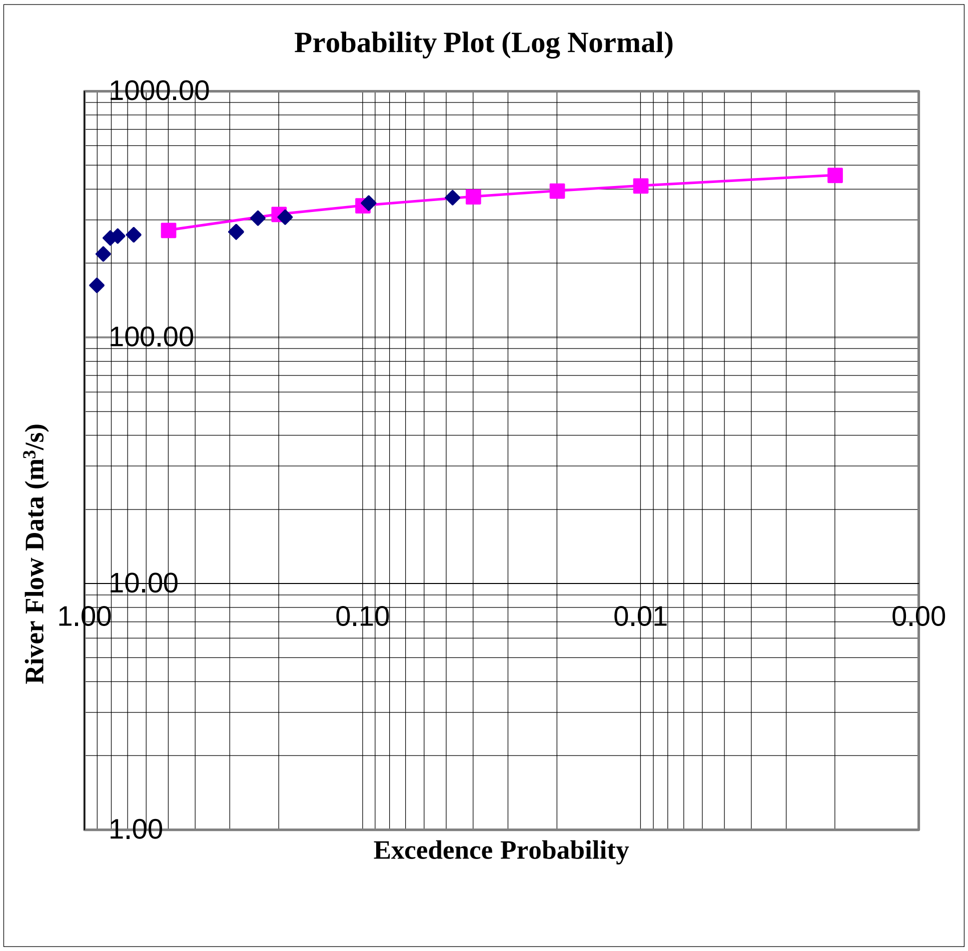
River Data Analysis using Log Normal Method

$$Y_T = Y_m + K_T S_y$$

$$X_T = 10^{Y_T}$$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	0.00	0.00	2.44	272.33
	5	20.0%		0.84	2.50	316.70
	10	10.0%		1.28	2.53	342.70
	25	4.0%		1.75	2.57	372.78
	50	2.0%		2.05	2.60	393.61
	100	1.0%		2.33	2.62	413.33
	500	0.2%		2.88	2.66	456.32

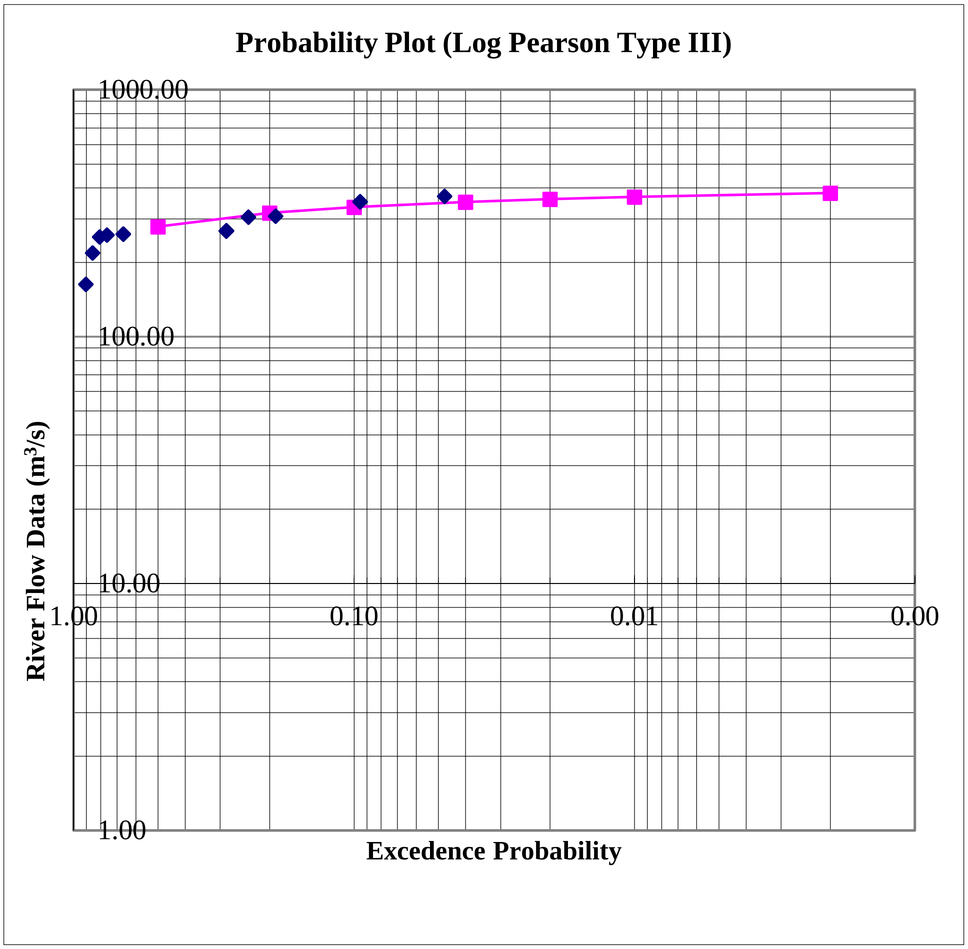
* from standard distribution table, f(Cs, T)



River Data Analysis using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	-0.87	0.14	2.45	279.37
	5	20.0%		0.85	2.50	317.44
	10	10.0%		1.15	2.52	334.90
	25	4.0%		1.42	2.55	351.39
	50	2.0%		1.57	2.56	360.81
	100	1.0%		1.69	2.57	368.46
	500	0.2%		1.88	2.58	381.56

* from standard distribution table, f(Cs, T)



Gheba nr Mekele River Flow Data Frequency Analysis Computations

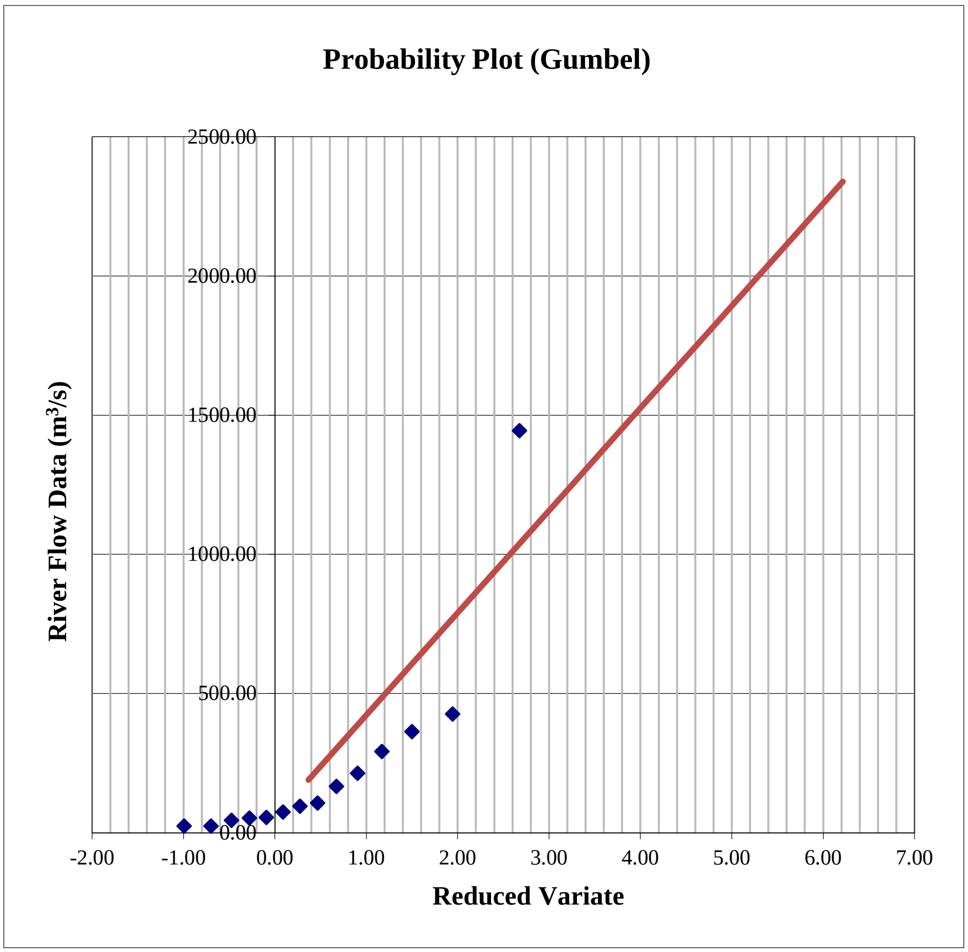
Year	River Flow Data (m^3/s)	Descending Order	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1967	166.56	1444.65	3.16	1.00	0.07	7%	15.00	2.67
1968	95.14	426.39	2.63	2.00	0.13	13%	7.50	1.94
1969	43.97	363.29	2.56	3.00	0.20	20%	5.00	1.50
1970	74.34	292.39	2.47	4.00	0.27	27%	3.75	1.17
1971	23.79	213.81	2.33	5.00	0.33	33%	3.00	0.90
1972	52.55	166.56	2.22	6.00	0.40	40%	2.50	0.67
1973	106.85	106.85	2.03	7.00	0.47	47%	2.14	0.46
1974	23.46	95.14	1.98	8.00	0.53	53%	1.88	0.27
1975	363.29	74.34	1.87	9.00	0.60	60%	1.67	0.09
1976	54.89	54.89	1.74	10.00	0.67	67%	1.50	-0.09
1977	426.39	52.55	1.72	11.00	0.73	73%	1.36	-0.28
1979	292.39	43.97	1.64	12.00	0.80	80%	1.25	-0.48
1980	1444.65	23.79	1.38	13.00	0.87	87%	1.15	-0.70
1981	213.81	23.46	1.37	14.00	0.93	93%	1.07	-1.00
n	14				K_N	2.21		
Mean (Xm)	241.58	Mean (Ym)	2.08		High Outlier Limit	1635.23		
Standard Deviation (Sx)	369.77	Standard Deviation (Sy)	0.51		Low Outlier Limit	8.77		

River Data Analysis using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	Ext. Flow X_T [m3/s]
Gheba nr Mekele	2	-0.14	0.37	189.2
	5	0.99	1.50	605.9
	10	1.73	2.25	881.9
	25	2.67	3.20	1230.6
	50	3.37	3.90	1489.2
	100	4.07	4.60	1746.0
	500	5.67	6.21	2339.3

*Gumble Distribution Frequency Factor (from standard table)



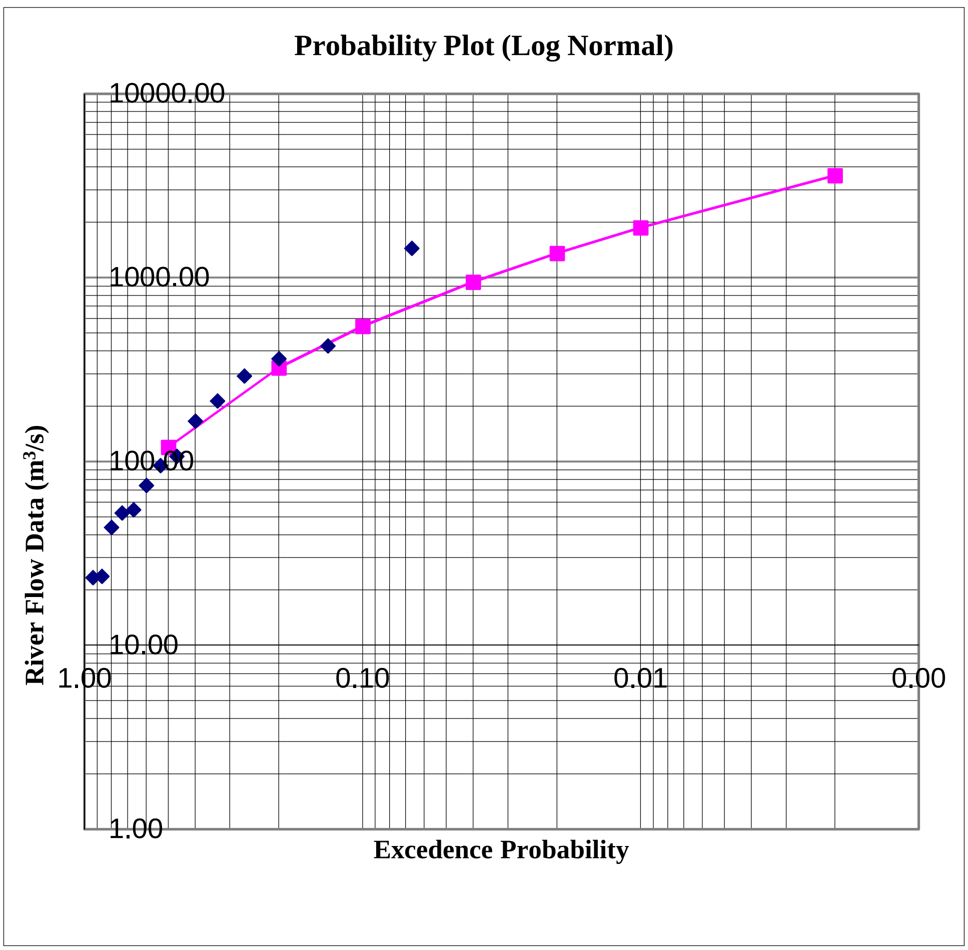
River Data Analysis using Log Normal Method

$$Y_T=Y_m+K_TS_y$$

$$X_T=10^{YT}$$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
Gheba nr Mekele	2	50.0%	0.00	0.00	2.08	119.75
	5	20.0%		0.84	2.51	323.61
	10	10.0%		1.28	2.74	544.19
	25	4.0%		1.75	2.98	947.13
	50	2.0%		2.05	3.13	1354.90
	100	1.0%		2.33	3.27	1869.63
	500	0.2%		2.88	3.55	3587.90

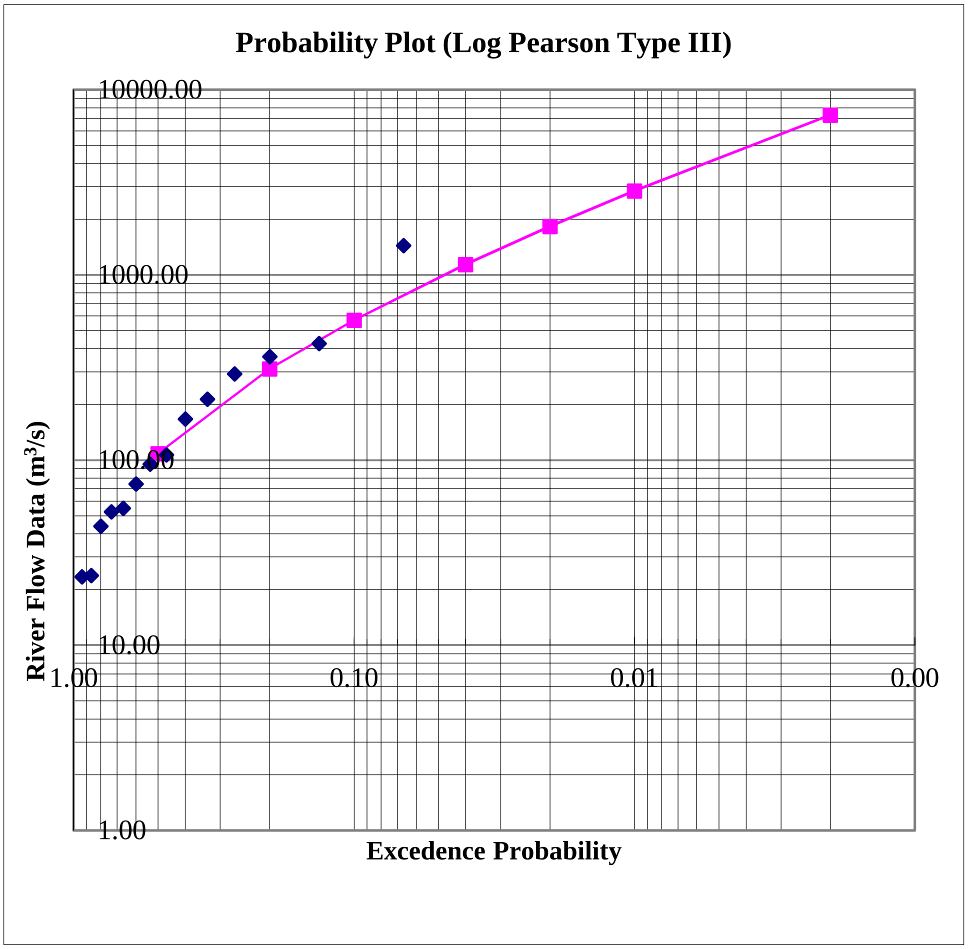
* from standard distribution table, f(Cs, T)



River Data Analysis using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
Gheba nr Mekele	2	50.0%	0.49	-0.08	2.04	108.68
	5	20.0%		0.81	2.49	311.16
	10	10.0%		1.32	2.76	570.99
	25	4.0%		1.91	3.06	1140.74
	50	2.0%		2.31	3.26	1828.81
	100	1.0%		2.68	3.45	2844.20
	500	0.2%		3.48	3.86	7311.01

* from standard distribution table, f(Cs, T)



Weib nr Agarfa River Flow Data Frequency Analysis Computations

Year	River Flow Data (m^3/s)	Descending Order	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1989	176.68	176.68	2.25	1.00	0.03	3%	29.00	3.35
1987	166.07	166.07	2.22	2.00	0.07	7%	14.50	2.64
1993	138.77	138.77	2.14	3.00	0.10	10%	9.67	2.21
1997	134.39	134.39	2.13	4.00	0.14	14%	7.25	1.91
1981	121.01	121.01	2.08	5.00	0.17	17%	5.80	1.66
1990	114.50	114.50	2.06	6.00	0.21	21%	4.83	1.46
1992	113.45	113.45	2.05	7.00	0.24	24%	4.14	1.29
2007	111.42	111.42	2.05	8.00	0.28	28%	3.63	1.13
1998	99.73	99.73	2.00	9.00	0.31	31%	3.22	0.99
2008	97.98	97.98	1.99	10.00	0.34	34%	2.90	0.86
1994	96.76	96.76	1.99	11.00	0.38	38%	2.64	0.74
1983	94.30	94.30	1.97	12.00	0.41	41%	2.42	0.63
2000	78.93	78.93	1.90	13.00	0.45	45%	2.23	0.52
1988	65.98	65.98	1.82	14.00	0.48	48%	2.07	0.42
2006	65.15	65.15	1.81	15.00	0.52	52%	1.93	0.32
1986	62.88	62.88	1.80	16.00	0.55	55%	1.81	0.22
2005	61.33	61.33	1.79	17.00	0.59	59%	1.71	0.13
1995	58.27	58.27	1.77	18.00	0.62	62%	1.61	0.03
1999	53.37	53.37	1.73	19.00	0.66	66%	1.53	-0.06
1982	43.78	43.78	1.64	20.00	0.69	69%	1.45	-0.16
1991	43.25	43.25	1.64	21.00	0.72	72%	1.38	-0.25
1996	40.12	40.12	1.60	22.00	0.76	76%	1.32	-0.35
2003	36.57	36.57	1.56	23.00	0.79	79%	1.26	-0.45
1985	35.92	35.92	1.56	24.00	0.83	83%	1.21	-0.56
2004	28.71	28.71	1.46	25.00	0.86	86%	1.16	-0.68
2001	27.39	27.39	1.44	26.00	0.90	90%	1.12	-0.82
1984	20.82	20.82	1.32	27.00	0.93	93%	1.07	-0.98
2002	16.78	16.78	1.22	28.00	0.97	97%	1.04	-1.21

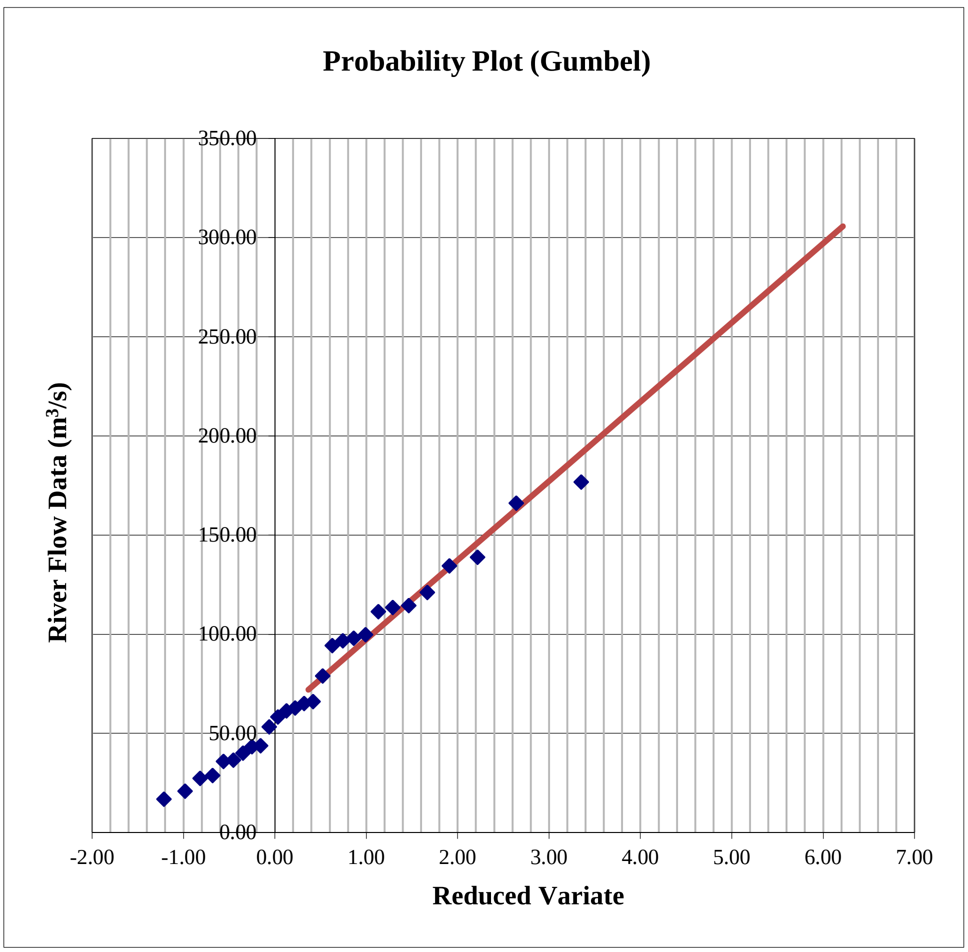
n	28				K_N	2.53
Mean (Xm)	78.73	Mean (Ym)	1.82		High Outlier Limit	328.74
Standard Deviation (Sx)	44.10	Standard Deviation (Sy)	0.27		Low Outlier Limit	13.32

River Data Analysis using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	Ext. Flow X_T [m3/s]
	2	-0.15	0.37	72.0
	5	0.88	1.50	117.3
	10	1.55	2.25	147.3
	25	2.41	3.20	185.2
	50	3.05	3.90	213.3
	100	3.68	4.60	241.2
	500	5.15	6.21	305.6

*Gumble Distribution Frequency Factor (from standard table)



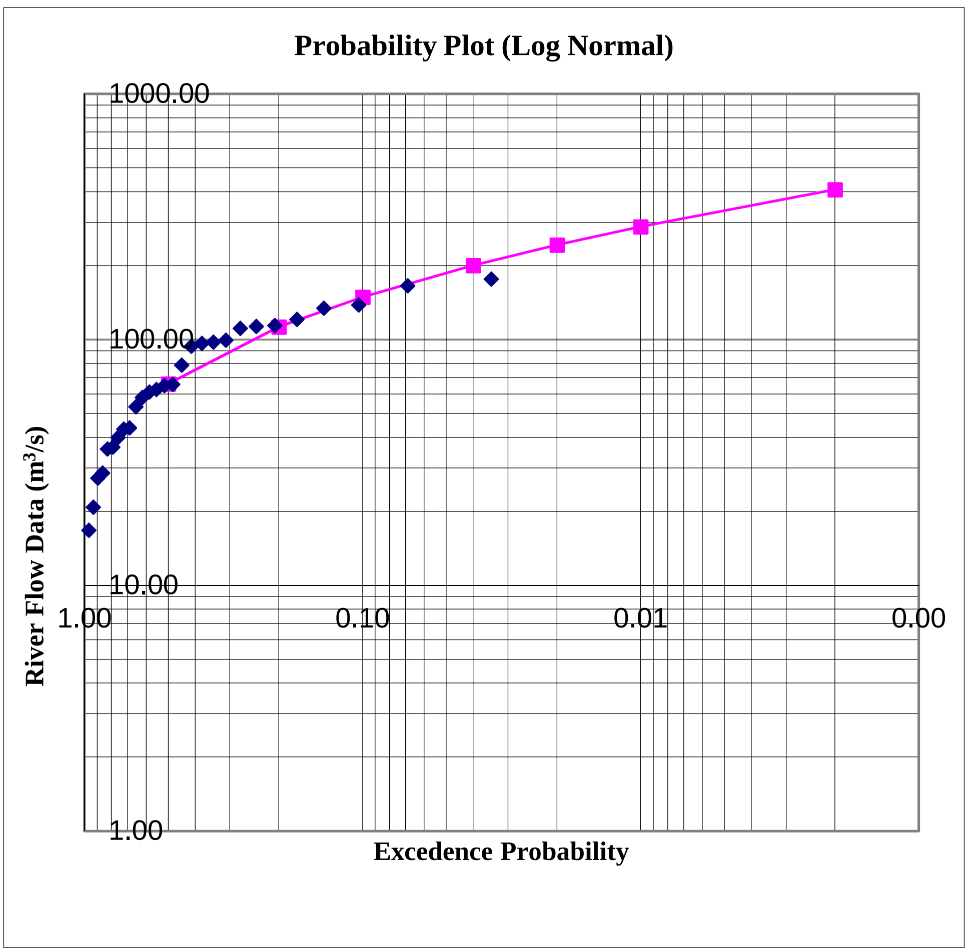
River Data Analysis using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{Y_T}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	0.00	0.00	1.82	66.17
	5	20.0%		0.84	2.05	112.69
	10	10.0%		1.28	2.17	148.86
	25	4.0%		1.75	2.30	200.29
	50	2.0%		2.05	2.38	242.62
	100	1.0%		2.33	2.46	288.28
	500	0.2%		2.88	2.61	408.71

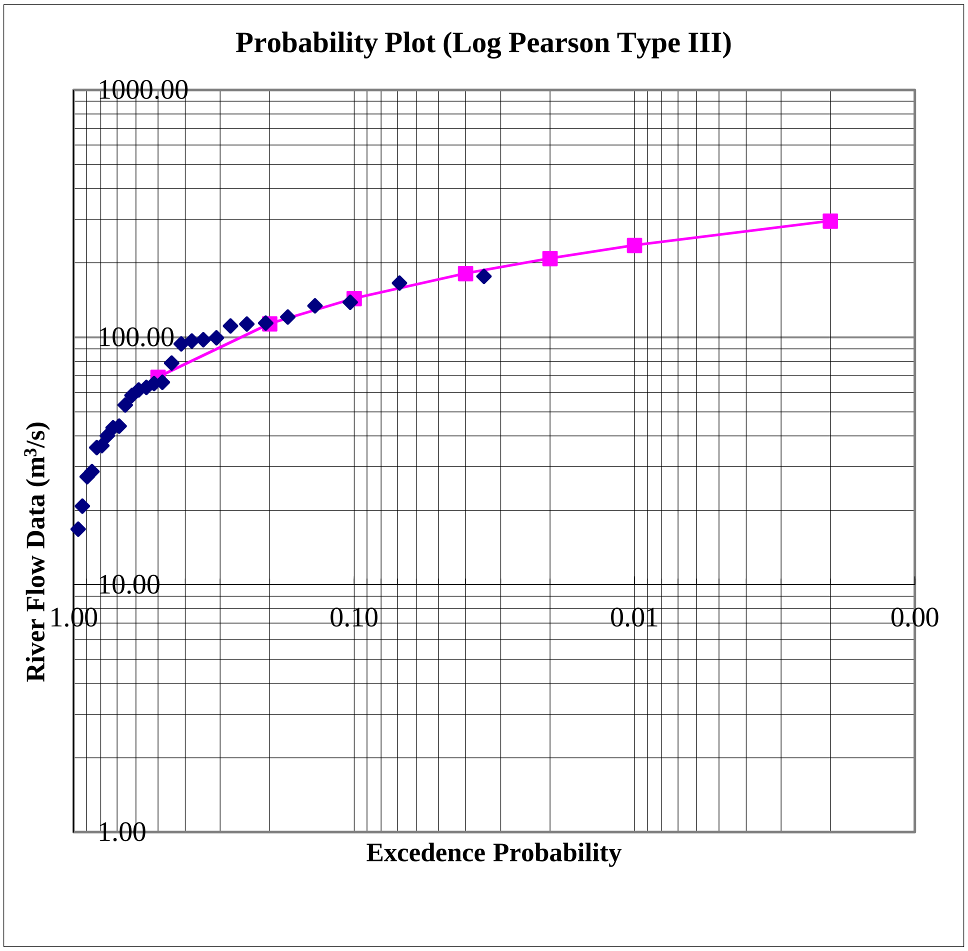
* from standard distribution table, f(Cs, T)



River Data Analysis using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	-0.43	0.07	1.84	69.22
	5	20.0%		0.86	2.06	113.68
	10	10.0%		1.23	2.16	143.79
	25	4.0%		1.59	2.26	181.50
	50	2.0%		1.82	2.32	208.99
	100	1.0%		2.01	2.37	235.79
	500	0.2%		2.37	2.47	295.87

* from standard distribution table, f(Cs, T)



Weito River Flow Data Frequency Analysis Computations

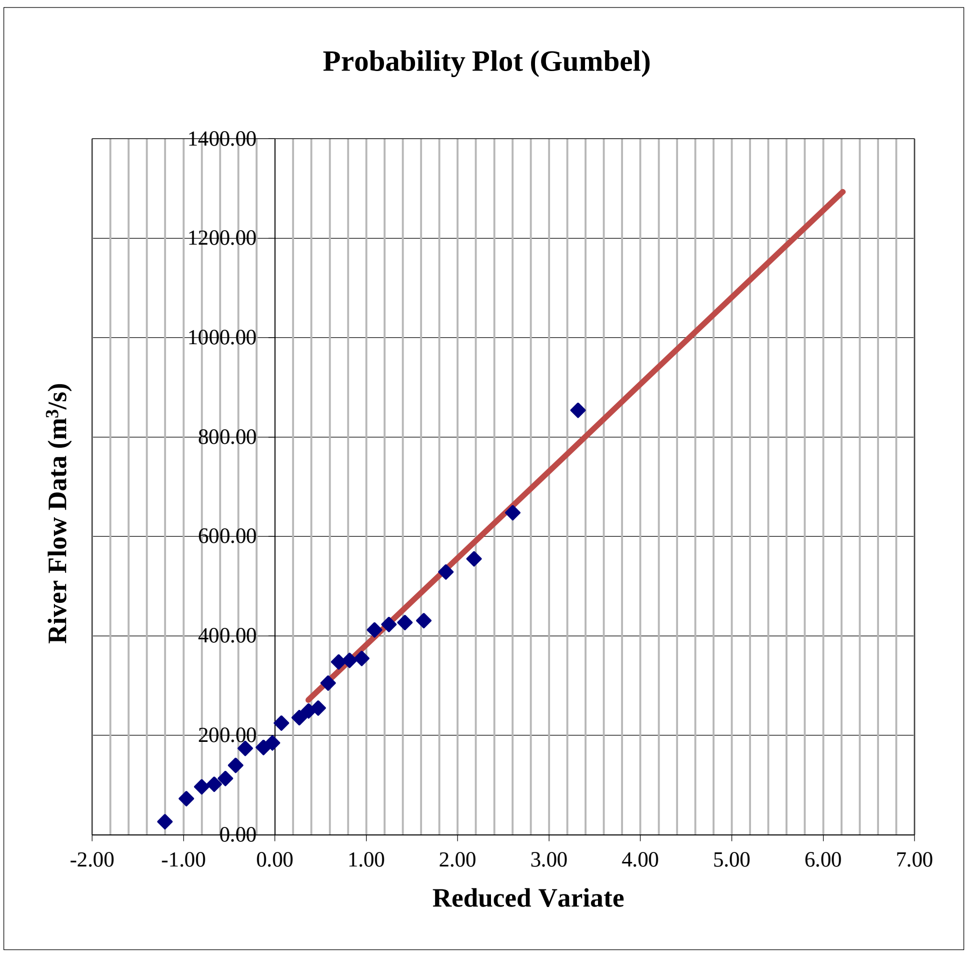
Year	River Flow Data (m^3/s)	Descending Order	Y = Log X	Rank	Plotting Positions	Probability, P [%]	Return Period, Tr [yr]	Reduced Variate, y
1980	101.31	854.19	2.93	1.00	0.04	4%	28.00	3.31
1981	173.45	647.99	2.81	2.00	0.07	7%	14.00	2.60
1982	72.72	554.90	2.74	3.00	0.11	11%	9.33	2.18
1983	113.25	528.60	2.72	4.00	0.14	14%	7.00	1.87
1984	26.52	430.76	2.63	5.00	0.18	18%	5.60	1.63
1985	139.49	426.93	2.63	6.00	0.21	21%	4.67	1.42
1986	96.43	423.12	2.63	7.00	0.25	25%	4.00	1.25
1987	184.95	411.83	2.61	8.00	0.29	29%	3.50	1.09
1988	254.67	354.55	2.55	9.00	0.32	32%	3.11	0.95
1989	423.12	351.14	2.55	10.00	0.36	36%	2.80	0.82
1990	249.05	347.74	2.54	11.00	0.39	39%	2.55	0.70
1992	426.93	305.34	2.48	12.00	0.43	43%	2.33	0.58
1993	647.99	254.67	2.41	13.00	0.46	46%	2.15	0.47
1994	347.74	249.05	2.40	14.00	0.50	50%	2.00	0.37
1995	235.34	235.34	2.37	15.00	0.54	54%	1.87	0.26
1996	235.34	235.34	2.37	15.00	0.54	54%	1.87	0.26
1997	854.19	224.70	2.35	17.00	0.61	61%	1.65	0.07
1998	554.90	184.95	2.27	18.00	0.64	64%	1.56	-0.03
1999	224.70	175.72	2.24	19.00	0.68	68%	1.47	-0.13
2000	305.34	175.72	2.24	19.00	0.68	68%	1.47	-0.13
2001	354.55	173.45	2.24	21.00	0.75	75%	1.33	-0.33
2002	175.72	139.49	2.14	22.00	0.79	79%	1.27	-0.43
2003	351.14	113.25	2.05	23.00	0.82	82%	1.22	-0.54
2004	175.72	101.31	2.01	24.00	0.86	86%	1.17	-0.67
2005	430.76	96.43	1.98	25.00	0.89	89%	1.12	-0.80
2006	411.83	72.72	1.86	26.00	0.93	93%	1.08	-0.97
2007	528.60	26.52	1.42	27.00	0.96	96%	1.04	-1.20
n	27				K_N	2.51		
Mean (Xm)	299.84	Mean (Ym)	2.38		High Outlier Limit	1585.51		
Standard Deviation (Sx)	192.26	Standard Deviation (Sy)	0.33		Low Outlier Limit	35.95		

River Data Analysis using Gumbel Method

$X_T = X_M + K_T S_X$

Station	Frequency (yr)	*Frequency factor, K_T	Reduced Variate, y	Ext. Flow X_T [m3/s]
	2	-0.15	0.37	270.7
	5	0.88	1.50	468.9
	10	1.56	2.25	600.1
	25	2.42	3.20	765.8
	50	3.06	3.90	888.8
	100	3.70	4.60	1010.9
	500	5.17	6.21	1293.0

*Gumble Distribution Frequency Factor (from standard table)



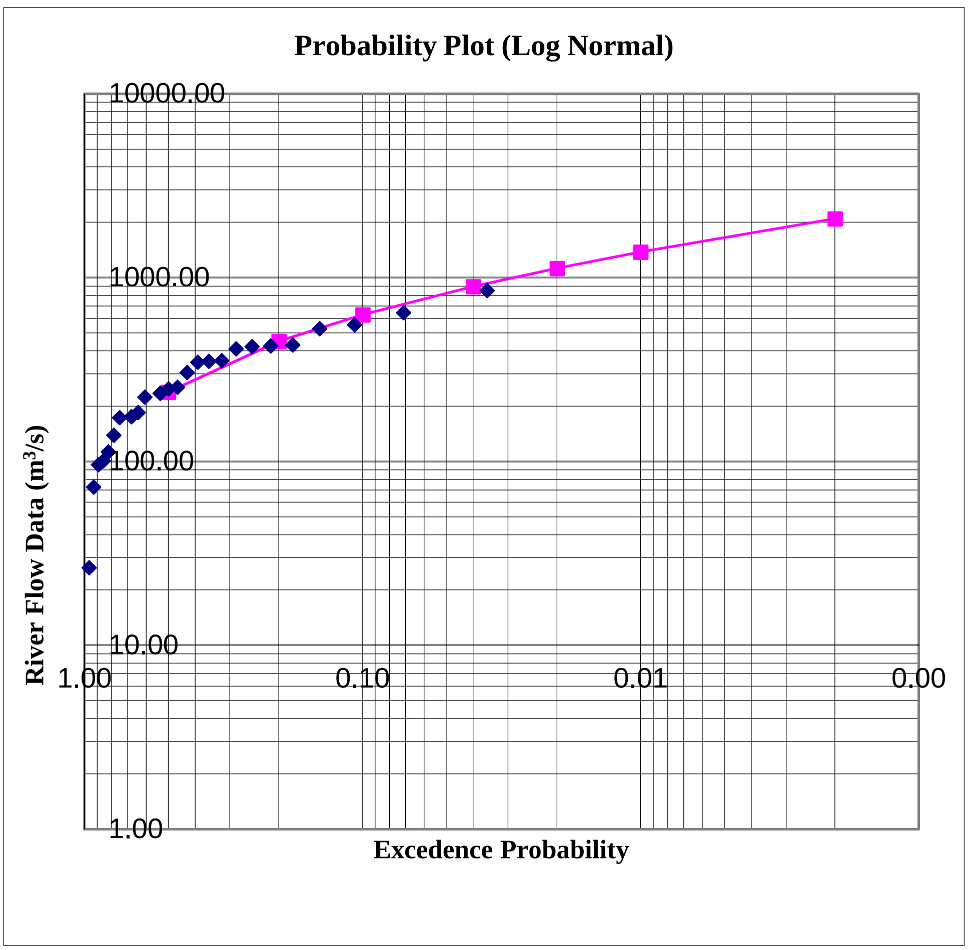
River Data Analysis using Log Normal Method

$Y_T = Y_m + K_T S_y$

$X_T = 10^{Y_T}$

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	0.00	0.00	2.38	238.74
	5	20.0%		0.84	2.65	450.43
	10	10.0%		1.28	2.80	627.72
	25	4.0%		1.75	2.95	894.20
	50	2.0%		2.05	3.05	1123.89
	100	1.0%		2.33	3.14	1380.46
	500	0.2%		2.88	3.32	2093.08

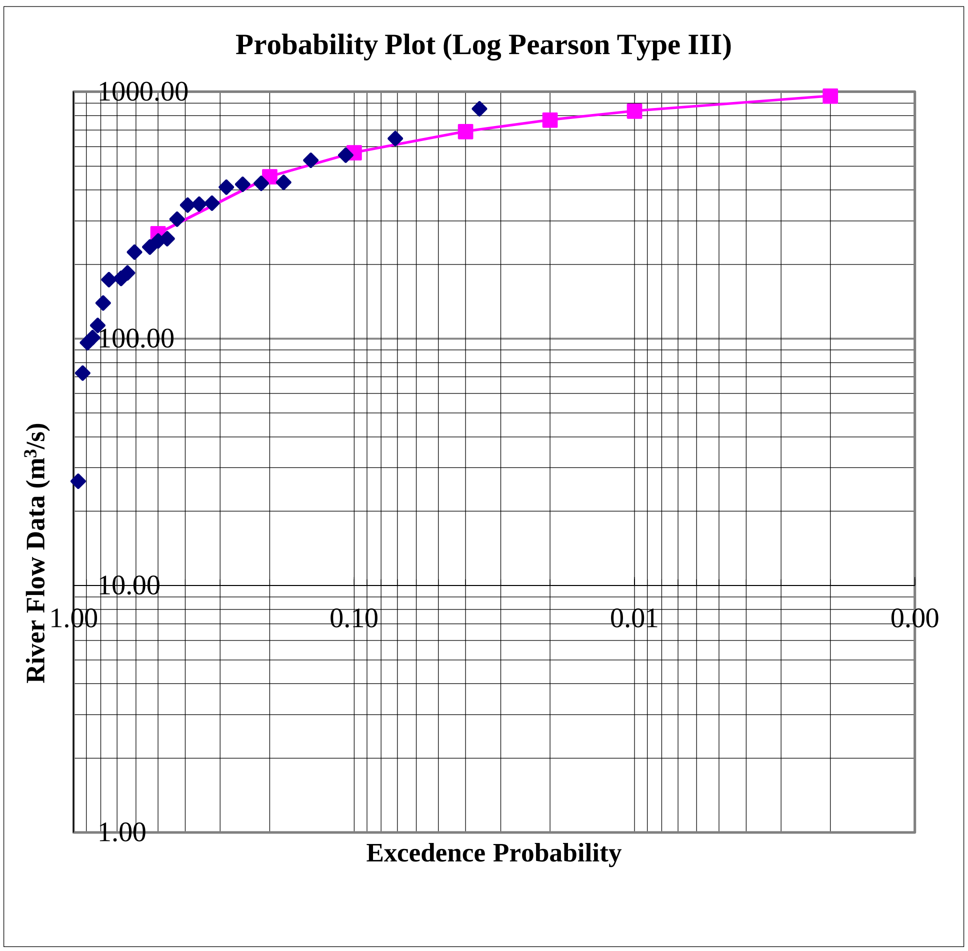
* from standard distribution table, f(Cs, T)



River Data Analysis using Log Pearson Type III Method

Station	Return Period, T [yr]	Exeedence Probability	Skewness Coeff, Cs	*Frequency factor, K_T	Y_T	Ext. Flow X_T [m3/s]
	2	50.0%	-0.89	0.15	2.43	266.75
	5	20.0%		0.85	2.66	454.66
	10	10.0%		1.15	2.75	567.45
	25	4.0%		1.41	2.84	691.23
	50	2.0%		1.55	2.89	769.92
	100	1.0%		1.66	2.92	838.10
	500	0.2%		1.85	2.98	964.09

* from standard distribution table, f(Cs, T)



ANNEX 7: FEEDBACK FORM EXPERIENCED HYDROLOGIST IN THE FIELD

Feedback received via email from **Ato Engida Zemedagegnehu** (MSC in Hydrogeology) an experienced Hydrologist with more than 19 years of experience in road drainage structure is as presented below.

Observed problems in peak flood estimation for Roads drainage structures sizing

<u>*Reference materials*</u>: The basic reference materials for flood estimation especially for Rainfall-runoff models are Topographic maps, DEM, land use maps and soil maps

Topographic maps: There are two scales maps 1:50, 000 and 1:250,000 maps. These maps are old maps. It was observed that some topo maps do not represent the catchment properly especially in the rift margins upstream of alluvial fans. In these areas the topo maps should be used with Google earth which more or else represent the current situation.

DEM contours especially for flat areas are not representative of the area under study.

Here is recommended to integrate Top maps, DEM and Google earth satellite imagery for a better understanding of the topographic condition and land use of the catchment under study

Land use maps: The available land use maps are old and a lot may have been changed and require further updating by field observations and Google earth satellite imagery

Soil maps: Soils data are static therefore the available maps could be used unless there is error in their mapping process

Some of the problems I have observed in estimation of peaks floods methods:

The methods for flood estimation are mainly statistical analysis peak annual flow (based on gauged flow data), rainfall-runoff models and empirical methods. The reliability of the estimated peak floods depends on the input data. To mention some of the input data that affects on estimation, here is given few examples which require further research and monitoring:

Input data for statistical analysis of peak annual flood of gauged flood data

These data are generated from manually or automatic gauging stations. The following problems are observed which highly affects on the quality of the data

<u>*Manually gauged stations*</u>

Gauges are read two times a day at 12:00am and 12:00pm. The peak flood can pass during at night times or in between the measuring hours. The personnel hired for gauging station measurement are local people without any knowledge on the importance of the data and sometimes they record without going to the river. Manual gauged stations peak flood data are not representative especially for moderate and small river catchments, where the duration of the peak period is short. For big river catchment like (Awash, Abbay, etc.) the peak flood duration is long period and manually it can be peaked up during the two times per day measurement periods. Moderate and small rivers catchment peak flood events are short sometimes less than an hour and can happen at any time of the day and the probability of manual measuring the peak is very low. Therefore, the peak flow data from manually gauged station of moderate and small catchment rivers should be used cautiously and should be compared with rainfall-runoff models and empirical formula flood analysis results

The other problems of manually gauged rivers flow data is rivers with deformable channels. Those rivers in the margin of the rift valley, in the rift valley and low lands of Ethiopia, the rivers channels are highly deforming, changing the geometry, the location and the size from season to season even from one flood to another flood in one rainy season. As it known, the rivers floods is measured two times a year (at high and low floods period) of the year, sometimes this is missing and stage-discharge curves are prepared to determine the floods from gauge measured data. It should be that the flood estimated by (Q= V*A) , where V-velocity, m/s and A-channel x-section, m2. Therefore, for channel deforming rivers unless artificial channels are constructed it would be difficult to consider these river data reliable (example, rivers, Borkena, Mile, etc.).

Automatic gauged stations

Rivers with intensive channel deformation as stated for manual gauging station

Rainfall-Runoff Models

Some of the problems of in determining peak floods

Lack of considering future land use change: Most of the time in determining peak floods it is considered to assume the current land use to be constant. One of the dynamic parameters in flood estimation is–land use which is highly affected by human activity. As an example, I could an example the road where I travelled for the last 24years from Megenagna to Kotebe along the Israel embassy. On the section of the from Megenagna –Israel embassy there is a pipe culvert that pass the flood from upstream. In the past (from 1980 to the beginning of 2000) the catchment was forested with dense eucalyptus trees and no urbanization and there was no big floods and the pipe culvert passes the floods. After 2000 the upstream of this culvert is built up tress were removed and coefficient runoff was increased by more than threefold and flood becomes so big and the culvert and the side drains could not pass the floods generated and every once or more the culvert is eroded and the road is heavy damaged and frequently maintained. The problem is becoming more serous from year to year since the built area upstream (catchment) is increasing from to year. Therefore, especially at the suburb of urban areas we should have to consider the land use change in the peak flood estimation for sizing culverts and side drains.

Storage effect: In some part of the country in the rift valley especially with porous soils and flat areas only considering the catchment area and other parameters will lead to exaggerated flood estimation and unnecessary sizing of bridges and culverts.

Empirical formulas: These formulas are not calibrated for our country conditions and their reliability is under question

Feedback received via email from **Wro Amarech Fikre** (MSC in Hydrology) an experienced Hydrologist with more than 12 years of experience in road sector is as presented below.

First of all I would like to thank you for giving me the opportunity to take part in your study. The following are points that might require some improvement in relation to estimating road drainage design discharge.

1. Catchment delineation data problem
    a. done using 30x30 DEM data only; no lesser DEM data is readily available and difficult to verify in topographic map since
        i. topographic map is outdated
        ii. not complete for all points in Ethiopia
        iii. only 1:50000 scale map is available
    b. Not possible to delineate all minor and major catchments in topographic map since only too big scale map is available (1:50000); small scale map should be developed and made available
    c. No sufficient study made/available around medium and larger catchments characteristics

2. Project-based rainfall data (regional rainfall data in manual) problem
    a. Regional values cover too large area. These do not actually represent the whole area in that region.
    b. Require to use project based rainfall data but insufficient no of daily rainfall data available for most stations
    c. Available stations throughout the country are far apart to use for the design
    d. Project based rainfall data has a number of missing and has human error
    e. Is not easily available for study

3. Gauged data scarcity problem
    a. Almost no data available for most rivers in Ethiopia
    b. Available data has human error and it is for short period
    c. Is not easily available for study

4. Soil types and land use/land cover maps problems
    a. Old and do not show current catchment characteristics condition.
    b. No update in catchment characteristics every time after each project completion inside the catchment

In general there is no satisfactory study made in relation to water resource in the country. It is particularly difficult to find regression equations or simple discharge estimation methods developed based on study for several locations in Ethiopia.