REGIONAL FLOOD FREQUENCY ANALYSIS FOR ZAMBIAN RIVER BASINS

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CHAPTER 1

INTRODUCTION

1.1 Location

The Republic of Zambia is a landlocked state and lies between latitudes 8 degrees 15 minutes and 18 degrees south of the equator. Formerly known as Northern Rhodesia, it is bounded by eight other countries, namely Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zaire, and Zimbabwe as shown in Fig. 1.1 (given at the end of this chapter). Zambia is named after the Zambezi River, has a population of about 8 million (as at August, 1991) and covers an area of over 752,600 km^2, an area equivalent to that of Texas and a third of Oklahoma combined. The total land mass amounts to 98.8% of the total area and the remaining 1.2% is covered by water bodies, such as natural lakes and man made reservoirs. A summary of the land utilization breakdown is shown in Table 1.1.

Zambia's topography, with its favorable climate, enables a variety of crops to be grown. The principal crops are maize, sugar cane, cassava, millet, sorghum, cotton and tobacco. Most Zambians are traditional farmers, who grow food for their own subsistence and produce little surplus for the market.

For many years, the mining of copper, which accounted for about 93% of all Zambia's foreign exchange earnings, has dominated the Zambian economy, although its contribution has declined significantly since the mid-1980's, reflecting price fluctuations on the international commodity markets. The country is the world's fifth largest producer of copper. Cobalt, a by-product of copper mining, has recently gained in significance, and Zambia has been steadily expanding its cobalt production in an attempt to offset falls in copper prices.

Despite Zambia's favorable topography, climate and relatively abundant mineral wealth, the country is still economically weak and is one of the less advantaged countries in the world.

1.2 Physical Features

The topography of Zambia is dominated by the even skylines of uplifted planation surfaces and most of it lies at an altitude of over 1000 meters above sea level. The highest elevations (2165 meters) are reached on the Nyika plateau in the north eastern part of the country near the Malawi border. Elevations decline westward, where the country extends into the fringe of the vast Kalahari desert. The plateau surfaces are interrupted by localized depressions (occupied by lakes and swamp areas, such as in the Bangweulu and Lukanga basins), and by the rifted troughs of the mid-Zambezi and Luangwa. Cross sections showing important physical features of the country are given in Fig. 1.2.

1.2.1 Geology

Geologically, the Zambian plateau consists of very ancient Precambrian rock. Katangan rocks of the upper-Precambrian age yield the copper ores exploited on the Copperbelt. Younger Karoo sedimentaries floor the rift troughs of the Luangwa and the mid-Zambezi rivers, while a basalt flow of this age has been incised by the Zambezi below the

Victoria Falls to form the spectacular gorges. Over the western third of the country there are extensive and deep wind-deposited sands (Kalahari Sands).

1.2.2 Drainage Patterns

Zambia forms part of the Central African Plateau, which is believed to be an uplifted remnant of a denudational plain that was probably shaped during the Miocene. This plateau is drained by two major river systems, namely the Congo, flowing into the Atlantic Ocean, and the Zambezi which debouches into the Indian Ocean. The frontier with Zaire north west of the Copperbelt forms part of the continental divide separating the Congo and the Zambezi drainage systems. Over 75% of the country is drained to the Indian Ocean by the Zambezi River and its two main tributaries, the Kafue and the Luangwa, with the remainder being drained principally by the Chambeshi and the Luapula via the Congo (Zaire) river system to the Atlantic Ocean.

The Zambezi river, the fourth longest river in Africa, rises in the Northwestern part of Zambia, near the borders with Angola and Zaire, at an elevation of 1400 meters. It is over 2500 kilometers long, drains an area of more than 1,300,000 km^2 and carries an annual average discharge of 7,000 m^3/sec. During the rainy season the plains surrounding the upper Zambezi and its tributaries are extensively flooded. Downstream, it forms the boundaries between Zambia, Namibia, Botswana, Zimbabwe and Mozambique. In 1959 the Kariba Dam, 128 meters high and 617 meters long, was built across the Zambezi river at Kariba gorge and impounds a lake 280 km long and about 5000 km^2 in area.

The Kafue river, the largest tributary of the Zambezi, starts from the Zaire-Zambia border and flows with a low gradient generally southwestwards. At Itesh Teshi the river turns sharply to the east and enters a vast flood plain known as the Kafue Flats. To the east of Kafue town the flood plain ends as the river enters a gorge cut through ancient metamorphic rocks and eventually joins the Zambezi near the border town of Chirundu after a journey of 960 km. Of all the major rivers in Zambia, the Kafue river is probably the most regulated with two major dams at Itesh Teshi and Kafue gorge.

Most of eastern Zambia is drained by another tributary of the Zambezi, the Luangwa river. From its source near Isoka, it flows 800 km south westwards meandering in a Rift Trough to join the Zambezi river between the border towns of Luangwa and Zumbo. The Rift Trough is the site of several national parks and game management areas.

The Chambeshi and the Luapula drain 25% of the Zambia north of the continental divide. The Chambeshi river rises at the extreme north of the country and flows south eastwards with a gentle gradient into the Bangweulu swamps. The Luapula river , which can be considered as a continuation of the Chambeshi river, starts at the south west corner of the Bangweulu swamps turns northwards flowing over a series of falls before entering a broad rifted zone and eventually entering Lake Mweru.

The country's large lakes (Tanganyika, Mweru, Bangweulu) including the man made lakes of Kariba and Itesh Teshi offer possibilities of water use as yet relatively little developed. The network of rivers that drain Zambia are shown in Fig. 1.3.

1.3 Climate

Although Zambia is relatively close to the equator, its climate is moderated by its elevation. There are three seasons, namely, a cool dry season (May to August), a hot dry season (August to November) and a warm wet season from November to April. The mean maximum temperature in most of the country ranges between 30° to 35°C. It may however exceed 35°C in the southern low-lying areas in October. July, the coldest month, has mean minimum temperature of 5° to 10°C over most of the country.

The mean annual rainfall is considerably higher in the north and northwest parts of Zambia (1500 mm) decreasing to about half this value in the southern and southwestern regions of the country, Fig. 1.4. The rainy season normally begins in November and tapers off towards the end of April.

1.4 Statement of problem

Despite its relatively abundant natural resources, Zambia is still a developing country and lacks the infrastructure required for the acquisition of adequate hydrologic data, such as river flows and rainfall data. Adequate hydrologic data both in quantity and quality are the primary inputs to the design and successful operation of hydraulic and drainage structures such as dams, spillways, bridges and culverts. Unfortunately these vital inputs are usually inadequate and in most cases totally unavailable at points of interest. Due to the paucity of the required data, engineers responsible for the design of water resources projects have had to depend on some unsatisfactory sources of information for their input parameters. The application of empirical or semi-empirical formulas which were originally developed elsewhere with data from specific areas and conditions has often failed to produce satisfactory results. For example, models such as Talbot's formula and the Rational method contain a coefficient to adjust the basic equation for local conditions. However, the selection of a proper coefficient often proves difficult due to the lack of observed data. This lack of data forces engineers to adopt more conservative approaches in their design techniques with the obvious implication of higher costs on the projects, which needless to say is a burden on an already meager financial resource of most developing countries including Zambia.

1.5 Objectives of this study

The magnitude and frequency of hydrologic events (floods) are the primary inputs for the design of hydraulic and drainage structures such as culverts, bridges, embankments and dams. These inputs have to be derived from observed data using a statistical procedure known as frequency analysis. Unfortunately gaging stations, the source of observed data, are operated at only a few of the many sites where streamflow information is potentially required. The primary objective of this study is therefore to investigate the possibilities of transferring flood data (magnitude and frequency) from the few gaged watersheds to sites that have no flow records (ungaged sites) using a technique known as Regional Flood Frequency Analysis (RFFA). Two such techniques, namely the Index Flood and the Regional regression methods, will be applied to the Zambian condition.

Table 1.1 : Land utilization (*Source: Shalwinidi, 1985*)

Land utilization type	Area covered	
	Km^2	% of total area
Land available for agriculture	426570	56.7
Protected forest	70900	9.4
National Parks	59430	7.9
Escarpment and hills	73100	9.7
Seasonally flooded area and swamps	104390	13.9
Municipalities and townships	8990	1.2
Land under water bodies	9220	1.2

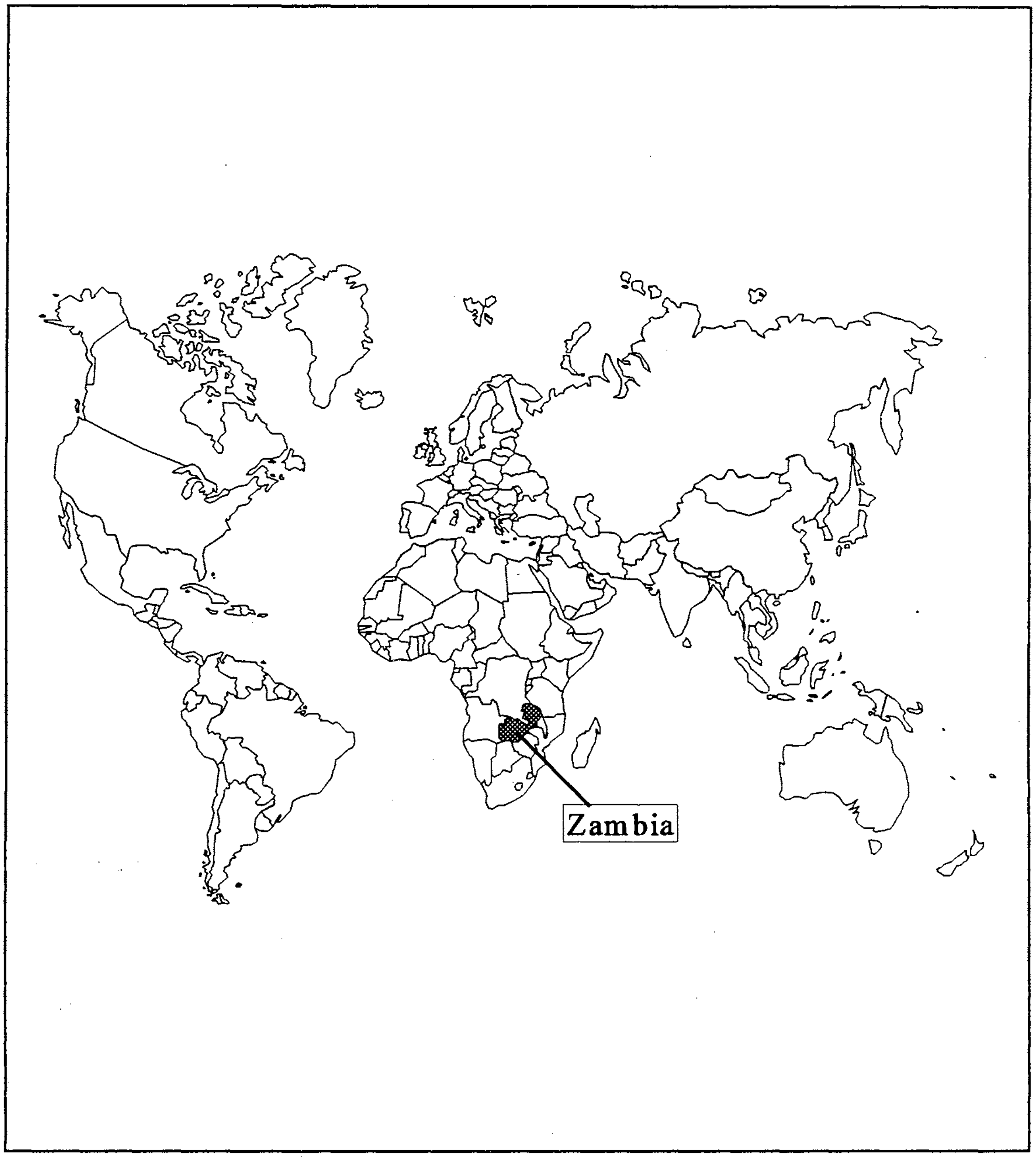


Fig. 1.1 : Location Map

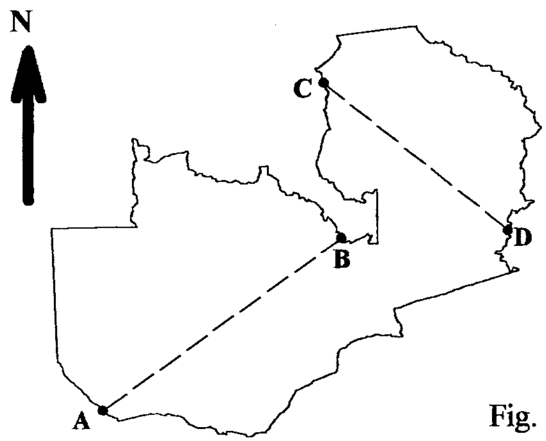
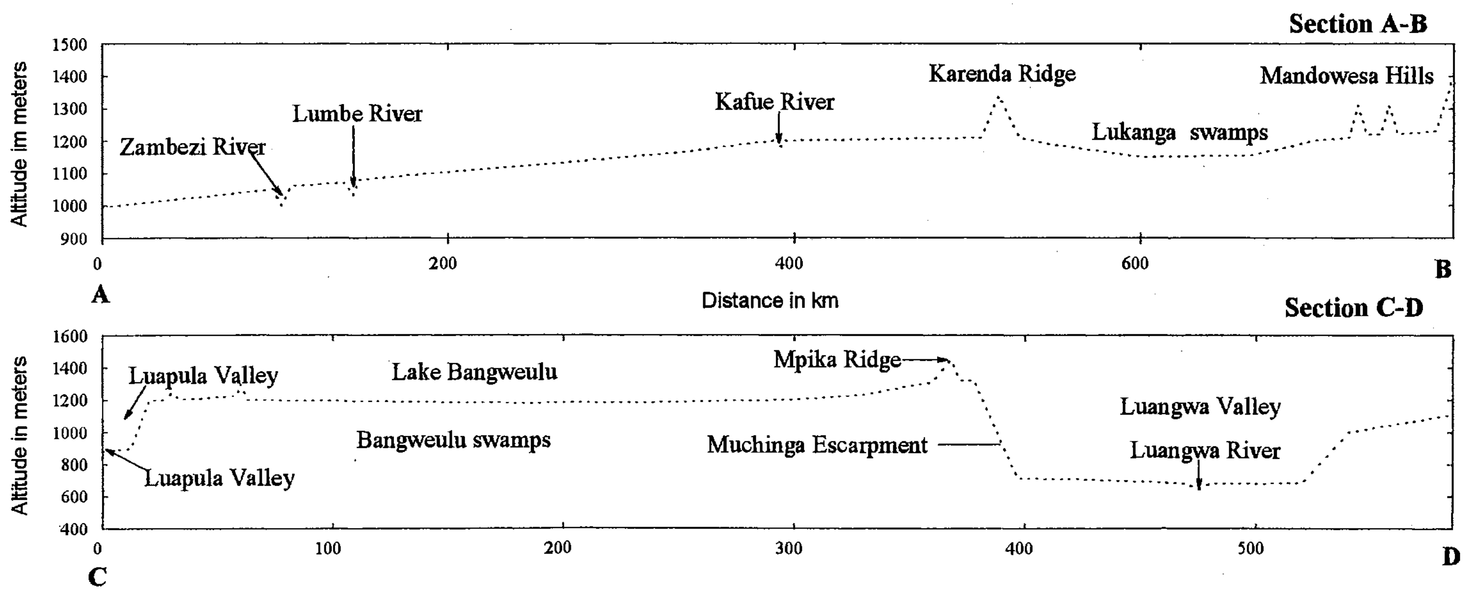


Fig. 1.2 : Cross sections of Zambia



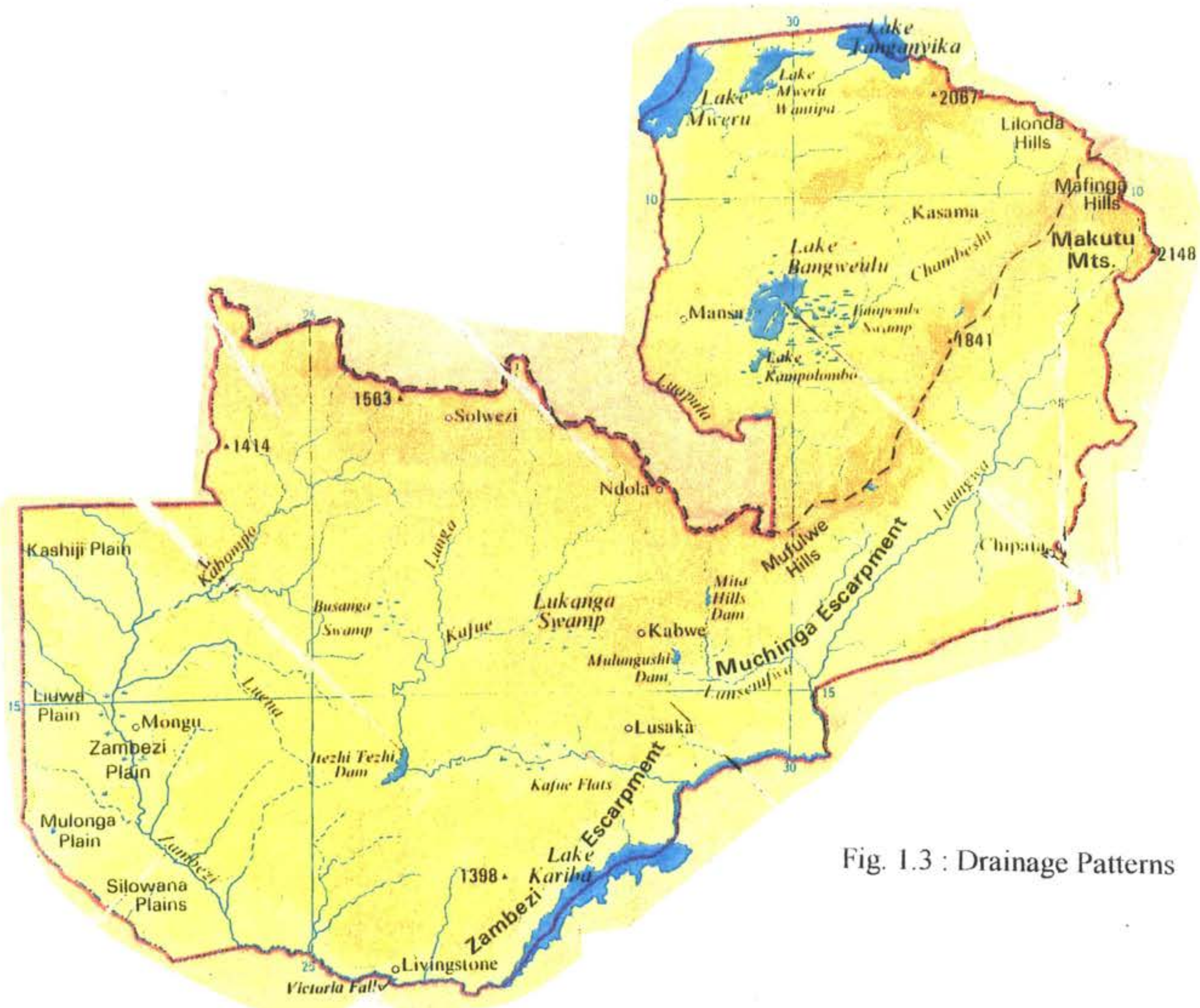


Fig. 1.3 : Drainage Patterns

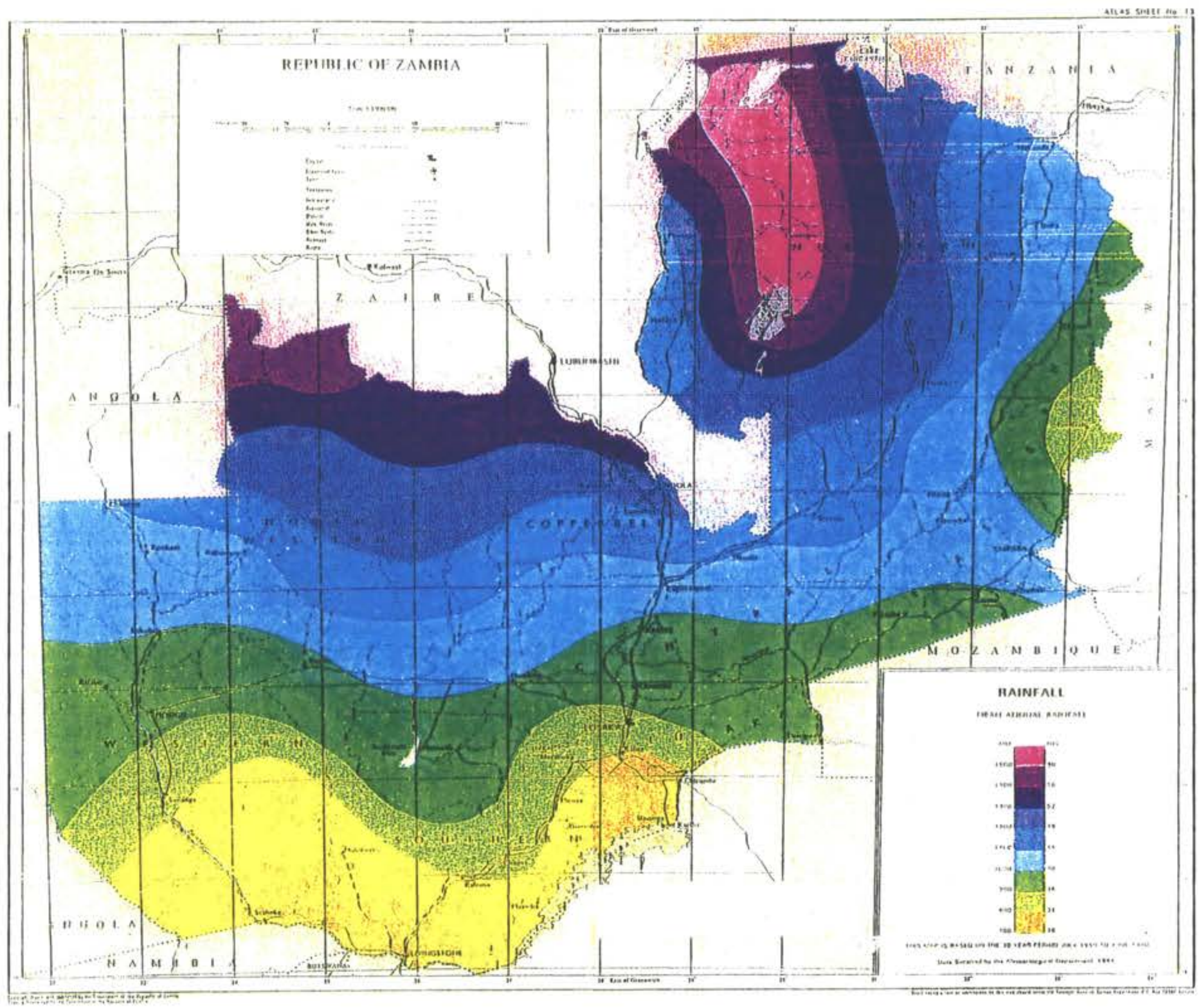


Fig. 1.4 : Rainfall Distribution

CHAPTER 2

LITERATURE REVIEW

2.1 Empirical Relationships

The earliest approach to the regionalization problem was to use empirical equations relating flood flow to drainage area within a particular region (*Benson, 1962*). The formulas were based on few data for a particular region and contain one or more constants whose values are based on judgment. Such a formula, in generalized form, is:

$$Q = CA^{n} \tag{2.1}$$

where Q is the flow, C is coefficient related to the region and A is the drainage area. The above equation, although simple to derive and apply, does not address the frequency of the flow and the effect of variations in precipitation or topography on the flows are not accounted for. The various "culvert formulas" used by railroad and highway engineers, such as the Talbot formula (*AISI, 1967*) are of this general type. The Talbot formula is widely used and is denoted by:

$$a = CA^{0.75} \tag{2.2}$$

where a = cross-sectional area of culvert in ft^2.

Various empirical formulas were later devised that attempt to include the concept of frequency and that involve rainfall in computing flood peaks. Perhaps the most widely used of such formulas is the Rational Formula (*Shaw, 1980*), which expresses the peak flow (Q_p) in terms of the rainfall intensity (i), drainage area (A) and a coefficient that accounts for basin characteristics (C) as follows:

$$Q_p = CiA \tag{2.3}$$

One major weakness in this type of empirical formulas is that the coefficients will remain constant only within regions in which other hydrologic factors vary little, which implies that the regions must of necessity be fairly small.

2.2 Statistical Methods

Other methods of regionalization include the application of statistical techniques to hydrologic data. Statistics provides a means of reducing a mass of data to a few useful and meaningful figures. The distribution of the data could be represented by a probability density function or a curve that defines the frequency of values of the variable. Statistical procedures may also provide methods of relating dependent variables to one or more independent variables through regression analysis. Another widely used statistical procedure in regional flood frequency analysis is the index-flood method. This method first described by *Dalrymple (1960)*, involves the derivation and use of a dimensionless flood frequency distribution applicable to all basins within a homogeneous region.

Regional flood frequency analysis has three major components, namely delineation of homogeneous regions, determination of appropriate probability density functions (or frequency curves) of the observed data and the development of a regional flood frequency model (i.e. a relationship between flows of different return periods, basin characteristics and climatic data).

2.2.1 Delineation of Homogeneous Regions

Although regional estimation techniques, such as the regional flood frequency analysis have been useful in the transfer of data from gaged to ungaged sites, they have also ushered in several problems. If all the gaged stations simply represent realizations of the same underlying population, then a straightforward pooling approach would be appropriate. The Index Flood method discussed earlier makes such an assumption. This method assumes that the region from which the observed data are obtained is homogeneous. The first task which must be completed in the process of regional flood frequency analysis is therefore the identification of homogeneous regions.

Homogeneous regions may be defined as regions having similar hydrologic, climatic and physiographic characteristics. The criteria most often used to delineate homogeneous regions are based on either geographic consideration (basin characteristic, weather regimes) or basin response characteristics (such as probability distributions and regional statistical flood parameters, e.g. skewness, coefficient of variation, etc). There seems to be no uniquely objective approach to the delineation of homogeneous regions. It is generally agreed, however, that grouping basins within a homogeneous region will yield regional relationships with lower standard errors than those for entirely different areas *(Kite,1977)*. Residual analysis has occasionally been used as a tool for defining homogeneous regions. The residual pattern from a linear regression of a given design flood for the entire study area is examined and regions are then delineated on the basis of geographic proximity of the positive and negative residuals, (*Gingras and Adamowski, 1993*).

A second approach of defining homogenous regions is to group all stations with the same probability distributions or those that have constant distribution parameters, (*Hosking and Wallis, 1991*). *De Coursey (1972*) applied discriminant analysis, a multivariate procedure, to flood data from Oklahoma to form groups of basins having a similar flood response. *Burns (1988, 1989, 1990)* described techniques for identifying homogeneous regions based on the correlation structure of the observed data, cluster analysis and the Region of Influence (ROI) approach respectively. The importance of identifying hydrologically homogeneous regions was further demonstrated by *Lettenmaier et al (1987)* in a study that showed the effect on extreme flow estimation of regions containing heterogeneity.

Of the many approaches that have been used to identify homogeneous regions, cluster analysis, a multivariate technique, has been getting more prominence in this field. This is primarily due to the fact that although cluster analysis does not entirely eliminate subjective decisions associated with the other methods, it greatly facilitates interpretation of a data set. The objective of cluster analysis is to group gaging stations that have similar hydrologic or basin characteristics. The most common similarity measures in cluster analysis is the Euclidean distance described in equation (3.20).

2.2.2 Frequency Distributions

After a homogeneous region has been identified, the next stage in the specification of the regional flood frequency model is the choice of appropriate frequency distribution(s) to represent the observed data. The distributions most commonly used in hydrology are normal, log normal, Gumbel extreme value distribution (type I) and log Pearson type III. The *United States Water Resources Council (1982)* conducted studies involving comparison amongst different probability distribution functions and their recommendation was to use the log Pearson type III as the basic distribution for defining the annual flood series. The Council also recommended that this distribution be fitted to sample data using the method of moments. In a more detailed study, the *UK Natural Environment Research Council (1975)* found that three parameter distributions such as the log Pearson type III and the general extreme value distribution (GEV) were found to fit data from 35 annual flood series better than the two parameter distribution functions.

The log Pearson type III (LP III) distribution has extensively been used in flood frequency analysis since its favorable recommendation by the *Water Resources Council in 1976*. The frequent use of the LP III attracted a number of detailed mathematical and statistical studies regarding its role in flood frequency analysis. Various alternative fitting techniques for the log Pearson type III distribution have been suggested by *Matalas and Wallis (1973)* and *Condie (1977)*. These researchers carried out comparisons between the method of moments and the method of maximum likelihood and concluded that the latter method yielded solutions that are less biased than the method of moment estimates. *Bobee (1975)* and *Bobee and Robitaille (1977)* suggested using moments of the original data instead of using moments of the logarithmic values. *Nozdryn-Plotnicki and Watt (1979)* studied the method of moments, the method of maximum likelihood and the procedure proposed by *Bobee (1975)* and found that none of the methods were superior than the others and concluded that the method of moments was the best because of its computational ease.

2.3 Regional Flood Frequency Models

Regional flood frequency models have extensively been used in hydrology for transferring data from gaged to ungaged sites. Two such regionalization procedures, namely the index-flood and regression-based methods, have evolved over the years and have extensively been used in regional flood frequency analysis.

2.3.1 Index-flood method

One of the statistical methods widely used to perform regional frequency analysis is the index-flood (IF) method developed by the *U.S. Geological Survey (Dalrymple, 1960; Benson, 1962).* The basic premise of the method is that a combination of streamflow records maintained at a number of gaging stations will produce a more reliable record than that of a single station and thus will increase the reliability of frequency analysis within a region. The IF method consists of two major steps. The first involves the development of dimensionless ratios by dividing the floods at various frequencies by an index flood, such as the mean annual flood for each gaging station, (*Stedinger, 1983; Lettenmaier and Potter, 1985; Lettenmaier, et al, 1987*). The averages of the ratios are then determined for each return period to estimate a dimensionless regional frequency curve. The second step consists of the development of a relationship between the index-flood and physiographic and climatic characteristics of the basin. Flood magnitudes and frequencies at required locations within the region can then be estimated by rescaling the corresponding dimensionless quantile by the index flood. The index-flood method, once the standard U.S. Geological Survey (USGS) approach, is based on the assumption that the floods at every station in the region arise from the same or similar distributions *(Chowdhury et al. 1991*). At some stage this procedure fell out of favor primarily due to the fact that the coefficient of variation of the flows, which is assumed to be constant in an index-flood method, was found to be inversely related to the watershed area (*Stedinger, 1983*). This implies that the standard deviations of the normalized data do not remain constant for various values of basin areas, since the coefficient of variation of the observed data is equal to the standard deviation of the normalized flows. This can be demonstrated as follows. Let Y_i be the normalized flows given by:

$$Y_i = \frac{X_i}{\bar{X}} \Rightarrow X_i = Y_i \bar{X} \tag{2.4}$$

where X_i represent the ordered observed flows (with X_1 being the largest observation and X_n the smallest) and $\bar{X}$ is the mean observed flow, then the coefficient of variation of the observed data, CV_x is given by:

$$CV_x = \left[\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}\right]^{\frac{1}{2}} \bar{X}^{-1} \tag{2.5}$$

substituting the value of X_i from equation (2.4) into (2.5)

$$CV_x = \left[\frac{\sum_{i=1}^{n}\bar{X}^2(Y_i - 1)^2}{\bar{X}^2(n-1)}\right]^{\frac{1}{2}} = \left[\frac{\sum_{i=1}^{n}(Y_i - 1)^2}{(n-1)}\right]^{\frac{1}{2}} \tag{2.6}$$

the right hand side of equation (2.6) is nothing but the standard deviation of the normalized flows. The index-flood method started to be popular once again in the late 1970's and early

80's since the introduction of the probability weighted moments (PWM), a generalization of the usual moments of a probability distribution, (*Greenwood et al., 1979*). *Greis and Wood (1981)* reported that improved regional estimates of flood quantiles were obtained by applying the PWM over the conventional methods such as the method of moments and maximum likelihood estimation. Parameter estimation by PWM requires the calculation of moments M_{ijk} defined as

$$M_{ijk} = E[x^{i} F(x)^{j} (1 - F(x))^{k}] \tag{2.7}$$

where i, j and k are real numbers and X is a random variable with distribution function, F(X) where F(X)=Prob(X≤x). $M_{1,0,0}$ is identical to the conventional moment about the origin and the probability weighted moments corresponding to $M_{1,0,k}$ or M_k are denoted as

$$M_k = \frac{1}{n} \sum_{i=1}^{n} \left[\frac{\binom{n-i}{k}}{\binom{n-1}{k}} \right] x_i \tag{2.8}$$

It can be seen from equation (2.8) that all higher-order PWM's are linear combinations of the ranked observations $X_n \leq \ldots \leq X_1$, which is an indication that PWM estimators are subject to less bias than ordinary moments. Ordinary moment estimators such as variance (s^2) and coefficient of skewness (C_s) involve squaring and cubing of observations respectively, with a potential to give greater weight to outliers resulting in a substantial bias and variance. However, one major weakness of the PWM is that it cannot be used to estimate parameters for those distributions which cannot be expressed in inverse form, such as log Pearson type III.

2.3.2 Regression-based procedures

An important element of any hydrological network is the mechanism for transferring information from gaged to ungaged sites. One procedure that has been used extensively as a transfer mechanism for streamflow information is multiple regression analysis. This method attempts to estimate the magnitude of a flood event that will occur on average once in T years, denoted by Q_T, by using physical and climatic characteristics of the watershed, *(Benson, 1962, 1964; Benson and Matalas, 1967; Thomas and Benson, 1970). Sauer (1974)* developed regional equations relating flood frequency data for unregulated streams in Oklahoma to basin characteristics through multiple linear regression techniques. *The Hydrology Committee of the U.S. Water Resources Council (1981)* investigated numerous methods of estimating peak flows from ungaged watersheds and found that the results obtained using regional regression compared favorably well with more complex watershed models. The regression technique consists of three major steps. The first step is to determine the magnitude and frequency of flood events for each gaging station using at site frequency analysis. The second step involves the process of collecting physiographic and climatic data that describe the watershed and climatic conditions upstream of a given gaging station. Physiographic information may include watershed area, stream length, stream slope, vegetation and soil type. Annual average rainfall, evaporation and temperature are some examples of climatic data. The final and most difficult step is determining appropriate regression equations that relate Q_T to physiographic and climatic characteristics. A logarithmic transformation of the Q_T, physiographic and climatic data may be required to linearize the regression model and to satisfy other assumptions of regression analysis. The relationship most commonly used is of the form:

$$Q_T = b_o X_1^{b_1} X_2^{b_2} \ldots X_k^{b_K} \qquad (2.9)$$

where $X_1, X_2 \ldots X_k$ represent the basin and climatic data , and $b_o, b_1, b_2, \ldots b_k$ are the regression parameters. Regression parameters may be estimated using the ordinary least squares (OLS), weighted least squares (WLS) or generalized least squares (GLS). Ordinary least squares do not account for unequal variances in flood characteristics or any correlations that may exist between streamflows from nearby stations. To overcome these deficiencies in the ordinary least squares method, *Tasker (1980)* proposed the use of weighted least squares regression with the variance of the errors of the observed flow characteristics estimated as an inverse function of the record length. Using a weighting function of

$$\hat{w}_i = \left[\hat{c}_o + \hat{c}_1 \frac{1}{n_i} \right]^{-1} \quad for \quad i = 1,2,\ldots,N \qquad (2.10)$$

where N is the number of stations, $\hat{c}_o$ and $\hat{c}_1$ are constants and n_i is the record length of station *i*, *Tasker, (1980)* reported that the WLS produced a smaller expected standard error of predictions than the OLS. Using Monte Carlo simulation, (*Stedinger and Tasker, 1985, 1986*) demonstrated that the WLS and GLS provide more accurate estimates of regression parameters than the OLS. A major drawback of the WLS and GLS is the need to estimate the covariance matrix of the residual errors. The covariance matrix of the residual errors is a function of the precision with which the model can predict the streamflow values.

2.4 Regional Flood Frequency Studies in Zambia

No major work related to regional frequency analysis has been carried out in Zambia so far. Most of the work that has been done has been geared towards solving specific problems at particular sites. However, some studies (*Sharma, 1982; Mhango et al, 1977*) dealing with the water resources inventory of some Zambian river basins have been reported by the National Council for Scientific Research, Zambia.

CHAPTER 3

BACKGROUND THEORY

3.1 Introduction

Conventional methods of collecting data for hydrologic studies are generally time consuming and costly. This is why statistical methods have extensively been used in the development of models to study the behavior of hydrologic systems. These models are intended, among other things, to provide insight into and describe the temporal and spatial variations in watershed runoffs, required for the design, construction and operation of numerous engineering projects, such as dams, reservoirs, bridges and culverts.

This chapter briefly addresses the theoretical background of the statistical procedures used in this study, namely frequency analysis, parameter estimation, Goodness of Fit Tests, Cluster analysis and Regression analysis.

3.2 Hydrologic Models

Several types of mathematical and statistical models are employed to analyze and represent the behavior of hydrologic processes. Most conventional mathematical models are deterministic and assume that the variables are independent of time variations. In such type of models once the model parameters are determined, the same inputs to the model always generate the same model response. An example of such type model might be, the Rational Method, a relationship that provides peak discharges from basin characteristics and climatic data.

Deterministic models are neither designed nor intended to generate future hydrologic events or inputs. Generation of such events and inputs is best carried out by statistical relationships known as stochastic models. Stochastic processes are time dependent and it is this time dependency that enables stochastic models to generate possible future flow values and rainfall data. Unlike deterministic models, stochastic models are not formulated to convert one type of variable or group of variable to other type of variables, such as rainfall to runoff.

There are yet another group of models that employ the concept of probability but are time independent. This implies that the sequences of occurrence of the variables involved in the process is ignored and the chance of their occurrences is assumed to follow a definite probability distribution. An example would be the fitting of a probability distribution to flood records to determine the flood frequencies or recurrence intervals. The process of identifying and fitting probability distributions to observed data is known as frequency analysis.

3.3 Frequency Analysis

The primary objective of the frequency analysis of hydrologic data is to determine the recurrence interval, return period or the frequency of the hydrologic event of a given magnitude. The concept of return period is quite simple. A flood magnitude which has a probability of being equalled or exceeded, on average, once in 50 years is referred to as a 50-year flood. This does not imply that a flood of this magnitude is expected to occur at regular intervals of 50 years or that, having occurred once, it will not occur again for 50 years. The return period (T) of a hydrologic event and the design life (L) of a proposed project are vital inputs to any design exercise since they determine the risk of failure associated with that design. In other words the risk of failure is a function of the return period and the design life. If the return period, T is defined by

$$T = \frac{1}{p} \tag{3.1}$$

where p is the probability of the flood being equalled or exceeded in T years, then the probability of that flood occurring in the next year is given by:

$$p = \frac{1}{T} \tag{3.2}$$

and the probability that the flood will not occur in the next year is:

$$q = 1 - p = 1 - \frac{1}{T} \tag{3.3}$$

and the probability, r, that a flood with return period of T will occur at least once in L years is given by:

$$r = 1 - \left(1 - \frac{1}{T}\right)^{L} \tag{3.4}$$

Equation (3.4) above provides a means of relating the risk of failure r, the design life L and the return period, T. This relationship is expressed in tabular for in Table 3.1 below.

Table 3.1 : Probability, r, that a flood with return period T will occur within the next L years

Return period in years	**Design life in years or number of observations (peak annual flows)**					
	5	10	25	50	100	200
2	0.9688	0.9990	*	*	*	*
5	0.6723	0.8926	0.9962	*	*	*
10	0.4095	0.6513	0.9282	0.9948	*	*
25	0.1846	0.3352	0.6396	0.8701	0.9831	0.9997
50	0.0961	0.1829	0.3965	0.6358	0.8674	0.9824
100	0.0490	0.0956	0.2222	0.3950	0.6340	0.8660
200	0.0248	0.0489	0.1178	0.2217	0.3942	0.6330

(* ..... indicate probabilities in excess of 0.9999)

Two important observations can be made from Table 3.1 above:

i. If the design life of a hydraulic structure is the same as its design return period, then the probability that the capacity of the structure will be exceeded is in excess of 63%, (i.e. the risk of failure is 63%), see shaded areas in Table 3.1.

ii. The table also shows that there is about a 64% probability that any 25-year sample will contain a 25-year flood. It also indicates that there is only a 22% probability that a 25-year sample may contain a flood with a return period of 100 years. This clearly indicates that there may be serious errors inherent in the frequency estimates of hydrologic events if the number of observations is small. To minimize these errors it is important to make sure that the observed data are random (unbiased), independent and homogeneous before any frequency analysis is performed.

Hydrologic variables such as flows and rainfall depth are continuous random variables and, during any time period, can take any positive values. The probability of the flows or the rainfall depths assuming any values within a range can only be defined through their probability density functions (pdf) or probability distributions. The most important pdf's used in hydrologic frequency analysis are normal, log normal, Gumbel and Log Pearson Type III.

3.3.1 Normal Distribution

The normal distribution is probably the most important and widely used distribution. It is bell shaped, symmetrical about the mean, continuous and extends from minus infinity to infinity. Since hydrologic process, such as flow data, cannot have negative values, the normal distribution is limited in its relevance to hydrology. However, the normal distribution can be useful since the assumption of normality is the basis for some important statistical procedures such as the analysis of variance and test of hypotheses. It has two parameters, the mean μ and the standard deviation σ. The normal probability density function of a random variable x is defined by (*Bras, 1990*) :

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \qquad (3.5)$$

Where $f(x)$ = Normal density function (ordinates of the normal curve)

x = Continuous random variable.

μ = Population mean of variable x.

σ = Population standard deviation of variable x .

One important feature of the normal distribution is that the mean, median and mode are all the same and its coefficient of skewness is zero. The sample coefficient of skewness, C_s is the most commonly used measure of symmetry and is defined as follows:

$$C_s = \frac{n^2 M_3}{(n-1)(n-2)\ s^3} \tag{3.6}$$

Where n is the sample size, s is the standard deviation and M_3 is the third moment about the mean given by :

$$M_3 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^3 \tag{3.7}$$

The coefficient of skewness C_s is dimensionless and for a symmetrical distribution is equal to zero, since the third moment , M_3, is zero. For distributions that have long tail to the right side, $C_s > 0$, and that to the left $C_s < 0$.

3.3.2 Log Normal Distribution

Many hydrologic variables such as discharges and rainfall data exhibit a marked right skewness, partly due to the influence of natural phenomena having values greater than or equal to zero. In such cases the normal distribution may not adequately describe the observed data. However the observed data could be transformed into a new set of variables which may be normally distributed. If such a transformation takes the form of the logarithms of the observed (original) data and if the new set of variables are normally distributed, then the original data are said to be log-normally distributed. The probability distribution function of the log normal distribution is given by *(Haan, 1977)*:

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \mu_y)^2}{2\sigma_y^2}\right] \tag{3.8}$$

Where σ_y : the standard deviation of the transformed variables (i.e. the standard deviation of the y's, where $y_i = \ln x_i$).

and μ_y : the mean of the transformed variables.

Here again the log normal distribution has two parameters, the mean and the standard deviation. The following are some useful relationships between the parameters of the log transformed variables (σ_y and μ_y) and the parameters of the original data (σ and μ) :

$$\mu = e^{\mu_y + \frac{\sigma_y^2}{2}} \quad \textit{and} \quad \sigma^2 = \mu^2(e^{\sigma_y^2} - 1) \tag{3.9a}$$

and the coefficient of skewness of the observed data is given by:

$$C_s = \left(\frac{s}{\bar{x}}\right)^3 + 3\left(\frac{s}{\bar{x}}\right) \tag{3.9b}$$

It can be seen from equation (3.9b) that C_s is always positive, indicating that the log normal distribution is skewed to the right. Since most hydrologic variables have values greater than or equal to zero and are positively skewed, the log normal distribution has extensively been used in hydrology. Annual maximum discharges and rainfall depths are two examples of hydrologic variables that are commonly modeled as log normal distribution. However, a frequently arising practical problem with log normal distribution (or other distributions involving log transformation) is the fact that many observations may have zero values and consequently, logarithmic transformation of such observed data may result in values which are not amenable to further analysis. A number of methods have been suggested (*Haan, 1977, Kite, 1977*) to take care of observed data with zero magnitudes. One solution is to add a small positive value to all or part of the observed data. This approach is not very satisfactory in that it may significantly alter the parameters of the distribution. A second and theoretically more convincing approach is to use the theorem of total probability which states that:

$$\text{Prob}(X \geq x) = \text{Prob}(X \geq x | X=0)\ \text{Prob}(X=0) + \text{Prob}(X \geq x | X \neq 0)\text{Prob}(X \neq 0)$$

but $\text{Prob}(X \geq x | X=0) = 0$, therefore the above relationship simplifies to

$$\text{Prob}(X \geq x) = \text{Prob}(X \geq x | X \neq 0)\text{Prob}(X \neq 0)$$

where $\text{Prob}(X \neq 0)$ is the probability that a variable has non zero value and can be estimated by the ratio of the number of observations with values greater than zero to the total number of observations, and $\text{Prob}(X \geq x | X \neq 0)$ is estimated by conducting frequency analysis on observed data with values greater than zero.

3.3.3 Extreme Value Distribution

The objective of frequency analysis is to accurately estimate the magnitude and frequency of rare floods or droughts because these events are the ones that cause greatest economic losses and sometime loss of life. These events are known as extreme values and their distributions are of great interest to hydrologists. A number of probability distributions have been used to describe extreme events and one of them is the Gumbel distribution (also known as Extreme Value Type I). This distribution is a member of a family of distributions collectively known as Extreme Value Distributions. It is one of the most widely used distribution for frequency analysis of peak floods and maximum rainfall.

The Gumbel distribution is a two parameter distribution (u and α) with a constant coefficient of skewness of 1.139. The probability density function of the Gumbel distribution is given by *(Bras, 1990)*:

$$f(x) = \alpha e^{-\alpha(x-u)-e^{-\alpha(x-u)}} \tag{3.10a}$$

where α and u are the scale and location parameters given by :

$$\alpha = \frac{1.283}{\sigma} \quad and \quad u = \mu - 0.45\sigma \tag{3.10b}$$

3.3.4 Log Pearson Type III Distribution (LPT III)

Unlike the previous distributions, the log Pearson type III is a three parameter distribution and is a member of the Pearson system of distributions (*Chow,1964*). It has extensively been used in flood frequency analysis, particularly here in the United States since it was recommended by the Water Resources Council (*WRC, 1976*) for adoption as the standard flood frequency distribution by all U.S. government agencies. The probability density function of the log Pearson type III is represented by *(Bras, 1990)*:

$$f(x) = \frac{1}{ax\Gamma(b)}\left(\frac{\ln x - c}{a}\right)^{b-1} \exp\left(\frac{\ln x - c}{a}\right) \tag{3.11}$$

where a is the scale parameter, b is the shape parameter, c is the location parameter and Γ is Gamma function. The three parameters are related to the mean (μ_y), standard deviation (σ_y)

and coefficient of skewness (γ_y) of the LPT III as follows :

$$\mu_y = c + ab \ , \quad \sigma_y = a(b)^{0.5} \ , \quad and \quad \gamma_y = \frac{2}{b^{0.5}} \tag{3.12}$$

Both the LPT III and the log normal distribution are applied to the logarithms of the observed data and therefore present similar practical problems in the event that some of the observations have zero values. The LPT III like the log normal is skewed to the right (has longer upper tail), a characteristic which makes them suitable for modeling annual peak flows.

3.4 Parameter estimation

The shapes and behaviors of the distributions described above are not necessarily obvious from the formulas of the probability density functions. It is therefore important to define some quantities that may be able to give insight into the shapes and behaviors of the various distributions. Unfortunately these quantities, known as parameters , cannot be directly measured. These parameters give important information concerning the position (mean, mode, median), the spread (variance) and the skewness of the distributions. The process of assigning numerical values to parameters is called parameter estimation.

Two methods are commonly used to estimate distribution parameters. The first group is based on establishing equality between measures of shape of the model and that of the observed data. In the second approach, the values of the parameters are determined such that the probability of obtaining the observed outcome is as high as possible. The first is known as the *method of moments* and the second approach is the basis for the second estimation technique known as the *method of maximum likelihood.*

3.4.1 Method of Moments

The shape of both the distribution and observed data can be defined by their respective means, variances and skewness, in other words by their moments. Method of moments estimates of parameters of a distribution are therefore obtained by equating the sample moments with the theoretical moments of the distribution, resulting in a system of equations which are often easily solved. In this method the theoretical moment (the mean, variance and skewness) given by:

$$\mu = E[X], \quad \sigma^2 = Var[x] = E[(X-\mu)^2], \quad \gamma = \frac{E[(X-\mu)^3]}{\sigma^3} \tag{3.13}$$

are equated to the following sample moments (the sample mean $\overline{X}$, sample variance s^2, and the sample skewness C_s):

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \quad s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2 \ , \quad C_s = \frac{1}{s^3}\left[\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^3\right] \tag{3.14}$$

The primary advantages of the method of moments estimators include the ease with which they are computed and their conceptual simplicity. However there is one major problem associated with this method when estimating parameters that require the use of higher than three moments. Higher moments of observed data may have large and increasing variability and therefore may not be reliable estimates of the corresponding population (theoretical) moments, which in turn may lead to unreliable parameter estimates.

3.4.2 Method of Maximum Likelihood

The method of maximum likelihood attempts to estimate parameters that maximize the probability of obtaining the set of observed variables by maximizing the likelihood function. If a set of n observations, x_1 , x_2 , ... x_n , are available and the probability distribution f(x) is a function of the parameters θ_1, θ_2, ... θ_m, then the probability of observing these n independent observations is

$$f(x_1,..,x_n:\theta_1,..,\theta_m) = \prod_{i=1}^{n} f(x_i:\theta_1,\theta_2,...,\theta_m) \tag{3.15}$$

The right hand side of equation (3.15) is proportional to the joint probability that the observed values would be obtained from the population distribution and is called the likelihood, **L** of the sample and is denoted by

$$L(\theta_1,\theta_2,...,\theta_m) = \prod_{i=1}^{n} f(x_i:\theta_1,\theta_2,...,\theta_m) \tag{3.16}$$

The maximum likelihood estimators are therefore the values of the parameters θ_1 ,θ_2 ,... , θ_m that maximize **L**. This is usually done by taking partial derivative of the logarithm of **L**(θ_1 , θ_2 , ... , θ_m) with respect to each of the parameters and setting the resulting expression to zero and then solving for the parameters.

3.5 Goodness of fit Tests

Parameter estimation is not the end of modeling process. The model must be tested to determine whether it adequately represents the observed data. Graphical and statistical techniques are used to assess the quality of fit of the model. The basis of the graphical approach is whether the shape of the theoretical relative frequency curve corresponds to that of the observed data. In this method decisions as to the suitability of the model are made by visual inspection. The statistical method on the other hand is more objective in its approach and involves the computation of a test statistic upon which the decision is based to determine the suitability of the model. The Chi-square test (χ^2) and the Kolmogorov-Smirnov test are two most commonly used statistical tests.

3.5.1 Chi-squared goodness of fit test (χ^2)

The Chi-squared test simply makes a direct comparison between the number of data points actually observed (O_i) and the expected number of observations from the fitted model (E_i) in a given class interval. This test procedure consists of obtaining a set of *n* observed values whose probability distribution is unknown. These *n* observations are then grouped into *k* class intervals and the following test statistic is computed :

$$\chi_o^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \tag{3.17}$$

where the right hand side of equation (3.17) approximately follows the chi-squared distribution with *k-p-1* degrees of freedom, where *p* is the number of parameters estimated from the observed data. It can be concluded (at a significance level of α), that the fitted model does not adequately represent the observed data if

$$\chi_o^2 > \chi^2_{1-\alpha, k-p-1}$$

For the chi-square to be an effective goodness of fit test, the number of observations needs to be large and the expected number of observations in each class interval should not be less than five.

3.5.2 Kolmogorov-Smirnov Test (KS Test)

Unlike the chi-squared test, the KS test does not require grouping the observed data and each data point is therefore allowed to contribute to the test statistic. In this test the comparison is made between the cumulative frequency distribution for the observed data $F_o(x)$, and the cumulative distribution for the fitted distribution , $F_m(x)$. The test statistic D, is then the maximum absolute deviation between the observed and the fitted cumulative distributions denoted as :

$$D = \max \left| F_m(x) - F_o(x) \right| \tag{3.19}$$

If D exceeds the critical Kolmogorov-Smirnov statistic D_c, then the fitted distribution model is considered to be inadequate to effectively represent the observed data.

3.6 Cluster Analysis

The main objective of a regional flood frequency analysis is to develop regional regression models which can be used to estimate flow characteristics at ungaged stream sites. Hydrologic data from several gaging stations in hydrologically homogeneous regions are collected and analyzed to obtain estimates of the regression parameters. Identification of these hydrologically homogeneous regions is a vital component in any regional frequency analysis. One method used to identify these regions is a multivariate statistical procedure known as cluster analysis.

Cluster analysis is a method used to group objects with similar characteristics. Two clustering methods are used for this purpose. The first group of procedures are known as hierarchical methods, and they attempt to group objects by a series of successive mergers. The most similar objects are first grouped and as the similarity decreases, all subgroups are progressively merged into a single cluster. The second group are collectively referred to as nonhierarchical clustering techniques and, if required, can be used to group objects into a specified number of clusters. The clustering process starts from an initial set of seed points, which will form the nuclei of the final clusters.

The most commonly used similarity measure in cluster analysis is the Euclidean distance defined by:

$$D_{ij} = \left[\sum_{k=1}^{p} (z_{ik} - z_{jk})^2 \right]^{\frac{1}{2}} \tag{3.20}$$

where D_{ij} is the Euclidean distance from site i to site j, p is the number of variables included in the computation of the distance (i.e. the basin and climatic variables) and z_{ik} is a standardized value for variable k at site i.

In many applications the variables describing the objects to be clustered (discharges, watershed areas, stream lengths etc.) will not be measured in the same units. It is reasonable to assume that it would not be sensible to treat say, discharge measured in cubic meter per second, area in square kilometer and stream length in kilometer as equivalent in determining a measure of similarity. The solution suggested most often is to standardize each variable to unit variance prior to analysis. This is done by dividing the variables by the standard deviations calculated from the complete set of objects to be clustered. The standardization process eliminates the units from each variable and reduces any differences in the range of values among the variables.

3.7 Regression analysis

The purpose of the distribution models described above is to provide a summary of the probabilistic information contained in a set of observed data in a neat and compact way. Frequency distribution models involve a single variable. These types of models are therefore not designed to describe or represent relationships between two or more variables. One widely used statistical procedure to quantify relationships among variables is Regression analysis. Variables that are generated by multiple factors such hydrologic events are therefore good candidates for analysis using regression models. Regression techniques are frequently used to relate rainfall and runoff and to develop rating curves to express discharges in terms of stages.

Regression is one of the tools used in the development of mathematical expressions that describe the relationship between dependent and independent variable(s). Independent variables provide information on the behavior of the dependent variables and are incorporated into the regression model as predictors or explanatory variables. In addition to the independent variables, regression models will involve unknown constants called parameters, which control the behavior of the model. A regression model uses one or more independent variables to predict or explain variations in a dependent variable. Symbolically a linear regression model can be represented as:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ip} + \epsilon_i \tag{3.21}$$

Where *y's* are the dependant variable and *x's* are independent variables. The error term ϵ is in recognition of the fact that every prediction is in error to some degree, and therefore accounts for the effects of unpredictable and ignored factors. The terms β_0, β_1 through β_p are the model parameters.

3.7.1 Estimation of Regression Parameters

Estimation of regression parameters is usually based on some measure of discrepancy between the fitted regression model and the observed data. Such methods are collectively referred to as methods of minimum deviation. These methods attempt to find model parameters that minimize Ψ, defined by :

$$\Psi = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^{\eta} = \sum_{i=1}^{n} (e_i)^{\eta} \tag{3.22}$$

where ϵ_i is the observed residual for the *ith* observation. If $\eta = 2$, then Ψ represents the sum of squares of the residuals and the method that minimizes Ψ is referred to as the method of least squares. This is the most commonly used estimation technique and is based on the following assumptions:

i. The errors (ϵ), are assumed to be independent of each other with mean equal to zero, i.e **E**[ϵ] = 0. This implies that the mean of the dependent variable, y, is equivalent to the deterministic component of the model, i.e

$$E[y] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_p x_p \tag{3.23}$$

ii. For all setting of the independent variables $x_1, x_2, ...x_n$, the variance of ϵ, is constant. Since the only random element in the model is ϵ, this assumption implies that the dependent variable (y) also has constant variance. This assumption in turn implies that every observation on the dependent variable contains the same amount of information and is therefore given the same weight. On the other hand, heterogeneous variances indicate that some observations contain more information than others.

iii. For the purposes of making tests of significance and construction of confidence intervals, the random errors are assumed to be normally distributed.

The model parameters that minimize the sum of squared errors (SSE) given by:

$$SSE = \sum (y_i - \hat{y}_i)^2 = \sum [y_i - (\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + ... + \beta_k p_{pi})]^2 \tag{3.24}$$

are obtained by taking partial derivatives of SSE with respect to each of the parameters and equating the resulting expressions to zero as follows:

$$\frac{\partial SSE}{\partial \beta_0} = 0 \ , \quad \frac{\partial SSE}{\partial \beta_1} = 0 \ \ . \ . \ . \quad \frac{\partial SSE}{\partial \beta_p} = 0 \tag{3.25}$$

The above set of differential equations generate (p+1) least squares linear equations which when solved simultaneously give estimates of the model parameters.

A neat and more compact way of determining the regression parameters is to use matrix algebra. In order to apply matrix algebra to regression analysis, the observed data must be arranged in matrices form as follows:

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ . \\ . \\ y_n \end{pmatrix}, \quad X = \begin{pmatrix} 1 & x_{11} & x_{21} & . & . & . & x_{p1} \\ 1 & x_{12} & x_{22} & . & . & . & x_{p2} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 1 & x_{1n} & x_{2n} & . & . & . & x_{pn} \end{pmatrix}, \quad \beta = \begin{pmatrix} \beta_0 \\ \beta_1 \\ . \\ . \\ \beta_p \end{pmatrix}, \quad \epsilon = \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ . \\ . \\ \epsilon_n \end{pmatrix}$$

Where **Y** is the **n x 1** column vector of observations of the dependent variable.

X is the **n x p+1** matrix consisting of a column of ones, followed by the p column vectors of the observations on the independent variables.

β is the **p+1 x 1** vector of unknown parameters to be estimated from the observed data.

and ϵ is the **n x 1** vector of random errors.

With these definitions, the general linear model can be expressed in matrix form as:

$$\mathbf{Y} = \mathbf{X}\beta + \epsilon \qquad (3.26)$$

and the resulting normal equations, in matrix notation, are:

$$(X'X)\beta = X'Y \qquad (3.27)$$

and the least square parameter estimates are given by:

$$\beta = (X'X)^{-1}X'Y \tag{3.28}$$

The term **X'X** generates a **p x p** matrix where the diagonal elements are the sums of squares of each of the independent variables and plays an important role in estimating the variance of the parameters, β_i's.

3.7.2 Model validation

The process of model validation in regression analysis involves checking whether the predicted values closely match the observed data and verifying the assumptions on which the prediction model is based. A well fitting regression model will generate residuals that are independent variables with zero mean, constant variance and possibly normally distributed. If the residuals do not show these properties then the model is considered to be inadequate. These inadequacies can be detected by plotting the residuals as follows:

a. Residuals against independent variables , (Fig.3.1)

If the model is correctly specified, then the residuals should vary in a random pattern as the independent variable increases. Fig. 3.1 shows a systematic variation in the residuals, an indication that the specified model (first-order model in this particular case) is not appropriate and a higher order model may be necessary.

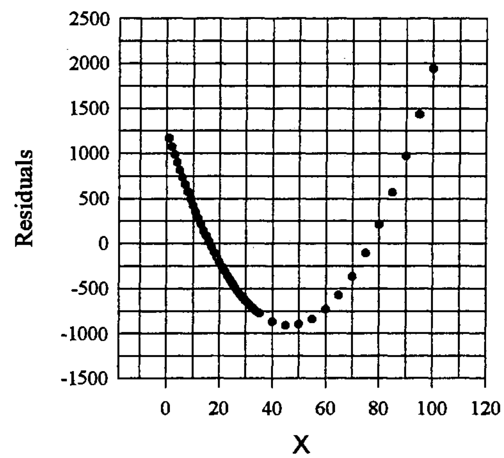


Fig. 3.1 : Residuals Vs. X

b. **Residuals against the fitted values (estimates), (Fig. 3.2)**

This plot indicates a systematic change in the residuals as the fitted value increases, thus violating the assumption of homoscedasticity or homogeneity of variance . If this happens then a variance-stabilizing transformation may be required before the regression model is fitted.

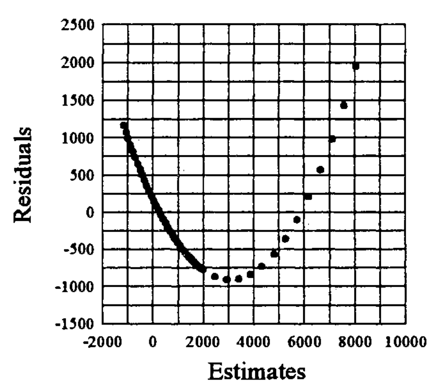


Fig. 3.2 : Residuals Vs. Estimates

c. **Autocorrelation of residuals, (Fig.. 3.3)**

The assumption of independence of the errors can be examined by plotting the autocorrelations of the residuals. A systematic change in the autocorrelation function indicates that the residuals are not independent and an important explanatory variable may be missing from the model.

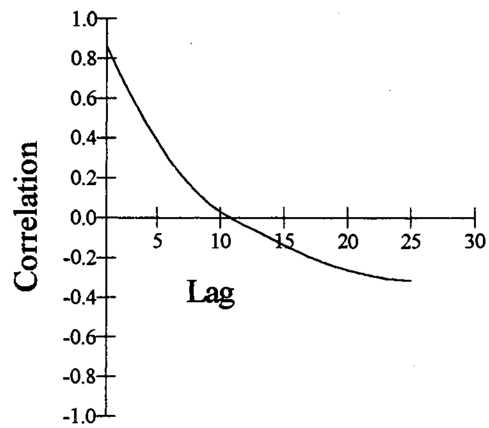


Fig. 3.3 : Plot of Autocorrelations

The coefficient of determination R^2, is another commonly used statistic to assess the adequacy of regression models. It represents the proportion of the total variation in the dependant variables explained by the independent variables. Thus $R^2=0$ implies a complete lack of fit of the model to the data or the predictor variables have no influence on the response. Whereas $R^2=1$ implies a perfect fit. In general, the larger the value of R^2, the better the model fits the data. The coefficient of determination, R^2, is define as:

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2} = 1 - \frac{SSE}{SS_{yy}} \tag{3.29}$$

$$where \quad SSE = \sum (y_i - \hat{y}_i)^2 \quad and \quad SS_{yy} = \sum (y_i - \bar{y})^2$$

and $\hat{y}_i$ is the predicted value of y_i. The value of R^2 will increase as more and more variables are added to the model. R^2 could be forced to take a value close to 1 even though the model contributes no information for the prediction of y. An alternative to R^2 is the adjusted coefficient of determination, R^2adj., expressed as:

$$R^2_{adj} = 1 - \frac{(n-1)}{n-(k+1)}(1 - R^2) \tag{3.30}$$

Unlike R^2, R^2adj. is "adjusted for" both for the sample size n and the number of parameters β in the model. R^2adj. will always be smaller than R^2, and cannot be forced to 1 by simply adding more and more independent variables to the model. More importantly R^2 can be used to determine whether the data provide sufficient evidence to support the fact that the model could effectively be used for prediction purposes. This is done in conjunction with the F-test to examine the hypothesis that none of the variables included in the model has any predictive value. In other words :

$H_o : \beta_1 = \beta_2 = \beta_3 = \ldots = \beta_k = 0$

H_a : At least one $\beta_j \neq 0$

The test statistic used to test this null hypothesis is, *(Mendenhall and Sincich, 1992):*

$$F = \frac{R^2/p}{(1-R^2)/[n-(p+1)]} \tag{3.31}$$

With [p, n-(p+1)] degrees of freedom. If $F > F_{\alpha}$ (tabulated F-values) then the data support the fact that at least one of the model parameters (β) is nonzero, indicating that the model is useful for predicting the dependent variable.

CHAPTER 4

DATA ACQUISITION

4.1 Introduction

Flood frequency information derived from observed data, basin and climatic characteristics are the major inputs to any transfer function used to estimate flood magnitudes and frequencies in ungaged watersheds. The drainage basin can be thought as a system that converts rainfall to runoff. It also controls the rate at which the runoff will occur and the degree to which the runoff water will be concentrated. In other words, it governs the runoff volume from the rainfall, and the shape and magnitude of the runoff hydrograph. Thus the key to predicting the runoff response from any drainage basin is the understanding of the basin itself and its climatic environment. This chapter reviews some of the basin and climatic characteristics that are useful, when quantified, in evaluating the hydrologic response of the basins. These characteristics relate to either the physical aspects of the basins such as drainage area, stream length, stream slope or to the climatic variable such as rainfall, evaporation and temperature. The basin characteristics that will be used in this study are, the watershed area, stream slope, stream length and soil type.

4.2 Rainfall

Daily rainfall values were obtained from the Department of Meteorology of Zambia. The daily depth of rainfall is usually measured at 0800 hours Zambian time and the observer enters the reading against the previous date in the rainfall register. At the end of each month the return is mailed to the Meteorological Department where the data are checked and monthly totals of rainfall depths and number of rainy days are computed. The monthly totals are compared with the totals of adjacent stations before they are accepted and published. Rainfall data from 33 stations, shown in Table 4.1 (given at the end of this chapter), will be used in this study. Fig. 4.1 shows the locations of the various rain gaging stations. These stations were selected because they have the most complete and reliable rainfall records and are also evenly distributed throughout the country.

The long term annual average rainfall (P) over the various watersheds was extracted from isohyetal maps prepared by the Department of Meteorology of Zambia shown in Fig. 1.4. This map was based on rainfall data collected during the 30-year period spanning from July 1950 to June 1980. It is usually the case that a watershed traverses regions with different mean annual rainfalls as shown in Fig. 4.2. If such a situation occurs, then the average annual rainfall for the given watershed is estimated either as the mean annual rainfall corresponding to that of the centroid of the watershed or as the mean annual rainfall averaged over the entire basin. The latter approach is used in this study, since unlike the former, it involves the whole watershed and is therefore more likely to provide a more accurate and realistic estimate of the mean annual rainfall. The average annual rainfall for the watershed shown in Fig. 4.2 is expressed by the weighted average of depths (P) between the isohyets as follows:

$$P = \frac{A_1\left(\frac{P_0+P_1}{2}\right) + A_2\left(\frac{P_1+P_2}{2}\right) + A_3\left(\frac{P_2+P_3}{2}\right) + A_4\left(\frac{P_3+P_4}{2}\right)}{A_1 + A_2 + A_3 + A_4} \qquad (2.1)$$

or in general, equation (2.1) can be represented as:

$$P = \left[\frac{\sum_{i=1}^{n} A_i(P_{i-1}+P_i)}{\sum_{i=1}^{n} A_i}\right] * 0.5 \qquad (2.2)$$

4.3 Stream flows

The data on stream flows and watershed areas were obtained from the Hydrological Branch of the Department of Water Affairs, Zambia. Most water levels and gaging stations operated by the Department are recorded on staff gage plates calibrated in feet and tenths of a foot but the majority of weir stations and some "Flashy" river sites are equipped with autographic water level recorders. Water levels at gaging stations are read once a day but additional readings are usually taken on large and "Flashy" rivers. Measurement of discharges at regular gaging stations are carried out by current meters in order to derive suitable rating curves.

For the purpose of data collection, the country is divided into six main watersheds, namely the Zambezi, Luangwa, Kafue, Luapula, Chambeshi and Tanganyika. Flood records from 58 stations scattered throughout Zambia are used in this study. The locations of the gaging stations are shown in Table 4.2 and Fig. 4.3. The criteria used to select these stations were:

i. A station must have at least 10 years of data

ii. Fig. 4.4 shows a plot of the watershed area versus the length of record for the 58 stations used in this study. It can be concluded from the figure that in general longer records are available for larger streams than for smaller ones. This is an indication that little attention had been given to small size streams, particularly those with watershed areas less than 100 sq. miles. In this study the focus will therefore be on the small to medium size watersheds with areas not exceeding 2500 sq. miles.

iii. The flow is not significantly altered by regulation, diversion or other man made structures.

A summary of the distribution of the watershed areas, the number of gaging stations and the average length of record is given in Table 4.3.

4.4 Basin characteristics

The basin characteristics that will be used in this study are the watershed area, stream slope, stream length and soil type.

i. Drainage area (watershed area) :

The basin area is the area contained within the vertical projection of the watershed divide on a horizontal plane. Most of the watershed areas used in this study were obtained from the Department of Water Affairs' (Zambia) hydrological year books and a few were measured from topographic maps using SEDCAD3, a software package *(Schwab,1987-992)*.

ii. **Stream or channel length:**

The channel length is the distance measured along the main channel from the location of the gaging station to the basin divide, is again measured from topographic maps using SEDCAD3.

iii. **Stream (channel) slope:**

Channel slope has an important influence on the velocity of flow in a channel, and, consequently, on the flow characteristics of runoff from watershed. The slope varies longitudinally and an average value of slope is therefore used. Three methods, namely arithmetic method, the 10-85 and the 'equal areas' are commonly used to determine the average stream slopes. The arithmetic method involves computing the fall from the head of the uppermost first-order channel to the basin outlet and dividing this fall by the length of the channel. The 10-85 method computes the slope of the stream between 85% (excluding the upper 15%) and 10% (excluding the lower 10%) of the distance along the stream from the basin outlet to the watershed divide. The 'equal areas' method defines the average slope as the slope of a straight line drawn along the stream profile such that the area above the line is the same as that below it as shown in Fig. 4.5, that is line BC is drawn such that the shaded areas S_1 and S_2 are equal.

The topography of Zambia is generally gentle and the differences among the slopes computed using the different methods are therefore not large. Any marginal increase in the level of accuracy obtained using the 'equal areas' method is nullified by the huge amount of work involved in the computation of the slopes. Computational simplicity and the relative accuracy of the arithmetic method make it the most attractive alternative for determining the stream slopes for the Zambian condition. This method will therefore be adopted in this study

iv. Soil type

Information on the type of soils in the watersheds are obtained from various maps and literature prepared by the Department of Agriculture of Zambia. On the basis of this information the country was divided into three major types of soil regimes, namely clay, loam and sandy soils with permeabilities of 5 to 15 cm/hr, 15 to 50 cm/hr and more that 50 cm/hr respectively.

A summary of the basin characteristics used in this study is given in Table 4.4.

Table 4.1 : Selected statistics of observed rainfall

	Station	Location Lat		long		Period of record	Missing data	Length of record (years)	mean (mm)	std (mm)
1	CHIP2	13	34	32	35	1946 - 1992	1960	46	68.5	18.5
2	CHOMA1	16	51	27	04	1950 - 1992		43	62.5	17.7
3	ISOKA1	10	10	32	38	1978 - 1992		15	62.4	0.2
4	KABOM1	13	26	24	12	1961 - 1992		32	65.2	16.8
5	KABW1	14	25	28	29	1950 - 1992		43	66.7	16.8
6	KAFIR1	12	38	28	10	1968 - 1992		26	78.2	26.2
7	KAFUE1	15	45	28	12	1958 - 1992		35	84.3	75.5
8	KAOMA1	14	48	24	48	1961 - 1992		32	62.1	19.3
9	KASA1	10	13	31	08	1934 - 1992	1942 - 45	55	65.7	11.9
10	KASE1	13	27	25	50	1938 - 1992	1980	54	78.9	38.6
11	KAWAM1	09	48	29	05	1957 - 1992		36	65.1	9.8
12	LIVI2	17	50	25	50	1933 - 1992	1938 - 46	51	66.8	23.8
13	LUNDA1	12	17	33	12	1956 - 1992		37	67.2	18.2
14	LUSAKA1	15	24	28	16	1967 - 1992		26	64.3	18.4
15	MAGOY1	16	02	27	38	1978 - 1992		15	59.7	12.8
16	MANSA1	11	06	28	51	1960 - 1992		33	63.5	13.6
17	MBALA1	08	51	31	20	1961 - 1992		32	66.2	15.2
18	MFUWE1	13	00	31	52	1979 - 1992		14	62.6	16.0
19	MISA1	10	11	31	13	1974 - 1992		19	75.0	0.2
20	MONG2	15	15	23	09	1936 - 1992	39 - 44, 49, 53 - 54	48	70.8	32.9
21	MPIKA1	11	54	31	26	1932 - 1992	39 - 42, 46	56	75.2	60.3
22	MSEKE1	13	39	32	34	1982 - 1992		11	61.3	15.6
23	MTMAK1	15	32	28	15	1961 - 1992		32	77.9	51.4
24	MUMBW1	14	59	27	04	1978 - 1992		15	89.5	83.6
25	MWINI1	11	45	24	26	1950 - 1992		43	71.8	18.6
26	NDOL2	13	00	28	39	1942 - 1992	1943, 1949	49	94.2	162.1
27	PETA1	14	15	31	17	1950 - 1992		43	67.4	17.9
28	SAMFY1	11	21	29	32	1958 - 1983		26	103.4	36.7
29	SENA1	16	07	23	16	1980 - 1992		13	63.6	22.4
30	SERE1	13	14	30	13	1957 - 1992		36	75.9	21.6
31	SESHE1	17	28	24	18	1950 - 1992	1971, 79 - 81	39	66.4	43.7
32	SOLW1	12	11	26	23	1961 - 1992		32	74.3	19.4
33	ZAMBE1	13	34	23	06	1954 - 1992		39	95.3	179.5

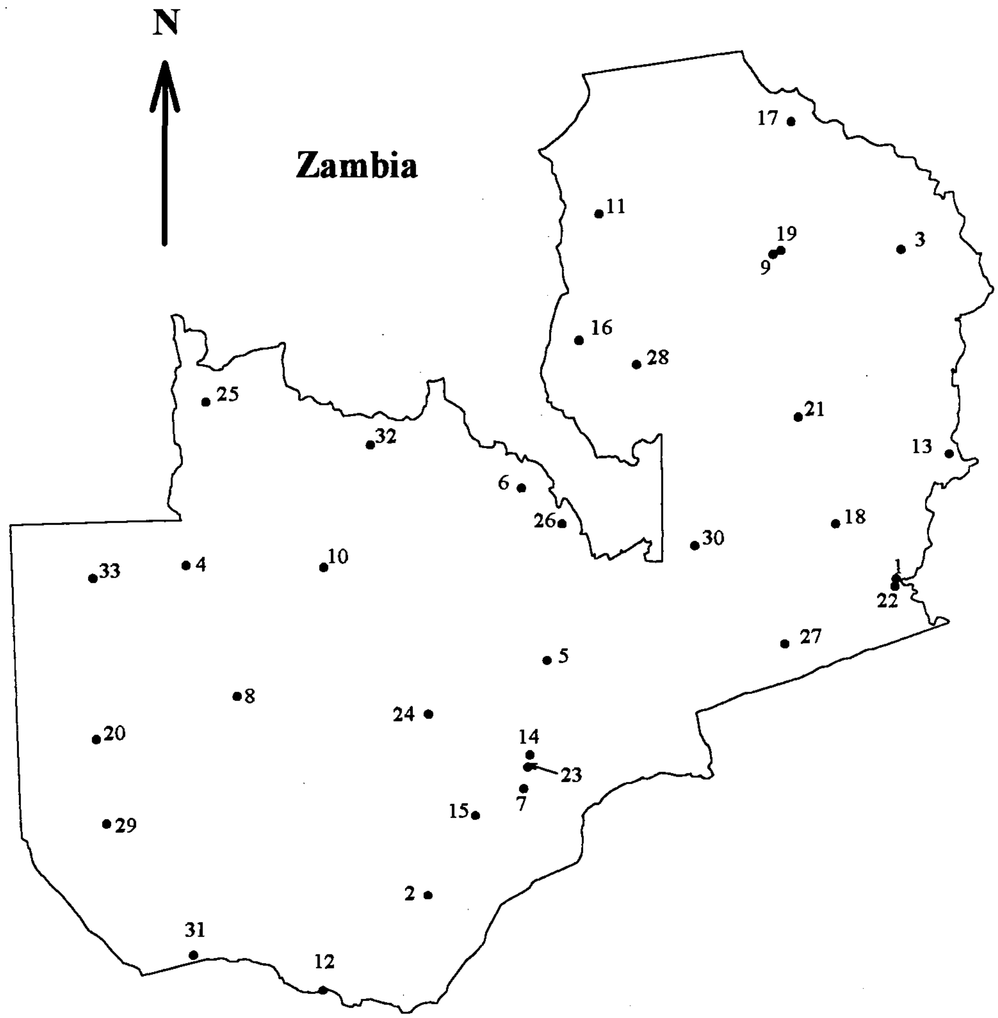


Fig. 4.1 : Locations of Rainfall Measuring Stations

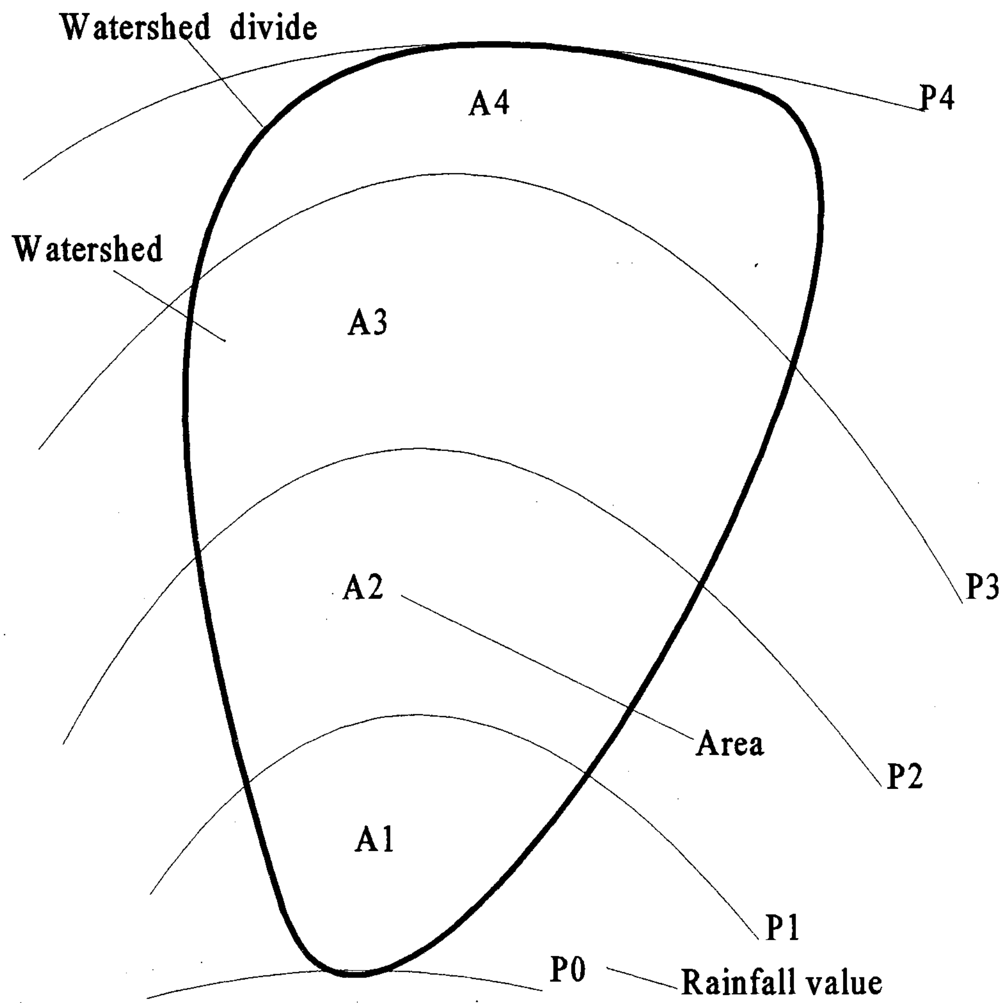


Fig. 4.2 : Plot of watershed and isohyets

Table 4.2 : Location of flow gaging stations

	Station number	Gaging Station	Location Lat.*	Long.*
1	1080	Zambezi River at Kaleni Hill Road Bridge	11 08	24 15
2	1145	Makondu River at Chivatu Village	13 20	23 09
3	1205	Kabompo River at Solwezi-Mwinilunga Road	11 54	25 15
4	1305	West Lumwana River at Solw.-Mwinil Road	11 50	25 09
5	1315	East-Lumwana River at Solw.-Mwinil.Road	14 14	25 41
6	1425	Luakela River at Sachibondo	11 31	24 25
7	1430	West Lunga River at Mwinilunga	11 44	24 27
8	2360	Kataba River at Siandi Road Bridge	15 33	23 15
9	2475	Lui River at Luatembo School	15 16	23 49
10	3370	Nang'ombe River near Tobonte village	17 07	27 32
11	4005	Kafue River at Kipushi Road	11 47	27 10
12	4050	Kafue River at Raglan Farm	12 25	27 44
13	4090	Kafue River at Kafironda	12 38	28 09
14	4100	Mutundu River at Mutundu	12 37	28 20
15	4120	Mwambahi River at Mwambahi	12 43	28 13
16	4152	Kamfinsa River at Kamfinsa	12 52	28 22
17	4170	Baluba River at Baluba	12 59	28 16
18	4205	Kafulafuta River at Ibenga Mission	13 21	28 38
19	4210	Kafubu River at Itawa Dambo	12 59	28 38
20	4239	Munkulungwe River at Kaposa	13 09	28 35
21	4240	Kafue River at Fisenge	13 11	28 35
22	4245	Kafubu River at Masaiti Road Bridge	13 13	28 24
23	4250	Kafulafuta River at Miputu Hills	13 15	28 13
24	4266	Mpopo River at Mpopo School	12 52	27 36
25	4272	Lufwanyama River at Kanakila	13 18	27 43
26	4281	Ipumbu River at Machiya	13 39	27 39
27	4302	Luswishi River at Lwendo	12 55	27 21
28	4310	Luswishi River at Kilundu	13 09	27 14
29	4460	Lunga River at Konikombe Hills	12 16	26 48
30	4500	Mutanda River at Mutanda Mission	12 24	26 15
31	4620	Lufupa River below Kasempa pump house	13 27	25 52
32	4821	Munyeke River at Mapanza Mission	16 15	26 54
33	4850	Mutama River at Mutama Rapids	16 28	27 07
34	4940	Mwembeshi River near Shibuyunji	15 27	27 44
35	4941	Kaleya River at Kaleya Dam Site	16 11	28 02
36	4945	Kaleya River at Avilion Weir	16 02	27 54
37	4950	Kaleya River at Heale's Estate Weir	15 53	27 39
38	4952	Nakambala River at Nakambala upper weir		

Table 4.2 : Location of flow gaging stations (cont)

	Station number	Gaging Station	Location Lat.*	Long.*
39	4958	Mazabuka River at Eruaff Farm	15 52	27 51
40	5030	Kapiriombwa River at Exchange Farm	15 21	28 20
41	5670	Lusiwasi River at Masase	13 13	31 02
42	6140	Chambeshi River at Chandaweyaya	09 47	31 41
43	6145	Chambeshi River at Mbesuma Ferry	10 00	32 10
44	6160	Mansenke River at Nansala Falls	10 06	32 33
45	6170	Kalungu (Wiwa) River at Chunga Ranch	09 49	3 2 30
46	6200	Chozi River at Chozi	09 24	32 16
47	6235	Kalungu Bemba River at Kalungu	10 00	31 54
48	6242	Chimanabuwi River at Chipoma Falls	10 44	32 00
49	6250	Lubu River at Bridge	10 20	32 15
50	6275	Manshya River at Shiwangandu	11 13	31 40
51	6330	Luombe River at Chishimba Falls	10 07	30 55
52	6340	Milima River at Milima pump house	10 09	31 15
53	6480	Lwitikila River below Lwitikila Falls	11 44	31 29
54	6486	Lwitikila River at Mpika Road Bridge	11 50	31 23
55	6500	Kanchibiya River at Mpika-Kasama Road	11 29	31 17
56	6510	Kanchibiya River at Kopa Bridge	11 47	30 49
57	6860	Luangwa River at Mumbulima Falls	09 33	29 44
58	6935	Mwambeshi River near Nsama	08 52	29 56

Lat.* Latitude
Long.* Longitude

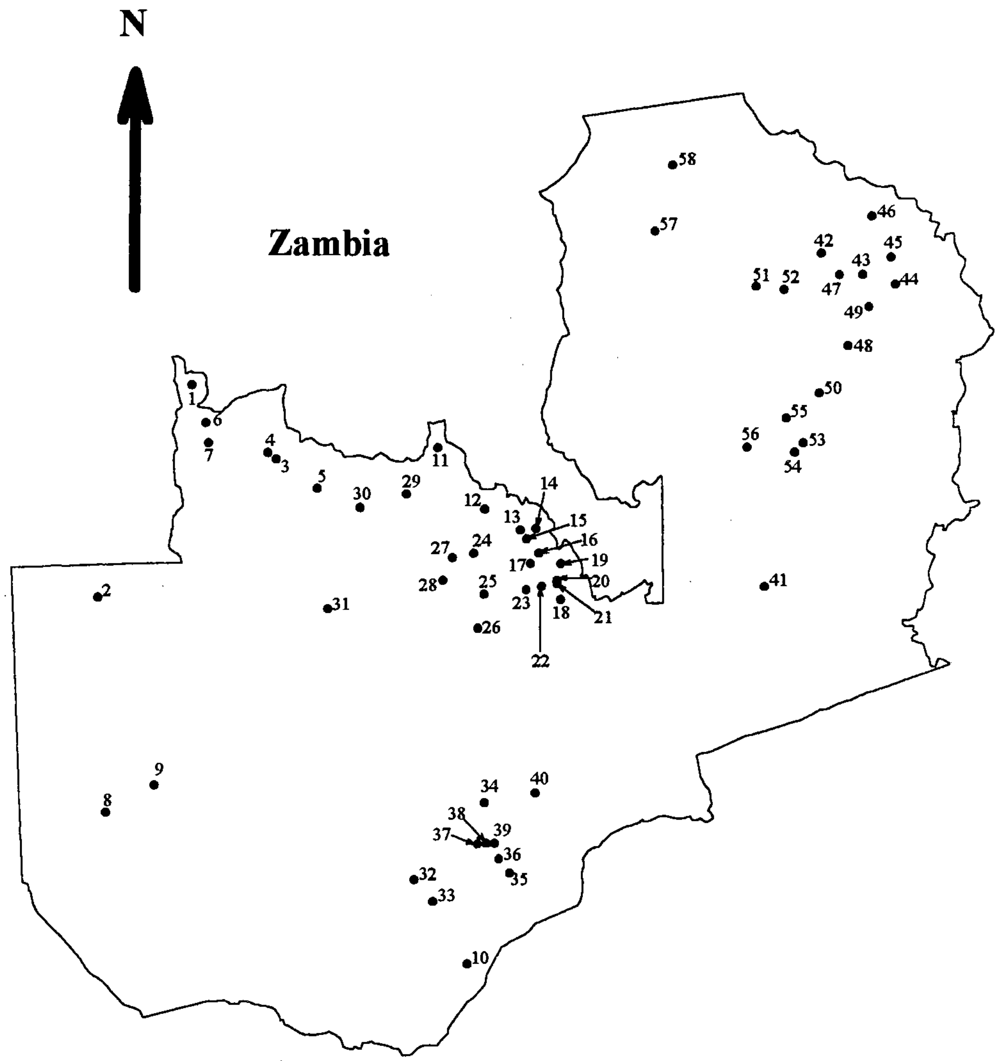


Fig. 4.3 : Locations of streamflow gaging stations

Table 4.3 : Summary of watershed areas, number of stations and average record length

Watershed area in km^2	Number of stations	Average length of record in years
0000 to 1000	29	22
1000 to 2000	9	22
2000 to 3000	9	25
3000 to 4000	3	27
4000 to 5000	6	23
over 5000	2	25

Table 4.4 : Watershed characteristics

Station	Length of record (years)	Watershed area (sq. km)	Stream Length (km)	Stream Slope (m/km)	Annual average rainfall (m)	Soil type	Peak annual flow statistics: Mean m3/sec	Std. m3/sec	Skew
1080	19	764	70.1	3.9	1.5	2	20.7	5.5	-0.1
1145	30	3354	169.8	2.2	1.3	2	39.0	10.5	-0.2
1205	21	1075	59.7	3.8	1.4	2	89.2	68.5	1.2
1305	12	469	39.9	3.1	1.5	2	24.0	4.8	2.1
1315	12	640	55.8	2.7	1.4	1	19.0	2.2	-0.4
1425	13	632	49.1	1.5	1.5	2	39.4	19.7	0.2
1430	16	4537	192.0	1.0	1.5	2	252.3	107.5	1.0
2360	16	435	31.8	1.1	0.9	3	18.4	9.4	0.4
2475	24	1854	50.4	0.4	1.0	3	3.7	0.5	-0.8
3370	12	798	22.7	27.5	0.8	2	3.8	1.1	-0.5
4005	29	440	28.2	2.7	1.4	1	10.9	1.9	-0.7
4050	32	4998	199.4	0.5	1.4	1	205.9	450.4	5.5
4090	32	7148	296.4	0.6	1.4	1	163.4	113.8	1.2
4100	29	300	25.3	3.0	1.4	1	10.1	3.8	-0.2
4120	31	4998	56.4	1.8	1.3	1	38.5	29.2	3.9
4152	27	192	24.0	6.0	1.3	1	11.6	7.3	1.1
4170	18	339	46.4	2.8	1.3	1	11.7	3.6	0.9
4205	23	2499	78.6	1.6	1.2	1	41.1	26.3	0.3
4210	12	306	23.0	2.2	1.3	1	15.3	8.1	0.6
4239	17	210	29.2	9.6	1.3	1	5.5	3.1	0.4
4240	20	950	48.2	1.6	1.3	1	13.2	4.5	0.3
4245	22	1375	70.6	1.4	1.2	1	45.3	23.6	0.8
4250	24	4817	113.2	1.3	1.2	1	24.2	3.4	-1.1
4266	15	69	5.1	4.9	1.3	1	1.8	0.7	-0.7
4272	12	2924	123.9	1.4	1.2	1	45.6	32.9	2.3
4281	21	598	33.9	2.2	1.1	1	14.0	15.1	1.4
4302	22	2668	104.6	2.2	1.3	1	94.3	42.7	-0.7
4310	21	3600	142.3	1.8	1.3	1	67.8	17.6	-1.9
4460	19	619	45.1	3.8	1.4	1	15.0	6.3	-0.5
4500	23	1704	84.1	3.2	1.4	1	46.6	20.9	0.8
4620	29	1062	56.7	3.1	1.3	1	32.5	28.1	1.3
4821	25	1787	81.1	4.0	0.9	2	45.8	38.9	1.3
4850	23	1735	59.9	5.4	0.9	2	1646.5	2086.6	1.5

Table 4.4 : Watershed characteristics (cont.)

Station	Length of record (years)	Watershed area (sq. km)	Stream Length (km)	Stream Slope (m/km)	Annual average rainfall (m)	Soil type	Peak annual flow statistics: Mean m3/sec	Std. m3/sec	Skew
4940	29	3885	105.3	2.3	0.9	2	18.8	9.8	0.6
4941	32	45	8.0	11.3	0.8	2	5.3	3.7	0.6
4945	30	206	30.3	7.4	0.8	2	81.1	70.9	1.5
4950	35	596	67.3	5.1	0.8	2	15.4	11.3	1.4
4952	28	7	3.0	10.0	0.9	2	14.1	3.1	0.2
4958	32	140	23.5	10.7	0.8	2	27.1	30.8	1.4
5030	32	109	6.2	10.0	0.9	2	5.9	4.8	1.6
5670	26	995	71.5	1.4	1.2	1	32.1	18.2	1.0
6140	19	4628	105.5	3.6	1.2	2	68.2	14.8	-0.4
6145	17	6045	144.5	3.7	1.1	2	116.2	19.3	-1.0
6160	13	96	11.9	6.4	1.1	1	1.9	0.2	0.2
6170	32	2901	89.8	5.6	1.1	2	25.2	6.1	-0.4
6200	28	2199	95.7	4.7	1.2	2	15.3	8.9	1.0
6235	31	2098	91.4	1.5	1.2	1	43.0	6.9	0.4
6242	35	640	45.2	5.5	1.2	2	3.4	1.0	1.3
6250	27	2838	115.5	2.4	1.1	2	48.5	15.5	0.5
6275	20	1039	56.9	4.4	1.2	2	8.8	24.1	4.3
6330	31	2548	107.4	3.3	1.3	2	259.0	426.0	3.4
6340	16	67	7.9	6.4	1.3	1	1.3	1.0	2.7
6480	28	174	23.3	16.1	1.3	2	4.4	3.1	1.6
6486	20	839	55.1	6.8	1.3	2	51.8	55.0	2.2
6500	10	1215	51.4	9.1	1.3	2	31.0	4.0	-0.6
6510	22	2564	134.1	4.0	1.3	2	7.6	0.4	-1.6
6860	15	4895	172.8	2.2	1.5	2	137.4	34.8	0.7
6935	30	707	56.8	9.2	1.6	2	40.4	14.5	0.1

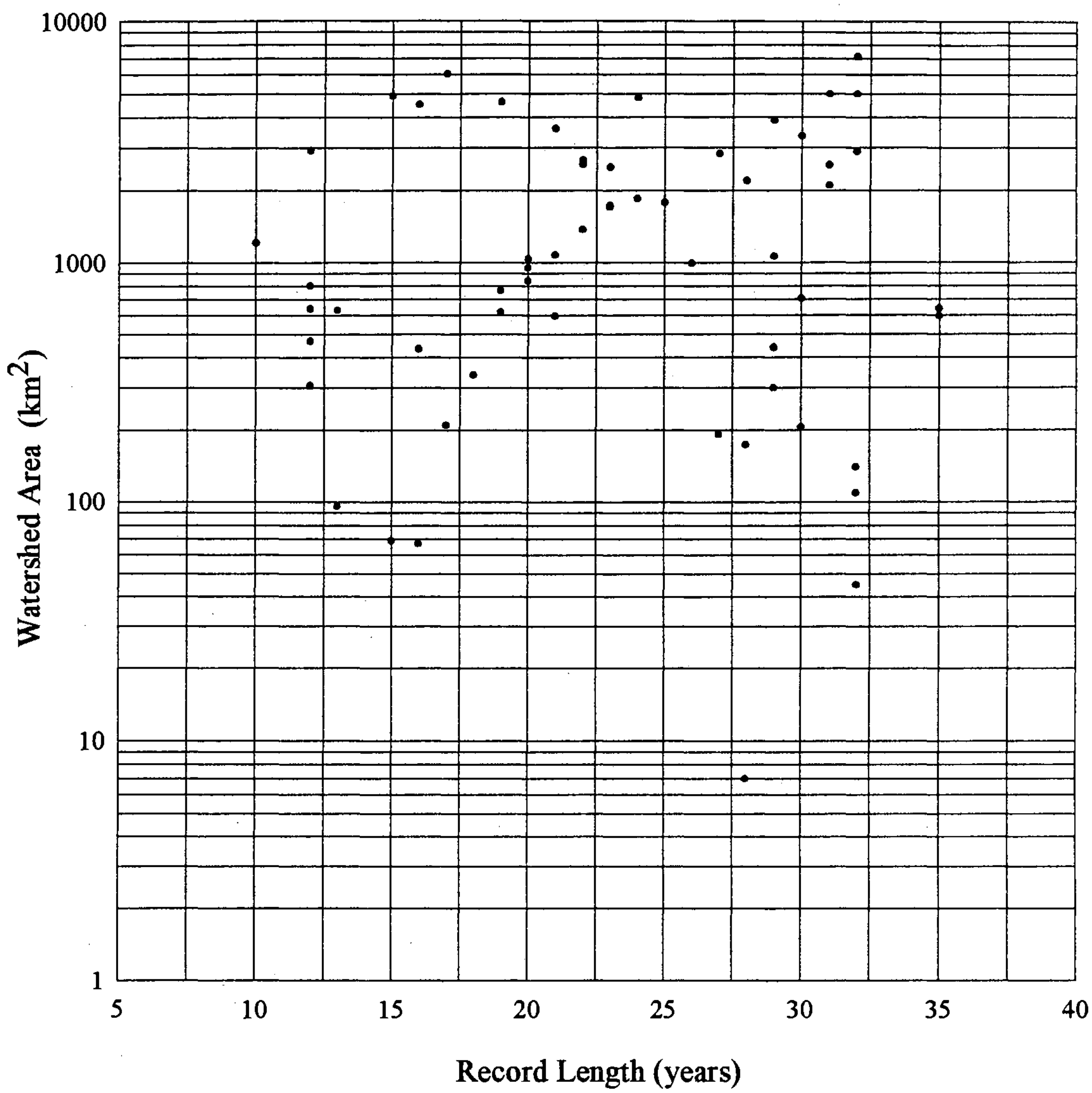


Fig. 4.4 : Relationships between watershed areas and record lengths

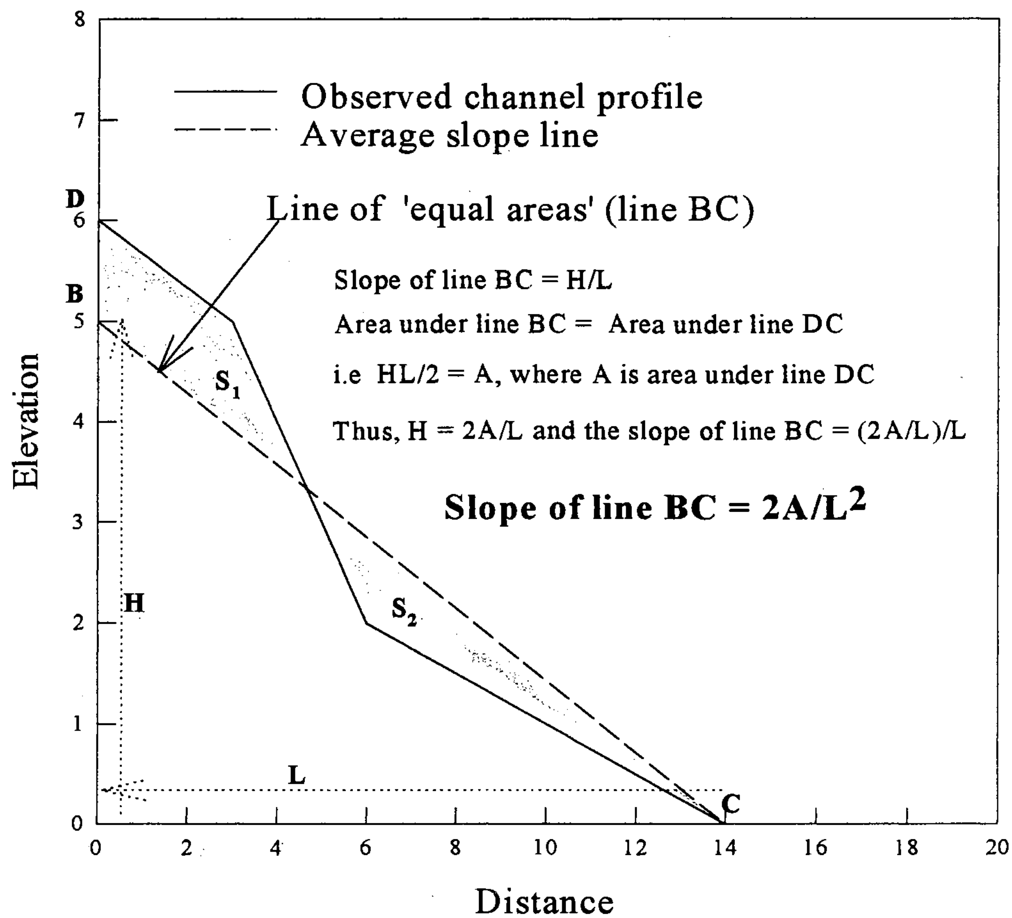


Fig. 4.5 : Channel profile and average slope line

CHAPTER 5

METHODOLOGY AND RESULTS

5.1 Outline of study

The primary objective of this study is to investigate the possibilities of transferring flood-frequency data from gaged watersheds to sites that have no flow records (ungaged sites). The transfer of flood frequency data from one site to another is carried out using Regional Flood Frequency Analysis (RFFA) and is therefore the subject of this investigation. The steps required to perform the RFFA are outlined below and are also shown in Fig. 5.1 (all figures and tables are given at the end of the chapter):

a. Test observed flow and rainfall data for independence and homogeneity.

b. Develop flood-frequency curves from annual peak flows observed at 58 gaging stations located throughout the country.

c. Develop rainfall-frequency curves from daily rainfall records observed at 33 stations located at various places in the country.

d. Estimate the 2, 5, 10, 25, 50 and 100-year floods/rainfalls from the distributions that best fit the observed data.

e. Assemble data and divide the country into hydrologically homogeneous regions.

f. Develop regional equations relating the 2, 5, 10, 25, 50 and 100-year floods to the watershed and climatic variables. The relationships between floods, basin and climatic variables will be analyzed using multiple regression techniques of the form:

$$Q_T = cA^a S^s L^l R^r P^p SI^g \tag{5.0}$$

Where

Q_T	:	Flow with T-year return period
A	:	Watershed area
S	:	Channel slope
L	:	Channel length
P	:	Mean annual precipitation over watersheds
R	:	Daily rainfall
SI	:	Soil Type Index
a, c, etc	:	Regression parameters

g. Finally, the results will be presented in such a way that the magnitudes and frequencies of floods at ungaged watersheds could be estimated directly or from graphic representation of the relationships derived above.

Data used in frequency analysis are assumed to be independent and homogenous. In other words the observed data are assumed to represent a random sample from a single population. The assumption of independence is not unreasonable in this study since the data used are annual flows. However, homogeneity, which may be violated due to changes in watershed management, may not be a reasonable assumption unless proven otherwise. Assessment of the adequacy and applicability of observed data is therefore a necessary first step in flood frequency analysis. In this chapter statistical procedures to test these assumptions are discussed, the frequency distributions presented in chapter 3 are fitted to the observed data, hydrologically homogeneous regions are delineated and the relationship between flood quantiles and watershed and climatic variables are determined, for each homogeneous region, using two regional flood frequency techniques. This chapter will end with a discussion on the adequacy of the models developed above.

5.2 Validity of Assumptions

Since the flow and rainfall values used in this study are essentially time series, time dependence is expected to be the main source of non randomness in the data. In frequency analysis, dependence among the observed values will result in an increase in the degree of uncertainty in the quantile estimates and must thus be minimized or totally eliminated using some form of transformation of the observed data. Independence cannot be proved but it can be disproved by the presence of some features of a non random nature, such as trend or serial correlation. The Spearman rank serial correlation technique, a nonparametric method, was applied to test for any trend or persistence in the data. A distribution free approach was selected because most of the observed data from the various gaging stations are not normally distributed, a requirement for most parametric tests. The test statistic in the Spearman rank correlation method r_s, is the correlation coefficient between the ranks of the raw data and is given by:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \tag{5.1}$$

where d_i is the difference between the rank of the flows (or rainfall) and that of time. If the calculated Spearman's r_s is smaller that the critical value, then it can be inferred that the data are independent. This was done for all the stations and the results are shown in Table 5.1. The results indicate that data from five stations, namely 2360, 2475, 4152, 4941 and 6330 may not be independent. Further, examination of plots of the data from these stations shown in Fig. 5.2, confirm that stations 2360, 2475 and 4152 do indeed show some trend in the data, whereas the data from the other two stations do not appear to suggest the presence of trend or persistence. On the basis of the above tests, the data from stations 2360, 2475 and 4152 will be rejected and therefore will not be considered for further analysis.

Homogeneity implies that all the observations in a sample come from the same population. Occasionally some values that appear to deviate markedly from the other members of the sample may be observed. These are classified as outliers and may be extreme values of the variable being observed or simply the result of recording errors. The statistic used to test for outliers (in this study only high outliers will be considered since the main objective of the study is the estimation of flood quantiles with high return periods) is that proposed in Bulletin #17 , (*WRC, 1982*) which is denoted as:

$$K_{cal} = \frac{X_H - \bar{X}}{s_y} \tag{5.2}$$

where K_{cal} is the test statistic, X_H is the high outlier threshold in log units, $\bar{X}$ and s_y are the mean and standard deviation of the log transformed observed data. If the calculated value of the test statistic, K_{cal} is larger than the critical value K_{crt}, (obtained from *Grubbs and Beck, 1972*) for a given significance level, then all values higher than X_H are assumed to be outliers. This test was applied to the observed data and the results are shown in Tables 5.2 and 5.3. As can be see from these tables, the rainfall and flow samples were found to have 12 and 4 outliers respectively, indicating that rainfall values are inherently more variable than runoffs. In the absence of historic data, no adjustment was made to the observations and the outliers were therefore treated as extreme manifestations of the random variability inherent in the data and thus were retained and processed in the same manner as the other observations in the sample.

Finally, a few stations had some annual peak flows missing due to gage malfunctioning. In these cases, the different record segments were analyzed as a continuous record with length equal to the sum of the various record segments. This is made possible due to the fact that "time independence" is a fundamental assumption on which frequency analysis is based. Details of the missing data are shown in Table 5.4.

5.3 Frequency Analysis

Hydrologic events are a result of several factors and therefore do not fit any one specific known statistical distribution. Four distributions, namely Normal, Lognormal, Extreme Value type I and Log Pearson type III will be investigated in this study and the best one selected for each station. The selections is done on the basis of visual inspection (graphical) and goodness of fit tests (statistical).

The graphical evaluation of the adequacy of a distribution is performed by plotting the observed data and the fitted distributions on the same probability plot where the best fitting distribution can be determined visually. The plotting of the observed data require the knowledge of plotting positions. Plotting position refers to the probability value assigned to each piece of data to be plotted. Numerous methods have been proposed for the determination of plotting positions (*Viessman et. al., 1977*) but the Weibull method has gained prominence because of its desirable properties (*Haan, 1977*). The Weibull plotting position is given by:

$$P = \frac{m}{n+1} \qquad (5.3)$$

where P is the probability of occurrence of an events, m is the rank starting with the highest observed event having a rank of 1 and n is the length of record. A procedure to compute the plotting positions is described in Table 5.5 using data from station number 1080. The observed data were plotted on normal probability scale using the above plotting positions as shown in Fig. 5.3. The rainfall and flow data for the rest of the stations were plotted using similar procedures and are shown in Figs. A1 to A46 in Appendix A.

The next step in frequency analysis is to fit the observed data with suitable frequency distributions. This was carried out using the frequency factor method explained below. *Chow (1951)* demonstrated that the magnitude and frequency X_T of a hydrologic event could be represented as

$$X_T = \bar{X} + K_T\, s \qquad (5.4)$$

where $\bar{X}$ and s are the mean and standard deviation of the observed data respectively and K_T is a frequency factor which is a function of the return period, probability distribution selected and properties of the observed data. The relationships between K_T and the return period T for the four distributions used in this study are :

i. Normal and Lognormal distributions:

The frequency factors for the normal and Lognormal distributions are the same as the standard normal variate z except that in case of the Lognormal it is applied to the logarithms of the original variables.

a. For normal distribution, $K_T = \frac{X_T - \bar{X}}{s} \Rightarrow X_T = \bar{X} + K_T s$

b. For the Lognormal , $K_T = \frac{Y_T - \bar{Y}}{s_y} \Rightarrow X_T = e^{Y_T}$

ii. Gumbel extreme value distribution:

The cumulative distribution function of this distribution is given by

$$F(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right] \Rightarrow 1-\frac{1}{T} = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right]$$
$$\Rightarrow \quad x = u - \alpha \ln\left(\ln\frac{T}{T-1}\right) \tag{5.5}$$

where α and u are the scale and location parameters of the distribution and are related to the mean and variance by

$$\alpha = \frac{\sqrt{6}}{\pi} s \quad and \quad u = \bar{X} - 0.45\, s \tag{5.6}$$

substituting the values of α and u from equation (5.6) into last relationship in equation (5.5)

$$X_T = \bar{X} + s\left[-0.45 - \frac{\sqrt{6}}{\pi}\ln\left(\ln\frac{T}{T-1}\right)\right] \tag{5.7}$$

therefore the frequency factor is give by

$$K_T = -0.45 - \frac{\sqrt{6}}{\pi}\ln\left(\ln\frac{T}{T-1}\right) \tag{5.8}$$

iii. Log Pearson type III

The frequency factor for this distribution depends on the return period and the coefficient of skewness C_s, and it is computed using the following relationship (*Chow et al.1988*):

$$K_T = z+(z^2-1)k+\frac{1}{3}(z^3-6z)k^2-(z^2-1)k^3+zk^4+\frac{1}{3}k^5 \tag{5.9}$$

where $k = \frac{C_s}{6}$. The logarithms of the required flow or rainfall quantiles are initially computed using the frequency factor given by equation (5.9), the mean $\overline{Y}$ and standard deviation s_y of the logarithms of the original data using the following relationship:

$$Y_T = \bar{Y}-K_T s_y \tag{5.10}$$

then the antilog of Y_T is computed to get the actual frequency and magnitude of the flows and rainfalls X_T, that is

$$X_T = e^{Y_T} \tag{5.11}$$

The application of the above procedures to compute the flood and rainfall quantiles are demonstrated using data from station 1080 in Tables 5.6a, 5.6b, 5.6c and 5.6d for normal, Lognormal, Gumbel and log Pearson distributions respectively. The results for the rest of the stations were computed using SWAMP, *Storm Water Management Programs (Haan, 1995)* and are shown in Table A1 to A91, in Appendix A. The observed data and the fitted distributions were plotted for each station on the same graph as shown in Figs. A1 to A46. The best fitting distributions can now be visually selected from these figures. A second, and probably a more objective way of identifying best fitting distributions is through the use of goodness of fit tests. The chi-square and the Kolmogorov-Smirnov (KS) are two commonly used goodness-of-fit tests. As indicated in section *3.5.1*, the chi-square test has severe limitations when applied to samples with few observations. Since the average length of flow records used in this study is just over 20 years, the chi-square test may not be able to reliably discriminate between competing distributions. Unlike the chi-square test, the KS test is distribution-free and does not require grouping of the data into class intervals. The KS test in conjunction with visual inspection will therefore be used to identify the best fitting distributions to the observed data. The KS test is based on the maximum difference D between the observed and fitted cumulative distributions and the procedure is explained in Table 5.7 and Fig. 5.4. If the maximum difference is less than the critical values D_{crt}, then the fitted distribution is considered to be a good fit to the observed data. On the basis of the KS test results shown in Tables 5.8a and 5.8b and visual inspection, the theoretical distributions that best fit the observed data are selected and the resulting quantiles (i.e flows and rainfalls of various return periods) determined as shown in Tables 5.9a and 5.9b.

5.4 Delineation of Homogeneous Regions

A problem that arises within regional flood frequency analysis is that different basins may be hydrologically distinct even when they are not separated by large distances. There is therefore a need to identify regions that are homogeneous with respect to relevant basin and climatic characteristics before proceeding with flood frequency studies. Cluster analysis, a multivariate statistical procedure, will be used to group watersheds that have similar characteristics.

Since the objective of this study is to develop procedures to estimate hydrological parameters for ungaged watersheds using data from gaged basins, it appears that the only available method by which an ungaged watershed can be judged similar to, or different from, others is by comparing basin and climatic characteristics. The first stage in the delineation of homogeneous regions is, therefore, the identification of relevant watershed and climatic characteristics that can be used as discriminating variables. The attributes that are used in the delineating process are restricted to those variables that are readily obtainable and available for all watersheds including rainfall pattern, physiographic characteristics, soil type and drainage area. The criteria used to delineate the homogeneous regions are:

a. The regions must be as small as possible to ensure homogeneity. To achieve this the number of clusters must be as large as possible.

b. In order to avoid "over fitting" of models in regression analysis, it is desirable that the number of parameters should not exceed 35% of the number of observations or stations in this case (*Haan, 1977*). In this study, preliminary investigations indicate that two parameters may be sufficient to describe the proposed models adequately. It is therefore recommended that the number of gaging stations in each cluster should not be less than five.

c. The clustering process should be able to produce results such that each watershed can be assigned to well defined geographic region.

A cluster analysis technique known as *K-means* (*Johnson and Wichern, 1992*) is used to carry out the grouping of the watershed into homogeneous regions. This technique divides the entire set of watersheds into *K* clusters based on the attributes of the basins. The number of clusters, *K*, can be varied and the characteristics of the resulting groups evaluated before a final decision is made as to the number of clusters appropriate for the specific application. The starting point for the *K-means* procedure is the partitioning of the watersheds into *K* initial clusters. The watersheds are then assigned to the cluster with the nearest centroid on the basis of a Euclidean distance measure. The centroid for the clusters receiving and losing a basin is recalculated until no more reassignments take place. The *K-means* algorithm in SYSTAT (*Wilkinson,1990*), a statistical software package, was used to identify clusters with similar characteristics. After several trials four clusters were identified that meet the above criteria. The results indicate that average annual rainfall was the only attribute that could provide well defined geographic regions. The country was therefore divided into four regions as shown in Fig.5.5 according to the following range of mean annual rainfall values:

Regions	Mean Annual Rainfall (mm)	Number of stations
Region 1	1200 to 1350	7
Region 2	< 1000	28
Region 3	> 1350	11
Region 4	1000 to 1200	12

5.5 Regional flood Frequency Models

The data required to develop regional models have now been assembled and the homogeneous regions identified. Two methods, namely the index-flood and regression-based, described in detail in sections 2.3.1 and 2.3.2 will be used to determine the model parameters.

5.5.1 Index flood method

The first step in the index-flood method involves the derivation of a dimensionless regional frequency curve for each region. This process is illustrated in Fig. 5.6 and is outlined as follows:

i. Prepare at site flood frequency curves and determine the magnitude and frequency of floods Q_T for each station, Fig. 5.6a.

ii. The flows of selected return periods at each station are divided by the index-flood, Q_2 in this case, to reduce them to dimensionless ratios and the means of the ratios for each frequency are computed, Fig. 5.6b. Q_2 is selected as the index flood primarily because it can be estimated with the greatest accuracy than any other flood with higher frequency. The 2-year flood is also closer to the mean flow given by $Q_{2.33}$ for flows that follow Gumbel distribution.

iii. Plot the mean ratios against return periods to produce a dimensionless regional flood frequency curve for each homogeneous region, Fig. 5.6c.

Using the procedure outlined above, dimensionless regional frequency curves were developed for each region and are shown in Fig. 5.7 and Figs. C1 to C4 in Appendix C. The next step involves the development of a relationship by which the index flood Q_2 can be determined using basin and climatic data. Once the index flood is determined, the transfer of data from gaged to ungaged sites can be effected by multiplying the dimensionless ratio Q_T/Q_2 by the index-flood Q_2. The relationship between the index-flood and the basin and climatic variables is determined using multiple regression analysis. The dependent variable in this relationship will be the index-flood, that is the flood with 2-year return period (Q_2) and the independent variables consist of watershed area, stream length, stream slope, average annual rainfall, daily rainfall and soil index. Details of the procedure are given in the following section.

5.5.2 Regression based methods.

The second technique used to determine regional frequency relationships is a regression based method. In this method multiple regression procedures are used to relate estimates of the 2-, 5-, 10-, 25-, 50-, and 100-year flows obtained from the individual station flood frequency analysis to watershed and climatic characteristics. The technique is based on the assumption that certain physiographic and climatic variables produce or affect streamflow from a basin. The regression equation most commonly used in hydrology has the general form given in equation (5.0). The coefficients *c, a, s, l, r, p* and *g* are regression parameters and are determined by regression analysis of the information collected at gaged sites.

Logarithmic transformations were performed on all flows and basin characteristics prior to the regression analysis. This was done in order to obtain linear relations between the dependent and independent variables.

The regression parameters which define the regional frequency models were determined using stepwise regression procedures. Stepwise regression was employed to help screen out those independent variables that do not significantly contribute to the prediction of the flows. The ease and accuracy of measurement of the basin and climatic variables were also considered in the selection of independent variables to include in the models. Here again SYSTAT (*Wilkinson, 1990*) was used to perform the regression analysis.

Of all the variables investigated, the watershed area and the annual average rainfall were found to be the most significant contributors for the prediction of the flow quantiles. For Region 1 the most significant variables were the watershed area and the annual average rainfall, whereas area alone was the main contributing factor for Regions 3 and 4. The models developed for Regions 1, 3 and 4 are summarized in Tables 5.10a to 5.10c and in Figs. 5.8a to 5.8f. In addition to the regression equations, the tables show the coefficient of determination R^2 and the standard error of estimates in log units.

Region 2 with an annual rainfall of less than 1000 mm per year is the driest region in the country. Unlike the other regions, the data from this region appear to behave independently of the basin characteristics. In regions 1, 3 and 4 the correlation coefficients between the 2-year flow and watershed areas are 0.76, 0.90 and 0.79 respectively, whereas in Region 2 the coefficient is only 0.22. It is therefore not surprising that the data from this region could not support the development of a meaningful relationships between the flows, basin and climatic variables. Alternative approaches that relate the index-flood to the mean of the observed peak flows were therefore investigated. Out of the many relationships that were studied, a simple linear regression of Q_2 on the mean flows shown in equation (5.12) gave the best result with a coefficient of determination of 0.992.

$$Q_2 = 1.659 + 0.765 Q_m , \qquad R^2 = 0.992 \tag{5.12}$$

Where Q_m is the mean observed flow. Equation (5.12) as it stands is applicable to gaged watersheds only since it requires Q_m, a quantity derived from measured data. Q_m cannot be directly estimated from ungaged stations. Of the several options that were investigated to estimate Q_m from ungaged basins, the "regional mean flow" method appears to be more convincing. A regional contour map of the mean observed flows was therefore prepared for this region and is shown in Fig. 5.9. The value of Q_m at any location within the region can now be estimated using this map. This is made possible due to the fact that there appear to be no relationships between flows and basin and climatic variables in this region. The only information needed to apply equation (5.12) is the location of the ungaged station for which data is required. Once the location is identified, Q_m can be determined from Fig. 5.9 and subsequently Q_2 is computed using equation (5.12). The value of Q_2 can then be used together with the dimensionless regional frequency curves developed in section 5.5.1 to determine the magnitude and frequency floods at ungaged sites. The uniqueness of this region could be attributed to the fact that the western part of the region is at the fringes of the Kalahari desert. This part of the region is extremely flat forming vast plains comprising of deep kalahari sands which are flooded annually.

5.5.3 Adequacy of Models

The regression models developed above are based on several assumptions concerning the residuals or the differences between the predicted and observed values. For a regression model to be an effective predictive tool, not only do the residuals have to be small but the regression assumptions must at the same time be satisfied. The analysis of regression residuals is therefore an important tool for detecting inadequacies in the models. As discussed in section 3.7.2 a well fitting regression model will generate residuals that are independently and normally distributed with constant variance. To test these assumptions the residuals were plotted against estimated (predicted) values and the independent variables (Area and Rainfall) shown in Figs. B1 to B18 in Appendix B. Despite the few number of data points in some of the plots, the figures still show random scattering of the residual above and below the zero-residual line indicating that the residuals are indeed independent. These figures also show the absence of any significant pattern in the residuals associated with changes in the estimated values or the independent variables, an indication that the variances of the residuals are fairly constant. Of all the assumptions about the residuals, the assumption that the residuals are normally distributed is the least restrictive. Non normality of the residuals is detected using normal probability plots shown in Figs. B1 to B18. The expected results from a normal probability plot when the residuals are a sample from a normal distribution is a straight line. The figures indicate that some of the residuals particularly those from Region 1 show moderate departures from the assumption of normality. Finally, the plots for the observed against predicted values indicate the quality of the predictive ability of the regression models diminishes as the return period increases. The correlation coefficients between the observed and predicted values for Regions 1, 3 and 4 for the 2-year flood are 0.86, 0.91 and 0.86 respectively whereas for the 100-year flood they are 0.68, 0.76 and 0.66 respectively. This is reasonable in that the average record length in this study being 20 years, the probability that a sample of this size will contain a 2-year flood is almost 100% as shown in equation (3.4) but the probability drops drastically to less than 20% that this sample will contain a 100-year flood. The reduction in the predictive ability of the model is therefore not a weakness in the model itself but the result of inadequate data.

5.5.4 Models Limitations

a. The regional flood frequency models developed in this study provide estimates of flow in streams where the flow is not significantly altered by dams, diversions or other man made influences such as channel improvements.

b. The models are valid for watershed areas not exceeding 2500 square miles (6500 km^2).

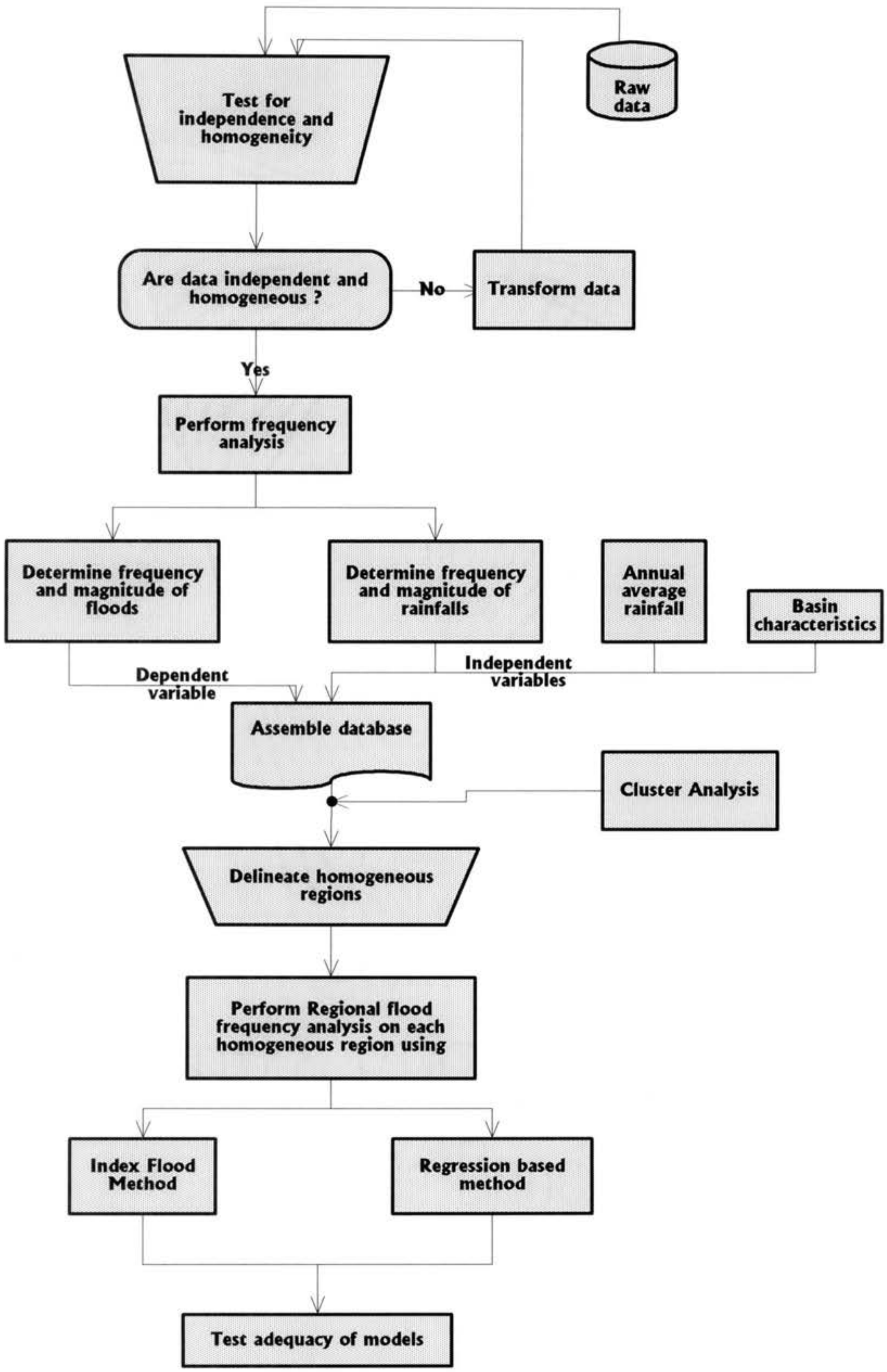


Fig. 5.1 : Methodology

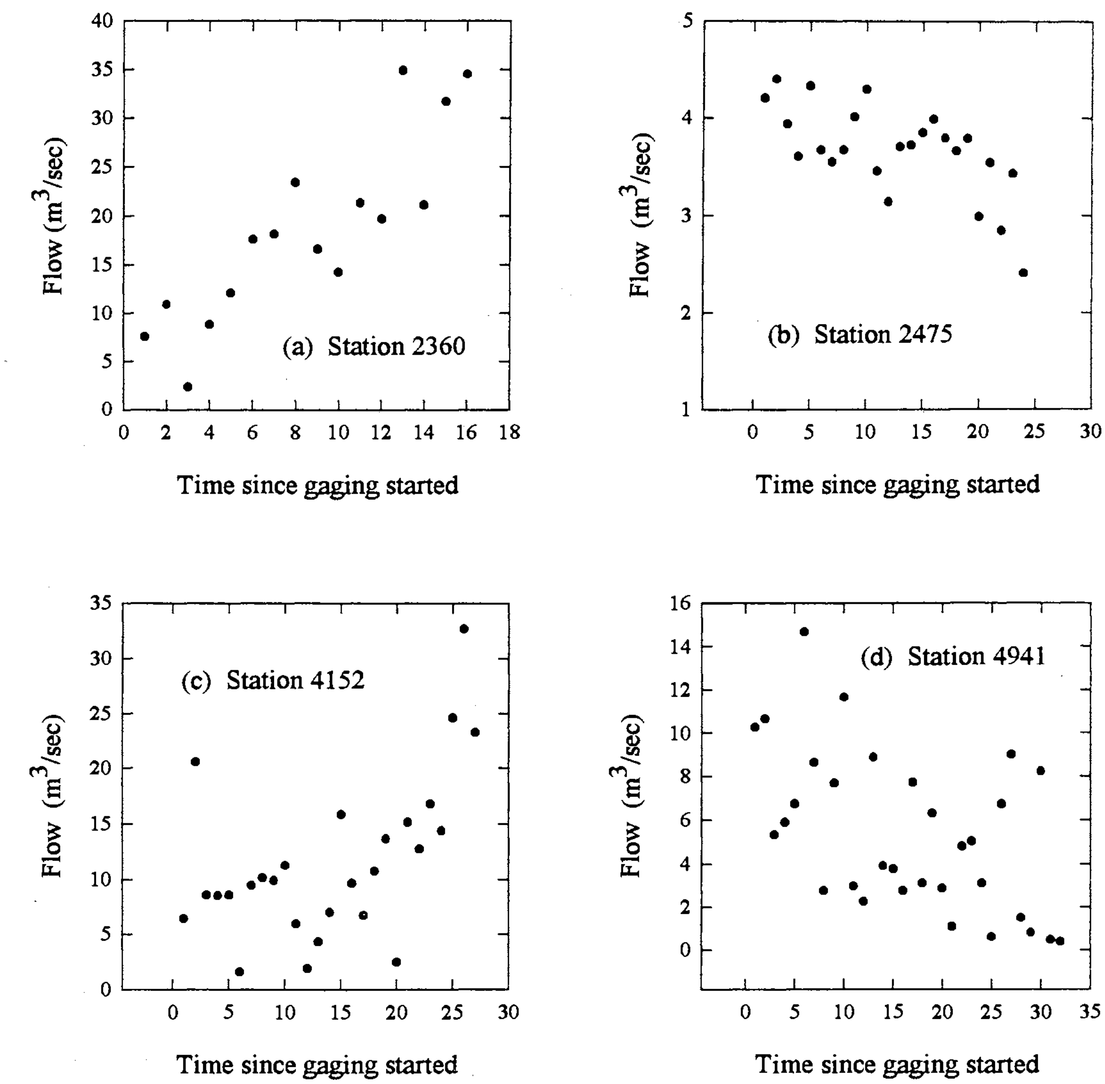
Table 5.1a : Results of Spearman's rank correlation test

Station	Record length	Rank correlation	Critical value at a = 0.01	Are data independent ?
1080	19	0.082	0.608	yes
1145	30	0.458	0.478	yes
1205	21	0.026	0.576	yes
1305	12	0.137	0.780	yes
1315	12	0.042	0.780	yes
1425	13	0.132	0.745	yes
1430	16	0.566	0.666	yes
2360	16	0.870	0.666	No
2475	24	0.604	0.537	No
3370	12	0.601	0.780	yes
4005	29	0.383	0.487	yes
4050	32	0.268	0.478	yes
4090	32	0.399	0.478	yes
4100	29	0.037	0.487	yes
4120	31	0.202	0.478	yes
4152	27	0.531	0.505	No
4170	18	0.110	0.625	yes
4205	23	0.162	0.549	yes
4210	12	0.476	0.780	yes
4239	17	0.048	0.645	yes
4240	20	0.275	0.591	yes
4245	22	0.331	0.562	yes
4250	24	0.064	0.537	yes
4266	15	0.170	0.689	yes
4272	12	0.375	0.780	yes
4281	21	0.416	0.576	yes
4302	22	0.181	0.562	yes
4310	21	0.047	0.576	yes
4460	19	0.441	0.608	yes
4500	23	0.076	0.549	yes
4620	29	0.355	0.487	yes

Table 5.1a : Results of Spearman's rank correlation test (cont)

Station	Record length	Rank correlation	Critical value at $\alpha = 0.01$ *	Are data independent ?
4821	25	0.142	0.526	yes
4850	23	0.352	0.549	yes
4940	29	0.066	0.487	yes
4941	32	0.524	0.478	No
4945	30	0.248	0.478	yes
4950	35	0.190	0.478	yes
4952	28	0.275	0.478	yes
4958	32	0.357	0.478	yes
5030	32	0.053	0.478	yes
5670	26	0.001	0.505	yes
6140	19	0.075	0.608	yes
6145	17	0.206	0.645	yes
6160	13	0.176	0.745	yes
6170	32	0.034	0.478	yes
6200	28	0.449	0.496	yes
6235	31	0.149	0.478	yes
6242	35	0.132	0.478	yes
6250	27	0.100	0.505	yes
6275	20	0.255	0.591	yes
6330	31	0.575	0.478	No
6340	16	0.025	0.666	yes
6480	28	0.042	0.496	yes
6486	20	0.188	0.591	yes
6500	10	0.450	0.794	yes
6510	22	0.248	0.562	yes
6860	15	0.023	0.689	yes
6935	30	0.224	0.478	yes

* ... Source : Mendenhall and Sincich 1992



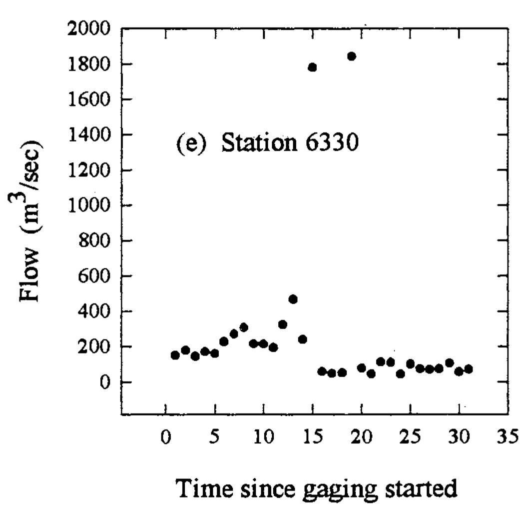


Fig. 5.2 : Plot of selected flow data

Table 5.2 : Test for outliers, flows

Station	Lmean **	Lstd	N	Kcrt	Max	Lmax	Kcal	Presence of outlier
1080	2.994	0.288	19	2.532	28.95	3.366	1.288	No
1145	3.622	0.309	30	2.745	59.38	4.084	1.497	No
1205	4.225	0.750	21	2.58	241.11	5.485	1.680	No
1305	3.163	0.177	12	2.285	37.29	3.619	2.571	Yes
1315	2.938	0.120	12	2.285	21.75	3.080	1.185	No
1425	3.510	0.687	13	2.331	77.15	4.346	1.217	No
1430	5.443	0.447	16	2.443	529.76	6.272	1.857	No
2360	2.748	0.675	16	2.443	34.87	3.552	1.191	No
2475	1.291	0.139	24	2.644	4.4	1.482	1.375	No
3370	1.284	0.335	12	2.285	5.19	1.647	1.083	No
4005	2.367	0.200	29	2.73	13.51	2.603	1.179	No
4050	4.802	0.801	32	2.773	2647.9	7.882	3.845	Yes
4090	4.788	0.912	32	2.773	501.12	6.217	1.566	No
4100	2.229	0.455	29	2.73	16.87	2.826	1.311	No
4120	3.509	0.483	31	2.759	177.3	5.178	3.458	Yes
4152	2.234	0.732	27	2.698	32.7	3.487	1.713	No
4170	2.419	0.296	18	2.504	19.98	2.995	1.943	No
4205	3.431	0.878	23	2.624	88.95	4.488	1.204	No
4210	2.580	0.599	12	2.285	31.31	3.444	1.443	No
4239	1.456	0.886	17	2.475	10.69	2.369	1.030	No
4240	2.513	0.422	20	2.557	24.88	3.214	1.663	No
4245	3.642	0.699	22	2.603	105.33	4.657	1.454	No
4250	3.177	0.156	24	2.644	29	3.367	1.222	No
4266	0.474	0.683	15	2.409	2.98	1.092	0.905	No
4272	3.544	0.951	12	2.285	140.59	4.946	1.474	No
4281	1.865	1.552	21	2.58	53.28	3.976	1.360	No
4302	4.357	0.773	22	2.603	155.18	5.045	0.890	No
4310	4.153	0.441	21	2.58	89.61	4.495	0.775	No
4460	2.500	0.937	19	2.532	25.68	3.246	0.795	No
4500	3.748	0.445	23	2.624	92.15	4.523	1.743	No
4620	3.037	1.118	29	2.73	113.11	4.728	1.512	No
4821	3.251	1.474	25	2.663	162.89	5.093	1.250	No
4850	6.502	1.505	23	2.624	7322.28	8.899	1.592	No

Table 5.2 : Test for outliers, flows (cont.)

Station	Lmean **	Lstd	N	Kcrt	Max	Lmax	Kcal	Presence of outlier
4940	2.728	0.833	29	2.73	42.62	3.752	1.230	No
4941	1.342	0.956	32	2.773	14.68	2.686	1.407	No
4945	4.048	0.897	30	2.745	250.83	5.525	1.646	No
4950	2.393	1.062	35	2.811	51.06	3.933	1.449	No
4952	2.624	0.224	28	2.714	20.54	3.022	1.780	No
4958	2.479	1.500	32	2.773	103.29	4.638	1.439	No
5030	1.475	0.831	32	2.773	20.64	3.027	1.869	No
5670	3.314	0.577	26	2.681	72.72	4.287	1.685	No
6140	4.198	0.237	19	2.532	91.48	4.516	1.346	No
6145	4.741	0.186	17	2.475	137.72	4.925	0.994	No
6160	0.607	0.137	13	2.331	2.41	0.880	1.998	No
6170	3.192	0.272	32	2.773	37.85	3.634	1.622	No
6200	2.521	0.752	28	2.714	39.63	3.680	1.541	No
6235	3.750	0.160	31	2.759	59.45	4.085	2.103	No
6242	1.173	0.281	35	2.811	6.53	1.876	2.505	No
6250	3.826	0.358	27	2.698	88.66	4.485	1.843	No
6275	0.964	1.392	20	2.557	110.15	4.702	2.685	Yes
6330	4.991	0.922	31	2.759	1842.84	7.519	2.742	No
6340	0.078	0.708	16	2.443	4.74	1.556	2.087	No
6480	1.257	0.694	28	2.714	14.21	2.654	2.013	No
6486	3.630	0.712	20	2.557	197.13	5.284	2.322	No
6500	3.425	0.134	10	2.176	37.14	3.615	1.421	No
6510	2.033	0.055	22	2.603	8.28	2.114	1.479	No
6860	4.893	0.250	15	2.409	218.24	5.386	1.970	No
6935	3.627	0.400	30	2.745	71.62	4.271	1.610	No

** ....

Station	Station identification number
Lmean	Mean logatithm of systematic peaks
Lstd	Standard deviation of systematic peak
N	Length of record or number of observations
Kcrt	Critical values of test statistic at 5% significance level (from Grubb and Bech, 1972)
Max	Maximum of peak flows
Lmax	Logarith of maximum peak flows
Kcal	Calculated test statistic using equation (5.1)
Lskew	Skew coefficient of log transformed observations.

Table 5.3 : Test for outliers , rainfall

Station **	Lmean	Lstd	N	Kcrt	Max	Lmax	Kcal	Presence of outlier
CHIP2	4.193	0.260	46	2.923	138.7	4.932	2.843	No
CHOMA1	4.092	0.308	43	2.896	116.3	4.756	2.153	No
ISOKA1	4.115	0.200	15	2.409	83.7	4.427	1.562	No
KABOM1	4.145	0.263	32	2.773	98.6	4.591	1.696	No
KABW1	4.171	0.241	43	2.896	121.9	4.803	2.622	No
KAFIR1	4.318	0.275	26	2.681	180	5.193	3.181	Yes
KAFUE1	4.283	0.465	35	2.881	495	6.205	4.135	Yes
KAOMA1	4.092	0.262	32	2.773	144.5	4.973	3.364	Yes
KASA1	4.169	0.183	55	2.992	94.5	4.549	2.076	No
KASE1	4.283	0.396	54	2.986	253.2	5.534	3.157	Yes
KAWAM1	4.165	0.159	36	2.823	80.7	4.391	1.424	No
LIVI2	4.146	0.333	51	2.964	147.8	4.996	2.554	No
LUNDA1	4.170	0.284	37	2.835	121.9	4.803	2.231	No
LUSAKA1	4.124	0.293	26	2.681	105.1	4.655	1.816	No
MAGOY1	4.069	0.202	15	2.409	93.9	4.542	2.340	No
MANSA1	4.129	0.215	33	2.786	95	4.554	1.980	No
MBALA1	4.170	0.213	32	2.773	115.4	4.748	2.718	No
MFUWE1	4.104	0.281	14	2.371	90.9	4.510	1.444	No
MISA1	4.287	0.245	19	2.532	140.2	4.943	2.674	Yes
MONG2	4.188	0.363	48	2.940	236.7	5.467	3.527	Yes
MPIKA1	4.200	0.415	56	3.000	497	6.209	4.845	Yes
MSEKE1	4.088	0.248	11	2.234	94.9	4.553	1.875	No
MTMAK1	4.231	0.455	32	2.773	208	5.338	2.431	No
MUMBW1	4.296	0.556	15	2.409	380	5.940	2.956	Yes
MWINI1	4.241	0.259	43	2.896	122.5	4.808	2.188	No
NDOL2	4.287	0.494	49	2.948	1198	7.088	5.671	Yes
PETA1	4.177	0.258	43	2.896	118.4	4.774	2.316	No
SAMFY1	4.588	0.310	26	2.681	226.8	5.424	2.695	Yes
SENA1	4.097	0.342	13	2.331	98.4	4.589	1.438	No
SERE1	4.292	0.271	36	2.823	141.7	4.954	2.441	No
SESHE1	4.095	0.395	39	2.857	307.6	5.729	4.132	Yes
SOLW1	4.280	0.239	32	2.773	130.4	4.871	2.478	No
ZAMBE1	4.226	0.566	39	2.857	1180	7.073	5.027	Yes

** .. Station — Station identification number
Lmean — Mean of logarithms of observed data
Lstd — Standard deviation of logarithms of observed data
N — Number of observation
Kcrt — Critical values of test stattistic at 5% significance level (Grubb and Bech, 1972)
Max — Maximum of peak values at each station
Lmax — Logarithm of maximum observation
Kcal — Calculated test statistic

Table 5.4 : Missing data

Station	Number of data missing	Year(s) for which data are missing
4050	1	1975
4120	1	1961
4272	1	1973
4620	1	1964
6200	1	1964
6340	2	1977 and 78
6860	2	1974, 77
6935	1	1969

Table 5.5 : Computation of plotting positions

Original data Flow in m3/sec	Sorted in decending order	Order m	Plotting positions P = (m/n+1) or (Prob. of exceedance)	Return period T = 1/P
22.31	28.95	1	0.05	20.00
21.67	28.83	2	0.10	10.00
15.55	28.00	3	0.15	6.67
12.31	27.30	4	0.20	5.00
21.86	25.01	5	0.25	4.00
19.49	23.78	6	0.30	3.33
18.50	22.31	7	0.35	2.86
28.00	21.86	8	0.40	2.50
16.74	21.67	9	0.45	2.22
21.60	21.60	10	0.50	2.00
23.78	20.04	11	0.55	1.82
25.01	19.49	12	0.60	1.67
20.04	18.50	13	0.65	1.54
16.99	16.99	14	0.70	1.43
28.83	16.74	15	0.75	1.33
28.95	15.55	16	0.80	1.25
27.30	14.56	17	0.85	1.18
14.56	12.31	18	0.90	1.11
10.32	10.32	19	0.95	1.05

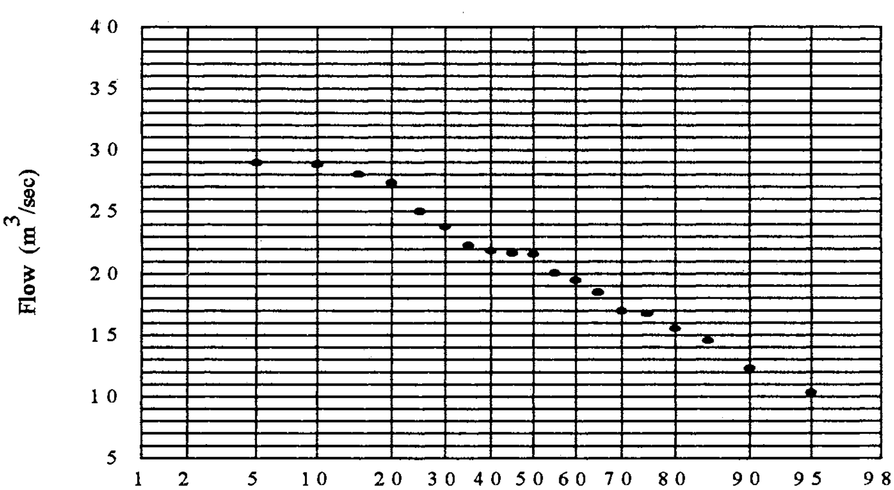


Fig. 5.3 : Peak flows plotted on normal probability scale

Table 5.6a : Fitting normal distribution to observed data

Mean	20.727
std	5.494
skew	-0.133

Normal Distribution

1	2	3	4
Probability of exceedence	Return period	Frequency factor	Magnitude of event with T return period
P	T=1/P	$K_T = z$	$X_T = X + K_T s$
99	1.01	-2.33	7.94
80	1.25	-0.84	16.11
70	1.43	-0.53	17.82
60	1.67	-0.28	19.19
50	2.00	0.00	20.73
43	2.33	0.18	21.72
30	3.33	0.52	23.58
20	5.00	0.84	25.34
15	6.67	1.02	26.33
10	10.00	1.28	27.76
7	14.29	1.50	28.97
5	20.00	1.65	29.76
4	25.00	1.75	30.34
2	50.00	2.05	31.99
1	100.00	2.33	33.51
0.2	500.00	2.88	36.55
0.1	1000.00	3.09	37.70

Mean	Mean of observed data
std	Standard deviation of observed data
Column 1	Probability of exceedence, P
Column 2	Return period T= 1/ Column 1
Column 3	Frequency factor K_T = standard normal variate z
Column 4	Magnitude of hydrologic event with a return period of T

Table 5.6b : Fitting lognormal distribution to observed data

Lmean	2.994
Lstd	0.288
Lskew	-0.700

Lognormal Distribution

1 Probability of exceedance	2 Return period	3 Frequency factor	4 logs of events with a return period of T	5 Magnitude of event with T return period
P	T=1/P	$K_T = z$	$Y_T = Y + K_T s_y$	$X_T = \exp(Y_T)$
99	1.01	-2.33	2.32	10.21
80	1.25	-0.84	2.75	15.68
70	1.43	-0.53	2.84	17.15
60	1.67	-0.28	2.91	18.43
50	2.00	0.00	2.99	19.98
43	2.33	0.18	3.05	21.04
30	3.33	0.52	3.14	23.20
20	5.00	0.84	3.24	25.45
15	6.67	1.02	3.29	26.80
10	10.00	1.28	3.36	28.89
7	14.29	1.50	3.43	30.78
5	20.00	1.65	3.47	32.09
4	25.00	1.75	3.50	33.08
2	50.00	2.05	3.59	36.06
1	100.00	2.33	3.67	39.06
0.2	500.00	2.88	3.82	45.81
0.1	1000.00	3.09	3.89	48.67

Lmean	Mean of log transformed data, Y = Ln X
Lstd	Standard deviation of log transformed data
Lskew	Skewness of the log transformed data
Column 1	Probability of exceedence, P
Column 2	Return period T= 1/ Column 1
Column 3	Frequency factor K_T = standard normal variate z
Column 4	Log of hydrologic event with a return period of T
Column 5	Magnitude of hydrologic event with a return period of T

Table 5.6c : Fitting Gumbel distribution to observed data

Mean	20.727
std	5.494
skew	-0.133

Gumbel Distribution

1 Probability of exceedance	2 Return period	3 Frequency factor	4 Magnitude of event with T return period
P	T = 1/P	K_T	$X_T = X + K_T s$
99	1.01	-1.64	11.71
80	1.25	-0.82	16.22
70	1.43	-0.59	17.46
60	1.67	-0.38	18.63
50	2.00	-0.16	19.82
43	2.33	0.00	20.72
30	3.33	0.35	22.67
20	5.00	0.72	24.68
15	6.67	0.97	26.04
10	10.00	1.30	27.89
7	14.29	1.60	29.49
5	20.00	1.87	30.98
4	25.00	2.04	31.96
2	50.00	2.59	34.97
1	100.00	3.14	37.96
0.2	500.00	4.39	44.87
0.1	1000.00	4.94	47.84

Mean	Mean of observed data
std	Standard deviation of observed data
Column 1	Probability of exceedence, P
Column 2	Return period T= 1/ Column 1
Column 3	Frequency factor K_T computed using equation (5.8)
Column 4	Magnitude of hydrologic event with a return period of T

Table 5.6d : Fitting Log Pearson Type III distribution to observed data

Lmean	2.994
Lstd	0.288
Lskew	-0.7
Lskew/6	-0.117

Log Pearson type III

1 Probability of exceedence	2 Return period	3 Standard normal variate	4 Frequency factor	5 log of events with a return period of T	6 Magnitude of event with T return period
P	T = 1/P	z	K_T	$Y_T = Y+K_TS_y$	$X_T = \exp(Y_T)$
99	1.01	-2.33	-2.83	2.18	8.84
80	1.25	-0.84	-0.79	2.77	15.93
70	1.43	-0.53	-0.43	2.87	17.63
60	1.67	-0.28	-0.17	2.95	19.04
50	2	0	0.12	3.03	20.65
43	2.33	0.18	0.29	3.08	21.69
30	3.33	0.52	0.59	3.16	23.68
20	5	0.84	0.85	3.24	25.55
15	6.67	1.02	0.99	3.28	26.59
10	10	1.28	1.18	3.33	28.08
7	14.29	1.5	1.33	3.38	29.31
5	20	1.65	1.42	3.41	30.12
4	25	1.75	1.49	3.42	30.69
2	50	2.05	1.67	3.47	32.28
1	100	2.33	1.81	3.52	33.69
0.2	500	2.88	2.07	3.59	36.29
0.1	1000	3.09	2.16	3.62	37.19

Lmean	Mean of log transformed data, Y = Ln X
Lstd	Standard deviation of log transformed data
Lskew	Skewness of the log transformed data
Column 1	Probability of exceedence, P
Column 2	Return period T= 1/ Column 1
Column 3	Standard normal variate z
Column 4	Frequency factor K_T is computed using equation (5.9)
Column 5	Log of hydrologic event with a return period of T
Column 6	Magnitude of hydrologic event with a return period of T

Table 5.7: Kolmogorov - Sminrov Test

Parameters of Gumbel distribution

a = 4.284
u = 18.254

1 Original data	2 Rank m	3 Observed cumulative frequency Fo(x) = m/(n+1)	4 Fitted cumulative frequency Fm(X)	5 Difference between fitted and observed
10.32	1	0.050	0.002	0.048
12.31	2	0.100	0.018	0.082
14.56	3	0.150	0.094	0.056
15.55	4	0.200	0.153	0.047
16.74	5	0.250	0.241	0.009
16.99	6	0.300	0.261	0.039
18.50	7	0.350	0.389	0.039
19.49	8	0.400	0.473	0.073
20.04	9	0.450	0.517	0.067
21.60	10	0.500	0.633	0.133
21.67	11	0.550	0.637	0.087
21.86	12	0.600	0.650	0.050
22.31	13	0.650	0.678	0.028
23.78	14	0.700	0.759	0.059
25.01	15	0.750	0.813	0.063
27.30	16	0.800	0.886	0.086
28.00	17	0.850	0.902	0.052
28.83	18	0.900	0.919	0.019
28.95	19	0.950	0.921	0.029

Column 1	Observed data arranged in ascending order
Column 2	Rank of observation
Column 3	The cumulative observed distribution function = m/(n+1)
Column 4	Theoretical or fitted cumulative probability distribution
Column 5	Difference between cumulative observed and fitted distribution

- In this particular case the maximun deviation D = 0.133
- The critical tabulated value at 5% significance level = 0.301
- Since the calculated D is less than the critical D, it can be concluded that the fitted distribution, in this case Gumbel distribution, is a good fit.

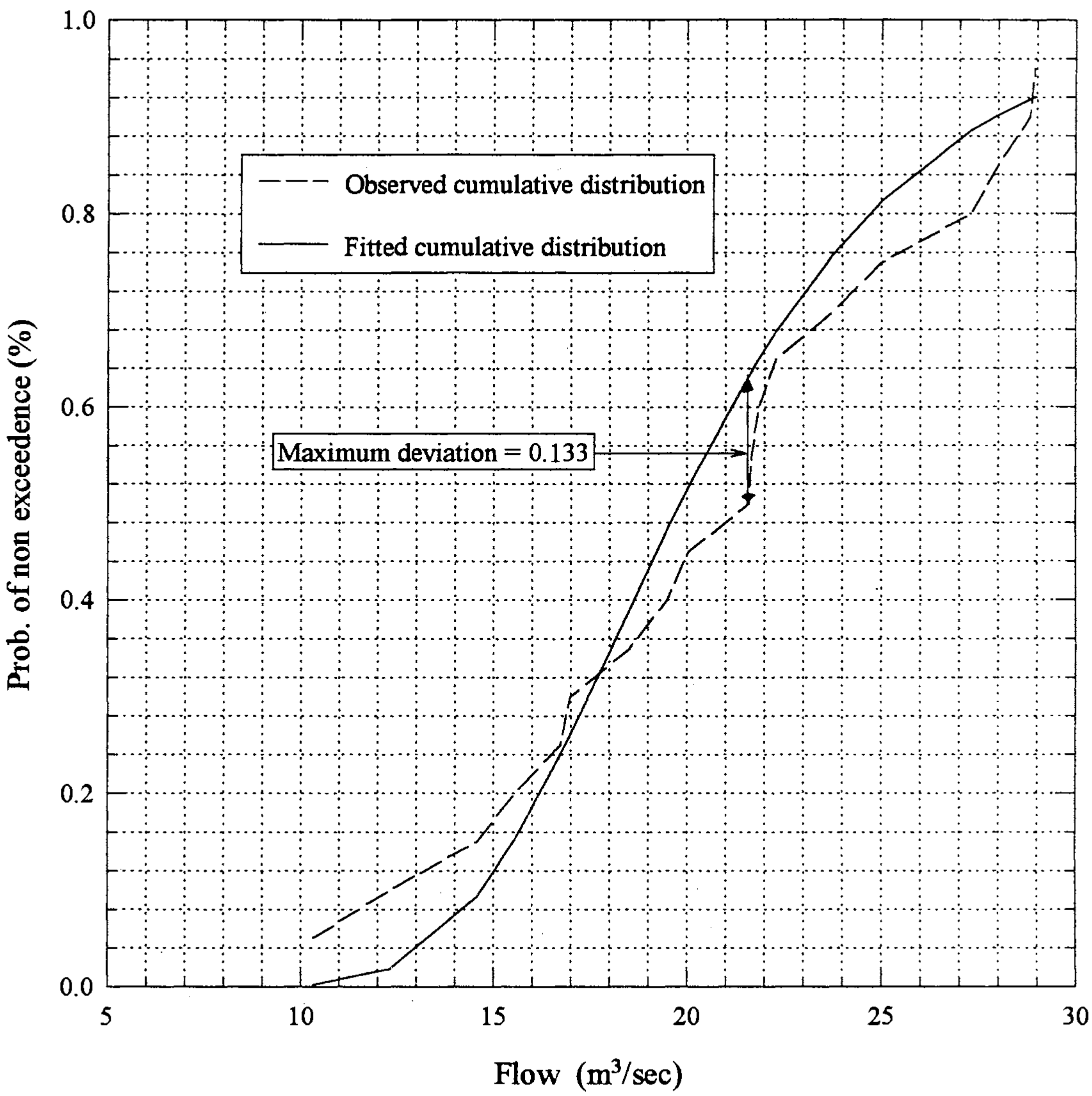


Fig. 5.4 : Kolmogorov-Smirnov Test

Table 5.8a : Results of Kolmogorov-Smirnov tests for flow data

Calculated values of KS statistic

Station	n	Normal	Log normal	Log Pearson	Gumbel	Minimum KS	Critical KS $\alpha = 5\%$	Preferred Distribution
1080	19	.101	.136	.092	.133	.092	.301	Lp3
1145	30	.109	.173	.106	.172	.106	.242	Lp3
1205	21	.205	.126	.124	.144	.124	.288	Lp3
1305	12	.367	.335	.284	.296	.284	.375	Lp3
1315	12	.146	.144	.123	.172	.123	.375	Lp3
1425	13	.126	.206	.138	.133	.126	.361	N
1430	16	.213	.183	.175	.178	.175	.328	Lp3
2360	16	.126	.163	.112	.110	.110	.328	Ev
2475	24	.142	.173	.143	.209	.142	.270	N
3370	12	.189	.217	.190	.208	.189	.375	N
4005	29	.104	.142	.132	.165	.104	.246	N
4050	32	.403	.159	.192	.384	.159	.237	Ln
4090	32	.164	.231	.163	.136	.136	.237	Ev
4100	29	.129	.197	.130	.176	.129	.246	N
4120	31	.285	.141	.172	.142	.141	.240	Ln
4152	27	.145	.153	.109	.080	.080	.255	Ev
4170	18	.129	.074	.078	.076	.074	.309	Ln
4205	23	.167	.152	.122	.141	.122	.276	Lp3
4210	12	.153	.181	.147	.135	.135	.375	Ev
4239	17	.142	.208	.151	.109	.109	.318	Ev
4240	20	.195	.278	.216	.252	.195	.294	N
4245	22	.143	.219	.165	.124	.124	.282	Ev
4250	24	.118	.142	.138	.182	.118	.270	N
4266	15	.182	.351	.253	.255	.182	.338	N
4272	12	.312	.286	.268	.234	.234	.375	Ev
4281	21	.225	.176	.103	.156	.103	.288	Lp3
4302	22	.173	.253	.104	.207	.104	.282	Lp3
4310	21	.256	.369	.274	.320	.256	.288	N
4460	19	.150	.267	.296	.195	.150	.301	N
4500	23	.152	.108	.111	.123	.108	.276	Ln
4620	29	.168	.115	.091	.161	.091	.264	Lp3
4821	25	.173	.210	.114	.115	.114	.264	Lp3
4850	23	.272	.101	.106	.218	.101	.276	Ln

Table 5.8a : Results of Kolmogorov-Smirnov tests for flow data (cont)

Calculated values of KS statistic

Station	n	Normal	Log normal	Log Pearson	Gumbel	Minimum KS	Critical KS $\alpha = 5\%$ *	Preferred Distribution
4940	29	.115	.185	.112	.088	.088	.264	Ev
4941	32	.137	.142	.078	.116	.078	.237	Lp3
4945	30	.260	.146	.134	.195	.134	.242	Lp3
4950	35	.178	.197	.128	.097	.097	.230	Ev
4952	28	.141	.143	.134	.138	.134	.251	Lp3
4958	32	.230	.161	.156	.196	.156	.237	Lp3
5030	32	.166	.082	.075	.125	.075	.237	Lp3
5670	26	.176	.111	.100	.110	.100	.260	Lp3
6140	19	.165	.180	.173	.188	.165	.301	N
6145	17	.162	.204	.156	.231	.156	.318	Lp3
6160	13	.334	.185	.186	.214	.185	.361	Ln
6170	32	.161	.200	.112	.191	.112	.237	Lp3
6200	28	.269	.238	.202	.208	.202	.251	Lp3
6235	31	.117	.108	.113	.142	.108	.240	Ln
6242	35	.150	.099	.086	.080	.080	.230	Ev
6250	27	.121	.160	.124	.142	.121	.255	N
6275	20	.402	.155	.177	.405	.155	.294	Ln
6330	31	.340	.104	.121	.339	.104	.253	Ln
6340	16	.280	.207	.205	.171	.171	.328	Ev
6480	28	.196	.101	.097	.102	.097	.251	Lp3
6486	20	.451	.345	.323	.399	.323	.294	Lp3
6500	10	.172	.192	.224	.219	.172	.409	N
6510	22	.184	.191	.244	.238	.184	.282	N
6860	15	.133	.143	.158	.164	.133	.338	N
6935	30	.082	.120	.058	.108	.058	.242	Lp3

n	Record length (years)
N	Normal
Ln	Log normal
Ev	Gumbel extreme value 1
Lp3	Log Pearson typ 3
*	Source : Haan, 1977

Table 5.8b : Results of the Kolmogorov-Smirnov tests for rainfall data

Calculated values of KS statistic

Station	N	Normal	Log normal	Log Pearson	Gumbel	Minimum KS	Critical KS $\alpha = 5\%$	Preferred Distribution
CHIP2	46	.080	.087	.105	.091	.080	.198	N
CHOMA1	43	.100	.151	.118	.166	.100	.204	N
ISOKA1	15	.133	.140	.131	.134	.131	.338	Lp3
KABOM1	32	.127	.104	.101	.110	.101	.237	Lp3
KABW1	43	.130	.101	.092	.087	.087	.204	Ev
KAFIR1	26	.185	.117	.072	.106	.072	.260	Lp3
KAFUE1	35	.309	.125	.131	.139	.125	.230	Ln
KAOMA1	32	.153	.086	.091	.103	.086	.237	Ln
KASA1	55	.093	.098	.093	.127	.093	.180	N / Lp3
KASE1	54	.204	.108	.074	.135	.074	.182	Lp3
KAWAM1	36	.064	.096	.058	.127	.058	.206	Lp3
LIVI2	51	.121	.059	.047	.066	.047	.188	Lp3
LUNDA1	37	.146	.123	.127	.140	.123	.222	Ln
LUSAKA1	26	.113	.082	.080	.092	.080	.260	Lp3
MAGOY1	15	.152	.140	.175	.144	.140	.338	Ln
MANSA1	33	.115	.076	.082	.074	.074	.235	Ev / Ln
MBALA1	32	.122	.102	.078	.081	.078	.237	Lp3
MFUWE1	14	.188	.122	.117	.136	.117	.349	Lp3
MISA1	19	.166	.110	.095	.090	.090	.301	Ev / Lp3
MONG2	48	.190	.117	.122	.110	.110	.194	Ev
MPIKA1	56	.281	.147	.150	.148	.147	.178	Ln / Ev
MSEKE1	11	.130	.097	.123	.110	.097	.391	Ln
MTMAK1	32	.277	.164	.116	.168	.116	.237	Lp3
MUMBW1	15	.408	.292	.241	.314	.241	.338	Lp3
MWINI1	43	.079	.070	.064	.075	.064	.204	Lp3
NDOL2	49	.439	.222	.305	.392	.222	.192	Ln
PETA1	43	.133	.081	.074	.068	.068	.204	Ev
SAMFY1	26	.182	.125	.078	.124	.078	.260	Lp3
SENA1	13	.251	.221	.220	.223	.220	.361	Lp3
SERE1	36	.098	.095	.093	.091	.091	.206	Ev / Lp3
SESHE1	39	.254	.158	.161	.155	.155	.212	Ev
SOLW1	32	.163	.111	.102	.093	.093	.237	Ev
ZAMBE1	39	.441	.179	.246	.424	.179	.212	Ln

Table 5.9a : Estimated flows for various return periods

1	2	3	4	5	6	7	8
Station	**Best fitting distribution**	Q2**	Q5	Q10	Q25	Q50	Q100
1080	Lp3	20.65	25.55	28.08	30.69	32.28	33.69
1145	Lp3	39.69	48.46	52.29	55.69	57.45	58.81
1205	Lp3	66.77	127.35	181.02	266.35	342.77	434.4
1305	Lp3	22.74	26.75	29.89	34.41	38.12	42.3
1315	Lp3	19.07	20.91	21.82	22.75	23.22	23.83
1425	N	39.44	55.97	64.63	73.87	79.77	85.22
1430	Lp3	240.07	338.52	397.23	464.5	509.44	552.03
2360	Ev	16.89	25.22	30.73	37.7	42.87	48
2475	Lp3	3.74	4.08	4.22	4.33	4.38	4.43
3370	Lp3	3.78	4.8	5.31	5.82	6.12	6.37
4005	Lp3	11.13	12.6	13.19	13.67	13.9	14.07
4050	Ln	121.74	238.56	339.35	494.44	628.72	784.88
4090	Ev	144.74	245.3	311.87	395.99	458.39	520.34
4100	N	10.14	13.35	15.03	16.83	17.97	19.03
4120	Lp3	30.15	46.95	63.35	92.38	121.51	160.35
4152	Ev	10.4	16.83	21.09	26.47	30.46	34.43
4170	Ln	11.23	14.41	16.42	18.87	20.63	22.39
4205	Lp3	35.48	65.11	83.57	104.18	117.2	128.77
4210	Ev	13.96	21.14	25.89	31.89	36.34	40.76
4239	Ev	4.95	7.71	9.54	11.84	13.56	15.26
4240	N	13.24	17.05	19.04	21.17	22.53	23.79
4245	Ev	41.41	62.29	76.11	93.57	106.53	119.39
4250	Lp3	25	27.13	27.8	28.24	28.4	28.48
4266	N	1.83	2.38	2.66	2.97	3.16	3.34
4272	Ev	40.21	69.27	88.51	112.82	130.85	148.75
4281	Lp3	7.85	24.26	39.62	62.44	80.58	99.66
4302	N	94.31	130.15	148.93	168.98	181.78	193.6
4310	N	67.78	82.57	90.31	98.59	103.87	108.75
4460	N	15.02	20.33	23.1	26.07	27.97	29.72
4500	Ln	42.45	61.68	75.01	92.46	105.66	119.51
4620	Lp3	36.52	63.1	72.01	76.74	77.8	78.01
4821	Ev	39.45	73.85	96.63	125.41	146.76	167.96
4850	Ev	1303.82	3147.85	4368.76	5911.38	7055.78	8191.73
4940	Ev	17.19	25.83	31.55	38.79	44.15	49.47
4941	Lp3	4.43	8.61	11.35	14.49	16.53	18.38

Table 5.9a : Estimated flows for various return periods (cont)

1 Station	2 Best fitting distribution	3 Q2 **	4 Q5	5 Q10	6 Q25	7 Q50	8 Q100
4945	Lp3	61.77	123.25	170.06	233.07	280.79	330.17
4950	Ev	13.55	23.55	30.18	38.55	44.76	50.92
4952	N	14.13	16.73	18.09	19.55	20.48	21.34
4958	Ev	22	49.26	67.31	90.11	107.02	123.81
5030	Lp3	4.61	8.87	12.15	16.65	20.14	23.83
5670	Ev	29.08	45.14	55.77	69.2	79.17	89.06
6140	Lp3	68.75	81.38	87.43	93.33	96.74	99.64
6145	Lp3	119.25	133.53	139.02	143.43	145.51	146.98
6160	Lp3	1.85	2.06	2.17	2.29	2.36	2.43
6170	Lp3	25.46	30.64	33.03	35.25	36.48	37.48
6200	Ev	13.83	21.73	26.96	33.57	38.48	43.35
6235	Ln	42.5	48.6	52.13	56.2	58.95	61.62
6242	Ln	3.23	4.09	4.63	5.28	5.75	6.21
6250	N	48.45	61.44	68.24	75.51	80.15	84.44
6275	Ln	2.62	8.45	15.58	29.97	45.51	66.92
6330	Ln	147.13	319.14	478.78	738.42	973.67	1256.93
6340	Ev	1.17	2.09	2.69	3.46	4.02	4.59
6480	Ev	3.88	6.63	8.45	10.75	12.46	14.16
6486	Lp3	31.91	61.27	96.46	172.45	264.3	408.59
6500	N	30.96	34.28	36.02	37.88	39.07	40.16
6510	Lp3	7.75	7.98	8.05	8.09	8.11	8.12
6860	N	137.36	166.59	181.9	198.25	208.69	218.32
6935	Lp3	39.13	52.93	60.71	69.25	74.75	79.81

Column 1	Station identification number
Column 2	Best fitting distribution selected by visual inspection and statistical tests
Column 3	Q2 ** refres to flood with a return period of two years
N	Normal distribution
Ln	Lognormal distribution
Ev	Gumbel extreme value type 1
Lp3	Log Pearson type III

Table 5.9b : Estimated rainfall values for various return periods

Station	Best fitting distribution	R2*	R5	R10	R25	R50	R100
CHIP2	N	68.47	84.01	92.16	100.85	106.41	111.53
CHOMA1	Lp3	62.25	77.89	85.87	94.00	98.89	103.15
ISOKA1	Lp3	61.51	72.51	78.85	86.07	90.94	95.61
KABOM1	Lp3	63.68	78.90	87.87	98.24	105.30	112.12
KABW1	Ev	63.96	78.77	88.57	100.96	110.15	119.28
KAFIR1	Lp3	70.94	91.32	108.12	133.56	155.61	181.53
KAFUE1	Ln	72.44	107.03	131.31	163.37	187.81	213.61
KAOMA1	Ln	59.85	74.59	83.70	94.67	102.42	110.13
KASA1	Lp3	64.83	75.45	81.56	88.55	93.26	97.79
KASE1	Lp3	68.75	98.47	122.79	159.62	191.55	229.15
KAWAM1	Lp3	65.77	73.69	77.37	80.89	82.90	84.60
LIVI2	Lp3	62.44	83.21	97.36	115.73	129.60	144.16
LUNDA1	Ln	64.73	82.15	93.08	106.35	115.80	125.27
LUSAKA1	Lp3	62.38	79.19	89.25	101.03	109.12	117.00
MAGOY1	Ln	58.51	69.34	75.79	83.34	88.55	93.65
MANSA1	Ln	62.09	74.37	81.74	90.42	96.44	102.35
MBALA1	Lp3	63.27	76.59	85.81	97.95	107.23	117.09
MFUWE1	Lp3	63.51	76.80	82.88	88.51	91.60	94.09
MISA1	Lp3	70.12	87.69	100.90	119.48	134.54	151.30
MONG2	Ev	65.44	94.53	113.79	138.13	156.19	174.11
MPIKA1	Ev	65.34	118.65	153.95	198.55	231.64	264.48
MSEKE1	Ln	59.64	73.43	81.89	92.00	99.09	106.13
MTMAK1	Lp3	62.02	94.13	125.51	181.09	236.86	311.30
MUMBW1	Lp3	62.76	103.61	150.48	247.20	359.56	530.58
MWINI1	Lp3	69.55	86.40	96.72	109.05	117.70	126.26
NDOL2	Ln	72.76	110.18	136.92	172.70	200.29	229.65
PETA1	Lp3	64.68	80.73	91.08	103.98	113.37	122.96
SAMFY1	Lp3	94.15	124.80	148.59	183.03	211.70	244.32
SENA1	Lp3	58.98	79.59	94.22	113.89	129.21	145.70
SERE1	Lp3	72.09	91.34	104.27	120.92	133.39	146.43
SESHE1	Ev	59.25	97.89	123.48	155.81	179.79	203.60
SOLW1	Ev	71.16	88.28	99.61	113.94	124.56	135.11
ZAMBE1	Ln	68.46	110.16	141.33	184.43	218.59	255.71

N	Normal
LN	Log normal
Ev	Gumbel Extreme value 1
Lp3	Log Pearson type 3
R2*	2-year daily rainfall

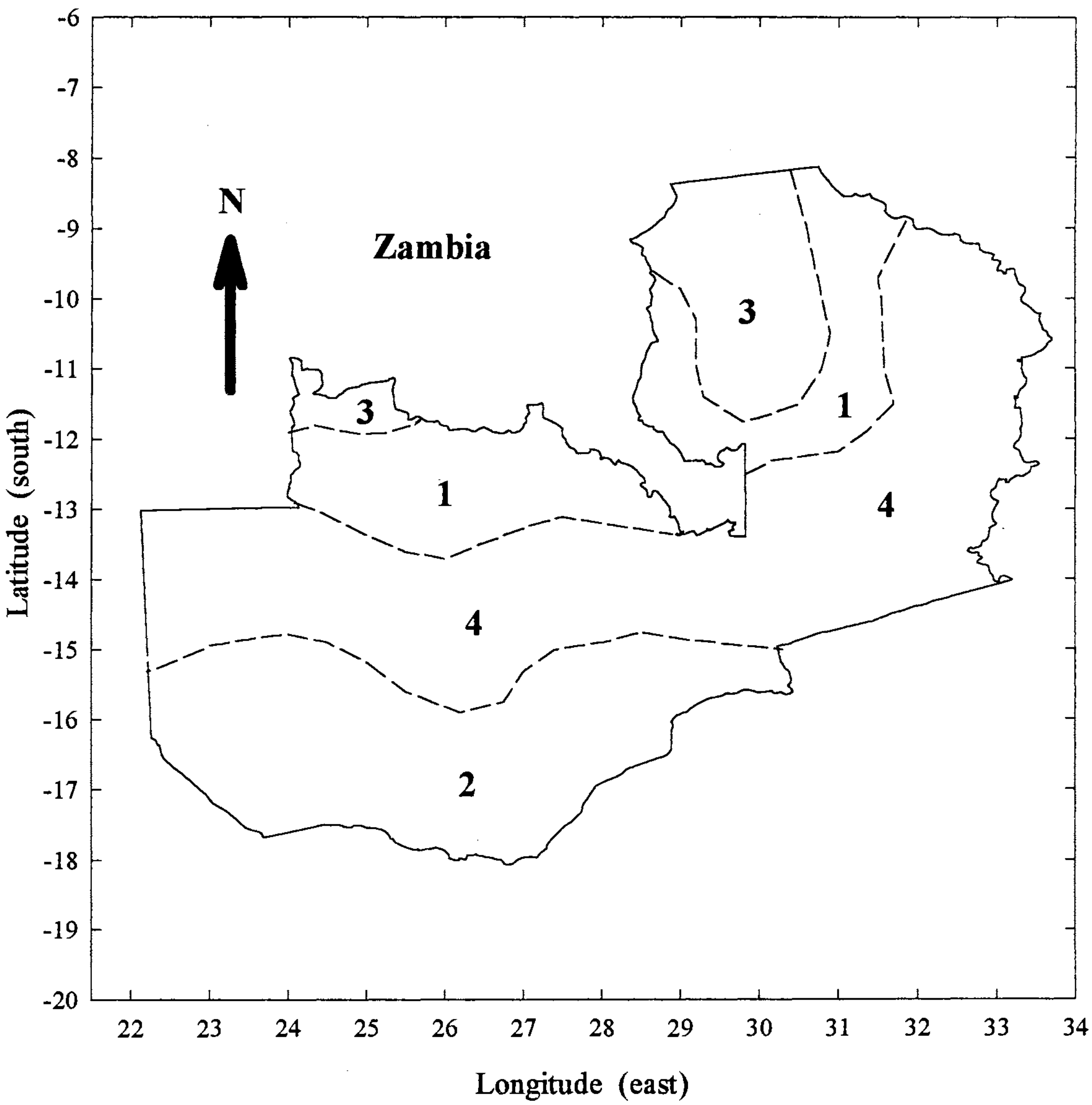
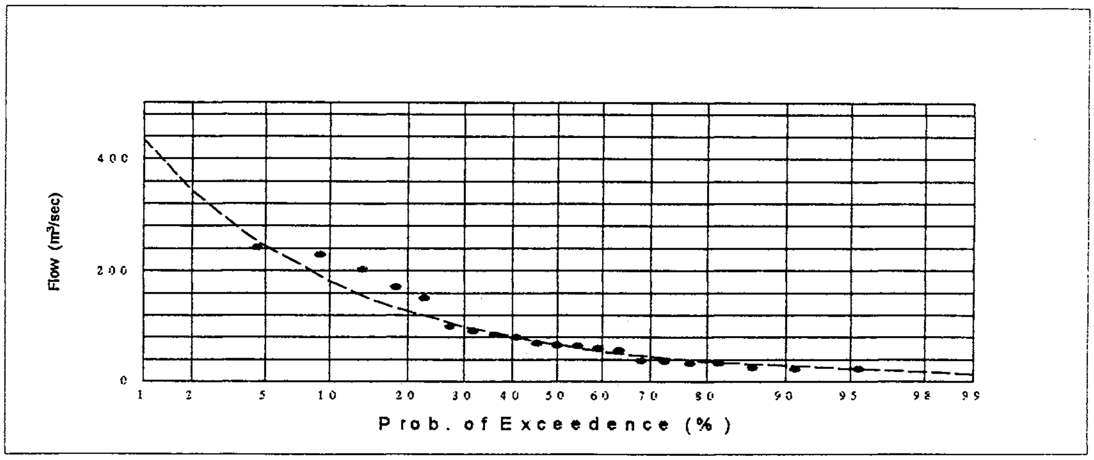


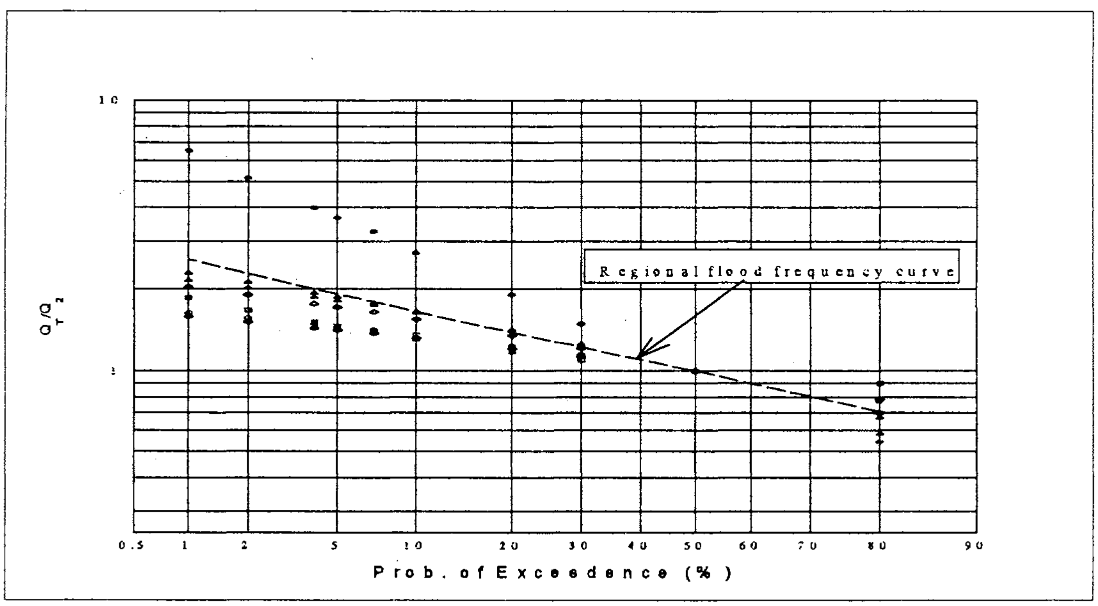
Fig. 5.5 : Hydrologic Regions



(a)

Station	Return period 1.25	2	3.33	5	10	14.28	20	25	50	100
1080	0.77	1.00	1.15	1.24	1.36	1.42	1.46	1.49	1.56	1.63
1205	0.54	1.00	1.49	1.91	2.71	3.24	3.66	3.99	5.13	6.51
1305	0.90	1.00	1.10	1.18	1.31	1.40	1.46	1.51	1.68	1.86
1425	0.58	1.00	1.26	1.42	1.64	1.75	1.82	1.87	2.02	2.16
1430	0.67	1.00	1.24	1.41	1.65	1.78	1.87	1.93	2.12	2.30
6860	0.79	1.00	1.13	1.21	1.32	1.38	1.42	1.44	1.52	1.59
6935	0.70	1.00	1.21	1.35	1.55	1.65	1.72	1.77	1.91	2.04
Mean	0.71	1.00	1.23	1.39	1.65	1.80	1.92	2.00	2.28	2.58

(b)



(c)

Fig. 5.6 : Index flood method of regional flood frequency analysis
(a) single station flood frequency curve, (b) Ratios of QT/Q2
(c) Regional flood frequency curve

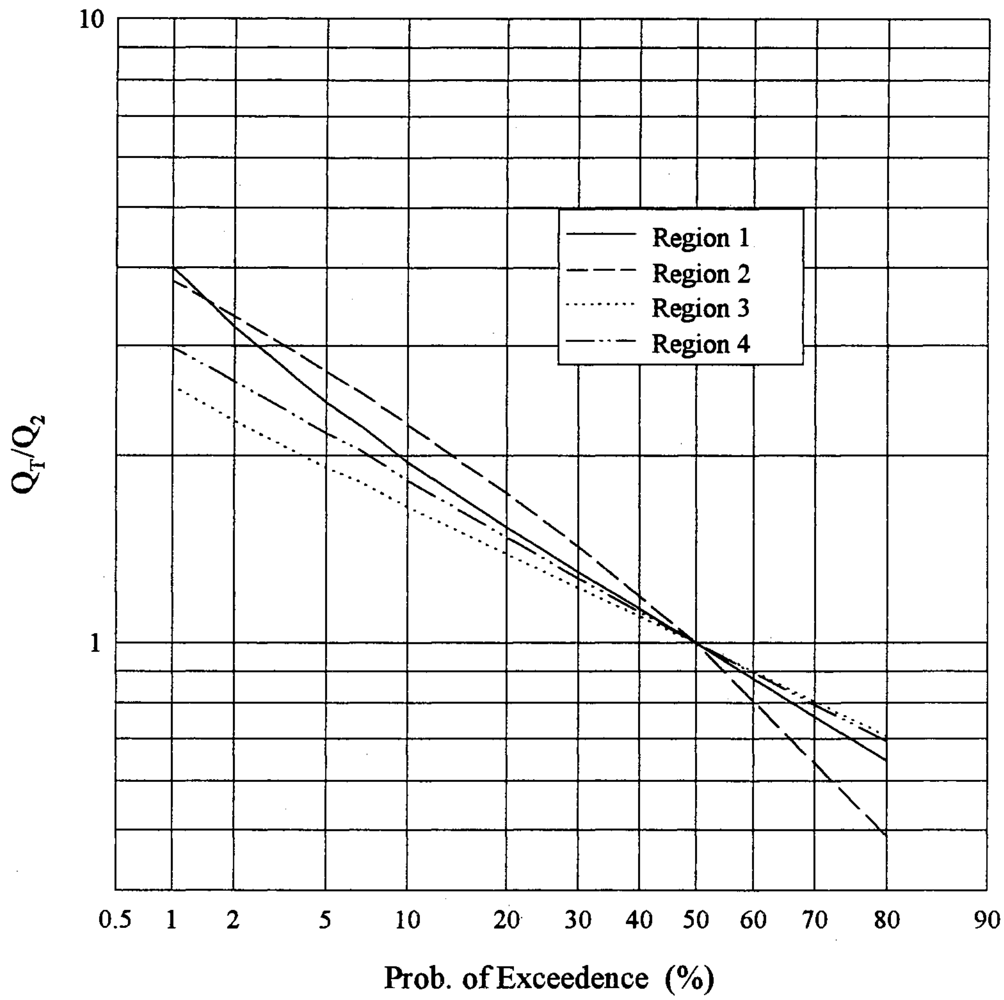


Fig. 5.7 : Dimensionless regional frequency curves for Regions 1, 2, 3 and 4

Table 5.10a : Equations for estimating magnitude and frequency of flows in Region 1

$$Q_2 = 0.0094\, A^{0.824}\, P^{8.146}, \qquad R^2 = 0.742, \qquad SE = 0.664$$

$$Q_5 = 0.0184\, A^{0.832}\, P^{6.778}, \qquad R^2 = 0.717, \qquad SE = 0.703$$

$$Q_{10} = 0.0248\, A^{0.842}\, P^{6.039}, \qquad R^2 = 0.687, \qquad SE = 0.757$$

$$Q_{25} = 0.1082\, A^{0.871}, \qquad R^2 = 0.635, \qquad SE = 0.849$$

$$Q_{50} = 0.1156\, A^{0.879}, \qquad R^2 = 0.605, \qquad SE = 0.912$$

$$Q_{100} = 0.1218\, A^{0.888}, \qquad R^2 = 0.573, \qquad SE = 0.982$$

Where Q is the flow to be estimated in m^3/sec, A is the watershed area in km^2 and P is the average annual rainfall in m.

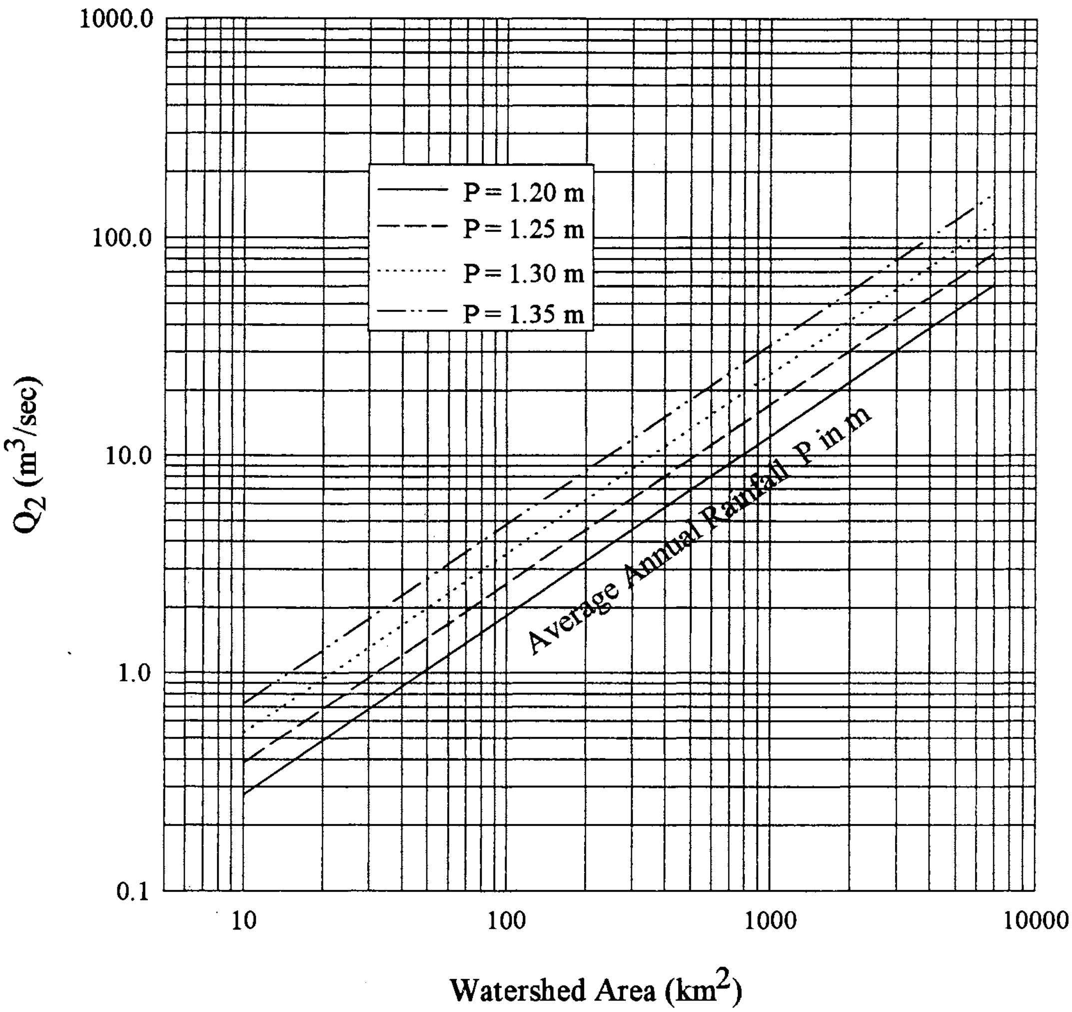


Fig. 5.8a : Frequency curves for Q_2 (Region 1)

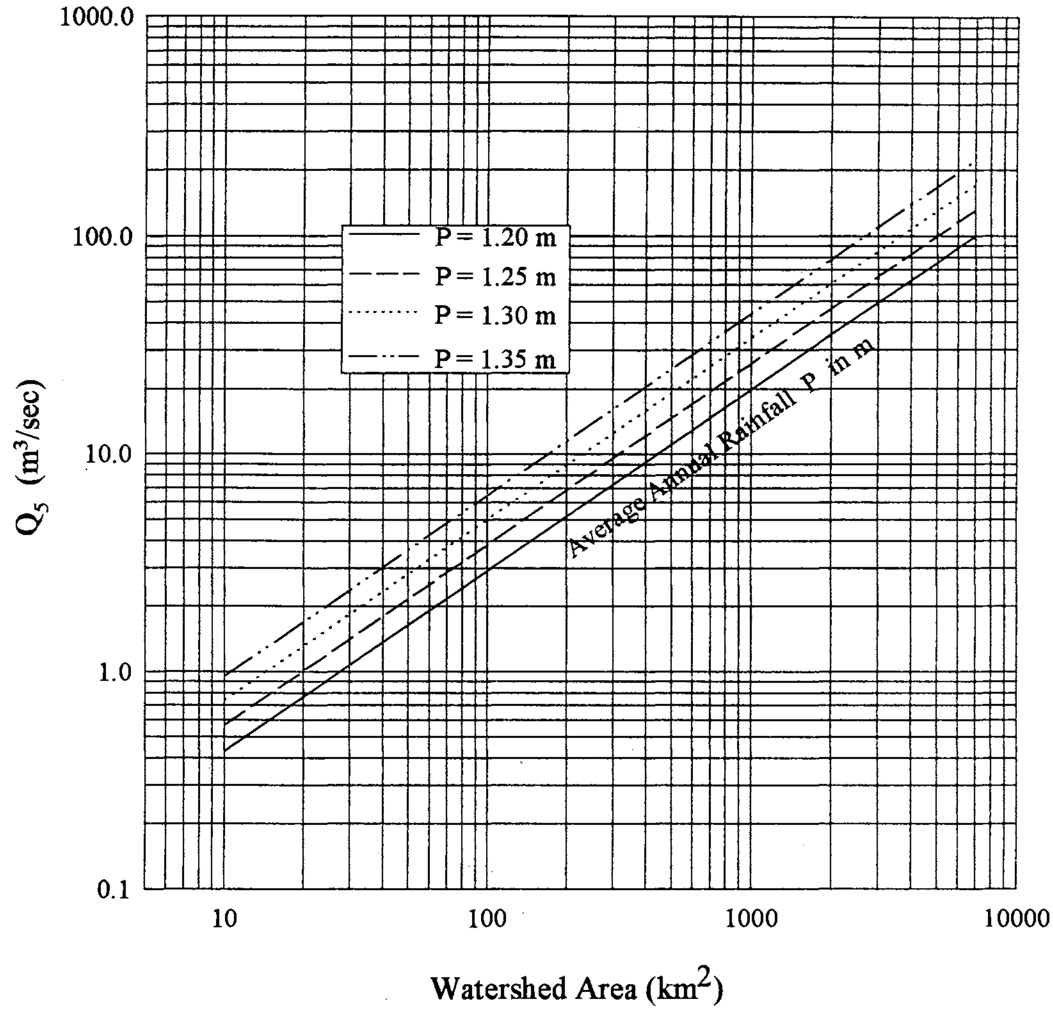


Fig. 5.8b : Frequency curves for Q_5 (Region 1)

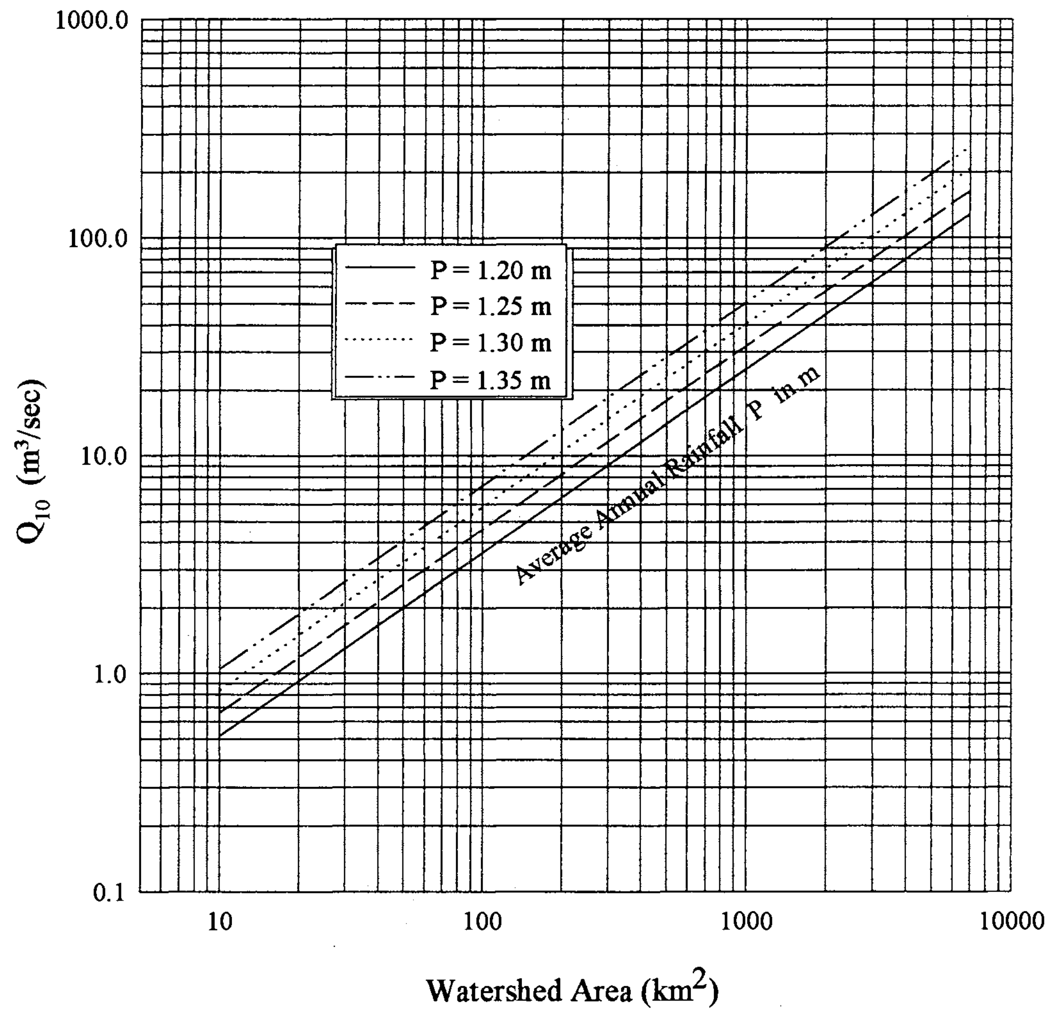


Fig. 5.8c : Frequency curves for Q_{10} (Region 1)

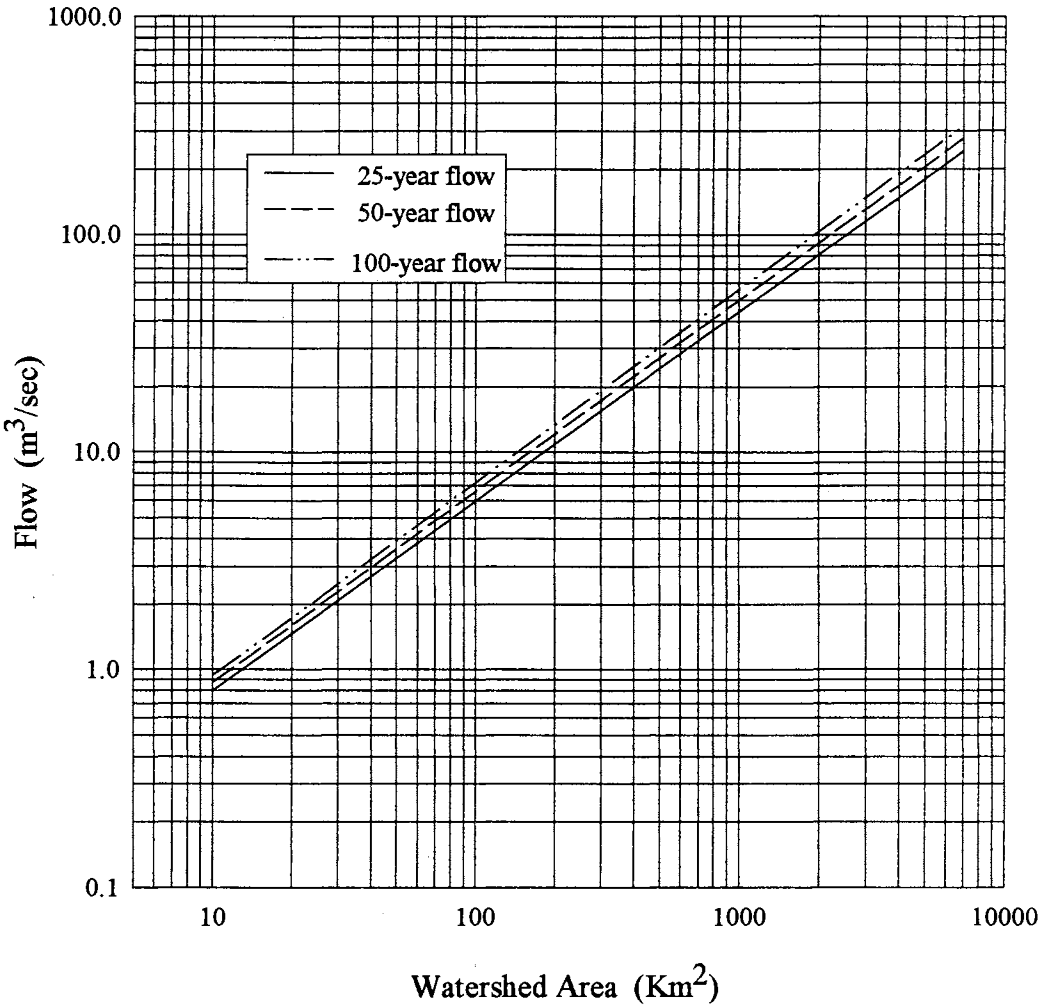


Fig. 5.8d : Frequency curves for Q_{25}, Q_{50} and Q_{100} (Region1)

Table 5.10b : Equations for estimating magnitude and frequency of flows in Region 3

$Q_2 = 0.1044 A^{0.884}$,	$R^2 = 0.834$,	$SE = 0.372$
$Q_5 = 0.1426 A^{0.884}$,	$R^2 = 0.725$,	$SE = 0.508$
$Q_{10} = 0.1717 A^{0.880}$,	$R^2 = 0.654$,	$SE = 0.589$
$Q_{25} = 0.2152 A^{0.871}$,	$R^2 = 0.570$,	$SE = 0.684$
$Q_{50} = 0.2531 A^{0.862}$,	$R^2 = 0.514$,	$SE = 0.749$
$Q_{100} = 0.2979 A^{0.852}$,	$R^2 = 0.459$,	$SE = 0.812$

Where Q is the flow to be estimated in m^3/sec, A is the watershed area in km^2.

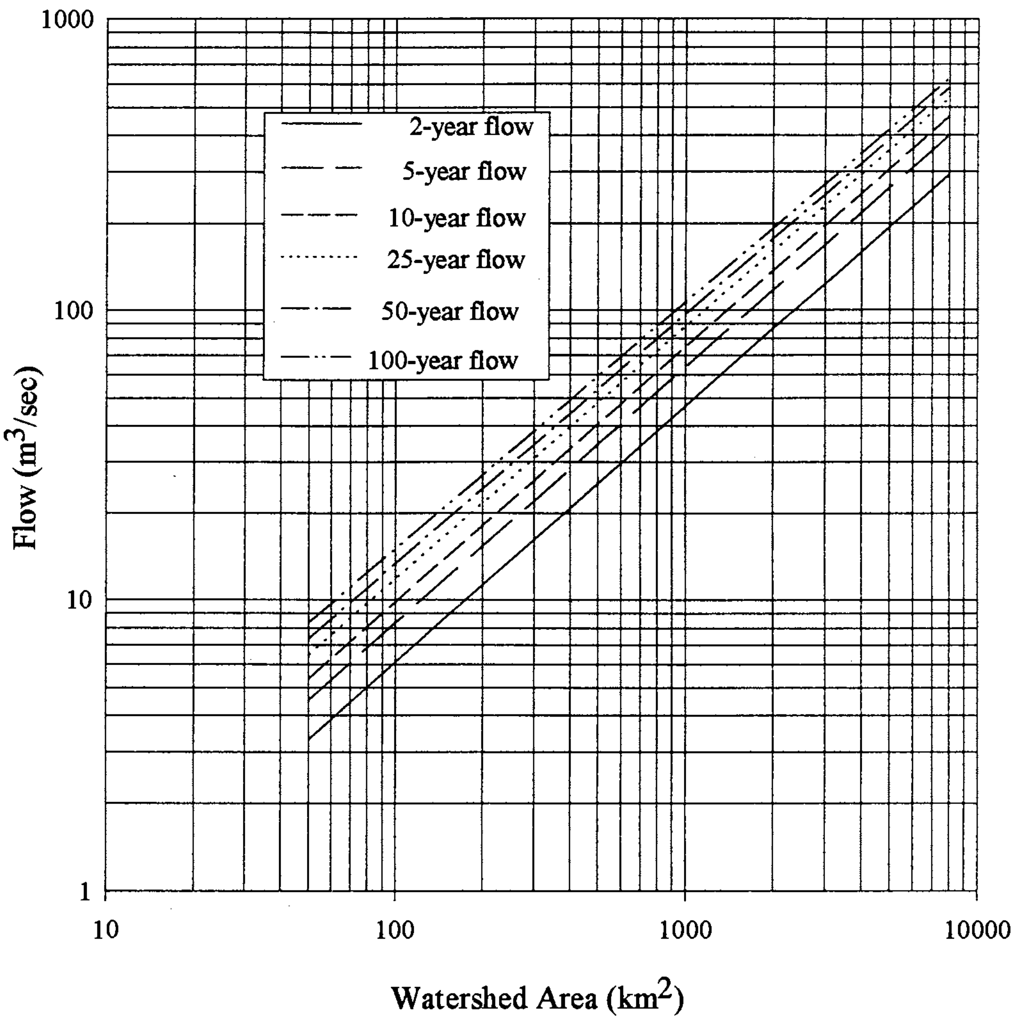


Fig. 5.8e : Frequency curves (Region 3)

Table 5.10c : Equations for estimating magnitude and frequency of flows in Region 4

$$Q_2 = 0.0241\,A^{0.909}, \qquad R^2 = 0.739, \qquad SE = 0.627$$

$$Q_5 = 0.0491\,A^{0.858}, \qquad R^2 = 0.657, \qquad SE = 0.714$$

$$Q_{10} = 0.0695\,A^{0.831}, \qquad R^2 = 0.591, \qquad SE = 0.790$$

$$Q_{25} = 0.0990\,A^{0.803}, \qquad R^2 = 0.519, \qquad SE = 0.873$$

$$Q_{50} = 0.1222\,A^{0.785}, \qquad R^2 = 0.476, \qquad SE = 0.924$$

$$Q_{100} = 0.1476\,A^{0.769}, \qquad R^2 = 0.438, \qquad SE = 0.969$$

Where Q is the flow to be estimated in m^3/sec, A is the watershed area in km^2

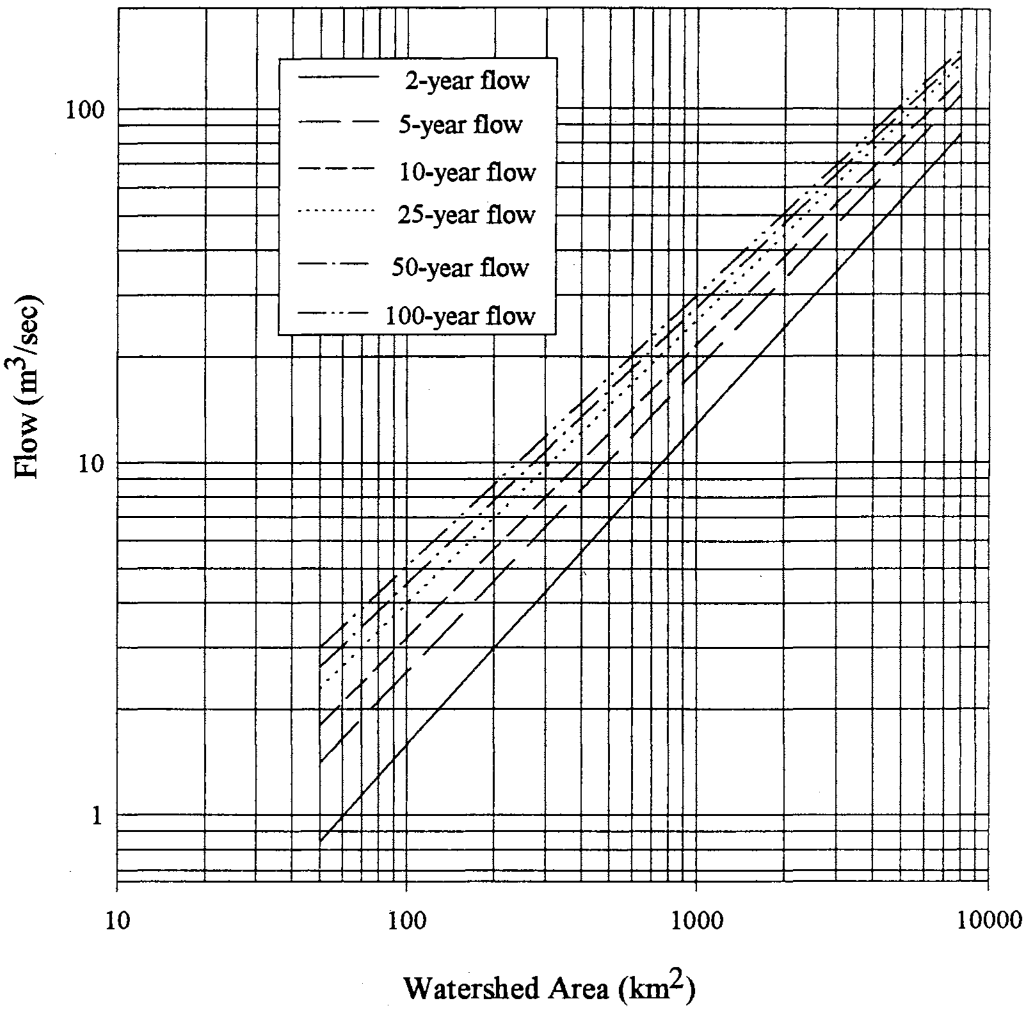


Fig. 5.8f : Frequency curves (Region 4)

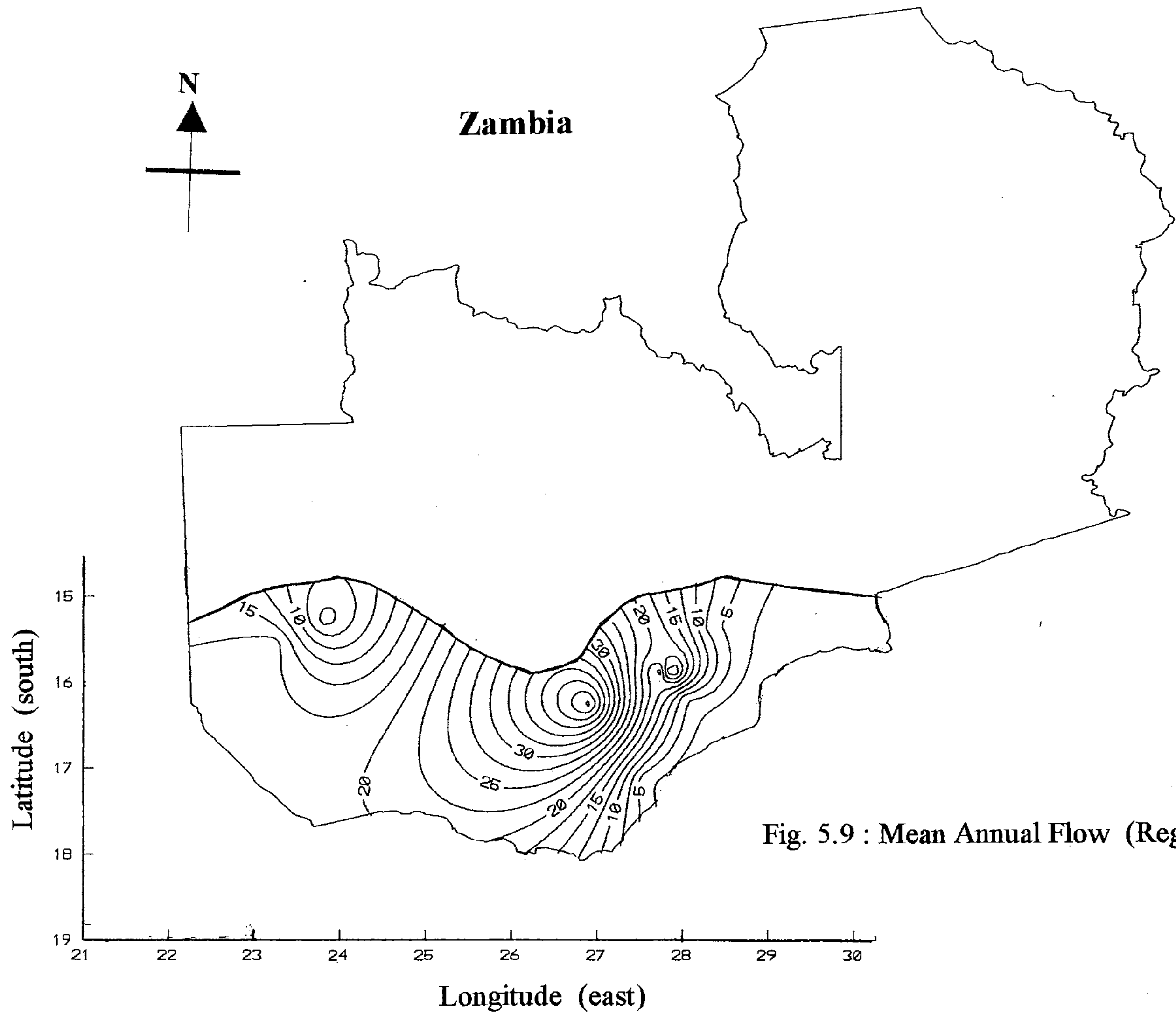


Fig. 5.9 : Mean Annual Flow (Region 2)

CHAPTER 6

SUMMARY AND DISCUSSION OF RESULTS

Adequate hydrologic data are the primary input to the design and successful operation of hydraulic and drainage structures. Unfortunately these important inputs are usually not available at locations of interest. This lack of data forces engineers to adopt more conservative approaches in their design techniques with the obvious implication of higher costs on the projects, which needless to say puts further strains on already weak economies of most developing countries, including Zambia. The primary objective of this study was therefore to investigate the possibilities of transferring flow data from gaged to ungaged watersheds. This was done in several stages. First the data from gaged stations were analyzed individually to check for data independence and homogeneity. Second at-site flood frequency analysis was performed to determine flood quantiles (magnitude and frequency) for each station. These flood quantiles were then related to basin and climatic variables to develop regional relationships that could be used to estimate flow values at ungaged sites. Two regionalization techniques, namely the index-flood and regression-based methods were investigated. The results are summarized in Figs. 5.7, 5.9 and equation (5.12) for the index-flood method and in equations shown in Tables 5.10a to 5.10c and Figs. 5.8a to 5.8f for the regression based procedure.

Of the several basin and climatic variables that were examined in this study, the watershed area and mean annual rainfall were found to be the most significant variables for estimating flood magnitudes.

Comparison of flow predictions using the two methods indicate that in general the index-flood method gives higher values than the regression based technique. This is particularly so for large watersheds as shown in Figs. 6.1a to 6.1c. The 5-, 10-, 25-, 50- and 100-year flows estimated using the index flood method are 4%, 8%, 17%, 28% and 37% higher than the flows with corresponding frequencies estimated using the regression method. The two methods gave similar results for Region 3 with slight deviations in the high frequency ranges for large watersheds.

There is very little to choose between the two methods for estimating flows with 2-, 5-, 10- and 25-year return periods. For these frequencies the index-flood gives flow values that are on average 7% higher than the regression method. For the 50- and 100-year floods, the index-flood estimates are on average 32% higher than those obtained by regression method.

The coefficient of determinations R^2 indicate that the reliability of the flow estimates decreases as the return period increases. This observation is confirmed by the inverse relationship between the standard error of estimates SE and the flow frequencies. This is reasonable in that the average record length in this study being about 20 years, the probability that a sample of this size will contain a 25-year flood is almost 60% as shown in equation (3.4) but the probability drops drastically to less than 20% that this sample will contain a 100-year flood.

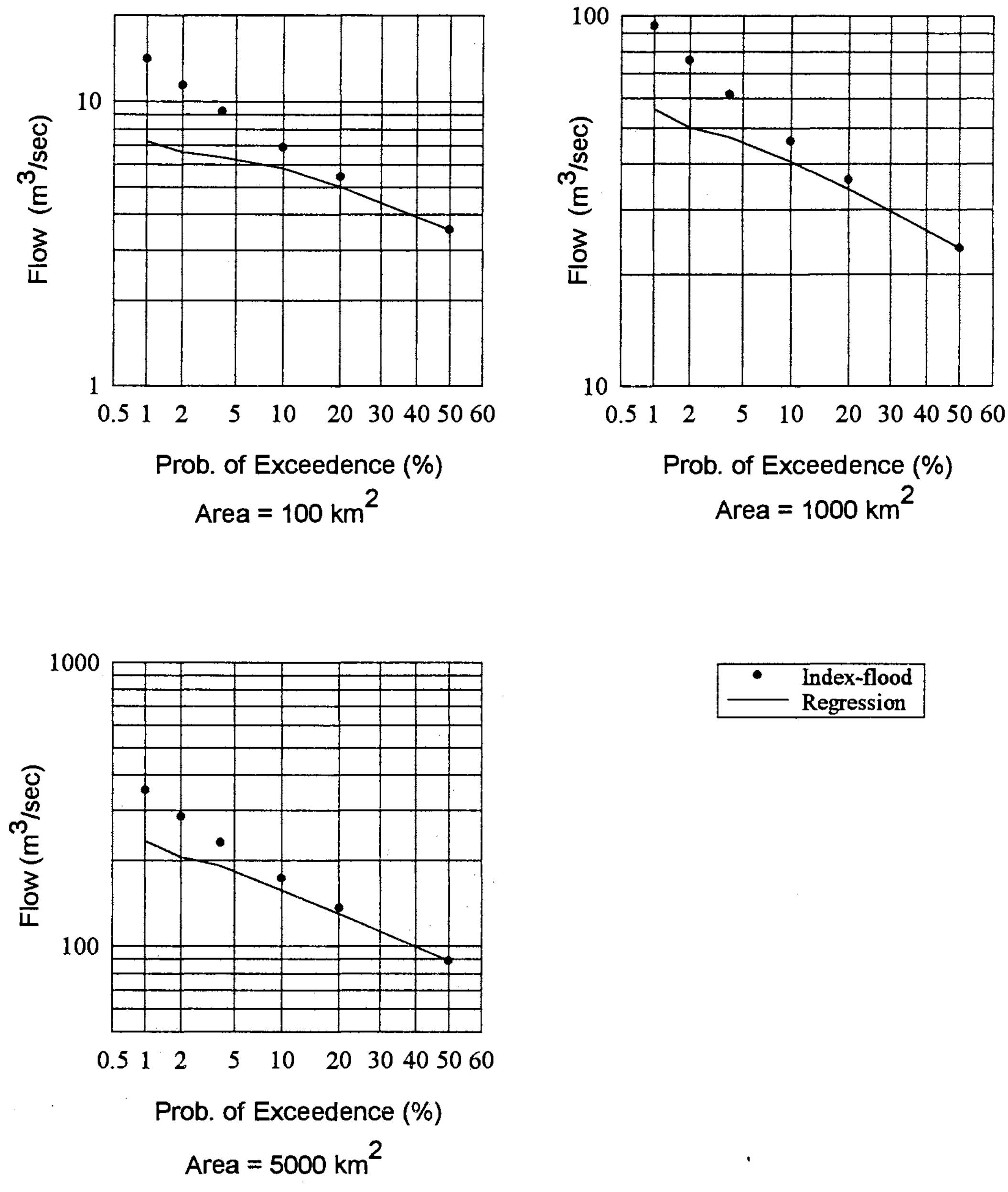


Fig. 6.1a : Comparisons between model predictions (Region 1)

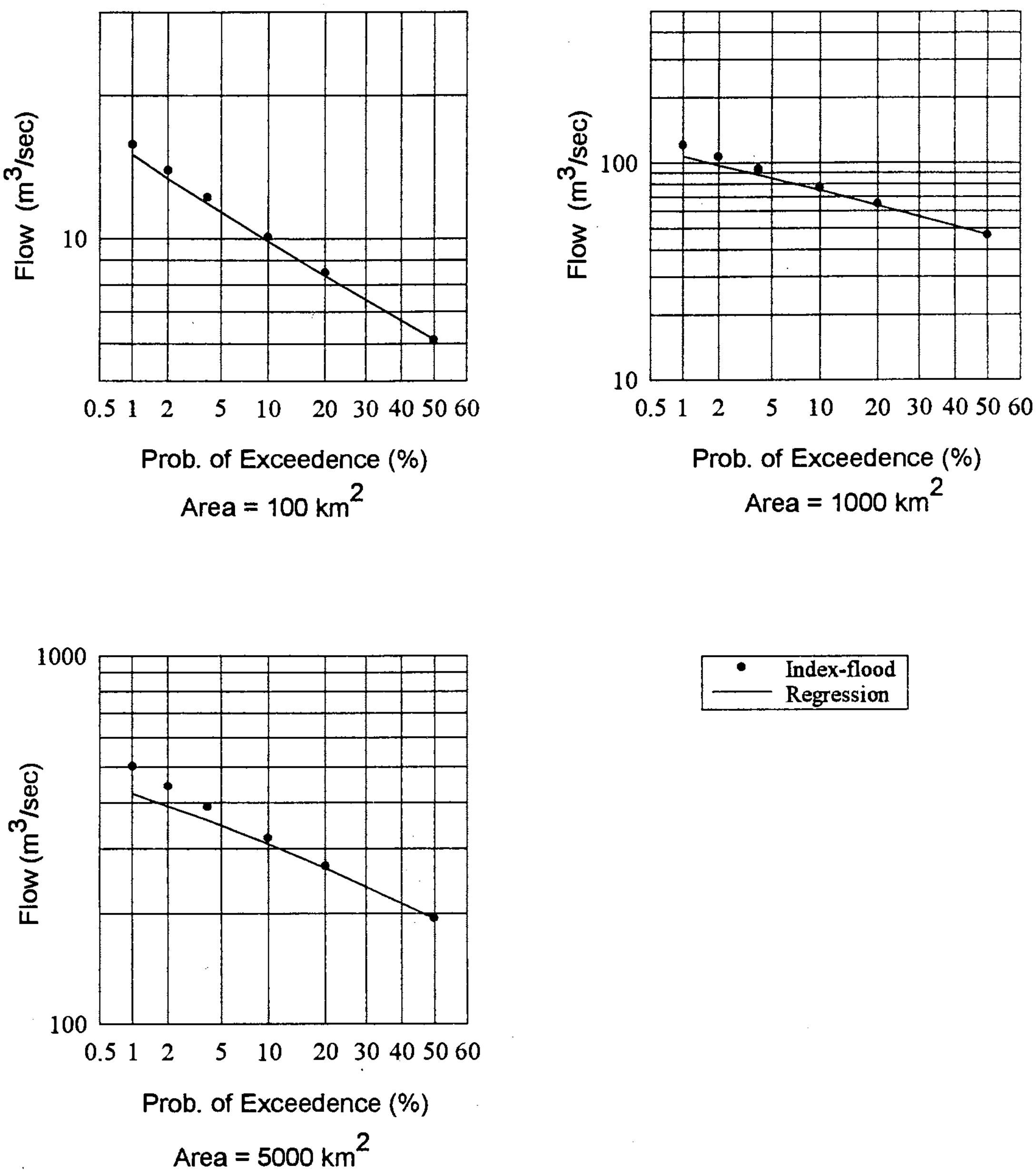


Fig. 6.1b : Comparisons between model predictions (Region 3)

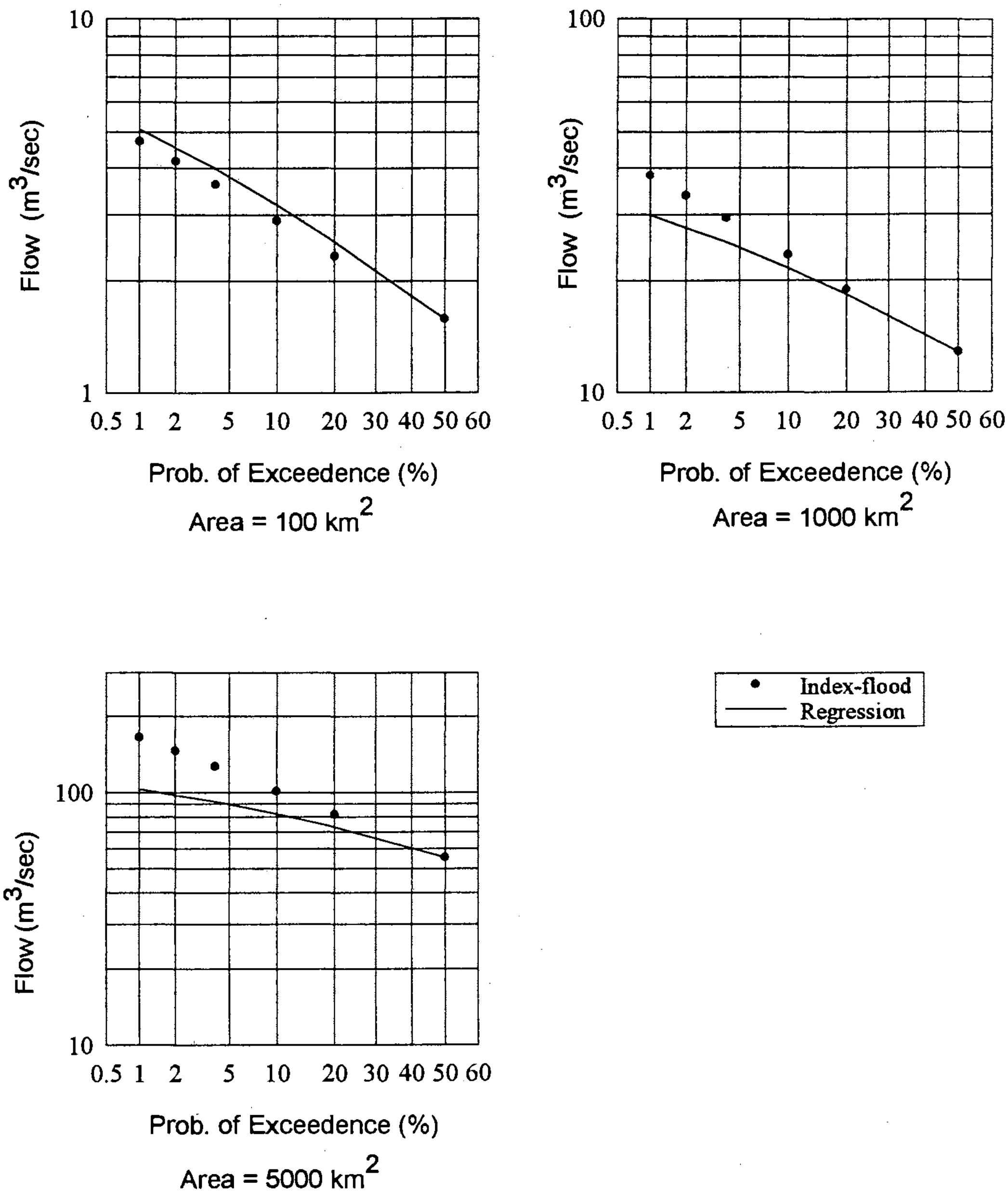


Fig. 6.1c : Comparisons between model predictions (Regon 4)

CHAPTER 7

APPLICATION OF MODELS

Application of the regional flood frequency models developed above to estimate flow values will be illustrated using the following example. A highway engineer is given the task of designing a culvert to pass the 25-year flood on a small stream in Region 4. The watershed area is known to be 1000 km^2. Before the engineer can design the culvert he needs to know the amount of flow expected at the location of the proposed culvert. The two methods developed above will be used to estimate this flow.

a. Index flood method

To apply this method, the value of Q_{25}/Q_2 for the required region (Region 4 in this case) must first be determined either from Table 7.1 or from Fig. 5.7.

$$\frac{Q_{25}}{Q_2} = 2.29 \quad \textit{from Table } 7.1$$

and the index-flood is determined from Table 5.10c for Region 4 as follows:

$$Q_2 = 0.0241*(1000)^{0.909} = 12.85 \ m^3/\text{sec}$$

therefore the 25-year flood is given by:

$$Q_{25} = \frac{Q_{25}}{Q_2} * Q_2 \Rightarrow Q_{25} = 2.29 * 12.85 = 29.4\ m^3/sec$$

b. **Regression method**

Unlike the Index flood method, the regression models provide a one step procedure to estimate the desired flows. For Region 4 the equation needed to estimate the 25-year flood is given in Table 5.10c and shown below:

$$Q_{25} = 0.0990\, A^{0.803}$$

substituting the value of the watershed area A into the above equation, the 25-year flow is estimated as follows:

$$Q_{25} = 0.0990 * (1000)^{0.803} = 25.4\ m^3/sec$$

Table 7.1 : Average Q_T/Q_2 values for Regions 1, 2, 3 and 4.

Return period (years)	Probability of exceedence (%)	Average Q_T/Q_2 values for			
		Region 1	Region 2	Region 3	Region 4
2	50	1.00	1.00	1.00	1.00
5	20	1.53	1.74	1.39	1.48
10	10	1.95	2.24	1.65	1.83
25	4	2.61	2.88	2.00	2.29
50	2	3.22	3.35	2.28	2.63
100	1	4.01	3.82	2.58	2.98

CHAPTER 8

CONCLUSIONS AND LIMITATIONS

a. The watershed area and the average annual rainfall were found to be the most significant variables for estimating floods.

b. The regional flood frequency models developed in this study are valid for unregulated streams only.

c. The models are applicable for watershed areas not exceeding 2500 square miles (or 6500 km^2). Projects that will be associated with these sizes of basins will be small to medium sized drainage or retaining structures such as culverts, bridges and community dams with design lives of 20 to 30 years. These structures are usually designed to accommodate the 20- to 25-year flows. The regional frequency models were thus developed to cater for these types of projects which are by far the most common in small economies like Zambia.

d. In general the index flood method gave higher estimates than the regression based method. The 2-, 5-, 10- and 25-year floods estimated using the index flood method are on average 7% higher than the regression method. The 7% difference between the two model estimates was found to be statistically not significant and either method can therefore be used to estimate low frequency flows at ungaged sites.

e. Various empirical equations developed elsewhere (such as the Talbot and Rational formulas) have been used to estimate floods in Zambia. These equations contain constants whose values are based on judgment resulting in inconsistent flow values. In addition, some of these relationships do not address the frequency of the floods and the effect of variations in precipitation on the flows is not accounted for. The regional flood frequency models developed in this study overcome these deficiencies and provide consistent and rational relationships for estimating flow values for any region in Zambia.

f. Regional flood frequency studies consisting of at-site frequency analysis, delineation of homogeneous regions and derivation of regional flood frequency models have been carried out for the purpose of estimating flow values in ungaged sites. This study is the first of its kind in Zambia and it is hoped that the models developed in this study would replace those empirical formulas that are currently in use.

CHAPTER 9

SUGGESTIONS FOR FUTURE STUDIES

1. Although peak flow is commonly mentioned as the primary input to the design of hydraulic structures, the total flood volume is often required for the design and operation of reservoirs, irrigation schemes and hydropower stations. It is therefore suggested a study similar to the current work be carried out to relate flood volumes to basin and climatic variables.

2. The regional frequency models developed above provide means of estimating flow quantiles at ungaged sites provided that no major changes take place in watershed management, river channel regimes and land use patterns. It is therefore prudent to check and update these frequency models if and when these changes do take place.

3. Where flow data do not support regional frequency analysis, the use of hydrologic methods, such as rainfall-runoff relationships and unit hydrograph techniques should be investigated.

4. Since stream channels are formed by the amount and velocity of the flows they carry, it is reasonable to assume that there may be relationships between channel geometry (width, cross section, maximum depth etc.) and peak flows. This needs to be examined.

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APPENDIX A

1. **Tables A1 to A91 : Fitted and observed data**

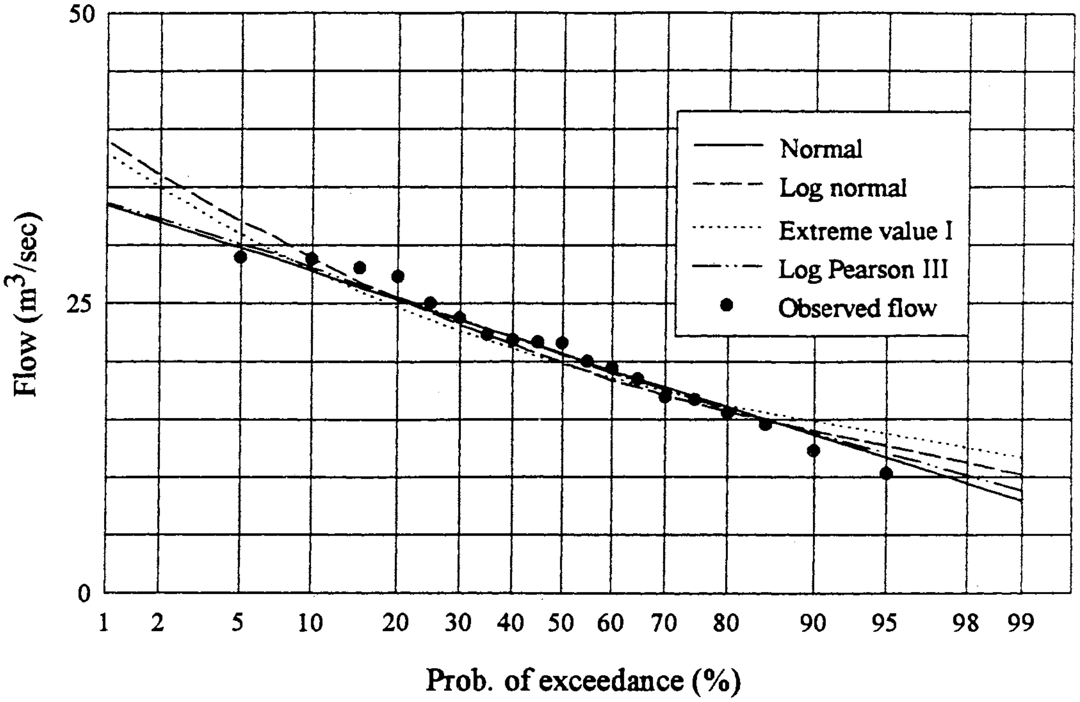
2. **Figs. A1 to A46 : Probability plots of fitted distributions and observed data**

Table A1: Fitted anf observed flows, station 1080

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	7.94	10.21	11.71	8.84	95.00	10.32
80.00	16.11	15.68	16.22	15.93	90.00	12.31
70.00	17.82	17.15	17.46	17.63	85.00	14.56
60.00	19.19	18.43	18.63	19.04	80.00	15.55
50.00	20.73	19.98	19.82	20.65	75.00	16.74
43.00	21.72	21.04	20.72	21.69	70.00	16.99
30.00	23.58	23.20	22.67	23.68	65.00	18.50
20.00	25.34	25.45	24.68	25.55	60.00	19.49
15.00	26.33	26.80	26.04	26.59	55.00	20.04
10.00	27.76	28.89	27.89	28.08	50.00	21.60
7.00	28.97	30.78	29.49	29.31	45.00	21.67
5.00	29.76	32.09	30.98	30.12	40.00	21.86
4.00	30.34	33.08	31.96	30.69	35.00	22.31
2.00	31.99	36.06	34.97	32.28	30.00	23.78
1.00	33.51	39.06	37.96	33.69	25.00	25.01
0.20	36.55	45.81	44.87	36.29	20.00	27.30
0.10	37.70	48.67	47.84	37.19	15.00	28.00
					10.00	28.83
					5.00	28.95

Table A2 : Fitted and observed flows, station 1145

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	14.66	18.25	21.83	14.12	96.77	14.73
80.00	30.20	28.87	30.40	29.91	93.55	20.76
70.00	33.45	31.77	32.77	33.55	90.32	21.98
60.00	36.06	34.32	34.99	36.48	87.10	23.88
50.00	38.99	37.41	37.27	39.69	83.87	28.89
43.00	40.87	39.55	38.98	41.70	80.65	32.58
30.00	44.42	43.92	42.69	45.31	77.42	32.71
20.00	47.77	48.48	46.51	48.46	74.19	34.82
15.00	49.65	51.25	49.09	50.10	70.97	35.25
10.00	52.37	55.53	52.63	52.29	67.74	36.13
7.00	54.67	59.43	55.67	53.98	64.52	36.16
5.00	56.19	62.15	58.50	54.99	61.29	36.75
4.00	57.28	64.20	60.36	55.69	58.06	37.11
2.00	60.42	70.42	66.09	57.45	54.84	37.87
1.00	63.32	76.71	71.78	58.81	51.61	38.40
0.20	69.10	90.98	84.94	60.80	48.39	39.24
0.10	71.30	97.07	90.59	61.33	45.16	39.44
					41.94	39.78
					38.71	40.85
					35.48	43.11
					32.26	43.52
					29.03	43.86
					25.81	46.23
					22.58	47.28
					19.35	47.35
					16.13	47.35
					12.90	53.09
					9.68	54.73
					6.45	56.39
					3.23	59.38



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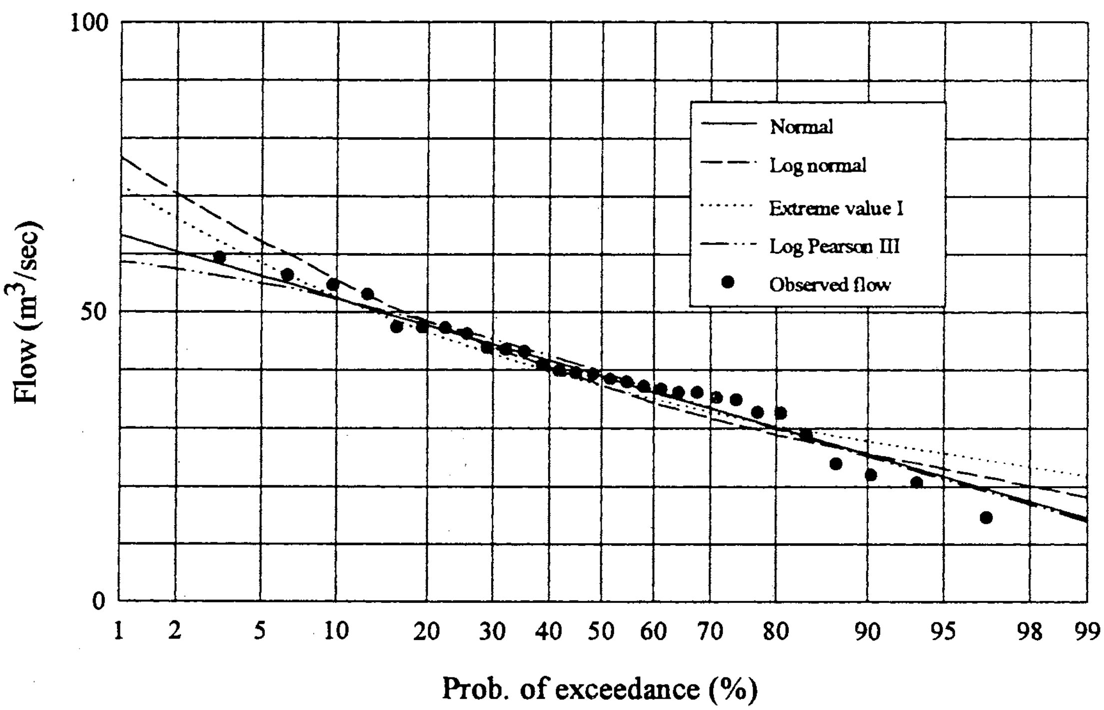


(b)

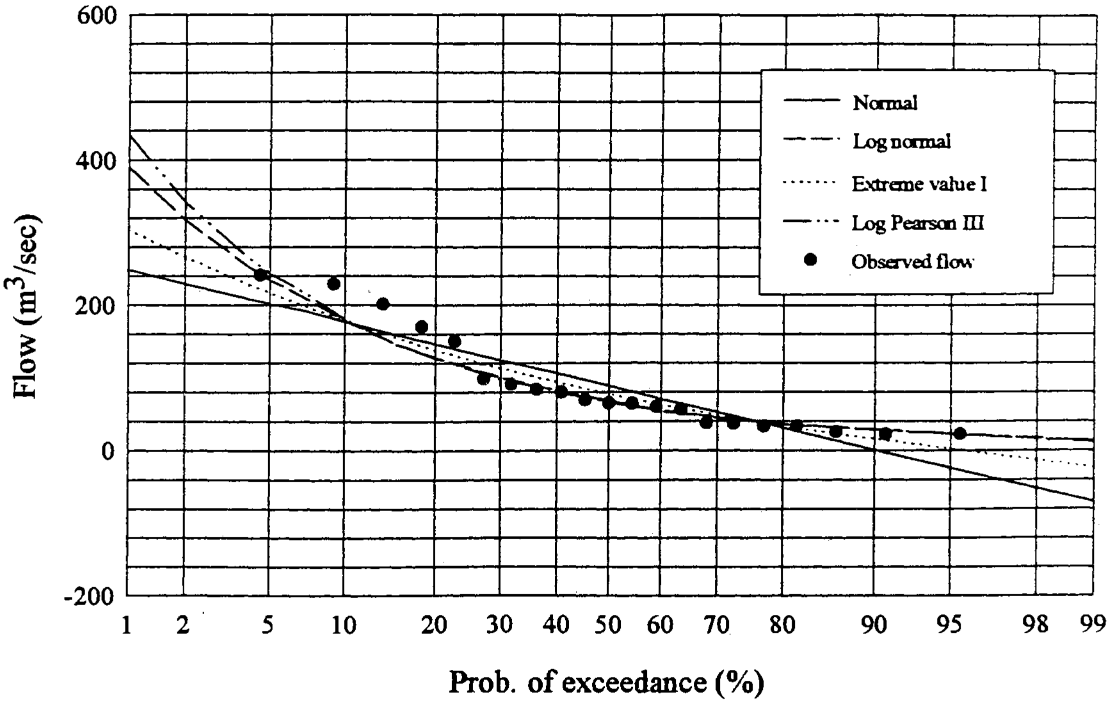
Fig. A1 : Observed and fitted distributions (a) station 1080, (b) station 1145

Table A3 : Fitted and observed flows, station 1205

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flows
99.00	-70.21	11.93	-23.19	13.25	95.45	22.31
80.00	31.69	36.41	32.98	36.19	90.91	22.61
70.00	52.93	45.94	48.49	45.20	86.36	25.25
60.00	70.06	55.41	63.08	54.25	81.82	33.29
50.00	89.25	68.36	77.99	66.77	77.27	33.45
43.00	101.58	78.25	89.19	76.46	72.73	37.16
30.00	124.88	100.98	113.49	99.18	68.18	37.59
20.00	146.81	128.37	138.55	127.35	63.64	56.37
15.00	159.15	146.93	155.49	146.89	59.09	59.84
10.00	176.96	178.57	178.65	181.02	54.55	64.69
7.00	192.04	210.61	198.57	216.60	50.00	65.25
5.00	201.97	234.81	217.11	244.11	45.45	69.48
4.00	209.17	254.05	229.31	266.35	40.91	80.08
2.00	229.73	318.16	266.89	342.77	36.36	83.88
1.00	248.71	391.64	304.20	434.40	31.82	91.43
0.20	286.61	592.97	390.41	705.24	27.27	98.85
0.10	301.00	694.14	427.47	851.21	22.73	150.62
					18.18	170.44
					13.64	201.59
					9.09	228.92
					4.55	241.11

Table A4 : Fitted and observed flows, station 1305

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	12.89	15.65	16.17	18.65	92.31	17.84
80.00	20.00	20.37	20.09	20.42	84.62	20.11
70.00	21.48	21.52	21.17	21.12	76.92	21.81
60.00	22.67	22.50	22.19	21.81	69.23	22.90
50.00	24.01	23.64	23.22	22.74	61.54	23.08
43.00	24.87	24.41	24.01	23.42	53.85	23.26
30.00	26.49	25.92	25.70	24.96	46.15	23.48
20.00	28.02	27.44	27.45	26.75	38.46	23.48
15.00	28.88	28.33	28.63	27.93	30.77	23.62
10.00	30.12	29.66	30.24	29.89	23.08	23.62
7.00	31.17	30.84	31.63	31.83	15.38	27.62
5.00	31.87	31.65	32.92	33.27	7.69	37.29
4.00	32.37	32.24	33.77	34.41		
2.00	33.80	34.00	36.39	38.12		
1.00	35.13	35.71	38.99	42.30		
0.20	37.77	39.39	45.00	53.58		
0.10	38.77	40.89	47.59	59.23		



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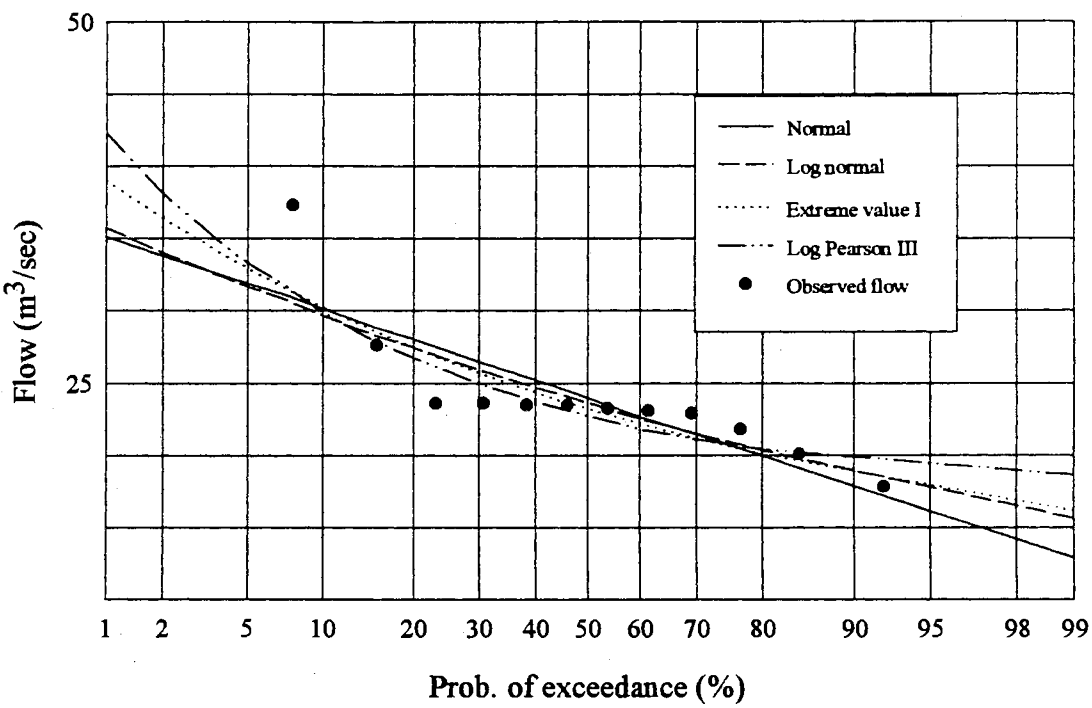


(b)

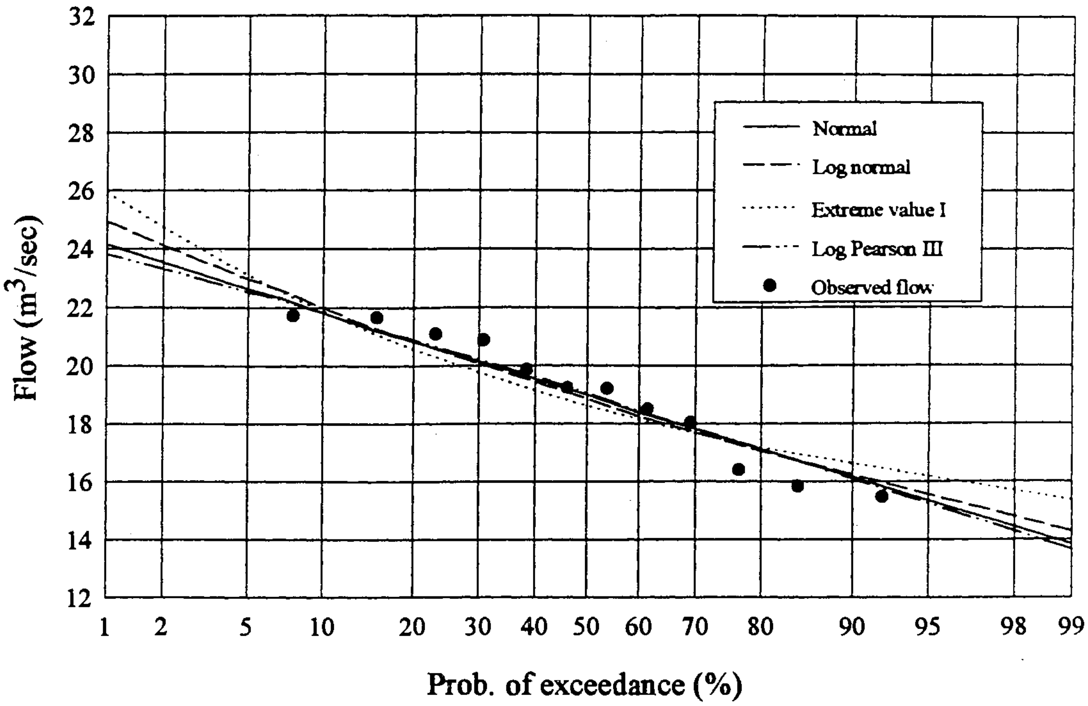
Fig. A2 : Observed and fitted distributions, (a) station 1205, (b) station 1305

Table A5 : Fitted and observed flows, station 1315

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	13.85	14.29	15.36	13.66	92.31	15.47
80.00	17.14	17.07	17.18	17.14	84.62	15.83
70.00	17.82	17.71	17.68	17.86	76.92	16.41
60.00	18.38	18.25	18.15	18.43	69.23	18.03
50.00	19.00	18.87	18.63	19.07	61.54	18.51
43.00	19.39	19.28	18.99	19.47	53.85	19.21
30.00	20.15	20.09	19.78	20.22	46.15	19.24
20.00	20.85	20.87	20.59	20.91	38.46	19.85
15.00	21.25	21.32	21.14	21.28	30.77	20.88
10.00	21.83	22.00	21.88	21.82	23.08	21.09
7.00	22.32	22.59	22.53	22.26	15.38	21.68
5.00	22.64	22.98	23.12	22.55	7.69	21.75
4.00	22.87	23.27	23.52	22.75		
2.00	23.53	24.12	24.73	23.32		
1.00	24.15	24.94	25.94	23.83		
0.20	25.37	26.64	28.72	24.79		
0.10	25.83	27.32	29.92	25.13		

Table A6 : Fitted anf observed flows, station 1425

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-6.33	6.77	7.17	3.24	92.86	5.40
80.00	22.92	18.79	23.29	21.16	85.71	17.28
70.00	29.02	23.24	27.74	27.53	78.57	26.38
60.00	33.94	27.60	31.93	33.11	71.43	27.50
50.00	39.44	33.45	36.21	39.63	64.29	28.31
43.00	42.99	37.85	39.43	43.85	57.14	31.43
30.00	49.67	47.80	46.41	51.63	50.00	36.66
20.00	55.97	59.55	53.60	58.39	42.86	42.13
15.00	59.51	67.38	58.46	61.84	35.71	50.45
10.00	64.63	80.56	65.11	66.28	28.57	51.99
7.00	68.95	93.69	70.83	69.49	21.43	56.98
5.00	71.81	103.50	76.15	71.31	14.29	61.12
4.00	73.87	111.24	79.65	72.49	7.14	77.15
2.00	79.77	136.69	90.44	75.22		
1.00	85.22	165.33	101.15	76.96		
0.20	96.10	241.70	125.90	78.65		
0.10	100.23	279.19	136.54	78.86		



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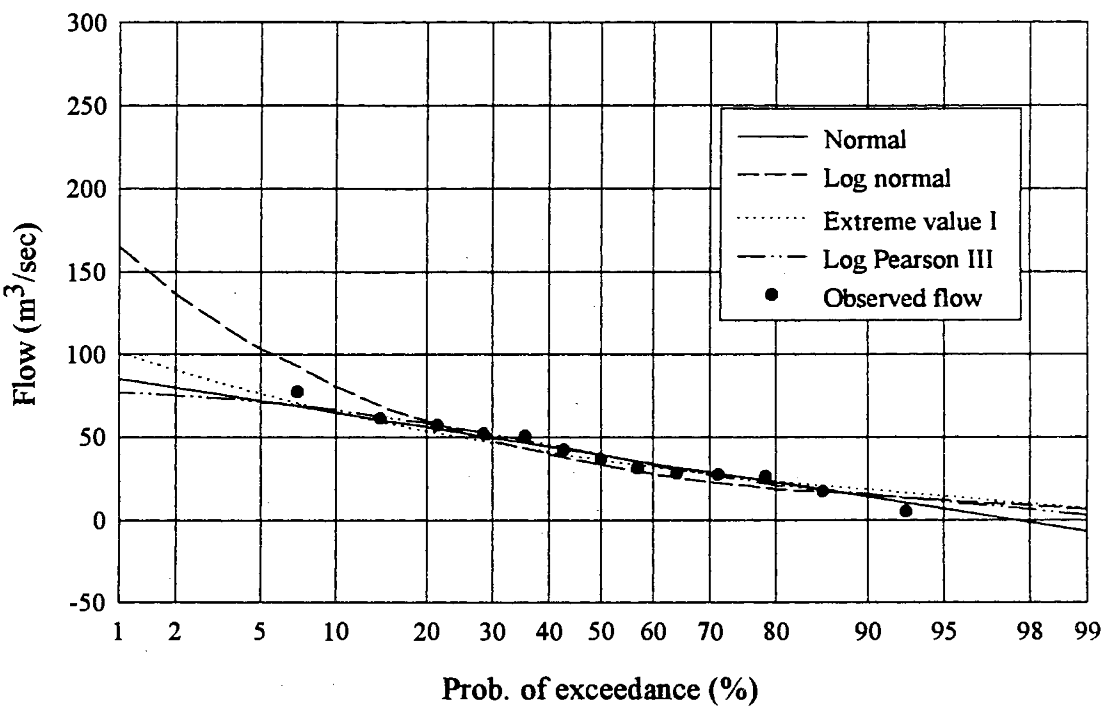


(b)

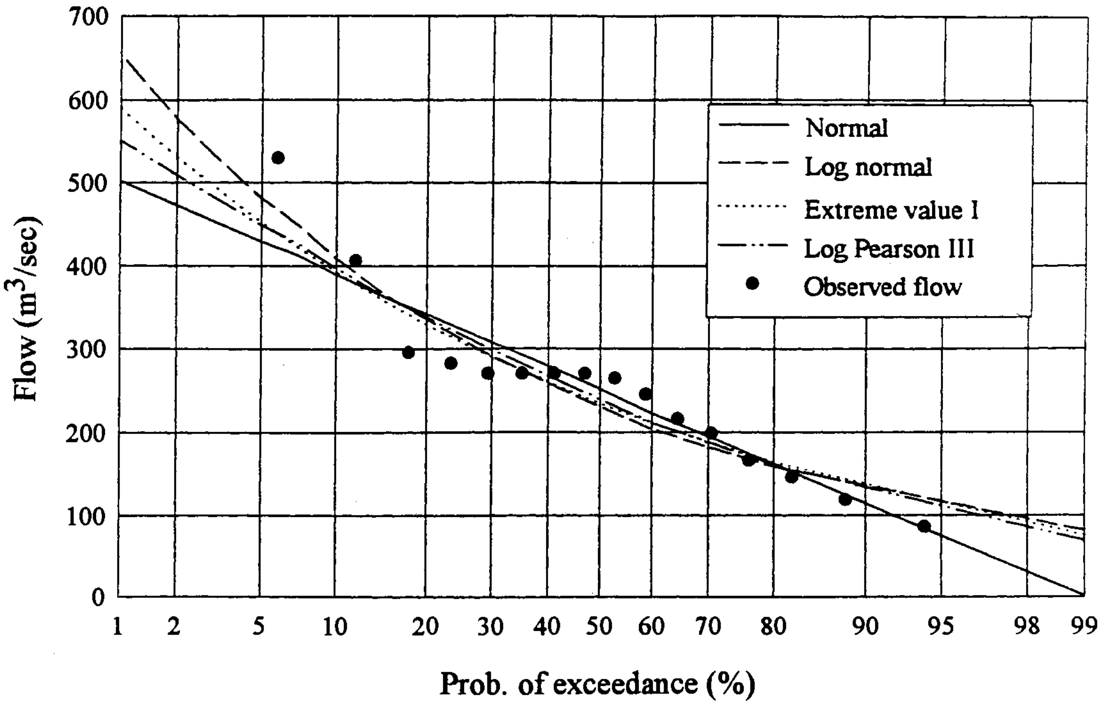
Fig. A3 : Observed and fitted distributions (a) station 1315, (b) station 1425

Table A7 : Fitted and observed flows, station 1430

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	2.08	81.74	75.88	69.24	94.12	86.32
80.00	162.00	158.82	164.04	161.38	88.24	118.53
70.00	195.34	182.41	188.38	188.07	82.35	145.72
60.00	222.22	203.96	211.27	211.60	76.47	166.22
50.00	252.34	231.14	234.67	240.07	70.59	198.82
43.00	271.69	250.49	252.24	259.55	64.71	215.92
30.00	308.26	291.58	290.39	298.79	58.82	245.56
20.00	342.67	336.38	329.71	338.52	52.94	264.02
15.00	362.03	364.55	356.30	362.00	47.06	270.28
10.00	389.99	409.44	392.64	397.23	41.18	270.28
7.00	413.65	451.72	423.90	428.19	35.29	270.28
5.00	429.25	481.95	453.00	449.11	29.41	270.28
4.00	440.54	505.09	472.15	464.50	23.53	282.97
2.00	472.80	577.52	531.13	509.44	17.65	295.87
1.00	502.59	653.59	589.67	552.03	11.76	406.55
0.20	562.07	836.73	724.97	639.13	5.88	529.76
0.10	584.65	919.02	783.13	672.57		

Table A8 : Fitted and observed flows, station 2360

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-3.49	3.25	2.97	1.67	94.12	2.37
80.00	10.52	8.86	10.70	9.80	88.24	7.58
70.00	13.44	10.92	12.83	12.67	82.35	8.82
60.00	15.80	12.93	14.84	15.20	76.47	10.93
50.00	18.44	15.62	16.89	18.20	70.59	12.10
43.00	20.14	17.64	18.43	20.17	64.71	14.24
30.00	23.34	22.18	21.77	23.88	58.82	16.62
20.00	26.36	27.53	25.22	27.22	52.94	17.64
15.00	28.05	31.08	27.55	28.98	47.06	18.16
10.00	30.50	37.04	30.73	31.32	41.18	19.70
7.00	32.58	42.96	33.47	33.08	35.29	21.08
5.00	33.94	47.38	36.02	34.12	29.41	21.31
4.00	34.93	50.85	37.70	34.82	23.53	23.39
2.00	37.76	62.26	42.87	36.52	17.65	31.67
1.00	40.37	75.05	48.00	37.71	11.76	34.54
0.20	45.58	108.98	59.86	39.16	5.88	34.87
0.10	47.56	125.57	64.96	39.44		



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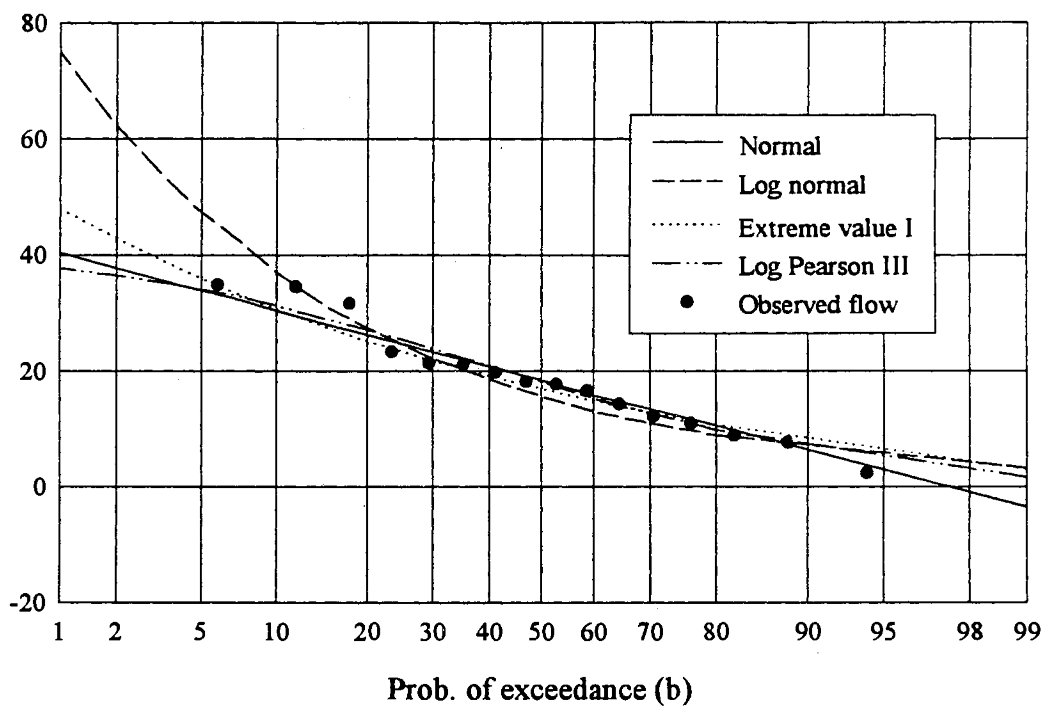


(b)

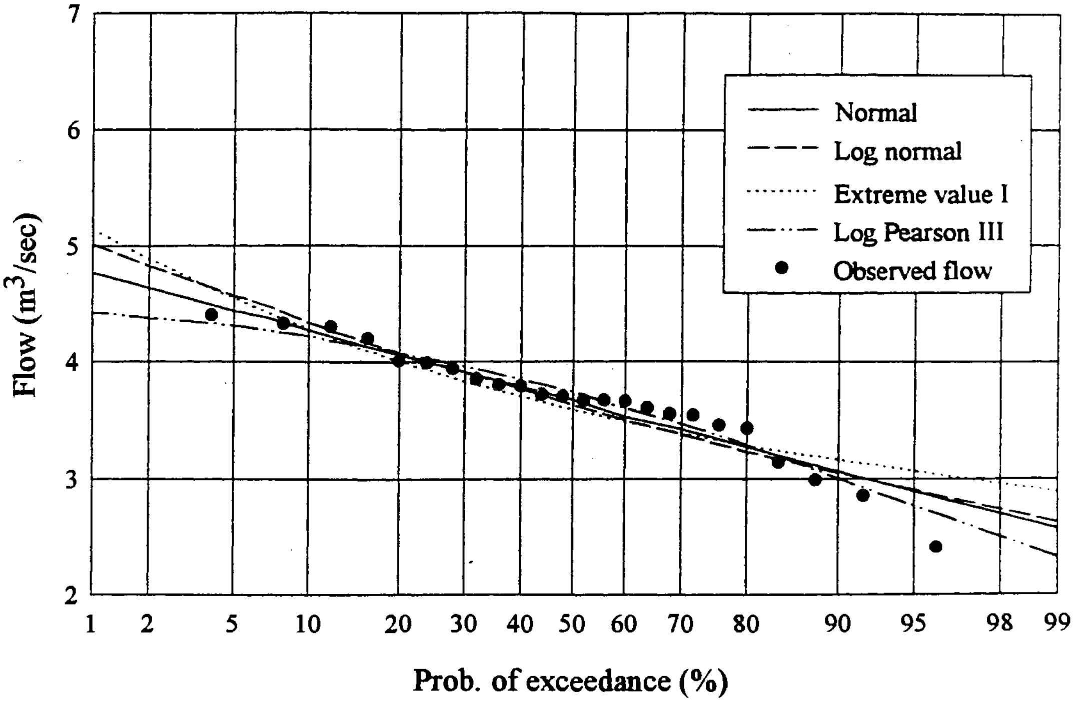
Fig. A4 : Observed and fitted distributions, (a) station 1430, (b) station 2360

Table A9 : Fitted and observed flows, station 2475

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	2.57	2.63	2.89	2.33	96.00	2.41
80.00	3.27	3.23	3.28	3.29	92.00	2.85
70.00	3.42	3.38	3.39	3.47	88.00	2.99
60.00	3.53	3.50	3.49	3.60	84.00	3.14
50.00	3.67	3.63	3.59	3.74	80.00	3.43
43.00	3.75	3.73	3.67	3.82	76.00	3.46
30.00	3.91	3.91	3.83	3.96	72.00	3.54
20.00	4.06	4.08	4.01	4.08	68.00	3.55
15.00	4.15	4.19	4.12	4.14	64.00	3.60
10.00	4.27	4.34	4.28	4.22	60.00	3.66
7.00	4.38	4.48	4.42	4.27	56.00	3.67
5.00	4.44	4.57	4.55	4.31	52.00	3.67
4.00	4.49	4.64	4.63	4.33	48.00	3.70
2.00	4.64	4.83	4.89	4.38	44.00	3.72
1.00	4.77	5.02	5.15	4.43	40.00	3.79
0.20	5.03	5.42	5.75	4.48	36.00	3.80
0.10	5.13	5.58	6.00	4.50	32.00	3.85
					28.00	3.94
					24.00	3.99
					20.00	4.01
					16.00	4.20
					12.00	4.30
					8.00	4.33
					4.00	4.40

Table A10 : Fitted and observed flows, station3370

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	1.20	1.65	1.96	1.35	92.31	1.92
80.00	2.85	2.72	2.87	2.79	84.62	2.31
70.00	3.19	3.02	3.12	3.15	76.92	2.34
60.00	3.47	3.29	3.36	3.45	69.23	3.24
50.00	3.78	3.61	3.60	3.78	61.54	3.49
43.00	3.98	3.83	3.78	4.00	53.85	4.03
30.00	4.36	4.30	4.18	4.42	46.15	4.31
20.00	4.72	4.78	4.58	4.80	38.46	4.32
15.00	4.92	5.08	4.86	5.01	30.77	4.62
10.00	5.21	5.54	5.24	5.31	23.08	4.66
7.00	5.45	5.97	5.56	5.55	15.38	4.98
5.00	5.61	6.27	5.86	5.71	7.69	5.19
4.00	5.73	6.49	6.06	5.82		
2.00	6.06	7.18	6.67	6.12		
1.00	6.37	7.88	7.27	6.37		
0.20	6.99	9.48	8.67	6.82		
0.10	7.22	10.17	9.27	6.97		



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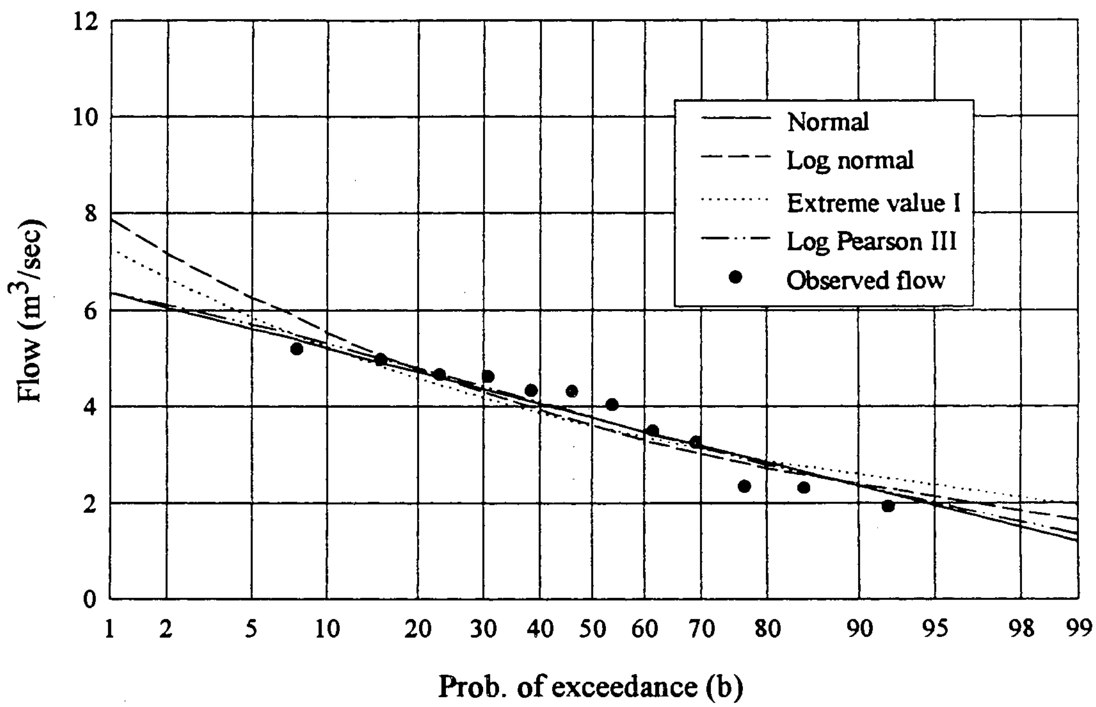


(b)

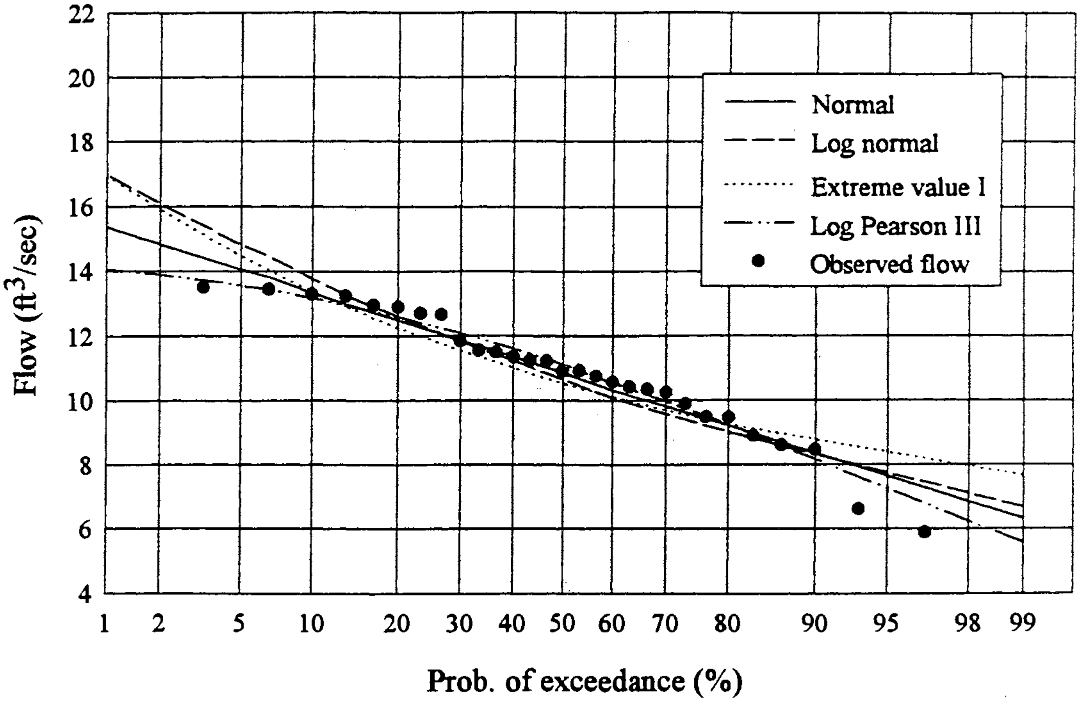
Fig. A5 : Observed and fitted distributions, (a) station 2475, (b) station 3370

Table A11 : Fitted and observed flows, station 4005

Prob.	Nor	Ln	Ev	Lp3	Plotting position	Flow
99.00	6.33	6.69	7.67	5.58	96.67	5.89
80.00	9.23	9.02	9.26	9.26	93.33	6.61
70.00	9.83	9.59	9.70	9.98	90.00	8.47
60.00	10.32	10.09	10.12	10.54	86.67	8.61
50.00	10.86	10.67	10.54	11.13	83.33	8.90
43.00	11.21	11.06	10.86	11.48	80.00	9.46
30.00	11.87	11.84	11.55	12.09	76.67	9.48
20.00	12.50	12.62	12.26	12.60	73.33	9.89
15.00	12.85	13.09	12.74	12.86	70.00	10.24
10.00	13.35	13.79	13.40	13.19	66.67	10.35
7.00	13.78	14.41	13.97	13.43	63.33	10.43
5.00	14.06	14.83	14.49	13.57	60.00	10.58
4.00	14.27	15.15	14.84	13.67	56.67	10.76
2.00	14.85	16.09	15.91	13.90	53.33	10.92
1.00	15.39	17.00	16.97	14.07	50.00	10.92
0.20	16.47	18.99	19.42	14.30	46.67	11.23
0.10	16.88	19.81	20.47	14.35	43.33	11.25
					40.00	11.35
					36.67	11.49
					33.33	11.55
					30.00	11.84
					26.67	12.67
					23.33	12.71
					20.00	12.90
					16.67	12.96
					13.33	13.24
					10.00	13.31
					6.67	13.44
					3.33	13.51

Table A12 : Fitted and observed flows, station 4050

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-842.11	18.88	-533.04	42.73	97.00	21.52
80.00	-172.41	62.13	-163.87	62.96	94.00	30.00
70.00	-32.80	79.63	-61.95	73.15	91.00	45.90
60.00	79.80	97.29	33.93	84.39	88.00	68.50
50.00	205.90	121.74	131.94	101.55	85.00	70.90
43.00	286.97	140.62	205.51	116.10	82.00	70.90
30.00	440.09	184.63	365.25	154.69	79.00	76.30
20.00	584.21	238.56	529.94	211.64	76.00	80.90
15.00	665.28	275.56	641.27	257.46	73.00	91.00
10.00	782.38	339.35	793.46	350.82	70.00	93.30
7.00	881.46	404.73	924.38	467.53	67.00	94.70
5.00	946.76	454.56	1046.23	572.48	64.00	96.20
4.00	994.05	494.44	1126.41	667.39	61.00	96.80
2.00	1129.16	628.72	1373.41	1068.46	58.00	108.60
1.00	1253.92	784.88	1618.59	1724.43	55.00	109.30
0.20	1502.97	1222.21	2185.16	5131.45	52.00	119.90
0.10	1597.55	1446.07	2428.74	8159.25	48.00	120.50
					45.00	124.70
					42.00	132.60
					39.00	133.60
					36.00	149.20
					33.00	149.70
					30.00	158.70
					27.00	164.00
					24.00	165.00
					21.00	166.10
					18.00	181.40
					15.00	201.70
					12.00	241.50
					9.00	244.20
					6.00	333.30
					3.00	2647.90



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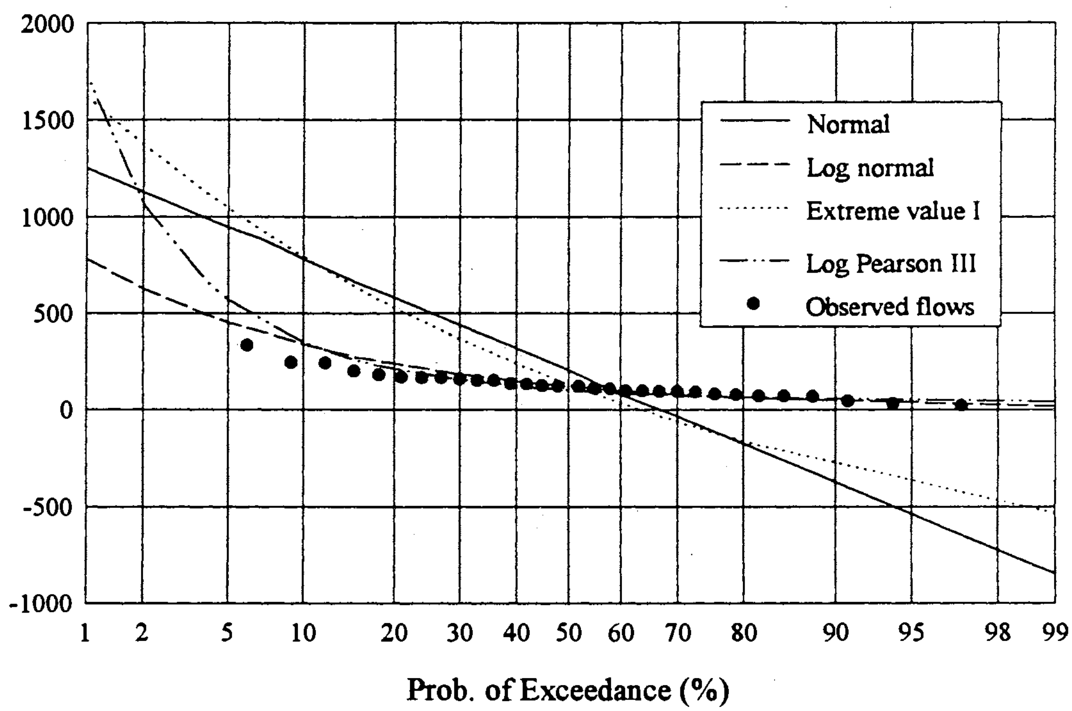


(b)

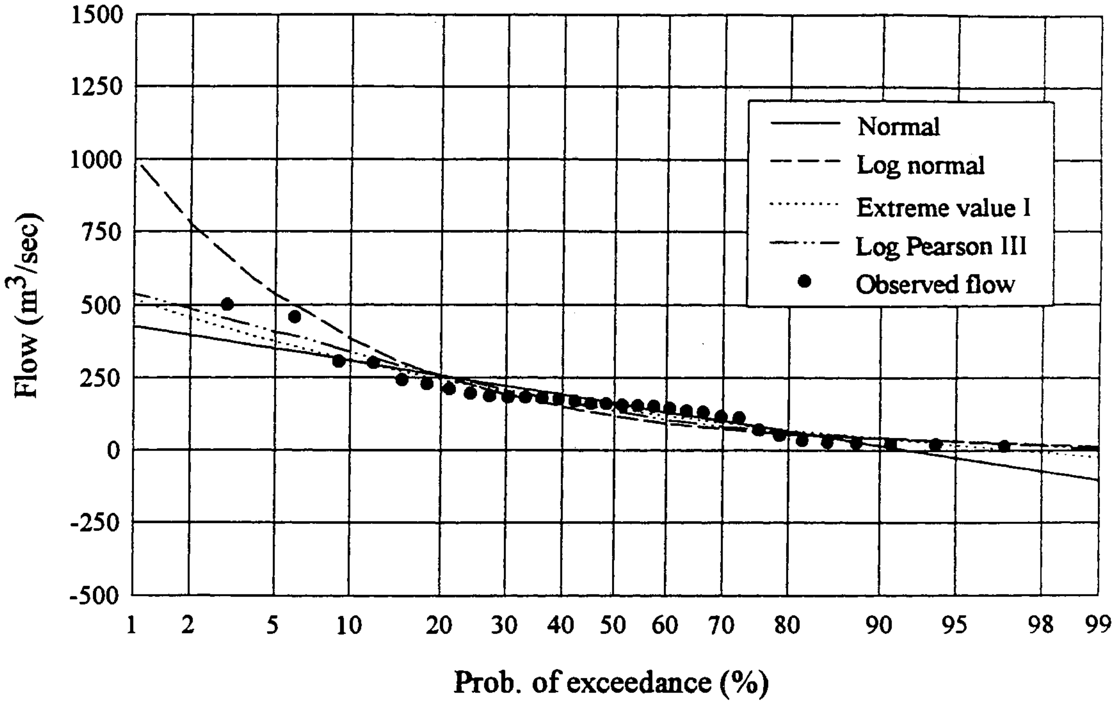
Fig. A6 : Observed and fitted distributions, (a) station 4005, (b) station 4050

Table A13 : Fitted and observed flows, station 4090

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-101.34	14.37	-23.26	7.89	96.97	14.57
80.00	67.85	55.82	70.01	60.01	93.94	20.49
70.00	103.12	74.06	95.76	83.57	90.91	23.25
60.00	131.57	93.04	119.98	106.89	87.88	26.19
50.00	163.43	120.11	144.74	137.84	84.85	26.71
43.00	183.91	141.55	163.33	160.48	81.82	35.32
30.00	222.60	193.03	203.69	208.91	78.79	52.43
20.00	259.01	258.48	245.30	260.71	75.76	69.81
15.00	279.49	304.61	273.42	292.13	72.73	113.27
10.00	309.07	386.15	311.87	339.81	69.70	116.32
7.00	334.10	471.99	344.95	381.72	66.67	132.41
5.00	350.60	538.75	375.73	409.84	63.64	136.98
4.00	362.55	592.91	395.99	430.33	60.61	145.28
2.00	396.68	779.57	458.39	488.83	57.58	151.75
1.00	428.20	1003.71	520.34	541.76	54.55	155.19
0.20	491.12	1662.35	663.48	639.75	51.52	156.72
0.10	515.02	2013.39	725.01	673.05	48.48	160.19
					45.45	160.58
					42.42	169.07
					39.39	177.39
					36.36	181.12
					33.33	182.31
					30.30	183.64
					27.27	188.50
					24.24	196.93
					21.21	212.82
					18.18	230.37
					15.15	243.03
					12.12	300.64
					9.09	305.98
					6.06	459.39
					3.03	501.12

Table A14 : Fitted and observed flows, station 4100

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	1.25	3.23	3.87	2.41	96.67	3.12
80.00	6.93	6.34	7.00	6.57	93.33	4.08
70.00	8.12	7.30	7.87	7.75	90.00	4.33
60.00	9.07	8.18	8.68	8.76	86.67	4.54
50.00	10.14	9.30	9.51	9.94	83.33	4.77
43.00	10.83	10.09	10.14	10.73	80.00	6.65
30.00	12.13	11.77	11.49	12.24	76.67	6.69
20.00	13.35	13.62	12.89	13.68	73.33	6.94
15.00	14.04	14.78	13.83	14.49	70.00	7.52
10.00	15.03	16.63	15.12	15.63	66.67	8.03
7.00	15.87	18.38	16.24	16.58	63.33	9.04
5.00	16.42	19.64	17.27	17.19	60.00	10.06
4.00	16.83	20.60	17.95	17.62	56.67	10.54
2.00	17.97	23.61	20.04	18.80	53.33	10.56
1.00	19.03	26.77	22.12	19.81	50.00	10.76
0.20	21.14	34.43	26.93	21.58	46.67	10.87
0.10	21.95	37.87	29.00	22.15	43.33	11.44
					40.00	11.84
					36.67	12.25
					33.33	12.67
					30.00	12.71
					26.67	12.83
					23.33	13.03
					20.00	13.07
					16.67	13.54
					13.33	13.54
					10.00	15.77
					6.67	16.00
					3.33	16.87



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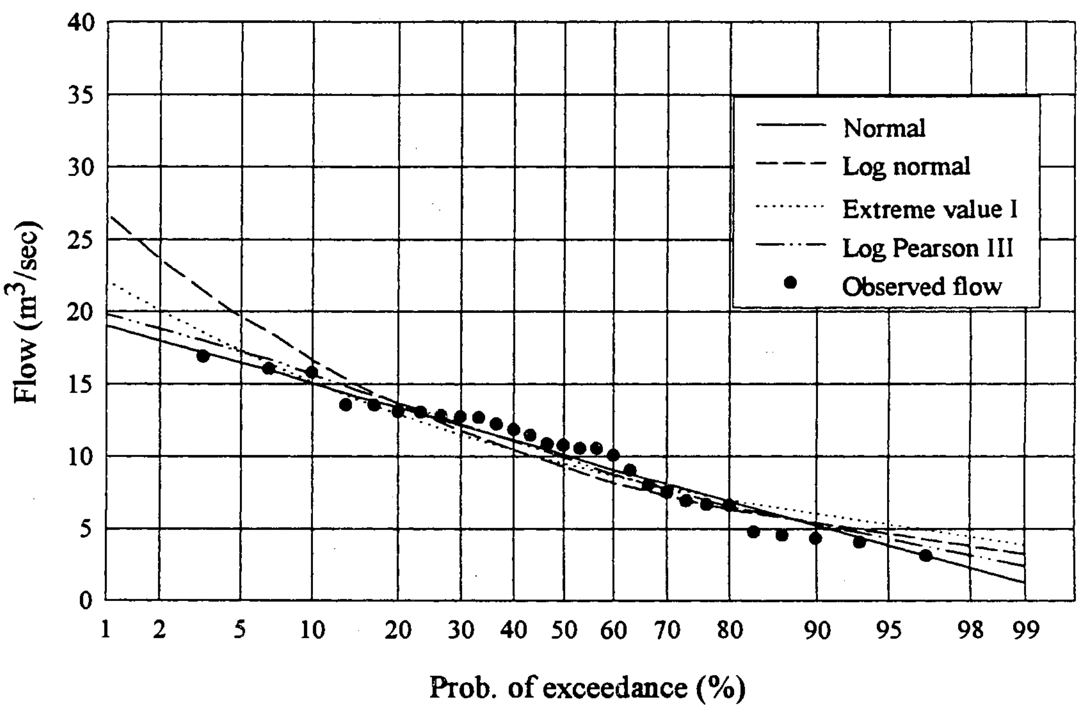


(b)

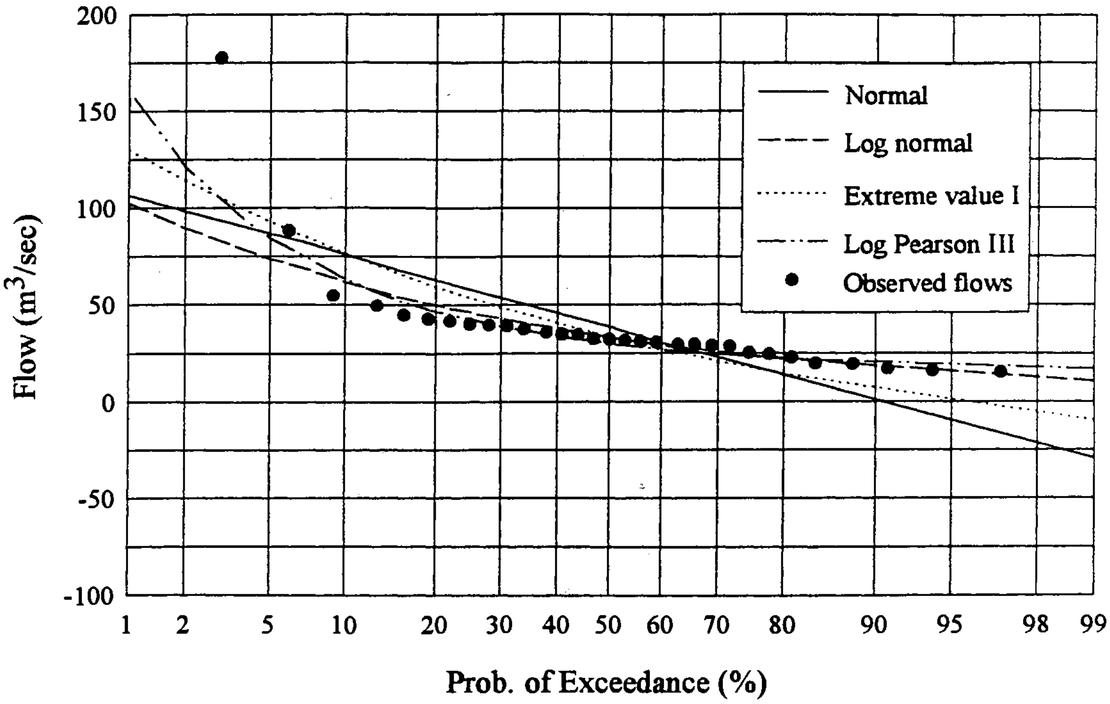
Fig. A7 : Observed and fitted distributions, (a) station 4090, (b) station 4100

Table A15 : Fitted and observed flows, station 4120

Prob.	Nor	Ln	Ev	LP3	Plottting positions	Flow
99.00	-29.50	10.86	-9.44	17.24	97.00	15.40
80.00	13.97	22.27	14.53	22.38	94.00	16.10
70.00	23.04	25.86	21.14	24.60	91.00	17.10
60.00	30.35	29.18	27.37	26.90	88.00	19.50
50.00	38.53	33.40	33.73	30.15	84.00	19.90
43.00	43.80	36.44	38.51	32.71	81.00	22.98
30.00	53.74	42.93	48.88	38.91	78.00	24.50
20.00	63.09	50.11	59.57	46.95	75.00	25.00
15.00	68.36	54.65	66.80	52.75	72.00	28.40
10.00	75.96	61.96	76.68	63.35	69.00	28.90
7.00	82.39	68.90	85.18	75.01	66.00	29.30
5.00	86.63	73.90	93.09	84.46	63.00	29.30
4.00	89.70	77.74	98.29	92.38	59.00	30.40
2.00	98.47	89.85	114.33	121.51	56.00	31.10
1.00	106.57	102.71	130.24	160.35	53.00	31.60
0.20	122.74	134.13	167.03	300.43	50.00	32.10
0.10	128.88	148.44	182.84	391.83	47.00	32.40
					44.00	34.60
					41.00	34.90
					38.00	35.70
					34.00	37.56
					31.00	39.20
					28.00	39.61
					25.00	40.28
					22.00	41.60
					19.00	42.70
					16.00	44.80
					13.00	49.60
					9.00	54.60
					6.00	88.10
					3.00	177.30

Table A16 : Fitted and observed flows, station 4152

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-5.35	1.70	-0.35	1.10	96.43	1.60
80.00	5.48	5.05	5.62	5.31	92.86	1.90
70.00	7.73	6.34	7.26	6.90	89.29	2.44
60.00	9.55	7.61	8.81	8.40	85.71	4.31
50.00	11.59	9.34	10.40	10.31	82.14	5.97
43.00	12.90	10.65	11.59	11.67	78.57	6.41
30.00	15.38	13.66	14.17	14.49	75.00	6.73
20.00	17.71	17.27	16.83	17.42	71.43	7.00
15.00	19.02	19.70	18.63	19.16	67.86	8.52
10.00	20.91	23.82	21.09	21.79	64.29	8.58
7.00	22.51	27.98	23.21	24.08	60.71	8.58
5.00	23.57	31.12	25.17	25.61	57.14	9.49
4.00	24.33	33.60	26.47	26.73	53.57	9.65
2.00	26.52	41.85	30.46	29.93	50.00	9.93
1.00	28.53	51.25	34.43	32.85	46.43	10.16
0.20	32.56	76.81	43.58	38.39	42.86	10.73
0.10	34.09	89.57	47.52	40.33	39.29	11.32
					35.71	12.74
					32.14	13.65
					28.57	14.38
					25.00	15.15
					21.43	15.84
					17.86	16.78
					14.29	20.58
					10.71	23.27
					7.14	24.59
					3.57	32.70



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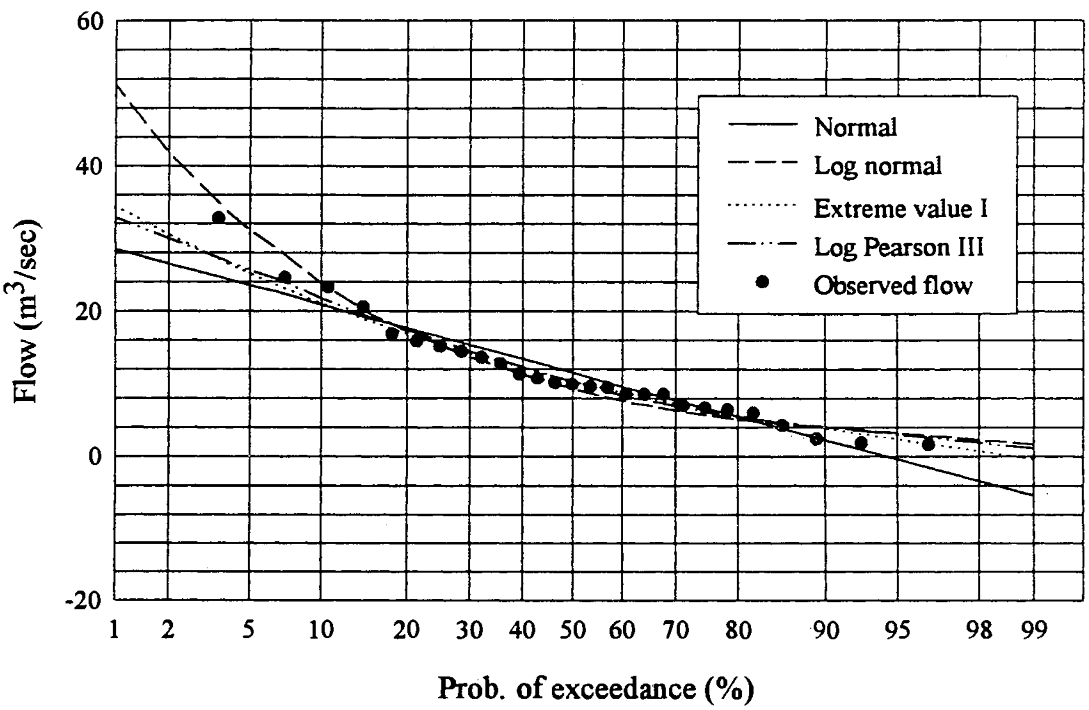


(b)

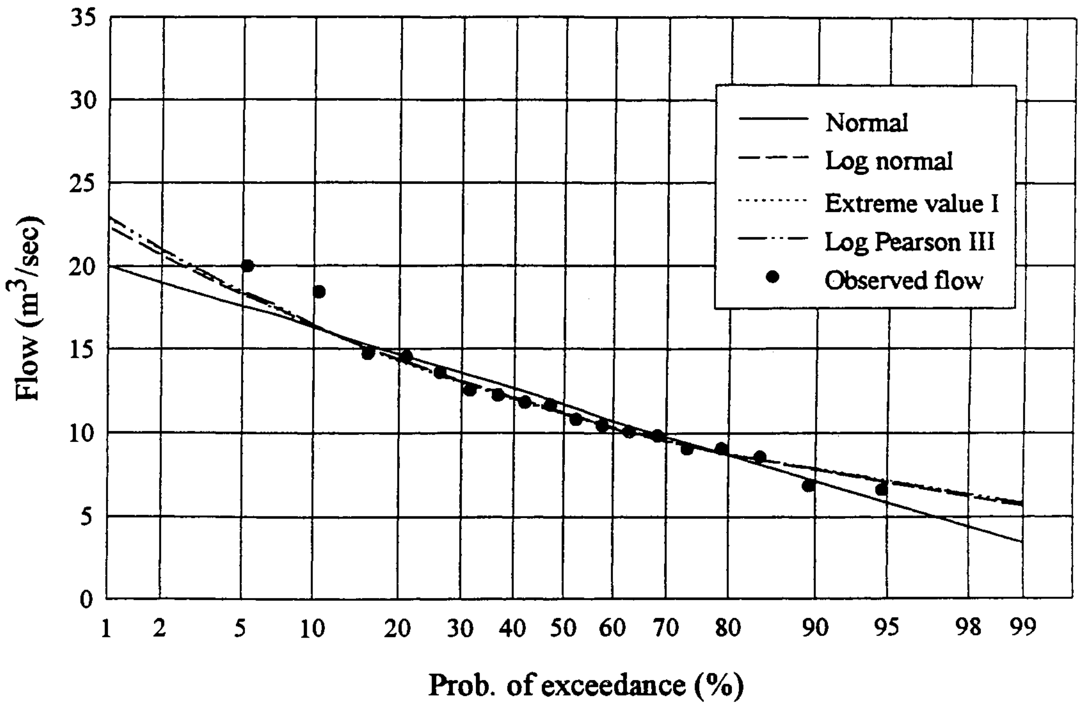
Fig. A8 : Observed and fitted distributions, (a) station 4120, (b) station 4152

Table A17 : Fitted and observed flows, station 4170

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99	3.42	5.64	5.86	5.79	94.74	6.61
80	8.72	8.76	8.79	8.74	89.47	6.88
70	9.82	9.6	9.59	9.56	84.21	8.59
60	10.72	10.34	10.35	10.28	78.95	9.08
50	11.71	11.23	11.13	11.17	73.68	9.08
43	12.36	11.85	11.71	11.78	68.42	9.85
30	13.57	13.11	12.97	13.05	63.16	10.09
20	14.71	14.41	14.28	14.38	57.89	10.45
15	15.35	15.2	15.16	15.2	52.63	10.78
10	16.28	16.42	16.36	16.48	47.37	11.65
7	17.06	17.52	17.4	17.65	42.11	11.79
5	17.58	18.29	18.37	18.47	36.84	12.24
4	17.95	18.87	19	19.1	31.58	12.53
2	19.02	20.63	20.96	21.02	26.32	13.59
1	20.01	22.39	22.9	22.98	21.05	14.55
0.2	21.98	26.38	27.38	27.55	15.79	14.7
0.1	22.73	28.07	29.31	29.55	10.53	18.4
					5.26	19.98

Table A18 : Fitted and observed flows, station 4205

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99	-20.19	4.01	-2.12	2.2	95.83	3
80	18.97	14.79	19.47	15.92	91.67	7.33
70	27.13	19.42	25.43	21.92	87.5	10.43
60	33.71	24.18	31.03	27.79	83.33	12.67
50	41.09	30.92	36.76	35.48	79.17	16.56
43	45.83	36.21	41.07	41.03	75	18.18
30	54.78	48.81	50.41	52.77	70.83	18.31
20	63.21	64.64	60.04	65.11	66.67	21.16
15	67.95	75.7	66.54	72.5	62.5	21.59
10	74.8	95.11	75.44	83.57	58.33	29.48
7	80.59	115.38	83.1	93.18	54.17	37.3
5	84.41	131.04	90.22	99.56	50	38.22
4	87.17	143.7	94.91	104.18	45.83	42.03
2	95.07	186.99	109.36	117.2	41.67	43.14
1	102.37	238.47	123.69	128.77	37.5	50.37
0.2	116.93	387.5	156.82	149.62	33.33	57.56
0.1	122.46	465.95	171.06	156.51	29.17	60.41
					25	72.94
					20.83	72.94
					16.67	73.03
					12.5	73.85
					8.33	75.58
					4.17	88.95



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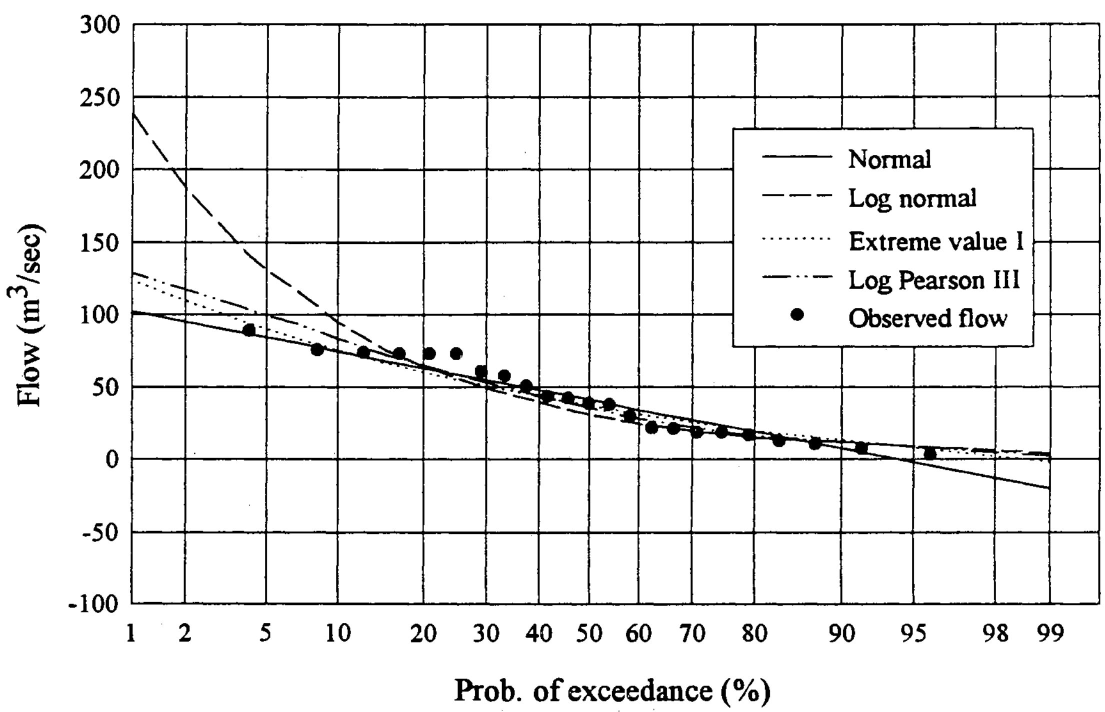


(b)

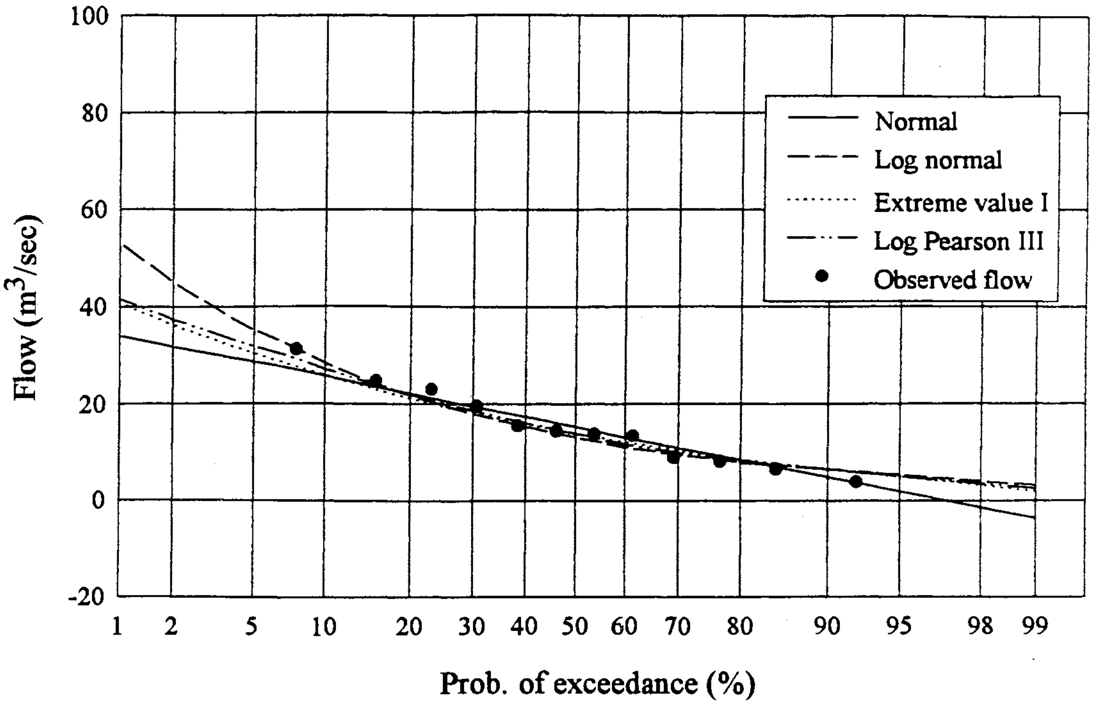
Fig. A9 : Observed and fitted distributions (a) station 4170, (b) station 4205

Table A19 : Fitted and observed flows, station 4210

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-3.60	3.27	1.98	2.57	92.31	3.99
80.00	8.48	7.97	8.63	8.17	84.62	6.52
70.00	10.99	9.60	10.47	10.04	76.92	8.13
60.00	13.02	11.15	12.20	11.77	69.23	9.02
50.00	15.30	13.19	13.96	13.94	61.54	13.47
43.00	16.76	14.69	15.29	15.47	53.85	13.85
30.00	19.52	18.01	18.17	18.66	46.15	14.40
20.00	22.11	21.82	21.14	22.01	38.46	15.56
15.00	23.58	24.31	23.14	24.04	30.77	19.57
10.00	25.69	28.41	25.89	27.16	23.08	22.96
7.00	27.47	32.41	28.25	29.96	15.38	24.76
5.00	28.65	35.35	30.44	31.89	7.69	31.31
4.00	29.50	37.64	31.89	33.31		
2.00	31.94	45.06	36.34	37.54		
1.00	34.19	53.19	40.76	41.63		
0.20	38.67	74.09	50.97	50.16		
0.10	40.38	84.02	55.36	53.49		

Table A20 : Fitted and observed flows, station 4239

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-1.80	0.55	0.34	0.17	94.44	0.25
80.00	2.84	2.04	2.90	2.56	88.89	2.51
70.00	3.81	2.68	3.61	3.60	83.33	2.51
60.00	4.59	3.35	4.27	4.54	77.78	2.58
50.00	5.46	4.29	4.95	5.62	72.22	3.39
43.00	6.02	5.03	5.46	6.30	66.67	3.41
30.00	7.09	6.80	6.57	7.49	61.11	3.69
20.00	8.09	9.03	7.71	8.41	55.56	4.12
15.00	8.65	10.59	8.48	8.84	50.00	4.63
10.00	9.46	13.34	9.54	9.31	44.44	5.62
7.00	10.15	16.21	10.44	9.60	38.89	6.15
5.00	10.60	18.43	11.29	9.73	33.33	7.01
4.00	10.93	20.23	11.84	9.81	27.78	7.42
2.00	11.86	26.39	13.56	9.93	22.22	8.22
1.00	12.73	33.74	15.26	9.96	16.67	10.25
0.20	14.45	55.09	19.18	9.98	11.11	10.41
0.10	15.11	66.36	20.87	10.04	5.56	10.69



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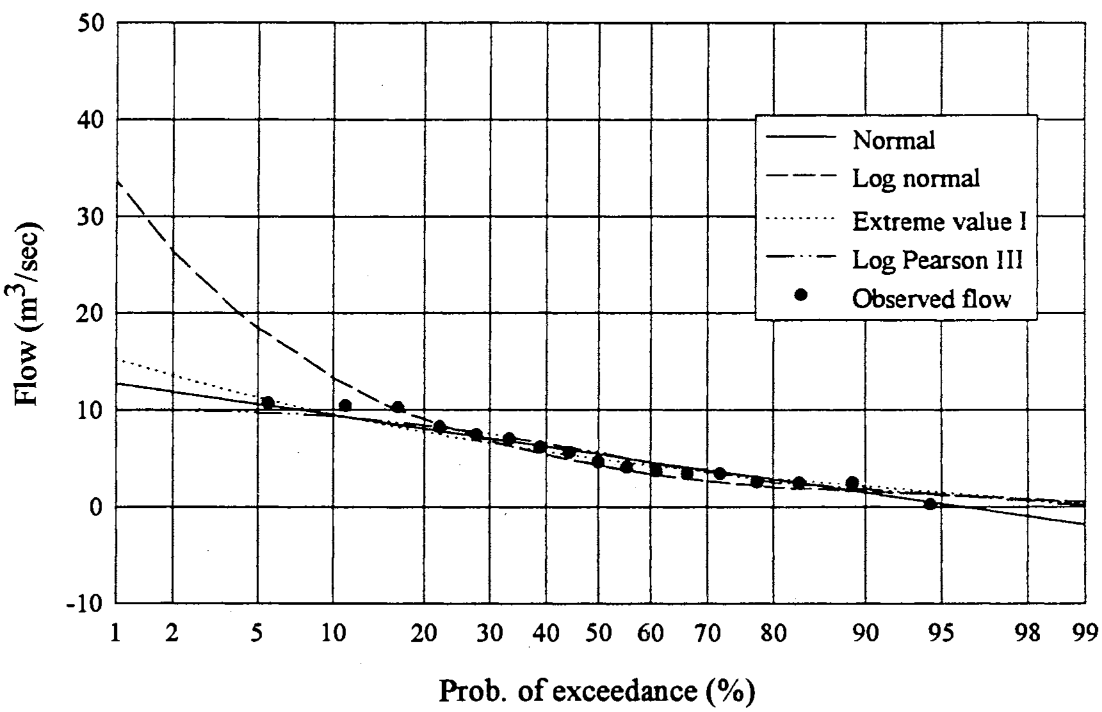


(b)

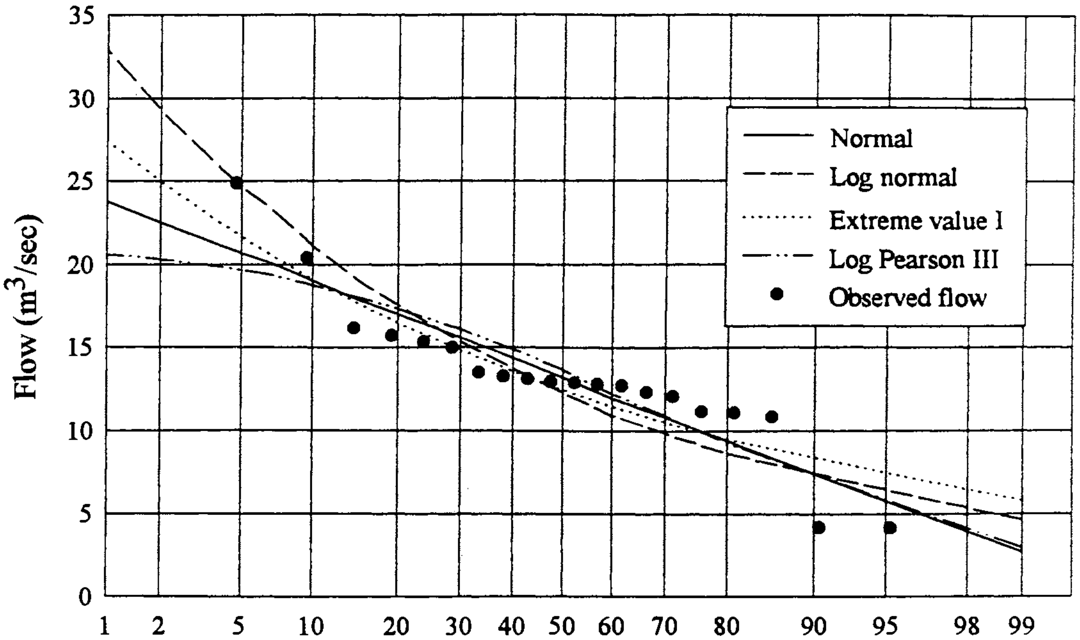
Fig. A10 : Observed and fitted distributions, (a) station 4210, (b) station 4239

Table A21 : Fitted and observed flows, station 4240

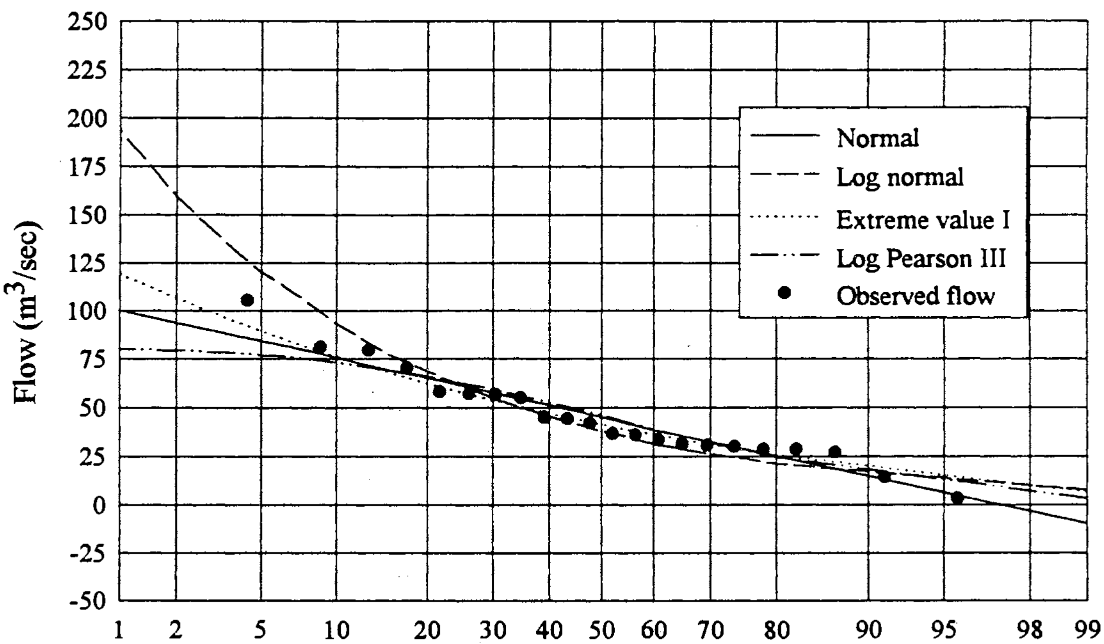
Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	2.69	4.62	5.80	2.95	95.24	4.14
80.00	9.43	8.66	9.52	9.31	90.48	4.19
70.00	10.84	9.87	10.54	10.94	85.71	10.86
60.00	11.97	10.96	11.51	12.25	80.95	11.11
50.00	13.24	12.34	12.49	13.69	76.19	11.23
43.00	14.05	13.31	13.23	14.57	71.43	12.10
30.00	15.60	15.36	14.84	16.11	66.67	12.34
20.00	17.05	17.58	16.50	17.38	61.90	12.74
15.00	17.86	18.97	17.62	18.01	57.14	12.81
10.00	19.04	21.17	19.15	18.79	52.38	12.91
7.00	20.04	23.23	20.47	19.35	47.62	12.96
5.00	20.70	24.69	21.70	19.67	42.86	13.12
4.00	21.17	25.81	22.50	19.87	38.10	13.29
2.00	22.53	29.29	24.99	20.33	33.33	13.49
1.00	23.79	32.92	27.46	20.63	28.57	14.97
0.20	26.30	41.57	33.16	20.91	23.81	15.32
0.10	27.25	45.42	35.61	20.95	19.05	15.74
					14.29	16.17
					9.52	20.39
					4.76	24.88

Table A22 : Fitted and observed flows, station 4245

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-9.69	7.51	6.53	3.21	95.65	3.54
80.00	25.44	21.22	25.89	24.69	91.30	14.38
70.00	32.77	26.35	31.24	32.34	86.96	27.18
60.00	38.67	31.37	36.27	38.92	82.61	28.68
50.00	45.29	38.15	41.41	46.38	78.26	28.89
43.00	49.54	43.26	45.27	51.08	73.91	30.03
30.00	57.57	54.86	53.65	59.36	69.57	30.67
20.00	65.13	68.60	62.29	66.08	65.22	31.43
15.00	69.39	77.80	68.13	69.30	60.87	33.66
10.00	75.53	93.29	76.11	73.17	56.52	36.01
7.00	80.73	108.79	82.98	75.72	52.17	36.87
5.00	84.15	120.39	89.37	77.05	47.83	42.28
4.00	86.63	129.55	93.57	77.86	43.48	44.49
2.00	93.72	159.75	106.53	79.49	39.13	44.91
1.00	100.26	193.86	119.39	80.27	34.78	55.16
0.20	113.33	285.28	149.11	80.63	30.43	56.82
0.10	118.29	330.35	161.89	80.64	26.09	57.16
					21.74	58.00
					17.39	70.48
					13.04	79.32
					8.70	81.05
					4.35	105.33



Prob. of exceedance (%)
(a)



Prob. of exceedance (%)
(b)

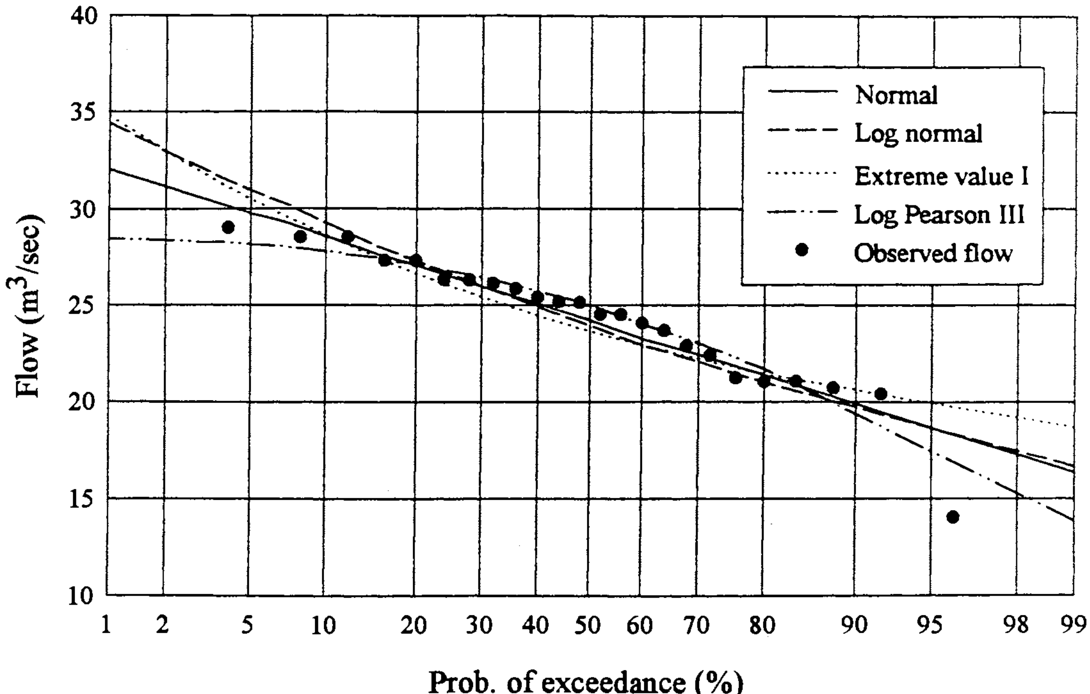
Fig. A11 : Observed and fitted distributions, (a) station 4240, (b) station 4245

Table A23 : Fitted and observed flows, station 4250

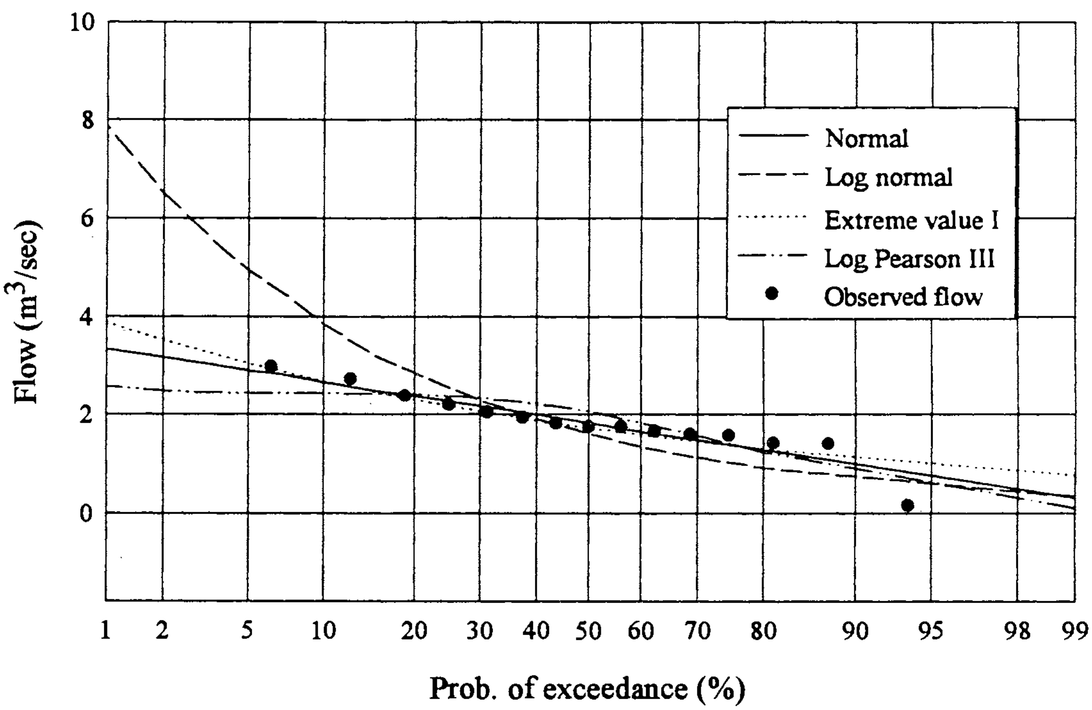
Prob.	Nor	LN	Ev	Lp3	Plotting positions	Flow
99.00	16.37	16.67	18.69	13.88	96.00	14.03
80.00	21.39	21.02	21.45	21.70	92.00	20.42
70.00	22.44	22.07	22.22	23.05	88.00	20.71
60.00	23.28	22.94	22.94	24.03	84.00	21.03
50.00	24.23	23.97	23.67	25.00	80.00	21.05
43.00	24.83	24.65	24.22	25.55	76.00	21.24
30.00	25.98	25.99	25.42	26.45	72.00	22.40
20.00	27.06	27.32	26.65	27.13	68.00	22.87
15.00	27.67	28.10	27.49	27.44	64.00	23.68
10.00	28.55	29.26	28.63	27.80	60.00	24.06
7.00	29.29	30.28	29.61	28.04	56.00	24.51
5.00	29.78	30.97	30.52	28.16	52.00	24.51
4.00	30.13	31.49	31.13	28.24	48.00	25.14
2.00	31.15	32.99	32.98	28.40	44.00	25.17
1.00	32.08	34.45	34.81	28.48	40.00	25.42
0.20	33.95	37.55	39.06	28.53	36.00	25.84
0.10	34.66	38.80	40.89	28.53	32.00	26.10
					28.00	26.28
					24.00	26.32
					20.00	27.30
					16.00	27.32
					12.00	28.50
					8.00	28.52
					4.00	29.00

Table A24 : Fitted and observed flows, station 4266

Prob.	Nor	LN	Ev	Lp3	Plotting positions	Flow
99.00	0.31	0.33	0.76	0.10	93.75	0.16
80.00	1.28	0.91	1.29	1.23	87.50	1.40
70.00	1.48	1.12	1.44	1.57	81.25	1.41
60.00	1.65	1.33	1.58	1.83	75.00	1.57
50.00	1.83	1.61	1.72	2.06	68.75	1.60
43.00	1.95	1.82	1.83	2.18	62.50	1.66
30.00	2.17	2.29	2.06	2.34	56.25	1.76
20.00	2.38	2.85	2.30	2.41	50.00	1.76
15.00	2.49	3.22	2.46	2.42	43.75	1.82
10.00	2.66	3.85	2.68	2.43	37.50	1.94
7.00	2.81	4.47	2.87	2.43	31.25	2.05
5.00	2.90	4.94	3.04	2.43	25.00	2.20
4.00	2.97	5.31	3.16	2.44	18.75	2.38
2.00	3.16	6.51	3.52	2.48	12.50	2.73
1.00	3.34	7.87	3.87	2.57	6.25	2.98
0.20	3.70	11.48	4.69	3.02		
0.10	3.84	13.25	5.04	3.36		



(a)



(b)

Fig. A12 : Observed and fitted distributions, (a) station 4250, (b) station 4266

Table A25 : Fitted and observed flows, station 4272

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-30.91	3.79	-8.34	1.06	92.31	2.35
80.00	17.99	15.58	18.61	19.93	84.62	22.79
70.00	28.18	20.92	26.05	28.80	76.92	28.60
60.00	36.40	26.53	33.05	36.86	69.23	37.61
50.00	45.61	34.62	40.21	46.32	61.54	40.05
43.00	51.53	41.08	45.58	52.34	53.85	41.53
30.00	62.71	56.76	57.24	62.91	46.15	43.01
20.00	73.23	76.93	69.27	71.21	38.46	44.78
15.00	79.15	91.29	77.40	75.00	30.77	44.78
10.00	87.70	116.89	88.51	79.26	23.08	47.28
7.00	94.93	144.08	98.07	81.81	15.38	53.92
5.00	99.70	165.37	106.96	83.01	7.69	140.59
4.00	103.15	182.73	112.82	83.66		
2.00	113.02	243.03	130.85	84.73		
1.00	122.13	316.23	148.75	85.01		
0.20	140.31	534.94	190.12	85.21		
0.10	147.22	653.13	207.91	85.73		

Table A26 : Fitted and observed flows, station 4281

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-21.18	0.17	-10.79	0.07	95.45	0.27
80.00	1.32	1.75	1.61	1.93	90.91	0.36
70.00	6.01	2.84	5.03	3.35	86.36	0.56
60.00	9.80	4.18	8.26	5.08	81.82	0.79
50.00	14.03	6.46	11.55	7.85	77.27	2.29
43.00	16.76	8.54	14.02	10.22	72.73	3.71
30.00	21.90	14.47	19.39	16.27	68.18	5.16
20.00	26.74	23.77	24.92	24.26	63.64	5.37
15.00	29.47	31.43	28.66	29.88	59.09	5.43
10.00	33.40	47.05	33.77	39.62	54.55	9.63
7.00	36.73	66.19	38.17	49.45	50.00	10.00
5.00	38.93	82.89	42.27	56.74	45.45	10.63
4.00	40.51	97.55	44.96	62.44	40.91	10.92
2.00	45.05	155.38	53.26	80.58	36.36	13.60
1.00	49.25	238.80	61.50	99.66	31.82	15.41
0.20	57.61	563.19	80.54	143.25	27.27	15.41
0.10	60.79	780.12	88.72	161.15	22.73	17.95
					18.18	34.45
					13.64	36.61
					9.09	42.85
					4.55	53.28

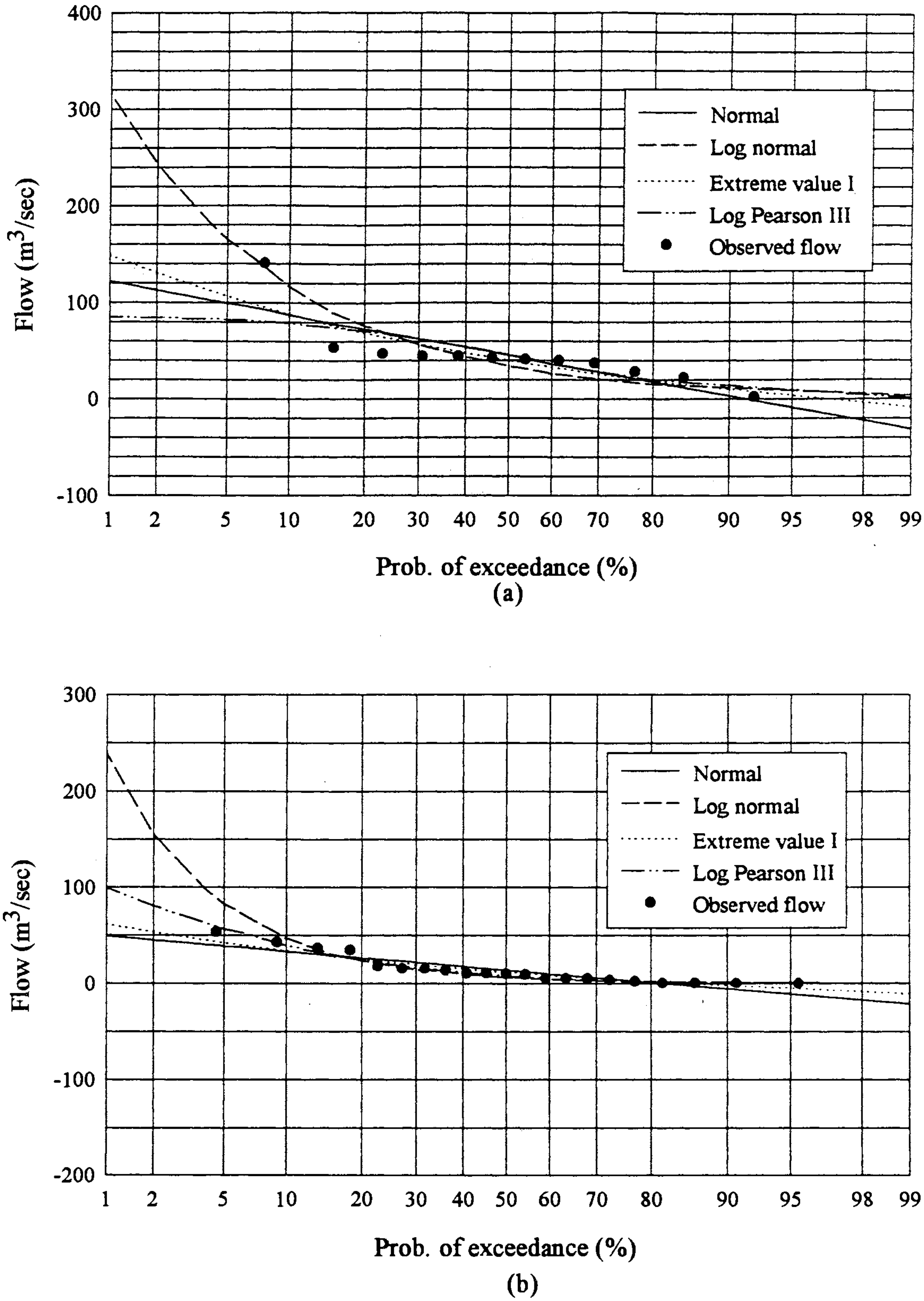


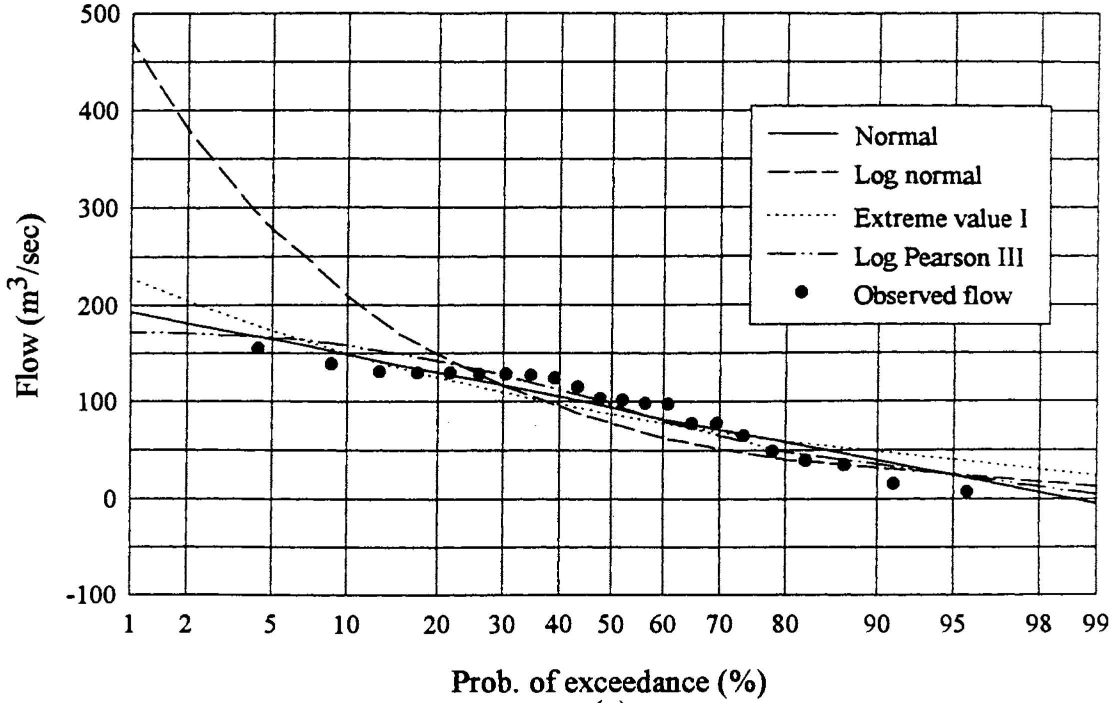
Fig. A13 : Observed and fitted distributions, (a) station 4272, (b) station 4281

Table A27 : Fitted and observed flows, station 4302

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-4.99	12.93	24.30	4.90	95.65	7.21
80.00	58.47	40.79	59.27	48.69	91.30	15.78
70.00	71.69	51.83	68.93	65.65	86.96	34.90
60.00	82.36	62.87	78.02	80.48	82.61	39.45
50.00	94.31	78.05	87.30	97.49	78.26	49.12
43.00	101.99	89.69	94.27	108.23	73.91	64.79
30.00	116.50	116.64	109.41	127.18	69.57	77.43
20.00	130.15	149.35	125.01	142.45	65.22	77.54
15.00	137.83	171.63	135.56	149.66	60.87	97.67
10.00	148.93	209.81	149.98	158.20	56.52	98.13
7.00	158.31	248.67	162.38	163.69	52.17	101.63
5.00	164.50	278.15	173.93	166.49	47.83	102.96
4.00	168.98	301.65	181.52	168.14	43.48	114.98
2.00	181.78	380.33	204.93	171.32	39.13	124.23
1.00	193.60	471.07	228.16	172.67	34.78	127.33
0.20	217.20	722.14	281.84	173.10	30.43	128.38
0.10	226.16	849.34	304.91	173.24	26.09	128.51
					21.74	129.69
					17.39	129.96
					13.04	130.88
					8.70	139.04
					4.35	155.18

Table A28 : Fitted and observed flows, station 4310

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	26.81	22.80	38.90	10.35	95.45	11.44
80.00	52.99	43.94	53.33	54.07	90.91	34.10
70.00	58.45	50.38	57.31	63.32	86.36	61.23
60.00	62.85	56.26	61.06	69.51	81.82	61.32
50.00	67.78	63.65	64.89	74.83	77.27	62.43
43.00	70.95	68.92	67.76	77.35	72.73	63.20
30.00	76.93	80.07	74.01	80.35	68.18	64.45
20.00	82.57	92.21	80.45	81.54	63.64	65.26
15.00	85.74	99.84	84.80	81.76	59.09	66.83
10.00	90.31	111.97	90.75	81.81	54.55	67.03
7.00	94.19	123.39	95.86	81.86	50.00	69.98
5.00	96.74	131.54	100.63	82.03	45.45	71.97
4.00	98.59	137.78	103.76	82.25	40.91	73.92
2.00	103.87	157.27	113.42	83.67	36.36	74.20
1.00	108.75	177.72	123.00	86.45	31.82	75.47
0.20	118.48	226.83	145.15	99.15	27.27	77.88
0.10	122.18	248.86	154.67	107.92	22.73	79.48
					18.18	81.63
					13.64	84.11
					9.09	87.84
					4.55	89.61



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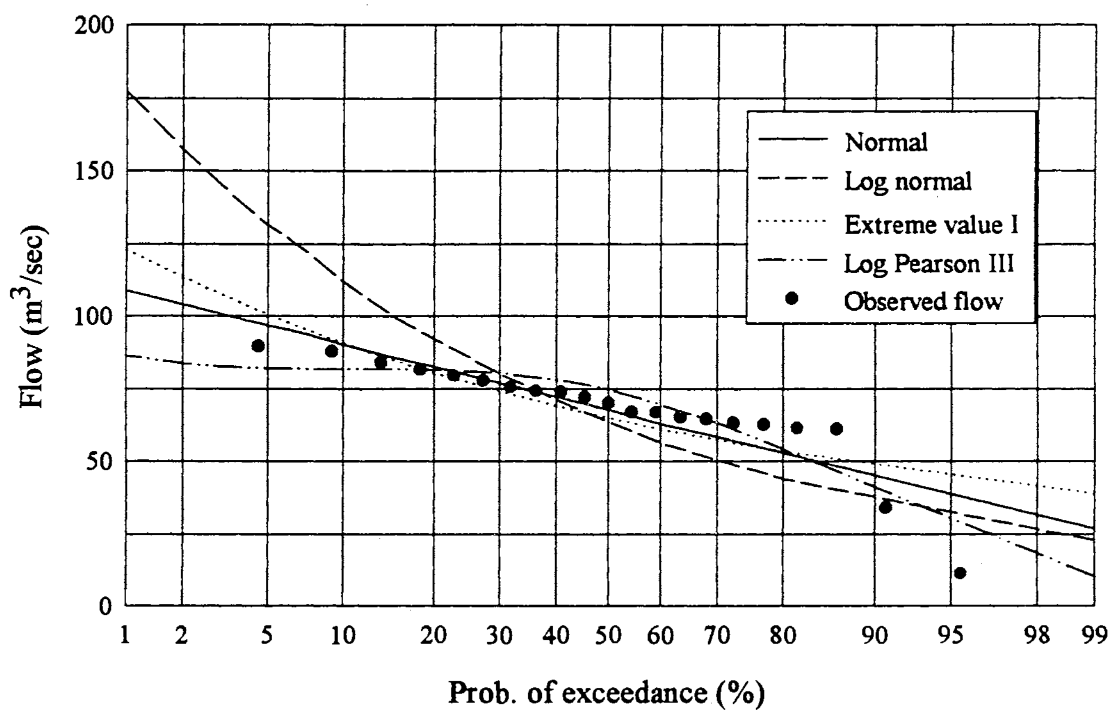


(b)

Fig. A14 : Observed and fitted distributions, (a) station 4302, (b) station 4310

Table A29 : Fitted and observed flows, station 4460

Prob	Nor	Ln	EV1	LP3	Plotting positions	Flow
99.00	0.33	1.38	4.66	0.26	95.00	0.36
80.00	9.72	5.55	9.84	8.52	90.00	5.33
70.00	11.67	7.41	11.27	11.96	85.00	8.29
60.00	13.25	9.37	12.61	14.63	80.00	9.33
50.00	15.02	12.19	13.98	17.19	75.00	9.48
43.00	16.16	14.42	15.02	18.50	70.00	13.07
30.00	18.31	19.84	17.26	20.17	65.00	14.49
20.00	20.33	26.78	19.57	20.90	60.00	14.99
15.00	21.46	31.70	21.13	21.05	55.00	15.28
10.00	23.10	40.44	23.26	21.10	50.00	16.29
7.00	24.49	49.71	25.10	21.11	45.00	16.92
5.00	25.41	56.94	26.80	21.17	40.00	17.30
4.00	26.07	62.83	27.93	21.26	35.00	18.39
2.00	27.97	83.23	31.39	21.90	30.00	18.39
1.00	29.72	107.90	34.83	23.23	25.00	18.45
0.20	33.21	181.19	42.77	30.07	20.00	18.99
0.10	34.53	220.60	46.19	35.35	15.00	19.08
					10.00	25.30
					5.00	25.68

Table A30 : Fitted and observed flows, station 4500

Prob	Nor	Ln	EV1	LP3	Plotting positions	Flow
99.00	-1.95	15.07	12.37	15.25	95.83	16.97
80.00	29.09	29.21	29.49	29.19	91.67	24.08
70.00	35.56	33.53	34.21	33.47	87.50	24.34
60.00	40.78	37.47	38.65	37.38	83.33	28.66
50.00	46.63	42.45	43.20	42.33	79.17	29.36
43.00	50.38	45.98	46.61	45.86	75.00	31.83
30.00	57.48	53.49	54.01	53.39	70.83	32.20
20.00	64.16	61.68	61.64	61.63	66.67	32.74
15.00	67.92	66.82	66.80	66.82	62.50	33.09
10.00	73.35	75.01	73.86	75.14	58.33	35.59
7.00	77.94	82.72	79.93	83.00	54.17	38.73
5.00	80.97	88.24	85.58	88.64	50.00	42.25
4.00	83.16	92.46	89.29	92.97	45.83	43.70
2.00	89.42	105.66	100.74	106.57	41.67	45.42
1.00	95.20	119.51	112.11	120.94	37.50	46.96
0.20	106.75	152.85	138.37	155.88	33.33	48.87
0.10	111.13	167.82	149.66	171.72	29.17	56.28
					25.00	64.76
					20.83	68.46
					16.67	76.38
					12.50	78.15
					8.33	81.41
					4.17	92.15

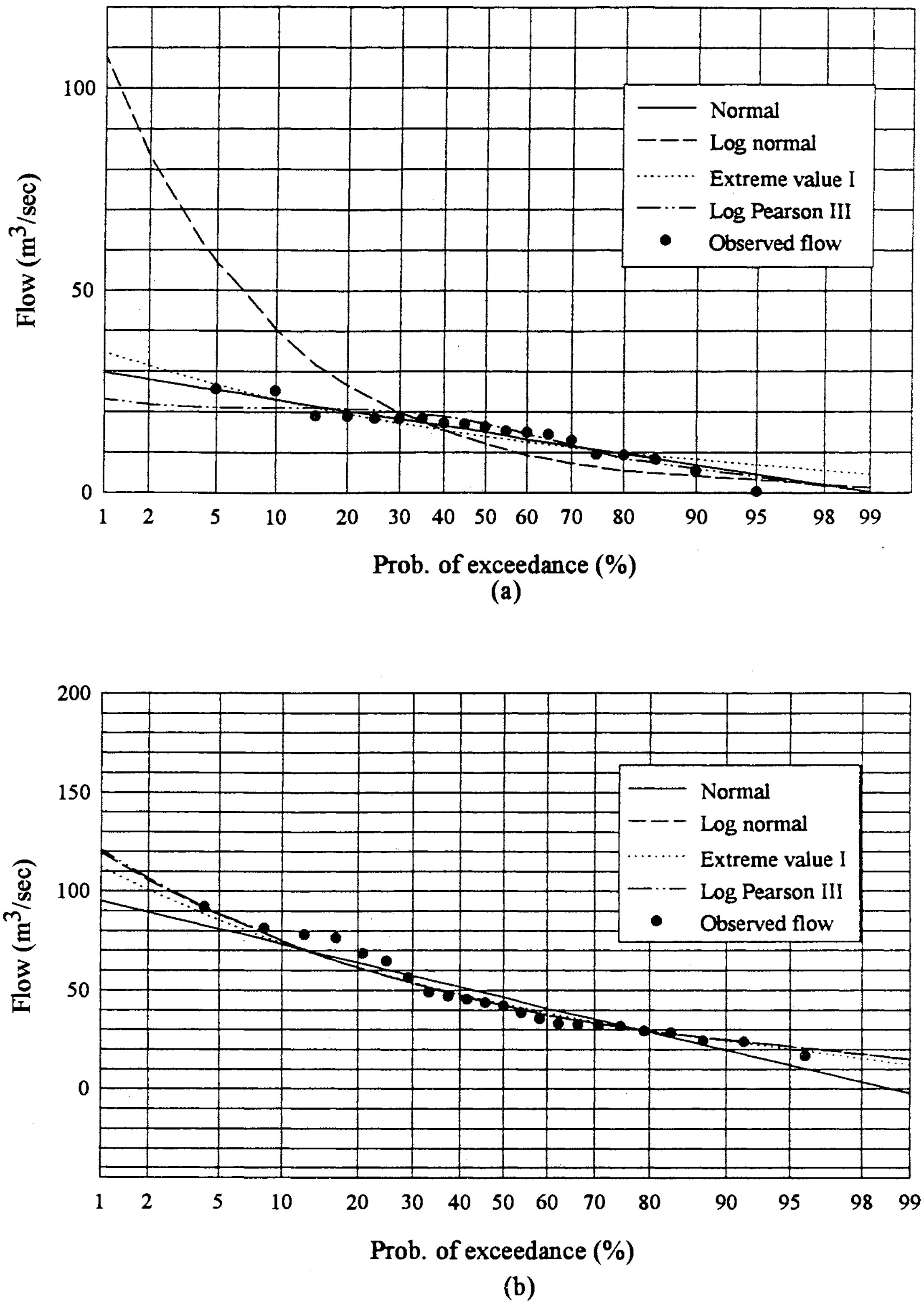


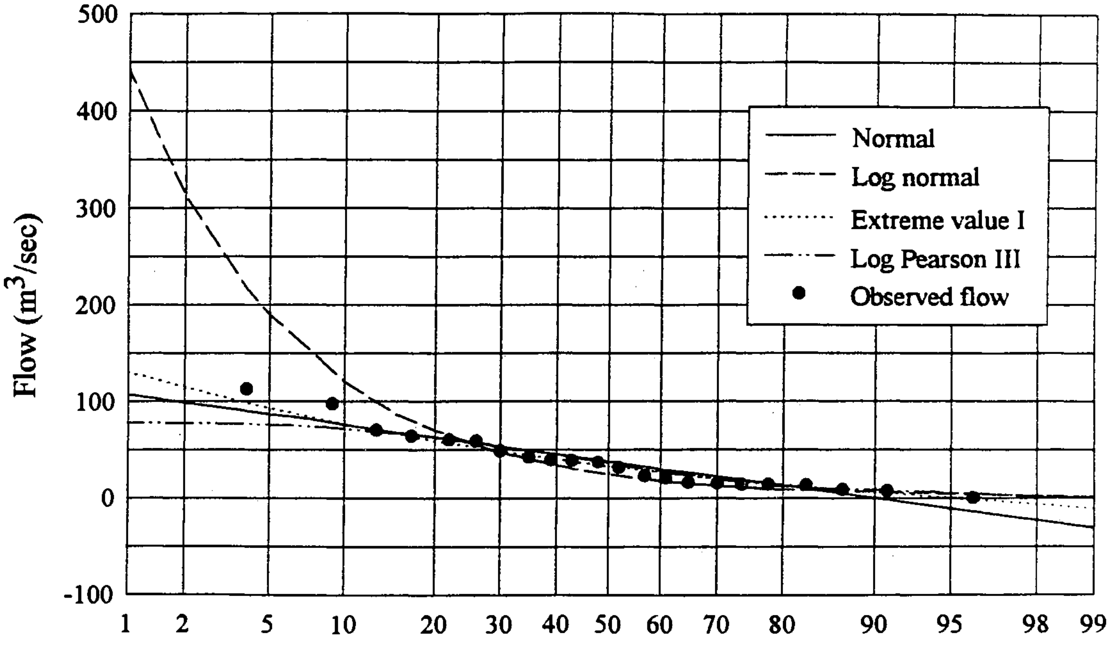
Fig. A15 : Observed and fitted distributions, (a) station 4460, (b) station 4500

Table A31 : Fitted and observed flows, station 4620

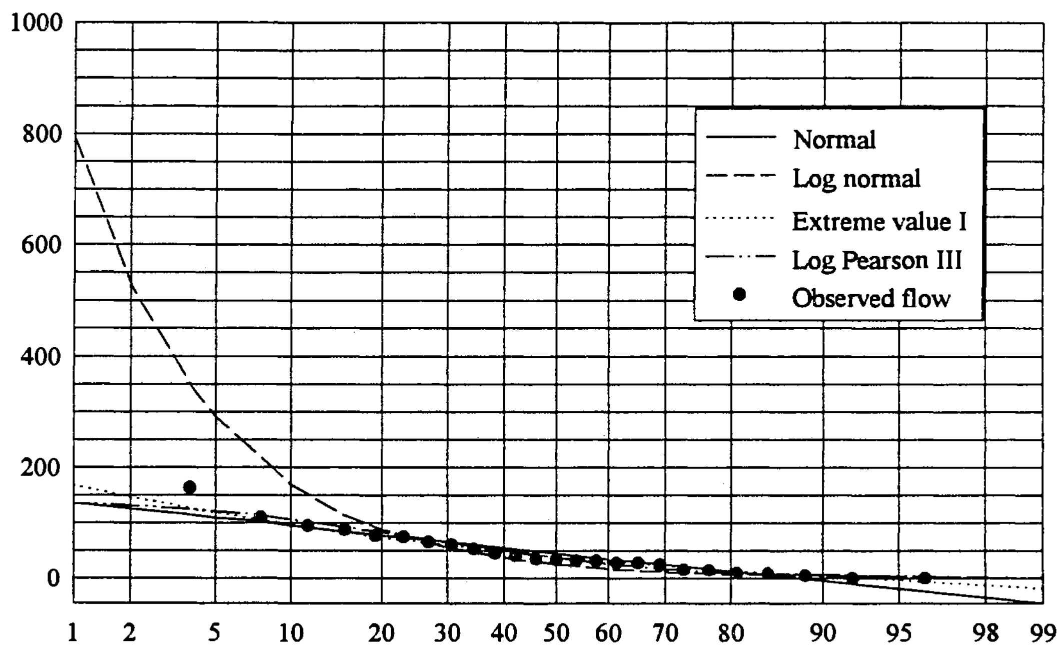
Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-30.73	1.40	-10.42	0.26	96.00	0.31
80.00	13.28	8.81	13.84	12.25	91.00	7.56
70.00	22.46	12.92	20.54	19.77	87.00	9.16
60.00	29.86	17.60	26.84	27.21	83.00	13.92
50.00	38.14	24.87	33.28	36.52	78.00	14.05
43.00	43.47	31.07	38.12	42.71	74.00	14.42
30.00	53.53	47.30	48.62	53.98	70.00	15.89
20.00	63.00	70.26	59.44	63.10	65.00	16.09
15.00	68.33	87.76	66.75	67.29	61.00	21.11
10.00	76.03	121.03	76.76	72.01	57.00	22.97
7.00	82.54	158.86	85.36	74.79	52.00	31.75
5.00	86.83	190.04	93.37	76.06	48.00	37.39
4.00	89.94	216.38	98.64	76.74	43.00	39.03
2.00	98.82	313.52	114.87	77.80	39.00	39.96
1.00	107.02	441.54	130.98	78.01	35.00	42.30
0.20	123.38	874.67	168.21	78.40	30.00	48.79
0.10	129.60	1133.92	184.22	79.23	26.00	59.16
					22.00	60.44
					17.00	64.12
					13.00	70.12
					9.00	97.51
					4.00	113.11

Table A32 : Fitted and observed flows, station 4821

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flows
99.00	-44.76	0.84	-18.04	0.15	96.15	0.39
80.00	13.14	7.49	13.87	10.02	92.31	0.49
70.00	25.21	11.82	22.69	17.68	88.46	5.78
60.00	34.94	17.09	30.97	26.20	84.62	9.19
50.00	45.84	25.82	39.45	38.21	80.77	9.60
43.00	52.85	33.66	45.81	47.12	76.92	14.96
30.00	66.08	55.55	59.61	65.64	73.08	15.37
20.00	78.54	89.03	73.85	83.67	69.23	24.86
15.00	85.55	116.07	83.47	93.40	65.38	28.50
10.00	95.67	170.27	96.63	106.26	61.54	28.52
7.00	104.24	235.48	107.95	115.62	57.69	32.26
5.00	109.88	291.58	118.48	120.89	53.85	32.61
4.00	113.97	340.38	125.41	124.24	50.00	34.73
2.00	125.65	529.64	146.76	131.65	46.15	34.90
1.00	136.43	796.66	167.96	135.87	42.31	40.79
0.20	157.96	1799.77	216.94	138.83	38.46	45.57
0.10	166.14	2452.60	237.99	138.93	34.62	53.57
					30.77	61.13
					26.92	65.65
					23.08	75.10
					19.23	76.90
					15.38	87.86
					11.54	94.41
					7.69	109.96
					3.85	162.89



(a)



(b)

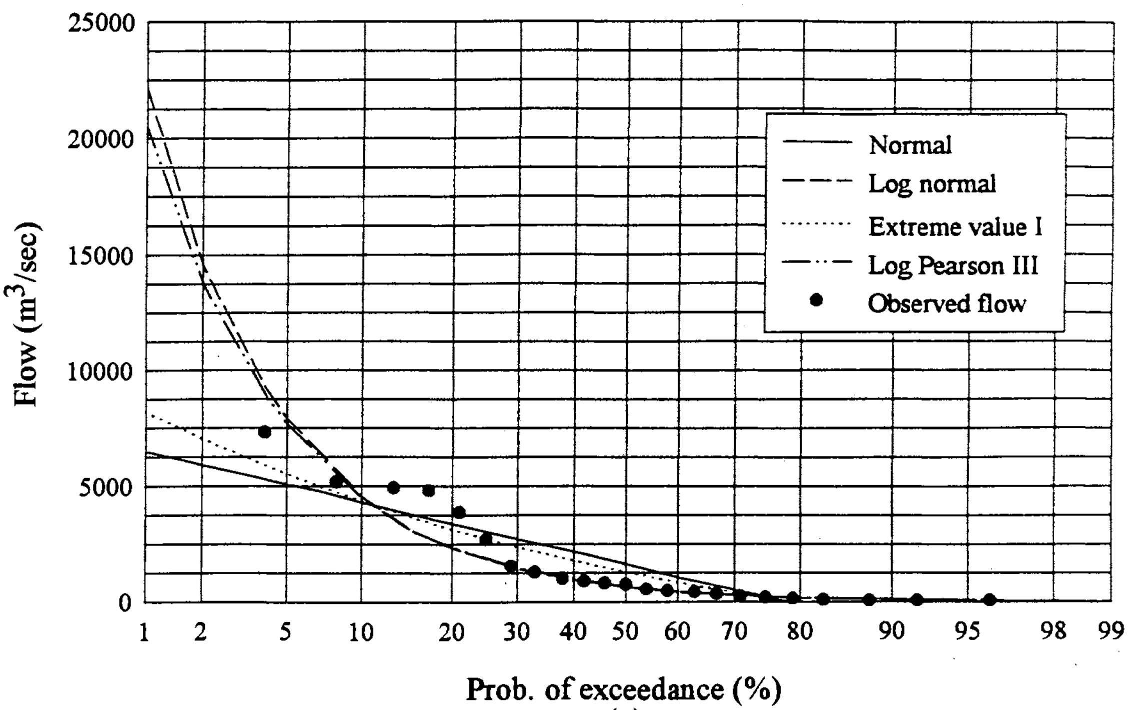
Fig. A16 : Observed and fitted distributions, (a) station 4620, (b) station 4821

Table A33 : Fitted and observed flows, station 4850

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-3209.10	20.06	-1777.12	18.61	96.00	60.34
80.00	-106.27	188.15	-66.71	189.15	92.00	62.61
70.00	540.59	300.04	405.52	303.79	88.00	69.79
60.00	1062.26	437.14	849.76	444.10	83.00	97.17
50.00	1646.52	666.32	1303.82	677.76	79.00	156.33
43.00	2022.11	873.70	1644.72	888.15	75.00	197.12
30.00	2731.57	1457.63	2384.80	1475.57	71.00	244.95
20.00	3399.29	2359.70	3147.85	2370.89	67.00	354.52
15.00	3774.89	3094.13	3663.63	3091.00	63.00	435.31
10.00	4317.42	4576.38	4368.76	4525.27	58.00	480.25
7.00	4776.48	6373.15	4975.33	6236.66	54.00	557.78
5.00	5079.04	7927.80	5539.88	7698.11	50.00	772.67
4.00	5298.14	9285.38	5911.38	8961.94	46.00	829.00
2.00	5924.13	14585.94	7055.78	13808.49	42.00	891.99
1.00	6502.13	22132.59	8191.73	20527.77	38.00	1023.85
0.20	7656.05	50883.18	10816.74	44958.34	33.00	1298.21
0.10	8094.24	69802.11	11945.27	60388.41	29.00	1552.45
					25.00	2697.74
					21.00	3860.49
					17.00	4805.41
					13.00	4932.46
					8.00	5167.12
					4.00	7322.28

Table A34 : Fitted and observed flows, station 4940

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-3.97	2.20	2.75	0.59	97.00	0.48
80.00	10.58	7.60	10.76	10.27	93.00	4.73
70.00	13.61	9.84	12.98	14.09	90.00	6.96
60.00	16.06	12.12	15.06	17.23	87.00	9.70
50.00	18.79	15.30	17.19	20.50	83.00	9.96
43.00	20.56	17.77	18.79	22.36	80.00	10.56
30.00	23.88	23.59	22.26	25.17	77.00	11.73
20.00	27.01	30.80	25.83	26.89	73.00	12.00
15.00	28.77	35.78	28.25	27.50	70.00	12.89
10.00	31.31	44.43	31.55	28.00	67.00	14.21
7.00	33.47	53.37	34.40	28.17	63.00	14.46
5.00	34.88	60.22	37.04	28.21	60.00	14.86
4.00	35.91	65.72	38.79	28.21	57.00	15.71
2.00	38.85	84.38	44.15	28.24	53.00	16.20
1.00	41.55	106.28	49.47	28.45	50.00	16.41
0.20	46.96	168.46	61.78	30.29	47.00	17.84
0.10	49.02	200.66	67.07	31.83	43.00	19.06
					40.00	19.74
					37.00	21.72
					33.00	21.75
					30.00	24.81
					27.00	25.51
					23.00	25.93
					20.00	26.83
					17.00	26.96
					13.00	28.51
					10.00	35.93
					7.00	36.97
					3.00	42.62



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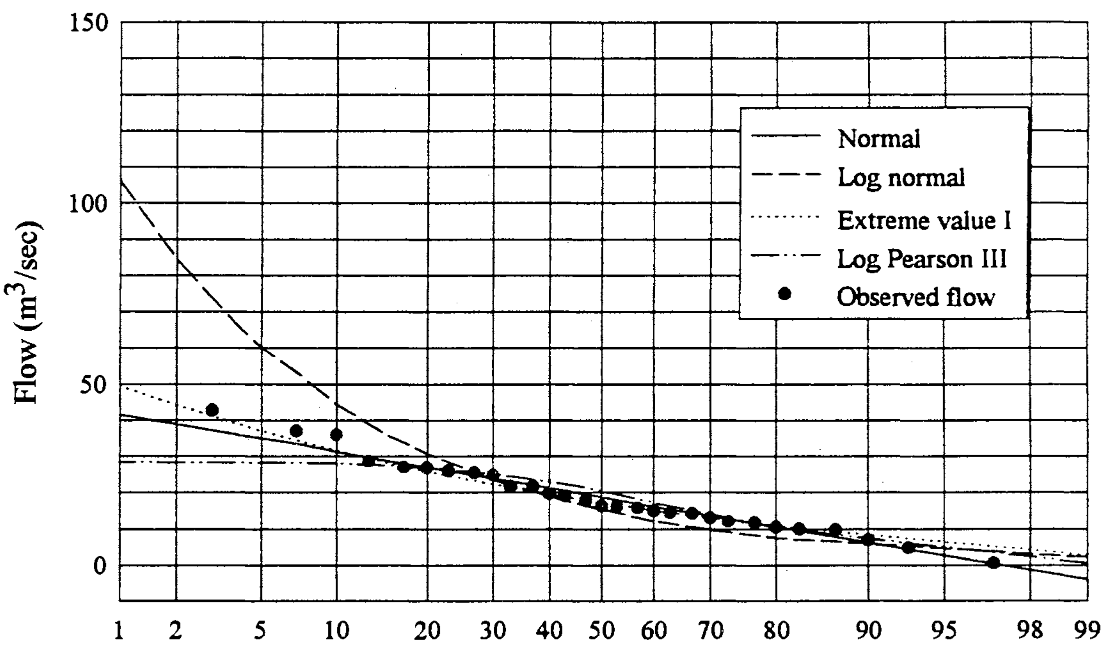


(b)

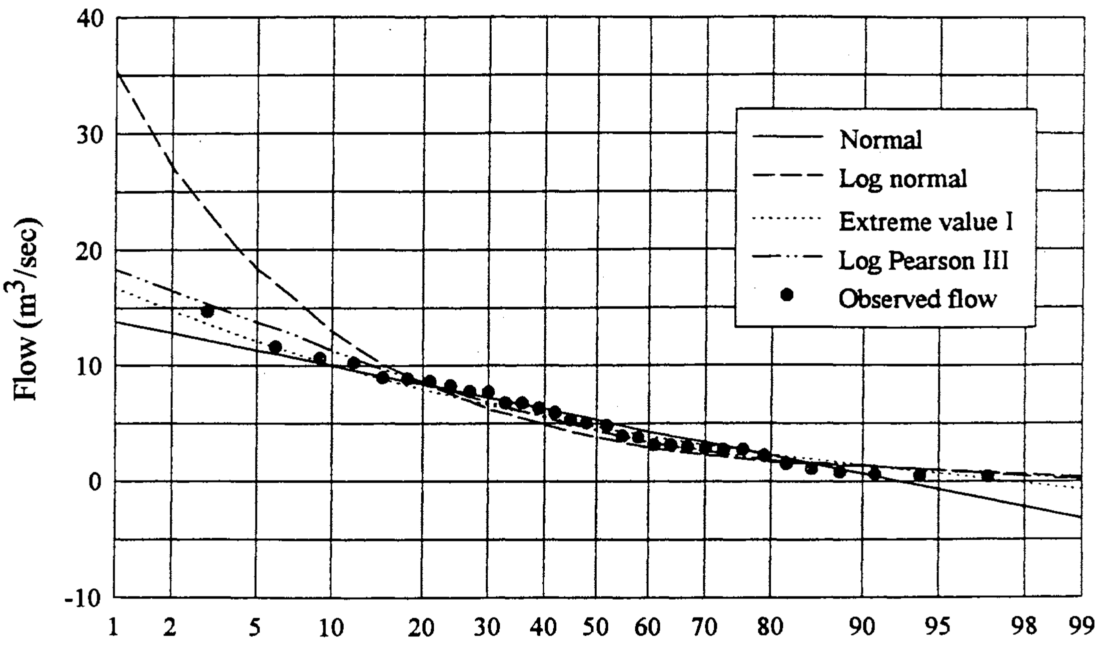
Fig. A17 : Observed and fitted distributions, (a) station 4850, (b) station 4940

Table A35 : Fitted and observed flows, station 4941

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-3.17	0.41	-0.66	0.22	97.00	0.40
80.00	2.26	1.72	2.33	1.85	94.00	0.49
70.00	3.39	2.31	3.16	2.62	91.00	0.60
60.00	4.31	2.93	3.94	3.39	88.00	0.83
50.00	5.33	3.83	4.73	4.43	85.00	1.09
43.00	5.99	4.55	5.33	5.19	82.00	1.51
30.00	7.23	6.29	6.62	6.84	79.00	2.24
20.00	8.40	8.54	7.96	8.61	76.00	2.74
15.00	9.05	10.14	8.86	9.70	73.00	2.76
10.00	10.00	13.00	10.09	11.35	70.00	2.87
7.00	10.81	16.05	11.16	12.80	67.00	2.95
5.00	11.34	18.43	12.14	13.78	64.00	3.12
4.00	11.72	20.38	12.79	14.49	61.00	3.12
2.00	12.82	27.14	14.80	16.53	58.00	3.77
1.00	13.83	35.37	16.79	18.38	55.00	3.91
0.20	15.85	60.00	21.38	21.80	52.00	4.81
0.10	16.61	73.33	23.35	22.95	48.00	5.04
					45.00	5.32
					42.00	5.90
					39.00	6.30
					36.00	6.72
					33.00	6.74
					30.00	7.68
					27.00	7.72
					24.00	8.22
					21.00	8.63
					18.00	8.87
					15.00	8.99
					12.00	10.25
					9.00	10.64
					6.00	11.65
					3.00	14.68

Table A36 : Fitted and observed flows, station 4945

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-83.99	7.10	-35.30	5.10	97.00	4.83
80.00	21.50	26.96	22.85	27.83	94.00	9.25
70.00	43.50	35.61	38.91	37.83	90.00	19.59
60.00	61.23	44.56	54.01	47.94	87.00	31.27
50.00	81.10	57.28	69.45	61.77	84.00	31.27
43.00	93.87	67.32	81.04	72.25	81.00	32.28
30.00	117.99	91.33	106.20	95.88	77.00	33.31
20.00	140.69	121.70	132.14	123.25	74.00	35.43
15.00	153.46	143.02	149.68	141.06	71.00	36.30
10.00	171.91	180.60	173.65	170.06	68.00	42.73
7.00	187.52	220.00	194.28	197.81	65.00	42.73
5.00	197.80	250.56	213.47	217.77	61.00	46.18
4.00	205.25	275.31	226.10	233.07	58.00	47.19
2.00	226.54	360.34	265.01	280.79	55.00	49.78
1.00	246.19	461.99	303.63	330.17	52.00	53.26
0.20	285.42	758.72	392.88	443.90	48.00	59.46
0.10	300.32	916.01	431.25	492.14	45.00	61.52
					42.00	65.76
					39.00	67.31
					35.00	70.16
					32.00	70.48
					29.00	86.51
					26.00	97.74
					23.00	114.81
					19.00	120.85
					16.00	141.02
					13.00	218.72
					10.00	242.89
					6.00	249.50
					3.00	250.83



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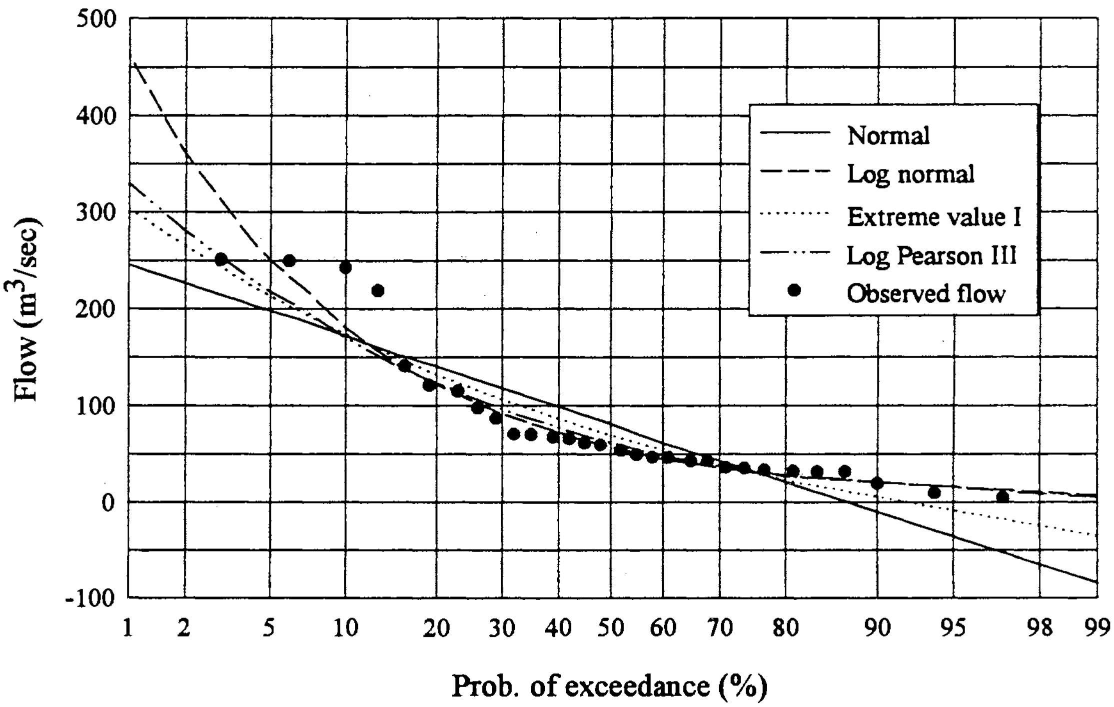


(b)

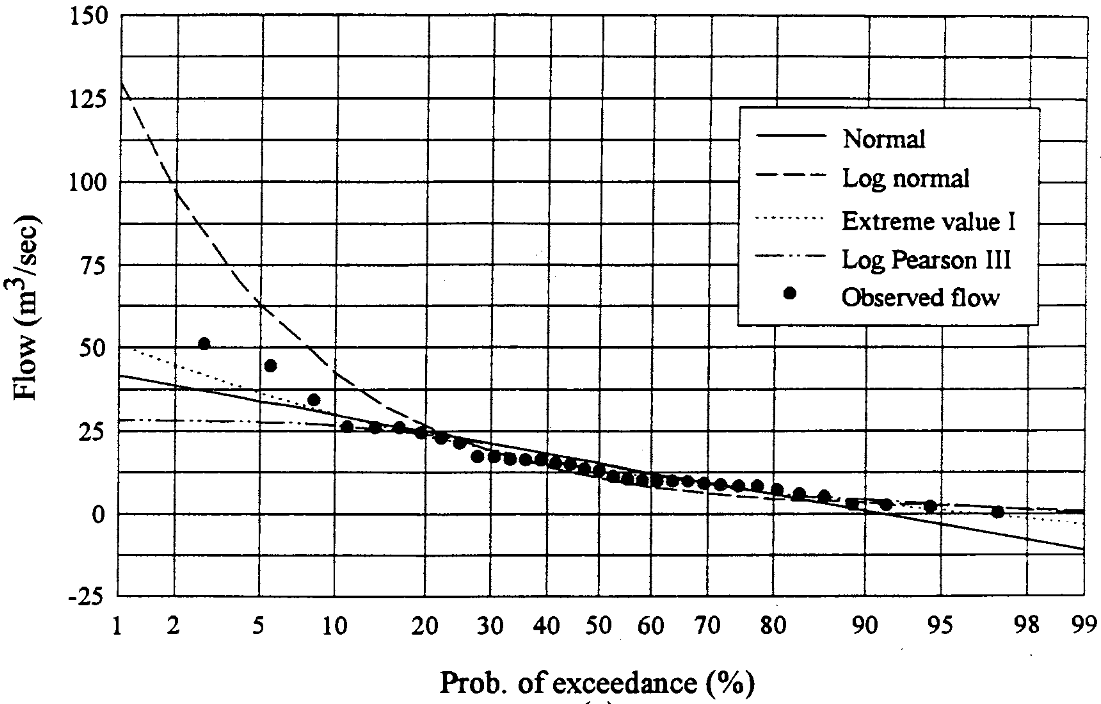
Fig. A18 : Observed and fitted distributions, (a) station 4941, (b) station 4945

Table A37 : Fitted and observed flows, station 4950

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flows
99.00	-10.94	0.92	-3.17	0.21	97.22	0.13
80.00	5.90	4.49	6.11	6.04	94.44	2.17
70.00	9.41	6.24	8.67	9.11	91.67	2.53
60.00	12.24	8.13	11.08	11.97	88.89	2.67
50.00	15.41	10.95	13.55	15.35	86.11	5.32
43.00	17.44	13.26	15.40	17.50	83.33	5.94
30.00	21.29	19.03	19.41	21.25	80.56	7.09
20.00	24.92	26.73	23.55	24.12	77.78	8.33
15.00	26.96	32.36	26.35	25.39	75.00	8.37
10.00	29.90	42.66	30.18	26.75	72.22	8.76
7.00	32.39	53.89	33.47	27.51	69.44	9.11
5.00	34.03	62.86	36.53	27.84	66.67	9.79
4.00	35.22	70.28	38.55	28.01	63.89	9.83
2.00	38.62	96.66	44.76	28.24	61.11	9.99
1.00	41.75	129.73	50.92	28.27	58.33	10.16
0.20	48.02	233.44	65.17	28.51	55.56	10.45
0.10	50.39	291.79	71.29	28.90	52.78	11.20
					50.00	12.92
					47.22	13.58
					44.44	14.85
					41.67	15.31
					38.89	16.34
					36.11	16.38
					33.33	16.48
					30.56	17.19
					27.78	17.24
					25.00	21.40
					22.22	23.00
					19.44	24.48
					16.67	26.03
					13.89	26.03
					11.11	26.25
					8.33	34.29
					5.56	44.57
					2.78	51.06

Table A38 : Fitted and observed flows, station 4952

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	6.92	8.20	9.05	7.99	96.55	9.53
80.00	11.53	11.44	11.59	11.46	93.10	9.66
70.00	12.49	12.26	12.29	12.31	89.66	9.94
60.00	13.26	12.96	12.95	13.03	86.21	10.55
50.00	14.13	13.80	13.62	13.88	82.76	10.55
43.00	14.69	14.36	14.13	14.44	79.31	10.59
30.00	15.74	15.50	15.22	15.56	75.86	10.62
20.00	16.73	16.65	16.36	16.67	72.41	10.91
15.00	17.29	17.33	17.12	17.32	68.97	12.69
10.00	18.09	18.37	18.17	18.29	65.52	13.25
7.00	18.78	19.29	19.07	19.15	62.07	13.27
5.00	19.22	19.93	19.91	19.73	58.62	13.39
4.00	19.55	20.40	20.46	20.15	55.17	13.54
2.00	20.48	21.82	22.16	21.41	51.72	13.78
1.00	21.34	23.21	23.85	22.62	48.28	14.17
0.20	23.05	26.26	27.74	25.18	44.83	14.60
0.10	23.70	27.53	29.42	26.20	41.38	14.65
					37.93	15.09
					34.48	15.32
					31.03	15.71
					27.59	16.10
					24.14	17.14
					20.69	17.61
					17.24	17.72
					13.79	18.18
					10.34	18.26
					6.90	18.27
					3.45	20.54



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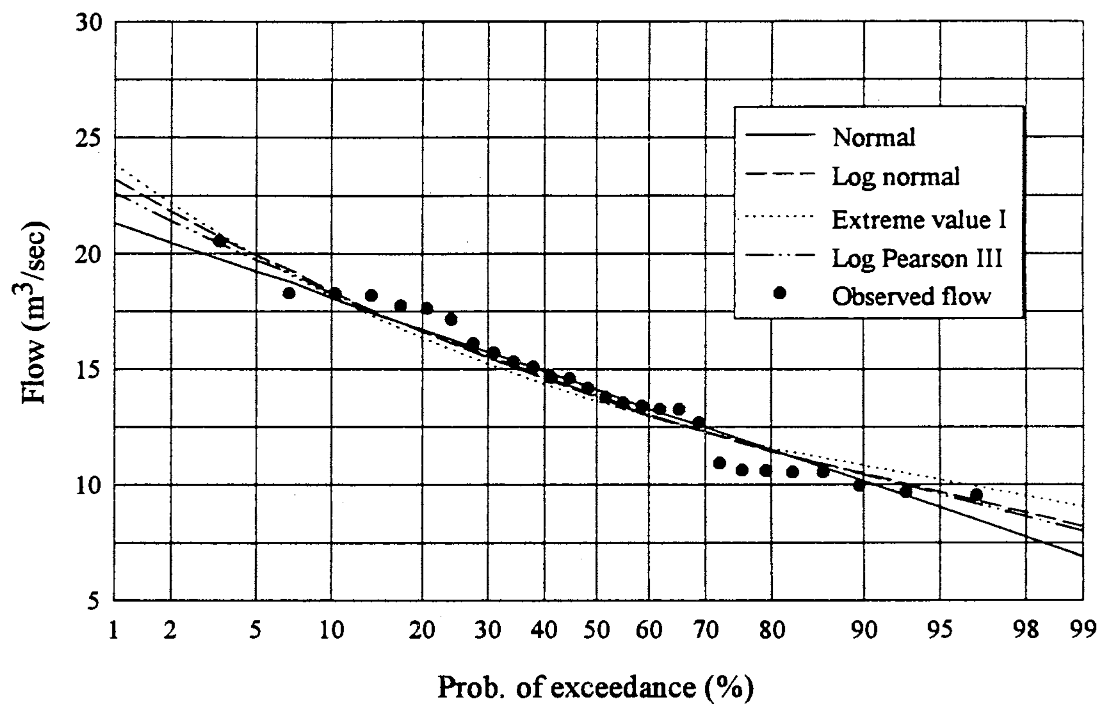


(b)

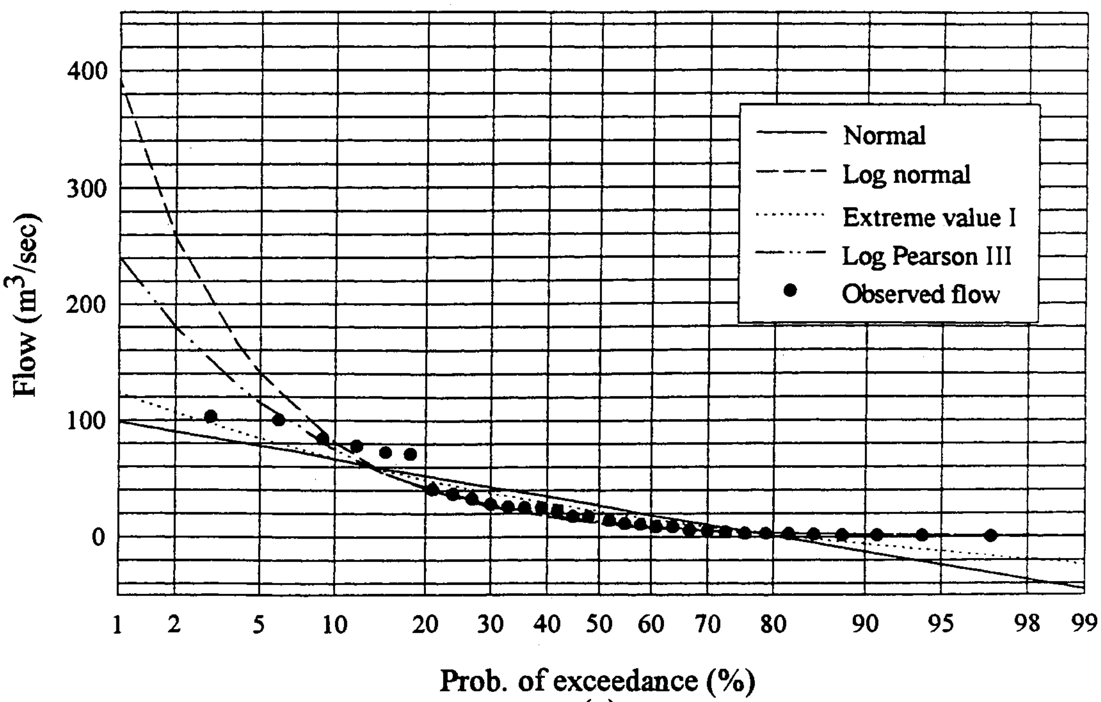
Fig. A19 : Observed and fitted distributions, (a) station 4950, (b) station 4952

Table A39 : Fitted and observed flows, station 4958

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-44.70	0.36	-23.53	0.23	97.00	0.38
80.00	1.16	3.39	1.75	3.54	94.00	0.91
70.00	10.72	5.39	8.73	5.87	91.00	1.34
60.00	18.43	7.84	15.29	8.70	88.00	1.56
50.00	27.07	11.93	22.00	13.30	85.00	1.91
43.00	32.62	15.63	27.04	17.31	82.00	2.48
30.00	43.11	26.03	37.98	27.95	79.00	2.74
20.00	52.98	42.06	49.26	42.92	76.00	3.10
15.00	58.53	55.09	56.88	54.13	73.00	4.22
10.00	66.55	81.36	67.31	74.82	70.00	5.29
7.00	73.33	113.16	76.27	97.39	67.00	5.66
5.00	77.80	140.64	84.62	115.28	64.00	8.78
4.00	81.04	164.62	90.11	129.92	61.00	8.83
2.00	90.30	258.15	107.02	180.77	58.00	10.89
1.00	98.84	391.08	123.81	241.66	55.00	11.54
0.20	115.89	896.22	162.61	414.09	52.00	14.27
0.10	122.37	1227.95	179.29	501.08	48.00	17.58
					45.00	17.65
					42.00	22.65
					39.00	24.89
					36.00	25.42
					33.00	25.60
					30.00	28.26
					27.00	32.86
					24.00	36.82
					21.00	40.90
					18.00	71.21
					15.00	72.71
					12.00	78.08
					9.00	84.14
					6.00	100.26
					3.00	103.29

Table A40 : Fitted and observed flows, station 5030

Prob	Nor	Ln	Ev1	Lp3	Plotting positions	Flows
99	-5.28	0.63	-1.98	0.5	96.97	0.48
80	1.88	2.17	1.97	2.22	93.94	0.94
70	3.37	2.81	3.06	2.93	90.91	1.55
60	4.57	3.46	4.08	3.64	87.88	1.65
50	5.92	4.37	5.13	4.61	84.85	2.24
43	6.79	5.07	5.92	5.34	81.82	2.4
30	8.43	6.73	7.63	6.97	78.79	2.46
20	9.97	8.78	9.39	8.87	75.76	2.55
15	10.83	10.2	10.58	10.12	72.73	2.61
10	12.09	12.65	12.2	12.15	69.7	2.73
7	13.15	15.19	13.6	14.12	66.67	2.86
5	13.84	17.14	14.91	15.55	63.64	3.36
4	14.35	18.7	15.76	16.65	60.61	3.4
2	15.79	23.99	18.4	20.14	57.58	3.65
1	17.13	30.2	21.03	23.83	54.55	3.93
0.2	19.79	47.81	27.08	32.65	51.52	4.13
0.1	20.8	56.92	29.69	36.54	48.48	4.29
					45.45	5.02
					42.42	5.07
					39.39	5.82
					36.36	6.1
					33.33	7.07
					30.3	7.65
					27.27	7.74
					24.24	7.95
					21.21	8.55
					18.18	8.66
					15.15	9.52
					12.12	12.07
					9.09	13.78
					6.06	18.66
					3.03	20.64



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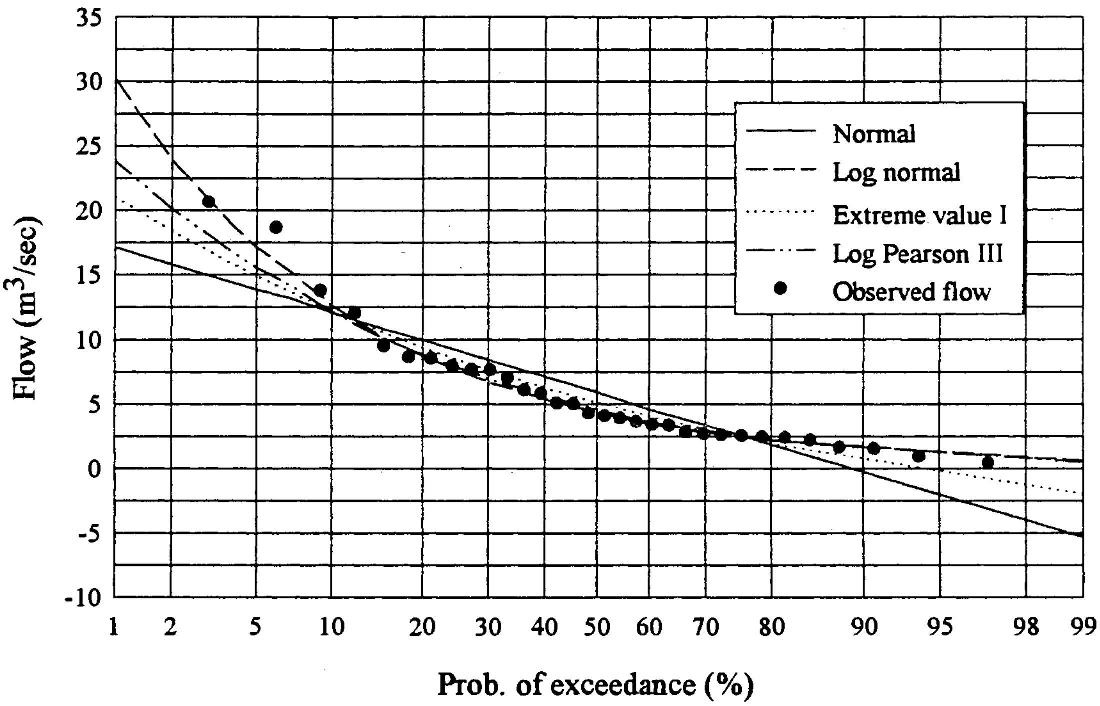


(b)

Fig. A20 : Observed and fitted distributions, (a) station 4958, (b) station 5030

Table A41 : Fitted and observed flows, station 5670

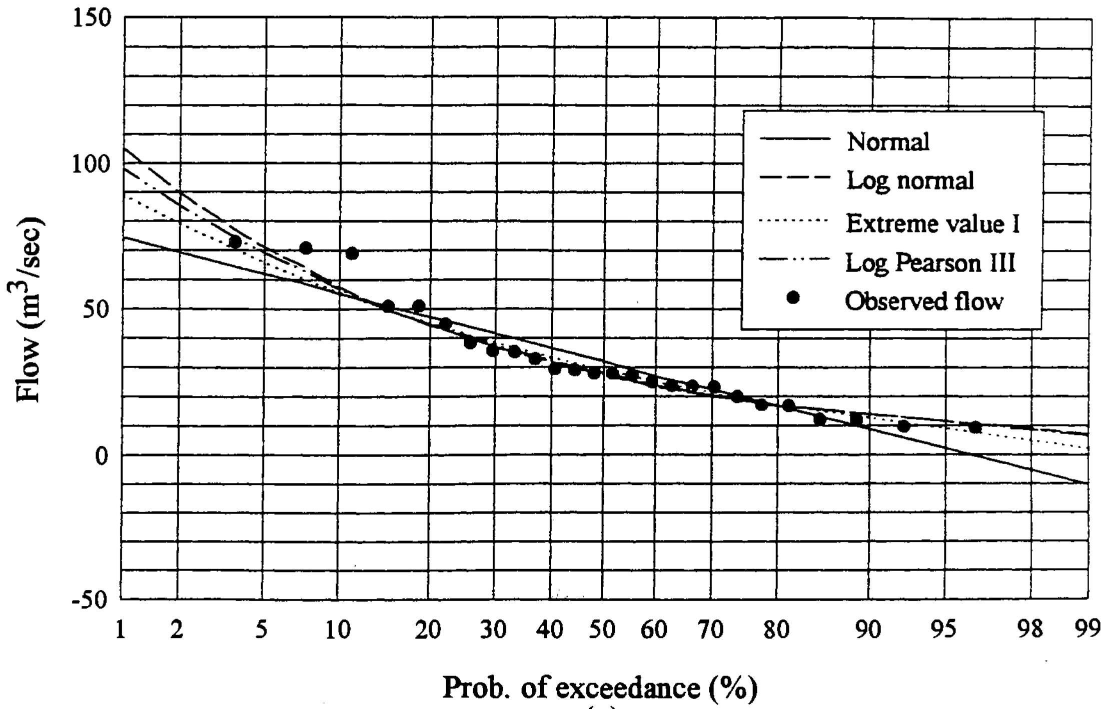
Prob.	Nor	Ln	Ev1	Lp3	Plotting positions	Flow
99	-10.21	7.18	2.26	6.71	96.3	9.21
80	16.81	16.94	17.15	17.03	92.59	9.6
70	22.44	20.26	21.26	20.5	88.89	11.81
60	26.98	23.4	25.13	23.75	85.19	12.04
50	32.07	27.51	29.08	27.94	81.48	16.77
43	35.34	30.52	32.05	30.98	77.78	17.13
30	41.52	37.13	38.5	37.54	74.07	19.86
20	47.33	44.66	45.14	44.84	70.37	23.14
15	50.6	49.55	49.63	49.48	66.67	23.4
10	55.33	57.57	55.77	56.96	62.96	23.58
7	59.32	65.36	61.05	64.05	59.26	25.04
5	61.96	71.07	65.97	69.15	55.56	27.24
4	63.87	75.51	69.2	73.06	51.85	27.74
2	69.32	89.78	79.17	85.36	48.15	27.84
1	74.35	105.34	89.06	98.31	44.44	28.95
0.2	84.4	144.93	111.92	129.48	40.74	29.36
0.1	88.21	163.6	121.75	143.42	37.04	32.69
					33.33	35.2
					29.63	35.67
					25.93	38.33
					22.22	44.72
					18.52	50.88
					14.81	51.03
					11.11	68.99
					7.41	70.84
					3.7	72.72

Table A42 : Fitted and observed flows, station 6140

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	33.86	38.37	43.99	33.27	95.00	41.41
80.00	55.81	54.55	56.09	55.46	90.00	42.11
70.00	60.39	58.70	59.43	60.38	85.00	46.33
60.00	64.08	62.27	62.57	64.35	80.00	54.07
50.00	68.21	66.54	65.79	68.75	75.00	54.42
43.00	70.87	69.43	68.20	71.55	70.00	63.65
30.00	75.89	75.24	73.44	76.71	65.00	66.24
20.00	80.61	81.16	78.83	81.38	60.00	67.09
15.00	83.27	84.69	82.48	83.91	55.00	67.24
10.00	87.11	90.06	87.47	87.43	50.00	72.35
7.00	90.36	94.87	91.76	90.27	45.00	75.41
5.00	92.50	98.18	95.76	92.07	40.00	76.06
4.00	94.05	100.65	98.39	93.33	35.00	76.55
2.00	98.48	108.05	106.48	96.74	30.00	76.96
1.00	102.57	115.37	114.52	99.64	25.00	77.04
0.20	110.73	131.49	133.09	104.65	20.00	77.62
0.10	113.83	138.19	141.08	106.28	15.00	78.69
					10.00	91.31
					5.00	91.48

Table A43 : Fitted and observed flows, station 6145

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	71.24	74.35	84.51	62.37	94.44	71.05
80.00	100.00	97.98	100.37	100.57	88.89	85.65
70.00	106.00	103.79	104.74	107.89	83.33	88.77
60.00	110.83	108.72	108.86	113.45	77.78	108.41
50.00	116.25	114.51	113.07	119.25	72.22	108.41
43.00	119.73	118.40	116.23	122.71	66.67	109.24
30.00	126.31	126.12	123.09	128.66	61.11	114.76
20.00	132.50	133.83	130.17	133.53	55.56	118.52
15.00	135.98	138.38	134.95	135.94	50.00	122.20
10.00	141.01	145.22	141.48	139.02	44.44	123.43
7.00	145.26	151.27	147.11	141.27	38.89	124.42
5.00	148.07	155.40	152.34	142.57	33.33	126.40
4.00	150.10	158.46	155.78	143.43	27.78	128.39
2.00	155.90	167.53	166.39	145.51	22.22	134.80
1.00	161.26	176.37	176.92	146.98	16.67	136.97
0.20	171.96	195.43	201.25	148.82	11.11	137.08
0.10	176.02	203.20	211.72	149.21	5.56	137.72



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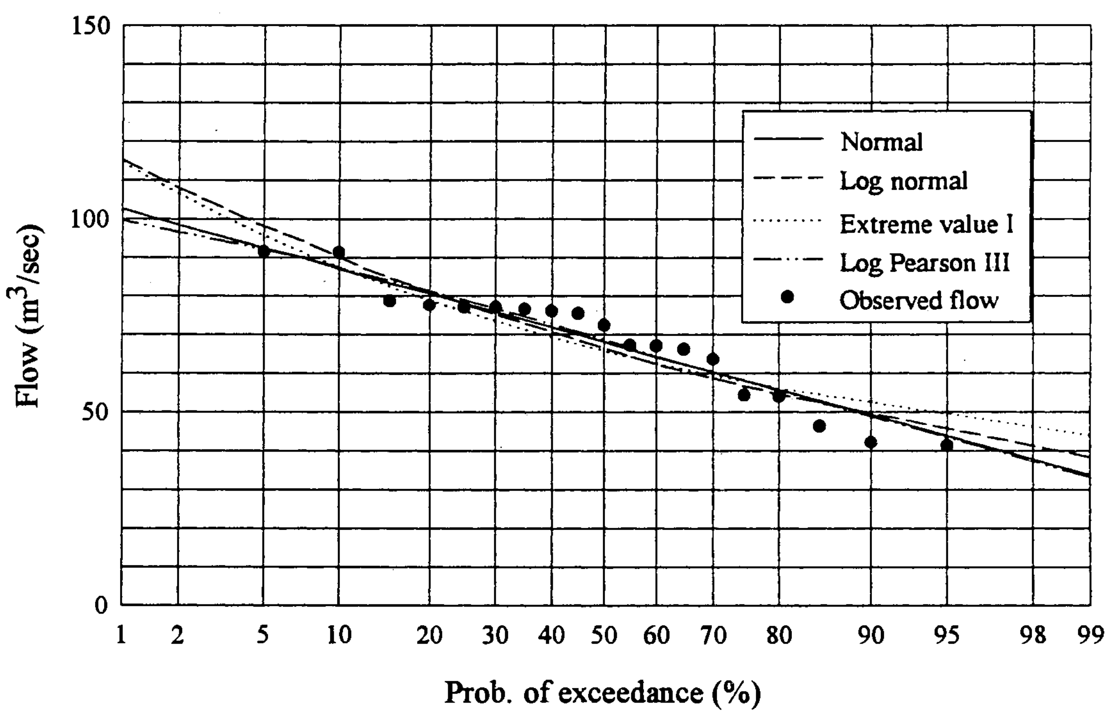
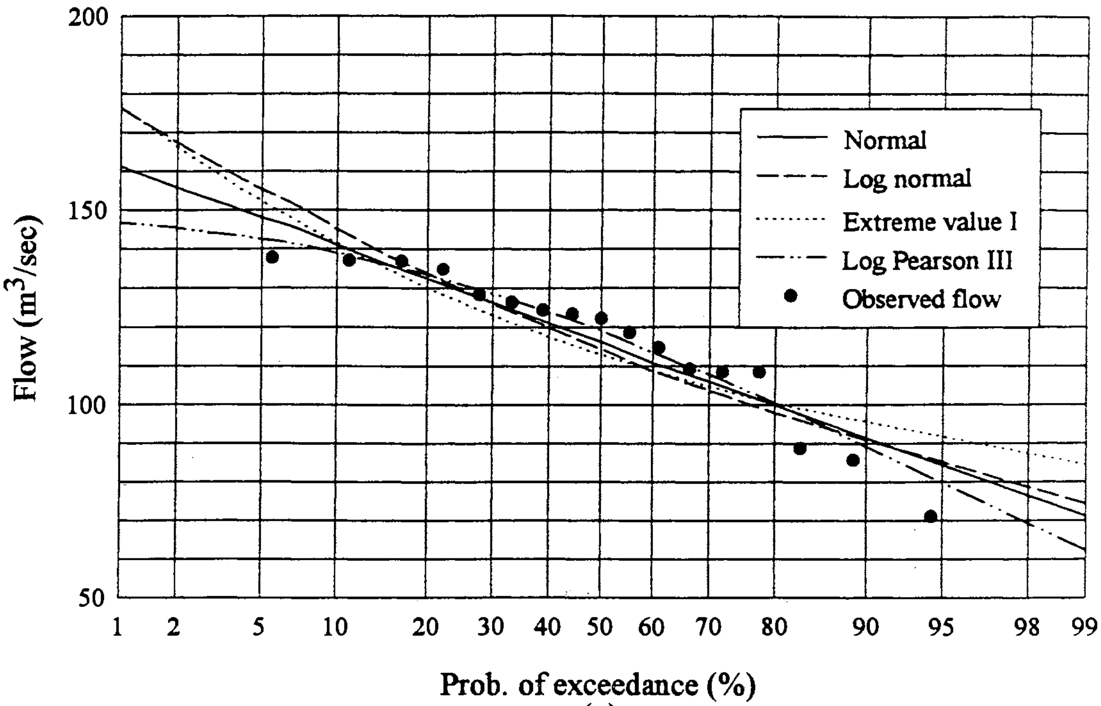


(b)

Fig. A21 : Observed and fitted distributions, (a) station 5670, (b) station 6140

Table A44 : Fitted and observed flows, station 6160

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	1.27	1.33	1.44	1.29	93.00	1.37
80.00	1.64	1.64	1.65	1.64	86.00	1.53
70.00	1.72	1.71	1.70	1.72	79.00	1.68
60.00	1.78	1.77	1.75	1.78	71.00	1.78
50.00	1.85	1.83	1.81	1.85	64.00	1.83
43.00	1.89	1.88	1.85	1.89	57.00	1.83
30.00	1.98	1.97	1.94	1.98	50.00	1.86
20.00	2.06	2.06	2.03	2.06	43.00	1.87
15.00	2.10	2.11	2.09	2.11	36.00	1.92
10.00	2.17	2.18	2.18	2.17	29.00	1.98
7.00	2.22	2.25	2.25	2.23	21.00	1.98
5.00	2.26	2.30	2.32	2.26	14.00	2.01
4.00	2.29	2.33	2.36	2.29	7.00	2.41
2.00	2.36	2.43	2.50	2.36		
1.00	2.43	2.52	2.63	2.43		
0.20	2.57	2.72	2.95	2.56		
0.10	2.62	2.80	3.08	2.61		



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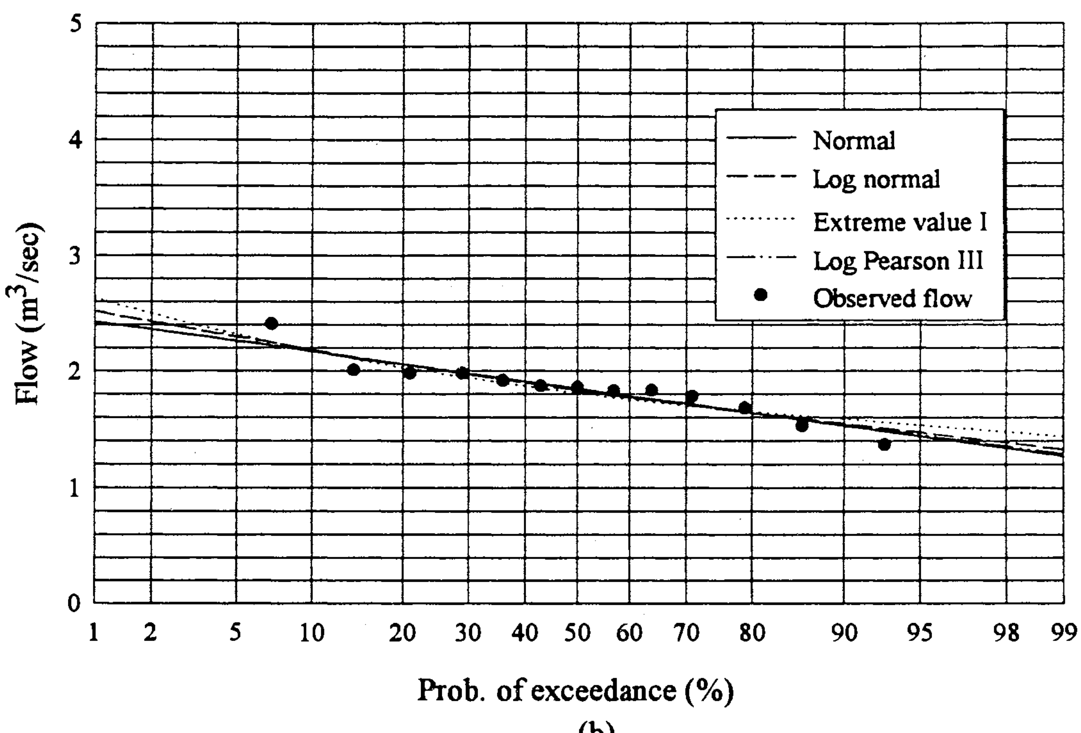


(b)

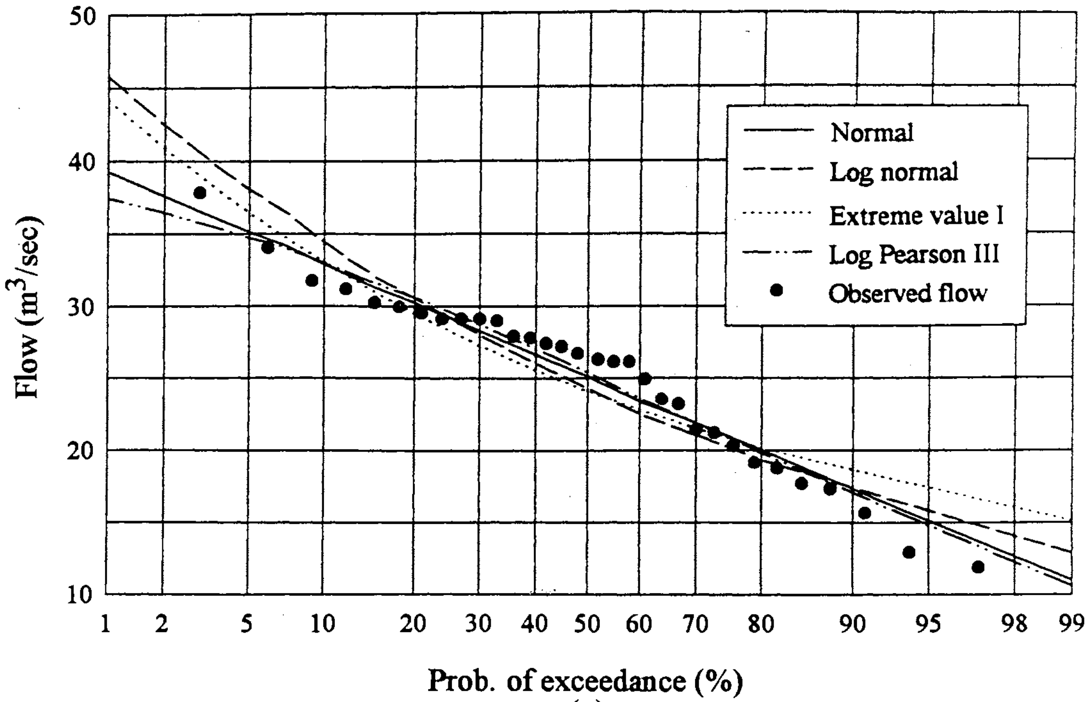
Fig. A22 : Observed and fitted distributions, (a) station 6145, (b) station 6160

Table A45 : Fitted and observed flows, station 6170

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	11.00	12.92	15.18	10.62	97.00	11.87
80.00	20.04	19.36	20.16	19.85	94.00	12.97
70.00	21.93	21.07	21.54	21.93	91.00	15.69
60.00	23.45	22.55	22.83	23.61	88.00	17.35
50.00	25.15	24.34	24.15	25.46	85.00	17.73
43.00	26.25	25.56	25.15	26.62	82.00	18.76
30.00	28.31	28.04	27.30	28.75	79.00	19.15
20.00	30.26	30.59	29.53	30.64	76.00	20.34
15.00	31.35	32.13	31.03	31.65	73.00	21.23
10.00	32.93	34.48	33.08	33.03	70.00	21.45
7.00	34.27	36.61	34.85	34.11	67.00	23.20
5.00	35.15	38.09	36.49	34.78	64.00	23.55
4.00	35.79	39.19	37.58	35.25	61.00	24.94
2.00	37.61	42.53	40.91	36.48	58.00	26.16
1.00	39.30	45.86	44.22	37.48	55.00	26.16
0.20	42.66	53.31	51.87	39.09	52.00	26.32
0.10	43.94	56.45	55.16	39.57	48.00	26.73
					45.00	27.20
					42.00	27.45
					39.00	27.82
					36.00	27.91
					33.00	28.98
					30.00	29.11
					27.00	29.11
					24.00	29.11
					21.00	29.54
					18.00	29.95
					15.00	30.24
					12.00	31.17
					9.00	31.75
					6.00	34.04
					3.00	37.85

Table A46 : Fitted and observed flows, station 6200

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-5.52	2.16	0.62	1.00	97.00	1.16
80.00	7.78	6.62	7.95	7.47	93.00	1.93
70.00	10.55	8.36	9.97	9.94	90.00	6.06
60.00	12.79	10.08	11.88	12.18	86.00	7.60
50.00	15.29	12.45	13.83	14.86	83.00	7.60
43.00	16.90	14.25	15.29	16.64	79.00	10.65
30.00	19.94	18.40	18.46	20.00	76.00	10.85
20.00	22.81	23.40	21.73	23.03	72.00	10.85
15.00	24.42	26.79	23.94	24.61	69.00	11.07
10.00	26.74	32.58	26.96	26.71	66.00	11.70
7.00	28.71	38.44	29.56	28.28	62.00	11.79
5.00	30.01	42.86	31.98	29.19	59.00	11.85
4.00	30.95	46.38	33.57	29.79	55.00	12.75
2.00	33.63	58.11	38.48	31.24	52.00	12.75
1.00	36.11	71.56	43.35	32.22	48.00	12.84
0.20	41.05	108.45	54.60	33.31	45.00	12.90
0.10	42.93	126.99	59.44	33.49	41.00	13.16
					38.00	13.18
					34.00	13.28
					31.00	16.97
					28.00	20.28
					24.00	20.28
					21.00	23.97
					17.00	24.16
					14.00	27.56
					10.00	30.49
					7.00	30.92
					3.00	39.63



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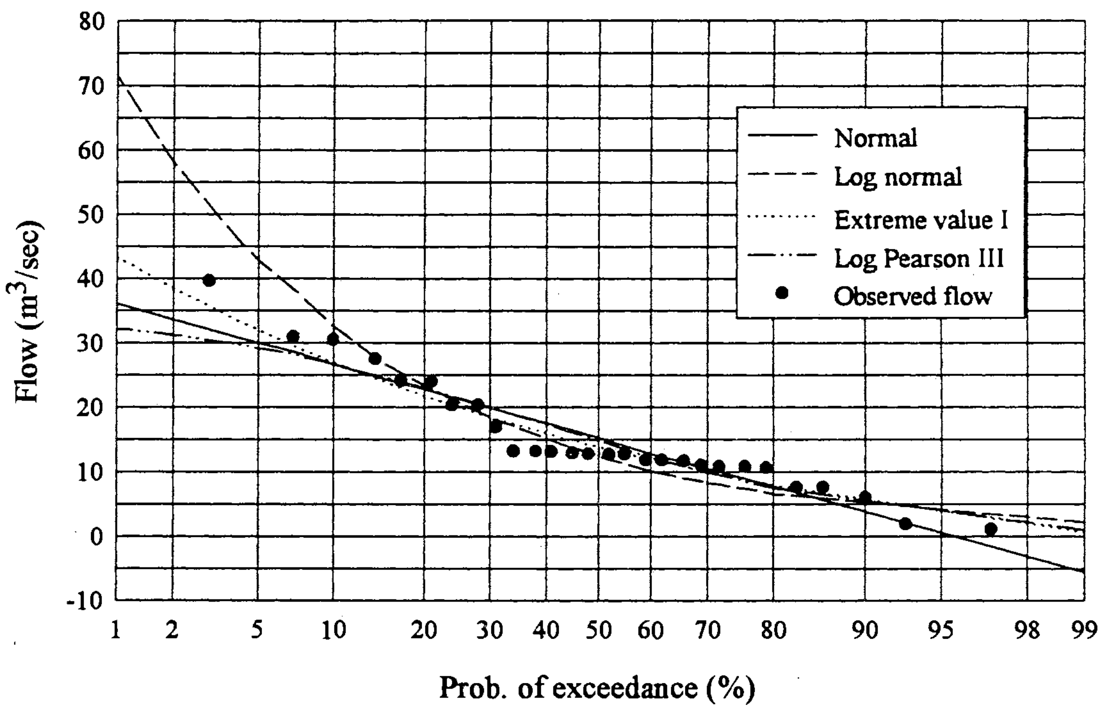


(b)

Fig. A23 : Observed and fitted distributions, (a) station 6170, (b) station 6200

Table A47 : Fitted and observed flows, station 6235

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	27.04	29.31	31.75	29.15	96.88	31.01
80.00	37.25	37.17	37.38	37.18	93.75	31.62
70.00	39.38	39.05	38.94	39.09	90.63	32.90
60.00	41.10	40.64	40.40	40.69	87.50	33.95
50.00	43.03	42.50	41.90	42.55	84.38	35.91
43.00	44.26	43.74	43.02	43.79	81.25	36.09
30.00	46.60	46.18	45.46	46.22	78.13	36.22
20.00	48.80	48.60	47.97	48.62	75.00	39.59
15.00	50.04	50.02	49.67	50.01	71.88	39.90
10.00	51.82	52.13	51.99	52.09	68.75	40.82
7.00	53.33	54.00	53.99	53.91	65.63	41.01
5.00	54.33	55.26	55.85	55.14	62.50	41.32
4.00	55.05	56.20	57.07	56.05	59.38	41.38
2.00	57.11	58.95	60.84	58.72	56.25	42.18
1.00	59.02	61.62	64.58	61.28	53.13	42.36
0.20	62.82	67.30	73.23	66.70	50.00	42.67
0.10	64.26	69.60	76.94	68.86	46.88	42.67
					43.75	43.53
					40.63	43.96
					37.50	45.01
					34.38	45.56
					31.25	46.05
					28.13	46.12
					25.00	46.24
					21.88	46.36
					18.75	48.58
					15.63	50.49
					12.50	51.29
					9.38	51.48
					6.25	58.09
					3.13	59.45

Table A48 : Fitted and observed flows, station 6242

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	0.99	1.68	1.69	1.85	97.22	1.85
80.00	2.51	2.55	2.53	2.54	94.44	2.18
70.00	2.82	2.79	2.76	2.75	91.67	2.24
60.00	3.08	2.99	2.98	2.93	88.89	2.31
50.00	3.36	3.23	3.20	3.16	86.11	2.40
43.00	3.55	3.40	3.36	3.33	83.33	2.45
30.00	3.89	3.74	3.73	3.68	80.56	2.51
20.00	4.22	4.09	4.10	4.06	77.78	2.58
15.00	4.40	4.30	4.35	4.30	75.00	2.58
10.00	4.67	4.63	4.69	4.68	72.22	2.67
7.00	4.89	4.93	4.99	5.04	69.44	2.73
5.00	5.04	5.13	5.27	5.31	66.67	2.73
4.00	5.15	5.28	5.45	5.51	63.89	2.86
2.00	5.45	5.75	6.01	6.15	61.11	2.87
1.00	5.74	6.21	6.56	6.83	58.33	3.00
0.20	6.30	7.25	7.85	8.53	55.56	3.02
0.10	6.52	7.69	8.40	9.32	52.78	3.17
					50.00	3.32
					47.22	3.35
					44.44	3.39
					41.67	3.46
					38.89	3.47
					36.11	3.47
					33.33	3.49
					30.56	3.68
					27.78	3.77
					25.00	3.79
					22.22	3.80
					19.44	3.83
					16.67	4.28
					13.89	4.60
					11.11	4.62
					8.33	4.89
					5.56	5.87
					2.78	6.53

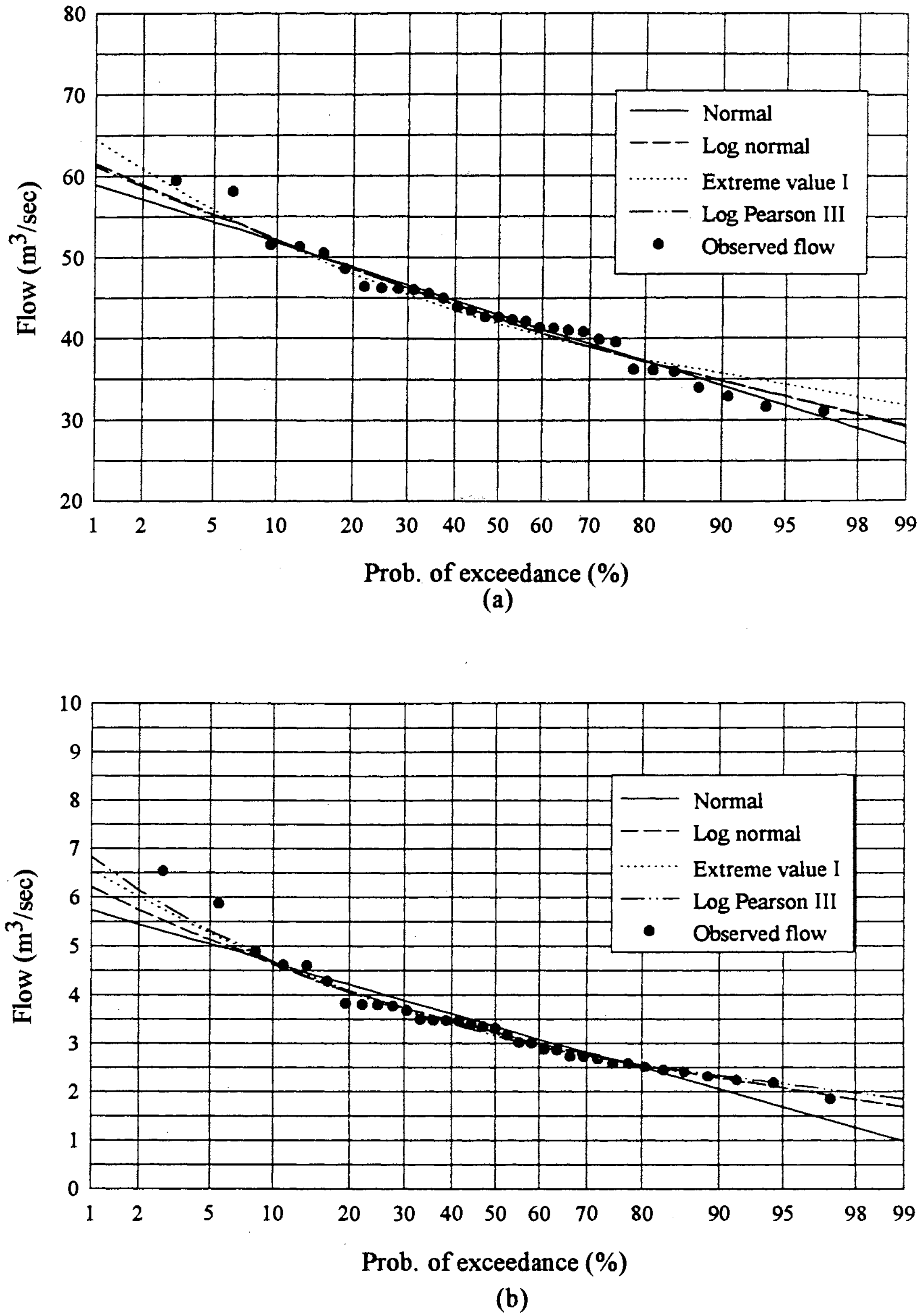


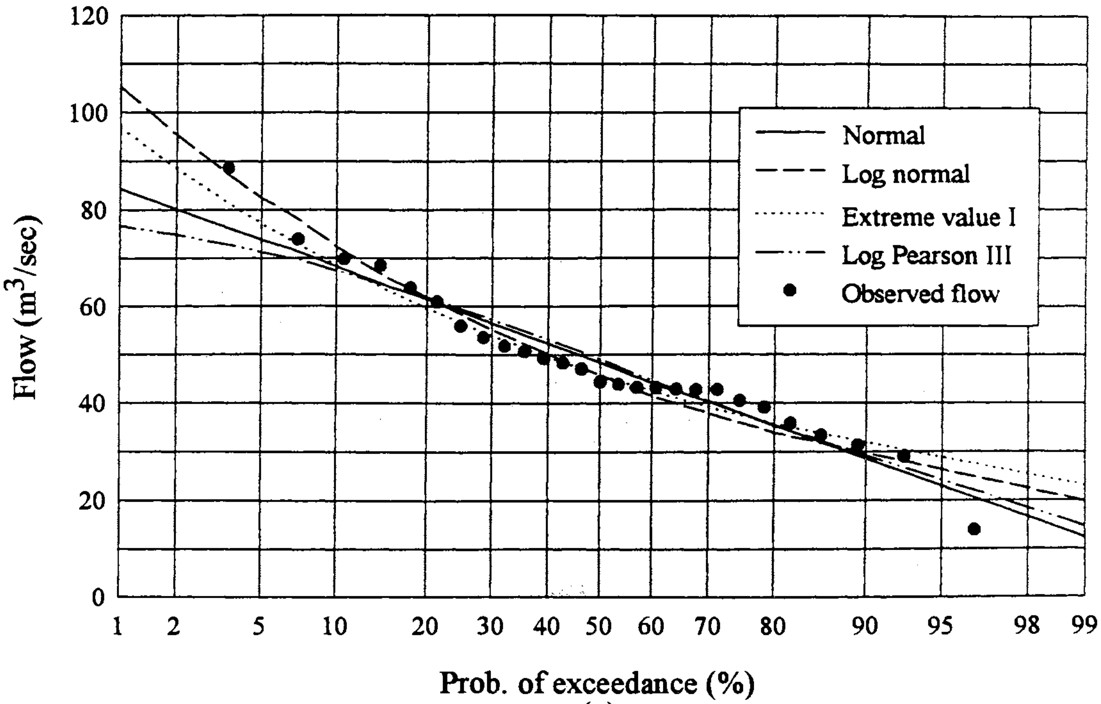
Fig. A24 : Observed and fitted distributions, (a) station 6235, (b) station 6242

Table A49 : Fitted anf observed flows, station 6250

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99	12.46	19.95	23.08	14.72	96.43	13.74
80	35.46	33.96	35.75	35.43	92.86	28.94
70	40.25	37.94	39.25	40.5	89.29	31.26
60	44.12	41.49	42.55	44.62	85.71	33.37
50	48.45	45.86	45.91	49.19	82.14	35.72
43	51.23	48.91	48.44	52.07	78.57	39.09
30	56.49	55.23	53.92	57.29	75	40.49
20	61.44	61.93	59.58	61.86	71.43	42.69
15	64.22	66.05	63.4	64.25	67.86	42.69
10	68.24	72.48	68.63	67.45	64.29	42.9
7	71.65	78.41	73.12	69.9	60.71	43.26
5	73.89	82.59	77.3	71.39	57.14	43.26
4	75.51	85.75	80.06	72.39	53.57	43.98
2	80.15	95.46	88.54	74.95	50	44.49
1	84.44	105.4	96.96	76.91	46.43	47.19
0.2	92.99	128.45	116.41	79.73	42.86	48.38
0.1	96.24	138.47	124.78	80.45	39.29	49.27
					35.71	50.77
					32.14	51.75
					28.57	53.5
					25	55.97
					21.43	60.84
					17.86	63.8
					14.29	68.44
					10.71	69.76
					7.14	73.94
					3.57	88.66

Table A50 : Fitted and observed flows, station 6275

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-47.19	0.10	-30.67	0.19	95.00	0.14
80.00	-11.39	0.81	-10.93	0.80	90.00	0.59
70.00	-3.92	1.25	-5.48	1.15	86.00	0.68
60.00	2.10	1.78	-0.36	1.58	81.00	0.76
50.00	8.84	2.62	4.88	2.29	76.00	1.00
43.00	13.17	3.37	8.82	2.95	71.00	1.50
30.00	21.36	5.41	17.36	4.84	67.00	1.72
20.00	29.07	8.45	26.16	7.96	62.00	1.75
15.00	33.40	10.85	32.12	10.67	57.00	1.92
10.00	39.66	15.58	40.25	16.57	52.00	2.14
7.00	44.96	21.16	47.25	24.43	48.00	2.82
5.00	48.45	25.90	53.77	31.81	43.00	2.82
4.00	50.98	29.97	58.05	38.67	38.00	3.25
2.00	58.20	45.51	71.26	68.89	33.00	3.56
1.00	64.87	66.92	84.37	120.47	29.00	3.63
0.20	78.19	144.50	114.66	396.83	24.00	8.26
0.10	83.24	193.57	127.68	641.37	19.00	8.85
					14.00	9.56
					10.00	11.68
					5.00	110.15



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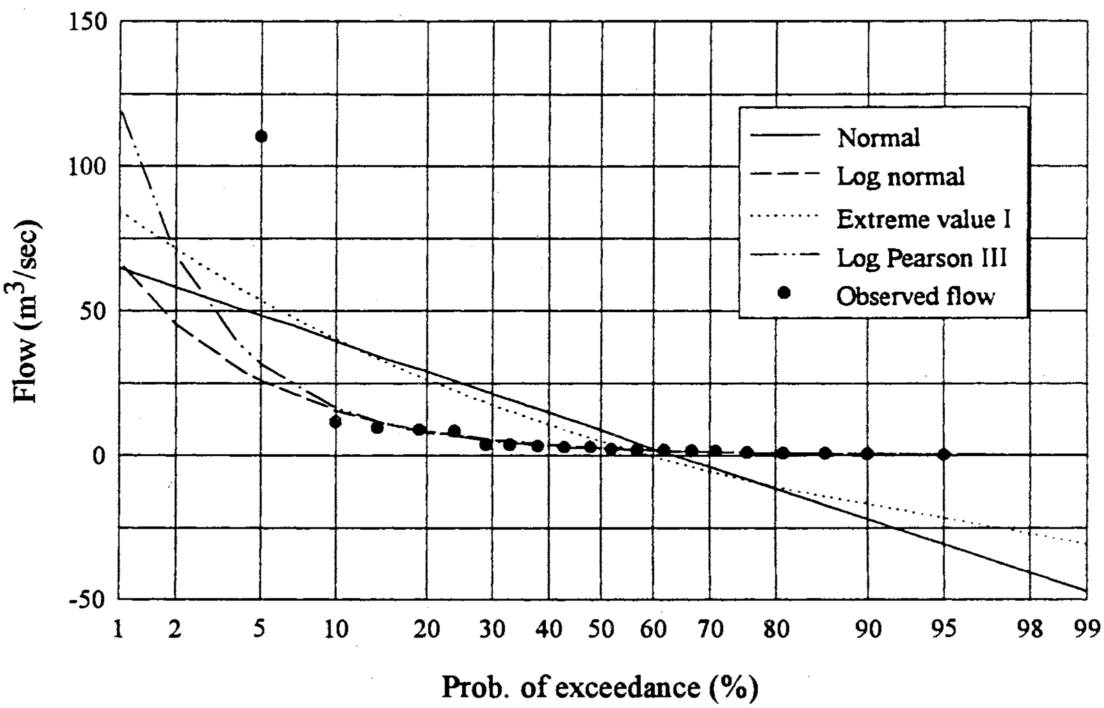


(b)

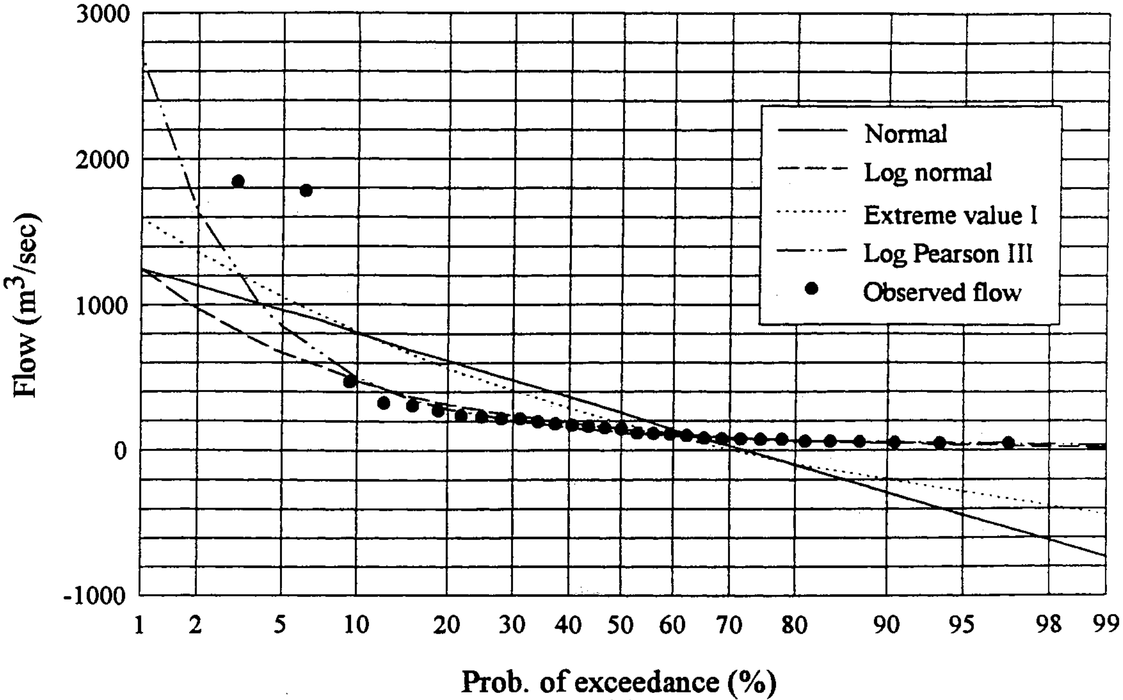
Fig. A25 : Observed and fitted distributions, (a) station 6250, (b) station 6275

Table A51 : Fitted and observed flows, station 6330

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-732.43	17.22	-440.05	37.88	96.88	44.58
80.00	-98.90	67.83	-90.83	67.89	93.75	47.09
70.00	33.17	90.26	5.59	82.47	90.63	50.84
60.00	139.68	113.65	96.29	98.60	87.50	53.67
50.00	258.97	147.13	189.00	123.45	84.38	58.01
43.00	335.66	173.68	258.60	144.71	81.25	60.97
30.00	480.51	237.61	409.71	201.83	78.13	71.62
20.00	616.85	319.14	565.51	287.59	75.00	72.18
15.00	693.53	376.75	670.82	357.49	71.88	76.75
10.00	804.30	478.78	814.79	501.61	68.75	76.75
7.00	898.03	586.43	938.63	683.90	65.63	80.00
5.00	959.81	670.30	1053.90	849.16	62.50	99.75
4.00	1004.54	738.42	1129.75	999.37	59.38	109.00
2.00	1132.35	973.67	1363.41	1638.98	56.25	112.67
1.00	1250.37	1256.93	1595.34	2693.21	53.13	115.06
0.20	1485.97	2092.69	2131.30	8191.24	50.00	144.41
0.10	1575.44	2539.68	2361.72	13061.31	46.88	153.14
					43.75	162.03
					40.63	171.11
					37.50	180.35
					34.38	194.53
					31.25	215.65
					28.13	215.65
					25.00	227.34
					21.88	239.24
					18.75	270.79
					15.63	307.42
					12.50	326.33
					9.38	467.94
					6.25	1780.41
					3.13	1842.84

Table A52 : Fitted and observed flows, station 6340

Prob.	Nor	Ln	Ev1	Lp3	Plotting positions	Flows
99.00	-1.06	0.21	-0.35	0.14	93.75	0.17
80.00	0.47	0.60	0.49	0.62	87.50	0.54
70.00	0.79	0.74	0.73	0.80	81.25	0.68
60.00	1.05	0.89	0.95	0.97	75.00	0.92
50.00	1.34	1.08	1.17	1.18	68.75	0.97
43.00	1.53	1.23	1.34	1.33	62.50	1.04
30.00	1.88	1.56	1.71	1.65	56.25	1.08
20.00	2.21	1.96	2.09	1.98	50.00	1.15
15.00	2.40	2.23	2.34	2.18	43.75	1.22
10.00	2.67	2.68	2.69	2.48	37.50	1.27
7.00	2.89	3.13	2.99	2.75	31.25	1.32
5.00	3.04	3.47	3.27	2.93	25.00	1.54
4.00	3.15	3.73	3.46	3.06	18.75	1.56
2.00	3.46	4.62	4.02	3.44	12.50	1.93
1.00	3.75	5.62	4.59	3.80	6.25	4.74
0.20	4.32	8.31	5.89	4.50		
0.10	4.54	9.65	6.45	4.76		



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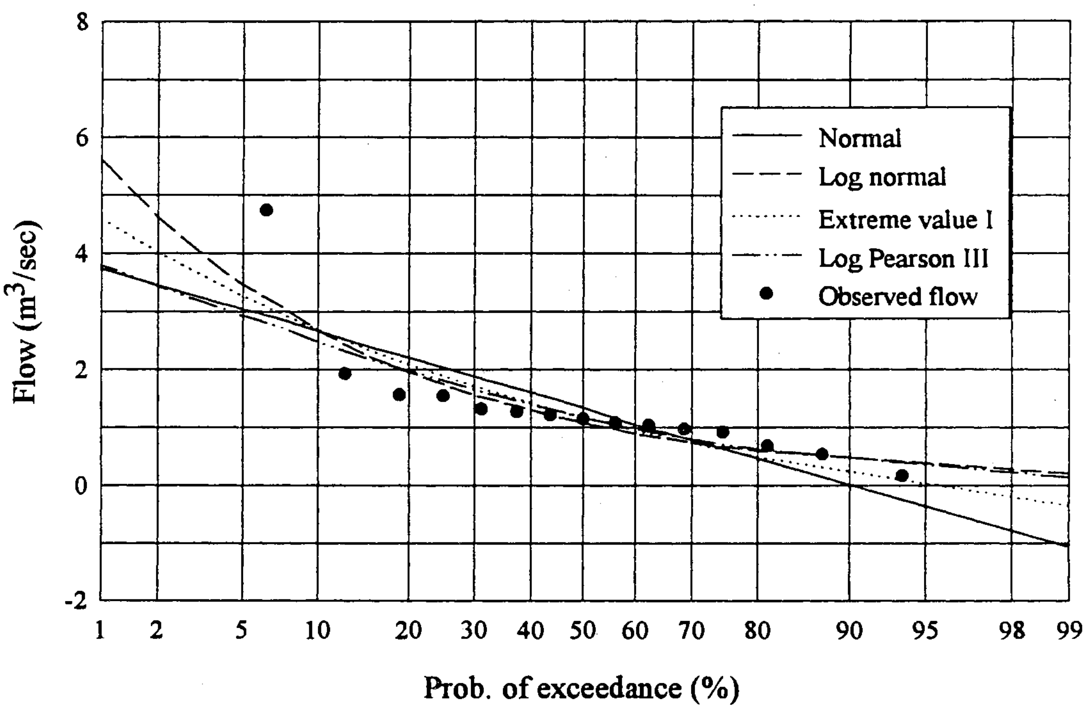


(b)

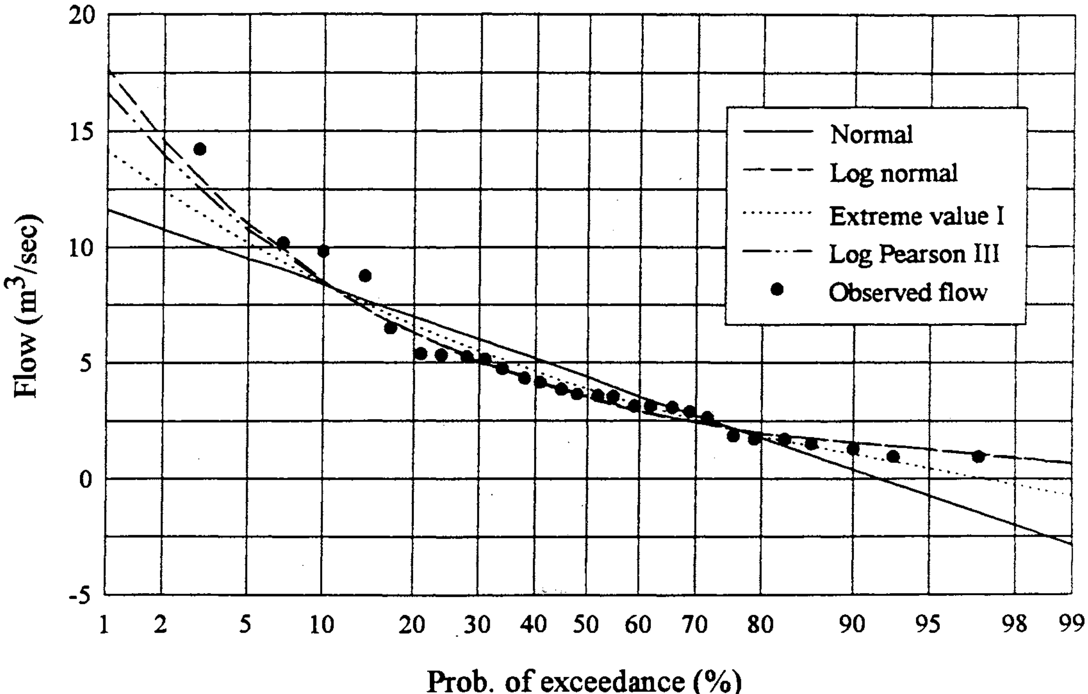
Fig. A26 : Observed and fitted distributions, (a) station 6330, (b) station 6340

Table A53 : Fitted and observed flows, station 6480

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-2.85	0.70	-0.71	0.66	97.00	0.93
80.00	1.78	1.96	1.84	1.97	93.00	0.96
70.00	2.74	2.43	2.54	2.46	90.00	1.28
60.00	3.52	2.89	3.21	2.93	86.00	1.51
50.00	4.39	3.51	3.88	3.56	83.00	1.70
43.00	4.95	3.98	4.39	4.03	79.00	1.70
30.00	6.01	5.04	5.50	5.09	76.00	1.84
20.00	7.01	6.30	6.63	6.32	72.00	2.62
15.00	7.57	7.13	7.40	7.13	69.00	2.89
10.00	8.38	8.54	8.45	8.47	66.00	3.07
7.00	9.06	9.95	9.36	9.79	62.00	3.12
5.00	9.51	11.01	10.20	10.76	59.00	3.12
4.00	9.84	11.84	10.75	11.52	55.00	3.53
2.00	10.77	14.58	12.46	13.98	52.00	3.58
1.00	11.64	17.67	14.16	16.68	48.00	3.64
0.20	13.36	25.93	18.07	23.61	45.00	3.84
0.10	14.01	29.99	19.75	26.89	41.00	4.14
					38.00	4.32
					34.00	4.74
					31.00	5.13
					28.00	5.23
					24.00	5.33
					21.00	5.37
					17.00	6.49
					14.00	8.74
					10.00	9.82
					7.00	10.19
					3.00	14.21

Table A54 : Fitted and observed flows, station 6486

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	-76.18	7.19	-38.44	15.27	95.00	15.40
80.00	5.58	20.74	6.63	21.05	90.00	15.43
70.00	22.63	25.86	19.07	23.96	86.00	22.86
60.00	36.37	30.90	30.78	27.13	81.00	23.99
50.00	51.77	37.72	42.74	31.91	76.00	25.40
43.00	61.67	42.88	51.72	35.91	71.00	26.48
30.00	80.36	54.63	71.22	46.32	67.00	29.31
20.00	97.96	68.61	91.33	61.27	62.00	30.67
15.00	107.85	77.99	104.92	73.04	57.00	30.72
10.00	122.15	93.86	123.50	96.46	52.00	33.56
7.00	134.25	109.78	139.49	124.98	48.00	33.85
5.00	142.22	121.72	154.36	150.09	43.00	34.66
4.00	147.99	131.17	164.15	172.45	38.00	35.69
2.00	164.49	162.42	194.31	264.30	33.00	36.18
1.00	179.72	197.84	224.24	408.59	29.00	36.28
0.20	210.13	293.33	293.41	1106.43	24.00	37.53
0.10	221.67	340.65	323.15	1692.30	19.00	38.02
					14.00	142.66
					10.00	189.59
					5.00	197.13



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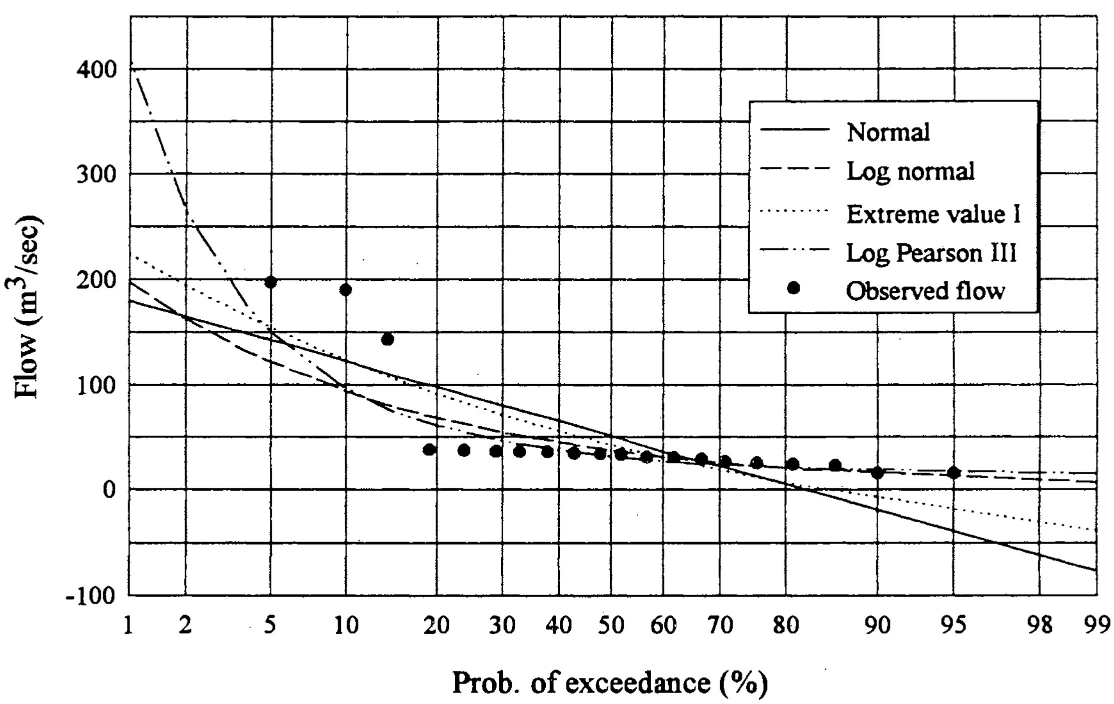


(b)

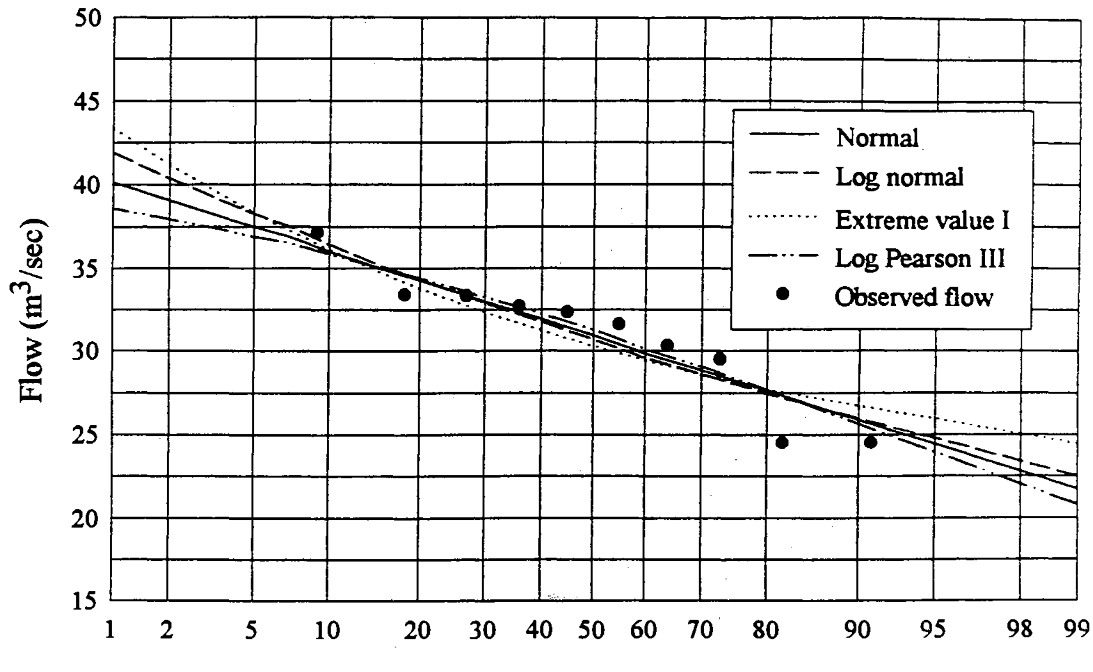
Fig. A27 : Observed and fitted distributions, (a) station 6480, (b) station 6486

Table A55 : Fitted and observed flows. station 6500

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	21.75	22.51	24.47	20.78	91.00	24.53
80.00	27.63	27.46	27.71	27.71	82.00	24.53
70.00	28.86	28.62	28.60	29.07	73.00	29.52
60.00	29.85	29.59	29.45	30.14	64.00	30.32
50.00	30.96	30.72	30.31	31.29	55.00	31.64
43.00	31.67	31.46	30.95	32.00	45.00	32.38
30.00	33.01	32.93	32.36	33.28	36.00	32.73
20.00	34.28	34.36	33.80	34.42	27.00	33.35
15.00	34.99	35.20	34.78	35.02	18.00	33.43
10.00	36.02	36.44	36.12	35.85	9.00	37.14
7.00	36.89	37.53	37.27	36.50		
5.00	37.46	38.27	38.34	36.91		
4.00	37.88	38.81	39.04	37.20		
2.00	39.07	40.39	41.21	37.97		
1.00	40.16	41.92	43.36	38.61		
0.20	42.35	45.13	48.34	39.71		
0.10	43.18	46.41	50.48	40.06		

Table A56 : Fitted and observed flows, station 6510

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	6.72	6.73	6.99	6.31	95.65	6.44
80.00	7.31	7.29	7.32	7.38	91.30	6.85
70.00	7.44	7.42	7.41	7.53	86.96	7.29
60.00	7.54	7.52	7.49	7.64	82.61	7.33
50.00	7.65	7.64	7.58	7.75	78.26	7.50
43.00	7.72	7.71	7.65	7.81	73.91	7.50
30.00	7.86	7.86	7.79	7.91	69.57	7.60
20.00	7.98	8.00	7.94	7.98	65.22	7.61
15.00	8.06	8.07	8.03	8.01	60.87	7.65
10.00	8.16	8.19	8.17	8.05	56.52	7.74
7.00	8.25	8.29	8.29	8.07	52.17	7.76
5.00	8.31	8.36	8.39	8.08	47.83	7.78
4.00	8.35	8.40	8.47	8.09	43.48	7.79
2.00	8.47	8.54	8.69	8.11	39.13	7.81
1.00	8.58	8.67	8.90	8.12	34.78	7.82
0.20	8.80	8.94	9.41	8.12	30.43	7.82
0.10	8.88	9.04	9.62	8.12	26.09	7.83
					21.74	7.85
					17.39	7.96
					13.04	7.99
					8.70	8.05
					4.35	8.28



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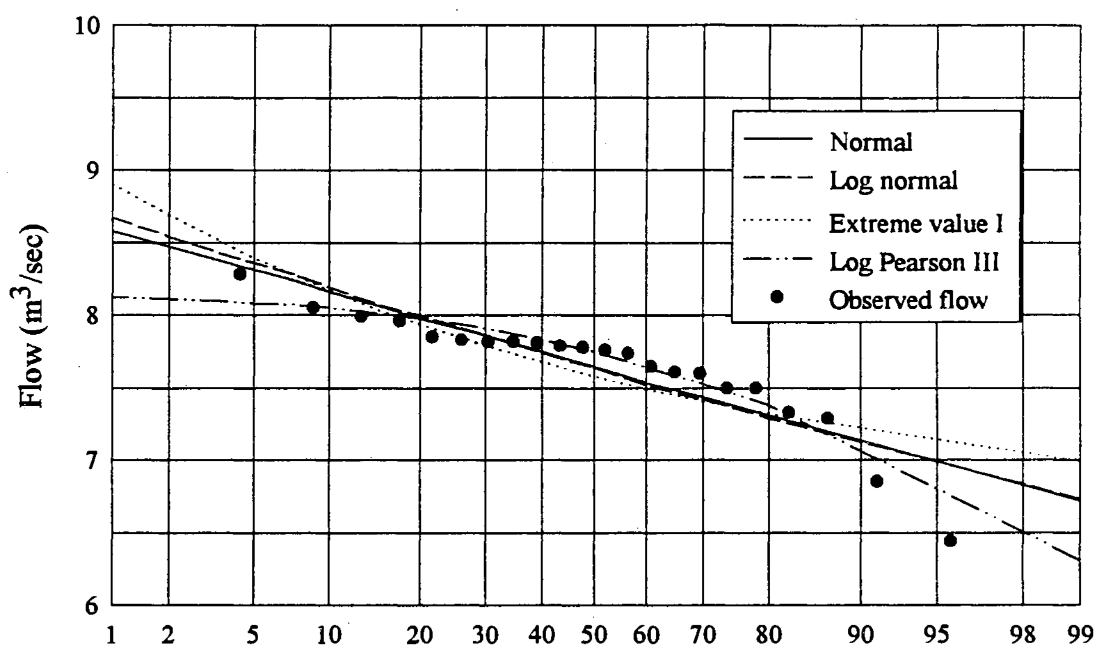


(b)

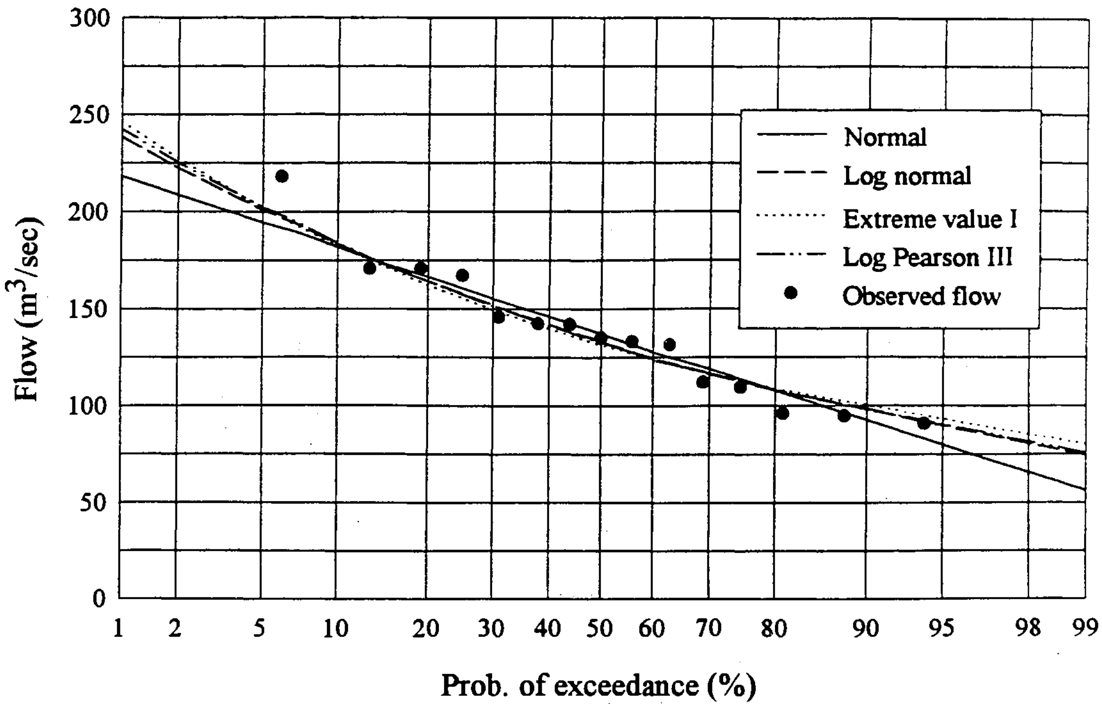
Fig. A28 : Observed and fitted distributions, (a) station 6500, (b) station 6510

Table A57 : Fitted anf observed flows, station 6860

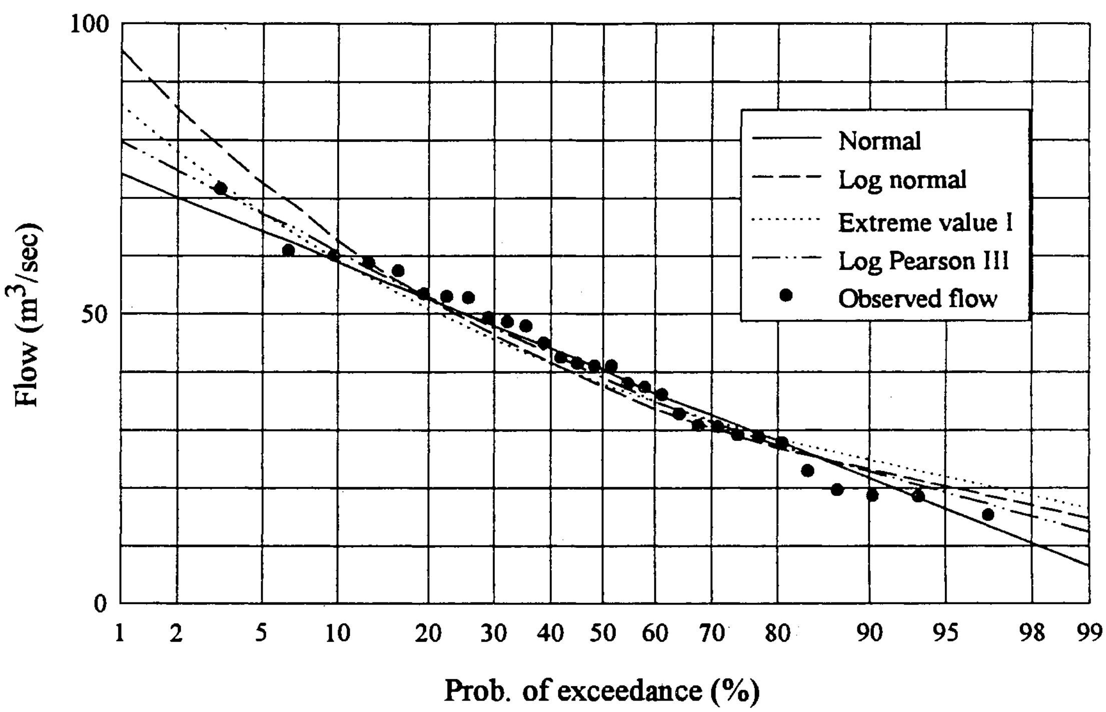
Prob	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	56.40	74.59	80.28	75.84	94.00	90.72
80.00	108.14	108.15	108.80	108.04	88.00	94.94
70.00	118.92	116.86	116.67	116.55	81.00	96.00
60.00	127.62	124.39	124.08	123.96	75.00	109.37
50.00	137.36	133.41	131.65	132.90	69.00	112.18
43.00	143.63	139.54	137.33	139.03	63.00	131.52
30.00	155.45	151.92	149.67	151.49	56.00	133.28
20.00	166.59	164.56	162.40	164.36	50.00	135.04
15.00	172.85	172.13	171.00	172.14	44.00	142.07
10.00	181.90	183.68	182.75	184.11	38.00	142.42
7.00	189.55	194.06	192.87	194.96	31.00	145.93
5.00	194.60	201.22	202.28	202.50	25.00	167.00
4.00	198.25	206.57	208.47	208.17	19.00	170.87
2.00	208.69	222.65	227.55	225.34	13.00	170.87
1.00	218.32	238.61	246.49	242.61	6.00	218.24
0.20	237.56	273.96	290.26	281.64		
0.10	244.87	288.72	309.08	298.24		

Table A58 : Fitted and observed flows, station 6935

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Flow
99.00	5.87	14.53	15.97	12.37	97.00	15.33
80.00	27.75	26.53	28.03	26.96	93.00	18.63
70.00	32.31	30.08	31.36	31.00	90.00	18.66
60.00	35.99	33.29	34.49	34.50	87.00	19.70
50.00	40.11	37.28	37.70	38.68	83.00	22.92
43.00	42.76	40.10	40.10	41.51	80.00	27.85
30.00	47.77	46.02	45.32	47.11	77.00	28.79
20.00	52.48	52.38	50.70	52.69	73.00	29.10
15.00	55.12	56.34	54.34	55.94	70.00	30.59
10.00	58.95	62.60	59.31	60.75	67.00	30.77
7.00	62.19	68.43	63.59	64.93	63.00	32.85
5.00	64.32	72.56	67.57	67.72	60.00	36.16
4.00	65.87	75.71	70.19	69.76	57.00	37.42
2.00	70.28	85.49	78.26	75.65	53.00	38.02
1.00	74.36	95.64	86.27	81.13	50.00	40.98
0.20	82.50	119.63	104.79	92.09	47.00	41.08
0.10	85.59	130.25	112.75	96.21	43.00	41.50
					40.00	42.42
					37.00	44.91
					33.00	48.56
					30.00	49.26
					27.00	52.64
					23.00	52.92
					20.00	53.39
					17.00	57.35
					13.00	58.86
					10.00	60.08
					7.00	60.94
					3.00	71.62



(a)



(b)

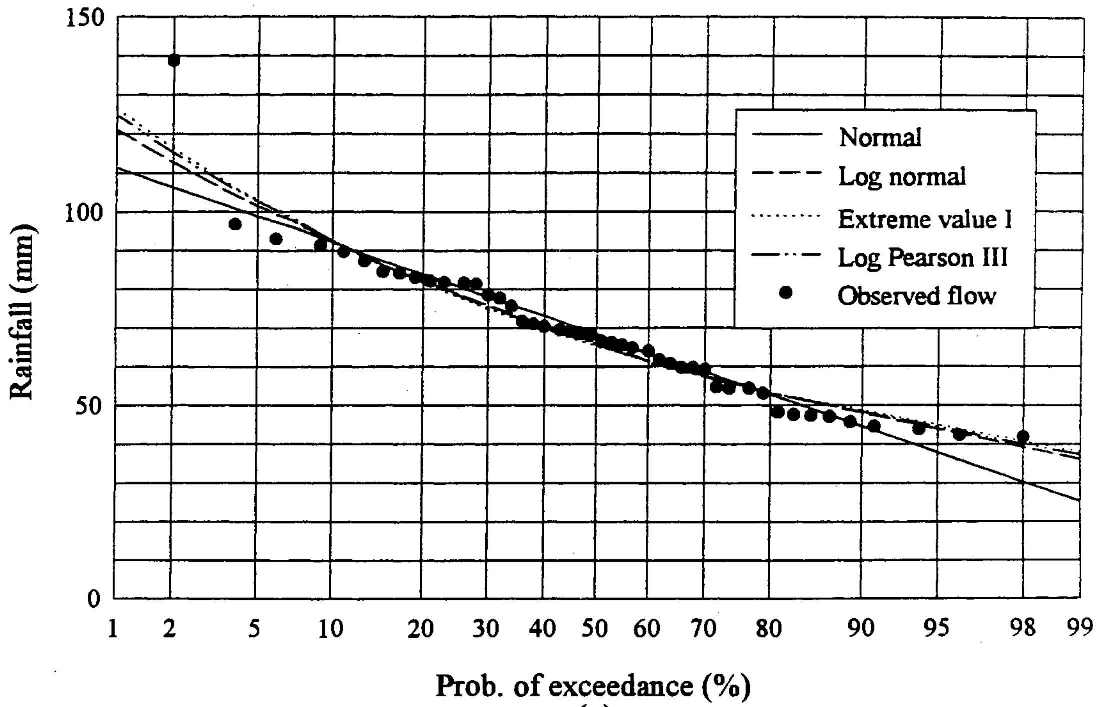
Fig. A29 : Observed and fitted distributions, (a) station 6860, (b) station 6935

Table A59 : Fitted and observed daily rainfalls, Station Chipata

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	25.41	36.15	38.11	37.25	98.00	41.90
80.00	52.92	53.22	53.28	53.12	96.00	42.30
70.00	58.66	57.69	57.46	57.42	94.00	43.90
60.00	63.29	61.56	61.40	61.18	91.00	44.50
50.00	68.47	66.21	65.43	65.76	89.00	45.70
43.00	71.80	69.39	68.45	68.93	87.00	47.00
30.00	78.09	75.80	75.02	75.41	85.00	47.40
20.00	84.01	82.38	81.78	82.20	83.00	47.50
15.00	87.35	86.33	86.36	86.33	81.00	48.20
10.00	92.16	92.37	92.61	92.74	79.00	53.10
7.00	96.23	97.81	97.99	98.61	77.00	54.40
5.00	98.91	101.57	103.00	102.72	74.00	54.40
4.00	100.85	104.38	106.29	105.82	72.00	54.70
2.00	106.41	112.85	116.44	115.31	70.00	59.20
1.00	111.53	121.29	126.52	124.96	68.00	59.70
0.20	121.77	140.05	149.80	147.21	66.00	59.70
0.10	125.65	147.91	159.81	156.84	64.00	60.70
					62.00	61.70
					60.00	64.00
					57.00	64.80
					55.00	65.50
					53.00	66.30
					51.00	66.70
					49.00	68.30
					47.00	68.60
					45.00	69.20
					43.00	69.60
					40.00	70.40
					38.00	71.10
					36.00	71.80
					34.00	75.50
					32.00	77.70
					30.00	78.50
					28.00	81.30
					26.00	81.60
					23.00	81.80
					21.00	82.00
					19.00	83.10
					17.00	84.20
					15.00	84.60
					13.00	87.40
					11.00	89.70
					9.00	91.40
					6.00	93.00
					4.00	96.80
					2.00	138.70

Table A60 : Fitted and observed rainfalls, station Choma 1

Prob	Nor	Ln	Ev	Lp3	Plotting Positions	Rainfall
99.00	21.31	29.23	33.46	24.67	97.73	28.40
80.00	47.64	46.22	47.98	47.10	95.45	28.40
70.00	53.13	50.86	51.99	52.56	93.18	30.50
60.00	57.56	54.93	55.76	57.09	90.91	34.30
50.00	62.52	59.88	59.61	62.25	88.64	38.90
43.00	65.71	63.30	62.51	65.60	86.36	42.00
30.00	71.73	70.29	68.79	71.95	84.09	44.20
20.00	77.40	77.58	75.26	77.89	81.82	45.80
15.00	80.59	82.01	79.64	81.19	79.55	46.70
10.00	85.19	88.85	85.63	85.87	77.27	50.00
7.00	89.09	95.08	90.78	89.74	75.00	53.30
5.00	91.66	99.43	95.57	92.23	72.73	53.40
4.00	93.52	102.70	98.72	94.00	70.45	53.80
2.00	98.83	112.65	108.44	98.89	68.18	56.10
1.00	103.74	122.69	118.08	103.15	65.91	57.00
0.20	113.53	145.50	140.36	110.87	63.64	59.90
0.10	117.25	155.23	149.94	113.50	61.36	60.00
					59.09	61.20
					56.82	63.20
					54.55	63.30
					52.27	63.30
					50.00	63.50
					47.73	64.50
					45.45	65.60
					43.18	65.80
					40.91	66.00
					38.64	66.20
					36.36	68.00
					34.09	68.10
					31.82	68.70
					29.55	68.80
					27.27	69.80
					25.00	70.10
					22.73	72.40
					20.45	73.40
					18.18	79.20
					15.91	81.00
					13.64	82.80
					11.36	84.00
					9.09	84.40
					6.82	85.90
					4.55	90.20
					2.27	116.30



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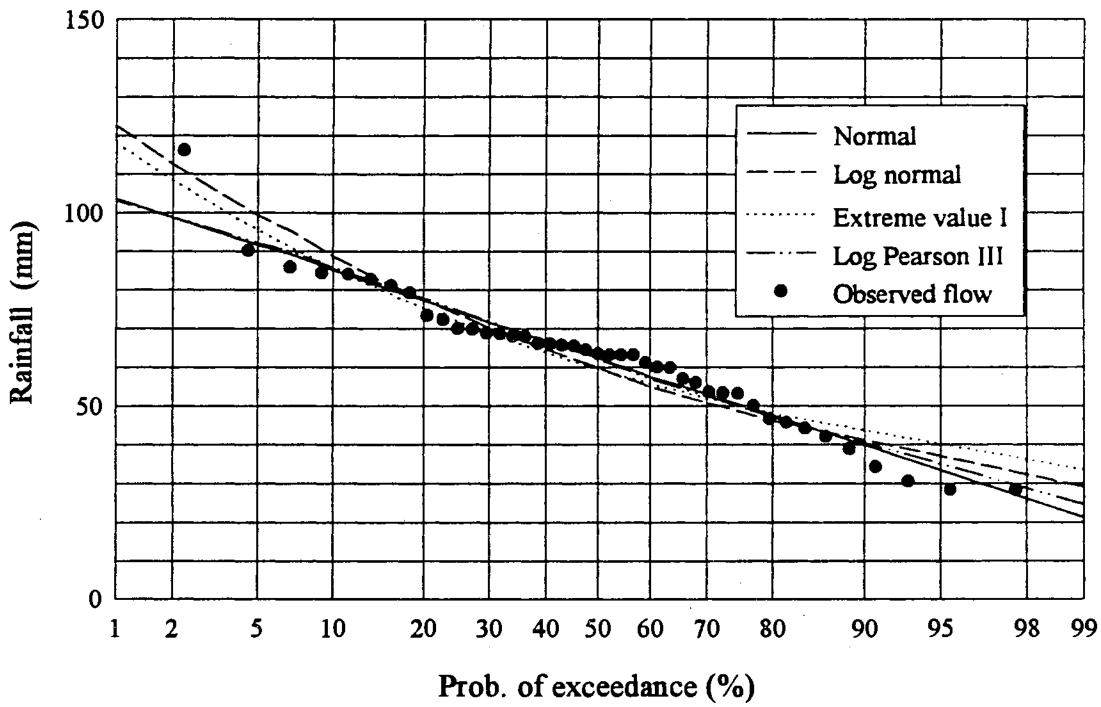


(b)

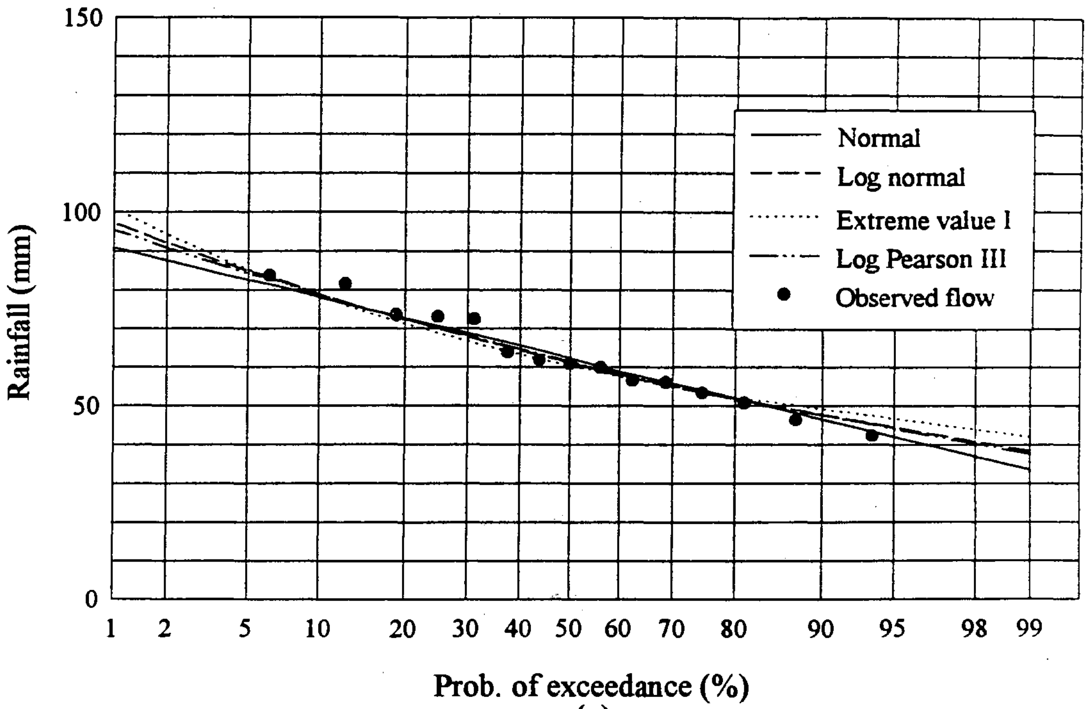
Fig. A30 : Observed and fitted distributions for stations (a) Chip2, (b) Choma1

Table A61 : Fitted and observed rainfalls, Station Isoka 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	33.71	38.48	42.17	37.74	93.75	42.30
80.00	52.03	51.78	52.26	51.86	87.50	46.30
70.00	55.85	55.09	55.05	55.27	81.25	50.70
60.00	58.93	57.91	57.68	58.15	75.00	53.30
50.00	62.38	61.24	60.36	61.51	68.75	56.00
43.00	64.60	63.48	62.37	63.75	62.50	56.60
30.00	68.79	67.94	66.74	68.15	56.25	59.90
20.00	72.73	72.43	71.24	72.51	50.00	60.80
15.00	74.95	75.08	74.29	75.05	43.75	61.80
10.00	78.15	79.08	78.45	78.85	37.50	63.80
7.00	80.86	82.63	82.03	82.17	31.25	72.40
5.00	82.65	85.06	85.37	84.42	25.00	73.00
4.00	83.94	86.87	87.56	86.07	18.75	73.60
2.00	87.64	92.23	94.32	90.94	12.50	81.50
1.00	91.05	97.48	101.02	95.61	6.25	83.70
0.20	97.86	108.86	116.52	105.47		
0.10	100.45	113.53	123.19	109.40		

Tabl3 A62 : Fitted and observed rainfalls, Station Kabompo 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	26.15	34.27	37.68	33.03	96.97	36.10
80.00	51.14	50.65	51.46	50.79	93.94	38.20
70.00	56.35	54.94	55.26	55.29	90.91	42.20
60.00	60.55	58.67	58.84	59.13	87.88	45.80
50.00	65.25	63.15	62.49	63.68	84.85	51.60
43.00	68.28	66.21	65.24	66.74	81.82	51.60
30.00	73.99	72.39	71.20	72.81	78.79	51.80
20.00	79.37	78.74	77.34	78.90	75.76	52.10
15.00	82.39	82.55	81.50	82.48	72.73	52.60
10.00	86.76	88.38	87.17	87.87	69.70	53.30
7.00	90.46	93.64	92.06	92.62	66.67	53.30
5.00	92.89	97.28	96.60	95.85	63.64	55.30
4.00	94.66	100.00	99.60	98.24	60.61	57.40
2.00	99.70	108.19	108.81	105.30	57.58	57.60
1.00	104.35	116.36	117.96	112.12	54.55	58.50
0.20	113.64	134.55	139.10	126.65	51.52	62.20
0.10	117.17	142.18	148.18	132.48	48.48	64.30
					45.45	69.00
					42.42	70.60
					39.39	70.70
					36.36	72.70
					33.33	73.90
					30.30	76.20
					27.27	77.00
					24.24	77.50
					21.21	77.60
					18.18	78.60
					15.15	80.00
					12.12	87.00
					9.09	96.30
					6.06	98.50
					3.03	98.60



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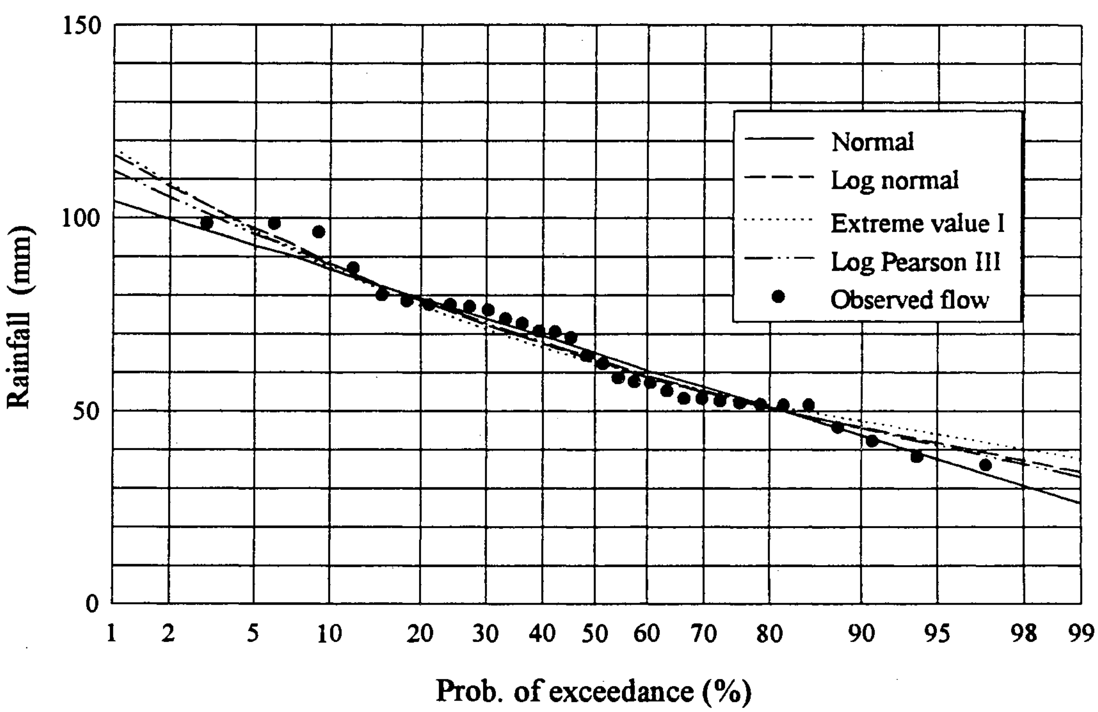


(b)

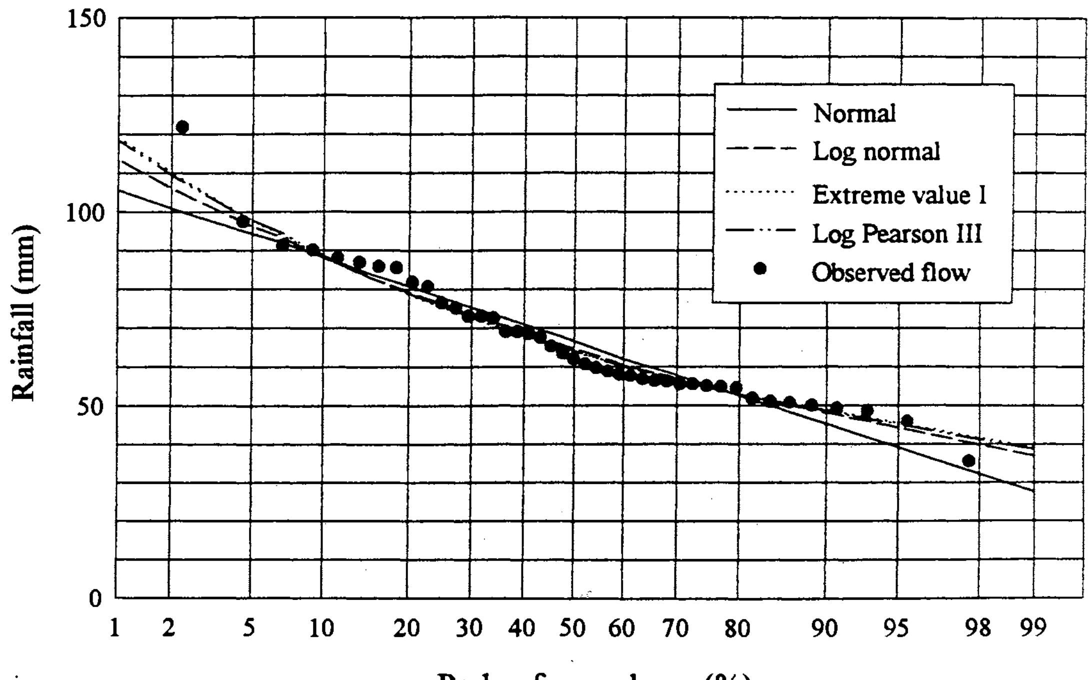
Fig. A31 : Observed and fitted distributions for stations (a) Isoka1, (b) Kabom1

Table A63 : Fitted and observed rainfalls, Station Kabwe 1

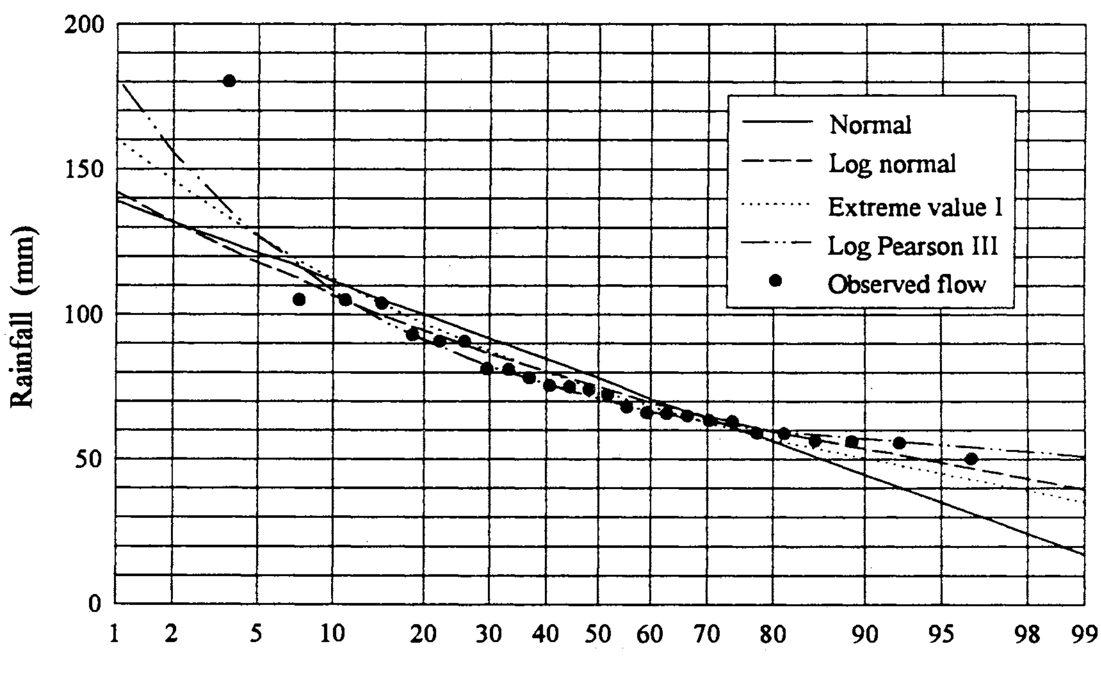
Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	27.72	37.00	39.22	38.66	97.73	35.60
80.00	52.63	52.94	52.95	52.82	95.45	45.90
70.00	57.83	57.04	56.75	56.66	93.18	48.60
60.00	62.02	60.58	60.31	60.05	90.91	49.20
50.00	66.71	64.81	63.96	64.17	88.64	50.10
43.00	69.73	67.68	66.70	67.03	86.36	50.80
30.00	75.43	73.46	72.64	72.90	84.09	51.10
20.00	80.79	79.35	78.77	79.07	81.82	51.90
15.00	83.80	82.87	82.91	82.84	79.55	54.60
10.00	88.16	88.22	88.57	88.71	77.27	54.90
7.00	91.85	93.02	93.45	94.11	75.00	55.10
5.00	94.28	96.33	97.98	97.90	72.73	55.60
4.00	96.04	98.80	100.96	100.76	70.45	55.60
2.00	101.07	106.20	110.15	109.57	68.18	56.20
1.00	105.71	113.53	119.28	118.58	65.91	56.40
0.20	114.97	129.71	140.36	139.54	63.64	56.90
0.10	118.49	136.44	149.42	148.70	61.36	57.70
					59.09	58.10
					56.82	58.80
					54.55	59.70
					52.27	60.70
					50.00	62.00
					47.73	63.50
					45.45	65.30
					43.18	67.60
					40.91	68.60
					38.64	69.00
					36.36	69.10
					34.09	72.60
					31.82	73.00
					29.55	73.00
					27.27	75.20
					25.00	76.50
					22.73	80.80
					20.45	81.90
					18.18	85.50
					15.91	85.90
					13.64	86.90
					11.36	88.10
					9.09	90.00
					6.82	91.20
					4.55	97.50
					2.27	121.90

Table A64 : Fitted and observed rainfalls, Station Kafironda 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	17.24	39.55	35.20	50.89	96.30	50.00
80.00	56.16	59.55	56.66	59.65	92.59	55.70
70.00	64.28	64.85	62.59	63.06	88.89	56.00
60.00	70.82	69.47	68.16	66.42	85.19	56.40
50.00	78.15	75.03	73.85	70.94	81.48	58.70
43.00	82.87	78.84	78.13	74.35	77.78	59.00
30.00	91.77	86.57	87.42	82.10	74.07	63.00
20.00	100.14	94.54	96.99	91.32	70.37	63.40
15.00	104.86	99.34	103.46	97.54	66.67	65.00
10.00	111.66	106.70	112.31	108.12	62.96	65.70
7.00	117.42	113.36	119.91	118.87	59.26	66.10
5.00	121.22	117.98	127.00	127.04	55.56	68.00
4.00	123.96	121.43	131.66	133.56	51.85	72.20
2.00	131.82	131.88	146.01	155.61	48.15	74.00
1.00	139.07	142.33	160.27	181.53	44.44	75.00
0.20	153.55	165.71	193.20	256.93	40.74	75.40
0.10	159.04	175.57	207.36	297.45	37.04	78.00
					33.33	81.00
					29.63	81.10
					25.93	90.70
					22.22	90.70
					18.52	92.90
					14.81	103.90
					11.11	104.90
					7.41	105.20
					3.70	180.00



(a)



(b)

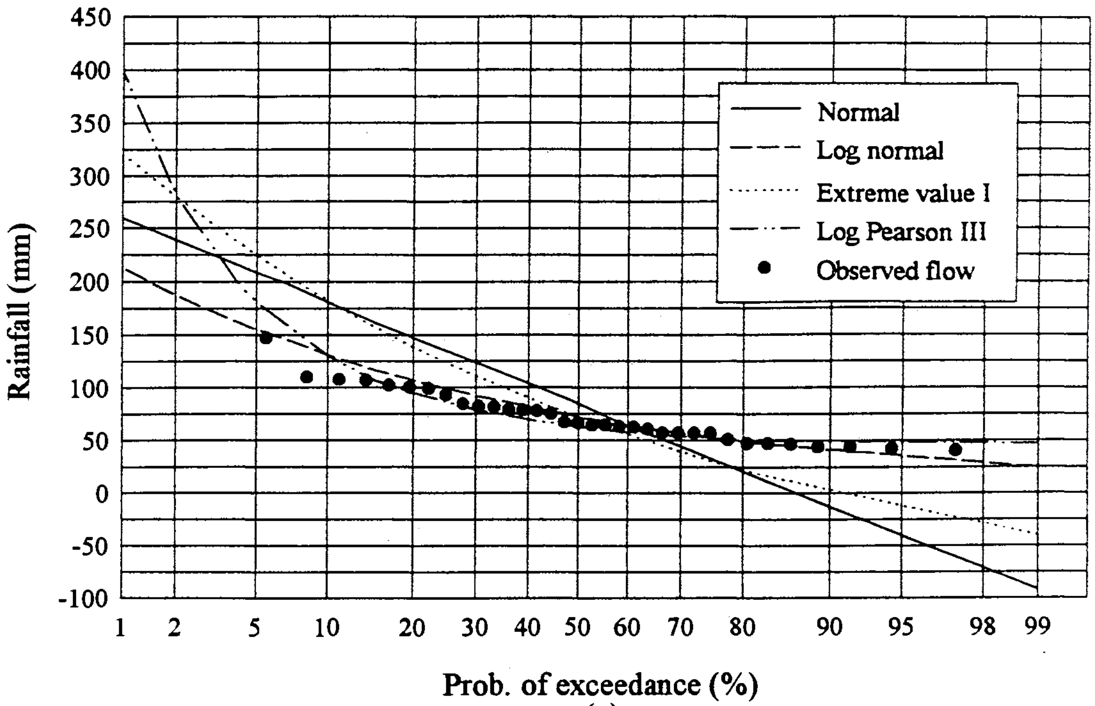
Fig. A32 : Observed and fitted distributions for stations (a) Kabwl, (b) Kafir1

Table A65 : Fitted and observed rainfalls, Station Kafue 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-91.41	24.56	-39.60	46.66	97.22	40.10
80.00	20.85	49.03	22.28	50.90	94.44	41.90
70.00	44.26	56.62	39.37	53.97	91.67	43.60
60.00	63.13	63.60	55.44	57.47	88.89	44.00
50.00	84.27	72.44	71.87	62.84	86.11	46.40
43.00	97.86	78.76	84.21	67.34	83.33	46.80
30.00	123.53	92.24	110.98	78.87	80.56	47.00
20.00	147.69	107.03	138.59	94.92	77.78	50.50
15.00	161.28	116.37	157.25	107.14	75.00	56.40
10.00	180.91	131.31	182.77	130.62	72.22	56.40
7.00	197.52	145.45	204.71	158.02	69.44	56.70
5.00	208.47	155.59	225.14	181.31	66.67	57.00
4.00	216.39	163.37	238.58	201.55	63.89	60.20
2.00	239.04	187.81	279.99	280.97	61.11	62.50
1.00	259.96	213.61	321.09	398.03	58.33	62.70
0.20	301.71	276.21	416.07	907.69	55.56	64.00
0.10	317.56	304.53	456.90	1302.71	52.78	64.10
					50.00	66.70
					47.22	67.10
					44.44	75.00
					41.67	77.50
					38.89	78.00
					36.11	78.40
					33.33	81.00
					30.56	82.00
					27.78	84.20
					25.00	92.50
					22.22	98.80
					19.44	100.20
					16.67	101.90
					13.89	106.70
					11.11	107.20
					8.33	109.70
					5.56	147.30
					2.78	495.00

Table A66 : Fitted and observed rainfalls, Station Kaoma 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	17.21	32.53	30.44	39.28	96.97	36.80
80.00	45.88	48.03	46.24	47.93	93.94	40.50
70.00	51.85	52.09	50.61	50.90	90.91	42.70
60.00	56.67	55.62	54.71	53.71	87.88	46.10
50.00	62.07	59.85	58.91	57.39	84.85	46.20
43.00	65.54	62.74	62.06	60.09	81.82	47.30
30.00	72.10	68.59	68.89	66.05	78.79	48.80
20.00	78.26	74.59	75.94	72.91	75.76	50.00
15.00	81.73	78.19	80.71	77.40	72.73	51.30
10.00	86.75	83.70	87.22	84.87	69.70	51.80
7.00	90.99	88.67	92.82	92.24	66.67	52.00
5.00	93.78	92.10	98.04	97.72	63.64	53.80
4.00	95.81	94.67	101.47	102.04	60.61	54.80
2.00	101.59	102.42	112.04	116.22	57.58	55.10
1.00	106.93	110.13	122.54	132.25	54.55	56.60
0.20	117.59	127.30	146.79	175.90	51.52	58.70
0.10	121.64	134.50	157.22	197.97	48.48	59.10
					45.45	60.60
					42.42	63.10
					39.39	64.70
					36.36	66.30
					33.33	67.20
					30.30	67.20
					27.27	67.30
					24.24	68.30
					21.21	71.60
					18.18	76.10
					15.15	77.80
					12.12	78.60
					9.09	78.80
					6.06	82.60
					3.03	144.50



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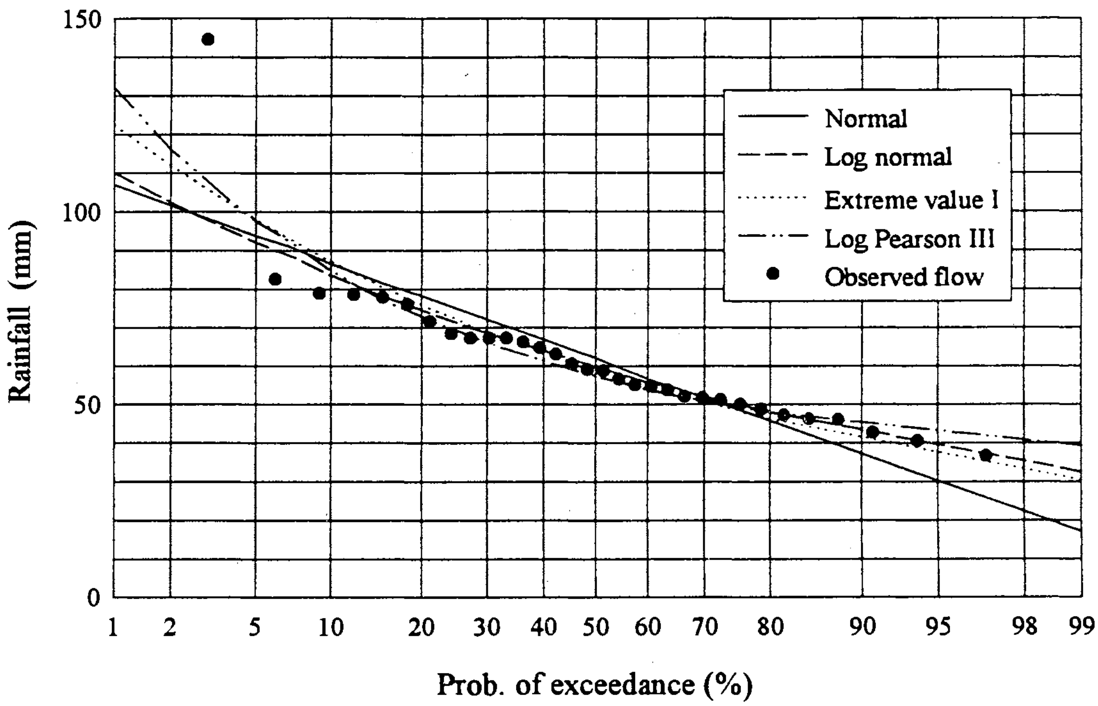


(b)

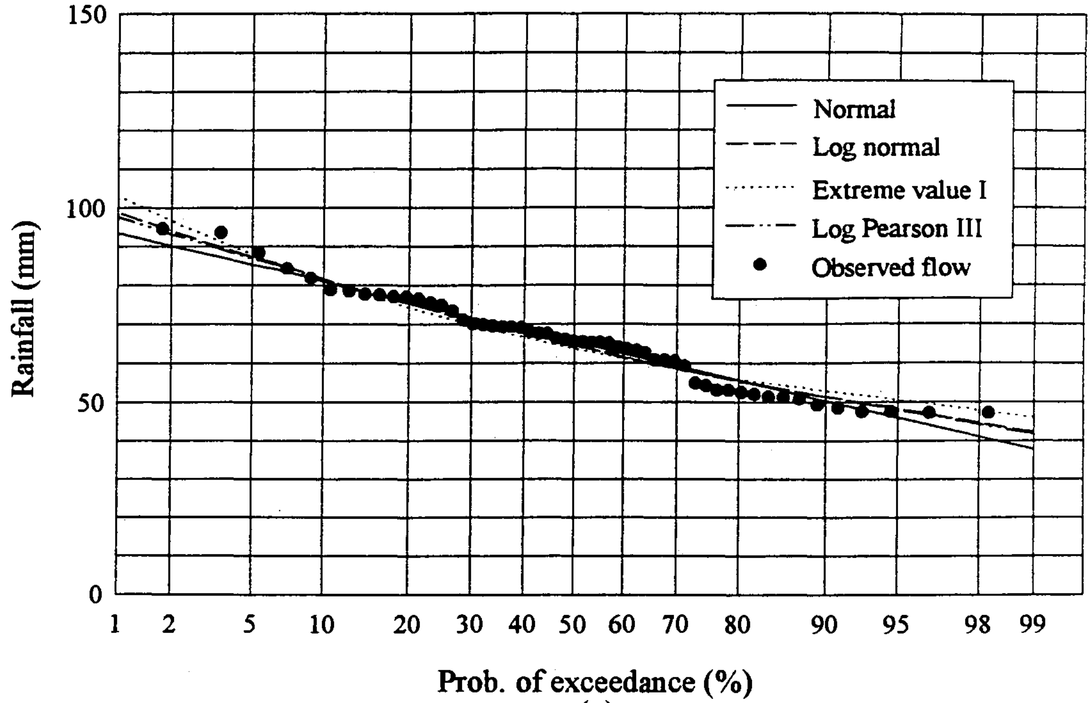
Fig. A33 : Observed and fitted distributions for stations (a) Kafue1, (b)Kaoma1

Table A67 : Fitted and observed rainfalls, Station Kasama 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	37.93	42.26	46.13	41.77	98.21	47.20
80.00	55.69	55.46	55.92	55.50	96.43	47.20
70.00	59.39	58.69	58.62	58.81	94.64	47.50
60.00	62.38	61.44	61.16	61.59	92.86	47.50
50.00	65.72	64.66	63.76	64.83	91.07	48.50
43.00	67.87	66.82	65.71	66.99	89.29	49.30
30.00	71.93	71.11	69.95	71.24	87.50	50.80
20.00	75.76	75.39	74.32	75.45	85.71	51.30
15.00	77.91	77.91	77.27	77.90	83.93	51.40
10.00	81.01	81.71	81.30	81.56	82.14	52.10
7.00	83.64	85.06	84.78	84.77	80.36	52.60
5.00	85.37	87.34	88.01	86.94	78.57	53.00
4.00	86.62	89.04	90.13	88.55	76.79	53.10
2.00	90.21	94.05	96.68	93.26	75.00	54.20
1.00	93.52	98.94	103.19	97.79	73.21	54.90
0.20	100.12	109.46	118.21	107.38	71.43	59.30
0.10	102.63	113.74	124.67	111.22	69.64	60.50
					67.86	60.70
					66.07	60.70
					64.29	62.50
					62.50	63.20
					60.71	63.50
					58.93	64.00
					57.14	65.00
					55.36	65.30
					53.57	65.30
					51.79	65.40
					50.00	65.50
					48.21	66.00
					46.43	66.30
					44.64	67.60
					42.86	67.60
					41.07	68.10
					39.29	69.10
					37.50	69.30
					35.71	69.30
					33.93	69.60
					32.14	69.90
					30.36	70.00
					28.57	71.00
					26.79	73.40
					25.00	74.90
					23.21	75.60
					21.43	76.50
					19.64	77.00
					17.86	77.00
					16.07	77.50
					14.29	77.70
					12.50	78.60
					10.71	78.80
					8.93	81.80
					7.14	84.30
					5.36	88.40
					3.57	93.50
					1.79	94.50

Table A68 : Fitted and observed rainfalls, Station Kasempa 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-10.79	28.82	15.68	36.46	98.18	30.70
80.00	46.56	51.94	47.29	51.69	96.36	38.60
70.00	58.52	58.73	56.02	56.96	94.55	42.20
60.00	68.16	64.85	64.23	62.03	92.73	42.70
50.00	78.96	72.46	72.62	68.75	90.91	45.70
43.00	85.90	77.81	78.92	73.76	89.09	46.50
30.00	99.01	89.04	92.60	85.08	87.27	49.80
20.00	111.35	101.07	106.71	98.47	85.45	49.80
15.00	118.30	108.55	116.24	107.47	83.64	52.20
10.00	128.32	120.33	129.27	122.79	81.82	52.60
7.00	136.81	131.29	140.49	138.35	80.00	52.80
5.00	142.40	139.05	150.92	150.16	78.18	53.10
4.00	146.45	144.96	157.79	159.62	76.36	56.10
2.00	158.02	163.26	178.94	191.55	74.55	56.90
1.00	168.71	182.20	199.94	229.15	72.73	57.90
0.20	190.03	226.84	248.46	338.42	70.91	58.50
0.10	198.13	246.52	269.31	397.03	69.09	59.40
					67.27	61.00
					65.45	61.50
					63.64	62.20
					61.82	63.20
					60.00	63.40
					58.18	63.80
					56.36	63.80
					54.55	64.80
					52.73	66.50
					50.91	70.10
					49.09	71.60
					47.27	72.40
					45.45	72.60
					43.64	73.00
					41.82	73.60
					40.00	73.90
					38.18	74.30
					36.36	75.70
					34.55	78.10
					32.73	80.00
					30.91	80.50
					29.09	81.30
					27.27	83.40
					25.45	85.90
					23.64	86.10
					21.82	91.00
					20.00	93.80
					18.18	99.30
					16.36	101.90
					14.55	104.10
					12.73	119.00
					10.91	133.10
					9.09	136.70
					7.27	149.90
					5.45	162.10
					3.64	171.40
					1.82	253.20



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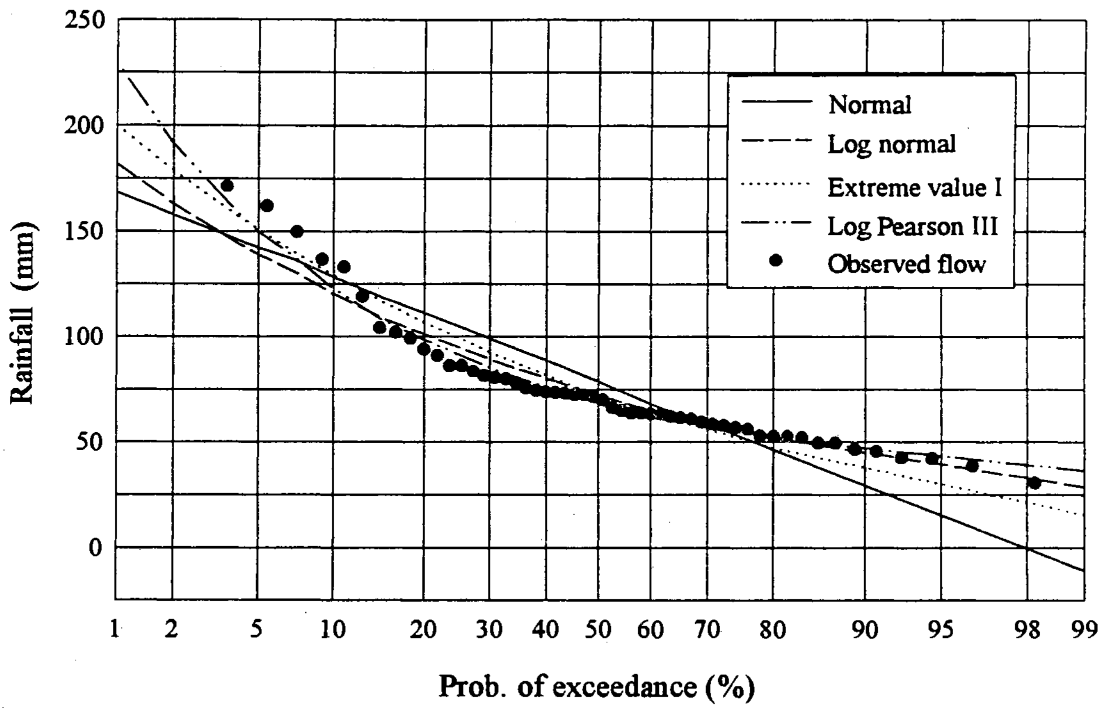


(b)

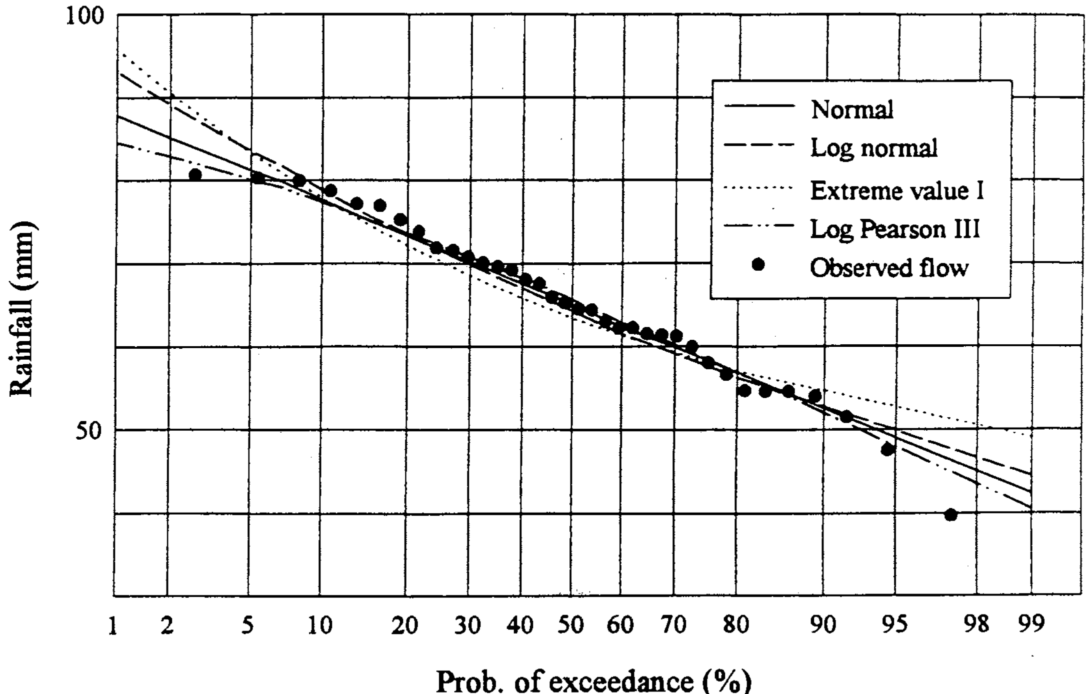
Fig. A34 : Observed and fitted distributions for stations (a) Kasal, (b) Kasel

Table A69 : Fitted and observed rainfalls, Station Kawambwa 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	42.37	44.49	49.08	40.51	97.30	39.70
80.00	56.91	56.33	57.10	56.94	94.59	47.50
70.00	59.95	59.17	59.31	60.28	91.89	51.50
60.00	62.39	61.57	61.40	62.91	89.19	54.00
50.00	65.13	64.37	63.52	65.77	86.49	54.60
43.00	66.89	66.24	65.12	67.55	83.78	54.60
30.00	70.22	69.91	68.59	70.80	81.08	54.70
20.00	73.35	73.55	72.17	73.69	78.38	56.60
15.00	75.11	75.68	74.59	75.24	75.68	58.00
10.00	77.65	78.87	77.89	77.37	72.97	60.00
7.00	79.80	81.68	80.73	79.07	70.27	61.20
5.00	81.22	83.58	83.38	80.14	67.57	61.40
4.00	82.25	84.98	85.12	80.89	64.86	61.50
2.00	85.18	89.13	90.49	82.90	62.16	62.20
1.00	87.89	93.14	95.81	84.60	59.46	62.20
0.20	93.30	101.68	108.11	87.52	56.76	63.00
0.10	95.35	105.13	113.40	88.47	54.05	64.40
					51.35	64.60
					48.65	65.30
					45.95	66.00
					43.24	67.60
					40.54	68.10
					37.84	69.20
					35.14	69.60
					32.43	70.10
					29.73	70.80
					27.03	71.60
					24.32	71.90
					21.62	73.80
					18.92	75.20
					16.22	76.90
					13.51	77.20
					10.81	78.70
					8.11	80.00
					5.41	80.30
					2.70	80.70

Table A70 : Fitted and observed rainfalls, Station Livingstone 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	11.38	29.11	27.72	30.64	98.08	28.30
80.00	46.78	47.76	47.23	47.62	96.15	32.00
70.00	54.16	52.95	52.62	52.53	94.23	41.30
60.00	60.11	57.54	57.69	56.95	92.31	41.70
50.00	66.78	63.16	62.87	62.44	90.38	41.90
43.00	71.06	67.06	66.76	66.31	88.46	42.40
30.00	79.16	75.10	75.20	74.44	86.54	44.70
20.00	86.77	83.54	83.91	83.21	84.62	44.80
15.00	91.06	88.70	89.79	88.68	82.69	46.20
10.00	97.25	96.72	97.83	97.36	80.77	47.50
7.00	102.49	104.06	104.75	105.49	78.85	47.80
5.00	105.94	109.21	111.19	111.30	76.92	48.50
4.00	108.44	113.09	115.43	115.73	75.00	50.70
2.00	115.58	124.97	128.49	129.60	73.08	51.10
1.00	122.17	137.04	141.45	144.16	71.15	51.30
0.20	135.34	164.74	171.39	179.33	69.23	52.60
0.10	140.34	176.66	184.27	195.22	67.31	53.00
					65.38	54.40
					63.46	54.90
					61.54	56.40
					59.62	58.30
					57.69	59.40
					55.77	59.70
					53.85	61.70
					51.92	62.00
					50.00	62.70
					48.08	63.00
					46.15	63.50
					44.23	63.70
					42.31	66.80
					40.38	68.30
					38.46	69.30
					36.54	71.10
					34.62	71.90
					32.69	72.40
					30.77	75.90
					28.85	76.10
					26.92	79.50
					25.00	80.30
					23.08	81.30
					21.15	81.50
					19.23	81.50
					17.31	84.50
					15.38	86.40
					13.46	91.40
					11.54	92.70
					9.62	98.60
					7.69	99.30
					5.77	99.80
					3.85	143.80
					1.92	147.80



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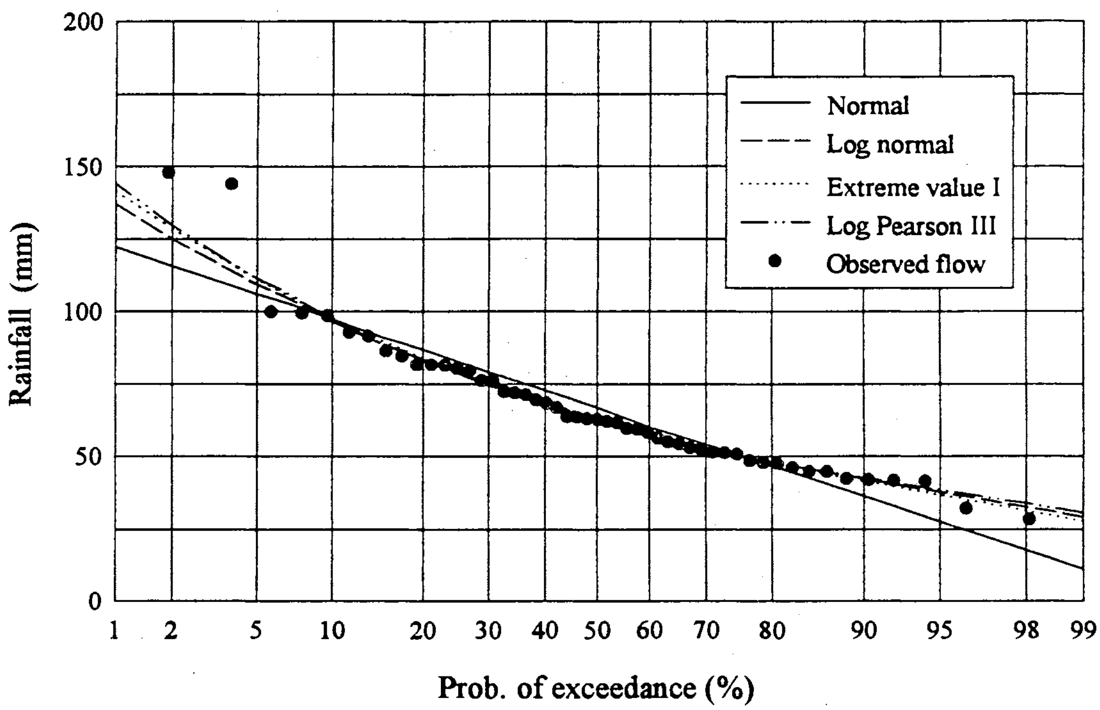


(b)

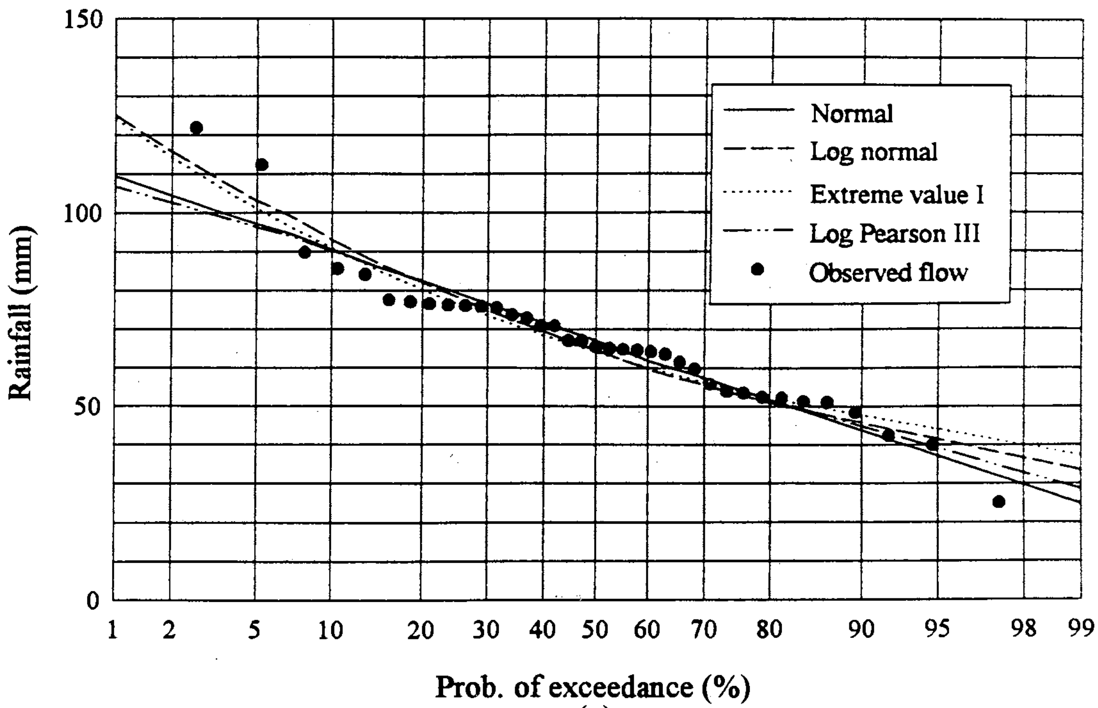
Fig. A35 : Observed and fitted distributions for stations (a) Kawam1, (b) Livi2

Table A71 : Fitted and observed rainfalls, Station Lundazi 1

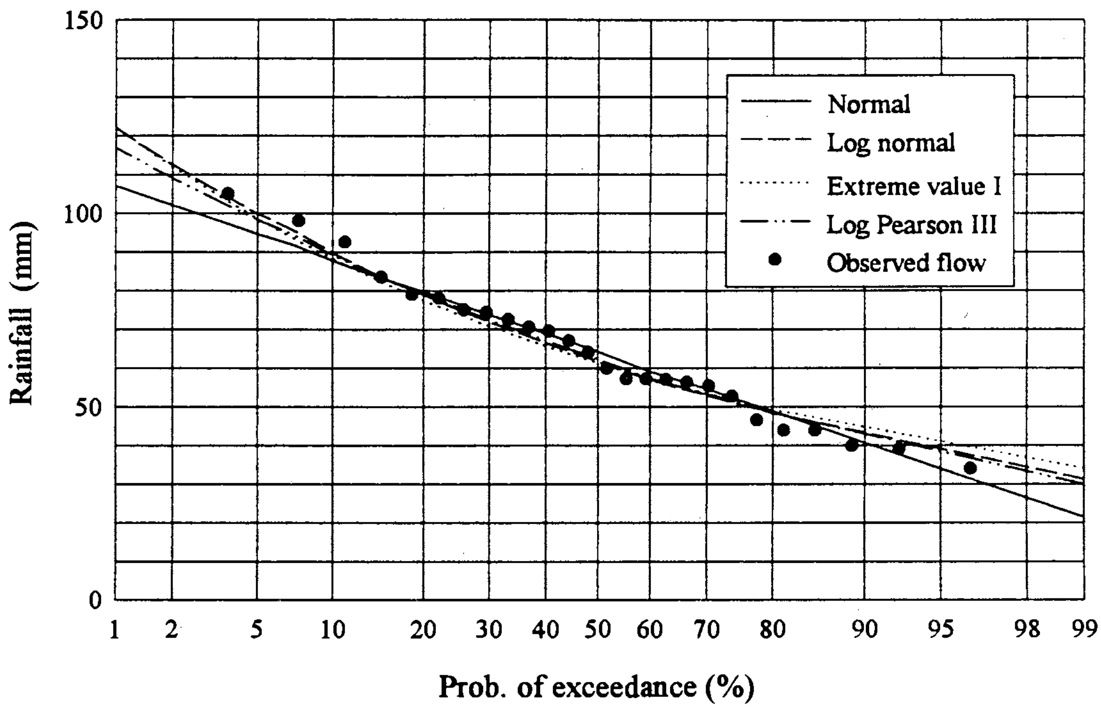
Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	24.83	33.45	37.32	28.64	97.37	25.10
80.00	51.89	51.01	52.23	51.89	94.74	39.90
70.00	57.53	55.69	56.35	57.40	92.11	42.40
60.00	62.08	59.79	60.22	61.94	89.47	48.30
50.00	67.17	64.73	64.18	67.08	86.84	51.00
43.00	70.45	68.12	67.16	70.40	84.21	51.30
30.00	76.64	75.02	73.61	76.65	81.58	52.20
20.00	82.46	82.15	80.27	82.46	78.95	52.40
15.00	85.73	86.46	84.76	85.67	76.32	53.60
10.00	90.46	93.08	90.91	90.21	73.68	53.90
7.00	94.47	99.07	96.20	93.95	71.05	55.80
5.00	97.11	103.23	101.12	96.35	68.42	59.70
4.00	99.02	106.35	104.36	98.05	65.79	61.50
2.00	104.48	115.80	114.34	102.75	63.16	63.50
1.00	109.52	125.27	124.25	106.83	60.53	64.20
0.20	119.58	146.55	147.14	114.20	57.89	64.50
0.10	123.40	155.55	156.98	116.70	55.26	64.80
					52.63	65.00
					50.00	65.60
					47.37	67.00
					44.74	67.10
					42.11	70.90
					39.47	70.90
					36.84	72.90
					34.21	73.70
					31.58	75.50
					28.95	75.90
					26.32	76.10
					23.68	76.20
					21.05	76.50
					18.42	77.00
					15.79	77.60
					13.16	84.00
					10.53	85.50
					7.89	89.70
					5.26	112.30
					2.63	121.90

Table A72 : Fitted and observed rainfalls, Station Lusaka 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	21.48	31.28	34.11	30.00	96.30	34.00
80.00	48.86	48.33	49.21	48.49	92.59	39.00
70.00	54.57	52.92	53.38	53.30	88.89	39.90
60.00	59.17	56.93	57.30	57.44	85.19	43.90
50.00	64.33	61.79	61.30	62.38	81.48	43.90
43.00	67.64	65.13	64.31	65.73	77.78	46.50
30.00	73.90	71.94	70.84	72.42	74.07	52.80
20.00	79.80	79.00	77.58	79.19	70.37	55.40
15.00	83.11	83.27	82.13	83.19	66.67	56.40
10.00	87.90	89.85	88.35	89.25	62.96	57.10
7.00	91.95	95.82	93.70	94.63	59.26	57.20
5.00	94.62	99.97	98.69	98.31	55.56	57.30
4.00	96.55	103.09	101.96	101.03	51.85	59.90
2.00	102.08	112.55	112.06	109.12	48.15	64.00
1.00	107.18	122.05	122.09	117.00	44.44	67.00
0.20	117.36	143.48	145.25	133.93	40.74	69.50
0.10	121.23	152.56	155.21	140.79	37.04	70.50
					33.33	72.50
					29.63	74.40
					25.93	75.00
					22.22	78.10
					18.52	79.10
					14.81	83.50
					11.11	92.50
					7.41	98.00
					3.70	105.10



(a)



(b)

Fig. A36 : Observed and fitted distributions for stations (a) Lunda1, (b) Lusaka1

Table A 73 : Fitted and observed rainfalls, Station Magoye 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	29.76	36.56	38.58	40.21	93.75	42.50
80.00	48.88	49.37	49.12	49.23	87.50	47.80
70.00	52.86	52.57	52.03	51.89	81.25	48.50
60.00	56.08	55.29	54.77	54.28	75.00	49.40
50.00	59.68	58.51	57.57	57.27	68.75	49.40
43.00	61.99	60.68	59.67	59.39	62.50	52.80
30.00	66.37	65.00	64.23	63.84	56.25	55.60
20.00	70.48	69.34	68.93	68.67	50.00	60.70
15.00	72.80	71.91	72.11	71.69	43.75	62.20
10.00	76.14	75.79	76.46	76.50	37.50	63.40
7.00	78.97	79.23	80.20	81.03	31.25	64.10
5.00	80.83	81.59	83.67	84.27	25.00	64.40
4.00	82.18	83.34	85.96	86.75	18.75	67.00
2.00	86.04	88.55	93.02	94.55	12.50	73.50
1.00	89.60	93.65	100.02	102.81	6.25	93.90
0.20	96.72	104.72	116.20	123.01		
0.10	99.42	109.26	123.15	132.27		

Table A74 : Fitted and observed rainfalls, Station Mansa 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	31.78	37.67	41.13	37.40	97.06	40.60
80.00	52.04	51.84	52.30	51.87	94.12	41.70
70.00	56.27	55.41	55.38	55.47	91.18	42.70
60.00	59.67	58.47	58.29	58.55	88.24	48.00
50.00	63.49	62.09	61.25	62.19	85.29	49.00
43.00	65.94	64.54	63.48	64.64	82.35	50.10
30.00	70.57	69.43	68.31	69.51	79.41	53.80
20.00	74.93	74.37	73.29	74.40	76.47	54.10
15.00	77.39	77.30	76.66	77.29	73.53	55.10
10.00	80.93	81.74	81.26	81.65	70.59	56.50
7.00	83.93	85.69	85.23	85.52	67.65	57.40
5.00	85.90	88.41	88.91	88.16	64.71	57.70
4.00	87.33	90.42	91.34	90.12	61.76	57.90
2.00	91.42	96.44	98.81	95.95	58.82	58.50
1.00	95.20	102.35	106.23	101.63	55.88	59.90
0.20	102.73	115.26	123.37	113.93	52.94	59.90
0.10	105.59	120.58	130.74	118.95	50.00	60.10
					47.06	61.20
					44.12	63.20
					41.18	63.80
					38.24	65.50
					35.29	67.30
					32.35	67.60
					29.41	69.00
					26.47	72.00
					23.53	74.70
					20.59	77.40
					17.65	79.60
					14.71	80.40
					11.76	83.70
					8.82	84.10
					5.88	87.60
					2.94	95.00

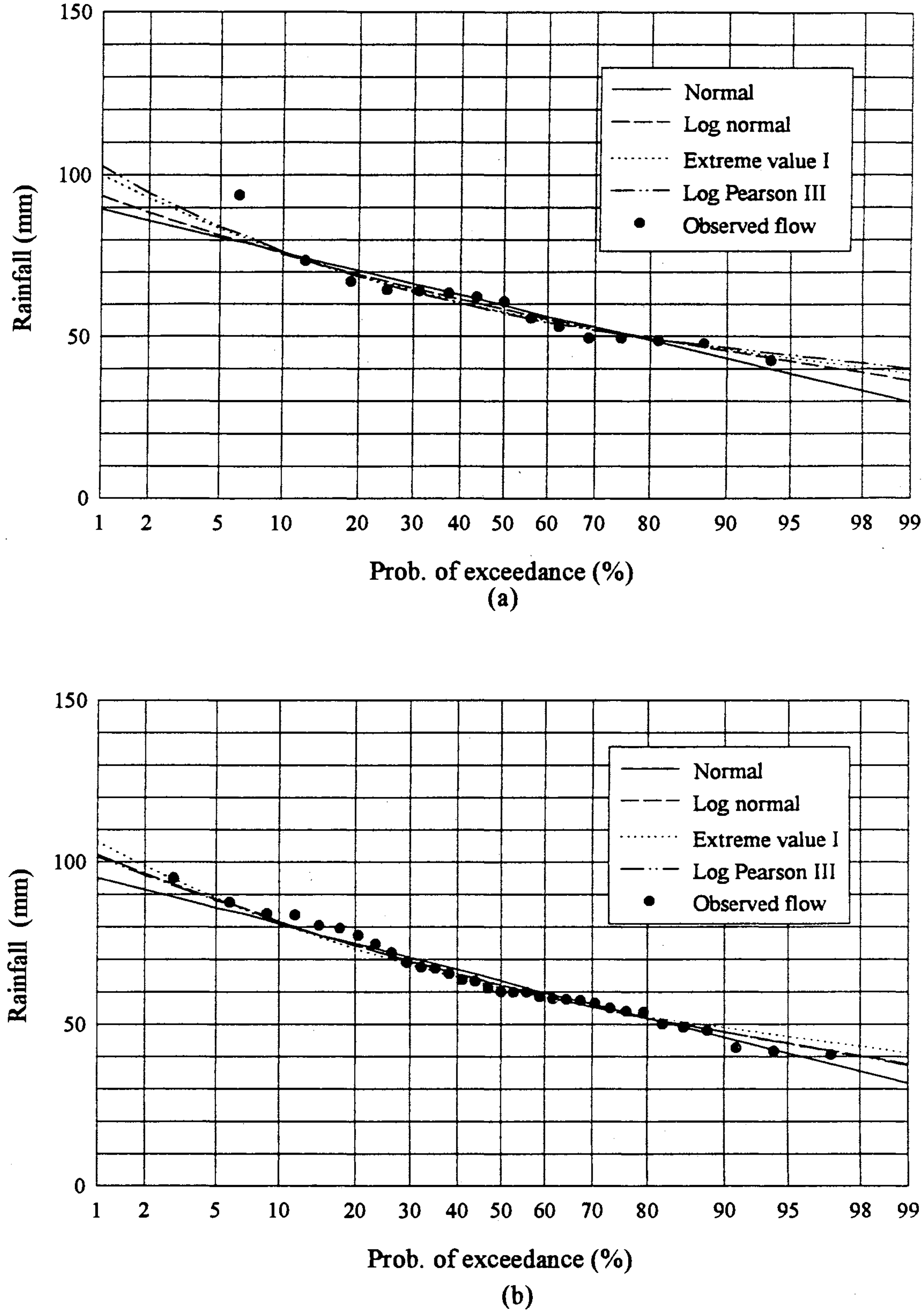


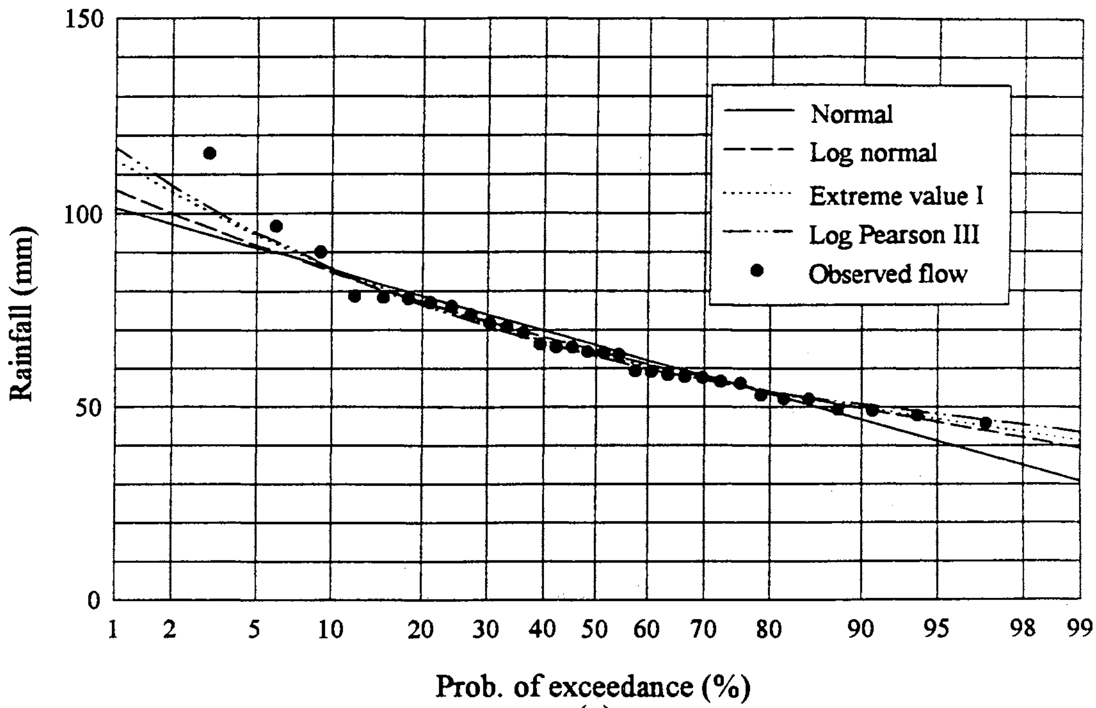
Fig. A37 : Observed and fitted distributions for stations (a) Magoy1, (b) Mansa1

Table A75 : Fitted and observed rainfalls, Station Mbala 1

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	30.90	39.42	41.31	43.55	96.97	45.70
80.00	53.45	54.10	53.74	53.94	93.94	47.80
70.00	58.16	57.79	57.17	57.01	90.91	49.00
60.00	61.95	60.95	60.40	59.79	87.88	49.30
50.00	66.20	64.70	63.71	63.27	84.85	52.00
43.00	68.93	67.23	66.18	65.73	81.82	52.00
30.00	74.09	72.27	71.56	70.94	78.79	53.00
20.00	78.94	77.37	77.11	76.59	75.76	56.10
15.00	81.67	80.39	80.86	80.14	72.73	56.60
10.00	85.61	84.97	85.99	85.81	69.70	57.50
7.00	88.95	89.04	90.40	91.16	66.67	57.70
5.00	91.15	91.84	94.50	95.00	63.64	58.20
4.00	92.74	93.91	97.20	97.95	60.61	59.00
2.00	97.30	100.11	105.52	107.23	57.58	59.20
1.00	101.50	106.19	113.78	117.09	54.55	63.50
0.20	109.89	119.46	132.87	141.38	51.52	64.10
0.10	113.07	124.93	141.07	152.59	48.48	64.30
					45.45	65.50
					42.42	65.60
					39.39	66.30
					36.36	69.30
					33.33	70.80
					30.30	71.80
					27.27	73.90
					24.24	76.00
					21.21	77.00
					18.18	78.00
					15.15	78.30
					12.12	78.70
					9.09	90.00
					6.06	96.70
					3.03	115.40

Tabl3 A76 : Fitted and observed rainfalls, Station Mfuwe 1

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	25.47	31.47	36.43	25.59	93.33	29.50
80.00	49.23	47.81	49.53	49.10	86.67	47.90
70.00	54.18	52.17	53.14	54.45	80.00	51.00
60.00	58.17	55.97	56.54	58.76	73.33	53.00
50.00	62.64	60.55	60.02	63.51	66.67	56.50
43.00	65.52	63.70	62.63	66.50	60.00	57.50
30.00	70.95	70.09	68.29	71.96	53.33	58.00
20.00	76.06	76.69	74.14	76.80	46.67	64.30
15.00	78.94	80.67	78.08	79.38	40.00	66.00
10.00	83.09	86.79	83.48	82.88	33.33	67.50
7.00	86.60	92.33	88.13	85.63	26.67	72.50
5.00	88.92	96.17	92.45	87.34	20.00	75.50
4.00	90.60	99.06	95.29	88.51	13.33	86.90
2.00	95.39	107.78	104.05	91.60	6.67	90.90
1.00	99.81	116.51	112.75	94.09		
0.20	108.65	136.11	132.84	98.05		
0.10	112.00	144.39	141.48	99.22		



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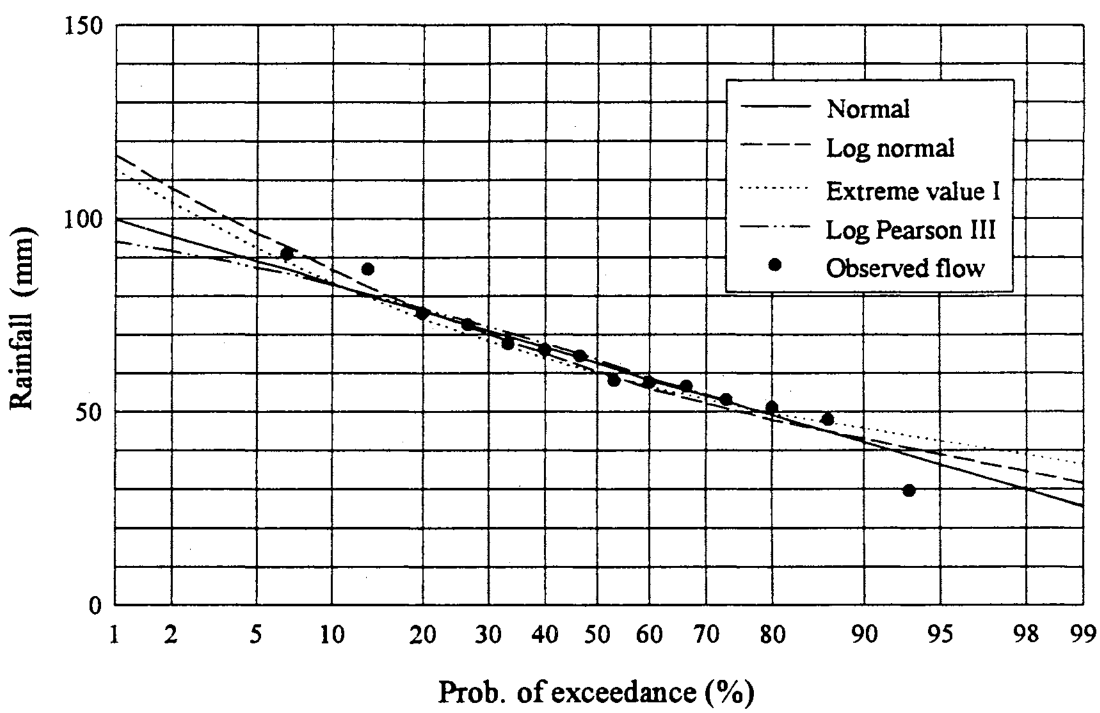


(b)

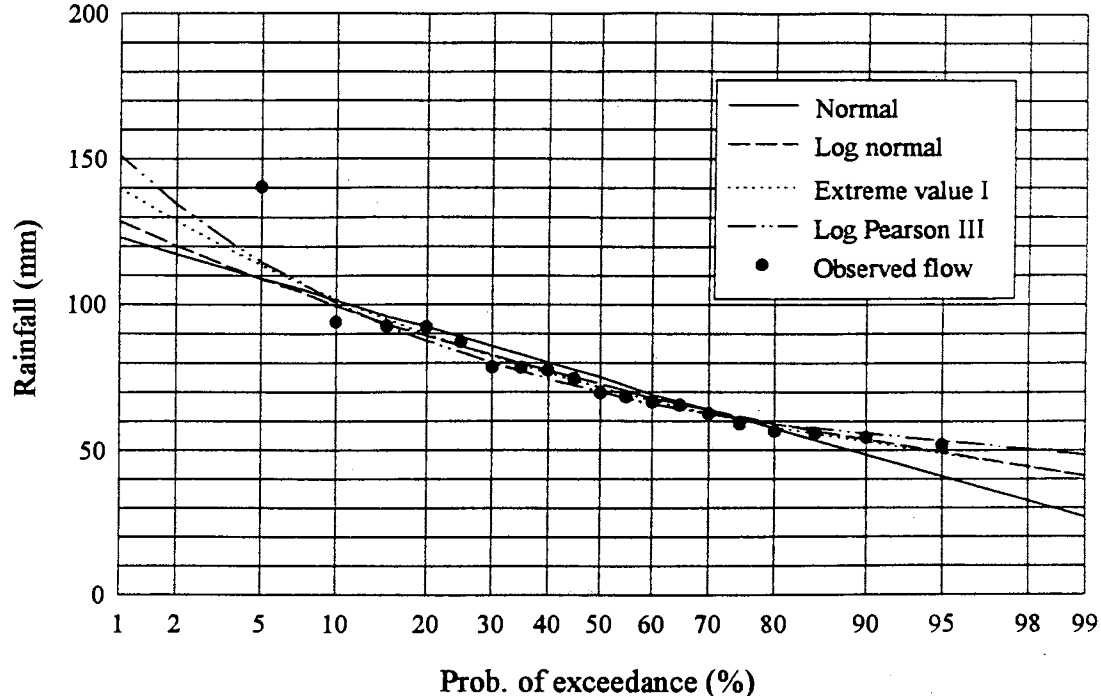
Fig. A38 : Observed and fitted distributions for stations (a) Mbala1, (b) Mfuwe1

Table A77 : Fitted and observed rainfalls, Station Misamfu 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	26.86	41.12	41.07	48.54	95.00	51.90
80.00	57.64	59.22	58.03	59.08	90.00	54.40
70.00	64.05	63.89	62.71	62.58	85.00	55.90
60.00	69.23	67.94	67.12	65.87	80.00	56.40
50.00	75.02	72.77	71.62	70.12	75.00	59.00
43.00	78.75	76.05	75.00	73.22	70.00	62.60
30.00	85.78	82.67	82.34	80.00	65.00	65.50
20.00	92.40	89.42	89.91	87.69	60.00	66.60
15.00	96.13	93.45	95.03	92.68	55.00	68.30
10.00	101.51	99.61	102.02	100.90	50.00	69.60
7.00	106.06	105.13	108.04	108.93	45.00	74.60
5.00	109.06	108.94	113.63	114.85	40.00	77.50
4.00	111.24	111.78	117.32	119.48	35.00	78.30
2.00	117.45	120.32	128.67	134.54	30.00	78.60
1.00	123.18	128.78	139.94	151.30	25.00	87.30
0.20	134.62	147.48	165.97	195.84	20.00	92.20
0.10	138.97	155.28	177.16	217.85	15.00	92.50
					10.00	94.00
					5.00	140.20

Table A78 : Fitted and observed rainfalls, Station Mongu 2

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-5.76	28.31	16.83	36.42	97.96	35.30
80.00	43.19	48.56	43.81	48.41	95.92	37.80
70.00	53.40	54.34	51.26	52.67	93.88	39.60
60.00	61.63	59.50	58.27	56.78	91.84	39.70
50.00	70.84	65.86	65.44	62.26	89.80	40.10
43.00	76.77	70.30	70.82	66.37	87.76	43.70
30.00	87.96	79.53	82.49	75.65	85.71	44.50
20.00	98.50	89.32	94.53	86.69	83.67	45.90
15.00	104.42	95.35	102.67	94.12	81.63	47.80
10.00	112.98	104.78	113.79	106.80	79.59	48.20
7.00	120.23	113.48	123.36	119.71	77.55	50.30
5.00	125.00	119.61	132.27	129.53	75.51	51.10
4.00	128.46	124.25	138.13	137.40	73.47	51.30
2.00	138.33	138.54	156.19	164.07	71.43	52.30
1.00	147.45	153.18	174.11	195.60	69.39	54.00
0.20	165.66	187.21	215.52	287.99	67.35	56.60
0.10	172.57	202.03	233.33	337.95	65.31	59.40
					63.27	60.90
					61.22	61.40
					59.18	61.50
					57.14	61.50
					55.10	61.70
					53.06	63.20
					51.02	64.50
					48.98	65.00
					46.94	65.50
					44.90	66.40
					42.86	66.50
					40.82	66.50
					38.78	67.60
					36.73	67.80
					34.69	68.90
					32.65	74.40
					30.61	75.70
					28.57	79.50
					26.53	81.70
					24.49	83.10
					22.45	84.50
					20.41	84.60
					18.37	85.50
					16.33	89.20
					14.29	97.70
					12.24	97.80
					10.20	103.50
					8.16	104.40
					6.12	107.90
					4.08	147.80
					2.04	236.70



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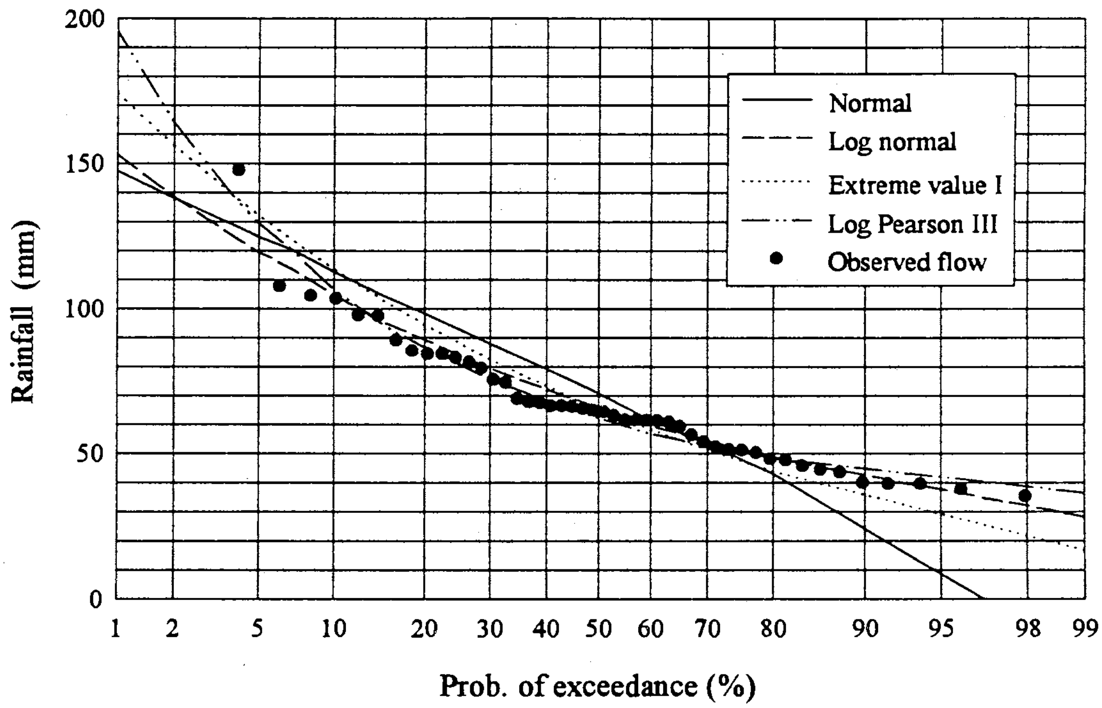


(b)

Fig. A39 : Observed and fitted distributions for stations (a) Misa1, (b) Mong2

Table A79 : Fitted and observed rainfalls, Station Mpika 1

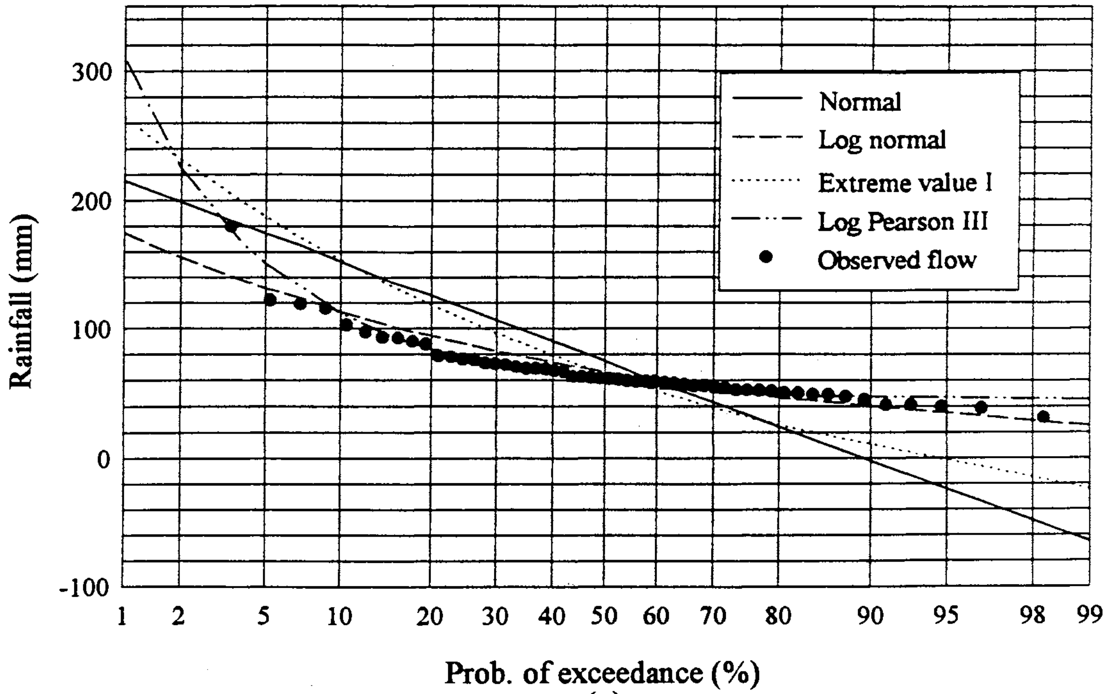
Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-65.14	25.42	-23.74	45.70	98.25	31.50
80.00	24.57	47.08	25.71	48.89	96.49	38.60
70.00	43.27	53.54	39.37	51.35	94.74	39.90
60.00	58.35	59.38	52.21	54.19	92.98	41.10
50.00	75.25	66.69	65.34	58.56	91.23	41.10
43.00	86.11	71.86	75.19	62.21	89.47	45.40
30.00	106.62	82.73	96.59	71.54	87.72	47.70
20.00	125.92	94.47	118.65	84.38	85.96	49.00
15.00	136.78	101.79	133.56	94.05	84.21	49.30
10.00	152.47	113.37	153.95	112.42	82.46	50.00
7.00	165.74	124.19	171.49	133.52	80.70	50.00
5.00	174.49	131.89	187.81	151.25	78.95	51.80
4.00	180.82	137.76	198.55	166.49	77.19	52.10
2.00	198.92	156.00	231.64	225.29	75.44	52.50
1.00	215.63	174.98	264.48	309.66	73.68	52.60
0.20	248.99	220.06	340.37	659.54	71.93	54.10
0.10	261.66	240.08	373.00	919.62	70.18	55.40
					68.42	55.90
					66.67	55.90
					64.91	56.60
					63.16	57.90
					61.40	58.10
					59.65	59.20
					57.89	59.20
					56.14	59.40
					54.39	59.50
					52.63	60.80
					50.88	61.20
					49.12	61.50
					47.37	62.20
					45.61	62.50
					43.86	63.00
					42.11	67.30
					40.35	67.50
					38.60	68.80
					36.84	69.10
					35.09	69.30

Table A79 : Fitted and observed rainfalls, Station Mpika 1 (cont)

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
					33.33	70.40
					31.58	72.00
					29.82	72.90
					28.07	73.10
					26.32	75.80
					24.56	76.20
					22.81	78.00
					21.05	78.70
					19.30	87.90
					17.54	89.90
					15.79	92.70
					14.04	93.10
					12.28	97.00
					10.53	102.90
					8.77	115.80
					7.02	119.40
					5.26	122.00
					3.51	180.00
					1.75	479.00

Table A80 : Fitted and observed rainfalls, Station Msekera

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	25.03	33.51	35.74	34.94	91.67	41.50
80.00	48.24	48.44	48.53	48.33	83.33	43.10
70.00	53.07	52.30	52.06	51.97	75.00	48.20
60.00	56.98	55.64	55.39	55.17	66.67	53.60
50.00	61.35	59.64	58.78	59.08	58.33	57.80
43.00	64.15	62.36	61.33	61.78	50.00	60.10
30.00	69.46	67.84	66.87	67.35	41.67	62.60
20.00	74.45	73.43	72.57	73.19	33.33	65.00
15.00	77.26	76.78	76.43	76.76	25.00	73.40
10.00	81.32	81.89	81.71	82.32	16.67	74.60
7.00	84.75	86.47	86.24	87.44	8.33	94.90
5.00	87.02	89.63	90.46	91.03		
4.00	88.66	92.00	93.24	93.74		
2.00	93.34	99.09	101.80	102.08		
1.00	97.66	106.13	110.30	110.61		
0.20	106.29	121.71	129.93	130.45		
0.10	109.57	128.21	138.37	139.12		



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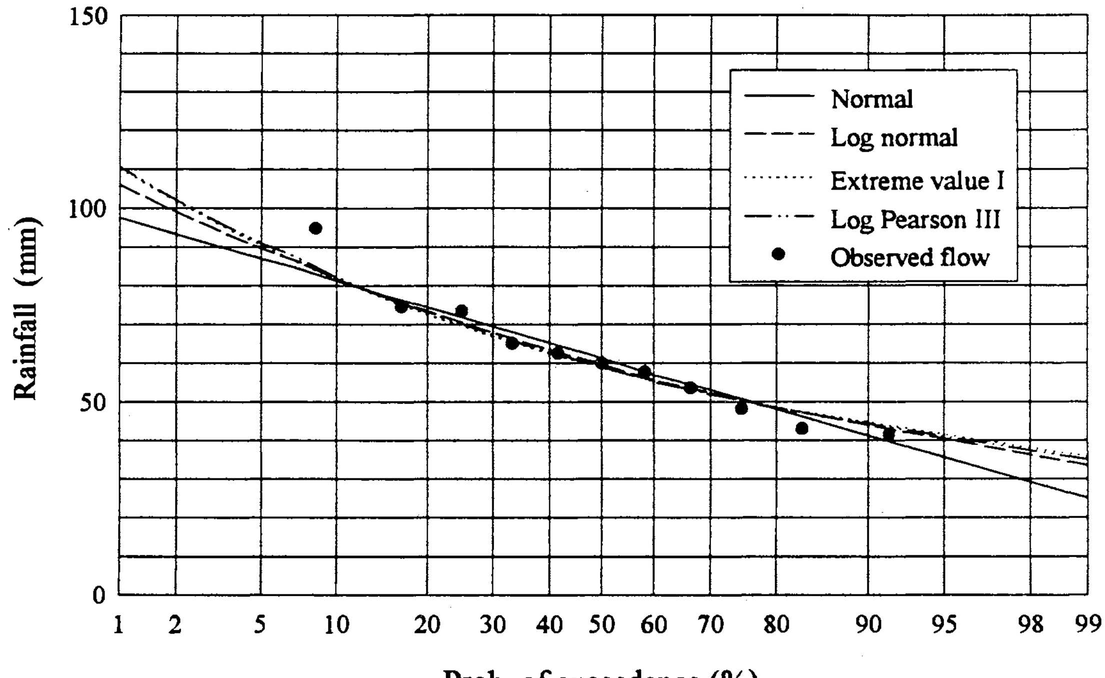


(b)

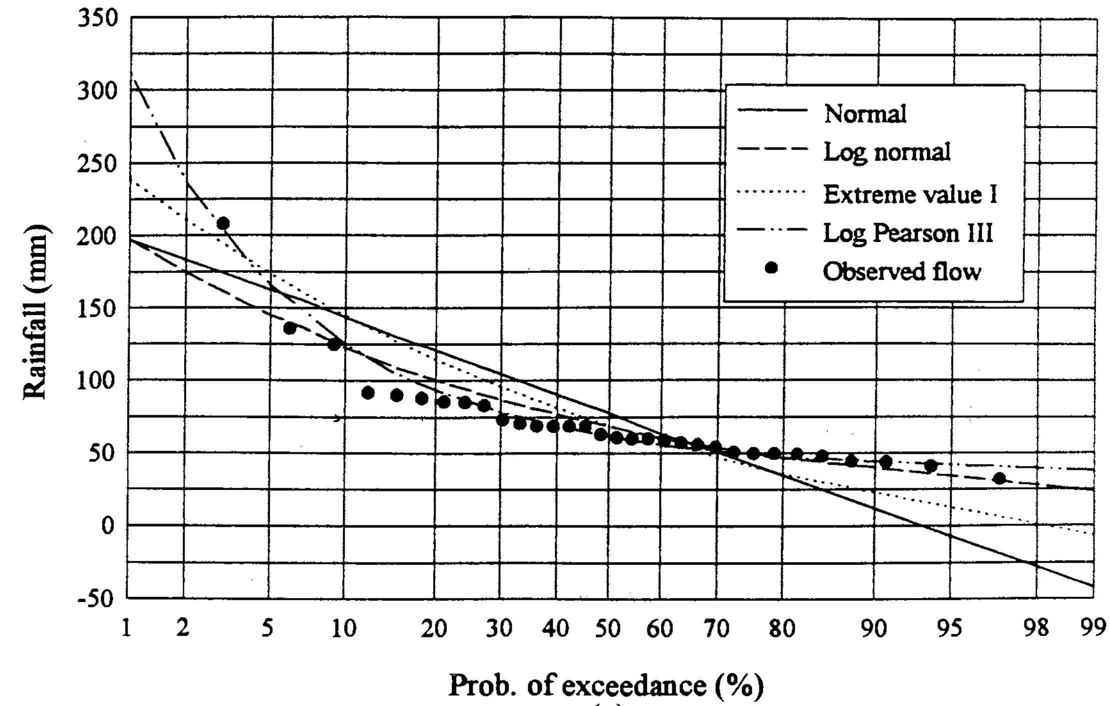
Fig. A40 : Observed and fitted distributions for stations (a) Mpika1, (b) Mseke1

Table A81 : Fitted and observed rainfalls, Station Mt. Makulu 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-41.74	23.86	-6.45	38.08	96.97	32.00
80.00	34.72	46.94	35.70	47.32	93.94	40.90
70.00	50.67	54.05	47.34	51.50	90.91	43.90
60.00	63.52	60.57	58.29	55.84	87.88	44.40
50.00	77.92	68.80	69.48	62.02	84.85	48.00
43.00	87.18	74.67	77.88	66.91	81.82	49.50
30.00	104.66	87.17	96.12	78.76	78.79	49.80
20.00	121.12	100.84	114.92	94.13	75.76	49.80
15.00	130.38	109.44	127.63	105.23	72.73	50.60
10.00	143.75	123.19	145.01	125.51	69.70	54.00
7.00	155.06	136.17	159.96	147.83	66.67	55.90
5.00	162.52	145.46	173.87	165.92	63.64	57.10
4.00	167.92	152.57	183.03	181.09	60.61	59.20
2.00	183.34	174.90	211.23	236.86	57.58	59.90
1.00	197.59	198.39	239.23	311.30	54.55	60.00
0.20	226.03	255.17	303.92	580.43	51.52	61.00
0.10	236.83	280.76	331.73	756.63	48.48	63.30
					45.45	68.80
					42.42	68.80
					39.39	69.00
					36.36	69.00
					33.33	70.60
					30.30	73.30
					27.27	83.30
					24.24	85.30
					21.21	85.90
					18.18	88.60
					15.15	90.50
					12.12	92.10
					9.09	125.00
					6.06	136.00
					3.03	208.00

Table A82 : Fitted and observed rainfalls, Station Mumbwa

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-104.96	20.13	-47.61	40.88	93.75	37.00
80.00	19.30	46.02	20.88	47.48	87.50	39.50
70.00	45.20	54.68	39.79	51.50	81.25	43.70
60.00	66.10	62.84	57.59	55.97	75.00	60.00
50.00	89.49	73.43	75.77	62.76	68.75	60.40
43.00	104.54	81.16	89.42	68.43	62.50	63.00
30.00	132.95	98.04	119.06	83.04	56.25	64.50
20.00	159.69	117.14	149.62	103.61	50.00	69.30
15.00	174.73	129.47	170.27	119.49	43.75	74.70
10.00	196.46	149.61	198.51	150.48	37.50	77.00
7.00	214.84	169.08	222.80	187.35	31.25	79.20
5.00	226.96	183.28	245.41	219.20	25.00	79.60
4.00	235.73	194.30	260.29	247.20	18.75	81.20
2.00	260.80	229.57	306.12	359.56	12.50	133.30
1.00	283.95	267.80	351.61	530.58	6.25	380.00
0.20	330.16	364.21	456.74	1318.24		
0.10	347.71	409.32	501.93	1957.16		



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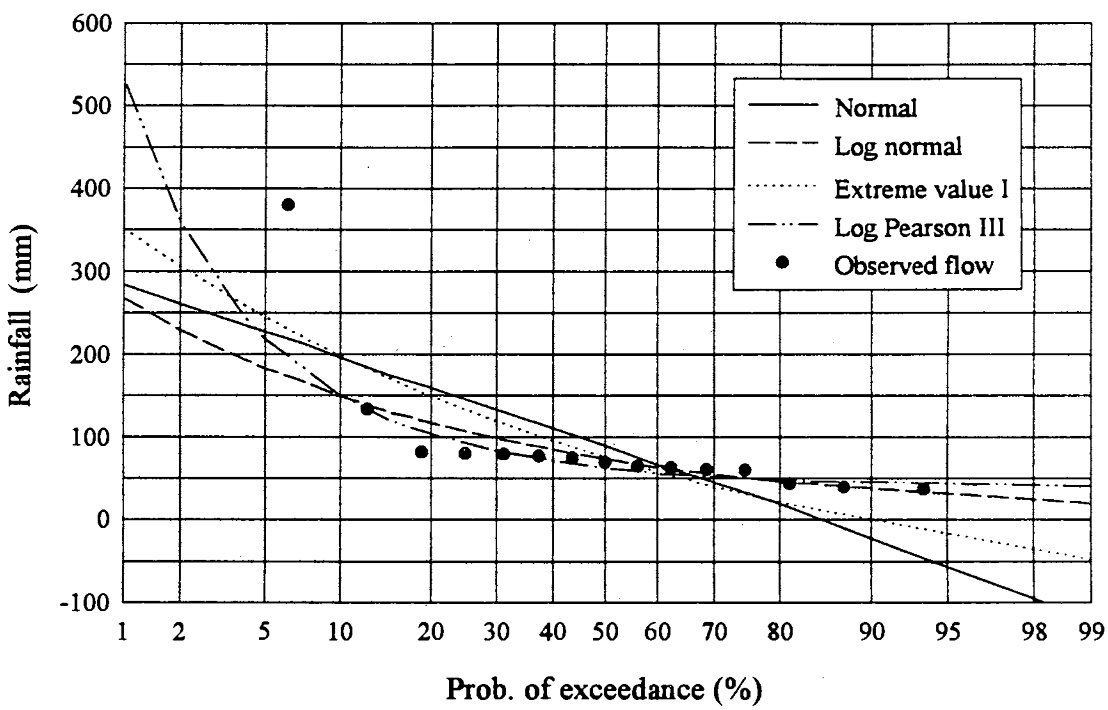


(b)

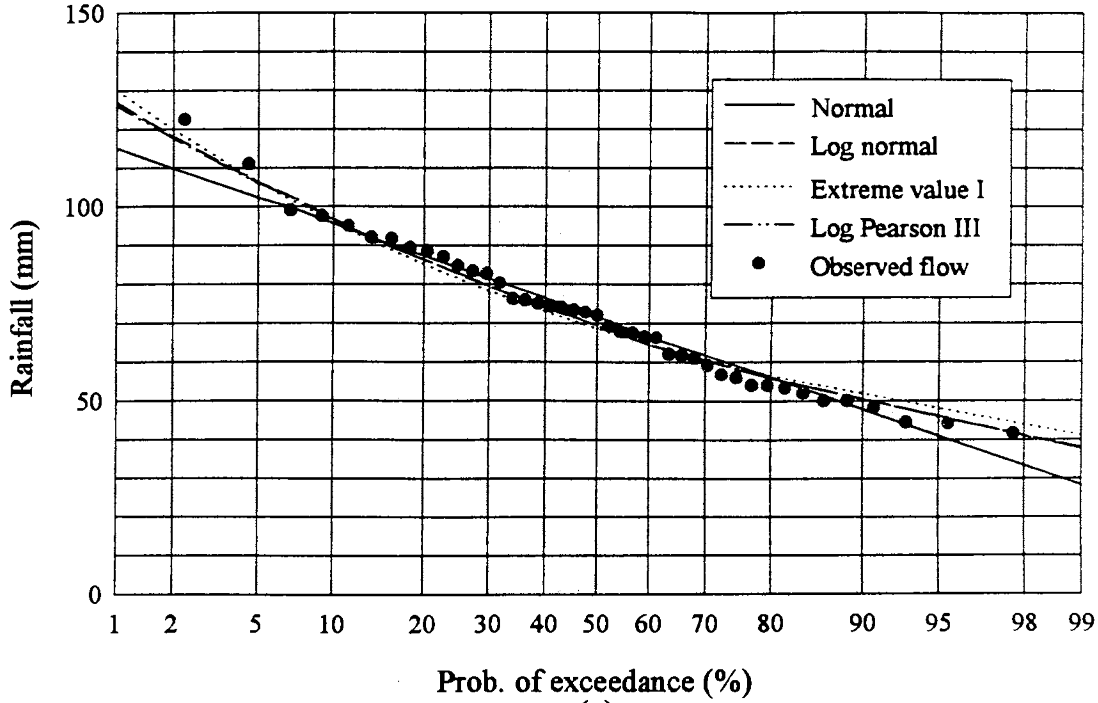
Fig. A41 : Observed and fitted distributions for stations (a) Mtmak1, (b) Mumbw1

Table A83 : Fitted and observed rainfalls, Station Mwinilunga 1

Prob	Nor	Ln	EV	Lp3	Plotting positions	Rainfall
99.00	28.42	37.98	41.20	37.76	97.73	41.70
80.00	56.12	55.86	56.47	55.88	95.45	44.20
70.00	61.89	60.53	60.68	60.59	93.18	44.50
60.00	66.55	64.59	64.65	64.67	90.91	48.30
50.00	71.76	69.45	68.70	69.55	88.64	50.00
43.00	75.11	72.77	71.74	72.87	86.36	50.00
30.00	81.45	79.48	78.35	79.56	84.09	52.10
20.00	87.41	86.36	85.16	86.40	81.82	53.30
15.00	90.76	90.49	89.76	90.49	79.55	54.00
10.00	95.60	96.80	96.06	96.72	77.27	54.10
7.00	99.70	102.49	101.47	102.32	75.00	56.10
5.00	102.40	106.42	106.51	106.17	72.73	56.80
4.00	104.35	109.36	109.83	109.05	70.45	59.20
2.00	109.94	118.21	120.04	117.70	68.18	61.00
1.00	115.10	127.01	130.18	126.26	65.91	61.70
0.20	125.40	146.60	153.61	145.18	63.64	62.00
0.10	129.31	154.81	163.68	153.05	61.36	66.30
					59.09	66.50
					56.82	67.60
					54.55	67.90
					52.27	69.30
					50.00	72.10
					47.73	72.80
					45.45	73.40
					43.18	74.00
					40.91	74.40
					38.64	75.00
					36.36	75.90
					34.09	76.20
					31.82	80.30
					29.55	82.70
					27.27	83.40
					25.00	84.80
					22.73	87.10
					20.45	88.60
					18.18	89.40
					15.91	91.70
					13.64	92.00
					11.36	95.00
					9.09	97.60
					6.82	99.10
					4.55	111.10
					2.27	122.50

Table A84 : Fitted and observed rainfalls, Station Ndola 2

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-283.10	23.05	-171.84	49.56	98.00	29.00
80.00	-42.02	48.05	-38.95	57.46	96.00	36.00
70.00	8.24	56.00	-2.25	57.81	94.00	44.20
60.00	48.77	63.36	32.26	58.80	92.00	47.50
50.00	94.17	72.76	67.54	61.16	90.00	47.80
43.00	123.35	79.53	94.03	63.68	88.00	48.80
30.00	178.48	94.07	151.53	71.61	86.00	50.20
20.00	230.36	110.18	210.82	84.95	84.00	52.50
15.00	259.54	120.42	250.90	96.42	82.00	54.30
10.00	301.69	136.92	305.68	120.99	80.00	54.40
7.00	337.36	152.64	352.81	153.39	78.00	54.90
5.00	360.87	163.97	396.68	183.84	76.00	56.30
4.00	377.89	172.70	425.54	212.36	74.00	58.20
2.00	426.53	200.29	514.46	342.00	72.00	58.30
1.00	471.44	229.65	602.72	582.10	70.00	61.00
0.20	561.10	301.78	806.68	2263.57	68.00	61.70
0.10	595.15	334.76	894.36	4248.61	66.00	63.00
					64.00	63.50
					62.00	64.50
					60.00	64.80
					58.00	65.80
					56.00	67.30
					54.00	69.10
					52.00	70.40
					50.00	70.90
					48.00	72.50
					46.00	76.70
					44.00	77.70
					42.00	78.30
					40.00	78.50
					38.00	79.50
					36.00	80.00
					34.00	81.20
					32.00	81.40
					30.00	83.10
					28.00	84.40
					26.00	86.10
					24.00	87.60
					22.00	88.10
					20.00	88.10
					18.00	88.30
					16.00	90.30
					14.00	90.50
					12.00	90.90
					10.00	96.00
					8.00	105.40
					6.00	105.90
					4.00	110.50
					2.00	1198.90



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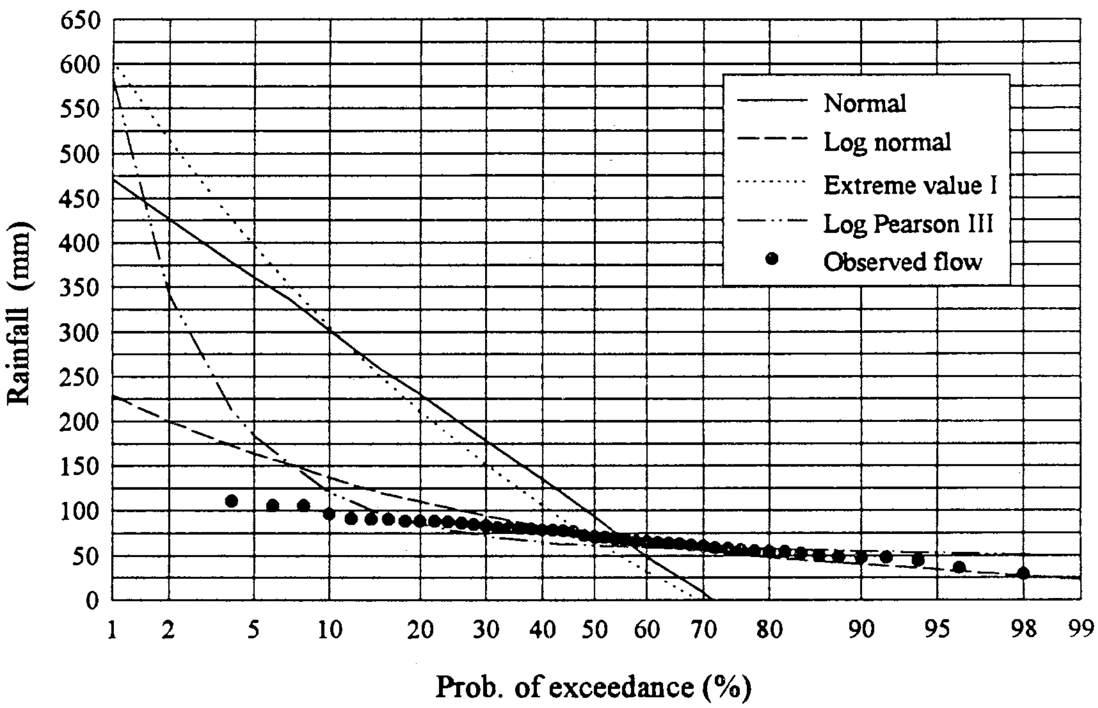


(b)

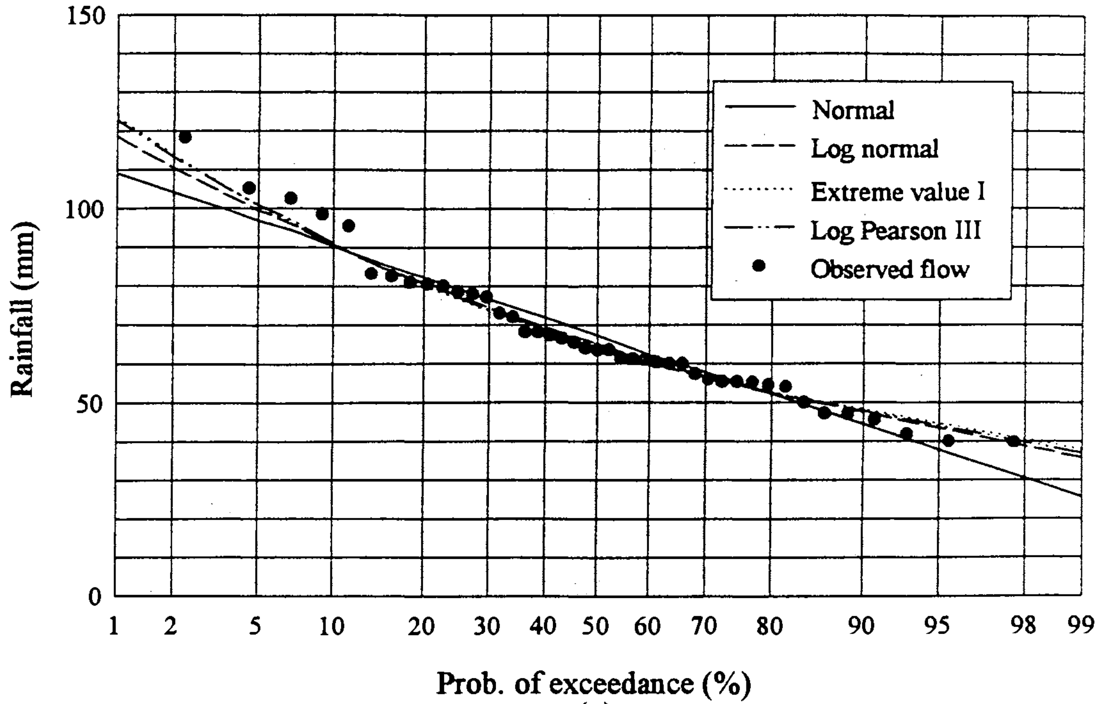
Fig. A42 : Observed and fitted distributions for stations (a) Mwini1, (b) Ndol2

Table A85 : Fitted and observed rainfalls, Station Petauke 1

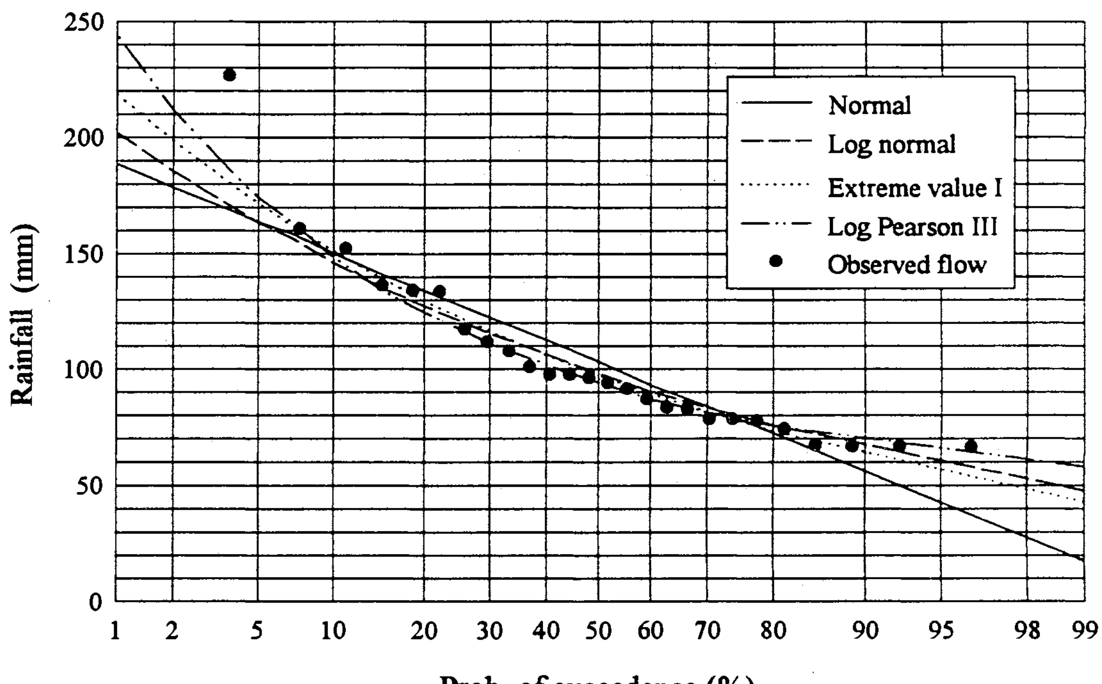
Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	25.65	35.80	37.96	37.08	97.73	39.80
80.00	52.31	52.51	52.65	52.41	95.45	40.00
70.00	57.87	56.88	56.71	56.57	93.18	41.90
60.00	62.35	60.66	60.53	60.23	90.91	45.50
50.00	67.37	65.20	64.43	64.68	88.64	47.00
43.00	70.60	68.29	67.36	67.76	86.36	47.20
30.00	76.70	74.54	73.72	74.09	84.09	50.00
20.00	82.44	80.95	80.27	80.73	81.82	54.10
15.00	85.66	84.79	84.71	84.78	79.55	54.60
10.00	90.32	90.66	90.77	91.08	77.27	55.30
7.00	94.27	95.95	95.98	96.86	75.00	55.40
5.00	96.87	99.60	100.83	100.92	72.73	55.40
4.00	98.75	102.33	104.02	103.98	70.45	56.10
2.00	104.13	110.55	113.85	113.37	68.18	57.40
1.00	109.10	118.73	123.62	122.96	65.91	60.00
0.20	119.01	136.91	146.17	145.17	63.64	60.10
0.10	122.78	144.52	155.87	154.83	61.36	60.40
					59.09	61.00
					56.82	61.20
					54.55	61.50
					52.27	63.50
					50.00	63.50
					47.73	64.00
					45.45	65.50
					43.18	66.60
					40.91	67.30
					38.64	68.20
					36.36	68.20
					34.09	72.00
					31.82	73.00
					29.55	77.20
					27.27	78.00
					25.00	78.50
					22.73	80.00
					20.45	80.50
					18.18	81.00
					15.91	82.70
					13.64	83.30
					11.36	95.50
					9.09	98.60
					6.82	102.50
					4.55	105.20
					2.27	118.40

Table A86 : Fitted and observed rainfalls, Station Samfya 1

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	17.85	47.77	43.07	57.99	96.30	66.50
80.00	72.49	75.76	73.19	75.50	92.59	66.60
70.00	83.88	83.41	81.50	81.36	88.89	66.80
60.00	93.07	90.13	89.33	86.91	85.19	67.30
50.00	103.36	98.31	97.32	94.15	81.48	74.10
43.00	109.97	103.96	103.33	99.47	77.78	77.70
30.00	122.47	115.52	116.36	111.23	74.07	78.30
20.00	134.23	127.57	129.80	124.80	70.37	78.40
15.00	140.84	134.89	138.88	133.72	66.67	82.50
10.00	150.39	146.22	151.30	148.59	62.96	83.30
7.00	158.48	156.55	161.98	163.35	59.26	87.10
5.00	163.81	163.75	171.92	174.35	55.56	91.40
4.00	167.66	169.17	178.46	183.03	51.85	94.00
2.00	178.69	185.66	198.62	211.70	48.15	96.30
1.00	188.87	202.32	218.62	244.32	44.44	97.50
0.20	209.19	240.17	264.85	334.12	40.74	97.60
0.10	216.91	256.34	284.72	379.97	37.04	100.80
					33.33	107.70
					29.63	111.80
					25.93	117.30
					22.22	133.60
					18.52	134.30
					14.81	136.40
					11.11	152.40
					7.41	160.80
					3.70	226.80



(a)



(b)

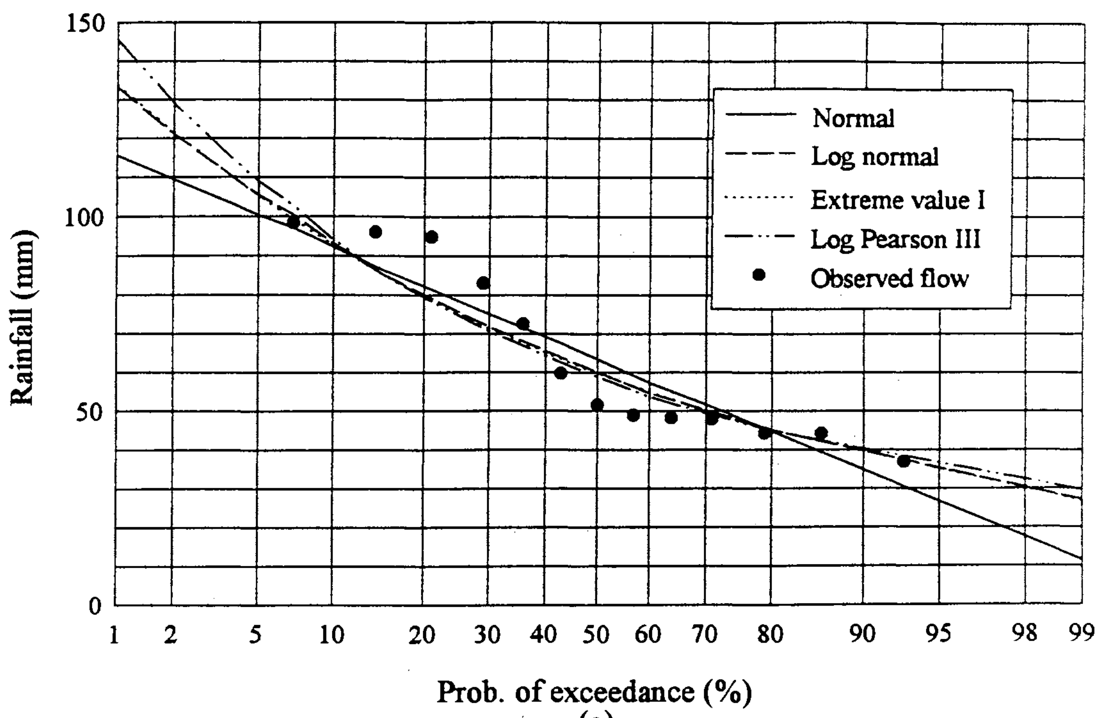
Fig. A43 : Observed and fitted distributions for stations (a) Peta1, (b) Samfya1

Table A87 : Fitted and observed rainfalls, Station Senanga 1

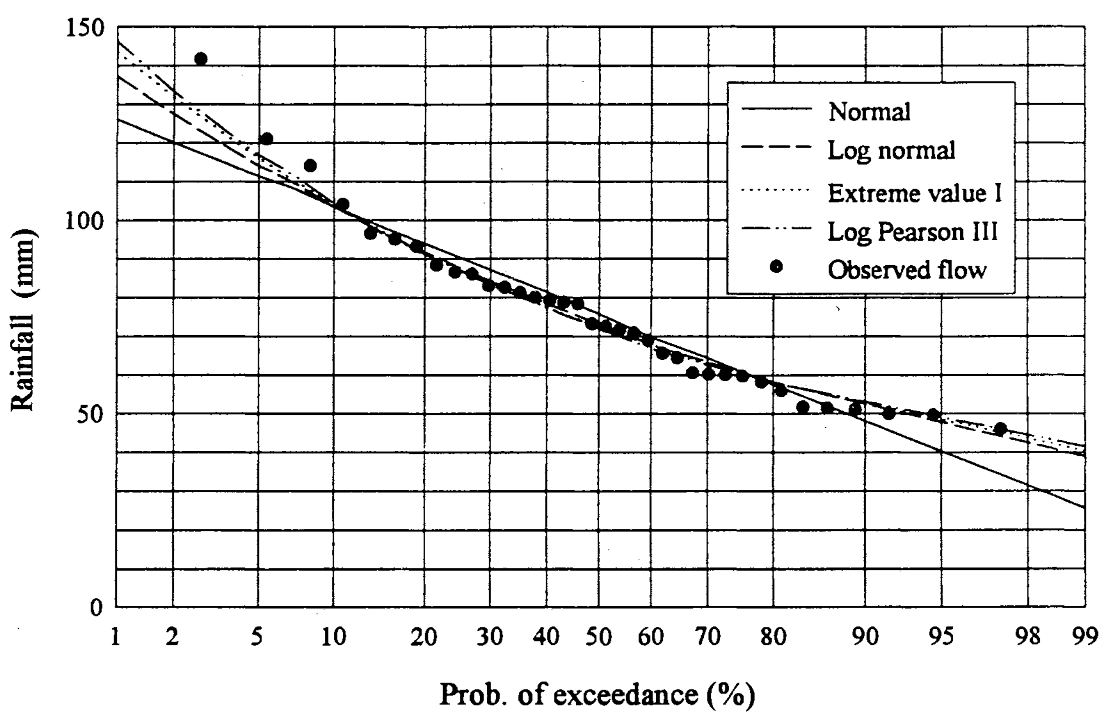
Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	11.48	27.17	26.85	29.72	93.00	36.90
80.00	44.78	45.17	45.21	44.98	86.00	44.20
70.00	51.72	50.21	50.27	49.55	79.00	44.30
60.00	57.32	54.69	55.04	53.72	71.00	47.90
50.00	63.59	60.19	59.91	58.98	64.00	48.30
43.00	67.62	64.01	63.57	62.74	57.00	48.90
30.00	75.24	71.89	71.52	70.76	50.00	51.50
20.00	82.40	80.20	79.70	79.59	43.00	59.80
15.00	86.43	85.29	85.24	85.19	36.00	72.60
10.00	92.25	93.22	92.81	94.22	29.00	83.00
7.00	97.18	100.50	99.32	102.84	21.00	94.90
5.00	100.43	105.61	105.37	109.08	14.00	96.00
4.00	102.78	109.47	109.36	113.89	7.00	98.40
2.00	109.50	121.29	121.64	129.21		
1.00	115.70	133.33	133.83	145.70		
0.20	128.08	161.08	162.00	187.16		
0.10	132.79	173.06	174.11	206.61		

Table A88 : Fitted and observed rainfalls, Station Serenje 1

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	25.57	38.94	40.40	41.54	97.30	46.00
80.00	57.71	58.26	58.12	58.08	94.59	49.80
70.00	64.41	63.36	63.01	62.75	91.89	49.90
60.00	69.82	67.80	67.62	66.93	89.19	51.00
50.00	75.87	73.15	72.32	72.09	86.49	51.40
43.00	79.76	76.80	75.85	75.71	83.78	51.80
30.00	87.11	84.21	83.52	83.26	81.08	55.90
20.00	94.03	91.83	91.42	91.34	78.38	58.30
15.00	97.92	96.42	96.76	96.35	75.68	59.70
10.00	103.54	103.46	104.07	104.27	72.97	60.00
7.00	108.29	109.81	110.35	111.66	70.27	60.20
5.00	111.43	114.21	116.20	116.91	67.57	60.50
4.00	113.70	117.50	120.05	120.92	64.86	64.40
2.00	120.18	127.45	131.90	133.39	62.16	65.50
1.00	126.17	137.38	143.67	146.43	59.46	68.90
0.20	138.12	159.58	170.86	177.74	56.76	70.90
0.10	142.66	168.92	182.55	191.82	54.05	71.70
					51.35	72.50
					48.65	73.20
					45.95	78.40
					43.24	78.70
					40.54	79.20
					37.84	80.00
					35.14	81.30
					32.43	82.50
					29.73	83.00
					27.03	86.10
					24.32	86.50
					21.62	88.40
					18.92	93.20
					16.22	95.00
					13.51	96.60
					10.81	104.10
					8.11	114.00
					5.41	121.00
					2.70	141.70



(a)



(b)

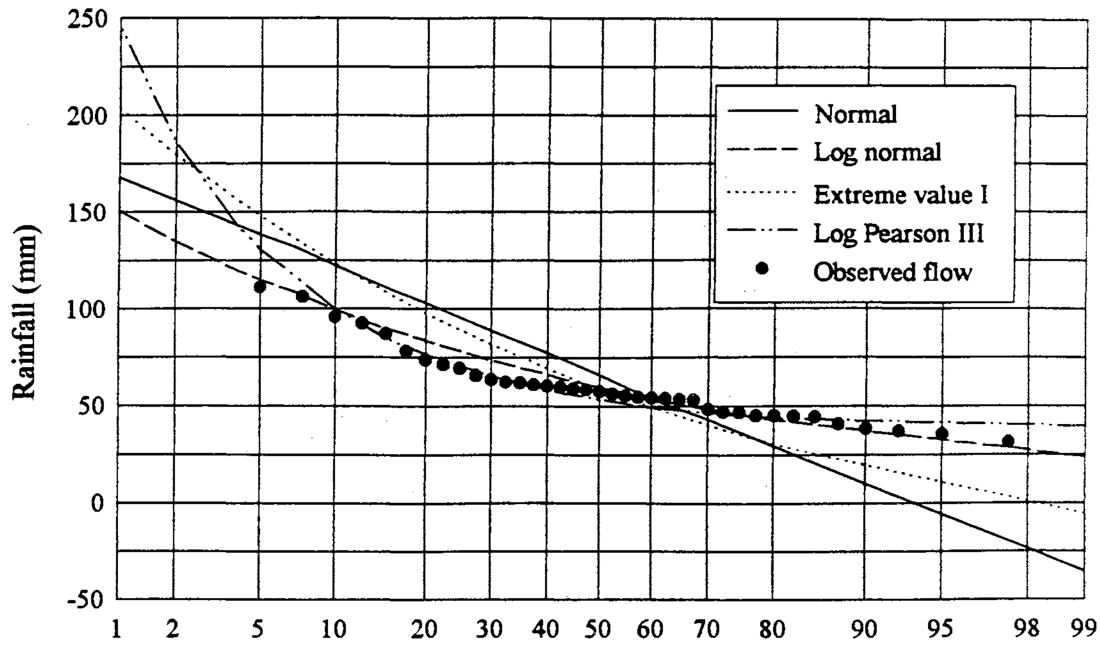
Fig. A44 : Observed and fitted distributions for stations (a) Sena1, (b) Sere1

Table A89 : Fitted and observed rainfalls, Station Sesheke 1

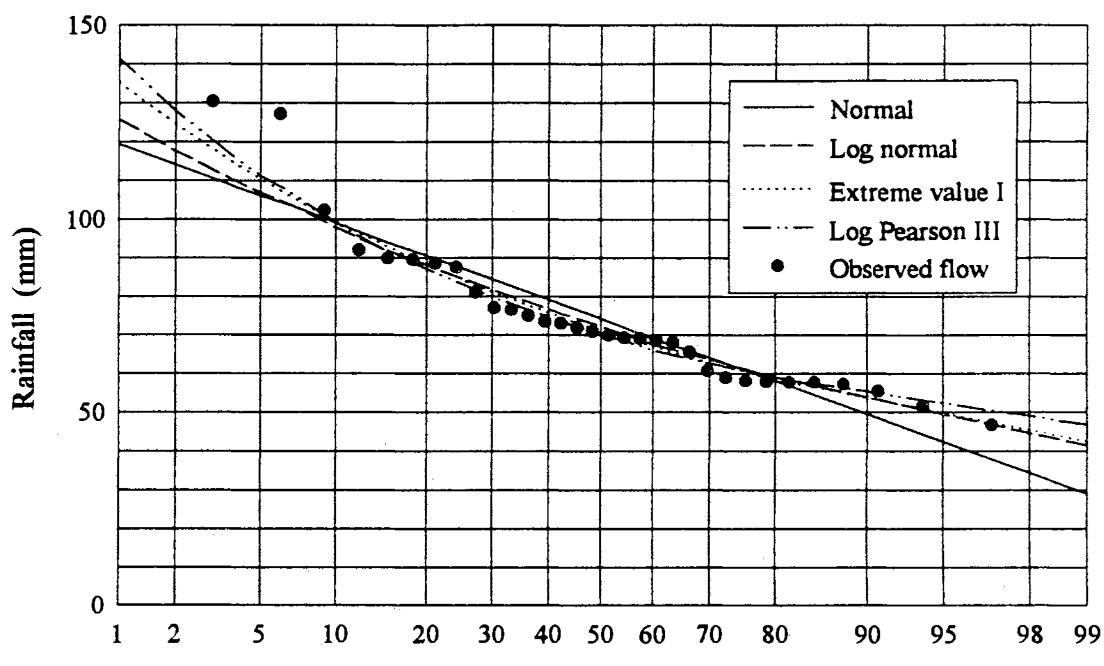
Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-35.33	23.94	-5.32	39.70	97.50	31.50
80.00	29.70	43.09	30.53	44.08	95.00	35.60
70.00	43.25	48.71	40.42	46.68	92.50	37.10
60.00	54.19	53.77	49.73	49.51	90.00	38.40
50.00	66.43	60.07	59.25	53.70	87.50	40.80
43.00	74.30	64.50	66.39	57.09	85.00	44.50
30.00	89.17	73.77	81.90	65.50	82.50	44.70
20.00	103.16	83.72	97.89	76.67	80.00	45.00
15.00	111.03	89.90	108.70	84.86	77.50	45.20
10.00	122.40	99.63	123.48	100.00	75.00	46.70
7.00	132.02	108.68	136.19	116.89	72.50	47.20
5.00	138.37	115.09	148.02	130.74	70.00	48.50
4.00	142.96	119.97	155.81	142.43	67.50	53.10
2.00	156.08	135.07	179.79	186.07	65.00	53.30
1.00	168.19	150.71	203.60	245.61	62.50	54.10
0.20	192.37	187.53	258.61	470.37	60.00	54.40
0.10	201.55	203.76	282.26	623.80	57.50	54.90
					55.00	55.50
					52.50	56.50
					50.00	57.70
					47.50	58.60
					45.00	59.20
					42.50	60.20
					40.00	60.50
					37.50	61.00
					35.00	62.00
					32.50	62.50
					30.00	63.70
					27.50	65.80
					25.00	69.40
					22.50	71.40
					20.00	73.70
					17.50	78.00
					15.00	87.20
					12.50	92.30
					10.00	95.80
					7.50	106.20
					5.00	111.00
					2.50	307.60

Table A90 : Fitted and observed rainfalls, Station Solwezi 1

Prob	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	29.25	41.45	42.55	46.78	96.97	46.70
80.00	58.06	59.10	58.43	58.91	93.94	51.60
70.00	64.07	63.64	62.81	62.61	90.91	55.40
60.00	68.91	67.55	66.94	66.00	87.88	57.20
50.00	74.34	72.21	71.16	70.28	84.85	57.70
43.00	77.83	75.38	74.32	73.35	81.82	57.80
30.00	84.41	81.75	81.19	79.90	78.79	57.90
20.00	90.61	88.23	88.28	87.13	75.76	58.00
15.00	94.10	92.10	93.07	91.72	72.73	58.90
10.00	99.14	97.99	99.61	99.12	69.70	60.70
7.00	103.40	103.27	105.25	106.21	66.67	65.50
5.00	106.21	106.91	110.49	111.33	63.64	68.10
4.00	108.24	109.62	113.94	115.30	60.61	68.60
2.00	114.06	117.75	124.56	127.93	57.58	69.00
1.00	119.42	125.79	135.11	141.58	54.55	69.20
0.20	130.14	143.53	159.49	176.12	51.52	69.80
0.10	134.21	150.90	169.96	192.44	48.48	70.90
					45.45	71.90
					42.42	73.10
					39.39	73.50
					36.36	75.00
					33.33	76.60
					30.30	77.00
					27.27	81.10
					24.24	87.60
					21.21	88.50
					18.18	89.60
					15.15	89.90
					12.12	92.00
					9.09	102.40
					6.06	127.20
					3.03	130.40



(a)



(b)

Fig. A45 : Observed and fitted distributions for stations (a) Seshe1, (b) Solw1

Table A91 : Fitted and observed rainfalls, Station Zambezi 1

Prob.	Nor	Ln	Ev	Lp3	Plotting positions	Rainfall
99.00	-322.35	18.33	-199.17	46.01	97.50	36.80
80.00	-55.44	42.54	-52.04	50.21	95.00	38.60
70.00	0.20	50.71	-11.42	51.01	92.50	39.40
60.00	45.08	58.42	26.80	52.53	90.00	39.90
50.00	95.34	68.46	65.86	55.66	87.50	42.00
43.00	127.64	75.80	95.18	58.79	85.00	43.20
30.00	188.67	91.90	158.84	68.26	82.50	43.90
20.00	246.11	110.16	224.48	83.88	80.00	45.20
15.00	278.42	121.98	268.85	97.31	77.50	46.70
10.00	325.09	141.33	329.51	126.32	75.00	47.20
7.00	364.58	160.08	381.68	165.13	72.50	49.80
5.00	390.60	173.79	430.25	202.13	70.00	50.80
4.00	409.45	184.43	462.20	237.17	67.50	51.60
2.00	463.30	218.59	560.64	400.13	65.00	54.80
1.00	513.02	255.71	658.36	712.22	62.50	55.00
0.20	612.28	349.76	884.17	3040.49	60.00	57.10
0.10	649.97	393.93	981.24	5918.13	57.50	60.70
					55.00	61.50
					52.50	63.00
					50.00	64.50
					47.50	67.00
					45.00	68.60
					42.50	73.40
					40.00	74.90
					37.50	75.60
					35.00	76.50
					32.50	78.20
					30.00	78.20
					27.50	78.40
					25.00	86.40
					22.50	88.70
					20.00	95.00
					17.50	95.80
					15.00	97.30
					12.50	98.00
					10.00	98.80
					7.50	105.40
					5.00	110.20
					2.50	1180.00

Station : Zambel

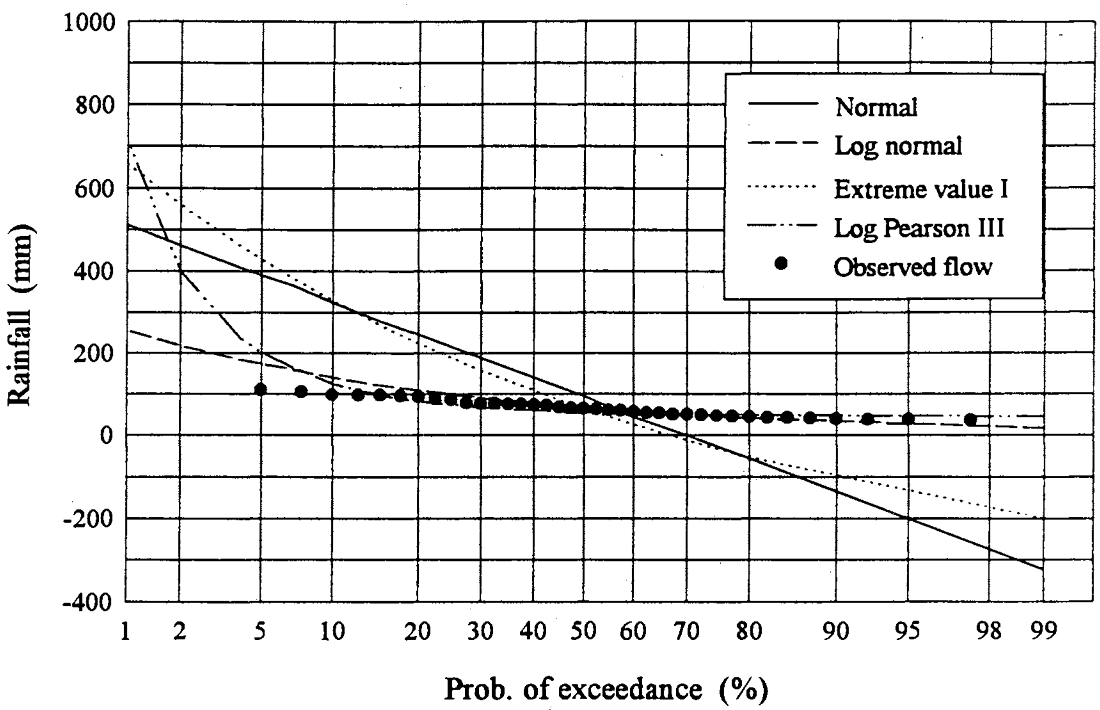


Fig. A46 : Observed and fitted distributions for station Zambel

APPENDIX B

Figs. B1 to B18 : Residual Analysis

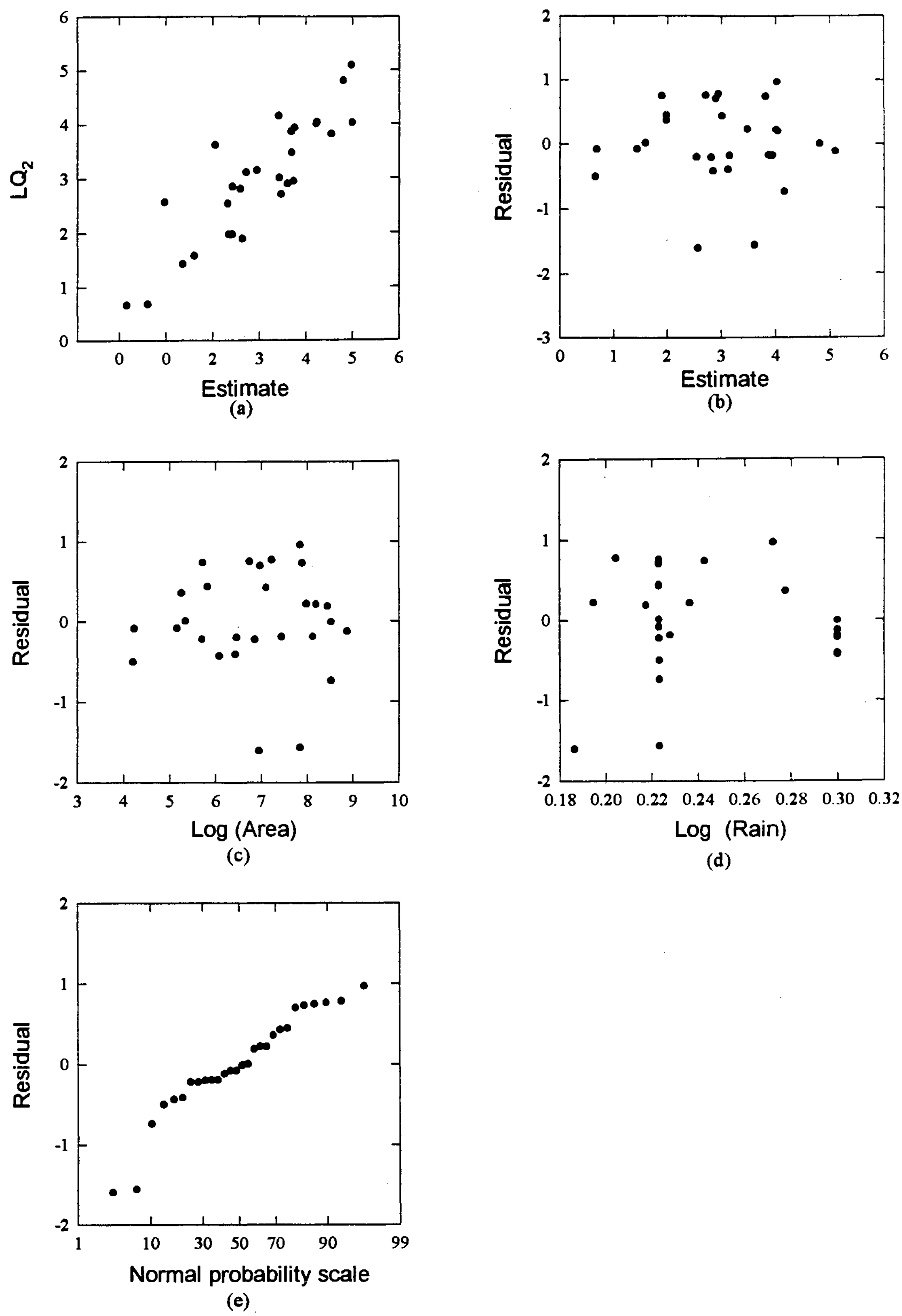


Fig. B1 : Residual Analysis for Q_2 in Region 1

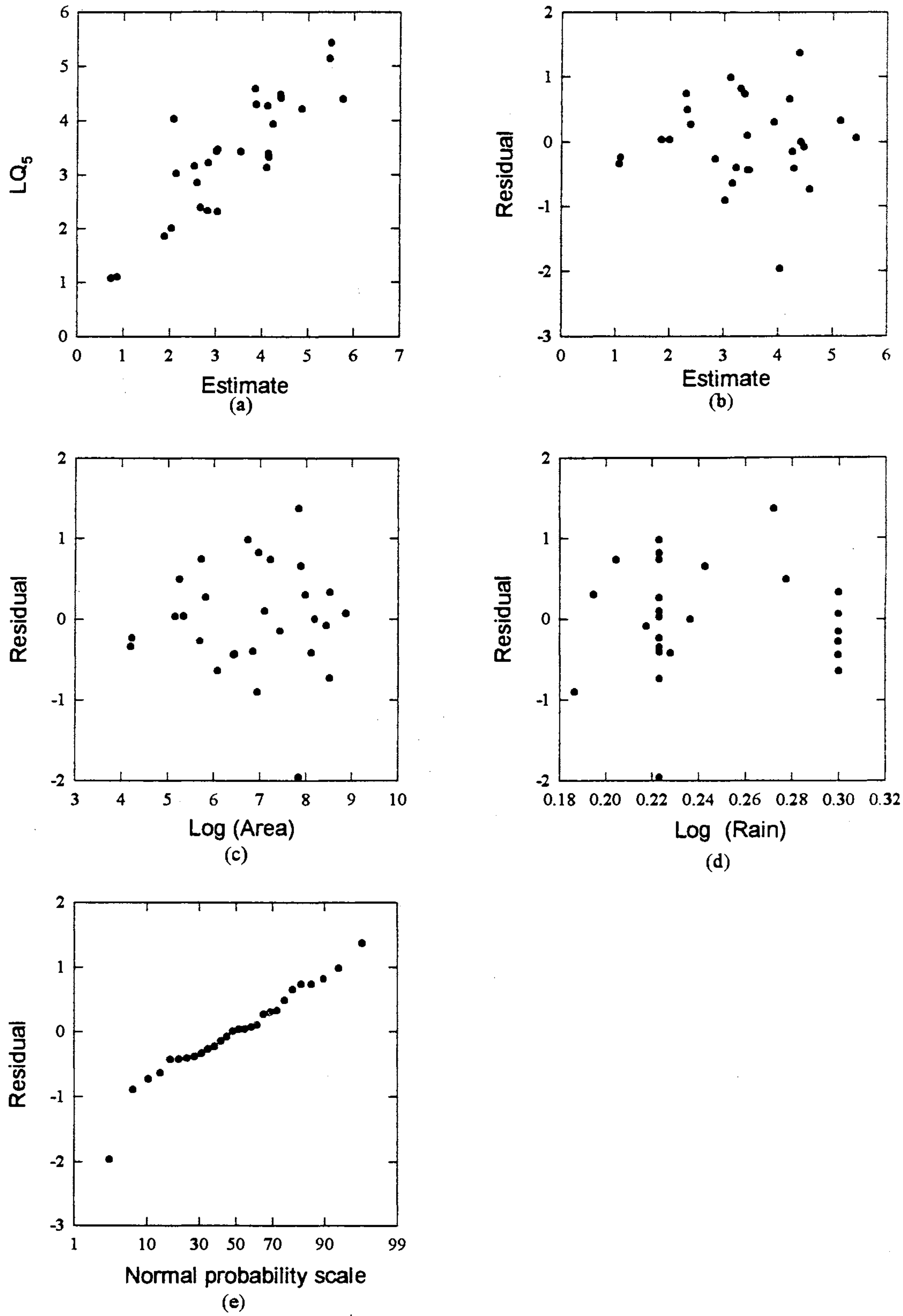


Fig. B2 : Residual Analysis for Q_5 in Region 1

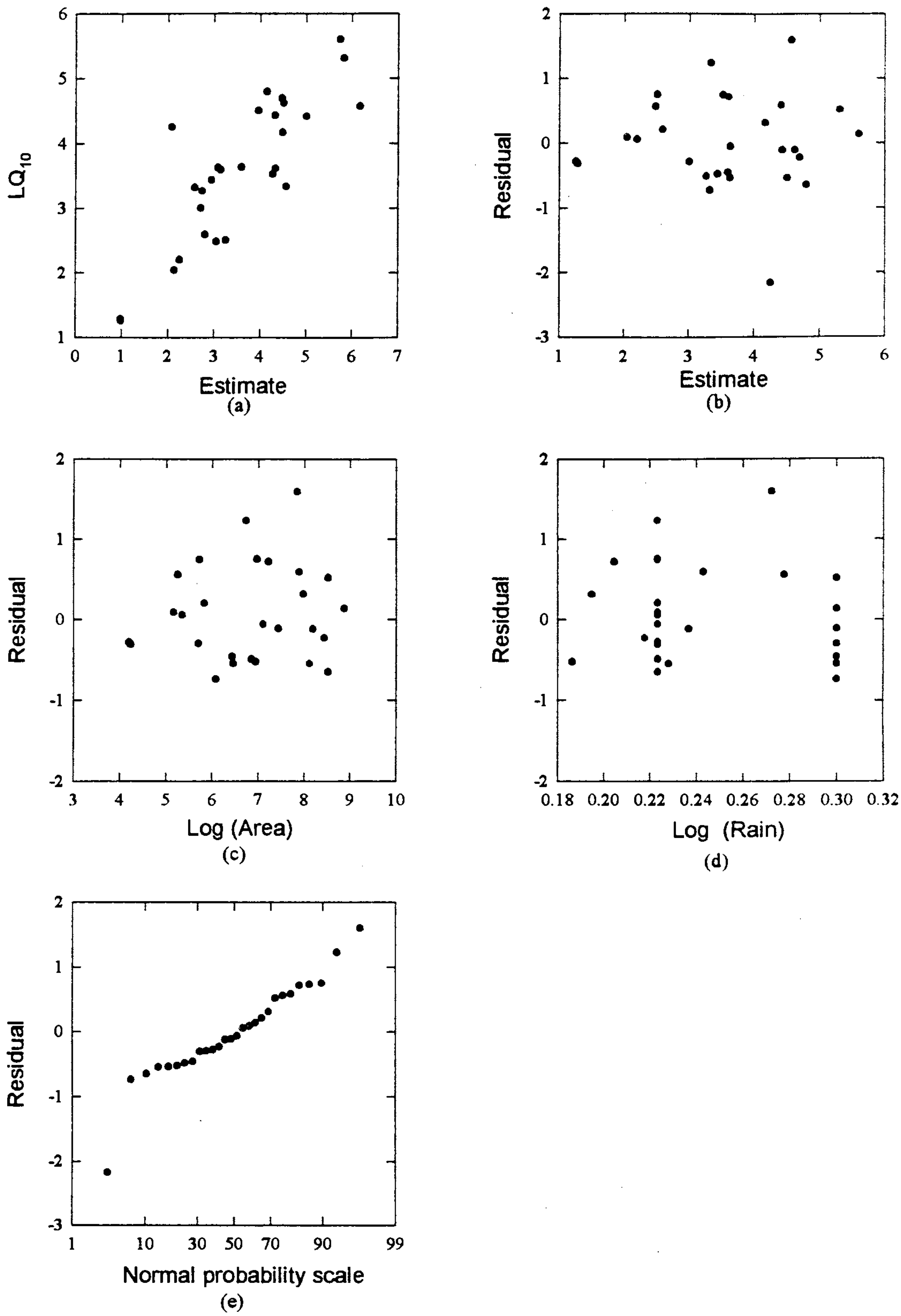


Fig. B3 : Residual Analysis for Q_{10} in Region 1

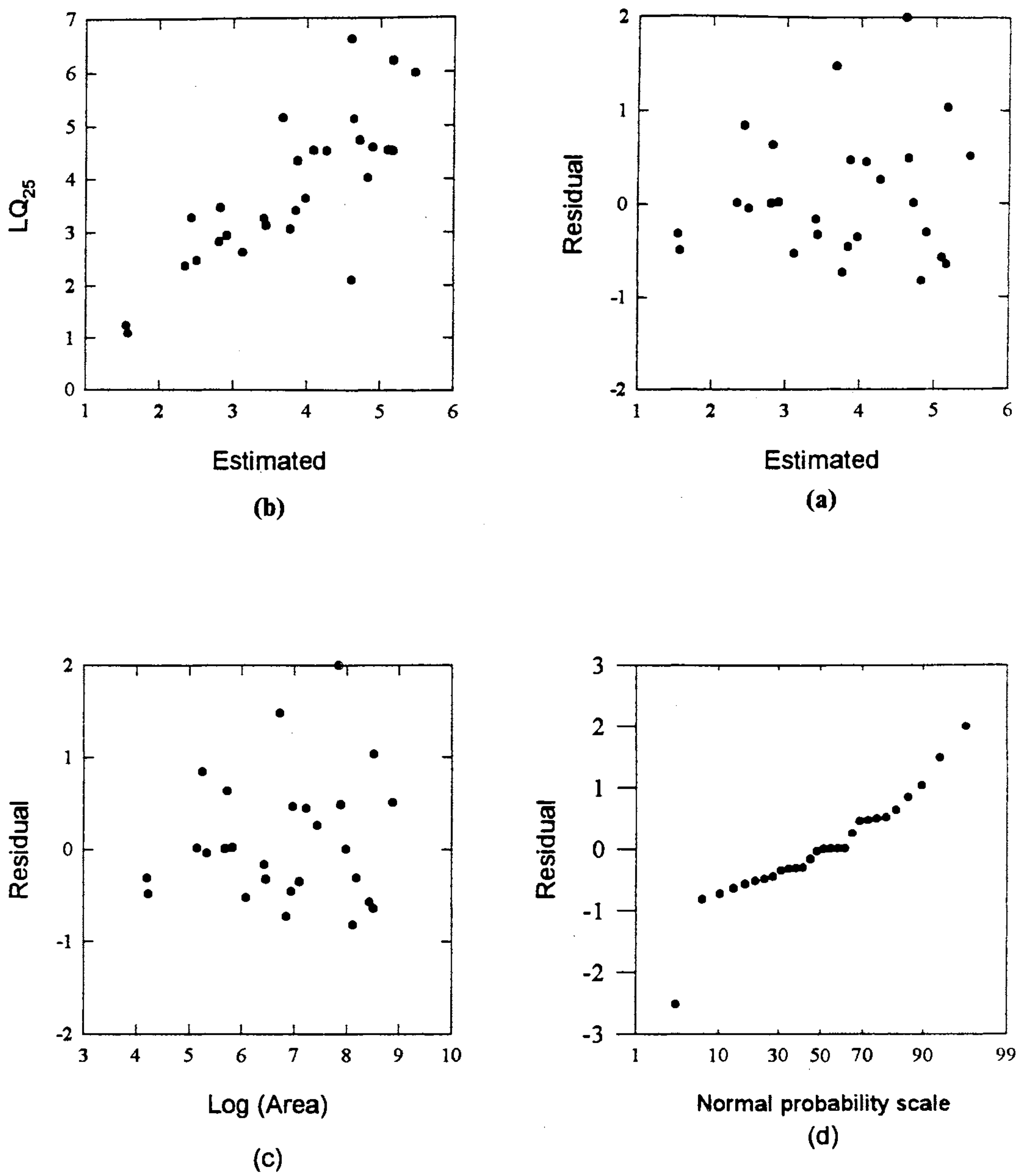


Fig. B4 : Residual Analysis for Q_{25} in Region 1

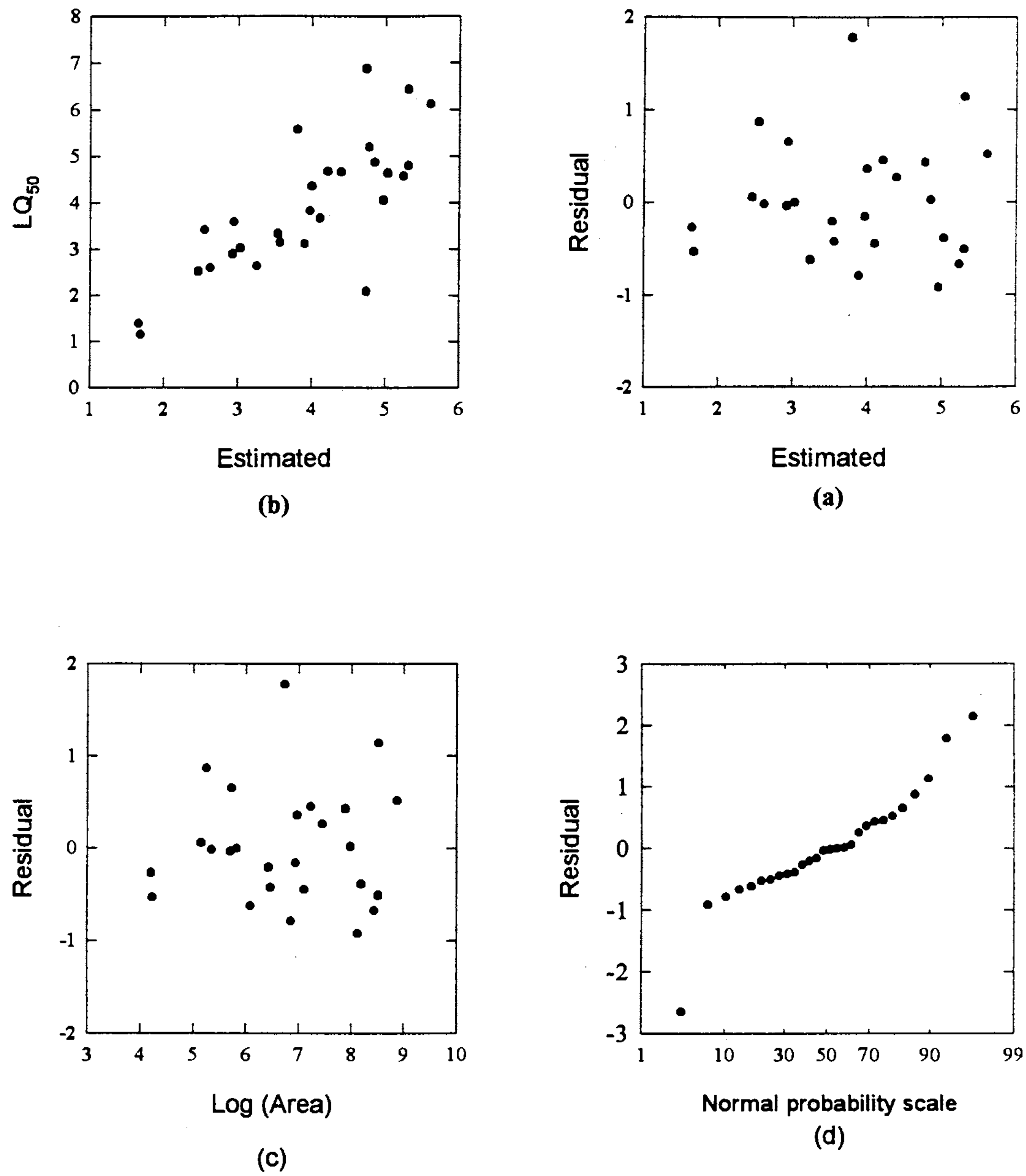


Fig. B5 : Residual Analysis for Q_{50} in Region 1

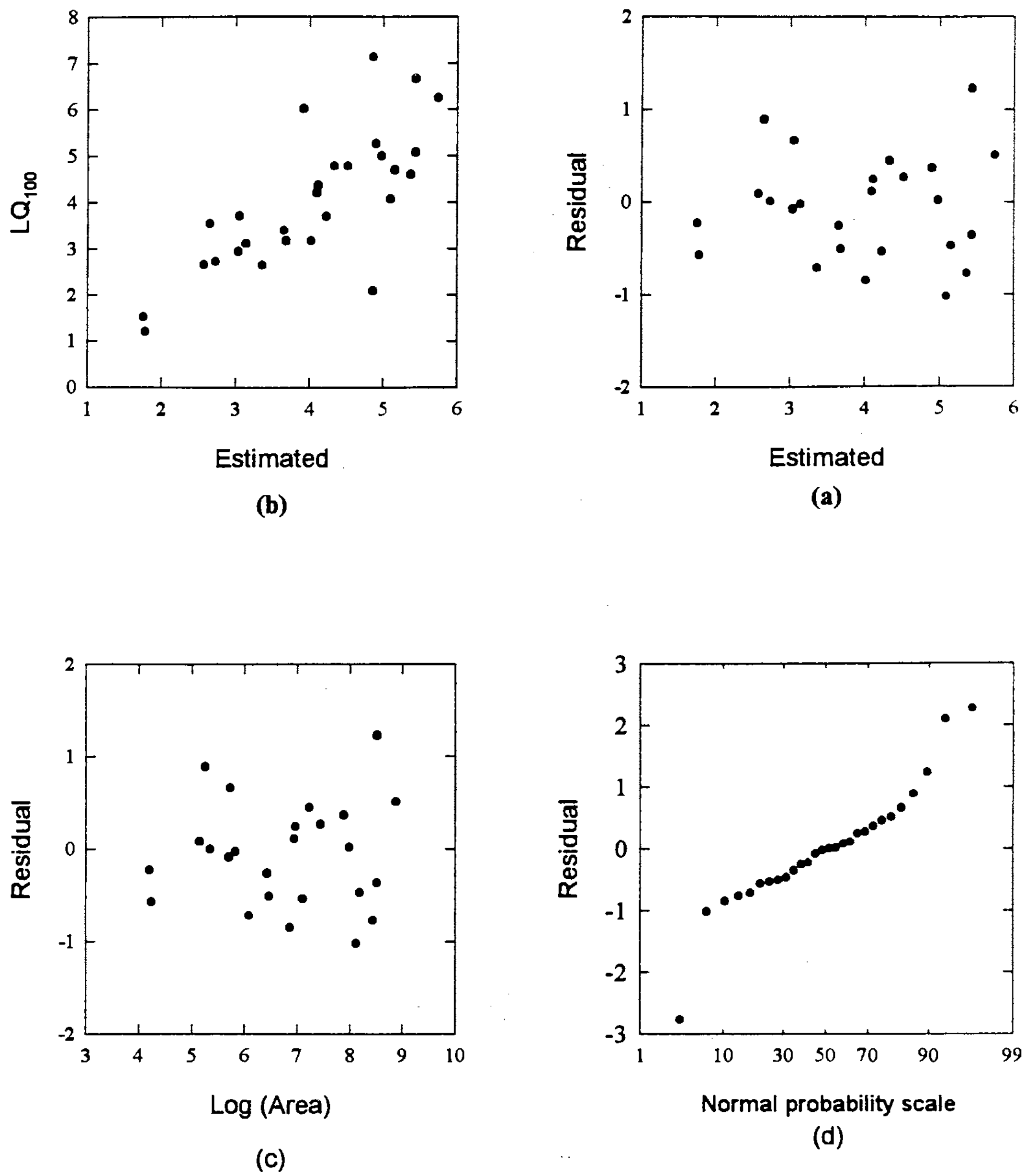


Fig. B6 : Residual Analysis for Q_{100} in Region 1

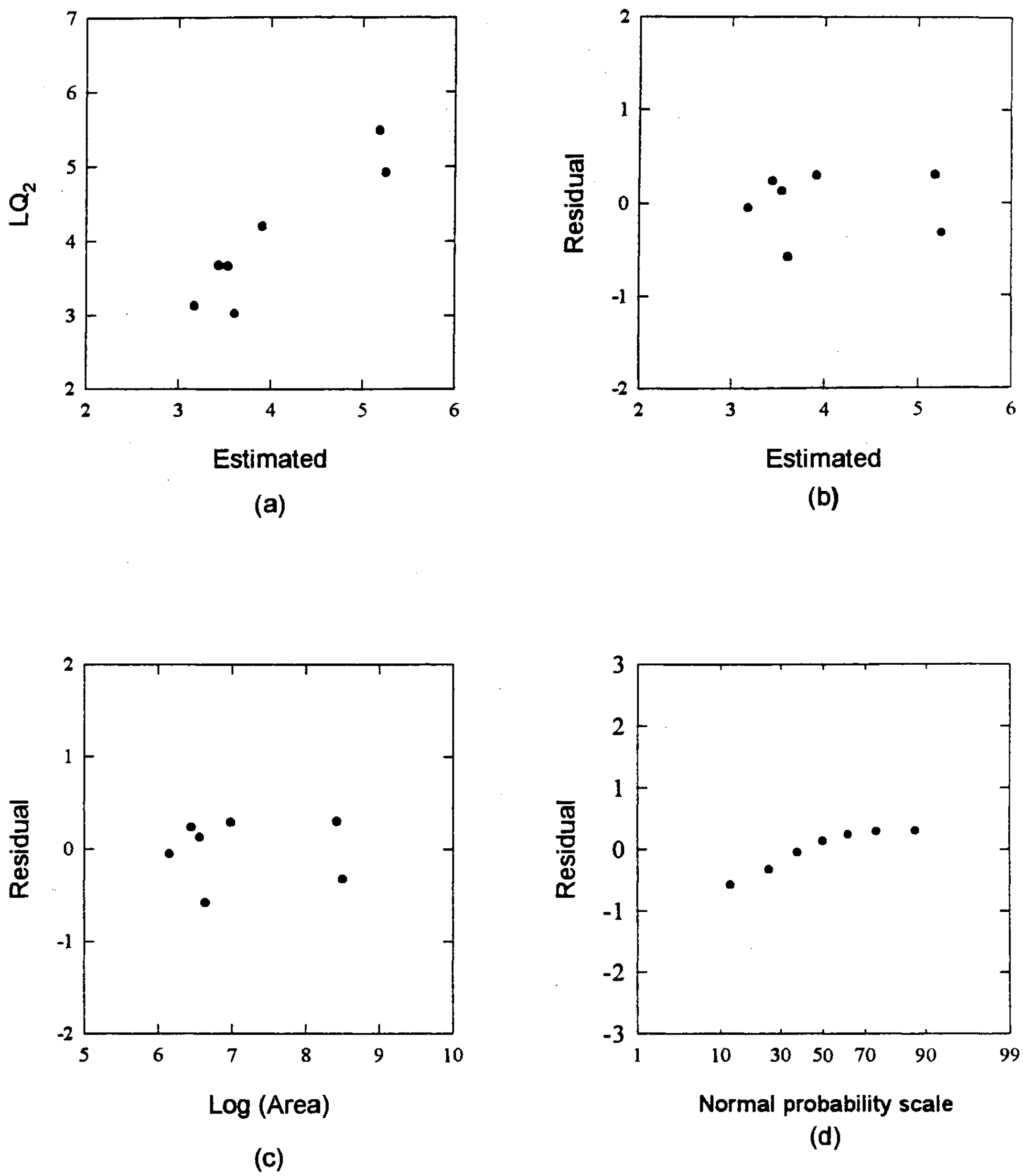


Fig. B7 : Residual Analysis for Q_2 in Region 3

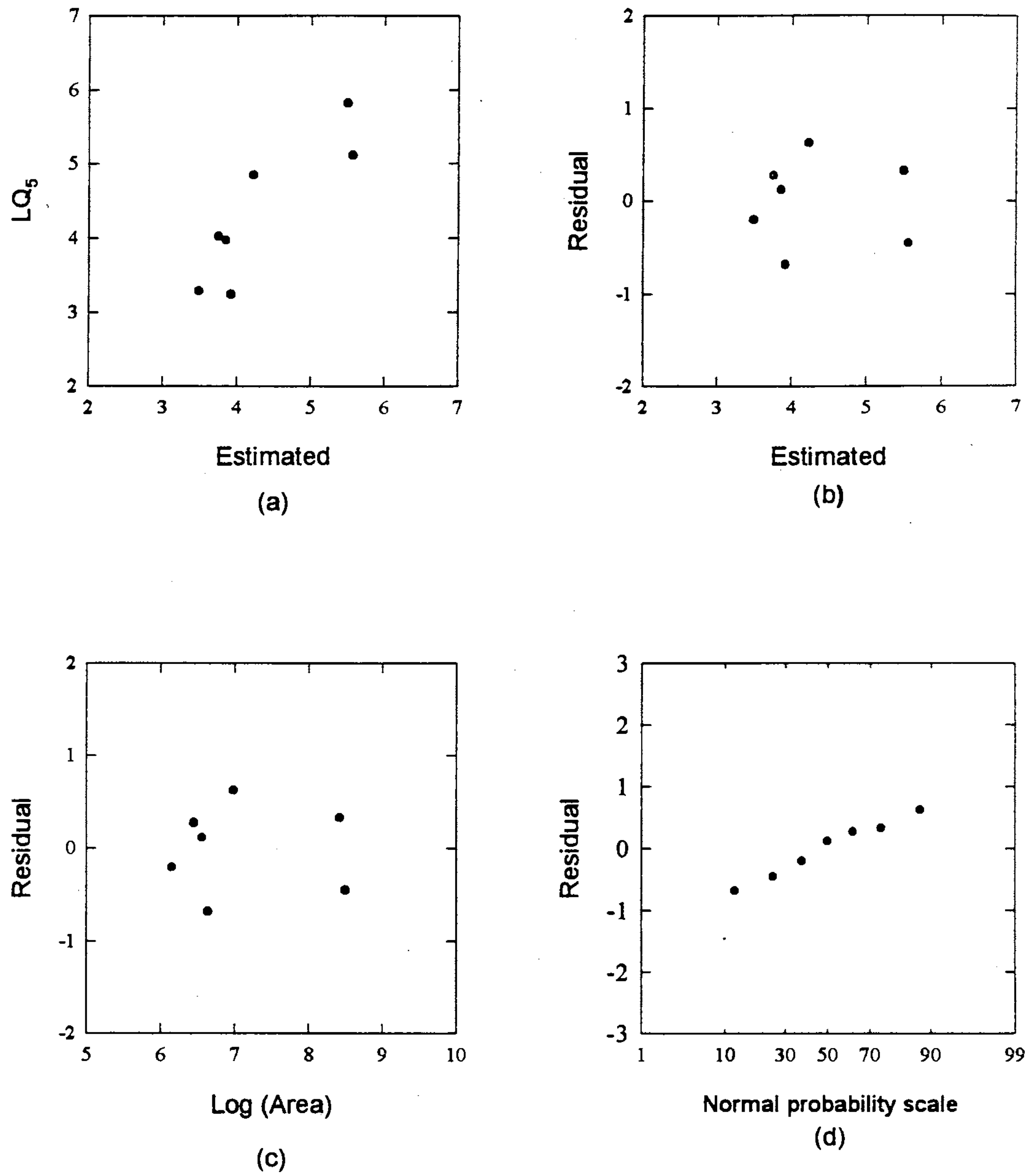


Fig. B8 : Residual Analysis for Q_5 in Region 3

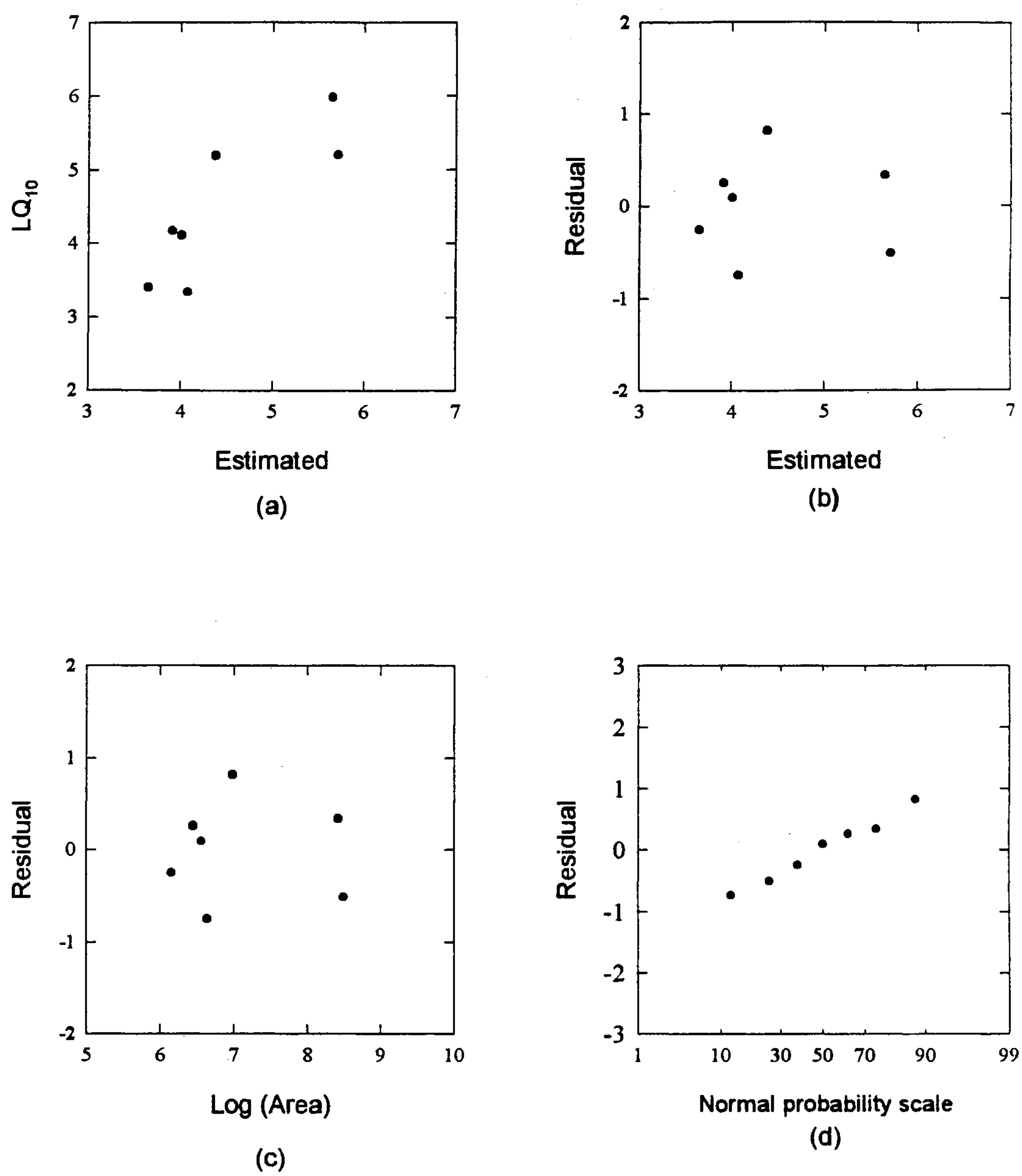


Fig. B9 : Residual Analysis for Q_{10} in Region 3

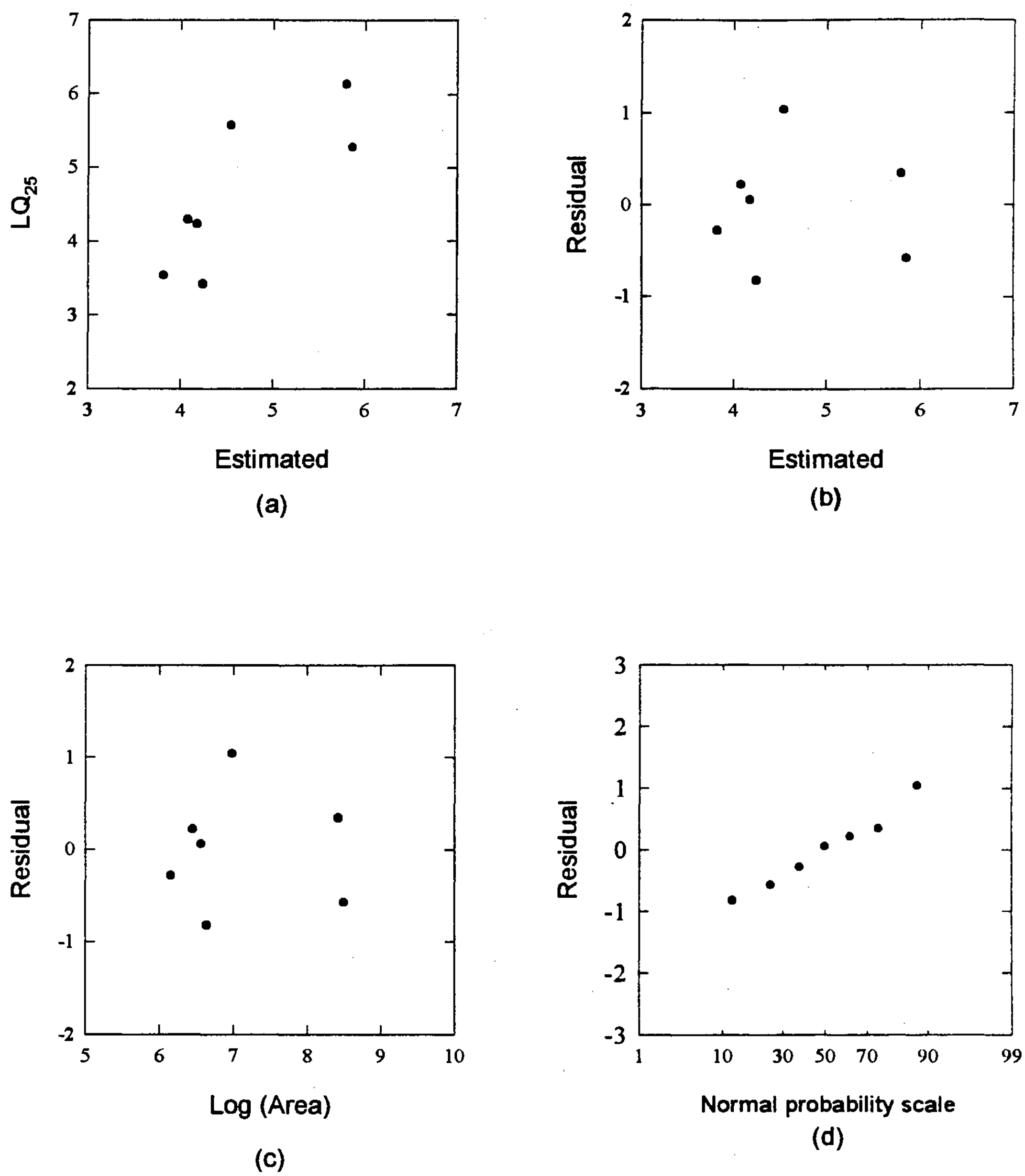


Fig. B10 : Residual Analysis for Q_{25} in Region 3

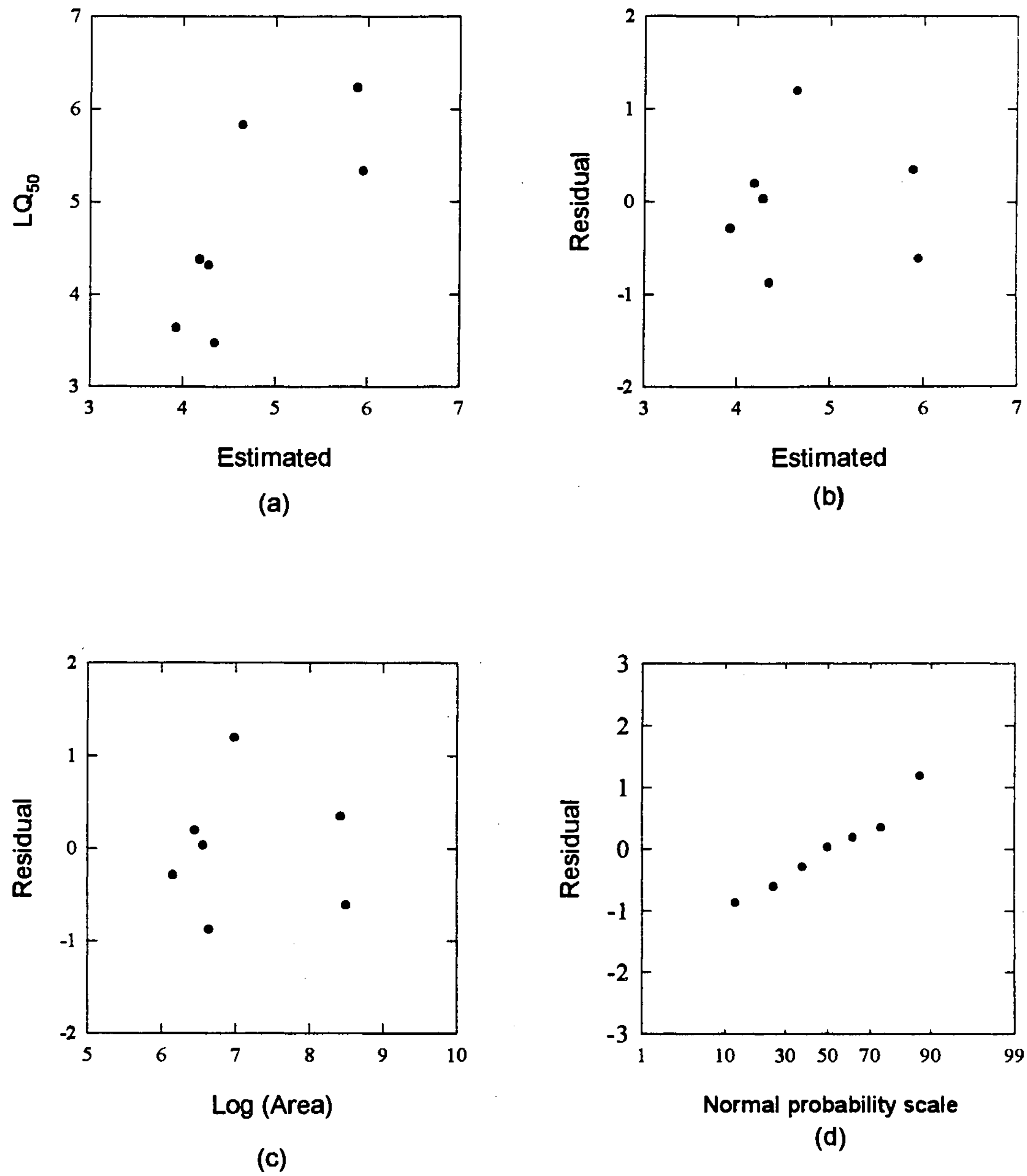


Fig. B11 : Residual Analysis for Q_{50} in Region 3

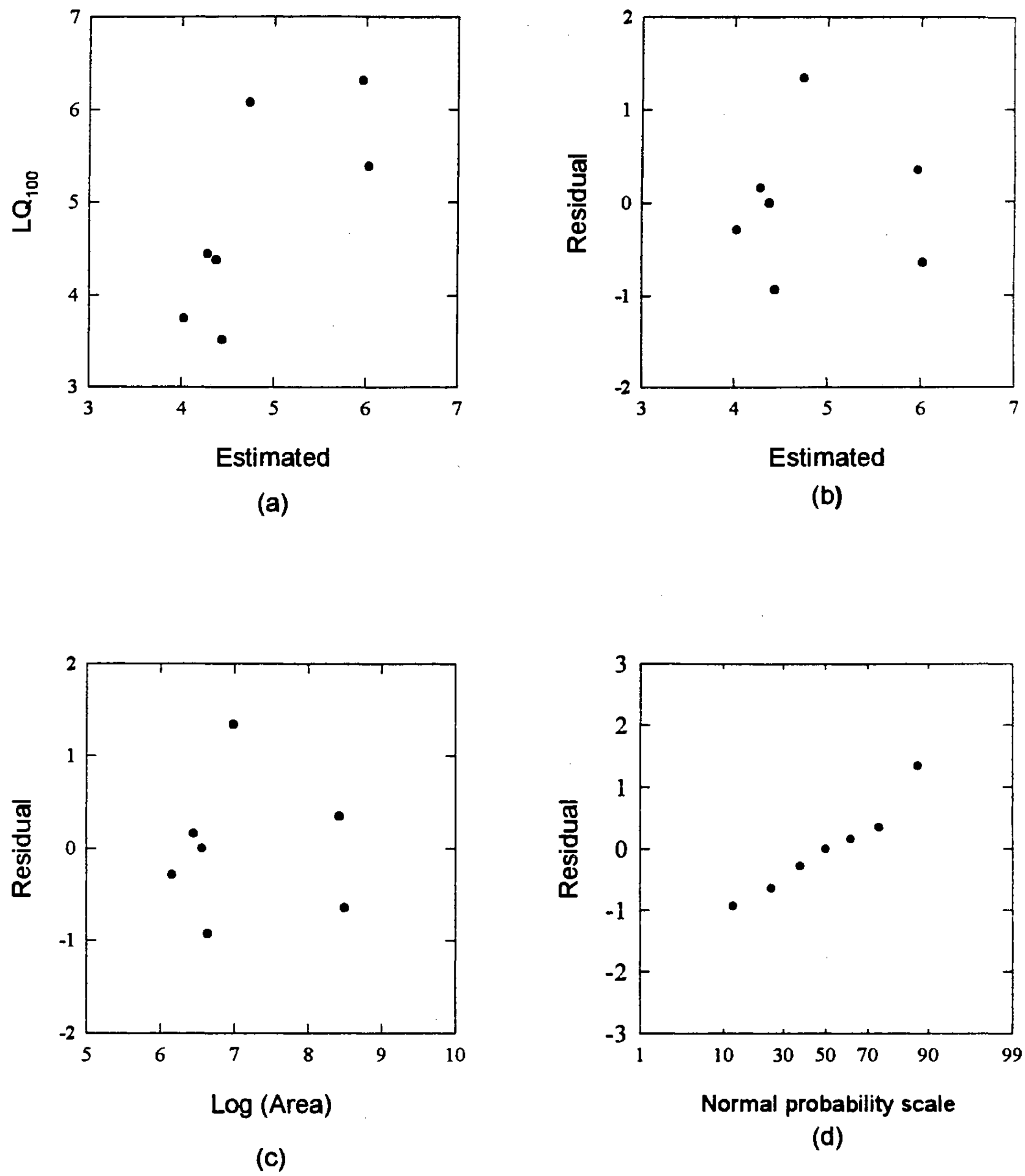


Fig. B12 : Residual Analysis for Q_{100} in Region 3

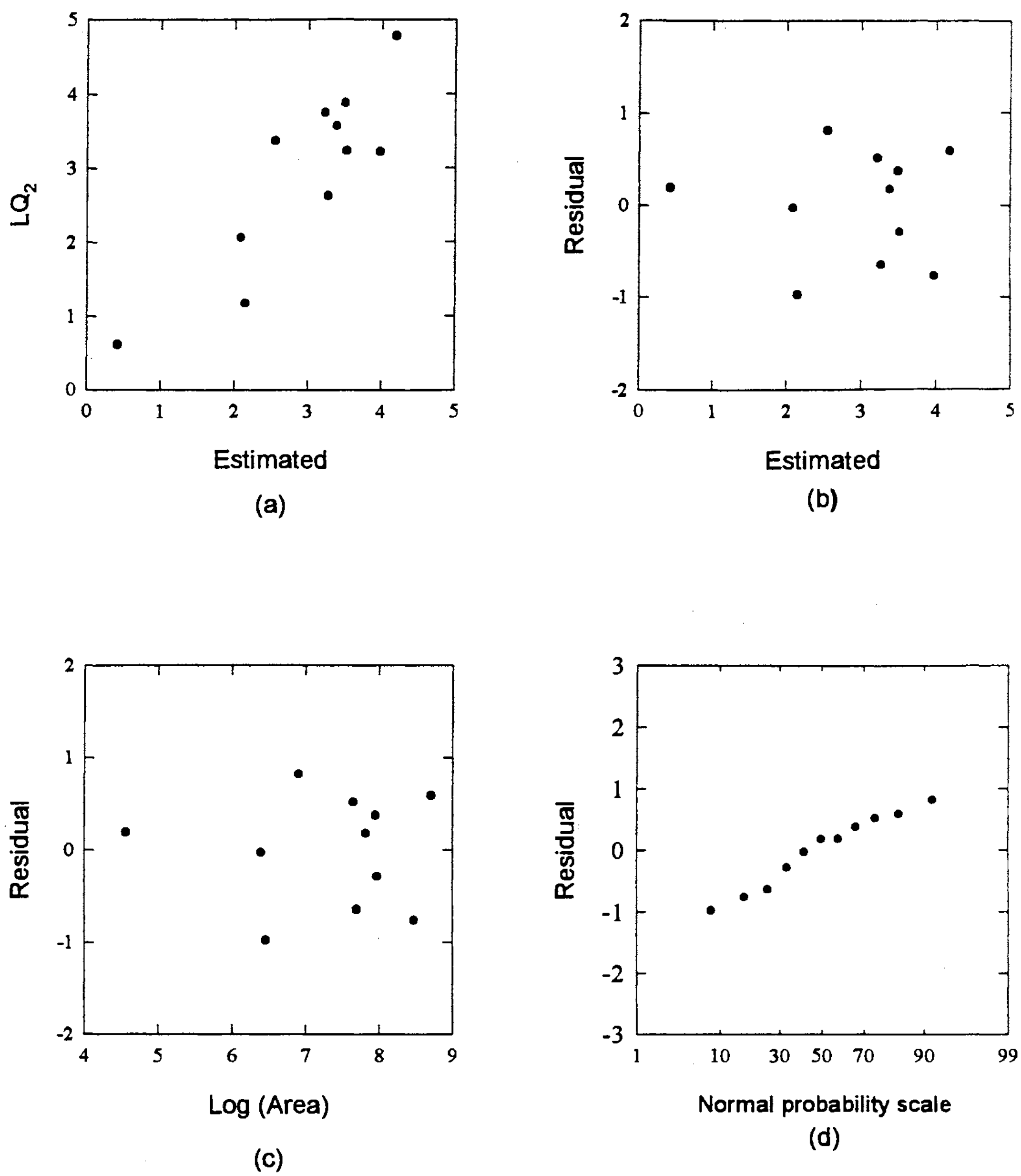


Fig. B13 : Residual Analysis for Q_2 in Region 4

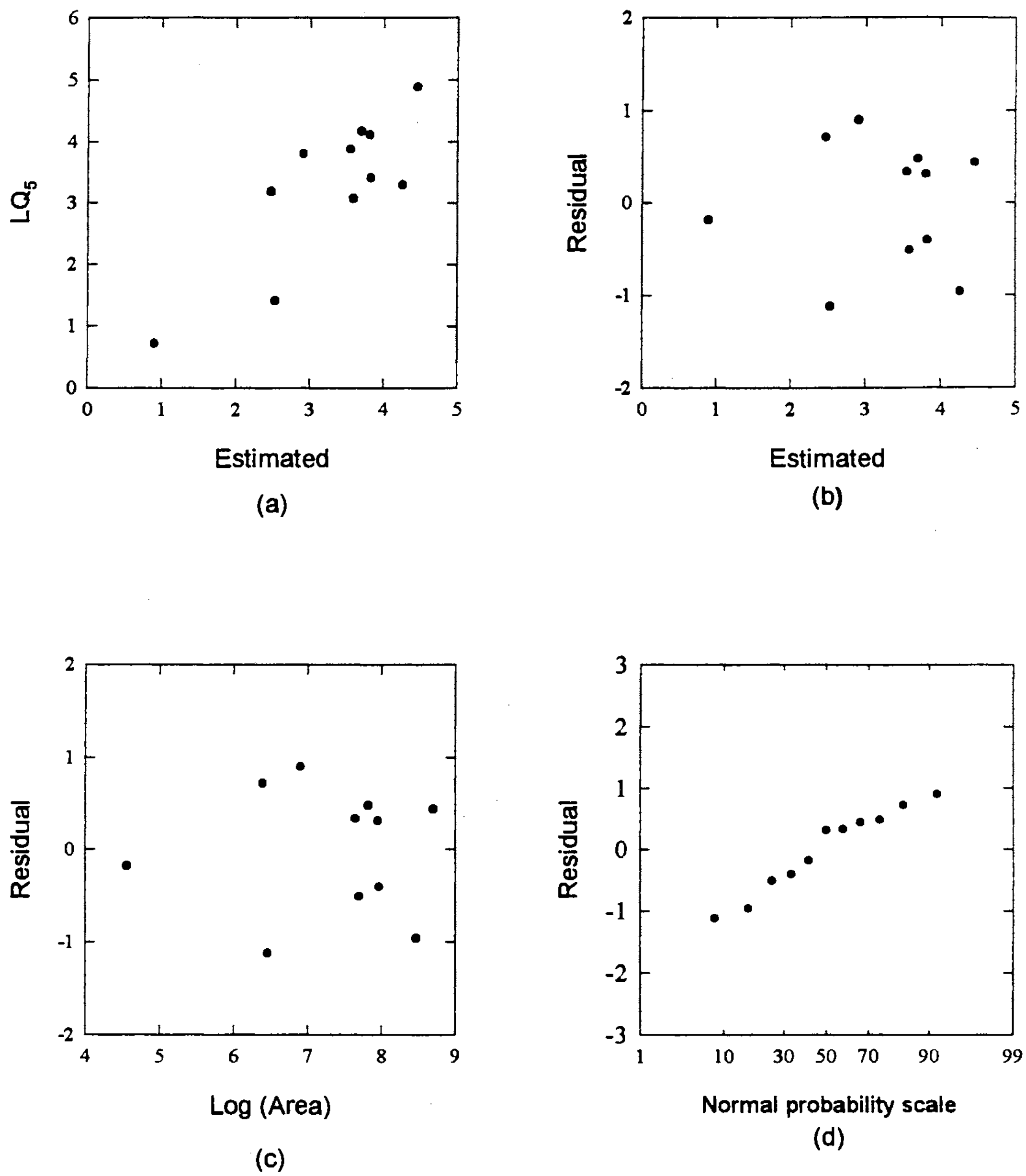


Fig. B14 : Residual Analysis for Q_5 in Region 4

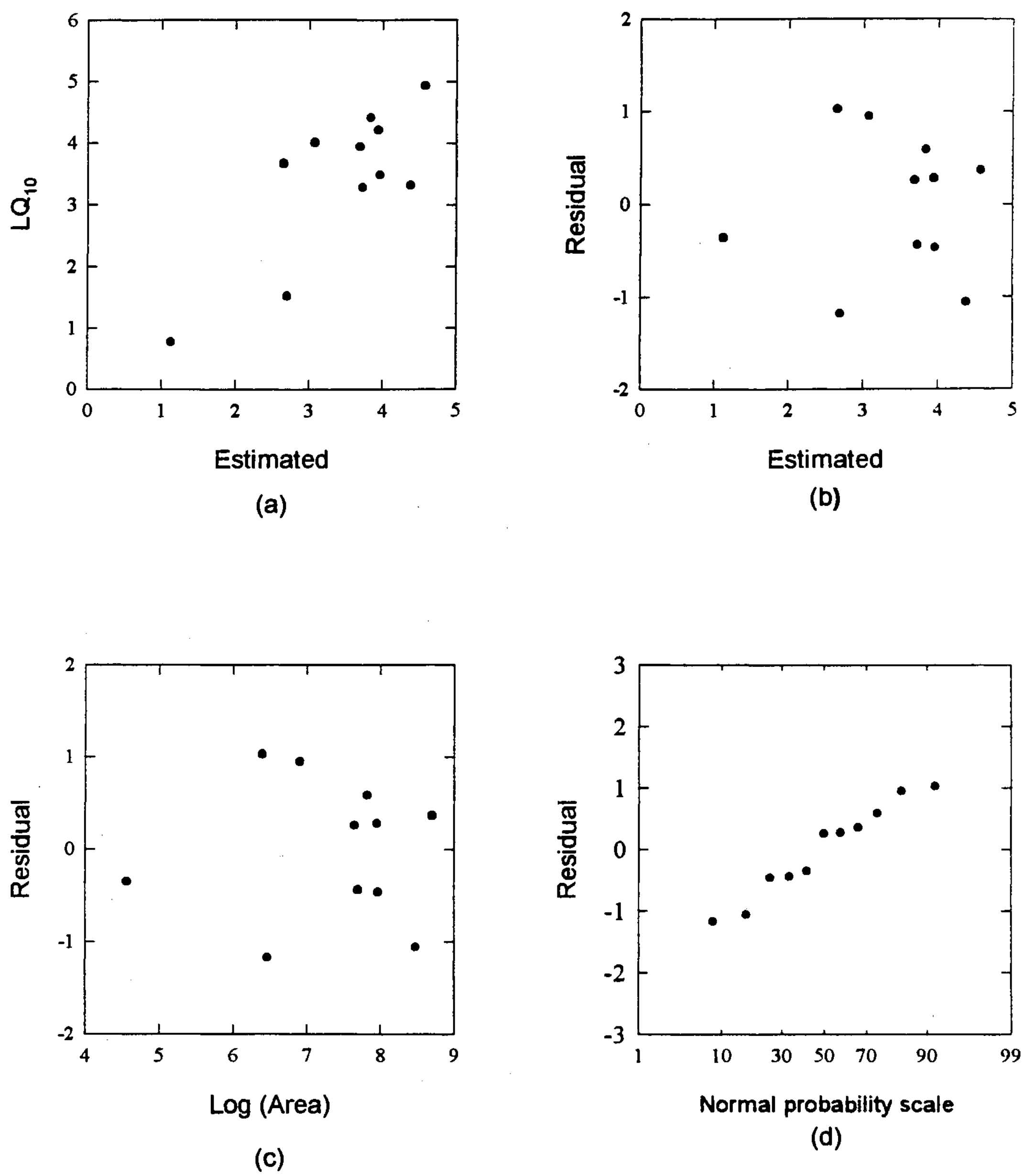


Fig. B15 : Residual Analysis for Q_{10} in Region 4

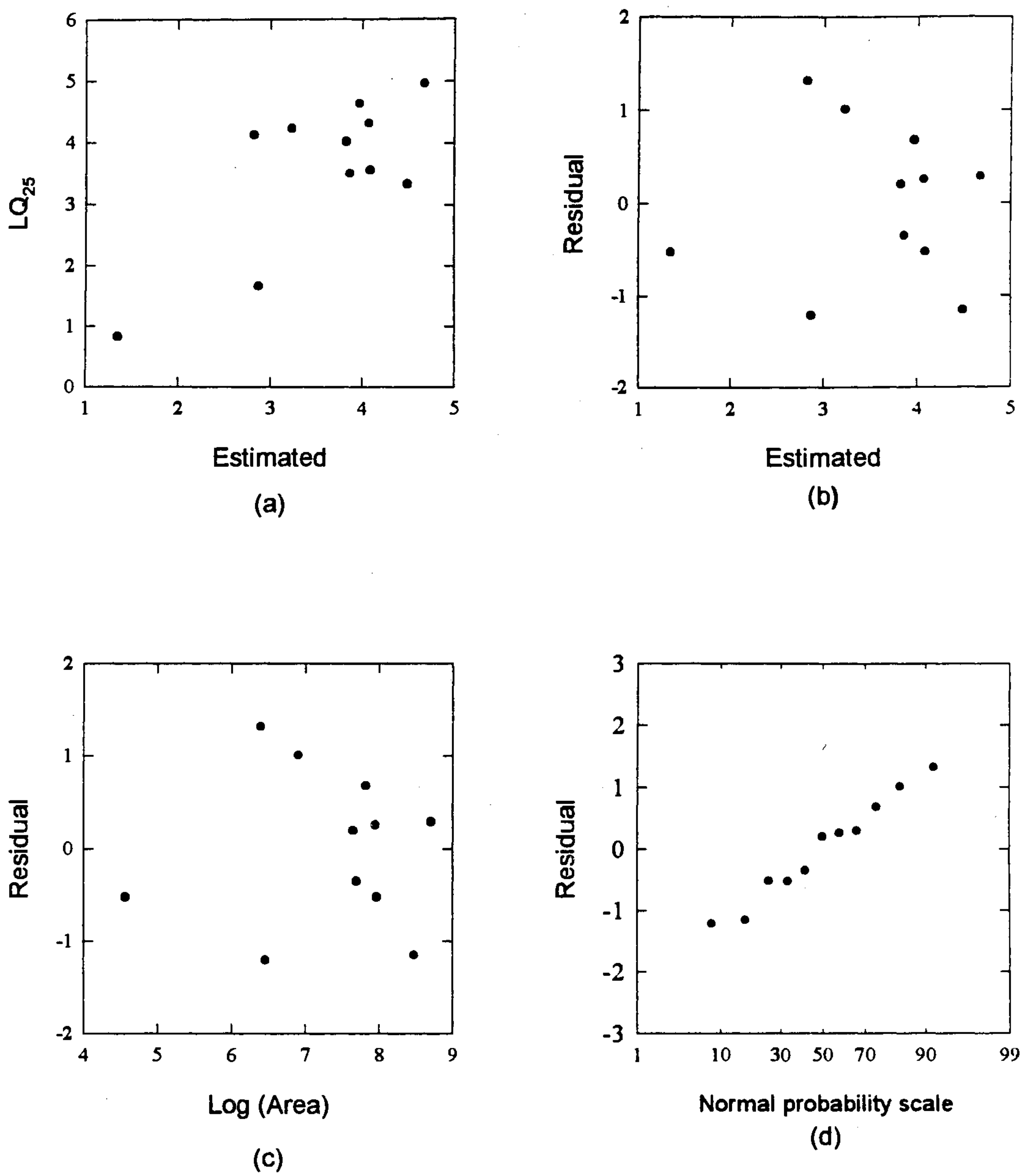


Fig. B16: Residual Analysis for Q_{25} in Region 4

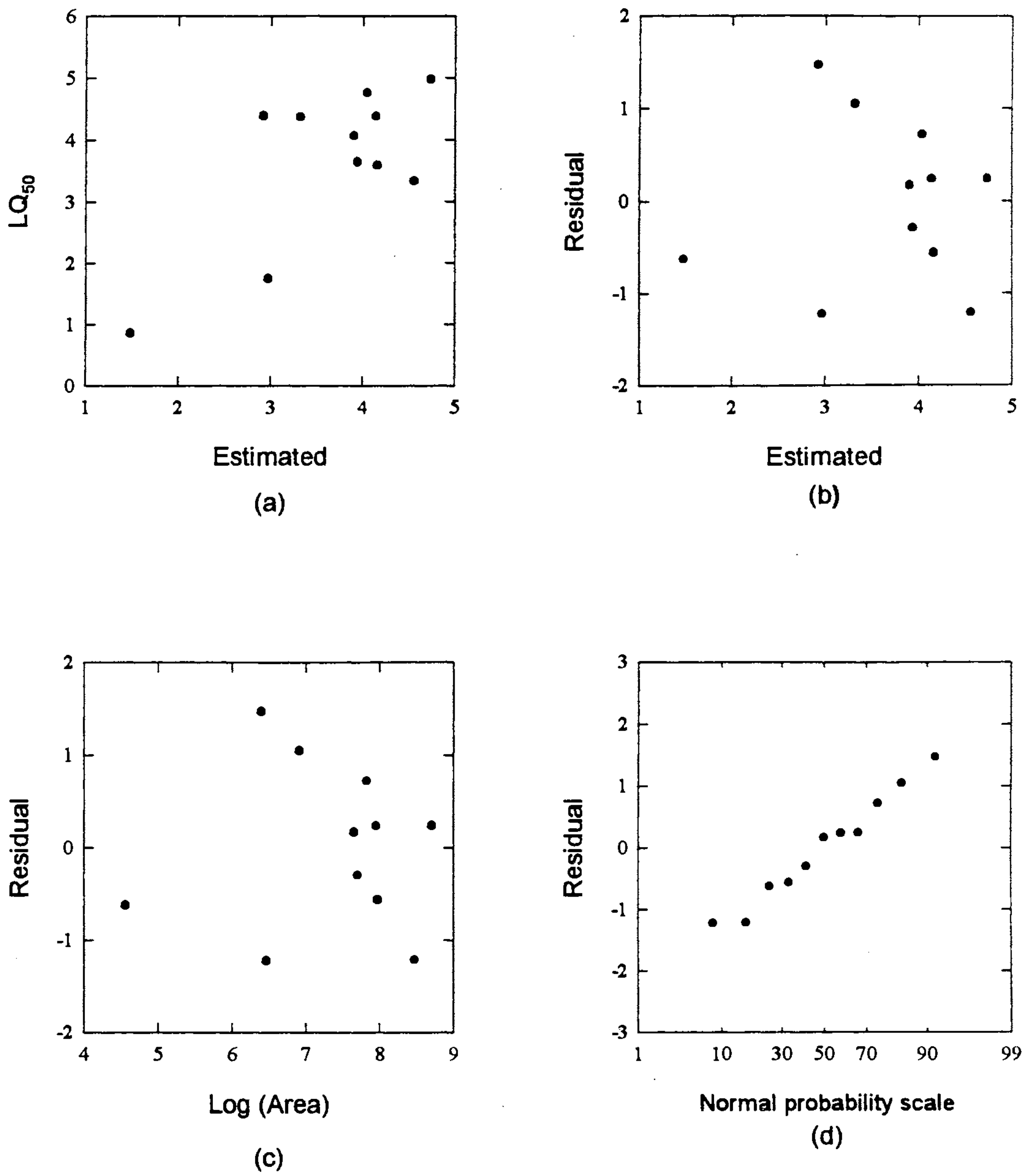


Fig. B17 : Residual Analysis for Q_{50} in Region 4

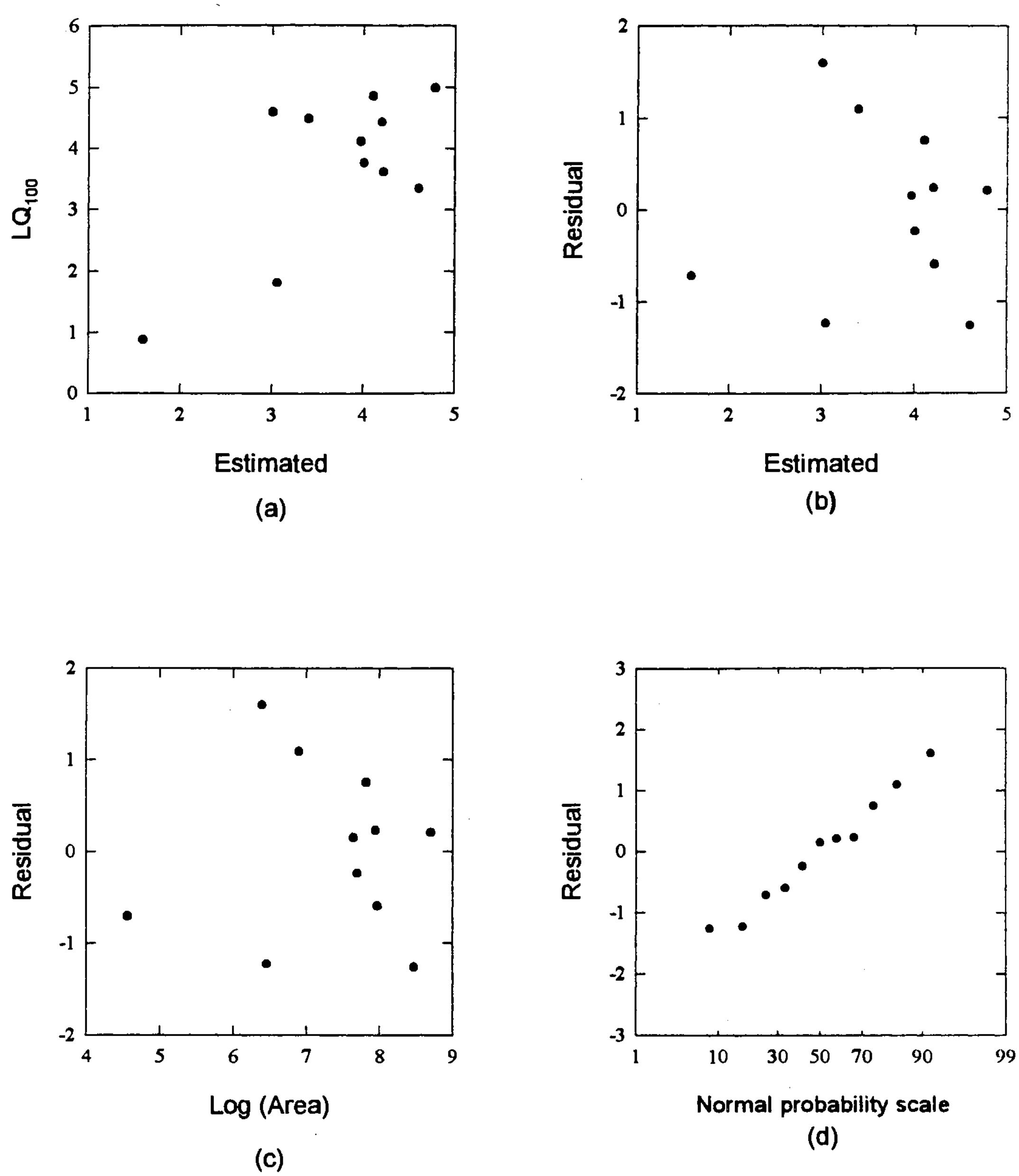


Fig. B18 : Residual Analysis for Q_{100} in Region 4

APPENDIX C

Figs. C1 to C4 : **Dimensionless regional frequency curves for Regions 1, 2, 3 and 4**

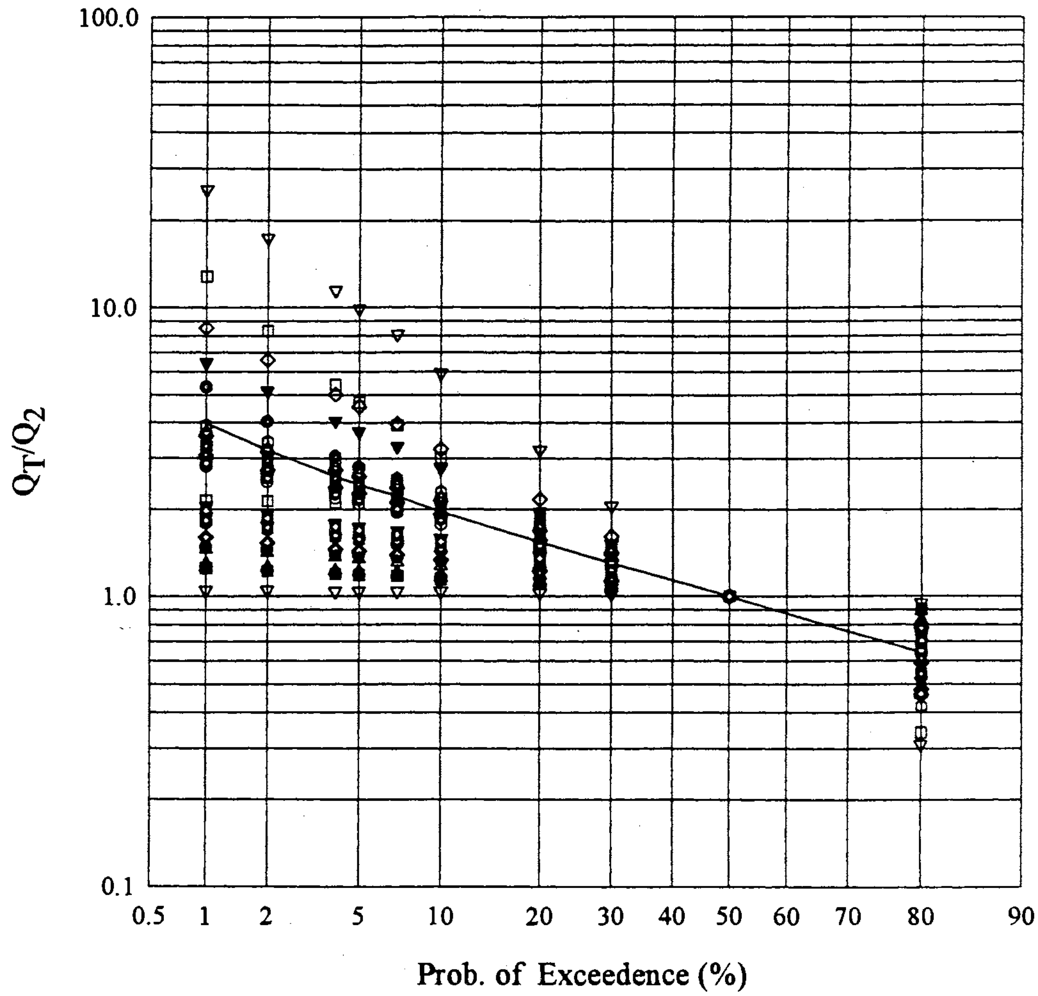


Fig. C1 : Dimensionless regional frequency curve (Region 1)

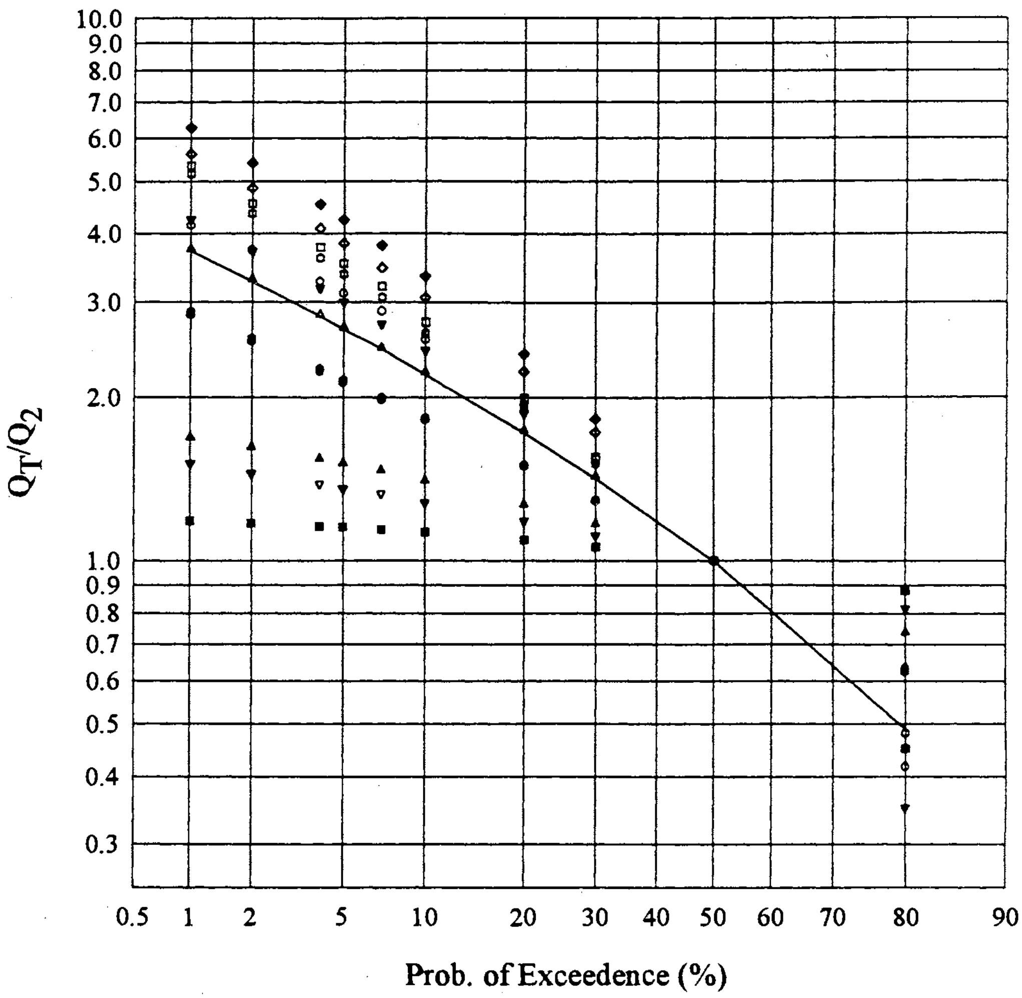


Fig. C2 : Dimensionless regional frequency curve (Region 2)

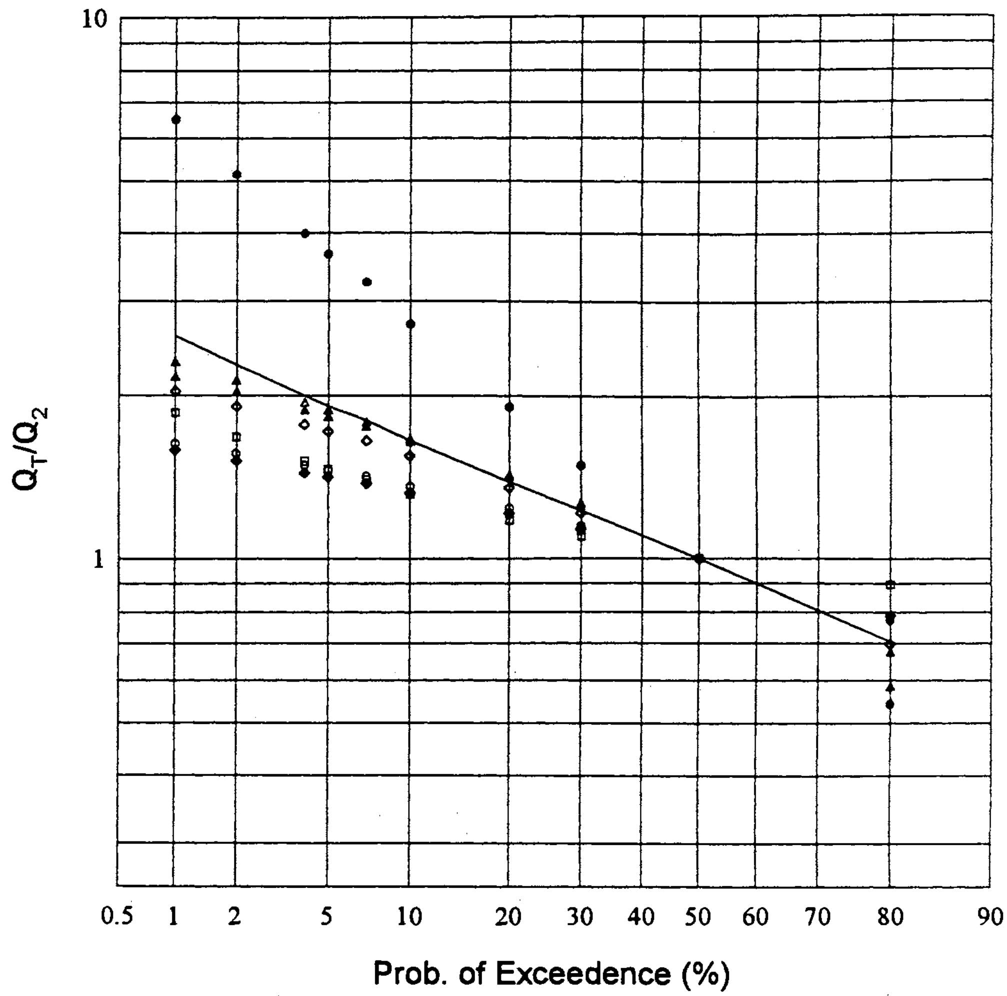


Fig. C3 : Dimensionless regional frequency curve (Region 3)

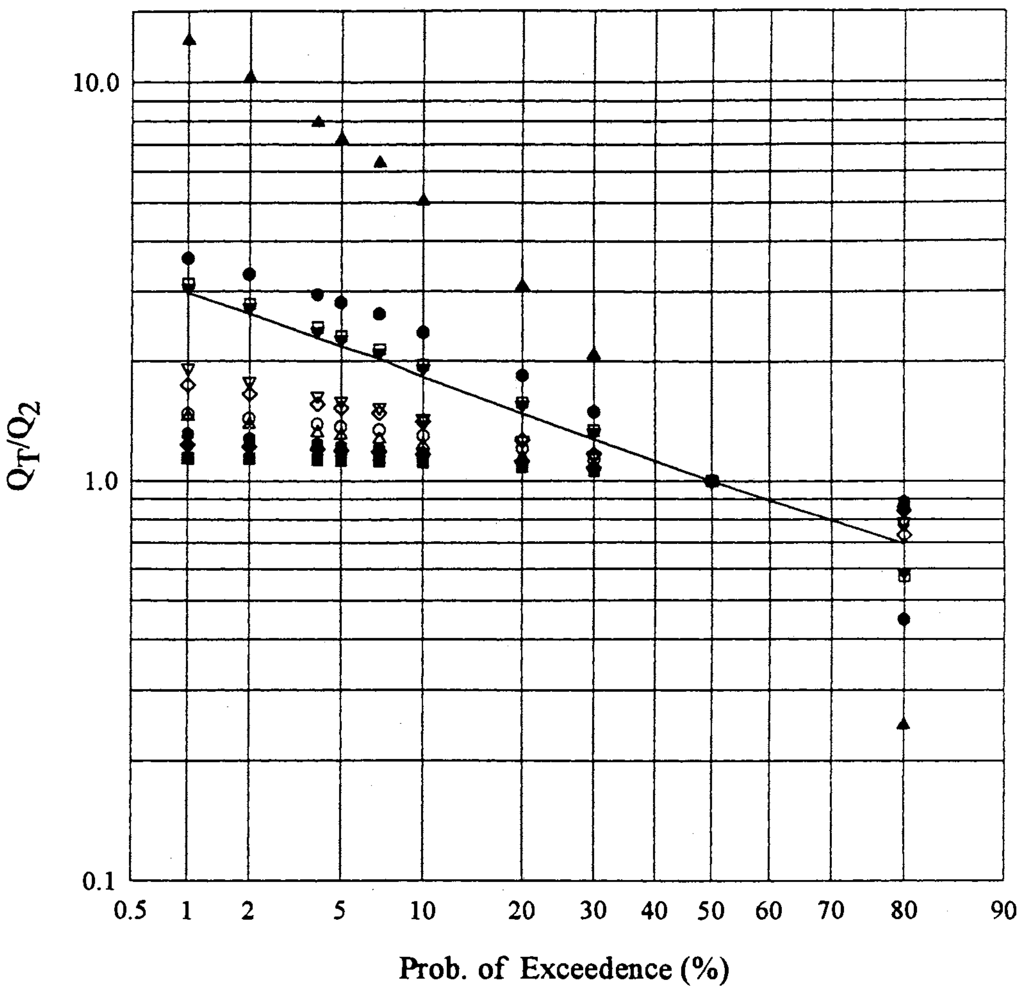


Fig. C4 : Dimensionless regional frequency curve (Region 4)

VITA

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