REVISION OF THE REGIONAL MAXIMUM FLOOD CALCULATION METHOD FOR LESOTHO

by

Billy T.J. Makakole

Thesis presented in fulfillment of the requirements for the Degree of Master of Engineering (MEng) in Civil Engineering at the Stellenbosch University

Supervisor: Dr. J. A. Du Plessis

Faculty of Engineering

December 2014

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained herein is my own original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by the Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

December 2014

ABSTRACT

The Francou and Rodier (1967) empirical approach uses the original concept of envelope curves for the definition of the regional maximum flood (RMF).

Kovacs (1980) adopted the Francou and Rodier empirical flood calculation method and applied it to 355 catchments in South Africa. He revised his study in 1988 to also include the southern portions of the Southern Africa subcontinent.

No method other than the Francou and Rodier empirical flood approach in the reviewed literature was found to be suitable for the purpose of this study. Therefore the Francou and Rodier empirical approach, as applied by Kovacs in 1988, was reapplied and used in this study to update the RMF for Lesotho.

Maximum recorded flood peaks were derived from annual maximum time series and an up to date catalogue of flood peaks for 29 catchments was compiled for Lesotho. The maximum recorded flood peaks were then plotted on the logarithmic scale against their corresponding catchment areas.

There are 3 major river systems that divide Lesotho into hydrologically homogenous basins. Envelope curves were drawn on the upper bound of the cloud of plotted points for these 3 river basins. These envelope curves represent the maximum flood peaks that can reasonably be expected to occur within the respective river basins in Lesotho.

The slopes to the drawn envelope curves were determined and the corresponding Francou and Rodier regional coefficients (K_e values) were established as follows:

- K_e = 5.27 for Senqu River basin
- K_e = 5.12 for Mohokare River basin and
- K_e = 4.90 for Makhaleng River basin

The established K_e values were then used to derive the regional maximum flood (RMF) formula for each river basin as follows:

- Senqu basin: $Q = 164.44A^{0.473}$
- Mohokare basin: $Q = 124.74A^{0.488}$
- Makhaleng basin: $Q = 83.176A^{0.51}$

The newly developed K_e values for the Lesotho river basins has moved from $K_e = 5$ in Kovacs (1988) to $K_e = 5.27$ for the Senqu basin, $K_e = 5.12$ for the Mohokare basin and $K_e = 4.90$ for the Makhaleng basin.

Opsomming

Francou en Rodier (1967) se empiriese benadering maak gebruik van die oorspronklike konsep van boonste limiet kurwes vir die definisie van die streeks maksimum vloed (SMV).

Kovacs (1980) het die Francou en Rodier empiriese vloed berekening metode toegepas op 355 opvanggebiede in Suid-Afrika. Hy hersien sy studie in 1988 om ook die suidelike gedeeltes van die Suider-Afrikaanse subkontinent in te sluit.

Geen ander metode as die Francou en Rodier empiriese vloed benadering is in die literatuur gevind wat as geskik aanvaar kan word vir die doel van hierdie studie nie. Daarom is die Francou en Rodier empiriese benadering, soos toegepas deur Kovacs in 1988, weer in hierdie studie toegepas en gebruik om die SMV metode vir Lesotho op te dateer.

Maksimum aangetekende vloedpieke is verkry vanuit jaarlikse maksimum tyd-reekse en ’n opgedateerde katalogus van vloedpieke vir 29 opvanggebiede saamgestel vir Lesotho. Die maksimum aangetekende vloedpieke is grafies aangetoon op logaritmiese skaal teenoor hul opvanggebiede.

Daar is 3 groot rivierstelsels wat Lesotho in hidrologiese homogene gebiede verdeel. Boonste limiet kurwes is opgestel om die boonste grens van die gestipte punte vir hierdie 3 gebiede aan te toon. Hierdie krommes verteenwoordig die maksimum vloedpieke wat redelikerwys verwag kan word om binne die onderskeie rivierstelsels in Lesotho voor te kan kom.

Die helling van limietkurwes is bepaal en die ooreenstemmende Francou en Rodier streeks- koëffisiënte (K_e waardes) is soos volg bepaal:

- K_e = 5.27 vir Senqu Rivierstelsel
- K_e = 5.12 vir Mohokare Rivierstelsel

- K_e = 4.90 vir Makhaleng Rivierstelsel

Die berekende K_e waardes is gebruik om die streek maksimum vloed (SMV) formule vir elk rivier stelsel te bepaal:

- Senqu Rivierstelsel : $Q = 164.44A^{0.473}$
- Mohokare Rivierstelsel : $Q = 124.74A^{0.488}$
- Makhaleng Rivierstelsel : $Q = 83.176A^{0.51}$

Die nuwe voorgestelde K_e waardes vir die Lesotho riviere het van K_e = 5 in Kovacs (1988) tot K_e = 5.27 vir die Senqu Rivierstelsel, K_e = 5.12 vir die Mohokare Rivierstelsel en K_e = 4.90 vir die Makhaleng Rivierstelsel verander.

ACKNOWLEDGEMENTS

I would firstly thank the Almighty for providing me with the opportunity, the health and the strength from the beginning to the end of this study. Otherwise this study could not have succeeded. Thank you God for I was blessed.

My passionate gratitude is given to my supervisor, **Doctor J. A. Du Plessis** for his tireless and inspirational guidance, supervision and mentoring throughout the study. You stood out tall Dr. Du Plessis. You were everything to me; you were there when I had personal problems. You listened, assisted and drove the entire process towards the achievement of this milestone. I am grateful.

I wish to thank my family; my wife ‘Mamoliehi Makakole, my kids; Moliehi Makakole, Keamohetsoe Makakole, Kelebeletsoe Makakole and their aunt Pontso Mokapane for giving me permission to continue my studies, when they needed me most. You are great guys and your struggles and pains are written in bold and will never be forgotten. “Daddy is coming home Khotsi”. My mum Mamotlamisi, you were supportive and wished me luck, success and blessings. My brother Tseliso Makakole, your support and financial assistance will be remembered. Thank you.

My further acknowledgements and gratitude are given to the following people and organizations for their generous and valued help and provision of data:

- The Lesotho National Manpower Development Secretariat (NMDS) for making funds available throughout my entire study.

- The International Postgraduate Office of the University of Stellenbosch for providing additional funding that eventually took this research work to the completion line. I am thankful.

- The Department of Water Affairs (DWA) of Lesotho for the provision of hydrological data, provision of GIS facilities and assistance.

➢ The Lesotho Meteorological Services (LMS) for the provision of the required length of the rainfall data.

➢ The Lesotho Highlands Development Authority (LHDA) for providing GIS assistance with very accurate Hydrological and Meteorological Maps. The demarcation of hydrological catchments, their sizes and stream lengths were outstanding. Though your uninformed decision to provide the ten (10) years hydrological and rainfall data when I needed more was disappointing.

➢ Mrs. ‘Maphera Lintša of LHDA for her passion to provide hydrological data within the Lesotho Highlands Water Project area.

➢ Mr. Stephen Majoro of LHDA for providing the Maps as said in bullet 5 above.

➢ Mr. Molefi Pule of DWA Lesotho for going an extra mile to provide the hydrological data that form the basis for this study.

➢ Mr. Thabo Mefi of DWA Lesotho for all his efforts to provide catchment areas for each station in the study, and finally

➢ Mr. Victor Ralenkoane of LMS; you were the first to provide full rainfall data that also form the basis for this research.

➢ Mrs. Merentia Meyer; administrative officer within the Institute of Water and Environmental Engineering of the Department of Civil Engineering for all her support and assistance, including the translating of the abstract into Afrikaans.

I am also thankful to the University of Stellenbosch; the Institute for Water and Environmental Engineering of the Department of Civil Engineering for providing all the required tools; internet for research materials, books and courses etc.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

A	Catchment area
AMS	Annual Maximum Series
C	Regional parameter in Creager formula
CV	Covariance
DWA	Department of Water Affairs of Lesotho
DEA	Department of Environmental Affairs of Lesotho
EV1	Extreme Value Type 1 Distribution
F(Q)	Probability of Non - Exceedance
GEV	Generalised Extreme Value Distribution
ha	Hectas
hr	Hours
i	Rainfall Intensity
K	Individual Francou and Rodier Coefficient
K_e	Francou – Rodier Regional Coefficient
K_T	Frequency Factor
km^2	Square Kilometers
LHDA	Lesotho Highlands Development Authority
LMS	Lesotho Meteorological Services
m^3/s	Flow Rate in cubic meters per second
mm	millimeters
NMDS	National Manpower Development Secretariat
P	Annual Average Rainfall
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation

P(Q)	Probability of Exceedance
Q	Discharge
Q_{max}	Maximum Discharge
Q_{mean}	Mean Annual Maximum Discharge
Q_{P}	Peak Discharge
Q_{T}	T year Recurrence Interval flood
RMF	Regional Maximum Flood
T	Return Period (Recurrence Interval)
T(Q)	Return Period of the T years flood Q
^{0}C	Degree Celsius
α	Slope of the envelope curve
σ	Variance
ΔK	Change in Francou – Rodier Coefficient

1. INTRODUCTION

1.1 Background

Lesotho has water resources in relative abundance. It is a mountainous country that is characterized by a network of perennial streams that owe their origin from the wells, springs and wetlands in the mountains of Lesotho. The knowledge of exceptionally large floods is essential for planning and design of development projects that are aimed at controlling, managing and harnessing water resources of Lesotho and to assess the susceptibility of flooding of structures in and around river systems.

There are three main flood estimation approaches, namely; empirical, deterministic and probabilistic. An empirical flood calculation method was employed by Kovacs (1980; 1988) in the estimation of the regional maximum flood (RMF) in South Africa and the entire Southern Africa subcontinent. This method is especially useful to estimate maximum flood peak magnitudes in areas for which no flow records are available or for areas where very few records are available.

The calibration of the method is based on available historical flood records from gauged sites in the region or country. The empirical method portrays the existing relationship between flood peak discharges and physically measured catchment characteristics of the country/region, such as the catchment area.

The extreme flood events (1:50, 1:100 or 1:200 years) can be defined as exceptionally large amount of water flowing over the land surface and stream channels, as a result of the occurrence of high rainfall intensity or prolonged rainfall. These floods usually overtop river banks, flow over and along flood plains, inundate development areas and are eventually measured at a gauging site if available at the outlet of the catchment.

1.2 Problem Statement

The empirical flood calculation method (RMF) that is available for Lesotho was developed by Kovacs in 1988 as part of the Southern Africa subcontinent study. 12 catchments from Lesotho were included in Kovacs' study. This method therefore requires to be updated as more data and catchments are available for inclusion in the analysis.

A reliable method is required to determine design floods and identify flood risk areas. Extreme floods have the potential for destruction as they propagate along the water courses due to high specific forces and powers entailed within the flood water. They can cause unbearable disasters and destroy development areas, wash away and/or demolish bridges and other hydraulic structures. They can change the characteristics and features of water courses, through scouring and deposition, thereby encouraging meandering and the formation of Oxbow – lake features.

Extreme floods are potential threats to human and animal lives, as well as development areas, hence flood conditions are of great concern (Shaw, 1994). The realistic estimate of the maximum flood peak is imperative if the related inundation could result in deaths or great economic damage. Notable flood events therefore need to be studied in details and associated flood levels determined adequately (Kovacs, 1988). The regional maximum flood (RMF) method enables the maximum flood peak magnitude that can be expected at a site to be identified, whether the site is gauged or ungauged.

The conditions that influence and cause flood peaks vary significantly for different countries and regions. They range from heavy rainfall (high intensity rainfall) over short durations on small catchments to prolonged moderate rainfall over large catchments (Shaw, 1994).

Empirical flood calculation method forms the bases for this study, particularly the regional maximum flood (RMF), and this method will be re – evaluated for Lesotho, following the Kovacs (1988) approach.

The relative importance of a regional maximum flood (RMF) method is its ability and accuracy with which it can estimate maximum flood peak discharges in ungauged catchments once it has been calibrated for a country. This RMF method aims at finding the ensuing relationship between the peak discharge and the catchment area for a specific region. The many empirical formulae that are found in the literature of engineering hydrology have been derived from historical flood records in specific countries and/or climate regions and the derived formulae are valid specifically for those particular countries/climate regions (Shaw, 1994).

1.3 Study Area: Geographical Location

Lesotho is a landlocked country, completely surrounded by the Republic of South Africa (Figure 1.1). It has the total catchment area of approximately 29 582 square kilometers (km^2).

Figure 1.1: Geographical Location of Lesotho

Lesotho's population was estimated to be approximately 1.8 million people during the 2006 census (Bureau of Statistics, 2006).

The country is situated between 28^0 and 31^0 South Latitudes and between 27^0 and 30^0 East Longitudes in the southern hemisphere. Lesotho is located at a very high altitude above sea level, and it is characterized by mountainous ranges, wetlands and a network of perennial streams. The wetlands (Figure 1.2) are the head waters to many river systems of Lesotho and they supply adequate amount of water resource to sustain higher levels of river flow throughout the year.

Figure 1.2: The Wetlands that characterize the Mountain Kingdom of Lesotho.

1.4 Climate and Weather Conditions

Lesotho's rainfall pattern is predominantly the orographic rainfall due to its mountainous features where the warm, moist air blowing from the sea (mostly the Atlantic Ocean) is forced to rise over mountain tops and adiabatically condense to form precipitation. Other types of rainfall such as frontal, cyclonic and convective do occur in Lesotho. Rainfall predominantly occurs during summer months and heavy snow is usually experienced during winter months.

There are four climatic seasons in a year that characterise Lesotho; of paramount importance is that summer months are warm to hot with ambient temperatures reaching 29^0C in the lowlands, while winter months are very cold with temperatures dropping below 0^0C to -10^0C in the highlands.

1.5 River Flow

There are basically 3 major river basins for the hydrological catchments in Lesotho. These basins are portrayed in Figure 1.3 and they are; Senqu (Orange) River basin, which has the total catchment area of 19 875 km^2 (the bottom part in Figure 1.3), Makhaleng River basin which has the catchment area of 2 876 km^2 (the middle part) and the Mohokare (Caledon) River basin (the top part) which has the total catchment area of 6 830 km^2. Each catchment has a number of flow gauging stations included in this study (Figure 1.4).

There are 93 flow gauging stations in Lesotho, 56 of which are equipped with automatic recording equipment to continuously record water level, which is then converted into corresponding flow rates. 18 stations are only equipped to provide for staff gauge readings while 19 stations are closed.

Only 3 of the 56 automatic flow gauging stations in Lesotho are weir structures. The rest of the stations are rated sections (stable river sections), which are equipped with cableway winch facilities for measuring high and large flood flows. The rating tables and rating equations to convert the stage measurements into their corresponding discharge values have been developed through using both the current meter and the cableway winch measurements.

The 3 river systems that are equipped with Crump Weir structures, where the rated hydrometric stations are also available at the downstream side of the weir structures, are the Malibamatšo River @ Paray (SG 8A), Senqunyane River @ Marakabei (SG 17A) and the Senqu River @ Whitehill (SG 4A).

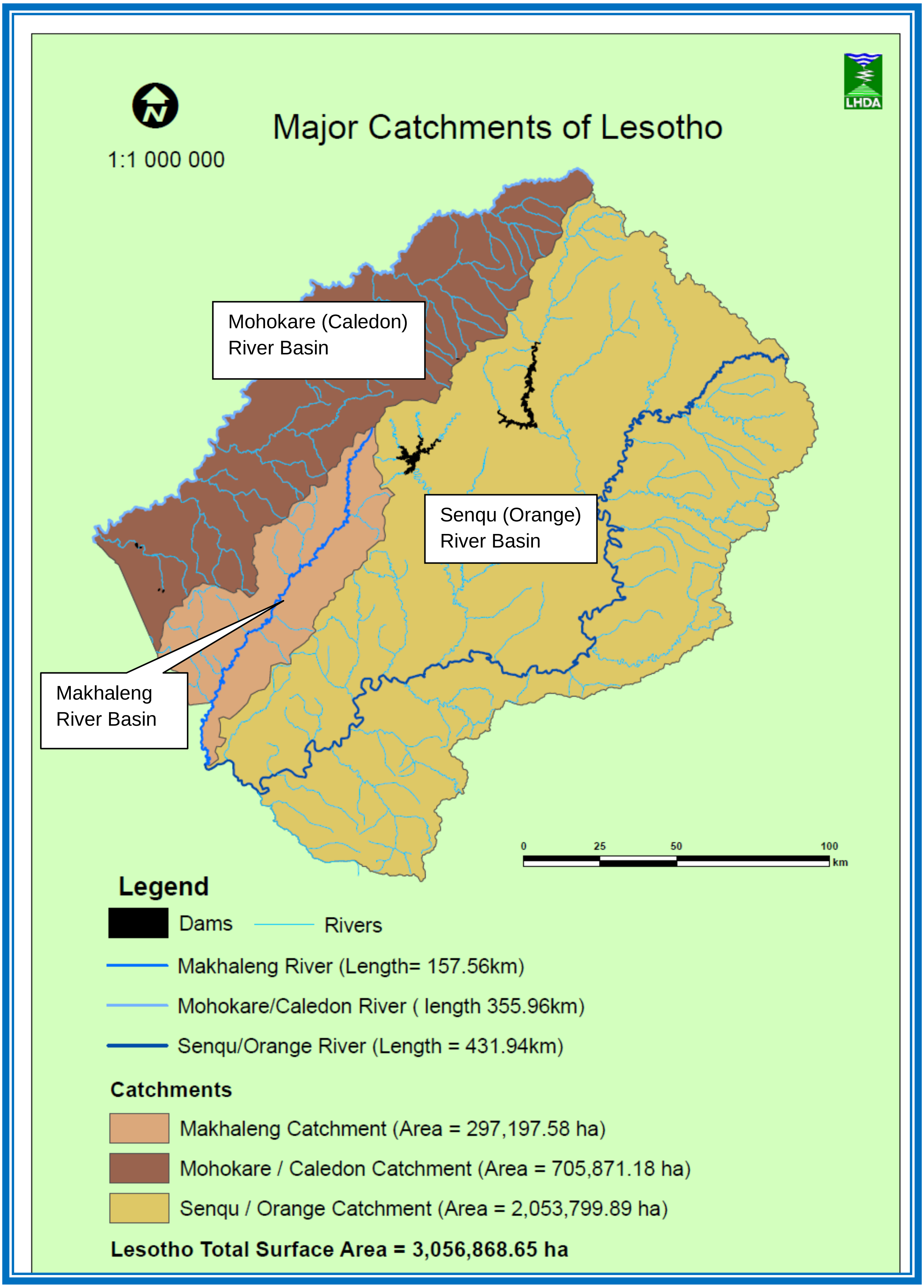


Figure 1.3: Major River Basins in Lesotho

The relationship between the flows that are measured at both the rated sections and the weir structures have been found to be a one to one relationship, that is, these facilities always record similar flows, except during high flows when the incremental catchments between the weir structures and the rated sections provide significant flows to the downstream rated sections (Appendix 1). The rated downstream sections therefore record marginally higher flows during rainy seasons as expected and provided by the incremental catchment.

The similarity of the measured flows at both the weir structures and the rated sections shows that the flow measurements are accurately determined, that the developed rating equations at the rated sections are sufficiently derived to provide similar flows as the theoretical equations for the weir structures.

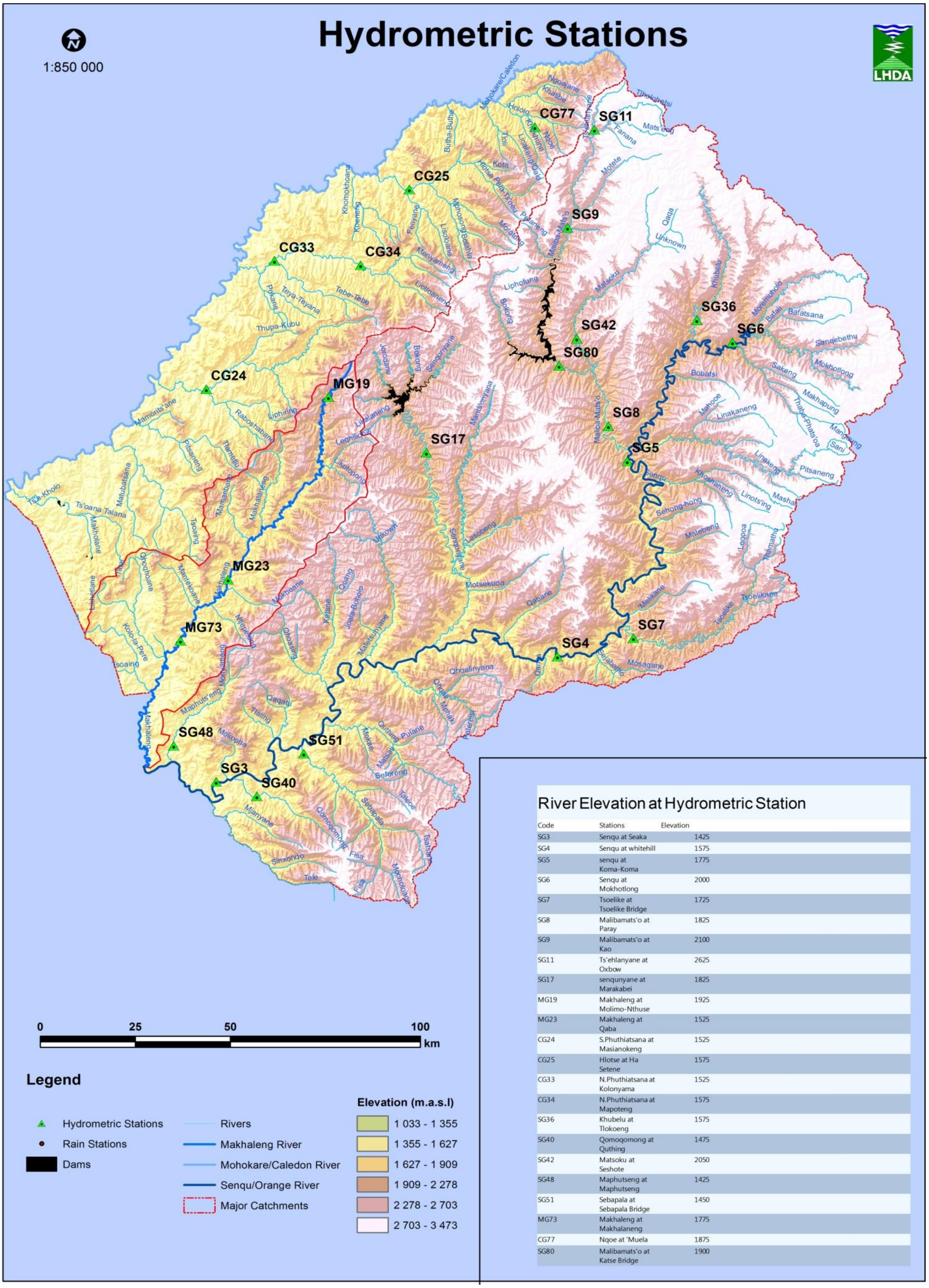
Hence the slope – area calculation method has not been effectively implemented in Lesotho as no incidences of any submergence of the weir structure, nor the rated hydrometric station, have been reported. The largest flood magnitude of 7, 598 m^3/s that occurred at the Senqu River @ Koma – Koma gauging station, on the 21st March 1976, was fully contained within the capacity of the rated river section and was determined with the developed rating table for this river section. The slope – area method is used during the design phase of the hydrometric station structure to ensure that the structure is properly constructed to overcome strong specific forces that are contained within the flood water and to accurately capture the flood. There is, however, a need to consider the slope – area calculation method to extend the theoretical weir and stable river section rating equations in future revisions of the RMF in Lesotho.

The Department of Water Affairs (DWA) in Lesotho is the custodian of all the water resources and any activity associated with these resources. The hydrological data is collected on monthly bases from the field as flow charts and recently also in electronic format. The electronic devices (loggers) and automatic water level recorders record the continuous water level of all the flow events within Lesotho river systems (where they are installed).

The collected data is processed, analysed and stored within the hydrological database of the Department using the HYDATA database. The Department (DWA of Lesotho) is responsible for all the river systems and all the stations that are available within the country.

However the responsibility for some of the rivers and flow measuring stations was given to the Lesotho Highlands Development Authority (LHDA) upon its establishment in 1986. The responsibility for data collection has been divided between these organizations since then, but after the LHDA has done its analysis and data storage, it returns the original records to the DWA in Lesotho as the custodian, for safe keeping.

The HYDATA database is common to both organizations therefore the flow data from stations that are monitored by the LHDA are also available in the Lesotho's DWA database (duplicate). The LHDA is responsible for most of the stations within the Senqu River Basin (Figure 1.4) where the Katse Dam has been constructed. Most of the reliable flow records for this study were obtained from the LHDA database.



River Elevation at Hydrometric Station

Code	Stations	Elevation
SG3	Senqu at Seaka	1425
SG4	Senqu at whitehill	1575
SG5	senqu at Koma-Koma	1775
SG6	Senqu at Mokhotlong	2000
SG7	Tsoelike at Tsoelike Bridge	1725
SG8	Malibamats'o at Paray	1825
SG9	Malibamats'o at Kao	2100
SG11	Ts'ehlanyane at Oxbow	2625
SG17	senqunyane at Marakabei	1825
MG19	Makhaleng at Molimo-Nthuse	1925
MG23	Makhaleng at Qaba	1525
CG24	S.Phuthiatsana at Masianokeng	1525
CG25	Hlotse at Ha Setene	1575
CG33	N.Phuthiatsana at Kolonyama	1525
CG34	N.Phuthiatsana at Mapoteng	1575
SG36	Khubelu at Tlokoeng	1575
SG40	Qomoqomong at Quthing	1475
SG42	Matsoku at Seshote	2050
SG48	Maphutseng at Maphutseng	1425
SG51	Sebapala at Sebapala Bridge	1450
MG73	Makhaleng at Makhalaneng	1775
CG77	Nqoe at 'Muela	1875
SG80	Malibamats'o at Katse Bridge	1900

Figure 1.4: Selected Hydrometric Stations for the Study

1.6 Rainfall

The mean annual precipitation (MAP) that is computed from available LHDA rainfall records within the highlands of Lesotho is 1 455 mm. The highest observed annual rainfall in the LHDA database was 2 107 mm recorded during the 2001/2002 hydrological year.

Rainfall stations are widely distributed all over the country. Most of these rainfall stations are not taken care of and no record is readily available from them. There are approximately 62 rainfall stations in Lesotho but only 24 rainfall stations are well monitored and maintained. Rainfall records available for use were obtained from these 24 rainfall stations. The rainfall data quality is however poor since there are considerable gaps in the rainfall time series.

The Lesotho Meteorological Services (LMS) is the custodian of all the meteorological and weather data in Lesotho. The data is collected on monthly bases from the field as observer records and recently from pluviographs and automatic weather stations. The pluviograph and weather station devices record the continuous weather and rainfall data.

The collected data is processed, analysed and stored within the LMS database and HYDATA database for LHDA. The LMS covers all the meteorological requirements for the country.

However, as was the case with flow stations some of the rainfall stations' data were provide to LHDA. The LHDA therefore monitors all the rainfall and automatic weather stations that are situated within the Lesotho Highlands Water Project (LHWP) area. Rainfall and weather data are collected, analysed and stored in the HYDATA database. These records are also provided to the LMS as the custodian for safe keeping.

1.7 Objectives

The main objective of this study is to revise the regional maximum flood (RMF) calculation method for Lesotho through analyzing the available maximum recorded flood peaks. Other objectives are to:

- Compile an up to date catalogue of maximum recorded flood peaks for Lesotho.

- Determine the K_e values for the 3 distinct river basins in Lesotho.

- Evaluate the Francou – Rodier regional coefficient (K_e) value derived by Kovacs for Lesotho against the newly established K_e values for the 3 river basins.

- Evaluate the results of the empirical approach instituted by Kovacs for Lesotho in his study in 1988 against the results that will be derived from the updated catalogue.

- Determine the RMF equations for the 3 distinct river basins in Lesotho. It has not been possible to provide all the catchment areas in Lesotho with flow measuring stations due to the costs associated with construction requirements, inaccessibility of some rivers due to their remote location and topographical features. The RMF equations will enable flooding conditions, both in gauged and ungauged catchments in Lesotho, to be adequately determined.

- Determine design floods through the application of probabilistic flood frequency analysis to establish the discharge – return period (Q – T) relationship for the Lesotho catchments and finally,

- Derive the relationship between the RMF values and the calculated Q_T values from fitted probabilistic distributions.

2. LITERATURE REVIEW

2.1 Introduction

Numerous empirical formulae for calculating floods were established in various parts of the World during the period 1930 to 1960. The literature that exists on different empirical flood calculation methods that are developed by various authors, in different parts of the world, to portray the existing relationship between the peak discharge and catchment characteristics has been reviewed in this study and a decision to employ and follow Kovacs' approach has been made based on the findings of the literature review.

Empirical flood studies were carried out and continue to be carried out to derive existing relationships between flood peak discharges and the ensuing physical catchment characteristics. In such studies the maximum flood peak discharges from major events in gauged catchments in the region are assembled for comprehensive analysis. The three principal flood estimation techniques are statistical (probabilistic), deterministic and empirical. These methods were developed over the years to simulate processes that convert rainfall into corresponding flood peak discharges and they are calibrated using available historical flood records obtained from gauged catchments (Pegram and Parak, 2004).

Nash and Shaw (1965) studied 57 catchments in Great Britain and found that catchment area alone correlated very well with the peak discharge. The relationship was improved drastically when the mean annual precipitation (MAP) was included in the analysis. The logarithms of catchment area (A) and the mean annual precipitation (MAP) accounted for high variation in the logarithms of the mean of the annual maximum series (Q_{mean}).

The Flood Studies Report (1975) analysed 533 catchments in Great Britain and Ireland. This study considered several catchment parameters where their relationships with floods were investigated and whether those parameters could be used to improve on the flood estimation methods. Up to 7 variables were included in the analysis. This however could not improve the results obtained in Nash and Shaw (1965) study with 2 variables. The catchment area alone still accounted for a high variation in the logarithms of the discharge Q_{mean}.

Pegram and Parak (2004) studied 130 catchments to review Kovacs' study and they investigated the use of landscape parameters to see if they can improve on Kovacs' empirical approach because they believed that catchment area alone could not accurately provide flood peak estimates for the region. Their results could not improve on Kovacs' work and they concluded that use of catchment area for the determination of RMF is justified.

Several formulae that are found in hydrological textbooks that were published during the period before 1950 are defined by the algebraic expression of equation 1.

$$Q_{max} = CA^{x} \quad \ldots\ldots (1)$$

Where: A is the catchment area (km^2)

C and x are regional coefficients

2.2 Creager Approach to Empirical Flood Flow (1945)

The empirical approach that was well known during the period 1930 to 1960 was that of Creager, published in 1945. This formula (equation 2) was almost exclusively based on American data.

$$Q = 46CA^{\left(0.894A^{(-0.048)}\right)} \quad \ldots\ldots (2)$$

Where: A is the catchment area (km^2) and

C is the regional parameter, with the maximum C = 100.

Maximum design floods were determined on the basis of these empirical formulae (equations 1 and 2), of which Creager's approach (equation 2) was the best at that time.

The Creager formula (equation 2) is however difficult to interpret. Thus empirical formulae employed during the period prior to 1960 lacked physical meaning and their application was restricted to well – defined catchment areas (Kovacs, 1980).

Hence there was an urgent need, at that time, for an approach that could provide more realistic and consistent maximum design flood peak estimation results. As engineering hydrologists and civil engineers became more familiarized and acquainted with the sophisticated and more universal probabilistic and deterministic methods, empirical approach was considered outdated and unscientific. No mention of these methods was found and seen almost in all hydrological textbooks published after 1950 (Kovacs, 1980).

2.3 Gordon Cole Approach to Empirical Flood Flow (1965)

Although the attention of both engineering hydrologists and civil engineers had completely shifted towards the more elaborate and sophisticated universal probabilistic and deterministic approaches, these methods could still produce grossly unrealistic and inconsistent results (Kovacs, 1980).

Cole (1965) identified the need to establish a relationship that can provide accurate estimates of design flood peak magnitudes based on catchment area. He stated that a method is needed that is reliable, universal and applicable without undue effort to schemes of all sizes, whether flow records exist or not.

Cole (1965) studied a method that was developed in the United States and applied it to readily available data in Great Britain. He submitted that a flood formula should be regarded as the result of the analysis of a particular set of data for a particular area and period, not to be applied generally. He indicated that a flood formula is only acceptable when it has a sound statistical basis.

In his remarks, Cole quoted Jarvis statement: ‘at best a general formula is only a temporary substitute for observed or logically derived flood information, and should be superseded by or amended in accordance with authentic physical data as they became available’. He showed appreciation to Fuller’s formulae developed from multiple correlation analysis of the more important of the many factors that determine discharge magnitude.

Fuller’s formula gave good results associated with frequencies according to Cole. He has shown that the mean annual maximum flood can be determined by multiple correlation analysis and give the equation of the form:

$$Q_{mean} = CA^{0.8} \quad \text{………………………………………} \quad (3)$$

Where Q_{mean} (m^3/s) is the mean of annual maximum series associated with the catchment area

C is the regional coefficient and

A is the catchment area (km^2)

The determined mean annual flood peak can be used to evaluate the flood peak of any return period according to the following relationship:

$$Q_T = Q_{mean}\,(1+0.8\log T) \quad \text{…………………………......} \quad (4)$$

Cole then compiled a catalogue of 23 mean annual maximum floods from the annual maximum series and plotted them against their corresponding catchment areas on the logarithmic scale. When the envelope curves were drawn, Cole (1965) submitted that the curves showed a marked tendency, with only an occasional anomaly, to fall into groups according to certain catchment characteristics, and along lines that were for all practical purposes parallel and defined by the relationship of the form:

$$Q_{mean} = CA^{0.85} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (5)$$

This is essentially similar to Fuller's equation, though the power of the area of 0.85 is similar to the power derived by Nash and Shaw (1965).

Cole (1965) does not explicitly display his approach and the procedure that he followed in determining his coefficients. It is not known whether he used multiple linear regression analysis and fitted his results to the logarithmic regression equation to calculate his coefficients (the power of 0.85 he used in his formula is similar to the value that was derived by Nash and Shaw (1965) using regression analysis) or the coefficients were obtained from the parallel envelope curves that he drew himself.

The mean annual maximum flood data that were available to Cole do not seem to have been effectively utilized for analyses to authenticate his statement that a formula is only a temporary substitute for observed or logically derived flood information, and should be superseded by or amended in accordance with physical data as they became available. The approach and the results look fine but the procedure that he followed is not explicitly defined. This restricts his method to be widely applied. It might be possible that Cole used Fuller's formula as it is in his study as he mentioned that the method was developed in the US and applied to available data in UK.

2.4 Nash and Shaw Empirical Flood Calculation Approach (1965)

An intensive empirical flood estimation study was instituted by Nash and Shaw on 57 different catchments in Great Britain (Nash and Shaw, 1965).

They developed the relationship that estimates the regional mean annual flood based on catchment characteristics. Their method used the mean annual maximum flood peaks derived from the annual maximum series on each of the 57 catchments.

They compiled a catalogue of the mean annual maximum discharges (Q_{mean}), catchment area (A), mean annual rainfall/precipitation (MAP) and catchment slope S for the 57 catchments. Nash and Shaw examined the models of the form:

$$Q_{mean} = CA^{a}MAP^{p}S^{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where C is the coefficient and other parameters retain their meaning as given before. The parameter values were fitted by the logarithmic regression as follows:

$$Log(Q_{mean}) = Log(C) + aLog(A) + pLog(MAR) + sLog(S) \ldots\ldots \text{(7)}$$

Nash and Shaw then applied the technique of multiple linear regression analysis on several separate sets of predictor variables to obtain the coefficients a, p and s.

The coefficients are substituted back into equation (7) and the average values of $Log(Q_{mean})$, Log(A), Log(MAP) and Log(S) are calculated from the data in the catalogue and substituted back into equation (7) for the determination of the regional coefficient C.

Nash and Shaw found through regression analysis that $Log(Q_{mean})$ correlates very well with Log(A) but not so well with Log(MAP) and Log(S). They found that Log(A) alone accounted for more than 60% of the variation in $Log(Q_{mean})$ between catchments while the other variables individually accounted for very little.

They also found that Log(A) and Log(MAP) together accounted for more than 90% of the variation in Log(Q_{mean}) and that addition of Log(S) when both Log(A) and Log(MAP) are already included, was not justified. The statistical test of significance has shown that addition of the third variable is not warranted. This finding reduced the number of variables in equation 6 to only 2 variables (equation 8) that relates Log(Q_{mean}) to Log(A) and Log(MAP).

$$Q_{mean} = CA^{a}MAP^{p} \quad \text{.....................................} \quad (8)$$

They referred to equation (8) as the best equation and in the case of the 57 catchments analysed in Great Britain, the best prediction equation was derived as:

$$Q_{mean} = 0.0093A^{0.85}MAP^{2.22} \quad \text{.........................} \quad (9)$$

Nash and Shaw argued that design floods are required on the basis of their recurrence intervals for engineers to be able to plan and design accordingly. The calculations of the required return periods of flood events could be calculated from the covariance (CV) of the Q_{mean} from the catalogue. Nash and Shaw had shown that the covariance (CV) of the recorded mean floods correlates well with mean annual precipitation (MAP). The corresponding equation obtained for the covariance was given as:

$$CV = 219MAP^{-0.5} \quad \text{....................................} \quad (10)$$

The standard deviation can then be calculated and the flood magnitude of any required return period can be evaluated from the extreme value and log normal distribution equations of the form:

$$Q_T = Q_{mean} + \sigma K_T \quad \text{....................................} \quad (11)$$

This empirical flood method, unlike the method presented by Cole, is very simple, well presented by developers and requires data that is readily available. It has a physical meaning and can be applied to any region where historical data for calibration is available.

2.5 Francou and Rodier Empirical Approach (1967)

In 1967 Francou and Rodier employed and followed a different approach to empirical flood calculation methods. They published an original concept of flood peak envelope curves (Figure 2.1) for regional maximum flood peak classifications.

They compiled a catalogue of 1 200 maximum recorded flood peaks that represented most regions of the world. Francou and Rodier plotted the flood peaks against their corresponding catchment areas on a logarithmic scale and found that in hydrologically homogeneous regions, and for catchment areas larger than about 100 km^2, the cloud of points on the plot is aligned along a straight line in the flood zone, and that when the regional upper bound curve to the points are drawn, Figures 2.1 and 2.2 are established. The upper bound line represents the regional envelope curve that marks the upper limit of flood peaks that can reasonably be expected at a given site.

The regional envelope curves are characterized and/or denoted by the regional Francou – Rodier coefficient K_e.

Figure 2.1 clearly illustrates the existence of three distinct zones; the flood zone, storm zone and the transition zone.

In the flood zone, which is the zone of focus for this study, the envelope curves are found to be straight and apparently converging towards a single point. Francou and Rodier (1967) have described this point as an approximate total drainage area of the globe and the corresponding total mean discharge of all the rivers on earth. The value of the converging envelope lines, K_e, describes the upper limit of flood peaks within a region. The relationship between the discharge and the catchment area at a given site can be determined by the Francou – Rodier formula (equation 12), which is only valid for use to the envelope curves in the flood zone.

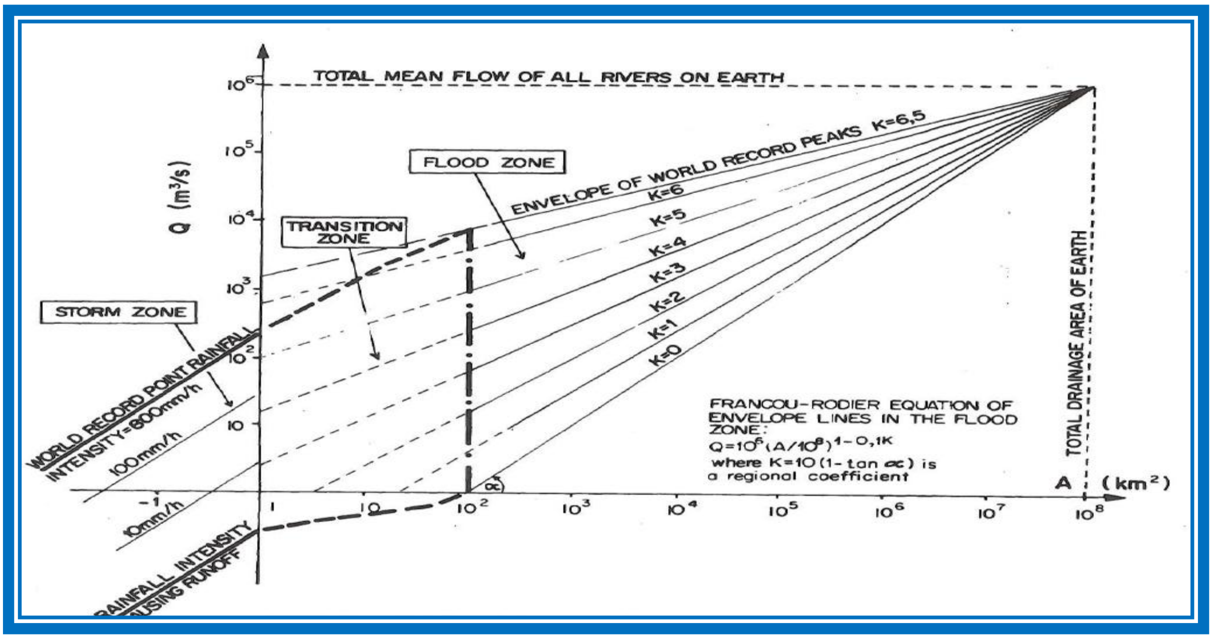


Figure 2.1: Francou and Rodier diagram of envelope curves (Reproduced from Kovacs 1988)

The algebraic expression of Francou – Rodier equation is given as:

$$\frac{Q}{10^6} = \left(\frac{A}{10^8}\right)^{1-0.1K} \quad \text{.................................} \; (12)$$

Where: Q is the flood peak (m^3/s)

10^6 is the mean annual discharge from all the rivers of the earth (m^3/s)

A is the catchment area (km^2)

10^8 is the approximate total drainage area of the earth excluding deserts and Polar Regions (km^2), and

K is the Francou – Rodier coefficient expressing relative flood peak magnitude (The K value here refers to the individual Francou – Rodier coefficient that is associated with the recorded maximum peak flood in a given catchment area).

The value of the Francou – Rodier regional coefficient K_e, ranges between 0 and 6.5, and it is given by the following algebraic expression:

$$K_e = 10(1 - \tan\alpha) \quad (13)$$

Where α is the slope of the envelope line. Note should be taken that K refers to the Francou – Rodier coefficient for individual catchments whilst K_e refers to the coefficient for regional envelope curves.

Francou, in 1968, has commended that in the flood zone where the catchment areas are usually larger than 100 km^2, the flood peak depends both upon the storm rainfall (intensity, area and duration) and catchment characteristics. He further indicated that the catchment area is, however, usually less than 1km^2 in the storm zone, and that the flood peak entirely depends upon rainfall intensity in this zone. Francou also showed that for a 1 km^2 catchment area the discharge is expressed as:

$$Q = 0.278i \quad (14)$$

Where: Q is the peak discharge and

i is the maximum 15 minutes rainfall intensity (mm/hr)

Francou has proclaimed that 15 minutes is an approximate time of concentration in a catchment area of 1 km^2 where the discharge (Q) versus catchment area (A) envelope lines represent constant storm intensities and will plot as 45^0 lines. In catchment areas smaller than 1 km^2 the lines turn to become slightly steeper. He therefore deduced from Figure 2.1 that the lower bound envelope lines in the storm zone indicate a rainfall intensity which is just capable of generating a flood (Figure 2.1) whilst the upper bound line corresponds to the world record rainfall intensities (±800 mm/hr) for 15 minutes storm durations.

The last comment made by Francou on Figure 2.1 is that the transition zone exists between the storm zone and the flood zone. In this zone the envelope lines are supposed to provide a smooth transition from the storm zone to the flood zone.

The envelope lines are entirely defined by the Francou and Rodier regional coefficient K_e in the flood zone. It can be shown that the discharge Q for different catchment areas in the flood zone is influenced by this regional coefficient K_e that actually expresses the relative flood peak magnitude. In an attempt to further elaborate on the concept of the influence of the required K_e value (equation 13) on discharge, Francou and Rodier applied equation (12) to a set of K_e values from 0 to 6.5 (the first column in Table 2.1) and calculated the discharge for each K_e value for given catchment areas. Table 2.1 presents catchment areas and calculated discharge values.

Table 2.1: Influence of Francou – Rodier Regional Coefficient K_e on Discharge Q

	Catchment Area (km^2)			
	100	1000	10000	100000
Francou - Rodier K_e	**Discharge Determine by the Francou - Rodier Regional Coefficient K_e**			
0.00	1	10	100	1 000
0.50	2	18	158	1 413
1.00	4	32	251	1 995
1.50	8	56	398	2 818
2.00	16	100	631	3 981
2.50	32	178	1 000	5 623
3.00	63	316	1 585	7 943
3.50	126	562	2 512	11 220
4.00	251	1 000	3 981	15 849
4.50	501	1 778	6 310	22 387
5.00	1 000	3 162	10 000	31 623
5.50	1 995	5 623	15 849	44 668
6.00	3 981	10 000	25 119	63 096
6.50	7 943	17 783	39 811	89 125

When these discharge values are plotted on a logarithmic scale against their corresponding catchment areas for each K_e value, the concept of straight and converging envelope curves is perfectly demonstrated (Figure 2.2). Thus in hydrologically homogeneous regions the envelope lines are straight and apparently converge towards a single point. These envelope curves correspond to the Francou and Rodier regional coefficient K_e and they represent the upper limit of flood peaks that can be expected in a region.

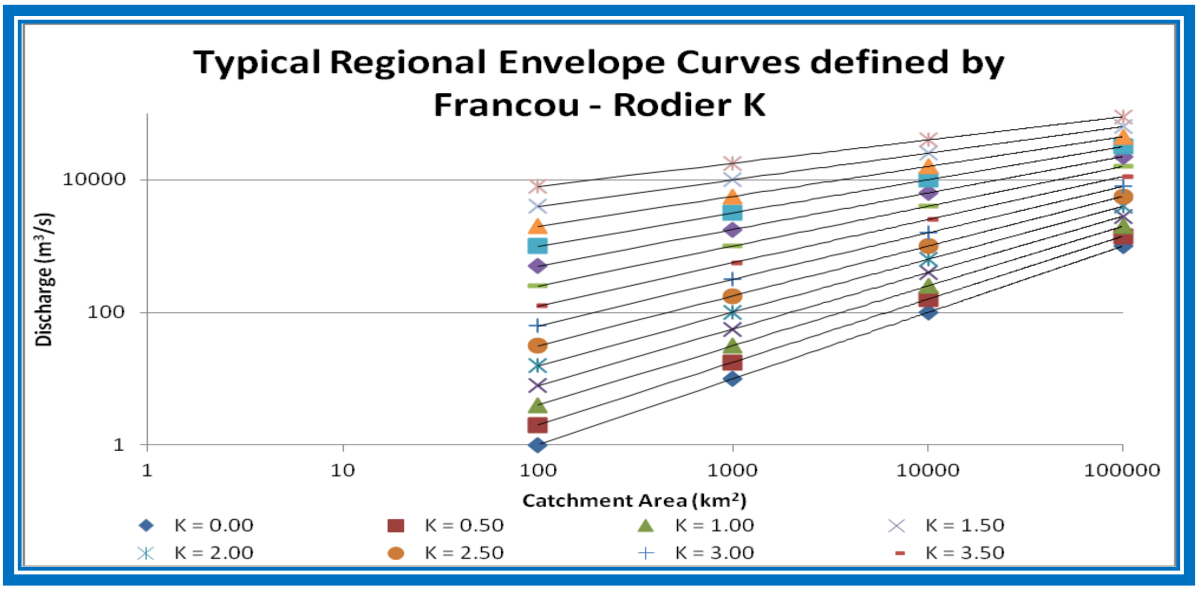


Figure 2.2: Converging Envelope Curves in the Flood Zone

Francou and Rodier derived some maximum K_e values for different parts of the World. These K_e values can enable the maximum design flood peaks to be computed once the catchment area and geographic location of the region under consideration are known. Table 2.2 presents K_e values for different parts of the World.

Table 2.2: Typical Maximum Francou – Rodier K_e values in the World (Reproduced from Kovacs 1988)

Region	**Francou – Rodier K_e**
Tropical Africa	2.0 – 3.0
Central Europe, UK, USSR, Canada	3.0 – 4.0
Argentina, Uruguay, Most parts of USA	4.0 – 5.0
Mediterranean Europe	5.0 – 5.5

Region		Francou – Rodier K_e
Madagascar, New Zealand, India		5.5 – 6.0
Far East, Central America, Texas		6.0 – 6.5
Southern Africa	Kalahari	< 3
	Highveld	4.5 – 5.0
	South Eastern Coastal Belt	5.0– 5.5

2.6 The Flood Studies Report Approach to Empirical Flood Method (1975)

The Wallingford Flood Studies (1975) was a very extensive study of the relation between the average annual maximum flood (Q_{mean}) and catchment characteristics for British and Irish rivers. Values of Q_{mean} were extracted from the annual maximum series records that were gathered from 533 gauging sites.

Measured catchment and climatic variables were also available for corresponding gauging sites. Up to 11 variables were available and include the following:

- Catchment area (km^2)
- Main stream length (m)
- Stream Frequency (Drainage Density)
- Soil Index: Area Under Soil Type (km^2)
- Lakes Index: Area covered by lakes (storage) (km^2)
- Urban Index: Developed area – urbanized (km^2)
- 10@85 channel slope
- Taylor Schwarz channel slope
- Median overland slope for 112 Irish catchments
- Standard average annual rainfall (SAAR) (mm)
- Rainfall and Soil Moisture Deficit relationship (R_{smd} = 1day R_5 - $\overline{smd}$ (average soil moisture deficit))

Several separate sets of regression analysis were performed as in the Nash and Shaw study and the best pair of predictor variables, the best three variables, up to the best seven variables were found.

An equation, similar to equation (7) in Nash and Shaw (1965), was then developed with the addition of other catchment variables and the model coefficients were obtained, which were in turn substituted in the equation of the form similar to equation (8).

It had naturally been expected that with almost ten times as much data as had been available to Nash and Shaw (1965) that much more useful and reliable results could be obtained, especial when the variables to explain the variation had also been increased.

The Flood Studies Report found that with six variables in the equation the coefficient of determination (R^2) is 0.916 which is almost the same as that obtained by Nash and Shaw with only two variables ($R^2 = 0.92$).

The Wallingford Flood Studies Report had concluded that with up to 6 variables included in the analysis their model could not improve the results that were obtained from Nash and Shaw study with only 2 variables. When the number of catchments studied is increased the total variation among them also increases and a larger number of variables are required to explain this variation to the same degree.

2.7 Kovacs Empirical Approach (1980)

After carrying out flood frequency analysis at more than 100 dam sites in South Africa with both the probabilistic and deterministic approaches, Kovacs was also convinced that these approaches were frequently providing extremely unacceptable and inconsistent results.

The probabilistic approach aims at estimating flood peaks with very large return periods, in the range of 10 000 years, based on a relatively short available flow time series. The short flow time series is fitted with a probabilistic distribution and higher flows extrapolated. Such extrapolations have proven to be most unsatisfactory, especially when flow records are very short. If the flow time series is however sufficiently long, more than 50 years, and covers large catchment areas, probabilistic methods can provide reliable results.

The assumption of the Probable Maximum Precipitation (PMP) falling on a saturated catchment form the basis for the estimation of Probable Maximum Flood Peak (PMF) for the deterministic approach, upon which the unit – graph principles are applied (Kovacs, 1980). Kovacs (1980) has also shown that the disadvantage on the usage of the deterministic approach are the large number of assumptions that themselves can become a serious source of cumulative error, thus the South African experience has shown that the application of Synthetic Unit – graph model generally provides PMF estimates that are much too high.

The failure of both the statistical and deterministic approaches to produce the much expected, more realistic and consistent maximum design flood peaks arose the desire and urgent need among hydrologists and civil engineers to establish a simple but more realistic method that would need to be based upon an up to date catalogue of maximum observed flood peaks and upon the use of regional envelope curves.

Kovacs was thereafter convinced that a more stable approach for the estimation of maximum design flood peaks was urgently needed in South Africa. He examined and investigated the work of Francou and Rodier empirical approach with a view to develop an approach that will yield more realistic, consistent and accurate maximum design flood peaks for South Africa (Kovacs, 1980).

After Kovacs had thoroughly examined the Francou and Rodier empirical approach in 1980, he concluded that the Francou and Rodier method was eminently suited for the definition of regional maximum flood peak envelope curves by virtue of the incorporated physical boundary conditions and according to the testimony of Figure 2.1. The Francou and Rodier method was therefore applied to South African regions for the first time in 1980.

Kovacs undertook the similar analysis to that of Francou and Rodier empirical approach for South Africa. He compiled a catalogue of 355 maximum flood peaks in South Africa.

Kovacs then plotted the flood peaks against their corresponding catchment areas on a logarithmic scale. He found, as in Francou – Rodier approach, that in hydrologically homogeneous regions the cloud of points in the flood zone is aligned along a straight line. When the upper bound lines to the points of different homogeneous regions are drawn on one plot of area against discharge, on the logarithmic scale, Kovacs found that indeed the envelope curves were converging towards a single point as established in Figure 2.1. This result gave substantial credence to the application of Francou – Rodier approach to the empirical appraisal of maximum flood peaks in South Africa (Kovacs, 1980).

The individual K values for the recorded maximum flood peak values and corresponding catchment areas in the catalogue were calculated by the known Francou – Rodier equation (12) and Kovacs, in delimiting the regional boundaries to the maximum flood peak regions, gave consideration to the individual K values that evidently play the most important role in characterizing the regional boundaries, the maximum recorded 3 day storm rainfall depth and the catchment characteristics. A total of 5 maximum flood peak regions, referred to as Regional Maximum Flood (RMF) regions were delimited as shown in Figure 2.3 for South Africa.

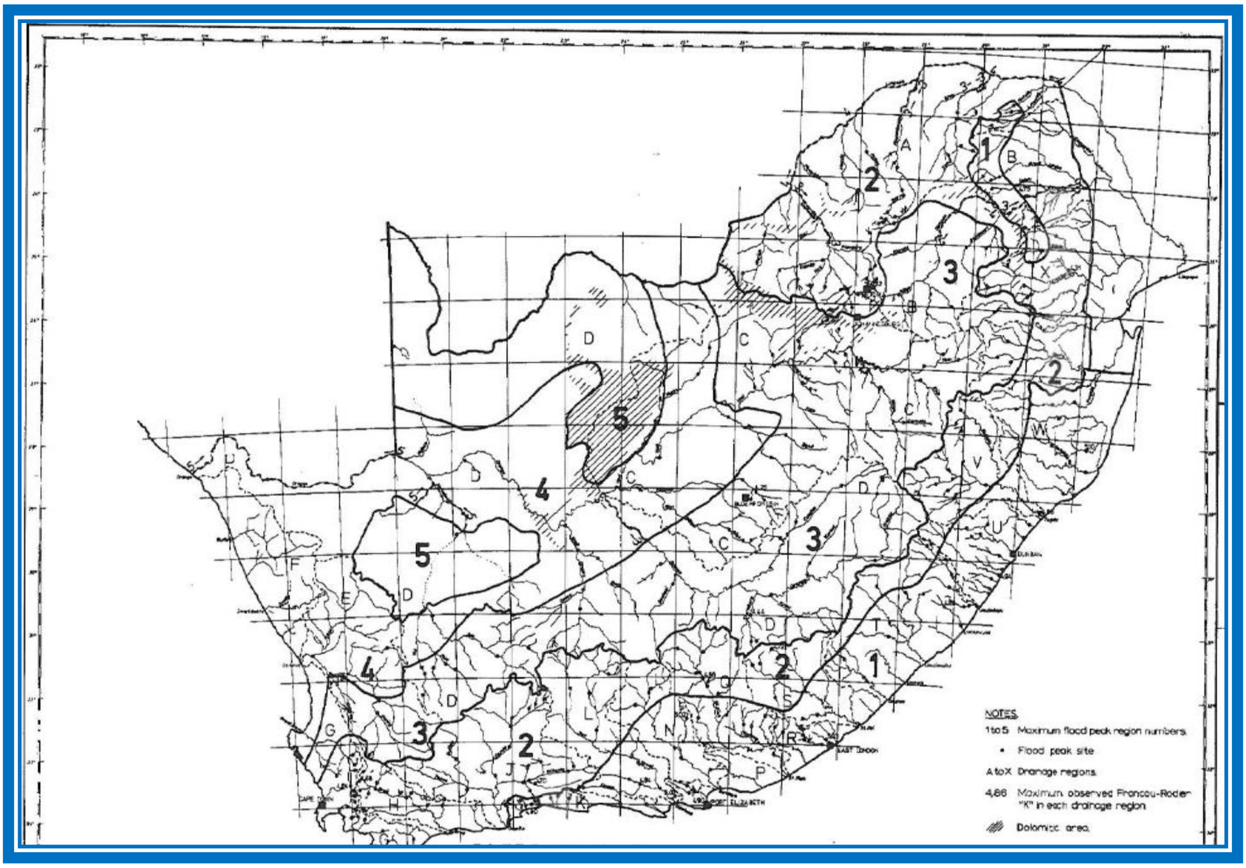


Figure 2.3: Maximum Flood Peak Regions in South Africa (Reproduced from Kovacs, 1980)

The RMF regions are ideally characterized by the corresponding Francou – Rodier regional coefficient K_e values, which are basically the upper bound envelope curves to the points in specific regions. The derived K_e values for the 5 determined RMF regions in South Africa are presented in Table 2.3. (See Figure 2.3 for the labels of the Regions).

Table 2.3: Determined Francou – Rodier K values for Regions in South Africa (Reproduced from Kovacs 1980)

Region	1	2	3	4	5
K_e - Values	5.25	5.00	4.60	3.60	2.50

The regional maximum flood (RMF) can be calculated using Francou – Rodier equation once the catchment area and the region (geographic location) of the site under consideration are known.

The Francou and Rodier approach provides realistic and consistent results that drove Kovacs to conclude that Francou – Rodier empirical approach was eminently suited for the definition of regional maximum flood peak envelope curves.

However, shortly after the publication of Kovacs empirical approach to maximum flood peak estimations for South Africa in 1980, South Africa had experienced more than 5 extraordinary, really large area storms that resulted in the highest recorded flood peaks at many sites. The regional envelope curves developed in 1980 were exceeded at 18 sites. The recalculated K_e values at these sites exceeded the original K_e values (upper limit of the discharge points) on average with a value of 0.2 (ΔK = 0.2), which represent an exceedance of between 15% and 30% of the original flood peak estimates based on the regional K_e values.

In 1984 the floods that were caused by the tropical cyclone, 'Domoina', occurred in Northern Natal and a change in the regional coefficient (ΔK) of 0.31 (ΔK = 0.31) was attained.

It was therefore evident after the occurrence of the Domoina floods that many RMF regions in South Africa still did not adequately address extreme flood peak events. The 1980 data base required updating. The catalogue of maximum flood peaks that was compiled in 1980 was due for revision and the regional boundaries also required adjustments. The uncertainty of the regional coefficient K_e values along international borders due to absence of data from neighbouring countries was also to be taken into account. Thus the revised and updated catalogue ought to cover the entire Southern Africa subcontinent (Kovacs, 1988).

Maximum flood peak data collection for updating the catalogue that would also cover the flood records in neighbouring countries commenced in 1985 and it was completed in 1988, after the Orange – Vaal region floods that occurred during February to March 1988. The sources of the maximum flood peak records were as follows:

- Flood peaks retained from the 1980 catalogue
- Flood peaks gauged since 1980 at the departmental stations
- Flood peaks surveyed since 1980 by the Department in slope – area reaches, at bridges, culverts and weirs.
- Flood peaks calculated to flood levels recorded by the South African Transport Services at some of their oldest bridges. The earliest of these records dates from 1874.
- Flood peaks obtained from Lesotho, Swaziland, Botswana, Zimbabwe, Mozambique and South – West Africa.

Kovacs presented a revised catalogue that contained 519 maximum flood peaks for the Southern Africa subcontinent. 354 flood peaks were derived from South Africa whilst 165 peaks were recorded in the neighbouring countries; Lesotho, Swaziland, Zimbabwe, Mozambique, Botswana and South – West Africa as shown in Figure 2.4 (Kovacs, 1988).

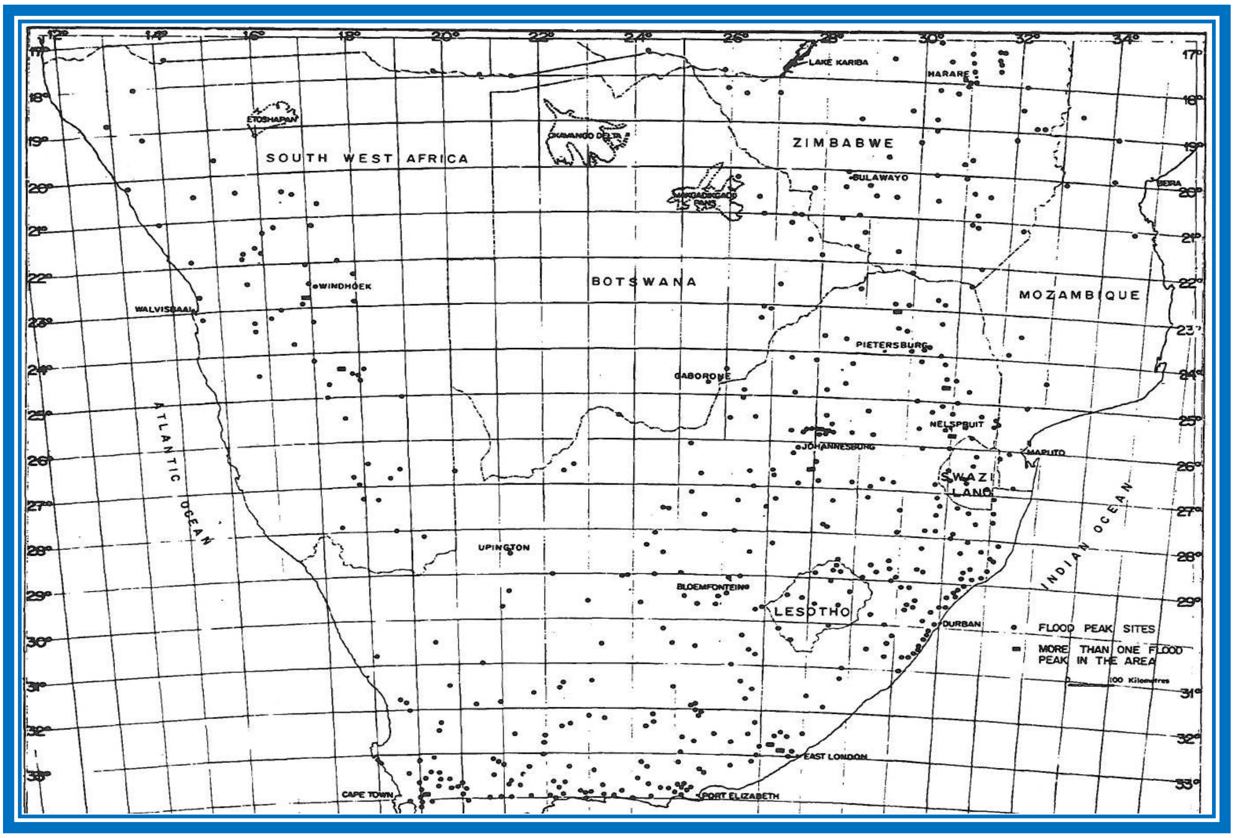


Figure 2.4: Maximum Southern Africa Subcontinent Flood Peak Sites (Reproduced from Kovacs, 1988)

Kovacs found that seven flood peaks were not representative since they were derived from dam breaks and they were omitted. Thus the individual Francou and Rodier coefficients K were established for 512 flood peaks of the catalogue. Kovacs repeated the same procedure as in 1980 for delimiting regional boundaries to the maximum flood peak regions. He gave consideration to the individual K values that evidently play the most important role in characterising the regional boundaries, the number and accuracy of data in a particular area, existing boundaries, the maximum recorded 3 day storm rainfall depth and the catchment characteristics. A total of 8 maximum flood peak (RMF) regions were delimited (Figure 2.5) for Southern Africa subcontinent. Kovacs denoted the RMF regions by K instead of K_e. The K refers to the value of K_e that characterize the regions. For K_e = 5 the corresponding region is denoted as K5 for presentation purpose (Figure 2.5).

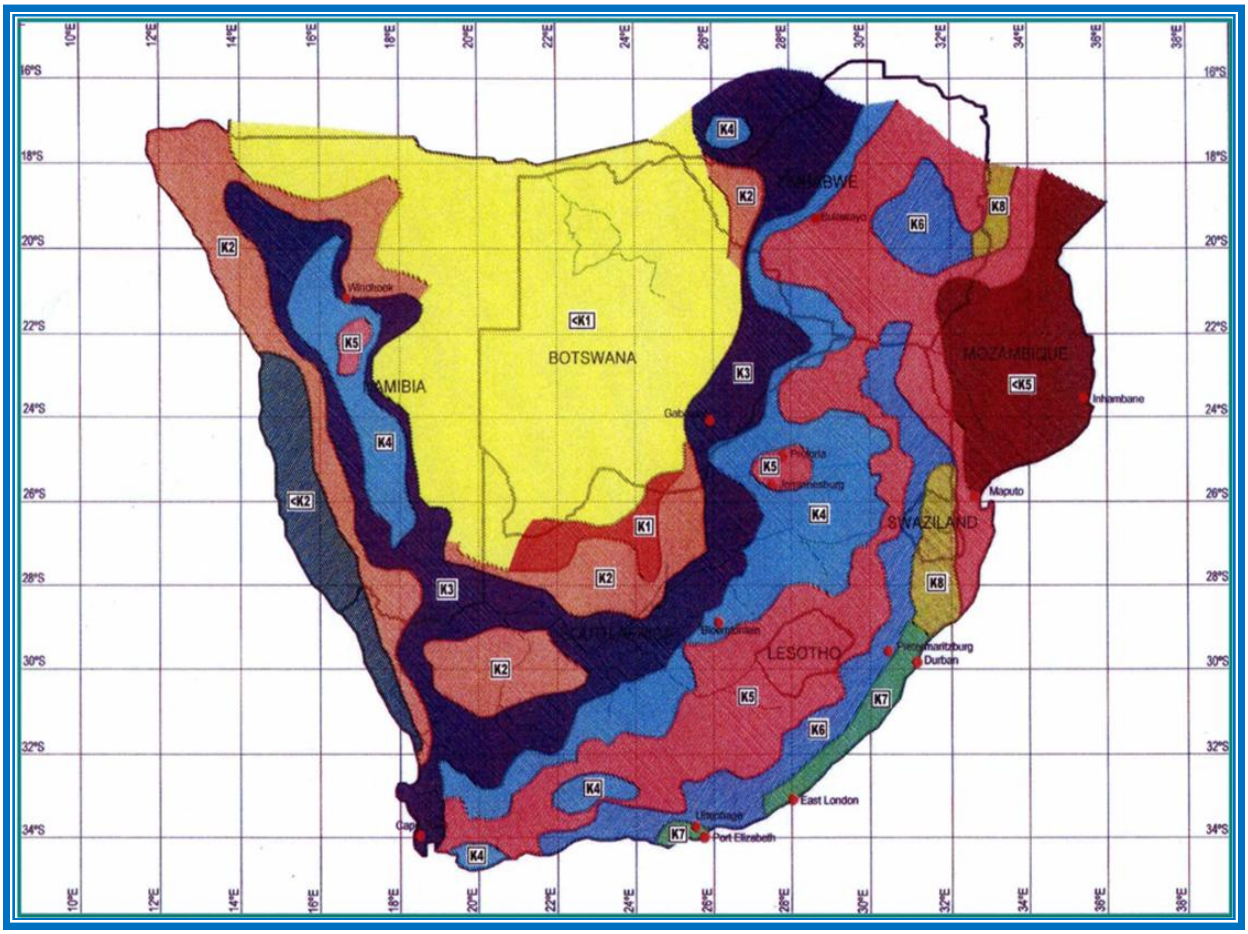


Figure 2.5: Maximum Flood Peak Regions in Southern Africa (Reproduced from SANRAL, 2006)

Although maximum flood peaks data was collected in all the six mentioned neighbouring countries to South Africa, more meaningful and adequate data was obtained from South Africa, Lesotho, Swaziland, South – West Africa and Zimbabwe. Therefore the plots of flood peaks versus catchment areas on the logarithmic scale were effectively performed for these countries and the corresponding envelope curves established. The maximum flood peaks data was lacking in extreme flood peak events in Mozambique and Botswana and it was imperative for these countries to collect and compile more complete and reliable maximum flood peaks database for a meaningful graphical presentation of the envelope curves.

In order to justify the compatibility and suitability of the Francou – Rodier empirical approach, Kovacs (1988) plotted the World record flood peaks (as in 1960 and 1984) and Southern Africa record flood peaks (as in 1960 and 1988) on the logarithmic scale against corresponding catchment areas as shown in Figure 2.6.

Figure 2.6 illustrates that the World record flood peaks seem to have stabilized between K_e = 6 and K_e = 6.5.

Rodier has noted that the upper envelope line of the World record peaks has not moved upwards in 30 years, illustrating the completeness of the World record sample. And Kovacs (1988) has also found that indeed the World record upper envelope line has not moved upwards. The upper envelope line for Southern Africa record has however moved upwards from K_e = 5.2 to K_e = 5.6 because the sample size for Southern Africa flood peak record was much larger in 1988 than in 1980 (Kovacs, 1988).

The trends of both sets of data, in Figure 2.6, are strikingly similar, the cloud of points are well aligned to the direction of the upper envelope lines in the flood zone. Thus Figure 2.6 illustrates the sufficiency and consistency of the Francou and Rodier empirical approach.

The upper envelope lines, that actually mark the upper limit of maximum flood peaks that can reasonably be expected at a given site, characterize the regional maximum flood regions and the regions are identified by the corresponding Francou – Rodier regional coefficient K_e values presented as K value (e.g. K5) in Figure 2.5.

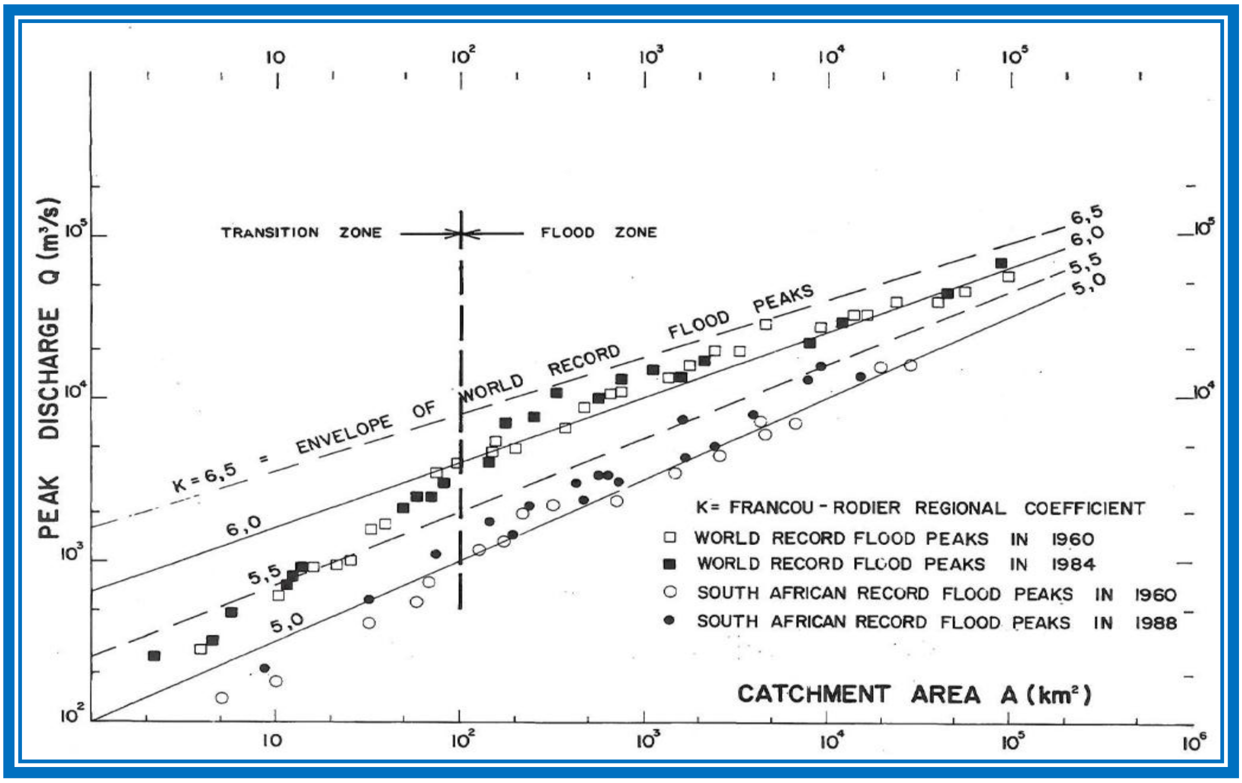


Figure 2.6: World Record and South African Flood Peaks (Reproduced from Kovacs, 1988)

2.8 Pegram and Parak Empirical Approach (2004)

Pegram and Parak felt that determining maximum flood peaks on the bases of catchment area alone could not satisfactory provide accurate flood peak estimates that can be expected at a given site (Pegram and Parak, 2004). They reviewed the basic flood calculation methods of empirical, deterministic and probabilistic in order to determine the accurate method for design flood estimations.

Pegram and Parak (2004) utilized the database for annual flood peak records from 130 sites around South Africa that were used inter alia by Kovacs (1988) in his study. It had been anticipated that other parameters of the fluvial landscape might play an important role in flood response and derive more accurate flood peak estimates.

The following linear landscape parameters were identified as significantly affecting flood response in a catchment:

- Stream order
- Stream length
- Catchment area
- Catchment shape
- Drainage density
- Catchment relief
- Catchment slope
- Channel slope and
- Ruggedness number

They expected such a relationship between flood discharge and catchment morphometry to exist because a catchment is effectively an "open system trying to achieve a state of equilibrium" (Strahler, 1964).

Pegram and Parak argued that precipitation is input to the system and soil (eroded material) and excess precipitation leave the system through the catchment outlet. Within this system an energy transformation takes place converting potential energy of elevation into kinetic energy where erosion and transportation processes result in the formation of topographic characteristics. Hence it is evident that floods, and the landscape through which they drain, form a mutual relationship and ultimately catchment morphometry should reflect this phenomenon.

An effort is made in Pegram and Parak (2004) study to determine if landscape parameters could improve the prediction of floods in empirical equations based solely on catchment area. They claimed that when determining a design flood the exact magnitude of the flood and its probability of exceedance need to be known. The absence of an estimate of the return period associated with the RMF makes the quantification of risk by this method problematic and, as it represents maximum discharges, it tends to be used by designers as a conservative method. In their study, Pegram and Parak also aimed to, inter alia; determine a return period associated with the RMF method by simultaneously plotting the floods determined from the RMF method and the historical floods extrapolated to the 50 year to 200 years recurrence intervals modeled with the GEV distribution.

They were concerned that they were not able to associate a return period with the estimated floods. They pointed out that the envelope lines (from which the RMF is estimated) have been described as the maximum flood that can be expected at a site, which is not easy to quantify in terms of a return period. Kovacs himself estimated the return period to be greater than 200 years (Kovacs, 1988), although he did not explicitly model their probability distribution. He used estimates based on the assumption that the ratio of the 200 year peak to RMF, $Q_{200}/RMF = 0.65$

Landscape data from 25 catchments that corresponded with the peak discharges of the catchments were extracted by Pegram and Parak (2004). They supplemented this with further data through map work from Midgley et al. (1994).

The extracted landscape data were utilized to assess whether it can be used to improve the prediction of floods compared with the RMF, which only uses catchment area alone.

The historical flood data of the catchments were modeled using the GEV distribution to derive the flow rate of the 1 in 20 year event for the comparison with the RMF. The rationale for using the 1 in 20 year flood event was that:

- It would be the least likely estimate to be affected by fitting the wrong probability distribution.
- Many of the records were longer than 20 years.

The floods and landscape data were split into two groups, one for calibration and the other for validation.

The criteria for choosing an appropriate model was based on the coefficient of determination 'R^2' statistics through stepwise regression and the model similar to equation (6) was selected after examining the literature on geomorphological estimates of floods and carefully plotting pairs of variables.

Several separate sets of independent variables were included in the logarithmic regression equation similar to equation (7). When further landscape data were added to catchment area in the hope of improving the fit of the empirical models, the results were no better. The addition of landscape data as independent variables in the prediction of floods did not improve flood prediction and it seemed as though the best model of floods and landscape is simply area based.

Pegram and Parak (2004) concluded that catchment area on its own is a sufficiently good predictor of floods and the addition of landscape variables does not improve this by much, the use of RMF (area based) empirical equation is therefore justified.

2.9 Empirical Approach for Lesotho

In his study in 1988 Kovacs has included twelve (12) catchments from Lesotho and the Francou – Rodier method has been successfully applied to the entire subcontinent for which Lesotho was party to the study. Kovacs established the envelope curve with Francou – Rodier coefficient value of 5 ($K_e = 5$) for all Lesotho catchments.

Kovacs' study in 1988 where Lesotho was part of the investigated area is the only available method for flood calculations in Lesotho, other than the probabilistic method.

No other empirical flood studies in the field of flood hydrology are available and have been done in Lesotho since then. And Kovacs has stated, in 1988, that the catalogue he has compiled was the first attempt for a combined gathering of maximum flood peaks in the subcontinent. He indicated that the results were tentative and might require considerable modifications on the basis of more representative data in neighbouring countries. He also projected that future adjustments were expected to be minimal for Lesotho.

There is therefore a need to evaluate and re – develop the empirical flood calculation method for Lesotho.

Lesotho is also implementing massive water resources development projects, of which the Lesotho Highlands Water Project is an example. Adequately determined maximum flood peak estimates are therefore essential and important for appropriate planning and designs for such projects to ensure safety, efficiency, reliability and sustainability as more phases are also anticipated to be implemented in the highlands of Lesotho.

2.10 Probabilistic Approach

The probabilistic approach is one of the available and universally used flood calculation methods for the determination of discharge and return period (Q – T) relationships for design floods. This method was considered as a sophisticated and more universal approach and it was intensively applied since 1960 after the older empirical methods were abandoned due to their lack of physical meaning (Kovacs, 1980).

Probabilistic methods deal with the frequency of occurrence of specific river flows and flood events. They estimate the average length of time during which a particular event is expected to be equaled or exceeded once every T – years over a long record. This period is referred to as the return period or recurrence interval. The relationship between the discharge and recurrence interval (Q – T) is derived by probabilistic methods, hence flood frequency analysis forms the most important skill required of an engineering hydrologist (Shaw, 1994)

In attempting to provide answers to the question of frequency, the reliable hydrological flow records with sufficiently long record lengths, usually more than 50 years, are required. The needed time series is then extracted from the available hydrological time series, usually the annual maximum flood series which takes one maximum flood peak value in each year of record. The variables in the annual maximum series (AMS) should be random samples that are completely independent (Shaw, 1994).

The AMS is then arranged in descending order of magnitude, starting with the largest value and ending with the lowest ranking discharge value. The plotting positions (Gringorton, Cunane, and Weibull etc) are then applied to calculate the probabilities of exceedances and non – exceedances of the random discharge variables. The probability of the discharge (Q) being equaled or exceeded is denoted as P(Q) and the probability of Q not being equaled or exceeded in any one year is denoted as F(Q). The expression for calculating the plotting positions for Gringorton, which is considered to be the best of the several formulae in use, according to Shaw (1994), is as follows:

$$P(Q) = \frac{r-0.44}{N+0.12} \quad \text{.................................} \quad (15)$$

Where r is the rank of the peak discharge (r = 1 for the largest flood peak)

P(Q) is the probability of exceedance and

N is the total number of peak discharges (or years) in the sample

The probability of non – exceedance F(Q) of any chosen plotting position is calculated using the formula:

$$F(Q) = 1 - P(Q) \quad \text{...................................} \quad (16)$$

The arranged peak discharges in descending order of their magnitude are plotted against their corresponding probabilities of exceedance (P(Q)), with P(Q) being made the abscissa and Q the ordinate.

The probabilistic distribution is selected and the parameters of the selected distribution model are calculated from the available historical flow time series (AMS). The equation of the distribution is then applied to calculate the discharges for the required return periods.

The three parameter Log Pearson Type III probabilistic distribution, as applied in this study, has the following algebraic form:

$$\text{Log } Q_T = \text{Log } Q_{mean} + \sigma_{logQ} W_P \quad \text{.....................} \quad (17)$$

Where Log Q_T is the logarithm of the require flood associated with a return period (T)

Log Q_{mean} is mean of the logarithms of discharge (Q)

σ_{logQ} is the standard deviation of the logarithms of Q and

W_P is the standardized variate obtained from Tables (Appendix 6)

The standardized variate (W_P) is found by calculating the value of the skewness of the time series and then look – up for the corresponding W_P from the provided Table (Appendix 6) for the application of the Log Pearson Type III distribution.

The algebraic expression for calculating the skewness is given as:

$$g = \frac{\left(\frac{N}{(N-1)(N-2)}\right)\left(\sum_{i=1}^{N}(LogQ_i - LogQ_{mean})^3\right)}{\sigma^3} \quad \text{.............} \quad (18)$$

The antilogarithm of the result obtained from equation (17) gives the required flood peak magnitude (Q_T).

A note is taken that Log Normal distribution is a special case of Log Pearson Type III distribution where the skewness is zero (g = 0), hence the same Table (Appendix 6) will still be applicable in the case of the skewness of zero with the standardized variate obtained at g = 0.

2.11 Conclusion on Literature Review

In the many empirical flood estimation approaches studied, Francou and Rodier approach (also applied by Kovacs), is considered to be the best approach and it is followed in this study.

Nash and Shaw approach focuses on the mean of the maximum recorded annual flood series. Its sound determination of the mean annual flood from the catchment area can combine well with Kovacs to accurately determine flood peaks for any required return period in the region (both methods use catchment area). The Fuller formula, equation (4), for determining floods for any given return period has a sound mathematical expression and needs to be investigated further. The process followed for establishing the constants that have been used in the equation needs to be investigated as little information has been provided by Cole (1965). The combination of RMF, Fuller, Nash and Shaw can help in solving the uncertainty that the RMF is not associated with any return period, as it calculates the upper limit of the floods to be expected in a region, though this problem was addressed by Pegram and Parak (2004).

Kovacs (1980; 1988) has adopted the Francou and Rodier empirical approach to maximum flood peak estimations for design floods in Southern Africa subcontinent. Kovacs has concluded that Francou and Rodier empirical approach is well suited for the definition of regional maximum flood peak (RMF) determination. The method provides consistent and realistic figures for design flood purposes.

This method is based on a simple but more realistic approach that is based upon an up to date catalogue of maximum observed flood peaks and upon the use of regional envelope curves, where the observed maximum flood peaks are plotted against their corresponding catchment areas on the logarithmic scale. The envelope curves are then drawn aligned to the cloud of points on the upper bound. This line represents the regional coefficient K_e, named after Francou and Rodier.

The Francou – Rodier regional coefficient K_e thus characterises and determines the discharge in a region and these K_e values represent the upper limit of the coefficients that can be used to calculate the maximum discharges that can be expected to occur in a given region. The regions are therefore identified by the corresponding Francou – Rodier regional coefficient values e.g. region K5, region K5.12 and region K5.27 etc for K_e = 5, K_e = 5.12 and K_e = 5.27 respectively.

A total of 8 maximum flood peak regions were delimited for the Southern Africa subcontinent, among which Lesotho was characterized under region K5.

Pegram and Parak empirical approach is mainly a duplication of the Wallingford Flood Studies approach where it was concluded by Nash and Shaw that when two variables of catchment area and rainfall are included in the analysis the addition of the third variable is not warranted. The Wallingford flood studies and Pegram and Parak empirical approaches are also both very expensive as they require special data of landscape parameters to be collected whereas the flow and rainfall data are readily available in the database for most catchments. Pegram and Parak fitted the GEV distribution to the AMS and have shown that the regional maximum flood (RMF) corresponds to the 1:200 year flood (Q_{200}).

3. METHODOLOGY

The existing literature on available empirical flood calculation methods was reviewed for this study. Opinions, conclusions and procedures followed by various authors from different parts of the world were examined and various developed empirical flood methods (Francou and Rodier, Nash and Shaw, Cole, Kovacs, Flood Studies and Pegram and Parak etc.) were studied in detail.

The Francou and Rodier empirical approach, as applied and adopted by Kovacs in his study for the Southern Africa subcontinent in 1988 was found to be the best approach and was adopted. This study therefore revises and updates Kovacs method for Lesotho.

Required hydrological data and catchment characteristics to be used for accomplishing results in this study were identified and the river basins that divide Lesotho into 3 hydrologically homogeneous regions were also identified.

The demarcation of these distinct river basins in Lesotho; the Senqu River basin, the Mohokare River basin and the Makhaleng River basin was done through assistance from the LHDA. The Senqu River basin is the dominant basin that has the largest catchment area (19 875 km^2) as illustrated in Figures 1.3 and 5.2. The water divide separates these catchments into hydrological homogeneous basins. The delimitation of the regions, as provided by the water divide, was adopted and the derived K_e values will be assigned to the corresponding basins. A similar notation as used by Kovacs (Figure 2.5), for the classification of the regions will be used in this study (e.g. region K5, K5.27, K5.12 and K4.90 etc.).

The Organizations and/or Departments that are responsible for the collection, processing, analysis and achieving of flow and rainfall records were identified and approached for the provision of available and required data sets. These organizations are; Lesotho Highlands Development Authority (LHDA), Department of Water Affair (DWA) in Lesotho and the Lesotho Meteorological Service (LMS).

An up to date catalogue that will be comprised of all the required catchment characteristics; flow station names, coordinates and the flood flows will be compiled and a plot of the discharge against the catchment area will be drawn on the logarithmic scale. The enveloping curve will be drawn on the upper bound of the points and the slope of the curve will be determined. Equation (13) will be applied to compute the Francou – Rodier regional coefficient K_e values that characterize the maximum discharge flows that can be expected at the respective river basins in Lesotho.

Each river basin will be analysed separately and the Francou – Rodier regional coefficient (K_e) value will be calculated for each basin. The data used by Kovacs in 1988 to develop the empirical flood calculation method for Lesotho will also be analysed separately.

The obtained study results will be compared with the results of the study instituted by Kovacs in 1988 where 12 catchments of Lesotho (Table 5.1 – Kovacs Data 1988) were included as part of the regional maximum flood investigations for the Southern Africa subcontinent.

Probabilistic distributions will also be fitted to available annual maximum flood series and the discharge – return period relationships will be derived for the Lesotho catchments. The relationship between the derived RMF to the values calculated with probabilistic distributions will be assessed. The ratios of Q_T to Q_{RMF} will be derived for respective river basins.

The challenges experienced during data collection, processing and analysis will be highlighted with a view to also propose recommendations regarding data collection systems, structures and employed methodologies.

The results that will be derived from this study will be discussed. The conclusions and recommendations will then be drawn based on the findings of the re – developed empirical flood calculation method for Lesotho.

4. DATA COLLECTION AND PROCESSING

Annual maximum flood peaks time series was collected from 56 flow recording stations in Lesotho. Flow time series was found to be inadequate in some of the 56 flow measuring stations, therefore only 29 stations that have adequate and usable data were selected. A catalogue of 29 maximum recorded flood peaks was then compiled for Lesotho (Appendix 1). Maximum recorded flood peaks data of the 29 stations were extracted from the LHDA and DWA databases.

Additional maximum flood peaks for inclusion in the analysis was obtained from the 12 stations that were used by Kovacs in his study in 1988 (Appendix 2). It was found that 8 stations out of the 12 stations that constituted Kovacs' study are among the 29 stations already identified and data from the other 4 stations are only found in Kovacs' study as these stations are closed and no new analysis was possible.

The 2 datasets (29 stations collected recently and 12 stations originally used by Kovacs) were compared for consistency and reliability in order to compile an up to date catalogue of maximum recorded flood peaks for Lesotho.

Some discrepancies in the data were identified in the 8 Kovacs' stations that are among the 29 selected stations. The magnitudes of flood peaks are different for the 2 datasets and their corresponding lengths of record are also different. The data used by Kovacs have higher flood peaks with longer record lengths than the newly selected datasets. The dates of occurrences of the flood peaks in both datasets are noted to have taken place before 1988 (Appendices 1 and 2), which means that recorded flood peaks must be the same if the flood peaks come from the same single database of the same stations.

The observation is that the first flow measuring station (SG 9) in Lesotho was established during the 1961/1962 hydrological year. This station is situated on Malibamatšo River at Kao. SG 9 had a record length of 28 years at the time (1988/89) of the Kovacs' study (SG 9 was however not part of Kovacs' study). It is being sited because it had the longest flow record length of 28 years in 1988 when Kovacs instituted the empirical flood study for the Southern Africa subcontinent.

Table 4.1 summaries the differences between the reported record lengths and peak floods as used by Kovacs as opposed to the actual collected data.

The record lengths in Kovacs' study far exceed the length of the oldest station (SG 9) with available data in Lesotho. SG 5 that was established in 1966/67 hydrological year had 22 years of record in 1988. This station was reported to have a record length of 200 years in the Kovacs (1988) study. The magnitude of the SG 5 flood peak in Kovacs data is however less than the magnitude that is observed in the dataset collected from the water authorities of Lesotho (Appendices 1 and 2, also Table 4.1).

The maximum flood peak value recorded by Kovacs on CG 24 (Phuthiatsana River @ Masianokeng) is noted to have occurred before the station was commissioned in the 1973/74 hydrological year. The peak occurred on the 22nd January 2010 (Appendix 1).

Table 4.1: Record Length and Flood Peak Comparisons

Comparison of Record Lengths and Maximum Flood Peak Values							
Number	**Station Name**	**Start Date**	**Kovacs Study Date**	**Actual Length to Kovacs' Study Date**	**Kovacs' Length**	**Kovacs' Flood Peak**	**Actual Data Peak**
1	SG 4	1964	1988	24	42	5 000	1 691
2	SG 5	1966	1988	22	200	6 820	7 598
3	SG 6	1967	1988	21	20	1 850	1 361
4	SG 10	Closed	1988			710	
5	SG 11	Closed	1988			146	
6	SG 14	Closed	1988			334	
7	SG17	1963	1988	25	24	1 100	860
8	SG 40	1976	1988	12	16	325	84
9	SG 45	Closed	1988			1 690	1 001
10	MG 19		1988			196	166

Comparison of Record Lengths and Maximum Flood Peak Values							
Number	**Station Name**	**Start Date**	**Kovacs Study Date**	**Actual Length to Kovacs' Study Date**	**Kovacs' Length**	**Kovacs' Flood Peak**	**Actual Data Peak**
11	CG 24	1973	1988	15	23	1 140	1 024
12	CG 25	1974	1988	14	150	1 650	602

As a result of these observations (Table 4.1) Kovacs' data could not be verified and its origin could not be established. It was therefore decided to keep both sets of maximum flood peaks and also analyse them separately for comparison purposes.

9 maximum flood peaks that are collected from Kovacs' study, and are situated within the Senqu River basin, and those from stations within the Senqu River basin in the newly established catalogue, were jointly plotted on the logarithmic scale against their corresponding catchment areas. The Senqu River basin has been selected because 9 out of 12 stations that were used by Kovacs (1988) come from this basin and dominated the results of his study (Figure 4.1).

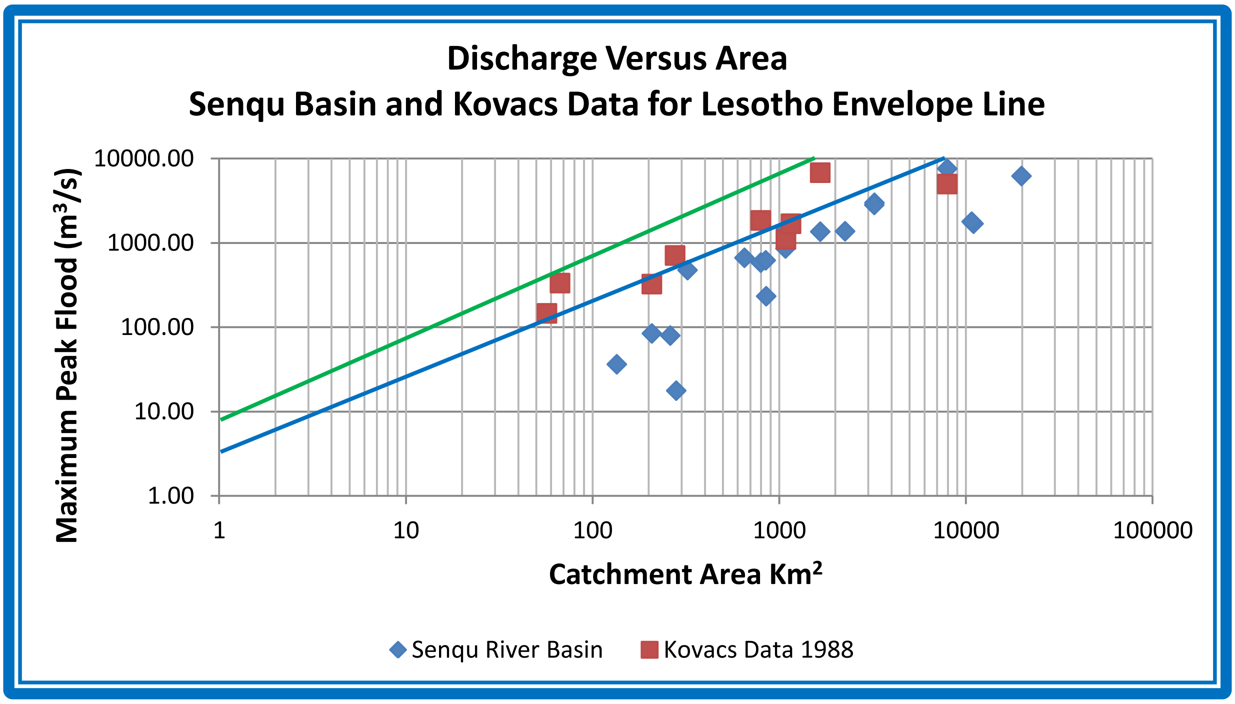


Figure 4.1: Lesotho Data against Kovacs Data Plots

The plotted points portray clear characteristics of different river basins (Figure 4.1) where each river basin can be represented by its own envelope curve. A solution was to analyse the datasets separately.

Figure 4.2 illustrates a plot of all the 33 maximum flood peaks used in this study (including Kovacs data) against their corresponding catchment areas. The points are seen to be diffusely scattered and clearly presenting features of various hydrologically homogenous basins.

No meaningful single envelope curve could be drawn from this data as a single set as clear effects of different homogenous basins and/or regions can be visualized (Figure 4.2).

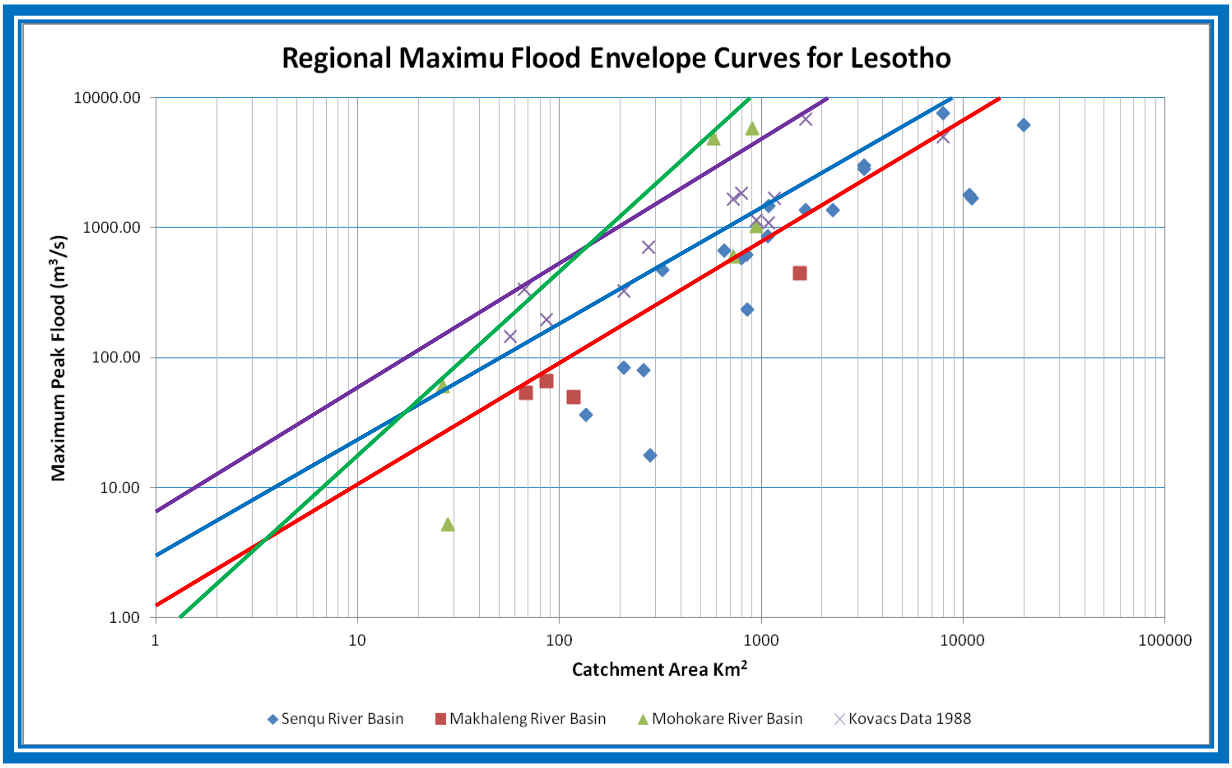


Figure 4.2: A Single Envelope Curve cannot be drawn

If a single envelope curve is accepted to represent Lesotho, as illustrated in Figure 4.3, a slope of approximately 30^0 for this curve is determined. When this slope value is substituted into equation (13) the Francou – Rodier regional coefficient K_e value of 4.23 is calculated. This value is less than the original K_e value of 5 derived by Kovacs in 1988. The K_e value is expected to increase as more data becomes available and previous flood peak values are exceeded. The envelope curve on the upper bound of the flood peak points has to be moved upwards to incorporate new information as it becomes available (Kovacs, 1988).

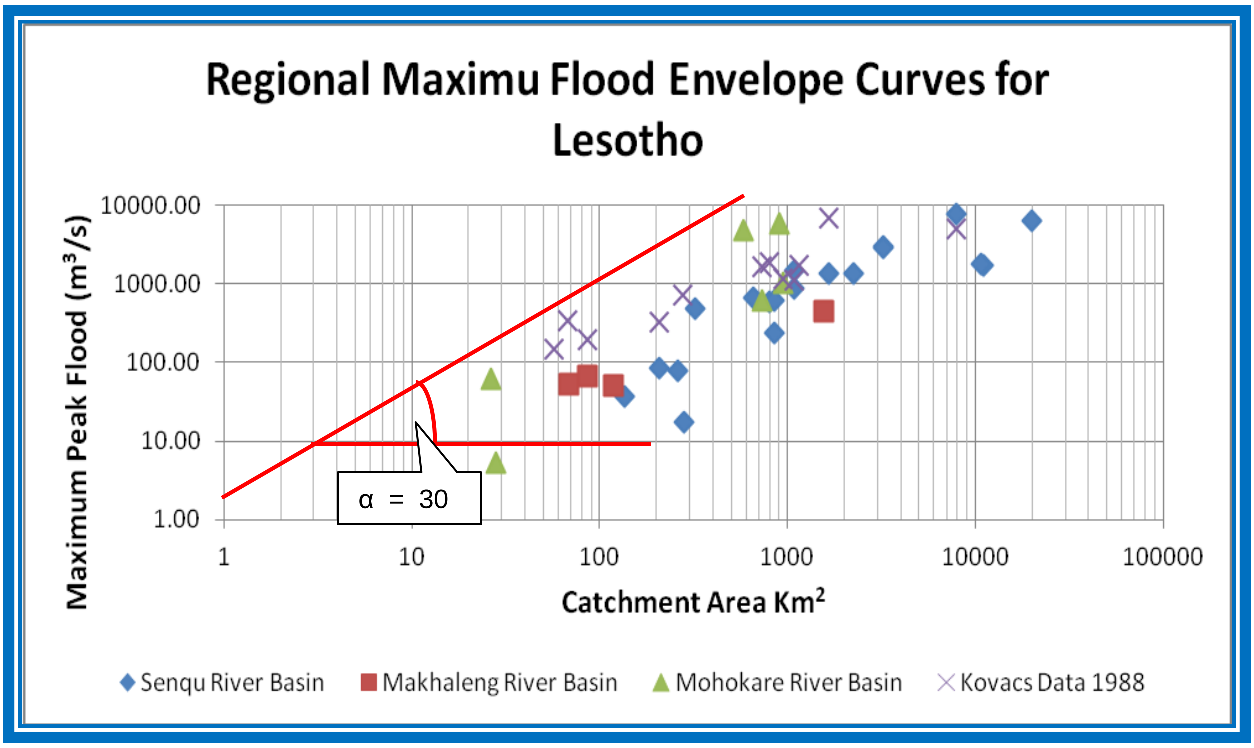


Figure 4.3: Single Envelope Curve for all the 29 stations and Kovacs data

The separation of the basins is therefore warranted and each basin needs to be analysed on its own.

The catchment area data was obtained from the GIS section of the Water Resources Division of the DWA and it was check and verified with the assistance of the GIS section. The demarcation of the Lesotho hydrological map was sourced from the LHDA. The coordinates to the stations to locate their position on the map was also done with the assistance of LHDA.

The delimitation of the river basins map and the corresponding catchment areas of the basins, as separated by the water divide, were collected from the LHDA.

4.1. Limitations

The major limiting factor in this study was insufficient funding. Intensive travelling was required between Lesotho and the Republic of South Africa (RSA) for data collection, and substantial funding was required. The study had been sponsored by the Lesotho Government through its Department of the National Manpower Development Secretariat (NMDS).

Data collection had also been a limiting factor. Once the required data that has to be used in the analyses has been identified a request for data has to be submitted to the responsible organization and/or department. Thereafter the data is provided by those responsible departments to the user, the user is not allowed to collect the data or to access the database to extract or to ensure that the provided data covers the whole length of the database. The provided information has to be accepted as is and used.

There is no readily available annual maximum flow time series that is kept within the flow databases of water authorities in Lesotho. Only mean daily, mean monthly and mean annual flows are readily available. The data would be extracted when there is a requirement and it takes a long time to extract the AMS from many flow measuring stations that have long records. The concerned organization/department would first look for the highest water level that has occurred in each year, from the record of ±40 years and then apply the rating equation. This is a limiting factor because the rate at which the AMS will be produced is dependent on the organization/department and the user might end up not getting the full number of required stations for analysis.

Some of the hydrological flow datasets of some stations obtained from the DWA portray inconsistency and unreliability. The flood peaks are found to be lower than the mean daily flows in some years and this shows inconsistency in the application of the rating equations. Different ratings might have been used and no proper quality control has been done after processing the data. Hence only 29 stations that are assumed to have good quality data are selected for inclusion in this study.

The verification of maximum flood peaks data or any other form of hydrological data, from other sources such as that used by Kovacs (1988), is a limiting factor and causes problems. All hydrological data must come from the same source to enable proper analysis and updating of the developed methods.

The LHDA made a decision to provide a record length of 10 years. This is a limiting factor because flood frequency analysis requires many years of record (normally more than 50 years) to give reliable results. Each year of record adds a value to the accuracy and reliability of flood frequency analysis and, if possible, the available hydrological record must extend beyond the expected life of the engineering scheme being considered (Shaw, 1994). The entire length of record was specified in the request but could not be honoured by the LHDA. As a result the duplicate LHDA datasets that are stored within the DWA database were sourced and used.

5. Data Analysis and Findings

Empirical flood calculation method is derived from maximum observed flood peak records that are obtained from available datasets from all the 29 selected flow measuring stations within Lesotho. The ultimate purpose of the empirical method is to determine the RMF for design floods, plan development projects and assess flooding conditions in gauged and ungauged catchments of Lesotho.

The datasets of the 3 hydrologically homogeneous river basins, namely; Senqu, Mohokare and Makhaleng basins were analysed separately. The previously used data in Kovacs (1988) was also analysed separately.

The individual Francou – Rodier coefficients (K values) for each of the actual recorded maximum flood peaks were calculated using equation (12). The results of the calculated individual K values are presented in Table 5.1.

Table 5.1: Individual K Values

The Francou - Rodier Coefficient K calculations for Individual Sites						
No.	**Station Number**	**Station Name**	**Area (km^2)**	**Peak Discharge (Q_P) (m^3/s)**	**Actual Date of Q_P**	**Francou Rodier K Values**
Senqu River Basin						
1	SG3	Senqu River @ Seaka	19 875	6 216	12-Mar-88	4.04
2	SG4	Senqu River @ Whitehill	11 000	1 691	17-Feb-89	3.00
3	SG4A	Senqu River @ Whitehill Weir	10 749.8	1 788	17-Feb-89	3.08
4	SG5	Senqu River @ Koma - Koma	7 950	7 598	21-Mar-76	4.83
5	SG6	Senqu River @ Mokhotlong	1 660	1 361	12-Mar-88	4.00
6	SG7	Tsoelike River @ Tsoelike Bridge	797	584	01-Feb-67	3.66
7	SG8	Malimatšo River @ Paray	3 240	2 996	12-Mar-88	4.38
8	SG8A	Malimatšo River @ Paray Weir	3 232.8	2 823	12-Mar-88	4.32
9	SG9	Malimatšo River @ Kao	847	622	17-Oct-09	3.68
10	SG17	Senqunyane River @ Marakabei	1087	1 479	31-Jan-67	4.30
11	SG17A	Senqunyane River @ Marakabei Weir	1 080.9	860	22-Sep-87	3.83
12	SG36	Khubelu River @ Tlokoeng	852	233	23-Feb-88	2.84
13	SG40	Qomoqomong River @ Quthing	208	325	10-Dec-76	3.86
14	SG42	Matsoku River @ Ha - Seshote	652	667	12-Feb-09	3.88
15	SG48	Maphutseng River @ Maphutseng	323	476	03-Jun-08	3.95
16	SG51	Sebapala River @ Sebapala	261	80	15-Feb-09	2.66
17	SG67	Qhoali River @ Qhoali Bridge	135	36	10-Feb-09	2.44
18	SG 79	Mjanyane River @ Mjanyane	281	18	11-Oct-92	1.44

The Francou - Rodier Coefficient K calculations for Individual Sites						
No.	**Station Number**	**Station Name**	**Area (km^2)**	**Peak Discharge (Q_P) (m^3/s)**	**Actual Date of Q_P**	**Francou Rodier K Values**
19	SG80	Malibamatšo River @ Katse Bridge	2 255	1 376	03-Nov-06	3.84
			Average Coefficient K			**3.58**
Makhaleng River Basin						
20	MG19	Makhaleng River @ Molimo - Nthuse	86	66	31-Mar-90	3.10
21	MG23	Makhaleng River @ Ha - Qaba	1554	444	27-Sep-87	3.03
22	MG 72	Makhaleng River @ Thabana Limmele	68	53	17-Mar-06	3.07
23	MG73	Makhaleng River @ Makhalaneng	118	50	09-May-99	2.74
			Average Coefficient K			**2.99**
Mohokare River Basin						
24	CG24	South Phuthiatsana River @ Masianokeng	945	1 024	22-Jan-10	4.0
25	CG25	Hlotse River @ Ha - Setene	728	602	19-Oct-87	3.7
26	CG33	North Phuthiatsana River @ Kolonyama	905	384	02-Jan-83	3.2
27	CG34	North Phuthiatsana River @ Mapoteng	579	58	22-Jan-87	1.9
28	CG77	Nqoe River @ ‘Muela	26.3	72	26-Feb-11	3.7
29	CG77A	Nqoe River @ ‘Muela Downstream	28	5	19-Mar-11	1.9
			Average Coefficient K			**3.07**
Kovacs Data (1988)						
1	SG4	Senqu River @ Whitehill	11 000	5 000	01-Feb-67	4.19
2	SG5	Senqu River @ Koma - Koma	7 950	6 820	21-Mar-76	4.72
3	SG6	Senqu River @ Mokhotlong	1 660	1 850	01-Feb-67	4.28
4	SG10	Malibamatšo River @ Ox - Bow	277	710	31-Jan-67	4.33
5	SG11	Tsehlanyane River @ Ox - Bow	57	146	Dec-1970	3.86
6	SG14	Motete River @ Mahlasela	67	334	31-Jan-67	4.37
7	SG17	Senqunyane River @ Marakabei	1 087	1 100	05-Mar-77	4.04
8	SG40	Qomoqomong River @ Quthing	208	325	Feb-1974	3.86
9	SG45	Malibamatšo River @ Ha - Lejone	1 157	1 690	10-Apr-82	4.39
10	MG19	Makhaleng River @ Molimo - Nthuse	86	196	31-Mar-78	3.40
11	CG24	South Phuthiatsana River @ Masianokeng	945	1 140	21-Jan-66	4.14
12	CG25	Hlotse River @ Ha - Setene	728	1 650	10-Dec-78	4.58
				Average Coefficient K		**4.33**

Table 5.1 is structured such that the classified river basins for Lesotho catchments are separated and dealt with individually. The highest K value computed for the Senqu River basin is 4.83 obtained at Senqu River at Koma - Koma and the average of the K values for the basin is 3.53. The Makhaleng basin has the highest K value of

3.10 and the average K value of 2.99. Mohokare basin has the highest K value of 4.0 and the average K value of 3.08.

The flow data for the Senqu basin is mostly collected by the LHDA and it can be considered as reliable (duplicate flow database for LHDA records are available in DWA database as DWA is the custodian of water resources in Lesotho). The Makhaleng and Mohokare basins' data entirely come from the DWA. The quality of flow records obtained from some of the recording stations, which fall within the responsibility of the DWA, was found to be poor. There are huge gaps in the flow time series and this led to a selection of stations where good length of data was available for use in the analysis. As a result only 4 stations from the Makhaleng basin and 6 stations from the Mohokare basin could be used. The selected stations, including those monitored by the LHDA, are however distributed well over the entire country (Figures 1.4, 5.2, 5.4 and 5.6) and represent the hydrological conditions of Lesotho satisfactorily.

Maximum recorded flood peaks from the river basins in Lesotho were then plotted on the logarithmic scale against their corresponding catchment areas and the envelope curve was drawn. This curve designates the maximum flood peaks that can reasonably be expected in various river basins of Lesotho.

The Lesotho Highlands Water Project (LHWP) dams experience full supply level conditions during rainy seasons. Both the Katse and the Mohale Dams spill every year and the low level outlet gates (valves) are often operated to control the rising dam levels.

Hence flooding conditions in Lesotho usually occur when these dams are at their full supply levels (FSL) and they are believed to impose insignificant influence on the attenuation of floods. The maximum recorded flood peaks data also shows that the floods on downstream catchments are independent from upstream conditions, that is, the downstream stations could experience flooding conditions whilst the upstream catchments are not flooding. This is due to spatial variation in rainfall events due to the mountainous features of the country. For instance the Senqu River @ Koma – Koma station is downstream of both the Malibamatšo River at Paray and Senqu River @ Mokhotlong. The Koma – Koma station experienced a huge flood magnitude of 7 598 m^3/s in March 1976 but there were insignificant occurrences of floods at both the upstream stations, hence the maximum recorded flood peaks at these stations bear different occurrence dates to the Koma – Koma flood. Therefore the flood attenuation of large dams in Lesotho has been ignored in this analysis. More supporting data is however needed for future verification on the impacts of the Katse and Mohale Dams on the RMF of the country.

The analyses of the data from the separate basins are presented as follows:

5.1 Senqu River Basin

Following the separation of maximum flood peak series according to their river basins, the flood peaks were plotted against their corresponding catchment areas in the Senqu River basin. The result is presented in Figure 5.1.

The plotted discharge points are clustered along a straight line and the scatter that was observed when all the data points were plotted together is minimized (Figure 4.2).

The envelope curve was drawn at the upper bound of the cloud of points, Figure 5.1, and its slope was determined as $\alpha = 25.3^0$. When this value of the slope is substituted into equation (13) the regional Francou – Rodier coefficient (K_e) is calculated to be 5.27.

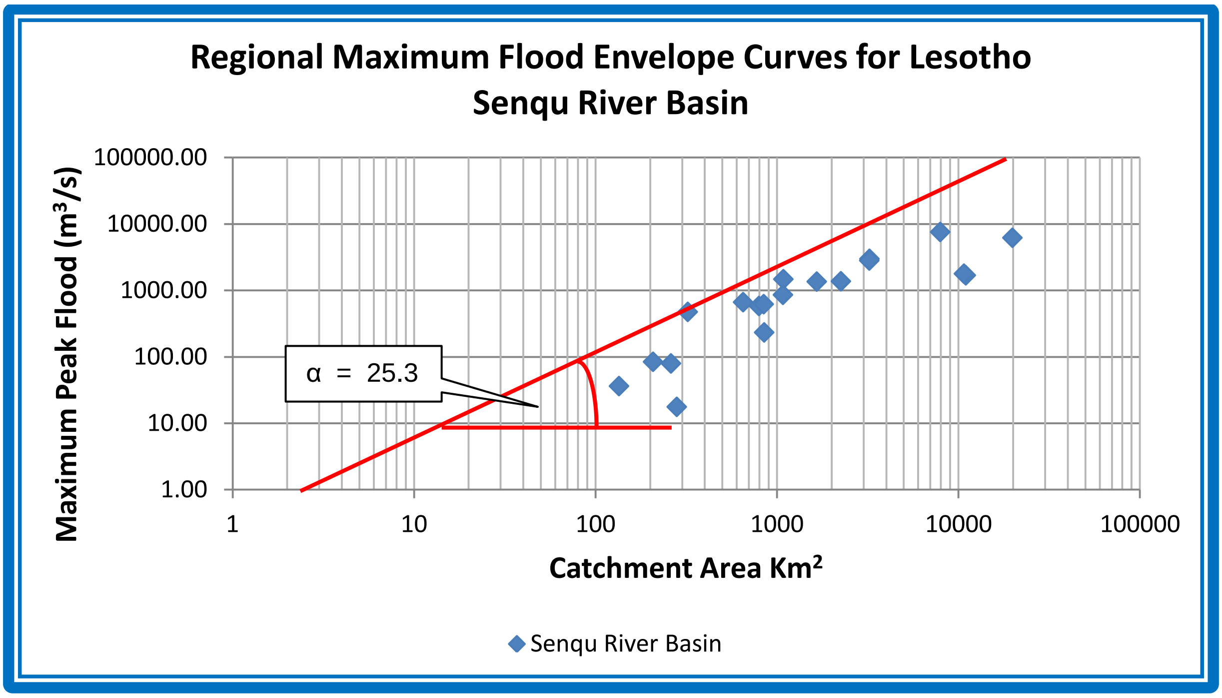


Figure 5.1: Envelope Curve for the Senqu River Basin

Since there is no objective, specific or scientific criterion with which to draw the envelope curve (Kovacs, 1988), the envelope line was traced close to the highest observed K value as illustrated in Figure 5.1. There is a change of 0.44 ($\Delta K = 0.44$) in K_e values between the highest individual K value of 4.83 and the newly established Francou – Rodier regional coefficient (K_e) value of 5.27. Kovacs (1988) has recommended a change in K value that is not higher than the highest observed K value by 0.1 to 0.3 ($\Delta K = 0.1$ to $\Delta K = 0.3$). He proclaimed that shifting the line too far above the observed maxima would be tantamount to the abandonment of the essence of the empirical approach. The ΔK of 0.44 is accepted in this study as the envelope line is appropriately drawn very close and touching the point of the observed maxima for the highest individual K value of 4.83.

According to the nomenclature given in Figure 2.5 the Senqu basin could be referred to as region K5.27 (Figure 5.2).

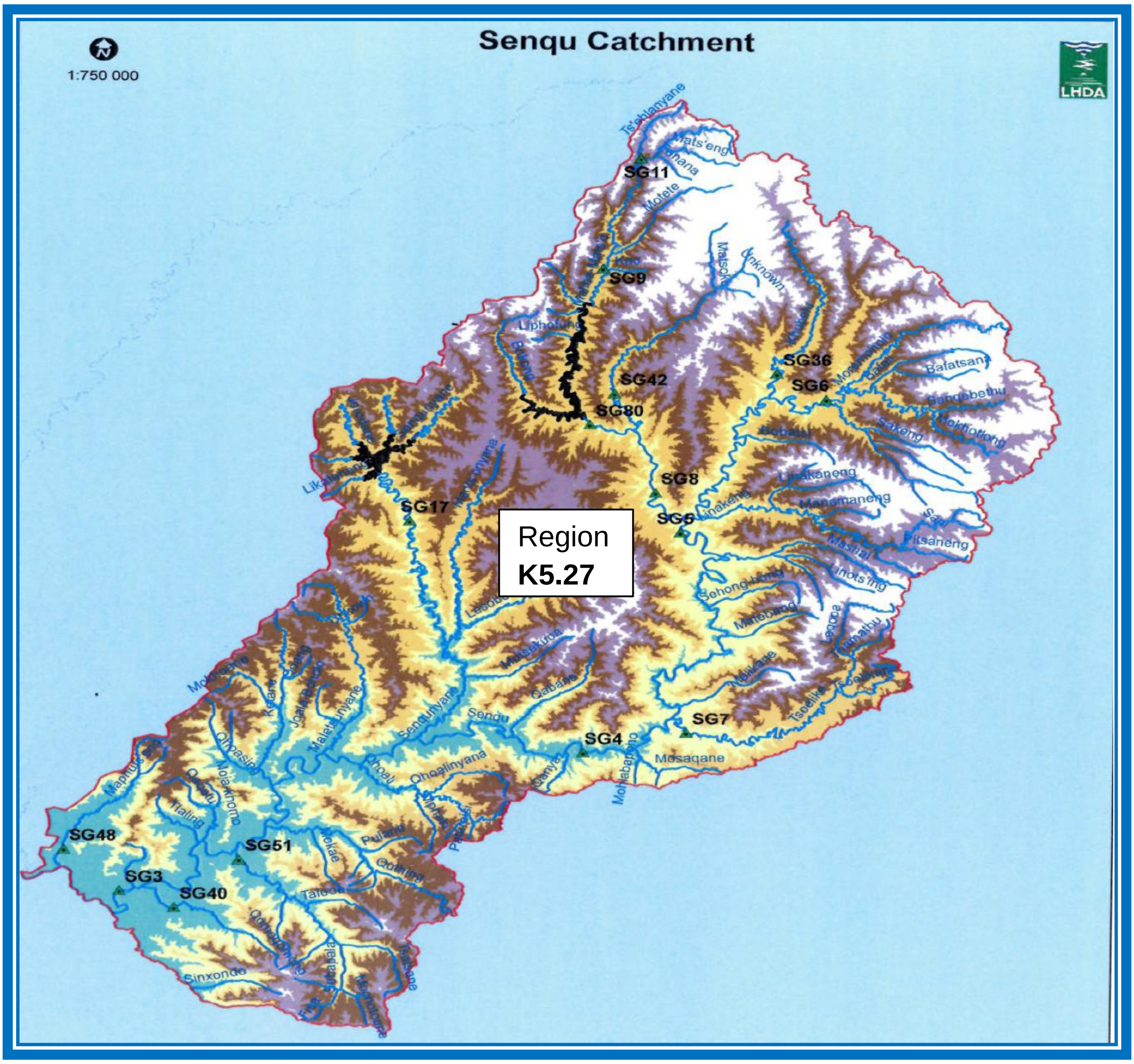


Figure 5.2: Senqu River Basin (K5.27)

The K_e value of 5.27 is then substituted back into equation (12) to provide equation (19), which gives an easier way to calculate the RMF for any given catchment area within the Senqu River basin.

$$Q = 164.44A^{0.473} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

5.2 Mohokare River Basin

The maximum recorded flood peaks in the Mohokare River Basin were obtained from the DWA, with the exception of CG 77 (Nqoe River at 'Muela) which is obtained from the LHDA.

Maximum flood peaks are plotted against their corresponding catchment areas on the logarithmic scale and the envelope curve drawn on the upper bound of the points (Figure 5.3). The slope of the envelope line was determined and the Francou and Rodier regional coefficient (K_e value) was calculated by substituting the value of the slope into equation (13). The determined slope is $\alpha = 26^0$ (Figure 5.3). The regional coefficient value, $K_e = 5.12$ was calculated for the Mohokare basin.

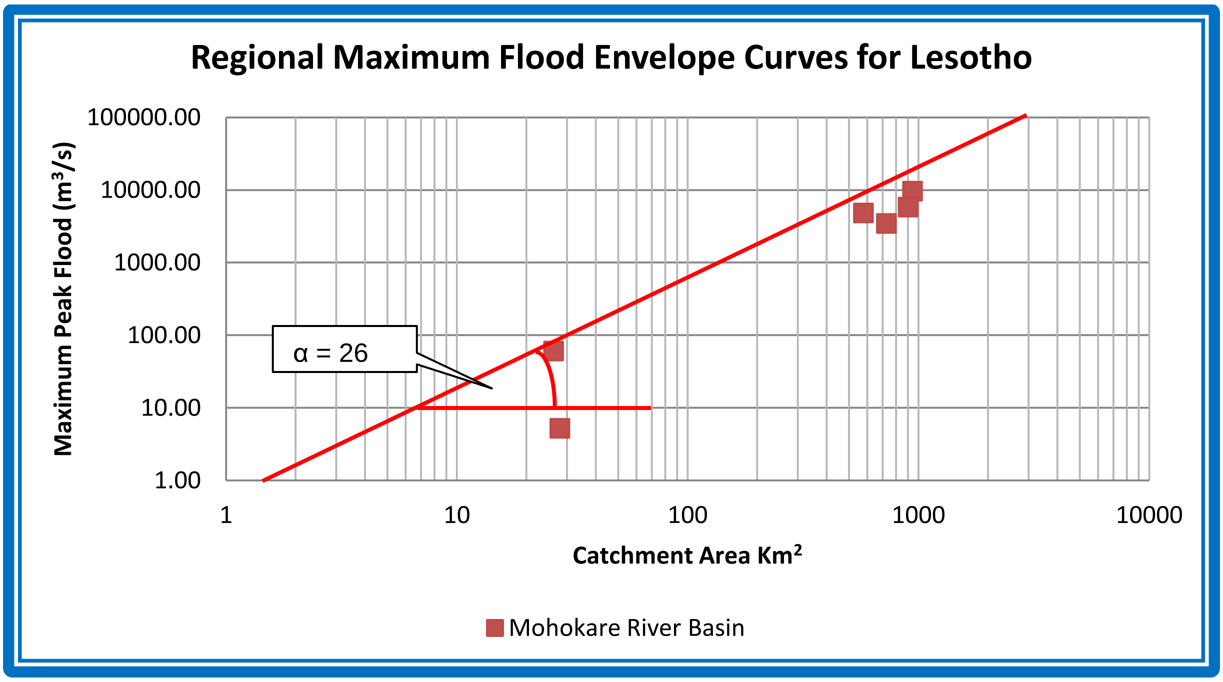


Figure 5.3: Mohokare River Basin Curve

The derived K_e value of 5.12 was accepted as the representative of the true regional coefficient for the Mohokare basin. The Mohokare basin is therefore renamed region K5.12 (Figure 5.4) in accordance with Kovacs' nomenclature in Figure 2.5.

The envelope line was traced close to the highest observed K value as illustrated in Figure 5.3. There is a change ($\Delta K = 1.12$) in K_e values between the highest individual K value of 4.00 and the newly established Francou – Rodier regional coefficient (K_e) value of 5.12. The ΔK of 1.12 is accepted in this study as the envelope line is drawn very close and touching the point of the observed maxima for the highest individual K value of 4.00.

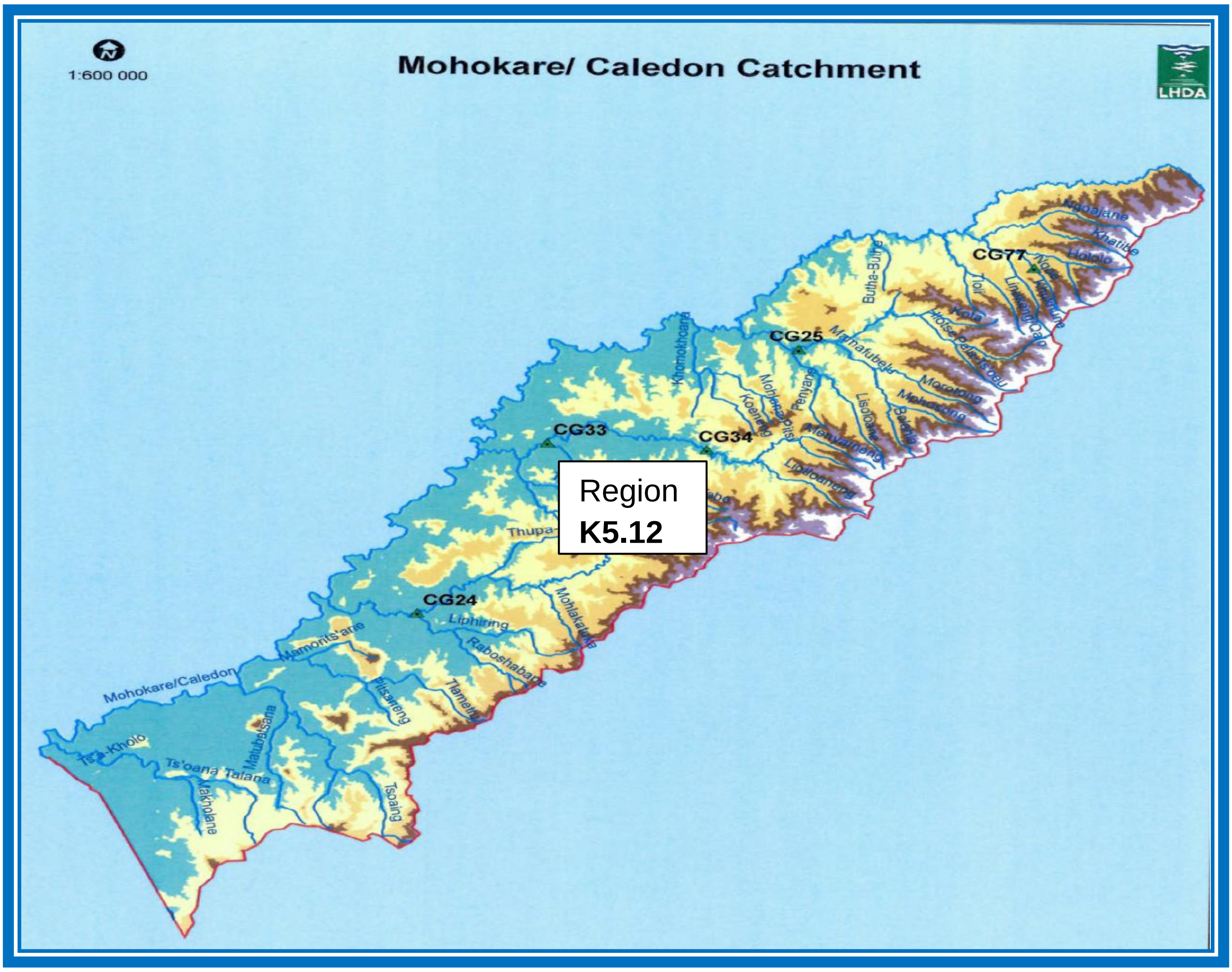


Figure 5.4: Mohokare River Basin (K5.12)

The K_e value of 5.12 is then substituted back into equation (12) to provide equation (20), which gives an easier way of calculating the RMF for any given catchment area within the Mohokare River basin.

$$Q = 124.74A^{0.488} \quad \text{......................................} \quad (20)$$

5.3 Makhaleng River Basin

Maximum flood peak records for the Makhaleng basin were also plotted against their corresponding catchment areas (Figure 5.5).

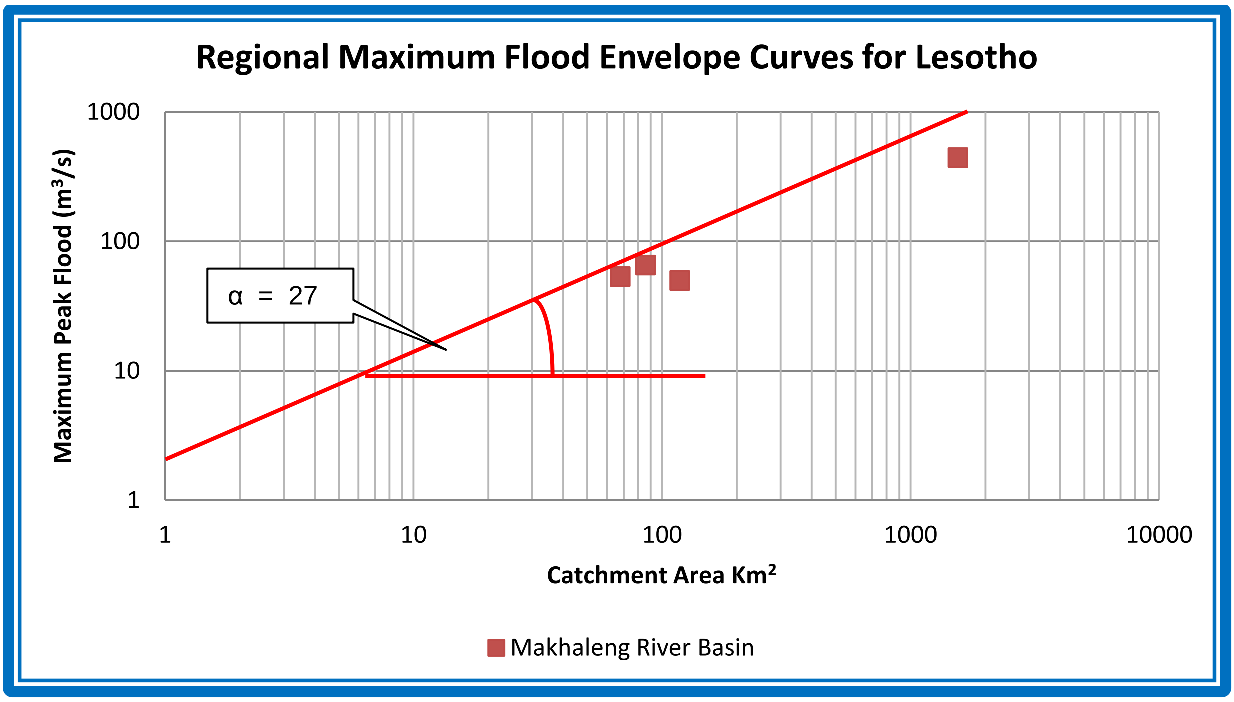


Figure 5.5: Makhaleng River Basin Curve

The envelope curve is drawn on the upper bound of the discharge points and the slope of the envelope line is determined as α = 27^0 (Figure 5.5). The corresponding K_e value for this slope is therefore calculated as 4.90 (K_e = 4.90). The Makhaleng River basin can be referred to as region K4.90 (Figure 5.6).

The envelope line was traced very close to the highest observed K value as illustrated in Figure 5.5. There is a change (ΔK = 1.8) in K_e values between the highest individual K value of 3.10 and the newly established Francou – Rodier regional coefficient (K_e) value of 4.90. The ΔK of 1.8 is accepted in this study as the envelope line is appropriately drawn very close and touching the point of the observed maxima for the highest individual K value of 3.10.

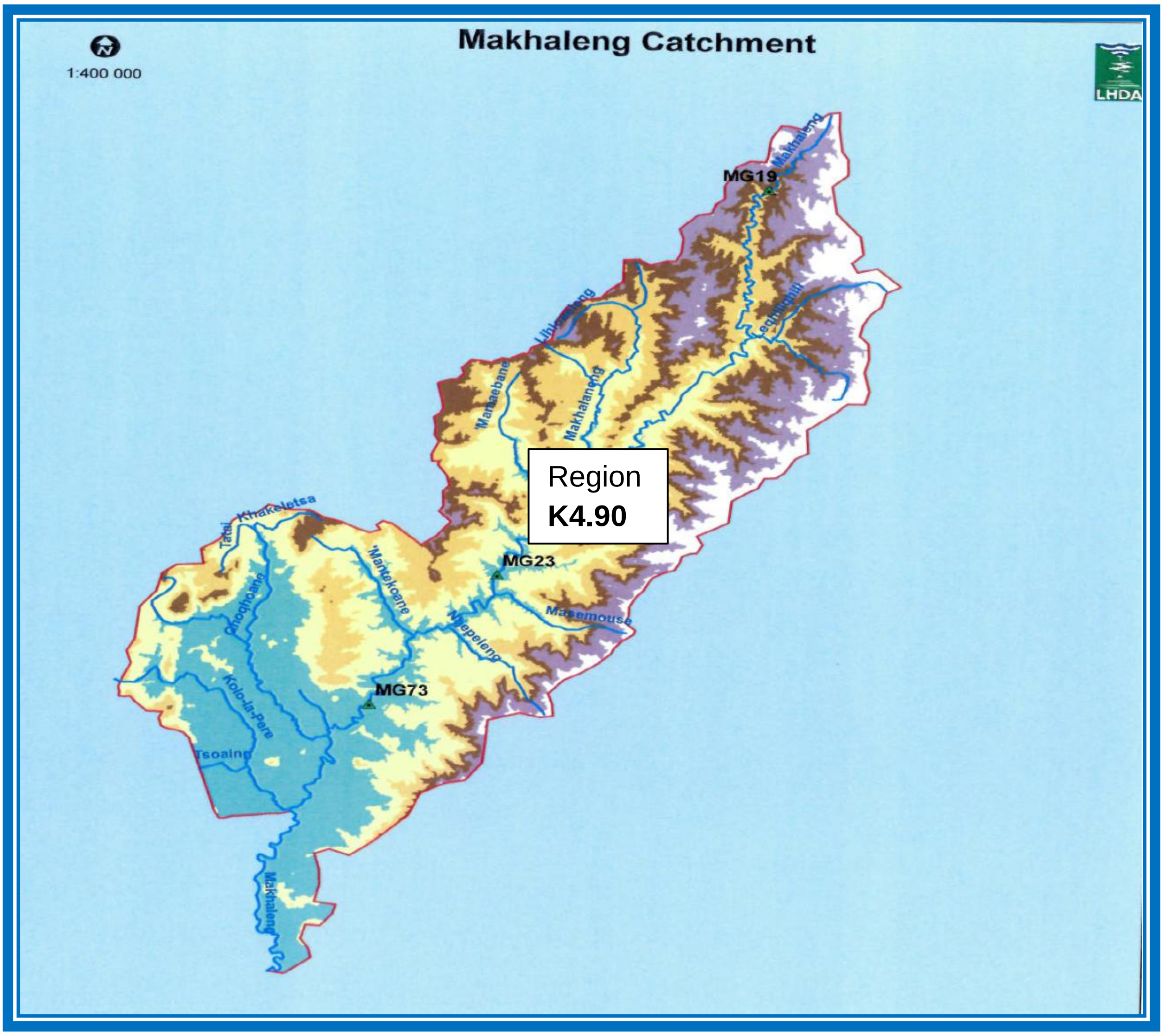


Figure 5.6: Makhaleng River Basin (K4.9)

The K_e value of 4.90 is then substituted back into equation (12) to provide equation (21), which gives a way of calculating the RMF for any given catchment area within the Makhaleng River basin with ease.

$$Q = 83.176A^{0.51} \quad \text{.....} \quad (21)$$

5.4 Re – analysis of Kovacs Data

The maximum flood peaks data that are retained from Kovacs' (1988) study are plotted against their corresponding catchment areas on the logarithmic scale and the envelope curve is drawn on the upper bound of the points (Figure 5.7). The slope of the envelope line was determined and the Francou – Rodier regional coefficient (K_e) value calculated by substituting the value of the slope into equation (13). The envelope slope is therefore determined as $\alpha = 25^0$ (Figure 5.7) and the Francou and Rodier regional coefficient K_e value was calculated to be 5.34 for Kovacs' data.

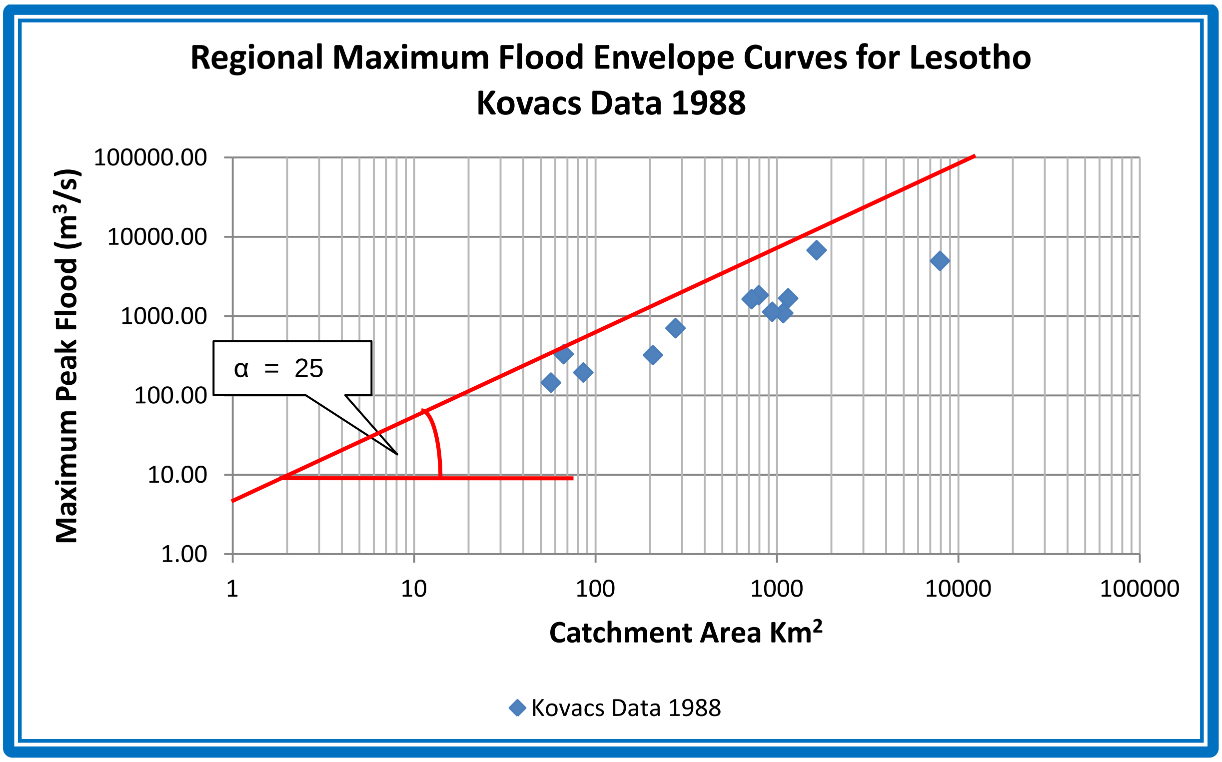


Figure 5.7: Envelope Curve for Kovacs (1988)

The derived K_e value of 5.34 (K_e = 5.34) is different and higher than the K_e value of 5 that was initially derived by Kovacs in his study. The problem with Kovacs' data is that it could not be verified and its source is not known. Kovacs' data could not be updated with recently collected information because his dataset and the newly established catalogue of maximum recorded flood peaks are different for the same periods (prior to 1988).

The lengths of both datasets are different as well, with very long periods being observed in Kovacs' dataset. No station in Lesotho had the record length of 200 years in 1988. Some flood peaks in Kovacs' data are observed to have occurred before the stations from which they are collected were commissioned.

It has therefore been difficult to update Kovacs' data as it could not be verified and its origin could not be established. A newly compiled catalogue has been used instead, to update Kovacs' empirical flood study on Lesotho catchments.

5.5 Fitting Probability Distributions

The regional maximum flood (RMF) represents the maximum flood peak that can be expected at a given site. Once the RMF is known for different river basins it then becomes necessary to investigate the relationship between the established RMF and its associated return period, using a probabilistic approach.

The Log Pearson Type III, Log Normal, EV1 and GEV probabilistic distributions were therefore fitted to the annual maximum flood series (AMS) of the flow measuring stations within the 3 hydrologically homogeneous river basins that characterize the hydrological conditions of Lesotho. The distributions were fitted to the historical AMS to enable the selection and adoption of the distribution that portrays the best fit to the annual maximum series (Figure 5.8).

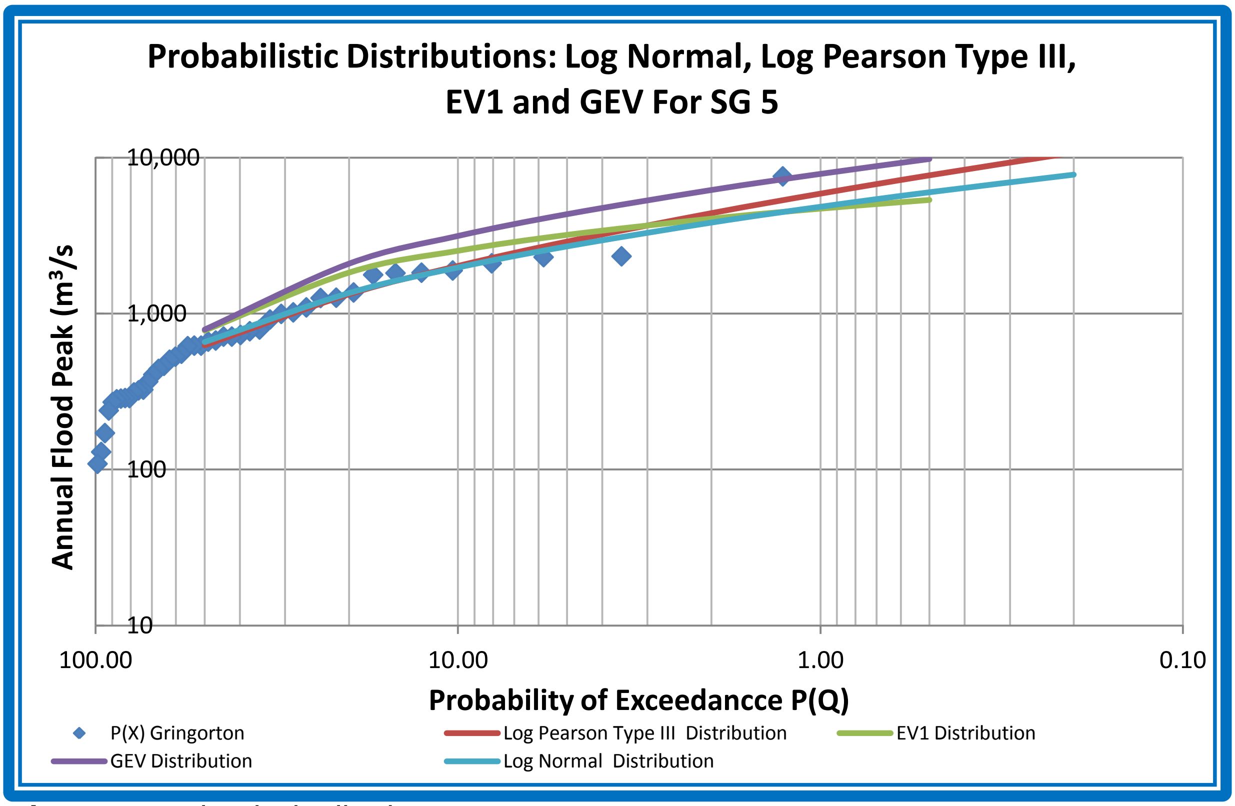


Figure 5.8: Fitted Distributions

Figure 5.8 portrays the fitted flood frequency distributions to the annual maximum flood series of the Senqu River @ Koma – Koma (SG 5). The AMS for this station is considered accurate with the longer record length of 44 years. Figure 5.8 illustrates that the Log Pearson Type III distribution has the best fit to the AMS of SG 5 as compared with other distributions.

The hypothesis for the goodness of fit for the respective distributions is further verified with the analysis of the coefficient of determination (R^2) of all the fitted distribution curves to the AMS of SG 5 as an example. Figure 5.9 portrays the best fit of the Log Pearson Type III distribution on SG 5 flood time series.

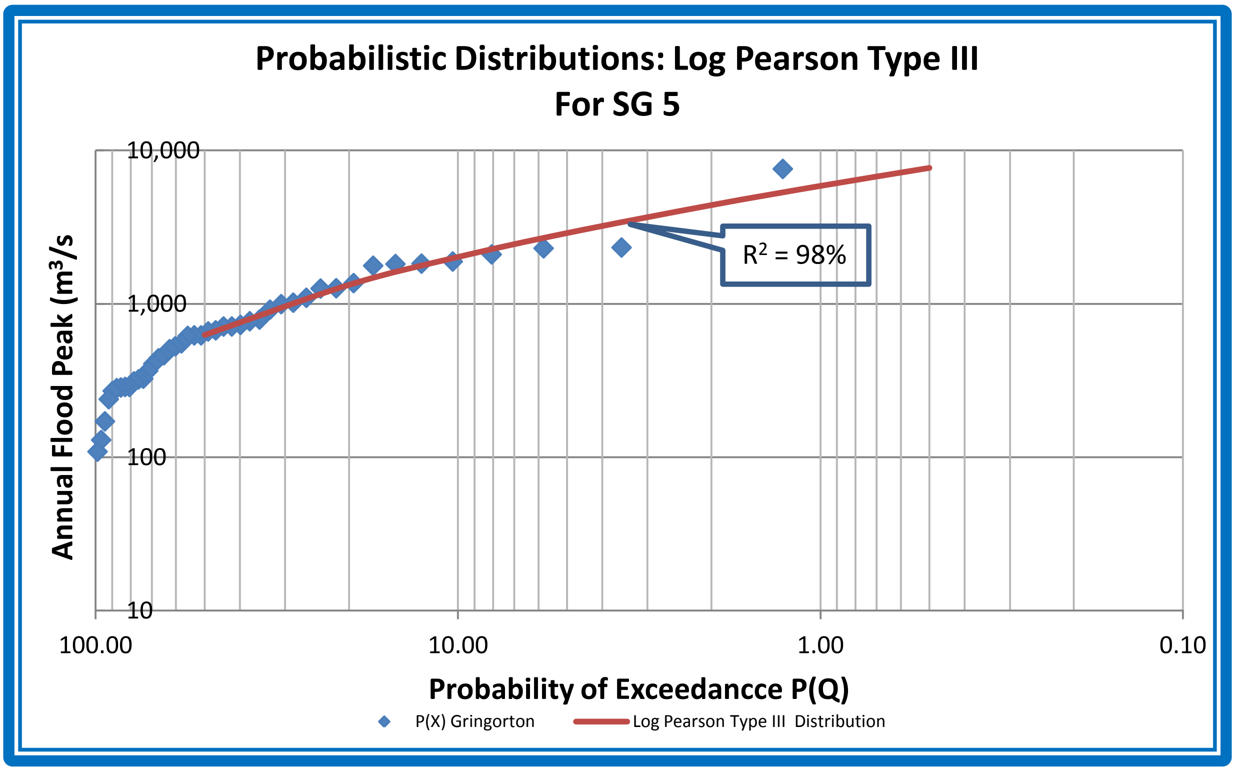


Figure 5.9: Determination of Goodness of Fit

The selection of the best fit of the distribution to the AMS is based on the coefficient of determination (R^2) of the fitted distribution in respective basins (Figure 5.9). The AMS is arranged in descending order of magnitude and the corresponding plotting positions are calculated according to Gringorton (equation 15). The annual maximum flood peak discharges are then plotted against their corresponding probabilities of exceedances (P(Q)). The P(Q) values are made the abscissa and the discharge (Q) values are made the ordinate. Figure 5.9 illustrates the 98% goodness of fit for the Log Pearson Type III distribution to the SG 5 flood time series as an example.

5.5.1 Senqu River Basin

A test for the goodness of fit of 4 selected probabilistic distributions was done on all stations within the Senqu River basin where AMS is available. The results for the goodness of fit are presented in Table 5.2. The data and relevant calculations for each hydrometric station are presented in Appendix 7 (7A, 7B, 7C, etc.)

Table 5.2: Coefficients of Determination in Senqu Basin

Test for Goodness of Fit for Probabilistic Distributions											
Senqu River Basin % of Goodness of Fit											
Distribution	**SG3**	**SG4**	**SG4A**	**SG5**	**SG6**	**SG7**	**SG8**	**SG17**	**SG36**	**SG40**	**SG42**
EV1	92	95	94	90	92	91	93	96	94	94	96
GEV	93	92	95	94	93	94	95	84	96	94	97
Log Pearson Type III	**96**	91	**97**	**98**	**98**	96	94	96	**98**	**97**	88
Log Normal	95	**97**	97	97	97	**97**	**97**	**97**	97	97	**97**

The Log Pearson Type III distribution has the highest percentage for the goodness of fit (bold) and dominates the majority of the stations within the Senqu River basin. The Log Normal Distribution is also giving good results for the goodness of fit (it must however be noted that where both the Log Pearson Type III and Log Normal distributions are seen to be tied on 97%, the rounding off from 97.3 and 96.6 has been respectively effected, hence Log Pearson Type III distribution is selected).

Therefore the Log Pearson Type III distribution has been selected to fit the annual maximum series within the Senqu River basin. Table 5.3 provides the flood discharges calculated for required return periods using the Log Pearson Type III distribution. The corresponding fitted curves of the Log Pearson Type III distribution to the annual maximum series are illustrated in Appendix 9A.

Table 5.3: Q_T calculations with Log Pearson Type III Distribution

Log Pearson Type III Discharge Q_T (m^3/s) For Lesotho River Basins											
Senqu River Basin											
Return Period	SG3	SG4	SG4A	SG5	SG6	SG7	SG8	SG17	SG36	SG40	SG42
2	1 039	609	1 206	627	236	100	512	257	92	89	99
5	2 316	1 057	2 268	1 329	526	237	1 001	660	158	171	146
10	3 473	1 340	3 176	2 019	812	363	1 365	1 056	215	242	171
20	4 822	1 591	4 207	2 892	1 173	512	1 731	1 539	281	322	190
50	6 925	1 882	5 794	4 397	1 789	744	2 215	2 323	387	446	210
100	8 770	2 077	7 188	5 864	2 384	947	2 579	3 034	483	554	222
200	10 867	2 253	8 768	7 687	3 111	1 178	2 944	3 857	595	677	232
500	14 019	2 458	11 175	10 746	4 320	1 522	3 417	5 121	774	863	244

The relationship between the calculated discharge (Q_T), with the T – years return period, and the derived Q_{RMF} for the flow measuring stations within the Senqu River basin can be deduced as provided in Table 5.4. The Q_T/Q_{RMF} ratios and their calculated average values are presented in Table 5.4. These average ratios can be applied to the RMF of any flow measuring station with any given catchment area to calculate the required discharge with the specified return period within the Senqu basin.

Table 5.4: Q_T/Q_{RMF} Ratios in the Senqu Basin

Q_T/Q_{RMF} Ratios For Lesotho River Basins											
Senqu River Basin											
Return Period	SG3	SG4	SG4A	SG5	SG6	SG7	SG8	SG17	SG36	SG40	SG42	Average
2	0.06	0.05	0.09	0.05	0.04	0.03	0.07	0.06	0.02	0.04	0.03	0.05
5	0.13	0.08	0.17	0.12	0.10	0.06	0.13	0.15	0.04	0.08	0.04	0.10
10	0.20	0.10	0.24	0.18	0.15	0.09	0.18	0.24	0.05	0.12	0.05	0.14
20	0.27	0.12	0.32	0.25	0.21	0.13	0.23	0.34	0.07	0.16	0.05	0.20
50	0.39	0.14	0.44	0.38	0.33	0.19	0.29	0.52	0.10	0.22	0.06	0.28
100	0.49	0.15	0.54	0.51	0.43	0.24	0.34	0.68	0.12	0.27	0.06	0.35
200	0.61	0.17	0.66	0.67	0.57	0.30	0.39	0.86	0.15	0.33	0.07	0.43
500	0.79	0.18	0.84	0.93	0.79	0.39	0.45	1.14	0.19	0.42	0.07	0.56

5.5.2 Mohokare River Basin

A test for the goodness of fit of 4 selected probabilistic distributions was also performed for all stations within the Mohokare River basin and Table 5.5 presents the results for the coefficient of determination for each distribution. The data and relevant calculations are presented in Appendix 3 (3A, 3B, 3C, etc.)

Table 5.5: Coefficients of Determination in Mohokare basin

Goodness of Fit Table				
Mohokare River Basin % of Goodness of Fit				
Distribution Type	CG24	CG25	CG33	CG34
EV1	92	94	94	96

Goodness of Fit Table				
Mohokare River Basin % of Goodness of Fit				
GEV	94	93	85	89
Log Pearson Type III	**98**	93	91	N/A
Log Normal	97	**97**	**97**	**97**

The North Phuthiatsana River @ Mapoteng (CG 34) has the skewness value of -3.20 as a result the value of the standardized variate for the Log Pearson Type III distribution could not be established from Appendix 6, which has the range between 1.4 and -1.4.

The Log Normal probabilistic distribution is observed to have the higher percentage (bolded) for the goodness of fit to the AMS within the Mohokare River basin. The Log Normal distribution is observed to constantly give the best fit with 97% goodness of fit for all stations.

Therefore the Log Normal distribution has been selected to fit the annual maximum series within the Mohokare River basin. Table 5.6 presents the flood discharges that are calculated for required return periods using the Log Normal distribution. The corresponding fitted curves of the Log Normal distribution to the annual maximum series are illustrated in Appendix 9B.

Table 5.6: Q_T for Mohokare River Basin

Log Normal For Lesotho River Basins				
Mohokare River Basin				
Return Period	**CG24**	**CG25**	**CG33**	**CG34**
2	135	178	140	32
5	299	341	352	69
10	453	479	570	103
20	638	634	848	142
50	939	870	1 326	206
100	1 214	1 073	1 785	264
200	1 537	1 301	2 345	331

The relationship between the calculated discharge (Q_T), with the T – years return period, and the derived Q_{RMF} for the flow measuring stations within the Mohokare River basin can be deduced as provided in Table 5.7. The Q_T/Q_{RMF} ratios and their calculated average values are presented in Table 5.7. These average ratios can be applied to the RMF of any flow measuring station with any given catchment area to calculate the associated discharge with the specified return period within the Mohokare basin.

Table 5.7: Q_T/Q_{RMF} Ratios in the Mohokare Basin

Q_T/Q_{RMF} Ratios For Lesotho River Basins					
Mohokare River Basin					
Return Period	**CG24**	**CG25**	**CG33**	**CG34**	**Average**
2	0.04	0.06	0.04	0.01	0.04
5	0.09	0.11	0.10	0.02	0.08
10	0.13	0.16	0.16	0.04	0.12
20	0.18	0.21	0.25	0.05	0.17
50	0.27	0.29	0.38	0.07	0.25
100	0.35	0.35	0.52	0.09	0.33
200	0.45	0.43	0.68	0.12	0.42
500	0.59	0.54	0.94	0.16	0.56

5.5.3 Makhaleng River Basin

The test for the goodness of fit of 4 selected probabilistic distributions was also performed for all stations within the Makhaleng River basin and Table 5.8 presents the results for the coefficient of determination for each distribution. The data and relevant calculations are presented in Appendix 4 (4A, 4B, 4C, etc.)

Table 5.8: Coefficients of Determination in Makhaleng basin

Goodness of Fit Table				
Makhaleng River Basin % of Goodness of Fit				
Distribution Type	**MG19**	**MG23**	**MG72**	**MG73**
EV1	96	96	94	96
GEV	96	90	95	78
Log Pearson Type III	N/A	87	91	N/A
Log Normal	**97**	**97**	**97**	**97**

The Log Normal distribution is also observed to have the higher percentage for the goodness of fit to the AMS within the Makhaleng River basin. Table 5.8 constantly potrays the Log Normal distribution at 97% goodness of fit to the AMS for all the catchments within the Makhaleng River basin.

Hence the Log Normal probabilistic distribution has been selected to fit the AMS within the Makhaleng River basin. Table 5.9 presents the flood discharges that are calculated for required return periods using the Log Normal distribution. The corresponding fitted curves of the Log Normal distribution to the annual maximum series are illustrated in Appendix 9C.

Table 5.9: Q_T for Makhaleng River Basin

Log Normal For Lesotho River Basins				
Makhaleng River Basin				
Return Period	**MG19**	**MG23**	**MG72**	**MG73**
2	19	170	12	27
5	34	303	26	59
10	46	410	38	89
20	60	526	52	125
50	80	696	74	182
100	97	839	93	235
200	116	996	116	296

The relationship between the calculated discharge (Q_T), with the T – years return period, and the derived Q_{RMF} for the flow measuring stations within the Makhaleng River basin can then be deduced as provided in Table 5.10. The Q_T/Q_{RMF} ratios and their calculated average values are presented in Table 5.10. These average ratios can be applied to the RMF of any flow measuring station with any given catchment area to calculate the required discharge with the specified return period within the Makhaleng basin.

Table 5.10: Q_T/Q_{RMF} Ratios in the Makhaleng Basin

Q_T/Q_{RMF} Ratios For Lesotho River Basins					
Makhaleng River Basin					
Return Period	**MG19**	**MG23**	**MG72**	**MG73**	**Average**
2	0.02	0.05	0.02	0.03	0.03
5	0.04	0.09	0.04	0.06	0.06
10	0.06	0.12	0.05	0.09	0.08
20	0.07	0.15	0.07	0.13	0.11
50	0.10	0.20	0.10	0.19	0.15
100	0.12	0.24	0.13	0.25	0.18
200	0.14	0.28	0.16	0.31	0.22
500	0.18	0.35	0.21	0.41	0.29

The magnitudes of annual maximum flood peaks within the Makhaleng basin are very small compared to their RMF. The ratios of Q_T/Q_{RMF} are also very small and indicate the ratio of 0.22 for the 1:200 year flood (Table 5.10). The Makhaleng basin is the hydrologically dry basin whilst the other two basins are relatively wet and experience good flow every year.

6 RESULTS AND DISCUSSIONS

6.1 Regional Maximum Flood Results – Empirical Approach

The RMF results for the maximum recorded flood peak analysis done in chapter 5 are presented in Tables 6.1, 6.2 and 6.3 for the Senqu, Mohokare and Makhaleng basins respectively.

The Tables provide the actual maximum recorded flood peaks as well as the RMF calculated using the 3 derive empirical equations for the river basins as follows;

$Q = 164.44A^{0.473}$ for Senqu

$Q = 124.74A^{0.488}$ for Mohokare

$Q = 83.176A^{0.51}$ for Makhaleng

Kovacs' RMF values computed with the re – established K_e value of 5.34 are provided in the last column but are not considered to be of value due to the difficulties in verifying the originally used flood peaks.

Table 6.1: Senqu Basin Regional Maximum Flood Calculations

Regional Envelope Curve Equations K_e Values					
No.	**Station Number**	**Catchment Area (km^2)**	**Maximum Recorded Flood Peak Q_P**	**Derived Equation for $K_e = 5.27$ $Q = 164.44A^{0.473}$**	**Kovacs Data $K_e = 5.34$**
1	SG3	19 875	6 216	17 746	
2	SG4	11 000	1 691	13 415	
3	SG4A	10 749.8	1 788	13 270	
4	SG5	7 950	7 598	11 505	12 291
5	SG6	1 660	1 361	5 484	5 923
6	SG7	797	584	3 876	4 208
7	SG8	3 240	2 996	7 525	
8	SG8A	3 232.8	2 823	7 517	
9	SG9	847	622	3 989	
10	SG10	277	710	2 351	2 572
11	SG11	57	146	1 113	1 231
12	SG14	67	334	1 202	1 327
13	SG17	1 087	1 479	4 489	4 863
14	SG17A	1 080.9	860	4 477	

Regional Envelope Curve Equations K_e Values					
No.	**Station Number**	**Catchment Area (km^2)**	**Maximum Recorded Flood Peak Q_P**	**Derived Equation for $K_e = 5.27$ $Q = 164.44A^{0.473}$**	**Kovacs Data $K_e = 5.34$**
15	SG36	852	233	4 000	
16	SG40	208	84	2 053	2 250
17	SG42	652	667	3 525	
18	SG45	1 157	1 001	4 623	5 006
19	SG48	323	476	2 528	
20	SG51	261	80	2 286	
21	SG67	135	36	1 674	
22	SG 79	281	18	2 367	
23	SG80	2 255	1 376	6 339	

Table 6.2: Mohokare Basin Regional Maximum Flood Calculations

Regional Envelope Curve Equations K_e Values					
	Station Number	**Area km^2**	**Maximum Recorded Flood Peak Q_P**	**Derived Equation for $K_e = 5.12$ $Q = 124.74A^{0.488}$**	**Kovacs Data K = 5.34**
1	CG24	945	1 024	3 493	4 556
2	CG25	728	602	3 079	4 034
3	CG33	905	384	3 421	
4	CG34	579	58	2 756	
5	CG77	26	61	618	

Table 6.3: Makhaleng Basin Regional Maximum Flood Calculations

Regional Envelope Curve Equations K_e Values					
	Station Number	**Area Km^2**	**Maximum Recorded Flood Peak Q_P**	**Derived Equation for $K_e = 4.9$ $Q = 83.176A^{0.51}$**	**Kovacs Data K = 5.34**
1	MG19	86	66	806	1 491
2	MG23	1 554	444	3 529	
3	MG 72	68	53	715	
4	MG73	118	50	948	

The results from the analysis using Kovacs original data with the newly established K_e value of 5.34 and the originally accepted K_e value of 5 are presented in Table 6.4. The K_e value of 5.34 was obtained using the same procedure as used by Kovacs

(1988) and it is seen to overestimate flood peak magnitudes, while the original K_e value of 5 under estimates design flood peaks.

Table 6.4: Kovacs Regional Maximum Flood Calculations

Kovacs Data 1988	Station Number	Area (km^2)	Maximum Recorded Flood Peak Q_P	K = 5 Flood	Revised K = 5.34 Flood
1	SG5	7 950	5 000	8 916	12 291
2	SG6	1 660	6 820	4 074	5 923
3	SG7	797	1 850	2 823	4 208
4	SG10	277	710	1 664	2 572
5	SG11	57	146	755	1 231
6	SG14	67	334	819	1 327
7	SG17	1 087	1 100	3 297	4 863
8	SG40	208	325	1 442	2 250
9	SG45	1 157	1 690	3 401	5 006
10	MG19	86	196	927	1 491
11	CG24	945	1 140	3 074	4 556
12	CG25	728	1 650	2 698	4 034

The huge differences between calculated and measured values in Kovacs' data (Table 6.4) clearly indicates a problem with the identification of homogeneous regions for the application of one single K_e value as proposed by him (K_e = 5). The K_e values derived in this study clearly demonstrate hydrologically homogeneous regions as illustrated in Figure 6.1, where the newly calculated RMF results for the 3 basins are plotted against their corresponding catchment areas on a logarithmic scale.

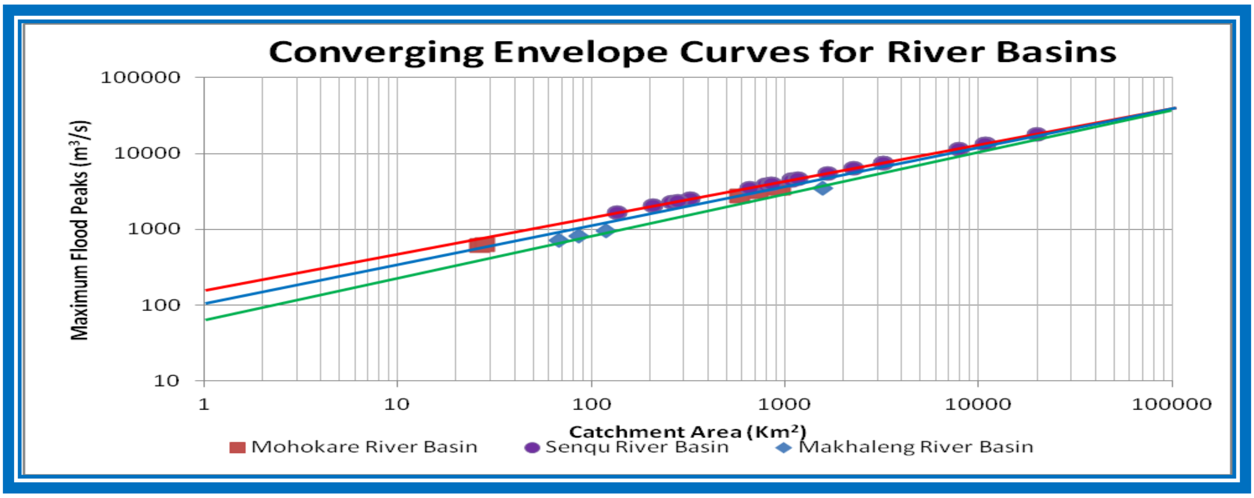


Figure 6.1: Derived envelope curves for Lesotho catchments

It can therefore be concluded that the Lesotho catchments adhere to the original basic principle of the methodology used by Francou and Rodier and that the newly established RMF equations can be used for any further calculations.

It is worth mentioning that the catchments in the highlands are characterized by wetlands. The wetlands have the features of very large storages and are able to influence flooding conditions. They would absorb most of the flood water, attenuate it and later release it as constant flow to the river channels. This is why most of Lesotho rivers have substantial flow throughout the year (are perennial streams) and got Lesotho to be classified as a water abundant country.

6.2 Flood Frequency Analysis

Probabilistic flood frequency distributions; Log Pearson Type III, EV1, GEV and Log Normal were fitted to the AMS data of the 3 river basins in Lesotho.

The Log Pearson Type III distribution has been adopted to be applied within the Senqu River basin, while the Log Normal distribution has been selected and adopted for use within the Mohokare and Makhaleng River basins.

The Q_T discharge values obtained with the application of these distributions (Tables 5.3, 5.6 and 5.9) were used for the calculation of the ratios of the Q_T to Q_{RMF} relationship for the respective river basins in Lesotho. The calculated average ratios are provided in Table 6.5.

Table 6.5: Regional Q_T/Q_{RMF} for Lesotho

QT/QRMF Ratios For Lesotho River Basins			
Return Period	**Senqu Basin**	**Mohokare Basin**	**Makhaleng Basin**
2	0.05	0.04	0.03
5	0.10	0.08	0.06
10	0.14	0.12	0.08
20	0.20	0.17	0.11
50	0.28	0.25	0.15
100	0.35	0.33	0.18
200	0.43	0.42	0.22
500	0.56	0.56	0.29

7 CONCLUSIONS

The existing literature regarding various empirical flood approaches was reviewed in order to enable the appropriate selection of a suitable and applicable empirical flood calculation procedure for Lesotho.

The Francou and Rodier empirical approach that uses the original concept of envelope curves was found to be well suited for the definition of regional maximum flood (RMF) determination. In this method the envelope curve is drawn on the upper bound of the individual K - values in hydrologically homogeneous regions. The curve represents the upper limit of maximum flood peaks that can reasonably be expected at a given site.

The Nash and Shaw approach is an acceptable technique though it focuses on the mean of the recorded annual maximum series. Its sound determination of the parameter values required to be used in equation (16) can be used alongside Kovacs to determine flood peaks for any required return period in the region. Fuller’s formula, equation (4), for determining floods for any given return period needs to be investigated further to establish its usefulness as RMF calculation procedure.

Kovacs (1980) adopted the Francou and Rodier empirical flood approach and applied it to 355 catchments in South Africa. He revised his work in 1988 and included the whole of Southern Africa subcontinent.

No method other than the Francou and Rodier empirical flood approach in the literature was found to be suitable for the purpose of this study and it was, as applied by Kovacs, selected to revise the RMF methodology for Lesotho.

Maximum recorded flood peaks were collected from Lesotho and an up to date catalogue of 29 catchments was compiled. A plot of the collected flood peaks against their corresponding catchment areas was constructed on a logarithmic scale.

An envelope curve was then drawn on the upper bound of the cloud of points on the plot. This envelope curve represents the maximum flood peaks that can be expected within the respective basins in Lesotho.

Lesotho has been divided into 3 major hydrologically homogenous river basins. The envelope curve was drawn for each river basin and regional maximum flood peaks estimated according to Francou and Rodier equation. The slopes to the envelope curves were determined and the corresponding Francou and Rodier regional coefficients (K_e values) were established and used to derive the regional maximum flood (RMF) values for each river basin.

The established K_e values for the river basins in Lesotho are given as:

- 5.27 for Senqu River basin
- 5.12 for Mohokare River basin and
- 4.90 for Makhaleng River basin

The derived relationships between maximum recorded flood peaks and the corresponding catchment areas are derived from the K_e values as:

- Senqu basin: $Q = 164.44A^{0.473}$
- Mohokare basin: $Q = 124.74A^{0.488}$
- Makhaleng basin: $Q = 83.176A^{0.51}$

This update has confirmed Kovacs' statement that some modifications might be expected to occur in Lesotho. Indeed the envelope curve has moved from $K_e = 5$ for the whole of Lesotho in Kovacs (1988) to $K_e = 5.27$ for the Senqu basin, $K_e = 5.12$ for the Mohokare basin and $K_e = 4.90$ for the Makhaleng basin in 2013.

A probabilistic distribution was fitted to annual maximum series and the Log Pearson Type III distribution has been adopted and used to fit the Senqu River basin, while the Log Normal distribution has been adopted for both the Mohokare River and Makhaleng River basins.

The Q_T/Q_{RMF} ratios for the relationship between the Q_T and the RMF are computed as provided in Table 7.1.

Table 7.1: Comparison of Q_T/Q_{RMF} for this Study and Kovacs (1988)

QT/QRMF Ratios For Lesotho River Basins				
Return Period	**Senqu Basin**	**Mohokare Basin**	**Makhaleng Basin**	**Kovacs Estimates**
2	0.05	0.04	0.03	
5	0.10	0.08	0.06	
10	0.14	0.12	0.08	
20	0.20	0.17	0.11	0.20
50	0.28	0.25	0.15	0.50
100	0.35	0.33	0.18	0.58
200	0.43	0.42	0.22	0.65
500	0.56	0.56	0.29	

The 1:20 years flood for both Senqu and Mohokare basins are observed to have the Q_T/Q_{RMF} results that are similar to Kovacs' estimate. Thereafter the Kovacs ratios are significantly higher for return periods larger than 1:20 years (Table 7.1). These ratios are characteristic of the historical annual maximum series from which they are derived and they can only be applied in those particular catchments or regions.

Although data accuracy plays an extremely important role, it is clearly observed from the results presented in Table 7.1 that the RMF represents a flood event that is significantly larger than the 1:200 year event as what is generally accepted. This is because the RMF ≥ 1:10 000 year flood for some stations in this study.

The Makhaleng basin Q_T values and associated ratios seem suspicious and more detailed analysis will be required to validate the results.

8 RECOMMENDATIONS

It is firstly recommended that organizations that are entrusted to collect flow data must ensure appropriate collection at all times. The DWA of Lesotho must pay more attention to data collection and timely processing and analysis to ensure that adequate records are available and provided as the need arises. Good flow records were obtained from the LHDA and there should not be any differences in standards.

It is recommended that regular evaluations on the quality of collected data must be in place within the Department of Water Affairs of Lesotho to ensure that its objectives of collecting good reliable data are adequately met. Quality control measures should also be in place to ensure that processing of collected data is done adequately.

The statistics and records for annual maximum series must be processed and updated on annual bases to avoid last minute processing to meet the dissemination requirements. Many mistakes could occur and render a useless product.

The newly established K_e values for the 3 river basins in Lesotho are recommended to be adopted for the determination of the regional maximum floods (RMFs) within the respective river basins in Lesotho.

The derived Q_T/Q_{RMF} ratios are recommended to be used to enable the calculation of flood peaks for required return periods in ungauged catchments in Lesotho. It is further recommended that this study should be repeated after 5 years during which intensive data collection would be effected within the Makhaleng and some parts of the Mohokare basins.

9 REFERENCES

1 Adamson, P. T. 1978. The statistics of extreme values and analyses of floods in South Africa. Department of Water Affairs, Division of Hydrology. South Africa: Division of Hydrology.

2 Adamson, P. T. 1983. Southern African storm rainfall. Technical Report TR102. Department of Environment Affairs, Division of Hydrology. Pretoria, South Africa: Division of Hydrology.

3 Alexander, W. J. R. 2000. Flood risk reduction measures. Pretoria, South Africa: University of Pretoria, South Africa: Department of Civil Engineering.

4 Beable, M. E. and Mckerchar, A. I. 1982. Regional flood estimation in New Zealand. New Zealand: Ministry of Works and Development.

5 Beirlant, J., Goegebeur, Y., Teugels, J. and Segers, J. 2005. Statistics of extremes. Theory and Applications. New Jersey: John Wiley.

6 Biondić, D., Barbalić, D. and Petraš, J. 2002. Envelope curves of maximum specific discharges in the Danube River catchment area. Conference of the Danube Countries on hydrological forecasting and hydrological bases of water management. Romania, Croatia: Bucharest.

7 Boorman, D. B. 1985. A review of the Flood Studies Report. Rainfall – runoff model parameter estimation equations. London: NERC.

8 Boorma, D. B., Acreman, M. C. and Packman, J. C. 1990. A review of design flood estimation using the FRS rainfall – runoff method. London: Institute of Hydrology Report No. 111.

9 Bureau of Statistics. 2006. 2006 Analytical Report Volume IIIB Socio – Economic Characteristics. Maseru, Lesotho: Bureau of Statistics.

10 Camacho, L. A. and Lee, M. J. 1999. Multi linear discrete lag – cascade model for channel routing. London, UK: Department of Civil and Environmental Engineering.

11 Campbell, A. P. 1953. Provisional standard for empirical estimation of flood discharges. New Zealand.

12 Chow, V. T. 1964. Handbook of applied hydrology. New York: McGraw – Hill.

13 Chow, V. T., Maidment, D. R. and Mays, L. W. 1988. Applied hydrology. New York: McGraw – Hill.

14 Cole, G. 1965. An application of the regional analysis of flood flows. Proceedings of the London Symposium on river flood hydrology. London: Institution of Civil Engineers.

15 Creager, W. P., Justin, J. D. and Hinds, J. 1945. Engineering for dams. New York, USA: John Wiley & Sons.

16 Cunnane, C. and Lynn, M. A. 1975. Flood estimation following the flood studies report. Ireland: Institution of Engineers of Ireland.

17 Cunnane, C. 1988. Methods and merits of regional flood frequency analysis. Journal of Hydrology, 100.

18 Dooge, J. C. I. 1973. Linear theory of hydrologic systems. Washington, DC: Agricultural Research Service.

19 Francou, J and Rodier, J. A. 1967. Essai de classification des crues maximales. Proceedings of the Laningrad Symposium on floods and their computation. Laningrad: UNESCO.

20 George, A. G. and Alistair, I. M. 2008. Dependence of flood peak magnitude on catchment area. New Zealand.

21 Griffiths, G. A. 1989. Nonparametric solutions of the design flood problem. Proceedings of the hydrology and water resources symposium. New Zealand: New Zealand Hydrological Society.

22 Hydrological Research Unit (HRU). 1972. Design flood determination in South Africa. Report No. 1/72. Johannesburg, South Africa: University of the Witwatersrand.

23 Hydrological Research Unit (HRU). 1981. Surface water resources of South Africa. University of Witwatersrand, Department of Civil Engineering. South Africa: University of Witwatersrand.

24 Institute for Water and Environmental Engineering. 2012. Flood Hydrology Course. Stellenbosch University, South Africa: Department of Civil Engineering.

25 Johnstone, D. and Cross, W. P. 1949. Elements of applied hydrology. New York: Ronald Press.

26 Kjeldsen, T. R. 2007. The revitalized Flood Studies Report (FSR)/FEH rainfall – runoff method. Wallingford, UK: Centre of Ecology and Hydrology.

27 Kovacs, Z. P. 1980. Maximum flood peak discharge in South Africa. An empirical approach. Technical Report TR105. Department of Water Affairs, Forestry and Environmental Conservation. Pretoria, South Africa: Division of Hydrology.

28 Kovacs, Z. P. 1988. Regional maximum flood peaks in Southern Africa. An empirical approach. Technical Report TR137. Department of Water Affairs, Directorate of Hydrology. Pretoria, South Africa: Directorate of Hydrology.

29 Lynn, M. A. 1971. Flood estimation for ungauged catchments. Ireland: Institution of Engineers of Ireland.

30 McKerchar, A. I. and Pearson, C. P. 1989. Flood frequency in New Zealand. New Zealand: Division of Water Sciences.

31 Meigh, J. 1995. Regional flood estimation methods for developing countries. Wallingford, London: Institute of Hydrology.

32 Midgley, D. C., Pitman, W. V. and Middleton, B. J. 1994. Surface water resources of South Africa. Pretoria, South Africa: Water Research Commission (WRC).

33 Nash, J. E. and Shaw, B.L. 1965. Flood frequency as a function of catchment characteristics. Proceedings of the London Symposium on river flood hydrology. London: Institution of Civil Engineers.

34 Natural Environment Research Council (NERC). 1975. Flood Studies Report. Wallingford, London: NERC

35 Němec, J. 1972. Engineering Hydrology. London, UK: McGraw – Hill.

36 Nortje, J. H. 2010. Estimation of extreme flood peaks by selected statistical analyses of relevant flood peak data within similar hydrological regions. Pretoria, South Africa.

37 Pegram, G. and Parak, M. 2004. A review of the regional maximum flood and rational formula using geomorphological information and observed floods. Civil Engineering Programme. University of KwaZulu – Natal. Durban, South Africa: University of KwaZulu – Natal.

38 Rodier, J. A. and Roche, M. 1984. World catalogue of maximum observed floods. Wallingford, London: IAHS publication.

39 South African National Commission on Large Dams (SANCOLD). 1991. Guidelines on safety in relation to floods. Pretoria, South Africa: SANCOLD.

40 Shaw, E. M. 1994. Hydrology in Practice. 3rd edition. London, UK: Chapman & Hall.

41 South African National Roads Agency Limited (SANRAL). 2006. Drainage Manual. 5th Edition. Pretoria, South Africa: SANRAL.

42 Stanescu, V. A. and Matreata, M. 1997. Large floods in Europe. Flow regimes from International Experimental and Network Data (FRIEND). France: Cemagref Editions.

43 Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology. New York: McGraw – Hill.

APPENDICES

Appendix 1: Catalogue of Recorded Maximum Flood Peaks in Lesotho used in this study.

	Station Number	Geographic Position		River Name	Catchment Area (Km^2)	Mean Daily Flood Peak Q_P (m^3/s)	Peak Flood Q_P (m^3/s)	Francou Rodier K Values for this Study	Date of Peak	Record Length to 2012	Method of Measurement	RMF Region K_e	Notes
		Latitude	Longitude										
1	SG3	30^{0}21'08"	27^{0}34'05"	Senqu	19 875	4 496	6 216	4.04	12-Mar-88	39	Hydrometric Gauging station Rated Section	5.27	Seaka Bridge commenced in 1972/73
2	SG4	30^{0}03'08"	28^{0}30'04"	Senqu	11 000	1 532	1 691	3.00	17-Feb-89	47	Hydrometric Gauging station Rated Section	5.27	White Hill commenced in 1964/65.
3	SG4A	28^{0}45'38"	28^{0}14'58"	Senqu	10 749.8	1 310	1 788	3.08	17-Feb-89	25	Gauging Crump Weir Structure	5.27	Mantilane Weir at Whitehill commenced in 1986/87
4	SG5	29^{0}35'24"	28^{0}42'48"	Senqu	7 950	5 028	7 598	4.83	21-Mar-76	45	Hydrometric Gauging station Rated Section	5.27	Koma - Koma station commenced in 1966/67.
5	SG6	29^{0}17'00"	28^{0}59'00"	Senqu	1 660	959	1 361	4.00	12-Mar-88	44	Hydrometric Gauging station Rated Section	5.27	Mokhotlong station commenced in 1967/68
6	SG7	30^{0}01'30"	28^{0}43'24"	Tsoelike	797	307	584	3.66	01-Feb-67	46	Hydrometric Gauging station Rated Section	5.27	Tsoelike station in Qhacha's Nek, commenced in 1965/66.
7	SG8	29^{0}29'53"	28^{0}39'00"	Malibamatšo	3 240	2 388	2 996	4.38	01-Feb-67	45	Hydrometric Gauging station Rated Section	5.27	Paray station in Thaba - Tseka, commenced in 1966/67
8	SG8A	29^{0}29'02"	28^{0}38'45"	Malibamatšo	3 232.8	1 880	2 823	4.32	12-Mar-88	26	Gauging Crump Weir Structure	5.27	Paray Weir commenced in 1985/86

	Station Number	Geographic Position		River Name	Catchment Area (Km^2)	Mean Daily Flood Peak Q_P (m^3/s)	Peak Flood Q_P (m^3/s)	Francou Rodier K Values for this Study	Date of Peak	Record Length to 2012	Method of Measurement	RMF Region K_e	Notes
		Latitude	Longitude										
9	SG9	28^{0}32'00"	29^{0}01'06"	Malibamatšo	847	382	622	3.68	17-Oct-09	50	Hydrometric Gauging station Rated Section	5.27	Kao station in Thaba - Tseka, commenced in 1961/62
10	SG17	29^{0}33'36"	28^{0}09'24"	Senqunyane	1 087	989	1 479	4.30	31-Jan-67	48	Hydrometric Gauging station Rated Section	5.27	Marakabei station in Ha - Mohale, commenced in 1963/64
11	SG17A	29^{0}33'07"	28^{0}09'07"	Senqunyane	1 080.9	489	860	3.83	22-Sep-87	26	Gauging Crump Weir Structure	5.27	Marakabei Weir in Ha - Mohale, commenced in 1985/86
12	SG36	29^{0}14'03"	28^{0}53'01"	Khubelu	852	221	233	2.84	23-Feb-88	42	Hydrometric Gauging station Rated Section	5.27	Tlokoeng station in Mokhotlong, commenced in 1969/70
13	SG40	30^{0}24'00"	27^{0}41'48"	Qomoqomong	208	84	325	3.86	10-Dec-76	35	Hydrometric Gauging station Rated Section	5.27	Quthing station in Quthing, commenced in 1976/77.
14	SG42	29^{0}16'54"	28^{0}34'00"	Matsoku	652	257	667	3.88	12-Feb-09	41	Hydrometric Gauging station Rated Section	5.27	Ha - Seshote station in Matsoku, commenced in 197071
15	SG48	30^{0}17'00"	27^{0}29'00"	Maphutseng	323	48	476	3.95	03-Jun-08	34	Hydrometric Gauging station Rated Section	5.27	Maphutseng station in Quthing, commenced in 1977/78

	Station Number	Geographic Position		River Name	Catchment Area (Km^2)	Mean Daily Flood Peak Q_P (m^3/s)	Peak Flood Q_P (m^3/s)	Francou Rodier K Values for this Study	Date of Peak	Record Length to 2012	Method of Measurement	RMF Region K_e	Notes
		Latitude	Longitude										
16	SG51	$31^0 16'04''$	$27^0 48'05''$	Sebapala	261	15	80	2.66	15-Feb-09	33	Hydrometric Gauging station Rated Section	5.27	Sebapala Bridge station in Quthing, commenced in 1978/79
17	SG67	$30^0 09'00''$	$29^0 03'00''$	Qhoali	135	2	36	2.44	10-Feb-09	23	Hydrometric Gauging station Rated Section	5.27	Qhoali Bridge station in Quthing, commenced in 1988/89
18	SG 79	$30^0 53'47''$	$27^0 02'47''$	Mjanyane	281	13	18	1.44	11-Oct-92	20	Hydrometric Gauging station Rated Section	5.27	Mjanyane station in Mohale's hoek, commenced in 1990/91
19	SG80	$29^0 21'00''$	$28^0 31'00''$	Malibamatso	2 255	998	1 376	3.84	03-Nov-06	21	Hydrometric Gauging station Rated Section	5.27	Katse Bridge station in Thaba - Tseka, commenced in 1990/91
20	MG19	$29^0 26'$	$27^0 54'$	Makhaleng	86		66	3.10	31-Mar-90	32	Hydrometric Gauging station Rated Section	4.90	Molimo - Nthuse station in Ha - Mohale.
21	MG23	$29^0 52'00''$	$27^0 33'42''$	Makhaleng	1 554		444	3.03	27-Sep-87	31	Hydrometric Gauging station Rated Section	4.90	Qaba station in Mafeteng, commenced in 1981/82
22	MG 72	$29^0 35'00''$	$27^0 46'00''$	Makhaleng	68		53	3.07	17-Mar-06	24	Hydrometric Gauging station Rated Section	4.90	Thabana Limmele station, Commenced in 01/01/1988

	Station Number	Geographic Position		River Name	Catchment Area (Km^2)	Mean Daily Flood Peak Q_P (m^3/s)	Peak Flood Q_P (m^3/s)	Francou Rodier K Values for this Study	Date of Peak	Record Length to 2012	Method of Measurement	RMF Region K_e	Notes
		Latitude	Longitude										
23	MG73	29^{0}36'00"	28^{0}45'32"	Makhaleng	118		50	2.74	09-May-99	22	Hydrometric Gauging station Rated Section	4.90	Makhalaneng station, commenced in 1990/91
24	CG24	29^{0}23'09"	27^{0}33'07"	South Phuthiatsana	945	698	1 024	4.05	22-Jan-10	38	Hydrometric Gauging station Rated Section	5.12	Masianokeng station in Maseru, commenced in 1973/74.
25	CG25	28^{0}54'07"	28^{0}06'05"	Hlotse	728	566	602	5.21	19-Oct-87	38	Hydrometric Gauging station Rated Section	5.12	Ha - Setene station in Leribe, commenced in 1974/75.
26	CG33	29^{0}07'00"	27^{0}45'00"	North Phuthiatsana	905	381	384	5.57	02-Jan-83	38	Hydrometric Gauging station Rated Section	5.12	Kolonyama station in Leribe, commenced in 1973/74
27	CG34	29^{0}07'00"	28^{0}00'00"	North Phuthiatsana	579	60	70	5.58	22-Jan-87	40	Hydrometric Gauging station Rated Section	5.12	Mapoteng station in Teya - Teyaneng, commenced in 1971/72
28	CG77	28^{0}46'00"	28^{0}32'00"	Nqoe	26.3	61	72	3.59	26-Feb-11	21	Hydrometric Gauging station Rated Section	5.12	Muela station in Butha - Buthe, commenced in 1990/91
29	CG77A			Nqoe		4.95	5.24	1.94	19-Mar-11	3	Hydrometric Gauging station Rated Section	5.12	Muela station downstream of Muela dam, commenced in 2008/09

Appendix 2: Catalogue of Maximum Flood Peaks Used by Kovacs (1988) in Lesotho (Reproduced from Kovacs, 1988).

	Station Number	**Geographic Position**		**River Name**	**Catchment Area (km^2)**	**Peak Flood (m^3/s)**	**Francou Rodier K**	**Date of Peak**	**Record Length to 1988**	**Method of Measurement**	**RMF Region K_e**	**Notes**
		Latitude	Longitude									
1	SG4	$30^0$03'08"	$28^0$30'04"	Senqu	11 000	5 000	4.19	01-Feb-67	42	Hydrometric Gauging station Rated Section	5	White Hill commenced in 1964/65
2	SG5	$29^0$35'24"	$28^0$42'48"	Senqu	7 950	6 820	4.72	21-Mar-76	200	Hydrometric Gauging station Rated Section	5	Koma - Koma station commenced in 1966/67.
3	SG6	$29^0$17'00"	$28^0$59'00"	Senqu	1 660	1 850	4.28	01-Feb-67	20	Hydrometric Gauging station Rated Section	5	Mokhotlong station commenced in 1967/68.
4	SG10	$28^0$47'	$28^0$37'	Malibamatšo	277	710	4.33	31-Jan-67	29	Hydrometric Gauging station Rated Section	5	Ox-Bow station in Mokhotlong.
5	SG11	$28^0$43'	$28^0$37'	Tsehlanyane	57	146	3.86	Dec-70	30	Hydrometric Gauging station Rated Section	5	Ox-Bow station in Mokhotlong.
6	SG14	$28^0$50'	$28^0$42'	Motete	67	334	4.37	31-Jan-67	26	Hydrometric Gauging station Rated Section	5	Mahlasela station in Mokhotlong
7	SG17	$29^0$33'36"	$28^0$09'24"	Senqunyane	1 087	1 100	4.04	05-Mar-77	24	Hydrometric Gauging station Rated Section	5	Marakabei station in Ha - Mohale, commenced in 1963/64

	Station Number	**Geographic Position**		**River Name**	**Catchment Area (km^2)**	**Peak Flood (m^3/s)**	**Francou Rodier K**	**Date of Peak**	**Record Length to 1988**	**Method of Measurement**	**RMF Region K_e**	**Notes**
		Latitude	Longitude									
8	SG40	$30^0$24'00"	$27^0$41'48"	Qomoqomong	208	325	3.86	Feb-74	16	Hydrometric Gauging station Rated Section	5	Quthing station in Quthing, commenced in 1976/77.
9	SG45	$29^0$04'	$28^0$30'	Malibamatso	1 157	1 690	4.39	10-Apr-82	16	Hydrometric Gauging station Rated Section	5	Lejone station in Katse
10	MG19	$29^0$26'	$27^0$54'	Makhaleng	86	196	3.40	31-Mar-78	24	Hydrometric Gauging station Rated Section	5	Molimo - Nthuse station in Ha – Mohale.
11	CG24	$29^0$23'09"	$27^0$33'07"	South Phuthiatsana	945	1 140	4.14	21-Jan-66	23	Hydrometric Gauging station Rated Section	5	Masianokeng station in Maseru, commenced in 1973/74.
12	CG25	$28^0$54'07"	$28^0$06'05"	Hlotse	728	1 650	4.58	10-Dec-78	150	Hydrometric Gauging station Rated Section	5	Ha - Setene station in Leribe, commenced in 1974/75.

Appendix 3A: Flood Frequency Analysis (CG24)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - South Phuthiatsana River @ Masianokeng (945 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	(Qi - Qmean)^3	Log Q	(Log Q - Log Q_{mean})^3	Log Q - Log Q_{mean}
1965/1966	698	6	1	1024	0.01	0.99	542289826.72	3.01	0.68	0.88
1966/1967	220	48	2	698	0.03	0.97	117866440.33	2.84	0.36	0.71
1967/1968	70	47	3	669	0.06	0.94	98083598.38	2.83	0.33	0.69
1968/1969	-	516	4	557	0.08	0.92	42509166.13	2.75	0.23	0.61
1969/1970	27	24	5	516	0.10	0.90	29275833.61	2.71	0.20	0.58
1970/1971	-	557	6	498	0.12	0.88	24419462.48	2.70	0.18	0.57
1971/1972	137	84	7	350	0.15	0.85	2861212.95	2.54	0.07	0.41
1972/1973	188	78	8	350	0.17	0.83	2837637.06	2.54	0.07	0.41
1973/1974	127	92	9	347	0.19	0.81	2684210.10	2.54	0.07	0.41
1974/1975	226	53	10	278	0.21	0.79	347958.33	2.44	0.03	0.31
1975/1976	347	52	11	274	0.23	0.77	281161.85	2.44	0.03	0.31
1976/1977	516	33	12	263	0.26	0.74	164590.82	2.42	0.02	0.29
1977/1978	669	77	13	226	0.28	0.72	5336.15	2.35	0.01	0.22
1978/1979	557	194	14	225	0.30	0.70	4684.03	2.35	0.01	0.22
1979/1980	184	125	15	224	0.32	0.68	3705.66	2.35	0.01	0.22
1980/1981	278	151	16	220	0.34	0.66	1674.43	2.34	0.01	0.21

Flood Frequency Analysis for Annual Maximum Series in Lesotho - South Phuthiatsana River @ Masianokeng (945 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1981/1982	92	69	17	205	0.37	0.63	-36.94	2.31	0.01	0.18
1982/1983	57	20	18	194	0.39	0.61	-2622.54	2.29	0.00	0.16
1983/1984	59	6	19	188	0.41	0.59	-8647.08	2.27	0.00	0.14
1984/1985	75	21	20	184	0.43	0.57	-13356.44	2.27	0.00	0.13
1985/1986	151	51	21	151	0.46	0.54	-186505.22	2.18	0.00	0.05
1986/1987	194	20	22	151	0.48	0.52	-190360.54	2.18	0.00	0.05
1987/1988	225	198	23	137	0.50	0.50	-364381.59	2.14	0.00	0.00
1988/1989	151	43	24	127	0.52	0.48	-531132.26	2.10	0.00	-0.03
1989/1990	78	74	25	107	0.54	0.46	-1042106.88	2.03	0.00	-0.10
1990/1991	205	96	26	96	0.57	0.43	-1416410.98	1.98	0.00	-0.15
1991/1992	52	51	27	92	0.59	0.41	-1571590.04	1.96	0.00	-0.17
1992/1993	39	34	28	89	0.61	0.39	-1707574.45	1.95	-0.01	-0.18
1993/1994	224	150	29	78	0.63	0.37	-2188003.48	1.89	-0.01	-0.24
1994/1995	44	40	30	75	0.66	0.34	-2338090.17	1.88	-0.02	-0.25
1995/1996	498	37	31	74	0.68	0.32	-2413292.35	1.87	-0.02	-0.26
1996/1997	89	74	32	70	0.70	0.30	-2640678.92	1.84	-0.02	-0.29
1997/1998	274	107	33	70	0.72	0.28	-2652445.84	1.84	-0.02	-0.29
1998/1999	96	63	34	66	0.74	0.26	-2887206.96	1.82	-0.03	-0.31
1999/2000	61	59	35	61	0.77	0.23	-3155843.57	1.79	-0.04	-0.34
2000/2001	49	46	36	59	0.79	0.21	-3339305.08	1.77	-0.05	-0.36
2001/2002	350	66	37	57	0.81	0.19	-3474327.29	1.75	-0.05	-0.38
2002/2003	698	49	38	52	0.83	0.17	-3790965.72	1.72	-0.07	-0.41
2003/2004	37	21	39	49	0.85	0.15	-4050802.37	1.69	-0.09	-0.44
2004/2005	74		40	49	0.88	0.12	-4052022.23	1.69	-0.09	-0.44

Flood Frequency Analysis for Annual Maximum Series in Lesotho - South Phuthiatsana River @ Masianokeng (945 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	(Qi - Qmean)^3	Log Q	(Log Q - Log Q_{mean})^3	Log Q - Log Q_{mean}
2005/2006	107		41	44	0.90	0.10	-4453466.22	1.64	-0.12	-0.49
2006/2007	263		42	39	0.92	0.08	-4829578.04	1.59	-0.16	-0.54
2007/2008	70		43	37	0.94	0.06	-5026953.62	1.56	-0.18	-0.57
2008/2009	350		44	27	0.97	0.03	-5922403.38	1.43	-0.34	-0.70
2009/2010	66		45	21	0.99	0.01	-6560554.96	1.32	-0.54	-0.81
2010/2011	1 024									
2011/2012	21									
			45							
			Mean	**208.03**			**792825833.89**	**2.13**	**0.47**	**0.00**
			STDEV	**211.47**				**0.41**		

Appendix 3B: Flood Frequency Analysis (CG25)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Hlotse River @ Ha - Setene (728 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log Q}_{mean})^3$	$\text{Log Q} - \text{Log Q}_{mean}$
1974/1975	49	43	1	602	0.01	0.99	52341437.79	2.78	0.15	0.53
1975/1976	34	10	2	588	0.04	0.96	46546549.18	2.77	0.14	0.52
1976/1977	297	274	3	456	0.07	0.93	11902838.16	2.66	0.07	0.41
1977/1978	588	566	4	456	0.09	0.91	11902838.16	2.66	0.07	0.41
1978/1979	456	433	5	438	0.12	0.88	9314720.80	2.64	0.06	0.39
1979/1980	30	29	6	427	0.15	0.85	7846820.63	2.63	0.05	0.38
1980/1981	427	367	7	398	0.17	0.83	4951096.08	2.60	0.04	0.35
1981/1982	205	177	8	385	0.20	0.80	3850055.24	2.59	0.04	0.33
1982/1983	214	180	9	297	0.22	0.78	332614.79	2.47	0.01	0.22
1983/1984	108	105	10	268	0.25	0.75	65999.36	2.43	0.01	0.18
1984/1985	-	-	11	264	0.28	0.72	47176.08	2.42	0.01	0.17
1985/1986	179	139	12	260	0.30	0.70	32456.48	2.41	0.00	0.16
1986/1987	254	211	13	256	0.33	0.67	21270.67	2.41	0.00	0.16
1987/1988	602	378	14	254	0.36	0.64	16832.86	2.40	0.00	0.15
1988/1989	385	284	15	241	0.38	0.62	2409.48	2.38	0.00	0.13
1989/1990	137	53	16	214	0.41	0.59	-2545.39	2.33	0.00	0.08
1990/1991	268	78	17	205	0.43	0.57	-11897.21	2.31	0.00	0.06
1991/1992	43	40	18	196	0.46	0.54	-31935.66	2.29	0.00	0.04

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Hlotse River @ Ha - Setene (728 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	(Qi - Qmean)^3	Log Q	(Log Q - Log Q_{mean})^3	Log Q - Log Q_{mean}
1992/1993	165	65	19	195	0.49	0.51	-37530.53	2.29	0.00	0.04
1993/1994	195	98	20	189	0.51	0.49	-57874.06	2.28	0.00	0.03
1994/1995	84	51	21	179	0.54	0.46	-116140.91	2.25	0.00	0.00
1995/1996	241	114	22	171	0.57	0.43	-184810.50	2.23	0.00	-0.02
1996/1997	189	89	23	166	0.59	0.41	-235407.76	2.22	0.00	-0.03
1997/1998	256	107	24	165	0.62	0.38	-253897.43	2.22	0.00	-0.03
1998/1999	171	57	25	163	0.64	0.36	-273204.43	2.21	0.00	-0.04
1999/2000	166	84	26	160	0.67	0.33	-314053.86	2.20	0.00	-0.05
2000/2001	160	84	27	137	0.70	0.30	-764222.04	2.14	0.00	-0.12
2001/2002	260	-	28	109	0.72	0.28	-1686124.81	2.04	-0.01	-0.21
2002/2003	84	1	29	108	0.75	0.25	-1722723.30	2.03	-0.01	-0.22
2003/2004	59	30	30	104	0.78	0.22	-1907349.67	2.02	-0.01	-0.23
2004/2005	114	110	31	84	0.80	0.20	-2999424.23	1.92	-0.04	-0.33
2005/2006	264	163	32	84	0.83	0.17	-2999424.23	1.92	-0.04	-0.33
2006/2007	438	308	33	59	0.85	0.15	-4803261.41	1.77	-0.11	-0.48
2007/2008	163	123	34	49	0.88	0.12	-5717836.47	1.69	-0.17	-0.56
2008/2009	196	135	35	43	0.91	0.09	-6336321.46	1.63	-0.24	-0.62
2009/2010	109	70	36	34	0.93	0.07	-7329164.01	1.53	-0.38	-0.72
2010/2011	398	172	37	30	0.96	0.04	-7707916.18	1.48	-0.45	-0.77
2011/2012	456	193	38							
			38							
			Mean	**227.99**			**103682050.17**	**2.25**	**-0.80**	**0.00**
			STDEV	**150.30**				**0.34**		

Appendix 3C: Flood Frequency Analysis (CG33)

Annual Maximum Series for North Phuthiatsana River @ Kolonyama (905 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log } Q - \text{Log } Q_{mean})^3$	$\text{Log } Q - \text{Log } Q_{mean}$
1972/1973	24	-	1	384.198	0.01	0.99	5102477.03	2.58	0.08	0.44
1973/1974	24	2	2	383.584	0.04	0.96	5048077.67	2.58	0.08	0.44
1974/1975	375	114	3	383.528	0.06	0.94	5043135.49	2.58	0.08	0.44
1975/1976	345	114	4	382.081	0.09	0.91	4916549.05	2.58	0.08	0.43
1976/1977	312	65	5	377.593	0.11	0.89	4537436.65	2.58	0.08	0.43
1977/1978	324	312	6	375.445	0.14	0.86	4363102.60	2.57	0.08	0.43
1978/1979	206	40	7	370.408	0.16	0.84	3971930.85	2.57	0.07	0.42
1979/1980	300	103	8	344.78	0.19	0.81	2338862.57	2.54	0.06	0.39
1980/1981	384	381	9	343.169	0.21	0.79	2254734.98	2.54	0.06	0.39
1981/1982	370	83	10	332.126	0.24	0.76	1731714.62	2.52	0.05	0.37
1982/1983	384	98	11	325.999	0.26	0.74	1479943.14	2.51	0.05	0.37
1983/1984	384	247	12	325.999	0.29	0.71	1479943.14	2.51	0.05	0.37
1984/1985	378	17	13	323.859	0.31	0.69	1398124.80	2.51	0.05	0.36
1985/1986	51	23	14	323.846	0.34	0.66	1397637.22	2.51	0.05	0.36
1986/1987	343	109	15	323.778	0.36	0.64	1395088.65	2.51	0.05	0.36
1987/1988	382	63	16	311.708	0.39	0.61	990070.80	2.49	0.04	0.35
1988/1989	63	35	17	307.724	0.41	0.59	876025.90	2.49	0.04	0.34
1989/1990	75	28	18	307.724	0.44	0.56	876025.90	2.49	0.04	0.34
1990/1991	332	122	19	299.901	0.46	0.54	678246.11	2.48	0.04	0.33
1991/1992	38	18	20	262.487	0.49	0.51	128381.99	2.42	0.02	0.27
1992/1993	255	90	21	255	0.51	0.49	81678.29	2.41	0.02	0.26

Annual Maximum Series for North Phuthiatsana River @ Kolonyama (905 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1993/1994	78	28	22	206	0.54	0.46	-209.17	2.31	0.00	0.17
1994/1995	69	28	23	203	0.56	0.44	-726.11	2.31	0.00	0.16
1995/1996	308	122	24	163	0.59	0.41	-115302.73	2.21	0.00	0.07
1996/1997	308	106	25	158	0.61	0.39	-156582.76	2.20	0.00	0.05
1997/1998	324	114	26	124	0.64	0.36	-677555.06	2.09	0.00	-0.05
1998/1999	262	66	27	78	0.66	0.34	-2388000.12	1.89	-0.02	-0.25
1999/2000	203	76	28	75	0.69	0.31	-2565899.30	1.88	-0.02	-0.27
2000/2001	158	42	29	69	0.71	0.29	-2932808.60	1.84	-0.03	-0.31
2001/2002	163	69	30	63	0.74	0.26	-3309685.98	1.80	-0.04	-0.35
2002/2003	16	10	31	51	0.76	0.24	-4178888.28	1.71	-0.09	-0.44
2003/2004	22	18	32	41	0.79	0.21	-5034683.92	1.61	-0.16	-0.54
2004/2005	32	25	33	38	0.81	0.19	-5235219.41	1.58	-0.18	-0.56
2005/2006	32	26	34	32	0.84	0.16	-5789150.26	1.51	-0.26	-0.64
2006/2007	28	20	35	32	0.86	0.14	-5789150.26	1.51	-0.26	-0.64
2007/2008	324	15	36	24	0.89	0.11	-6618841.69	1.39	-0.44	-0.76
2008/2009	326	37	37	24	0.91	0.09	-6618841.69	1.39	-0.44	-0.76
2009/2010	124	28	38	22	0.94	0.06	-6811897.56	1.35	-0.50	-0.80
2010/2011	436	326	39	18	0.96	0.04	-7268923.19	1.26	-0.69	-0.88
2011/2012	41		40	12	0.99	0.01	-8055095.00	1.06	-1.27	-1.08
			Mean	**212.04**			**-23458273.61**	**2.15**	**-3.21**	**0.00**
			STDEV	**141.07**				**0.47**		

Appendix 3D: Flood Frequency Analysis (CG34)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - North Phuthiatsana @ Mapoteng (579 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log } Q_{mean})^3$	$\text{Log Q} - \text{Log } Q_{mean}$
1971/1972	55	26	1	58	0.01	0.99	6573.34	1.77	0.02	0.26
1972/1973	30	15	2	58	0.04	0.96	6573.34	1.77	0.02	0.26
1973/1974	58	39	3	58	0.06	0.94	6318.79	1.77	0.02	0.26
1974/1975	49	24	4	58	0.09	0.91	6318.79	1.77	0.02	0.26
1975/1976	54	26	5	58	0.11	0.89	6239.15	1.76	0.02	0.26
1976/1977	35	8	6	58	0.14	0.86	6239.15	1.76	0.02	0.26
1977/1978	54	30	7	58	0.16	0.84	5691.70	1.76	0.02	0.25
1978/1979	45	12	8	58	0.18	0.82	5608.90	1.76	0.02	0.25
1979/1980	46	25	9	57	0.21	0.79	5535.36	1.76	0.02	0.25
1980/1981	58	46	10	57	0.23	0.77	5320.41	1.76	0.02	0.25
1981/1982	54	40	11	56	0.26	0.74	4568.09	1.75	0.01	0.24
1982/1983	58	26	12	56	0.28	0.72	4497.43	1.75	0.01	0.24
1983/1984	58	26	13	55	0.31	0.69	3615.03	1.74	0.01	0.23
1984/1985	27	17	14	54	0.33	0.67	3098.40	1.73	0.01	0.23
1985/1986	56	39	15	54	0.35	0.65	2860.56	1.73	0.01	0.22
1986/1987	58	35	16	49	0.38	0.62	825.95	1.69	0.01	0.18
1987/1988	58	34	17	49	0.40	0.60	825.95	1.69	0.01	0.18
1988/1989	57	53	18	49	0.43	0.57	825.95	1.69	0.01	0.18
1989/1990	56	35	19	46	0.45	0.55	283.14	1.67	0.00	0.16
1990/1991	58	36	20	45	0.48	0.52	123.02	1.65	0.00	0.14
1991/1992	35	2	21	44	0.50	0.50	57.40	1.64	0.00	0.13
1992/1993	43	10	22	44	0.52	0.48	57.40	1.64	0.00	0.13

Flood Frequency Analysis for Annual Maximum Series in Lesotho - North Phuthiatsana @ Mapoteng (579 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log Q}_{mean})^3$	$\text{Log Q} - \text{Log Q}_{mean}$
1993/1994	57	26	23	44	0.55	0.45	57.40	1.64	0.00	0.13
1994/1995	26	9	24	43	0.57	0.43	32.60	1.63	0.00	0.12
1995/1996	44	25	25	37	0.60	0.40	-15.10	1.57	0.00	0.06
1996/1997	44	21	26	35	0.62	0.38	-124.74	1.54	0.00	0.03
1997/1998	37	23	27	32	0.65	0.35	-545.84	1.50	0.00	-0.01
1998/1999	49	32	28	27	0.67	0.33	-1977.84	1.43	0.00	-0.07
1999/2000	44	30	29	26	0.69	0.31	-2343.90	1.42	0.00	-0.09
2000/2001	24	21	30	26	0.72	0.28	-2605.01	1.41	0.00	-0.09
2001/2002	37	26	31	26	0.74	0.26	-2884.22	1.41	0.00	-0.10
2002/2003	24	23	32	24	0.77	0.23	-3813.61	1.38	0.00	-0.13
2003/2004	18	17	33	23	0.79	0.21	-4877.98	1.36	0.00	-0.15
2004/2005	23	20	34	23	0.82	0.18	-4877.98	1.36	0.00	-0.15
2005/2006	28	26	35	22	0.84	0.16	-5664.04	1.34	0.00	-0.17
2006/2007	22	21	36	18	0.86	0.14	-10408.08	1.25	-0.02	-0.25
2007/2008	49	35	37	16	0.89	0.11	-13814.52	1.20	-0.03	-0.31
2008/2009	22	16	38	15	0.91	0.09	-15642.84	1.17	-0.04	-0.34
2009/2010	32	30	39	8	0.94	0.06	-31989.39	0.90	-0.22	-0.61
2010/2011	60	58	40	5	0.96	0.04	-42726.38	0.68	-0.57	-0.83
2011/2012	49	36	41	0	0.99	0.01	-60802.83	-0.38	-6.75	-1.89
			41							
			Mean	**39.74**			**-122967.04**	**1.51**	**-7.38**	**0.00**
			STDEV	**17.55**				**0.39**		

Appendix 4A: Flood Frequency Analysis (MG19)

Annual Maximum Series for Makhaleng River @ Molimo Nthuse (86 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1980/1981	31	31	1	66	0.02	0.98	82151.73	1.82	0.16	0.55
1981/1982	33	31	2	33	0.05	0.95	1148.26	1.51	0.01	0.25
1982/1983	23	31	3	33	0.08	0.92	1148.26	1.51	0.01	0.25
1983/1984	33	31	4	33	0.11	0.89	1131.23	1.51	0.01	0.24
1984/1985	26	6	5	33	0.14	0.86	1131.23	1.51	0.01	0.24
1985/1986	32	21	6	32	0.17	0.83	1079.92	1.51	0.01	0.24
1986/1987	54	33	7	32	0.20	0.80	1046.17	1.51	0.01	0.24
1987/1988	33	16	8	32	0.24	0.76	905.52	1.50	0.01	0.23
1988/1989	32	24	9	31	0.27	0.73	791.35	1.50	0.01	0.23
1989/1990	66	49	10	26	0.30	0.70	63.60	1.42	0.00	0.15
1990/1991	41	32	11	26	0.33	0.67	59.44	1.42	0.00	0.15
1991/1992	58	13	12	25	0.36	0.64	16.09	1.39	0.00	0.12
1992/1993	10	9	13	24	0.39	0.61	7.06	1.38	0.00	0.11
1993/1994	25	15	14	23	0.42	0.58	1.04	1.37	0.00	0.10
1994/1995	17	8	15	20	0.45	0.55	-16.22	1.29	0.00	0.02
1995/1996	20	9	16	19	0.48	0.52	-21.10	1.29	0.00	0.02
1996/1997	17	7	17	19	0.52	0.48	-21.10	1.29	0.00	0.02
1997/1998	16	6	18	19	0.55	0.45	-21.10	1.29	0.00	0.02

Annual Maximum Series for Makhaleng River @ Molimo Nthuse (86 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1998/1999	11	9	19	19	0.58	0.42	-21.80	1.29	0.00	0.02
1999/2000	12	7	20	19	0.61	0.39	-26.37	1.28	0.00	0.01
2000/2001	24	10	21	17	0.64	0.36	-130.82	1.23	0.00	-0.04
2001/2002	26	21	22	17	0.67	0.33	-134.56	1.23	0.00	-0.04
2002/2003	20	17	23	17	0.70	0.30	-159.52	1.23	0.00	-0.04
2003/2004	3	2	24	16	0.73	0.27	-227.25	1.21	0.00	-0.06
2004/2005	24	17	25	16	0.76	0.24	-242.32	1.20	0.00	-0.07
2005/2006	42	16	26	16	0.80	0.20	-275.18	1.20	0.00	-0.07
2006/2007	16	13	27	13	0.83	0.17	-695.13	1.13	0.00	-0.14
2007/2008	44	19	28	11	0.86	0.14	-1304.82	1.05	-0.01	-0.22
2008/2009	19	10	29	10	0.89	0.11	-1651.15	1.02	-0.02	-0.25
2009/2010	19	11	30	7	0.92	0.08	-3755.97	0.82	-0.09	-0.45
2010/2011	19	9	31	3	0.95	0.05	-6968.32	0.49	-0.47	-0.78
2011/2012	19	12	32	2	0.98	0.02	-8781.86	0.20	-1.23	-1.07
			32							
			Mean	**22.21**			**66226.28**	**1.27**	**-1.52**	**0.00**
			STDEV	**11.87**				**0.31**		

Appendix 4B: Flood Frequency Analysis (MG23)

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhaleng River @ Qaba (1554 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log } Q_{mean})^3$	$\text{Log Q} - \text{Log } Q_{mean}$
1981/1982	300	167	1	444	0.02	0.98	13825053.55	2.65	0.07	0.42
1982/1983	185	135	2	341	0.05	0.95	2585856.53	2.53	0.03	0.30
1983/1984	341	305	3	341	0.08	0.92	2585856.53	2.53	0.03	0.30
1984/1985	171	166	4	336	0.11	0.89	2328104.81	2.53	0.03	0.30
1985/1986	320	277	5	326	0.15	0.85	1805601.69	2.51	0.02	0.28
1986/1987	444	327	6	320	0.18	0.82	1546893.92	2.50	0.02	0.27
1987/1988	341	306	7	301	0.21	0.79	924895.73	2.48	0.02	0.25
1988/1989	301	254	8	301	0.24	0.76	924895.73	2.48	0.02	0.25
1989/1990	289	238	9	300	0.28	0.72	894311.58	2.48	0.02	0.25
1990/1991	301	289	10	289	0.31	0.69	610838.38	2.46	0.01	0.23
1991/1992	147	125	11	281	0.34	0.66	465161.86	2.45	0.01	0.22
1992/1993	93	74	12	238	0.37	0.63	40665.34	2.38	0.00	0.15
1993/1994	141	135	13	238	0.40	0.60	40665.34	2.38	0.00	0.15
1994/1995	95	87	14	193	0.44	0.56	-1338.97	2.29	0.00	0.06
1995/1996	190	189	15	190	0.47	0.53	-2819.90	2.28	0.00	0.05
1996/1997	166	154	16	188	0.50	0.50	-3894.27	2.27	0.00	0.04
1997/1998	108	107	17	185	0.53	0.47	-6497.23	2.27	0.00	0.04
1998/1999	108	107	18	184	0.56	0.44	-8069.69	2.26	0.00	0.03
1999/2000	50	-	19	171	0.60	0.40	-35068.22	2.23	0.00	0.00
2000/2001	193	-	20	166	0.63	0.37	-55262.38	2.22	0.00	-0.01
2001/2002	281	-	21	147	0.66	0.34	-183520.63	2.17	0.00	-0.06
2002/2003	79	-	22	141	0.69	0.31	-253731.15	2.15	0.00	-0.08

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhaleng River @ Qaba (1554 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	(Qi - Qmean)^3	Log Q	(Log Q - Log Q_{mean})^3	Log Q - Log Q_{mean}
2003/2004	53	-	23	108	0.72	0.28	-878334.49	2.03	-0.01	-0.20
2004/2005	22	-	24	108	0.76	0.24	-878334.49	2.03	-0.01	-0.20
2005/2006	238	-	25	95	0.79	0.21	-1288655.94	1.98	-0.02	-0.25
2006/2007	238	-	26	93	0.82	0.18	-1379192.30	1.97	-0.02	-0.26
2007/2008	336	-	27	91	0.85	0.15	-1430974.50	1.96	-0.02	-0.27
2008/2009	184	-	28	79	0.89	0.11	-1961194.05	1.90	-0.04	-0.33
2009/2010	91	-	29	53	0.92	0.08	-3415315.44	1.73	-0.13	-0.50
2010/2011	326	-	30	50	0.95	0.05	-3672928.89	1.70	-0.15	-0.53
2011/2012	188	-	31	22	0.98	0.02	-6010788.30	1.35	-0.69	-0.89
			31							
			Mean	**203.956**			**7112880.15**	**2.23**	**-0.81**	**0.00**
			STDEV	**107.46**				**0.30**		

Appendix 4C: Flood Frequency Analysis (MG72)

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhalaneng River @ Thabanalimmele (68 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1989/1990	15	-	1	53	0.02	0.98	50380.03	1.73	0.26	0.64
1990/1991	13	-	2	28	0.06	0.94	1699.40	1.45	0.05	0.36
1991/1992	9	-	3	28	0.11	0.89	1699.40	1.45	0.05	0.36
1992/1993	9	-	4	28	0.15	0.85	1699.40	1.45	0.05	0.36
1993/1994	16	-	5	28	0.19	0.81	1699.40	1.45	0.05	0.36
1994/1995	2	-	6	24	0.23	0.77	383.04	1.38	0.02	0.29
1995/1996	20	-	7	24	0.27	0.73	383.04	1.38	0.02	0.29
1996/1997	28	-	8	20	0.31	0.69	60.86	1.31	0.01	0.22
1997/1998	28	-	9	20	0.35	0.65	28.16	1.29	0.01	0.20
1998/1999	4	-	10	17	0.40	0.60	0.00	1.22	0.00	0.13
1999/2000	7	-	11	16	0.44	0.56	-0.45	1.20	0.00	0.11
2000/2001	9	-	12	15	0.48	0.52	-2.54	1.18	0.00	0.09
2001/2002	10	-	13	14	0.52	0.48	-9.54	1.16	0.00	0.07
2002/2003	2	-	14	13	0.56	0.44	-40.62	1.12	0.00	0.03
2003/2004	14	-	15	13	0.60	0.40	-54.34	1.11	0.00	0.01
2004/2005	2	-	16	10	0.65	0.35	-266.29	1.00	0.00	-0.09
2005/2006	24	-	17	9	0.69	0.31	-424.34	0.96	0.00	-0.14
2006/2007	53	-	18	9	0.73	0.27	-424.34	0.96	0.00	-0.14

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhalaneng River @ Thabanalimmele (68 km^2)										
Year	**Instantaneous Flood Peak**	**Daily Mean Flow**	**Rank**	**AM Order**	**P(X) Gringorton**	**F(X) Gringorton**	**$(Qi - Qmean)^3$**	**Log Q**	**$(Log Q - Log Q_{mean})^3$**	**$Log Q - Log Q_{mean}$**
2007/2008	17	-	19	9	0.77	0.23	-424.34	0.96	0.00	-0.14
2008/2009	20	-	20	7	0.81	0.19	-978.73	0.82	-0.02	-0.27
2009/2010	24	-	21	4	0.85	0.15	-2176.07	0.55	-0.15	-0.54
2010/2011	28	-	22	2	0.89	0.11	-2805.36	0.39	-0.35	-0.70
2011/2012	28	-	23	2	0.94	0.06	-2957.20	0.34	-0.42	-0.75
2012/2013	13	-	24	2	0.98	0.02	-2957.20	0.34	-0.42	-0.75
			24							
			Mean	**16.5436**			**44511.3501**	**1.09**	**-0.86**	**0.00**
			STDEV	**11.77**				**0.38**		

Appendix 4D: Flood Frequency Analysis (MG73)

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhaleng River @ Makhalaneng Bridge (118 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1990/1991	44	30	1	50	0.03	0.97	3468.98	1.70	0.02	0.27
1991/1992	6	6	2	47	0.07	0.93	1788.28	1.67	0.01	0.24
1992/1993	44	18	3	47	0.12	0.88	1788.28	1.67	0.01	0.24
1993/1994	18	8	4	47	0.16	0.84	1788.28	1.67	0.01	0.24
1994/1995	4	2	5	47	0.21	0.79	1788.28	1.67	0.01	0.24
1995/1996	44	38	6	47	0.25	0.75	1788.28	1.67	0.01	0.24
1996/1997	25	23	7	47	0.30	0.70	1788.28	1.67	0.01	0.24
1997/1998	47	12	8	46	0.34	0.66	1507.80	1.67	0.01	0.23
1998/1999	17	7	9	45	0.39	0.61	1074.36	1.65	0.01	0.22
1999/2000	50	49	10	44	0.43	0.57	840.95	1.65	0.01	0.21
2000/2001	43	38	11	44	0.48	0.52	840.95	1.65	0.01	0.21
2001/2002	47	26	12	44	0.52	0.48	840.95	1.65	0.01	0.21
2002/2003	47	19	13	42	0.57	0.43	421.19	1.63	0.01	0.19
2003/2004	16	6	14	41	0.61	0.39	288.01	1.62	0.01	0.18
2004/2005	4	2	15	38	0.66	0.34	31.55	1.58	0.00	0.15
2005/2006	47	27	16	25	0.70	0.30	-990.44	1.40	0.00	-0.04
2006/2007	41	31	17	18	0.75	0.25	-4450.64	1.26	0.00	-0.17
2007/2008	42	26	18	17	0.79	0.21	-5330.99	1.24	-0.01	-0.19

Flood Frequency Analysis for Annual Maximum Series in Lesotho Makhaleng River @ Makhalaneng Bridge (118 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
2008/2009	47	20	19	16	0.84	0.16	-6800.73	1.20	-0.01	-0.23
2009/2010	46	43	20	6	0.88	0.12	-23222.42	0.80	-0.26	-0.64
2010/2011	47	42	21	4	0.93	0.07	-29161.36	0.60	-0.57	-0.83
2011/2012	45	23	22	2	0.97	0.03	-36294.43	0.23	-1.75	-1.21
			22							
			Mean	**34.80**			**-86206.55**	**1.43**	**-2.43**	**0.00**
			STDEV	**16.36**				**0.40**		

Appendix 5: Generalised Extreme Value Standardised Variate W_P

Generalised Extreme Value Distribution Parameters														K	E(y)	Var(y)
Distribution Skewness (g)		**Probability of Exceedance (%)**														
		50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**			
Return Period in Years		**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**			
	Skewness (g)	**Standardised Variate W_P**														
	-1.4	0.3183	0.8790	1.0520	1.1450	1.2090	1.2330	1.2480	1.2580	1.2620	1.2640	1.2650	1.2660	0.7893	0.9286	0.5447
	-1.2	0.3224	0.9200	1.1190	1.2320	1.3130	1.3470	1.3670	1.3820	1.3890	1.3930	1.3960	1.3970	0.7149	0.9115	0.4359
	-1.0	0.3267	0.9650	1.1930	1.3300	1.4350	1.4810	1.5110	1.5340	1.5450	1.5520	1.5570	1.5600	0.6394	0.8986	0.3447
	-0.8	0.3311	1.0120	1.2750	1.4420	1.5770	1.6410	1.6850	1.7210	1.7380	1.7500	1.7600	1.7640	0.5636	0.8899	0.2687
	-0.6	0.3356	1.0630	1.3650	1.5680	1.7430	1.8310	1.8930	1.9490	1.9770	1.9980	2.0160	2.0250	0.4884	0.8859	0.2056
	-0.4	0.3400	1.1170	1.4630	1.7070	1.9330	2.0530	2.1430	2.2270	2.2730	2.3070	2.3400	2.3580	0.4149	0.8866	0.1536
	-0.2	0.3443	1.1720	1.5660	1.8600	2.1470	2.3090	2.4360	2.5630	2.6350	2.6930	2.7500	2.7830	0.3442	0.8918	0.1113
	0.0	0.3485	1.2270	1.6740	2.0230	2.3830	2.5980	2.7740	2.9600	3.0730	3.1660	3.2640	3.3230	0.2776	0.9011	0.0772
	0.2	0.3524	1.2810	1.7830	2.1930	2.6370	2.9170	3.1560	3.4220	3.5900	3.7350	3.8960	3.9990	0.2158	0.9141	0.0504
	0.4	0.3560	1.3340	1.8910	2.3660	2.9050	3.2600	3.5760	3.9430	4.1870	4.4050	4.6590	4.8270	0.1595	0.9300	0.0299
	0.6	0.3593	1.3840	1.9960	2.5380	3.1790	3.6190	4.0250	4.5160	4.8550	5.1700	5.5510	5.8160	0.1089	0.9478	0.0153
	0.7	0.3608	1.4070	2.0460	2.6215	3.3160	3.8020	4.2585	4.8215	5.2190	5.5945	6.0585	6.3875	0.0865	0.9574	0.0105
GEV 3	0.72	0.3610	1.4116	2.0560	2.6382	3.3434	3.8386	4.3052	4.8826	5.2918	5.6794	6.1600	6.5018	0.0820	0.9593	0.0096

Generalised Extreme Value Distribution Parameters

Distribution Skewness (g)		Probability of Exceedance (%)												K	E(y)	Var(y)
		50	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01			
Return Period in Years		2	5	10	20	50	100	200	500	1 000	2 000	5 000	10 000			
	Skewness (g)	Standardised Variate W_P														
	0.74	0.3613	1.4162	2.0660	2.6549	3.3708	3.8752	4.3519	4.9437	5.3646	5.7643	6.2615	6.6161	0.0775	0.9612	0.0086
	0.76	0.3616	1.4208	2.0760	2.6716	3.3982	3.9118	4.3986	5.0048	5.4374	5.8492	6.3630	6.7304	0.0730	0.9631	0.0077
	0.78	0.3619	1.4254	2.0860	2.6883	3.4256	3.9484	4.4453	5.0659	5.5102	5.9341	6.4645	6.8447	0.0685	0.9650	0.0067
	0.8	0.3622	1.4300	2.0960	2.7050	3.4530	3.9850	4.4920	5.1270	5.5830	6.0190	6.5660	6.9590	0.0640	0.9669	0.00576
	1.0	0.3649	1.4730	2.1890	2.8640	3.7210	4.3500	4.9660	5.7630	6.3530	6.9340	7.6860	8.2430	0.0246	0.9864	0.000924
	1.1	0.3661	1.4920	2.2330	2.9410	3.8510	4.5300	5.2030	6.0860	6.7500	7.4100	8.2780	8.9310	0.0067	0.9962	0.0000722
	1.13	0.3664	1.4980	2.2460	2.9630	3.8900	4.5830	5.2740	6.1830	6.8700	7.5550	8.4600	9.1430	0.0016	0.9991	0.00000417
GEV 1	1.13955	0.3665	1.5000	2.2500	2.9700	3.9020	4.6000	5.2960	6.2140	6.9070	7.6010	8.5170	9.2100	0.0000	1.0000	0.00000000
	1.15	0.3660	1.5020	2.2550	2.9780	3.9150	4.6190	5.3200	6.2470	6.9490	7.6510	8.5800	9.2840	-0.0017	1.0010	0.00000509
	1.18	0.3670	1.5070	2.2670	3.0000	3.9530	4.6720	5.3910	6.3440	7.0690	7.7970	8.7640	9.5000	-0.0067	1.0039	0.0000757
	1.28	0.3680	1.5250	2.3080	3.0710	4.0780	4.8460	5.6230	6.6680	7.4710	8.2870	9.3850	10.2310	-0.0225	1.0135	0.00089
	1.30	0.3682	1.5285	2.3158	3.0848	4.1020	4.8800	5.6688	6.7322	7.5515	8.3860	9.5125	10.3808	-0.0254	1.0154	0.0012
	1.32	0.3684	1.5320	2.3237	3.0987	4.1260	4.9140	5.7147	6.7963	7.6320	8.4850	9.6400	10.5307	-0.0283	1.0172	0.0016
	1.33	0.3689	1.5410	2.3441	3.1351	4.1910	5.0062	5.8397	6.9735	7.8560	8.7622	9.9980	10.9605	-0.0358	1.0223	0.0030
GEV 2	1.34	0.3686	1.5355	2.3315	3.1125	4.1500	4.9480	5.7605	6.8605	7.7125	8.5840	9.7675	10.6805	-0.0312	1.0191	0.0019

Generalised Extreme Value Distribution Parameters

Distribution Skewness (g)	Probability of Exceedance (%)												K	E(y)	Var(y)
	50	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01			
Return Period in Years	2	5	10	20	50	100	200	500	1 000	2 000	5 000	10 000			
Skewness (g)	Standardised Variate W_P														
1.36	0.3688	1.5390	2.3393	3.1263	4.1740	4.9820	5.8063	6.9247	7.7930	8.6830	9.8950	10.8303	-0.0341	1.0210	0.0023
1.38	0.3690	1.5425	2.3472	3.1402	4.1980	5.0160	5.8522	6.9888	7.8735	8.7820	10.0225	10.9802	-0.0370	1.0228	0.0026
1.40	0.3692	1.5460	2.3550	3.1540	4.2220	5.0500	5.8980	7.0530	7.9540	8.8810	10.1500	11.1300	-0.0399	1.0247	0.00295
1.42	0.3694	1.5491	2.3621	3.1667	4.2449	5.0825	5.9422	7.1159	8.0338	8.9800	10.2780	11.2850	-0.0425	1.0265	0.0035
1.44	0.3696	1.5522	2.3692	3.1794	4.2678	5.1150	5.9864	7.1788	8.1136	9.0790	10.4060	11.4400	-0.0451	1.0283	0.0041
1.46	0.3697	1.5553	2.3763	3.1921	4.2907	5.1475	6.0306	7.2417	8.1934	9.1780	10.5340	11.5950	-0.0477	1.0301	0.0047
1.48	0.3699	1.5584	2.3834	3.2048	4.3136	5.1800	6.0748	7.3046	8.2732	9.2770	10.6620	11.7500	-0.0503	1.0319	0.0052
1.50	0.3701	1.5615	2.3905	3.2175	4.3365	5.2125	6.1190	7.3675	8.3530	9.3760	10.7900	11.9050	-0.0530	1.0337	0.0058
1.52	0.3703	1.5646	2.3976	3.2302	4.3594	5.2450	6.1632	7.4304	8.4328	9.4750	10.9180	12.0600	-0.0556	1.0355	0.0064
1.54	0.3705	1.5677	2.4047	3.2429	4.3823	5.2775	6.2074	7.4933	8.5126	9.5740	11.0460	12.2150	-0.0582	1.0373	0.0070
1.56	0.3706	1.5708	2.4118	3.2556	4.4052	5.3100	6.2516	7.5562	8.5924	9.6730	11.1740	12.3700	-0.0608	1.0391	0.0075
1.58	0.3708	1.5739	2.4189	3.2683	4.4281	5.3425	6.2958	7.6191	8.6722	9.7720	11.3020	12.5250	-0.0634	1.0409	0.0081

Generalised Extreme Value Distribution Parameters														K	E(y)	Var(y)
Distribution Skewness (g)		**Probability of Exceedance (%)**														
		50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**			
Return Period in Years		**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**			
	Skewness (g)	**Standardised Variate W_P**														
	1.59	0.3709	1.5738	2.4258	3.2928	4.4876	5.4470	6.4613	7.8745	9.0245	10.2402	11.9283	13.3096	-0.0946	1.0535	0.0163
	1.60	0.3710	1.5770	2.4260	3.2810	4.4510	5.3750	6.3400	7.6820	8.7520	9.8710	11.4300	12.6800	-0.0660	1.0427	0.00869
	1.62	0.3712	1.5797	2.4325	3.2927	4.4722	5.4056	6.3820	7.7428	8.8300	9.9689	11.5600	12.8370	-0.0683	1.0444	0.0095
	1.64	0.3713	1.5824	2.4390	3.3044	4.4934	5.4362	6.4240	7.8036	8.9080	10.0668	11.6900	12.9940	-0.0705	1.0461	0.0103
	1.66	0.3715	1.5851	2.4455	3.3161	4.5146	5.4668	6.4660	7.8644	8.9860	10.1647	11.8200	13.1510	-0.0728	1.0478	0.0112
	1.68	0.3716	1.5878	2.4520	3.3278	4.5358	5.4974	6.5080	7.9252	9.0640	10.2626	11.9500	13.3080	-0.0751	1.0495	0.0120
	1.70	0.3718	1.5905	2.4585	3.3395	4.5570	5.5280	6.5500	7.9860	9.1420	10.3605	12.0800	13.4650	-0.0774	1.0512	0.0128
	1.72	0.3719	1.5932	2.4650	3.3512	4.5782	5.5586	6.5920	8.0468	9.2200	10.4584	12.2100	13.6220	-0.0796	1.0529	0.0136
	1.74	0.3721	1.5959	2.4715	3.3629	4.5994	5.5892	6.6340	8.1076	9.2980	10.5563	12.3400	13.7790	-0.0819	1.0546	0.0144
	1.76	0.3722	1.5986	2.4780	3.3746	4.6206	5.6198	6.6760	8.1684	9.3760	10.6542	12.4700	13.9360	-0.0842	1.0563	0.0153
	1.78	0.3724	1.6013	2.4845	3.3863	4.6418	5.6504	6.7180	8.2292	9.4540	10.7521	12.6000	14.0930	-0.0864	1.0580	0.0161
	1.80	0.3725	1.6040	2.4910	3.3980	4.6630	5.6810	6.7600	8.2900	9.5320	10.8500	12.7300	14.2500	-0.0887	1.0597	0.0169

Generalised Extreme Value Distribution Parameters

Distribution Skewness (g)	Probability of Exceedance (%)												K	E(y)	Var(y)
	50	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01			
Return Period in Years	2	5	10	20	50	100	200	500	1 000	2 000	5 000	10 000			
Skewness (g)	Standardised Variate W_P														
1.82	0.3726	1.6065	2.4968	3.4087	4.6825	5.7095	6.7997	8.3481	9.6078	10.9460	12.8580	14.4070	-0.0907	1.0613	0.0179
1.84	0.3728	1.6090	2.5026	3.4194	4.7020	5.7380	6.8394	8.4062	9.6836	11.0420	12.9860	14.5640	-0.0927	1.0629	0.0189
1.86	0.3729	1.6115	2.5084	3.4301	4.7215	5.7665	6.8791	8.4643	9.7594	11.1380	13.1140	14.7210	-0.0947	1.0645	0.0200
1.88	0.3731	1.6140	2.5142	3.4408	4.7410	5.7950	6.9188	8.5224	9.8352	11.2340	13.2420	14.8780	-0.0967	1.0661	0.0210
2.00	0.3739	1.6290	2.5490	3.5050	4.8580	5.9660	7.1570	8.8710	10.2900	11.8100	14.0100	15.8200	-0.1086	1.0756	0.0271
2.10	0.3744	1.6390	2.5732	3.5500	4.9426	6.0910	7.3334	9.1348	10.6360	12.2580	14.6240	16.5860	-0.1165	1.0826	0.0334
2.20	0.3749	1.6388	2.5730	3.5499	4.9424	6.0909	7.3334	9.1347	10.6361	12.2582	14.6243	16.5866	-0.1123	1.0824	0.0336
2.30	0.3753	1.6386	2.5729	3.5498	4.9423	6.0909	7.3334	9.1348	10.6363	12.2586	14.6247	16.5873	-0.1088	1.0822	0.0337
2.40	0.3757	1.6385	2.5729	3.5497	4.9422	6.0909	7.3334	9.1348	10.6366	12.2589	14.6251	16.5881	-0.1060	1.0821	0.0338
2.44	0.3760	1.6547	2.6117	3.6218	5.0777	6.2909	7.6157	9.5569	11.1899	12.9754	15.6071	17.8129	-0.1228	1.0935	0.0437
2.50	0.3766	1.6790	2.6700	3.7300	5.2810	6.5910	8.0390	10.1900	12.0200	14.0500	17.0800	19.6500	-0.1480	1.1106	0.0584
2.52	0.3767	1.6790	2.6701	3.7359	5.3065	6.6500	8.1523	10.3944	12.3335	14.5050	17.7438	20.5335	-0.1752	1.1179	0.0600

Generalised Extreme Value Distribution Parameters

Distribution Skewness (g)	Probability of Exceedance (%)											K	E(y)	Var(y)
	50	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01			
Return Period in Years	2	5	10	20	50	100	200	500	1 000	2 000	5 000	10 000			
Skewness (g)	Standardised Variate W_P														
2.60	0.3770	1.6868	2.6888	3.7654	5.3488	6.6932	8.1858	10.4160	12.3220	14.4460	17.6340	20.3560	-0.1538	1.1163	0.0656
2.70	0.3774	1.6946	2.7076	3.8008	5.4166	6.7954	8.3326	10.6420	12.6240	14.8420	18.1880	21.0620	-0.1596	1.1221	0.0727
2.80	0.3779	1.7024	2.7264	3.8362	5.4844	6.8976	8.4794	10.8680	12.9260	15.2380	18.7420	21.7680	-0.1653	1.1278	0.0799
2.90	0.3783	1.7102	2.7452	3.8716	5.5522	6.9998	8.6262	11.0940	13.2280	15.6340	19.2960	22.4740	-0.1711	1.1336	0.0870
2.95	0.3785	1.7141	2.7546	3.8893	5.5861	7.0509	8.6996	11.2070	13.3790	15.8320	19.5730	22.8270	-0.1740	1.1364	0.0906
3.00	0.3787	1.7180	2.7640	3.9070	5.6200	7.1020	8.7730	11.3200	13.5300	16.0300	19.8500	23.1800	-0.1769	1.1393	0.0942
3.50	0.3802	1.7470	2.8380	4.0480	5.8940	7.5200	9.3810	12.2600	14.8200	17.7500	22.3000	26.3400	-0.1987	1.1628	0.1312
3.60	0.3804	1.7518	2.8496	4.0706	5.9388	7.5888	9.4822	12.4200	15.0400	18.0460	22.7280	26.8980	-0.2021	1.1667	0.1385
3.68	0.3806	1.7556	2.8589	4.0887	5.9746	7.6438	9.5632	12.5480	15.2160	18.2828	23.0704	27.3444	-0.2047	1.1697	0.1443
3.70	0.3807	1.7566	2.8612	4.0932	5.9836	7.6576	9.5834	12.5800	15.2600	18.3420	23.1560	27.4560	-0.2054	1.1705	0.1457
3.80	0.3809	1.7614	2.8728	4.1158	6.0284	7.7264	9.6846	12.7400	15.4800	18.6380	23.5840	28.0140	-0.2088	1.1744	0.1530
3.85	0.3810	1.7638	2.8786	4.1271	6.0508	7.7608	9.7352	12.8200	15.5900	18.7860	23.7980	28.2930	-0.2105	1.1763	0.1566

Generalised Extreme Value Distribution Parameters														K	E(y)	Var(y)
Distribution Skewness (g)		Probability of Exceedance (%)														
		50	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01			
Return Period in Years		2	5	10	20	50	100	200	500	1 000	2 000	5 000	10 000			
	Skewness (g)	Standardised Variate W_P														
	3.90	0.3812	1.7662	2.8844	4.1384	6.0732	7.7952	9.7858	12.9000	15.7000	18.9340	24.0120	28.5720	-0.2121	1.1782	0.1602
	4.00	0.3814	1.7710	2.8960	4.1610	6.1180	7.8640	9.8870	13.0600	15.9200	19.2300	24.4400	29.1300	-0.2155	1.1821	0.1675
	4.50	0.3823	1.7890	2.9430	4.2530	6.3020	8.1500	10.3100	13.7400	16.8500	20.5000	26.3100	31.5800	-0.2288	1.1983	0.2022
	5.00	0.3831	1.8050	2.9820	4.3290	6.4550	8.3890	10.6700	14.3200	17.6600	21.6000	27.9300	33.7200	-0.2396	1.2118	0.2346
	5.50	0.3837	1.8170	3.0140	4.3920	6.5840	8.5920	10.9700	14.8100	18.3500	22.5500	29.3400	35.6100	-0.2484	1.2233	0.2648
	6.00	0.3842	1.8280	3.0420	4.4470	6.6950	8.7680	11.2400	15.2400	18.9600	23.3900	30.6000	37.2900	-0.2558	1.2332	0.2931
	6.50	0.3847	1.8380	3.0660	4.4950	6.7940	8.9240	11.4700	15.6300	19.5100	24.1500	31.7500	38.8300	-0.2625	1.2424	0.3208
	7.00	0.3851	1.8460	3.0880	4.5390	6.8840	9.0670	11.6900	15.9900	20.0100	24.8600	32.8200	40.2800	-0.2688	1.2512	0.3494

Appendix 6: Log Normal and Log Pearson Type III Standardised Variate W_P

Log Normal and Log Pearson Type III Distributions: Standardised Variate W_P For Log Normal distribution W_P is determined at g = 0												
Skewness (g)	**Probability of Exceedance (%)**											
	50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**
Return Period - Years	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**
	Standardised Variate W_P											
-1.4	0.225	0.832	1.041	1.168	1.270	1.319	1.352	1.380	1.394	1.404	1.412	1.416
-1.2	0.195	0.844	1.086	1.243	1.380	1.450	1.502	1.551	1.578	1.598	1.618	1.628
-1.0	0.164	0.852	1.128	1.317	1.492	1.589	1.664	1.747	1.787	1.824	1.862	1.885
-0.99	0.162	0.852	1.130	1.321	1.498	1.596	1.673	1.757	1.799	1.837	1.876	1.900
-0.98	0.161	0.852	1.132	1.324	1.503	1.603	1.681	1.767	1.810	1.849	1.890	1.915
-0.96	0.158	0.853	1.136	1.331	1.515	1.618	1.699	1.787	1.833	1.875	1.918	1.945
-0.94	0.154	0.853	1.139	1.339	1.526	1.632	1.716	1.807	1.856	1.900	1.946	1.975
-0.92	0.151	0.854	1.143	1.346	1.538	1.647	1.733	1.827	1.879	1.925	1.974	2.005
-0.90	0.148	0.854	1.147	1.353	1.549	1.661	1.751	1.848	1.903	1.951	2.003	2.036
-0.85	0.140	0.855	1.157	1.371	1.578	1.697	1.794	1.898	1.960	2.014	2.073	2.111
-0.8	0.132	0.856	1.166	1.389	1.606	1.733	1.837	1.948	2.018	2.077	2.143	2.186
-0.7	0.116	0.857	1.183	1.423	1.663	1.806	1.926	2.057	2.140	2.213	2.296	2.351
-0.6	0.099	0.857	1.200	1.458	1.720	1.880	2.016	2.168	2.267	2.355	2.457	2.525
-0.5	0.083	0.857	1.216	1.491	1.777	1.954	2.108	2.282	2.398	2.502	2.625	2.708
-0.48	0.080	0.857	1.219	1.498	1.788	1.969	2.126	2.305	2.425	2.532	2.660	2.746
-0.46	0.077	0.856	1.222	1.504	1.799	1.984	2.145	2.329	2.452	2.562	2.694	2.784
-0.45	0.074	0.856	1.224	1.509	1.807	1.994	2.157	2.344	2.469	2.583	2.717	2.810
-0.44	0.073	0.856	1.225	1.511	1.811	1.999	2.163	2.352	2.478	2.593	2.729	2.823

Log Normal and Log Pearson Type III Distributions: Standardised Variate W_P For Log Normal distribution W_P is determined at g = 0												
Skewness (g)	**Probability of Exceedance (%)**											
	50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**
Return Period - Years	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**
	Standardised Variate W_P											
-0.42	0.070	0.855	1.228	1.517	1.822	2.014	2.182	2.376	2.505	2.623	2.763	2.861
-0.40	0.067	0.855	1.231	1.524	1.833	2.029	2.200	2.399	2.532	2.653	2.798	2.899
-0.3	0.050	0.853	1.245	1.555	1.889	2.104	2.294	2.517	2.668	2.808	2.977	3.096
-0.29	0.048	0.853	1.246	1.558	1.895	2.111	2.303	2.529	2.682	2.824	2.995	3.116
-0.28	0.047	0.852	1.248	1.561	1.900	2.119	2.313	2.541	2.696	2.840	3.014	3.137
-0.27	0.045	0.852	1.249	1.564	1.906	2.126	2.322	2.553	2.710	2.855	3.032	3.157
-0.26	0.043	0.852	1.250	1.567	1.911	2.134	2.332	2.565	2.724	2.871	3.051	3.177
-0.25	0.042	0.852	1.252	1.571	1.917	2.141	2.341	2.577	2.738	2.887	3.069	3.198
-0.24	0.040	0.851	1.253	1.574	1.923	2.148	2.350	2.588	2.751	2.903	3.087	3.218
-0.23	0.038	0.851	1.254	1.577	1.928	2.156	2.360	2.600	2.765	2.919	3.106	3.238
-0.22	0.036	0.851	1.255	1.580	1.934	2.163	2.369	2.612	2.779	2.934	3.124	3.258
-0.21	0.035	0.850	1.257	1.583	1.939	2.171	2.379	2.624	2.793	2.950	3.143	3.279
-0.2	0.033	0.850	1.258	1.586	1.945	2.178	2.388	2.636	2.807	2.966	3.161	3.299
-0.1	0.017	0.846	1.270	1.616	2.000	2.252	2.482	2.757	2.948	3.127	3.349	3.507
Log Normal Distribution g = 0.00	0.000	0.842	1.282	1.645	2.054	2.326	2.576	2.878	3.090	3.291	3.540	3.719
0.02	-0.003	0.841	1.284	1.651	2.065	2.341	2.595	2.902	3.119	3.324	3.579	3.762
0.03	-0.005	0.840	1.285	1.653	2.069	2.347	2.602	2.912	3.130	3.337	3.594	3.779
0.04	-0.007	0.840	1.286	1.656	2.075	2.356	2.614	2.927	3.148	3.357	3.618	3.805
0.041	-0.007	0.840	1.286	1.656	2.076	2.356	2.615	2.928	3.149	3.359	3.620	3.808
0.042	-0.007	0.839	1.286	1.657	2.076	2.357	2.615	2.929	3.150	3.360	3.621	3.810

Log Normal and Log Pearson Type III Distributions: Standardised Variate W_P For Log Normal distribution W_P is determined at g = 0												
Skewness (g)	**Probability of Exceedance (%)**											
	50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**
Return Period - Years	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**
	Standardised Variate W_P											
0.043	-0.007	0.839	1.286	1.657	2.077	2.358	2.616	2.930	3.152	3.362	3.623	3.812
0.044	-0.007	0.839	1.286	1.657	2.077	2.359	2.617	2.932	3.153	3.364	3.625	3.814
0.045	-0.008	0.839	1.287	1.658	2.078	2.359	2.618	2.933	3.155	3.365	3.627	3.816
0.046	-0.008	0.839	1.287	1.658	2.078	2.360	2.619	2.934	3.156	3.367	3.629	3.818
0.047	-0.008	0.839	1.287	1.658	2.079	2.361	2.620	2.935	3.158	3.369	3.631	3.821
0.048	-0.008	0.839	1.287	1.658	2.079	2.362	2.621	2.937	3.159	3.370	3.633	3.823
0.049	-0.008	0.839	1.287	1.659	2.080	2.362	2.622	2.938	3.161	3.372	3.635	3.825
0.050	-0.009	0.839	1.287	1.659	2.081	2.363	2.623	2.939	3.162	3.374	3.637	3.827
0.051	-0.009	0.839	1.287	1.659	2.081	2.364	2.624	2.940	3.163	3.375	3.639	3.829
0.052	-0.009	0.839	1.287	1.660	2.082	2.364	2.625	2.941	3.165	3.377	3.641	3.831
0.053	-0.009	0.839	1.287	1.660	2.082	2.365	2.626	2.943	3.166	3.378	3.643	3.833
0.054	-0.009	0.839	1.287	1.660	2.083	2.366	2.627	2.944	3.168	3.380	3.645	3.836
0.055	-0.009	0.839	1.288	1.660	2.083	2.367	2.628	2.945	3.169	3.382	3.647	3.838
0.056	-0.010	0.839	1.288	1.661	2.084	2.367	2.629	2.946	3.171	3.383	3.649	3.840
0.057	-0.010	0.839	1.288	1.661	2.084	2.368	2.630	2.948	3.172	3.385	3.651	3.842
0.058	-0.010	0.839	1.288	1.661	2.085	2.369	2.631	2.949	3.174	3.387	3.653	3.844
0.059	-0.010	0.838	1.288	1.662	2.085	2.370	2.631	2.950	3.175	3.388	3.654	3.846
0.06	-0.010	0.838	1.288	1.662	2.086	2.370	2.632	2.951	3.176	3.390	3.656	3.849
0.07	-0.012	0.838	1.289	1.665	2.091	2.378	2.642	2.963	3.191	3.407	3.676	3.870
0.08	-0.014	0.837	1.290	1.667	2.096	2.385	2.651	2.976	3.205	3.423	3.695	3.892

Log Normal and Log Pearson Type III Distributions: Standardised Variate W_P For Log Normal distribution W_P is determined at g = 0												
Skewness (g)	**Probability of Exceedance (%)**											
	50	**20**	**10**	**5**	**2**	**1**	**0.5**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**
Return Period - Years	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1 000**	**2 000**	**5 000**	**10 000**
	Standardised Variate W_P											
0.1	-0.017	0.836	1.292	1.673	2.107	2.400	2.670	3.000	3.234	3.456	3.734	3.935
0.2	-0.033	0.830	1.301	1.700	2.159	2.472	2.763	3.122	3.378	3.622	3.930	4.154
0.3	-0.050	0.824	1.309	1.726	2.211	2.544	2.857	3.244	3.522	3.789	4.128	4.375
0.35	-0.059	0.820	1.313	1.738	2.236	2.580	2.903	3.305	3.595	3.873	4.228	4.487
0.4	-0.067	0.816	1.317	1.750	2.261	2.616	2.949	3.366	3.667	3.957	4.327	4.598
0.5	-0.083	0.808	1.323	1.774	2.311	2.686	3.041	3.488	3.812	4.125	4.527	4.822
0.53	-0.088	0.814	1.367	1.887	2.543	3.063	3.609	4.322	4.942	5.611	6.477	7.266
0.6	-0.099	0.799	1.328	1.797	2.359	2.755	3.132	3.609	3.956	4.294	4.728	5.048
0.7	-0.116	0.790	1.333	1.819	2.407	2.824	3.223	3.730	4.100	4.462	4.929	5.274
0.8	-0.132	0.780	1.336	1.839	2.453	2.891	3.312	3.850	4.244	4.631	5.130	5.501
1.0	-0.164	0.758	1.340	1.877	2.542	3.022	3.488	4.087	4.530	4.966	5.533	5.955
1.2	-0.195	0.733	1.341	1.910	2.626	3.149	3.660	4.322	4.814	5.300	5.935	6.410
1.4	-0.225	0.705	1.337	1.938	2.706	3.271	3.828	4.553	5.095	5.632	6.336	6.864

Appendix 7A: Flood Frequency Analysis (SG3)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Seaka (19 875 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	Log Q - Log Q_{mean}
1972/1973	396	361	1	6 216	0.01	0.99	101664301138.07	3.79	0.49	0.79
1973/1974	849	518	2	5 192	0.04	0.96	48371514114.93	3.72	0.36	0.71
1974/1975	1 418	1 228	3	4 168	0.06	0.94	17985701925.26	3.62	0.23	0.61
1975/1976	2 279	2 091	4	3 754	0.09	0.91	10724795655.79	3.57	0.18	0.57
1976/1977	3 127	2 668	5	3 598	0.11	0.89	8608196423.23	3.56	0.17	0.55
1977/1978	1 170	1 069	6	3 127	0.14	0.86	3933696554.65	3.50	0.12	0.49
1978/1979	2 767	2 291	7	2 964	0.16	0.84	2840099526.52	3.47	0.10	0.47
1979/1980	722	643	8	2 767	0.18	0.82	1811329811.86	3.44	0.08	0.44
1980/1981	1 892	1 699	9	2 759	0.21	0.79	1774080266.69	3.44	0.08	0.43
1981/1982	321	214	10	2 363	0.23	0.77	539962218.05	3.37	0.05	0.37
1982/1983	316	264	11	2 279	0.26	0.74	390863683.43	3.36	0.04	0.35
1983/1984	278	224	12	1 976	0.28	0.72	78468327.81	3.30	0.02	0.29
1984/1985	822	789	13	1 892	0.31	0.69	40709462.97	3.28	0.02	0.27
1985/1986	1 170	789	14	1 606	0.33	0.67	194731.71	3.21	0.01	0.20
1986/1987	5 192	4 496	15	1 600	0.35	0.65	137358.49	3.20	0.01	0.20

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Seaka (19 875 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1987/1988	6 216	3 354	16	1 418	0.38	0.62	-2237487.15	3.15	0.00	0.15
1988/1989	3 754	885	17	1 298	0.40	0.60	-15672430.53	3.11	0.00	0.11
1989/1990	600	468	18	1 170	0.43	0.57	-54127991.44	3.07	0.00	0.06
1990/1991	1 298	1 133	19	1 170	0.45	0.55	-54127991.44	3.07	0.00	0.06
1991/1992	1 606	1 537	20	1 090	0.48	0.52	-96136559.39	3.04	0.00	0.03
1992/1993	632	525	21	944	0.50	0.50	-220626650.12	2.98	0.00	-0.03
1993/1994	2 964	2 868	22	915	0.52	0.48	-253814935.16	2.96	0.00	-0.04
1994/1995	289	210	23	849	0.55	0.45	-341779450.38	2.93	0.00	-0.08
1995/1996	2 759	2 183	24	822	0.57	0.43	-382882873.16	2.91	0.00	-0.09
1996/1997	1 090	961	25	800	0.60	0.40	-419508009.23	2.90	0.00	-0.10
1997/1998	1 600	1 538	26	722	0.62	0.38	-565171764.71	2.86	0.00	-0.15
1998/1999	341	285	27	709	0.65	0.35	-591472257.09	2.85	0.00	-0.16
1999/2000	709	493	28	632	0.67	0.33	-770506842.96	2.80	-0.01	-0.21
2000/2001	915	805	29	600	0.69	0.31	-851878938.43	2.78	-0.01	-0.23
2001/2002	1 976	1 708	30	494	0.72	0.28	-1171867916.32	2.69	-0.03	-0.31
2002/2003	374	295	31	491	0.74	0.26	-1183500509.83	2.69	-0.03	-0.32
2003/2004	347	265	32	396	0.77	0.23	-1530666730.22	2.60	-0.07	-0.41
2004/2005	491	416	33	374	0.79	0.21	-1620514892.50	2.57	-0.08	-0.43
2005/2006	800	799	34	350	0.82	0.18	-1720841762.75	2.54	-0.10	-0.46
2006/2007	84	64	35	347	0.84	0.16	-1733421676.00	2.54	-0.10	-0.47
2007/2008	350	348	36	341	0.86	0.14	-1758603403.94	2.53	-0.11	-0.47
2008/2009	4 168	998	37	321	0.89	0.11	-1846889846.05	2.51	-0.12	-0.50

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Seaka (19 875 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	Log Q - Log Q_{mean}
2009/2010	2 363	2 055	38	316	0.91	0.09	-1872135238.44	2.50	-0.13	-0.51
2010/2011	3 598	3 019	39	289	0.94	0.06	-1998260668.88	2.46	-0.16	-0.55
2011/2012	944	724	40	278	0.96	0.04	-2048575137.80	2.44	-0.18	-0.56
	494		41	84	0.99	0.01	-3139950832.30	1.92	-1.27	-1.08
			41							
			Mean Flow	**1548.32**			**172518878403.22**	**3.01**	**-0.44**	**0.00**
			Standard Deviation	**1445.93**				**0.42**		

Appendix 7B: Flood Frequency Analysis (SG4)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Whitehill (10 900 Km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1964/1965	67	66	1	1 691	0.01	0.99	981582410.73	3.23	0.11	0.49
1965/1966	111	109	2	1 669	0.03	0.97	916264571.89	3.22	0.11	0.48
1966/1967	543	382	3	1 545	0.05	0.95	608801305.75	3.19	0.09	0.45
1967/1968	541	379	4	1 495	0.08	0.92	507643881.68	3.17	0.08	0.43
1968/1969	318	246	5	1 325	0.10	0.90	247484751.37	3.12	0.05	0.38
1969/1970	333	279	6	1 299	0.12	0.88	217296125.17	3.11	0.05	0.37
1970/1971	496	444	7	1 272	0.14	0.86	189851329.99	3.10	0.05	0.36
1971/1972	1 299	1 202	8	1 214	0.16	0.84	137879702.58	3.08	0.04	0.34
1972/1973	307	250	9	1 206	0.18	0.82	131078492.27	3.08	0.04	0.34
1973/1974	740	708	10	1 115	0.20	0.80	72595067.35	3.05	0.03	0.30
1974/1975	1 214	950	11	1 018	0.22	0.78	32968617.46	3.01	0.02	0.27
1975/1976	1 325	1 044	12	1 010	0.25	0.75	30523356.83	3.00	0.02	0.26
1976/1977	1 495	1 305	13	991	0.27	0.73	25316806.51	3.00	0.02	0.25
1977/1978	814	645	14	837	0.29	0.71	2706931.52	2.92	0.01	0.18
1978/1979	1 545	1 298	15	814	0.31	0.69	1586414.12	2.91	0.00	0.17
1979/1980	629	422	16	772	0.33	0.67	409621.54	2.89	0.00	0.15
1980/1981	1 010	875	17	764	0.35	0.65	299038.80	2.88	0.00	0.14
1981/1982	376	326	18	764	0.37	0.63	299038.80	2.88	0.00	0.14

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Whitehill (10 900 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1982/1983	331	179	19	740	0.39	0.61	76218.14	2.87	0.00	0.13
1983/1984	764	646	20	721	0.42	0.58	12195.15	2.86	0.00	0.12
1984/1985	772	602	21	629	0.44	0.56	-327200.66	2.80	0.00	0.06
1985/1986	626	624	22	626	0.46	0.54	-361070.02	2.80	0.00	0.05
1986/1987	1 669	947	23	626	0.48	0.52	-361070.02	2.80	0.00	0.05
1987/1988	1 018	1 018	24	608	0.50	0.50	-717068.22	2.78	0.00	0.04
1988/1989	1 691	1 532	25	543	0.52	0.48	-3670670.70	2.74	0.00	-0.01
1989/1990	444	378	26	541	0.54	0.46	-3829164.49	2.73	0.00	-0.01
1990/1991	837	419	27	524	0.56	0.44	-5253711.28	2.72	0.00	-0.02
1991/1992	513	477	28	522	0.58	0.42	-5452080.49	2.72	0.00	-0.02
1992/1993	487	333	29	513	0.61	0.39	-6292205.61	2.71	0.00	-0.03
1993/1994	1 272	1 180	30	496	0.63	0.37	-8204796.32	2.70	0.00	-0.05
1994/1995	204	155	31	487	0.65	0.35	-9281690.78	2.69	0.00	-0.05
1995/1996	1 206	1 120	32	471	0.67	0.33	-11686925.96	2.67	0.00	-0.07
1996/1997	626	554	33	444	0.69	0.31	-16341868.92	2.65	0.00	-0.09
1997/1998	764	625	34	406	0.71	0.29	-24897414.54	2.61	0.00	-0.13
1998/1999	608	457	35	376	0.73	0.27	-33182699.00	2.58	0.00	-0.17
1999/2000	991	771	36	363	0.75	0.25	-37520439.44	2.56	-0.01	-0.18
2000/2001	406	382	37	333	0.78	0.22	-48566510.15	2.52	-0.01	-0.22
2001/2002	721	592	38	331	0.80	0.20	-49308643.33	2.52	-0.01	-0.22
2002/2003	524	435	39	318	0.82	0.18	-54675681.61	2.50	-0.01	-0.24
2003/2004	236	184	40	307	0.84	0.16	-59510978.94	2.49	-0.02	-0.25

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Whitehill (10 900 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log } Q - \text{Log } Q_{mean})^3$	$\text{Log } Q - \text{Log } Q_{mean}$
2004/2005	189	174	41	236	0.86	0.14	-98076316.99	2.37	-0.05	-0.37
2005/2006	142	131	42	204	0.88	0.12	-120050266.73	2.31	-0.08	-0.43
2006/2007	-	30	43	189	0.90	0.10	-131695311.75	2.28	-0.10	-0.47
2007/2008	522	244	44	142	0.92	0.08	-171287939.03	2.15	-0.20	-0.59
2008/2009	1 115	963	45	111	0.95	0.05	-201462222.47	2.05	-0.34	-0.70
2009/2010	471	264	46	109	0.97	0.03	-203808504.64	2.04	-0.35	-0.70
2010/2011	109	37	47	67	0.99	0.01	-250764816.53	1.83	-0.77	-0.92
2011/2012	363	45								
			47							
			Mean	**697.63**			**2548088609**	**2.74**	**-1.22**	**0.00**
			STDV	**436.14**				**0.33**		

Appendix 7C: Flood Frequency Analysis (SG4A)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Whitehill Weir (10 749.80 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1986/1987	2 410	140	1	5 000	0.03	0.97	40094746449.46	3.70	0.23	0.61
1987/1988	2 583	133	2	4 000	0.08	0.92	14219097381.96	3.60	0.14	0.52
1988/1989	1 418	145	3	2 583	0.13	0.87	1017045947.86	3.41	0.03	0.33
1989/1990	1 347	145	4	2 410	0.18	0.82	577281259.63	3.38	0.03	0.30
1990/1991	796	151	5	2 155	0.23	0.77	192749976.17	3.33	0.02	0.25
1991/1992	941	141	6	2 000	0.28	0.72	75499246.96	3.30	0.01	0.21
1992/1993	1 304	128	7	1 754	0.33	0.67	5512402.55	3.24	0.00	0.16
1993/1994	-	146	8	1 644	0.38	0.62	296074.13	3.22	0.00	0.13
1994/1995	2 155	156	9	1 418	0.43	0.57	-4046282.53	3.15	0.00	0.07
1995/1996	407	170	10	1 347	0.48	0.52	-12222629.57	3.13	0.00	0.04
1996/1997	5 000	548	11	1 304	0.52	0.48	-20424772.82	3.12	0.00	0.03
1997/1998	813	598	12	990	0.57	0.43	-202624016.22	3.00	0.00	-0.09
1998/1999	434	401	13	941	0.62	0.38	-257684410.57	2.97	0.00	-0.11
1999/2000	462	356	14	813	0.67	0.33	-446556905.61	2.91	-0.01	-0.18
2000/2001	675	226	15	796	0.72	0.28	-477020287.11	2.90	-0.01	-0.19
2001/2002	1 754	553	16	675	0.77	0.23	-734725423.73	2.83	-0.02	-0.26
2002/2003	414	391	17	462	0.82	0.18	-1387501671.06	2.66	-0.07	-0.42
2003/2004	990	137	18	434	0.87	0.13	-1494643398.55	2.64	-0.09	-0.45
2004/2005	1 644	316	19	414	0.92	0.08	-1574458371.90	2.62	-0.10	-0.47
2005/2006	4 000	545	20	407	0.97	0.03	-1603050775.02	2.61	-0.11	-0.48

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Whitehill Weir (10 749.80 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
2006/2007	2 000	251								
2007/2008	-	297								
2008/2009	-	984								
2009/2010	-	124								
2010/2011	-	1 310								
2011/2012	-	37								
			20							
			Mean	**1577.35**			**47967269794**	**3.09**	**0.051589773**	**0.00**
			STDEV	**1214.45**				**0.32199**		

Appendix 7D: Flood Frequency Analysis (SG5)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Koma - Koma (7 950 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1966/1967	713	713	1	7 598	0.01	0.99	290792292833.17	3.88	1.21	1.06
1967/1968	772	330	2	2 334	0.04	0.96	2522761751.16	3.37	0.17	0.55
1968/1969	239	148	3	2 307	0.06	0.94	2370551869.95	3.36	0.16	0.55
1969/1970	288	227	4	2 105	0.08	0.92	1449051565.71	3.32	0.13	0.51
1970/1971	367	310	5	1 892	0.10	0.90	776466699.67	3.28	0.10	0.46
1971/1972	1 261	1 023	6	1 833	0.13	0.87	635575448.31	3.26	0.09	0.45
1972/1973	288	184	7	1 821	0.15	0.85	609977893.32	3.26	0.09	0.44
1973/1974	998	830	8	1 776	0.17	0.83	517900339.55	3.25	0.08	0.43
1974/1975	1 776	1 427	9	1 368	0.19	0.81	61763543.10	3.14	0.03	0.32
1975/1976	7 598	5 028	10	1 268	0.22	0.78	25500805.14	3.10	0.02	0.29
1976/1977	2 105	1 571	11	1 261	0.24	0.76	23764753.94	3.10	0.02	0.28
1977/1978	918	671	12	1 098	0.26	0.74	1958208.95	3.04	0.01	0.22
1978/1979	1 833	1 020	13	1 020	0.28	0.72	104422.99	3.01	0.01	0.19
1979/1980	713	439	14	998	0.31	0.69	14586.46	3.00	0.01	0.18
1980/1981	662	947	15	918	0.33	0.67	-167490.41	2.96	0.00	0.15
1981/1982	673	352	16	792	0.35	0.65	-5971573.52	2.90	0.00	0.08

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Koma - Koma (7 950 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1982/1983	731	529	17	772	0.38	0.62	-8156364.18	2.89	0.00	0.07
1983/1984	1 020	248	18	731	0.40	0.60	-14253395.91	2.86	0.00	0.05
1984/1985	1 821	935	19	713	0.42	0.58	-17521227.25	2.85	0.00	0.04
1985/1986	792	683	20	713	0.44	0.56	-17589720.22	2.85	0.00	0.04
1986/1987	1 892	1 488	21	673	0.47	0.53	-26980466.53	2.83	0.00	0.01
1987/1988	1 268	956	22	662	0.49	0.51	-30081866.49	2.82	0.00	0.00
1988/1989	323	162	23	624	0.51	0.49	-42404361.51	2.80	0.00	-0.02
1989/1990	283	236	24	624	0.53	0.47	-42404361.51	2.80	0.00	-0.02
1990/1991	624	449	25	619	0.56	0.44	-44350073.95	2.79	0.00	-0.02
1991/1992	443	397	26	554	0.58	0.42	-73730116.97	2.74	0.00	-0.07
1992/1993	130	96	27	530	0.60	0.40	-86961644.88	2.72	0.00	-0.09
1993/1994	-	-	28	507	0.62	0.38	-101190550.35	2.71	0.00	-0.11
1994/1995	172	132	29	464	0.65	0.35	-132400397.93	2.67	0.00	-0.15
1995/1996	1 368	1 239	30	443	0.67	0.33	-149249477.17	2.65	0.00	-0.17
1996/1997	530	272	31	407	0.69	0.31	-181381700.47	2.61	-0.01	-0.21
1997/1998	326	296	32	367	0.72	0.28	-222865366.00	2.56	-0.02	-0.25
1998/1999	-	-	33	326	0.74	0.26	-271373642.88	2.51	-0.03	-0.30
1999/2000	271	215	34	323	0.76	0.24	-275465748.10	2.51	-0.03	-0.31
2000/2001	407	226	35	313	0.78	0.22	-287801424.09	2.50	-0.03	-0.32
2001/2002	507	340	36	288	0.81	0.19	-321781929.69	2.46	-0.05	-0.36
2002/2003	624	275	37	288	0.83	0.17	-321781929.69	2.46	-0.05	-0.36
2003/2004	109	84	38	285	0.85	0.15	-325210213.33	2.46	-0.05	-0.36
2004/2005	313	196	39	283	0.87	0.13	-329391959.91	2.45	-0.05	-0.37
2005/2006	464	415	40	271	0.90	0.10	-346148973.17	2.43	-0.06	-0.38

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Koma - Koma (7 950 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log } Q - \text{Log } Q_{mean})^3$	$\text{Log } Q - \text{Log } Q_{mean}$
2006/2007	2 307	1 302	41	239	0.92	0.08	-394942255.47	2.38	-0.08	-0.44
2007/2008	554	219	42	172	0.94	0.06	-514913611.19	2.23	-0.20	-0.58
2008/2009	1 098	854	43	130	0.96	0.04	-599822822.40	2.11	-0.35	-0.70
2009/2010	285	187	44	109	0.99	0.01	-645300990.11	2.04	-0.47	-0.78
2010/2011	2 334	1 756								
2011/2012	619	404								
			44							
			Mean	**973.18**			**293956089066.14**	**2.82**	**0.66**	**0.00**
			STDEV	**1191.43**				**0.37**		

Appendix 7E: Flood Frequency Analysis (SG6)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Mokhotlong (1 660 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log } Q_{mean})^3$	$\text{Log Q} - \text{Log } Q_{mean}$
1967/1968	178	23	1	1 278	0.03	0.97	759336063.19	3.11	0.37	0.72
1968/1969	-	26	2	1 120	0.09	0.91	429198034.05	3.05	0.29	0.66
1969/1970	447	11	3	876	0.15	0.85	132896716.56	2.94	0.17	0.56
1970/1971	-	40	4	447	0.21	0.79	537659.45	2.65	0.02	0.26
1971/1972	-	137	5	392	0.27	0.73	18221.98	2.59	0.01	0.21
1972/1973	133	39	6	296	0.32	0.68	-338394.59	2.47	0.00	0.09
1973/1974	97	87	7	277	0.38	0.62	-697517.06	2.44	0.00	0.06
1974/1975	-		8	266	0.44	0.56	-990588.50	2.42	0.00	0.04
1975/1976	85	65	9	245	0.50	0.50	-1757774.09	2.39	0.00	0.00
1976/1977	245	220	10	200	0.56	0.44	-4548329.18	2.30	0.00	-0.08
1977/1978	876	75	11	178	0.62	0.38	-6640992.75	2.25	0.00	-0.14
1978/1979	1 120	154	12	176	0.68	0.32	-6824973.77	2.25	0.00	-0.14
1979/1980	392	66	13	133	0.73	0.27	-12679539.30	2.12	-0.02	-0.26
1980/1981	176	176	14	111	0.79	0.21	-16520059.48	2.05	-0.04	-0.34
1981/1982	277	77	15	97	0.85	0.15	-19347101.89	1.99	-0.06	-0.40
1982/1983	111	23	16	85	0.91	0.09	-22066339.12	1.93	-0.09	-0.46
1983/1984	296	33	17	40	0.97	0.03	-34545735.78	1.60	-0.48	-0.78
1984/1985	200	187								

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqu River @ Mokhotlong (1 660 Km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log } Q_{mean})^3$	$\text{Log Q} - \text{Log } Q_{mean}$
1985/1986	40	26								
1986/1987	266	205								
1987/1988	1 278	959								
			17							
			Mean	**365.69**			**1195029349.70**	**2.39**	**0.17**	
			STDEV	**369.21131**				**0.40**		

Stellenbosch University http://scholar.sun.ac.za

Appendix 7F: Flood Frequency Analysis (SG7)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Tsoelike River @ Tsoelike Bridge (797 km^2)

Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1965/1966	227	0	1	774	0.03	0.97	234 504 629.63	2.89	0.74	0.90
1966/1967	28	20	2	410	0.07	0.93	16 130 352.30	2.61	0.25	0.63
1967/1968	58	29	3	327	0.12	0.88	4 884 156.63	2.51	0.15	0.53
1968/1969	774	6	4	227	0.17	0.83	338 123.30	2.36	0.05	0.37
1969/1970	39	14	5	223	0.22	0.78	283 161.96	2.35	0.05	0.36
1970/1971	9	3	6	200	0.26	0.74	77 672.30	2.30	0.03	0.32
1971/1972	-	110	7	169	0.31	0.69	1 587.96	2.23	0.01	0.24
1972/1973	67	55	8	144	0.36	0.64	-2 370.37	2.16	0.01	0.17
1973/1974	144	104	9	143	0.41	0.59	-2 944.70	2.16	0.01	0.17
1974/1975	85	66	10	113	0.45	0.55	-87 134.70	2.05	0.00	0.07
1975/1976	169	84	11	85	0.50	0.50	-378 456.04	1.93	-0.00	-0.05
1976/1977	83	21	12	83	0.55	0.45	-410 724.70	1.92	-0.00	-0.07
1977/1978	410	54	13	79	0.59	0.41	-480 662.04	1.90	-0.00	-0.09
1978/1979	223	81	14	69	0.64	0.36	-689 245.37	1.84	-0.00	-0.15
1979/1980	69	59	15	67	0.69	0.31	-737 130.04	1.83	-0.00	-0.16
1980/1981	143	24	16	58	0.74	0.26	-980 133.04	1.76	-0.01	-0.22
1981/1982	200	21	17	39	0.78	0.22	-1 656 995.37	1.59	-0.06	-0.39
1982/1983	79	17	18	35	0.83	0.17	-1 830 772.70	1.54	-0.09	-0.44

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Tsoelike River @ Tsoelike Bridge (797 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1983/1984	35	2	19	28	0.88	0.12	-2 163 373.04	1.45	-0.15	-0.54
1984/1985	22	14	20	22	0.93	0.07	-2 478 645.04	1.34	-0.26	-0.64
1985/1986	113	60	21	9	0.97	0.03	-3 263 745.37	0.95	-1.09	-1.03
			21							
			Mean	**157.33**			**241 057 351.56**	**1.98**	**-0.38**	
			STDEV	**175.373**				**0.46**		**0.00**

Appendix 7G: Flood Frequency Analysis (SG8)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Malibamatso River @ Paray (3 240 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	(Qi - Qmean)^3	Log Q	(Log Q - Log Q_{mean})^3	Log Q - Log Q_{mean}
1966/1967	2 996	2 388	1	3 023	0.01	0.99	13615216283.03	3.48	0.66	0.87
1967/1968	743	421	2	2 996	0.03	0.97	13154438743.24	3.48	0.65	0.87
1968/1969	386	208	3	1 367	0.06	0.94	392569304.91	3.14	0.15	0.53
1969/1970	325	235	4	1 182	0.08	0.92	163535646.53	3.07	0.10	0.46
1970/1971	409	263	5	1 166	0.10	0.90	149510145.15	3.07	0.10	0.46
1971/1972	573	519	6	1 129	0.12	0.88	120302309.14	3.05	0.09	0.44
1972/1973	305	202	7	1 077	0.15	0.85	86249689.93	3.03	0.08	0.42
1973/1974	320	272	8	1 072	0.17	0.83	83292722.21	3.03	0.08	0.42
1974/1975	1 077	605	9	972	0.19	0.81	38412362.43	2.99	0.05	0.38
1975/1976	305	263	10	786	0.21	0.79	3413435.49	2.90	0.02	0.29
1976/1977	1 367	829	11	764	0.23	0.77	2161714.13	2.88	0.02	0.28
1977/1978	786	558	12	752	0.26	0.74	1589171.94	2.88	0.02	0.27
1978/1979	1 072	627	13	743	0.28	0.72	1272571.92	2.87	0.02	0.26
1979/1980	667	383	14	715	0.30	0.70	504154.34	2.85	0.01	0.25
1980/1981	1 129	786	15	667	0.32	0.68	31991.67	2.82	0.01	0.22
1981/1982	764	383	16	655	0.34	0.66	8088.24	2.82	0.01	0.21
1982/1983	610	480	17	651	0.37	0.63	4258.04	2.81	0.01	0.21
1983/1984	415	110	18	610	0.39	0.61	-16506.84	2.79	0.01	0.18
1984/1985	312	201	19	573	0.41	0.59	-238417.19	2.76	0.00	0.15
1985/1986	391	291	20	541	0.43	0.57	-825867.46	2.73	0.00	0.13

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Malibamatso River @ Paray (3 240 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1986/1987	1 182	843	21	500	0.46	0.54	-2441980.97	2.70	0.00	0.09
1987/1988	3 023	1 880	22	465	0.48	0.52	-4959071.14	2.67	0.00	0.06
1988/1989	1 166	731	23	461	0.50	0.50	-5242246.79	2.66	0.00	0.06
1989/1990	352	225	24	415	0.52	0.48	-10654787.12	2.62	0.00	0.01
1990/1991	349	277	25	409	0.54	0.46	-11545893.46	2.61	0.00	0.00
1991/1992	406	382	26	409	0.57	0.43	-11545893.46	2.61	0.00	0.00
1992/1993	541	370	27	406	0.59	0.41	-12006587.36	2.61	0.00	0.00
1993/1994	715	538	28	391	0.61	0.39	-14462354.37	2.59	0.00	-0.02
1994/1995	130	90	29	386	0.63	0.37	-15515332.58	2.59	0.00	-0.02
1995/1996	651	585	30	352	0.66	0.34	-22682426.52	2.55	0.00	-0.06
1996/1997	461	187	31	349	0.68	0.32	-23344302.32	2.54	0.00	-0.06
1997/1998	-	128	32	347	0.70	0.30	-24015933.46	2.54	0.00	-0.07
1998/1999	158	104	33	325	0.72	0.28	-29735891.84	2.51	0.00	-0.10
1999/2000	165	118	34	320	0.74	0.26	-31260260.95	2.51	0.00	-0.10
2000/2001	-	165	35	312	0.77	0.23	-33615622.62	2.49	0.00	-0.11
2001/2002	409	331	36	305	0.79	0.21	-36051706.41	2.48	0.00	-0.12
2002/2003	500	133	37	305	0.81	0.19	-36051706.41	2.48	0.00	-0.12
2003/2004	44	39	38	165	0.83	0.17	-103871870.75	2.22	-0.06	-0.39
2004/2005	-	-	39	158	0.85	0.15	-108624692.15	2.20	-0.07	-0.41
2005/2006	-	-	40	130	0.88	0.12	-128970360.26	2.11	-0.12	-0.49
2006/2007	655	-	41	78	0.90	0.10	-172954613.13	1.89	-0.37	-0.72
2007/2008	31	30	42	69	0.92	0.08	-181544298.69	1.84	-0.46	-0.77

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Malibamatso River @ Paray (3 240 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
2008/2009	465	408	43	44	0.94	0.06	-206908223.66	1.64	-0.91	-0.97
2009/2010	752	266	44	31	0.97	0.03	-220194291.14	1.49	-1.38	-1.11
2010/2011	972	719	45	6	0.99	0.01	-249240257.05	0.76	-6.32	-1.85
2011/2012	347	194								
	69		45							
			Mean	**635.07**			**26113991196.24**	**2.61**	**-7.60**	**0.00**
			STDEV	**618.482**				**0.50**		

Appendix 7H: Flood Frequency Analysis (SG17)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqunyane River @ Marakabei (1 087 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log\ Q - Log\ Q_{mean})^3$	$Log\ Q - Log\ Q_{mean}$
1963/1964	144	76	1	1 479	0.01	0.99	1252953799.65	3.17	0.51	0.80
1964/1965	36	33	2	1 248	0.03	0.97	609170861.83	3.10	0.39	0.73
1965/1966	587	268	3	1 091	0.05	0.95	329023713.68	3.04	0.30	0.67
1966/1967	1 479	989	4	1 018	0.07	0.93	234951564.72	3.01	0.26	0.64
1967/1968	570	251	5	1 011	0.09	0.91	227614731.91	3.00	0.26	0.64
1968/1969	158	92	6	905	0.11	0.89	128428511.77	2.96	0.20	0.59
1969/1970	235	121	7	858	0.13	0.87	95686157.44	2.93	0.18	0.56
1970/1971	165	107	8	818	0.15	0.85	72796487.40	2.91	0.16	0.54
1971/1972	491	284	9	727	0.17	0.83	34682392.53	2.86	0.12	0.49
1972/1973	124	90	10	676	0.19	0.81	20968677.39	2.83	0.10	0.46
1973/1974	305	134	11	638	0.21	0.79	13351890.66	2.80	0.08	0.44
1974/1975	441	228	12	624	0.23	0.77	11117814.15	2.80	0.08	0.43
1975/1976	1 018	547	13	587	0.25	0.75	6515541.50	2.77	0.06	0.40
1976/1977	1 248	680	14	570	0.27	0.73	4837628.56	2.76	0.06	0.39
1977/1978	905	287	15	536	0.29	0.71	2456614.18	2.73	0.05	0.36
1978/1979	818	461	16	491	0.31	0.69	735194.03	2.69	0.03	0.32
1979/1980	434	352	17	471	0.33	0.67	355228.56	2.67	0.03	0.30
1980/1981	676	331	18	449	0.35	0.65	112044.16	2.65	0.02	0.28
1981/1982	1 011	373	19	449	0.37	0.63	112044.16	2.65	0.02	0.28
1982/1983	441	303	20	441	0.39	0.61	68118.17	2.64	0.02	0.28

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqunyane River @ Marakabei (1 087 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log } Q - \text{Log } Q_{mean})^3$	$\text{Log } Q - \text{Log } Q_{mean}$
1983/1984	449	343	21	441	0.41	0.59	68118.17	2.64	0.02	0.28
1984/1985	283	120	22	434	0.43	0.57	37781.46	2.64	0.02	0.27
1985/1986	140	176	23	385	0.45	0.55	-3472.32	2.59	0.01	0.22
1986/1987	858	462	24	314	0.47	0.53	-653425.65	2.50	0.00	0.13
1987/1988	1 091	461	25	305	0.49	0.51	-867836.26	2.48	0.00	0.12
1988/1989	214	356	26	286	0.51	0.49	-1514528.71	2.46	0.00	0.09
1989/1990	208	129	27	283	0.53	0.47	-1624215.83	2.45	0.00	0.08
1990/1991	449	227	28	278	0.55	0.45	-1856822.32	2.44	0.00	0.07
1991/1992	314	279	29	235	0.57	0.43	-4550019.80	2.37	0.00	0.00
1992/1993	727	329	30	214	0.59	0.41	-6477796.93	2.33	0.00	-0.04
1993/1994	624	451	31	208	0.61	0.39	-7191942.69	2.32	0.00	-0.05
1994/1995	62	36	32	165	0.63	0.37	-13051211.23	2.22	0.00	-0.15
1995/1996	536	395	33	161	0.65	0.35	-13675892.99	2.21	0.00	-0.16
1996/1997	286	169	34	158	0.67	0.33	-14310114.93	2.20	0.00	-0.17
1997/1998	638	393	35	144	0.69	0.31	-16931200.17	2.16	-0.01	-0.21
1998/1999	104	100	36	140	0.71	0.29	-17604776.79	2.15	-0.01	-0.22
1999/2000	161	113	37	124	0.73	0.27	-21057231.26	2.10	-0.02	-0.27
2000/2001	471	229	38	104	0.75	0.25	-26032717.98	2.02	-0.04	-0.35
2001/2002	385	366	39	103	0.77	0.23	-26390614.34	2.01	-0.05	-0.36
2002/2003	29	21	40	85	0.79	0.21	-31377430.06	1.93	-0.08	-0.44
2003/2004	19	17	41	79	0.81	0.19	-33131469.17	1.90	-0.10	-0.47
2004/2005	33	32	42	62	0.83	0.17	-38701529.58	1.79	-0.19	-0.57

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Senqunyane River @ Marakabei (1 087 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q} - \text{Log Q}_{mean})^3$	$\text{Log Q} - \text{Log Q}_{mean}$
2005/2006	79	48	43	37	0.85	0.15	-47880715.03	1.57	-0.50	-0.80
2006/2007	103	52	44	36	0.87	0.13	-48308809.51	1.56	-0.53	-0.81
2007/2008	37	26	45	33	0.89	0.11	-49556966.25	1.52	-0.61	-0.85
2008/2009	31	24	46	31	0.91	0.09	-50358615.62	1.50	-0.67	-0.87
2009/2010	85	52	47	31	0.93	0.07	-50358615.62	1.50	-0.67	-0.87
2010/2011	278	260	48	29	0.95	0.05	-51134965.69	1.47	-0.73	-0.90
2011/2012	31	21	49	19	0.97	0.03	-55566216.46	1.28	-1.30	-1.09
	15		50	15	0.99	0.01	-57511034.59	1.16	-1.75	-1.20
			50							
			Mean	**400.60**			**167216353.11**	**2.37**	**-4.26**	**0.00**
			STDEV	**357.9837**				**0.53**		

Appendix 7I: Flood Frequency Analysis (SG36)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Khubelu River @ Tlokoeng (852 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(Log Q - Log Q_{mean})^3$	$Log Q - Log Q_{mean}$
1969/1970	-	18	1	304	0.05	0.95	6716743.60	2.48	0.12	0.50
1970/1971	89	26	2	200	0.14	0.86	607156.41	2.30	0.03	0.32
1971/1972	304	73	3	150	0.23	0.77	41699.88	2.18	0.01	0.19
1972/1973	38	16	4	119	0.32	0.68	70.31	2.08	0.00	0.09
1973/1974	70	53	5	106	0.41	0.59	-947.76	2.02	0.00	0.04
1974/1975	-	38	6	89	0.50	0.50	-18238.65	1.95	0.00	-0.04
1975/1976	-	75	7	77	0.59	0.41	-55667.39	1.89	0.00	-0.10
1976/1977	150	77	8	70	0.68	0.32	-93099.66	1.85	0.00	-0.14
1977/1978	106	67	9	59	0.77	0.23	-180579.87	1.77	-0.01	-0.22
1978/1979	119	61	10	57	0.86	0.14	-201876.96	1.75	-0.01	-0.23
1979/1980	59	40	11	38	0.95	0.05	-462297.44	1.58	-0.07	-0.41
			11							
			Mean	**115.32**			**6352962.48**	**1.99**	**0.07**	**0.00**
			STDEV	**78.04**				**0.26**		

Appendix 7J: Flood Frequency Analysis (SG40)

Flood Frequency Analysis for Annual Maximum Series in Lesotho - Qomoqomong River @ Quthing (208 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Q_i - Q_{mean})^3$	Log Q	$(\log Q - \log Q_{mean})^3$	$\log Q - \log Q_{mean}$
1976/1977	325	3	1	325	0.05	0.95	9074045.52	2.51	0.18	0.56
1977/1978	45	28	2	198	0.14	0.86	542884.63	2.30	0.04	0.35
1978/1979	-	84	3	183	0.23	0.77	295105.97	2.26	0.03	0.31
1979/1980	183	49	4	131	0.32	0.68	3097.62	2.12	0.00	0.17
1980/1981	26	5	5	123	0.41	0.59	284.54	2.09	0.00	0.14
1981/1982	76	52	6	76	0.50	0.50	-66050.61	1.88	0.00	-0.07
1982/1983	66	44	7	70	0.59	0.41	-99785.82	1.85	0.00	-0.11
1983/1984	123	13	8	66	0.68	0.32	-128197.33	1.82	0.00	-0.13
1984/1985	198	24	9	45	0.77	0.23	-364342.04	1.65	-0.03	-0.30
1985/1986	131	16	10	38	0.86	0.14	-483971.95	1.58	-0.05	-0.37
1986/1987	38	11	11	26	0.95	0.05	-746703.68	1.41	-0.16	-0.54
1987/1988	70	29								
			11							
			Mean	**116.42**			**8026366.84**	**1.95**	**0.01**	**0.00**
			STDEV	**89.82**				**0.34**		

Appendix 7K: Flood Frequency Analysis (SG42)

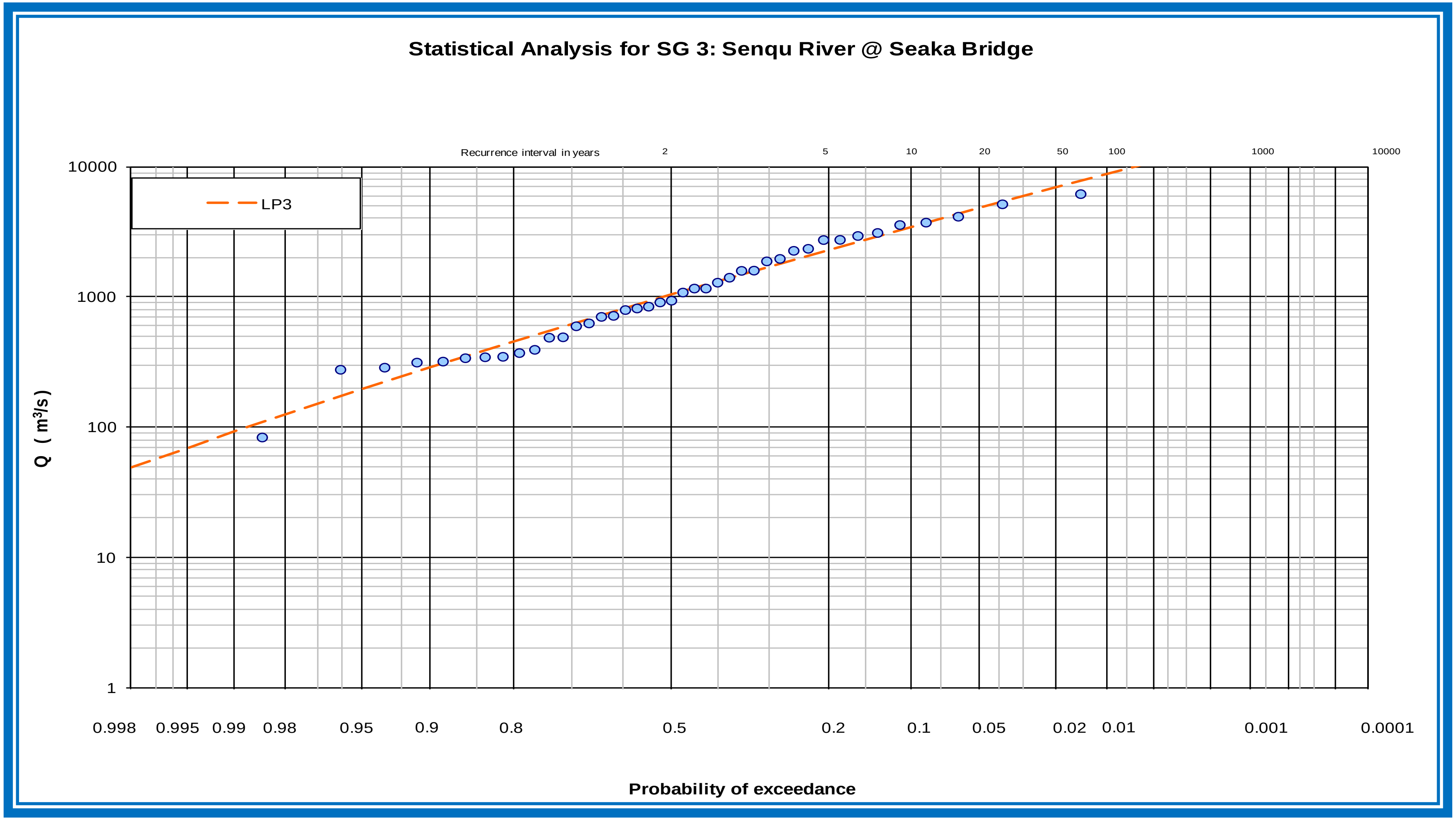
Flood Frequency Analysis for Annual Maximum Series in Lesotho - Matsoku River @ Ha - Seshote (662 km^2)										
Year	Instantaneous Flood Peak	Daily Mean Flow	Rank	AM Order	P(X) Gringorton	F(X) Gringorton	$(Qi - Qmean)^3$	Log Q	$(\text{Log Q - Log Q}_{mean})^3$	$\text{Log Q - Log Q}_{mean}$
1970/1971	-	18	1	240	0.05	0.95	2562213.96	2.38	0.08	0.42
1971/1972	94	41	2	165	0.13	0.87	236458.96	2.22	0.02	0.26
1972/1973	23	15	3	112	0.21	0.79	611.42	2.05	0.00	0.09
1973/1974	77	47	4	105	0.29	0.71	6.20	2.02	0.00	0.06
1974/1975	112	50	5	98	0.38	0.62	-137.59	1.99	0.00	0.03
1975/1976	240	125	6	94	0.46	0.54	-874.41	1.97	0.00	0.01
1976/1977	165	95	7	91	0.54	0.46	-1799.15	1.96	0.00	0.00
1977/1978	98	54	8	89	0.62	0.38	-2840.66	1.95	0.00	-0.01
1978/1979	77	49	9	77	0.71	0.29	-17907.61	1.89	0.00	-0.07
1979/1980	105	42	10	77	0.79	0.21	-17907.61	1.89	0.00	-0.07
1980/1981	-	61	11	68	0.87	0.13	-43474.96	1.83	0.00	-0.13
1981/1982	89	33	12	23	0.95	0.05	-520931.44	1.36	-0.22	-0.60
1982/1983	-	66								
1983/1984	91	47								
1984/1985	68	27								
			12							
			Mean	**103.16**			**2193417.10**	**1.96**	**-0.13**	**0.00**
			STDEV	**54.08**				**0.24**		

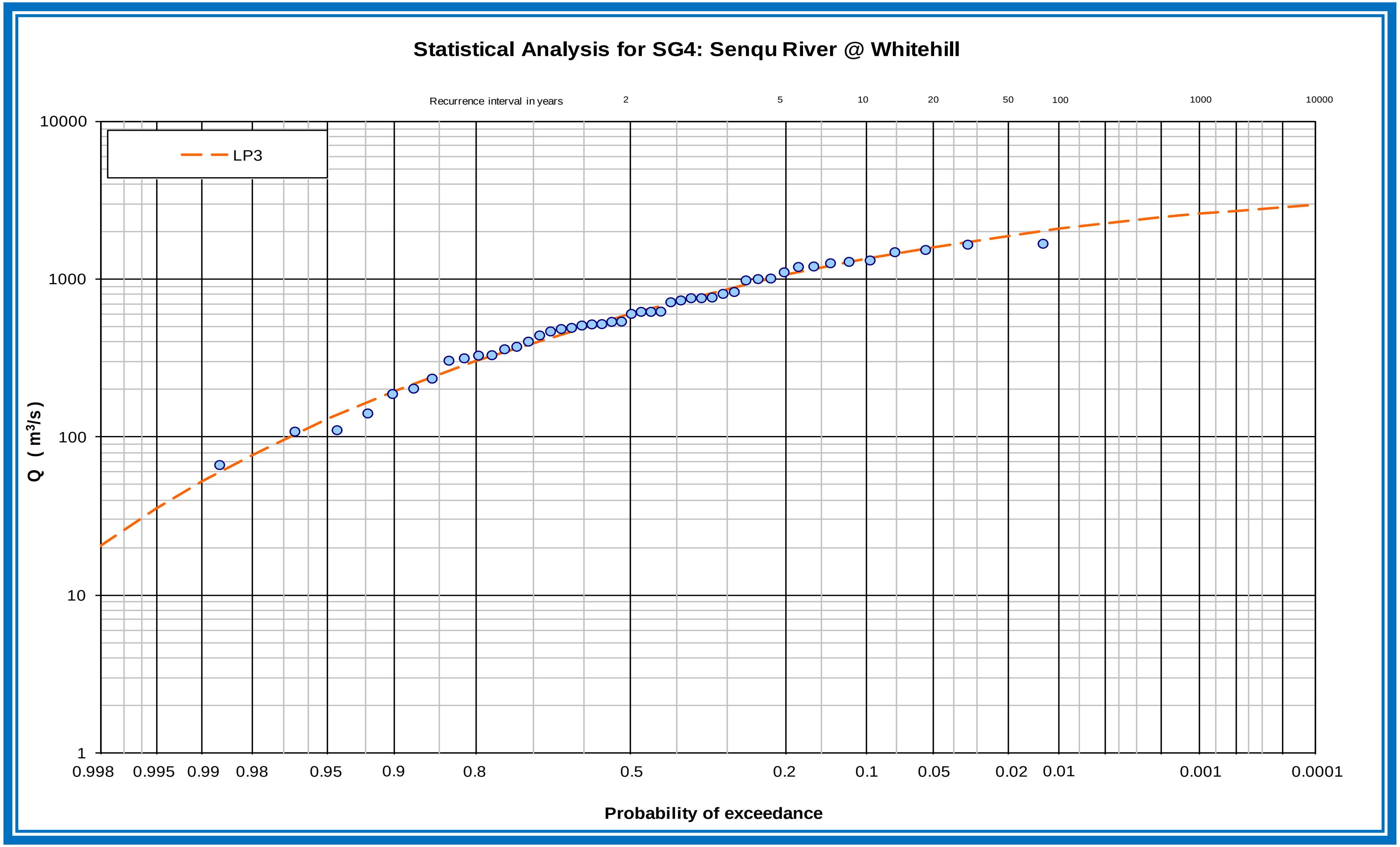
Appendix 8: Table of Calculated Parameter Values

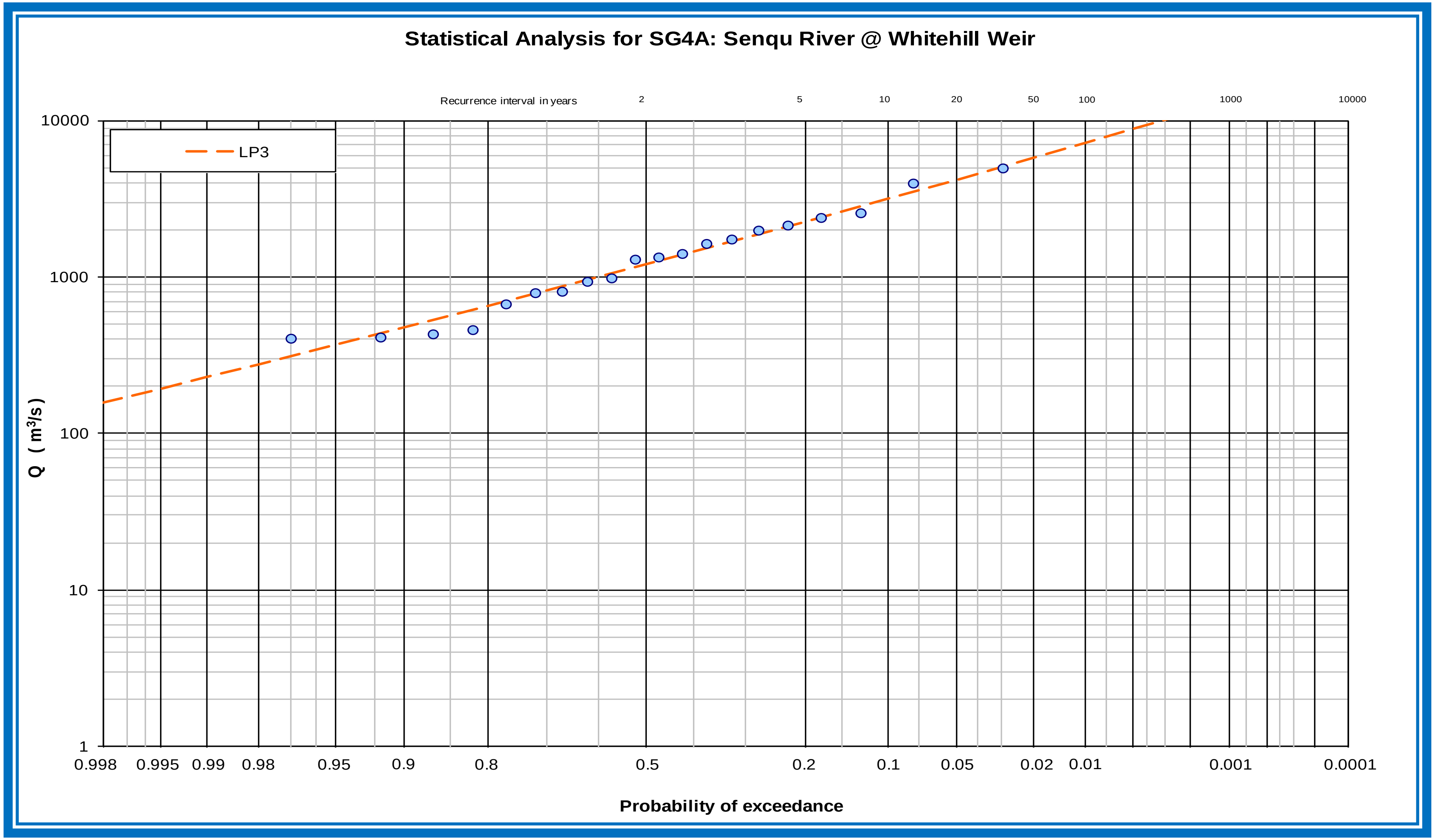
CALCULATED PARAMETER VALUES FOR AMS TO DETERMINE Q_T IN RESPECTIVE STATIONS								
Station Number	**Station Name**	**Number of Record Years**	**AMS Mean Q_{mean}**	**Standard Deviation σ**	**AMS Skewness g**	**Mean Of Log Q (Log Q_{mean})**	**Standard Deviation of Log Q (σ_{LogQ})**	**Log Q Skewness g**
SENQU RIVER BASIN								
SG 3	Senqu River @ Seaka Bridge	41	1 548	1 446	1.50	3.01	0.42	-0.15
SG 4	Senqu River @ Whitehill	47	698	436	0.70	2.74	0.33	-0.78
SG 4A	Senqu River @ Mantilane Weir	20	1 577	1 214	1.57	3.09	0.32	0.09
SG 5	Senqu River @ Koma - Koma	44	973	1 191	4.23	2.82	0.37	0.31
SG 6	Senqu River @ Mokhotlong	17	366	369	1.68	2.39	0.40	0.18
SG 7	Tsoelike River @ Tsoelike Bridge	21	157	175	2.47	1.98	0.46	-0.22
SG 8	Malibamatso River @ Paray	45	664	618	2.54	2.68	0.38	-0.51
SG 17	Senqunyane River @ Marakabei	50	408	357	0.06	2.39	0.50	-0.21
SG 36	Khubelu River @ Tlokoeng	11	115	78	1.63	1.99	0.26	0.46
SG 40	Qomoqomong River @ Quthing	11	116	90	1.35	1.95	0.34	0.04
SG 42	Matsoku River @ Ha – Seshote	12	103	54	1.51	1.96	0.24	-0.98
MOHOKARE RIVER BASIN								
CG24	South Phuthiatsana River @ Masianokeng	45	208	211	1.99	2.13	0.41	0.16
CG25	Hlotse River @ Ha - Setene	38	228	150	0.87	2.25	0.34	-0.61
CG33	North Phuthiatsana River @ Kolonyama	40	212	141	-0.23	2.15	0.47	-0.81
CG34	North Phuthiatsana River @ Mapoteng	41	40	18	-0.60	1.51	0.39	-3.20

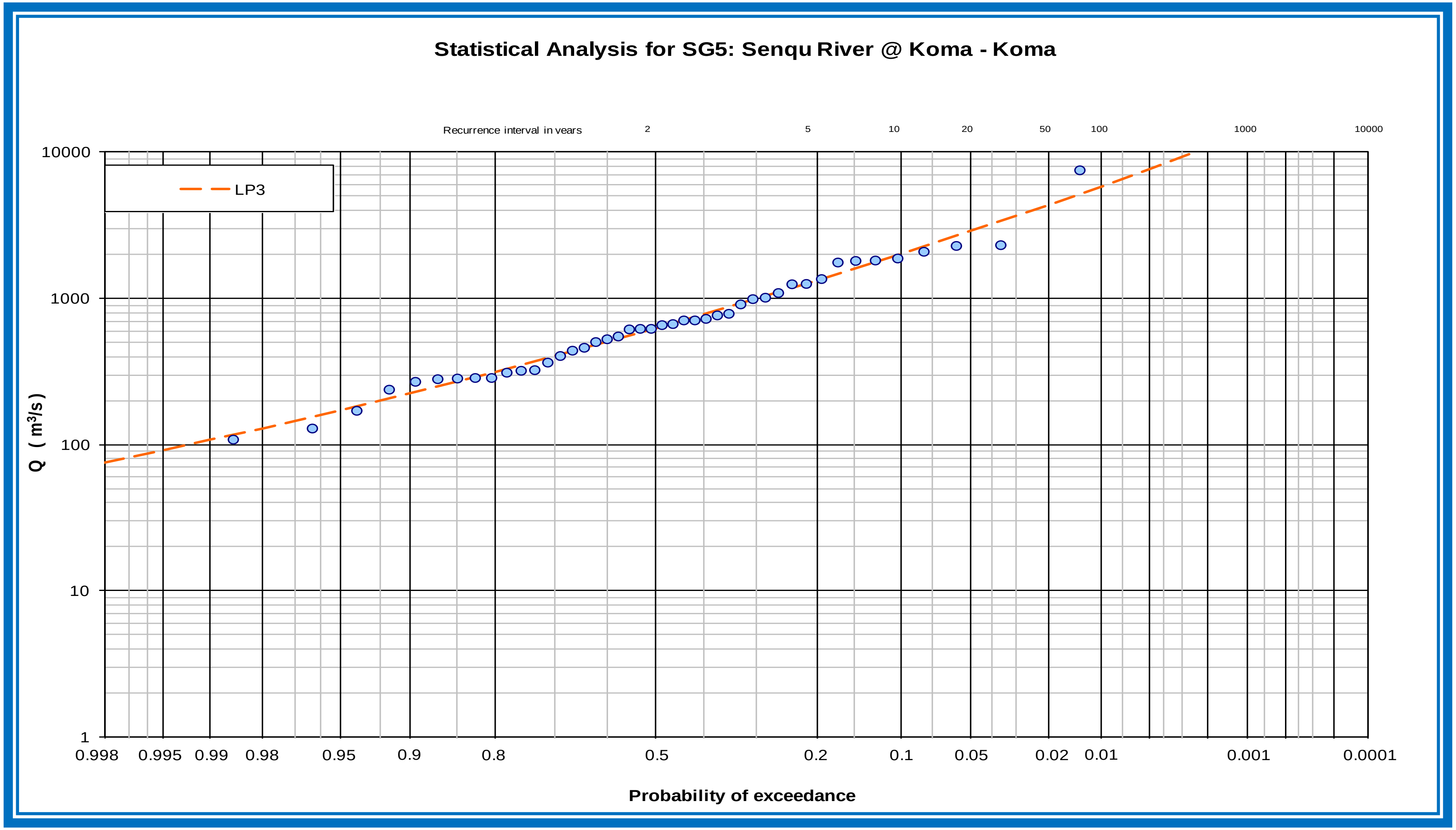
CALCULATED PARAMETER VALUES FOR AMS TO DETERMINE Q_T IN RESPECTIVE STATIONS								
Station Number	**Station Name**	**Number of Record Years**	**AMS Mean Q_{mean}**	**Standard Deviation σ**	**AMS Skewness g**	**Mean Of Log Q (Log Q_{mean})**	**Standard Deviation of Log Q (σ_{LogQ})**	**Log Q Skewness g**
MAKHALENG RIVER BASIN								
MG19	Makhaleng River @ Molimo - Nthuse	32	22	12	1.36	1.27	0.31	-1.79
MG23	Makhaleng River @ Ha - Qaba	31	204	107	0.20	2.23	0.30	-1.09
MG72	Makhalaneng River @ Thabanalimmele	24	17	12	1.30	1.09	0.38	-0.76
MG73	Makhaleng River @ Makhalaneng	22	35	16	-1.03	1.43	0.40	-1.95

Appendix 9A: Figures for Fitted Log Pearson Type III Distributions for the Senqu Basin

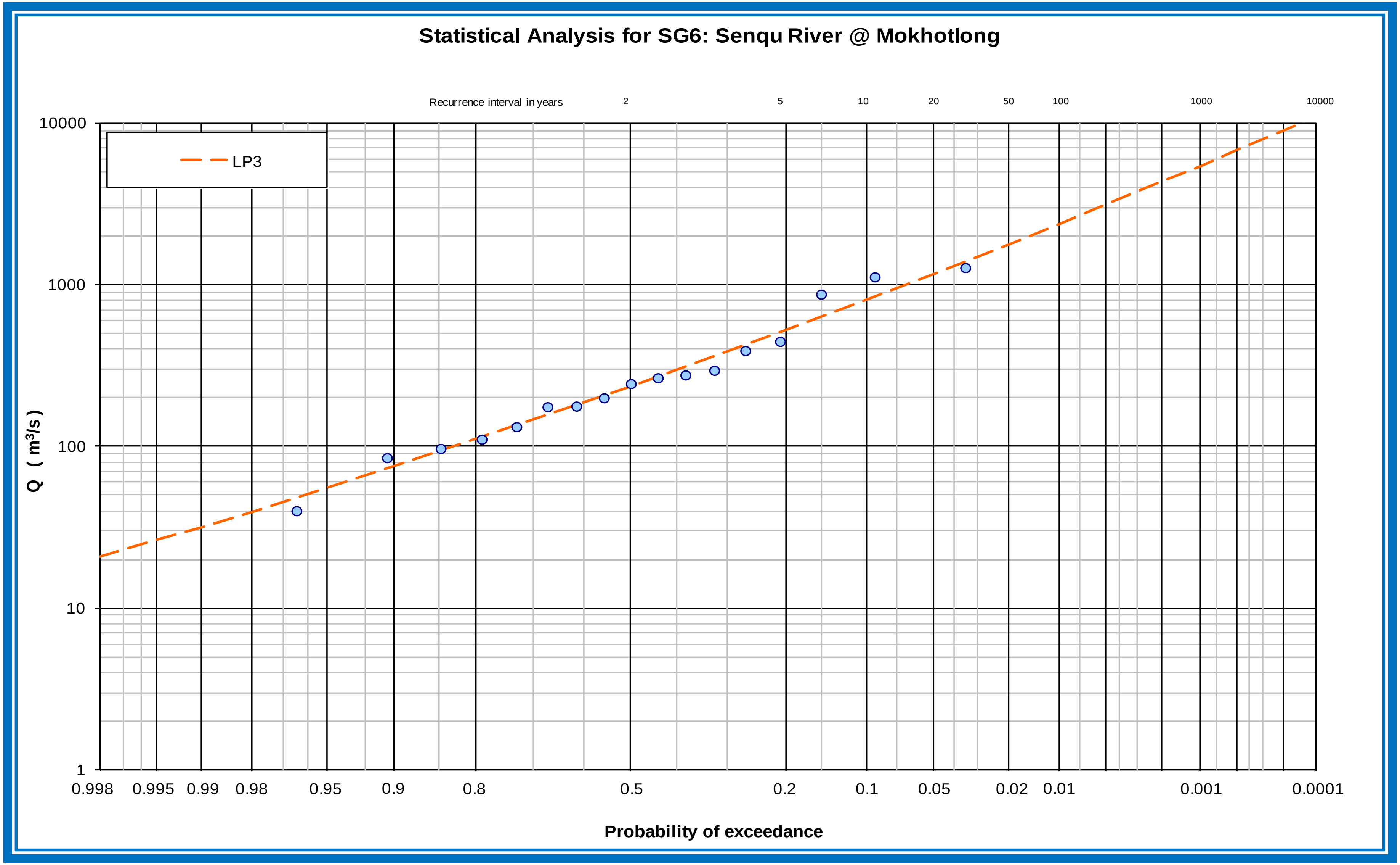



Statistical Analysis for SG4: Senqu River @ Whitehill
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
Q (m³/s)
10000
1000
100
10
1
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

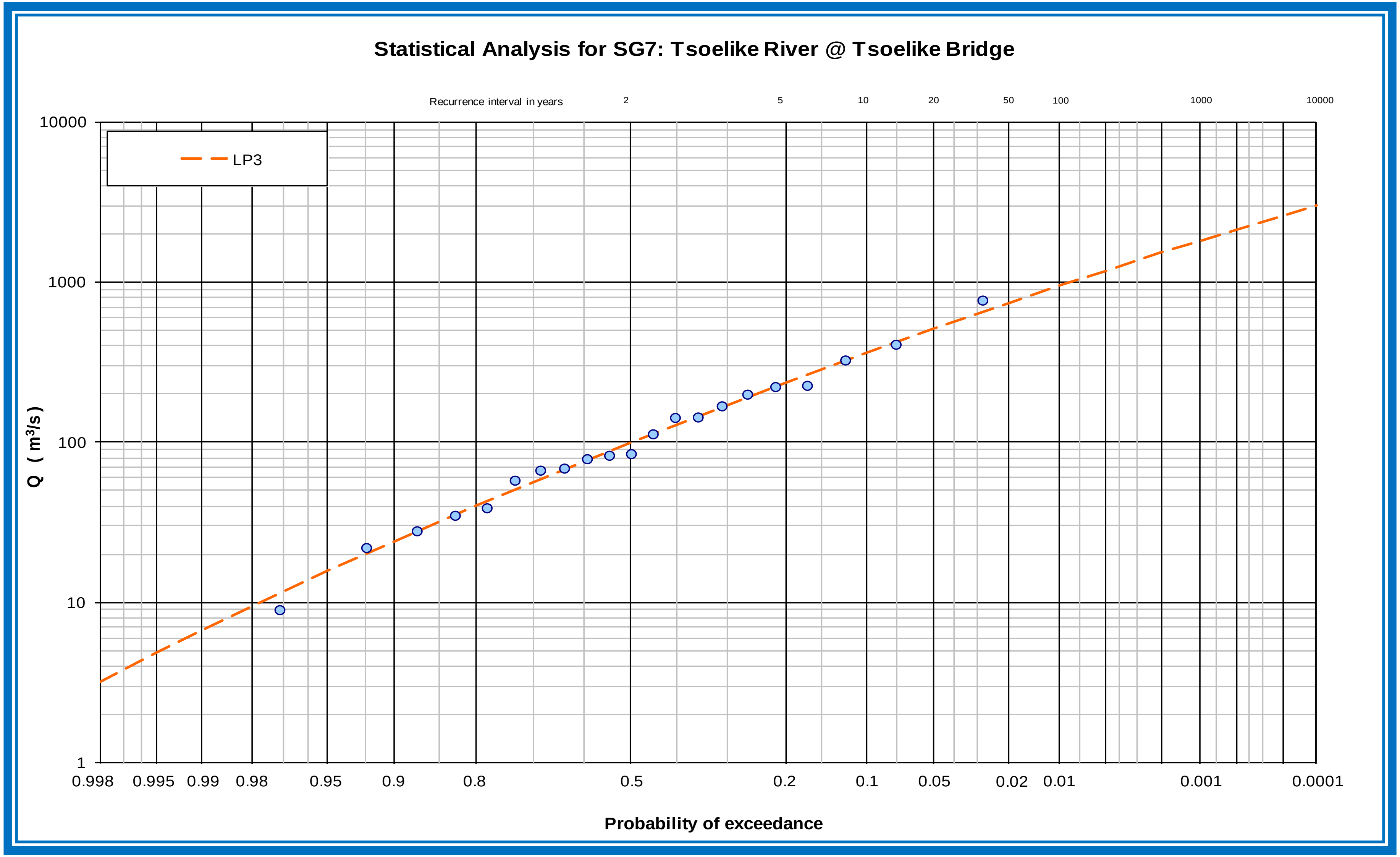

Statistical Analysis for SG4A: Senqu River @ Whitehill Weir
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

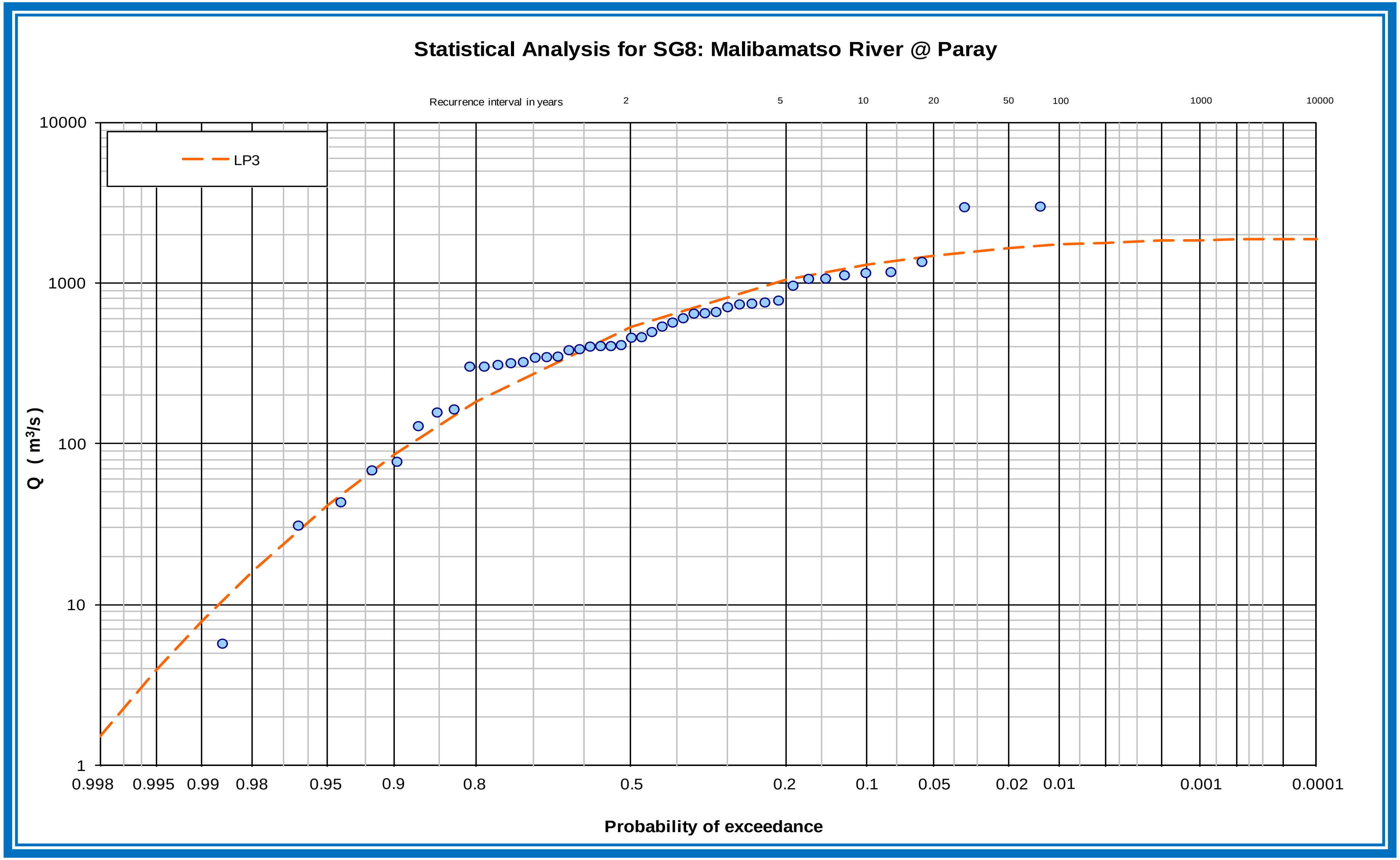


Statistical Analysis for SG5: Senqu River @ Koma - Koma
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
Q (m³/s)
10000
1000
100
10
1
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

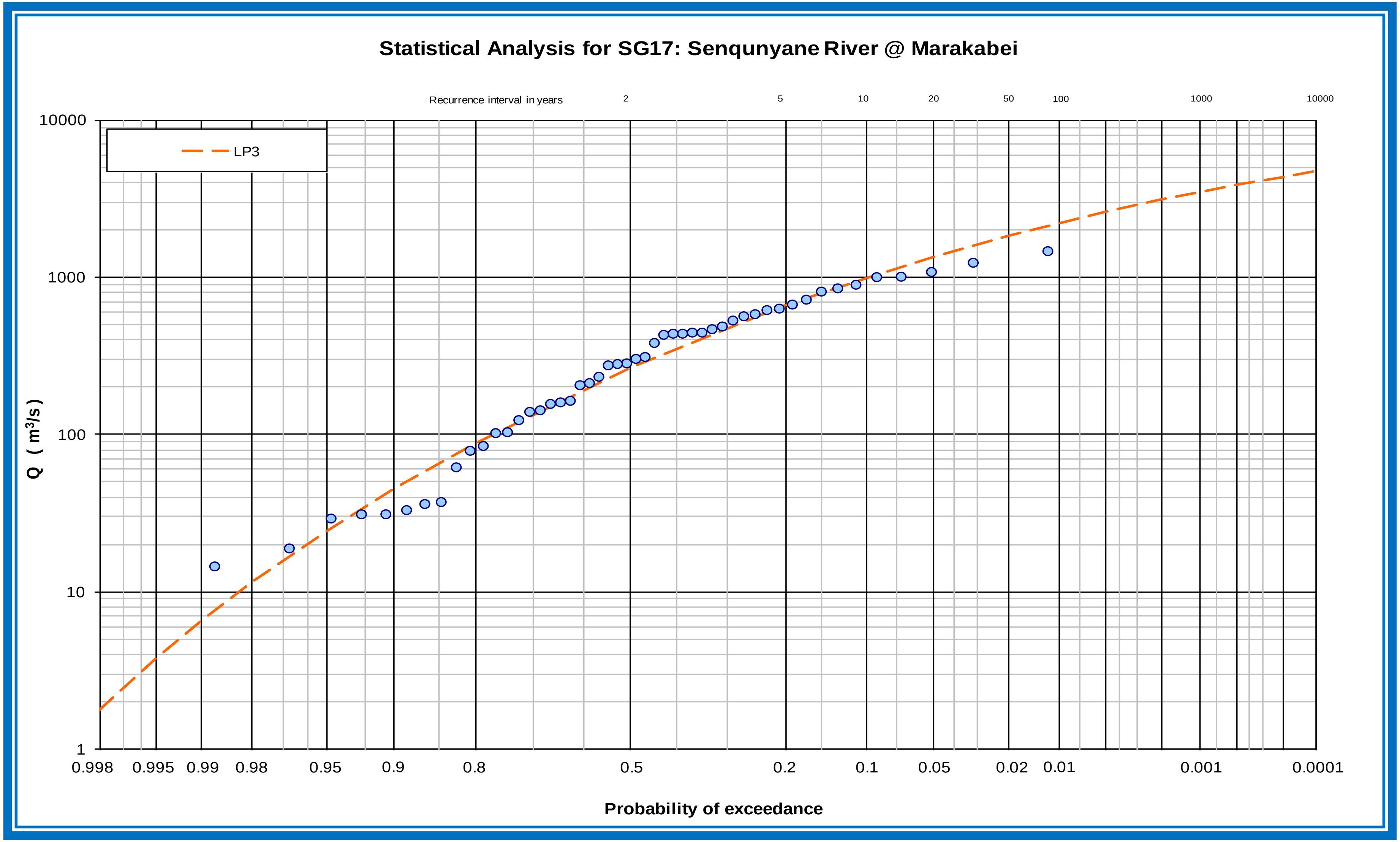


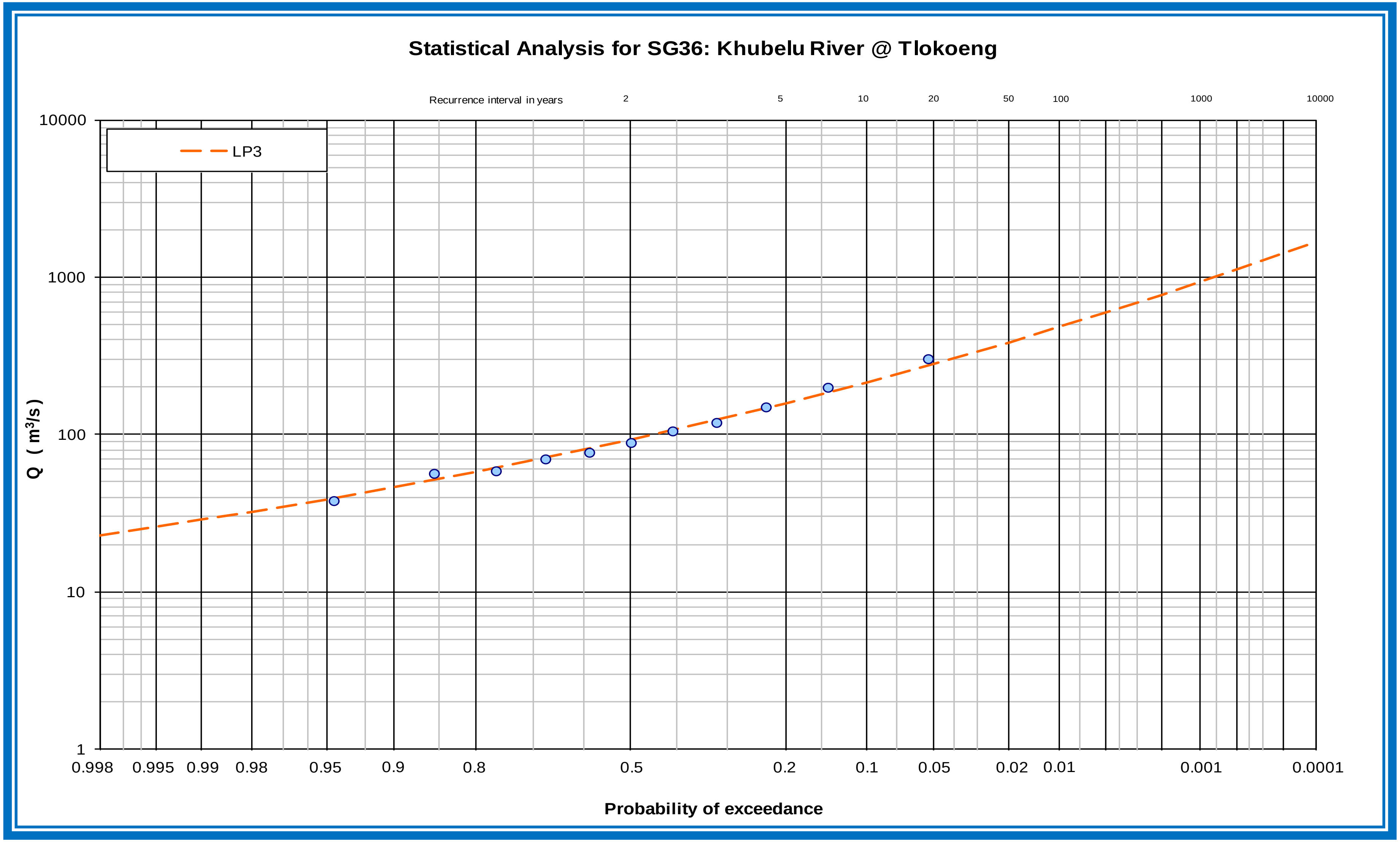
Statistical Analysis for SG6: Senqu River @ Mokhotlong
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

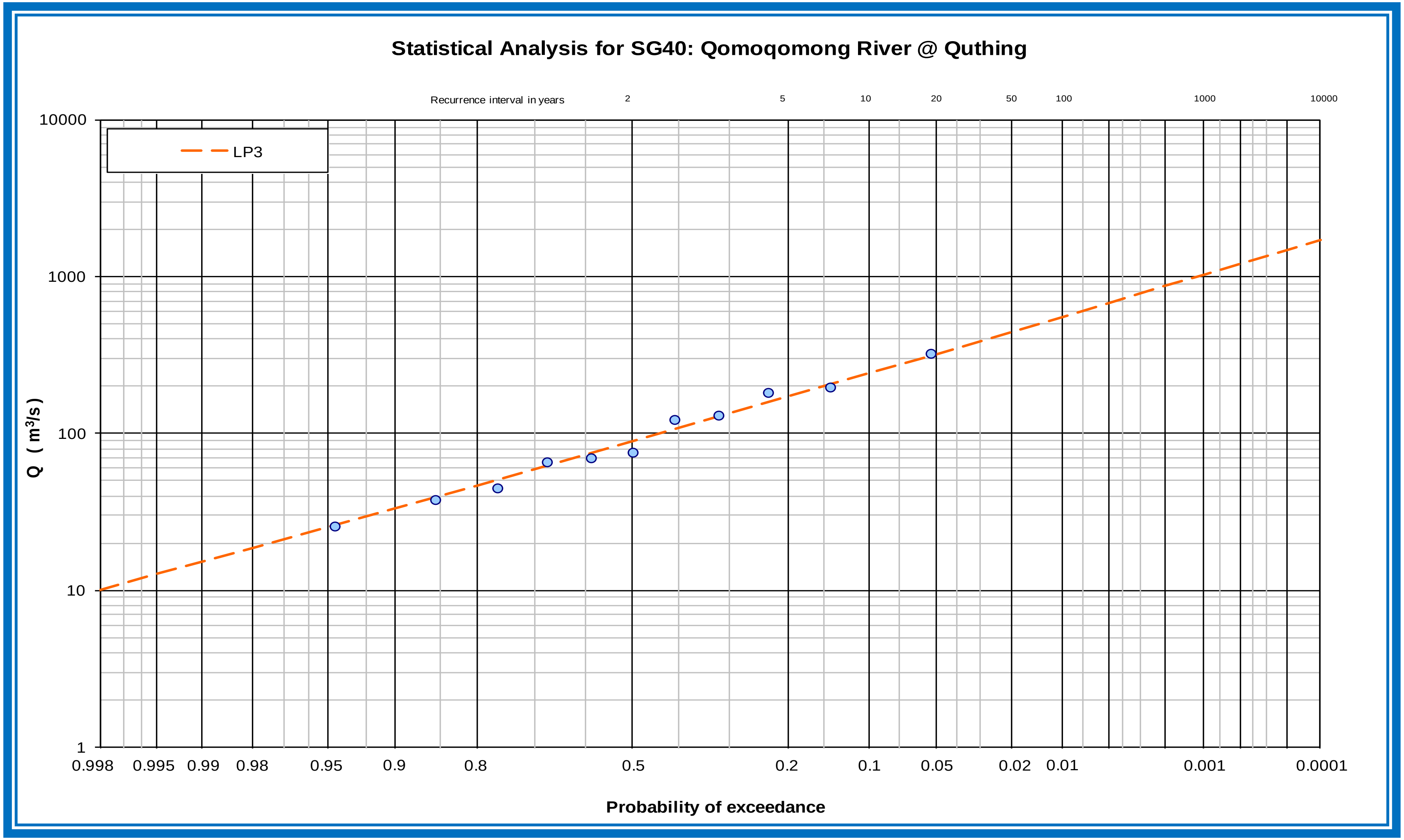

Statistical Analysis for SG7: Tsoelike River @ Tsoelike Bridge
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

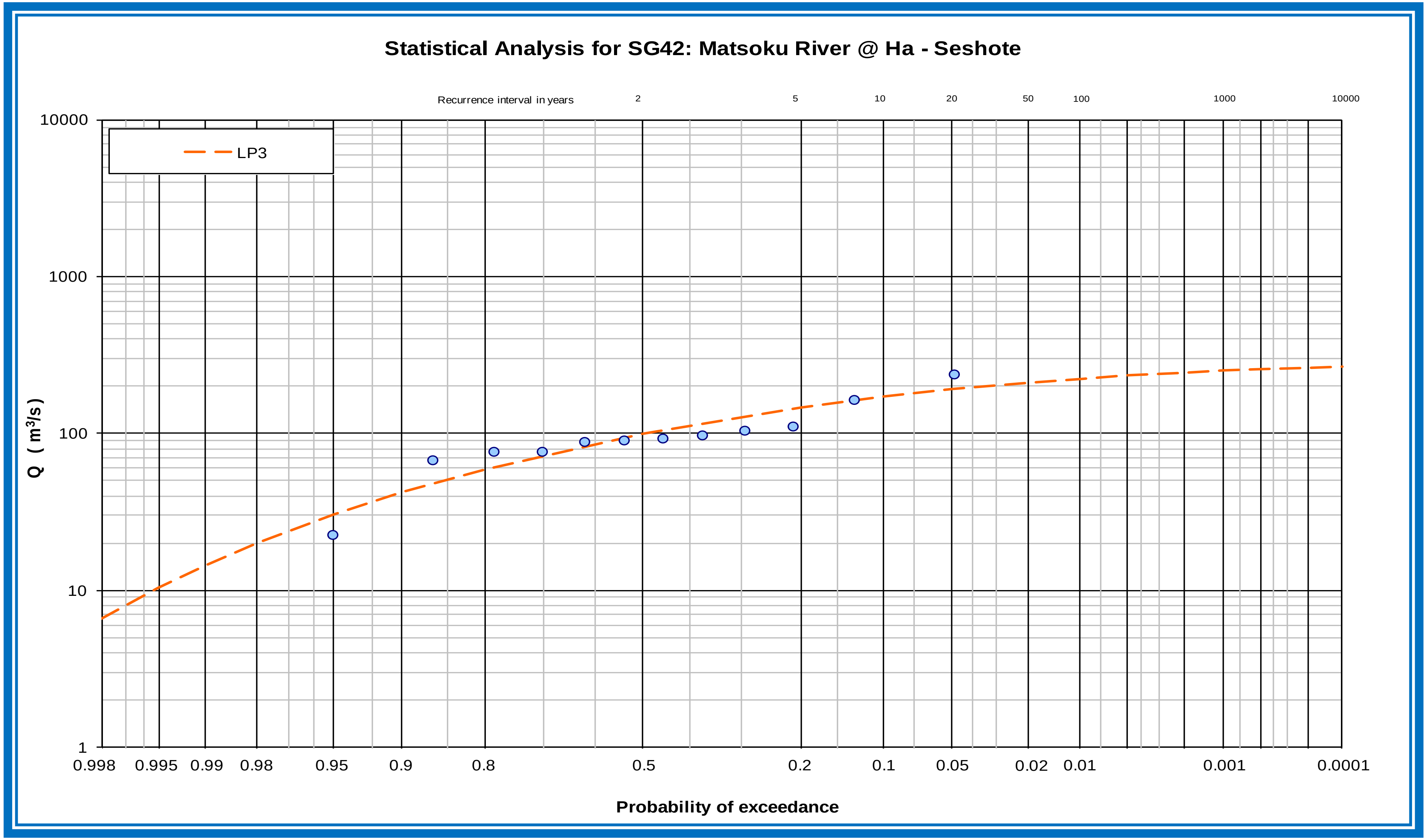


Statistical Analysis for SG8: Malibamatso River @ Paray
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

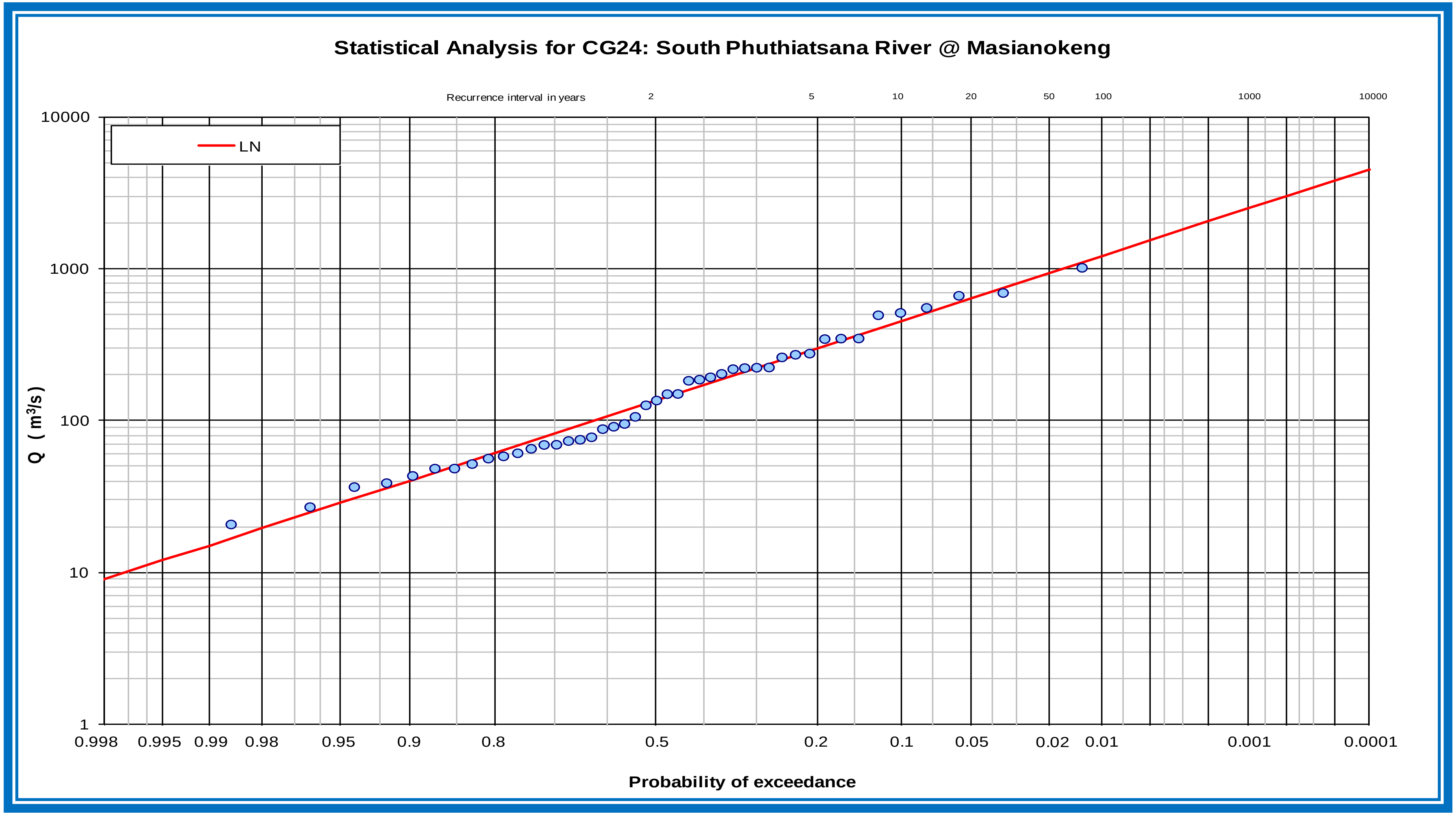

Statistical Analysis for SG17: Senqunyane River @ Marakabei
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
Q (m3/s)
10000
1000
100
10
1
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

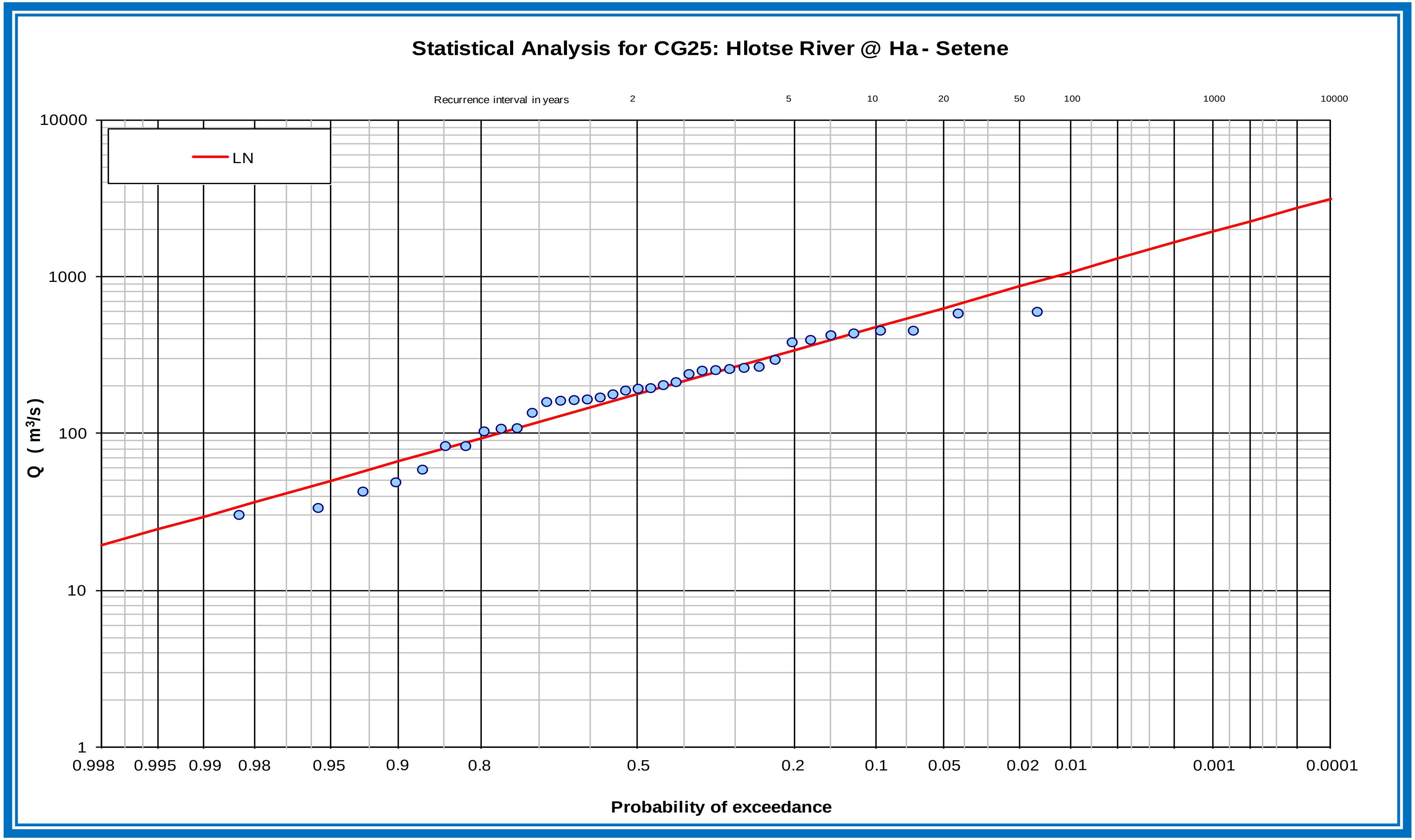

Statistical Analysis for SG36: Khubelu River @ Tlokoeng
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
Q (m³/s)
10000
1000
100
10
1
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

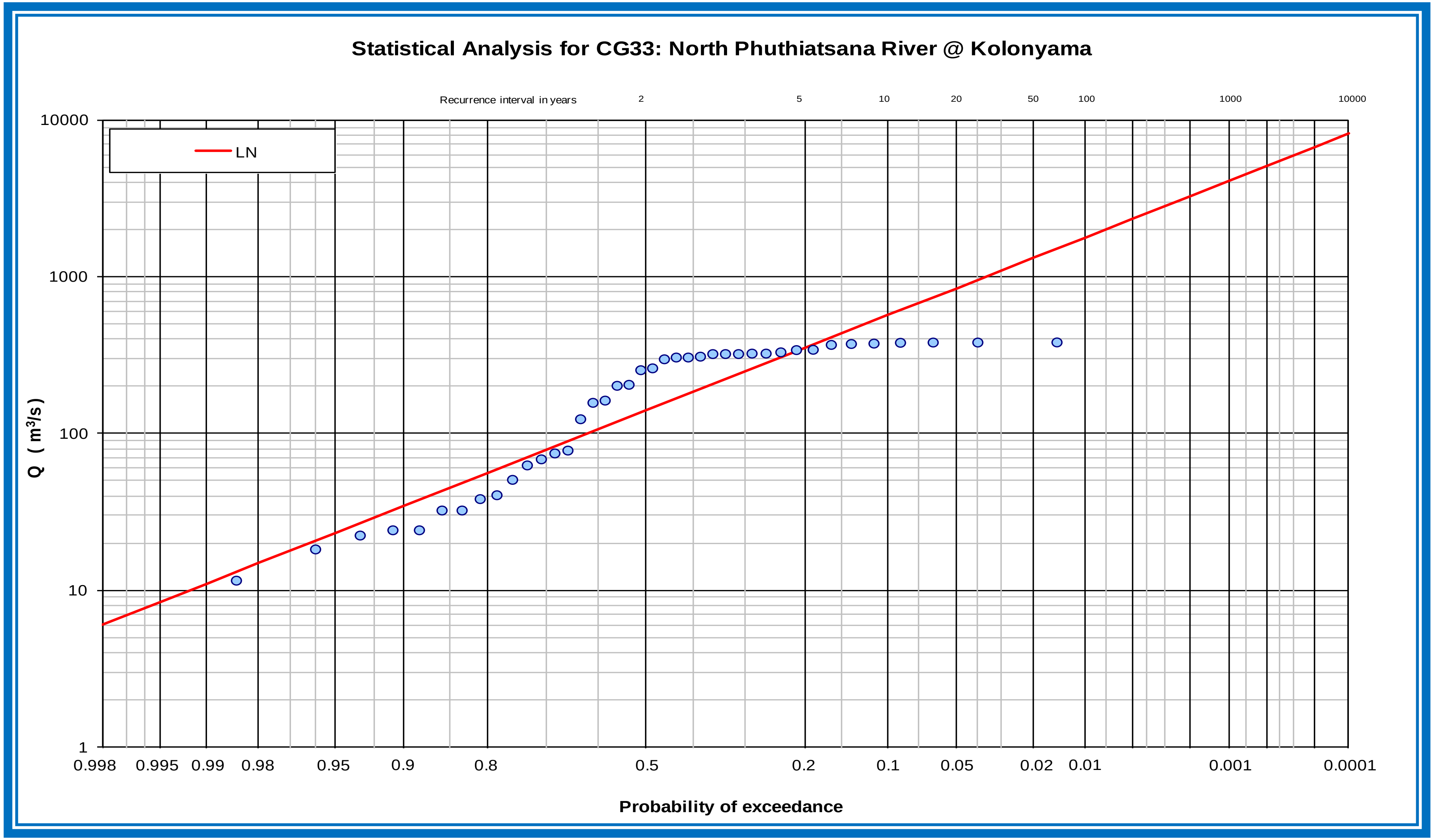

Statistical Analysis for SG40: Qomoqomong River @ Quthing
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

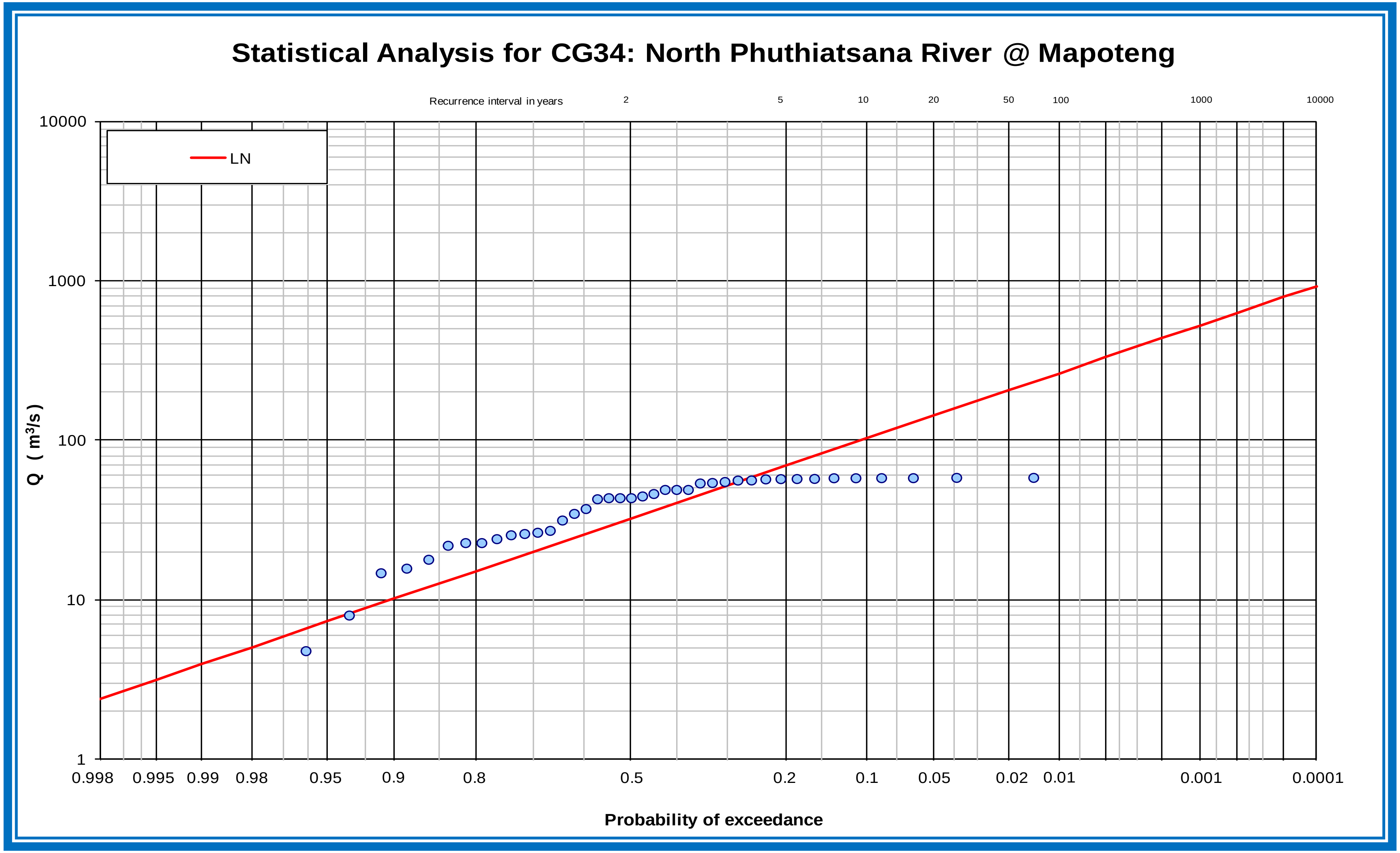

Statistical Analysis for SG42: Matsoku River @ Ha - Seshote
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LP3
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

Appendix 9B: Figures for Fitted Log Normal Distributions for the Mohokare Basin

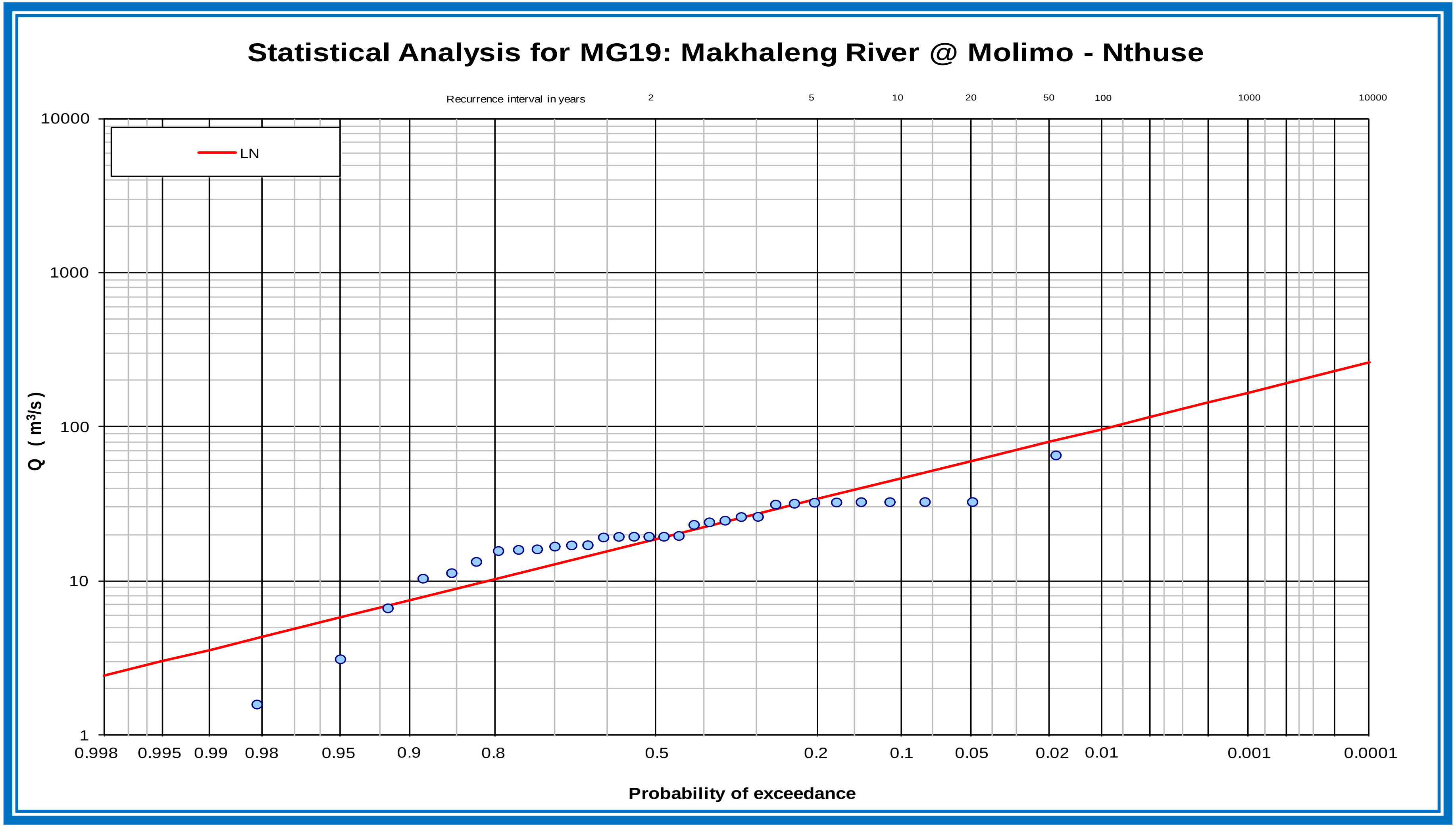


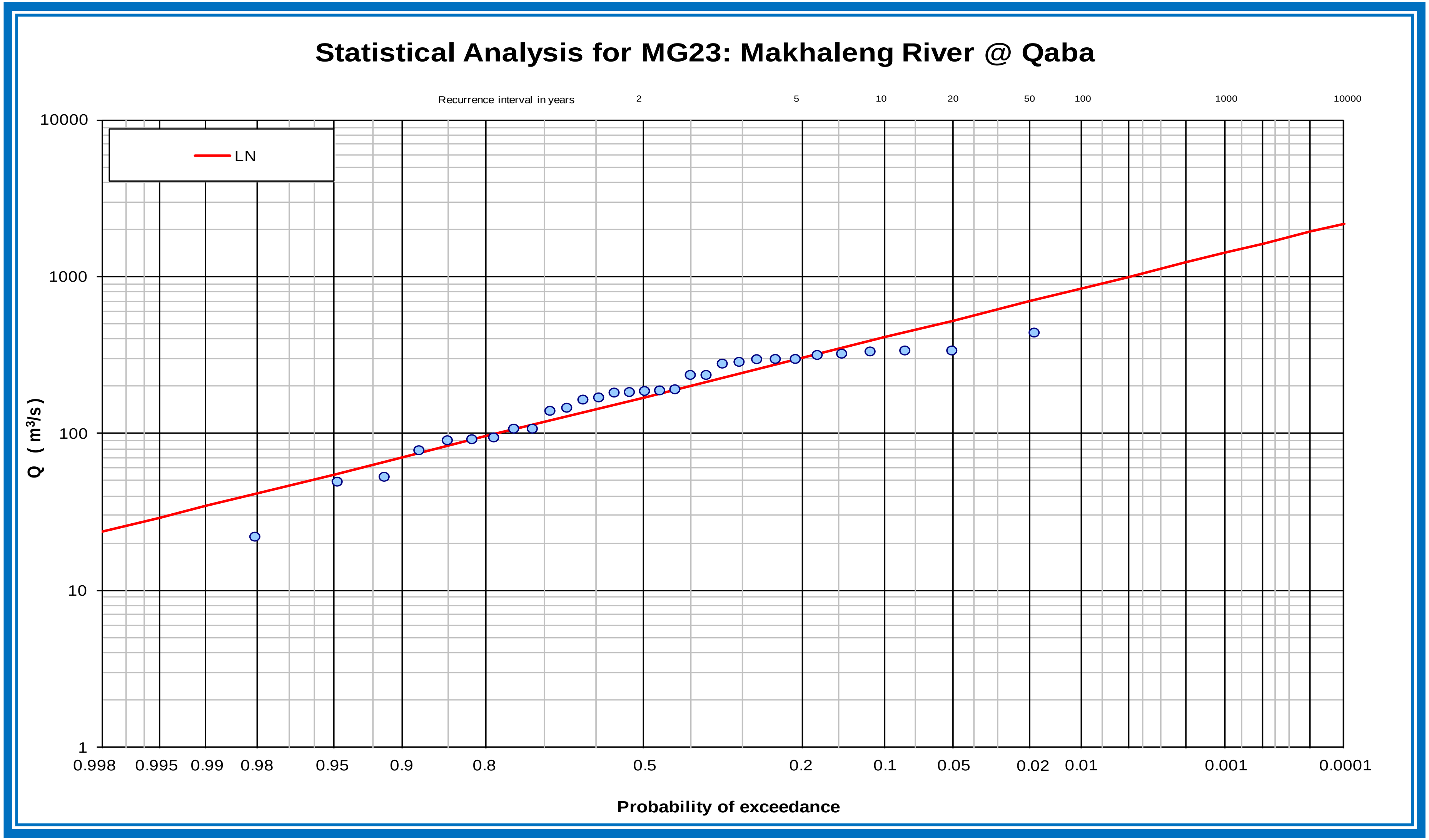

Statistical Analysis for CG25: Hlotse River @ Ha - Setene
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LN
10000
1000
100
10
1
Q (m3/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

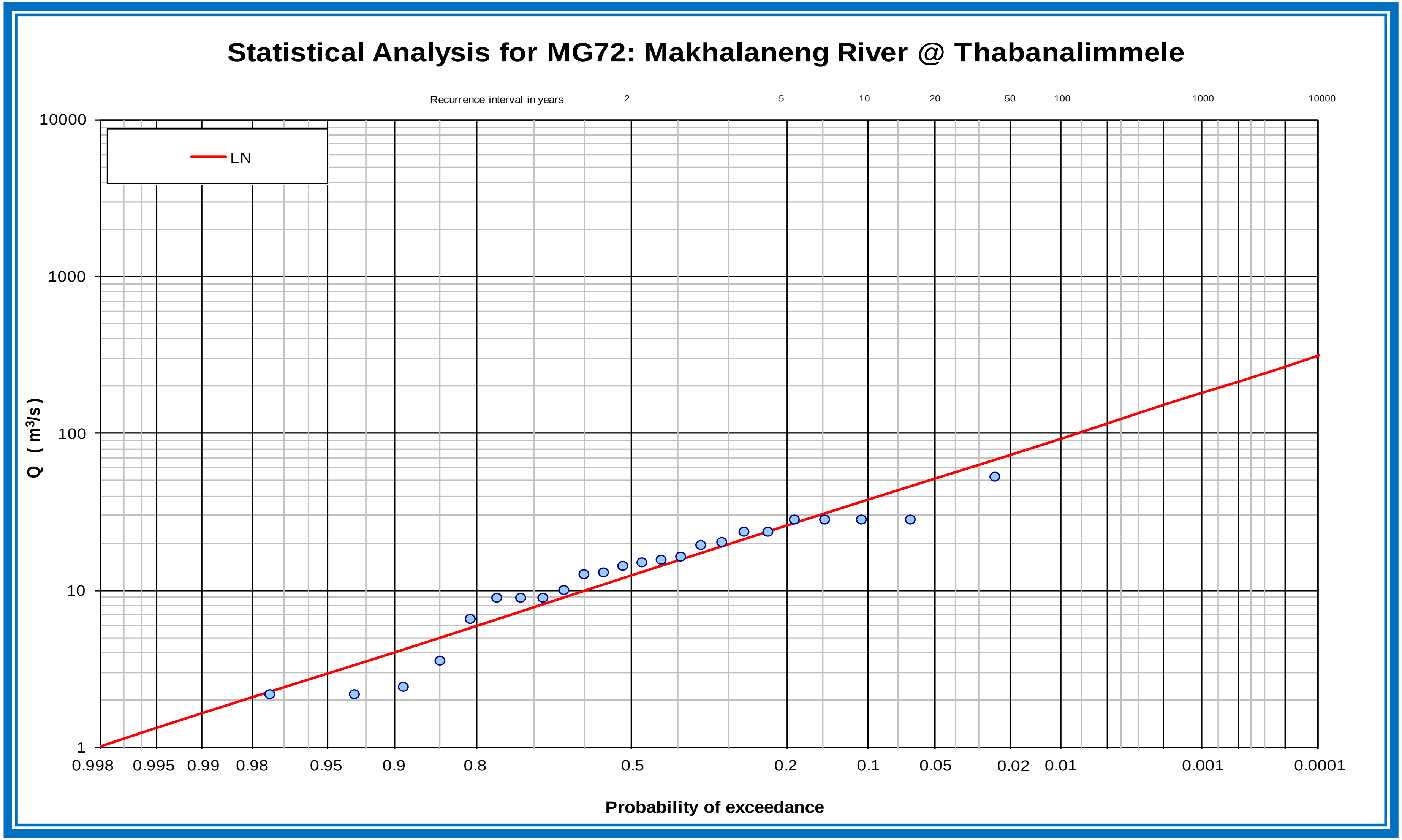

Statistical Analysis for CG33: North Phuthiatsana River @ Kolonyama
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LN
Q (m³/s)
10000
1000
100
10
1
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance


Statistical Analysis for CG34: North Phuthiatsana River @ Mapoteng
Recurrence interval in years
2
5
10
20
50
100
1000
10000
10000
1000
100
10
1
LN
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance

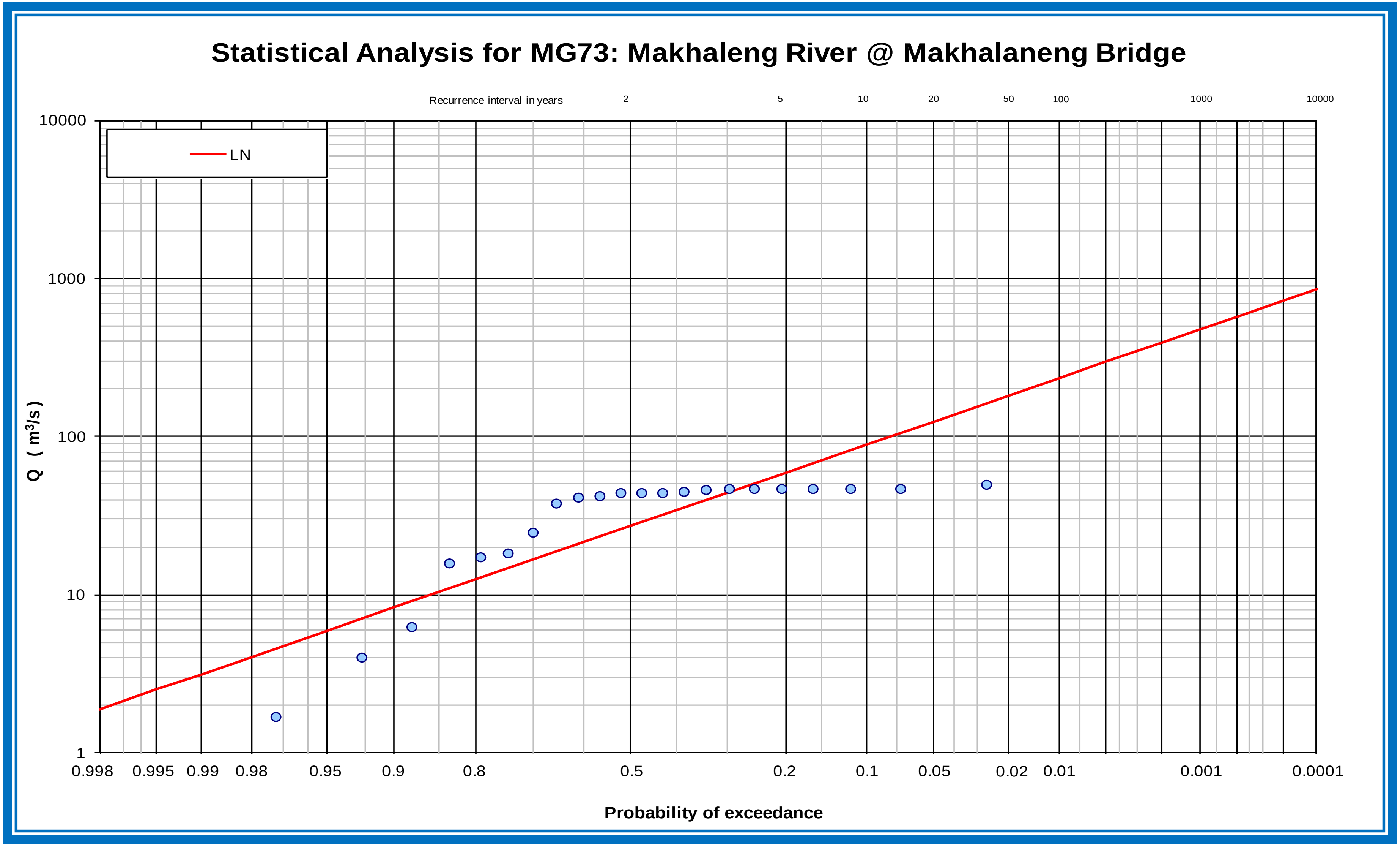
Appendix 9C: Figures for Fitted Log Normal Distributions for the Makhaleng Basin




Statistical Analysis for MG23: Makhaleng River @ Qaba
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LN
10000
1000
100
10
1
Q (m3/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance



Statistical Analysis for MG72: Makhalaneng River @ Thabanalimmele
Recurrence interval in years
2
5
10
20
50
100
1000
10000
LN
10000
1000
100
10
1
Q (m³/s)
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance


Statistical Analysis for MG73: Makhaleng River @ Makhalaneng Bridge
Recurrence interval in years
2
5
10
20
50
100
1000
10000
10000
1000
100
10
1
Q (m³/s)
LN
0.998
0.995
0.99
0.98
0.95
0.9
0.8
0.5
0.2
0.1
0.05
0.02
0.01
0.001
0.0001
Probability of exceedance