Status Review and Requirements of Overhauling Flood Determination Methods in South Africa

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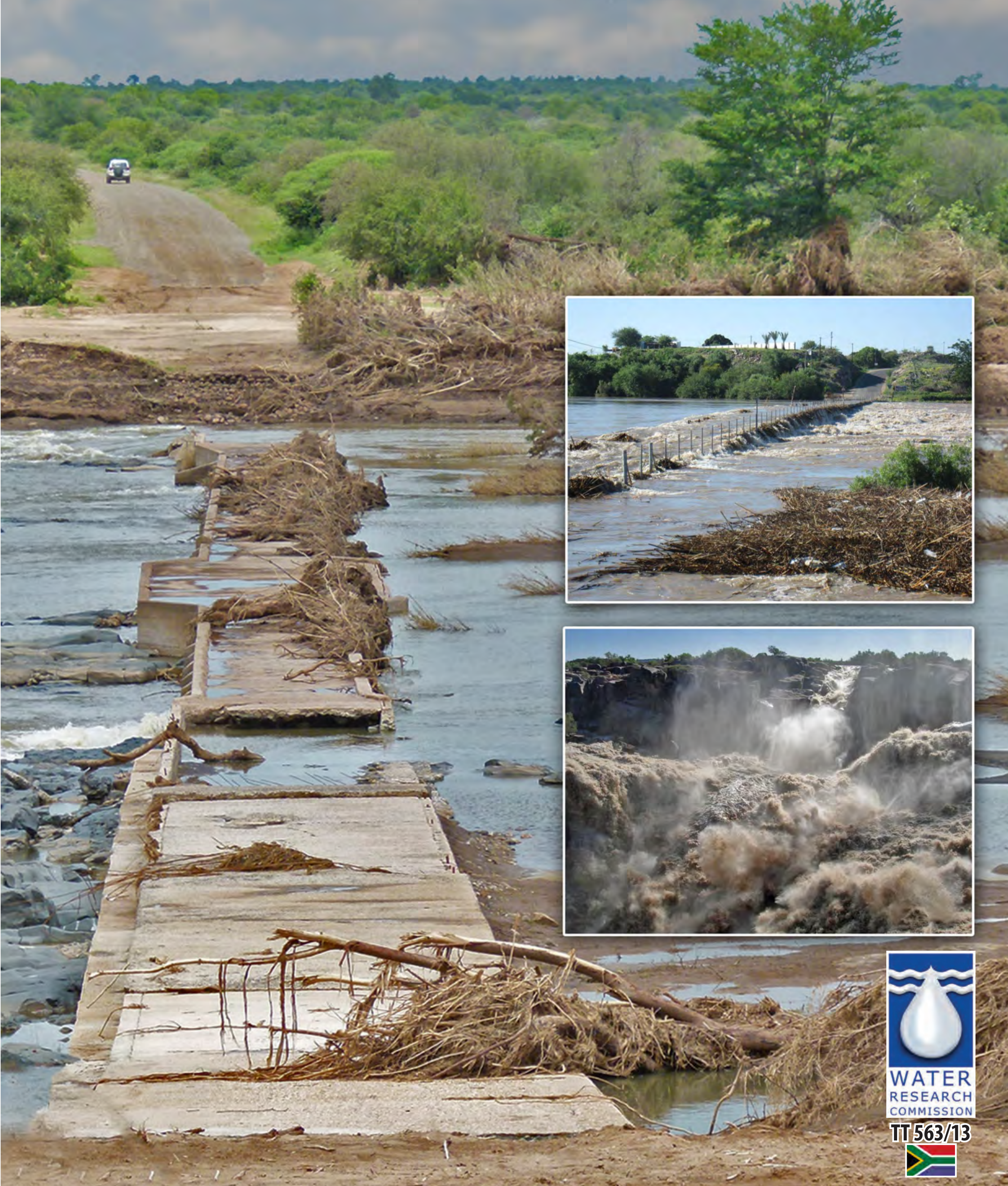

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TT 563/13: Status review and requirements of overhauling Flood Determination Methods in South Africa

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Status Review and Requirements of Overhauling Flood Determination Methods in South Africa

Executive Summary

Introduction and objectives of this research project

The University of Pretoria was appointed by the Water Research Commission to undertake this project with the objective to review the current flood calculations methods and to provide some guidance of the research focus to improve, extend and update the Flood Determination Procedures.

The intention of this project is to reflect the current state of flood determination methods used in South Africa, reflect the shortcomings in the existing methods. This will then provide the basis to identify the specific research areas and their priorities.

Deliverables of the research

The consultancy objectives of this research project will be served by the following deliverables:

- **Deliverable 1: A report reflecting the status quo of flood determination procedures and a reference list of available flood studies in South Africa; and**
- **Deliverable 2: Prioritization of research and required updates for flood determination procedures in South Africa.**

Flood calculation procedures used in South Africa

The procedures which were developed in South Africa for the estimation of design floods can be characterised as methods which related to the analysis of observed floods and those methods which asses the rainfall data and catchment response (Smithers and Schultz, 2003).

The development of most flood calculation procedures currently used, occurred prior to 1990 (HRU, Hiemstra, Schultze) while later contributions attempt to provide a calibrated standardized procedure for flood calculations (Alexander, 2003), reviewed the relationship between peak discharge and volume of the runoff hydrograph (Görgens, 2007) and proposed a new statistical assessment of flood peak determination (Nortje, 2010).

Shortcomings of the current flood estimation procedures

This project highlighted the following shortcomings in the flood estimation procedures. A general shortcoming of the current procedures is that the hydrological data sets which were used were short and in most cases excluded the severe weather incidences of the 1980s and the recent floods.

It is likely that in the case of rainfall-based methods, the relationships between catchment response and rainfall could change if longer data sets are used. The use of extended records might reflect:

- A different depth-duration frequency relationship for the determination of point rainfall;
- The procedure for the determination of the design storm rainfall might change if the record length is extended; and
- That for certain cases under consideration the antecedent moisture conditions in the catchment should be included.

Furthermore it is anticipated that the longer observed storm records might reflect:

- The number of catchments with similar hydrological response (be it for the RMF; SDF ; JPV or REFSSA procedure) might have to be redefined; and
- The statistical relationships to quantify flood peaks and flood volumes in terms of recurrence interval could be extended.

Proposed research priorities

Based on the findings of this research it is recommended that:

- The custodian positions of the Departments and other Institutions responsible for the maintenance and update of the hydrological database be reinforced;
- The verification and update of the hydrological data bases be supported;
- The sufficient career seeking individuals in the field be capacitated and trained;
- Longer hydrological data bases be used to:
    - Review the design storm relationships for different recurrence intervals and duration; and
    - Review the number of homogenous flood regions in South Africa.
- Detailed assessments of the catchment response on rainfall by the implementation of continuous monitoring be conducted;
- Regions and relationships for the extreme events (RMF) be reviewed;

- Data of palaeofloods, where possible, be included in the frequency estimation of the maximum flood peaks;
- The application of the REFSSA procedure in different other K-flood regions be investigated;
- The application of the JPV relationship on a more detailed regional qualification of the catchments be investigated;
- The influence of antecedent conditions of catchment response be researched;
- The influence of urban development on catchment response (runoff peaks and runoff volume) be reviewed;
- That the regions of the SDF procedure and the re-calibration of the relationships for predicting the floods be reviewed; and
- In recognition of the importance of flood risk management in a period of economic growth and potential climate change, and noting the shortcomings of the methods currently used by practitioners, a National Flood Studies Programme should be developed to study and develop new methods which will significantly improve the quality and capability of flood estimation for flood risk management in South Africa. The identification of research priorities will require the implementation of a coordinate research funding programme. This might require the identification of research focus areas from which a research programme, comprising of a number if work-packages could be defined.

Concerns identified during the execution of this study

Based on the findings of this research, the following concerns have been identified:

- The number of flow gauging stations has decreased by more than 100 since 1990 (**Figure 4-1**);
- An analyses of the current number of rainfall stations indicate that there are now less stations used to collect data than were active in 1920 (**Figure 4-2**);
- Whereas rainfall data is essential for further research there is a need for available records to be “patched” before use; and
- Whereas stream flow data is essential for further research there is a huge backlog in the verification of raw data and conversion to accurate flows.
- Table 5-12 reflects the research priorities which were identified during the Workshop held on 16 May 2012. These priorities were grouped under different “work groups”.

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Acknowledgements

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The report was compiled under the guidance of Mr Wandile Nonquphu from the WRC as a consultancy by Professor S J van Vuuren, Mr M van Dijk and Mr G L Coetzee of the Department of Civil Engineering, University of Pretoria.

The University of Pretoria would like to acknowledge the contribution of SANCOLD in the oversight of the final report.

This is a "Short Term Research Project" or "Consultancy".

Status Review and Requirements of Overhauling Flood Determination Methods in South Africa

Table of Contents

List of Figures

List of Tables

Notation

AEP	Annual Exceedance Probability
AMC	Antecedent Moisture Conditions
AMS	Annual Maximum Series
ARF	Area Reduction Factor
C	Catchment Coefficient
CAPA	Catchment Parameter
DDF	Depth-Duration-Frequency
DFET	Design Flood Estimation Tool
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EV/PWM	Extreme Value Probabilistic Weighted Moments
GC	Growth Curves
GC-NCAPA	Growth Curves New Catchment Parameter
GEV	General Extreme Value
GOF	Goodness of Fit
HRU	Hydrological Research Unit
JPV	Joint-Peak-Volume
K-region	Kovac-region
K_{RP}	Regional-Catchment-Distribution Constant
LEVI	log-Extreme Value Type I
LN	log-Normal
LPIII	log-Pearson Type III
MAF	Mean Annual Flood
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MIPI	Midgley and Pitman
NCAPA	New Catchment Parameter
NFSP	National Flood Studies Programme
OMF	Probable Maximum Flood
Q_i	Index Flood
Q_m	Mean Annual Flood Peak
Q_{mi}	Log Derived Mean Annual Flood
REFSSA	Regional Estimation of Extreme Floods by Selective Statistical Analysis
RMF	Regional Maximum Flood
SANCOLD	South African National Committee on Large Dams
SANRAL	South African National Roods Agency
SAWS	South African Weather Service
SCS	Soil Conservation Services
SCS-SA	Soil Conservation Services – South Africa
SDF	Standard Design Flood
SUH	Synthetic Unit Hydrograph

T-year	Recurrence Interval
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
WRC	Water Research Commission

Status Review and Requirements of Overhauling Flood Determination Methods in South Africa

1 Introduction

1.1 Background

The design of all hydraulic structures be it small culverts or spillways for major impoundments, requires the assessment of the flood frequency relationship with the objective to optimise the design and to quantify the possible risks of failure for the selected design event.

Due to the unique weather patterns and rainfall characteristics in South Africa, a number of flood calculation methods were developed locally while other methods have been adapted or calibrated to suit the local conditions. During the development of some of these flood determination methods, dated back to the early 1970, the following complications were experienced:

- Extremely short historical runoff records; and
- Sparsely spaced rainfall and flow gauging stations.

Most of the flood calculation procedures were event based, defining the response of the catchment to a specific event without considering the antecedent soil moisture conditions and the temporal and special distribution of the storm event. In other cases a calibration approach of catchment response (Alexander, 2003) from similar regions was developed.

Developments to predict the extent of extreme events were undertaken (Kovács, 1988). Some of these flood calculation methods in use have been reviewed while other procedures (Görgens, 2007) were developed to improve the understanding of the complex relationship between flood peaks, flood volume and recurrence intervals of these events.

1.2 Methodology

This project is a desktop study which will entail the following steps:

- Identification of the flood calculation documentation and the compilation of a database with all the available documents compiled on the development of flood calculation procedures;

- Obtain input from practitioners on the preferred flood calculation procedure methods;

- Compiling of a status quo report on flood determination methods in South Africa.

- Organize a workshop where the status quo report will be discussed and the attendee's views will be heard and used to formulate the strategic research focus areas from which a planning schedule to conduct the required investigations will follow.

- Based on the findings of the workshop, the research priorities associated with the development of flood determination methods will be finalised.

1.3 Objective of the research

The research aims to:

- Compile a summary of the flood determination literature in South Africa and creating an easily accessible format;
- Identifying the knowledgeable experts in the field of flood determination in South Africa and utilizing them to assist in the strategic planning; and
- Reflect the priorities for improving flood determination methods used in South Africa.

1.4 Layout of report

The report consists of the following chapters:

Chapter 1:	Introduction (This chapter)
Chapter 2:	Review of the development of flood deterministic procedures for South Africa
Chapter 3:	Practitioner's review of the commonly used flood calculation procedures
Chapter 4:	Identification of research priorities pertaining the review, extension and update of flood calculation procedures
Chapter 5	Research focus for the review, extension and upgrade of flood calculation procedures
Chapter 6	References

Deliverable 1 is addressed by the contents of Chapters 1 to 4, while Deliverable 2 is discussed in Chapter 5.

This report is accompanied by a CD, containing electronic copies of the documentation of flood calculation procedures in South Africa, software for the review of research proposals, articles and other documents of interest. **Table 1-1** reflects the details of the documentation on the accompanying CD.

Table 1-1: Details of Supporting Documentation

Directory	Documentation name
DWA	1980 – Maximum flood peak discharges in South Africa – An empirical approach 1981 – Southern African Storm Rainfall – Adamson TR102 1988 – Regional Maximum Flood Peaks in Southern Africa
HRU	1969 – Design Flood Determination in South Africa (pages missing) 1971 – Amendments to Design Flood Manual HRU 4-69 1972 – Design Flood Determination in South Africa 1974 – A simple procedure for synthesizing direct runoff hydrographs 1978 – A Depth-Duration-Frequency Diagram for Point Rainfall in South Africa 1978 – Flood Forecasting for Reservoir Operation by Deterministic hydrological Modelling 1979 – Analysis of SWA – Namibia rainfall data Report 3-79 1980 – Analysis of large-area storms in SWA – Namibia Report 2-80 1981 – Area-Time method of Flood Estimation for Small Catchments 1981 – Design flood determination in SWA – Namibia Report 14-81
SAICE	2002 – Statistical analysis of extreme floods 2002 – The Standard Design Flood 2010 – Estimation of extreme flood peaks by selective statistical analyses of relevant flood peak data within similar hydrological regions
WaterSA	1988 – Determination of runoff frequencies for ungauged urban catchments 1993 – Development and verification of hydrograph routing in a daily simulation model 1996 – Short-duration rainfall frequency model selection in Southern Africa 2001 – A hydrological perspective of the February 2000 floods- A case study in the Sabie River Catchment 2001 – Flood frequency analysis at ungauged sites in the KwaZulu-Natal Province, South Africa 2004 – A review of the regional maximum flood and rational formula using geomorphological information and observed floods 2004 – The estimation of design rainfalls for South Africa using a regional scale invariant approach 2006 – The rational formula from the runhydrograph 2008 – Merged rainfall fields for continuous simulation modelling 2008 – The development and assessment of a regionalised daily rainfall disaggregation model for South Africa 2011 – Evaluation of critical storm duration rainfall estimates used in flood hydrology in South Africa 2011 – Incorporating uncertainty in water resources simulation and assessment tools in South Africa
WRC	2000 – Development and evaluation of techniques for estimating short duration design rainfall in South Africa 2000 – Long duration design rainfall estimates for South Africa 2002 – Design rainfall and flood estimation in South Africa 2007 – Development and assessment of a continuous simulation modelling system for design flood estimation 2007 – Joint peak-volume (JPV) Design Flood Hydrographs for SA 2007 – Modernised SA design flood practice in the context of dam safety 2007 – Statistical Based Regional Flood Frequency Estimation Study for South Africa Using Systematic, Historical and Palaeoflood Data
Miscellaneous	1970 – Synthetic generation of seasonal precipitation 1976 – A method of finding the family of run-hydrographs for given return periods 2005 – Verification of the Proposed Standard Design Flood (SDF) 2010 – Evaluation of the SDF method using a customised design flood estimation tool 2011 – Opportunities for design flood estimation in South Africa

2 Review of the development of flood deterministic procedures for South Africa

2.1 Introduction

The climatological characteristics in South Africa are in a sense unique, where regions could be classified as winter-, summer- or all year rainfall regions. The downpour could either occur as convectional thunderstorms, orographic precipitation, frontal precipitation or in the north eastern part of the country as occasional tropical cyclones or storms.

In the early 1960s, when the need was identified that applicable flood calculation relationships had to be developed for South Africa, the available stream flow data were limited and although long records of recorded rainfall were available for certain locations, the number of rainfall records with extended records were also sparsely located in the country.

Institutions like the HRU (Wits; University of the Witwatersrand), Department of Water Affairs (DWA), South African Weather Services, Department of Agriculture, to mention a few, used the limited information to develop design flood calculation procedures for the moderate and extreme events (Midgley and Pitman (1971); Kovács (1988); Hiemstra and Francis (1979)). This laid the foundation for further developments which followed.

In a recent article (Smithers, 2011) an overview of the flood determination procedures is provided and reference is made to the extension of work in this field. The article is attached on the supporting CD.

In the next paragraphs reference is provided on the:

- Available documents which describe the development of flood estimation procedures in South Africa;
- Currently used methods to conduct the flood calculations;
- Hydrological data which were used in the calibration of the different flood estimation procedures;
- Determination of the flood volumes; and
- Influence of urban catchment development on runoff.

2.2 Overview of the development of flood estimation procedures in SA

2.2.1 Available documents which reflects the development of flood calculation procedures in South Africa

Reports and documents of some of the original developments are out of print and it was decided that those which could be sourced will be converted into an electronic version which were included on the accompanying CD. **Table 2-1** provides a list of some of the contributions between 1969 and 1988 for which the relevant documents have been included on the accompanying CD.

Table 2-1: Details of some documents dated between 1969 and 1988 (included on supporting CD)

Publication year	Authors	Title	ISBN
South Africa			
1969	DC Midgley RA Pullen & WV Pitman, HRU, University of the Witwatersrand	Report 4/69: Design Flood Determination in South Africa	
1971	WV Pitman & DC Midgley, HRU, University of the Witwatersrand	Report 1/71: Amendments to Design Flood Manual HRU 4/69	
1972	HRU, University of the Witwatersrand. Department of Civil Engineering	Report 1/72: Design Flood Determination in South Africa	0854942165
1974	SW Bauer & DC Midgley, HRU, University of the Witwatersrand	Report 1/74: A Simple procedure for synthesizing direct runoff hydrographs	
1978	MS Basson, HRU, University of the Witwatersrand	Report 1/78: Flood Forecasting for the Reservoir Operation by Deterministic Hydrological Modelling	0854945105
1978	DC Midgley & WV Pitman, HRU, University of the Witwatersrand	Report 2/78: A Depth-Duration Frequency Diagram for Point Rainfall in Southern Africa	0854945296
1980	ZP Kovács, Department of Water Affairs	Technical Report TR 105: Maximum Flood peak discharges in South Africa: An empirical approach	0621070203
1981	MD Watson, HRU, University of the Witwatersrand	Report 7/81: Time-Area Method of Flood Estimation for Small Catchments	0854946969
1987	EJ Schmidt & RE Schulze – University of Natal	SCS-based design runoff. ACRU Report No. 24. Application of US Soil Conservation Service method	
1988	ZP Kovács, Department of Water Affairs	Technical Report TR 137: Regional Maximum Flood Peaks in Southern Africa	
Namibia			
1979	BFC Richardson & DC Midgley, HRU, University of the Witwatersrand	Report 3/79: Analysis of SWA-Namibia rainfall data	0854945970
1980	WV Pitman, HRU University of the Witwatersrand	Report 2/80: Analysis of Large-Area Storms in SWA-Namibia	0854946314
1981	WV Pitman & JA Stern, HRU, University of the Witwatersrand	Report 14/81: Design Flood Determination in SWA-Namibia	0 854947108

2.3 Flood estimation procedures currently used in South Africa

2.3.1 Introduction

Flood calculations can either be conducted by reviewing historical data (normally stream flow records) when it is available, or by describing the response of the catchment on a rainfall event using deterministic or empirical relationships.

Figure 2-1 provides a schematic breakdown of the flood calculation procedures commonly in use (see page 2-5).

2.3.2 Brief overview of the flood calculation methods

The Drainage Manual (SANRAL, 2006) and Schulze (2004) highlight the commonly used procedures for flood calculation in South Africa.

A brief overview of the following methods used is discussed below under the following headings:

- Flood frequency analyses;
- Deterministic and Empirical stream flow based procedures; and
- Deterministic/Empirical rainfall based procedures.

The available flood estimation procedures have been developed by various institutions, and are either based on measured stream flow data or on rainfall assessment. Except for the flood frequency analyses on current data, other methods required the calibration of the catchment response parameters which are contained in the empirical and deterministic procedures.

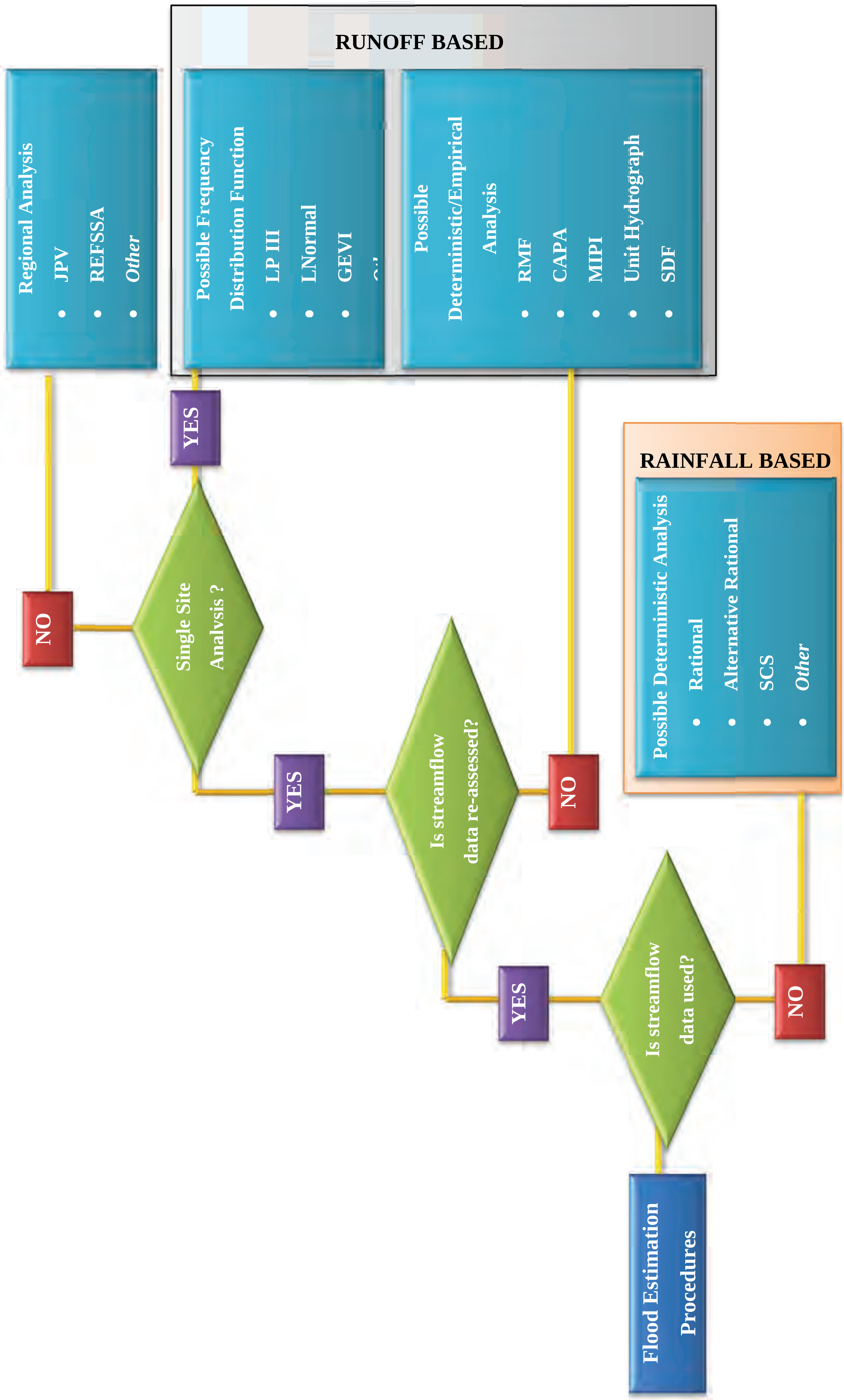

Figure 2-1: Schematic overview of the flood estimation procedures

2.3.2.1 Empirical methods

Empirical methods are based on regional parameters derived from the comparisons between historical peak flows and other catchment characteristics. The reliability of these methods depends largely on the realistic delineation of areas with homogeneous hydrological responses and flood producing characteristics.

2.3.2.2 Deterministic methods

Deterministic methods endeavour to estimate the expected result (run-off) from causative factors (precipitation), based on the assumption that the frequency of the estimated run-off and the input precipitation is equal, while being influenced by catchment representative inputs and model parameters (Gericke, 2010). In simplistic terms, the *T*-year recurrence interval precipitation will produce the *T*-year flood, if the catchment is at average condition.

Thus, the task concerns transforming excess precipitation for the *T*-year design storm into *T*-year flood run-off. This assumption considers the probabilistic nature of precipitation, but the probabilistic behaviour of other inputs and parameters is ignored (Alexander, 2001; Görgens, 1997).

According to the rules of joint probability (mean equals median), this concept is somewhat anomalous. Thus, ignoring the direct implications of joint probability, deterministic methods assume that the catchment would definitely (100% probability) be at its average state when it produces the design flood.

Table 2-2 lists the methods and the required input data and the limitations.

Table 2-2: Application and limitations of flood calculation methods

Hydrological data used	Method	Input data	Recommended area (km^2)	Return period of floods that could be determined (years)
Stream flow records	Flood frequency analysis	Historical flood peak records	No limitation (larger areas)	2-200 (depending on the record length)
	REFSSA	Record maximum flood peaks within similar hydrological regions	100-10 000	200 to 10 000
	Synthetic Hydrograph method	Catchment area, watercourse length, length to catchment centroid (centre), mean annual rainfall, veld type and synthetic regional unit hydrographs	15 to 5 000	2-100
	Standard Design Flood method	Catchment area, slope and SDF basin number	No limitation	2-200
	JPV	Rationalised pooling of statistical parameters for design flood estimations		Various
	RMF	Catchment area and K-region	>10	Maximum historical events analysed
	CAPA	Several catchment variables to estimate a lumped parameter (MAP, area, average catchment slope and shape parameter)	No limitation (larger areas)	2
	MIPI Empirical methods	Catchment area, watercourse length, distance to catchment centroid, mean annual rainfall		10-100, RMF
Rainfall records	Rational method	Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity	< 15 #	2-100, PMF
	Alternative Rational method		No limitation	2-200, PMF
	SCS method	Daily rainfall depth, potential maximum soil water retention, initial losses, hydrological soil properties, land cover properties and catchment antecedent soil moisture status.	< 30	2-100

Note:

\# *Contrary to the general understanding the procedure has been successfully used for much larger catchments.*

These procedures are briefly introduced below in an alphabetic order, with a full description in the literature of the procedures included on the supporting CD.

2.3.2.3 Alternative Rational and Rational methods

These methods can only estimate the flood peaks and empirical hydrographs. The following assumptions are relevant when applying these methods (SANRAL, 2006):

- Precipitation has a uniform area and time distribution.
- Peak run-off occurs at the end of the critical storm duration.
- Run-off coefficients remain constant throughout the duration of the storm.
- The frequency of the peak run-off and precipitation intensity is the same.

Pilgrim and Cordery (1993) identified the following weaknesses associated with these two methods:

- *The level of judgement required to determine the most realistic run-off coefficient is largely subjective.*
- *The variability of the coefficients between different hydrological regimes in the same catchment is not accommodated.*
- *The estimation of catchment response time is subjected to regional differences in the time of concentration and cannot be based only on measured catchment characteristics.*
- *The assumption of uniform precipitation intensity and the exclusion of temporary storage limit the use in urban and small rural catchments*.

The use of a probabilistic as opposed to a deterministic approach to determine the run-off coefficients is thus recommended (Alexander, 2001; Pilgrim & Cordery, 1993).

The **Alternative Rational method** is an adaptation of the standard rational method. Where the rational method uses the depth-duration-return period diagram to determine the point precipitation, the alternative method uses the modified recalibrated Hershfield equation as proposed by Alexander (2001) for storm durations up to 6 hours, and the Department of Water Affairs' technical report TR102 for durations from 1 to 7 days, or the Design Rainfall (Smithers and Schulze, 2003).

The **Rational method** is based on a simplified representation of the law of conservation of mass. Rainfall intensity is an important input in the calculations. Because uniform aerial and time distributions of rainfall have to be assumed, the method is normally only recommended for catchments smaller than about 15 km^2. Only flood peaks and empirical hydrographs can be determined by means of the rational method. Judgement and experience on the part of the user with regard to the run-off coefficient selection is important in this method, but thanks to improved methods, subjective judgement is becoming less important.

2.3.2.4 Catchment Parameter (CAPA) method

As described in Gericke (2010) the Catchment Parameter method was developed by McPherson (1983) and originates from an investigation conducted in South Africa on methods for estimating the mean annual and two-year return period floods with a 50% probability of exceedance. Statistical analyses of the flood peaks revealed that it is preferable to use the mean annual flood (MAF) instead of the two-year flood.

The correlation between the MAF and various catchment characteristics was also investigated and gave rise to the basis of the CAPA method. McPherson (1983) identified ten catchment characteristics which were likely to have an influence on the MAF. The CAPA method uses several catchment variables to estimate a lumped parameter and this is site specific method. The preliminary analysis of the investigation showed that four characteristics (MAP, area, average catchment slope and shape parameter) were possibly more influential than the other six.

Pegram and Parak (2004) also noted that a strong relationship exists between the MAF and the catchment area. DWA have developed some regional flood frequency growth curves for the CAPA method by means of frequency distribution analyses of the annual maximum series (AMS).

2.3.2.5 Direct run-off hydrograph method

A simple-to-apply method of design flood estimation in South Africa, known as the Direct or Lag-routed run-off hydrograph method which is based on the results of the SUH method was developed by Bauer and Midgley (1974). This method uses estimates the *T*-year flood hydrograph based on the *T*-year precipitation for the critical storm duration. Inherently, the method is based on the assumption that direct run-off from a catchment can be conveniently simulated by Muskingum routing if the inflow is assumed as excess precipitation and that outflow is run-off with the catchment storage represented by one or more reservoir-type storages. Thus, the run-off is subjected to a time lag and due to the temporary storage in the system; the run-off is released at a rate less than the precipitation input. The driving mechanism is the precipitation distribution over time which is expressed as the effective precipitation divided into time segments, and each segment is sequentially routed through the system. The shape of the hydrograph is determined by the precipitation distribution over time and the time of concentration. This method can be used in catchment areas up to 10 000 km², provided the catchment shape is not too unusual (Alexander, 2001).

2.3.2.6 Empirical methods

Empirical methods require a combination of experience, historical data and/or the results of other methods. Empirical methods are more suited to check the order of magnitude of the results obtained by means of the other methods.

2.3.2.7 Flood frequency analysis

Flood frequency analyses involve the use of historical data to determine the flood for a given return period. Their use is thus limited to catchments for which suitable flood records are available, or for catchments where records from adjacent catchments are comparable and may be used. Where accurate records covering a long period are available, statistical methods are useful to extrapolate the dataset using different frequency distributions to establish longer return period flood peaks.

2.3.2.8 The Joint Peak-Volume Hydrograph Procedure (JPV)

The JPV procedure attempts to incorporate the exceedance probability of flood volumes which is required for the safety evaluation of medium to large dams. The analyses were conducted on a regional pooled basis which provides the exceedance frequency of the design flood hydrograph (volume) for the flood peak that was determined. The results confirmed that log-Normal characteristics of the 139 gauging stations which were analysed. The regionalized pooling assessment was conducted on Veld Type Zones (3 zones were defined) and on the K-regions (3 regions were defined) as was proposed by Kovács (Kovács, 1988).

The research also reviewed procedures for flood peak determination for un-gauged catchments. In this case the GEV and LPIII probability distribution functions were used.

2.3.2.9 Midgley and Pitman method (MIPI)

The MIPI method as reported on in HRU report 1/72 method can be described as an empirical probabilistic method which is an improved version of the earlier method proposed by Roberts (Alexander, 2001). It is based on the correlation between geographical location, return period, catchment area and peak discharge. The MIPI method used frequency analyses of the AMS at 83 hydrological gauging stations in South Africa. It uses a regionalised catchment coefficient (C), resulting in a regional-catchment-distribution constant (K_{RP}) which is linked to seven homogeneous flood zones in South Africa.

A weakness in the method, which was emphasized by researchers showed that although the LEV1 distribution which was used in frequency analyses has a sound theoretical basis; it is less suitable than the LN and LPIII distributions (Adamson, 1978; Alexander, 2001). The method is simple to apply and produces acceptable design flood estimations which is used to compare the flood predictions from other methods. The MIPI method is a useful method to enable comparison with other design flood estimation methods and is suitable for rural catchments larger than 100 km² (SANRAL, 2006).

2.3.2.10 Midgley and Pitman Empirical method

An empirical-deterministic method to estimate flood peaks for return periods less than or equal to 100 years in catchments larger than 100 km² was also developed by Midgley and Pitman (1971). This method is a function of the MAP, catchment area, regional catchment constant, hydraulic length of the catchment, average slope of the main watercourse and the distance to the catchment centroid.

2.3.2.11 REFSSA (Regional Estimation of Extreme Flood Peaks by Selective Statistical Analyses

The REFSSA or *'Regional Estimation of Extreme Flood Peaks by Selective Statistical Analyses'* method was first described in 2010 (Nortje, 2010) with the objective to improve estimation of extreme flood peaks with annual exceedance probabilities (AEPs) between 1/200 and 1/10 000, in order to assist with the selection of design and safety evaluation flood peaks for dams. The method was refined in 2012 (Nortje, 2012). Unlike current *'regional flood frequency analysis'* (RFFA) methods, the REFSSA method analyses mainly *'record maximum flood peak'* data (one maximum value per independent site over the full observation period), thus excluding lesser annual maximum flood peak data, which are included in most RFFA methods. The REFSSA method is especially suitable in climates containing outliers, and where records of annual maximum flood peaks are limited.

Suitability of the method has provisionally been demonstrated for the estimation of extreme flood peaks with annual exceedance probabilities (AEPs) between 0,005 (1/200) and 0,0001 (1/10 000) for three *'similar hydrological regions'* in South Africa (Kovacs regions 4,6; 5 and 5,2), and for catchment sizes between 100 km^2 and 10 000 km^2. Applicability of the method for catchments outside the aforementioned regions and catchment sizes could not been tested due to a shortage of verified data. Excellent results have been obtained so far, with high correlation coefficients (r) between record maximum flood peak data and regression lines (r better than 0,99 and skewness coefficients approaching zero on log-Normal scale). Although it is an upper-bound method because the record maximum flood peak data reflect the most severe flood generating catchments within a *'similar hydrological region'*, estimates for extreme flood peaks are often significantly less than results obtained by other methods, for example the SDF method.

The REFSSA method was developed and tested on the basis of verified data in the catalogue of record maximum flood peaks published by Kovacs in 1988. The method would clearly benefit from improvement, expansion and updating of this catalogue.

2.3.2.12 The SCS procedure to calculate flood peaks

The United States Department of Agriculture's Soil Conservation Service (**SCS method**) based techniques for the estimation of design flood volume and peak discharge from small catchments (i.e. < 30 km^2) were originally adapted for use in southern Africa by Schulze and Arnold (1979). Based on extensive research by, Schulze (1982), Schmidt and Schulze (1984) and Dunsmore et al. (1986) and the development of extended databases, an updated version of the 1979 SCS design manual was produced in 1987 in the form of three reports published by the Water Research Commission:

- An extended theory-based "Flood volume and peak discharge from small catchments in southern Africa, based on the SCS technique" (Schmidt and Schulze, 1987a),
- A "User Manual for SCS-based design runoff estimation in southern Africa" (Schmidt and Schulze, 1987b), and
- Appendices to the above reports (Schmidt et al., 1987).

The above manually based method was computerised by Schulze et al. (2004) and the method is now widely used for the estimation of design floods from small catchments in South Africa.

2.3.2.13 The Standard Design Flood procedure

The **Standard Design Flood (SDF) method** was developed by Alexander (2002) to provide a uniform approach to flood calculations. The method is based on a calibrated discharge coefficient for a recurrence period of 2 and 100 years. Calibrated discharge parameters are based on historical data and were determined for 29 homogeneous basins in South Africa.

2.3.2.14 Synthetic unit hydrograph method

The **Synthetic Unit Hydrograph method** is suitable for the determination of flood peaks, as well as hydrographs for medium-sized rural catchments (15 to 5 000 km^2). The method is based mainly on regional analyses of historical data, and is independent of personal judgement. The results are reliable, although some natural variability in the hydrological occurrences is lost through the broad regional divisions and the averaged form of the hydrographs. This is especially true in the case of catchments smaller than say 100 km^2 in size.

The Synthetic unit hydrograph (SUH) method is used to estimate the *T*-year flood hydrograph based on the *T*-year precipitation for the critical storm duration, using a typical unit volume storm run-off hydrograph with storm losses based on regional trends in catchments between 15 and 5 000 km^2. The SUH method provides reliable results, but some natural variability in the hydrological occurrences is lost through the broad regional divisions and the averaged form of the hydrographs (HRU, 1972). The HRU (1972) derived nine dimensionless synthetic unit hydrographs for veld-type regions with similar catchment and precipitation characteristics from the observed data at 96 hydrological gauging stations in South Africa. The number of catchments represented in each region ranged from 5 to 18. The HRU (1972) also developed a co-axial diagram to estimate the average storm losses in the nine veld-type regions.

In the SUH method, precipitation of a specific intensity and duration is applied on the dimensionless one hour unit hydrograph of an identified region, resulting in the derivation of a series of different hydrographs for various precipitation storm durations (Gericke, 2010). Cullis *et al.* (2007) reviewed the SUH method by comparing the unit hydrograph based design flood estimates with the direct statistical analyses using the LPIII and EV/PWM distributions at 40 gauged catchments for return periods ranging from two to 100 years. The catchments were grouped according to the nine veld-type regions and co-axial diagram groups A (Veld-type region 2), B (Veld-type regions 4, 5, 6 and 7) and C (Veld-type regions 1, 3, 8 and 9) as proposed by the HRU (1972). In general it was found that the SUH method produced higher design flood peak estimates than the direct statistical analysis for veld-type region groups B and C, whilst group A compared well.

2.4 Hydrological data and delineation of homogeneous catchments used in the development of the flood determination procedures

The data that were used in the development of the flood calculation procedures are graphically reflected in **Figure 2-2** to **Figure 2-8.**

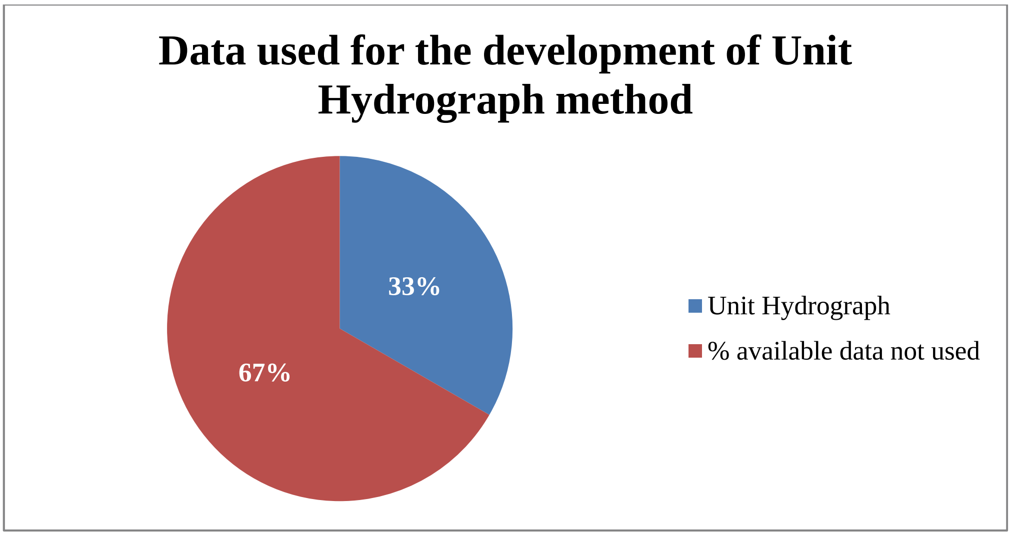

Figure 2-2: Data used in the development of the Unit Hydrograph

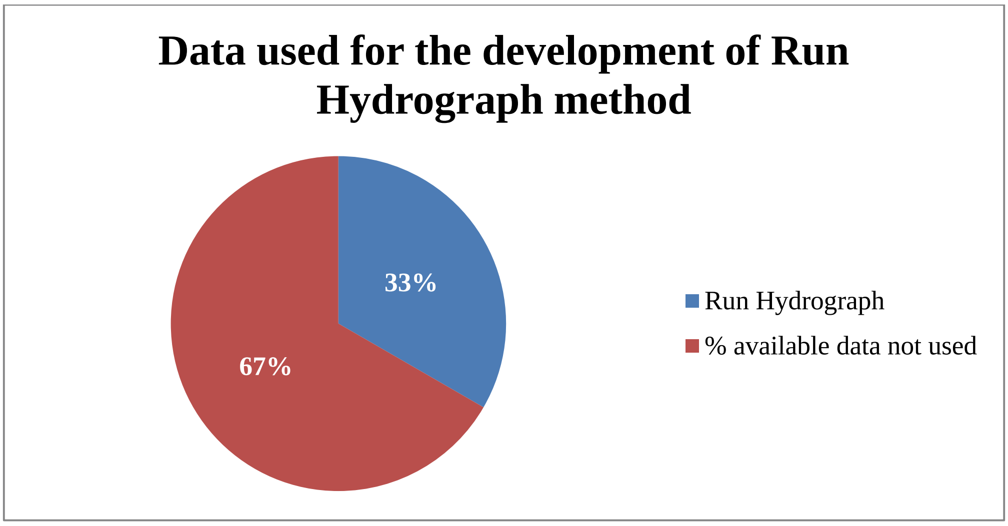

Figure 2-3: Data used in the development of the Run Hydrograph

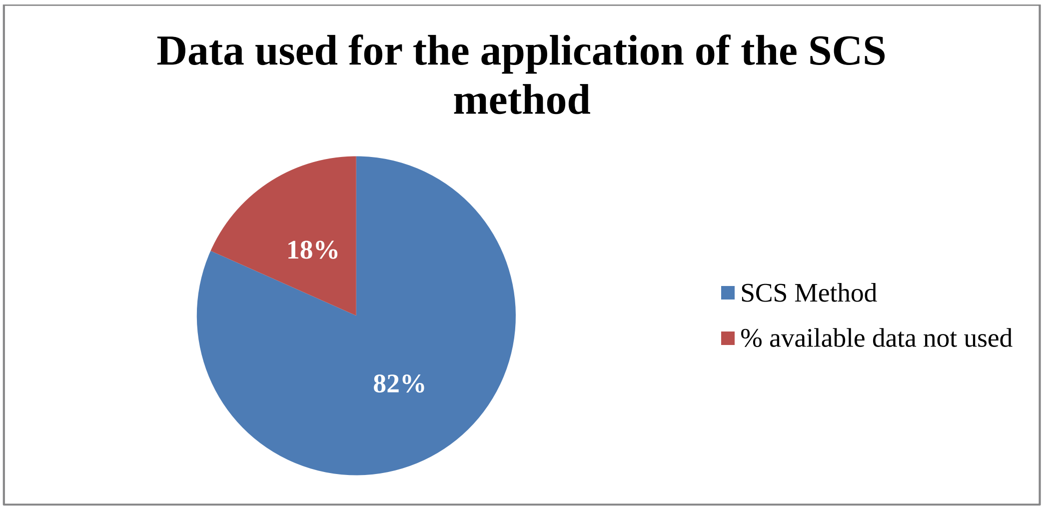

Figure 2-4: Data used in the application of the SCS Method

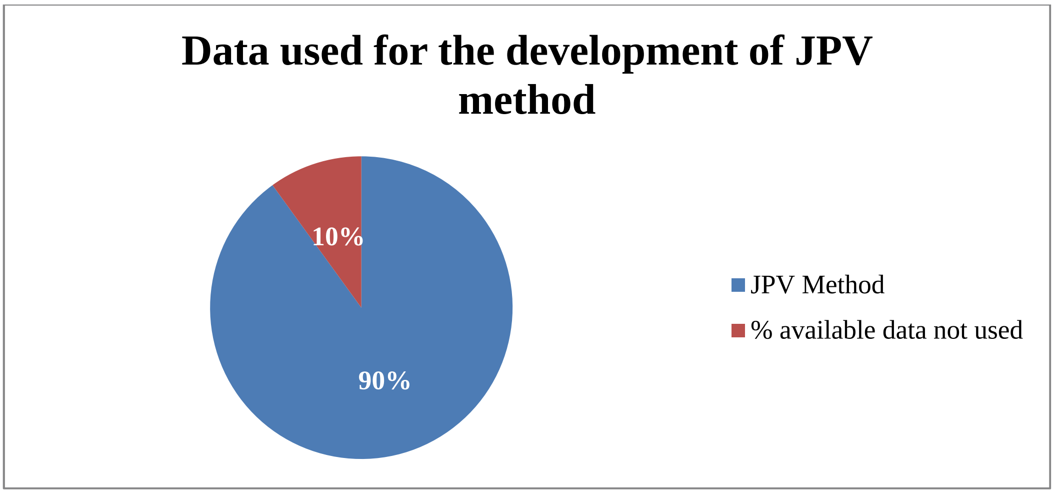

Figure 2-5: Data used in the development of the JPV method

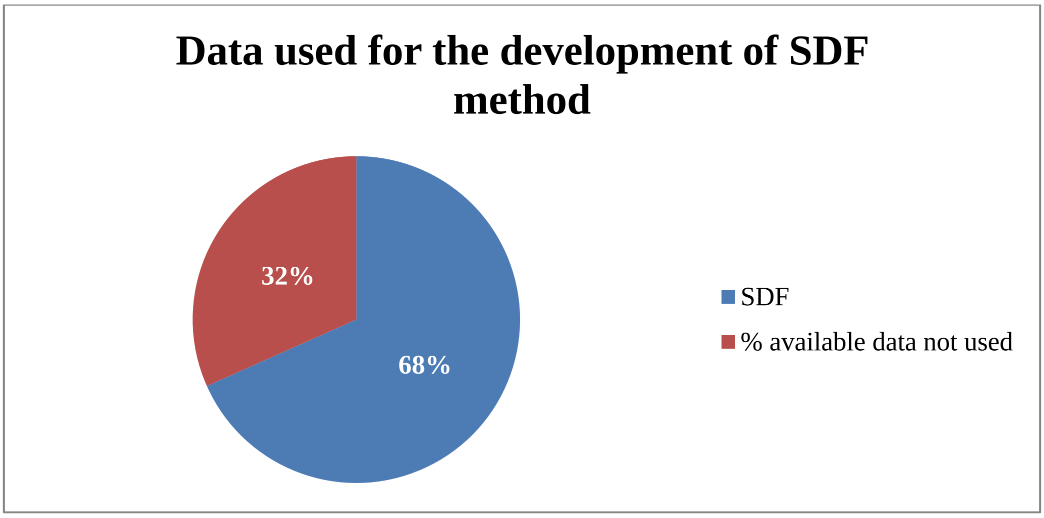

Figure 2-6: Data used in the development of the SDF method

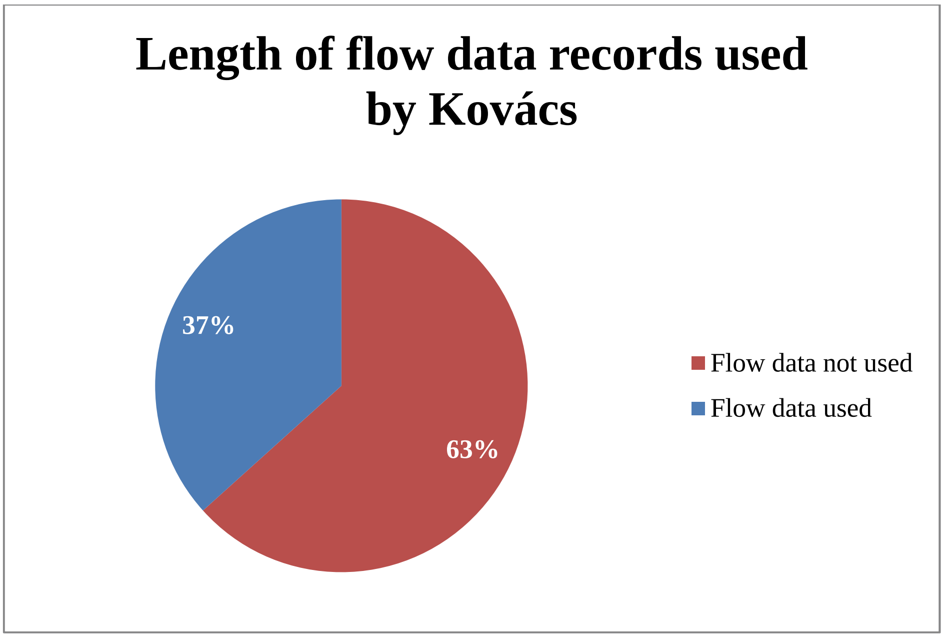

Figure 2-7: Graphical presentation of the length of the flow records used by Kovács

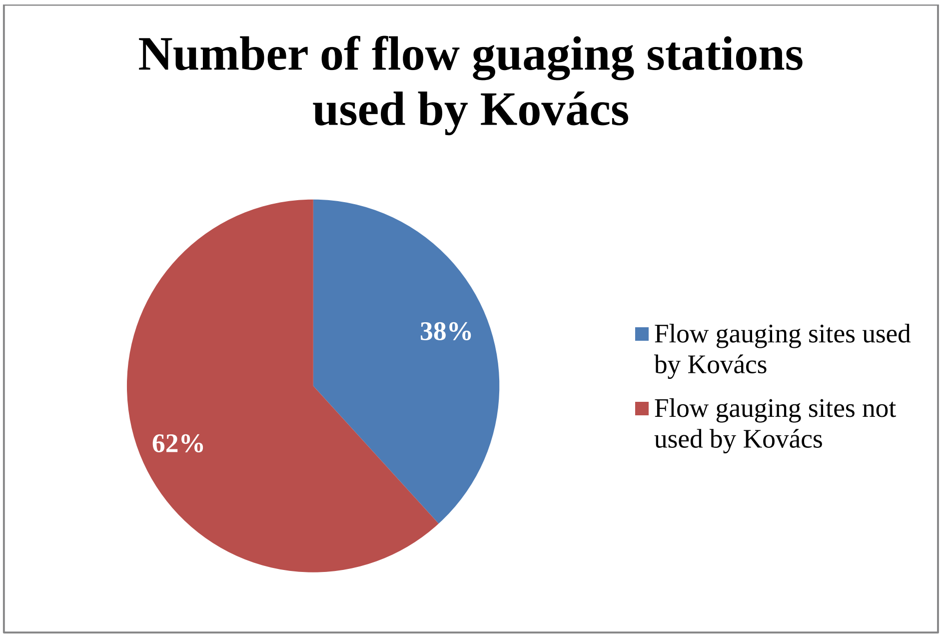

Figure 2-8: Graphical presentation of the flow gauges used by Kovács

It is clear from the above figures that consideration should be given to review the different flood calculation procedures by incorporating the **longer available hydrological data records** and also to consider the **following additional parameters** to verify and improve the following flood estimation procedures:

- Unit hydrographs – review the regions boundaries of these unit hydrographs regions which was based on the general veld types (**Figure 2-9**);
- Run Hydrograph – veld type zones should be reviewed (**Figure 2-9**);
- SDF – basins boundaries to be reviewed (**Figure 2-10**);
- JPV – The procedure should be reviewed on a refined regional selection basis (**Figure 2-11** and **Figure 2-12**);
- RMF – selected areas with similar flood producing characteristics (**Figure 2-13**); and
- Empirical procedures – delineation of homogeneous flood regions (**Figure 2-14**).

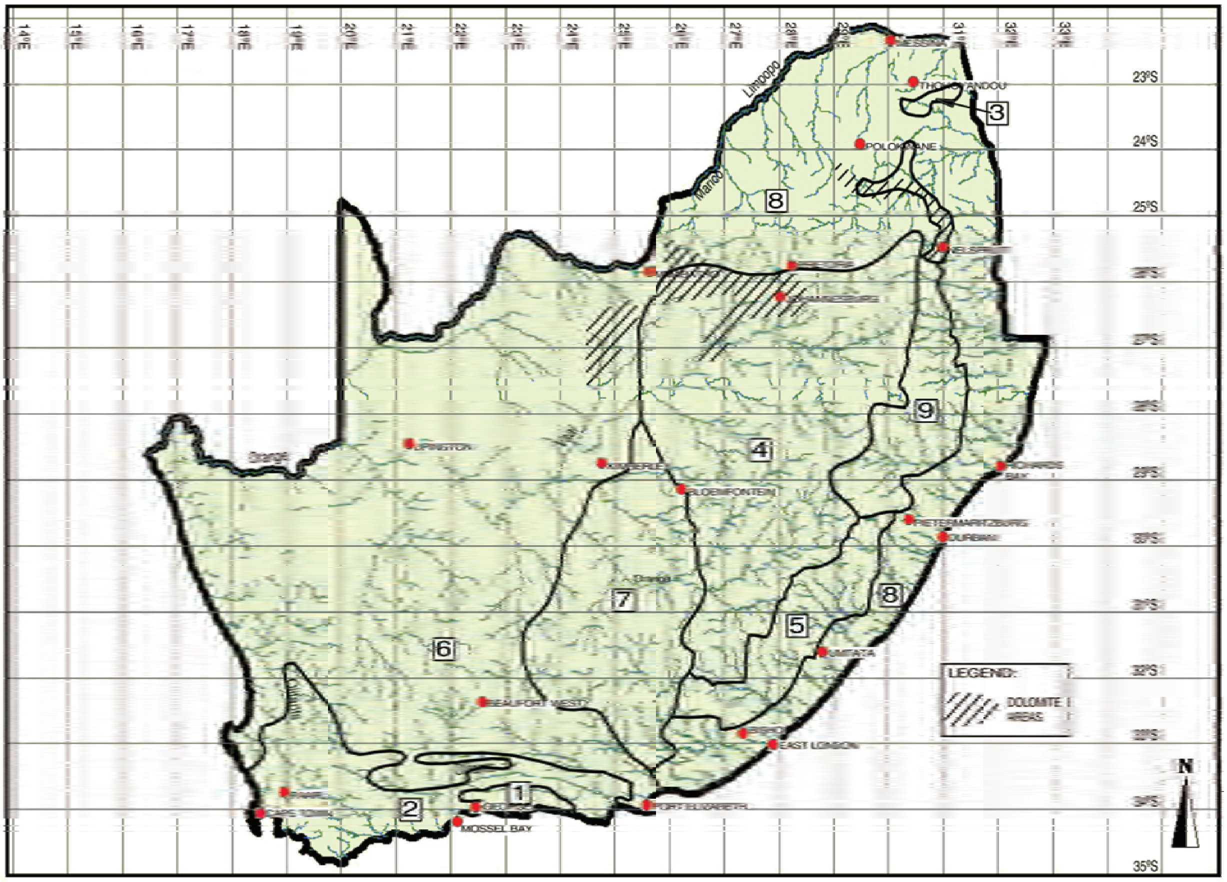

Figure 2-9: General Veld Type regions used in the Unit Hydrograph procedure

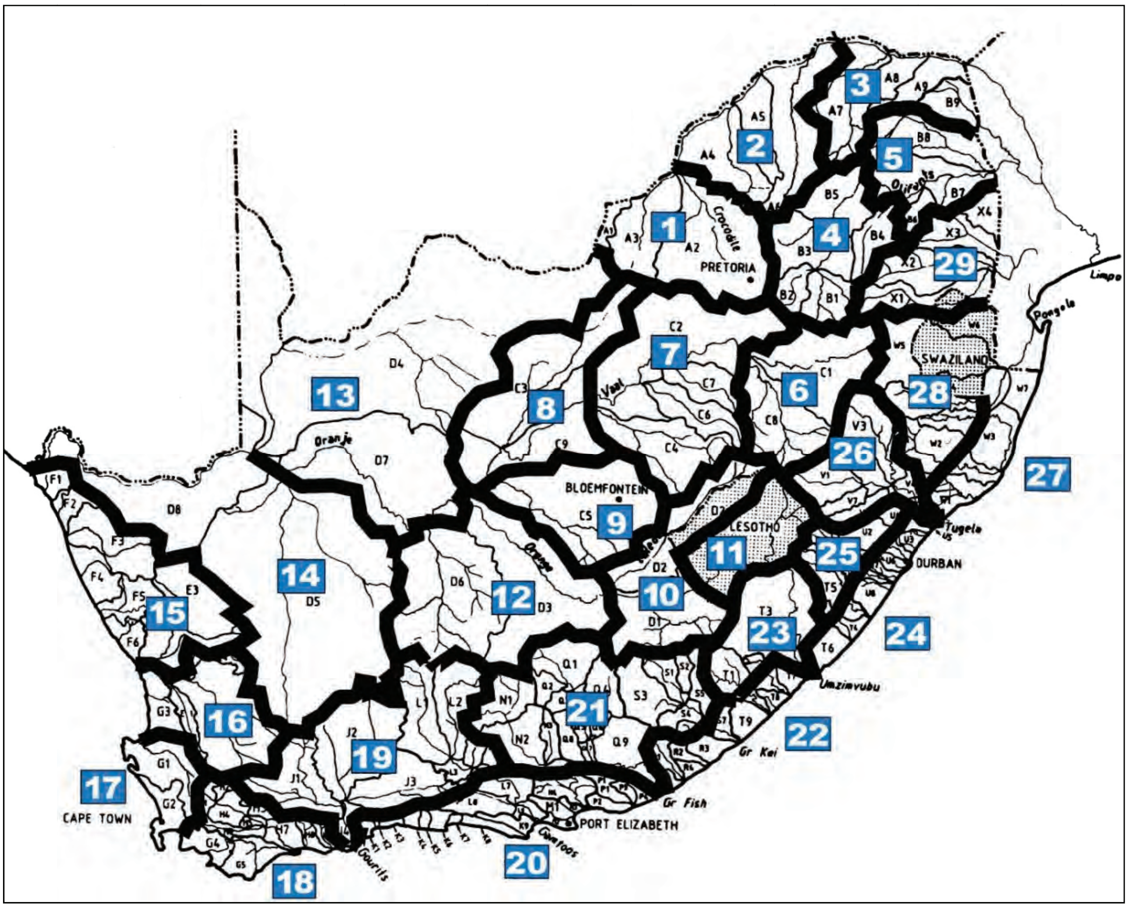

Figure 2-10: Drainage regions used in the application of the SDF procedure

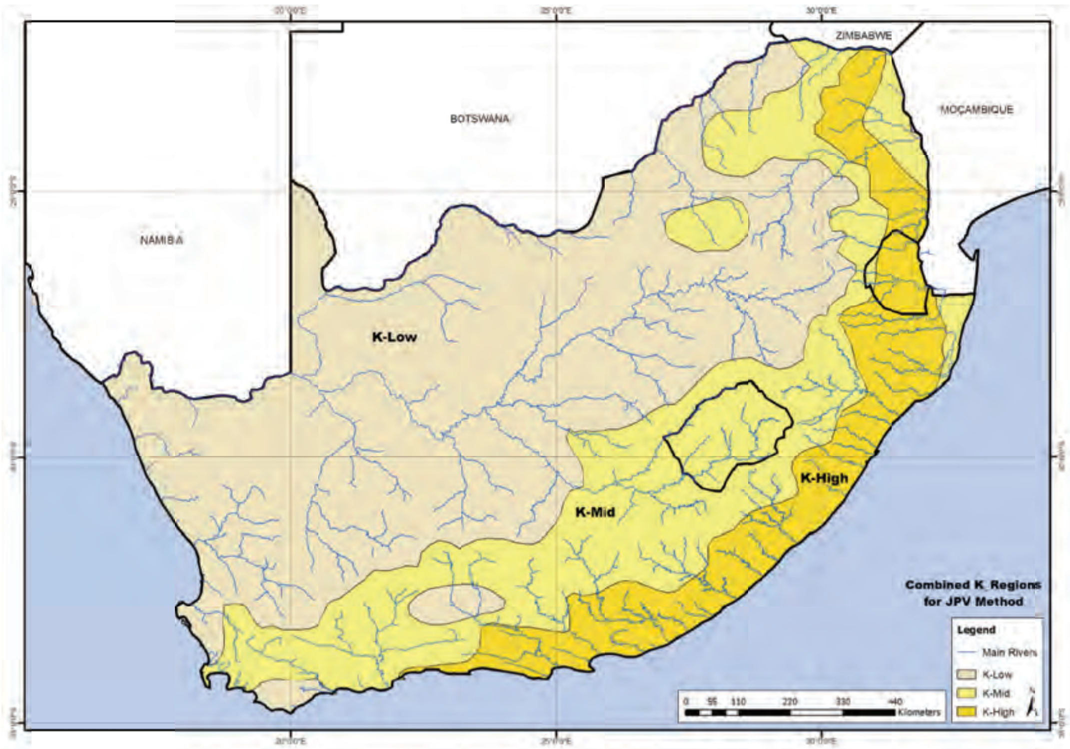

Figure 2-11: Regional analyses of the JPV method based on the K-regions

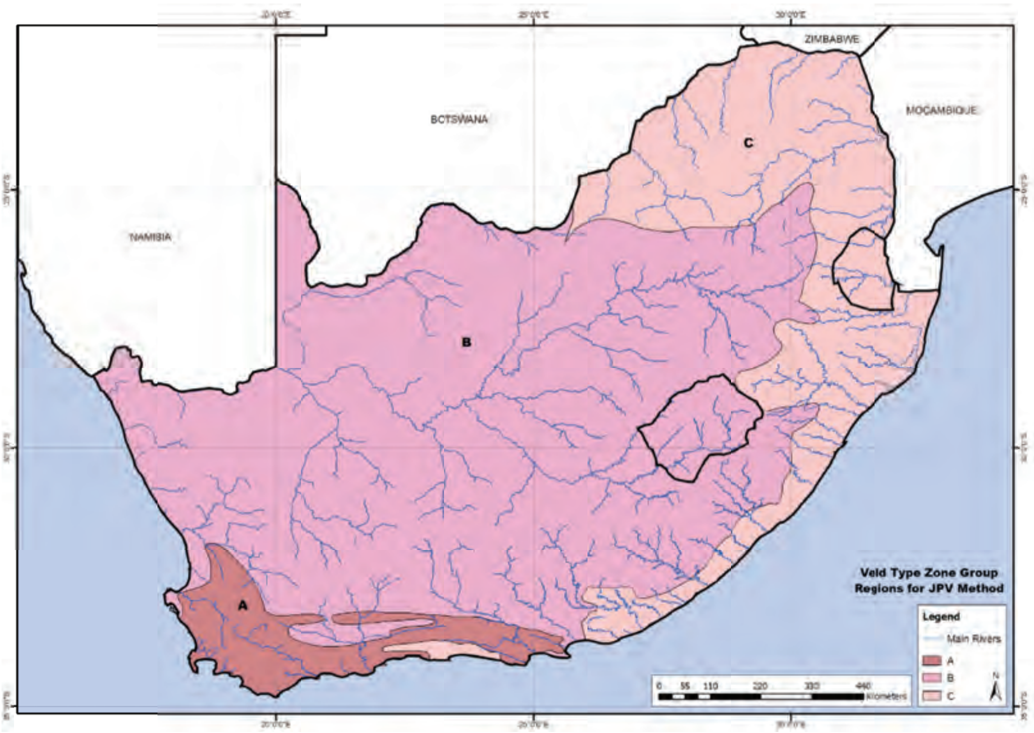

Figure 2-12: Regional analyses of the JPV method based on the Veld Type Zones

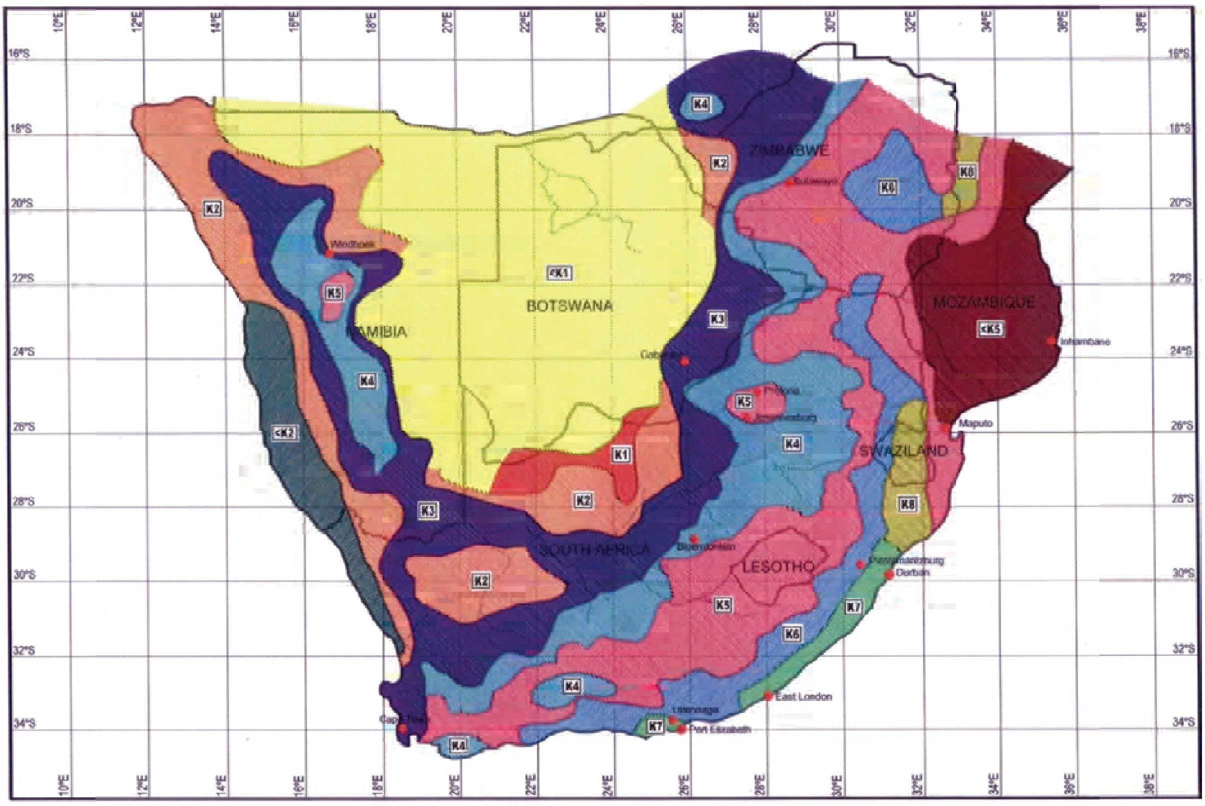

Figure 2-13: Kovács regions in Southern Africa

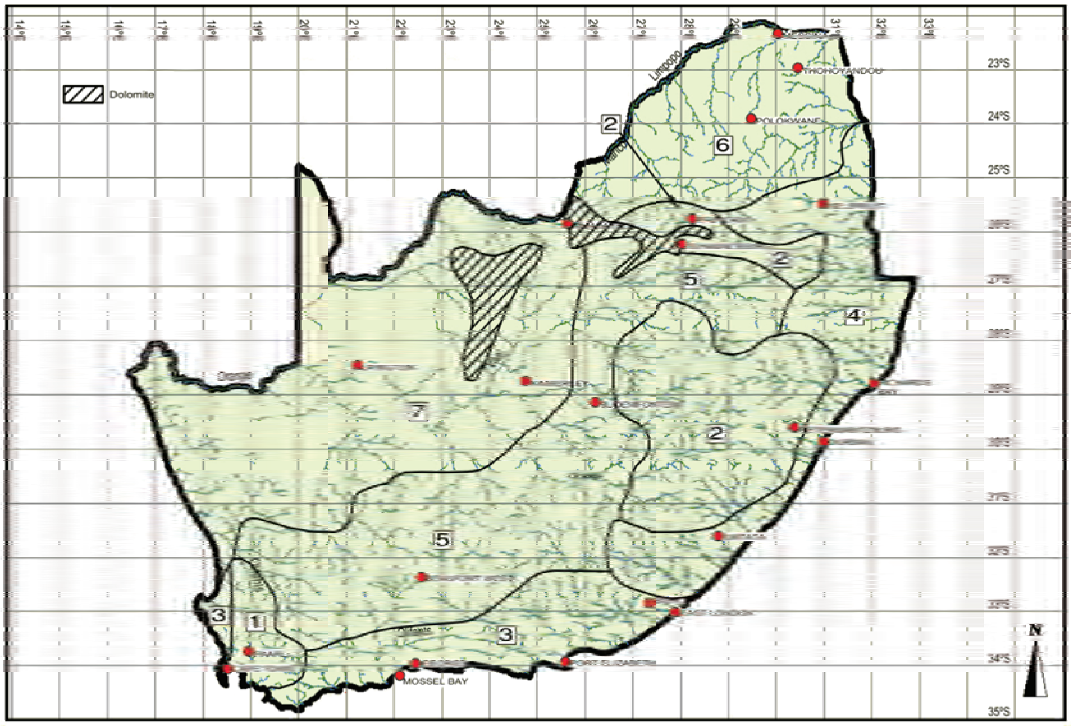

Figure 2-14: Homogeneous flood regions in South Africa

2.5 Determination of the volumetric balance

2.5.1 Introduction

One of the major shortcomings of the flood calculation procedures is the lack of a correlation between the discharge volume and the flood peaks and the recurrence intervals of these two parameters. In the case of the commonly applied rational relationship, it is assumed that the hydrograph can be presented as a triangular relationship between flow rate and time, as is indicated in **Figure 2-15**.

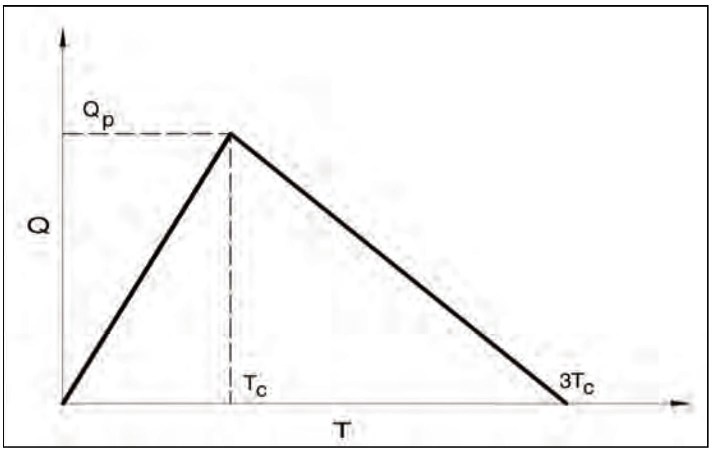

Figure 2-15: Triangular hydrograph

This simplification does not represent the complex nature of catchment's response to a rainfall event. In the case of smaller catchments, the declining limb of the hydrograph could be 3 to 4 times the T_c (Kovács, 2012). Furthermore the mass balance of the volumetric rainfall and the discharge is totally distorted as is simply shown below:

Based on the simplified runoff hydrograph the following relationship for the runoff volume (V_H is the runoff from an event with duration of T_c) can be postulated:

$$V_H = \frac{1}{2} \text{ x } 3T_c \text{ x } Q_P \quad \text{or} \quad V_H = \frac{1}{2} \text{ x } 3T_c \text{ x} \frac{C \text{ x } I \text{ x } A}{3.6} \qquad \dots (2.1)$$

Where:

V_H = Calculated accumulated volume of the flow from the hydrograph (m³)

O_P = Maximum calculated peak runoff (m³/s)

T_C = Time of concentration which represents the total required length of the storm for the whole catchment to contribute to the point of outflow (s)

Volume of rainfall introduced on the catchment, V_R, could be determined as follows:

$$V_R = \frac{I \text{ x } A \text{ x } T_c}{3.6} \qquad \dots (2.2)$$

Where:

V_R = Calculated volume of the rainfall on the catchment (m³)

A = Catchment area (m²)

I = Rainfall intensity (mm/h)

T_C = Time of concentration which represents the total required duration of the storm to allow the whole catchment area to contribute to the point of outflow (s)

The relationship between these volumes could be presented as follows:

$$\frac{V_H}{V_R} = \frac{\frac{1}{2} \text{ x } 3T_c \text{ x } Q_P}{\frac{I \text{ x } A \text{ x } T_c}{3.6}} \qquad \dots (2.3)$$

$$\frac{V_H}{V_R} = 1.5 \text{ x } C \qquad \dots (2.4)$$

This relationship suggests that for a case where the runoff coefficient becomes 1, the runoff volume exceeds the rainfall volume which is impossible. This has to be reviewed with reference to relationships proposed by the SCS, Run Hydrograph or Unit Hydrograph procedures.

The misconceptions related to the temporal and spatial distribution of rainfall and the response characteristics of the catchment are highlighted by reviewing the relationship between MAP (**Figure 2-16**) and MAR (**Figure 2-17**).

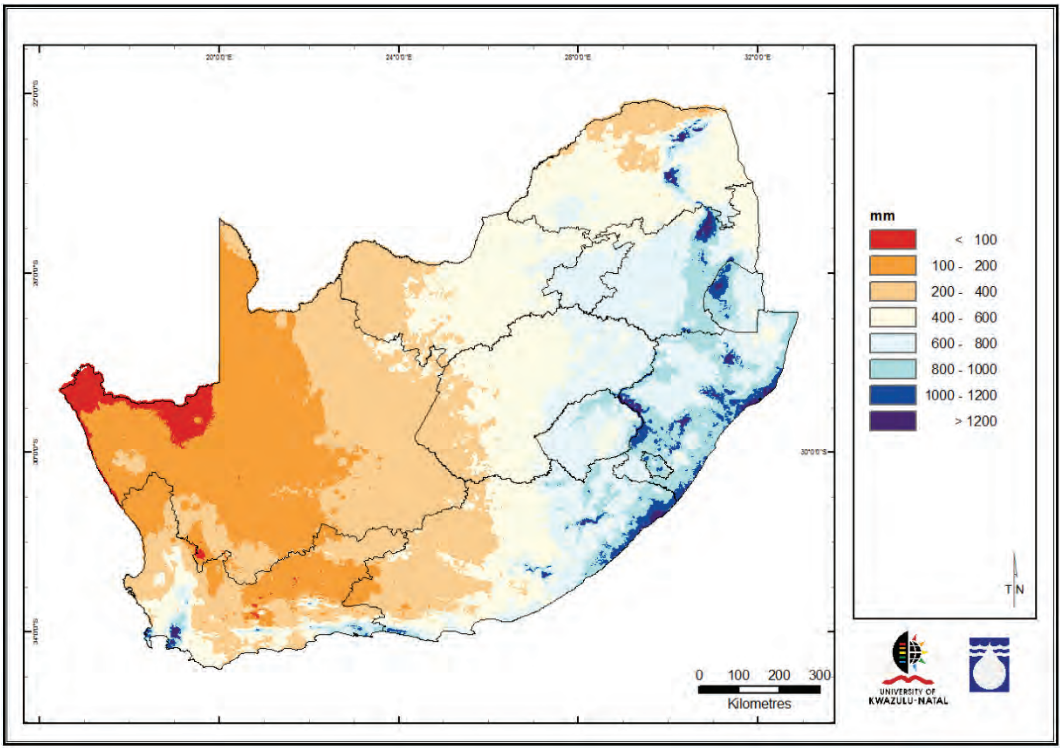

Figure 2-16: Mean annual precipitation variation in South Africa

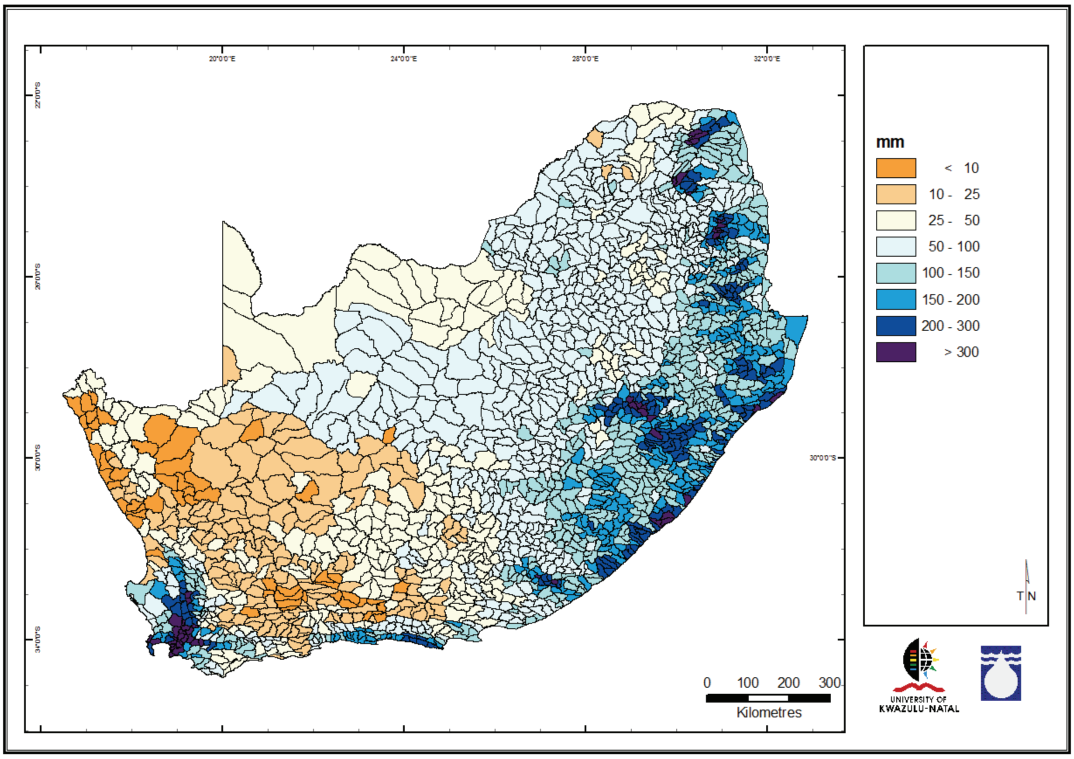

Figure 2-17: Mean annual runoff variation in South Africa

During the late 1980s the WRC contracted the University of KwaZulu-Natal (At that time the University of Natal) to form the Computer Centre for Water Research. In conjunction with this initiative, research at other Universities and Government Departments continued culminating in the improvements of flood calculation techniques and the development of new procedures (**Table 2-3**).

Table 2-3: Summary of major developments since 1990

Development	Institution/person	Year
SCS	UKZN (Schulze, Schmidt and Smithers)	1992 (continuous advancement)
Design Rainfall	UKZN (Schulze, Smithers and Lynch)	2003
SDF	UP (Alexander)	2003
JPV	Ninham Shand (Görgens)	2007
REFSSA	DWA (Nortje)	2010, 2012

2.6 Influence of urban catchment development on runoff

In a recent study (van Vuuren, 2011) the influence of urban development on the peak discharge and volume discharge was investigated. The rainfall was recorded and the discharge from the catchment was measured. This study revealed that the general notion that urban development will increase the flood peaks as well as the volume of discharge is unfounded, because the effect of temporal storage created by artificial barriers along the normal flow path and at all hydraulic structures designed for short design recurrence intervals is not considered.

2.7 Climate change

Conflicting views on the impact of human induced impact on the climate exists and will probably not be resolved in the near future. The review of the extended hydrological records might provide insight in the variability and governing parameters of the processes at work.

3 Practitioner's review of the commonly used flood calculation procedures

3.1 Introduction

A questionnaire was compiled to obtain input from practitioners on the use and needs pertaining flood calculations. This questionnaire was distributed at the recent SANCOLD Conference (2011), courses which were presented by the University of Pretoria (2012) and to some practitioners and researchers. **Table 3-1** reflects the information which was sought through the questionnaire, which addressed the following aspects:

- Experience;
- Qualification;
- Size of the catchments usually reviewed;
- Method to determine discharge peak:
- Project type;
- Methods used to calulate discharge volumes; and
- Identification of the reseach focus areas.

In total 35 responses were received. The data which were obtained are graphically represented in **Figure 3-1** to **Figure 3-10.**

Table 3-1: Details of the questionnaire on flood determination methods

Overview of Flood determination procedures

Please cross the appropriate boxes.

In cases where different procedures are used reflect the relative use by allocation of a %.

Personal details (optional)

Name:					
Contact details:					
Years experience	<5	5 to 10	10 to 15	15 to 20	More than 20
Formal qualification	BSc	BTech	BEng	Other	

Area of catchments	<15 km^2	<5000 km^2	>5000 km^2	Total
% of catchments in these area				100

Methods used to determine design discharge

Deterministic	Rational	Alt Rational	Unit hydrograph	Synthetic Hydrograph	SCS	SDF
Empirical	RMF					
Statistical	Log Normal	LP III	GEV			

Methods used to determine discharge volume

Method	Recorded records	Unit hydrograph	Simple triangle	JFV method	Total
% for method					100

Project type	Culverts	Bridges	Conveyance systems	Spillways (dams)	Other	Total
% of project type						100

Typical problems

1	
2	
3	
4	
5	

Proposed research focus

Variable	Priority for future research		
	Low	**Medium**	**High**
MAP			
Design Rainfall			
Flow records			
Rainfall intensity			
Unit hydrograph			
Area reduction factors			

User identified reseach needs and priorities:

Variable	Priority for research		
	Low	**Medium**	**High**

Comments:

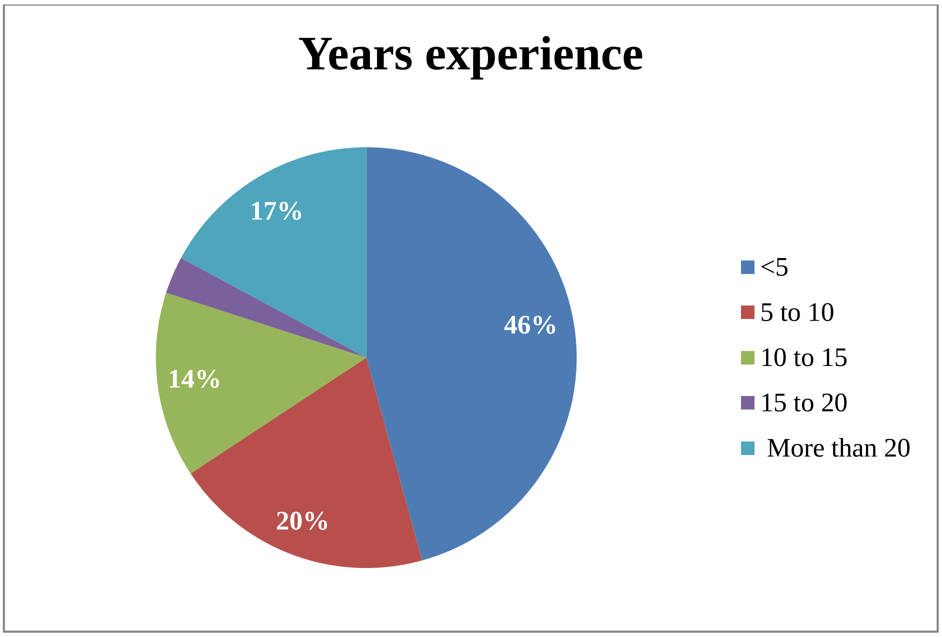

Figure 3-1: Pie diagram of years' experience from the respondents

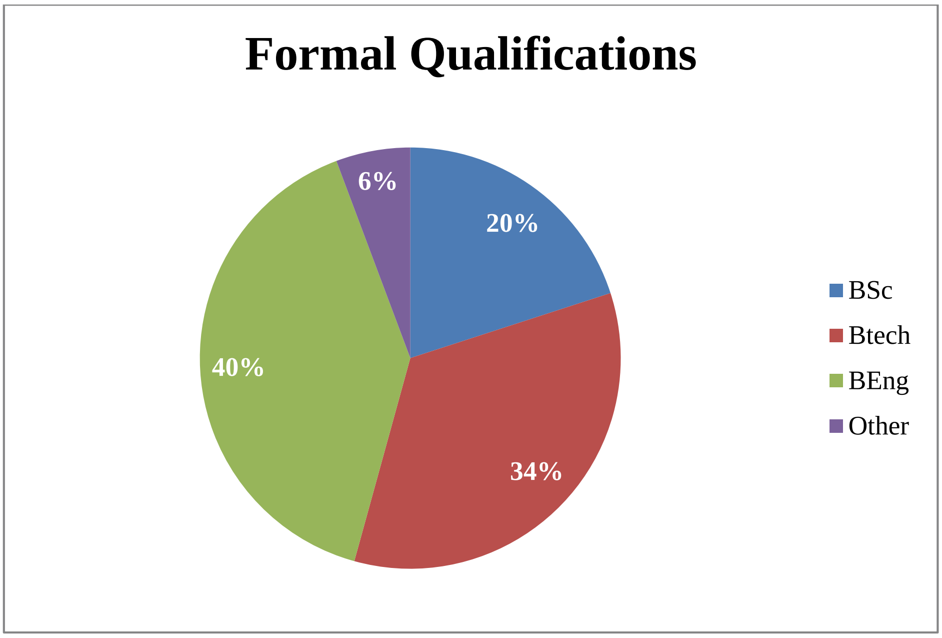

Figure 3-2: Pie diagram of formal qualifications of the respondents

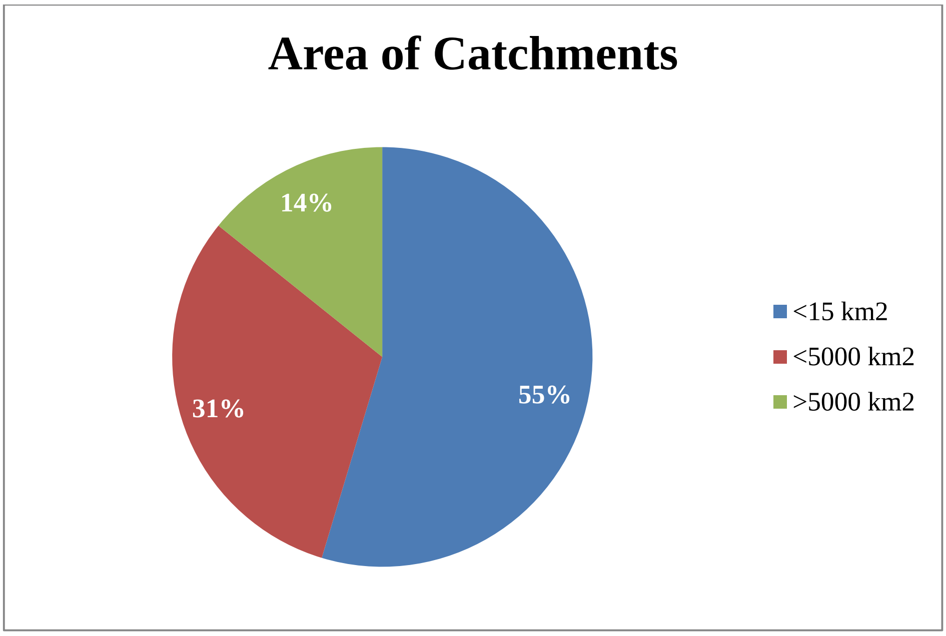

Figure 3-3: Pie diagram of the size of the catchments areas normally reviewed

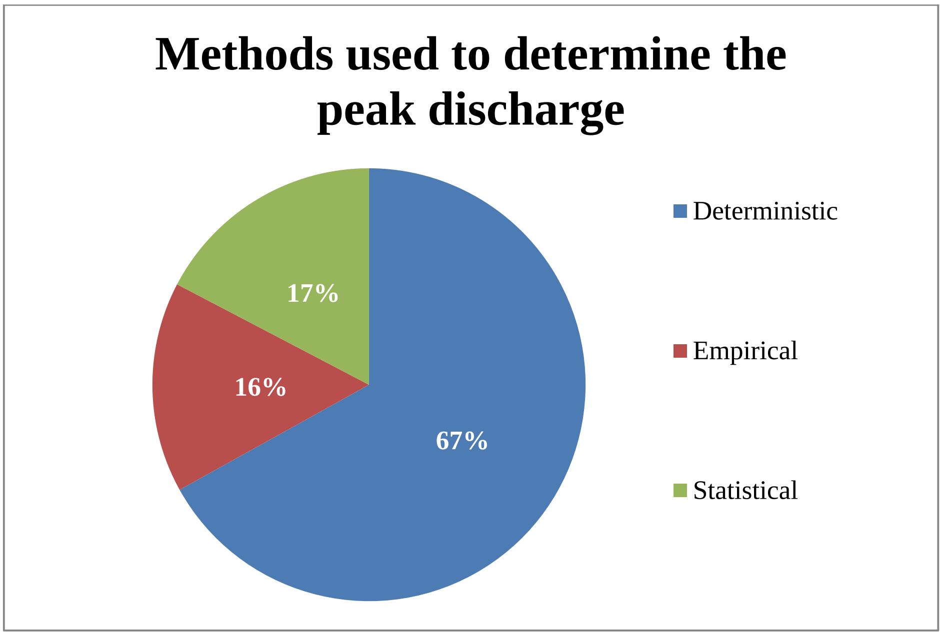

Figure 3-4: Pie diagram of the flood calculation methods used by the respondents

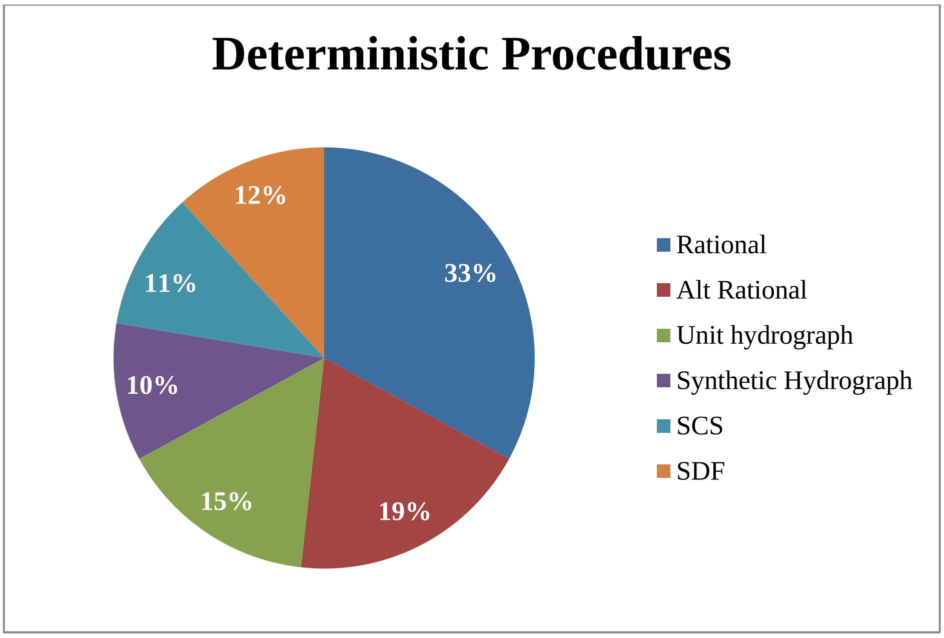

Figure 3-5: Pie diagram of the different deterministic flood calculation methods used by the respondents

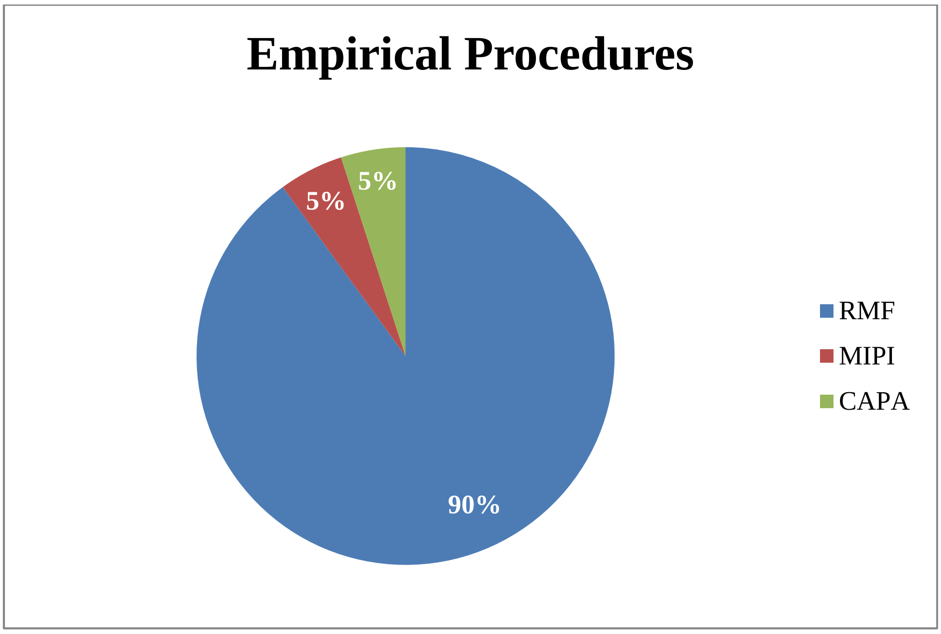

Figure 3-6: Pie diagram of the different empirical flood calculation methods used by the respondents

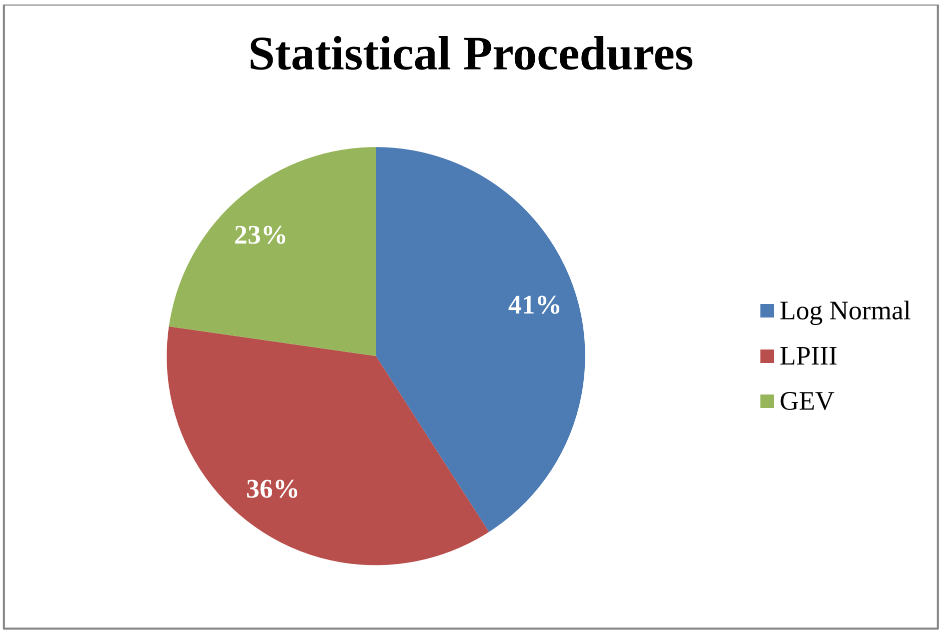

Figure 3-7: Pie diagram of the different statistical flood calculation methods used by the respondents

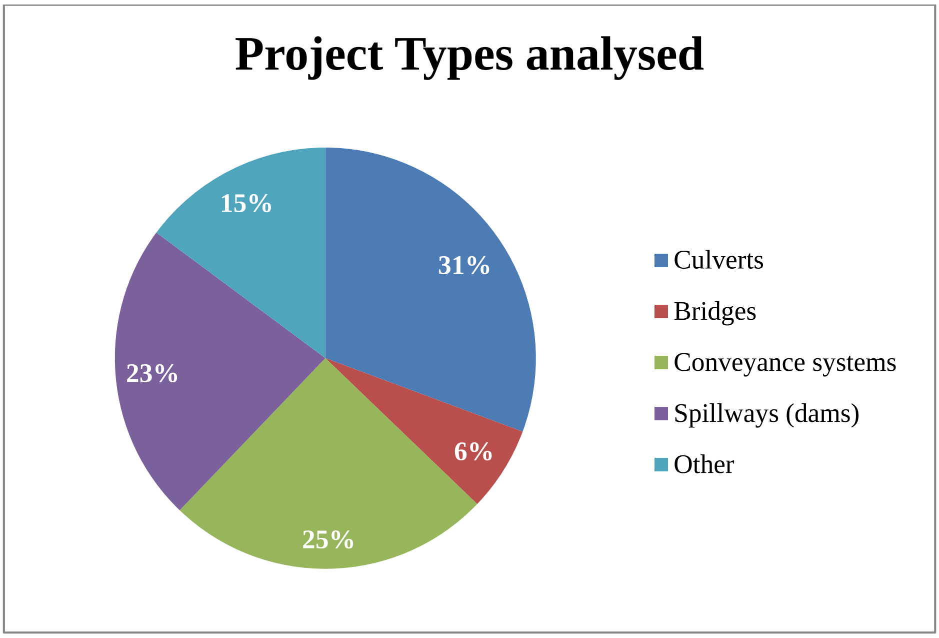

Figure 3-8: Pie diagram of the different project types analysed by the respondents

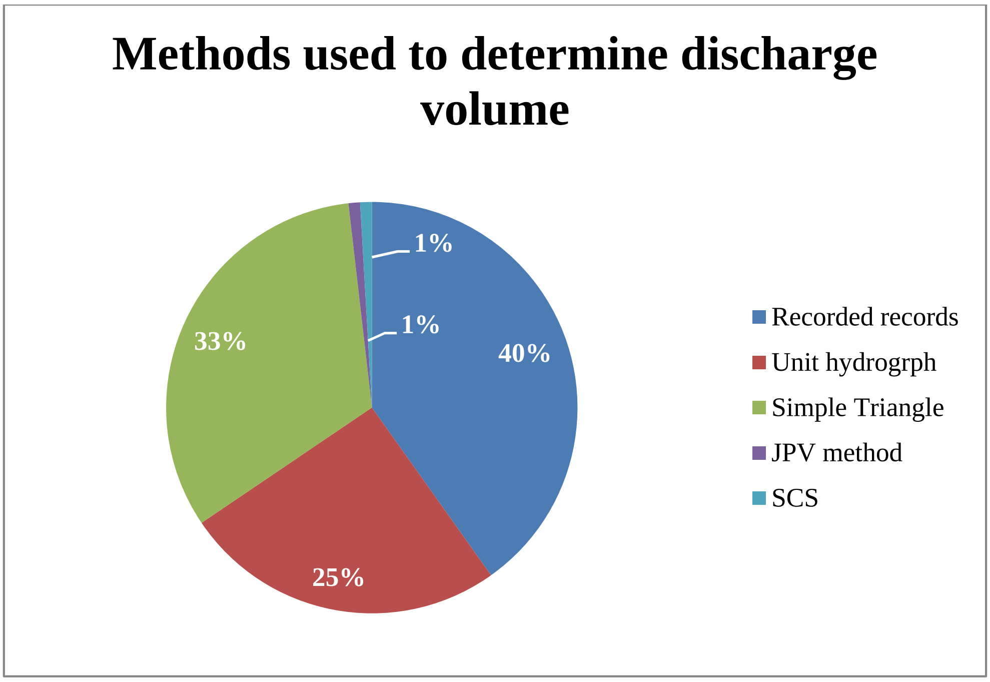

Figure 3-9: Pie diagram of the different methods used to determine the discharge volume by the respondents

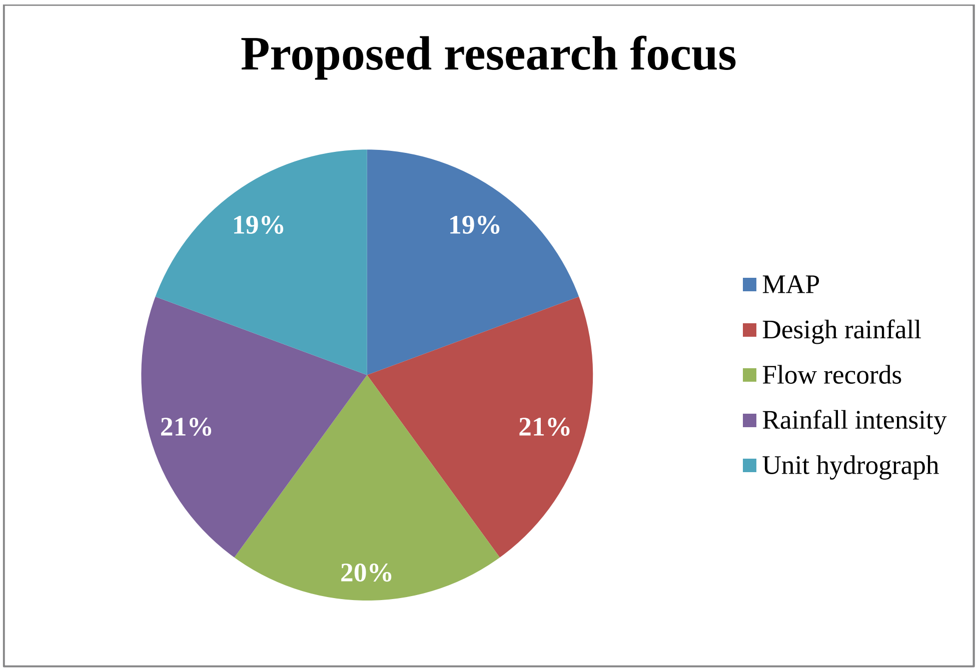

Figure 3-10: Pie diagram of the research focus areas listed by the respondents

3.2 Interim findings from the feedback

Based on the feedback from the practitioners, the following deductions could be made from this limited sample size which could be distorted by the circumstances the sample (respondents) has been selected (at courses and conferences). Each of the parameters is briefly discussed below.

3.2.1 Experience of the respondents

The majority of the respondents are inexperienced, with the majority (46%) having less than 5 year experience.

3.2.2 Qualification

Most of the respondents (54%) have a formal qualification (BTech or BEng degree).

3.2.3 Area of the catchments usually reviewed

The majority of the catchments (55%) for which flood calculations are conducted are relatively small (<15 km^2).

3.2.4 Method to determine discharge peaks

The Deterministic Flood Calculation procedure is the most commonly used method for flood peak determination on areas up to 5000 km^2. The simplicity of these methods is probably the greatest incentive for its use and the user therefore accepts the underlying assumptions of this procedure which are questionable.

3.2.5 Preferred deterministic procedure

The Rational and Alternative Rational Method are the most widely used (54%) procedure for the calculation of flood peaks. The next preferred method is the Unit Hydrograph Method (15%).

3.2.6 Preferred Empirical Procedure to determine extreame flood peaks

The RMF procedure is the most commonly used (90%) empirical procedure to determine extreme flood events.

3.2.7 Prefered Statistical procedure to determine the flood peak in gauged catchments

The different statistical procedures are all used with the Log Normal distribution the highest favoured procedure (41%).

3.2.8 Project type for which flood calculations are executed

The most common hydraulic structure types (project type) for which flood calculations are conducted is culverts (31%), followed by the determination of floods in conveyance systems (25%) and spillways (23%).

3.2.9 Preferred methods used to calculate discharge volumes

For un-gauged catchments, the preferred procedure for the determination of the runoff hydrograph discharge volume (time distribution of discharge) for a catchment is to assume that the triangular distribution (55%) applies.

3.2.10 Reseach focus areas identified by the respondents

Among the listed possible focus areas there is no favoured focus which could probably indicate that for all the areas the lack of continued updated data and research have been lacking, or that the respondents have no specific conviction on this matter. This could be expected with the majority respondents having less than 5 years' experience.

South Africa's hydrological practitioners are facing a challenge to ensure that the gap which will be created in the next 5 years by the retirement of experienced hydrologists needs to be addressed immediately. The incentives created by research opportunities is contributing to fill the gap but a national strategy needs to be formulated that will address the gathering of data, capacitating professionals and creating professional career opportunities.

4 Identification of research areas pertaining the review, extension and update of flood calculation procedures

4.1 Introduction

The perceived research focus obtained from the survey on a small sample (**Figure 3-10**) indicated that the need for data is paramount to understand the variability of the natural processes associated with runoff. This emphasised the need for long reliable hydrological records (rainfall and flow data) which is essential for the development of response relationships for catchments.

In the following paragraphs a number of focus areas are highlighted which is intended to provide a framework for further discussion. The following aspects are reviewed:

- Hydrological data recording and verification;
- Catchment response to rainfall events;
- Verification and improvements to flood calculation procedures;

4.2 Hydrological data recording and verification

4.2.1 Flow data

Figure 4-1 reflects the information on the current number of flow gauging stations in South Africa (Van Vuuren (2011) cited in Pitman (2011)).

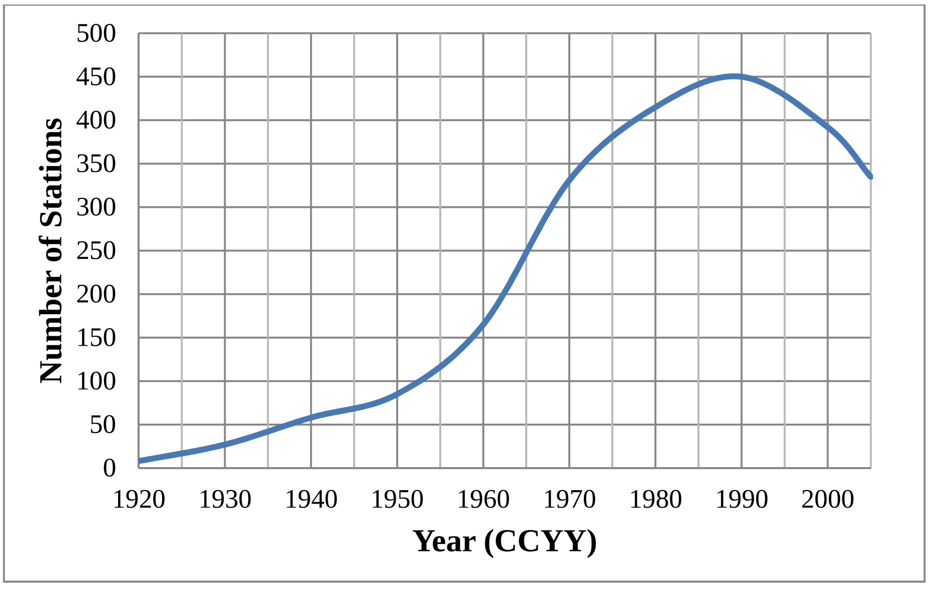

Figure 4-1: Number of flow gauging structures in South Africa

Van Bladeren et al. (2007) reflected the value of flow records for regional assessments and suggested that the data needs to be collected systematically and that consideration should be given to investigate palaeofloods. These aspects are highlighted below.

A wealth of information (Van Bladeren, 2007) is still available and needs to be sourced, retrieved, evaluated, worked up and stored for future use. The number of sites for which historical data could be sourced is 27, with a total observation period that includes the systematic data of 3394 years and an average observation period of 125 years.

It is recommended (Van Bladeren, 2007) that palaeoflood data should be pursued with greater enthusiasm and with the distinct aim of providing a detailed palaeoflood record at identified sites (river reaches) with the primary aim of using the temporal and flood magnitude estimates for flood estimation.

Van Bladeren et al. (2007) recommended:

- *That gauging stations relevant for flood studies be identified, formally calibrated (only one set of discharge tables) and to ensure that they are maintained. The closure of gauging stations with long periods of observation should be discouraged. These closures are often motivated on the bases that sufficient data has been gathered for water resources planning purposes, that no one will use the data or that the site is out of the way.*

- *The routing of instantaneous inflows for annual maximum flood peaks at dams is done as a matter of course for all dams in the area to add to the overall flood database. The continuous routing of dam inflows could also serve as source of annual maximum series data. At present this is only done on an "ad-hoc" basis.*

- *The gathering and collection of historical data be continued as a matter of routine and the data be processed and stored with the systematic data.*

- *The palaeoflood data gathering be undertaken as a separate but focussed study to add to the palaeoflood data vital for the estimation of the more extreme floods. A more detailed and country wide investigation will also serve as a data source for research into climate and the impact that past climate change events have had on flow regimes in South African rivers.*

- *A <u>national flood database be established</u> that should include data from all sources, including the data held by DWAF. This database should be updated annually and all individuals and organisations should be encouraged to contribute their actual flood data to the data base.*

4.2.2 Rainfall data recording

Figure 4-2 reflects the information on the number of rainfall stations in South Africa (Van Vuuren (2011) cited in Pitman (2011)). This reflects the reality that the number of rainfall station which are currently operational, is the less than the number of operational stations during 1920 (Van Vuuren (2011) cited in Pitman (2011)).

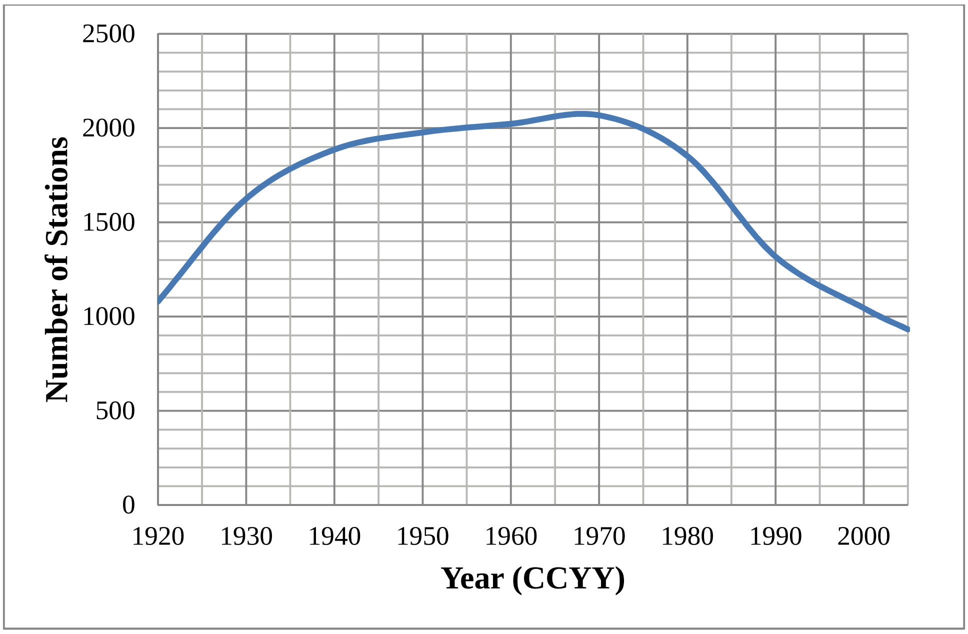

Figure 4-2: Number of rainfall stations in South Africa since 1920

Figure 4-3 reflects the number of records lengths available on short term rainfall events (Van Vuuren (2011) cited in Pitman (2011)). **Figure 4-3** visually reflects the slow pace at which a time series data set is populated.

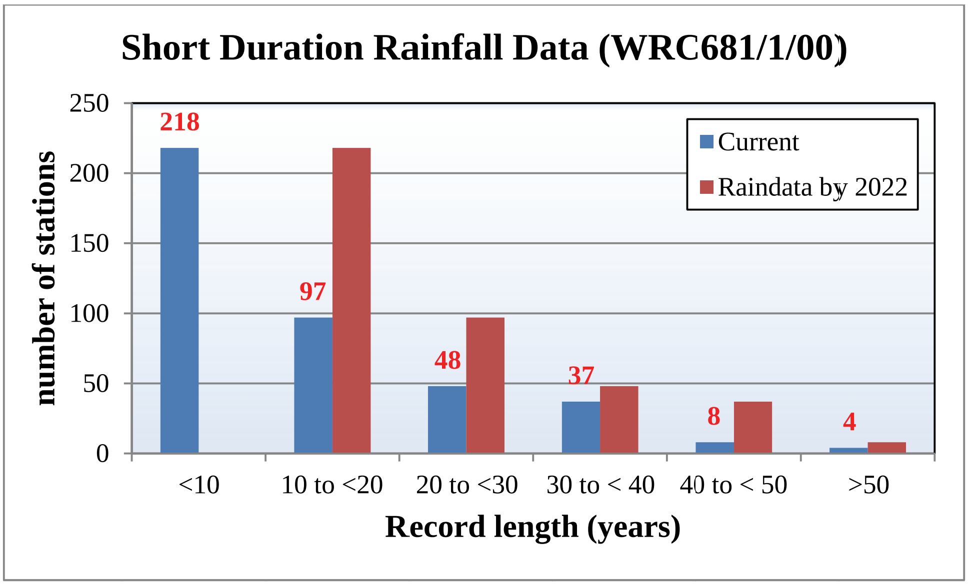

Figure 4-3: Graphical presentation of the record lengths of short duration rainfall data

There are a number of municipalities whom have started to record rainfall intensities and it is known that farmers also capture rainfall data. Verification of these data to be included into a central database could be beneficial.

The software developed by KwaZulu-Natal University (Smithers et al., 2003) to determine the design rainfall is generally used in SA. The database should be updated and consideration should be given to include other databases.

4.3 Catchment response to rainfall events

4.3.1 Catchment response time

The two most frequently used time parameters are the time of concentration (T_C) and the lag time (T_L). The calculation of these parameters could be subjective and could lead to erroneous peak discharge estimation. The catchment response time is also directly related to and influenced by the catchment and channel geomorphology, catchment variables (e.g. land cover, soils and storage), and climatological variables (meteorology and hydrology) (Schmidt and Schulze, 1984).

Both the assumption pertaining the spatial and temporal distributions of rainfall, as well as the critical duration of flood producing rainfall bears on the catchment response time which could lead to the failure of hydraulic structures (Alexander, 2002).

T_C can be defined as the time required for runoff, as a result of rainfall with a uniform spatial and temporal distribution, to contribute to the peak discharge at the catchment outlet, i.e. the time from the end of effective rainfall to the inflection point on the recession limb of a hydrograph. In simplistic terms, T_L is the time delay between the times runoff from a rainfall event over a catchment begins until the runoff reaches its maximum and is generally defined as the time between the centroid of effective rainfall and the resultant direct runoff hydrograph

In South Africa, the hydraulic T_C estimates for overland flow are based on the Kerby equation, and the empirical United States Bureau of Reclamation equation is used to estimate T_C as channel flow in a defined watercourse (SANRAL, 2006). The empirical estimates of T_L used in South Africa are limited to the family of equations developed by the Hydrological Research Unit (HRU, 1972); the United States Department of Agriculture Natural Resource Conservation Service (USDA SCS, 1985) and SCS-SA (Schmidt and Schulze, 1984) equations.

Unfortunately, these time parameter estimation methods are commonly used in South Africa, despite the fact that the use thereof was not verified and tested against local data in all cases. As an example the following table, **Table 4-1** indicates the various ways in which T_C can be computed.

Table 4-1: Formulas to calculate Time of Concentration

<table>
<tr><th>Formula</th><th>Formula and description</th><th>Parameters</th></tr>
<tr><td>Izzard's</td><td>Izzard (1944) conducted experiments on pavements and turf. A dimensionless hydrograph for surface flow laminar regions was developed for well-defined channels.
$$t_c = \frac{41KL^{\frac{1}{3}}}{i^{\frac{2}{3}}}\ for\ i \times L < 500$$
for (i x L <500)
$$K = \frac{0.007i + C_r}{S^{\frac{2}{3}}}$$</td><td>t_c = time of concentration (min)
L =overland flow distance (ft)
i = rainfall intensity (in/hr)
and
S = Slope (ft/ft)
c_r = Roughness coefficient, given as<table><tr><td>Very smooth asphalt</td><td>0.0070</td></tr><tr><td>Tar and sand pavement</td><td>0.0075</td></tr><tr><td>Crushed-slate roof</td><td>0.0082</td></tr><tr><td>Concrete</td><td>0.0120</td></tr><tr><td>Tar and gravel pavement</td><td>0.0170</td></tr><tr><td>Closely clipped sod</td><td>0.0460</td></tr><tr><td>Dense bluegrass</td><td>0.0600</td></tr></table></td></tr>
<tr><td>Kerby</td><td>Kerby (1957) developed an equation for overland flow.
$$t_c = 0.604\left(\ln s^{-\frac{1}{2}}\right)^{0.467}$$
This method is currently being used by DWAF to calculate time of concentration for overland flow.</td><td>t_c = time of concentration (min)
L = length of flow (m)
s = slope (m/m)
n = roughness coefficient, given as<table><tr><td>Smooth pavements</td><td>0.02</td></tr><tr><td>Poor grass, bare sod</td><td>0.30</td></tr><tr><td>Average grass</td><td>0.40</td></tr><tr><td>Dense grass</td><td>0.80</td></tr></table></td></tr>
<tr><td>TR55 Sheet Flow</td><td>With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes, the effect of raindrop impact, drag over the plane surface, obstacles such as litter, crop ridges, rocks, erosion and transportation of sediment.
$$t_c = 0.0288\left[\frac{(nL)^{0.8}}{P_2^{0.5}S^{0.4}}\right]$$</td><td>t_c = time of concentration (min)
L = overland flow distance (m)
P_2 = 2 year 24 hour rainfall depth (cm)
S = average land slope (m/m)</td></tr>
<tr><td>Kirpich</td><td>Kirpich (1940) developed an equation that can be used for rural areas to estimate t_c. The slope of these catchments was steep with well-drained soils. Timber cover ranged from zero to 56%, and catchment areas ranged from 1.2 to 112 acres.
$$t_c = 0.0195\left(\frac{L^{0.77}}{S^{0.385}}\right)$$</td><td>t_c = time of concentration (min)
L = length of travel (m)
S = slope (m/m)</td></tr>
<tr><td>Kinematic Wave</td><td>The kinematic wave equation (Ragan, 1971; Flemming, 1975) can be used to estimate time of concentration when there exists a kinematic wave (velocity not changing with distance but changing at a point).
$$t_c = \frac{6.92(L^{0.6}N^{0.6})}{i^{0.4}S^{0.3}}$$</td><td>t_c = time of concentration (min)
L = overland flow length (m)
N = Manning's roughness coefficient for overland flow
i = rainfall intensity (mm/hr)
S = average slope of overland flow path (m/m)</td></tr>
<tr><td>Soil Conservation Service (SCS)</td><td>The soil Conservation Service (SCS) (USDA, 1975) defined the lag equation to determine the time of concentration, which is in essence a hydraulic wave equation.
$$t_c = \frac{100L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{1900S_A^{0.5}}$$</td><td>t_c = time of concentration (min)
L = hydraulic length (ft)
S_A = average catchment slope (%)
CN= SCS runoff Curve number</td></tr>
<tr><td>Bransby-Williams</td><td>The Bransby-Williams formula was developed in India for urban areas.
$$t_c = 0.96\left(\frac{L^{1.2}}{H^{0.2}A^{0.1}}\right)$$</td><td>t_c = time of concentration (hr)
L = length of flow (km)
H = difference in elevation between the upper and lower limits of the catchment (km)
A = catchment area (km^2)</td></tr>
</table>

Formula	Formula and description	Parameters
Manning	$$t_c = \frac{3.6L}{V}$$ $$V = \frac{R^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$	t_c = time of concentration (min) L = hydraulic length (m) ν = velocity (m/s) R = hydraulic radius (m) S = slope (m/m) n = roughness coefficient
US Bureau of Reclamation	The US bureau of Reclamation Formula was suggested by the University of Witwatersrand in 1972. The formula is more applicable to rural areas and is also currently being used by DWAF to calculate time of concentration for channel flow. $$t_c = \left(\frac{0.87L^3}{H}\right)^{0.385}$$	t_c = time of concentration (min) L = main stream length (km) H = difference in elevation between the upper and the lower limits of the catchment (km) A = catchment area (km^2)
Hathaway's	Hathaway's equation was developed for channel flow and uses Manning's roughness coefficients. $$t_c = \left(\frac{2Ln}{3\sqrt{S}}\right)^{0.47}$$	t_c = time of concentration (min) L = channel length (ft) S = average catchment slope (m/m) n = Manning's roughness coefficient

4.3.2 Antecedent conditions and groundwater recharge

In a sense, the discharge coefficient, which is return period related and the area reduction factor incorporates the antecedent condition in a catchment. The correlation of the catchment response on similar events can only be determined by the detailed assessment of rainfall and discharge (Smithers, 2007).

4.3.3 Urban development on discharge

Different types of development in a catchment will influence the response of the catchment on rainfall. In South Africa where high boundary walls are a general feature of urban development, the creation of temporal storage by these structures across the flow paths, results in retention and attenuation. This reduces the peak discharge of intermediate floods. Determining the relationship between the urban development type, rainfall input, temporal storage, ground water recharge, evaporation and runoff will improve the understanding of the impact of urban development on runoff.

4.4 Verification and improvements to flood estimation procedures

4.4.1 Unit hydrographs

4.4.1.1 Run Hydrograph

Hiemstra reviewed the relationship of flood peaks and flood volumes for 43 flow gauging stations and indicated that the records adhered to a log-Normal distribution in the bi-variate space. The additional flood data should be incorporated and the regions for applying the procedure should be reviewed.

4.4.1.2 Synthetic Unit Hydrograph

There have been no developments or improvements of the synthetic unit hydrograph methods since these have been published by the HRU (1972) in the late 1960s and early 1970s. As described in Smithers (2011), subsequent to these studies, regional techniques for frequency analysis have become the standard and preferred approach in some countries. Longer rainfall and streamflow records are now also available as well as having detailed databases of catchment characteristics for the whole of South Africa. The original regionalisation of South Africa into 9 veld zone types based on data from the 92 flow gauging stations was ground-breaking work. It is however believed that these homogeneous hydrological veld type zones can be refined by assessing the available streamflow data.

4.4.2 JPV Procedure

The regionalized pooling assessment of the JPV method was conducted on 3 Veld Type Zones (associated to the 9 veld zone types classified in South Africa) and on 3 K-regions (associated to the 8 Kovács Regions) from Kovács (Kovács, 1988). Consideration should be given to extend the procedure for more regions. The index-flood approach developed by Görgens (2007) for application in South Africa should be further developed for use in practice and refined regionalisation should be investigated.

4.4.3 SCS Procedure

Schmidt and Schulze (1987) adapted the SCS approach for southern African conditions, accounting for regional differences in median antecedent soil moisture conditions prior to large events and for the joint association between rainfall and runoff (Smithers, 2011). Smithers (2011) indicated that with improved computing power and the currently available databases further refinement of the SCS method is possible which could include:

- *The regionalisation of South Africa could be improved to, at the broadest scale, reflect the 1946 Quaternary Catchments into which South Africa has been delineated and, where necessary, could also reflect heterogeneity of soils and current land use within each Quaternary Catchment.*
- *The method used to account for regional differences in AMC could be improved by utilising improved modelling inputs.*
- *The use of median conditions to account for AMC needs to be re-evaluated and possibly improved by the use of continuous simulation modelling.*
- *It is probable that the soil moisture status could be a function of the exceedance probability of the intended design.*
- *The method used to account for the joint association between rainfall and runoff could also be improved by using a continuous simulation approach and could include events larger than that equivalent to the 20 year return period, which is a limitation of the current version of the SCS-SA.*

4.4.4 Development of Index floods

Van Bladeren (2007) indicated that the parameters that yielded the best correlations to estimate an index flood (Q_i) are catchment area, river slope, rainfall (MAP) and river length. The latter has to be combined with catchment area to provide a catchment shape factor.

The components/variables used to develop the index flood should, however, be limited to those items that do have a significant impact on the index flood. Regionalisation is one way to ensure that the variables are limited. Regions could be defined on climate, vegetation, soils and possibly rainfall characteristics such as the dominant source and track of rainfall events and the general variation in rainfall.

Van Bladeren et al. (2007) proposed a new **lumped parameter** to estimate the Q_{mi} for a site. A comparison of this method's ability to estimate the Q_{mi} and the original CAPA to estimate the site Q_m indicated that the new parameter did fair better in several instances. The new lumped parameter referred to as NCAPA method, could form the basis of further development that could provide a more universal methodology.

4.4.5 Development of flood peak growth curves

Previous studies and experience suggested that the log-Pearson type III distribution, using the method of moments, is presently the most relevant in South Africa. The procedure suggested by

Alexander (1990) and the log-Pearson type III distribution was used to develop the growth curves for the systematic data and the data series that included historical data and palaeoflood data. Van Bladeren et al. (2007) proposes a growth curve splicing diagram that takes the period of observation of a particular data set into account. The suggested growth curves (GC) for all the events was thus based on actual observation and not on theoretical extrapolations. This could, however, be improved upon by including more data and sites.

According to Van Bladeren et al. (2007) comparing the performance of the GC-NCAPA with the other methods, the method proved itself to be relatively consistent between sites and with observed data.

The method does, however, provide slightly more conservative results for the extreme flood events. Most of the other methods tended to overestimate the lower return period events while under estimating the more extreme events. The exception being the RMF method that tended to overestimate and the SDF that tended to under estimate.

4.4.6 SDF Procedure

The Standard Design flood is a calibrated Rational method developed by Alexander (2002a; 2002b; 2003) and is a probabilistic-based approach which has the elements to overcome some of the deficiencies evident in the current flood calculation techniques.

According to Smithers (2011) independent studies have shown that the method results in very conservative design floods. The use of single site and out-dated design rainfall values, the subjective adjustments made, the method of incorporation of variability within regions and the method of regionalisation are all aspects which warrant further investigation according to Smithers (2011).

An investigation revealed (Van Bladeren, 2005) that the method was not always conservative. It was indicated that although the SDF as a method is fairly user friendly the results obtained during the assessment would suggest that it should subjected to a review of the regionalisation and rainfall stations (especially regions 6 and 11). The region specific assessment indicated that more regions would be required. In its present form the SDF is just another method used to estimate flood probabilities and does not provide any assurance to the user regarding flood peak estimates.

During the assessment the data sets used for catchment characteristics in the original development may have errors. A review of some of the site characteristics used indicated that errors of up to 100% were present in some of the characteristics. In one instance the river length used in the original study was 16 km while in a more recent study the river length is estimated to be 32 km. This has a very significant impact on the T_C estimate that in turn impacts on the rainfall intensity and ultimately the estimated flood peak. The annual maximum flood peak data sets that were used may also not have included all the historical data which was used in later studies (Van Bladeren, 2005). The following recommendations crystalize from this:

- Review the regional boundaries;
- Increase the number of regions;
- The data pool (sites) should be increased and the data sets must be updated to ensure that periods of observation are as long as possible. When available historical peaks should be included;
- Re-estimate/determine the catchment characteristics;
- The SDF method must be used with at least one other method to estimate the required flood peaks;
- An improvement to the SDF might be the development of an upper and lower envelope flood frequency growth curves based on the observed data (including historical data) for the each of the SDF regions;
- The SDF estimated flood peaks must be compared to estimates obtained using the RMF method (Kovács, 1988).

A more detailed study aimed at evaluating, calibrating and verifying the SDF run-off coefficients at a quaternary catchment level in the C5 secondary drainage region (SDF basin 9) and other selected SDF basins in South Africa by establishing the catchment parameters and SDF/probability distribution-ratios was undertaken by Gericke (Gericke, 2010).

Based on the findings of Gericke (2010), the following recommendations recognising possible future research on the SDF method were proposed:

- Review the current regional boundaries of the SDF basins by increasing the number of SDF basins based on the single or multiple quaternary catchment boundaries. The availability of hydrological (flow) and meteorological (precipitation) data, as well as the extent of the hydrological homogeneity within the identified catchments, will have an influence on the identification and delineation of the new basins;
- The data pool of hydrological and meteorological gauging sites should be increased and the data sets must be updated to ensure that periods of observation are as long as possible. All

available historical information of flood peaks should be included and made available from a central database;

- Conduct direct statistical analyses of the AMS for calibration purposes at a potential 326 reservoir gauging stations in the quaternary catchments. The number of reservoir gauging stations in the current SDF basins varies from three to 31 reservoirs per basin;
- Conduct direct statistical analyses of the AMS for verification purposes at all possible flow gauging stations in each quaternary catchment used during the calibration exercise;
- Investigate the use of the mean values of the logarithms of two or more probability distributions to accommodate the AMS consisting of a mixture of two or more statistical populations;
- Provide directives as to which probability distribution is the best suited for a specific return period range based on the statistical properties, visual inspection of the plotted data and GOF statistics;
- Select daily precipitation stations representative of the average meteorological conditions in each quaternary catchment of concern by making use of the precipitation database as proposed by Smithers and Schulze (2003).
- Numerically calibrate the run-off coefficients to be used in the revised SDF method to fit the results obtained by the direct statistical analyses for different return periods;
- Establish physical or regional descriptors on which to regress the calibrated run-off coefficients to enable the extension thereof to ungauged catchments. Descriptors such as the catchment area, slope, hydrological soil groups, land use and vegetation and MAP must be tested in combination with the calibrated run-off coefficients to examine if a relationship exists on which to regress the coefficients. In larger catchments, the effect of channel storage should also be taken into consideration.
- Improve the relationship which was established during this study between the time of concentration (T_C) and the catchment area (A) by investigating as many catchments as possible. It is also recommended that not only the catchment area, but also the catchment shape, must be taken into consideration. This will enable future users to get a good indication of the time of concentration associated with any catchment area and shape without being required to go through the tedious exercise of determining the length and average slope of main watercourses.
- Use the SAWS *n*-hour/day point precipitation depths as estimated by the software program, *Design Rainfall Estimation in South Africa* for all the critical storm durations under consideration in the revised version of the SDF method. By doing this, the current DDF (Hershfield) relationship and the variable and questionable parameter (the number of days per year during which thunder was heard) can be excluded from the calculation procedures.

- Improve the ARF relationship established during this study by using the improved T_C:*A* relationships.
- Update and improve the DFET by incorporating the revised version of the SDF method.
- Improve and extend the precipitation databases used in the developed DFET by incorporating the precipitation data beyond 2002.

4.4.7 Empirical methods

According to Gericke (2010) there exists a need to improve or replace these methods, since there are almost 40 years of additional data available which can be utilised to improve them. Van der Spuy and Rademeyer (2008) indicated that the criteria for this evaluation and improvement should be based on:

- Theoretical soundness, but by definition empirical methods normally do not meet this[#];
- Simple and robust application; and
- General acceptability to practising engineers and hydrologists.

Note:

\# *Kovács (2012) indicated that the reference to a theoretical base might be misplaced because the empirical assessment considers the data in a probabilistic manner. What is however required is that the longest available records should be reviewed.*

4.5 Flood frequency analysis

Floods can be estimated utilizing flood frequency analysis of observed flows where these are available and where the records have sufficient length and quality. In the following paragraphs the shortcomings of the flood frequency analyses procedures are reflected.

4.5.1 RMF

In the analyses during 1988, the yearly peak flood peaks from 130 sites around South Africa (354 maximum flood peaks) and 165 flood peaks in six neighbouring countries were used (Kovács, 1988, 2012). The procedure should be reviewed by including all the available applicable data to reproduce/verify the maximum peak envelopes.

4.5.2 Single site analysis

The analysis may be performed at a single site. For direct statistical analysis, Alexander (2001) recommends that either the Method of Moments or Probability Weighted Moments for fitting the distributions should be used. According to Smithers (2011) the literature indicates that L-moments are widely used and have been adopted as a standard approach in, for example, the UK. Although there is some caution in using L-moments, further investigation of L-moments for possible general use in South Africa is justifiable.

The development of a methodology to account for non-stationary data when performing a frequency analysis needs to be developed.

4.5.3 Regional analysis

The advantages of a regional approach to frequency analysis for design flood estimation are evident from previous studies (Smithers, 2011), leading to the adoption of a regional approach as the recommended approach for design flood estimation in some countries (e.g. Australia and UK). The index-flood approach developed by Görgens (2007) for application in South Africa should be further developed for use in practice and refined regionalisation should be investigated.

Another regional method, the REFSSA method, was developed by Nortje (2010, 2012) and tested on the basis of verified data in the catalogue published by Kovacs in 1988. This catalogue provides a reasonably good statistical sample of record maximum flood peaks for some regions of say the last 100 years. Collectively, the catalogue represents 5 000+ station-years against which estimates of extreme floods can be tested. It is important that this catalogue be expanded (especially for poorly represented regions) and updated to include data obtained during the last 24 years. It is also important to carefully record future extreme flood events, in order to observe the effect of possible climate change on extreme flood peaks.

4.5.4 Utilising palaeoflood data

The Water Research Commission's project by Van Bladeren et al. (2007) was a pilot project which concluded that the approach to develop an index flood and growth curve flood estimation methodology for South Africa is supported. It further concluded that:

- By including historical and palaeoflood data, the confidence of estimates for more extreme floods events, where most of the common design interests lie is improved and the applicability of the method covers a broader range of events.

- Possible research could include extending the study to the rest of the country and that all three data sources are expanded with special emphasis on the historical and palaeoflood data.

- Extend data gathering to the rest of country for systematic data, historical data and especially palaeoflood data.

- A concerted palaeoflood hydrology investigation be undertaken as a separate study that will provide information for flood studies, but, if extensive, could provide input into studies investigating the impacts of climate change.

- Refine index flood estimation methodology by establishing standards for characterisation and providing a common source of data for especially medium to large catchments. The CAPA and NCAPA, together with regionalisation, could serve as the bases for these studies.

- Review of statistical flood estimation methodologies including plotting positions, moment and parameter estimation, distributions and methods for treating the historical and palaeoflood data that is presently treated as two separate data sets.

- Development of computer application for the new proposed methods.

4.6 Benchmark catchments

Consideration should be given to the definition of benchmark sites in South Africa which could be recorded and from which the information could be used to improve our understanding of catchment response and be able to quantify the relative importance of rainfall and catchment parameters.

4.7 Identified research focus areas

4.7.1 Introduction

Relatively little research having been undertaken in the past 30 years, and there is a need to refine existing methods and to evaluate new methods which have been adopted for design flood estimation in other countries. The focus need to be to advance the estimates of both specific and probabilistic floods.

Although isolated pockets of research were undertaken, a well-coordinated effort is now required to define flood research and practice in South Africa.

4.7.2 Some directives

Alexander advocated (Alexander, 2003) that there needs to be consistency in flood determination methods when performed by different users. Smithers (2011) reiterated this same sentiment, i.e. similar results should be obtained by different users when applying the same method. According to Smithers (2011) consistent design rainfalls can be estimated for the whole of South Africa, however, there is considerable inconsistency in the estimation of the catchment response time which has a direct impact on the estimation of design floods.

4.7.3 Setting the scene to prioritize and schedule the hydrological research in South Africa

In the preceding sections reference was made to various contributions, shortcomings and proposals with regard to the required focus for the improvements required for flood estimations. This was discussed during the Workshop held on 16 May 2012 and the proposals from this discussion are reflected in Chapter 5.

The long term need in hydrological research will not easily be met with project type research and it is urgent that a national framework be considered at this stage. This will require an identification of research needs and national strategy on how this research should be undertaken and what funding it requires.

The following could be focus areas or work groups of such a "national flood studies programme":

- Rainfall focus (Study or work group);
- Flood frequency (Study or work group);
- Urban issues (Study or work group); and
- Hydrograph analysis (Study or work group);
- Environmental variations (all-encompassing); and
- Institution capacity and cooperation (Management group to ensure Human resource development and institutional cooperation).

In the next chapter reference is made to the discussions during a Workshop which was jointly hosted by the WRC and SANCOLD on 16 May 2012.

5 Research focus for the review, extension and upgrade of flood estimation procedures

5.1 Introduction

Over the last 40 years, flood estimation in South Africa has generally followed methods developed by the HRU, DWAF and academic institutions during the 1970s and 1980s. These methods were based on the available data, technologies and techniques available at the time. The assessment of the longest hydrological records are essential to ensure that the parameters of extreme events as well as the more contemporary information, which reflect current climate and catchment conditions and variations, are reviewed when the flood estimation procedures are extended, reviewed or new procedures developed. **Figure 5-1** reflects the information which was obtained from practitioners who conduct flood calculations.

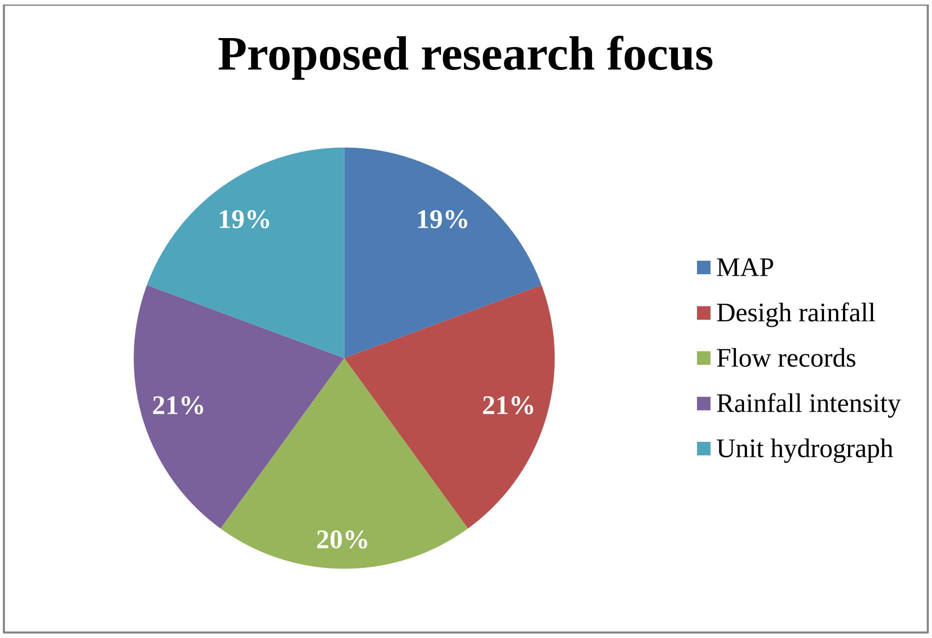

Figure 5-1: Proposed research focus based on information from practitioners

Improved analytical techniques are now available that should be utilised in updating of flood estimation procedures. While there is no broad agreement on the most appropriate flood estimation procedure, the estimation of extremes could now be reviewed using new technologies for the presentation and assimilation of large datasets and the computation of catchment descriptors.

When introduced, a new technology can change the way in which users interact with flood estimates. In recognition of the importance of flood risk management in a period of economic growth and potential climate change, a National programme should be developed to study and develop new methods which will significantly improve the quality and capability of flood estimation for flood risk management in South Africa.

"National Flood Studies Programme"

The development of a "National Flood Studies Programme" for Southern Africa could follow from this project which is a general scoping of the available literature, identifying of flood estimation methods and a reference to the available hydrological and meteorological data. The identification of research priorities will require the implementation of a coordinated research funding programme. This might require the identification of research focus areas from which a research programme, comprising of a number of work-packages (WPs) could be defined. These work packages could be arranged in work-groups (WGs) similar to the Flood Studies Update (Reed and Martin, 2005).

According to Reed and Martin (2005) the work groups WG1 to WG4 are defined by subject, and WG5 and WG6 are defined by purpose (see **Table 5-1** and the schematic interphase of the different focus areas depicted in **Figure 5-2** (Reed and Martin, 2005)).

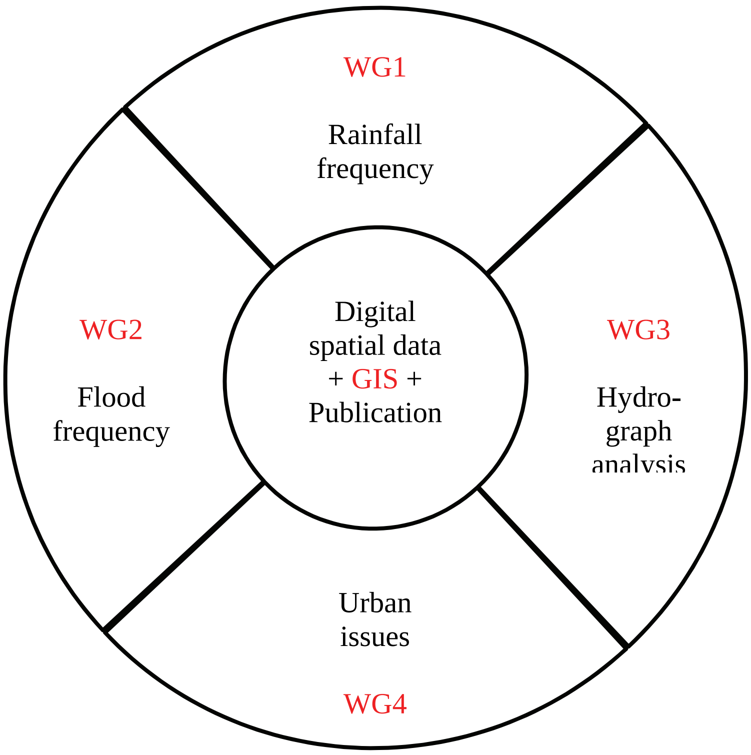

Figure 5-2: Structure of "National Flood Studies Programme" (Reed and Martin, 2005)

Table 5-1: Proposed structure of "National Flood Studies Programme" (Reed and Martin, 2005)

Work package		Summary
Work-Group 1		**Meteorological studies**
WP1.1	Meteorological data preparation	Review/extract & prepare quality-controlled annual maximum series of rainfall depths for a range of durations for use in WP1.2
WP1.2	Rainfall depth-duration-frequency analysis	Define & develop procedures for estimating rainfall depth-duration-frequency such that users can determine rainfall depths for any specified location, duration & frequency.
Work-Group 2		**Statistical analysis of floods**
WP2.1	Hydrological data preparation	Review/extract & prepare river level & flow data for use in WG2, and other parts of the NFSP.
WP2.2	Flood frequency analysis	Define & develop methods of flood frequency analysis for use at gauged sites, and methods of pooled growth curve derivation for use at gauged & ungauged sites.
WP2.3	Index flood estimation	Determine index flood & devise its estimation at ungauged sites.
Work-Group 3		**Flood hydrograph analysis**
WP3.1	Hydrograph width analysis	Analysis of hydrograph shapes from gauged catchments and subsequent analysis of relationships of shape/width parameters to catchment characteristics to enable hydrograph generation in ungauged catchments.
WP3.2	Flood event analysis	Rainfall-runoff analysis of selected events in selected catchments to illustrate Irish catchment flood behaviour.
WP3.3	Flood attenuation analysis	Analysis of impact of floodplain storage on index flood & growth curve, with subsequent analysis of relationships of floodplain attenuation parameters with catchment characteristics to enable generalised provision for floodplain storage effects.
WP3.4	Additional methodology analysis (provisional)	Depending on the outcome of WP 3.1, an additional method of developing flood hydrographs may be required, possibly based on the rational method.
Work-Group 4		**Urban catchment flood analysis**
WP4.1	Scoping study of urban flood issues	A review of the methods of flood estimation in urbanised catchments currently in use in South Africa.
WP4.2	Flood estimation for urbanised catchments (provisional)	The scope of other work-packages will be determined in the light of the outcome of WP4.1. These are expected to relate to R&D to improve methods of estimating flood runoff in urbanised/urbanising catchments.
Work-Group 5		**Development of digital spatial data and GIS**
WP5.1	Scoping study of information systems	Identification of digital spatial data & GIS availability & needs.
WP5.2	Bespoke development of digital / spatial datasets for flood estimation	Following WP5.1, work will be commissioned to generate data sets that are lacking or in inappropriate formats. One such work-package may relate to the hydrological mapping of flood events.
WP5.3	Development of GIS applications	Transition/migration of datasets, methodologies & products into GIS-based software applications.
Work-Group 6		**Publication of NFSP products**
WP6.1	Development of web-based product-application	Development of web-based GIS application incorporating outcomes of WP5.3, with testing & live-system commissioning.

The "boundaries" of the "National Flood Studies Programme (NFSP)" for South Africa should be directed by the following four questions:

- What are the perceived needs for an overhauling of flood estimation methods?
- What might the NFSP realistically deliver?
- What lessons were learned from the previous programmes?
- What makes flood estimation in South Africa different to other procedures implemented elsewhere?

During a Workshop held on 16 May 2012, priorities were identified, which should be incorporated in the NFSP. In the next paragraph the proceeding of the Workshop is reflected.

5.2 Workshop held on 16 May 2012 to prioritise the research needs pertaining flood determination procedures

5.2.1 Agenda for the Workshop (16 May 2012)

Table 5-2 reflects the agenda of the Workshop (16 May 2012).

Table 5-2: Agenda of the Workshop on the review of Flood Estimation Procedures

Item	Description	Responsible person
1.	Welcome	Mr Wandile Nonquphu (WRC)
2.	Presentation of the draft report on "Status review and requirements of overhauling Flood Determination Methods in South Africa".	Prof S J van Vuuren and Project Team (Mr M van Dijk and Mr G L Coetzee)
3.	Discussion	All the attendees
4.	Reaching consensus on required research contents and priority	
5.	Way forward and closure	Mr Willie Croucamp (SANCOLD) and Mr Wandile Nonquphu (WRC)

5.2.2 Attendees to the workshop

Researchers, Academics and Practitioners were identified and invited to attend the Workshop. **Table 5-3** indicates details of the attendees, while **Table 5-4** indicates details of the persons who could not attend the Workshop.

Table 5-3: Attendance register – Workshop 16 May 2012

Title	Name	Surname	Organization	E-mail Address
Dr	Andre	Gorgens	Aurecon	andre.gorgens@aurecongroup.com
Dr	Verno	Jonker	Aurecon	verno.jonker@aurecongroup.com
Mr	Danie	Badenhorst	BKS	danieb@bks.co.za
Mr	Gerald	de Jager	BKS	geraldd@bks.co.za
Mr	Jaco	Gericke	Central University of Technology	jgericke@cut.ac.za
Mr	Danie	van der Spuy	DWA	vanderspuyd@dwa.gov.za
Mr	Jan	Nortje	DWA	nortjej@dwa.gov.za
Mr	Pieter	Rademeyer	DWA	rademeyerp@dwa.gov.za
Mr	Louis	Hatting	Hatting Anderson Associates	halh@icon.co.za
Dr	Renias	Dube	Hydrosoft	xdubex@yahoo.com
Mr	Leon	Furstenburg	Knight Piesold	lfurstenburg@knightpiesold.com
Dr	Paul	Roberts	SANCOLD	paul.roberts@worldonline.co.za
Mr	Willie	Croucamp	SANCOLD	willie.croucamp@gmail.com
Mr	Allan	Bailey	SSI	allanb@ssi.co.za
Mr	Peter	Hirchowitz	SSI	peterh@ssi.co.za
Dr	Jeff	Smithers	University of KZN	smithers@ukzn.ac.za
Prof	Fanie	van Vuuren	University of Pretoria	fvuuren@eng.up.ac.za
Mr	Marco	van Dijk	University of Pretoria	marco.vandijk@up.ac.za
Mr	Louis	Coetzee	University of Pretoria	glouis.coetzee@up.ac.za
Dr	Kobus	du Plessis	University of Stellenbosch	iadup@sun.ac.za
Prof	Gerrit	Basson	University of Stellenbosch	grbasson@sun.ac.za
Mr	Wandile	Nomquphu	WRC	wandilen@wrc.org.za

Table 5-4: Persons which could not attend the Workshop

Title	Name	Surname	Organization	E-mail Address
Dr	Bill	Pitman	-	pitmanwv@iafrica.com
Mr	Zoltan	Kovacs	-	turanfi@lantic.net
Prof	Gerrit	Basson	University of Stellenbosch	grbasson@sun.ac.za
Mr	Dawid	van Wyk	Aurecon	dawid.vanwyk@aurecongroup.com
Mr	Peter	van Niekerk	DWA	niekerk@dwa.gov.za
Mr	Dumisani	Shezi	DWA	shezid@dwa.gov.za
Mr	Archinton	Thobejane	DWA	thobejanea@dwa.gov.za
Mr	Zacharia	Maswuma	DWA	maswumaz@dwa.gov.za

5.2.3 Presentation of the Draft Report

The contents of the Draft Reports (**DL1: Status quo of flood determination procedures and a reference list of available flood studies in South Africa** and DL2: **Prioritization of research and required updates for flood determination procedures in South Africa**) were first reviewed and comments and suggestions were documented. This was followed by a presentation by the Project Leader, Prof Fanie van Vuuren, who reflected the findings of this research consultancy. A copy of the presentation is included on the accompanying CD (**Appendix A**).

5.2.4 Feedback received on the Draft Report

Written feedback on the Draft Reports (DL1 and DL2) were received from:

- Mr Zoltan Kovács (turanfi@lantic.net) and
- Prof Andre Gorgens (andre.gorgens@aurecongroup.com)

The comments were incorporated in this document.

5.2.5 Defining the research focus areas

The attendees at the workshop were requested to identify potential research topics which had to be briefly introduced by the proposer. These topics were grouped under the following headings:

- A – Data: Rainfall, Floods and Hydrographs;
- B – Environment;
- C – Products; and
- D – Institutions which provide an input

After the list of topics were cleaned up by discarding duplicated proposals, the topics were then prioritised and assigned to be of **H**igh, **M**edium or **L**ow importance.

Figure 5-3 provides the flow diagram of the research focus areas (A bitmap titled “Flow Chart“ is included on the accompanying CD).

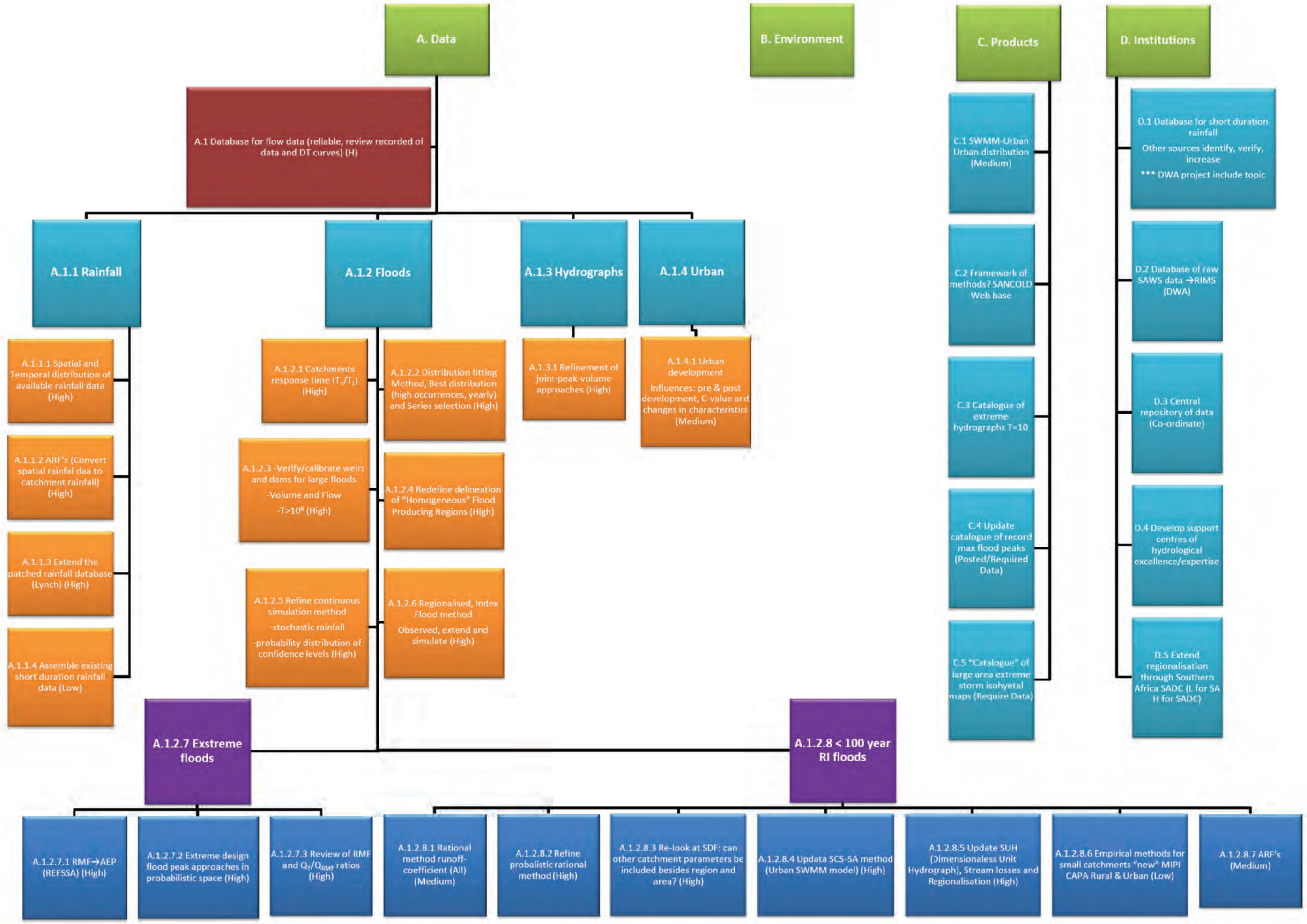

Figure 5-3: Flow diagram of the research focus areas which were agreed upon during the Workshop on 16 May 2012 (The "Flow Chart" is obtainable from the accompanying CD)

Adapted from Reed and Martin (2005), **Figure 5-4** reflects the possible working groups which could be applicable for South Africa.

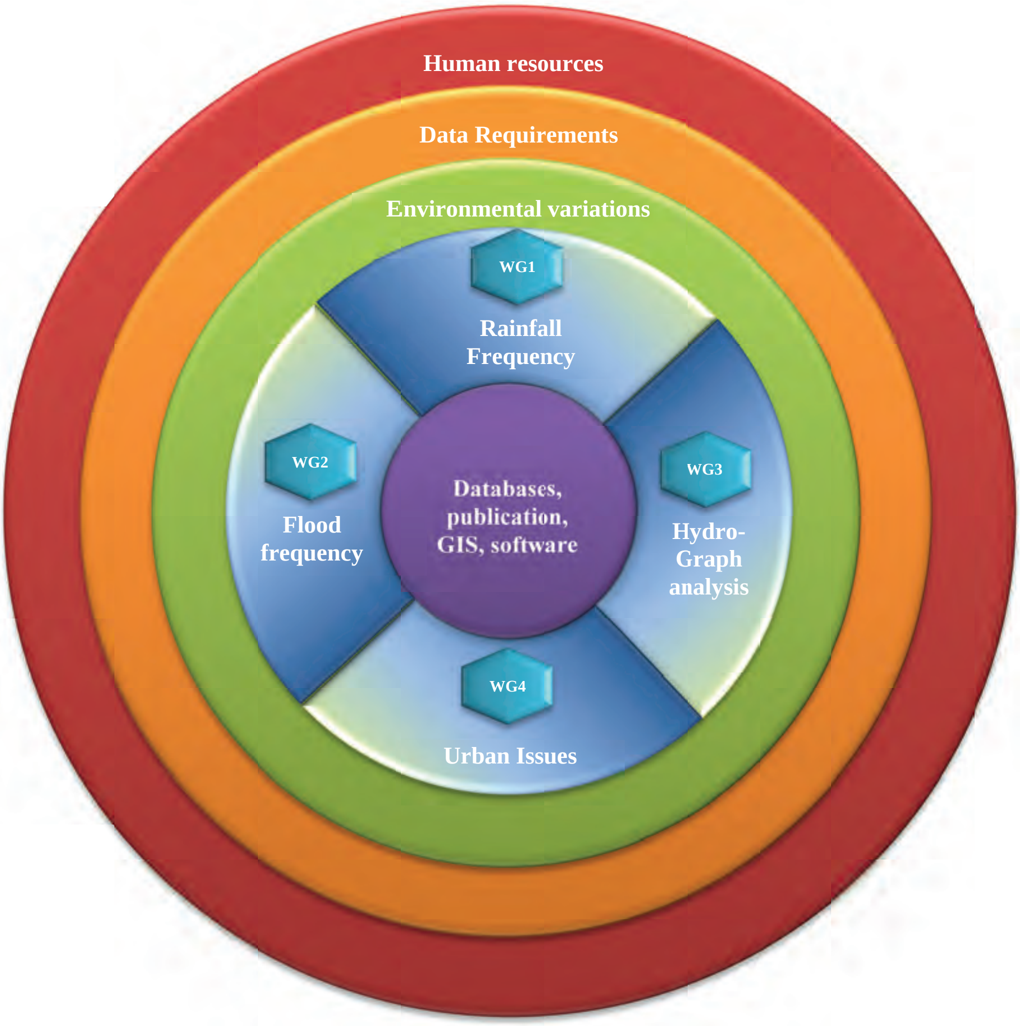

Figure 5-4: Possible working groups applicable to address the research needs in South Africa (Adapted from Reed and Martin, 2005)

In the following paragraphs these different research focus areas are briefly highlighted. The description is based on the information which was obtained from the write-up by the attendees. These "cryptic" and "abbreviated" descriptions were put into a more elaborated format in **Table 5-12**.

5.3 Rainfall analyses

Table 5-5 reflects the research topics and priorities related to rainfall data assessment.

Table 5-5: Research topics related to rainfall assessment

Item	Description *	Priority classification as determined during workshop		
		High	Medium	Low
A.1.1.1	Spatial and Temporal distribution of available rainfall data	*		
A.1.1.2	ARF's (Convert spatial rainfall data to catchment rainfall)	*		
A.1.1.3	Extend the patched rainfall database (Lynch)	*		
A.1.1.4	Assemble existing short duration rainfall data			*

Note: * The description is in a more elaborated format in **Table 5-12**.

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5.4 Flood analyses

Table 5-6 reflects the research topics and priorities related to flood analyses.

Table 5-6: Research topics related to flood assessment

Item	Description *	Priority classification as determined during workshop		
		High	Medium	Low
A.1.2.1	Catchments response time (Tc/T_L)	*		
A.1.2.2	Distribution Fitting Method, Best distribution (high occurrences, yearly) and Series selection	*		
A.1.2.3	-Verify/calibrate weirs and dams for large floods -Volume and Flow -$T>10^6$	*		
A.1.2.4	Redefine delineation of "Homogeneous" Flood Producing Regions	*		
A.1.2.5	Refine continuous simulation method -stochastic rainfall -probability distribution of confidence levels	*		
A.1.2.6	Regionalised, Index Flood method Observed, extend and simulate	*		
A.1.2.7	Extreme floods	n/a		
A.1.2.7.1	RMF→AEP (REFSSA)	*		
A.1.2.7.2	Extreme design flood peak approaches in probabilistic space	*		
A.1.2.7.3	Review of RMF and Q_T/Q_{RMF} ratios	*		
A.1.2.8	< 100 year RI floods	n/a		
A.1.2.8.1	Rational method runoff-coefficient (All)		*	
A.1.2.8.2	Refine probabilistic rational method	*		
A.1.2.8.3	Re-look at SDF: can other catchment parameters be included besides region and area?	*		
A.1.2.8.4	Update SCS-SA method (Urban SWMM model)	*		
A.1.2.8.5	Update SUH (Dimensionless Unit Hydrograph), Storm losses and Regionalisation	*		

Item	Description *	Priority classification as determined during workshop		
		High	Medium	Low
A.1.2.8.6	Empirical methods for small catchments "new" MIPI CAPA Rural & Urban	*		
A.1.2.8.7	ARF's			*

Note: * The description is in a more elaborated format in **Table 5-12**.

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5.5 Hydrograph analyses

Table 5-7 reflects the research topics and priorities related to hydrograph assessment.

Table 5-7: Research topics related to hydrograph analyses

Item	Description	Priority classification as determined during workshop		
		High	Medium	Low
A.1.3.1	Refinement of joint-peak-volume approaches	*		

Note: * The description is in a more elaborated format in **Table 5-12**.

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5.6 Urban influences

Table 5-8 reflects the research topics and priorities related to the assessment of urban influences on flood calculations.

Table 5-8: Research topics related to urban influences on floods

Item	Description	Priority classification as determined during workshop		
		High	Medium	Low
A.1.4.1	Influences: pre & post development, C-value and changes in characteristics		*	

Note: * The description is in a more elaborated format in **Table 5-12**.

5.7 Products used for flood determination

Table 5-9 reflects the research topics and priorities related to the products which are used in flood determination procedures.

Table 5-9: Research topics related to the products used in flood estimation

Item	Description	Priority classification as determined during workshop		
		High	Medium	Low
C.1	SWMM-Urban Urban distribution	These focus areas were defined during the Workshop but no priorities were defined.		
C.2	Framework of methods? SANCOLD Web base			
C.3	Catalogue of extreme hydrographs T=10			
C.4	Update catalogue of record max flood peaks (Posted/Required Data)			
C.5	"Catalogue" of large area extreme storm isohyet maps (Require Data)			

Note: * The description is in a more elaborated format in **Table 5-12**.

5.8 Institutional contribution and commitment to Flood Determination

Table 5-10 reflects the research topics and priorities related to institutional contribution to flood estimation procedures.

Table 5-10: Research topics related to Institutional contribution to flood estimation procedures

Item	Description	Priority classification as determined during workshop		
		High	Medium	Low
D.1	Database for short duration rainfall Other sources identify, verify, increase *** DWA project include topic	These focus areas were defined during the Workshop but no priorities were defined.		
D.2	Database of raw SAWS data →RIMS (DWA)			
D.3	Central repository of data (Co-ordinate)			
D.4	Develop support centres of hydrological excellence/expertise			
D.5	Extend regionalisation through Southern Africa SADC (L for SA H for SADC)			

Note: * The description is in a more elaborated format in **Table 5-12**.

Based on the above information an effort is still required to set up a research schedule. The compilation of a schedule is complicated by the availability of verified hydrological data, uncertainty of a medium and long term research funding model, accessibility of experiences knowledge as well as the lack of established research units.

It was therefor decided to develop a spreadsheet which could be used to obtain information from all the interested parties and workshop participants. The feedback could then be compiled to determine the required research budget, the research schedule and timescale of implementation. The Project Leader was instructed by the Research Coordinator of WRC not to proceed with the distribution of the spreadsheet to obtain information for the next implementation and budget phase. The spreadsheet (software) which might be used by the WRC or SANCOLD to define the budget and implementation schedule to overhaul the flood estimation procedures is briefly discussed in the next paragraph.

5.9 Supporting software development

On the accompanying CD a spreadsheet titled: "*Flood Overhauling Studies*" is included. This spreadsheet was developed with the aim to assist the WRC/SANCOLD in gathering the necessary research information to determine the priority, estimate required research time for the investigation, start time for the research and estimate the required funding as well as possible schedule (when which study should be undertaken).

This is a macro-enabled spreadsheet that contains a hidden sheet that capture all the input data by the user and can be then be exported to enable the WRC/SANCOLD to setup a database of all the different users' input data.

On default, the spreadsheet can be opened in Microsoft Excel 2010. For optimal viewing capabilities the program was developed for a wide screen configuration at a resolution of 1920 by 1080 pixels. Opening the spreadsheet, requires the user to ensure that the macro setting is enabled in order to proceed to the personal detail sheet (

Figure 5-5).

Figure 5-5: Opening sheet and personal details to be completed to be able to proceed

The user can then proceed to the "**flow diagram**" from which different dropdown menus will enable him/her to complete all the selected knowledgeable areas in` which research will be undertaken (**Figure 5-6**). The idea was developed with the mind-set that the user only complete those study field areas where he/she has adequate knowledge in and may leave the other study areas as blank open spaces (**Figure 5-7**).

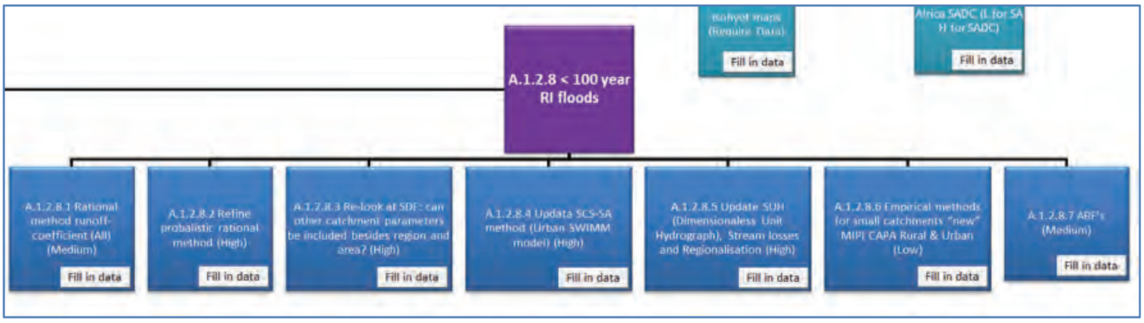

Figure 5-6: A portion of the flow diagram where the researcher can select which research areas he/she prefer to contribute

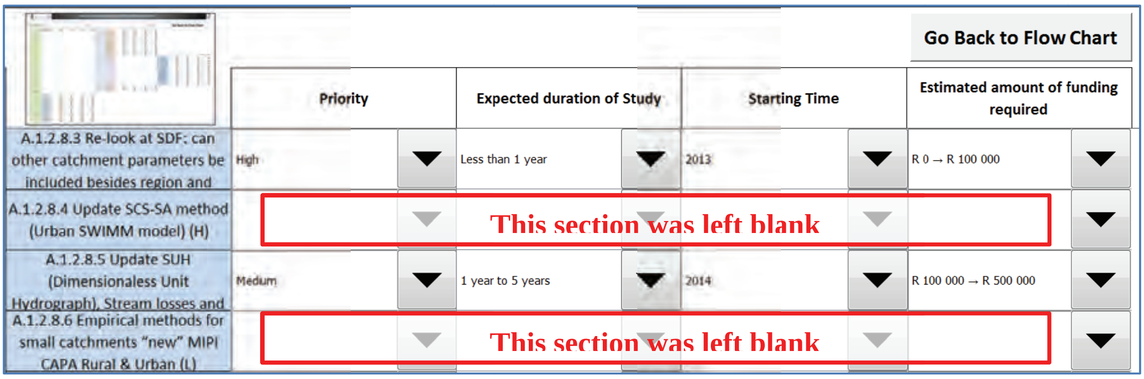

Figure 5-7: Example of screen capture of spreadsheet where potential researcher has populated the research areas where he/she has adequate knowledge and kept the irrelevant sections blank

On completion of the spreadsheet, the spreadsheet must be saved and sent back to a central data gathering institution i.e. the WRC/SANCOLD where all the input can be combined and evaluated to determine the research priority, the required time to undertake the research, cost estimate required to fund the intended research and the ideal proposed time schedule for the different research focus areas to address the upgrade of the Flood Estimation Procedures which should be seen as part of the NFSP.

The spreadsheet consists of a number of tabs which are hided when the program is run in default mode. **Figure 5-8** reflects the screen which will open up when one of the open tabs are selected and it is then "right clicked".

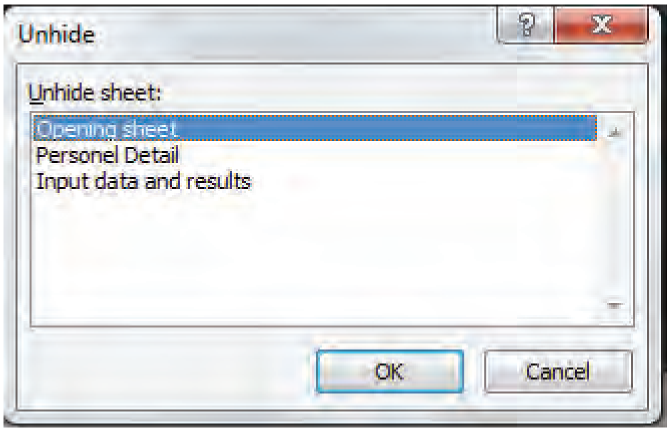

Figure 5-8: Different hided tabs which could be opened

Figure 5-9 reflects the different tabs of the software which have been " unhided" and which are used in the programme to determine the cost, schedule and duration of the potential research projects of the NFSP.

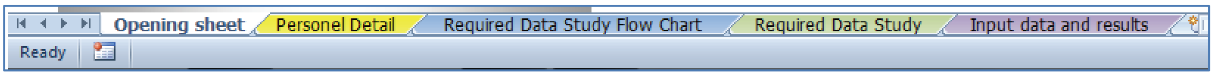

Figure 5-9: Different tabs in the software program

Table 5-11 reflects the details of the different tabs of the spreadsheet programme.

Table 5-11: Details of the different tabs of the spreadsheet programme

Tab name	Status	Description	Purpose
Opening sheet	Active but hidden when "Proceed"	Reflect the terms and conditions of the use of the programme.	Reflect the use of the software
Personnel details		Personal details which is a hidden worksheet.	Capture information form the researcher
Required Data Study Flow Chart	Active on default opening of spreadsheet.	Reflects the flow diagram of the research topics and link this flow diagram with a data input cells.	Reflects the flow diagram similar to that in **Table 5-12.**
Required Data Study		Data input feature requiring details about: priority, cost, schedule and required time to conduct the research.	Provide the opportunity to populate the cells for the selected research focus.
Input data and Results	Hidden	Information which has been incorporated by the research team.	Provide the reviewer of the research (WRC/SANCOLD) with a summarized detail of the intended research. Priority, Cost, scheduling and Start time are reflected.

5.10 The way forward

In the previous section reference was made to the strategy that was followed by Reed and Martin (2005) to address the research focus of flood calculations in Ireland. The final stage of their process, was the identification of work groups. It would have been the ideal if this could be achieved for South Africa, because it will unleash maximum synergy and ensure that the available experienced be mobilised.

This aspect was not addressed during the Workshop and the Project Team grouped the different research priorities, enabling the development of different work/research groups to attend to the research needs of South Africa. **Table 5-12** reflects the possible grouping of the research priorities. An extended description of the topics which were identified during the Workshop and which are shown in the “Flow Chart” (**Figure 5-3**) and grouped into different research focus areas shown in **Table 5-5** to **Table 5-10**, is shown in **Table 5-12**.

It must however be emphasised that the research needs and priorities might change and should be reviewed and adapted with time.

Table 5-12: Description of the research priorities identified at the Workshop

Details obtained during the Workshop (16 May 2012)		More elaborated description of the research topic
Work group	**ID number #**	
Rainfall work group		
Rainfall data	A.1.1.3	Patch and extend short duration rainfall
	A.1.1.4	Compile a register of Institutions/Contacts which owns and update short duration (intensity) rainfall data.
Catchment rainfall	A.1.1.1	Review of available spatial and temporal rainfall data with the objective to develop a strategy for rainfall data capturing.
	A.1.1.2	Relate spatial rainfall data to catchment rainfall
Rainfall modelling	A.1.2.5	Review the application of continues rainfall data recording on runoff modelling. Asses the recorded data parameters to determine probability distributions and confidence levels.
Floods work group		
Catchment parameter	A.1.2.1	Review different methods for the calculation of T_c and T_L on catchment response in South Africa.
	A.1.2.4	Redefine delineation of "Homogeneous" Flood Producing Regions
Flood data	A.1.2.3	Review and extend the stage discharge curves (rating curves) for flow gauging stations and identify extreme storm events to obtain the volume flow rate relationships.
	A.1.2.6	Extend the application of (regional) Index Flood Methods.
	A.1.3.1	Extend the JPV method for different "homogeneous" regions.
Stochastic analysis	A.1.2.2	Review the application of different frequency distributions and provide a guide for the selections of the most applicable distributions.
Flood calculation (T<100 years)	A.1.2.8.1	Review runoff coefficients (catchment response) for different catchment types.
	A.1.2.8.2	Refine the application of the SDF method (Catchment basins, C2 and C100 coefficients).
	A.1.2.8.3	Review the influence of other parameters which could be included in an improved SDF procedure.
	A.1.2.8.4	Update SCS-SA method. Review the application for urban areas and compare and relate to SWMM.
	A.1.2.8.5	Update SUH (Use available applicable data, review regions and storm losses).
	A.1.2.8.6	Extend the empirical procedures for flood calculations and investigate new methods for smaller catchments (rural and urban).
Flood calculation (T>100 years)	A.1.2.7.1	Review the RMF procedure by including all the available data and refine the Kovács regions. Investigate the REFSSA procedure for other Kovács regions.
	A.1.2.7.2	Investigate the probability of extreme flood events and develop a guide for design floods selection.
	A.1.2.7.3	Include the available peak flood data to update the Q_T/Q_{RMF} ratios (Refer to topic A.1.2.7.1).
Product used in industry		
Product update	C.3	All the research outputs should be compiled in such a format that it address the needs of the potential users, provides guidance on the procedures and lead the user in the selection of the most applicable data providing an accessible user friendly medium.
	C.4	
	C.5	
Develop new products	C.1	
	C.2	
Institutional focus		
Hydrological data	D.1	The "Coordination Authority" of the NFSP should coordinate the data acquisition and verification, prioritize research activities and manage research outputs. Funding should be allocated on a program basis.
	D.2	
	D.3	
SADC coordination	D.5	Coordinate the application of Hydrological studies a SADC regional contexts and manage the coordinated approach to the capturing and use of hydrological data.
Human resources	D.4	Harness current experience, invest in human resources to upgrade the methods and provide career opportunities to address future needs.

Note: # The ID relates to the numbers in the flow chart (**Figure 5-3**) and the description of the research focus areas covered in **Table 5-5** to **Table 5-10**.

S J van Vuuren

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APPENDIX A

Available material on flood calculations procedures in South Africa – Electronic copies on the material can be found on the accompanying CD.

The accompanying CD has the following file structure:

- **Report** (A copy of this Report in Adobe format);
- **Presentation**: Overhauling Flood presented during the Workshop on 16 May 2012 (*.pdf format);
- **Previous research documents** (refer to **Table 1-1** for details); and
- **Software**: Spreadsheet to evaluate the required funding and scheduling of the research focus areas, titled "**Flood Overhauling Studies.xlm**".