Statistical Based Regional Flood Frequency Estimation Study for South Africa Using Systematic, Historical and Palaeoflood Data

Pilot Study – Catchment Management Area 15

by

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EXECUTIVE SUMMARY

INTRODUCTION

During the past 10 years South Africa has experienced several devastating flood events that highlighted the need for more accurate and reasonable flood estimation. The most notable events were those of 1995/96 in KwaZulu-Natal and north eastern areas, the November 1996 floods in the Southern Cape Region, the floods of February to March 2000 in the Limpopo, Mpumalanga and Eastern Cape provinces and the recent floods in March 2003 in Montagu in the Western Cape. These events emphasized the need for a standard approach to estimate flood probabilities before developments are initiated or existing developments evaluated for flood hazards. The flood peak magnitudes and probabilities of occurrence or return period required for flood lines are often overlooked, ignored or dealt with in a casual way with devastating effects. The National Disaster and new Water Act and the rapid rate at which developments are being planned will require the near mass production of flood peak probabilities across the country that should be consistent, realistic and reliable.

At present the methodologies for flood frequency analysis in South Africa consists of three basic approaches, all of which have certain validity limits (Kovacs, 1993):

- Deterministic methods (Rational, Synthetic unit hydrograph, Direct runoff hydrograph, SCS, etc.)
- Statistical methods such as the LP3, GEV and Log-normal (annual maximum flood series data)
- Empirical methods (Midgley-Pitman, HRU 1/71, CAPA and RMF)

Experience in the Department of Water Affairs and Forestry (DWAF) has shown that these methods often give vastly different results and unless a certain amount of judgement and experience can be used, the selection of final values may be inconsistent and subjective. This pilot study provides a basis to develop simple and consistent methodologies for the rest of the country to estimate flood peaks and their associated probabilities for use by authorities, consultants and planners.

Since the last extensive review of the methodologies in 1970’s to early 1980’s the following should be noted that justify a review of the methodologies:

- The period of observation has been extended by a further 25 to 30 years i.e. more data,
- The number of sites are significantly more,
- South Africa has had several extreme flood events that added to the extreme flood peak data base,
- The technology regarding the statistical analysis of flood data has improved,
- The gathering of historical data by DWAF (van Bladeren, 1992) has in many areas increased the period of observation to between 100 to 150 years, and

- By including the modelling and dating of palaeofloods, where possible, this period may be extended to more than 200 years, which is the upper limit of the normally requested design flood peaks used in design and planning.

From the above it was clear that the revision and updating of the methods was long overdue and this project could be seen as one way to resuscitate the neglected field of flood research in South Africa. The inclusion of palaeofloods is based on the success of previous projects completed for the WRC by the Council for Geo-Science and DWAF. That project demonstrated the value that the inclusion of palaeoflood data in flood frequency studies (Zawada et al., 1996). This project integrates systematic, historical and palaeoflood data to provide flood growth curves that are scaled using an index flood to provide estimates of flood peaks and their associated probabilities. The development is motivated by the stated desire of the Committee of State Road Authorities in their guidelines for the hydraulic design and maintenance of river crossings (TRH 25, 1994) and Alexander (1990) who identified the lack of regional growth curves for southern Africa as a serious drawback when selecting applicable flood probabilities.

This report of the pilot study is an attempt to develop a robust and reliable method of estimating the full range of usually requested flood peaks used in design, based on index floods and regional growth curves that are obtained from the analysis of observed data. The project integrates systematic, historical and palaeoflood data to derive growth curves for floods and using selected catchment characteristics to develop an index flood estimation methodology. The pilot area selected for the study was Catchment Management Area (CMA) 15 in the Eastern Cape. CMA 15 includes drainage regions K7-9, L, M, N, P and Q. Drainage regions J, K3-6, R and S were also included to provide fringe information.

REVIEW OF FLOOD AND REGIONAL FLOOD HYDROLOGY IN SOUTH AFRICA

Flood hydrology in South Africa (Kovacs, 1993) is generally classified as deterministic, statistical or empirical. Several regional flood studies have been undertaken in South Africa using systematic data.

Most of the previous regional studies in South Africa defined regions based on climate or drainage regions. Data used to develop the methods for the previous studies only used gauged records and are thus based on relatively short periods of observation. The only study that included historical data is the recently developed SDF (Alexander, 2002) and the previous attempt by van Bladeren (1993).

From the review, the Catchment Parameter (CAPA) method developed by McPherson (1983) to estimate the mean annual flood was selected as the basis to estimate the index flood for this study. The CAPA method uses several catchment variables to estimate a lumped parameter and is site specific. Alexander (2002) and van Bladeren (1993) have evaluated several distributions in various studies throughout South Africa and have concluded that the log-Pearson type III distribution is the most appropriate for South Africa. Another contender is the general extreme value distribution.

REGIONAL FLOOD STUDY CMA 15

The regional flood study for CMA 15 consisted of the gathering of annual maximum flood (AMF) peak data, determination and estimation of relevant catchment characteristics, the development of a methodology to estimate the index flood (Q_i), the development of flood peak growth curves and the comparison or verification of the results obtained using the proposed methodology against those obtained, using other methods and actual observed flood data.

The 348 sites identified on the Hydrological Information System (HIS) of DWAF for the study area was reduced to 112 useable sites after assessment of the sites. All the sites originally identified are shown in Appendix A and the sites finally used and their AMF, historical and palaeoflood data are listed in Appendix B. A break-down of the data used is summarised in the table below.

Summary of Flood Peak Data Sets (Appendix B)

Drainage Region	Period of Observation (years)								
	Systematic Data			Including Historical Data			Including Palaeoflood Data		
	Sites	Average	Maximum	Sites	Average	Maximum	Sites	Average	Maximum
J	26	46	90	5	109	152	2	2996	3000
K	15	39	42	-	-	-	-	-	-
L	11	55	83	4	100	154	1	1901	1901
M	3	49	76	1	148	148	-	-	-
N	5	69	97	2	130	135	2	7996	8001
P	3	37	45	2	111	113	-	-	-
Q	20	63	96	6	141	182	-	-	-
R	17	61	79	6	141	154	-	-	-
S	12	40	54	1	127	127	-	-	-
Average	**-**	**51**	**-**	**-**	**125**	**-**	**-**	**4777**	**-**
Total	**112**	**5766**	**-**	**27**	**3394**	**-**	**5**	**23885**	**-**

The average period of observation for the systematic data is 51 years. With inclusion of the historical data the period of observation is 125 years and when the palaeoflood data is included, the period of observation is extended to 4777 years. The applicability of the combined data sets may thus be taken as 10000 years (twice the period of observation).

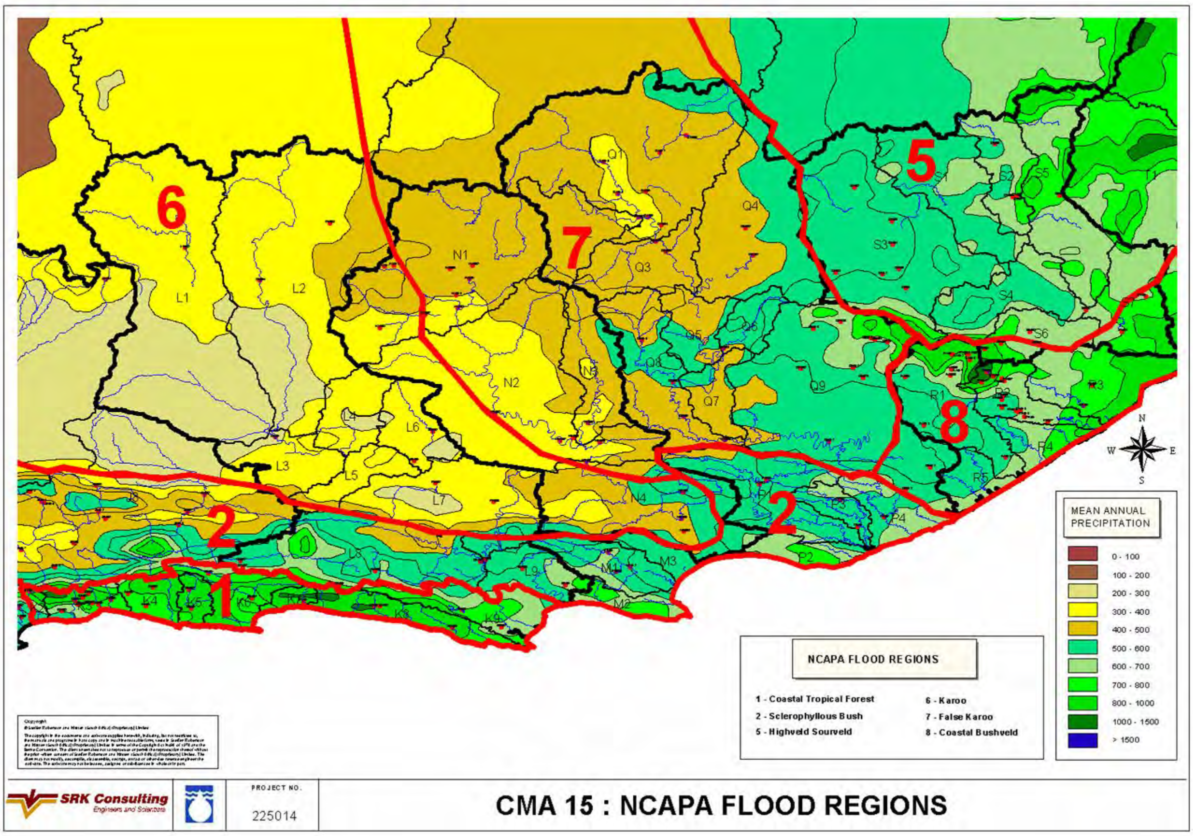
The development of the index flood used catchment characteristics generated by a GIS database using the WR90 data and topographical data derived from the 1:50000 mapping series supplied by DWAF. The index flood development used the same methodology as the CAPA method (McPherson, 1983) but during the analysis it was found that some of the variables used to calculate the lumped parameter M, used in the CAPA method, should be replaced and this resulted in a new lumped parameter M' being proposed.

This new methodology is presently referred to as NCAPA and the parameter M' and is defined as;

$$M' = MAP(100 * s\frac{\sqrt{A}}{L})^{1/2}$$

Where;
A=Catchment Area (km^2)
MAP=Mean Annual Precipitation (mm)
s=Standard River Slope – 1085 (m/m) and
L=Longest Stream Length (km)

The land-use or catchment characteristics defined by soils, geology, vegetation and MAP is taken into account by a regionalisation that is based on previous studies, MAP and vegetation. This regionalisation resulted in regional boundaries that are very similar to those shown for the veld types as shown in the HRU 1/72 report. The HRU 1/72 veld type zones were thus used for the classification of the regions identified in the study and is shown below.



The base used for the derivation of the index flood is the mean annual flood obtained from the analysis of the log transformed data and is referred to as the log derived mean annual flood (Q_{ml}) in the report. The Q_{ml} proved to be the most robust parameter and is least affected by period of observation and outliers than either the mean annual or median annual flood estimates. The methodology to estimate the index flood or the log derived mean annual using the NCAPA methodology is reduced to a set of equations for each of the regions as shown in the table below:

Summary of Index Flood (Q_i) Estimation Factors – CMA 15

Region	Constants			Relative Q_i estimate performance (R^2)	
	b	C	d	NCAPA	CAPA
Region 1	0.777	0.00013	1.355	0.62	0.46
Region 2	0.733	0.1316	0.132	0.85	0.69
Region 5	0.656	0.3616	0.125	0.99	0.93
Region 6	1.176	0.000000231	1.899	0.92	0.90
Region 7	0.856	0.0012	0.828	0.65	0.65
Region 8	0.831	0.3684	0.092	0.84	0.49
Study area				0.87	0.74

The form of the equation for the estimation of Q_{ml} is:

$$Q_{ml}=a*A^b$$

Where;

M’ = Lumped NCAPA catchment parameter

Q_{ml} = Estimated log derived mean annual flood

A = Catchment area (km^2)

a = Derived from constants in above table = $c(M')^d$

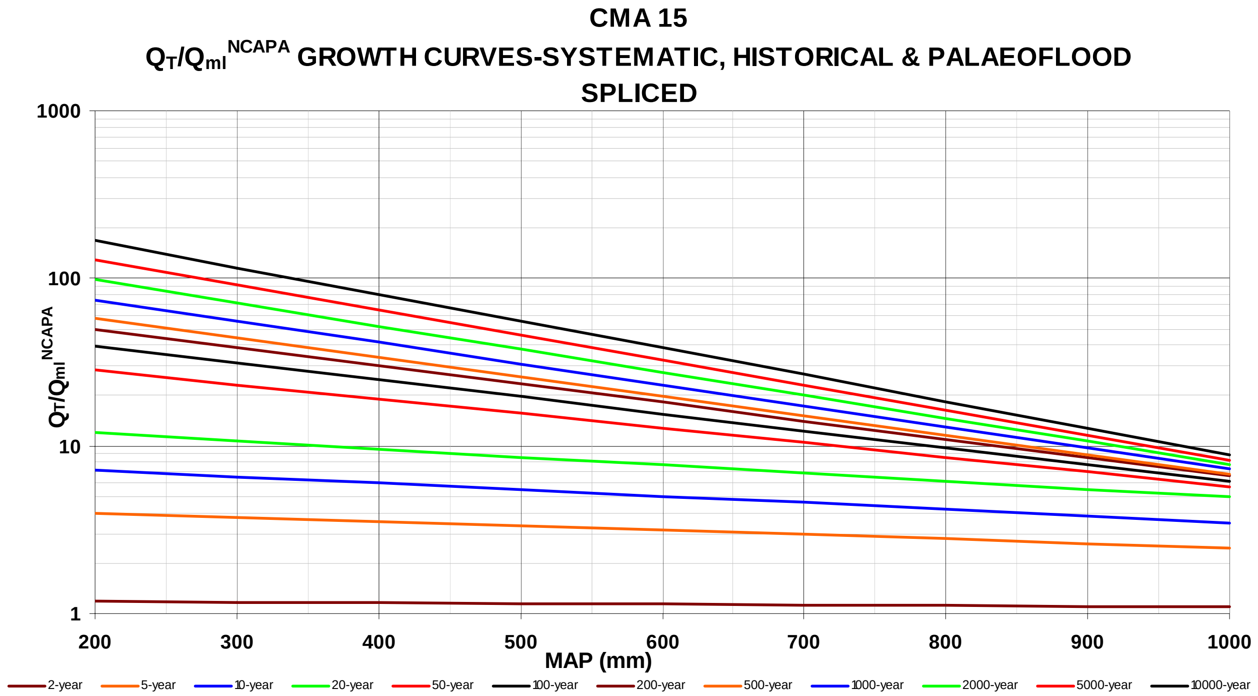
b = Constant from above table

c = Regional constant

d = Regional constant

The table above also shows the relative Q_i estimation performance of the CAPA and NCAPA methodologies for the regions. The coefficient of determination (R^2) for the NCAPA method is generally better and for the whole study area the R^2 improves from 0.74 to 0.87 and would suggest the NCAPA methodology provides better estimates for the index flood.

The development of the flood growth curves (GC) was undertaken by separate analysis of the systematic data, the systematic/historical data and the systematic/palaeoflood data. The analysis including the historical and palaeoflood data was done using the methodologies recommended by Alexander (1990) and the distribution used was the log Pearson type III. A relationship developed by DWAF between GC factors for various flood event probabilities and the mean annual rainfall (MAP) for a catchment was confirmed in this study and was used to develop GC factors for each of data sets analysed. A splicing diagram based on the three data set ranges of applicability is proposed and is used to develop a set of spliced GC's that include all three of the data sets. The suggested growth curves are shown in the figure and table below. The GC at present are only related to MAP and not to the regions identified. The regionalisation identified is included in the CG's by virtue of the fact that the index flood estimates are regionalised.



Growth Curves Based on Spliced Systematic/Historic/ Palaeoflood Data-CMA 15

MAP (mm)	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
	2	5	10	20	50	100	200	500	1000	2000	5000	10000
200	1.18	3.99	7.18	11.96	28.40	39.39	49.63	58.33	73.91	97.80	128.03	167.66
300	1.17	3.76	6.57	10.71	23.25	31.23	38.61	44.55	55.30	71.30	90.72	116.04
400	1.16	3.54	6.00	9.60	19.04	24.76	30.03	34.03	41.38	51.98	64.28	80.31
500	1.15	3.33	5.48	8.60	15.59	19.63	23.36	25.99	30.96	37.90	45.55	55.59
600	1.14	3.14	5.01	7.70	12.77	15.56	18.17	19.85	23.17	27.63	32.27	38.47
700	1.13	2.96	4.58	6.90	10.46	12.34	14.14	15.16	17.34	20.14	22.87	26.63
800	1.12	2.78	4.19	6.18	8.56	9.78	11.00	11.58	12.97	14.69	16.20	18.43
900	1.11	2.62	3.83	5.54	7.01	7.76	8.55	8.84	9.71	10.71	11.48	12.76
1000	1.10	2.47	3.50	4.96	5.74	6.15	6.65	6.75	7.26	7.81	8.14	8.83

The results obtained using the proposed NCAPA derived Q_{ml} and the GC's and the results of several other methods, including the SDF (Alexander, 2002), were compared to the complete observed data sets at several sites used in the study. The results are summarised in the table below. The recommended estimates are based on the actual recommended flood peak estimates based on the results from various methods used in the original flood peak estimation task. Low refers to events less than the 50-year flood and high refers to events larger than the 50-year flood event.

Summary of flood estimation method performance against observed flood data

Site	**Recommended**		**SDF**		**GC-NCAPA**	
	Low	**High**	**Low**	**High**	**Low**	**High**
L3R001-Groot	=	=	+	+	+	+
Q5R001-Great Fish	=	-	=	-	=	=
N2R001-Sundays	-	-	=	-	=	+
R2R001-Buffalo	=	=	-	-	=	=
K7H001-Bloukrans			-	-	-	-
L9R001-Kouga			-	=	-	-
S7H004-Great Kei			-	=	=	=
J4H002-Gourits			-	=	=	+
L9H003-Gamtoos			=	-	=	=
Good Fit	**75**	**50**	**33**	**33**	**67**	**44**
Under estimate	**25**	**50**	**56**	**56**	**22**	**22**
Over estimate			**11**	**11**	**11**	**33**

From the above it is clear that the proposed methodology performed relatively well with the other methods. The over estimation for the more rare events (> 50-year) would suggest that the GC's still over estimate the flood peak estimates for the less frequent events. This maybe due to the impact that catchment area may have on these values where the large catchment would tend to have lower GC values than the smaller to medium sized catchments. It would also suggest that more historical and palaeoflood data must be collected. A relationship between the GC factors and catchment area could, however, not be determined in this study.

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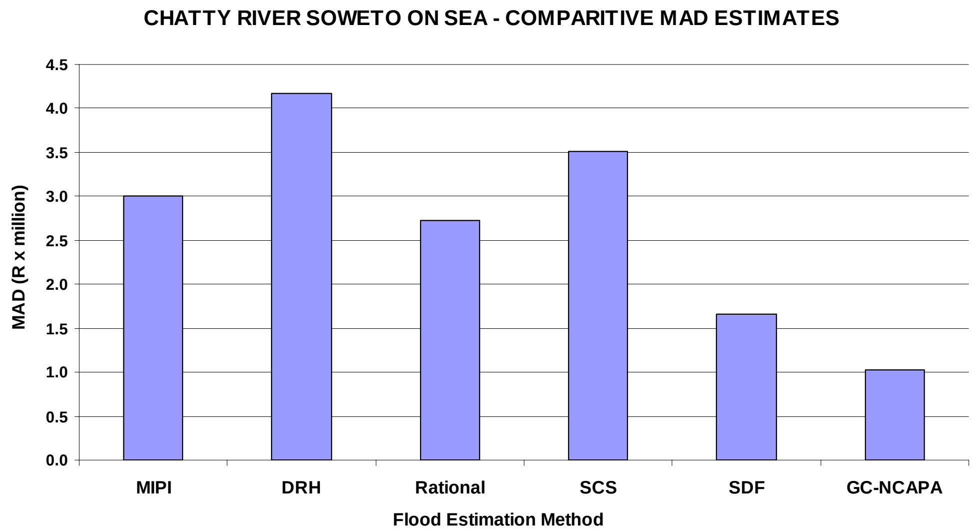
IMPACT OF METHOD ON DESIGN, FLOOD RISK AND FLOOD DAMAGE ESTIMATION

The impact that the estimation of design floods has on decision-making and design is obvious in that over estimation will result in over-expenditure while under estimation could result in more frequent flooding and damages than anticipated. Getting the estimation of flood discharges correct for the accepted or adopted level of risk will also enhance the value of this information in the eyes of the public and users. By using all the data available, results of flood estimates can be verified to a much greater degree than before. The inclusion of the historical and palaeoflood data provides greater confidence in the estimates for flood events greater than the 100-year event. The potential impact that flood estimation has on decision making is demonstrated by the results obtained for the mean annual flood damage (MAD) estimation for the Chatty River at Soweto-on-Sea. The variation in the estimate of the MAD that is used in hydro-economic analyses for river works is demonstrated in the figure below where the MAD estimate varies from R1,000,000 to R4,000,000.



CONCLUSIONS AND RECOMMENDATIONS

The most pertinent conclusions from the pilot study are that the:

- Use of index floods and growth curves as a method to estimate flood probabilities is viable in South Africa.
- Inclusion of historical and palaeoflood data along with the systematic records in a regional flood study significantly extend the range of probabilities for flood peak estimations and should provide more stable estimates that will not be subject to frequent amendments as the period of systematic observation increases.
- Use of the index flood methodology (though the derivation of the index flood is still crude and will require more refinement) and growth curves is based on observed data and is thus realistic and justifiable.
- Proposed methodology provides flood estimates that are more consistent with the observed records than the other methods that the methodology was compared with.
- Estimation of the rarer flood events (>100-years) for especially the larger catchments could be improved by the inclusion of more historical flood and palaeoflood data and by assessing the influence catchment area has on the growth curves.

Particular recommendations are:

- That all reservoir flow records be updated through routing to add to the database of flood peaks.

- The extension of the palaeoflood database to other regions in South Africa.
- The review and refinement of the index flood estimation method when the work is extended to the rest of South Africa.
- That the project be extended to the rest of the country.
- That the extension of the study be undertaken in conjunction with the present study WR2005, to ensure that data common, such as land use and MAP, to both studies are not duplicated.

FUTURE STUDIES

Specific studies and tasks that should be undertaken to establish a national methodology are:

- The establishing of a reliable and accurate digital topographical base to estimate the topographical catchment characteristics relevant to floods.
- The establishment of an accurate and reliable digital land-cover and use base that includes geology, soils, vegetation and endoreic areas (this could just consist of a verification of the WR2005 output).
- The establishment of an accurate and reliable digital rainfall information base that should provide the information usually considered in flood methods such as MAP, P_T, rain days, lightning strikes, rain months, etc. This information should be verified and updated frequently.
- The collection of systematic and historical data for the whole country. If possible the neighbouring states should be included.
- That a standalone study specifically be initiated to collect and date palaeoflood information. This will serve as a data source for a countrywide extension the project and also provide information regarding the impact, if any, that climate change has on the flood regimes in South Africa.
- That the index flood methodology using the log derived mean annual flood be refined.
- That the impact of catchment area on the development of the growth curves be assessed.

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List of Abbreviations

AMF : Annual Maximum Flood
CAPA : Catchment Parameter
CMA : Catchment Management Area
DT : Discharge Table
GC : Growth Curve
GEV : General Extreme Value
HRU : Hydrological Research Unit
LN : Log Normal
LP3 : Log Pearson Type 3
NCAPA : New Catchment Parameter
PD : Partial Duration
POT : Peaks Over Threshold
RMF : Regional Maximum Flood
SCS : Soil Conservation Services (USA)
SDF : Standard Design Flood

Notations

A = Catchment area (km^2)
f = Constant for GC
h = Constant for GC
i = Catchment slope (%)
j = j data point from 1 to N
L = Longest stream length (km)
M = Lumped CAPA method based catchment parameter
M' = Lumped NCAPA method based catchment parameter
MAP = Mean annual precipitation (mm)
N = Number of data points (j=1…N)
P = Catchment perimeter (km)
Q_i = Index flood (m^3/s)
Q_{ml} = Anti-log of the log derived mean annual flood peak (m^3/s)
Q_m = Mean annual flood peak (m^3/s)
Q_{med} = Median flood peak (m^3/s)
Q_T = Flood peak for T-year flood event (m^3/s)
S = Standard river slope or 1085 slope (m/m)
T = Return period (year)

CHAPTER 1
INTRODUCTION

1 INTRODUCTION

During the past 10 years South Africa has experienced several devastating flood events that have highlighted the need for more accurate, consistent and reasonable techniques for flood estimation. The most notable events where those of 1995/96 (Kwa-Zulu Natal and north eastern areas), the 1996/97 season that started with the November 1996 floods in the Southern Cape Region, the floods of February to March 2000 in the Limpopo and Mpumalanga provinces and more recently the March 2003 floods at Montagu in the Western Cape. These events emphasized the need for a standard approach to estimate flood probabilities before developments are initiated or existing developments evaluated for flood hazards. When planning any developments (housing, infrastructure etc.) along watercourses and rivers, one of the first aspects that should be investigated are the probable flood levels and their associated flood peak magnitudes and probabilities of occurrence (return period). This aspect is often overlooked, ignored or dealt with in a casual way with devastating effects. Examples from the 1995/96 flood season are Pietermaritzburg when 147 people lost their lives, Pretoria and Centurion where damages to the local authority in Centurion was R10 million (local newspapers). Damages to riverine properties in many instances were caused by floods much smaller than the 50-year flood. The damages in Mpumalanga in 1996, based on the province's aid request, amounted to R420 million. The damages in the 2000 floods in Limpopo and Mpumalanga were estimated to be more than R1.5 billion. The introduction of the National Disaster and New Water Act and the rapid rate at which developments are being planned will require reliable and consistent estimates of flood peak probabilities to be made frequently throughout South Africa.

At present the methodologies for flood frequency analysis in South Africa consists of three basic approaches, all of which have certain validity limits (Kovacs, 1993):

- Deterministic methods (Rational, Synthetic unit hydrograph, Direct runoff hydrograph, SCS, etc.).
- Statistical methods such the LP3, GEV and Log-normal (annual maximum flood series data).
- Empirical methods including flood envelope based methods (Midgley-Pitman, HRU 1/71, CAPA and RMF).

Experience in the Department of Water Affairs and Forestry (DWAF) has shown that these methods often give vastly different results and unless a certain amount of judgement and experience can be used, the selection of final values may be inconsistent and subjective (Kovacs, 1993 and van der Spuy and Rademeyer, 1997). Under- and over-estimation of flood peaks are both costly and may divert funds away from new developments and social programmes. Acceptance of low estimations of flood peaks obtained from one method, may subject the future tenants to more frequent flooding than is generally accepted. The opposite is also true that overly conservative estimations, while being safe, may lead to unjustifiably expensive solutions. The objective of this study is to investigate the viability of developing a method that provides authorities, consultants and planners with a simple and consistent method of determining flood peaks and their associated probabilities.

The one aspect that is also applicable to all the methods with the exception of the RMF (Kovacs, 1988) is the long period that has elapsed since their development in the early 1970's to early 1980's. The databases were also limited in terms of the number of stations (approximately 100 to 140 stations country wide) and period of observation (on average 25 to 30 years). In the period since the development of the methods and present;

- South Africa has had several extreme flood events,
- the systematic period of observation has increased by a further 15 to 25 years,
- the technology regarding the statistical analysis of flood data has improved,
- the gathering of historical data by DWAF (van Bladeren, 1992) has in many areas increased the period of observation to between 100 to 150 years and
- by including the modelling and dating of palaeofloods (evidence obtained from geological indicators), where possible, the period of observation may be extended to more than 200 years, which is the upper limit of the normally requested design flood peaks used in design and planning.

From the above it was clear that the revision and updating of the methods are long overdue and this project could be seen as one way to rectify the position and test the currently held status quo.

The inclusion of palaeofloods is based on the success of the recently completed WRC, Council for Geo-Science and DWAF study on palaeofloods and their application in flood frequency studies (Zawada, 1996). Although the analysis of systematic, historical and palaeoflood data for the purposes of flood frequency estimation is well documented the integration of systematic, historical and palaeoflood data in a country wide regional analysis may well be first in the world.

The Committee of State Road Authorities in their guidelines for the hydraulic design and maintenance of river crossings (TRH 25, 1994) and Alexander (1990) identified the lack of regional growth curves for southern Africa as a serious drawback when selecting applicable flood probabilities. Alexander (2002) in the study to develop the standard design flood (SDF) however suggests that no reliable growth curves can be developed for South Africa from the available observed annual flood peaks. Gorgens (1997) suggested the potential in South Africa to develop growth curves and later reported (Gorgens, 2002) that tentative growth curves had been developed for southern Africa that included Namibia and Botswana.

This report on a pilot study scale is an attempt to develop a robust and reliable method of estimating the full range of usually requested flood peaks used in design, based on index floods and regional growth curves derived from the analysis of observed data. The approach used in this report is the integration of systematic, historical and palaeoflood data in the analysis of data to derive growth curves for floods and using selected catchment characteristics to develop a methodology estimate index floods.

The pilot study area selected for the investigation is Catchment Management Area 15 (CMA 15) that includes drainage regions K7-9, L, M, N, P and Q. Regions J, K3-5, R and S were included to allow the regionalisation boundaries to be completed for the pilot area. CMA 15 was selected as the study area is shown as blue shaded area in Figure 1.1. The selections of the area were based on the fact that the area is well suited for palaeoflood hydrology, has a relatively long recorded historical record and has a relatively dense hydrological network. The motivation for the selection is expanded upon in Section 2.4.

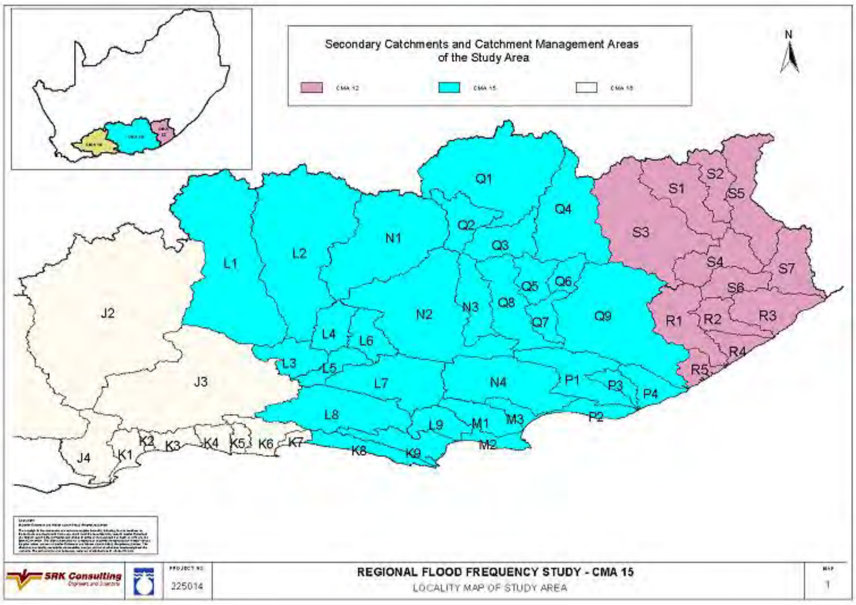

Figure 1.1: Study area-Catchment Management Area no. 15 (CMA 15)

CHAPTER 2

REVIEW OF FLOOD AND REGIONAL FLOOD HYDROLOGY IN SOUTH AFRICA

2 REVIEW OF FLOOD AND REGIONAL FLOOD HYDROLOGY IN SOUTH AFRICA

A brief review of flood estimation methodology and techniques applied in South Africa and previous regional flood studies in South Africa is provided in the following sections.

2.1 Flood Estimation in South Africa

Flood estimation methods in South Africa are generally classified as (Alexander, 1990 & Kovacs, 1993):

- Deterministic or rainfall-runoff methods.
- Statistical methods, either site specific or regional
- Empirical and pseudo-statistical or empirical-probabilistic (Gorgens, 1997) methods

Smithers and Schulze (2001) use a broad classification of design flood methods that are either an analysis of observed stream flow data or utilise design rainfall to estimate design floods. The methods that analyse stream flow data are the statistical- and empirical methods and flood envelopes. Rainfall based methods include Gradex-, Rational-, SCS- and unit hydrograph and runoff routing procedures. For the purposes of this project the classification flood estimation methods used by Kovacs (1993) is adopted.

2.1.1 Deterministic methods

Deterministic methods transform rainfall data into runoff, usually on an event basis, using a variety of models by taking into account catchment characteristics. These typically include area, length and slope of the main watercourse, catchment slope, land-use, soils etc. The most well known and earliest is the rational method. Other methods commonly used are the SCS, unit hydrograph, synthetic unit graph and the Gradex method. The latter method is however not really applied in South Africa (Kovacs, 1993).

Deterministic flood hydrology was initiated in South Africa by the Hydrological Research Unit (HRU) following the devastating floods of May 1959 and March/April 1961. The HRU published reports numbers HRU 1/72 and HRU 1/74 and updates of the reports in 1978 that provided users with the methodology to apply the rational method, the synthetic unit hydrograph and the direct runoff hydrograph. All these methods do have certain limitations that were placed on them by the developers of the methods. The SCS method was adapted for South Africa by Schulze and Schmidt in 1987 (Gorgens, 2002) as the SCS-SA method for application on small (<10 km^2) catchments.

The single most important critique against these methods is the basic assumptions that the run-off and rainfall input have the same probability of exceedance. Other disadvantages are that some of the methods are very data intensive and, to overcome this obstacle, generalised regional coefficients based on simplifications are provided (Kovacs, 1993). These models can cater for various design rainfall events and seasonal variability in soil moisture and vegetation cover, but as a rule the generalised regional coefficients or average conditions are used in practise.

Despite the disadvantages mentioned, deterministic methods can be applied at sites with no flow data, for a range of storm durations, changing catchment conditions and provide an indication of the expected hydrograph shape for a storm event. More information regarding these methods can be obtained from Alexander (1990).

Continuous simulation models advocated by Smithers and Schulze (2001) in its basic form would also fall in this group of methods. The method uses historical or stochastic rainfall data series, provided the model has been calibrated by past time series which can be a relatively short period, to generate a flow series, based on the longer rainfall data series. This data series can then be subjected to standard statistical methods of analysis. A major advantage of using the rainfall series is that the catchment condition before each storm can be determined directly and in South Africa the rainfall data series is generally longer and more complete than the flow data series. A disadvantage is that the method would require a significant amount of variables to calibrate.

2.1.2 Statistical methods

Statistical methods are based on the fitting of theoretical probability distributions to data for a site. It is important to realise that the distributions selected do not relate to any characteristics of the flood producing rainfall or the catchment.

The data abstracted for frequency analyses are either annual maximum flood peaks (AMF) or partial duration series (PD) data. The latter classifications are also referred to as peaks over threshold (POT). AMF data is obtained by abstracting the maximum flood peak for every hydrological year. Thus provided that there are no gaps in the record the number of data points is the same as the number of years of record. The POT data is extracted by selecting all flood peaks above a certain threshold and may include more than one peak in a specific hydrological year. The selection of peaks must however ensure that the peaks selected are not related and the number of data points may be more than the number of years of observation. As a data set, the AMF data is the most popular due to the ease with which this data is gathered and unlike POT data the independence requirement of the data points is satisfied in most instances. The choice of data series is also influenced by the record length. POT data is more applicable for short periods of observation when the influence of extreme values in a data series could significantly alter the estimated parameters of the data set. Robson and Reed (1999) recommend that the POT series data be used for data sets shorter than 13 years to estimate the median value and AMF data for periods longer than 14 years. Record lengths in this study are generally more than 15 years and as such AMF data is abstracted for all the sites used.

The choice of the probability distribution for a given set of data has over the years received a great deal of attention. Distributions generally used for flood estimation are log-normal (LN), Pearson Type 3 (P3), log-Pearson Type 3 (LP3), extreme value distributions such as the extreme value Type 1 and II (EVI & EVII) and the general extreme value distribution (GEV). Other distributions such as the Wakeby and Pareto have had brief incursions. In South Africa the LP3 and GEV, have been found to the most frequently used, and also the most applicable (van Bladeren, 1993 & Alexander, 2002b). The EV1 distribution was used in earlier work of the HRU.

The parameter estimation techniques for these distributions have also received a great deal attention. The various approaches to parameter estimation are the method of moments (MOM), maximum likelihood (ML), probability weighted moments (PWM) and L-moments (LM). The use of LM's for flood frequency estimation is currently receiving attention from several investigators (Kjeldsen et al., 2001 and Smithers, 2003). The most frequently used parameter estimation methods used at present in South Africa are the MOM and PWM although LM is gaining in popularity. The method of parameter estimation is furthermore also linked to the distribution used.

In terms of the visual presentation of the results and data, several different plotting positions have been developed and are fully described by Alexander (1990). At present the position plotting as given Cunnane is preferred as a general plotting position for the presentation of data and results on a log-probability plot and the plotting position proposed by Greenwood used for extreme value distributions or linear-probability plots.

These methods are applied for either site specific or regional analysis of floods.

When performing a frequency analysis by fitting probability distributions to the AMF data the following should however be noted (Kovacs, 1993):

- The data sets should be for periods greater than 10 years
- There is no restriction on the catchment area
- The maximum return period (in years) for which estimates of a flood can be made vary between N years to 5N years and is dependant on the quality of the data.

- Should a data set be long (greater than 40-years), reliable and representative, the results obtained from statistical methods would provide the best estimate of the flood probabilities for return periods of approximately 2N.

Statistical data should be checked for homogeneity (upstream land-use or utilisation changes) for the site from which the data is obtained (are the discharge tables acceptable and of sufficient accuracy). The reliability of the observations should also evaluated in terms of data quality, i.e. was the station closed, limit of the discharge table exceeded, was the station damaged, are the maximum flood levels recorded, etc. Other assumptions made and criteria regarding the data are that;

- The data points are independent
- The data set is stationary, i.e. no significant changes in the climate and hydrological behaviour
- That the data set is homogenous in terms of meteorological causes of the flood record
- That the data is free of any systematic measurement errors and is consistent
- The data points are random
- The record length is sufficient. For this study AMF data record length should be more than 15 years

If possible the period of observation should be increased by the inclusion of historical flood peaks (Alexander, 1990) and data from adjacent sites. Historical peaks, and per definition this includes palaeoflood peaks, are flood observation made outside the formal gauging period prior to the opening of a gauging station. In some instances it may include data collected after the closure of a gauging station. The inclusion and analysis of historical and palaeoflood data for use in flood probability estimation has received significant attention over a number of years (Stedinger & Cohen, 1986; Hirsch & Stedinger, 1987; Cohn & Stedinger, 1987; Hosking & Wallis, 1987; Sutcliffe, 1987; Stedinger et al., 1988; Danjiang & Tic, 1989; Stedinger & Jin, 1989; Alexander, 1990; Guo, 1990; Gou & Cunnane, 1991a; Gou, 1991b; Wang, 1991; van Bladeren, 1992a, 1992b, 1993; Stedinger & Martins, 2001;) but is mostly limited to at site analysis.

2.1.3 Empirical method and pseudo-statistical methods

These methods typically use observed or analysed flood information and relate these to certain catchment and rainfall characteristics and rainfall to provide estimates of the requested flood event discharges. The methods are furthermore usually applied using regions termed hydrologically homogeneous regions. Methods that are in this category are the Midgley-Pitman Method (MIPI), HRU 1/71, catchment parameter (CAPA) method and the regional maximum flood (RMF) method. The methods listed have methodologies that are applied in regional studies and as such they will be expanded upon in Section 2.2.

2.2 Regional Flood Estimation

Regional flood studies for the purposes of estimating flood probabilities in South Africa and the methods, assumptions and application are briefly reviewed. The basic assumptions in regional flood studies is to provide flood probability estimates at un-gauged sites using results obtained from gauged sites in hydrologically similar regions or by pooling data from sites with similar statistical characteristics. The methodologies developed would then typically use an index flood (Q_i) as a scaling factor that is applied to growth factors (K_T) for the required flood probabilities. Q_i is estimated at ungauged sites using various relevant catchment characteristics that are related to Q_i through correlation and K_T is derived from the statistical analysis of flood data from sites grouped either by homogenous regions, identified by based on physiographic and climatologically similar areas (Ponce, 1989), or by pooling techniques (Robson and Reed, 1999). The required flood magnitude for a specific probability is then estimated using the following;

$$Q_T = Q_i * K_T$$

Where Q_T is the required flood peak for return period T, Qi the index flood and K_T is the growth factor for return period T.

The development of a regional flood estimation method requires, according to McPherson (1983), that the following issues be resolved:

- the development of a technique to estimate Qi at ungauged sites,
- the development of growth curves (factors) from the analysis of flood data which after site specific scaling, comprise homogenous data series, and
- if possible, setting some maximum limit on the estimated floods.

The Flood Studies reports for the United Kingdom produced by the National Environmental Research Council (NERC) in 1975, is probably the most well known international study. This study used the mean annual flood as the index flood and estimated the index flood using a multi-variate regression of seven catchment and rainfall variables. The GEV distribution and PWM was used to develop the growth curves. The Institute of Hydrology expanded on the original study and used the generalised logistic distribution (GL) and L-moments for the regionalisation of the growth curves (Robson and Reed, 1999). Alexander (2002a) showed that the LG distribution was not suitable for South Africa and states that the LP3 distribution is the most suitable for South Africa.

Previous studies in South Africa that may be considered regional and, where applicable, their name used to refer to the method by DWAF (in brackets) are:

- Midgley-Pitman method referred as MIPI (HRU, 1972). The method is a statistical-empirical method that requires the geographical position, catchment area and required return period to estimate the flood peak (Kovacs, 1993). The country was divided into seven “homogeneous” flood regions with similar mean flood characteristics. For each of these regions typical EV1 (Gumbel) distributions were fitted and the results were plotted on a coaxial diagram. The results are flood peaks from the 2-year event to the 200-year event and the catchments for which the MIPI is applicable are 20 km^2 to 20 000 km^2. DWAF has found the method consistent and easy to apply. One criticism of the method is that, similar to other methods, the method uses a single skewness value for the whole country (van der Spuy, 1997).
- HRU 1/71 method referred to as HRU 1/71 (Pitman and Midgley, 1971). The method was derived from the synthetic unit hydrograph (SUH) method (Kovacs, 1993) after a review of the first report HRU in 1969. For this method the four parameters selected were catchment area (A), mean annual rainfall (MAP), a catchment shape parameter (B) and a combined coefficient (K_T). The parameter B combined A, slope (S), river length (L) and the distance to the catchment centriod (L_c). Coefficient K_T was depended on the meteorological region, the veld type zone and return period. The results are flood peaks from the 2-year event to the 200-year event and the catchment range is 20 km^2 to 100000 km^2. The method based on DWAF experience tended to provide slightly low estimates and the derivation of a similar approach to estimate the PMF resulted in unrealistically high estimates.
- Regional maximum flood (RMF) method (Kovacs, 1988). The development of the method is fully described in the original text and is based on the original work of Francou and Rodier (1967) through the application of their equation. Kovacs adapted the methodology for use in South Africa by dividing the country into eight regions based on maximum observed flood events, climate through the 3-day rainfall, catchment characteristics and the estimated “K” values for the flood events.
- McPherson (1983) developed the catchment parameter (CAPA) index method to estimate the mean annual flood at a site using certain catchment characteristics. As stated above this method was developed to address one of the questions that would need to be answered before an index flood and growth curve methodology could be developed. The mean annual flood peaks and catchment areas for the sites included in the study were plotted on a single log-log graph and sites that had a similar lumped parameter “M” were connected to provide a nomogram showing several families of “M” lines that maybe used to estimate the mean annual flood peak. The variables included in the method to estimate “M” are catchment area (A), catchment slope (i), river length (L) and mean annual rainfall (MAP). The method proved to be so reliable that DWAF developed growth curves for their own use to estimate flood peaks from the 5-year event to the 50-year event based on the site MAP. The method is also used for the whole country since it is not restricted by any regionalisation. McPherson (1983) does however suggest that regionalisation would be one way to improve the results of the method. This method and its

general approach forms bases for this project's efforts to estimate the Qi value and as such is described in greater detail in Section 3.3 of this report.

- World Flood Study by Meigh and Farquharson (1985) from the Institute of Hydrology. This study covered 70 countries and 1121 gauging stations with 31 000 station-years. The study was only concerned with the estimation of growth curves based on dividing the mean annual flood by the station mean annual flood (MAF) and only limited the regionalisation to the broader climatic classification of arid, semi-arid etc. based on MAP. This regionalisation was also broken down further by geographical regionalisation. The study indicated that although regions may have similar climatic (MAP) and physiographic characteristics, the shape of the growth curves are very different. This would suggest that more information regarding soils, geology, regional climate and topography also need to be considered. Furthermore the range of catchment areas also had an impact on the growth curves. The study intended to relate the MAF to certain catchment characteristics in future starting with the catchment area and MAP. As more catchment characteristics become available these would be included. For South Africa the study provided the following growth curve values:

  Q_{50}/Q_{MAF} = 4.56 (MAP<1250 mm) and 2.64 (MAP>1250 mm)

  Q_{100}/Q_{MAF} = 6.25 (MAP<1250 mm) and 3.13 (MAP>1250 mm)

  Q_{500}/Q_{MAF} = 12.58 (MAP<1250 mm) and 4.53 (MAP>1250 mm).

  The equivalent CAPA growth curve values for Q50/QMAF is 3.94 to 3.64 (MAP >1250 mm) and 3.94 to 8.5 (MAP<1250 mm).

- van Bladeren (1993) based a tentative regionalisation on the Francou-Rodier "K" regions identified by Kovacs (1988). Although a strong relationship was found between the mean annual flood and the catchment area, further regionalisation was recommended. A set of growth curves that could be applied to the estimated mean annual flood was also provided. The distributions used in the study were the GEV/PWM and the LP3/MM both having the same level of applicability.
- Smithers and Schulze (2001), citing Mkhandi et al. (2000), using L-moments identified thirteen homogeneous flood regions in South Africa. The Pearson Type 3 distribution was found to be the most appropriate in twelve of the regions while the LP3/MM was found to be the most suitable for the western coastal region.
- Kjeldsen et al. (2001) investigated a regionalisation of the annual maximum flood peaks in KwaZulu-Natal using the index flood method proposed by Hosking and Wallis (1997). The study identified two homogeneous regions and a regional frequency distribution was developed to provide a growth curve. The estimated index flood in this method is a function of the MAP and the catchment area.
- Alexander (2002) proposed the standard design flood (SDF) as a benchmark method for South Africa. The development of the method required the identification homogeneous flood regions of which 29 were eventually delineated based on watersheds or drainage basins as defined by

DWAF. The method itself numerically calibrated the rational method using the LP3 distribution and requires catchment area, river slope (1085) information and river length. The number of sites used in the development of the method was 152 with an average record length of 40 years. Each of the identified regions were assigned a representative rainfall station taken from TR102 (Adamson, 1981) that is used to as the rainfall input for the application of the SDF.

From the above it is evident regionalisation based on geographic proximity requires that the regions are homogenous in terms of hydrological response, meteorological character, land cover (vegetation, soil and geology) and statistical characteristics assigned to the data. The identification of the regions for this study is expanded upon in Section 3.4.3.

2.3 Approach adopted for the study

The approach adopted for this project consisted of:

- selection of the study area,
- collation and gathering of systematic or gauged annual maximum flood (AMF) data,
- collection and gathering of quantative historical flood data and qualitative information on flooding,
- collection and gathering, both quantative and qualitative, of palaeoflood data,
- compilation of data sets that include all the flood peaks from the three sources of information,
- abstracting and obtaining relevant catchment characteristics,
- deriving a method to estimate the index flood at ungauged sites by combining the statistics of the data with the catchment characteristics, and
- deriving flood growth curves, based on the data sets and the selected probability distribution (log-Pearson type III) that can be used with the index floods estimated at sites to derive the selected flood peaks magnitudes.

The selection of the pilot study area was based on the following criteria:

- The area must have a reasonable flow gauging station network. This includes gauging weirs, stream gauging sections, flood runs (older data) and dams.
- A well documented historical record of human occupation to provide information for historical flood events.
- Be well disposed to the preservation of palaeoflood evidence
- The area must have clearly identifiable climatic areas in terms of rainfall and other catchment variables such as vegetation and soils.

Considering the above, Catchment Management Area 15 (CMA 15) was selected. This consists of the drainage regions (DWAF) K7-9, L, M, N, P and Q. To ensure that the regionalisation is complete drainage regions, J and K3-K6 to the west of the area and drainage regions R and S to the east were included. The pilot study area was shown in Figure 1.1.

CHAPTER 3

REGIONAL FLOOD STUDY CMA 15

3 REGIONAL FLOOD STUDY CMA 15 (DRAINAGE REGION K8, K9, L, M, N, P AND Q)

This chapter describes the methodology followed in the study to derive the flood estimation technique and consists of the following:

- An introduction describing the motivation and methodology.
- The acquisition of the AMF series data including the systematic, historical and palaeoflood data.
- The acquisition of catchment characteristic relevant for the estimation of the index flood.
- The motivation and selection of the statistical parameter to be used to develop the index flood, the regionalisation selected used to estimate the index flood and the development of the methodology to estimate the index flood for the selected regions.
- The section then concludes with the development of the regional growth curves using the three data sources.

3.1 Introduction

The regional flood study for CMA 15 consisted of data gathering, analysis of the flood data and deriving methods to estimate the value of Q_i at ungauged sites and Q_T. The need for a regional flood estimation methodology has been motivated in Section 1 (Introduction) and the approach to the study was presented in Section 2.4. This section details the data gathering for flood peaks and catchment characteristics, the derivation of Q_i and the development of the growth curves (GC) for CMA 15.

3.2 Data Acquisition – Flood Peak Data

Data acquisition, for the three identified sources are presented in sections 3.2.1 to 3.2.3. Section 3.2.3.5 is a conclusion and discussion of the palaeoflood data gathered and section 3.2.3.6 discusses the relevance of palaeoflood data.

3.2.1 Systematic data

Systematic AMF data for the pilot study area were obtained from the Hydrological Information System (HIS) database held by DWAF. The systematic or gauged period data type selected for this study was the annual maximum flood (AMF) series data due to the relative ease of abstracting the data and to ensure that the data points are independent. The AMF series are also the most commonly data set for long records used in practise and research (Ponce, 1989 and Robson and Reed, 1999). All the stations where flow is gauged and collected by DWAF in the study area are listed in Appendix A. The data were supplied in text file format and then converted to an Excel file format for screening and checking. The data requested were for gauging stations and dams and included stations that are currently closed. The following aspects prevented the direct use of the data in several instances:

- Limited range of the gauging structure. This resulted in the annual maximum flood peaks at many stations being truncated at the limit of the discharge table (DT). Fortunately the actual flood level is often still recorded by the recorder.
- Gaps in the record. This was often due to flood damage at a station and loss of the recorder charts. The directorate of hydrology and their regional offices however frequently conducted field surveys to establish the maximum flood levels attained by the floods. Using the surveys, slope-area or bridge calculations were used to estimate the peak discharges. These surveys were done at most gauging stations that experienced floods that exceeded the stations gauging capacity with the purpose of using that information to extend the calibration of the gauging station above the discharge table limits. This data was also published as flood documentations (du Plessis, 1983; Kovacs, 1983 and du Plessis & Bain, 1987).
- Short period of observation. Some stations were closed due either to flood damage and were never opened again, poor location, conditions made calibration difficult, operational reasons or when a station was replaced by another station.
- Stations located downstream of dams. The data from these sites are of little value for the study of floods. The record for the dam was rather used after back routing to obtain the inflows (using level pool routing) to the dam to obtain a record of flows at a dam. Should the capacity of a dam be small relative to the mean annual runoff, then the data may still have some value for flood estimation.

Figure 3.1 shows the gauging structure on the Great Kei River downstream from Kei Bridge. The DT for this site was extended during the study using log-log extensions, backwater calculations and the estimated discharges for the historical floods indicated on the bridge plans for the Kei Bridge bridges.

Figure 3.1: Great Kei River – Gauging Station S7H004

Table 3.1 below summarises the number of gauging sites listed for the pilot study region and the final number of stations used. Some of the sites were combined into a single data set. A full listing of the gauging stations that include weirs, flood runs, indirect flood measuring sites, gauging sections and dams is provided in Appendix A.

Table 3.1: **Summary Gauging Stations Drainage Regions J,K,L,M,N,P,Q,R & S**

Region	River basin	Area (km^2)	Total of all stations				Selected stations			
			Gauging stations	Dams	Total	Density (km^2/site)	Gauging stations	Dams	Total	Density (Sites/km^2)
J	Gourits	45702	51	12	63	725	23	4	27	1693
K	Coastal rivers	7243	21	4	25	290	15	0	15	483
L	Gamtoos	38816	21	4	25	1553	10	3	13	2986
M	Swartkops	2630	4	5	9	292	2	1	3	877
N	Sundays	21248	25	3	28	759	3	2	5	4250
P	Bushmans, Kariega & Kowie	5322	4	3	7	760	3	0	3	1774
Q	Great Fish	30242	67	6	73	414	22	3	25	1210
R	Keiskamma, Buffalo, Gqunube & Nahoon	7936	33	6	39	203	16	2	18	441
S	Great Kei	20485	22	8	30	683	12	1	13	1576
	Average	179624	248	51	299	601	106	16	122	1472

Note: Sites denoted with an F (indirect measurement sites) in Appendix A are not included in Table 3.1. These sites only have data for extreme flood events and were included with data of the official DWAF sites when applicable. A further 10 sites from the list in Appendix A were discarded due to data inconsistencies or obvious calibration anomalies.

3.2.2 Historic data

Historic flood data is any information relating to flood events outside the gauged or systematic record. These could include flood levels and peaks and quantative information such as “the flood was the largest since 1819”. Sources for historic information were;

- *DWAF files and library*. The correspondence and calibration files of the gauging stations were consulted for references to historical floods and to obtain the surveyed flood levels of floods not recorded by the instrumentation. The information in the files was also used for the extension of the discharge tables. The library at DWAF contains old Irrigation Department reports that referenced and contained reports on flood events.
- *The South African Weather Service publications*, the most notable being Caelum (Viljoen, 1990). Viljoen provides dates and brief descriptions of significant storm and rainfall events. This aided searches in other sources such as the correspondence files of gauging stations or when abstracting data from the HIS. The occurrence of a flood event is sometimes indicated as a gap in the record in the HIS databank. The later would thus indicate that the peak level was not recorded by the instruments and that the peak flood level must be sought from surveys contained in the calibration or correspondence files. For more recent events, surveys could possibly requested or undertaken.
- *Newspapers held by the various libraries*. The dates provided by Viljoen (1990) provided a starting point for the newspaper searches. The information in the older newspapers was much more qualitative than the more recent publications. Newspaper information must however always be verified where possible. Newspaper articles also aid in the identification other flood events that may have occurred previously to the event reported on.
- *The National Archives in Cape Town and Port Elizabeth*. Old Department of Public Works files for the Cape Colony and district council files contained several bridge plans and references to floods events. Plans in the files often provided sectional information and flood levels for one or several previous floods. This information was then used collaborate information from other sources, such as newspapers and new surveys for recent flood events that maybe available were used with the sectional flood level information to estimate the flood peak discharges for the historical events.
- *The South African Railways, National roads and the Cape Provincial Administration bridge plans* showed flood levels and river sections that could be used to estimate historical flood peaks similar to the approach explained in the previous bullet.
- *Articles and books on the Sundays (Meiring, 1959) and Gamtoos (Malan, 1970) rivers*. These publications provided a reasonable chronology of flood events that affected these rivers and in some instances qualitative information such as high flood levels, discharges and damages were also provided.

- *Markers, beacons and inscriptions on structures or at sites* by locals or officials that indicate the high flood levels for specific events or several events. These levels and if required sections were surveyed to provide input for the estimation of the peak discharge for the flood event.

The above sources were used in conjunction with each other since one piece of information would often require that a previous source be revisited to confirm old information or to see if any information may have been missed.

Figures 3.2 and 3.3 show a commemorative plaque and the rebuilt bridge at Carlise Drift. Information on the commemorative plaque indicates that the bridge was completed in 1863. After a flood in 1874 destroyed the bridge it was rebuilt in 1876. The flood of 2 January 1932 again destroyed the bridge and the reconstruction of the bridge was completed in 1933. On the northern side of the bridge beacons have been placed next to the road to indicate the flood levels of the 1932, 1944 and 1974 floods. From other information in the correspondence files, held by DWAF, the flood of 1874 was 0.06m lower at Carlise's Bridge than the flood of March 1974 and from the archival and newspaper reports the flood was 7.54m over the existing bridge deck.

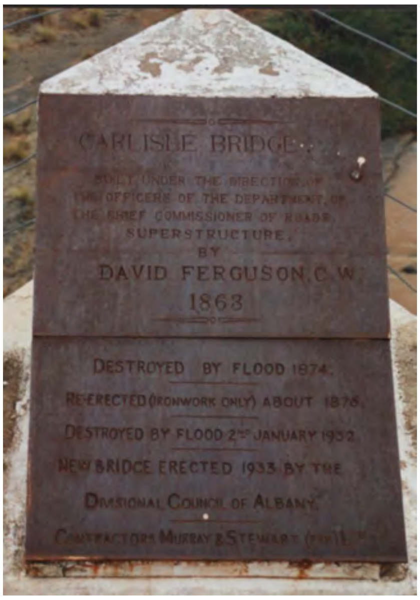

Figure 3.2: Commemorative Plaque at Carlise Bridge

Figure 3.3: Carlise's Drift on the Great Fish River

Figure 3.4 shows Piggott's Bridge on the Great Fish River, which is also flow gauging station Q9H012. The recorder tower is shown on the right bank of the river. The station was opened in 1935 and from the records the two largest flood events were that of February 1944 when the river level was 15.99m on the flood gauge and the March 1974 flood that rose to 20.73m. From the records of surrounding sites upstream and downstream the flood record for this site could be extrapolated back to 1905 for a systematic record and to 1819 for the historical period.

Figure 3.4: Piggott's Bridge – Great Fish River (Q9H012)

Figure 3.5 shows the bridge crossing the Great Fish River at Committees Drift. Gauging station Q9H006 located at this site. The recording of water levels was undertaken from September 1928 to May 1930 and again from 1957 to 1975 using gauge plates in the river section. The original bridge plans obtained from the archives in Cape Town provided seven flood levels for floods from 1848 to 1876. During this period the December 1874 flood attained the highest level of 21.78m or 0.76m below the current girder bed level. Newspapers at the time of the 1874 floods reported that the 1874 flood levels were the same as those attained around 1819. The highest level during the systematic gauging period was for the March 1974 flood that rose 22.86m.

Figure 3.5: Committee's Drift – Great Fish River (Q9H006)

The bridge crossing the Great Fish River at Fort Brown is shown in Figure 3.6. River levels were gauged at this site from January 1913 to May 1919 using a gauge plate (Q9H001). The highest the river rose in this period was 15.24m in March 1918. Bridge plans from the archives in Cape Town provided three flood levels from 1846 to 1874, of which the flood of December 1874 was the highest attaining a level of 19.36m. The planning reports held the DWAF library provided the level of a flood in 1901 and October 1905 flood, the latter, which rose 15.7m. The correspondence files held by the Hydrology Division of DWAF provided the flood levels of the January 1932 flood (17.07m) and the March 1974 flood (19.42m).

Figure 3.6: Fort Brown – Great Fish River (Q9H001)

To be able to use quantative historical information at a site, the occurrence of historical floods in the study area is important. The spatial extent, intensity and period of the flooding can provide vital information when asking the question “was the flood the largest since 1874?” Consider the flooding caused by the December 1874 flood. Quantative information regarding flood peaks is available for the Gamtoos and Great Fish rivers. Both these rivers have large catchments, that would suggests that the flooding had a large spatial extent. The flooding on the Gamtoos River was however not as significant indicating that the Gamtoos River was on the western most boundary of the event. On the Sundays River at Jansenville, information on the bridge plans indicates that the flood was the largest on record since 1867. From newspaper reports the flooding on the coastal rivers around Port Elizabeth, regions K and M was also significant, but larger floods are known to have occurred in the period since 1874 to the start of the systematic record. Thus on the lower Sundays River the floods of December 1874 could have been in the same order or maybe slightly larger than the floods of 1932 and 1971. The 1932 floods affected the whole Sundays River catchment while the floods of 1971 affected mostly the area downstream from Graaff Reinet. When the data for the lower Sundays River is analysed it would seem reasonable to accept that the flood events of 1932 and 1971 were the largest floods on that section of the river since 1874. The historical period of review in this case is 1874 to 2001 or 127 years.

To place the available historical data into context regarding spatial extent, period and intensity the most significant floods events that are known to have affected the study area since the 1800’s are:

- 1819: A flood similar to that of 1874 is reported to have occurred by locals on the Great Fish River in the vicinity of Fort Brown.
- July 1822: Flooding occurred all along the Cape coastal areas from Cape Town to East London. The recently established settlers in the interior around Grahamstown were also affected severely.

- November 1847: The Gamtoos River flooded at Hankey and several people were killed. The flooding also extended to the east and affected the Port Elizabeth area and the Swartkops and Sundays rivers.
- April 1848: The flooding impacted upon the Buffalo and to a lesser extent the Great Fish rivers.
- October/November 1867: The Gamtoos River attained its highest flood level on record at Hankey. The magnitude of the flood would suggest that both the Groot and Kouga rivers were in severe flood. Severe flooding was reported all along the Cape south coast and also east past the Sundays River. Port Elizabeth was severely affected.
- December 1874: The floods of 1874 were the most extensive recorded in South Africa at that stage. The area impacted upon was from the Gamtoos River in the south up north to beyond the Mvoti River in KwaZulu-Natal. In the interior the flooding affected Jansenville and Graaff Reinet (Sundays River), Cradock down to Fort Brown (Great Fish River), Queens Town (Great Kei River) and several of the smaller coastal rivers such as the Buffalo, Boesmans and Keiskamma rivers. The floods of 1874 would serve as design inputs in the area for many years.
- May 1885: Referred as the "Great Flood". Impacted on the western areas of the study area most notably the Gourits River catchment. The Groot River at Meiringspoort is known to have flooded to levels that were only exceeded in 1996.
- September/October 1905: Flooding occurred in the Gamtoos, Groot (Steytlerville), Swartkops, Sundays, Boesmans, Keiskamma, Buffalo and Great Kei rivers.
- May 1916: Flooding in the Olifants, Kammanasie, Gamtoos and Sundays rivers.
- November 1922: Severe flooding the Gamtoos and Sundays rivers.
- March 1928: Flooding in the Groot and Sundays rivers.
- January 1932: Extreme flooding in the Gamtoos, Sundays and Great Fish rivers. The flooding extended from the Gourits River in the west to the Great Kei River in the east.
- January 1941: Sundays River in severe flood.
- May 1944: Great Fish river floods.
- March/April 1961: The interior areas are affected by flooding. These include the Gamka and Groot (Gamtoos) rivers.
- August 1971: The lower Sundays and Gamtoos rivers flooded to similar levels as the flood of 1932.
- March 1974. The flood levels on the Great Fish River are similar and in some instances higher than those of 1874. The upper catchment of the Sundays River also flooded significantly.
- January 1981: Laingsburg floods. The Buffels (Groot), Touws and Gourits rivers and to a slightly lesser extend the Gamka River flooded and more than 100 people were killed. The flood peaks on the Buffels (Groot) and Touws rivers were and are still records.
- March to May 1981: A series of flooding events impacted on the Gamka River and on the coastal rivers from Gourits River to Port Elizabeth.

- November 1996: The Groot, Gamka, Olifants, Kammannasie and Gourits rivers flooded in the interior and rivers in the K region from the Gamtoos River to Port Elizabeth were in flood.
- March 2000: The interior areas over the Gamka River flooded again while the flood levels on the Gourits River were similar to those attained in 1996.

The gauging stations used in the study and the collated systematic, historical and palaeoflood AMF flood peaks for the various sites are summarised in Appendix B.

3.2.3 Palaeoflood data

Palaeoflood hydrology is the study of 'past or ancient flow events that occurred before direct measurement by modern hydrological procedures' (Baker 2000). The principal objective of the technique is to provide information on the peak discharge and recurrence of past floods that occurred up to 10 000 years ago. Before this time the prevailing hydroclimatic conditions that produced floods were probably dissimilar to that of today and therefore cannot be incorporated into the present-day flood record. Usually the palaeoflood records cover periods of hundreds to thousands of years (Zawada 1997; Baker 2000).

Palaeoflood hydrology can provide information on the following aspects of a rivers flooding behaviour:

- Identifying one or several floods that were larger than modern or historical flood records indicate. This can be used to verify the representivity of the modern and historical flood record in terms of magnitude and recurrence of floods;
- bracketing of periods in which no floods of a certain magnitude occurred;
- verification of the regional maximum flood, and
- testing the validity of the probable maximum flood of a river. This is of particular interest to high hazard developments such as nuclear related facilities and large dams.

The development of various palaeoflood techniques has occurred during the past 30 years in response to the observation that many flood records of rivers, which are based on modern hydrological measurements and even reliable historical records, are still comparatively short. Because palaeoflood hydrology is not dependent on human recording of floods and is based on erosional and depositional features produced by floods it can extend the period of flood record considerably. Palaeoflood hydrology should therefore be viewed not as an alternative methodology but as a suite of techniques that complement the hydrological analysis of floods in rivers.

Palaeoflood hydrology is a multidisciplinary method and therefore comprises several techniques. These include:

- relating the maximum particle size analysis to a measure of flood magnitude such as flow competency (stream power values);
- using botanical evidence as a proxy indicator of past floods, and
- using slack-water sediments as proxy indicators of palaeostage, and therefore discharge.

In South Africa several palaeoflood investigations have been done (Smith and Zawada, 1990 (primarily a palaeocompetence investigation); Boshoff et al., 1993; Zawada, 1994; Hattingh and Zawada, 1995; Zawada, 1995; Zawada et al., 1996) that focussed on using slack-water sediments in stable bedrock-controlled reaches as this method has been shown to provide the most accurate information on past floods (Baker, 2000). For this investigation on the palaeoflood hydrology of the Gourits, Sundays, Great Fish and Great Kei Rivers, bedrock-controlled reaches that favour slack-water deposition were selected as preferred palaeoflood sites.

A detailed review of the methodology of palaeoflood hydrology using slack-water sediments in South Africa and internationally with an extensive bibliography is given in Zawada (1997). The following is a brief overview of slack-water sediments and their application in identifying palaeofloods since these were primarily used in the palaeoflood study on southern and eastern Cape rivers.

Slack-water sediments represent the most accurate palaeoflood evidence for reconstructing the magnitude and recurrence frequency of floods that are hundreds to thousands of years old. The technique is dependent on recognising slack-water sediments, which are usually fine grained and deposited from heavily sediment-laden flood waters at sites that experience sudden reductions of flow regime. Each successive flood with a stage capable of inundating previously accumulated slack-water sediment will deposit a new layer on top of the previous one. Smaller floods will deposit sediments as insets that exhibit an on lapping relationship with the existing slack-water sediments. The maximum elevation of the slack-water sediment is assumed to indicate the peak stage of the flood. This, together with hydraulic modelling of stable bedrock-controlled cross sections, can yield accurate estimates of palaeodischarge. Applying sedimentological, stratigraphic and chronostratigraphic techniques such as radiocarbon and luminescence dating, to the slack-water sediments, can furnish a catalogue of dated, flow modelled palaeoflood events.

Slack-water sediments form by suspension settling in regions of flow reductions across a wide spectrum of physiographic or geomorphic settings. These include back-flooded tributary mouths, downstream of abrupt channel expansions, upstream of channel constrictions (back-water effects), bedrock caves or alcoves along the channel or valley wall in which flow detachment and ponding occurs. For the southern and eastern Cape rivers palaeoflood study, the mouths of back-flooded tributaries were focussed on.

3.2.3.1 Gourits River

Figure 3.7 shows the location of the sites investigated on the Gourits River. The positions of site A and associated area of tributary back flooding, cave site and 'difficult tributary', which contains an extensive sequence of slack-water sediments deposited by the Gourits River in the Langeberg Mountains, southern Cape.

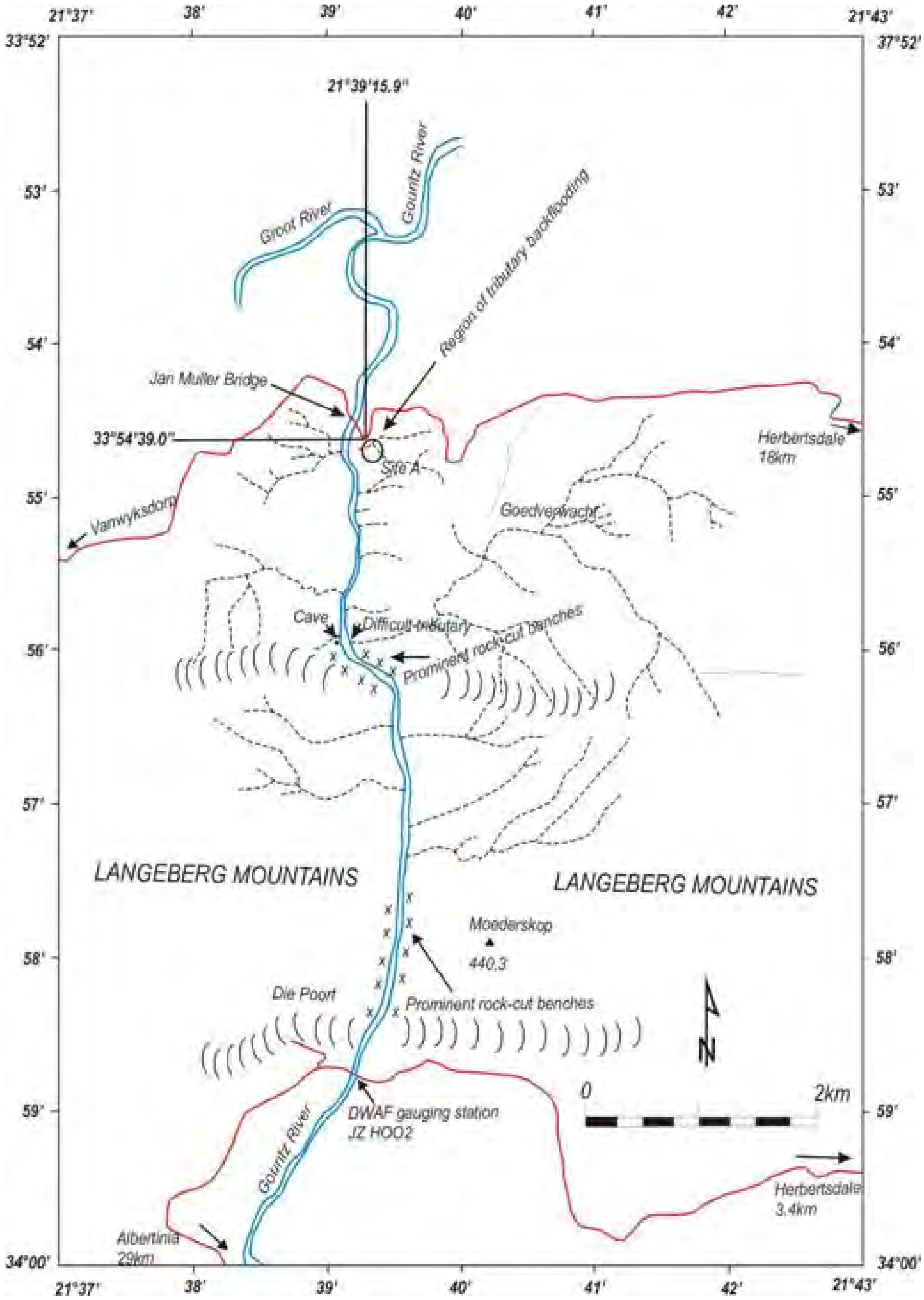

Figure 3.7: Location of Palaeoflood Sites – Gourits River

Site A: Gourits River, Jan Muller Bridge, 1:50 000 topocadastral sheet 3321DC Langberg, GPS coordinates: S33° 54” 39,00’ E 21° 39’15.9” (Figure 3.7). Date of the field investigation is 12-13 February 2002.

On the western side of the bridge on the rock face through which the Herbertsdale-Willowmore road passes through is a silver painted mark that was placed here by the Roads Department to indicate the maximum water level of the 1981 flood. The stage of this flood above channel base is 15,721 m (14,233 m above the Jan Muller bridge deck).

Site A comprises a thick sequence of flood-related slack-water sediments deposited on the eastern bank of the Gourits River that have choked the unnamed tributary of the Gourits. The Gourits River at site A is bedrock controlled and flows through a well-defined incised channel comprising black to dark-grey shale (slate like in places), siltstone and thin sandstone of the Gydo Formation, Bokkeveld Group of the Cape Supergroup. Immediately downstream of the Jan Muller Bridge the bedrock is exposed after which it is covered with a boulder bar of up to 3 m thick. The slack-water sediments on the eastern bank of the Gourits (Figure 3.8) occupy an area of approximately 0.1 km^2. Sediments extend from the side of the Gourits up to a moderately well defined break in slope in the slack-water sequence (Figure 3.8), which was interpreted as the uppermost position for the 1981 flood (Figure 3.8). The surveyed position for this feature is 14,79 m above the channel base, which is 0,93 m or 5,9% less than the 1981 flood (15,72 m) as observed by the Department of Roads. This relatively small difference indicates the close parity that can occur between the observed maximum flood stage and optimum sites of slack-water deposition. This observation was also confirmed in flume tank experiments of slack-water deposition by Kochel and Ritter (1987).

The 1981 sediments comprise light-grey, very fine-grained sand that for the most part is apparently massive. The sediments are distinctly non-indurated and are comparatively easy to excavate. The unconsolidated and non-indurated nature of the 1981 flood sediments results in the poor development of vertical exposure and their considerable reworking by wind, rain and local stream runoff. Closer to the Gourits River channel margin some exposures show ripple lamination and climbing-ripple lamination, the latter indicating high rates of vertical accretion as ripples migrated during flooding. It seems from site A that the 1981 flood smothered much of the pre-existing stratigraphy.

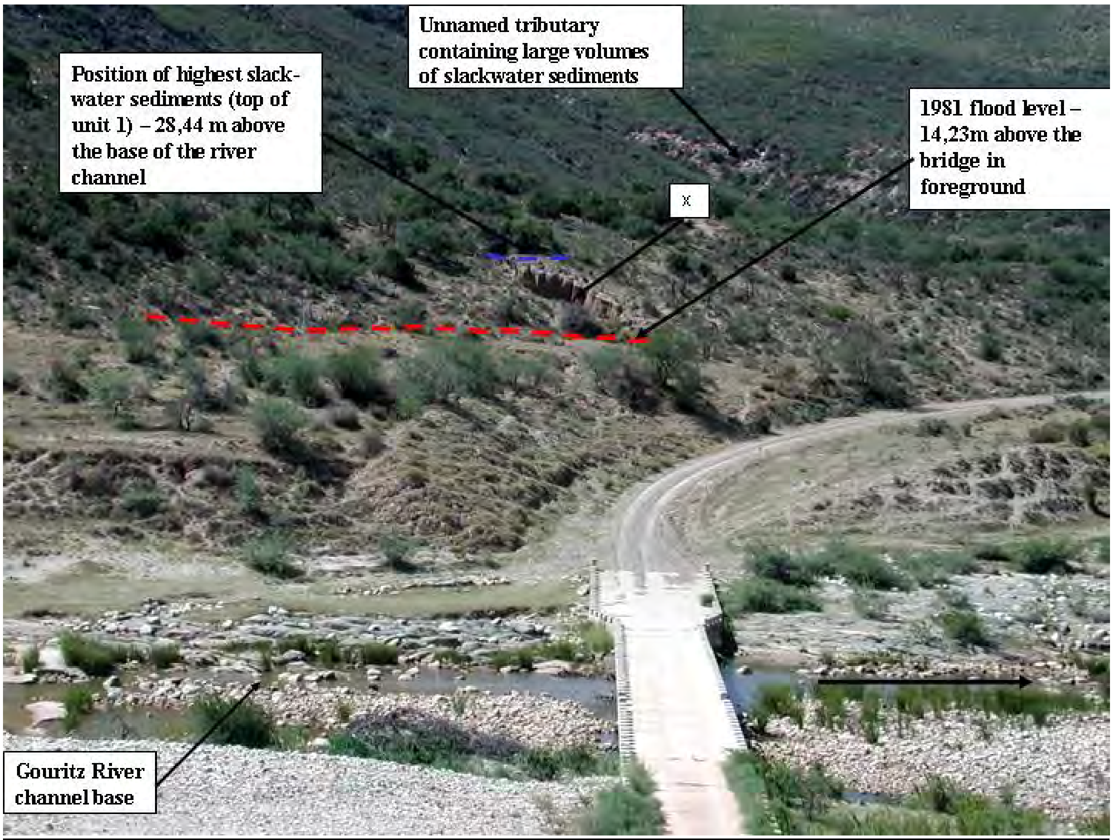

Figure 3.8: View of the Gourits River at site A with the Jan Muller bridge in the foreground

Palaeofloods higher than the 1981 flood stage

Figure 3.9 shows a stratigraphy at site A that is located higher than the 1981 flood level. The 1981 flood sediments laps up against this stratigraphy. The position of the 1981 flood level and the associated slack-water sediments are shown in the middle of the photograph. Above the 1981 flood level indicated by X is an outcrop comprising mainly non-flood related colluvial sediments (unit 3). Overlying these sediments are inclined fine-grained flood related slack-water sediments (unit 1), which are positioned 28,44 m above the base of the Gourits River. Of interest is the tributary in the background to the right that contains large volumes of slack-water sediments, which were not examined in detail.

The following stratigraphic section at site A was compiled and is described below from top to bottom and is also illustrated in Figure 3.9.

Unit 1: Variable thickness (40 – 90 cm) but has a maximum thickness of 90 cm, comprising very fine-grained, light-grey apparently structureless sand. The sediments are very similar to the 1981 slackwater sediments except that unit 1 is more indurated.

PKZ 1 sample was taken from unit 1 at 20 cm from the base for luminescence dating (Figure 3.9). An age of 3000 ±200 years was obtained for sample PKZ 1.

Unit 1 is interpreted as a slack-water deposit that was deposited by the Gourits River. Its similarity to the 1981 flood sediments is striking. There is no evidence of colluvial sedimentation such as coarse-grained beds and isolated clasts. The more indurated nature of unit 1 compared to the lower 1981 flood sediments indicates that unit 1 is older (perhaps considerably more so) than the lower-lying 1981 flood sediments. However, no evidence of pedogenesis was noted from this unit. The luminescence date of 3000 ±200 years is therefore significant as it supports the above macroscopic description and interpretation of these suspected palaeoflood sediments.

Unit 2: 1 – 7 cm thick gravel, comprising angular, schist, quartzite, quartz clasts 2 – 4 cm in size. Most are less than 5 cm. The basal contact of unit 2 appears to be gradational.

Unit 2 is interpreted as a non-flood related interval probably related to the underlying colluvially deposited unit 3 as evidenced from the lower gradational contact. The angular nature of the clasts indicates that they were sourced locally probably from the adjacent hillslope.

Unit 3: Unit 3 is at least 125 cm thick. The basal contact was not observed but extends to below the high water position for the 1981 flood (the 1981 slackwater sediments lap up against unit 3 (Figure 3.9). Unit 3 comprises brown to reddy-brown, very indurated (much harder than unit 1) very fine-grained sand with approximately a less than 10% clay (visually estimated). Unit 3 contains isolated, scattered or 'floating' surrounded clasts 3 – 15 cm in size. Lenses of gravel 10 – 15 cm wide containing gravel clasts 3 – 5 mm in size occur. A rhizocretion occurs towards the base of unit 3. Unit 3 contains small (1 mm) size carbonate blebs.

PKZ 2 sample was taken from unit 3 at 47 cm below the base of unit 2 for luminescence dating. An age of 85 200 ±790 years was obtained for unit 3.

Unit 3 was interpreted prior to the luminescence dating results as a colluvially deposited unit of considerable age that has undergone some pedogenesis. The rhizocretions, carbonate blebs, reddy-brown colour and highly indurated nature indicates that unit 3 is of a considerable age. The luminescence date of 85 200 ±790 years therefore supports the above macroscopic description and interpretation. The colluvial nature of unit 3 is indicated by the pebble and boulder clasts set in a silt – sandy matrix, and was probably deposited as a mud flow.

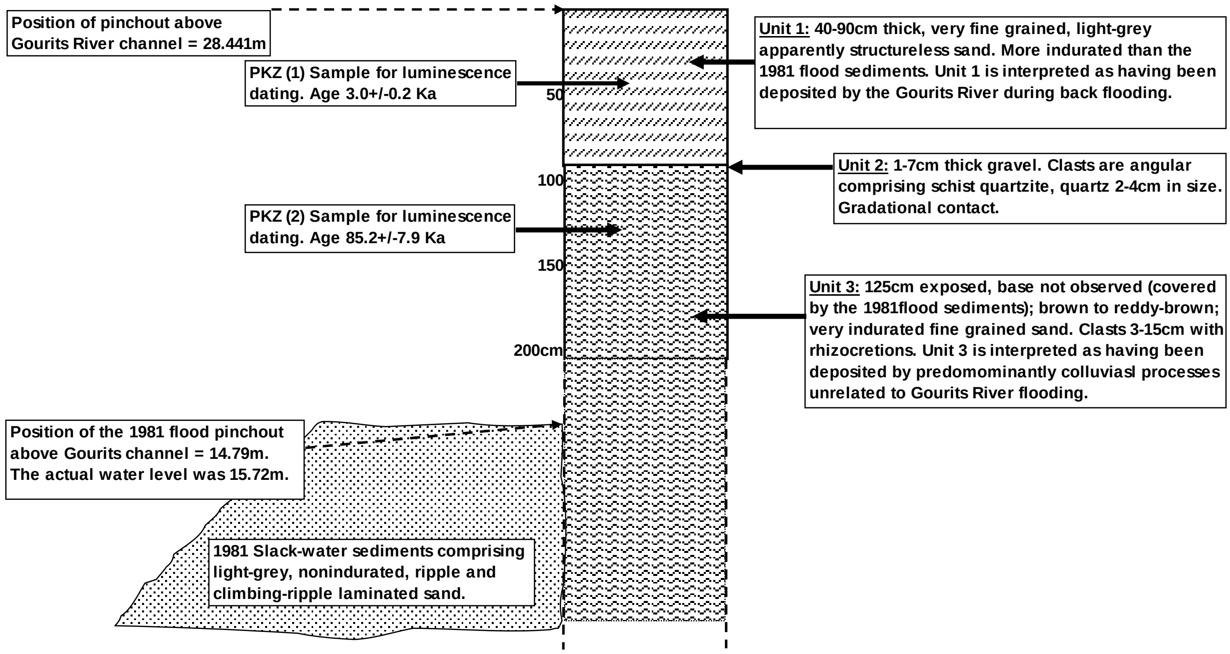

Figure 3.9: Slack-water Stratigraphy of the Gourits River at Site A

Figure 3.10 shows the relative level of Unit 1 to the level of the 1981 flood.

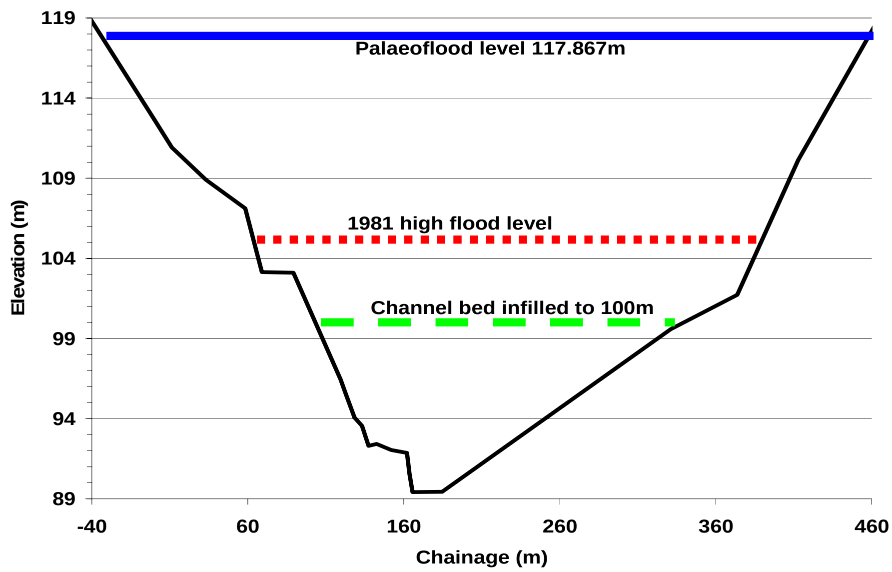

Figure 3.10: Surveyed cross-section of the Gourits River at the Jan Muller palaeoflood site

Site – 'Difficult tributary'

The 'difficult tributary' site is located approximately 2,5 km downstream of site A (Figure 3.7). The confluence of the tributary with the Gourits River is at S 33° 55' 57.5" E 21°39' 9.6" (measured from 1:50 000 scale topocadastral map). The mouth of the tributary is infilled with large volumes of mainly fine to very fine-grained light-grey sand that forms steep cliffs. The top of the cliff is marked by a well defined terrace that corresponds with the top of the 1981 flood sediments occurring on the western bank of the Gourits River. The slackwater sediments extend for approximately 500 – 750 m upstream in the tributary.

It was tentatively concluded that much of the sediments lower down in the tributary were deposited by the 1981 Gourits River flood. There is evidence of slackwater sediments with a stage higher than the 1981 floods further up in the tributary. These were briefly examined and found to be very-fine grained sand – silt grade sediments. Surveying and sampling these sediments should be done. The surveying of the slackwater sediments in the tributary will be difficult as it is densely vegetated.

CAVE SITE

The cave site is located opposite the confluence of the ‘difficult tributary’ on the western channel margin of the Gourits River approximately 10 m above the top of the highest 1981 flood sediments. The position of the cave is at S 33° 55’ 58,4” E 21° 39’ 3,9” (Figure 3.7).

The mouth of the cave faces in an upstream direction and has formed by the preferential weathering and erosion of the core on an anticlinally shaped fold. The height of the cave although above the 1981 flood level (Figure 3.11) may contain slackwater deposits from the same flood events indicated by unit 1 at site A. Fine-grained sediments similar to slackwater sediments occur in the cave (pers comm. Van Bladeren). If flood-related slack-water sediments do occur in the cave these would represent a flood or floods that are considerably larger in size than the 1981 flood level shown in the foreground, which could be correlated with the slackwater sediments of unit 1 at site A. In Figure 3.11 the approximate level of the 1981 flood level is indicated by the dashed red line. The person in the mouth of the cave should provide some indication of scale.

Figure 3.11: Cave site in the Gourits River taken from the ‘difficult tributary’ site

In view of this site having excellent potential for preserving flood related slack-water sediments it is recommended that the cave site should be further investigated to test the following hypotheses:

1. If no slackwater sediments occur at this site then depending on the height of the cave compared to the 28,44 m stage indicated for unit 1 at site A, this observation would provide a reliable maximum flood stage for the Gourits River. This would in turn place the unit 1 flood at site A and the 1981 flood in perspective.

2. Depending on the caves position above the Gourits River it could have recorded a similar size event to that indicated by unit 1 at site A. This would provide excellent corroboration of the large flood indicated at site A.

3. Depending on the caves position above the Gourits River the cave site could contain a valuable palaeoflood record for all floods larger than the 1981 flood.

Palaeoflood interpretations and conclusions for the Gouritz River sites

Significant palaeoflood information has been obtained from the Jan Muller Bridge palaeoflood site. In particular, importance is attached to the palaeoflood indicated in unit 1 and the luminescence date of 3 000 ±200 years. In terms of a flood stage this flood is 12,72 m higher than the 1981 flood stage and was deposited by a flood approximately 3000 years ago. The palaeoflood stage of unit 1 (28,44 m above the Gourits channel base) corresponds to a modelled palaeoflood discharge of 26 300m^3/s. In terms of the palaeoflood discharge modelling, the lower estimate is regarded as the more reliable. To put the unit 1 palaeoflood into perspective the 1981 flood had a discharge of 11 400 cumecs at Mullershoop (bridge immediately downstream of Die Poort at gauging station J4H002) (Figure 3.7).

Although texturally the sediments of unit 1 are almost identical to the 1981 slack-water sediments, which strongly suggests that unit 1 is a palaeoflood slackwater unit that was deposited by the Gourits River, the following issues require clarification:

1. A flood of this magnitude should be identified at other reaches. This will add confidence to the existence of such a large flood. It is therefore important to investigate the ‘Difficult tributary’ site and possibly the cave site. Due to the nature of this investigation, it was not possible to investigate in any detail further palaeoflood sites.

2. The unit 1 flood may have been generated when the channel infill of the Gourits River was much more extensive perhaps containing several meters of sediment. This would have the effect of increasing the flood stage. This condition indicates that the hydroclimatic regime of the

Gourits was different to that of today. However, even if this was the case and that channel infill resulted in increasing the position of the base of the channel from 89,42 m to 100 m the modelled palaeodischarge would be approximately 20 000 – 23 000 m^3/s (Figure 3.10). This would still indicate the existence of a very large flood that occurred approximately 3 000 years ago. It is likely though that a flood of this magnitude would be sufficiently competent to scour considerable volumes of fluvial sediment and is likely to have removed all the sediment down to the current position of the channel bedrock. It is not considered likely that the base of the channel has been lowered significantly through bedrock erosion in approximately 3000 years.

A further observation regarding the flood behaviour of the Gourits River is approximately 3 km downstream of the Jan Muller Bridge palaeoflood site where the river passes into a narrow, quartzite bedrock controlled reach. The downstream end of the reach at Die Poort was observed where the Herbertsdale – Albertinia road crosses the Gourits. Where the river leaves the Die Poort well defined rock-cut benches are present (Figure 3.12). The quartzite is smooth and exhibits a prominent knick point. The level of this knick point is close to the 1981 flood level. A possible interpretation of this feature is that it was formed by the relatively common (geologically speaking) occurrence of floods similar to the 1981 flood. This implies that the 1981 flood level cannot be regarded as a catastrophic flood and rather the palaeoflood discharge for unit 1 of approximately 26300m^3/s should be regarded as a catastrophic flood for the Gourits River.

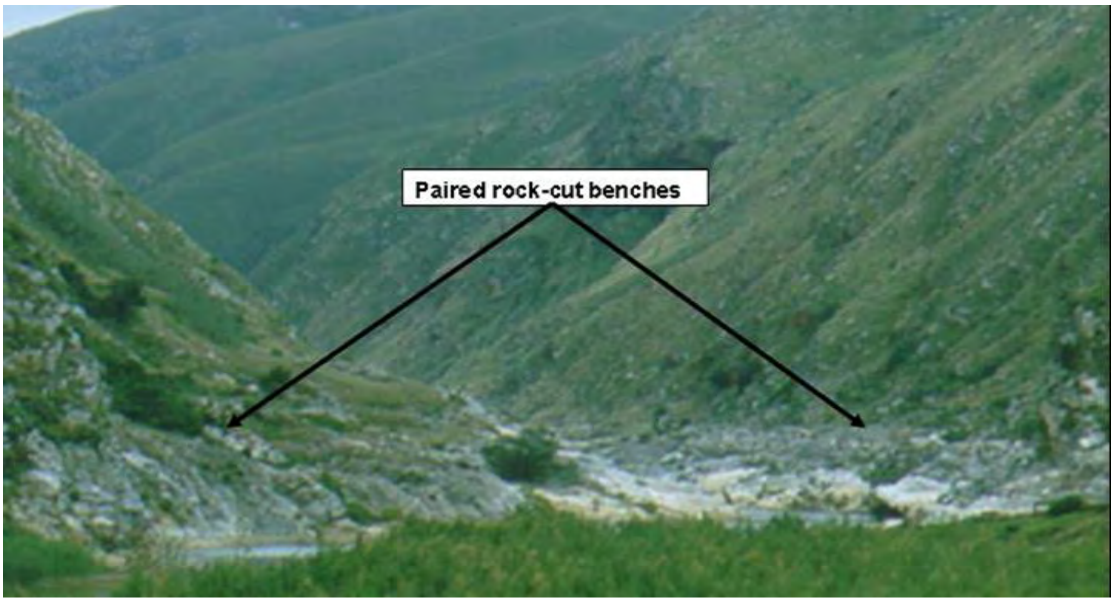

Figure 3.12: View looking upstream in the Gourits River Die Poort

3.2.3.2 Sundays River

Site: Darlington Dam

The palaeoflood site is approximately 9 km downstream of the Darlington Dam in the Sundays River Poort with the following GPS coordinates: S33° 14' 15.8", E025° 07' 49.4" (Figure 3.13). The site comprises a thick and laterally extensive sequence of fine to very fine-grained slackwater sediments that are interbedded with coarse-grained sand – gravel beds deposited by colluvial sedimentation from the adjacent hills. The slackwater sediments were deposited by backflooding of the unnamed tributary (Figures 3.13 and 3.14). The Sundays River Poort is bedrock controlled comprising shale, siltstone, subordinate sandstone and diamictite of the Kommadagga Formation of the Winterberg Group, Cape Supergroup.

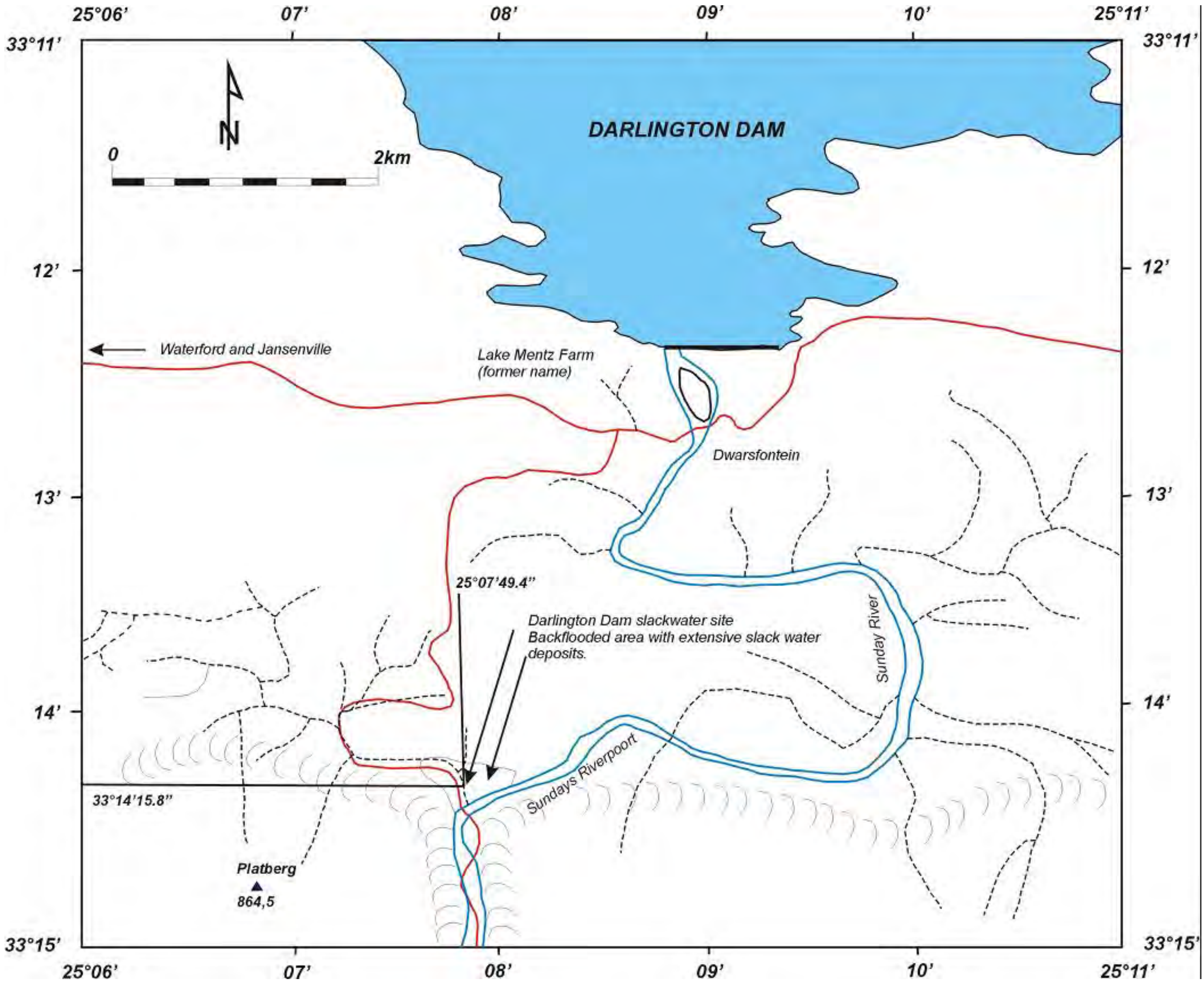

Figure 3.13: Position of the Darlington Dam slackwater site on the Sundays River in the Suurberg mountains, southern Cape

Figure 3.14: View of the slackwater sediments deposited in a tributary of the Sundays River during flooding. A composite sample of ostrich egg shells from the upper unit (unit 1) and the lower unit (unit 3) yielded a radiocarbon age of 4520± 60 years

The slackwater stratigraphy becomes more complex and is interbedded with beds and lenses of colluvially deposited gravel in the tributary sections located approximately 350 – 400 m upstream of the tributary – Sundays River confluence. Towards the confluence the slack-water sediments become thicker and more homogenous. Although the slack-water sediments are being eroded in this region, much of the outcrop comprises short 1 m thick sections. The following lithological profile was measured and described, which is also presented in Figure 3.15.

Unit 1: Unit 1 is approximately 7 m thick, the top of which represents the maximum elevation of slackwater sediments above the Sundays River at this site. It comprises very fine-grained, apparently massive, light-grey sand. The unit is friable and does not exhibit distinctive induration. Sample PKZ 3 was taken for luminescence dating and yielded an age of 8 000 ±600 years.

Unit 2: A 2 cm thick discontinuous bed containing 2 – 5 mm angular gravel. Although unit 2 is locally discontinuous it is generally present across much of the area. The thin and discontinuous nature of unit 2 is ascribed to the distal position of the underlying slack-water sediments from the nearest hillside that sheds colluvial deposits. The upper and lower contacts of unit 2 are sharp.

Unit 3: Unit 3 is at least 80 cm thick, the base of which was not observed due to insufficient exposure. The unit tends to form a negative weathering feature where it directly underlies unit 1. Unit 3 merges into the eroded slackwater ‘plain’ from which non-insitu fragments of ostrich eggs were collected from the surface for radio carbon dating (sample no: PKZ 5), which yielded an age of 4520 ±60 years (CSIR analysis number Pta-8650). Unit 3 comprises very fine-grained a more olive grey sand compared to unit 1. Unit 3 is apparently massive. Sample PKZ 4 was taken from unit 3 for luminescence dating, which yielded an age of 7 100 ± 1000 years.

The elevation of the top of unit 1 is 20 m above the channel base of the Sundays River. This corresponds to a discharge of 13 300 m^3/s. The top of the palaeoflood slackwater unit 3 has an elevation of approximately 13 m above the Sundays River, which corresponds to a discharge of approximately 6 130 m^3/s (Figure 3.15).

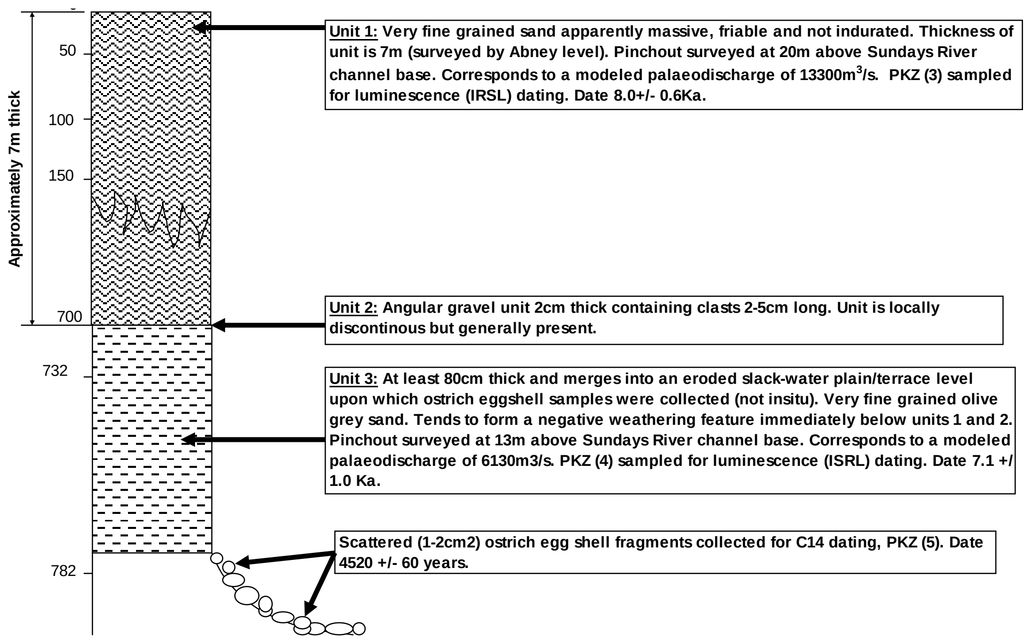

Figure 3.15: Slackwater stratigraphy of the Sundays River downstream of Darlington Dam

Palaeoflood interpretation of the Sundays River – Darlington Dam site

The systematic and historically recorded flood record for the Sundays River at Darlington Dam is presented in Table 3.2:

Table 3.2: Significant Historical And Systematic Floods Recorded-Sundays River At Darlington Dam

Year	Discharge (m^3/s)	Comments
1971	5300	Inflow peak from routing
1941	2500	Inflow peak from routing
1932	5400	Inflow peak from routing
1928	3960	Inflow peak from routing
1922	3730	Flood recorded at site during construction
1916	2500	Flood transferred from Korhaans Drift
1874	(approx. = 1932 flood)	Approximately similar to 1932 flood based on the peak at Jansenville.
1867	Discharge unknown	Generally large flood event in the eastern Cape.
1847	Discharge unknown	Generally large flood event in the eastern Cape.

The pinchout of slackwater sediments (unit 1; Figure 3.15) at 20,0 m above the Sundays River water level corresponds to a discharge of 13 300 m^3/s, which is slightly less than 2,5 times the maximum recorded historically recorded flood of 5 400 m^3/s in 1932. Luminescence dating of this unit indicates that these sediments were deposited 8 000 ±600 years ago. The pinchout of the next highest slackwater sediments (unit 3; Figure 3.15) occurs at 13,0 m above the Sundays River water level, which corresponds to a discharge of 6 130 m^3/s, which is still 12% higher than the maximum recorded historically recorded flood of 5 400 m^3/s in 1932. Luminescence dating of unit 3 indicates that these sediments were deposited 7 100 ±1000 years ago.

A further observation is the radiocarbon age of 4 520 ±60 years that was obtained from the not in-situ ostrich egg shell fragments that were collected on the surface comprising eroded unit 3 slackwater sediments (Figure 3.15). This age is at variance with the *circa* 8 000 year old luminescence dates obtained for units 1 and 3. A possible explanation for this is that the ostrich egg samples represent remnants of a younger landscape surface and therefore of sediments that were not probably occurring higher than the pinchout position of unit 3 of 13,0 m above the water level of the Sundays River. It is inferred that the host sediments from which the ostrich egg fragments originally were part of have been eroded away.

It is concluded that the palaeoflood sediments represented by units 1 and 3 were deposited at around 8000 years ago. Although it was not possible to place the age of these floods in the context of other palaeoclimate studies to verify their occurrence in a similar climatic regime to that of the present day, their age must be viewed as being on the maximum time span where palaeoflood events can inform modern flood prediction studies.

The comparatively old age for these sediments indicates that the floods of 1932 and 1971 with respective discharges of 5 400 and 5 300 m^3/s seem to represent maximum flood discharges for time periods of several thousands of years. An unresolved matter is the observation that if indeed the 1932 and 1971 floods represent maximum floods their recurrence within a comparatively short period of time (39 years) is puzzling. This could be ascribed to significant land use changes such as the introduction of livestock farming from the 1800's, which may have resulted in increased runoffs. A similar explanation was suggested for the magnitude of the 1981 Buffels River flood at Laingsburg.

3.2.3.3 Great Kei River

Site: Kei Cuttings

The Kei River was investigated at Kei cuttings upstream of the Kei road and rail bridge on the northern bank of the river on 12.03.2002 (area of investigation defined by longitude 27°57'37.5" latitude 32°30'23"; longitude 27°57'37.5" latitude 32°30'23.5"; longitude 27°58'43" latitude

32°30’23.5” and longitude 27°58’43” latitude 32°30’31”; 1:50 000 topocadastral sheet 3227DB Komga). No significant slackwater deposits were found in this area. An unnamed tributary (longitude 27°58’9” latitude 32°30’24”) did not contain significant slackwater sediments. This is attributed to the hydrologically active nature of the tributary (it exhibits a steep gradient and is highly erosive) and the dense vegetation that hinders identification of any slack-water sediments.

A tributary that flows into the Kei River on the northern bank of the Kei River approximately 1,1 km downstream of the Kei Cuttings road bridge (longitude 27°59’32” latitude 32°30’27”) also showed no significant slackwater deposits. This is ascribed to the hydrologically active nature of the tributary and the observation that the confluence with the Kei River is some distance removed from the valley sides of the tributary into which any slackwater sediments could be protected from erosion.

Site: Great Kei Drift (longitude 27°39’9” latitude 32°16’57” topocadastral sheet 3227BC Bolo). A sequence of sediments occur on the northern bank of the Great Kei extending for at least 1 km upstream from the Great Kei Drift. An approximate section was measured and is presented below.

Unit 2 – 3-5 m thick, pinkish, hard (indurated) fine-grained sand with calcareous concretions. This unit is interpreted to be old i.e. thousands of years old and is unrelated to the modern flood regime of the Great Kei River. Portions of this old, well-indurated sediments has been removed or collapsed into which appear to be younger light-grey fine-grained sediments that are similar to slackwater sediments. It is possible, however, that these sediments are pedological in origin that have slumped from a position higher up on the slope.

Unit 1 - basal 2 m and starts from the river level. Comprises a boulder gravel of at least 2 m thick.

Site: Great Kei Drift – Kei View Farm (topocadastral sheet no 3227BC Bolo). From the Great Kei Drift to the Kei View Farm a sequence of what appear to be slackwater sediments occur on the southern side of the road and against the hill side. No further investigation of these sediments was done.

Recommendations: Difficulty of access did not permit examination of two promising tributaries in which possibly back-flooded slackwater sediments may occur. These are the Cememe and the Caba rivers. It is recommended that an investigation to see if slackwater sediments are present in the Cememe River.

Site: 500 m NW along road from Great Kei Drift - (topocadastral sheet no 3227BC Bolo). From the Great Kei Drift carry on road towards Tsomo for approximately 500 – 750 m. A track on the left (not indicated on map) leads down towards the Great Kei River at longitude 27°38’38” and latitude

32°16’47”. At this position the river has incised into a sequence of argillaceous rythmites. At this point the Great Kei River has incised a prominent and distinctive rock-cut bench or step on the western bank of the river, which appears to correspond with the highest point of slackwater sediments that occur and eventually pinch out on the eastern side of the river.

In view of the distinctive flood/flow formed geomorphological feature at this location it may be worthwhile to survey the height of the erosional feature and see how it compares with the gauge and the historical flood record. Time constraints did not permit further investigation of this site.

Palaeoflood interpretations of the Great Kei River

The sites that were investigated on the Great Kei River did not indicate flood levels appreciably higher than those previously gauged or historically recorded. The available historical data for the lower Great Kei River at Kei Bridge are:

- December 1874, stage rise of 12.8m and a discharge of 10 800m^3/s
- July 1931, stage rise of 9.9m and a discharge of 6000m^3/s and
- May 1959 and a discharge of 3 000m^3/s

It is tentatively suggested that the maximum recorded floods for the Great Kei River are a fair representation of the maximum floods that can be expected. Although investigation indicated that there is no palaeoflood evidence is present of flooding that exceeded the available historical floods it is recommended that the sites identified should be investigated in more detail.

3.2.3.4 Great Fish River

Site: N2 Bridge over Great Fish River – (topocadastral sheet no 3326BB Breakfast Vlei). Longitude 26° 59’43” latitude 33° 14’11”. An unnamed tributary flows into the Great Fish River at Hunt’s Drift. Examining the tributary in an upstream direction one can observe slackwater sediments that thin in an upstream direction. Although no sections were measured it is possible to differentiate 2 – 3 flood events interbedded with non-flood colluvial sediments

The site requires further investigation in future as it contains the record of 2 - 3 large palaeoflood events. Although the position of the sediments are probably not higher than the stages recorded for the 1874 and 1974 floods (see Table below) dating of these sediments would furnish valuable information on the recurrence intervals of these large floods. The excellent exposure of the slackwater sediments would permit the accurate position of the pinchout of the sediments from which a detailed palaeoflood record could be compiled to augment the systematic and historical record for this reach of the Great Fish River. The most significant historical peaks on the Great Fish River at the N2 National Road bridge are:

- December 1874, stage rise of approximately 12m and a discharge of 9 000m^3/s and
- March 1974, stage rise of 12.1m and a discharge of 9 000m^3/s

Site: Committees Drift – (topocadastral sheet no: 3326BB Breakfast Vlei; S33° 09' 31", E 26° 50' 19"). No slackwater section or information indicating that a larger flood than the 1974 flood was identified. The two largest floods on record for the Great Fish River at Committee's Drift are:

- December 1874, stage rise of 21.8m and a discharge of 7 200m^3/s and
- March 1974, stage rise of 22.9m and a discharge of 9 000m^3/s

There is no recommendation to do further palaeoflood related work at this site.

Site: Bambespruit – Carlisle Bridge area (site 1) – topocadastral sheet no 3326AA Riebeeck-Oos. GPS position of slackwater deposits S33° 04'03.2" E026° 12'57.8". Position of section is in the meandering tributary (Bambespruit) of the Great Fish. The bedrock comprises shale of the Fort Brown Formation. The tributary has incised a series of slackwater sediments, which are thought to be due to backflooding followed by incision. The base of the tributary channel is 5 – 7m wide, is incised by up to 10 m and comprises in the base of the channel shale and siltstone gravel 1- 5 cm in diameter.

At this site the stratigraphy comprises 2 units (Figure 3.16)

Unit 2 – Unit 2 is at least 3 m thick and has a sharp basal contact with the underlying unit 1. The basal 10 cm of unit 2 is coarser grained, very fine – fine grained. It is also distinctively much softer than the overlying sediments. The basal portion of unit 2 exhibits flat lamination otherwise the rest of unit 2 is apparently structureless. The remainder of unit 2 is similar to unit 1 but is not as hard or indurated or crumbly in texture. General appearance of unit 2 is a very fine-grained sand and weathered has a lighter yellow or buff colour compared to unit 1. In fresh samples the colour is similar to unit 1. The surface exposure of unit 2 exhibits occasional white carbonate leaching marks where old roots grew. The basal contact of unit 2 is 6,67 m above the water level of the Great Fish River (Figure 3.16).

Unit 1 - The lower unit overlies the tributary base and is at least 3 m thick. It comprises very fine-grained, light-grey sand that is partially indurated and has a distinctive crumbly texture. The unit is homogenous, and is extensively bioturbated with numerous burrows of less than 1 mm in diameter. The upper contact with the overlying unit 2 is sharp. A sample for luminescence dating was taken at a position of 30 cm below the contact with the overlying unit 2 (sample number PKZ 6), which yielded an age of 2 100 ±200 years.

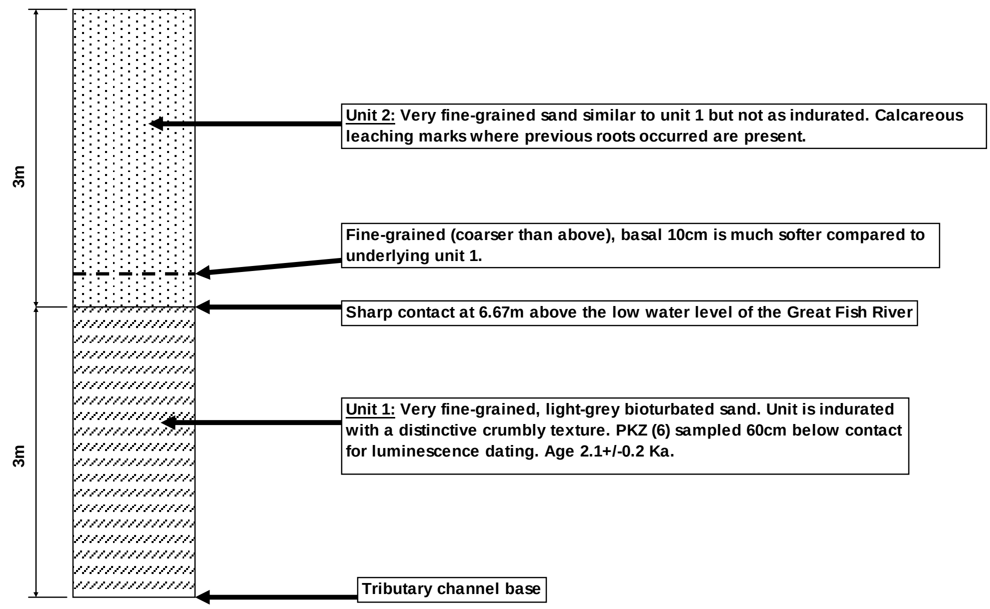

Figure 3.16: Slack-water sediments at Bambespruit at Carlisle Bridge (site 1)- Great Fish River

Bambespruit – Carlisle Bridge area (site 2) - topocadastral sheet no 3326AA Riebeeck-Oos. GPS position of slackwater deposits S33°03'58.0" E026°12'46.5". Position of section at site 2 is upstream of site 1. Site 2 is suspected to show the same stratigraphy as site 1 namely units 1 and 2. However there appears to be an additional unit (unit 3) that overlies units 1 and 2 that comprises very fine-grained sand, unconsolidated and non indurated that is quite different to units 1 and 2 observed in site 1 (Figure 3.17). The basal 10 cm of unit 3 comprises very fine – fine grained sand (coarser than the remainder of unit 3). The base of unit 3 was surveyed to be 9,62 m above the water level of the Great Fish River. It appears that unit 3 represents continuous flood sediments that pinch out at 19,42 m above the water level of the Great Fish River.

Unit X, which is correlated with unit 2 at site 1 was sampled for luminescence dating, which yielded an age of 2 000 ±200 years.

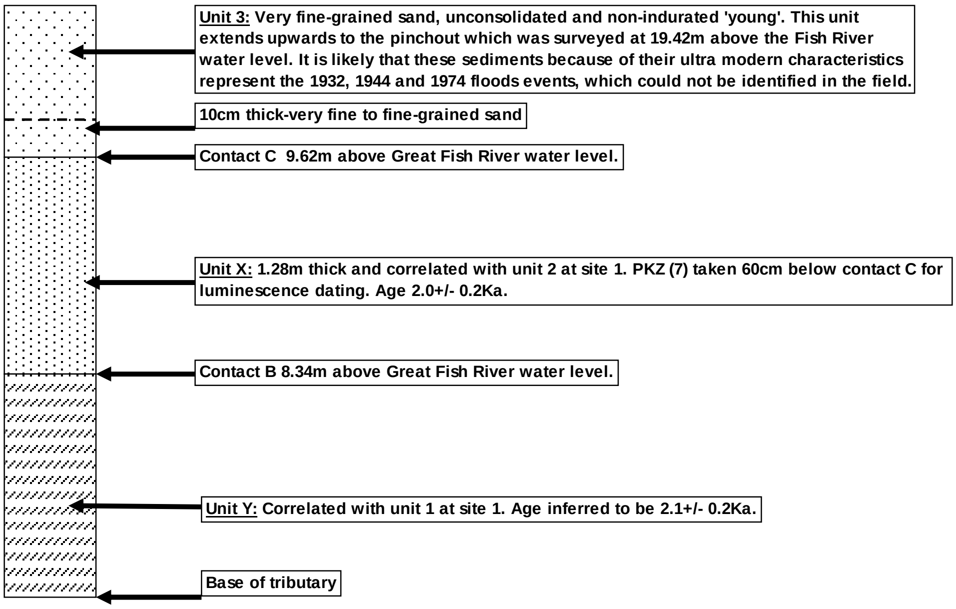

Figure 3.17: Schematic section of the slack-water sediments at Bambespruit (site 2)

Palaeoflood interpretations for the Great Fish River

A series of flood stages marks placed by the owner of the farm Schelm Drift just north of Carlisle Bridge. The flood stages are as follows:

- January 1932, stage rise 18.33m and discharge of 5 942m^3/s
- February 1944, stage rise of 17.177m and discharge of 4 400m^3/s and
- March 1974, stage rise of 19.151m and discharge of 9 231m^3/s

The slack-water stratigraphy at Bambespruit indicates that no floods occurred that were greater than the 1974 flood stage of 19,15 m (9 231 m^3/s). The slackwater sediments that are assumed to have been deposited during the 1932 and 1974 succession of floods (9,8 m and 11,08 m lower than the 1974 flood respectively) are probably buried beneath the 1974 flood deposited sediments and form part of unit 3. No evidence was noted that the sediments comprising unit 3 comprised or represented more than one flood event.

Of importance is the observation that the next largest flood event as represented by unit units X and Y (with maximum elevations of 9,62 m and 8,34 m respectively, flood discharge of 1 288 m^3/s and 1 018 m^3/s respectively) are 9,5 m and 10,81 m below the 1974 flood, which appears to be the largest flood on record. Furthermore, the luminescence dating for units X and Y indicate that these floods occurred circa 2000 years ago. This indicates that for the past 2000 years up to around the start of the historical flood record the Great Fish River has not experienced floods with a stage greater than 9,62 m or a modelled palaeodischarge of 1 288 m^3/s.

A similar pattern where a large gap in terms of magnitude occurs between the largest and the next largest flood occurs for the Buffels River downstream of Laingsburg (Gouritz River system) where the 1981 floods were considerably larger than the second highest flood (Zawada, 1996). For 6 palaeoflood sites investigated along the Buffels River the difference in discharge and stage between the 1981 flood and the second largest flood was on average 7,6 and 2,3 times respectively. Although this could be ascribed to erosion of the pre-existing slackwater stratigraphy it was concluded for the Buffels River that this flood pattern was not a remnant one, but instead represented an accurate record of the flood history of the Buffels River. This could be explained by non-stationarity of climate through time and/or anthropogenic factors such as changed land use.

Site: Fort Brown site (Topocadastral sheet no: 3326BA Fort Brown). A sequence of flood sediments occurs on the western bank of the Great Fish approximately 250 m downstream of the road bridge across the river. The GPS coordinates are: S33°07'32.1" E026°36'50.0".

The sequence of sediments do not occur in a tributary back-flooded environment and appear to have been deposited against older 'relict' alluvium. A sequence of very fine-grained grey sediments occur fairly continuously from the waters edge to a point of pinch out that was accurately surveyed to a level of 18,40 m above the water level of the Great Fish River. Of possible significance is that above this point a sequence of similar sediments occur that are more indurated, they exhibit a slight pinkish hue (indicating possibly a greater age) and contain calcrete nodules. The calcrete nodules are discontinuous with some examples of rhizocretions. The top of this sequence was accurately surveyed to be 25,452 m above the low water level of the Great Fish River. A sample (PKZ 8) for possibly IRSL dating was taken from this calcrete rich unit approximately 1 m below the point of pinch out. No age could be obtained from this sample.

In conclusion, the presence of calcrete and the pinkish hue of the sediments, which were deposited by the Fish River during high flow events, indicates their probable antiquity (thousands of years old) compared to the sediments that occur up to 18,408 m above low water level. An uncertainty is to ascertain how old these sediments are and to what extent they can be regarded as being part of the current flood regime of the Great Fish River. Even if luminescence dating would have indicated a comparatively young age of 2000 – 5000 years BP, further evidence (through correlation) would need to be found at other sites for a flood or floods of this magnitude. It is worth noting that no such flood was identified at the Bambespruit or Committee's Drift sites. This site indicates there are probably no floods larger than the 1974 flood preserved. The calcrete-rich sediments that occur 7,04 m above the pinchout of the younger slack-water sediments are probably relict features.

Site: Prudhoe (Topocadastral sheet no:3327AC Prudhoe). The GPS coordinates are S33°23'49.1" E027°01'13.4". A sequence of fine grained slackwater sediments occur that are arranged in a series of terraces from the low water level of the Great Fish River (Figure 3.18). No surveying was done. Estimates of the height of the pinch out position of the fine-grained slackwater sediments were about 15 m above the low flow stage of the Great Fish River. Of possible significance is the occurrence of a 30 cm thick bed of angular colluvially derived gravel occurring in an interbedded position at the top of a large terrace above which is a further sequence of fine-grained slack-water sediments.

It appears that the sediments above the colluvial unit were probably deposited during the 1932 – 1974 series of floods. Dating of the sediments underlying the colluvial units would give the period of time during which no floods exceeded the stage and associated discharge between the sediments immediately underlying the colluvial unit and the sediment thought to represent deposition during the 1932 - 1974 floods.

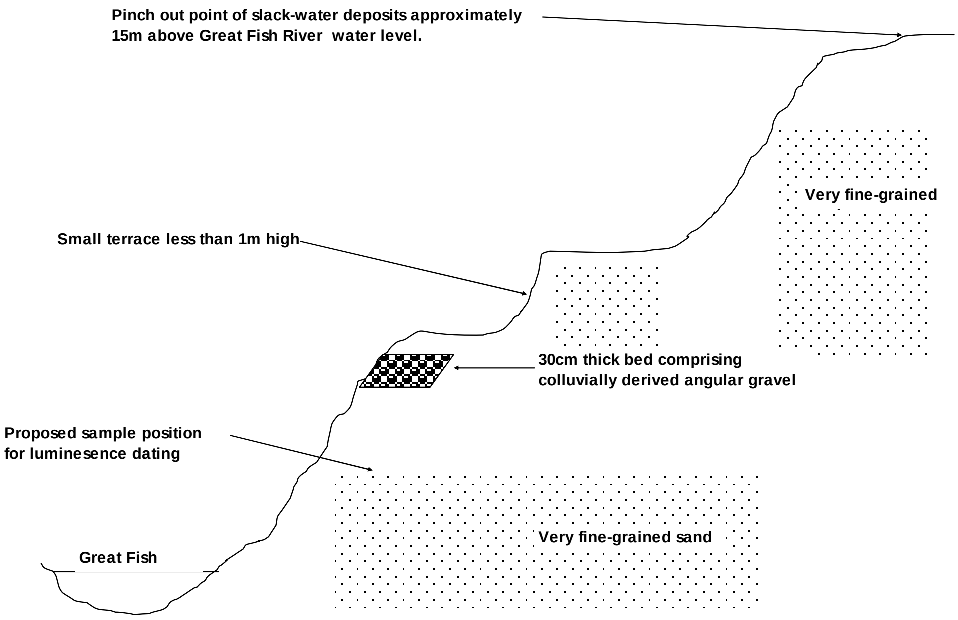

Figure 3.18: Schematic section of the slackwater sediments at Prudhoe, Great Fish River (approximately 15 km upstream of the mouth)

3.2.3.5 Conclusion - Palaeoflood data

Palaeoflood hydrological information was obtained from slack-water sites from the Gouritz River, the Sundays River, the Great Fish River and to a lesser extent the Great Kei River of the southern Cape region. Although resources did not permit studies of further promising sites and a detailed analysis of sites that were investigated, palaeoflood hydrological analysis has provided some important information on the magnitude and recurrence of large floods. This information would not have been available from conventional historical and systematic flood records.

The significant findings are listed by river investigated.

Gourits River

- The Gourits River at the Jan Muller Bridge experienced a flood with a discharge of 26 300 m^3/s 3 000 ±200 years ago. Even if one was to assume that the base level of the Gourits River was 10 m higher than today this still indicates that a flood of over 20 000 m^3/s occurred 3 000 years ago. This information is significant because the largest historically recorded flood was 11 400 m^3/s in 1981.

- In the light of the above finding and the observation of well-developed rock-cut benches in the bedrock it appears that the 1981 flood discharge should not be regarded as a catastrophic discharge but rather a relatively common large flood event. The palaeodischarges of 20 000 m^3/s and greater should be viewed as extreme for the Gourits River.

Sundays River

- Palaeoflood evidence of 2 floods with discharges of 13 300 m^3/s and 6 130 m^3/s exists for the Sundays River at Downlington Dam. These floods occurred approximately 6 100 – 8 600 years ago. In terms of historically recorded floods the largest floods recorded for the Sundays River were in 1932 and 1971 with discharges of 5 400 m^3/s and 5 300 m^3/s respectively. The comparatively old data for the palaeodischarges should be viewed as being on the maximum time span where palaeoflood events can inform modern flood prediction studies.

- The palaeoflood information indicates that the 1932 and 1971 floods seem to represent maximum flood discharges for a time period of about 6000 years.

Great Kei River

- Promising palaeoflood sites that were briefly investigated did not show palaeoflood levels appreciably higher than historically recorded ones, namely the 10 800 m^3/s in 1874. It is tentatively suggested that the maximum-recorded floods for the Great Kei River are an accurate representation of the maximum floods that can be expected. Further palaeoflood investigations are however still recommended for the Great Kei River.

Great Fish River

- Palaeoflood evidence close to Carlisle Bridge indicates that no floods occurred that were greater than the maximum recorded flood in 1974 of 9 231 m^3/s.

- The largest preserved palaeofloods (2 were identified) indicate discharges of no more than approximately 1300 m^3/s, which occurred circa. 2 000 years ago. This indicates that for the past 2 000 years up to around the start of the historical flood record (1819) the Great Fish River did not experience floods appreciably larger than 1 300 m^3/s. However, since 1919 at least 5 flood events with discharges varying between 4 400 – 9 231 m^3/s have occurred. This change in flood pattern could be explained by non-stationarity of climate through time or changed land use in the catchment.

3.2.3.6 Relevance of Palaeoflood Data

In placing the approximately 3 000 year old Gourits river palaeoflood and the other palaeoflood sites information into a climatic context with respect to the present climate, Jerardino (1995) noted the occurrence of three distinct Neoglacial episodes that occurred during the past 5 000 years, between 4 500 and 4 000 B.P., between 3 000 and 2 000 B.P. and during the last 1 000 years in southern South America and southern Africa. The middle Neoglacial episode that occurred between 3 000 and 2 000 B.P. was the most marked and was characterised by glacial advance in southern Chile, an average temperature decline of 1-3º with a marked increase in precipitation. In strong support of this contention, Talma and Vogel (1992) identified a marked cooling episode between 3 100 and 2 500 years B.P. based on an oxygen isotope temperature record of a speleothem at Cango Caves, in the southern Cape. Jerardino (1995) presented further evidence in support of this cooling period such as a buried organic-rich palaeosol that indicated a wet episode and yielded a radiocarbon age of 3 080 ±60 years old and palynological evidence from Cecilia Cave from Table Mountain that indicated cooler and wetter conditions were present around 3 000 years B.P. In conclusion it appears that the Gourits River palaeoflood can be placed into a palaeoclimatic context in which there is evidence that the flood producing system could have generated the Gourits River flood. Jerardino (1995) ascribed this climatic variation to minor northward latitudinal shifts of frontal systems and probably strong atmospheric circulation together with significant polar expansions into the Benguela current. Of importance is the observation that the short-term, low amplitude climatic change at around 3 000 – 2 000 years B.P. and its effect on the magnitude of generated floods should be viewed as part of the current flood series for the Gourits River.

3.2.4 Compilation of Data Sets for Analysis

The above data was combined at the identified sites and is shown in Appendix B for the regions included in the study. The annual maximum flood series for several sites with short records were extended using inter site correlation, combining site data for sites close to each other or transferring site peaks using the Francou-Rodier equation.

The assembled data for each of the drainage regions investigated at sites that included historical data and palaeoflood data are set out below:

Drainage region J- Gourits River system. Region J consists of four quaternary systems.

- Region J1-Buffels/Groot river with a total catchment area of 12 000 km^2. The most significant site in region J1 regarding historical and palaeoflood data is J1R003 the Buffels River at Floriskraal dam. From correspondence files for the sites used it is stated that the 1925 flood at Laingsburg was the largest since 1897. From this it is taken that no flood in the period 1897 to 1925 was larger than that of 1925. A previous palaeoflood investigation (Zawada, 1994) furthermore indicated that no flooding of a similar magnitude to the 1981 floods have occurred in this region. The 1981 floods did however smother any possible evidence of previous flood events under sediment that may have been present.
- Region J2-Gamka river with a total catchment of 18 000 km^2. No paleoflood information was sought in this region. The oldest reference to flooding was that of 1922 and as such the information provided in the files from DWAF (sections etc.) was sufficient to quantify the flood peak in the vicinity of site J2R006, Gamka River at Gamkapoort Dam.
- Region J3-Olifants River with a total catchment of 11 000 km^2. No palaeoflood information was sought in this region. Two sites did however have references two historical floods. The first site is the Groot River at J3H012 (Meiringspoort). Generally references always refer to the great flood of May 1885. After the floods of November 1996 it was stated that the flood of 1996 was the greatest since 1885. The second site for historical floods is the Olifants River at J3H011 (Warm water). Historical flood information from DWAF correspondence file provided flood information regarding the floods of 1897/98, 1916 and 1932. The floods of 1897/98 and 1932 were similar whilst that of 1916 was much greater. The information in the files was sufficient to provide quantative information for these three events. Several documents also referred to floods in 1849, 1869 and 1885.
- Region J4-Gourits River that includes J1, J2 and J3 with a total catchment area of 44 000 km^2. The Gourits River as shown in section 3.2.3.1 above was investigated for palaeofloods and some very significant historical information is available. The historical information was obtained from old Cape Colony Department of Public works files and newspapers and referred to three floods at the old rail bridge (Plan dated 1887 and in the same area as J4H001). The levels referred to were 40, 50 and 60 foot above riverbed level. The 50 foot stage or rise in water level was for the 1885 flood and is said to have been the highest since 1849.

From section 3.2.3.1 two significant palaeoflood levels and their associated slackwater units were identified. The largest slackwater unit with a stage 12.72m higher than the 1981 flood has an estimated discharge of 26300m^3/s and is dated at 3000 years before present. A second slackwater unit with a level similar to that of the 1981 flood (maybe slightly larger) was dated as 85000 years before present. The second unit could be discarded in terms of relevance, but higher unit 1 does have significance in terms of time (some micro climate changes maybe argued) and flow with the site being bedrock confined. The Francou-Rodier "K" of a flood with a discharge of 26300m^3/s is 5.3. The presently recommended "K" for the Gourits River is 5.0 (Kovacs, 1988). Considering the fact that during the 1981 floods the Groot (Buffels) River on its own contributed 11000m^3/s with the contributions by the other two major catchments being 3100m^3/s (Gamka) and 105m^3/s (Olifants) (Kovacs, 1983) each of the three main tributaries together do have the capacity to contribute to a flood of such a magnitude as that for slackwater unit 1 in the Gourits River.

Drainage region K- Southern Cape coastal rivers between Gourits and Gamtoos river mouths. The rivers in drainage region K all have relatively small catchments and moderate to high rainfall (MAP of 650 to 850 mm). No definitive historical floods were located. Generally flooding in the adjacent drainage regions J and L also resulted in flooding in region K. Furthermore the period of flow gauging is on average 40 years or more and floods that in a short record could be viewed as outliers have shown repetition to a certain extend. The well-vegetated state of the rivers and their flood plains, possible masking of palaeoflood evidence and time constraints precluded a palaeoflood evidence search for this region.

Drainage region L- Gamtoos river system and consists of 9 quaternary systems.

- Region L1- Sout River had two gauging stations that provide a combined period of observation from 1917-1988. No references to historical floods prior to this period were found and no palaeoflood evidence was looked for.
- Region L2-Buffels (Kariega) River. No additional historical or palaeoflood data was obtained. The gauging stations provide information for the period 1917 to 1992.
- Region L3-Groot River. No additional historical or palaeoflood data was obtained. The gauging station L3H001 and Beervlei Dam (L3R001) provide information for the period 1917 to 2001.
- Regions L4 and L5. No data.
- Region L6- Heuningklip River. No additional historical or palaeoflood data was obtained. The gauging stations provide information for the period 1928 to 2001.
- Region L7- Groot River. Historical information was obtained from bridge plans for Steytlerville for three floods (1897, 1907 and 1908). Further information for the same site was obtained for the 1905 flood from newspapers on the flooding in the Gamtoos River downstream. Previously investigated palaeoflood information (Hattingh and Zawada, 1995) for a cave site in the Grootrivierpoort is available. In all six palaeoflood events were identified with discharges varying between 2600m^3/s to 4400m^3/s. These events were dated as between 1900 to 1510 years before present. These lower events compares to the 1971 flood event.

- Region L8- Kouga river system. Only one historical event (1932) was obtained from DWAF files for the sites at L8H005 and L8R001 (Kouga Dam). The known palaeoflood evidence at the Kouga-Baviaans river confluence was not followed up due access and high dam levels.
- Region L9- Gamtoos River. Eight historical floods (1847, 1864, 1867, 1874, 1905, 1916, 1922 and 1932) were obtained for the Gamtoos River at Patensie, Hankey and at the rail bridge (DWAF files, Alexander, SPOORNET bridge plans, newspapers and Malan, 1959). The data could be cross-referenced at the various sites and as such provides confidence in the estimated flood discharges. The river reach was inspected for palaeoflood sites, but the extensive reworking by agriculture of the flood plains and the construction of canals destroyed any obvious evidence that may have been present. This should not however deter further searches for palaeoflood evidence.

Drainage region M- Coastal rivers between the Gamtoos and Sundays river mouths. The region has three quaternary systems of which only region M1 has any data of significance regarding systematic data. Historical data for region M1 was sourced for the Swartkops River between Uitenhage and the Swartkops River mouth. In all 13 historical flood peaks could be quantified between 1854 and 1983. The gauging station on the Swartkops River at Uitenhage was only opened in 1994/95. No palaeoflood data/evidence was looked for.

Drainage region N- Sundays River system and consists of four quaternary systems.

- Region N1- Upper Sundays River. No Historical or palaeoflood information, however the data recovered for gauging station N1H001 could be considered historical.
- Region N2- Middle Sundays River. Two historical peaks (1867 and 1874) were obtained from the bridge plans for the bridge at Jansenville. A third historical peak (1922) was obtained from DWAF files. The site at Darlington Dam (N2R001) had no historical floods, but flood data from the downstream gauging stations in the Sundays River Valley (N4H001 and N4H002) were transferred to Darlington Dam through correlations. Flood events prior to the record are only mentioned but could not be quantified at this stage. A palaeoflood site downstream from Darlington Dam yielded valuable data. One slackwater unit 20m above the riverbed is dated as 8000 years ago and has a discharge of 13300m^3/s. The second slackwater unit is 13m above the riverbed and is dated 7 100 years ago and has a discharge of 6100m^3/s. Although the relevance of these floods is open for debate they will be included in the analysis.
- Region N3-Voel River. One historical peak (1921) for the Voel River was also obtained from DWAF files. No palaeoflood data was sourced.
- Region N4- Lower Sundays River. Refer region N2.

Drainage region P- Coastal rivers between the Sundays and Great Fish river mouths. The region has four quaternary systems.

- Region P1-Bushmans River. Three historical peaks, 1893, 1905 and 1932, were obtained from bridge plans and reports held by the DWAF library. The flood of 1905 was however not used since flood peaks of a similar or greater magnitude could have occurred during the additional period of record. No palaeofloods were looked for.
- Region P2- No data.
- Region P3- Kariega River. No historical or palaeoflood information.
- Region P4- Kowie River. One historical peak (1889) outside the systematic record was obtained. No palaeoflood data.

Drainage region Q- Great Fish River system and consists of 9 quaternary systems.

- Region Q1-Upper Great Fish River and includes the Great and Little Brak and Teebus rivers. Only one historical flood peak on the Great Fish River (Q1H001) was included. This flood peak (1874) was transferred through correlation from the upstream site (Q2H002). No palaeoflood data was sourced for this region.
- Region Q2- Upper Great Fish River. One historical flood (1874) was sourced from DWAF records. No palaeoflood data.
- Region Q3- Great Fish River in the Cradock area. The 1974 flood was the largest flood in the area since 1874 and as such the 1974 flood was treated as a historical flood on both the Great Fish and Pauls rivers. No palaeoflood data.
- Region Q4- Tarka River. No historical or palaeoflood data.
- Region Q5- No data.
- Region Q6- Baviaans River. No historical or palaeoflood data.
- Region Q7- Middle Great Fish River in the Cookhouse area. In all three historical flood events (1846, 1874 and 1899) were quantified from DWAF files and bridge plans. No palaeoflood data.
- Region Q8-Little Fish River. No historical or palaeoflood data.
- Region Q9-Lower Great Fish River. In all 8 historical flood peaks (1846, 1848, 1870, 1872, 1873, 1874, 1876 and 1905) were sourced for this reach of the Great Fish river from DWAF files, newspaper reports and bridge plans. One more peak was added to the record from statements in the newspapers for the 1874 flood that a similar flood occurred in 1819. Two historical floods (1874 and 1881) were sourced for the Koonap River from DWAF files. None of the sites investigated for palaeofloods yielded information of floods greater than that of the 1974 flood.

Drainage region R- Coastal rivers between the Great Fish and Great Kei river mouths. The region has three quaternary systems.

- Region R1-Keiskamma River. Two historical flood peaks (1874 and 1918) were found on bridge plans obtained from Cape Provincial administration bridge plans. No palaeoflood information was obtained.

- Region R2- Buffalo River. Five historical flood peaks were obtained. Bridge plans for bridges at King Williams Town provided three flood peaks (1848, 1864 and 1874). Information on two further events (1905 and 1922) was obtained from DWAF files and Midgley (1970). No palaeoflood data was obtained.
- Region R3- Gqunube and Nahoon rivers. No historical or palaeoflood data.

Drainage region S- Great Kei River system and consists of 7 quaternary systems. Drainage region S is a boundary region and historical information was obtained at two sites. The first site is S3H006 on the Klaas Smits River (1960) and the second is at the railway and road bridges at the Kei River cuttings (1874, 1931, 1959 and 1963). The latter data was applied to gauging station S7H004 downstream from the bridges. The Palaeoflood information obtained during field work did not indicate any events that challenged the available flood peaks regarding discharges.

The collated data is attached in Appendix B and a summary of the period of observation of the data sets for the drainage regions are given in Table 3.3.

Table 3.3: Summary of Flood Peak Data Sets

Drainage Region	Period of Observation (years)								
	Systematic Data			Including Historical Data			Including Palaeoflood Data		
	Sites	Average	Maximum	Sites	Average	Maximum	Sites	Average	Maximum
J	26	46	90	5	109	152	2	2996	3000
K	15	39	42	-	-	-	-	-	-
L	11	55	83	4	100	154	1	1901	1901
M	3	49	76	1	148	148	-	-	-
N	5	69	97	2	130	135	2	7996	8001
P	3	37	45	2	111	113	-	-	-
Q	20	63	96	6	141	182	-	-	-
R	17	61	79	6	141	154	-	-	-
S	12	40	54	1	127	127	-	-	-
Average	**-**	**51**	**-**	**-**	**125**	**-**	**-**	**4777**	**-**
Total	**112**	**5766**	**-**	**27**	**3394**	**-**	**5**	**23885**	**-**

The average period of observation for the systematic record is 51 years, for the systematic and historic data this increases to 125 years and for the systematic and palaeoflood data the average period of observation is 4777 years.

3.3 Data Acquisition – Catchment Characteristics

The selection of catchment characteristics and parameters that need to be considered, based on previous studies in southern Africa are summarised in Table 3.4.

Table 3.4: Previous Studies-Catchment Characteristics

Date (year)	Title	Author (s)	Parameter	
			Abbr.	**Description**
1971	Report No. 1/71-Amendments to design flood manual HRU 4/69	Pitman, WV & Midgley, DC	A MAP S L Lc	Catchment Area (km^2) Mean annual precipitation (mm) River slope (m/m) Water course length (km) L distance to centriod (km) Meteorological region Veld type zone
1972	HRU Report 1/72	Midgley, D.C.	A MAP Kt Z	Catchment Area (km^2) Mean annual precipitation (mm) Factor related to return period Homogeneous flood zones
1983	Comparison of mean annual flood peaks calculated by various methods	McPherson, D.R.	A i L MAP	Catchment Area (km^2) Catchment slope (%) Water course length (km) Mean annual precipitation (mm)
1985	World Flood Study	Meigh, J & Farquharson, F	A MAP	Catchment Area (km^2) Mean annual precipitation (mm) Broader classification of climate
1988	Regional Maximum Flood Peaks in Southern Africa	Kovacs, Z	A	Catchment area (km^2) Geographical location
1993	Application of historical flood data in flood frequency analysis for the Natal and Transkei regions	Van Bladeren, D.	A	Catchment area (km^2) Geographical areas based on Kovacs (1988) regions.
2000	Regional flood frequency analysis for southern Africa	Mkhandi, S & Kachroo, S	A	Catchment area (km^2) DWAF drainage regions
2001	Flood frequency analysis at ungauged sites in the KwaZulu-Natal province, South Africa	Kjeldsen, TR, Smithers, JC & Schulze, RE	A MAP	Catchment Area (km^2) Mean annual precipitation (mm) Two homogeneous flood zones
2002	The Standard Design Flood – a new design philosophy	Alexander, WJR	A L S	Catchment Area (km^2) Water course length (km) River slope (1085) (m/km)

From the previous regional studies (Table 3.4) and recommendation regarding those studies and characteristics used in some of the deterministic methods, the following catchment characteristics were selected for possible inclusion in the regionalisation and development of the index flood and the relevant characteristics were obtained for the selected sites;

- Catchment area (A)
- Mean annual precipitation (MAP)
- River length (L)
- Catchment slope (I)
- Catchment perimeter (P) as a substitute for the enclosing circle
- Standardised or 1085 River slope (S)
- Vegetation classes (% of catchment)
- Soil types (% of catchment)
- Geology (% of catchment)

The selected characteristics and parameters above are either available or can be abstracted in bulk from readily available digital (GIS) data sources.

Digital 1:50 000 contour information containing 20 m contour intervals, of the study area was obtained from the Geomatics Department of DWAF. This information was used as the topographical bases for project. The information is referenced in decimal degrees using the Cape Datum. The positions of all DWAF flow gauges used in the study were also provided.

Spatial information regarding mean annual precipitation, vegetation, soil types and geology were obtained from the CD containing digital data of the project "Surface Water Resources of South Africa 1990" (or WR90) (WRC Report 298/1/94).

The correlation and relationship between the digitally derived topographical catchment data and manually derived topographical data (du Plessis & Petras, 1987 and Flood Studies) is reviewed and presented for the sake of users that do not have access to digital data in sections 3.3.1 to section 3.3.4.

The relationship that a variable has with flood runoff is undertaken using the mean annual flood estimated from taking the mean of the log transformed data in a series and is referred in this study as the log derived mean annual flood (Q_{ml}). The motivation for this selection is provided in Section 3.4.1.

3.3.1 Catchment area

Catchment area as a parameter is the most significant as a variable regarding flood runoff (Ponce, 1989) and this relationship, for all the sites in the study area, is shown in Figure 3.19. The coefficient of determination (R^2) and relationship between A and Q_{ml} for all the sites in the study region is also shown on Figure 3.19. Although this relationship does not include any regionalisation, A as a parameter does qualify for inclusion in the estimation of the index flood (Q_i).

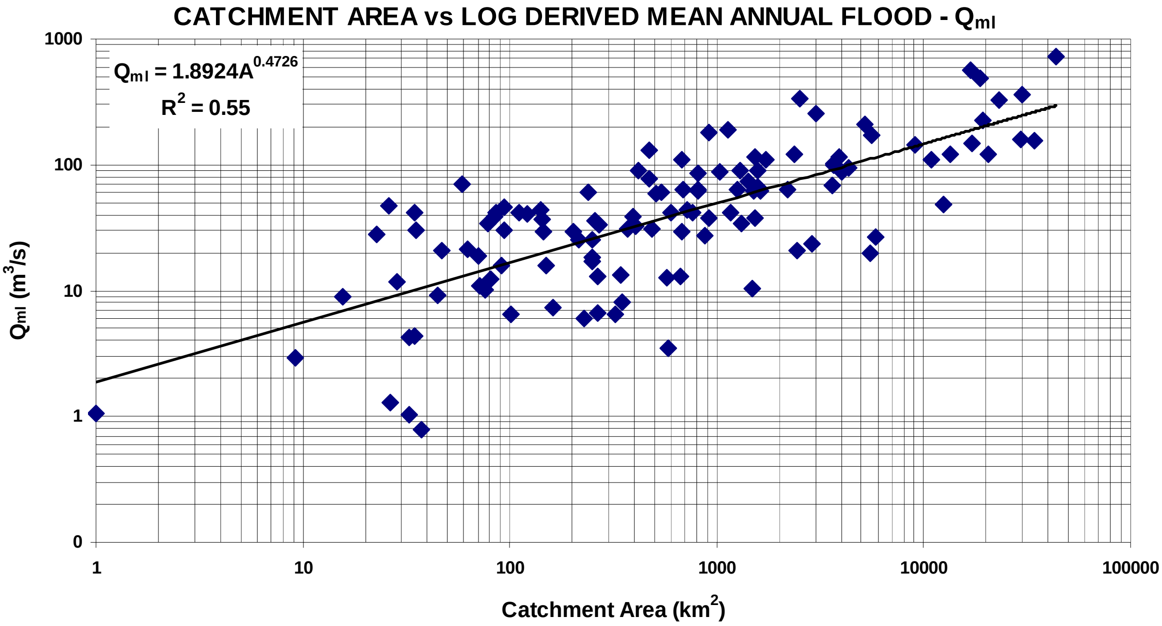

Figure 3.19: Catchment area vs Q_{ml}

Gauging station catchment boundary information was not available in the data supplied by DWAF. The digital quaternary drainage region catchment boundaries and the spatial position of the flow gauges used in the study were used to compile digital catchment boundaries for each gauge (in ArcView SHP file format with 100m grid based digital elevation model). It was projected to the appropriate L_O projection system to determine the catchment area (in km^2) and perimeter (in km). The catchment areas determined from the GIS compared to the published DWAF data, is shown in Figure 3.20 below.

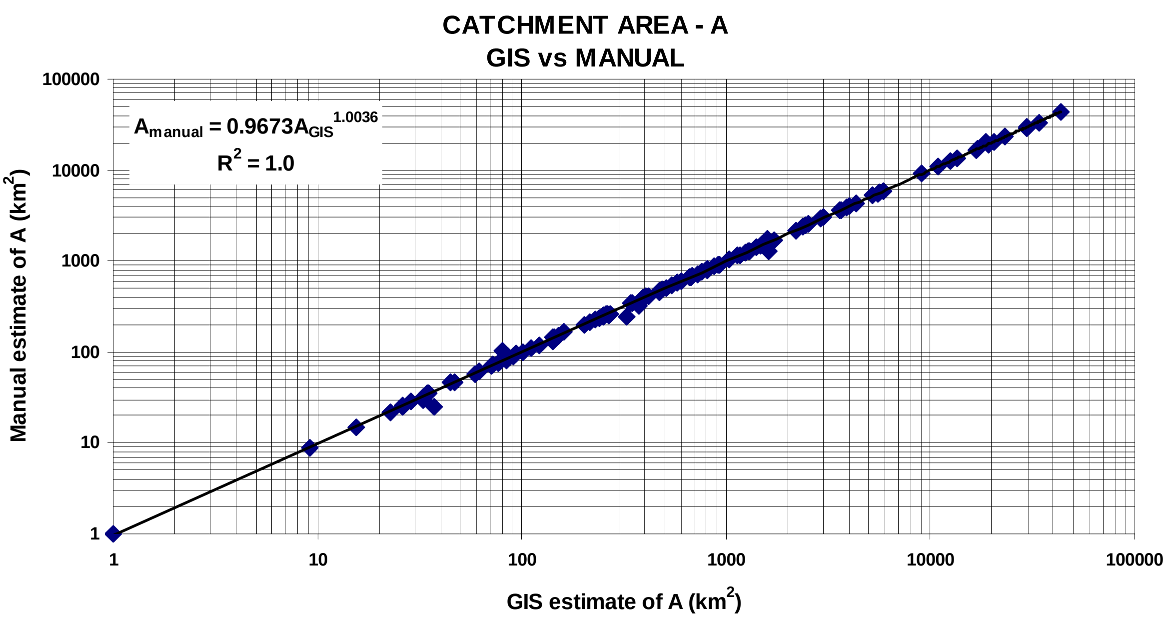

Figure 3.20: GIS vs DWAF published – catchment area

3.3.2 Mean catchment slope

The contour information (in ArcView SHP file format) was transformed into a digital elevation grid with a 100 m x 100 m resolution, using various ArcView 3.x extensions (including Spatial and 3D Analyst) and GIS techniques to determine the relevant parameters.

Information contained in the elevation grid and the catchment boundaries for each gauge were used to derive the percentage slope for all gauges. The percentage slope in the catchment of each gauge was determined for the following ranges of catchment slope:

0 – 1 %

1 – 3 %

3 – 10 %

10 – 30 %

30 – 50 %

50 – 100 %

100 – 200 %

> 200 %

The aerial weighted mean % catchment slope was then calculated for each site used in the study.

The mean catchment slope as a parameter in the CAPA method (McPherson, 1983) for the estimation of Qi, converted to a unit discharge (q_{ml} in $m^3/s/km^2$), is shown in Figure 3.21. Visually Figure 3.21 does suggest a direct relationship but the value of R^2 is relatively poor.

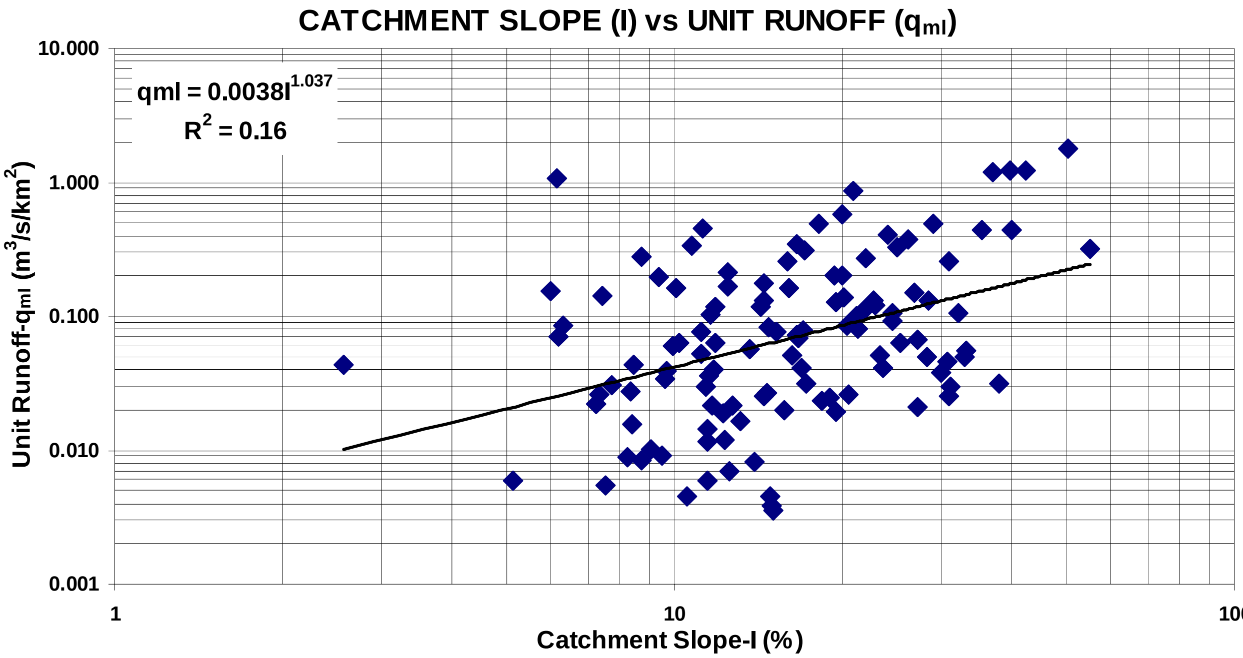

Figure 3.21: Mean catchment slope vs Qi

The comparison of the GIS based estimate and the available manual estimates of the catchment slope from DWAF and Petras and Du Plessis (1987) are shown in Figure 3.22. The correlation is 90% (square root of R^2) and GIS estimates are 2% lower than the manual estimates. This difference can be attributed to 100x100 m grid used by the GIS estimates vs the 50 node point minimum used by the manual methods.

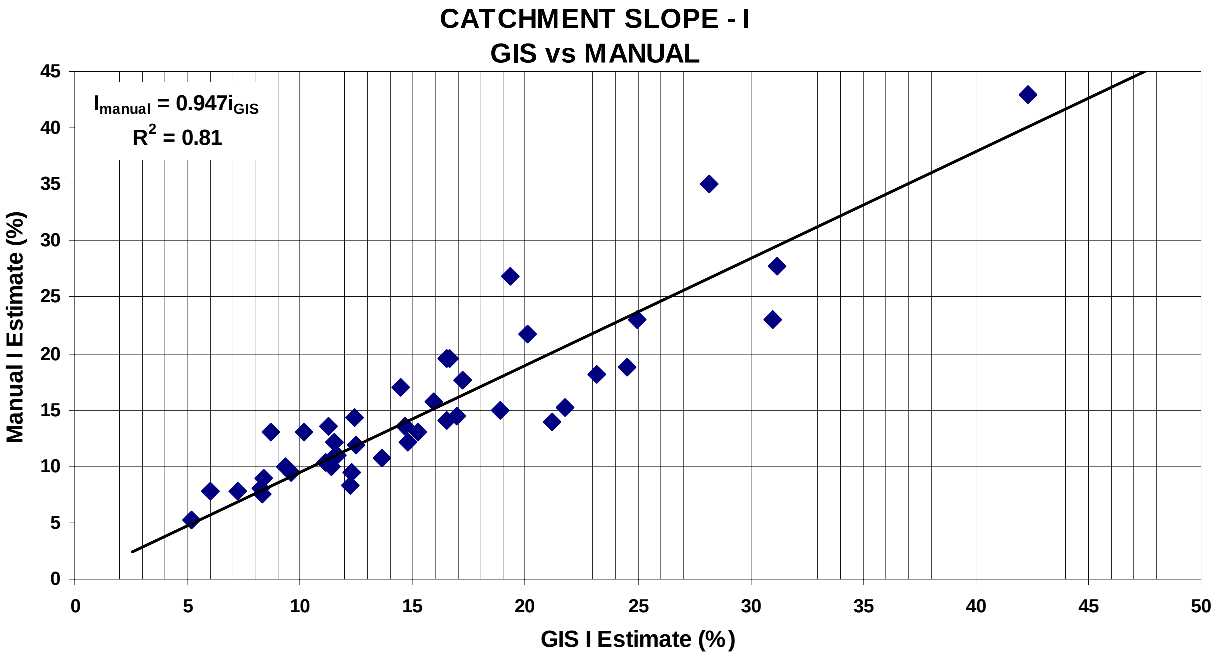

Figure 3.22: GIS vs Manual – Mean catchment steepness

3.3.3 River slope and main channel length

The standard river slope referred to as the 1085 slope was selected for the study due to ease of obtaining the data used to estimate it. The 1085 slope (m/m) is estimated using elevation difference of the river at positions 10% and 85% from the site of interest measured along the watercourse and dividing it by 75% of the total river length. Visual inspection showed that the existing digital river information provided by DWAF and also that contained in the WR90 data set did not fit the 20m contour data well, necessitating some data editing to correct the water course positions. The longest watercourse for each gauge was corrected and then projected onto the grid, using the appropriate L_O co-ordinate system for that gauge, to determine the stream length for the river upstream from the gauge. An ArcView extension previously developed was then used to determine the 1085 river slopes. The relationship of the 1085 river slope as a parameter to estimate Q_i converted to a unit discharge (q_{ml}) is shown in Figure 3.23. The R^2 of 0.4 for river slope would suggest that river slope as a variable is a much better contender than catchment slope for inclusion in the estimation of the index flood.

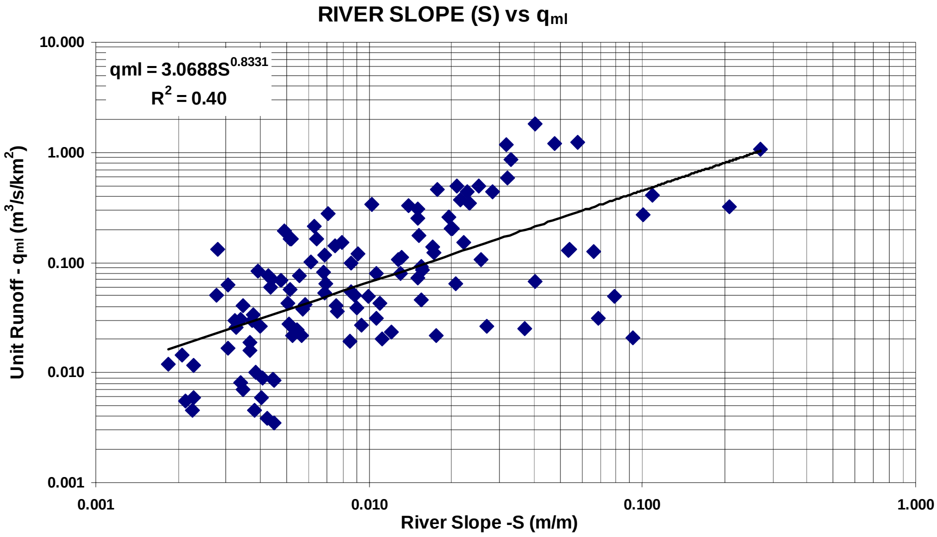

Figure 3.23: River slope (S) vs Q_{ml}

The DWAF and Petras and Du Plessis (1987) manual and GIS estimates for the length of the longest watercourse is shown in Figure 3.24. The correlation (R) is 98% between the two methods with manual estimates being about 6% larger. This could be due to the resolution difference and the methods used when estimating manually. Manual methods use a measuring wheel to determine the river length and the result is adjusted by recommended factors to compensate for the impact of the map scale.

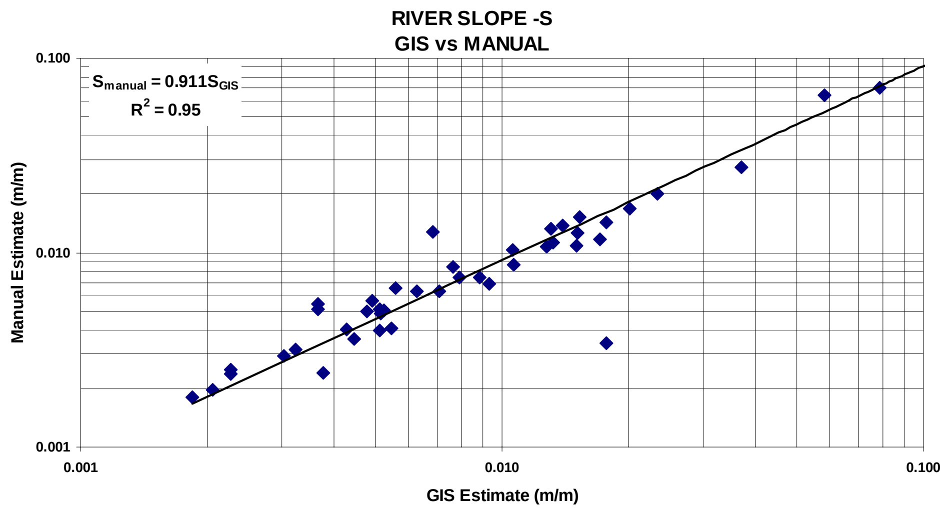

Figure 3.24: GIS vs Manual – Length of longest watercourse

3.3.4 Mean Annual Precipitation-MAP

The WR90 Report mean annual precipitation (MAP) isoline coverage was used for this project. The isolines were converted into ArcView SHP file format, and standard GIS techniques were then used to determine the area covered by the isolines in every catchment for the gauges used in the study. The estimated area coverage between two isolines and the average MAP for the two MAP isolines was then used to determine the aerially weighted MAP for the gauge of interest. The relationship of the MAP as a parameter to estimate Q_i converted to a unit discharge (q_{ml}) is shown in Figure 3.25 and shows a strong direct relationship with a R^2 of 0.56.

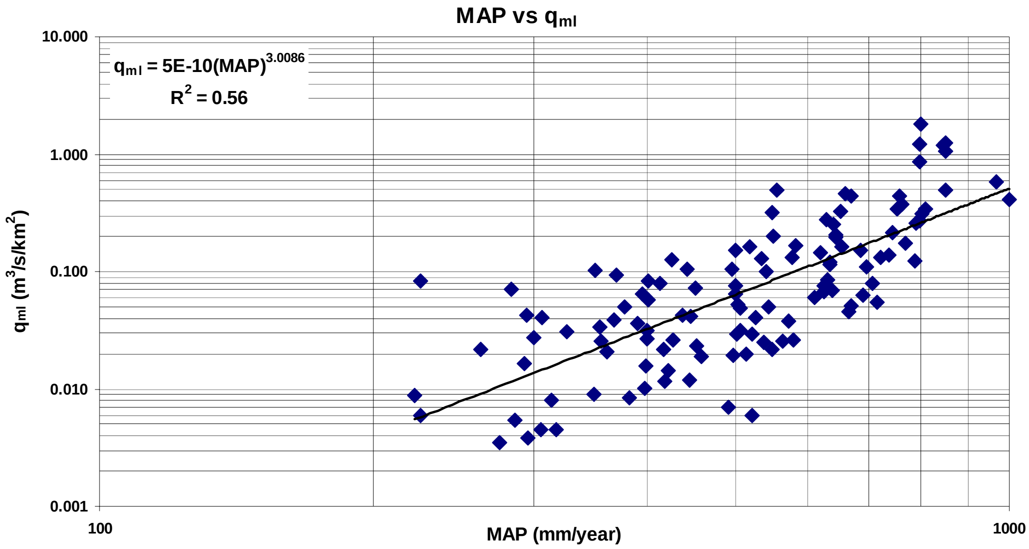

Figure 3.25: Mean annual precipitation (MAP) vs Qi

A comparison between the manual estimated catchment MAP, using various data and mapping sources by DWAF and Petras and Du Plessis (1987), and the GIS estimate is shown in Figure 3.26. The correlation was 91% with the manual estimates for MAP being 12% higher than the GIS based estimates. Although the base information for the MAP for manual estimates post WR90 are the same as those used by the GIS estimates, those used prior to WR90 were not always consistently the same as the MAP information was obtained from various sources.

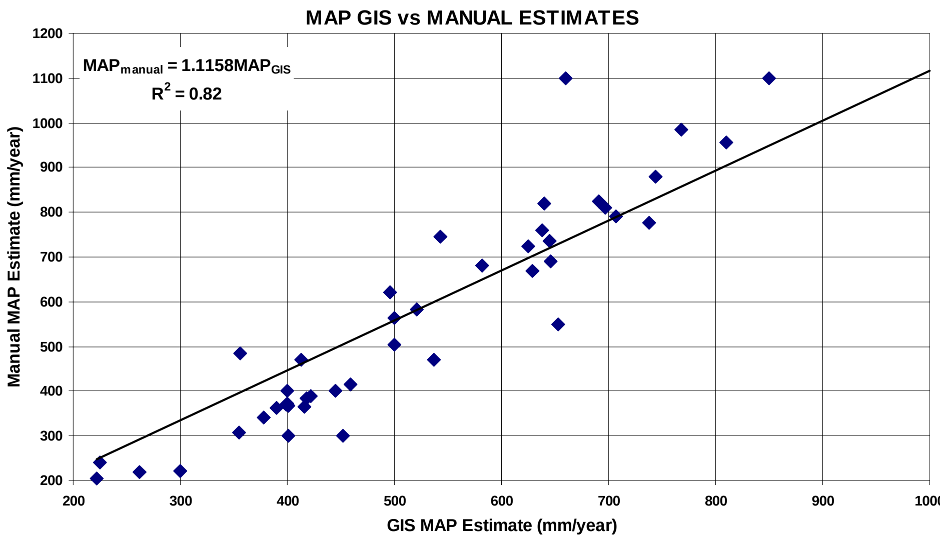

Figure 3.26: GIS vs Manual – Mean annual precipitation (MAP)

The MAP for the study area is shown Figure 3.27. The topographical catchment characteristics and MAP for the sites used in the study are shown in Appendix C1.

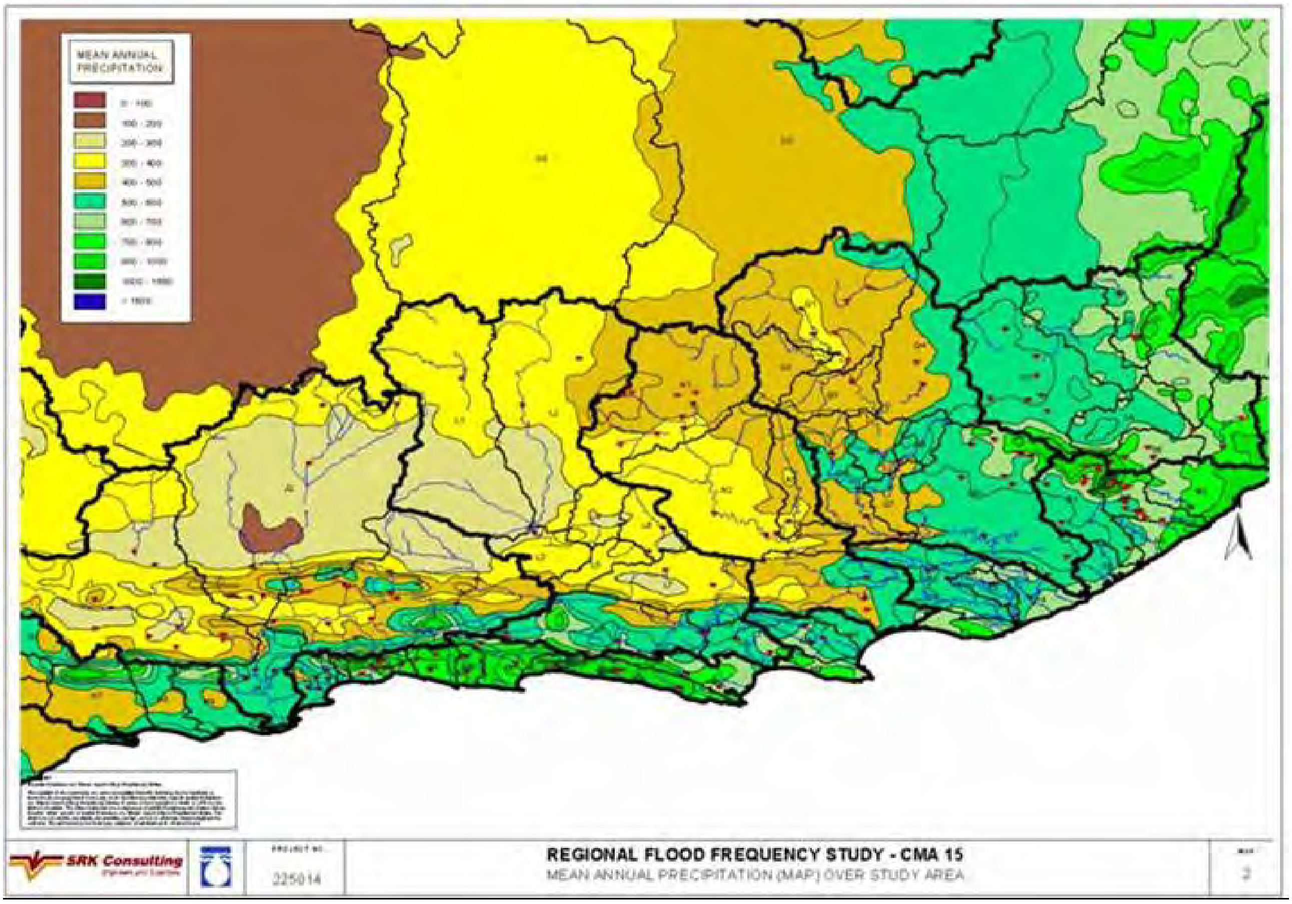

Figure 3.27: Mean Annual Precipitation For Study Area

3.3.5 Vegetation

The vegetation types identified in WR90 were used. (Figure 3.28)

Vegetation information used in this study was based on the WR90 vegetation coverage (called VEG in WR90), and is basically a digital version of the 10 main Acocks veld types of South Africa.

The VEG coverage was converted into ArcView SHP file format, and standard GIS techniques were used to determine the percentage of area covered by a particular vegetation type for every catchment of the gauges used in the study. The vegetation types for the sites used in the study are shown Appendix C2.

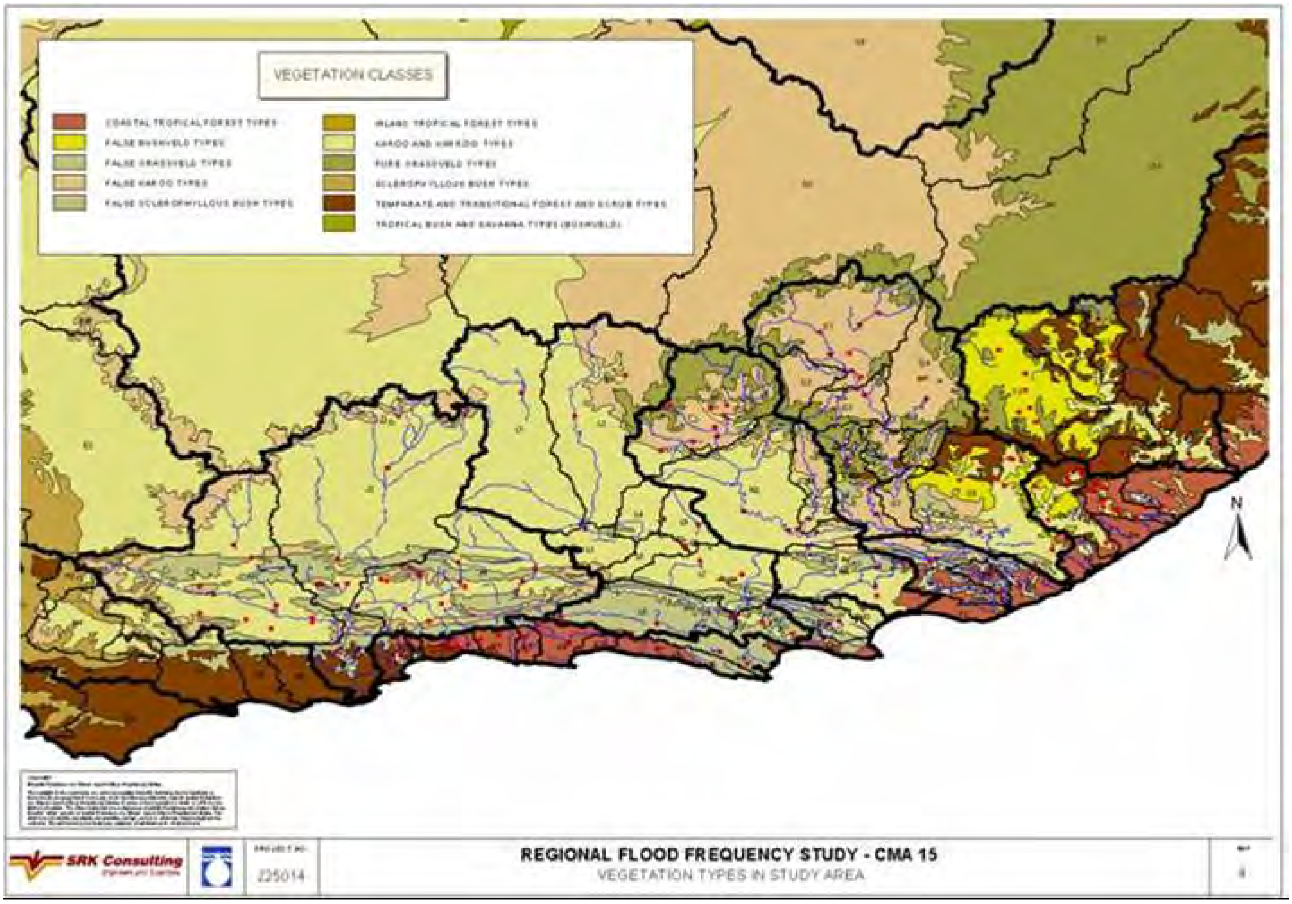

Figure 3.28: Vegetation Types in Study Area

3.3.6 Soil types

The soils types identified in WRC90 were used. (Figure 3.29).

Soil type information used in this study was based on the WR90 soils coverage (called SOI in WR90). This coverage contains various soil parameters, and it was decided to only use the average soil depth (ASD field in the coverage) and dominant series texture (DSTEXTURE field in the coverage) for the purposes of this study.

The SOI coverage was converted into ArcView SHP file format, and standard GIS techniques were used to determine the percentage of area covered by the relevant average soil depth and dominant series texture parameters for every catchment of the gauges used in the study. The soil types are shown in Appendix C3 for all the sites used in the study.

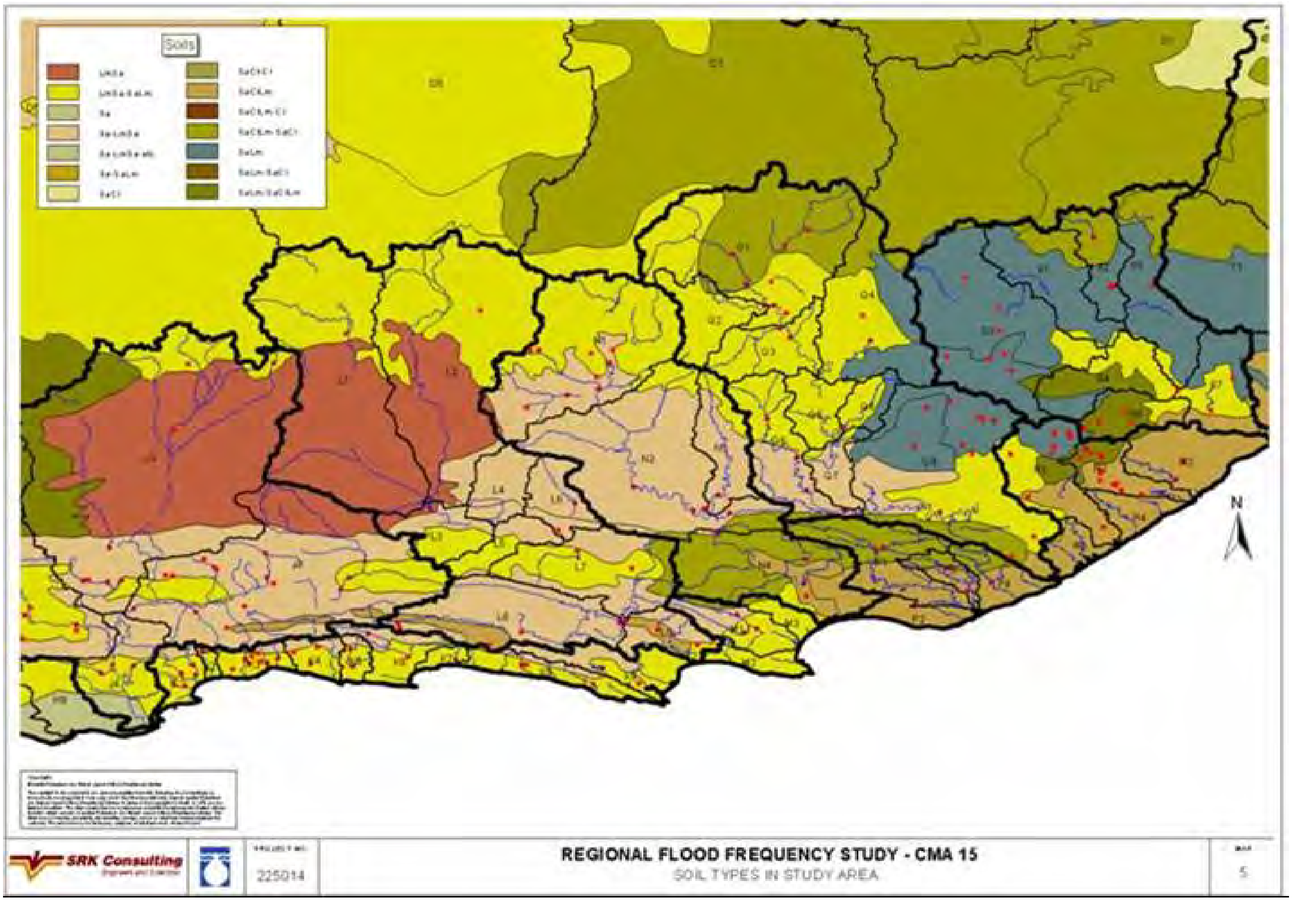

Figure 3.29: Soil Types in the Study Area

3.3.7 Geology

The base geology in WRC90 was used. (Figure 3.30).

Geological information used in this study was based on the WR90 geology coverage (called GEOL in WR90). The GEOL coverage was converted into ArcView SHP file format, and standard GIS techniques were used to determine the percentage of area covered by the relevant geological type present in every catchment of the gauges used in the study. The base geology for all the sites used in the study is shown in Appendix C4.

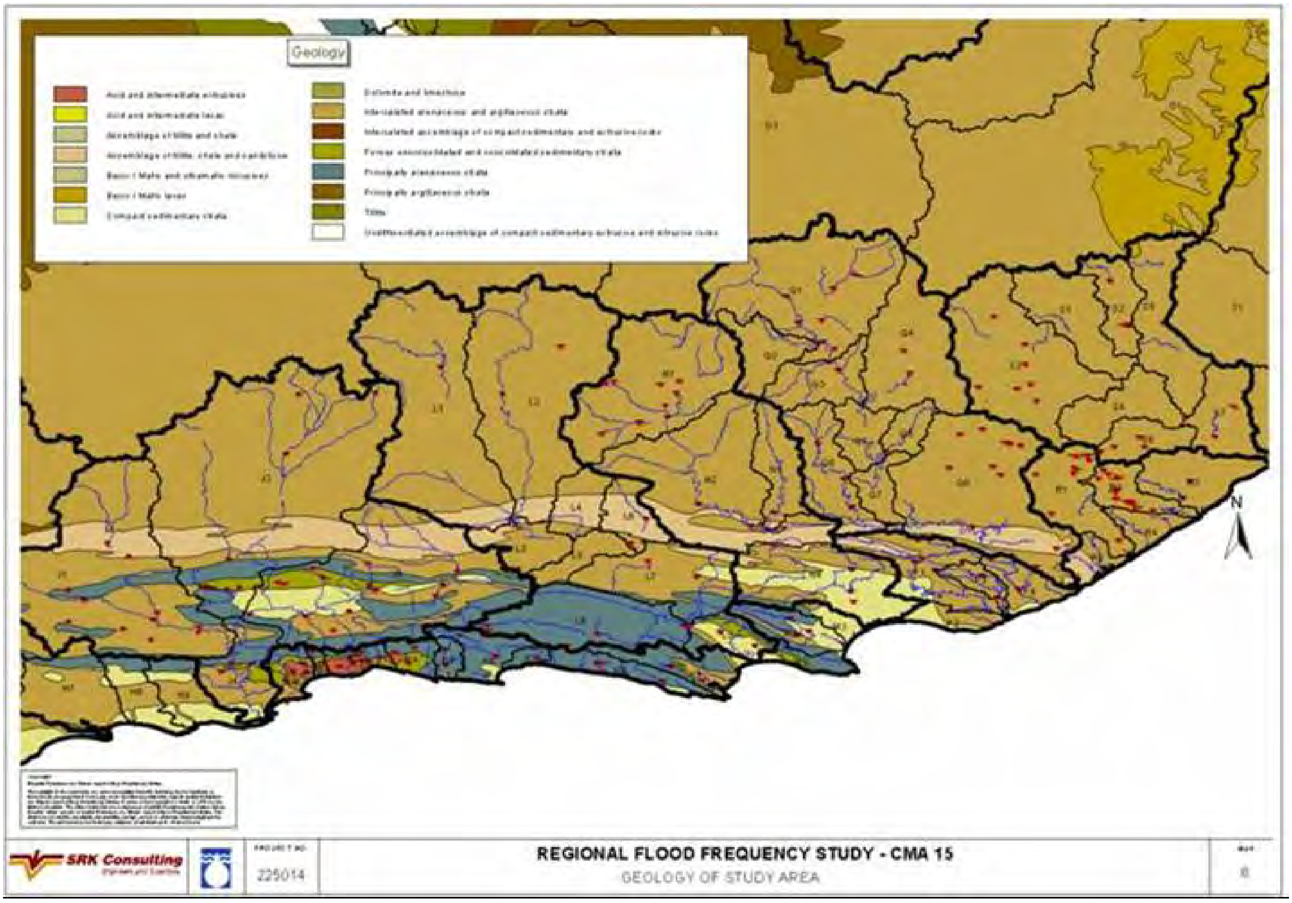

Figure 3.30: Geology of the Study Area

3.3.8 Catchment Shape Parameters

Properties considered to determine the catchment shape factor were catchment area (A), river length (L) and catchment perimeter (P). The inverse of the relative stream length as used in the CAPA method (Du Plessis and Petras, 1987 and defined as $A^{0.5}/L$

The relationship for the relative stream length and the unit discharge (q_{ml}) is shown in figures 3.31 and the choice of A and L also relate to the consistency of their estimation.

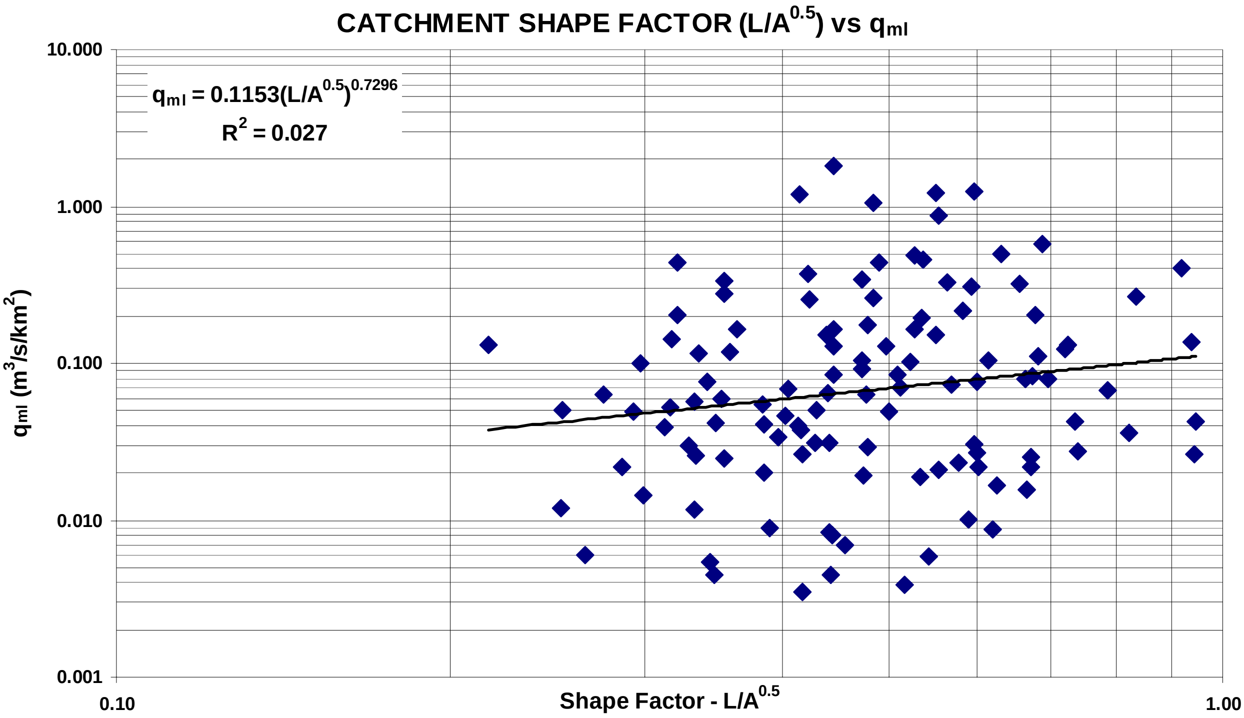

Figure 3.31: Catchment Shape Factor ($L/A^{0.5}$) vs q_{ml}

The catchment shape factor defined as $L/A^{0.5}$ is used in the CAPA method. The R^2 of 0.027 is however low.

3.3.9 Other Variables and Factors

Several other factors considered for possible inclusion are stream density, urban areas and open water surfaces. Urban areas and open water surfaces were not considered since these do not account for a significant portion of the catchment areas used in the study. Stream density, which is related to the catchment topography and geology, is deemed to be taken into account through the regionalisation that is under taken for the project. Stream density as a variable has also not found a great deal of use in South Africa.

The selection of topographical variables is not related to the regionalisation. By including all the sites in the assessment, the pool of data points is increased. The final regionalisation considering the influence of soils, vegetation and geology is undertaken in Section 3.4.3.

3.4 Development of Index Flood (Q_i)

The development of a method to estimate Q_i used the CAPA methodology as the basis. This section assesses the most common three possible candidates parameters used as $Q_{i.}$, These variables are the mean annual flood (Q_m), median annual flood (Q_{med}) and the mean annual flood derived from the mean of log transformed AMF data (Q_{ml}) that may also be used as an estimate of the median value.. The relationships between the various candidate bases are also evaluated. An alternative to the CAPA methodology to estimate the Q_i is proposed.

3.4.1 Selection of Q_i base

For a regional estimation of Q_i it is important that the parameter selected as Q_i remain robust showing very little change to impact of outliers in the data set or of record length on the estimated value for Q_i. McPherson (1983) had already evaluated other candidates such as Q_2 derived from statistical analysis using various distributions and the Rational method and found that the arithmetic mean of the data series was the least sensitive to variations in record length and outliers in the data series used. However from previous work by DWAF and members of the project team the stability of the arithmetic mean has been found to be sensitive to record length and outliers in the data series. This was specifically pronounced in the more arid areas and the eastern escarpment areas of South Africa. It was therefore decided to re-evaluate the arithmetic mean referred to as Q_m and to also evaluate the median value (Q_{med}) and mean (or estimate of the median value) derived from the arithmetic mean of the log transformed data of the data series (Q_{ml}).

In order to determine which of these three candidate indices is the most robust for providing the bases for Q_i, the AMF data from sites with the longest records were selected from each of the drainage regions included in the study. Historical and palaeoflood data at the sites were excluded from the estimation of the Q_i value. Data impacted upon significantly by upstream developments such as dams during the period of gauging was also excluded. The data was listed in chronological order and the three bases for the estimation of Q_i were then estimated for each set as the period of observation increased. The estimated Q_i for the record length as it increased was divided by the Q_i for the total record and the results are summarised in Tables 3.5, 3.6 and 3.7 and shown in figures 3.32, 3.33 and 3.34.

From Table 3.5 and Figure 3.32 the estimation of Q_i using the median flood from the varying length data it is clear that stability, defined as the deviation from the total record estimate, has a regional character that is influenced by the amount and variability of the rainfall. The sites in regions K, R and S, which are less arid and coastal or mountainous stabilise at data series lengths between 15 to 20 years. Sites in regions J and P also have this trend with J3R002 being stable from 5 to 10-years. The latter could however be considered anomalous. For regions L, N and Q the stability in the estimation of Q_{med} only starts after 40 years or more of data. The maximum variance with the long-term value is 3.15 for the site in drainage region Q. This would indicate a non-stationary record for Q7H005. An examination of the data and the moving average indicates a decrease in the lower flood events that would suggest that the record is impacted upon by upstream and catchment related activities such as dams, water transfer schemes and land use changes. The early period of the record is also characterised by a larger number of medium to large flood events.

Table 3.5: $Qmed_i$ Estimates vs Full Record Qmed

Record length (years)	$Qmed_i$/Qmed							
	J3R002	**K7H001**	**L7H006**	**N2H007**	**P1H003**	**Q7H005**	**R1H005**	**S6H001**
5	1.16	1.09	1.33	1.00	1.91	3.05	2.31	1.44
10	1.15	1.01	1.13	1.34	1.00	3.15	1.48	1.25
15	1.14	1.09	1.33	1.51	1.17	3.25	1.26	1.02
20	1.15	1.32	1.78	1.51	1.16	3.25	0.98	1.00
30	1.17	1.05	1.46	1.51	1.16	1.96	0.98	1.25
40	1.17	1.00	1.27	1.31	1.00	2.59	1.17	1.25
50	1.15	-	1.12	1.20	-	1.92	1.17	1.00
60	1.16	-	1.00	1.10	-	1.58	1.00	-
70	1.04	-	1.00	1.00	-	1.23	0.98	-
80	-	-	-	-	-	1.07	-	-
90		-	-	-	-	1.02	-	-
Record Length	78	40	74	78	45	96	74	54

Note: $Qmed_j$ where j=5 to N, where N is the record length in years.

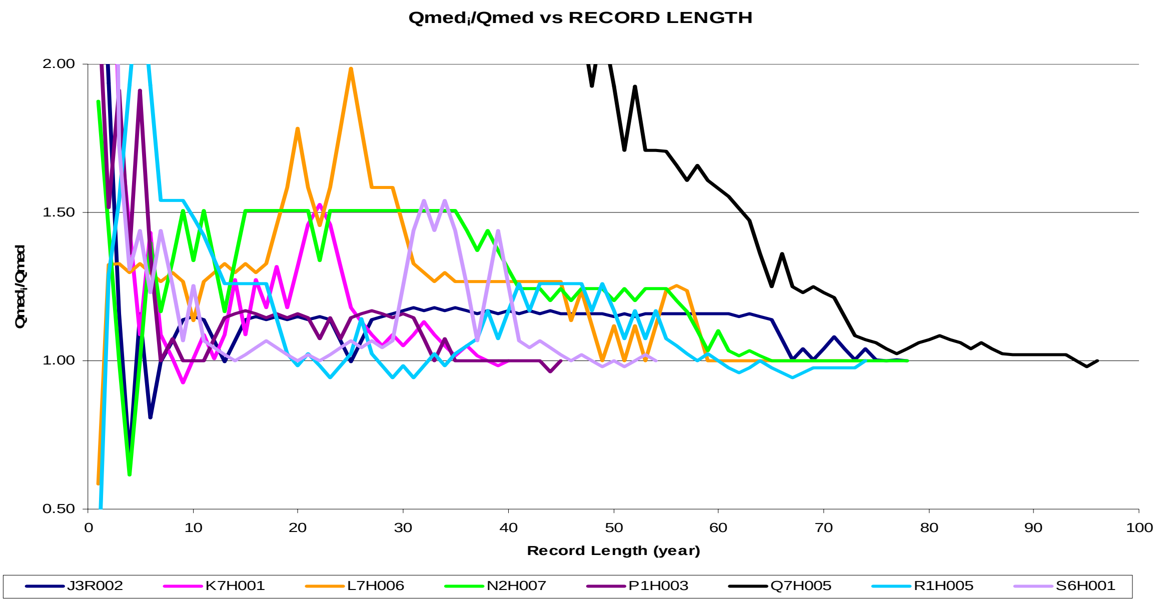

Figure 3.32: Index Flood Base Stability-Varying Data Set Length Median Flood ($Qmed_j$) vs Long Term Data Set Median (Qmed)

Table 3.6 and Figure 3.33 show the estimation of Q_i using the mean annual flood, estimated from the varying data period length, it is clear that stability of the Q_i defined as the deviation from the total record estimate also has a regional character that is related to rainfall. This is however not as well defined as for the Q_i estimate using the median values. The sites in regions N, Q and R stability of the Q_i estimate only start at periods of 50 years or more. For the other areas it is 20 or more years. The maximum variance with the long-term value after a 10 year period is 2.13 for the site selected in drainage region Q. The reason for the high variation is similar to that provided for the Q_{med} estimates above.

Table 3.6: Qm_i Estimates vs Full Record Qm

Record length (years)	Qm_i/Qm							
	J3R002	**K7H001**	**L7H006**	**N2H007**	**P1H003**	**Q7H005**	**R1H005**	**S6H001**
5	0.60	1.09	1.07	1.52	0.89	2.28	0.93	1.49
10	0.64	1.01	0.78	1.46	0.59	2.13	0.73	1.33
15	0.73	1.09	1.06	1.33	0.99	2.08	0.64	1.07
20	0.83	1.32	1.10	1.50	0.97	1.87	0.56	0.98
30	1.01	1.05	1.12	1.30	1.23	1.68	0.74	1.09
40	1.03	1.00	1.01	1.23	1.06	1.52	0.84	1.15
50	0.96	-	1.07	1.16	-	1.40	0.98	1.03
60	0.97	-	1.03	1.19	-	1.22	0.96	-
70	0.91	-	1.00	1.07	-	1.25	0.98	-
80	-	-	-	-	-	1.13	-	-
90	-	-	-	-	-	1.05	-	
Record Length	78	40	74	78	45	96	74	54

Note: Qm_j where j=5 to N, where N is the record length in years.

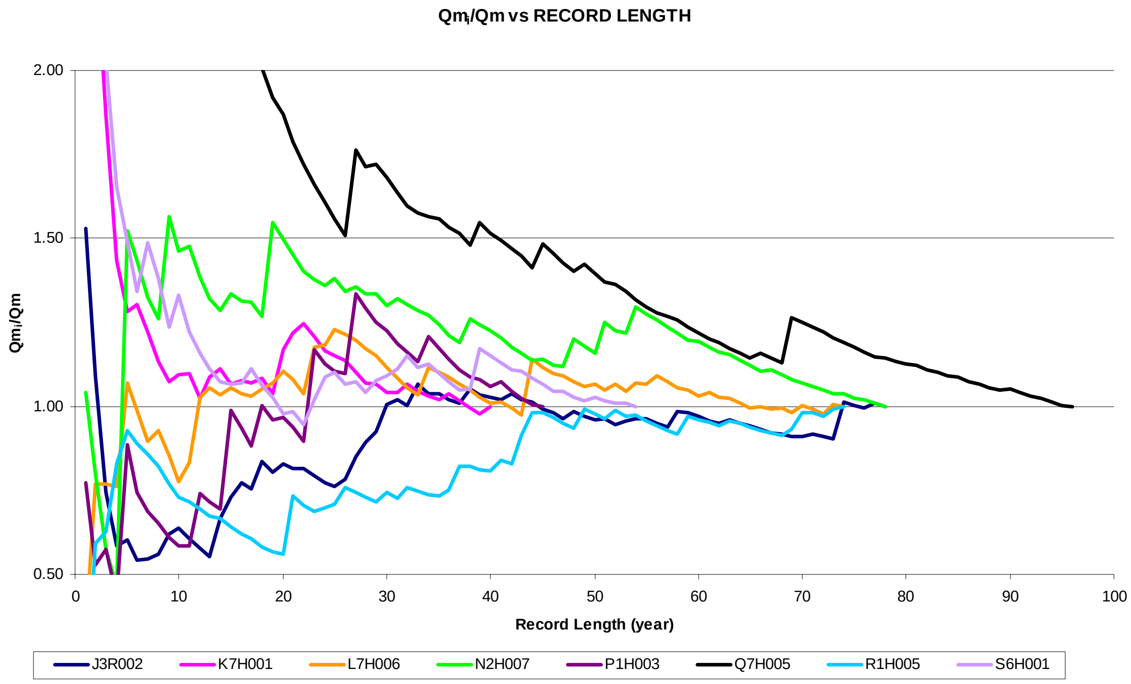

Figure 3.33: Index Flood Base Stability-Varying Data Set Length Mean Flood (Qm_j) vs Long Term Data Set Mean (Qm)

Table 3.7 and Figure 3.34 the estimation of Q_i using the mean flood estimated using the log transformed data (Q_{ml}), for the varying data period length, it is clear that stability of the Q_i estimate, defined as the deviation from the total record estimate also has a regional character that is related to rainfall. The sites in all the regions with the exception of the sites in regions P and Q stabilise after ten years and the variation amongst the regions are less than either of the other two. This is well demonstrated by figures 3.32, 3.33 and 3.34. The maximum variance with the long term value after a 10 year period is 1.24 for the site selected in drainage region Q which is significantly less than either estimates using the median or mean annual floods.

Table 3.7: Q_{ml} Estimates vs Full Record Q_{ml}

Record length (years)	Qml$_i$/Qml							
	J3R002	**K7H001**	**L7H006**	**N2H007**	**P1H003**	**Q7H005**	**R1H005**	**S6H001**
5	0.88	1.04	1.13	1.07	1.28	1.24	1.05	1.17
10	0.94	1.04	1.04	1.13	1.17	1.22	1.01	1.12
15	0.96	1.03	1.10	1.14	1.36	1.22	0.98	1.05
20	0.98	1.04	1.12	1.16	1.33	1.21	0.94	0.99
30	1.02	1.01	1.10	1.15	1.27	1.16	0.98	1.05
40	1.03	1.00	1.07	1.14	1.02	1.14	1.00	1.04
50	1.01	-	1.05	1.11	-	1.10	1.01	1.00
60	1.01	-	1.03	1.07	-	1.05	0.99	-
70	0.99	-	1.00	1.01	-	1.04	0.99	-
80	-	-	-	-	-	1.02	-	-
90	-	-	-	-	-	1.01	-	-
Record Length	78	40	74	78	45	96	74	54

Note: Qml_j where j=5 to N, where N is the record length in years.

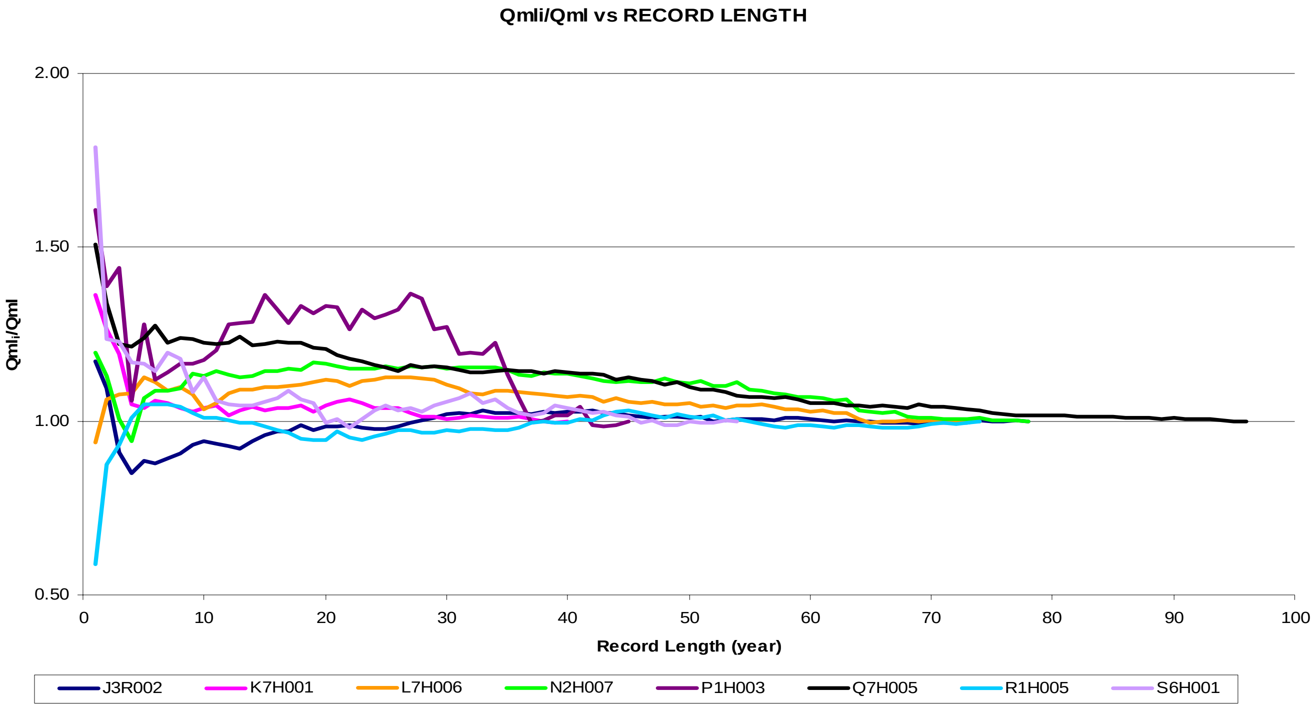

Figure 3.34: Index Flood Base Stability-Varying Data Set Length Logs Of Annual Maximum Flood (Qml_j) vs Long Term Data Set Logs Of Annual Maximum Flood Peaks (Ml)

From the above results it is clear that of the three parameters evaluated the log transformed data estimate of the mean annual flood (Q_{ml}) is the most robust and stabilises sooner than the either mean or median annual flood. By using the Qml sites with relatively short records (more than 15 years) may thus also be considered for the study.

The relationship between Q_m, Q_{med} and Q_{ml} for all sites in the study area is shown in figures 3.35, 3.36 and 3.37.

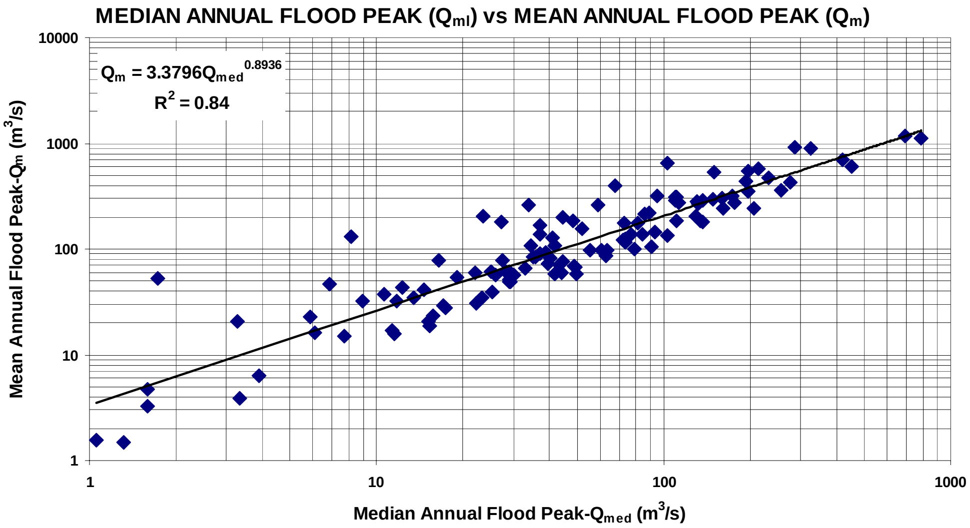

Figure 3.35: **Median Annual Flood vs Mean Annual Flood**

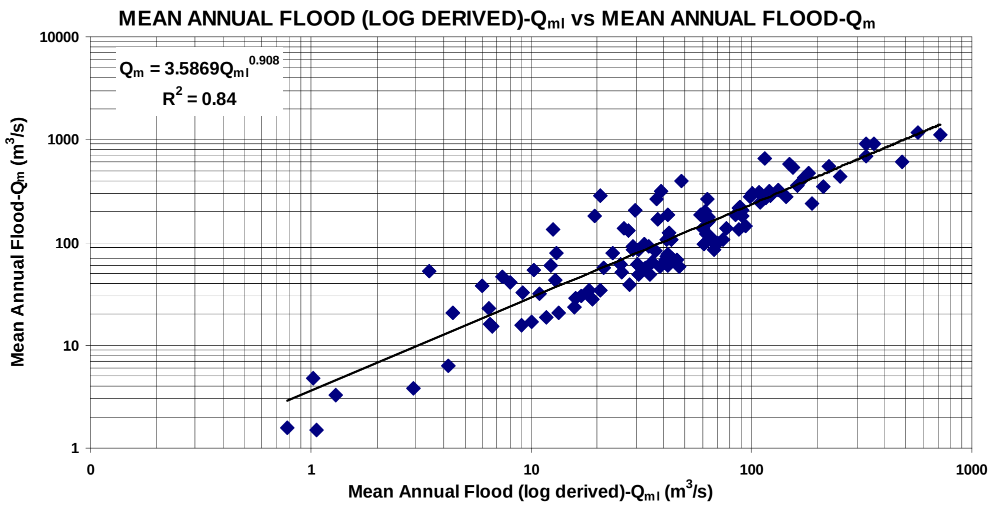

Figure 3.36: Mean annual flood (log derived) vs mean annual flood

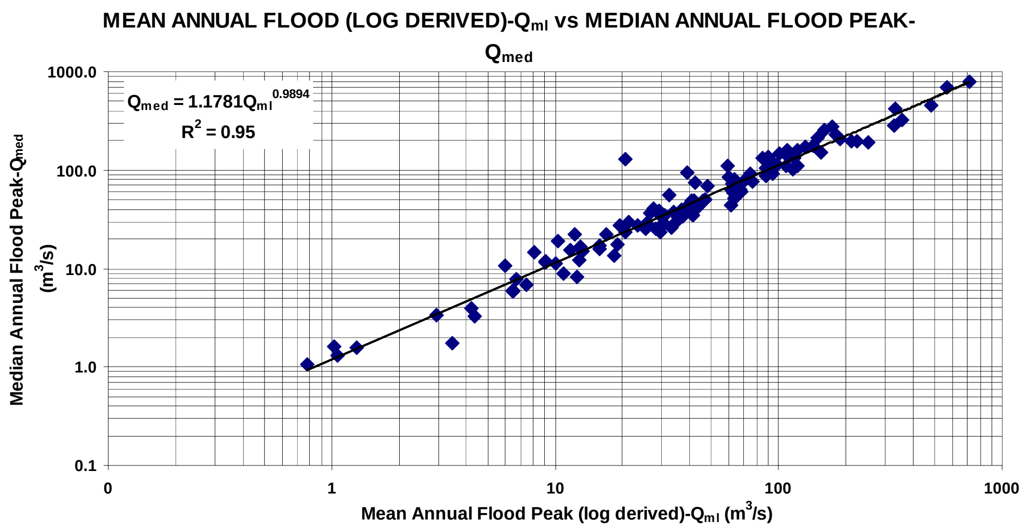

Figure 3.37: Mean annual flood (log derived) vs median annual flood

3.4.2 Development of Q_i estimation

From the literature survey and Section 3.3 it is evident that the CAPA methodology (McPherson, 1983) included most of the variables that impact on the estimation of the mean annual flood selected as Q_i in the CAPA method. From the original study and subsequent comments regarding the method the inclusion of more parameters or the regionalisation of the method are suggested to improve the results of the method.

The CAPA method requires that the lumped parameter "M" for the site of interest be estimated;

$$M = MAP\left(i\frac{\sqrt{A}}{L}\right)^{1/2}$$

Where;

MAP : Mean annual precipitation (mm)

i : Catchment slope (%)

L : Length of the longest water course (km) and

A : Catchment area (km^2)

The original study (McPherson, 1983) plotted the mean annual flood from the AMF series against catchment area and families of lines for sites with similar "M" were drawn to develop the nomograph shown in Figure 3.38.

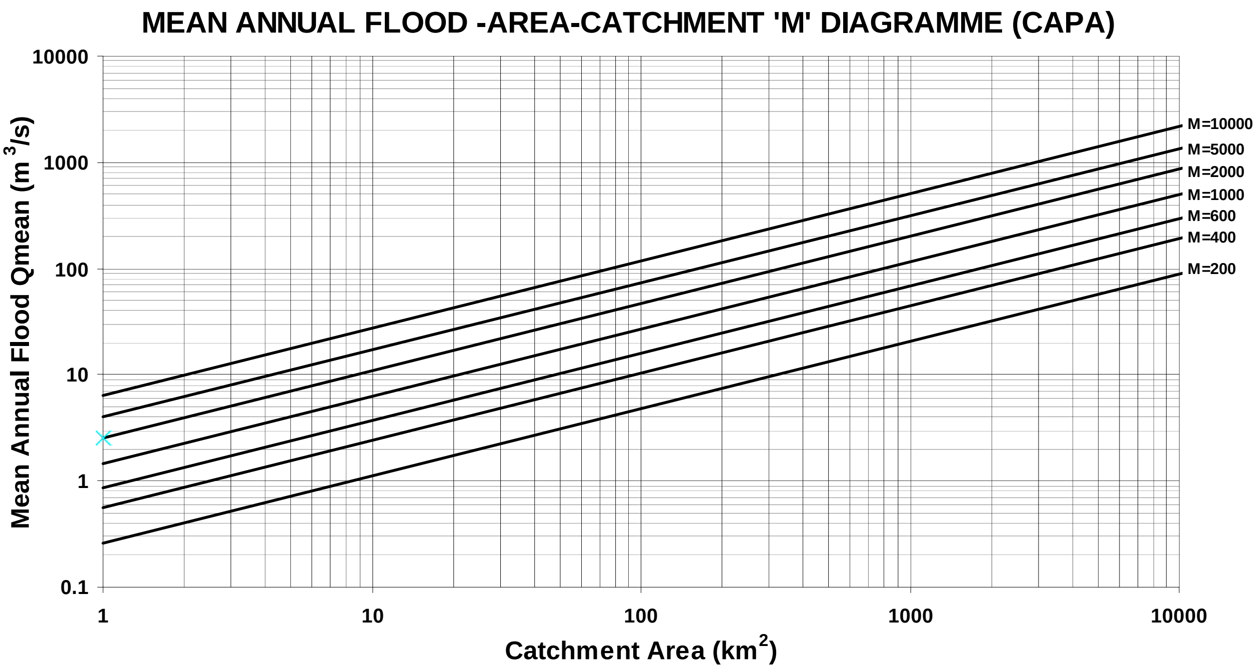

Figure 3.38: CAPA method Qi vs A – "M" diagram

The CAPA method for estimated MAF is still used by DWAF who have subsequently developed growth curves to estimate the various flood probabilities. The estimation of Q_m^{CAPA} can be simplified by using the following relationship:

$$Q_m^{CAPA}=a*A^{0.63245}$$

Where;

$a=0.0008*M^{1.0939}$ for M<1000
$a=1.5657*\ln(M)-9.3402$ for 1000<M<5000
$a=0.0113M^{0.6887}$ for M>5000

Figure 3.41 compares the estimation of Q_m using the CAPA methodology with the at site estimated mean annual flood peak. This figure includes all the sites in the study area with sufficient data to estimate the site MAF.

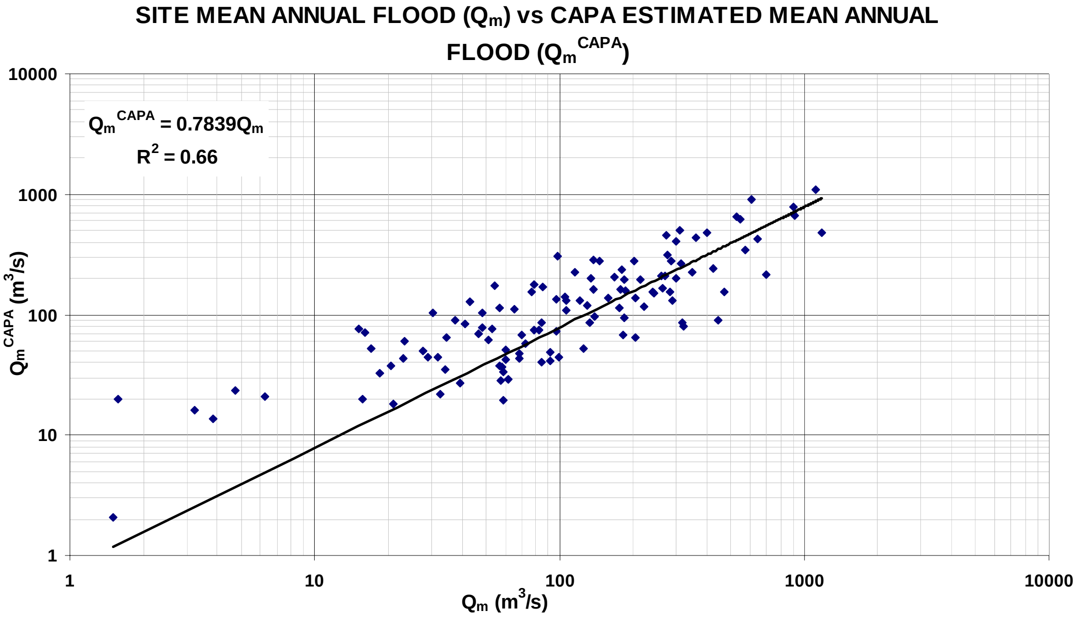

Figure 3.39: Q_m^{CAPA} vs Q_m-All sites in study area

The R^2 of 0.66 may be considered good but based on the observations in section 3.3 other parameters may provide an improvement. The replacement of Q_m in the CAPA methodology with Q_{med} did not provide a satisfactory result when compared to site observed Q_{ml} estimates. In order to develop an alternative method to estimate the index flood (Q_i) the log derived mean annual flood (Q_{ml}) that is shown to be more robust was used. In the interim due to the lack of a method descriptive name it is proposed that it will be referred to as the New Catchment Parameter (NCAPA) method.

The proposed lumped parameter (M’) for use in the NCAPA method is estimated:

$$M' = MAP(100 * s \frac{\sqrt{A}}{L})^{1/2}$$

Where;

A=Catchment Area (km^2)

MAP=Mean Annual Flood (mm)

s=Standard River Slope – 1085 (m/m) and

L=Longest Stream Length (km)

The variables listed in section 3.3 with the best correlations to the storm runoff were selected for inclusion. The river slope replaces the catchment slope in the CAPA equation.

The development NCAPA method to estimate the Q_i is undertaken for the regions that are identified in Section 3.4.3 and is thus not universal at present. The regionalisation in Section 3.4.3 will identify regions, develop the Q_{ml}^{NCAPA} for the regions identified and assess the Q_{ml}^{NCAPA} estimates and the Q_m^{CAPA} estimates against the observed data.

3.4.3 Regionalisation for Qi estimation

A visual assessment of the estimated Q_{ml} values for the various sites suggested that regionalisation would be required if the correlations achieved between the NCAPA methodology to estimate Q_i and those provided by the site data are to be improved upon. From the maps (figures 3.27 to 3.30) a relationship between broad regions as defined by MAP, vegetation, soils types and geology would seem to be present. The relationships are logical in that higher rainfall means more and denser vegetation and deeper soil profile due to weathering. These are shown in figures 3.40 and 3.41. It could be argued that a higher MAP will result in a higher Qi value, but due to denser vegetation and deeper soil profiles the rainfall for especially floods are intercepted more in a high MAP area than in an area with a lower MAP. This interpretation could result in a similar Qi value for two sites even if the characteristics for the two sites are totally different.

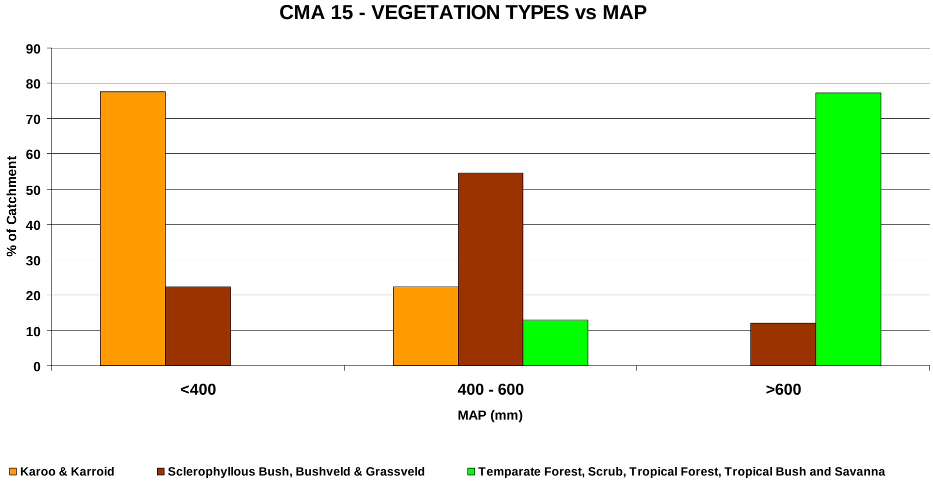

Figure 3.40: MAP vs Vegetation Types

The relationship between MAP and vegetations types is used by DWAF and MAP is used by DWAF to separate grassland from bare surface (Kovacs 1987 and van der Spuy & Rademeyer, 1997). The relationships are for dense bush cover and grassland. Where MAP is less than 600 mm dense bush as a % of the catchment is 0% and if the MAP is greater than 900 mm the dense bush % is 100%. For catchments where the MAP varies between 600 mm to 900 mm the maps, site visits or persons familiar with the area should be consulted. A differentiation between grassland cover and bare surface is also based on MAP, but where the MAP is greater than 900 mm the percentage of the catchment area where the slope is greater 50% will be considered bare surface. The lack of grassland cover is based on the assumption that steep slopes generally occur on mountains and koppies with little or no soil depth and therefore no vegetation. The range of MAP and the ratio of grassland and bare surface is:

- MAP<400 mm, grassland is 0% and bare surface is 100%,
- 400 mm<MAP<600 mm, grassland is 33% and bare surface is 67%,
- 600 mm<MAP<900 mm, grassland is 67% and bare surface is 33% and
- MAP>900 mm, the grassland area is 100% less the percentage area of the catchment where the slope is greater than 50%. The bare surface area is that area in % where the slope is greater than 50%.

DWAF at present do not distinguish between likely soil types based on MAP but Figure 3.41 would suggest that such a separation could be made. Soil type permeability, or runoff potential, decreases from soil type B/C (sandy/loams) to D (clays/silts).

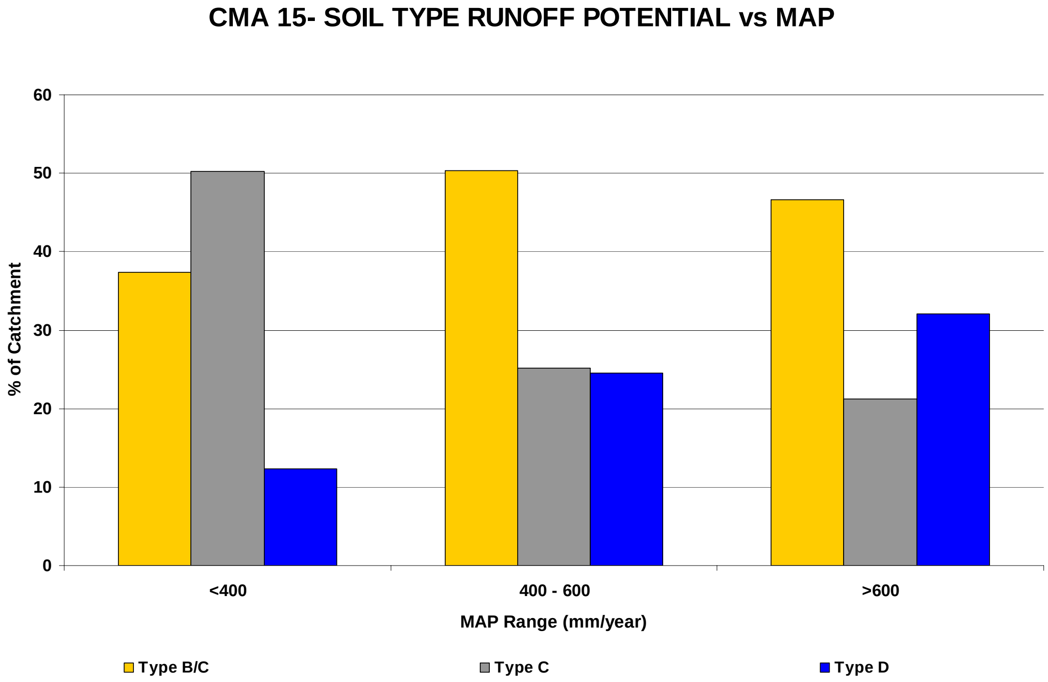

Figure 3.41: MAP vs Soil Run-off Potential

Previous work in southern Africa also indicated that certain regional areas could be defined based on rainfall. A broad based regionalisation is that used in rainfall studies where a distinction is made between coastal areas and inland areas. These studies include the rainfall studies of the HRU (1974), Adamson (1981) and Smithers and Schulze (2003). Some of the studies also provided an intermediate region between the coastal and inland areas. Kovacs (1988) provides three regions with "K" values of 5.4 for the coastal catchments, 5.2 for the transition area and 5.0 for the inland regions. For the KwaZulu-Natal area van Bladeren (1993, 1995 and 1998) also made a distinction between three regions.

Using the previous regionalisation and the MAP, six regions, loosely based on the generalised veld type zones of the HRU (HRU, 1972) report and MAP, were defined and are shown in Figure 3.42. These regions basically followed the general MAP, vegetation types and to some extend soil type. The sites selected for inclusion in the study were grouped in these regions.

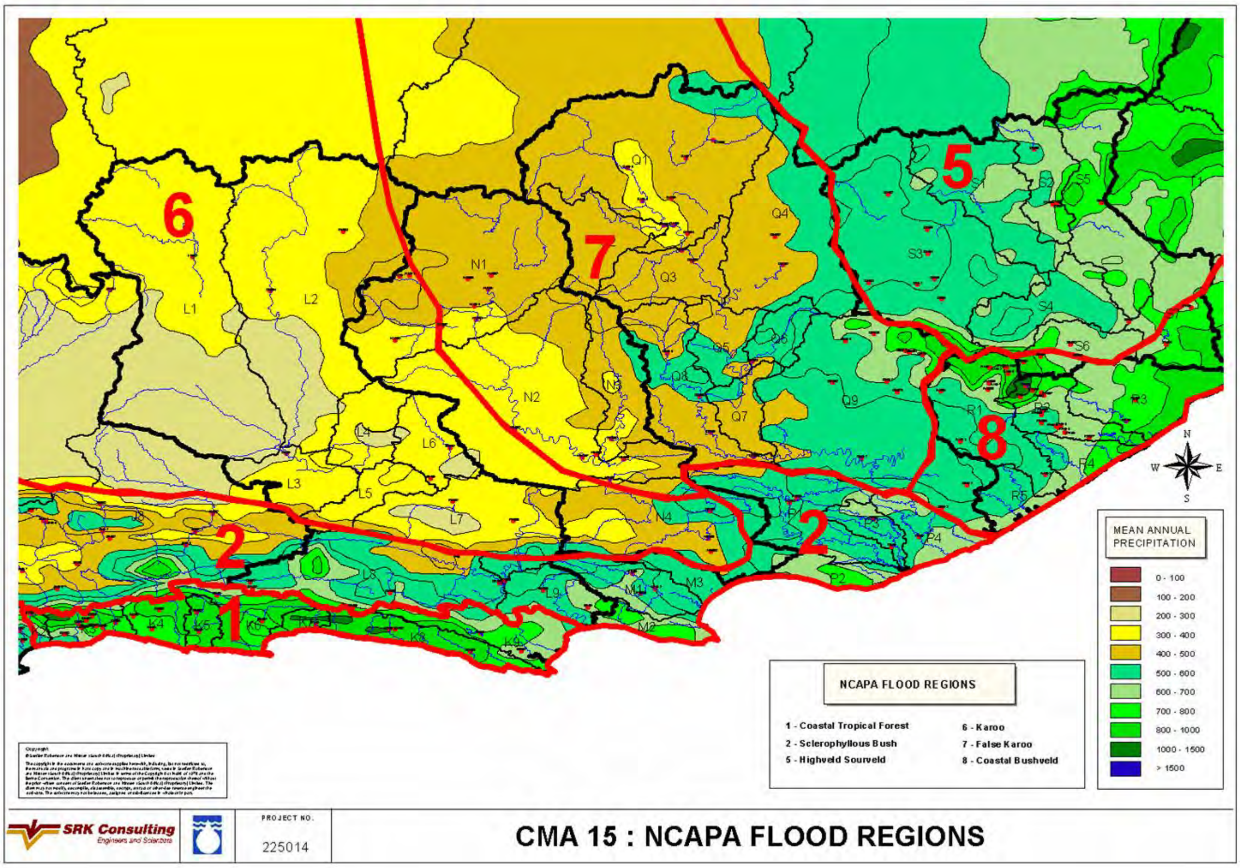

Figure 3.42: Proposed flood regions for CMA 15 pilot study

Before final acceptance of the regionalisation and to determine if the regions selected are appropriate the mean annual flood derived from the logs of the data (Q_{ml}) was plotted against catchment area. The results are shown in Figure 3.43 and grouping of the data for the identified regions is evident.

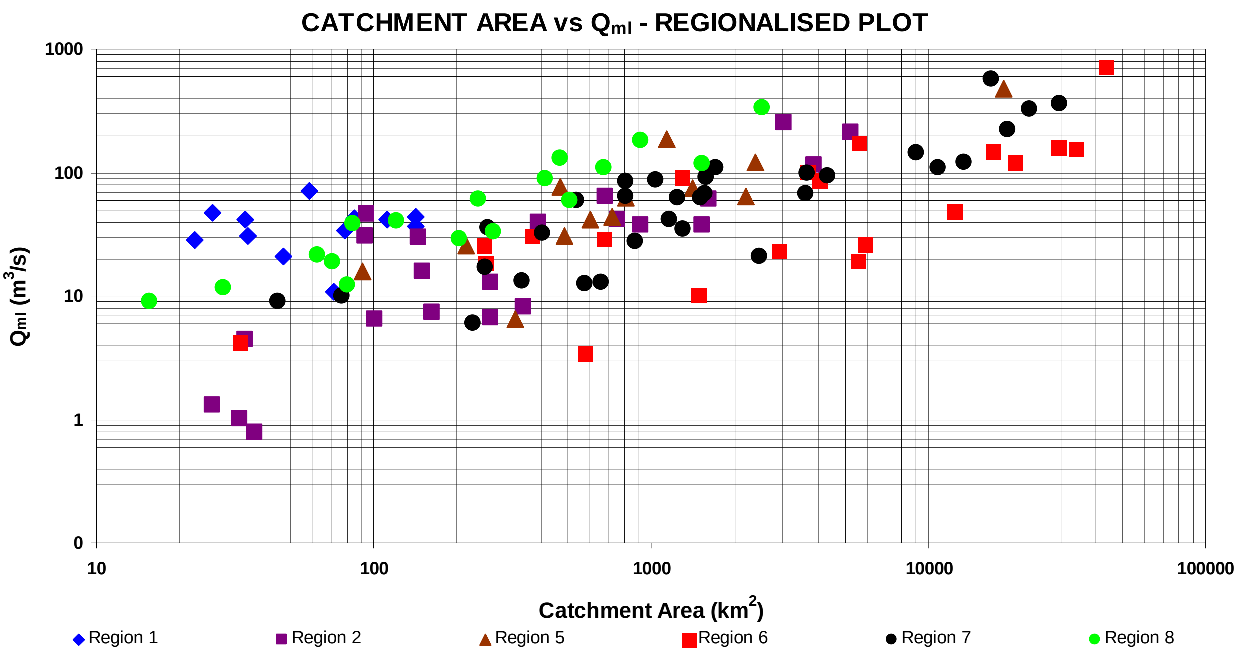

Figure 3.43: CA vs Qi Regionalised

Thus for the pilot study area the regions identified and using the veld type zones from HRU 1/72 are:

- Region 1; Coastal tropical forest that covers drainage regions K3, K4, K5, K6, K7 and K8. No data was available for K9 but based on MAP and topography K9 would be included in region 2.
- Region 2; Sclerophyllous bush that cover drainage regions J3, J4 (does not include Gourits River), M, P1, P2 and P3. Drainage region P4 was grouped into region 8 based on knowledge of the area.
- Region 5; Highveld sourveld that covers drainage region S in its entirety. Some areas in drainage region S do fall in region 4 and 8, as a percentage of the catchment areas investigated these do not represent a significant portion. Drainage region S is a boundary area that does not fall in CMA 15.
- Region 6; Karoo and includes drainage regions J1, J2, J4 (only the Gourits River), L and strictly speaking N2, and N4. The gauging stations in region N were however all grouped into region 7 based on MAP and general runoff characteristics.
- Region 7; False Karoo includes drainage regions N and all of Q. The inclusion of N is discussed in region 6.
- Region 8; Bushveld, that in the HRU covers the coastal areas from the Bushmans River (drainage region P1) all along the coast to Mozambique and onto the Limpopo River. This would include the coastal areas of regions S, T, U, V and W and drainage areas X, A and B. Studies undertaken after the publication of the HRU report of 1972 and experience would suggest that more regionalisation would be required as the region extends north.

Although some sites in Figure 3.43 do not adhere to the regionalisation a broad pattern is evident. Anomalous sites were further examined and sites with data that was considered doubtful were excluded from the study. The homogeneity test for the sites in identified regions is shown section 3.5.

3.4.4 Estimating Qi using CAPA and New CAPA (NCAPA)

For each site in the identified regions the lumped parameter M and M' was estimated using the CAPA and New CAPA methods. In order to determine a relationship that will estimate Q_{ml} an A vs Q_{ml} , similar to that used to derive the relationship for Q_m^{CAPA} is used. The estimated Q_{ml} for the method is referred to as Q_{ml}^{NCAPA}. To assess the merits of the two methods the Q_m^{CAPA} and Q_{ml}^{NCAPA} for each site was estimated and plotted against the site Q_m and Q_{ml}.

In order to derive Qi estimates for each of the identified regions the following steps were undertaken:

- Plotting A vs Q_{ml} on log-log scales
- Deriving a relationship similar to that of the CAPA method between A and Q_{ml} for sites with similar M' values (Same as in the CAPA method)
- Testing the Q_{ml}^{NCAPA} estimate against the observed Q_{ml} for each region. The Q_m^{CAPA} estimates for the sites are compared to the site gauged Qm.

The above information is provided for each region and is summarised at the end of the section.

Region 1 (Figure 3.44): The vegetation class for region is coastal tropical forest with a high MAP. For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 670 mm to 850 mm
- Catchment area range 1 km^2 to 142 km^2 and
- M' range is 700 to 1600.

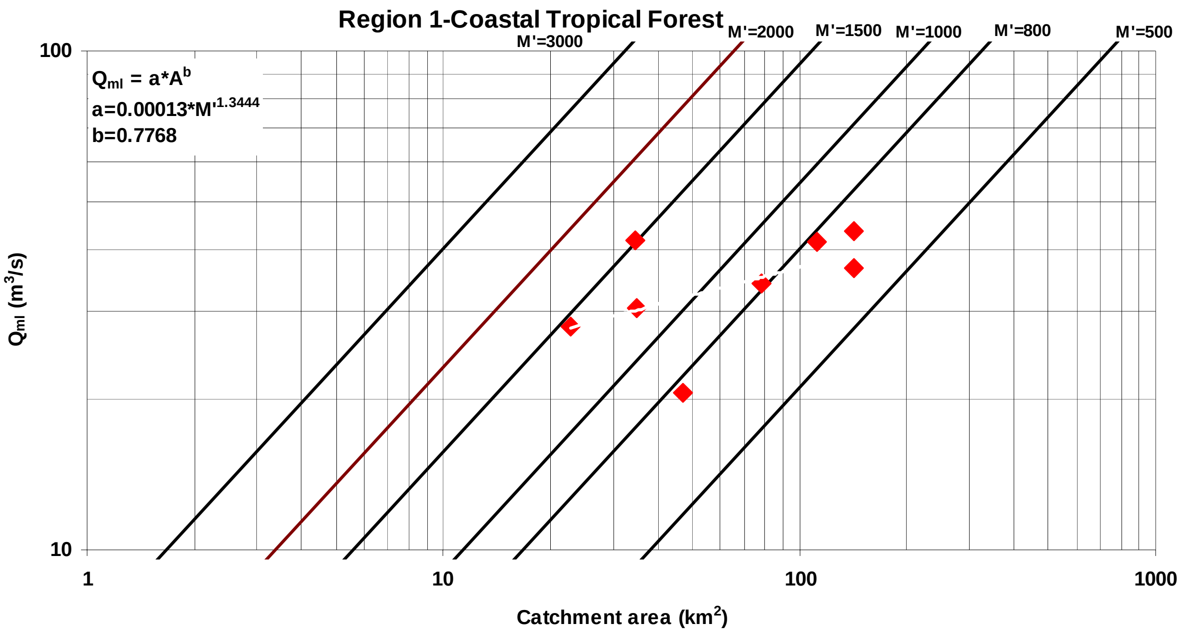

Figure 3.44: Catchment Area vs Q_{ml} – Region 1

The relative performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.45.

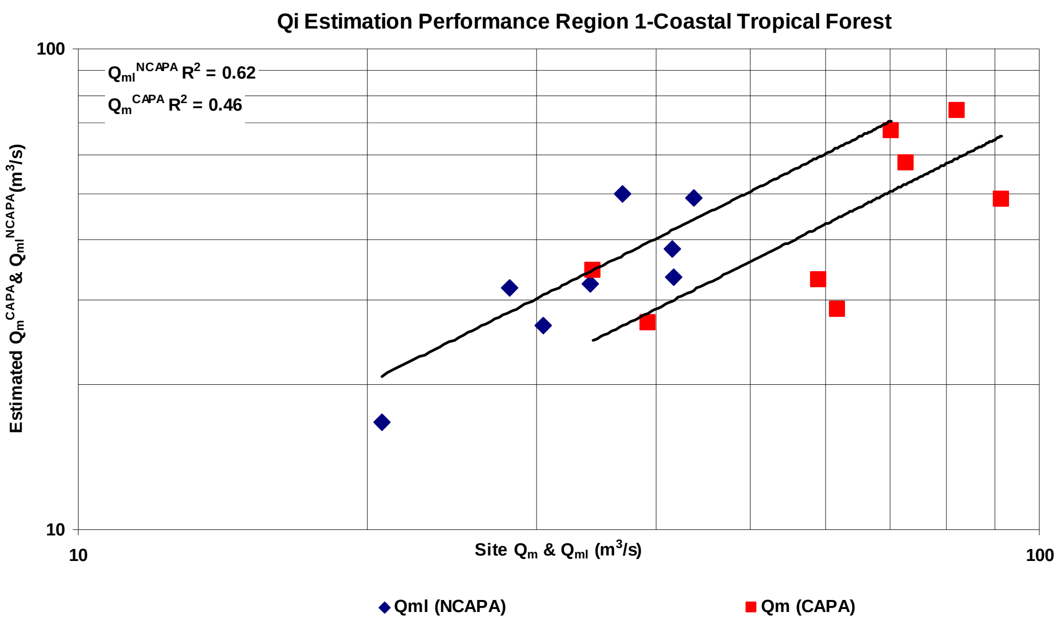

Figure 3.45: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 1

Region 2 (Figure 3.46): The vegetation class for region is sclerophyllous bush. For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 307 mm to 716 mm
- Catchment area range 33 km^2 to 5229 km^2 and
- M' range is 100 to 900.

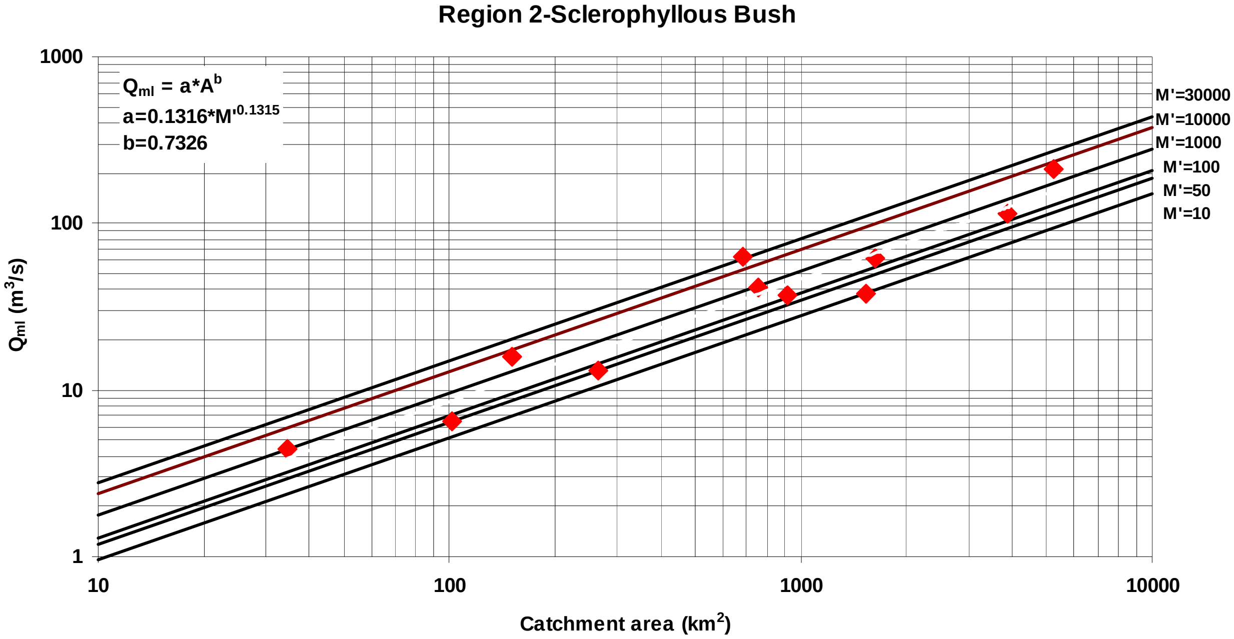

Figure 3.46: Catchment Area vs Q_{ml} – Region 2

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.47

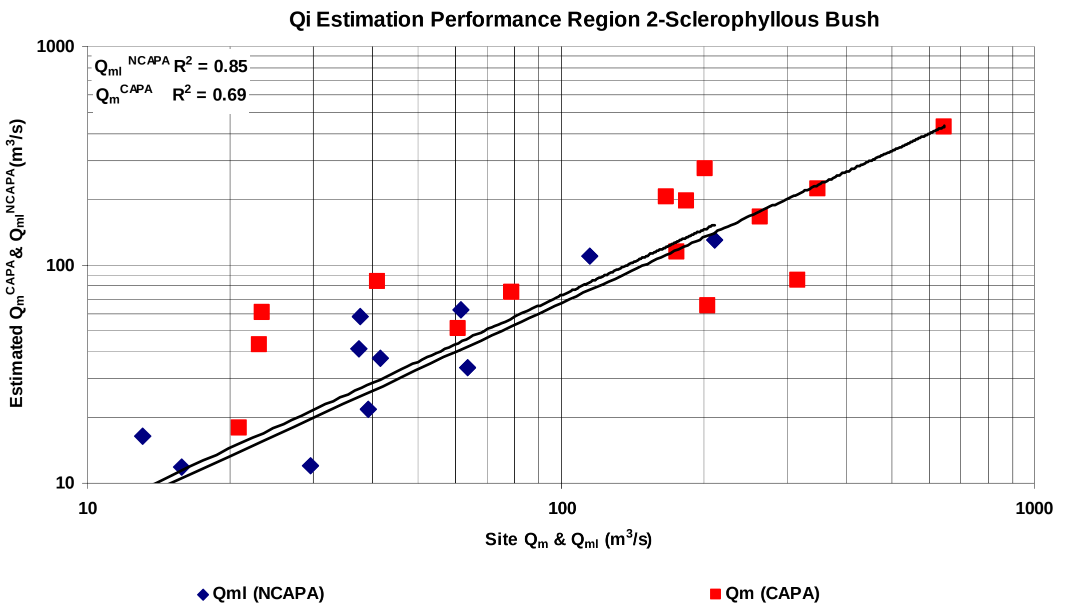

Figure 3.47: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 2

Region 5 (Figure 3.48): The vegetation class for the region is sourveld and grasslands. For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 500 mm to 768 mm
- Catchment area range 91 km^2 to 18799 km^2 and
- M' range is 100 to 700.

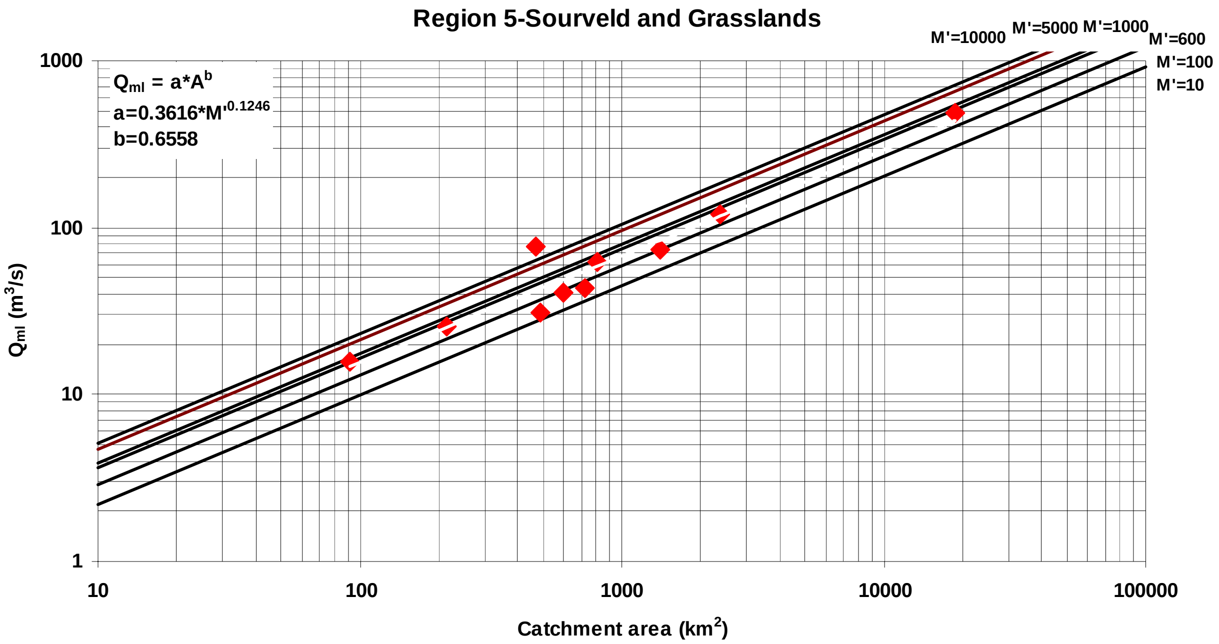

Figure 3.48: Catchment Area vs Q_{ml} – Region 5

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.49

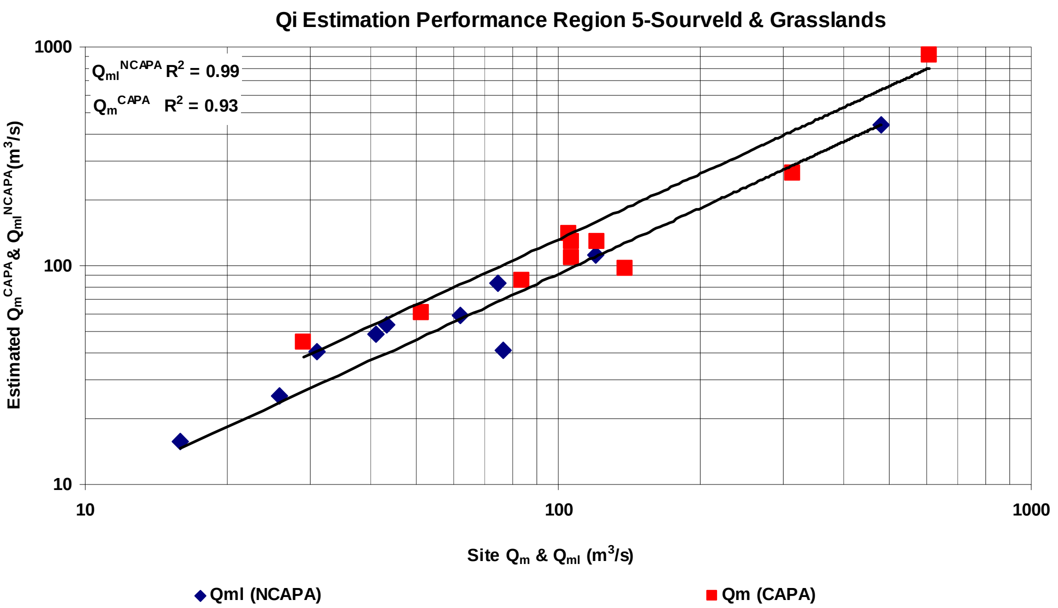

Figure 3.49: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 5

Region 6 (Figure 3.50): The vegetation class for region is Karoo with a relatively low MAP. For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 222 mm to 549 mm
- Catchment area range 9 km^2 to 20580 km^2 and
- M' range is 50 to 2000.

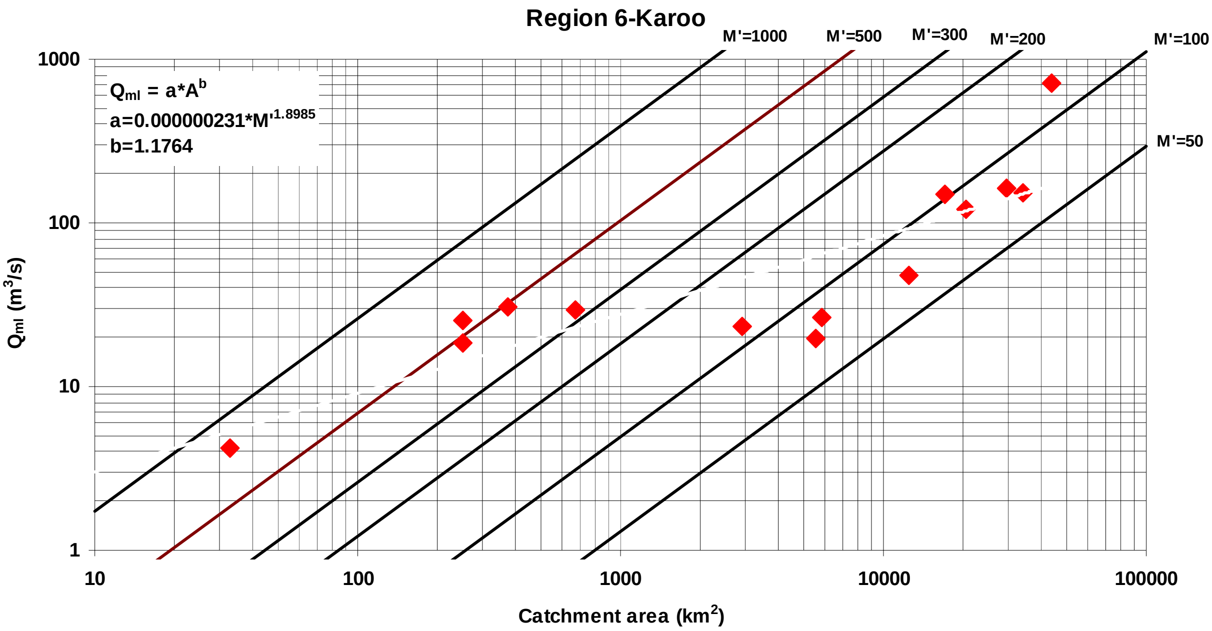

Figure 3.50: Catchment Area vs Q_{ml} – Region 6

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.51.

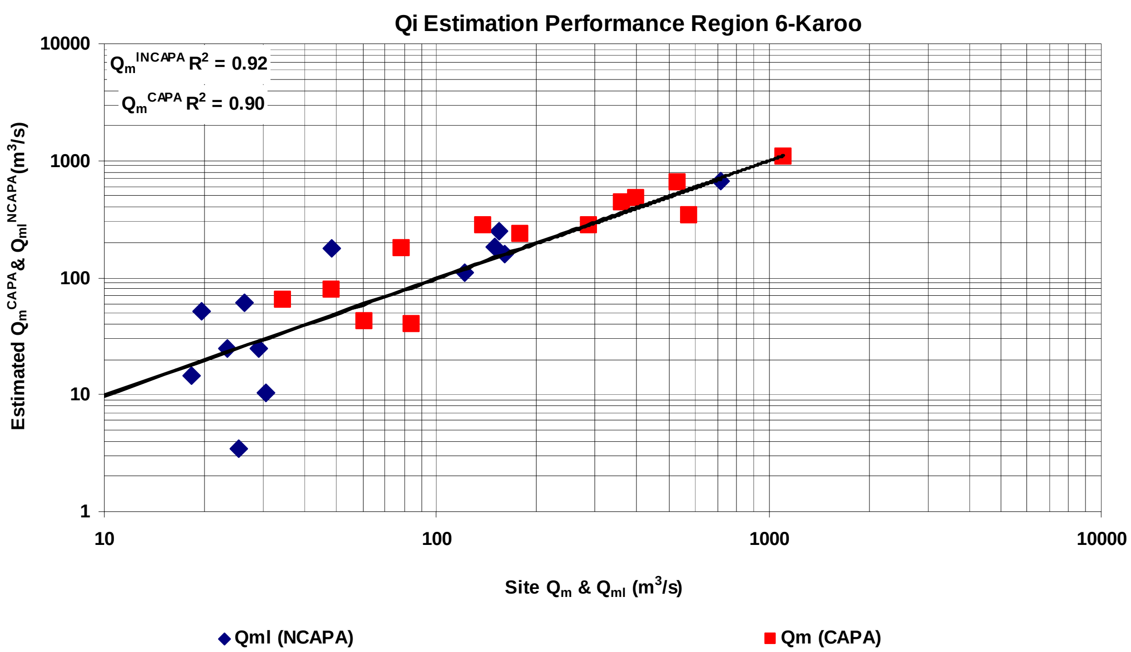

Figure 3.51: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 6

Region 7 (Figure 3.52): The vegetation class for region is False Karoo. For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 397 mm to 738 mm
- Catchment area range 259 km^2 to 29745 km^2 and
- M' range is 100 to 1000.

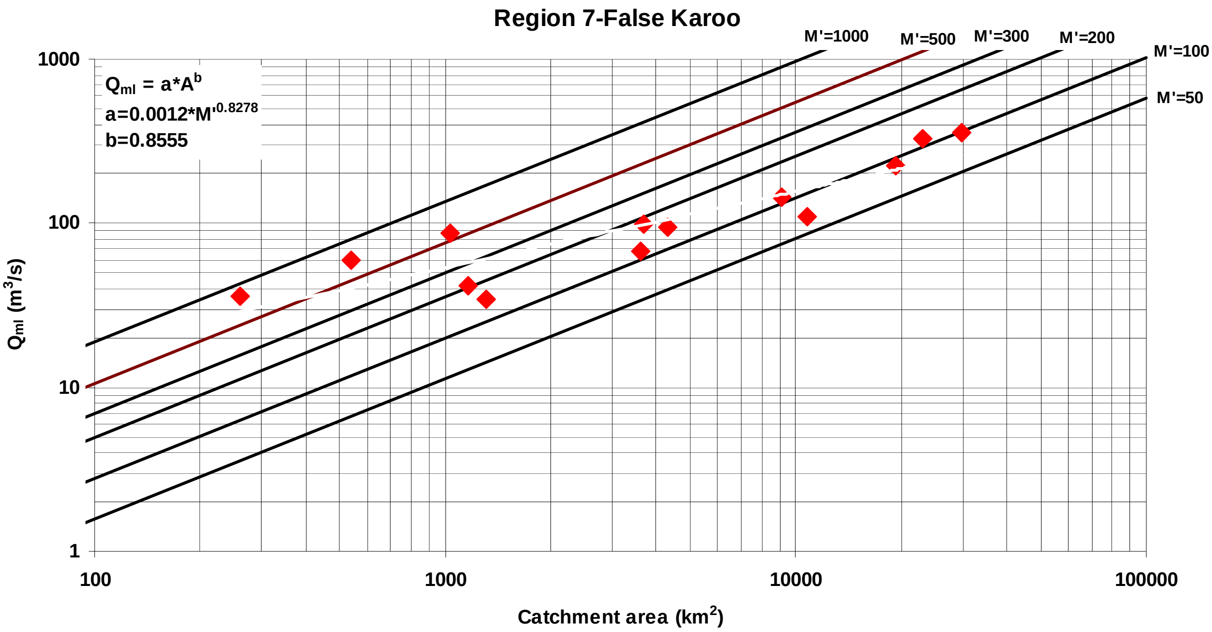

Figure 3.52: Catchment Area vs Q_{ml} – Region 7

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.53.

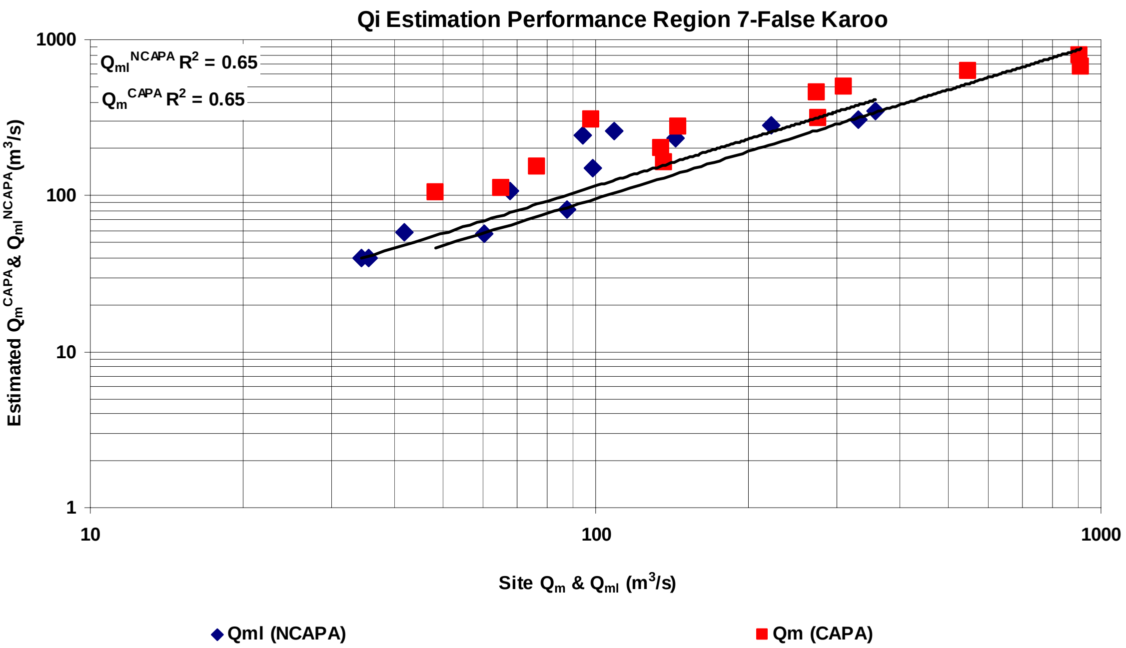

Figure 3.53: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 7

Region 8 (Figure 3.54): The vegetation class for region is bushveld (coastal). For the new CAPA method the MAP, catchment area and M' ranges for the sites used are:

- MAP range 578 mm to 1000 mm
- Catchment area range 29 km^2 to 2521 km^2 and
- M' range is 100 to 3000.

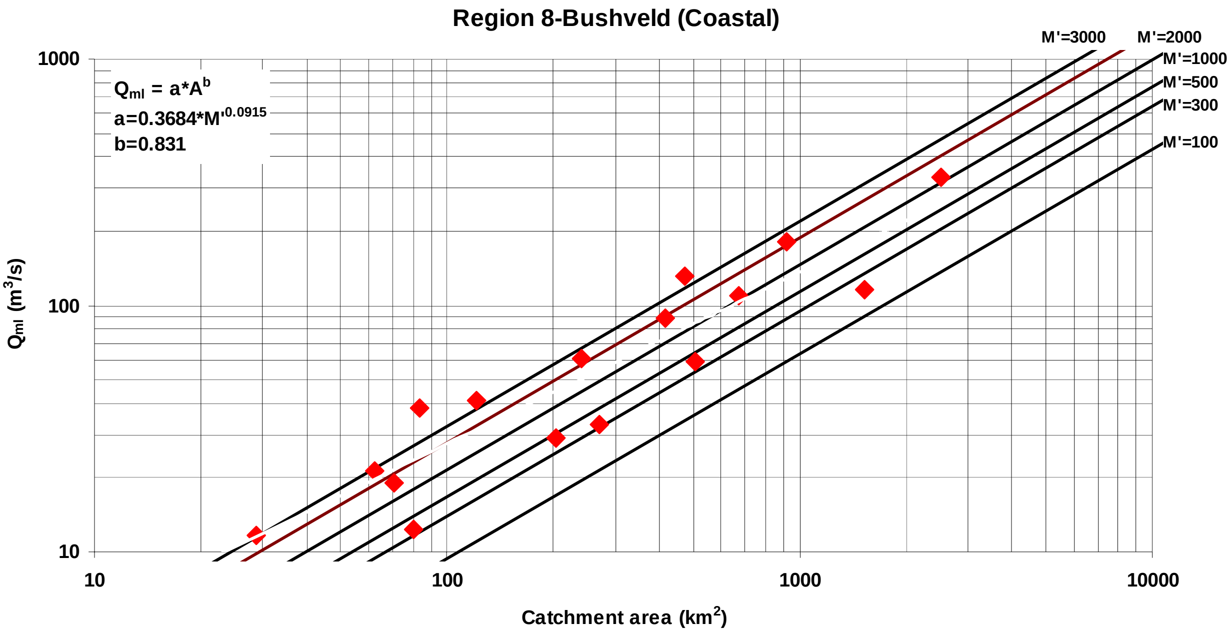

Figure 3.54: Catchment Area vs Q_{ml} – Region 8

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m is shown in Figure 3.55.

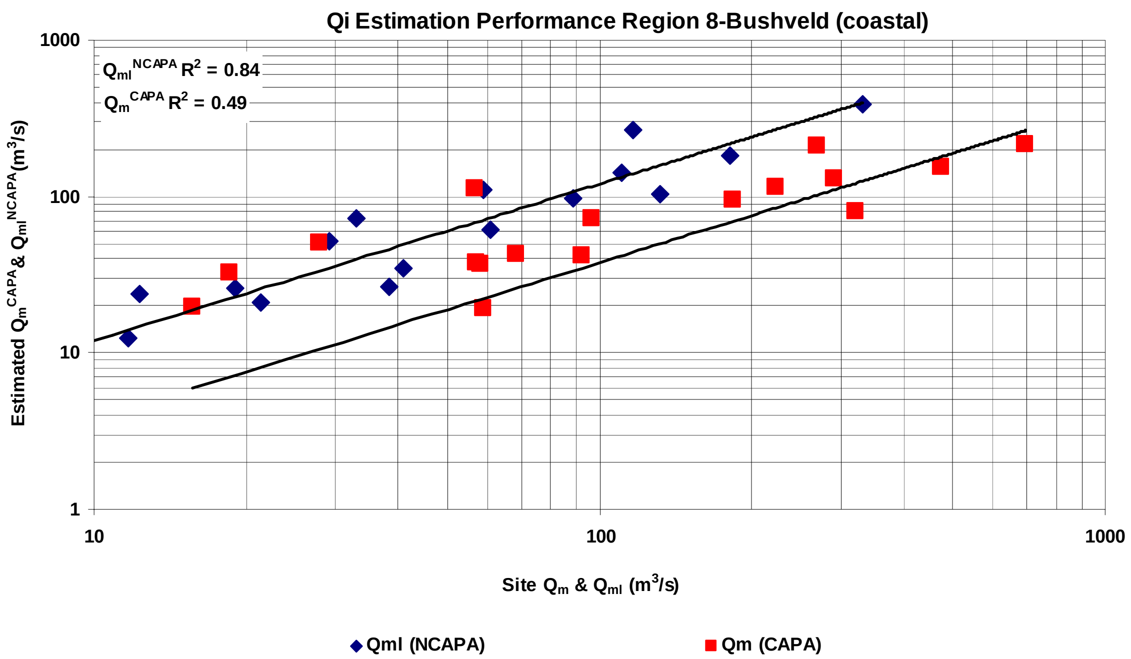

Figure 3.55: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}-Region 8

The performance of the Q_{ml}^{NCAPA} and Q_m^{CAPA} for estimating Q_{ml} and Q_m for the whole region is shown in Figure 3.56. The R^2 for the estimation of the index flood improves from 0.74 to 0.87.

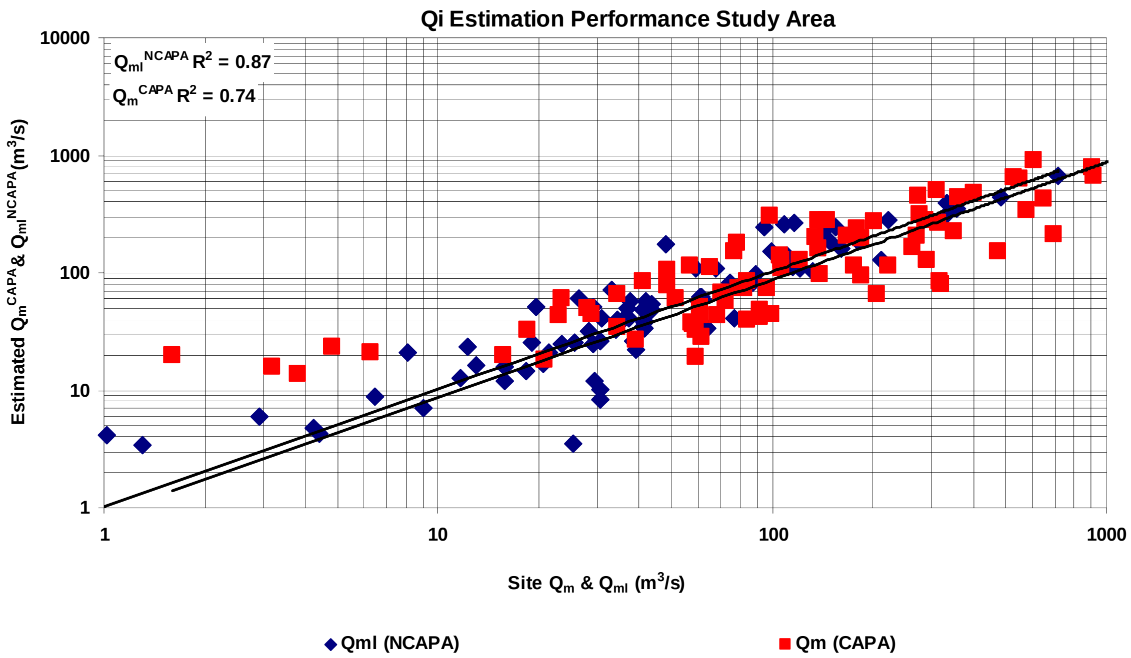

Figure 3.56: Performance of Q_{ml}^{NCAPA} and Q_m^{CAPA}- Study Area

The estimation of Q_i for the regions identified is summarised in Table 3.8. The equations developed should aid users when programming the methodology using even simple spreadsheets and hand held calculators. The performance of the NCAPA and CAPA to estimate the Q_i is split between the regions but as shown in Figure 3.56 and in Table 3.8 the NCAPA would seem provide a much estimate of the Q_i than the CAPA method.

Table 3.8: Summary of Index Flood Estimation Factors – CMA 15

Region	Constants			Relative Q_i estimate performance (R^2)	
	b	c	d	NCAPA	CAPA
Region 1	0.00013	1.35549	0.77685	0.62	0.46
Region 2	0.1316	0.1315	0.7326	0.85	0.69
Region 5	0.3616	0.1246	0.6558	0.99	0.93
Region 6	0.000000231	1.8985	1.1764	0.92	0.90
Region 7	0.0012	0.8278	0.8555	0.65	0.65
Region 8	0.3684	0.0915	0.831	0.84	0.49
Study area				0.87	0.74

A further site specific assessment of the method to estimate the Q_i is provided in Section 4 for selected sites.

3.5 Development of Flood Peak Growth Curves

The use of flood growth curves (GC) that are applied to some form of Qi is extensively applied internationally and in South Africa. The most well known example is that developed for the United Kingdom (NERC in 1975 and IH in 1998). In South Africa the most significant attempt is that initiated by the development of the CAPA method (McPherson, 1983) to provide an estimate of the Qi and the development of GC by the directorate Flood Studies of DWAF (van der Spuy & Rademeyer, 1997).

The methodology applied to develop the GC is:

- Separate the data sets in systematic sets, sets that include systematic and historical data and sets that include systematic and palaeoflood data.
- The data sets were analysed using the LP3 distribution.
- Each of the data sets were than split into the regions selected.
- The GC for each of the sets were then estimated using Q_{ml}^{NCAPA} as the Q_i and
- A regional GC was then estimated by applying a period of observation and number of data points weighting for each of the sites in a region. Sites with anomalous or unrealistic GC's were discarded.

The hydrological homogeneity using the 10-flood (Ponce, 1989) of the sites selected for the identified regions is shown in Figure 3.57. Only four sites in regions 2, 7 and 8, plot outside the 90% confidence lines.

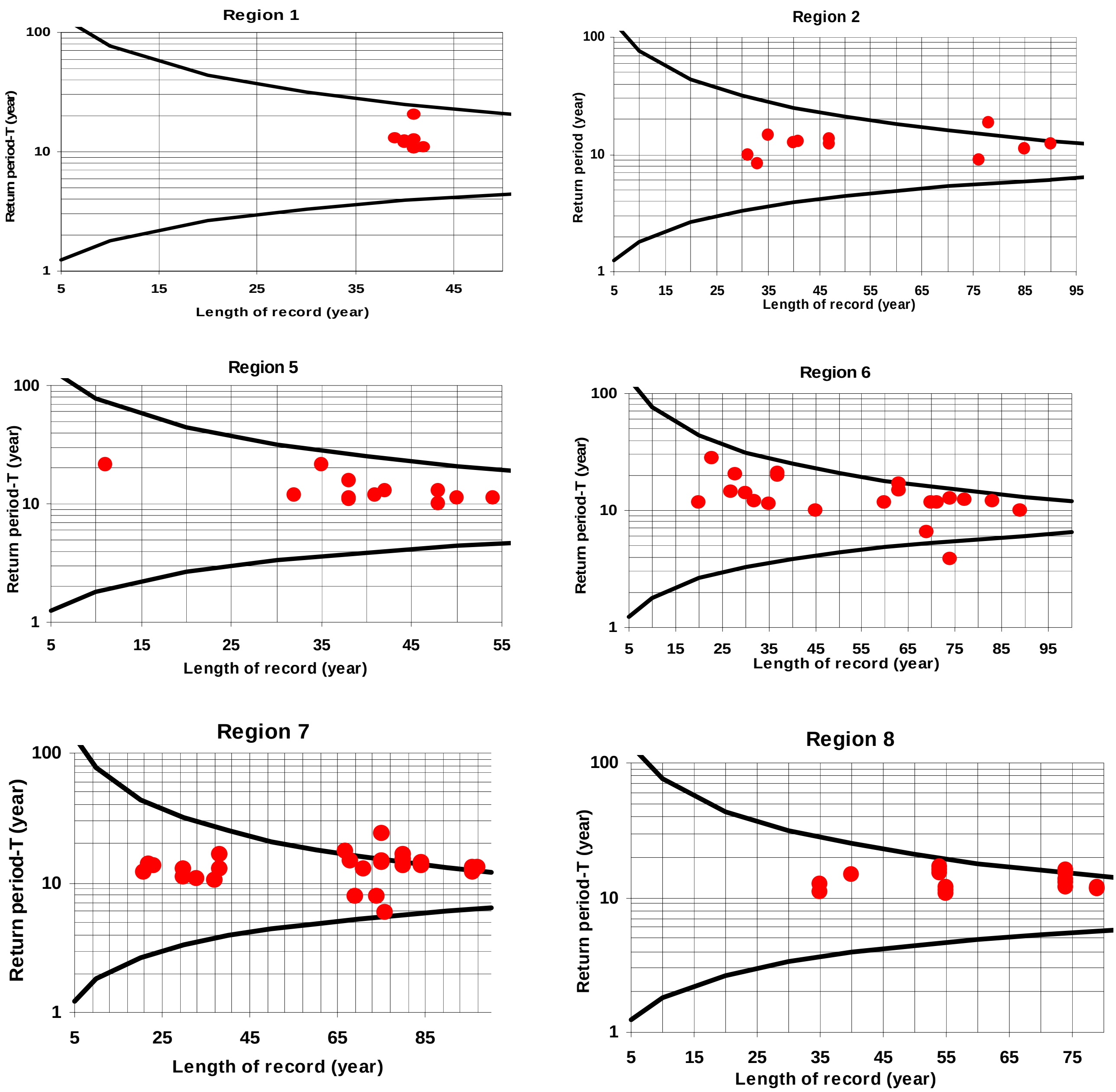

Figure 3.57: Hydrological Homogeneity Test Chart

The GC and their relationship to MAP for the systematic data sets are demonstrated in the Section 3.5.1 and a similar methodology was applied to the systematic/historical data set and the systematic/palaeoflood data sets. The results of the analyses for each of the data sets and regions are presented in sections 3.5.1, 3.5.2 and 3.5.3. The statistical properties of the data sets and their log-Pearson derived growth curves are shown in Appendixes D and E for all three scenarios analysed.

3.5.1 Regional flood peak growth curve development using systematic data sets

The data sets used in the analyses for each region are summarised in Table 3.9. In all 96 sites were eventually included in the analyses with the average period of observation being 52 years and the average number of data points being 48.

Table 3.9: Site Summary-Systematic Data

Region	Sites	MAP (mm)	Period length (years)	Data
1-Coastal Tropical Forest	8	801	41	41
2-Sclerophyllous Bush	11	437	55	52
5-Highveld Sourveld	12	600	40	38
6-Karoo	21	348	53	44
7-False Karoo	27	489	64	53
8-Bushveld (Coastal)	17	708	61	58
Average/Total	**96**		**52**	**48**

The GC's derived for each of the regions without any adjustments for MAP are tabulated in Table 3.10 and shown in Figure 3.58.

Table 3.10: Summary of Systematic Data Set Growth Curves

Region	MAP (mm)	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
		2	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**	**10000**
1	**801**	1.17	2.58	3.90	5.47	8.01	10.33	12.69	17.29	21.09	25.48	32.31	38.38
2	**437**	1.01	3.28	5.88	9.41	15.92	22.67	30.75	47.74	64.66	87.09	128.42	171.79
5	**600**	1.12	2.78	4.46	6.60	10.21	13.67	17.84	24.69	31.05	38.64	50.91	62.22
6	**348**	1.31	3.60	6.01	9.17	14.93	20.92	28.25	43.60	59.34	80.76	121.79	166.90
7	**481**	1.26	3.68	6.42	10.09	16.77	23.53	31.91	47.21	62.10	80.80	112.95	144.37
8	**708**	1.17	3.34	5.52	8.13	12.18	15.68	19.56	25.26	30.03	35.23	42.80	49.10

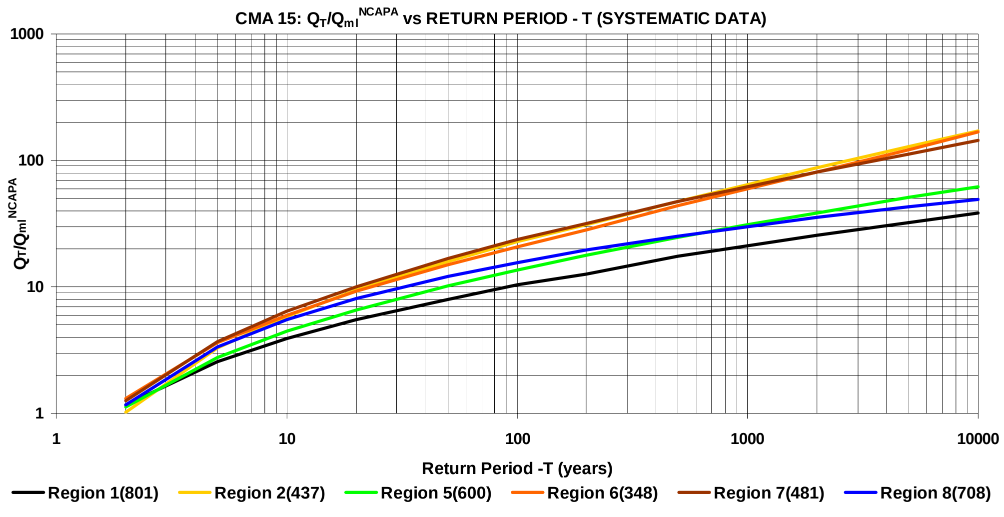

Figure 3.58: Systematic Data Set Regional Growth Curves

The generally accepted relationship between GC's and MAP is implied in Table 3.10 and Figure 3.60. This implication is shown in Figure 3.59 for the 10-, 50- and 100-year event GC's developed using the systematic data sets.

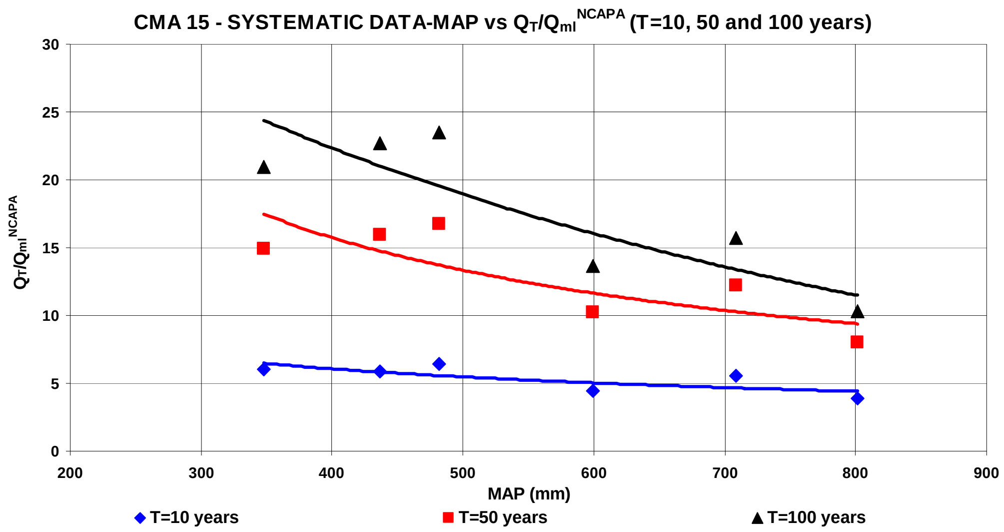

Figure 3.59: Systematic Data Set-Q_T/Q_{ml}^{NCAPA} vs MAP

Curve fitting of the data sets for the regions yielded an exponential relationship between GC's and MAP. The general form of the relationship is:

$$Q_T/Q_{ml}^{NCAPA}=f*e^{(h*MAP)}$$

Where f and h are constants and MAP is the mean annual rainfall in mm. This general form of the relationship was found to be valid for all the return periods and is also applied for the historical and palaeoflood data GC development. The values of a and b for the various return periods for the systematic data set derived GC's are tabulated in Table 3.11 and the R^2 for the various GC's and MAP are also shown. Although the R^2 values improved as the return period increased this should not be interpreted as a suggestion that the GC's for the lower T events should be discarded. This is mainly due to small variation in the GC values with MAP for the lower T events.

Table 3.11: Variables a and b for Q_T/Q_{ml}^{NCAPA} vs MAP Relationship-Systematic GC

Var.	Return Period – T (years)											
	2	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**	**10000**
f	1.2	4.5	8.6	14.9	27.9	43.4	65.1	115.8	176.2	269.1	475.3	736.6
h	-0.0001	-0.0006	-0.0009	-0.0011	-0.0014	-0.0017	-0.0019	-0.0023	-0.0026	-0.0029	-0.0034	-0.0038
R^2	0.03	0.54	0.55	0.65	0.66	0.76	0.80	0.85	0.88	0.90	0.92	0.93

The GC for the systematic data sets were estimated using the above and are represented in a tabular form in Table 3.12 and in a graphical format in Figure 3.60. By relating the GC's to MAP the bases for the regionalisation is still valid with the GC's for a particular site being specific for the site. The site specific character of the flood peak estimate is also reinforced by the estimated Q_i for the site.

Table 3.12: Growth Curves for Systematic Data Sets and MAP Adjusted-CMA 15

MAP	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
(mm)	2	5	10	20	50	100	200	500	1000	2000	5000	10000
200	1.18	3.99	7.18	11.96	21.09	31.14	44.52	73.25	104.75	150.07	241.28	347.25
300	1.17	3.76	6.57	10.71	18.33	26.38	36.82	58.26	80.77	112.07	171.91	238.42
400	1.16	3.54	6.00	9.60	15.94	22.34	30.45	46.33	62.28	83.69	122.48	163.70
500	1.15	3.33	5.48	8.60	13.85	18.92	25.18	36.85	48.02	62.49	87.26	112.40
600	1.14	3.14	5.01	7.70	12.04	16.03	20.82	29.31	37.03	46.67	62.17	77.17
700	1.13	2.96	4.58	6.90	10.47	13.58	17.22	23.31	28.55	34.85	44.30	52.99
800	1.12	2.78	4.19	6.18	9.10	11.50	14.24	18.54	22.01	26.03	31.56	36.38
900	1.11	2.62	3.83	5.54	7.91	9.74	11.77	14.74	16.97	19.44	22.49	24.98
1000	1.10	2.47	3.50	4.96	6.88	8.25	9.74	11.73	13.09	14.51	16.02	17.15

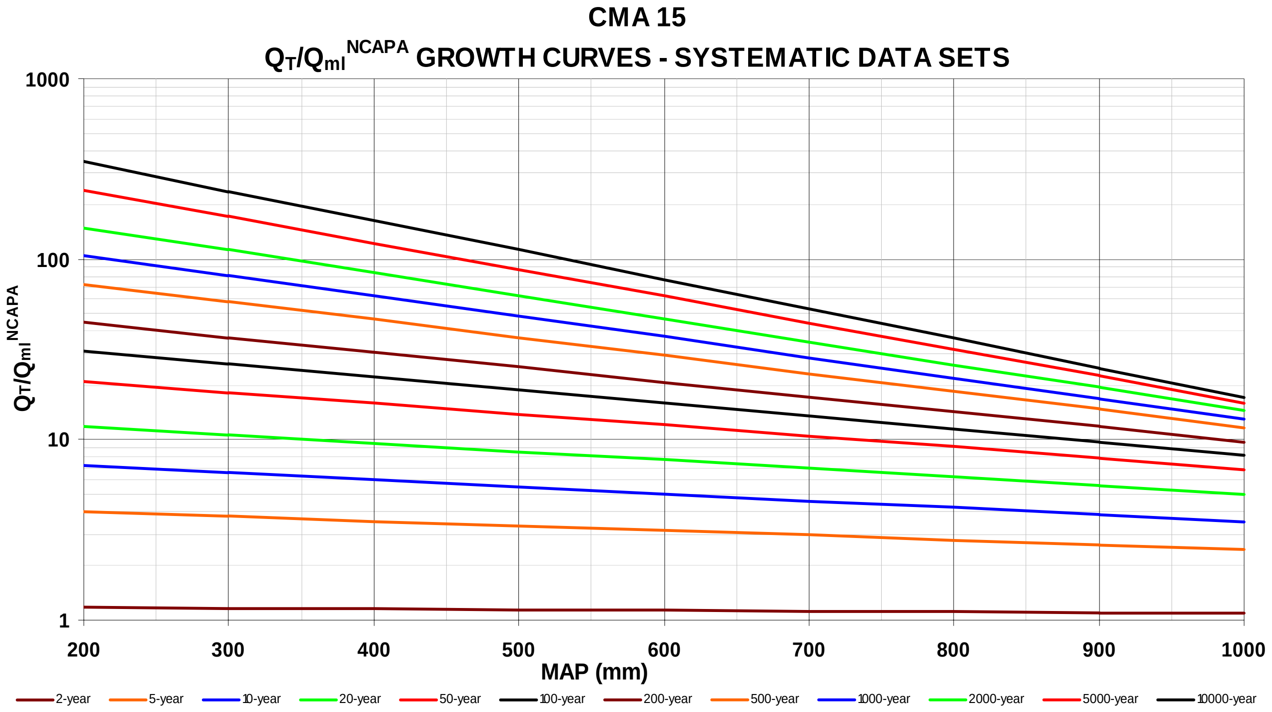

Figure 3.60: Growth Curves Based on Systematic Data and MAP – CMA 15

3.5.2 Regional flood peak growth curve development using systematic/historic data sets

The data sets used in the analyses for each region are summarised in Table 3.13. In all 23 sites with historical were eventually included in the analyses with the average period of observation being 125 years and the average number of years being 48.

Table 3.13: Site Summary-Systematic/Historic Data

Region	Sites	MAP (mm)	Period length (years)	Data
2-Sclerophyllous Bush	3	437	96	26
5-Highveld Sourveld	1	600	127	15
6-Karoo	4	348	116	60
7-False Karoo	9	489	144	70
8-Bushveld (Coastal)	6	708	141	70
Average/Total	**23**		**125**	**48**

The GC's derived for each of the regions without any adjustments for MAP are tabulated in Table 3.14 and shown in Figure 3.61. The historic and palaeoflood data were analysed separately using the procedure described by Alexander (1990). Regions 2 and 5 would seem to be anomalous especially for the lower return periods. This is mostly due to the limited number of sites with historical data and the relative short period of systematic observation for the sites used. Region 1 does not have any historical data and is therefore excluded.

Table 3.14: Summary of Systematic/Historical Data Set Growth Curves

Region	MAP (mm)	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
		2	5	10	20	50	100	200	500	1000	2000	5000	10000
2	**437**	6.85	11.72	15.77	20.50	28.29	35.75	45.00	60.75	76.06	95.06	127.25	158.23
5	**600**	1.03	2.30	3.58	5.26	8.22	11.19	14.93	21.38	27.66	35.44	48.55	61.10
6	**348**	0.51	3.86	7.07	11.42	19.15	26.68	34.21	50.48	63.75	79.00	102.40	122.69
7	**481**	1.22	3.35	5.76	9.09	15.40	22.09	30.84	47.19	63.88	85.53	124.08	162.95
8	**708**	0.93	2.77	4.61	6.83	10.31	13.36	16.77	21.83	26.10	30.76	37.55	43.19

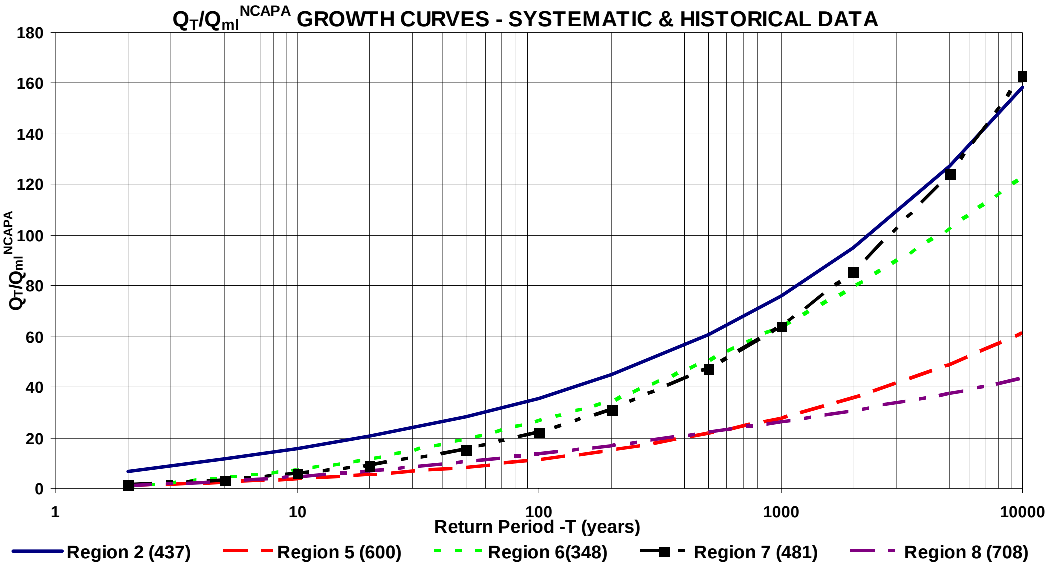

Figure 3.61: Systematic/Historical Data Set Regional Growth Curves

The generally accepted relationship between GC's and MAP with the inclusion of historical data is still implied in Table 3.14 and Figure 3.63 with the exception of region 7 whose GC values are greater than those of region 6 for T greater 1000-years and region 2 for T greater than 5000-years. This general implication is however still shown in Figure 3.62 for the 10-, 50- and 100-year event GC's developed using the systematic/historical data sets.

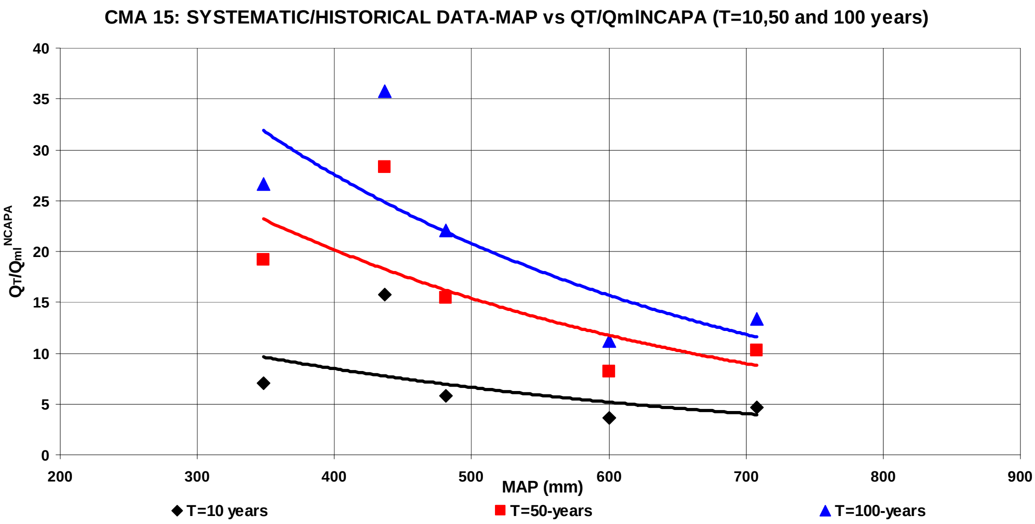

Figure 3.62: Systematic/Historic Data Set-Q_T/Q_{ml}^{NCAPA} vs MAP

Similar to the curve fitting of the systematic data sets for the regions, the systematic/historical data sets also yielded an exponential relationship between GC's and MAP. The general form of the relationship is thus similar to that of systematic data set (section 3.5.1). This general form of the relationship obtained from the analyses of the systematic data also provided the best correlations in general for all the return periods. The values of a and b for the various return periods for the systematic/historic data set derived GC's are tabulated in Table 3.15 and the correlation R^2 value for the various GC's and MAP are also shown. The correlations improved as the return period increased up to the 1000-year event after which it decreases to 0.74 for the 10000-year event. Similar to the systematic data set analyses this should not be interpreted as a suggestion that the GC's for the lower T events should be discarded. This is mainly due to small variation in the GC values with MAP for the lower T events.

Table 3.15: Variables a and b for Q_T/Q_{ml}^{NCAPA} vs MAP Relationship-Systematic/Historical GC

Var.	Return Period – T (years)											
	2	5	10	20	50	100	200	500	1000	2000	5000	10000
f	1.9	13.5	22.6	35.3	59.3	84.9	112.3	182.2	247.2	331.7	481.5	631.3
h	-0.0007	-0.0024	-0.0025	-0.0026	-0.0027	-0.0028	-0.0028	-0.0031	-0.0032	-0.0034	-0.0035	-0.0036
R^2	0.01	0.28	0.38	0.48	0.60	0.68	0.71	0.78	0.80	0.79	0.77	0.74

The GC for the systematic/historic data sets were estimated using the above and are represented in a tabular form in Table 3.16 and in a graphical format in Figure 3.63. By relating the GC's to MAP the bases for the regionalisation is still valid with the GC's for a particular site being specific for the site.

Table 3.16: Growth Curves Based on Systematic/Historical Data Sets-CMA 15

MAP	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
(mm)	2	5	10	20	50	100	200	500	1000	2000	5000	10000
200	1.65	8.35	13.71	20.99	34.56	48.50	64.15	98.01	130.35	168.04	239.11	307.29
300	1.54	6.57	10.68	16.18	26.38	36.65	48.48	71.89	94.65	119.61	168.50	214.39
400	1.44	5.17	8.31	12.48	20.14	27.70	36.64	52.73	68.73	85.13	118.74	149.57
500	1.34	4.07	6.48	9.62	15.37	20.94	27.69	38.67	49.91	60.60	83.67	104.35
600	1.25	3.20	5.04	7.42	11.74	15.82	20.93	28.36	36.24	43.13	58.96	72.80
700	1.16	2.52	3.93	5.72	8.96	11.96	15.82	20.80	26.32	30.70	41.55	50.79
800	1.09	1.98	3.06	4.41	6.84	9.04	11.96	15.26	19.11	21.85	29.28	35.44
900	1.01	1.56	2.38	3.40	5.22	6.83	9.04	11.19	13.88	15.55	20.63	24.72
1000	0.94	1.22	1.86	2.62	3.99	5.16	6.83	8.21	10.08	11.07	14.54	17.25

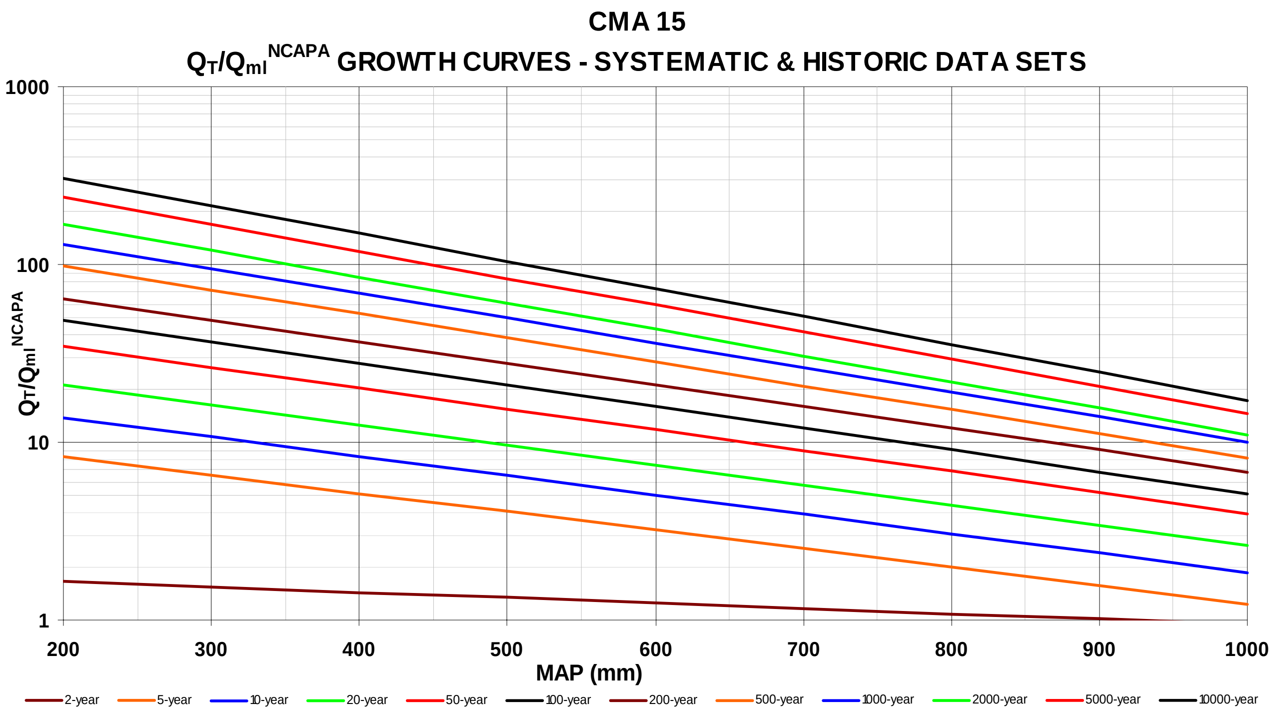

Figure 3.63: Growth Curves Based on Systematic and Historical Data – CMA 15

3.5.3 Regional flood peak growth curve development using systematic/palaeoflood data sets

The data sets used in the analyses for each region are summarised in Table 3.17. Only 5 sites with palaeoflood data and two regions were eventually included in the analyses with the average period of observation being 5314 years and the average number of data points being 51.

Table 3.17: Site Summary-Systematic and Palaeoflood Data

Region	Sites	MAP (mm)	Period length (years)	Data
6-Karoo	3	348	2631	54
7-False Karoo	2	489	7996	48
Average/Total	**5**		**5314**	**51**

The GC's derived for both of the regions with palaeoflood data, without any adjustments for MAP are tabulated in Table 3.18 and shown in Figure 3.64.

Table 3.18: Summary of Systematic and Palaeoflood Growth Curves

Region	MAP	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
	(mm)	2	5	10	20	50	100	200	500	1000	2000	5000	10000
6	348	1.28	3.60	6.04	9.15	14.41	19.39	25.21	34.89	43.59	53.75	69.76	84.12
7	481	1.98	4.87	7.45	10.42	15.03	19.13	23.38	31.27	37.91	45.58	57.59	68.29

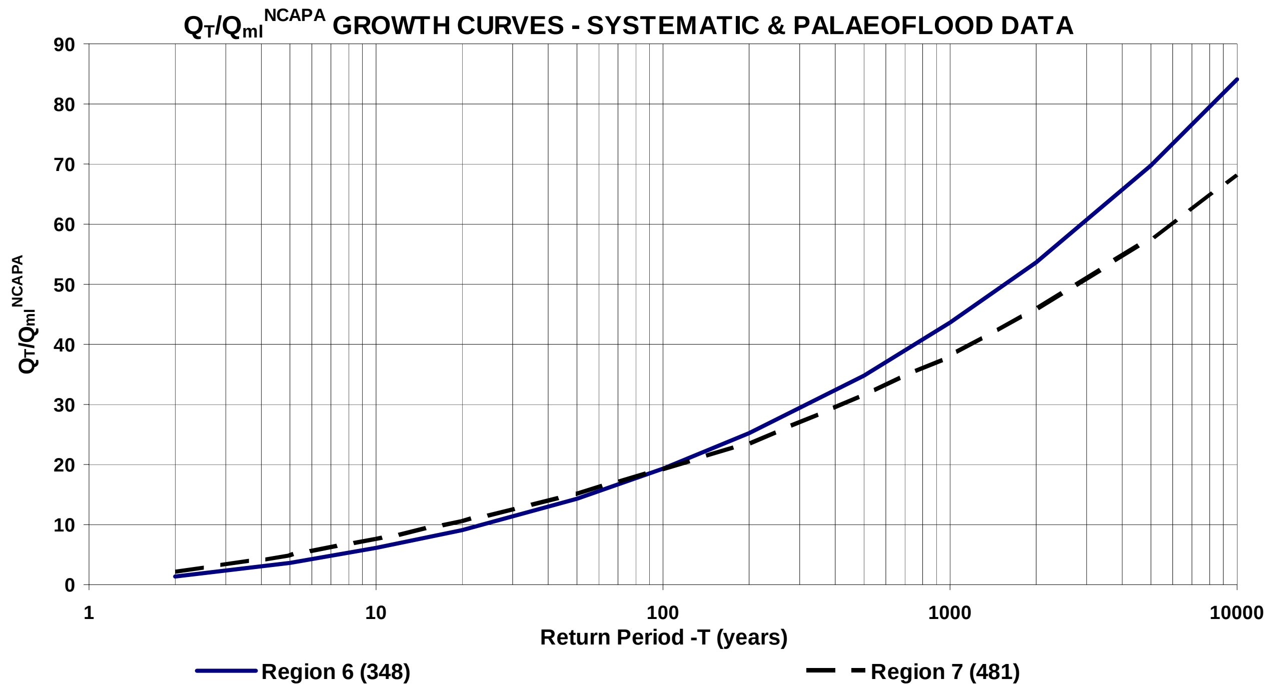

Figure 3.64: Systematic/Palaeoflood Data Set Regional Growth Curves

The generally accepted relationship between GC's and MAP with the inclusion of palaeoflood data still seems valid not withstanding the fact that only two regions with palaeoflood data are available. The general trend between MAP and GC is still implied in Table 3.18 and Figure 3.64 and Figure 3.65 shows the trend for the 100-, 500- and 5000-year event GC's developed using the systematic/palaeoflood data sets.

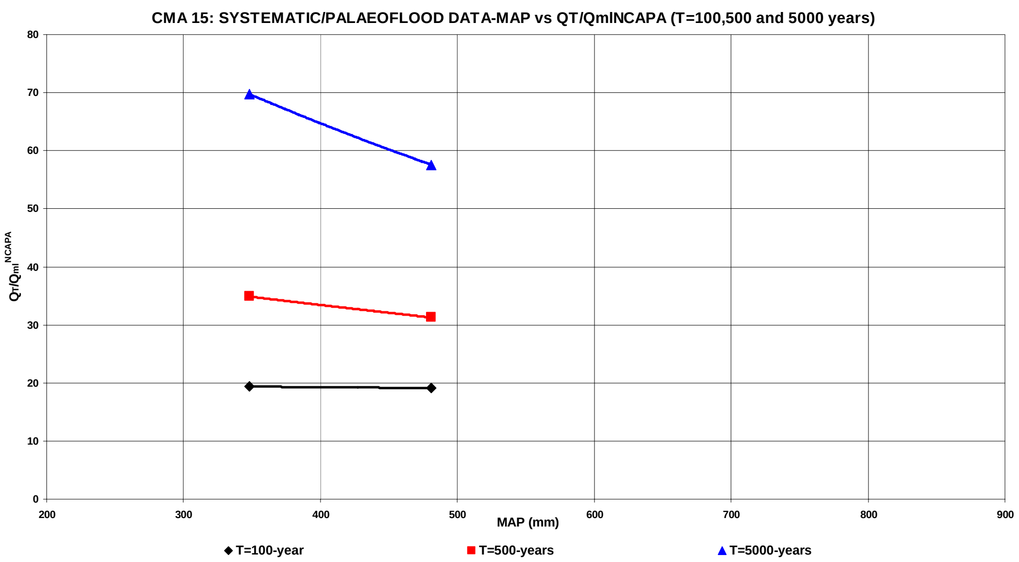

Figure 3.65: Systematic/Palaeoflood Data Set-Q_T/Q_{ml}^{NCAPA} vs MAP

Since only two data points were available for the systematic/palaeoflood data sets GC and MAP the assumption was made that the form of the relationship between the GC and MAP is similar to that of the systematic data sets and the systematic/palaeoflood data sets. Using the exponential relationship of the systematic data set and that obtained from the systematic/historic data set the values of the f and h constants for each return period was determined by trial and error with the values for regions 6 and 7 serving as reference points. The values of f and h obtained are listed in Table 3.19. No correlations are provided since only two points were available.

Table 3.19: Variables a and b for Q_T/Q_{ml}^{NCAPA} vs MAP Relationship -Systematic/Palaeoflood GC

Var.	Return Period – T (years)											
	2	5	10	20	50	100	200	500	1000	2000	5000	10000
f	1.9	8	13.5	21	35	50	65	100	132	184	255	350
h	-0.0004	-0.0015	-0.0017	-0.0019	-0.0021	-0.0022	-0.0024	-0.0027	-0.0029	-0.0032	-0.0034	-0.0037

The GC for the systematic/palaeoflood data sets were estimated using the above and are represented in a tabular form in Table 3.20 and in a graphical format in Figure 3.66. Similar to the two previous data sets by relating the GC's to MAP the bases for the regionalisation is still valid with the GC's for a particular site being specific for the site.

Table 3.20: Growth Curves Based on Systematic and Palaeoflood Data-CMA 15

MAP	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
(mm)	2	5	10	20	50	100	200	500	1000	2000	5000	10000
200	1.76	5.93	9.61	14.51	23.23	32.01	40.63	58.33	73.91	97.80	128.03	167.66
300	1.69	5.10	8.11	12.06	18.92	25.61	32.12	44.55	55.30	71.30	90.72	116.04
400	1.62	4.39	6.84	10.02	15.42	20.49	25.39	34.03	41.38	51.98	64.28	80.31
500	1.56	3.78	5.77	8.33	12.56	16.40	20.07	25.99	30.96	37.90	45.55	55.59
600	1.50	3.25	4.87	6.92	10.23	13.12	15.87	19.85	23.17	27.63	32.27	38.47
700	1.44	2.80	4.11	5.75	8.33	10.50	12.55	15.16	17.34	20.14	22.87	26.63
800	1.39	2.41	3.46	4.78	6.79	8.40	9.92	11.58	12.97	14.69	16.20	18.43
900	1.33	2.07	2.92	3.97	5.53	6.72	7.84	8.84	9.71	10.71	11.48	12.76
1000	1.28	1.79	2.47	3.30	4.51	5.38	6.20	6.75	7.26	7.81	8.14	8.83

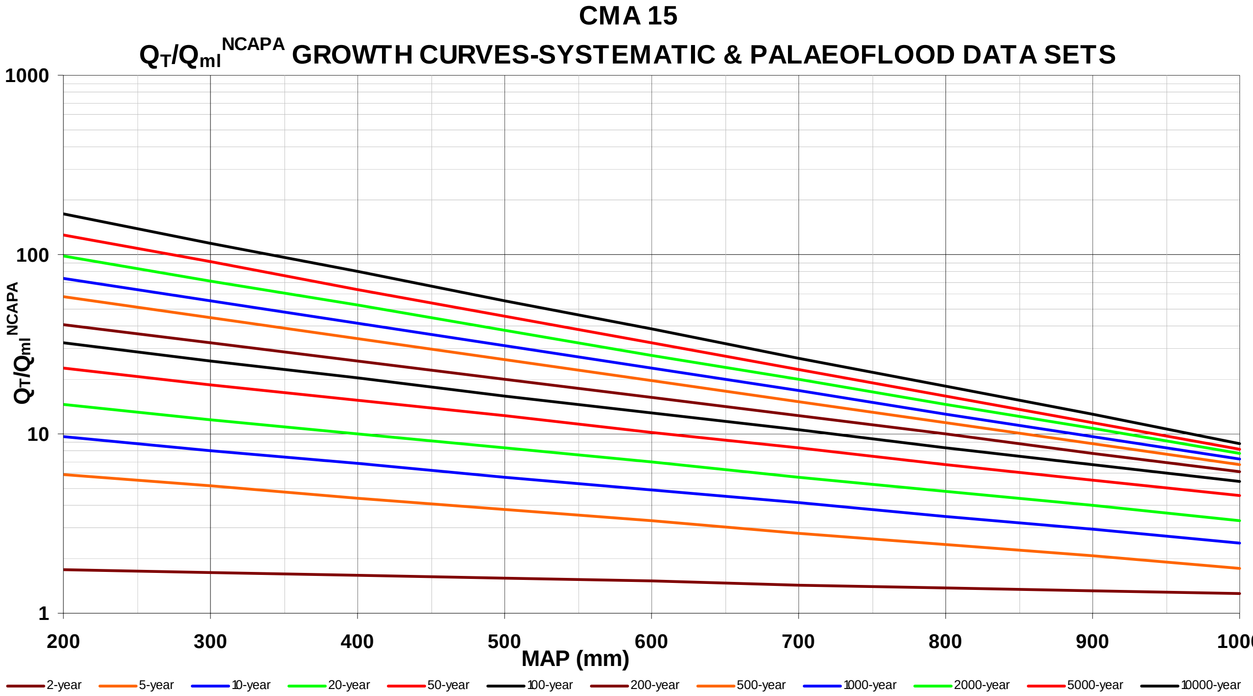

Figure 3.66: Growth Curves Based on Systematic and Palaeoflood Data – CMA 15

3.5.4 Splicing of Systematic, Historical and Palaeoflood Flood Peak GC's

Obtaining a single growth curve that includes systematic, historical and palaeoflood characteristics requires some form of joining or splicing of the various GC's over each GC's range that it applies to. The following assumptions were made for each data set used to derive the GC's.

- The systematic period GC is applicable up to flood events between 100- and 200-years. For events greater than or equal to the 200-year event the systematic data derived GC should not be used.
- The historic period GC is applicable from events between the 20-year event and the 500-year event. For events greater than or equal to the 500-year event the historical data derived GC should not be used.
- The palaeoflood period GC is applicable for events between the 50-year event to the 10000-year event. The palaeoflood derived GC should not be used for events less than the 50-year event due to its over estimation of flood event magnitudes for events less than 20-years. This is due to the impact that the relatively large palaeoflood peaks have on the estimated parameters of the data sets. Similar to the other data set derived GC's, the palaeoflood derived GC should not be used to estimate flood curves for events larger than the 10000-year event.

In order to obtain a single set of GC's the GC's derived for each of the data sets have to be spliced in a manner that will take into account the strengths and weaknesses of each data set. The splicing ratios deemed to best utilise these characteristics for the splicing the data sets and obtain a single set of GC's is shown in Figure 3.67.

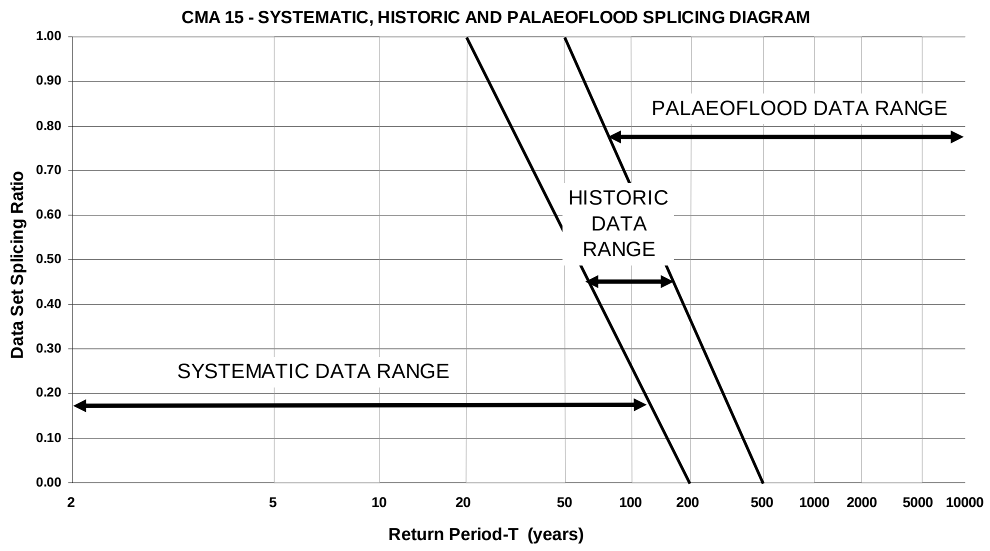

Figure 3.67: Systematic, historical and palaeoflood splicing diagram

The impact of the splicing ratios proposed in Figure 3.67 is demonstrated for regions 6 and 7 in figures 3.68 and 3.69 that have all three data sets used to derive the GC's.

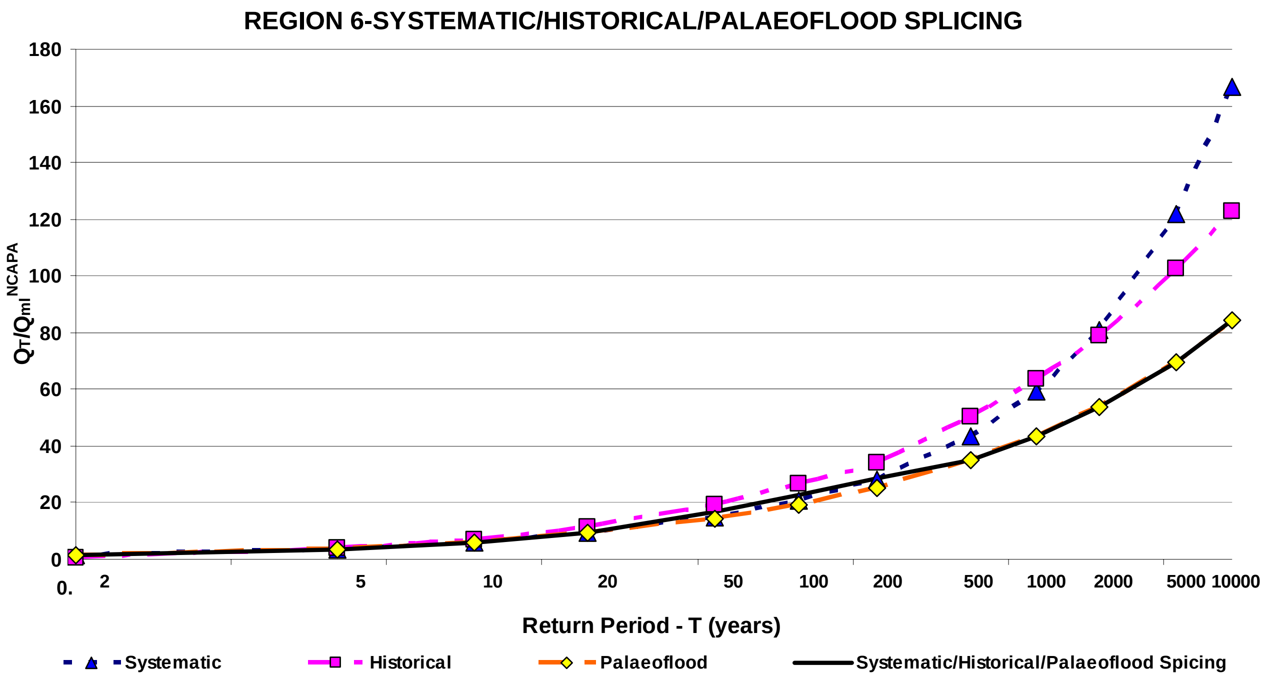

Figure 3.68: Region 6, systematic, historic and palaeoflood growth curve splicing

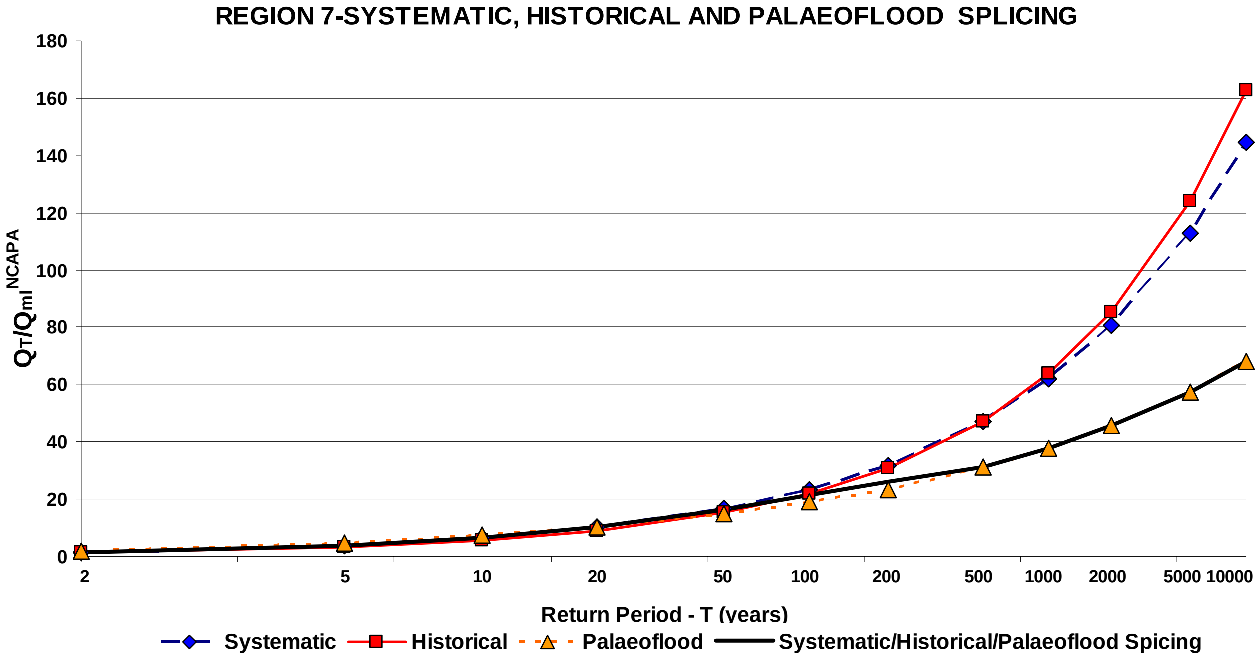

Figure 3.69: Region 7, systematic, historic and palaeoflood growth curve splicing

To obtain the single set of GC's the splicing ratios were also applied to the GC's and a new set of a and b values were obtained that is shown in Table 3.21.

Table 3.21: Variables a and b for Q_T/Q_{ml}^{NCAPA} vs MAP Relationship-spliced Systematic/ Historical/ Palaeoflood GC

Var.	Return Period – T (years)											
	2	5	10	20	50	100	200	500	1000	2000	5000	10000
f	1.9	8	13.5	21	35	50	65	100	132	184	255	350
h	-0.0004	-0.0015	-0.0017	-0.0019	-0.0021	-0.0022	-0.0024	-0.0027	-0.0029	-0.0032	-0.0034	-0.0037

The GC's for the spliced systematic/historic/palaeoflood data sets were estimated using the above and are represented in a tabular form in Table 3.22 and in a graphical format in Figure 3.70. Similar to the source GC's by relating the GC's to MAP the bases for the regionalisation is still valid with the GC's for a particular site being specific for the site.

Table 3.22: Growth Curves Based on Spliced Systematic/Historic/ Palaeoflood Data-CMA 15

MAP (mm)	Q_T/Q_{ml}^{NCAPA} growth values for various return periods – T											
	2	5	10	20	50	100	200	500	1000	2000	5000	10000
200	1.18	3.99	7.18	11.96	28.40	39.39	49.63	58.33	73.91	97.80	128.03	167.66
300	1.17	3.76	6.57	10.71	23.25	31.23	38.61	44.55	55.30	71.30	90.72	116.04
400	1.16	3.54	6.00	9.60	19.04	24.76	30.03	34.03	41.38	51.98	64.28	80.31
500	1.15	3.33	5.48	8.60	15.59	19.63	23.36	25.99	30.96	37.90	45.55	55.59
600	1.14	3.14	5.01	7.70	12.77	15.56	18.17	19.85	23.17	27.63	32.27	38.47
700	1.13	2.96	4.58	6.90	10.46	12.34	14.14	15.16	17.34	20.14	22.87	26.63
800	1.12	2.78	4.19	6.18	8.56	9.78	11.00	11.58	12.97	14.69	16.20	18.43
900	1.11	2.62	3.83	5.54	7.01	7.76	8.55	8.84	9.71	10.71	11.48	12.76
1000	1.10	2.47	3.50	4.96	5.74	6.15	6.65	6.75	7.26	7.81	8.14	8.83

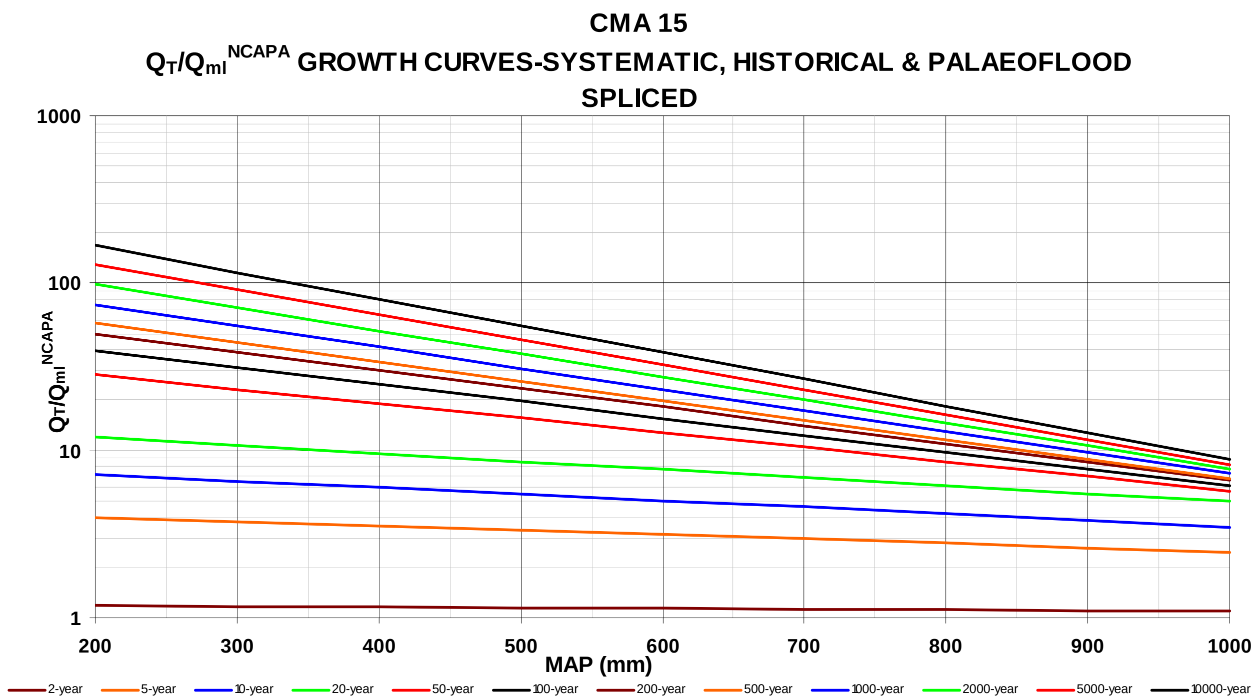

Figure 3.70: Q_T/Q_{ml}^{NCAPA} growth curves-Systematic, historical and palaeoflood data spliced

From sections 3.5.1 to 3.5.4 the benefit of including historical and palaeoflood data is clear. The flood peaks estimates for the more extreme events (greater 100-years) are more realistic and events with a return period of up to 10000 years may be estimated with more certainty of obtaining realistic results.

3.6 Summary of NCAPA Methodology - CMA15.

The NCAPA methodology to determine the Q_i has a similar form as the original CAPA method. The NCAPA is however regionalised and each region has its own set of constants. The growth curves (GC's) are a function of the MAP and are adjusted to take into account the impact of the historical and palaeoflood data. The methodology maybe summarised as follows:

- Determine the region in which the site is (Figure 3.42).
- Obtain the catchment area, standard river slope (1085) and MAP for the catchment.
- Estimate the NCAPA lumped parameter M' (section 3.4.2)
- Estimate Q_{ml}^{NCAPA} using the regionalised Q_{ml} equations in Table 3.8.
- The required Q_T values can now be estimated using the growth curve values in Table 3.22 or by using the Q_T/Q_{ml}^{NCAPA} equation with the parameters f and h from Table 3.21. Both methods require the MAP as input.
- If the site Q_{ml} can be estimated from the available data this value should be used. The minimum record length required is 10 years.

CHAPTER 4
COMPARISONS WITH OTHER METHODS

4 COMPARISONS WITH OTHER METHODS

The proposed method to estimate flood magnitudes is compared at several sites using previous flood estimates at these sites obtained from DWAF. The sub-directorate Flood Studies as a rule use several methods when estimating flood probabilities. Selection of which methods to apply for the requests for flood peak estimates are based on the methods applicability regarding region, catchment area and level of the request. The methods currently used by DWAF (van der Spuy et al., 1997 and Kovacs, 1993) are:

- Statistical methods (Statistical) that include the log-normal (LN), log-Pearson type 3 (LP3) and the general extreme value (GEV) using the method of moments (MM) and probability weighted moments (PWM)
- The Rational method (Rational) adapted by DWAF for use on catchment areas of up to 10000 km^2.
- Direct Runoff Hydrograph (DRH) from report HRU 1/74.
- Midgley-Pitman (MIPI) as reported on in HRU report 1/72 is a statistical/empirical method based on the correlation between geographical location, return period, catchment area and peak discharge. The country was divided into seven homogeneous flood zones and a typical "Gumbel" distribution was established for each region.
- Catchment parameter method (CAPA) used to estimate the mean annual flood peak and growth curve developed in the department for all return periods up to the 200-year event.
- Regional maximum flood (RMF) method (TR137) that applies multipliers to the RMF to estimate the 50-, 100- and 200-year flood events.
- Synthetic unit hydrograph (SUH) as described in HRU report no. 1/74
- HRU 1/71 (HRU 1/71) which is based on the original SUH method first reported on in HRU report 1/69 which after a review in 1971 resulted in only selected parameters being used. These parameters are catchment area, MAP, catchment parameter-B and combined coefficient K_T (based on meteorological region, veld type zone and return period). Catchment parameter B requires catchment area, river slope and river length in total and to catchment centriod.

The recently developed Standard Design Flood (SDF) (Alexander, 2002) is estimated for the sites without adjustments. The results from four selected sites at which DWAF performed analysis and the results obtained from the GC-NCAPA method and the SDF are discussed in section 4.2 to 4.5. Further comparisons of the GC-NCAPA method, the SDF and the LP3/MM estimates of flood peaks with observed data from several other sites are provided in section 4.6. The graphical comparison is done for the recommended flood peaks by DWAF (referred as recom in the figures), the SDF and the NCAPA method that estimates the Q_{ml} using the NCAPA lumped parameter M' and the growth curves developed in this study. The sites used for the verification of the proposed methodology, is shown in Figure 4.1.

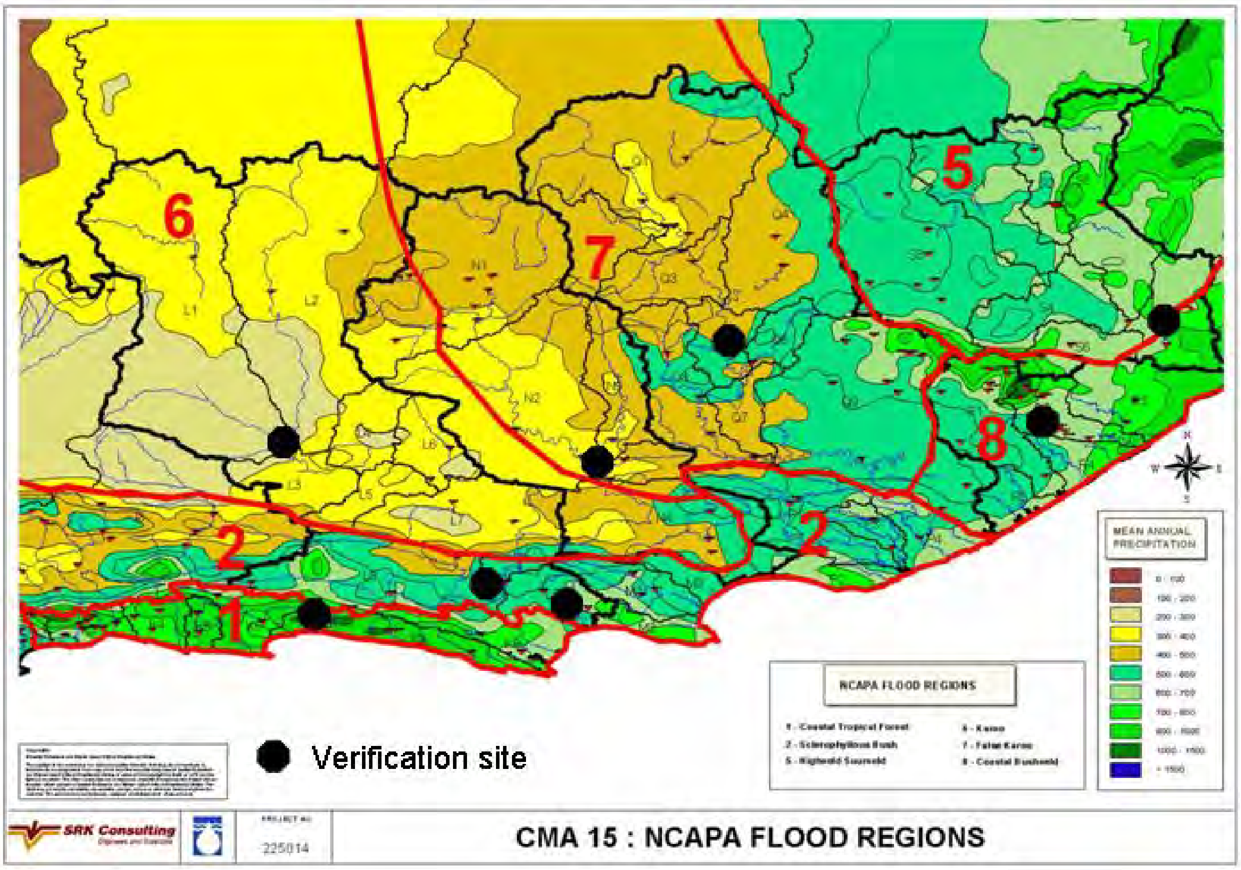

Figure 4.1: Locality Map for Verification Sites

4.1 Beervlei Dam-Region 6

Beervlei Dam is situated on the Groot River in region 6 with Karoo the predominant vegetation class. The dam is downstream from the confluence of the Sout and Kariga (Buffels) rivers. The catchment characteristics are:

- Catchment area = 20 580 km^2.
- River slope (1085) = 0.00227 m/m
- MAP = 225 mm
- Longest water course = 264.2 km

The lumped parameter M' is 79 and the Q_{ml}^{NCAPA} is 110. The site gauged Q_{ml} is 121m^3/s. The requested flood peaks are estimated by applying the GC in Table 3.22 or Figure 3.72. The results are shown in Table 4.1 with the estimates for other methods supplied by DWAF and the result provided by applying the SDF. The C2 and C100 values used in the SDF were not adjusted.

Table 4.1: Comparison of Flood Peak (m^3/s) Estimation Methods

Method	Return Period-T (years)							
Beervlei dam, L3R001 the Groot river. Catchment Area = 20 339 km^2								
DWAF	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**RMF**	**10000**
Statistical	191	594	1003	1495	2262	2921	3641	12923	
Rational	627	966	1254	1606	2313	3094	4080		
DRH	714	1198	1549	1932	2512	2976	3477		
HRU 1/71	318	800	1165	1570	2201	2770	3439		
TR 137					7030	8221	9449		
MIPI	403	973	1534	2206	3264	4195	5239		
CAPA	354	655	974	1400	2200	3051	4188		
Recommended	**190**	**590**	**1000**	**1500**	**2260**	**2920**	**3640**	**12923**	
SDF	**151**		**1282**	**1998**	**3258**	**4485**	**5994**		
GC-NCAPA	**138**	**463**	**828**	**1371**	**3184**	**4382**	**5495**		**18028**

The recommended flood peaks by DWAF and those estimated using the GC-NCAPA and the SDF are shown in Figure 4.2.

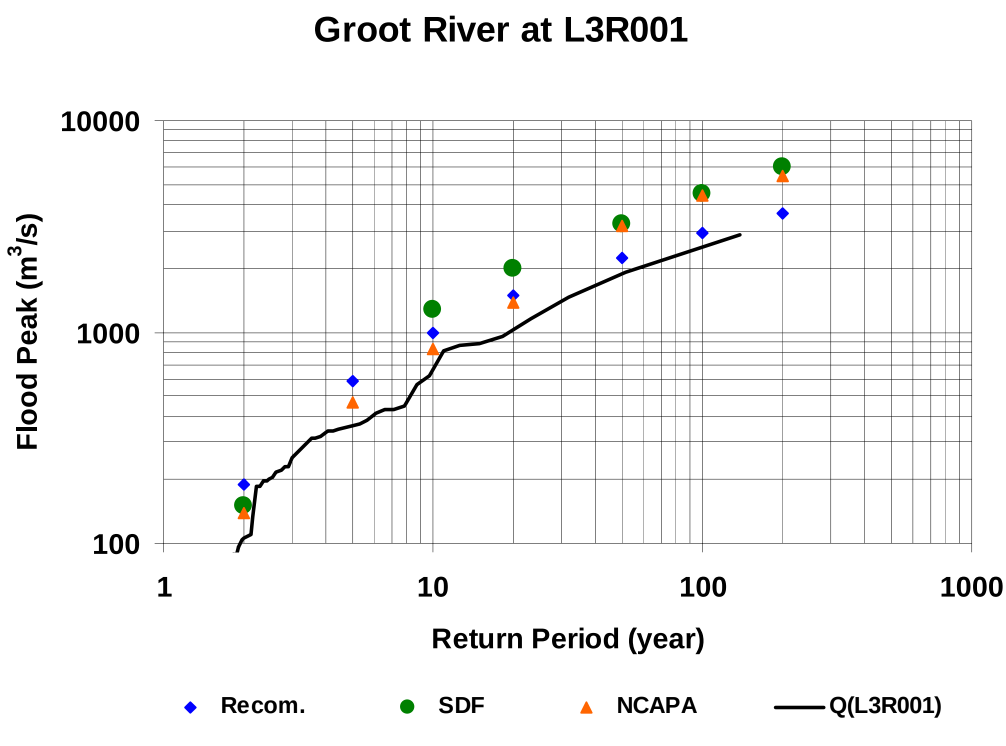

Figure 4.2: Comparison of Flood Estimates – Beervlei Dam, Groot River-Region 6

The recommended peaks by DWAF are only based on the results of the statistical analysis using an observed 83 year record. The GC-NCAPA using the total catchment area over estimate the flood peaks for all events greater than the 20-year flood. The SDF using the recommended C values provide estimates similar to those obtained using the NCAPA GC's for events larger than the 50-year event. For events less than the 20-year events the SDF would appear to over estimate flood peaks.

4.2 Elands Drift Dam, Great Fish River-Region 7

Elands Drift Dam is situated on the Great Fish River in region 7 with False Karoo the predominant vegetation class. The dam is between Cradock and Cookhouse. The catchment characteristics are:

- Catchment area = 16 864 km^2.
- River slope (1085) = 0.0027 m/m
- MAP = 412 mm
- Longest water course = 350 km

Using the total catchment area M' = 130. The Q_{ml}^{NCAPA} is 279m^3/s and the Q_{ml} from the gauged information is 209m3/s. The gauged information is taken from Q7H005 downstream from the site with a catchment area of 19240 km^2. All data from Q7H005 has been adjusted for the difference in catchment area. The requested flood peaks are estimated by applying the GC in Table 3.22 or Figure 3.72. The results are shown in Table 4.2 with the estimates for other methods supplied by DWAF and the result provided by applying the SDF. The C2 and C100 values used in the SDF were not adjusted.

Table 4.2: Comparison of Flood Peak (m^3/s) Estimation Methods

Method	**Return Period-T (years)**								
Elandsdrift dam, Q5R001 the Great Fish river. Catchment Area = 16 864 km^2									
DWAF	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**RMF**	**10000**
Statistical	293	863	1423	2126	2943	3713	4596		
Rational	466	977	1380	1805	2419	2938	3472		
DRH	923	1434	1801	2160	2679	3098	3541		
SUH	787	1223	1535	1841	2284	2641	3019		
MIPI	350	852	1345	1933	2856	3666	4572		
HRU 1/71	422	1061	1545	2083	2919	3674	4561		
CAPA	673	1218	1796	2570	4959				
TR137					7030	8222	9449	12924	
Recommended	**295**	**865**	**1420**	**2130**	**2940**	**3710**	**4600**	**12920**	
SDF	**324**		**1415**	**2006**	**2951**	**3806**	**4803**		
GC-NCAPA	**323**	**980**	**1656**	**2642**	**5187**	**6718**	**8130**		**11150**

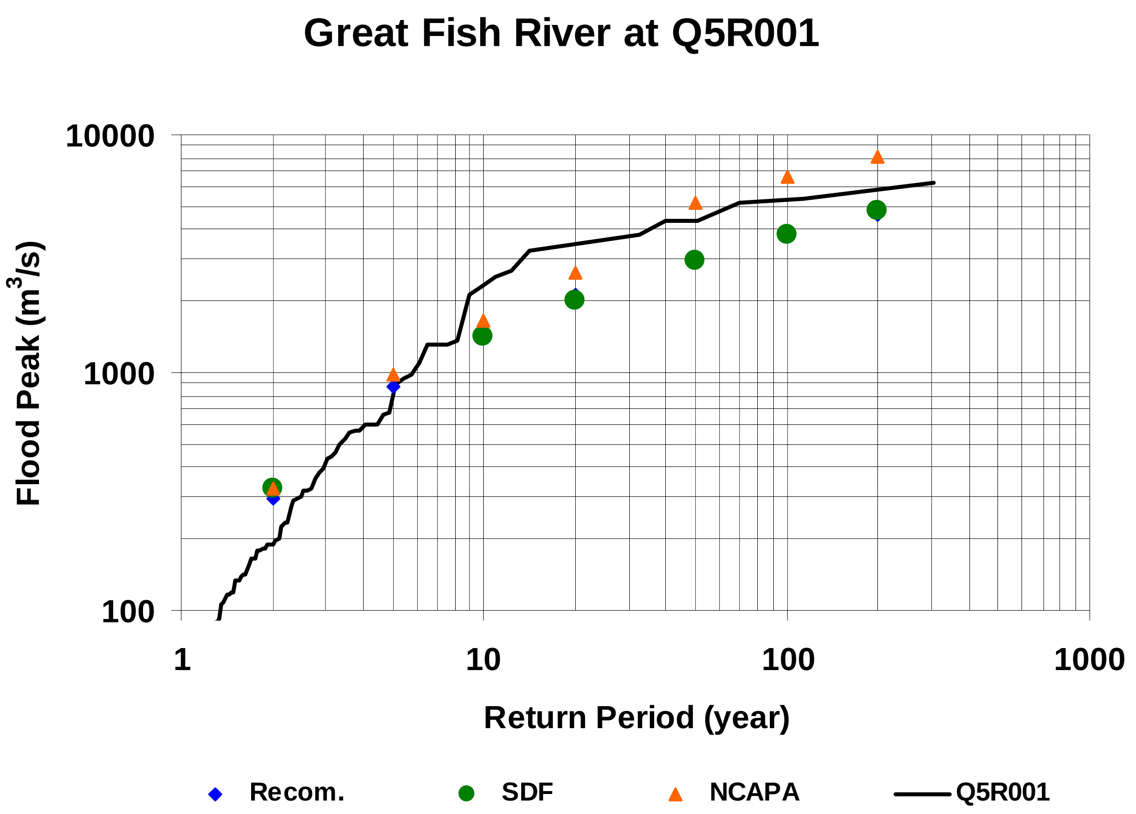

Figure 4.3: Comparison of Flood Estimates – Elands Drift Dam, Great Fish River-Region 7

Figure 4.3 would suggest that for the 2-year and 5-year events all the flood peak estimates are reasonable. Events less than the 50-year event For the 10-year and 20-year events the estimated floods peaks are under estimated. For the more extreme events such as the 50-year and larger events the recommended and SDF estimated flood peaks are under estimated. The NCAPA estimated flood peaks for the more extreme events would seem to be over estimated.

4.3 Darlington Dam, Sunday River-Region 7

Darlington (previous Mentz) Dam is situated on the Sundays River in region 7 with False Karoo the predominant vegetation class. The dam is upstream of the Sundays River valley. The catchment characteristics are:

- Catchment area = 16 826 km^2.
- River slope (1085) = 0.00376 m/m
- MAP = 355 mm
- Longest water course = 327 km

Using the total catchment area M' = 136. The Q_{ml}^{NCAPA} is 288m^3/s. No Q_{ml} is available for the site at present. At N2H007 upstream the Q_{ml} is 121m^3/s but is severely impacted upon by upstream impoundments. The requested flood peaks are estimated by applying the GC in Table 3.22 or Figure 3.72. The results are shown in Table 4.2 with the estimates for other methods supplied by DWAF and the result provided by applying the SDF. The C2 and C100 values used in the SDF were not adjusted.

Table 4.3: Comparison Of Flood Peak (m^3/s) Estimation Methods

Method	**Return Period-T (years)**								
Darlington dam, N2R001 the Sundays river. Catchment Area = 16 826 km^2									
	2	**5**	**10**	**20**	**50**	**100**	**200**	**RMF**	**10000**
Statistical	191	594	1003	1495	2262	2921	3641		
Rational	627	966	1254	1606	2313	3094	4080		
DRH	528	877	1146	1420	1808	2128	2481		
HRU 1/71	318	800	1165	1570	2201	2770	3439		
MIPI	403	973	1534	2206	3264	4195	5239		
CAPA	354	655	974	1400	2200	3051	4188		
TR137					7030	8221	9449	12923	
Recommended	**190**	**590**	**1000**	**1500**	**2260**	**2920**	**3640**	**12920**	
SDF	**365**		**1592**	**2259**	**3325**	**4291**	**5417**		
GC-NCAPA	**334**	**1047**	**1799**	**2903**	**5999**	**7916**	**9684**		**13579**

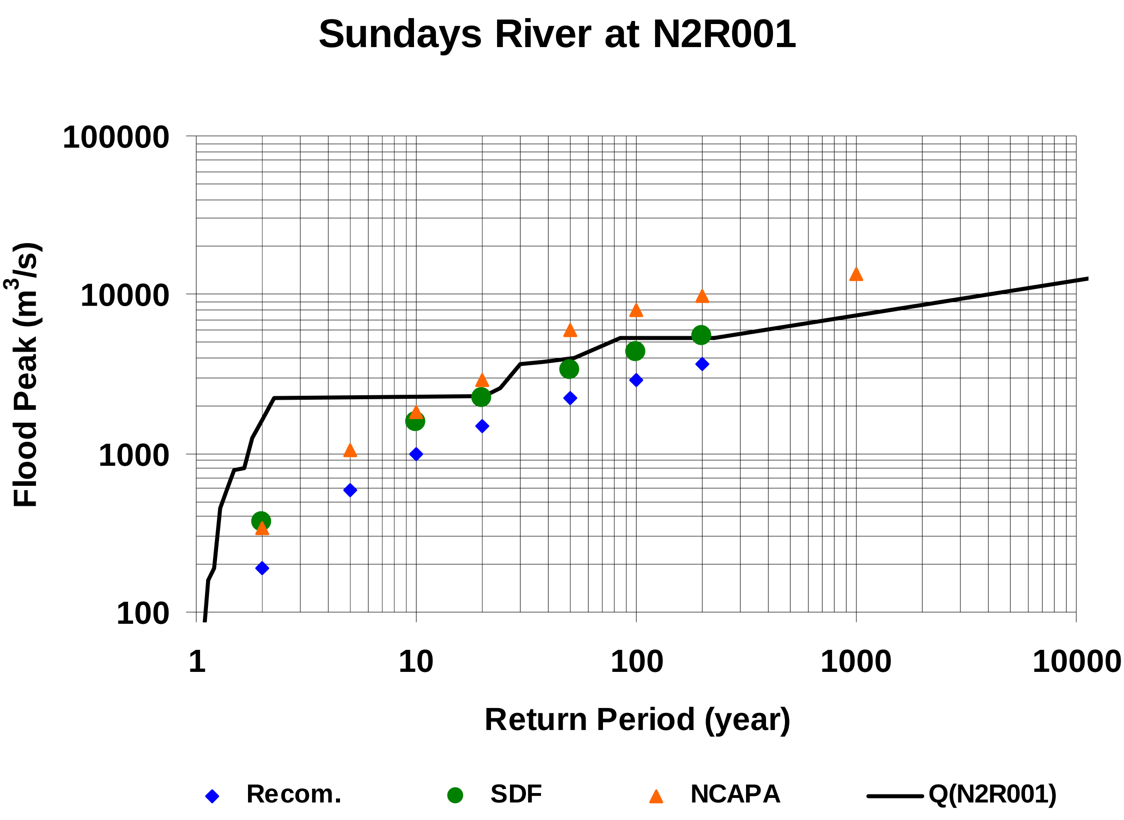

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Figure 4.4: Comparison of Flood Estimates – Darlington Dam, Sundays River-Region 7

From Figure 4.4 the results obtained using SDF would seem to the most reasonable while the recommended flood peaks estimates are generally lower than the observed data and the NCAPA estimates are over estimated for the 50-year and larger flood events.

4.4 Laing Dam, Buffalo River-Region 8

Laing Dam is situated on the Buffalo River downstream of King Williams Town in region 8 with Bushveld the predominant vegetation class. The catchment characteristics are:

- Catchment area = 931 km^2.
- River slope (1085) = 0.0049 m/m
- MAP = 625 mm
- Longest water course = 57 km

Using the total catchment area M' = 330. The Q_{ml}^{NCAPA} is 181m^3/s and the Q_{ml} from the gauged information is also 181m3/s. The requested flood peaks are estimated by applying the GC in Table 3.22 or Figure 3.72. The results are shown in Table 4.2 with the estimates for other methods supplied by DWAF and the result provided by applying the SDF. The C2 and C100 values used in the SDF were not adjusted.

Table 4.4: Comparison of Flood Peak (m^3/s) Estimation Methods

Method	**Return Period-T (years)**								
Laing dam, R2R001 the Buffalo river. Catchment Area = 913 km^2									
	2	**5**	**10**	**20**	**50**	**100**	**200**	**RMF**	**10000**
Statistical	167	472	796	1068	1517	1898	2316		
Rational	142	315	466	632	880	1105	1335		
DRH	166	286	389	497	658	804	950		
SUH	164	283	385	492	652	796	941		
MIPI	134	317	499	718	1065	1374	1722		
HRU 1/71	91	229	334	450	630	793	985		
CAPA	168	274	387	535	810				
RMF					2133	2660	3165	4806	
Recommended	**167**	**472**	**769**	**1068**	**1517**	**1898**	**2316**	**4806**	
SDF	**61**		**429**	**632**	**938**	**1196**	**1470**		
GC-NCAPA	**205**	**555**	**873**	**1330**	**2118**	**2544**	**2945**		**3690**

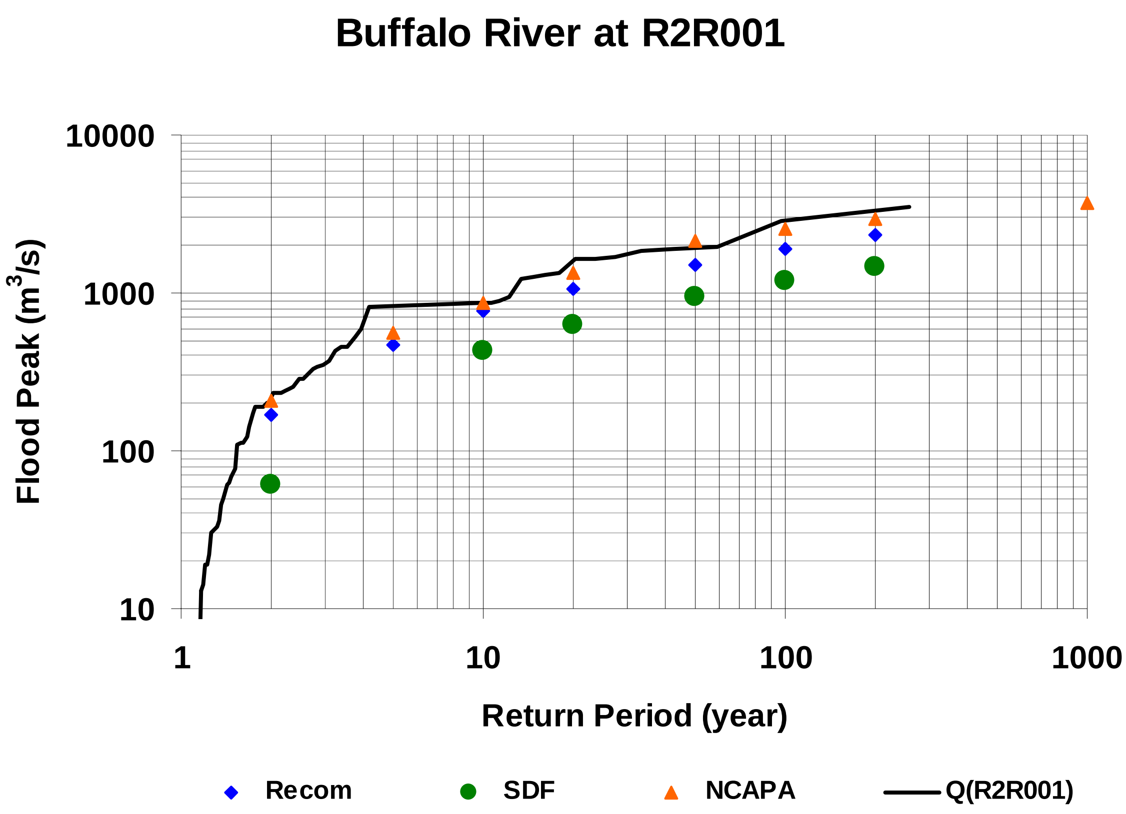

Figure 4.5: Comparison of Flood Estimates – Laing Dam, Buffalo River-Region 8

From Figure 4.5 the estimated flood peaks obtained for SDF and the recommended methods would seem to under estimate the flood peaks for all events. The NCAPA results however seem to track the observed data well.

4.5 Comparisons with Observed Data

The performance of the proposed Qi estimation technique and the GC's against observed data is evaluated at several sites to include sites not evaluated in sections 4.2 to 4.4. The SDF is also provided since the data input is similar to that of the NCAPA along with the previously calculated statistical results obtained using LP3/MM.

Bloukrans River (K7H001)-Region 1: The catchment characteristics are;

Catchment Area	$=59\ km^2$	River length	$=18.5$ km
River slope	$=0.03175$ m/m	MAP	$=845$ mm
M	$=970$	Q_{ml}^{NCAPA}	$=35\ m^3/s$
Q_{ml} (site)	$=70\ m^3/s$		

Table 4.5: Bloukrans River (K7H001)

Method	Estimated Q_T (m^3/s) for various return periods T (year)								
	2	10	20	50	100	200	500	1000	10000
SDF	16	110	162	240	306	376			
Stats.	72	217	291	401	493	579	739	860	1326
GC-NCAPA	39	141	206	273	308	344	359	398	547

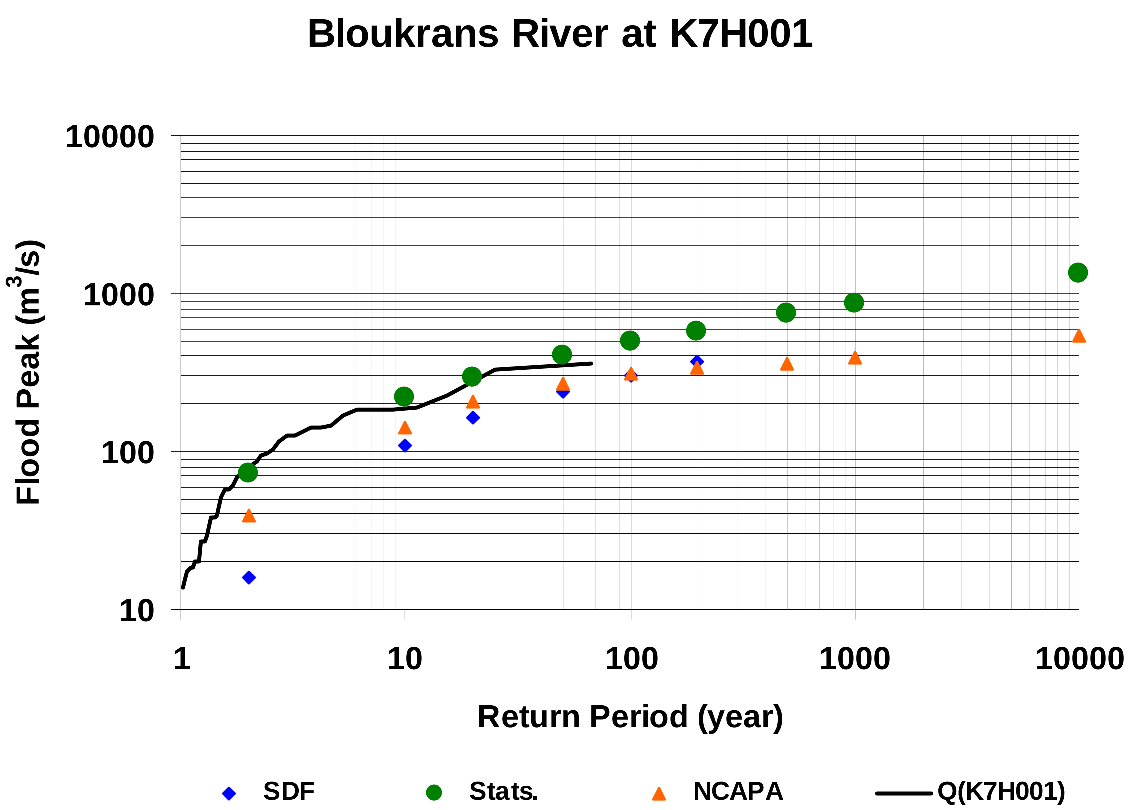

Figure 4.6: Estimated vs Observed Flood Peaks-Bloukrans River-Region 1

The GC-NCAPA and SDF estimates under estimate the flood peaks for all return periods. The statistical results using the LP3 distribution compare favourably with the observed data up to 70 years.

Kouga River (L9R001) -Region 2: The catchment characteristics are;

Catchment Area	=3890 km^2	River length	=189.6 km
River slope	=0.00324 m/m	MAP	=521 mm
M	=170	Q_{ml}^{NCAPA}	=110 m^3/s
Q_{ml} (site)	=115 m^3/s		

Table 4.6: Kouga River (L9R001)

Method	Estimated Q_T (m^3/s) for various return periods T (year)								
	2	10	20	50	100	200	500	1000	10000
SDF	150	955	1434	2245	3019	3955			
Stats. (LP3)	114	1346	2733	6092	10421	16203	31086	47417	166982
GC-NCAPA	126	593	927	1649	2062	2444	2709	3213	5674

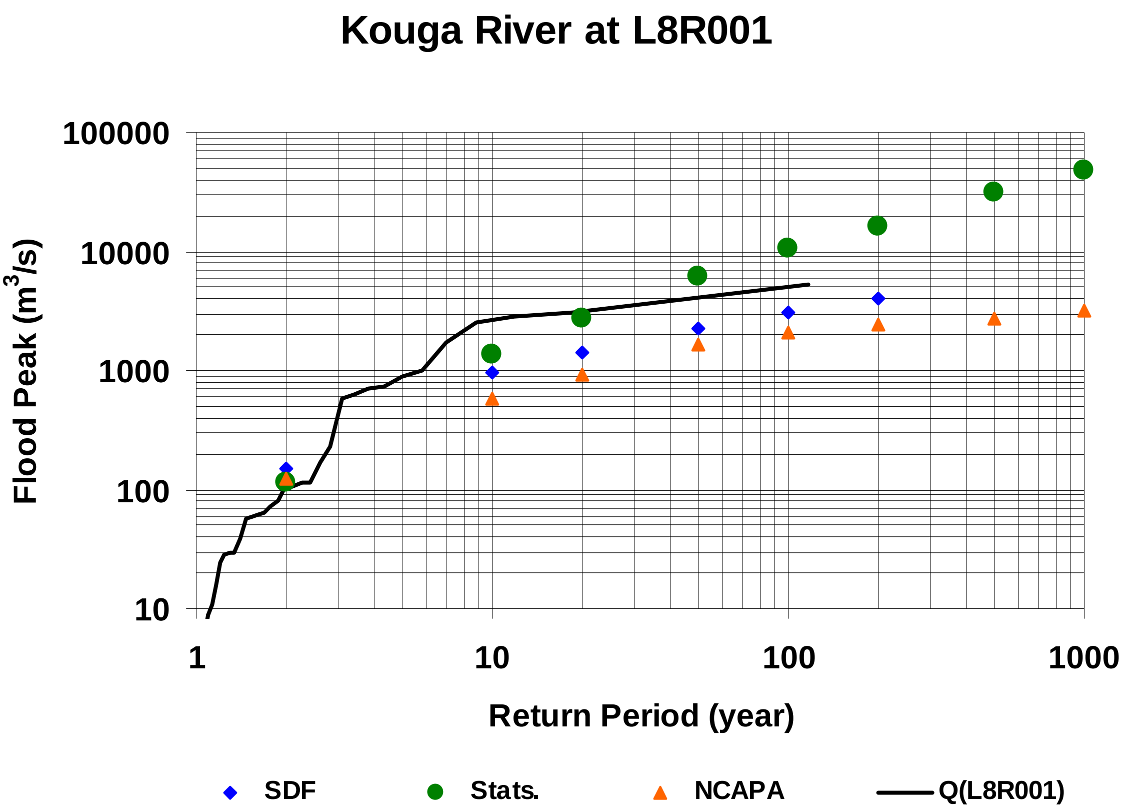

Figure 4.7: Estimated vs Observed Flood Peaks-Kouga River-Region 2

The NCAPA and SDF flood peak estimates are below the observed data for all events greater than the 5-year event. The LP3 estimates for this site demonstrate the unrealistic results that can be obtained from a single site analyses for return periods greater than 100-year or events that are longer than the observed period of observation. It should however be noted that the data for this site is of a poor quality since the inflow data is not complete.

Great Kei River (S7H004) -Region 5: The catchment characteristics are;

Catchment Area	=18799 km^2	River length	=410.3 km
River slope	=0.00327 m/m	MAP	=563 mm
M	=184	Q_{ml}^{NCAPA}	=440 m^3/s
Q_{ml} (site)	=482 m^3/s		

Table 4.7: Great Kei River (S7H004)

Method	Estimated Q_T (m^3/s) for various return periods T (year)								
	2	10	20	50	100	200	500	1000	10000
SDF	410	2662	4011	6288	8472	11102			
Stats.	506	1754	2572	4023	5474	7306	10462	13536	29897
GC-NCAPA	501	2278	3527	6046	7458	8769	9643	11341	19384

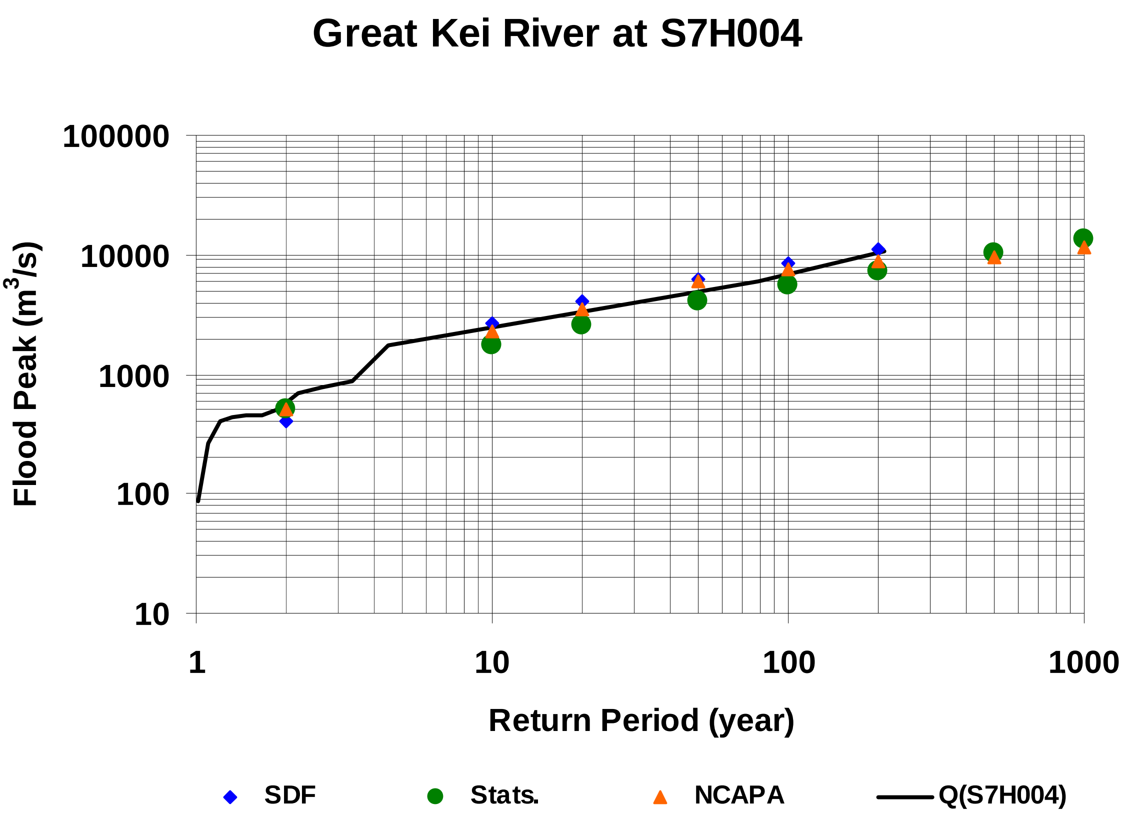

Figure 4.8: Estimated vs Observed Flood Peaks-Great Kei River-Region 5

All the methods applied for this site provided reasonable estimates with the observed record. The slight under estimation of the LP3 method is primarily due to the short systematic period that contained no large or extraordinary floods that may have tended to draw the estimates closer to the observed data.

Gourits River (J4H002) -Region 6: The catchment characteristics are;

Catchment Area	=43500 km^2	River length	=334.2 km
River slope	=0.00305 m/m	MAP	=293 mm
M	=128	Q_{ml}^{NCAPA}	=660 m^3/s
Q_{ml} (site)	=719 m^3/s		

Table 4.8: Gourits River (J4H002)

Method	Estimated Q_T (m^3/s) for various return periods T (year)								
	2	10	20	50	100	200	500	1000	10000
SDF	274	2334	3642	5947	8192	10956			
Stats.	617	3358	5093	7882	10354	13124	17223	20637	33722
GC-NCAPA	771	4362	7126	15568	20954	25940	29972	37257	76606

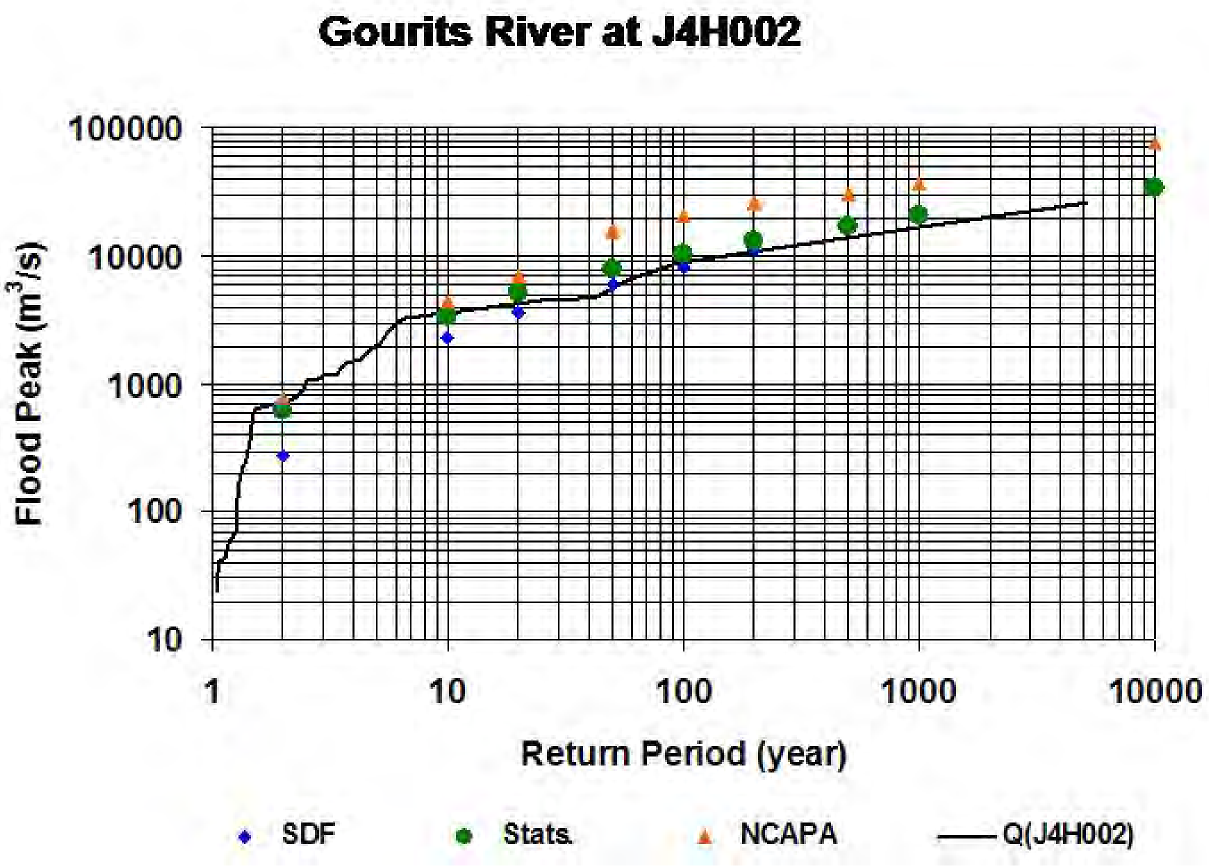

Figure 4.9: Estimated vs Observed Flood Peaks-Gourits River-Region 6

The LP3 method with the data set available provided the best estimates. The NCAPA estimates are generally inline with the observed data except for the higher return period flood events (>50-years) where the estimates would seem to be over estimated.

Gamtoos River (L9H003) -Region 6: The catchment characteristics are:

Catchment Area	=34063 km^2	River length	=531.5 km
River slope	=0.00225 m/m	MAP	=317 mm
M	=89	Q_{ml}^{NCAPA}	=247 m^3/s
Q_{ml} (site)	=154 m^3/s		

Table 4.9: Gamtoos River (L9H003)

Method	Estimated Q_T (m^3/s) for various return periods T (year)								
	2	10	20	50	100	200	500	1000	10000
SDF	156	1371	2156	3549	4918	6608			
Stats.	163	1228	2055	3565	5062	6572	9888	12615	24885
GC-NCAPA	247	1367	2497	4753	6348	7823	8999	11131	23049

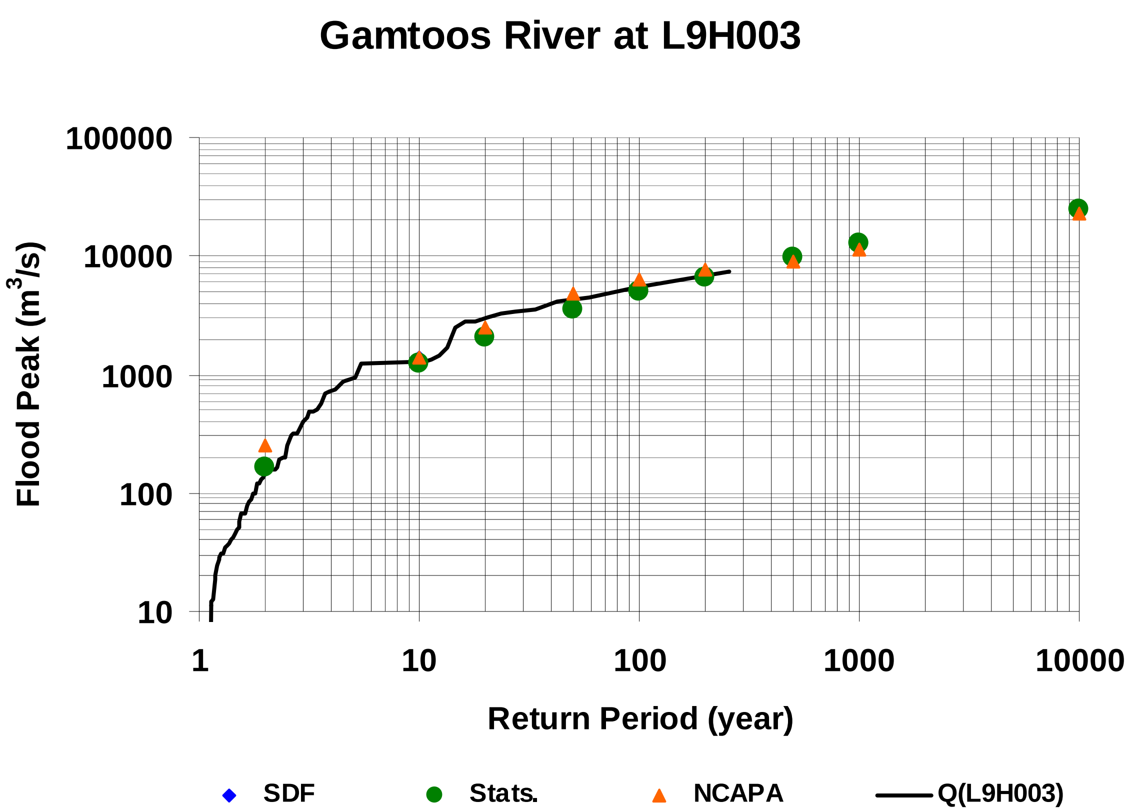

Figure 4.10: Estimated vs Observed Flood Peaks-Gamtoos River-Region 6

From Figure 4.10 the general shape of the GC-NCAPA estimates compare well with observed data suggesting that the GC is fairly representative. When applying the GC with the site estimated Q_{ml} the results compare favourably with the LP3 estimates that track the observed data well. The SDF results compare well to the observed data for the range of return periods that the method is developed for.

4.6 Concluding Remarks

The relative performance of the recommended peaks by DWAF, the SDF and GC-NCAPA are summarised in Table 4.10. The performance is considered good (=) if the estimates are within 10% of the observed values and under estimated (-) if the estimates are less by more than 10% and over-estimated (+) if the estimate is greater by more than 10% of the observed flood peak values. Performance of the methods is assessed for return periods less than 20-years (low) and return periods greater than the 50-event (high).

Table 4.10: Summary of flood estimation method performance against observed flood data

Site	Recommended		SDF		GC-NCAPA	
	Low	**High**	**Low**	**High**	**Low**	**High**
L3R001-Groot	=	=	+	+	+	+
Q5R001-Great Fish	=	-	=	-	=	=
N2R001-Sundays	-	-	=	-	=	+
R2R001-Buffalo	=	=	-	-	=	=
K7H001-Bloukrans			-	-	-	-
L9R001-Kouga			-	=	-	-
S7H004-Great Kei			-	=	=	=
J4H002-Gourits			-	=	=	+
L9H003-Gamtoos			=	-	=	=
Good Fit	**75**	**50**	**33**	**33**	**67**	**44**
Under estimate	**25**	**50**	**56**	**56**	**22**	**22**
Over estimate			**11**	**11**	**11**	**33**

In sections 4.2 to 4.5 it is clear that DWAF have a preference for the results obtained from statistical methods and is evident by the good comparisons for the lower return period estimates indicated in Table 4.10. This is due to the relatively long records (>30 years) that are available for the sites. The exception is the Sundays River at Darlington Dam where the data set for the gauging station at Jansenville (NH002) was used. The deterministic methods are mostly used to provide the design hydrograph calibrated with the recommended peaks. The SDF, which is based on the LP3 distribution and the RAT method provided favourable results for the lower return periods but performed less favourable for the higher return periods.

The GC-NCAPA estimated the lower return period events well while the higher return period events are over estimated in some instances. Table 4.10 tentatively suggests that the method even in its current form will provide reasonable estimates of Q_T using the NCAPA methodology.

CHAPTER 5

IMPACT OF METHOD ON DESIGN, FLOOD RISK AND FLOOD DAMAGE ESTIMATION

5 IMPACT OF METHOD ON DESIGN, FLOOD RISK AND FLOOD DAMAGE ESTIMATION

To assess the potential impact that the results obtained from the various flood peak estimation methods could have on decision making, risk assessment and hazard exposure, the project team was requested to perform an economic assessment of potential flood damages in a selected area. The impact that design flood estimation would have on afore mentioned aspect is evaluated using an estimation of potential flood damages for a developed area. The impact that design flood estimation has on flood lines, dam and bridge design, river crossings, dam safety and the environment are discussed briefly.

5.1 Chatty River Flood Damage Estimates

Soweto on Sea, situated along the Chatty River at Port Elizabeth, was selected as the site to assess potential flood damage scenarios. The motivation for the selection was that the site is within the study area and that the study team participants responsible for the assessment are familiar with the site having done a previous assessment. The assessment was done by the Department of Agricultural Economics of the University of the Free State. The report (du Plessis, 2002) by the University is provided in the Appendix G. The conclusion in the report, indicates that the author misunderstood the aims of the broader study and as such the conclusions are not valid. The data in the report relating to the derivation of damages for various flood return periods and by implication flood peaks provided sufficient information to derive a loss function (LF) for the area assessed. The LF for the area is shown in Table 5.1 and Figure 5.1. The definitions of the loss function are expanded upon in the report (Appendix G).

Table 5.1: Chatty River – Soweto On Sea Loss Function

Discharge-Q (m^3/s)	Damage (R)	Discharge-Q (m^3/s)	Damage (R)
50	1,016,330	970	7,541,834
60	1,846,730	988	7,558,493
80	3,157,003	1150	7,697,472
120	5,003,730	1290	7,804,321
150	6,020,057	1428	7,900,085
260	6,439,634	1610	8,014,630
360	6,696,080	1750	8,095,225
470	6,913,789	1880	8,165,134
660	7,201,279	3790	8,881,801
830	7,402,079	4790	9,134,917

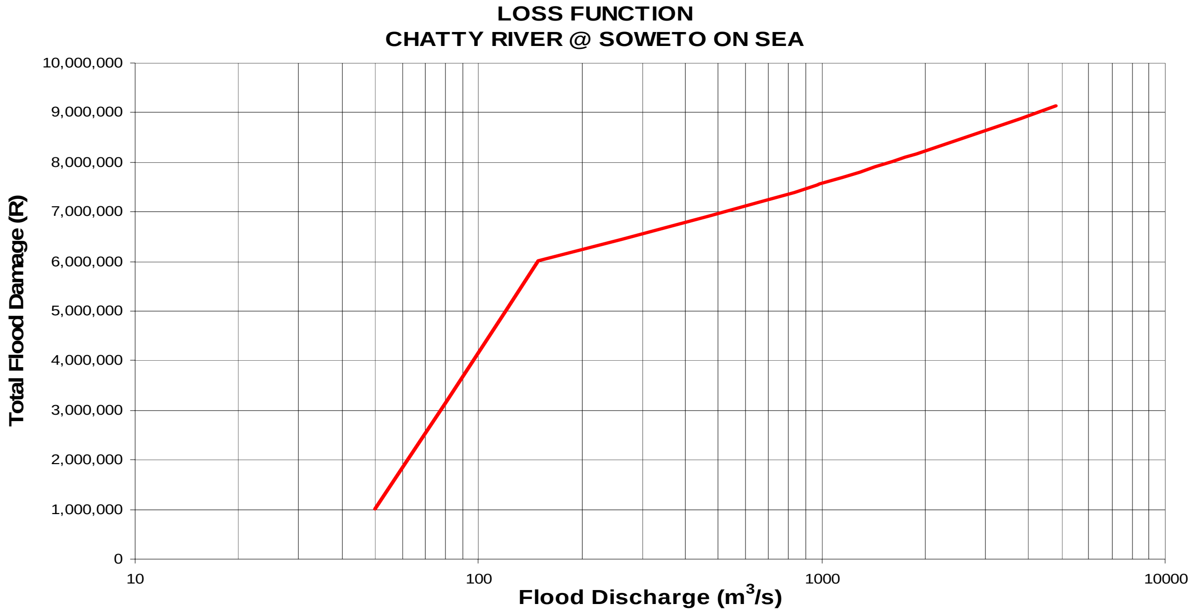

Figure 5.1: Chatty River – Soweto on Sea Loss Function

The site is not gauged and the flood hydrology for the site was assessed using several deterministic and empirical methods. The site characteristics relevant to the GC-NCAPA methodology and the SDF are:

Catchment area : 112 km^2

Longest watercourse : 26.1 km

River slope : 0.00867 m/m

MAP : 529 mm

Catchment slope : 6.12%

The estimated flood peaks using various methods are summarised in Table 5.2 and shown in Figure 5.2. The abbreviations used are the same as those in section 4. The SCS refers to Soil Conservation Services method..

Table 5.2: Chatty River-Estimated Flood Peaks

Method	Estimated Q_T (m^3/s) for various return periods T (year)						
	2	5	10	20	50	100	200
MIPI	56	114	167	251	373	481	603
DRH	96	181	265	373	564	756	999
Rational	54	87	121	167	267	385	549
SCS	69	140	208	289	421	541	683
SDF	16	49	113	167	247	315	387
GC-NCAPA	11	32	52	82	145	180	213

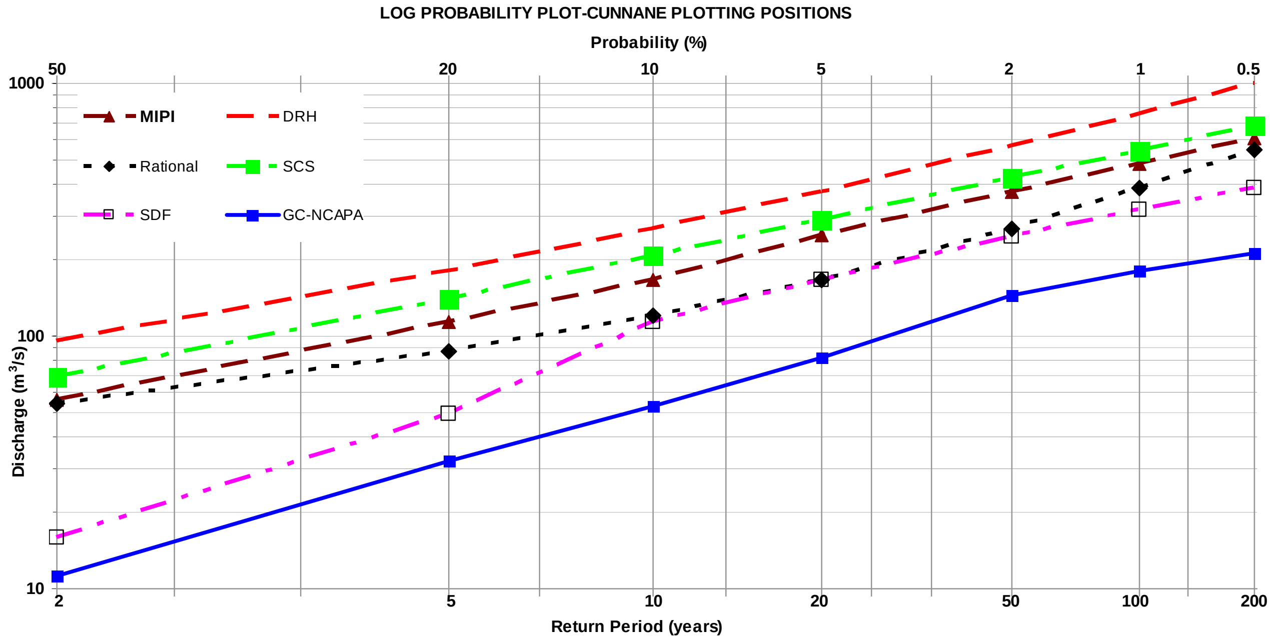

Figure 5.2: Chatty River estimated flood peaks

The mean annual flood damage (MAD) using the flood estimates for the various methods are estimated using loss function tabulated in Table 5.1 and the flood estimates and their annual probabilities. The MAD for each event and the total MAD is shown in Table 5.3. The total MAD estimated using the various methods is also shown in Figure 5.3.

Table 5.3: Total and Mean Annual Flood Damage – Chatty River

Estimation Method	Mean annual flood damage – MAD (R) for various return periods –T (year)							Total MAD (R)
	2	5	10	20	50	100	200	
MIPI	1,068,284	869,888	576,304	289,070	116,729	59,283	30,559	**3,010,117**
DRH	1,831,344	1,190,792	605,126	310,273	128,589	66,277	34,258	**4,166,660**
Rational	1,030,131	663,862	461,651	321,472	135,601	71,325	37,893	**2,721,936**
SCS	1,316,279	1,068,284	596,681	302,563	124,697	64,515	33,763	**3,506,781**
SDF	305,224	373,899	431,129	313,761	130,351	67,378	34,993	**1,656,736**
GC-NCAPA	214,420	245,492	200,151	155,984	110,265	63,230	32,276	**1,021,818**

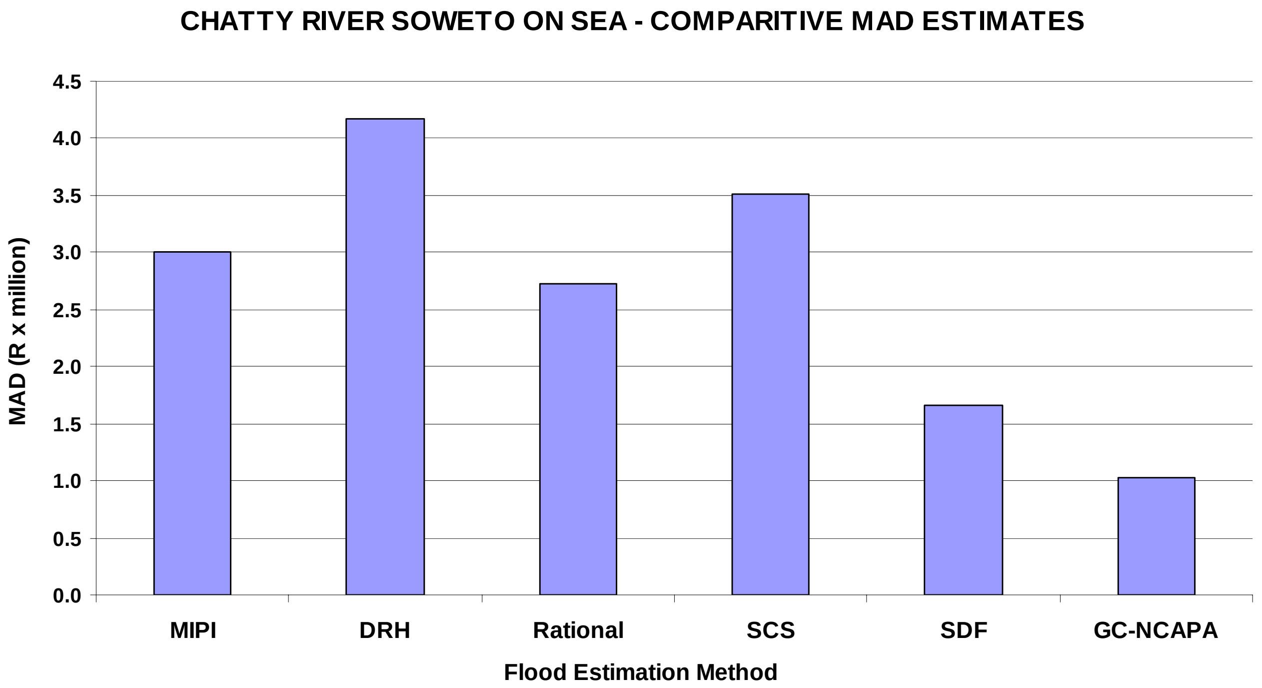

Figure 5.3: Impact on Flood Damage Estimates using the NCAPA Method and Conventional Methods

The impact that the choice of flood peak estimation method has on the estimation of the MAD is clear from Figure 5.3. This would affect decision making regarding insurance, the implementation of actions to mitigate the impact of floods and land development. From section 4 it would seem that most of the methods with the exception of the GC-NCAPA, statistical methods and to an certain extend the SDF, over estimate the more frequent events that constitute the bulk of the MAD and thus inflate the impact that flooding have on an area .

5.2 Impact on Dam spillways and Bridge Design

All developments located on or adjacent to rivers and watercourses require the estimation of flood peaks and volumes during their design or post design assessments. The estimation of flood peaks and their associated risks have financial, economic and safety impacts when these activities are designed, constructed and operated or occupied. These impacts are briefly discussed below for various activities.

<u>Flood lines for development</u>. Prior to any proposed township being approved for development authorities require that either the 50- or 100-year flood be determined and indicated on the plans submitted. Under estimation of the flood levels may subject tenants to frequent flooding with the associated damage. The opposite of over estimation may result in loss of sales or expensive measures to remedy the loss land for development.

<u>Dam safety and dam design</u>. Overtopping of the non over spill crest is the major cause of dam failures in South Africa. This is particularly true for privately owned earth and rock fill dams. The

flood hydrology for these dams is usually undertaken by inexperienced persons with little or no available data to aid in the selection of the design floods. Under sizing of spillway capacities are some times due to the costs that could be seen as excessive. The result is that there is pressure on the designer to adopt the values of methods that provide lower estimates of the design flood. From section 4 it is clear that the deterministic methods tend to under estimate the less frequent flood events used for spillway design while the empirical methods especially the TR137 method tends to over estimate. The GC-NCAPA also tends to over estimate the discharges of the more extreme events, but to a lesser extend.

Environmental issues. More and more designs are being requested to rehabilitate or re-instate rivers or design river diversions. These designs usually require realistic estimates of the more frequent 2-, 5- and 10-year flood events. While the under estimation of the discharges may result in frequent damage to the system over estimation could be just as damaging. The example of a river re-instatement designed to say the 5-year event for the main channel may if over designed result in excessive sedimentation and vegetation growth in the channel. This could result in the channel conveyance be reduced to such an extent that the designs flows are not conveyed as intended with resultant flooding. The flood impacts of the less frequent events could also be more than anticipated.

When conducting in channel flow requirement (IFR) studies for water resource development flood events are also estimated for input in to the management requirements of dams. Over-estimation of the discharges could result in an over estimation of the environmental water requirement that could result in an important development being rejected or the yield being substantially reduced on environmental grounds that maybe based on erroneous estimations of flood discharges.

Bridge and river crossings: The frequency of bridge failures during flood events in recent years has raised queries regarding the design of bridges. While many of the failures are due to construction or design flaws like embankments and piers being washed away with out the structure being over topped several bridges have failed due to over topping. The various methods to estimate flood discharges for design are evaluated in section 4 and the comments raised in the design of dam spillways is also applicable in this instance.

The above discussion only covers a small portion of the aspects that the estimation of a design flood could impact on. A methodology such as the GC-NCAPA could serve as a reference method for the estimation of flood discharges used in design. This would also ensure that consistency in results is achieved but should however not be at the cost of sound judgement from the professional estimating the discharges.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6 CONCLUSION AND RECOMMENDATIONS

The conclusions and recommendations for the various aspects of the project are discussed in the following sections.

6.1 Flow Data

Appendix A shows the total number of observation points, 348, in the study area. This includes weirs, river/flood runs, dams and indirect measurement sites such as bridges and slope area sites. After assessing the data for quality, combining sites that are close to each other or replaced each other and discarding stations that have suspect calibrations the number of sites was cut to 112 in total. The study utilised three distinct data types, i.e. systematic data, historical data and palaeoflood derived flood peak data and is included in Appendix B.

6.1.1 Systematic data

The systematic data in the area for gauging stations was well interrogated and provides data for other studies. The data provided in Appendix B, together with the gauge height information (available from DWAF), should aid researchers when calibrating sites with truncated data. In all, 112 sites with systematic (gauged) data with a total period of 5766 years of observation, is provided in Appendix B. The average period of observation is 60 years and is updated to the 2000/01 hydrological year.

6.1.2 Historical data

The historical sources have been well researched during previous work by DWAF and during this study, but from the information obtained to date it would seem that a wealth of information 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.

6.1.3 Palaeoflood data

The nature of the project precluded an extensive palaeoflood hydrological investigation of the study, but information gathered during the study proved extremely valuable. In all, 5 sites were identified with palaeoflood information of which four had actual floods and the fifth site was inferred from the fact that no flood in the past exceeded a recent event (Buffels River at Floriskraal Dam). The total observation period for the sites is 23885 years with an average period of 4777 years. Based on the observations at the sites that were assessed, the gathering of 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.

6.1.4 Recommendations regarding Flow Data

It is recommended that:

- That gauging stations relevant for flood studies be identified, formally calibrated (only one set of discharge table/s) 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 impact that record length has on the statistical parameters estimation is demonstrated in this study.
- 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 national flood database be established 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.

6.2 Catchment Characteristics

6.2.1 Data Sources

The data source used for land-use information for the project was primarily the information contained in WR90 series of reports. Topographical contour, river data and catchment data was obtained from DWAF. The latter data had to be cleaned up and corrected prior to transforming the information to a viable DTM for use in determining the topographical characteristics required.

6.2.2 Impact of the Various Data Sources on Estimated Catchment Characteristics

The impact that the various data sources have on the estimation of catchment characteristics varies dependent on the parameter estimated. The variations between the data sets were assessed, using the catchment parameters estimated manually by DWAF against those estimated, using the GIS based data. The differences were attributed to the resolutions of data abstraction with the manual methods deemed to be courser than the GIS resolution. This is due to simplifications that are used to undertake the manual estimations.

6.2.3 Relevance of Catchment Parameters

From the study it is clear that the parameters that yielded the best correlations to estimate an index flood (Qi) are catchment area, river slope, rainfall (MAP) and river length. The latter to be combined with catchment area to provide a catchment shape factor. These are all the parameters as proposed by McPherson (1983) with the exception of river slope.

6.3 Development of Index Flood

6.3.1 Development of Index Flood

The log transformed mean annual flood (Q_{ml}) is the most robust and stable base that should be used for the development of the index flood. The Q_{ml} is also less sensitive to record length and outliers and thus sites with relatively short records of between 10 to 15 years could also be used. The proposed methodology to estimate the index flood even in its present crude form does show promise and should be pursued further. 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.

A new lumped parameter to estimate the Q_{ml} for a site is proposed. A comparison of this method's ability to estimate the Q_{ml} 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, though still crude, could form the basis of further development that could provide a more universal methodology.

6.4 Development of the flood peak growth curves

6.4.1 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. A growth curve splicing diagram that takes the period of observation of a particular data set into account is proposed. The final recommended growth curve (GC) used this splicing diagram. The GC values for the more extreme events were the most affected by the historical and palaeoflood data and suggest that these GC values are more realistic. The suggested GC for all the events are thus based on actual observation and not on theoretical extrapolations. This could, however, be improved upon by including more data and sites.

6.5 Comparisons with other methods

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 over estimate the lower return period events while under estimating the more extreme events. The exception being the RMF method that tended to over estimate and the SDF that tended to under estimate.

6.6 Impact of method on design, flood risk and flood damage estimation

The impact of selecting design floods is demonstrated using the estimation of mean annual flood damage as the basis for comparison. From the results it is clear that using the lowest estimates as the basis for comparison, some methods may result in an over estimation of the mean annual flood damage (MAD) by 400%. This over estimation may result in no action to remedy a flood problem being taken or in the taking of the wrong decision to solve the problem. The impact on design and planning, using over or under estimated flood peaks is obvious. The proposed methodology which is based on actual observed data that in this instance spans thousands of years is one way of ensuring that realistic values are estimated and provide an aid in decision making. If site data (gauged) is available, this data should be used to estimate Q_{ml} for use with the proposed GC's.

6.7 Pilot project conclusion

As a pilot project to assess the viability of developing an index flood and growth curve flood estimation methodology for South Africa, the results of the project support this approach. Clear trends are apparent for both aspects of the approach. 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.

6.8 Recommendations

It is thus recommended that the study be extended to the rest of the country and that all three data sources be expanded with special emphasis on the historical and palaeoflood data.

CHAPTER 7

FUTURE STUDIES

7 FUTURE STUDIES

Further studies suggested are;

- Extend data gathering to 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 method.

These future studies could be run in conjunction with the broader based resources studies such as WR2005 that has just commenced since the data sources are common to both.

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APPENDICES

Maps (A4 landscape format)

Appendix A

List of all Flow Gauging Stations for Study Area

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
1	J1F001	33.1958	20.7556	Bobbejaans	Baviaanskrans	217	25/01/1981	25/01/1981	1	1
2	J1F002	33.1500	20.7833	Wilgehout	Zoutekloof	361	25/01/1981	25/01/1981	1	1
3	J1F003	33.1792	20.9889	Geelbek	D/s of N1 and railbridge	338	25/01/1981	25/01/1981	1	1
4	J1H001	33.1769	20.8703	Buffels	Laingsburg (Vischkuil)	2367	01/02/1921	31/12/1924	4	4
5	J1H002	33.2500	20.9667	Buffels	Floriskraal	3328	01/10/1922	30/09/1928	6	6
6	J1H003	33.7581	20.9483	Doring	Poortfontein	352	01/02/1923	01/02/1932	10	9
7	J1H004	33.2022	20.8542	Buffels	Laingsburg (Visch Kuil)	3072	10/06/1921	30/09/1955	35	35
8	J1H005	33.2914	20.9908	Buffels	Floriskraal	4001	01/07/1931	01/09/1946	15	15
9	J1H006	33.7636	21.1350	Brand	Adams Kraal	323	01/01/1938	08/10/1977	40	40
10	J1H007	33.5636	20.7361	Touws	Rietgat	2898	17/03/1938	31/07/1948	10	10
11	J1H008	33.7581	21.4703	Groot	Buffelfontein	12773	08/04/1964	13/04/1978	15	15
12	J1H009	33.8256	21.1361	Brand	Miertjes Kraal	252	16/04/1965	08/12/1983	20	20
13	J1H010	33.5719	20.7028	Touws	Zandfontein	2900	02/03/1969	23/01/1981	13	13
14	J1H011	33.4639	20.9867	Buffels	Slang Gat	4700	15/03/1971	25/02/1983	11	8
15	J1H012	33.6528	21.1747	Groot	Baviaanskrans	5565	15/03/1971	25/02/1983	12	12
16	J1H013	33.7364	21.1794	Touws	Riverside	2015	26/05/1971	25/01/1981	11	11
17	J1H014	33.5144	21.0886	Groot	Zeekoegats Drift	4882	15/03/1971	26/01/1981	11	0
18	J1H015	33.3544	19.7200	Bok	Lot B	8.8	05/07/1974	30/09/2001	28	28
19	J1H016	33.2886	19.7286	Smalblaar	Verloeren Valley	30	24/06/1974	30/09/2000	27	27
20	J1H017	33.7811	21.4419	Sand	Buffelfontein	254	14/11/1980	30/09/2000	20	20
21	J1H018	33.6972	21.1461	Touws	Okkerskraal	5837	07/04/1982	30/09/2001	20	20
22	J1H019	33.7500	21.4447	Groot	Buffelsfontein	12493	30/06/1982	30/09/2000	19	19
23	J1R001	33.5147	20.5978	Prins	Prinsrivier Dam	757	26/01/1926	30/09/2001	76	0
24	J1R002	33.7111	20.5978	Brak	Bellair Dam	558	30/01/1926	30/09/2001	76	1
25	J1R003	33.2911	20.9908	Buffels	Floriskraal Dam	4001	22/11/1956	30/09/2001	45	0
26	J1R004	33.8281	21.1344	Brand	Miertjieskraal Dam	251	19/01/1977	30/09/2000	24	24
27	J2F001	0.0000	0.0000	Wilgehout	Fraserburg road	3391	29/12/1921	29/12/1921	1	1
28	J2F002	0.0000	0.0000	Gamka	Fraserburg road	3236	29/12/1921	29/12/1921	1	1
29	J2F003	32.5875	22.0333	Leeu	Vlagfontein	1741	26/03/1981	26/03/1981	1	1
30	J2F004	32.5792	22.0167	Little Hottentots	Vlagfontein	336	26/03/1981	26/03/1981	1	1
31	J2F005	33.2583	21.7583	Gamka	Weltevreden	13087	26/03/1981	26/03/1981	1	1
32	J2F006	32.5292	21.2333	Dwyka	Rietvalley	74	25/01/1981	25/01/1981	1	1
33	J2F007	33.1208	21.5875	Dwyka	5km d/s N1	3073	25/01/1981	25/01/1981	1	1
34	J2F008	33.0167	21.9958	Gamka	Kweekkraal	9350	25/01/1981	25/01/1981	1	1
35	J2F009	33.5083	21.6042	Huis	B4941, Calitsdorp-Ladismith rd.	390	25/01/1981	25/01/1981	1	1
36	J2H001	33.0833	21.9408	Gamka	Klipfontein (Prince Albert)	10292	05/11/1911	31/01/1921	10	10
37	J2H002	33.5319	21.6931	Nels	Buffels Vallei (Calitzdorp)	182	06/12/1911	30/09/1918	7	7
38	J2H003	33.5261	21.6453	Gamka	Kleinberg	17815	01/01/1924	31/12/1942	21	21
39	J2H005	33.4944	21.4806	Huis	Zoar	253	01/02/1955	30/09/2001	47	47
40	J2H006	33.4906	21.4875	Boplaas (Wilgehout)	Opzoek	225	01/02/1955	30/09/2001	47	42
41	J2H007	33.4906	21.5139	Joubert	Opzoek	25	05/02/1955	30/09/2001	47	47
42	J2H008	33.5458	21.6833	Gamka	Calitzdorp	18199	04/09/1964	22/02/1983	19	3
43	J2H010	33.5017	21.6242	Gamka	Huisrivier	17805	01/09/1982	01/07/2001	19	19
44	J2H016	33.3081	21.6347	Gamka	Gamkapoort Dam (d/s)	17076	16/09/1964	30/09/2000	37	37
45	J2R001	33.4906	21.7053	Nels	Calitzdorp Dam	37	04/09/1919	30/09/2001	82	82
46	J2R002	32.6217	22.0075	Leeu	Leeugamka Dam	2088	22/10/1958	01/07/2001	43	43
47	J2R003	32.2456	22.0914	Cordiers	Oukloof Dam	141	14/09/1930	30/09/2001	71	71
48	J2R004	32.2383	22.5861	Gamka	Gamka (Beaufort-West) Dam	98	01/10/1958	30/09/2001	43	43
49	J2R006	33.3081	21.6347	Gamka	Gamkapoort Dam	17076	28/08/1970	30/09/2001	31	31
50	J2R007	32.6386	21.9914	Leeu	Ou Leeugamka Dam	2101	01/03/1920	30/09/1958	38	38
51	J3H001	33.6694	22.4208	Kammanasie	Kromhoogte (Vaalkloof)	1505	14/06/1912	31/05/1922	11	11
52	J3H002	33.3833	23.1156	Traka	Tuintjieskraal	3039	01/10/1912	30/09/1928	16	11
53	J3H003	33.3347	22.5367	Groot	Klaarstroom	426	15/02/1913	07/05/1965	53	52
54	J3H004	33.4769	23.0300	Olifants	Paardekloof (Barandas)	4252	01/10/1923	25/05/1993	70	70
55	J3H005	33.7792	22.3236	Klip	Klippe Drift	95	01/03/1926	24/10/1947	22	22
56	J3H007	33.6422	22.1919	Olifants	Welgevonden	9090	07/11/1930	01/07/1948	18	4
57	J3H008	33.5356	22.4667	Olifants	Rietvallei	6236	11/03/1949	03/06/1956	8	8
58	J3H009	33.6622	21.7744	Olifants	Warmwater	10928	14/03/1943	30/06/1950	8	2
59	J3H010	33.7694	22.3161	Klip	Welbedag	98	15/06/1963	31/10/1978	15	15
60	J3H011	33.6589	21.7739	Olifants	Warm Water	10927	20/05/1950	30/09/2001	51	40
61	J3H012	33.4756	22.5483	Groot	De Rust	688	05/05/1964	30/09/2001	38	32

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
62	J3H013	33.3683	22.1822	Perdepoort	Groenefontein (De Hoek)	29	07/04/1966	30/09/2001	35	35
63	J3H014	33.4203	22.2419	Grobbelaars	De Kombuys (Schoemanskloof)	151	07/04/1966	30/09/2001	35	35
64	J3H015	33.4269	22.2542	Klein-Leroux	De Kombuys (Schoemanskloof)	70	07/04/1966	30/09/2001	35	35
65	J3H016	33.5442	22.9747	Wilge	Wilge Houte Rivier	32	12/04/1967	30/09/2001	35	35
66	J3H017	33.6775	22.1333	Kandelaars	Paardendrift	348	08/04/1969	30/09/2001	33	33
67	J3H018	33.4675	22.0011	Wynands	Koetzers Kraal	137	18/06/1969	30/09/2001	33	33
68	J3H020	33.4603	21.9619	Meul	Vogelfontein	35	22/08/1974	30/09/2001	27	27
69	J3H021	33.4747	23.0231	Olifants	Pardekloof (Barandas)	4270	08/07/1982	19/01/1993	11	11
70	J3R001	33.6428	22.4150	Kammanasie	Kammanasie Dam	1506	01/07/1922	30/09/2001	79	26
71	J3R002	33.5117	22.5856	Olifants	Stompdrift Dam	5235	02/12/1962	30/09/2001	39	14
72	J4H001	34.1856	21.7536	Gourits	Bonavontuur (Gourits Bridge)	44686	01/03/1912	31/07/1931	20	20
73	J4H002	33.9819	21.6533	Gourits	Zeekoedrift/Die Poort	43451	01/05/1964	30/09/2000	36	20
74	J4H003	34.0314	21.5875	Weyers	Weyers River	95	14/04/1965	30/06/2001	37	37
75	J4H004	33.9875	21.7769	Langtou	Langfontein	99	31/03/1967	22/11/1996	29	29
1	K1H001	34.1031	22.0719	Hartenbos	Hartenbosch	144	01/05/1935	23/01/1977	41	34
2	K1H002	33.9833	22.1214	Beneke	Pine Grove Forest	3.8	02/07/1958	30/09/2001	44	44
3	K1H004	34.0319	22.0533	Brandwag	Brandwacht	215	25/03/1969	30/09/2001	33	33
4	K1H005	34.0397	22.1333	Moordkuil	Banff	198	26/04/1978	30/09/2001	24	24
5	K1R001	34.0958	22.0075	Hartenbos	Hartbeeskuil Dam	100	17/03/1970	30/09/2001	32	5
6	K2H002	34.0278	22.2225	Groot Bral	Wolwedans	131	04/05/1961	30/09/2001	41	41
7	K2H006	34.0150	22.2208	Groot Brak	WolweDans Dam	129	04/03/1992	30/09/2001	10	10
8	K2R001	33.9017	22.1747	Groot Brak	Ernest Robertson Dam	16.8	12/06/1958	30/09/2001	43	43
9	K2R002	34.2289	22.0136	Groot Brak	Wolwedans Dam	128	18/04/1990	30/09/2001	0	0
10	K3H001	33.9708	22.5483	Kaaimans	Upper Barbierskraal	47	23/03/1961	30/09/2001	40	40
11	K3H002	33.9333	22.4622	Rooi	George	1.04	21/03/1961	30/09/2001	40	40
12	K3H003	34.0058	22.3511	Maalgate	Buffelsdrift	145	06/04/1961	30/09/2001	40	40
13	K3H004	33.9506	22.4225	Malgas	Blanco	34	12/04/1961	30/09/2001	40	40
14	K3H005	33.9458	22.6133	Touws	Plaas 162	78	21/04/1969	30/09/2001	33	33
15	K3H006	33.9708	22.4431	Rooi	George (Hidro)	6.2	19/05/1987	30/09/2001	15	15
16	K3H007	33.9722	22.4414	Rooi	George (Hidro)	6.3	12/06/1989	30/09/2001	13	13
17	K3H008	33.9725	22.4392	Rooi	George (Hidro)	6.33	04/09/1987	13/12/1993	5	5
18	K3R001	33.9131	22.4953	Swart	George Dam	10			0	0
19	K3R002	33.9636	22.5147	Swart	Garden Route Dam (Farm 149-George)	35.6	10/08/1984	01/07/2001	17	17
20	K4H001	33.9797	22.8000	Hoekraal	Eastbrook	111	19/11/1959	17/05/1993	34	34
21	K4H002	33.8811	22.8386	Karatara	Karatara Forest Reserve	22	24/04/1961	30/09/2001	39	39
22	K4H003	33.9117	22.7058	Diep	Woodville Forest Reserve	72	13/05/1961	30/09/2001	41	41
23	K5H001	33.9911	23.0425	Gouna	Concordia Plantation	91	16/11/1959	22/01/1984	25	22
24	K5H002	33.8900	23.0317	Knysna	Milwood Forest Reserve	133	03/08/1961	30/09/2001	40	40
25	K6H001	33.8028	23.1361	Keurbooms	M'Kama (Peters River)	165	19/08/1961	30/09/2001	40	40
26	K6H002	33.9383	23.3678	Keurbooms	Newlands	764	05/09/1961	03/06/1981	21	21
27	K7H001	33.9542	23.6417	Bloukrans	Blaauw Krantz	57	05/06/1961	30/09/2001	40	40
28	K8H001	33.9806	24.0214	Kruis	Pineview	25.6	20/06/1961	30/09/2001	40	40
29	K8H002	33.9806	24.0506	Elands	Witelsbos	35	11/07/1961	30/09/2001	40	40
30	K8H005	34.0964	24.4392	Tsitsikama	Geelhoutboom	134	20/06/1995	30/09/2001	0	0
31	K9H001	34.0014	24.4931	Krom	Krommeriviersspoort	357	01/09/1948	30/09/2001	0	0
32	K9H003	34.0919	24.7000	Krom	Impofu (Elandsjagt, Charlie Malan) Dam (W-component)	851	28/07/1983	30/09/2001	0	0
33	K9R001	34.0014	24.4931	Krom	Krom River (Churchill) Dam	357	01/09/1948	30/09/2001	0	0
34	K9R002	34.0919	24.7000	Krom	Impofu (Elandsjagt, Charlie Malan) Dam	851	26/04/1983	30/09/2001	19	19
1	L1F001	31.8167	22.9667	Sout	Brakpoort	984			0	0
2	L1F002	32.9000	23.2167	Sout	Rietbron	8818			0	0
3	L1H001	32.2378	23.0511	Sout	Kamferskraal	3938	01/07/1917	30/09/1981	64	48
4	L1H002	32.0689	23.0081	Sout	Klipkraal	3675	01/02/1973	02/03/1988	16	16
5	L1H003	32.2378	23.0511	Sout	Kamferskraal	3938			0	0
6	L2F001	32.8500	23.5333	Buffels (Kariega)	Middelerf	9890			0	0

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
7	L2H001	32.2433	23.4119	Buffels (Kariega)	Stellenboschvallei	5582	01/12/1923	31/07/1948	25	25
8	L2H002	31.9817	23.8553	Buffels (Kariega)	Riet Valley	851	01/10/1925	31/01/1952	27	27
9	L2H003	31.9361	23.7833	Buffels (Kariega)	Marraysburg	1145	01/04/1954	04/04/1993	40	40
10	L2H004	32.2433	23.4119	Buffels (Kariega)	Stellenbosch Valley	5584	01/07/1961	30/11/1984	24	23
11	L3H001	33.0864	23.4956	Groot	Windheuwel	20339	01/06/1917	31/03/1960	44	44
12	L3R001	33.0769	23.4914	Groot	Beervlei Dam	20336	12/01/1958	30/09/2001	44	44
13	L6H001	33.2028	24.2356	Heuningklip	Campherspoort	1290	01/01/1926	30/09/2001	75	75
14	L6H002	33.0456	24.3333	Heuningklip	Klipplaat	675	28/04/1963	30/06/1987	25	25
15	L7H002	33.3219	24.3472	Groot	Steytlerville	25730	08/09/1928	30/11/1984	57	57
16	L7H004	33.4136	24.6528	Groot	Driekuilen	27746	01/01/1939	31/07/1948	10	10
17	L7H005	33.4225	24.6597	Groot	Driekuilen	27774	18/08/1963	18/06/1985	21	21
18	L7H006	33.7311	24.6183	Groot	Grootrivierspoort (HI Q10-24)	29232	17/03/1964	30/09/2001	38	38
19	L7H007	33.4244	24.6903	Groot	Sandpoort	28451	02/11/1982	30/09/2001	19	19
20	L8H001	33.8658	23.8361	Waboomsrivier	Diepkloof	21	03/04/1965	30/09/2001	37	37
21	L8H002	33.7375	23.3053	Haarlemspruit	Welgelegen	52	09/07/1970	30/09/2001	32	32
22	L8H005	33.7906	24.0247	Kouga	Stuurmanskraal	1303	06/04/1990	30/09/2001	12	12
23	L8H006	33.7400	24.5881	Kouga	Twee Rivieren (Kouga Dam)	3887	02/10/1961	01/02/1972	11	11
24	L8R001	33.7400	24.5881	Kouga	Kouga Dam	3887	02/10/1961	30/09/2001	40	40
25	L8R002	33.7708	23.3172	Haarlemspruit	Haarlem Dam	29.8			0	0
26	L9F001	33.8500	24.8833	Gamtoos	Hankey Drift	34200		22/08/1971	124	7
27	L9F002	33.9167	24.9500	Gamtoos	Gamtoos Railbridge	34300		01/01/1922	48	4
28	L9H002	33.7578	24.6592	Gamtoos	Andrieskraal	33200	01/06/1939	31/07/1948	10	10
29	L9H003	33.7775	24.8122	Gamtoos	Patensie	33296	10/07/1962	01/09/1971	10	10
30	L9R001	33.8661	25.0403	Loeriespruit	Loerie Dam	147	01/09/1969	30/09/2001	33	33
1	M1F001	33.8000	25.4333	Swartkops	Frans Claasens Bridge (PE-Uitenhage)	1080		26/07/1983	136	10
2	M1F002	33.8500	25.5333	Chatty	PE-Despatch road bridge.	127	26/03/1981	26/03/1981	1	1
3	M1F003	0.0000	0.0000	Swartkops	Wylde Bridge	1400		01/01/1944	90	2
4	M1H001	33.7356	25.3189	Swartkops	Springfield	349	01/03/1927	31/07/1930	4	4
5	M1H002	33.6900	25.2667	Swartkops	Groendal	261			0	0
6	M1H004	33.7972	25.3086	Elands	Wintcanton	400	06/04/1965	30/09/2001	36	32
7	M1H012	33.7711	25.3867	Swartkops	Uitenhage	906	01/11/1994	30/09/2001	7	7
8	M1R001	33.6900	25.2667	Swartkops	Groendal Dam	261	01/12/1938	30/09/2001	63	63
9	M1R002	33.8000	25.1769	Bulk	Bulk River Dam	34	01/01/1968	30/09/2001	34	1
10	M1R003	33.7278	25.0978	Sand	Sand River Dam	51	01/01/1968	30/09/2001	34	1
11	M2F001	22.9667	25.5167	Baakens	Kragakama road (PE)	35	26/03/1981	26/03/1981	1	1
12	M2F002			Baakens	Frame's Drift (PE)	67	16/11/1908	16/11/1908	1	1
13	M2F003	33.9500	25.5500	Baakens	Mangold Park (PE)	52	01/09/1968	01/09/1968	1	1
14	M2F004	33.9667	25.6167	Baakens	Target Kloof (PE)	69	01/09/1968	25/03/1981	14	2
15	M2F005	33.9667	25.6167	Baakens	Brickmakers Valley (PE)	72	01/09/1968	01/09/1968	1	1
16	M2F006	0.0000	0.0000	Papkuil	General Tyres (PE)	46	01/09/1968	01/09/1968	1	1
17	M2F007	33.9167	25.5833	Papkuil	Everite (PE)	39	26/03/1981	26/03/1981	1	1
18	M2F008	0.0000	0.0000	Humewood	Victoria Park (PE)	10.8	01/09/1968	01/09/1968	1	1
19	M2F009	33.9833	25.6667	Shark	Happy Valley (PE)	8.75	01/09/1968	01/09/1968	1	1
20	M2F010	33.9167	25.2000	Van Stadens	Van Stadens Pass (Bridge)	74	26/03/1981	27/07/1983	3	2
21	M2R001	33.8528	25.2236	Van Stadens	Van Stadens Dam - Upper	14			0	0
22	M2R002	33.8833	25.2117	Van Stadens	Van Stadens River Dam-Lower	36	01/01/1968	30/09/2001	34	1
1	N1H001	32.2375	24.5300	Sundays	Graaff-Reinet	3681	08/11/1921	31/03/1924	3	3
2	N1H002	32.1611	24.5489	Gats	Bloemkraal	1787.67	01/03/1927	01/07/1947	21	21
3	N1H003	32.3883	24.4694	Swart	Klipdrift	1040	01/03/1927	29/02/1932	6	6
4	N1H004	32.2144	24.5786	Broederstroom	Broederstroom	134	01/11/1927	01/02/1932	5	5
5	N1H006	32.1811	24.4247	Pienaars	Buffelshoek	196	01/03/1927	31/07/1948	0	0
6	N1H007	32.4253	24.2914	Kamdeboo	Groote Vlakte	1669			0	0
7	N1H008	32.4964	24.0500	Kraai	Aberdeen	490	01/11/1927	30/06/1947	0	0
8	N1H010	32.3203	24.4581	Moordenaars	Grasrand		19/06/1961	27/12/1971	0	0

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No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
9	N1H011	32.1689	24.0764	Toorberg Spruit No.1	Onbedacht	14.1	01/07/1961	25/11/1991	0	0
10	N1H012	32.1608	24.1264	Toorberg Spruit No.2	Langefontein	0.57	25/06/1961	25/11/1991	0	0
11	N1R001	32.2350	24.5289	Sundays	Van Ryneveldspass Dam	3681	01/01/1925	31/10/2001	77	9
12	N2F001	0.0000	0.0000	Skoenmakers	Darlington	414	29/12/1921	29/12/1921	1	1
13	N2H001	33.1167	25.1250	Sundays	Darlington	16047	30/09/1918	31/01/1922	4	4
14	N2H002	32.9500	24.6689	Sundays	Jansenville	11395	01/10/1923	07/12/1992	69	69
15	N2H003	32.8086	24.6667	Sundays	Blaauwkrants	10620	01/09/1928	30/09/1947	20	20
16	N2H004	32.6314	24.6794	Melk	Schoemansvlakte	1128	01/10/1927	31/01/1932	5	5
17	N2H005	33.0756	25.0156	Sundays	Waterford Allotment	13419	01/09/1928	30/09/1947	20	20
18	N2H007	33.0944	25.0128	Sundays	De Draay	13428	24/05/1978	30/09/2001	24	24
19	N2H008	33.0797	25.0789	Riet	Groene Leegte	341	20/06/1979	30/09/2001	23	23
20	N2H009	33.1036	25.2221	Volkers	Volkers River	536	28/09/1978	17/02/1989	12	12
21	N2R001	33.2072	25.1500	Sundays	Darlington Dam	16826	01/01/1923	30/09/2001	79	6
22	N3F001	0.0000	0.0000	Blijde	Pearston irrigation scheme	129	29/12/1921	11/01/1922	1	2
23	N3F002	0.0000	0.0000	Voel	U/s of Blijde confluence	562	11/01/1922	11/01/1922	1	1
24	N3H001	32.9797	25.1903	Voel	Rietvley	1597	01/09/1928	30/08/1948	21	21
25	N3H002	33.0017	25.1614	Voel	Riet Vley	1744	06/06/1978	01/04/1992	15	15
26	N4H001	32.3778	25.3547	Sundays	Courans Drift	17485	01/12/1914	01/09/1921	7	7
27	N4H002	33.4181	25.4822	Sundays	Strathsomers Estate (Cleveland Weir)	18909	01/03/1917	31/05/1921	5	5
28	N4H003	33.5814	25.6744	Sundays	Addo Drift East Bridge	20460	12/12/1984	19/05/1997	13	13
29	N4H005	33.5125	25.6592	Coerney	Selborne	590	19/05/1987	30/09/2001	0	0
30	N4H008	33.3697	25.6667	Wit	Slagboom	196	10/02/1955	31/07/1974	0	0
31	N4R001	33.3697	25.6667	Wit	Slagboom Dam	196	10/02/1955	12/06/1980	26	26
1	P1F001	33.5167	26.1167	Bushmans	N2 Bridge	2080		11/10/1905	0	0
2	P1F002	33.3667	26.0667	Bushmans	Alicedale (Road bridge to Mimosa)	1580	31/12/1931	31/12/1931	0	0
3	P1H002	33.2469	26.3614	Nuwejaars	Hilton	124	01/12/1948	01/10/1963	0	0
4	P1H003	33.3292	26.0775	Boesmans	Donkerhoek	1479	01/01/1957	30/09/2001	45	45
5	P1R003	33.3031	26.1139	Nuwejaars	Nuwejaars Dam	408	26/04/1978	30/09/2001	0	0
6	P3H001	33.5544	26.6036	Kariega	Smithfield	588	04/07/1969	30/09/2001	32	32
7	P3R001	33.3878	26.4875	Palmiet	Howisonpoort Dam	33	01/12/1966	01/12/1982	0	0
8	P3R002	33.4122	26.5092	Kariega	Settlers Dam	176	01/12/1966	01/12/1982	0	0
9	P4F001	33.6000	26.8833	Kowie	Port Alfred	731			0	0
10	P4H001	33.5064	26.7447	Kowie	Bathurst	576	09/07/1969	30/09/2001	33	33
1	Q1F001	31.4833	25.0167	Little Brak	Middelburg	386	03/03/1974	03/03/1974	1	1
2	Q1H001	31.9031	25.4822	Great Fish	Katkop	9091	01/03/1918	03/02/1993	76	76
3	Q1H002	31.7819	25.4528	Great Brak	Kliphevel	4385	01/10/1920	30/11/1923	3	3
4	Q1H003	31.7364	25.3333	Little Brak	Connay Farm	2412	01/10/1926	01/07/1947	0	0
5	Q1H004	31.9481	25.5533	Kwaai	Kwaayplaats	141	01/01/1927	01/07/1947	0	0
6	Q1H005	31.4667	25.6833	Hongerkloof	Weltevreden	449	01/03/1927	01/03/1942	0	0
7	Q1H006	31.5783	25.5392	Teebus	Jan Blaauws Kop	1577	29/03/1927	01/05/1948	21	21
8	Q1H008	31.5514	25.1667	Little Brak	Brakke Kuilen	1870	01/06/1927	30/06/1947	0	0
9	Q1H009	31.5328	25.0747	Little Brak	Buffels Valey	1211	21/02/1959	28/02/1974	15	14
10	Q1H010	31.6103	25.2442	Little Brak	Tafelberg	2046	01/02/1959	31/03/1974	15	15
11	Q1H011	31.5392	24.9100	Little Brak	Rietfontein	492	21/02/1959	03/03/1974	16	11
12	Q1H012	31.5583	25.5433	Teebus	Jan Blaauws Kop	1567	30/07/1977	30/09/2001	25	25
13	Q1H013	31.7778	25.3183	Little Brak	Zeeven Fontein	2445	16/08/1982	30/09/2001	20	20
14	Q1H023	31.7681	25.4667	Great Brak	Klipheuvel	4325	02/09/1925	10/01/1934	0	0
15	Q1R001	31.7681	25.4667	Great Brak	Grassridge Dam	4325	09/02/1924	30/09/2001	78	13
16	Q2H001	31.9139	25.4192	Great Fish	Zoutpans Drift	1702	01/12/1926	31/07/1948	22	22
17	Q2H002	31.9050	25.4300	Great Fish	Zoutpans Drift	1713	30/01/1975	30/09/2001	27	27
18	Q3H001	32.0356	25.5208	Pauls	Coutzenburg	872	01/12/1926	31/07/1948	22	22
19	Q3H002	32.0814	25.5858	Jenkins Spruit	Rietfontein	289	01/10/1930	01/02/1937	7	7
20	Q3H003	32.1936	25.6542	Great Fish	Scanlan	11282	01/01/1934	20/12/1938	6	6
21	Q3H004	32.0356	25.5208	Pauls	Coutzenburg	872	01/10/1975	30/09/2001	26	26
22	Q3H005	32.0883	25.5761	Great Fish	Rietfontein	10830	22/04/1977	30/09/2001	25	25
23	Q4H001	32.2369	25.8042	Tarka	Teeken Fontein	4508	12/01/1914	01/10/1931	18	11
24	Q4H002	31.9622	26.0000	Vlekpoort	Roberts Kraal	1273	01/11/1959	11/12/1964	5	5
25	Q4H003	31.9683	26.0017	Vlekpoort	Roberts Kraal	1300	11/12/1964	07/12/1992	29	29
26	Q4H004	32.0825	26.1894	Tarka	Beestekraal	671	09/09/1966	03/06/1987	21	20
27	Q4H005	32.3139	25.7414	Tarka	Bridge Farm	4742	20/09/1973	23/07/1980	8	8
28	Q4H008	32.2256	25.8183	Tarka	Vrischgewaagd	4497	01/04/1925	01/11/1996	0	0

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
29	Q4H012	32.2369	25.4815	Tarka	Teeken Fonteyn	4508	01/01/1914	30/09/1924	0	0
30	Q4H013	32.3139	25.4429	Tarka	Bridge Farm	4742	24/07/1980	30/09/2001	0	0
31	Q4R001	32.2256	25.8183	Tarka	Lake Arthur Dam	4497	09/02/1925	02/04/1997	0	0
32	Q4R002	32.1094	26.0417	Tarka	Kommando Drift Dam	3632	01/03/1956	30/09/2001	46	8
33	Q5H002	32.4233	25.7769	Rietspruit	Vrischgewaagd	158	01/01/1927	31/12/1940	0	0
34	Q5H004	32.6397	25.7536	Great Fish	Fonteins Hoek	17260			7	7
35	Q5R001	32.5303	25.7542	Great Fish	Elands Drift Dam	16864	04/08/1976	30/09/2001	0	0
36	Q6H001	32.5667	25.9472	Baviaans	Belvedere	694	01/10/1918	16/12/1937	8	8
37	Q6H002	32.6289	25.8833	Baviaans	Melrose	819	20/09/1973	22/08/1980	0	0
38	Q6H003	32.6053	25.8850	Baviaans	Botmansgat	814	08/09/1980	30/09/2001	21	21
39	Q7H001	32.9544	25.8156	Great Fish	Moordenaars Drift (Middleton)	18989	01/01/1906	30/11/1928	24	24
40	Q7H002	32.7197	25.8425	Great Fish	Doringdraai (Krugers Post)	18452	01/08/1922	30/09/1948	27	27
41	Q7H003	32.7783	25.5023	Great Fish	Leeuwe Drift	18534	01/11/1928	31/10/1948	20	20
42	Q7H004	32.7428	25.8114	Great Fish	Cookhouse	18485	28/11/1928	01/10/1973	26	26
43	Q7H005	33.0933	25.8936	Great Fish	Sout Vleij (Sheldon)	19134	14/02/1975	30/09/2001	27	27
44	Q8F001	0.0000	0.0000	Little Fish	Skietrug	1213	01/01/1932	01/01/1932	1	1
45	Q8F002	0.0000	0.0000	Little Fish	Vaal Bridge (u/s of Somerset East)	1265	01/01/1932	01/01/1932	1	1
46	Q8H001	32.6433	25.4414	Little Fish	Buffelfontein	980	01/07/1922	01/10/1947	25	22
47	Q8H002	32.7392	25.5714	Little Fish	Somerset East	1369	01/01/1931	31/12/1963	33	23
48	Q8H004	32.5636	25.4456	Little Fish	Grootvlakte	810	19/03/1957	12/02/1987	31	31
49	Q8H005	32.6244	25.2721	Little Fish	Luns Klip	917	28/03/1957	11/06/1981	25	22
50	Q8H008	32.7861	25.6150	Little Fish	Doorn Kraal	1512	07/08/1979	30/09/2001	23	23
51	Q8H010	32.5608	25.4456	Little Fish	Grootvlakte	808	12/02/1987	30/09/2001	15	15
52	Q8R001	32.9681	25.6719	Little Fish	De Mistkraal Dam	1873	01/10/1987	30/09/2001	14	14
53	Q9H001	33.1278	26.6139	Great Fish	Fort Brown	23582	01/01/1913	31/05/1919	6	3
54	Q9H002	32.7139	26.2967	Koonap	Adelaide	1245	01/09/1926	30/09/2001	75	75
55	Q9H003	33.1194	26.5058	Great Fish	Koesters Drift	23465	01/10/1926	30/11/1935	9	9
56	Q9H004	32.5603	26.6933	Kat	Fort Armstrong	404	01/10/1926	31/05/1964	38	37
57	Q9H005	32.5167	26.2536	Mankazana	Linton	231			0	0
58	Q9H006	33.1589	26.8386	Great Fish	Committees Drift	28937	20/02/1957	31/05/1975	18	18
59	Q9H007	32.5578	26.6719	Balfour	Mesopotamia	82			16	16
60	Q9H008	32.7111	26.3443	Kat	Heald Town Fingo	748	01/12/1921	02/09/1971	50	50
61	Q9H009	32.6536	26.6931	Mankazana	Drumbae	78			9	9
62	Q9H010	33.2086	26.9156	Great Fish	Blaauw Drift	29328	13/06/1930	31/03/1956	16	15
63	Q9H011	33.5733	26.6800	Kat	Harringay (Upsher)	539			30	30
64	Q9H012	33.0983	26.4456	Great Fish	Brandt Legte (Piggot's Bridge)	23067	01/10/1935	30/09/2001	66	66
65	Q9H013	33.3553	26.8619	Kap	Kap River Mountains	46	13/01/1963	05/01/1993	30	22
66	Q9H014	32.4647	26.5108	Koonap	Frisch Gewaagd	246	30/01/1964	02/07/1986	23	23
67	Q9H015	32.4875	26.4483	Koonap	SpioenKop	321	30/09/1966	31/10/1966	0	0
68	Q9H016	32.4992	26.3656	Koonap	Schurftekop	489	29/09/1966	23/03/1993	27	12
69	Q9H017	32.7081	26.5786	Blinkwater	Blinkwater	226	26/06/1965	30/09/2001	37	37
70	Q9H018	33.2378	26.9903	Great Fish	Matomela's Location (Hunt's Drift)	29745	30/07/1969	30/09/2001	32	29
71	Q9H019	32.5514	26.6714	Balfour	Grey Kirk	76	31/03/1972	30/09/2001	30	30
72	Q9H020	33.2028	26.6903	Brak	Lot BG	74	16/02/1976	12/10/1984	9	9
73	Q9H026	32.5719	26.7586	Kat	Kat River Dam	258			0	0
74	Q9H029	32.7611	26.6294	Kat	Fort Beaufort	1036	08/10/1991	30/09/2001	10	10
75	Q9H030	32.4647	26.5108	Koonap	Frisch Gewaagd	246	04/01/1982	30/09/2001	20	20
76	Q9R001	32.5719	26.7586	Kat	Kat River Dam	258	29/08/1970	30/09/2001	0	0
1	R1H001	32.7594	26.8553	Tyume	Goumahashe	238	01/06/1928	28/10/1980	53	50
2	R1H002	32.8247	27.0069	Keiskamma	Middle Drift (Anshan)	665	01/05/1938	30/09/1950	13	13
3	R1H003	32.6828	27.1553	Keiskamma	Keiskammahoek	266	01/02/1928	30/06/1948	21	21
4	R1H005	32.7517	27.0908	Keiskamma	Zanyokwe	482	01/11/1948	30/08/1995	47	43
5	R1H006	32.7517	27.0983	Rabula	Zanyokwe Location no.3	100	10/11/1948	30/04/1977	0	0
6	R1H007	32.6375	27.1931	Mtwaku	Mtwaku Location no.1	33	12/11/1948	01/04/1977	0	0
7	R1H008	32.6361	27.1881	Nqolonqolo	Mtwaku	39	20/11/1948	31/05/1977	0	0
8	R1H009	32.7167	27.1036	Wolf	Wolf River Location	57	23/11/1948	30/04/1977	0	0
9	R1H010	32.6661	27.2017	Gwiligwili	Gwili Gwili Location	31	26/11/1948	01/04/1975	0	0
10	R1H011	32.6383	27.1081	Mnyama	Nyameni Location	43	05/12/1948	01/09/1976	0	0
11	R1H012	32.6369	27.1119	Cata	Nyameni Location	56	08/12/1948	31/08/1976	0	0
12	R1H013	33.0117	26.9547	Keiskamma	Kamas Location	1515	01/01/1950	27/05/1986	0	0
13	R1H014	32.6400	26.9361	Tyume	Kwa Khayaletu	70	24/06/1953	30/09/2001	49	49

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
14	R1H015	33.1847	27.3936	Keiskamma	Farm 7	2530	31/07/1969	30/09/2001	32	32
15	R1H017	32.7181	27.1064	Keiskamma	Lower Mcqumeya (Sandile Dam)	367	22/08/1988	30/09/2001	14	14
16	R1H018	32.7517	27.0908	Keiskamma	Zanyokwe	482	04/11/1948	28/05/1959	0	0
17	R1R001	32.7181	27.1064	Keiskamma	Sandile Dam	357	01/10/1985	30/09/2001	0	0
18	R1R003	32.6797	26.9036	Tyume	Binfield Dam	113.9	18/01/1988	30/09/2001	0	0
19	R2H001	32.7319	27.2936	Buffalo	Pirie Main Forest Reserve	29	17/02/1963	30/09/2001	39	39
20	R2H002	32.9964	27.7967	Buffalo	Farm 830	1210	01/01/1934	30/04/1978	45	35
21	R2H003	32.9506	27.4794	Buffalo	Fort Murray	873	01/10/1938	28/02/1950	11	3
22	R2H004	32.7500	27.2936	Tyusha	Tyusha Location no.7	12	01/06/1941	01/03/1952	0	0
23	R2H005	32.8753	27.3731	Buffalo	King Williams Town (Wool Wash weir)	411	01/10/1947	30/09/2001	54	45
24	R2H006	32.8567	27.3764	Mgqakwebe	Msenge Ridge (Stewards Farm)	119	05/07/1948	30/09/2001	54	50
25	R2H007	32.7792	27.3856	Zele	Braunschweig	82	01/11/1947	30/12/1981	35	35
26	R2H008	32.7681	27.3742	Quencwe	Braunschweig	61	01/06/1947	30/09/2001	55	55
27	R2H009	32.9167	27.3731	Ngqokweni (Green)	Sheshegu	103	01/06/1947	30/09/2001	54	49
28	R2H010	32.9406	27.4614	Buffalo	135 K.W.T.Q (MacIntyre Bridge)	668	01/07/1950	30/09/2001	51	44
29	R2H011	32.9247	27.4794	Yellowwoods	Fort Murray	197	01/03/1957	19/11/1985	30	30
30	R2H012	32.7869	27.2633	Mgqakwebe	Jefta's Location no.29 (Pirie Mission)	15	07/11/1959	13/10/1997	38	38
31	R2H015	32.9319	27.4731	Yellowwoods	Fort Marray Uits	198.4	21/03/1988	30/09/2001	14	14
32	R2H016	32.9350	27.4467	Zwelitshaspruit	Malakalaka	6.65	22/03/1988	30/09/2001	14	14
33	R2H027	32.9936	27.6167	Buffalo	Mhlabati (Needs Camp)	1011	24/02/1994	30/09/2001	8	8
34	R2R001	32.9681	27.4942	Buffalo	Laing Dam	913	01/05/1949	30/09/1994	45	43
35	R2R002	32.7553	27.3281	Buffalo	Rooikrantz Dam	51	01/07/1951	30/09/1994	43	43
36	R2R003	32.9892	27.7311	Buffalo	Bridle Drift Dam	1176	01/09/1968	30/09/1994	26	26
37	R3H001	32.8028	27.8564	Gqunube	Outspan	500	21/04/1972	30/09/2001	29	29
38	R3H003	32.9064	27.8103	Nahoon	Farm 305	473	15/01/1965	30/09/2001	36	36
39	R3R001	32.9094	27.8114	Nahoon	Nahoon Dam	473	06/06/1966	15/03/1994	28	27
1	S1F001	32.0167	27.3667	White Kei	St Marks (d/s Indwe confluence)	4357		11/10/1905	32	0
2	S2H001	31.7744	27.4114	Indwe	Ncapa Farm	1139	01/02/1947	30/09/1965	20	20
3	S2H003	31.7914	27.4525	Lubisi	Southeyville Location no.26	8.4	01/12/1970	31/03/1983	0	0
4	S2H005	31.7958	27.4311	Indwe	Mutote Farm	1300	07/11/1968	30/09/2001	0	0
5	S2H006	31.5131	27.3347	Doorn	Indwe	295	07/12/1970	30/09/2001	0	0
6	S2R001	31.7958	27.4311	Lubisi	Lubisi Dam	1300	07/11/1968	30/09/2001	0	0
7	S2R002	31.5131	27.3347	Doorn	Doorn River Dam	295	01/12/1970	30/09/2001	31	31
8	S3H001	32.2028	20.4922	Black Kei	Doornhoek	231	01/06/1947	30/09/1958	11	11
9	S3H002	31.7442	26.5844	Klaas Smits	Wilgebosch (Grobbelaar)	796	01/07/1947	01/10/1997	50	45
10	S3H003	32.2000	26.4833	Black Kei	Doornhoek	240	29/03/1963	17/08/1995	33	30
11	S3H004	32.0500	26.7881	Black Kei	Cathcarts Gift	1413	17/04/1964	30/09/2001	38	38
12	S3H005	32.1811	26.8208	Oskraal	Whittlesea	462	10/05/1964	11/06/1997	34	32
13	S3H006	31.9233	26.7864	Klaas Smits	Weltevreden (Queenstown)	2170	05/05/1964	30/09/2001	37	37
14	S3H010	32.2850	26.8603	Klipplaat	Waterdown	603	01/08/1969	30/09/2001	0	0
15	S3H012	32.2103	26.7339	Oskraal	Oxkraal Kamastone	326.33	09/11/1989	30/09/2001	0	0
16	S3R001	32.2850	26.8603	Klipplaat	Waterdown Dam	603	06/02/1957	30/09/2001	0	0
17	S5H001	31.6608	27.6667	Tsomo	Lufuta	1375	17/06/1947	30/06/1959	0	0
18	S5H002	32.4000	27.8228	Tsomo	Wyk Maduma	2359	22/07/1964	30/09/2001	38	36
19	S5H004	31.7875	27.6792	Tsomo	Ncora Dam	1172.5	01/10/1975	30/09/2001	26	13
20	S5R001	31.7875	27.6792	Tsomo	Ncora Dam	1172.5	30/12/1998	30/09/2001	0	0
21	S6H001	32.5792	27.3667	Kubusi	Stutterheim	90	12/04/1947	30/09/2001	54	54
22	S6H002	32.5756	27.6231	Kubusi	Hammerhead	488.28	01/05/1947	21/08/1995	48	46
23	S6H003	32.5161	27.5247	Toise	Forkroad	215	27/08/1964	30/09/2001	38	38
24	S6H004	32.6103	27.2831	Gubu	Gubu Dam	22	22/09/1971	30/09/2001	31	31
25	S6H005	32.5753	27.5667	Kubisi	Wriggleswade	449	10/01/1989	30/09/2001	0	0
26	S6R001	32.6103	27.2794	Gubu	Farm 253	23	26/08/1970	30/09/2001	0	0
27	S6R002	32.5806	27.5592	Kubisi	Wriggleswade Dam	447	01/01/1990	30/09/2001	0	0
28	S7H001	32.3275	28.1447	Gcuwa	Butterworth	724	01/10/1951	30/09/2001	50	45
29	S7H004	32.5153	28.0156	Great Kei	Area 8, Springs B	20174	22/08/1990	30/11/2002	12	12
30	S7R001	32.3194	28.1350	Gcuwa	Gcuwa Dam	709	01/11/1979	30/09/2001	0	0

APPENDIX A: FLOW AND HISTORICAL FLOOD PEAK SITES - CMA 15 (REGIONS J, K, L, M, N, P, Q, R & S)

No	Site	Latitude	Longitude	River	Place	Catchment Area (km2)	Period of observation Start	End	Length (years)	Peaks
31	S7R002	32.1397	28.0981		Xilinxa Dam	200	01/06/1984	30/09/2001	0	0

Appendix B

Assembled Data Series including Historical and Palaeoflood Information and Data

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J1 (Buffels River)

Primary site	**J1R004**	**J1H006**	**J1H015**	**J1H016**	**J1H017**
River	**Brand**	**Brand**	**Bok**	**Smalblaar**	**Sand**
Catchment area (km^2)	**251.00**	**323.00**	**8.80**	**30.00**	**254.00**
Supplementary sites	J1H009				
Hydrological year					
1936/37					
1937/38		**4.81**			
1938/39		**88.39**			
1939/40		**24.83**			
1940/41		**53.41**			
1941/42		**7.85**			
1942/43		**9.04**			
1943/44		**56.30**			
1944/45		**16.01**			
1945/46		**33.22**			
1946/47		**33.22**			
1947/48		**65.19**			
1948/49		**107.09**			
1949/50		**65.19**			
1950/51		**140.41**			
1951/52		**65.19**			
1952/53		**103.16**			
1953/54		**187.83**			
1954/55		**26.86**			
1955/56		**5.74**			
1956/57		**19.33**			
1957/58		**12.99**			
1958/59		**92.04**			
1959/60		**24.83**			
1960/61		**2.16**			
1961/62		**84.92**			
1962/63		**28.88**			
1963/64		**16.01**			
1964/65	3.66	**24.83**			
1965/66	48.10	**22.95**			
1966/67	25.97	**28.88**			
1967/68	3.94				
1968/69	8.68				
1969/70	15.95				
1970/71	15.07				
1971/72	5.52				
1972/73	2.62				
1973/74	45.90		**2.40**	**3.78**	
1974/75	11.99		**1.65**	**2.37**	
1975/76	10.35		**8.42**	**15.46**	
1976/77	**86.28**		**8.18**	**15.26**	
1977/78			**0.43**	**5.10**	
1978/79			**1.84**	**1.64**	
1979/80			**0.61**	**0.72**	
1980/81	**124.63**		**7.70**	**26.33**	**414.78**
1981/82	**11.45**		**1.81**	**7.93**	**4.03**
1982/83	**76.29**		**4.98**	**7.68**	**33.99**
1983/84	**4.92**		**6.54**	**6.26**	**20.59**
1984/85			**12.16**	**16.49**	**4.29**
1985/86	**7.18**		**3.31**	**4.67**	**11.03**
1986/87			**3.66**	**1.82**	**21.44**
1987/88			**2.58**	**3.49**	**2.99**
1988/89			**3.49**	**3.55**	**106.23**
1989/90	**74.50**		**5.64**	**3.91**	**8.84**
1990/91			**2.60**	**5.31**	**23.96**
1991/92			**3.92**	**3.13**	**30.54**
1992/93	**85.71**		**5.24**	**6.22**	**119.03**
1993/94			**3.00**	**2.33**	**210.55**
1994/95			**2.58**	**2.66**	**26.17**
1995/96			**4.69**	**1.13**	**60.44**
1996/97	**79.02**		**3.37**	**4.11**	**31.61**
1997/98			**3.73**	**1.17**	**4.32**
1998/99	**11.54**		**1.16**	**1.77**	**15.69**
1999/00			**0.93**	**14.86**	**60.83**
2000/01			**1.02**		
Correlation-r^2					
Multiplier-linear					
Site					

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
<u>1260.78</u> Historic and palaeoflood data
<u>1260.78</u> Correlated data
<u>1260.78</u> Correlated historic and palaeoflood data

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J1 (Buffels River)

Primary site	**J1H010**	**J1H018**	**J1H012**	**J1H019**	**J1R003**
River	**Touws**	**Touws**	**Groot**	**Groot**	**Buffels**
Catchment area (km^2)	**2900.00**	**5837.00**	**5565.00**	**12493.00**	**4001.00**
Supplementary sites	J1H007		J1H014	J1H008	J1H001 J1H002 J1H004 J1H005
Hydrological year					
1921/22					
1922/23					23.64
1923/24					7.88
1924/25					805.57
1925/26					
1926/27					66.98
1927/28					7.53
1928/29					378.42
1929/30					8.94
1930/31					15.74
1931/32					19.76
1932/33					70.33
1933/34					532.47
1934/35					462.02
1935/36					133.95
1936/37					222.03
1937/38					872.71
1938/39	19.99	*27.72*			630.92
1939/40	112.11	*155.49*			86.06
1940/41	59.90	*83.08*			243.80
1941/42	27.34	*37.93*			101.13
1942/43	47.05	*65.26*			47.55
1943/44	34.39	*47.70*			55.52
1944/45	47.05	*65.26*			111.85
1945/46	6.14	*8.51*			18.72
1946/47	112.11	*155.49*			16.95
1947/48	18.73	*25.97*			20.43
1948/49					217.01
1949/50					
1950/51					111.85
1951/52					1005.58
1952/53					214.33
1953/54					85.06
1954/55					42.53
1955/56					
1956/57					
1957/58					
1958/59					
1959/60					
1960/61					**43.00**
1961/62					**58.00**
1962/63					
1963/64			*34.47*	74.93	
1964/65			*42.61*	92.64	
1965/66			*46.50*	101.08	
1966/67			*518.77*	1127.76	**1392.00**
1967/68			*1.14*	2.47	
1968/69	**45.59**	*63.23*	*3.11*	6.77	
1969/70			*42.61*	92.64	
1970/71	**32.58**	*45.19*	**27.14**	138.38	**1501.00**
1971/72	**43.74**	*60.66*	**5.13**	32.09	
1972/73	**0.29**	*0.40*	**4.21**	55.74	
1973/74	**156.59**	*217.19*	**16.89**	160.46	**1364.00**
1974/75	**113.69**	*157.69*	**8.08**	113.27	
1975/76	**74.22**	*102.94*	**25.22**	38.60	**275.00**
1976/77	**36.77**	*51.00*	**81.87**	26.16	**27.00**
1977/78	**117.91**	*163.54*	**85.66**	443.62	**259.00**
1978/79	**0.66**	*0.92*	**5.04**	*10.96*	
1979/80	**105.08**	*145.75*	**1.74**	*3.77*	
1980/81	**1670.00**	**3650.00**	**5062.41**	**11000.00**	**5740.00**
1981/82	*25.99*	**36.05**	**28.89**	**21.77**	
1982/83	*6.08*	**8.44**	*35.13*	**76.37**	
1983/84	*5.90*	**8.19**	*8.03*	**17.45**	
1984/85	*1.15*	**1.59**	*4.97*	**10.81**	
1985/86	*20.81*	**28.87**	*32.27*	**70.15**	
1986/87	*13.30*	**18.45**	*10.44*	**22.69**	
1987/88	*10.83*	**15.02**	*1.33*	**2.88**	
1988/89	*22.35*	**31.00**	*74.34*	**161.60**	**481.00**

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J1 (Buffels River)

Primary site	**J1H010**	**J1H018**	**J1H012**	**J1H019**	**J1R003**
River	**Touws**	**Touws**	**Groot**	**Groot**	**Buffels**
Catchment area (km^2)	**2900.00**	**5837.00**	**5565.00**	**12493.00**	**4001.00**
Supplementary sites	J1H007		J1H014	J1H008	J1H001 J1H002 J1H004 J1H005
Hydrological year					
1989/90	*5.42*	**7.52**	*40.30*	**87.61**	
1990/91	*5.27*	**7.32**	*6.85*	**14.88**	**46.00**
1991/92	*23.94*	**33.20**	*31.30*	**68.05**	
1992/93	*34.27*	**47.54**	*71.50*	**155.44**	
1993/94	*13.07*	**18.13**	*5.93*	**12.89**	
1994/95	*34.21*	**47.44**	*23.04*	**50.08**	
1995/96	*34.14*	**47.35**	*111.19*	**241.73**	
1996/97	*19.82*	**27.48**	*65.32*	**141.99**	
1997/98		**0.00**	*0.61*	**1.33**	
1998/99	*29.14*	**40.42**	*48.71*	**105.88**	
1999/00	*13.03*	**18.07**	*7.23*	**15.71**	
2000/01	*15.34*	**21.28**			
Correlation-r^2	1.00	1.00	1.00	1.00	
Multiplier-linear	0.72	1.39	0.46	2.17	
Site	**J1H018**	**J1H010**	**J1H019**	**J1H012**	

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Gourits River Catchment - Region J2 (Gamka River)

Primary site	J2H005	J2H006	J2H007	J2R006
River	Huis	Boplaas	Joubert	Gamka
Catchment area (km^2)	253.00	25.00	25.00	17076.00
Supplementary sites				J2H003 J2H008 J2H010 J2H016
Hydrological year				
1920/21				
1921/22				3502.97
1922/23				
1923/24				60.87
1924/25				416.08
1925/26				7.38
1926/27				3.41
1927/28				1084.84
1928/29				78.49
1929/30				356.89
1930/31				76.82
1931/32				254.46
1932/33				24.06
1933/34				69.49
1934/35				183.61
1935/36				1.15
1936/37				316.05
1937/38				395.74
1938/39				1407.66
1939/40				352.20
1940/41				654.65
1941/42				171.06
1942/43				
1943/44				
1944/45				
1945/46				
1946/47				
1947/48				
1948/49				
1949/50				
1950/51				
1951/52				
1952/53				
1953/54				
1954/55	1.33	0.18	0.17	
1955/56	4.16	1.26	0.08	
1956/57	31.69	0.92	0.10	
1957/58	8.36	0.03	0.84	
1958/59	2.29	0.17	0.27	
1959/60	7.24	3.15	0.13	
1960/61	7.70	1.79	1.53	2258.00
1961/62	8.64	*1.49*	0.22	
1962/63	3.31	*0.57*	0.34	
1963/64	10.11	*1.75*	1.76	320.42
1964/65	3.00	*0.52*	0.48	97.07
1965/66	19.37	*3.35*	4.93	9.33
1966/67	15.44	4.23	2.70	1252.68
1967/68	6.03	3.79	1.39	199.10
1968/69	3.92	1.59	0.63	141.60
1969/70	1.87	1.07	0.02	292.00
1970/71	11.04	2.44	1.56	1770.00
1971/72	1.62	4.53	2.48	117.00
1972/73	0.65	0.01	0.33	81.00
1973/74	10.40	1.10	0.53	620.00
1974/75	2.00	1.25	0.71	*10.93*
1975/76	5.58	0.68	2.19	514.00
1976/77	17.84	2.37	1.29	233.00
1977/78	2.43	4.71	2.64	*31.68*
1978/79	2.25	0.74	0.35	410.00
1979/80	1.60	0.05	1.16	119.00
1980/81	236.00	40.45	2.40	5707.00
1981/82	14.77	3.17	1.01	215.00
1982/83	8.65	1.57	0.24	*21.81*
1983/84	3.73	0.65	0.58	*6.58*
1984/85	9.47	0.83	0.22	888.00

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J2 (Gamka River)

Primary site	**J2H005**	**J2H006**	**J2H007**	**J2R006**
River	**Huis**	**Boplaas**	**Joubert**	**Gamka**
Catchment area (km^2)	**253.00**	**25.00**	**25.00**	**17076.00**
Supplementary sites				J2H003 J2H008 J2H010 J2H016
Hydrological year				
1985/86	**27.82**	**7.61**	**5.28**	*326.22*
1986/87	**5.08**	**2.39**	**1.58**	**284.00**
1987/88	**2.92**	**0.82**	**1.06**	**750.00**
1988/89	**11.43**	**3.97**	**1.08**	*9.65*
1989/90	**28.86**	**6.69**	**5.37**	**225.00**
1990/91	**0.91**	**0.04**	**0.20**	*14.38*
1991/92	**27.27**	**4.81**	**3.28**	*6.00*
1992/93	**21.91**	**3.03**	**2.06**	**213.00**
1993/94	**41.36**	**1.24**	**1.93**	**213.00**
1994/95	**14.55**	**0.34**	**0.07**	*31.88*
1995/96	**19.35**	**4.04**	**2.68**	*18.37*
1996/97	**13.77**	**12.24**	**6.02**	*1819.21*
1997/98	**0.83**	**1.82**	**0.66**	*20.93*
1998/99	**1.83**	**2.81**	**2.32**	*303.12*
1999/00	**27.45**	**9.76**	**6.76**	*4367.54*
2000/01	**2.89**	**0.75**	**0.07**	
Correlation-r^2		0.84		0.92
Multiplier-linear		0.17		1.32
Site		**J2H005**		**Outflows**

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J3 (Olifants River tributaries)

Primary site	**J3H005**	**J3H014**	**J3H016**	**J3H017**	**J3H020**	**J3H012**	**J3H002**
River	**Klip**	**Grobbelaars**	**Wilge**	**Kandelaars**	**Meul**	**Groot**	**Traka**
Catchment area (km^2)	**95.00**	**151.00**	**32.00**	**348.00**	**35.00**	**688.00**	**3039.00**
Supplementary sites	J3H010					J3H003	
Hydrological year							
1911/12							
1912/13						15.08	**288.86**
1913/14						38.19	**223.72**
1914/15						21.16	**193.43**
1915/16						592.01	**791.60**
1916/17						81.33	**1132.80**
1917/18						313.10	**1573.57**
1918/19						61.18	**185.24**
1919/20						358.09	**185.24**
1920/21						696.39	**83.20**
1921/22						204.24	**28.86**
1922/23						21.16	**185.24**
1923/24						267.76	
1924/25						97.17	
1925/26	**1.52**					21.16	
1926/27	**8.89**					0.70	
1927/28	**8.89**					899.73	
1928/29	**122.72**					313.10	
1929/30	**116.62**					237.53	
1930/31	**8.89**					629.81	
1931/32	**389.68**					423.23	
1932/33	**34.14**					762.96	
1933/34	**23.80**					696.39	
1934/35	**122.72**					116.96	
1935/36	**23.80**					26.70	
1936/37	**122.72**					313.10	
1937/38	**23.80**					15.08	
1938/39	**95.98**					26.70	
1939/40	**60.91**					12.96	
1940/41	**15.37**					237.53	
1941/42	**15.37**					1.08	
1942/43	**15.37**					19.86	
1943/44	**34.14**					26.70	
1944/45	**34.14**					47.72	
1945/46	**46.55**					9.79	
1946/47	**8.89**					47.72	
1947/48						21.16	
1948/49						77.38	
1949/50						77.38	
1950/51						170.95	
1951/52						61.18	
1952/53						11.20	
1953/54						116.96	
1954/55						21.16	
1955/56						170.95	
1956/57						503.85	
1957/58						237.53	
1958/59						2.73	
1959/60						160.15	
1960/61						184.27	
1961/62						696.39	
1962/63						331.09	
1963/64						170.95	
1964/65						**119.38**	
1965/66						**16.53**	
1966/67		**19.43**	**10.13**			**68.97**	
1967/68		**7.02**	**1.63**			**19.44**	
1968/69		**12.65**	**0.50**	**0.65**		**15.17**	
1969/70		**2.82**	**0.28**	**14.65**		**0.79**	
1970/71		**37.88**	**3.69**	**94.58**		**40.67**	
1971/72		**5.87**	**0.43**	**19.19**		**119.99**	
1972/73		**4.23**	**0.14**	**0.35**		**11.59**	
1973/74		**13.53**	**1.74**	**13.47**		**287.12**	
1974/75		**12.62**	**0.65**	**7.76**	**3.27**	**109.15**	
1975/76		**20.06**	**3.23**	**0.31**	**34.12**	**203.66**	
1976/77		**41.72**	**4.31**	**205.38**	**6.67**	**176.19**	
1977/78		**14.50**	**0.39**	**17.97**	**1.13**	**1.69**	
1978/79		**11.51**	**1.60**	**9.58**	**0.63**	**1.61**	
1979/80		**7.54**	**0.21**	**0.52**	**0.47**	**22.69**	
1980/81		**47.10**	**0.00**	**224.46**	**124.52**	**110.51**	
1981/82		**40.70**	**5.52**	**21.79**	**8.53**	**36.73**	

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Region J3 (Olifants River tributaries)

Primary site	**J3H005**	**J3H014**	**J3H016**	**J3H017**	**J3H020**	**J3H012**	**J3H002**
River	**Klip**	**Grobbelaars**	**Wilge**	**Kandelaars**	**Meul**	**Groot**	**Traka**
Catchment area (km^2)	**95.00**	**151.00**	**32.00**	**348.00**	**35.00**	**688.00**	**3039.00**
Supplementary sites	J3H010					J3H003	
Hydrological year							
1982/83		**15.77**	**11.94**	**21.79**	**0.81**	**16.04**	
1983/84		**12.33**	**0.82**	**28.95**	**1.58**	**27.71**	
1984/85		**33.31**	**0.15**	**0.36**	**2.27**	**92.37**	
1985/86		**32.95**	**7.32**	**32.48**	**4.88**	**31.02**	
1986/87		**16.61**	**5.15**	**7.55**	**135.19**	**46.84**	
1987/88		**4.20**	**0.43**	**0.87**	**0.52**	**448.72**	
1988/89		**6.86**	**1.07**	**21.36**	**11.51**	**2.99**	
1989/90		**28.81**	**11.77**	**64.37**	**3.47**	**112.62**	
1990/91		**2.13**	**0.06**	**0.25**	**0.23**	**6.57**	
1991/92		**19.79**	**1.32**	**14.24**	**2.25**	**91.39**	
1992/93		**29.28**	**10.95**	**124.03**	**3.08**	**382.49**	
1993/94		**9.20**	**0.68**	**115.66**	**2.08**	**249.76**	
1994/95		**10.62**	**1.60**	**11.88**	**1.02**		
1995/96		**17.87**	**4.67**	**21.40**	**3.29**		
1996/97		**115.25**	**70.17**	**221.52**	**102.44**	**1059.66**	
1997/98		**8.82**	**1.71**	**0.32**	**1.57**		
1998/99		**74.33**	**0.03**	**0.01**	**18.61**		
1999/00		**61.90**	**1.67**	**2.40**	**81.56**		
2000/01		**18.17**	**0.73**	33.18	**7.93**		
Correlation-r^2							
Multiplier-linear							
Site							

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gourits River Catchment - Regions J3 & J4 (Olifants and Gourits Rivers)

Primary site	J3R001	J3H004	J3R002	J3H011	J4H003	J4H004	J4H002
River	Kammanasie	Olifants	Olifants	Olifants	Weyers	Langtou	Gourits
Catchment area (km^2)	1506.00	4252.00	5235.00	10927.00	95.00	99.00	43451.00
Supplementary sites	J3H001	J3H021	J3H008 J3H004 J3H021	J3H009 J3H007			J4H001
Hydrological year							
85000BP							12000.00
3000BP							26300.00
1848/49							8960.00
1868/69							4380.00
1884/85							6500.00
1897/98			1038.00	1500.00			
1911/12	41.74						1083.00
1912/13	129.59						791.00
1913/14	48.06						737.00
1914/15	156.69						655.00
1915/16	2754.97		1869.00	2700.00			1183.00
1916/17	84.28						816.00
1917/18	781.63						1183.00
1918/19	13.48						155.00
1919/20	100.88						592.00
1920/21	300.19						1485.00
1921/22	46.76						61.00
1922/23	43.00						639.00
1923/24	34.00	481.35	534.11				1074.00
1924/25	312.00	205.70	228.25				1804.00
1925/26	53.00	16.92	18.77				655.00
1926/27	54.00	32.56	36.13				268.00
1927/28	19.00	209.24	232.17				1565.00
1928/29	14.00	80.82	89.68				4581.00
1929/30	41.00	177.20	196.62				696.00
1930/31	8.20	202.19	224.35	159.00			70.00
1931/32	2467.00	351.15	389.63	1699.00			3268.00
1932/33	26.00	246.55	273.57				
1933/34	7.50	90.74	100.68				
1934/35	293.10	90.74	100.68				
1935/36	69.40	76.63	85.03				
1936/37	42.00	668.99	742.31				
1937/38	12.00	507.24	562.83				
1938/39	39.00	445.88	494.74				
1939/40	16.00	154.87	171.84				
1940/41	17.00	704.61	781.84				
1941/42	37.00	57.53	63.84				
1942/43	7.80	421.38	467.56	102.00			
1943/44		154.87	171.84	86.00			
1944/45	159.00	258.34	286.65				
1945/46	20.00	95.55	106.02				
1946/47	29.00	90.74	100.68				
1947/48	16.00	158.52	175.89				
1948/49	50.00	435.20	482.90	215.00			
1949/50	110.00	803.30	891.34	783.59			
1950/51	528.00	647.66	718.64	823.21			
1951/52	39.00	578.13	641.49				
1952/53	87.00	1045.11	1159.66	303.14			
1953/54	573.00	469.91	521.41	227.79			
1954/55	33.00	132.73	147.27				867.00
1955/56	21.00	959.12	1064.24	295.09			
1956/57	21.00	51.64	57.30				
1957/58	9.90	326.09	361.83				
1958/59	22.00	138.78	153.99	85.49			
1959/60	8.00	170.74	189.45				
1960/61	3.40	822.96	913.15				2648.00
1961/62	225.00	138.78	153.99				
1962/63	60.00	243.04	269.67	168.18			
1963/64	172.00	205.52	228.04	215.04			52.50
1964/65	12.00	578.13	641.49		8.72		1055.00
1965/66	24.00	67.84	75.28	222.30	131.12		632.55
1966/67	82.00	227.39	252.31	156.67	133.13	108.48	2041.70
1967/68	46.00	24.36	27.03		7.97	2.33	64.92
1968/69	7.90	138.90	154.12		62.11	6.00	697.17
1969/70	6.90	59.91	66.47		31.64	1.83	24.52
1970/71	235.00	346.86	670.00	278.42	26.39	53.09	1415.74
1971/72	4.60	113.22	125.63		5.32	2.35	58.78
1972/73	8.60	131.58	146.00		21.68	0.32	
1973/74	17.00	84.79	429.00		45.96	1.71	229.00
1974/75	8.40	6.27	6.95		49.35	3.68	40.72

APPENDIX B | **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Gourits River Catchment - Regions J3 & J4 (Olifants and Gourits Rivers)

Primary site	**J3R001**	**J3H004**	**J3R002**	**J3H011**	**J4H003**	**J4H004**	**J4H002**
River	**Kammanasie**	**Olifants**	**Olifants**	**Olifants**	**Weyers**	**Langtou**	**Gourits**
Catchment area (km^2)	**1506.00**	**4252.00**	**5235.00**	**10927.00**	**95.00**	**99.00**	**43451.00**
Supplementary sites	J3H001	J3H021	J3H008 J3H004 J3H021	J3H009 J3H007			**J4H001**
Hydrological year							
1975/76	**8.90**	**135.50**	**529.00**		**18.94**	**0.51**	**1203.00**
1976/77	**85.00**	**39.44**	**427.00**		**121.40**	**29.23**	**681.04**
1977/78	**4.40**	**10.24**	**337.00**		**25.56**	**1.36**	**44.09**
1978/79	**17.00**	**0.56**	**116.00**		**29.82**	**5.70**	
1979/80	**1.50**	**12.82**	**114.00**		**7.80**	**0.18**	
1980/81	**902.00**	**926.69**	**1235.00**	**1334.09**	**242.48**	**159.75**	**11400.00**
1981/82	**104.00**	**45.43**	**288.00**	**174.88**	**37.75**	**10.61**	
1982/83	**414.00**	19.50	**138.00**	**287.11**	**30.12**	**16.49**	
1983/84	**104.00**	6.83	**27.00**	**222.84**	**28.46**	**24.71**	
1984/85	**2.00**	**26.50**	**138.00**		**88.64**	**2.11**	
1985/86	**27.00**	**113.74**	**596.00**	**200.23**	**85.37**	**48.51**	
1986/87	**40.00**	**45.90**	**50.93**	**194.09**	**22.25**	**3.03**	
1987/88	**6.20**	**178.00**	**197.51**		**40.38**	**0.73**	
1988/89	**5.10**	**99.48**	**110.38**		**87.22**	**3.64**	
1989/90	**75.00**	**61.38**	**68.11**	**175.39**	**108.41**	**37.59**	**684.00**
1990/91	**41.00**	**192.15**	**213.21**		**15.54**	**0.60**	**41.00**
1991/92	**50.00**	**134.75**	**149.52**		**254.97**	**88.24**	**237.00**
1992/93	**596.00**	**292.36**	**354.00**	**258.61**	**156.66**	**30.11**	**710.00**
1993/94	*35.62*		**431.00**		**81.04**	**5.85**	**383.00**
1994/95	**10.00**		**174.00**		**75.26**	**16.73**	
1995/96	**22.00**		**116.00**		**74.30**	**6.99**	
1996/97	**1561.00**	*1133.75*	**3138.00**	**2620.16**	**113.78**	**39.30**	**4525.00**
1997/98	**1.90**		**141.00**		**69.15**		
1998/99	**2.10**		**167.00**		**20.36**		
1999/00	**5.60**		**723.00**		**105.01**		**4672.00**
2000/01	**9.70**		**71.00**		**60.27**		
Correlation-r^2	1.00						
Multiplier-linear	1.20						
Site	Outflows	**J3R002**					

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

South Coast Rivers - Region K

Primary site	**K3H001**	**K3H002**	**K3H003**	**K3H004**	**K3H005**
River	**Kaaimans**	**Rooi**	**Maalgate**	**Malgas**	**Touws**
Catchment area (km^2)	**47.00**	**1.00**	**145.00**	**34.00**	**78.00**
Supplementary sites					
Hydrological year					
1959/60					
1960/61	**21.54**	**0.22**	**46.06**	**11.52**	*23.91*
1961/62	**75.62**	**1.65**	**167.80**	**93.70**	*194.51*
1962/63	**90.02**	**3.61**	**249.79**	**177.10**	*367.63*
1963/64	**84.65**	**5.34**	**242.97**	**212.79**	*441.72*
1964/65	**8.02**	**0.60**	**14.05**	**21.28**	*44.17*
1965/66	**70.28**	**2.56**	**149.84**	**61.83**	*128.35*
1966/67	**69.56**	**1.64**	**140.65**	**59.97**	*124.49*
1967/68	**19.65**	**0.66**	**13.38**	**17.89**	*37.14*
1968/69	**19.67**	**0.00**	**34.66**	**26.77**	**18.66**
1969/70	**24.92**	**1.63**	**49.70**	**44.14**	**16.02**
1970/71	**42.40**	**1.72**	**71.73**	**66.22**	**62.72**
1971/72	**8.55**	**1.24**	**21.59**	**35.13**	**10.31**
1972/73	**1.13**	**0.60**	**9.02**	**11.13**	**4.53**
1973/74	**7.25**	**0.92**	**28.25**	**31.52**	**21.04**
1974/75	**20.42**	**1.32**	**40.36**	**52.70**	**21.91**
1975/76	**7.68**	**1.28**	**29.41**	**35.30**	**4.54**
1976/77	**12.95**	**1.35**	**55.87**	**94.18**	**83.16**
1977/78	**6.04**	**0.42**	**9.35**	**11.88**	**4.57**
1978/79	**0.83**	**2.23**	**71.61**	**51.10**	**29.92**
1979/80	**3.42**	**0.68**	**12.11**	**10.14**	**2.65**
1980/81	**95.61**	**2.21**	**239.19**	**104.58**	**395.74**
1981/82	**22.11**	**0.92**	**42.93**	**36.37**	**23.67**
1982/83	**31.71**	**0.80**	**8.75**	**34.71**	**61.74**
1983/84	**45.22**	**1.80**	**30.17**	**51.83**	**55.79**
1984/85	**6.33**	**0.55**	**8.75**	**8.12**	**6.32**
1985/86	**34.98**	**2.30**	**43.28**	**65.60**	**41.81**
1986/87	**33.35**	**1.74**	**54.52**	**70.55**	**42.19**
1987/88	**4.38**	**0.58**	**10.53**	**10.08**	**2.99**
1988/89	**6.89**	**0.96**	**17.30**	**35.21**	**4.41**
1989/90	**57.79**	**1.77**	**69.86**	**62.40**	**76.24**
1990/91	**12.49**	**1.17**	**16.60**	**18.16**	**9.26**
1991/92	**52.56**	**2.16**	**164.71**	**89.32**	**77.08**
1992/93	**86.71**	**3.42**	**203.11**	**163.52**	**154.64**
1993/94	**27.71**	**1.82**	**57.44**	**51.70**	**32.57**
1994/95	**23.22**	**1.00**	**54.14**	**29.47**	**31.80**
1995/96	**34.44**	**1.64**	**96.96**	**56.01**	**41.48**
1996/97	**118.65**	**2.97**	**158.51**	**248.91**	**917.10**
1997/98	**13.51**	**0.54**	**33.17**	**32.30**	**16.29**
1998/99	**10.42**	**0.69**	**26.50**	**16.88**	**8.53**
1999/00	**40.81**	**1.55**	**30.02**	**31.63**	**45.15**
2000/01	**53.48**	**1.25**	**52.10**	**75.28**	**65.92**
Correlation-r^2					0.61
Multiplier-linear					2.08
Site					**K3H004**

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

South Coast Rivers - Region K

Primary site	**K4H001**	**K4H002**	**K4H003**	**K5H001**	**K5H002**
River	**Hoekraal**	**Karatara**	**Diep**	**Gouna**	**Knysna**
Catchment area (km^2)	**111.00**	**22.00**	**72.00**	**91.00**	**133.00**
Supplementary sites					
Hydrological year					
1959/60	**16.62**				
1960/61	**4.43**		**0.63**		
1961/62	**207.98**		**110.70**	**335.33**	**179.07**
1962/63	**246.27**	**98.54**	**111.75**	**181.80**	**160.10**
1963/64	**165.45**	**38.12**	**118.31**	**356.71**	**108.05**
1964/65	**6.79**	**14.55**	**7.93**	**24.82**	**11.01**
1965/66	**184.13**	**47.04**	**65.10**	**131.32**	**42.97**
1966/67	**85.72**	**38.44**	**33.67**	**64.36**	**70.27**
1967/68	**31.48**	**18.82**	**7.81**	**20.39**	**40.34**
1968/69	**20.16**	**25.38**	**5.41**	**22.47**	**29.91**
1969/70	**24.73**	**20.38**	**4.95**	**40.74**	**15.55**
1970/71	**121.85**	**39.91**	**28.68**	**240.62**	**110.58**
1971/72	**21.61**	**28.78**	**5.03**	**181.80**	**40.01**
1972/73	**4.87**	**12.12**	**0.53**	**1.96**	**6.98**
1973/74	**61.08**	**41.56**	**15.73**	**73.71**	**19.22**
1974/75	**35.42**	**22.88**	**6.45**	**3.84**	**26.01**
1975/76	**12.54**	**23.20**	**2.16**	**0.69**	**9.30**
1976/77	**102.54**	**56.94**	**37.23**	**318.50**	**43.10**
1977/78	**18.03**	**15.92**	**0.64**	**0.49**	**11.93**
1978/79	**34.71**	**35.54**	**6.34**	**48.76**	**43.10**
1979/80	**4.94**	**7.11**	**1.24**	**1.89**	**4.12**
1980/81	**399.21**	**189.60**	**265.74**	**311.63**	**519.94**
1981/82	**43.06**	**22.33**	**7.69**	**294.85**	**153.16**
1982/83	**86.33**	**12.64**	**39.63**	**110.33**	**143.24**
1983/84	**78.67**	**21.44**	**21.10**	**112.21**	**12.44**
1984/85	**13.06**	**9.58**	**3.72**		**11.87**
1985/86	**69.05**	**45.73**	**16.89**		**43.33**
1986/87	**68.10**	**45.73**	**10.13**		**49.01**
1987/88	**7.92**	**8.67**	**0.79**		**21.00**
1988/89	**21.51**	**16.57**	**3.26**		**7.18**
1989/90	**101.56**	**37.13**	**27.21**		**81.59**
1990/91	**15.37**	**13.57**	**1.70**		**10.84**
1991/92	**80.18**	**26.69**	**20.98**		**68.28**
1992/93	**129.50**	**184.82**	**76.96**		**339.35**
1993/94	*22.79*	**13.48**	**6.12**		**19.14**
1994/95	*35.16*	**20.80**	**8.97**		**33.85**
1995/96	*50.83*	**30.07**	**26.77**		**53.18**
1996/97	*180.22*	**106.60**	**156.45**		**658.91**
1997/98	*47.57*	**28.14**	**6.09**		**11.10**
1998/99	*23.46*	**13.88**	**3.49**		**8.20**
1999/00	*36.32*	**21.48**	**10.17**		**13.67**
2000/01	*129.07*	**76.35**	**27.02**		**56.82**
Correlation-r^2	0.61				
Multiplier-linear	1.69				
Site	**K4H002**				

Note:
1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Groot River Catchment - Regions L1 to L7

Primary site	**L1H002**	**L2H003**	**L2H004**	**L3R001**	**L6H002**	**L6H001**	**L7H006**
River	**Sout**	**Buffels**	**Buffels**	**Groot (In)**	**Heuningklip**	**Heuningklip**	**Groot**
Catchment area (km^2)	**3675**	**1145**	**5584**	**20336**	**675**	**1290**	**29232**
Supplementary sites	L1H001	L2H002	L2H001	L3H001			L7H002, L7H004
Hydrological year							
0100/01							**4400**
1874/75							
1896/97							**857.00**
1904/05							**3779.00**
1906/07							**736.00**
1908/09							**1739.00**
1911/12							
1915/16							
1916/17				316.17			
1917/18	114.24			198.75			
1918/19	196.31			268.19			
1919/20	99.58			320.26			
1920/21	311.13			345.42			
1921/22	403.88			1461.64			
1922/23	41.07			47.47			
1923/24	182.25		498.43	336.91			
1924/25	839.27		623.04	429.11			
1925/26	55.99	41.72	127.44	8.92			
1926/27	99.58	44.68	507.86	33.53			
1927/28	1112.94	106.43	835.44	568.53		**171.69**	118.00
1928/29	109.28	68.98	790.13	367.96		**125.09**	417.00
1929/30	90.20	33.17	703.47	280.09		**267.86**	268.00
1930/31	134.83	25.62	260.54	102.96		**253.96**	256.00
1931/32	150.98	143.87	808.25	449.42		**398.29**	801.00
1932/33	22.27	5.25	181.25	133.57		**223.80**	202.00
1933/34	119.73	46.98	790.13	197.61		**179.92**	118.00
1934/35	225.27	18.40	835.44	429.43		**163.66**	401.00
1935/36	41.21	27.92	693.84	109.59		**135.77**	89.00
1936/37	145.60	30.55	407.81	46.19		**103.43**	31.00
1937/38	705.81	18.40	790.13	622.22		**253.96**	484.00
1938/39	311.13	19.38	703.47	1159.99		**425.05**	1111.00
1939/40	801.97	53.22	835.44	812.90		**148.14**	484.00
1940/41	1112.94	19.38	741.98	205.59		**140.66**	256.00
1941/42	59.82	14.13	218.63	874.69		**263.86**	484.00
1942/43	67.89	53.22	880.75	316.17		**244.23**	256.00
1943/44	114.77	41.39	693.84	363.54		**425.05**	320.00
1944/45	253.39	56.50	835.44	337.19		**267.86**	484.00
1945/46	26.10	59.13	127.44	69.61		**482.57**	484.00
1946/47	421.92	129.65	506.93	78.63		**425.05**	627.00
1947/48	862.09	162.27	971.38	222.21		**214.65**	202.00
1948/49		65.37	600.38	39.27		**89.40**	46.00
1949/50	1001.80	394.18		298.91		**886.99**	1461.00
1950/51		261.21		229.13		**159.71**	484.00
1951/52		316.00		229.13		**263.86**	801.00
1952/53				73.47		**171.69**	320.00
1953/54		**22.57**		87.60		**263.86**	256.00
1954/55		**41.56**		13.42		**25.75**	158.00
1955/56		**131.07**		55.99		**171.69**	202.00
1956/57		**17.85**		25.12		**50.90**	31.00
1957/58		**8.46**		9.61		**13.05**	57.00
1958/59		**8.46**		9.94		**50.90**	31.00
1959/60		**8.46**		14.98		**18.67**	158.00
1960/61	1134.96	**219.10**	**1790.25**	**2889.00**		**316.11**	**1312.00**
1961/62	26.42	**101.53**	**70.74**	**31.00**		**171.69**	202.00
1962/63	170.57	**515.97**	**1085.34**	**944.00**		**351.93**	202.00
1963/64	145.24	**8.46**	**40.67**	**69.00**	**120.95**	**50.90**	**109.52**
1964/65	126.64	**52.57**	**88.84**	**108.00**	**12.14**	**372.25**	**137.19**
1965/66	286.67	**45.79**	**276.66**	**79.00**	**7.96**	**1.52**	**80.85**
1966/67	175.90	**41.56**	**61.34**	**202.00**	**21.98**	**50.90**	**124.38**
1967/68	42.39	**85.26**	**43.84**	**12.00**	**77.36**	**132.16**	**391.73**
1968/69	175.90	**143.58**	**276.66**	**185.00**	**24.53**	**58.35**	**101.10**
1969/70	165.32	**249.32**	**178.90**	**63.00**	**12.70**	**263.86**	**13.89**
1970/71	135.76	**59.71**	**96.29**	**1902.00**	**728.37**	**1128.70**	**2905.00**
1971/72	101.45	**37.36**	**86.77**	**12.00**	**35.66**	**25.75**	**20.96**
1972/73	**149.12**	**110.32**	**99.52**	**89.00**	**7.96**	**39.47**	**98.79**
1973/74	**850.65**	**119.95**	**203.11**	**417.00**	**113.72**	**11.09**	**249.73**
1974/75	**242.14**	**18.86**	**10.14**	**27.00**	**72.17**	**10.37**	**54.00**

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Groot River Catchment - Regions L1 to L7

Primary site	L1H002	L2H003	L2H004	L3R001	L6H002	L6H001	L7H006
River	Sout	Buffels	Buffels	Groot (In)	Heuningklip	Heuningklip	Groot
Catchment area (km^2)	3675	1145	5584	20336	675	1290	29232
Supplementary sites	L1H001	L2H002	L2H001	L3H001			L7H002, L7H004
Hydrological year							
1975/76	398.00	129.86	193.43	356.00	279.41	15.69	164.00
1976/77	149.12	74.65	7.39	105.00	35.66	25.75	519.00
1977/78	42.66	6.12	0.62	32.00	0.04	119.33	18.51
1978/79	0.02	43.23	1.22	6.00	21.37	642.24	674.89
1979/80	0.08		32.37	79.00	3.55	432.31	22.79
1980/81	0.08	83.19	1.76	385.00	85.56	149.36	827.19
1981/82	0.05	14.03	209.57	188.00	44.53	86.02	268.71
1982/83	173.64	43.23	1.22	37.00	15.29	1.19	893.00
1983/84	33.48				120.95	0.93	14.35
1984/85	173.64	18.86		15.00	31.67	58.71	40.87
1985/86	521.80	30.09		88.00	65.99	98.71	191.00
1986/87	21.81	2.87		6.00		11.05	9.96
1987/88	2238.00	89.81		862.00		68.81	580.12
1988/89		21.91		52.00		19.73	19.95
1989/90		48.69		49.00		38.28	333.33
1990/91		11.32					0.29
1991/92		55.94				15.75	11.12
1992/93		0.79				139.06	468.07
1993/94				216.00		187.26	192.34
1994/95				96.00		63.59	413.18
1995/96				34.00		64.67	34.06
1996/97				89.00		104.27	846.01
1997/98				254.00		5.90	41.80
1998/99				63.00			34.42
1999/00						237.28	1077.51
2000/01						34.51	161.85
Correlation-r^2							
Multiplier-linear							
Site							

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Gamtoos & Kouga River Catchments - Regions L8, L9

Primary site	L8H001	L8H002	L8H005	L8R001	L9H003	L9R001
River	Wabooms	Haarlem	Kouga	Kouga (In)	Gamtoos	Loerie
Catchment area (km^2)	21	52	1303	3887	33296	147
Supplementary sites					L9H001	
Hydrological year						
1847/48					2786	
1853/54						
1863/64					2451	
1866/67					7475	
1874/75					1306	
1896/97						
1904/05					3505	
1906/07						
1908/09						
1911/12						
1915/16					4386	
1916/17						
1917/18						
1918/19						
1919/20						
1920/21						
1921/22					4071	
1922/23						
1923/24						
1924/25						
1925/26						
1926/27						
1927/28						
1928/29						
1929/30						
1930/31						
1931/32			3033.86	5240.00	5333	
1932/33					202	
1933/34					118	
1934/35					401	
1935/36					89	
1936/37					31	
1937/38					484	
1938/39					346	
1939/40					155	
1940/41					66	
1941/42					161	
1942/43					37	
1943/44					732	
1944/45					77	
1945/46					37	
1946/47					66	
1947/48					84	
1948/49					46	
1949/50					1461	
1950/51					484	
1951/52					801	
1952/53					320	
1953/54					256	
1954/55					158	
1955/56					202	
1956/57					31	
1957/58					57	
1958/59					31	
1959/60					158	
1960/61					1717	
1961/62				5.00	193	
1962/63				9.00	305	
1963/64				231.00	439	
1964/65	9.99			2.00	122	
1965/66	35.53			16.00	98	
1966/67	21.60			114.00	133	
1967/68	51.66			700.00	1232	
1968/69	34.37			60.00	51	
1969/70	4.75	22.92		28.00	12	4.10
1970/71	28.85	102.18		1696.00	3374	49.00
1971/72	7.27	48.74		114.00	49	7.50
1972/73	4.24	11.79		11.00	27	4.00
1973/74	201.21	52.68		721.00	755	30.00
1974/75	19.17	18.98		103.00	67	41.00

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Gamtoos & Kouga River Catchments - Regions L8, L9

Primary site	L8H001	L8H002	L8H005	L8R001	L9H003	L9R001
River	Wabooms	Haarlem	Kouga	Kouga (In)	Gamtoos	Loerie
Catchment area (km^2)	21	52	1303	3887	33296	147
Supplementary sites					L9H001	
Hydrological year						
1975/76	10.95	14.00		*29.00*	*98*	6.40
1976/77	93.69	34.14		168.00	*515*	1820.00
1977/78	5.13	25.18			*19*	9.10
1978/79	129.75	38.89		998.00	*1347*	595.00
1979/80	7.91	6.80		*24.00*	*24*	11.00
1980/81	160.93	224.22		2885.00	*3070*	2514.00
1981/82	240.52	86.53		906.00	*927*	45.00
1982/83	145.54	146.16		2518.00	*2815*	496.00
1983/84	27.55	23.64		*105.00*	*36*	48.00
1984/85	10.74	3.17			*41*	5.10
1985/86	34.39	37.72		61.00	*148*	8.70
1986/87	29.87	39.19		*29.00*	*29*	14.00
1987/88	6.61	21.34			*580*	4.10
1988/89	8.80	6.13			*20*	1.80
1989/90	64.83	129.11	36.93	578.00	*704*	177.00
1990/91	8.18	3.56	12.60		*0*	2.70
1991/92	77.15	1.96	77.04		*11*	19.00
1992/93	64.83	60.29	262.91	638.00	*869*	178.00
1993/94	21.65	9.71	34.28	*64.00*	*151*	36.00
1994/95	27.99	20.29	24.68	*39.00*	*317*	28.00
1995/96	41.35	28.13	53.75	*58.00*	*12*	13.00
1996/97	229.02	90.75	1706.51	*3056.00*	*3230*	272.00
1997/98	21.98	11.92	45.49		*42*	18.00
1998/99	32.81	3.83	20.24		*34*	8.40
1999/00	19.80	5.03	43.62	*81.00*	*913*	37.00
2000/01	118.98	26.56	96.01	*72.00*	*132*	54.00
Correlation-r^2						
Multiplier-linear						
Site				Outflows	L7H006 & L8R001	

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Swartkops River Catchment - Region M1

Primary site	**M1H004**	**M1R001**	**M1H012**
River	**Elands**	**Swartkops**	**Swartkops**
Catchment area (km^2)	**400**	**261**	**906**
Supplementary sites		M1H001	
Hydrological year			
1847/48			
1853/54			**1410.00**
1863/64			
1866/67			
1874/75			**1116.00**
1896/97			
1904/05			**1312.00**
1906/07			
1908/09			
1911/12			**1813.00**
1915/16			
1916/17			
1917/18			
1918/19			**1451.00**
1919/20			
1920/21			
1921/22			
1922/23			
1923/24			
1924/25			
1925/26			
1926/27		33.90	
1927/28		795.60	**768.00**
1928/29		62.47	
1929/30		4.49	
1930/31			
1931/32			**1639.00**
1932/33			
1933/34			
1934/35			
1935/36			
1936/37			
1937/38			
1938/39		**8.58**	
1939/40		**1.6**	
1940/41		**17**	
1941/42		**3.2**	
1942/43		**3.4**	
1943/44		**199**	**1529.00**
1944/45		**2.8**	
1945/46		**11**	
1946/47			
1947/48		**65**	
1948/49		**9.8**	
1949/50		**114**	
1950/51		**62**	
1951/52		**130**	
1952/53		**1.81**	
1953/54		**326**	
1954/55		**23**	
1955/56		**5.3**	
1956/57		**184**	
1957/58		**31**	
1958/59		**3.9**	
1959/60		**0.5**	
1960/61		**2.4**	
1961/62		**1**	
1962/63		**78.7**	
1963/64		**78.7**	
1964/65		**1.09**	
1965/66	**80.58**	**17.77**	*75.00*
1966/67	**134.00**	**60.88**	*151.00*
1967/68	**550.59**	**103.56**	*600.00*
1968/69	**0.75**	**0.29**	*1.00*
1969/70		**0.2**	
1970/71	**702.54**	**564.97**	**1218.00**
1971/72	**0.90**	**0.29**	*1.00*
1972/73		**0.2**	
1973/74	**196.38**	**48.55**	*198.00*

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Swartkops River Catchment - Region M1

Primary site	**M1H004**	**M1R001**	**M1H012**
River	**Elands**	**Swartkops**	**Swartkops**
Catchment area (km^2)	**400**	**261**	**906**
Supplementary sites		M1H001	
Hydrological year			
1974/75	**16.77**	**40.87**	*35.00*
1975/76	**1.60**	**3.35**	*4.00*
1976/77	**1061.74**	**30.2**	*1066.00*
1977/78	**2.05**	**0.1**	
1978/79	**764.83**	**610.02**	**2041.00**
1979/80	**0.80**	**0.61**	*1.00*
1980/81	**1802.28**	**311.38**	**2130.00**
1981/82		**3.91**	
1982/83	**670.62**	**390**	**1525.00**
1983/84		**16**	
1984/85		**16**	
1985/86		**26**	
1986/87	**0.60**	**1.5**	
1987/88	**8.78**	**42**	*22.00*
1988/89		**0.6**	
1989/90	**285.61**	**195**	*396.00*
1990/91			
1991/92		**1.3**	
1992/93	**595.75**	**118**	*643.00*
1993/94	**9.97**	**12**	*10.00*
1994/95	**95.09**	**21**	**98.53**
1995/96	**3.31**	**0.5**	**2.60**
1996/97	**1347.65**	**86**	**1424.18**
1997/98	**7.63**	**11**	**10.13**
1998/99	**1.52**	**0.9**	**1.18**
1999/00	**95.55**	**83**	**146.72**
2000/01	**95.24**	**6.7**	**34.01**
2001/02		**128**	
Correlation-r^2			
Multiplier-linear			
Site			**M1H004 & M1R001**

Note:	**1260.78**	Systematic site data
	1260.78	Systematic supplementary site data
	1260.78	Historic and palaeoflood data
	1260.78	Correlated data
	1260.78	Correlated historic and palaeoflood data

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Sundays River Catchment - Region N

Primary site	**N1R001**	**N2H007**	**N2H008**	**N3H002**	**N2R001**
River	**Sundays**	**Sundays**	**Riet**	**Voel**	**Sundays**
Catchment area (km^2)	**3681**	**13428**	**341**	**1744**	**16826**
Supplementary sites	N1H001	N2H002		N3H001	N4H001, N4H002
Hydrological year					
8000BP		***4256.00***			**13300.00**
7100BP		***1961.60***			**6130.00**
1847/48					
1853/54					
1863/64					
1866/67		**1935.36**			***2266.80***
1874/75		**2183.38**			***2549.50***
1888/89					
1892/93					
1896/97					
1904/05	54.29				
1905/06	897.27				
1906/07	225.81				
1907/08	89.70				
1908/09	121.77				
1909/10	366.87				
1910/11	40.76				
1911/12					
1914/15					54.45
1915/16					2260.00
1916/17					775.10
1917/18					619.52
1918/19					159.73
1919/20					1619.90
1920/21					189.74
1921/22	207.89	**1358.63**		**447.20**	3732.58
1922/23	173.59				
1923/24	566.39	299.65			
1924/25		159.79			
1925/26	**12.00**	36.38			
1926/27	**1481.00**	36.38			
1927/28	**933.00**	1655.18		219.17	**3964.00**
1928/29	**236.00**	287.29		62.36	
1929/30	**220.00**	186.33		129.11	
1930/31	**1167.00**	240.95		129.11	
1931/32	**1852.13**	1141.92		985.02	**5402.00**
1932/33	**173.00**	159.79		129.11	
1933/34	**328.00**	462.11		151.55	
1934/35	**198.00**	109.46		129.11	
1935/36	**80.00**	159.79		93.07	
1936/37	**299.00**	240.95		203.62	
1937/38	**288.00**	577.46		129.11	
1938/39	**230.00**	287.29		93.07	
1939/40	**272.00**	364.41		345.32	
1940/41	**91.00**	159.79		38.22	
1941/42	**107.00**	1885.91		1138.95	*3630.00*
1942/43	**76.00**	159.79		52.00	
1943/44	**452.00**	159.79		537.16	
1944/45	**88.00**	94.64		27.36	
1945/46	**112.00**	240.95		22.68	
1946/47	**37.00**	263.64		79.44	
1947/48	**740.00**	544.23		288.81	
1948/49	**84.00**	109.46			
1949/50	**421.00**	511.95			
1950/51	**270.00**	198.39			
1951/52	**260.00**	391.93			
1952/53	**71.00**	68.28			
1953/54	**73.00**	577.46			
1954/55	**150.00**	219.11			
1955/56	**14.00**	198.39			
1956/57	**79.00**	240.95			
1957/58	**14.00**	68.28			
1958/59	**11.00**	29.50			
1959/60		125.19			
1960/61	**1554.00**	1123.27			
1961/62	**39.00**	142.04			
1962/63	**316.00**	165.35			
1963/64	**24.00**	100.43			
1964/65	**36.00**	27.92			

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Sundays River Catchment - Region N

Primary site	**N1R001**	**N2H007**	**N2H008**	**N3H002**	**N2R001**
River	**Sundays**	**Sundays**	**Riet**	**Voel**	**Sundays**
Catchment area (km^2)	**3681**	**13428**	**341**	**1744**	**16826**
Supplementary sites	N1H001	N2H002		N3H001	N4H001, N4H002
Hydrological year					
1965/66	**31.00**	94.64			
1966/67	**76.00**	58.86			
1967/68	**43.00**	391.93			
1968/69	**96.00**	94.64			
1969/70	**782.00**	263.64			
1970/71	**340.00**	1438.86			**5319.00**
1971/72	**21.00**	27.92			
1972/73	**113.00**	68.28			
1973/74	**3116.00**	1655.18			
1974/75	**40.00**	4.93			
1975/76	**195.00**	218.41			
1976/77		1602.81			
1977/78		**1.68**		**0.67**	
1978/79	**13.00**	**74.78**	**39.63**	**277.19**	
1979/80	**1.00**	**14.14**	**3.28**	**23.04**	
1980/81	**143.00**	**56.83**	**7.86**	**58.25**	
1981/82	**9.30**	**21.34**	**4.59**	**11.45**	
1982/83	**282.00**	**301.08**	**71.80**	**497.78**	**1267.00**
1983/84	**52.00**	**37.79**	**10.02**	**27.19**	
1984/85	**92.00**	**36.81**	**4.17**	**124.35**	**455.00**
1985/86	**269.00**	**230.05**	**59.86**	**310.47**	
1986/87	**22.00**	**0.01**	**2.30**	**8.65**	
1987/88	**214.00**	**40.19**	**17.50**	**12.14**	
1988/89	**171.00**	**40.90**	**15.15**	**159.03**	
1989/90	**185.00**	**368.79**	**20.89**	**419.66**	**816.00**
1990/91	**0.70**	**1.36**	**0.00**	**3.33**	
1991/92	**6.30**	**44.39**	**17.64**	**208.21**	
1992/93	**9.40**	**111.88**	**40.50**		
1993/94	**144.00**	**68.64**	**15.15**		
1994/95	**44.00**	**129.87**	**34.26**		
1995/96	**9.80**	**67.65**	**9.35**		
1996/97	**114.00**	**267.39**	**64.40**		
1997/98	**2.00**	**11.68**	**3.18**		
1998/99		**204.43**	**5.03**		
1999/00		**110.54**	**18.36**		
2000/01	**31.00**	**43.10**	**8.21**		
Correlation-r^2		0.85			
Multiplier-linear		0.32			
Site		**N2R001**			

Note:

1260.78 Systematic site data

1260.78 Systematic supplementary site data

1260.78 Historic and palaeoflood data

1260.78 Correlated data

1260.78 Correlated historic and palaeoflood data

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Bushmans, Kariega & Kowie River

Primary site	**P1H003**	**P3H001**	**P4H001**
River	**Boesmans**	**Kariega**	**Kowie**
Catchment area (km^2)	**1479**	**588**	**576**
Supplementary sites			
Hydrological year			
1888/89			**812.22**
1892/93	**1391.35**		
1905/06	**216.71**		
1931/32	**560.76**		
1956/57	**42.18**		
1957/58	**15.36**		
1958/59	**36.30**		
1959/60	**0.83**		
1960/61	**147.16**		
1961/62	**2.21**		
1962/63	**19.01**		
1963/64	**21.76**		
1964/65	**15.36**		
1965/66	**19.01**		
1966/67	**31.60**		
1967/68	**134.12**		
1968/69	**22.18**		**0.11**
1969/70	**22.85**	**1.66**	**120.21**
1970/71	**279.52**	**684.00**	**843.02**
1971/72	**5.22**	**0.43**	**3.88**
1972/73	**4.44**	**0.00**	**0.05**
1973/74	**166.61**	**1.31**	**490.93**
1974/75	**8.13**	**1.25**	**68.04**
1975/76	**62.47**	**6.00**	**9.55**
1976/77	**17.63**	**17.23**	**248.66**
1977/78	**0.84**	**10.18**	**350.69**
1978/79	**391.33**	**420.53**	**597.98**
1979/80	**6.16**	**0.81**	**1.84**
1980/81	**34.66**	**50.91**	**94.67**
1981/82	**51.41**	**0.53**	**18.97**
1982/83	**407.56**	**60.41**	**4.35**
1983/84	**9.55**	**0.26**	**3.80**
1984/85	**0.05**	**0.01**	**0.00**
1985/86	**31.19**	**31.40**	**475.62**
1986/87	**0.08**	**1.00**	**7.94**
1987/88	**18.98**	**2.31**	**8.18**
1988/89	**12.29**	**1.41**	**0.47**
1989/90	**201.31**	**152.58**	**674.46**
1990/91	**0.01**	**0.03**	**0.06**
1991/92	**0.06**	**0.01**	**1.03**
1992/93	**0.03**	**6.07**	**1.05**
1993/94	**15.87**	**2.92**	**8.56**
1994/95	**45.40**	**218.24**	**241.93**
1995/96	**11.06**	**0.00**	**0.57**
1996/97	**84.67**	**19.65**	**51.55**
1997/98	**0.07**	**1.79**	**1.03**
1998/99	**6.64**	**1.30**	**7.92**
1999/00	**14.96**	**0.00**	**7.83**
2000/01	**36.67**	**4.56**	**27.87**
Correlation-r^2			
Multiplier-linear			
Site			

Note:	**1260.78**	Systematic site data
	1260.78	Systematic supplementary site data
	1260.78 (underlined)	Historic and palaeoflood data
	1260.78 (underlined)	Correlated data
	1260.78 (underlined)	Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Great Fish River - Regions Q1, Q2, Q3, Q7 & Q9

Primary site	**Q2H002**	**Q1H001**	**Q3H005**	**Q7H005**	**Q9H012**	**Q9H018**
River	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**
Catchment area (km^2)	**1713**	**9091**	**10830**	**19134**	**23067**	**29745**
Supplementary sites	Q2H001	-	Q3H003	Q7H001 Q7H002 Q7H003 Q7H004	Q9H001 Q9H003	Q9H006 Q9H010
Hydrological year						
1818/19				***5498.90***	*7788.64*	**7090.00**
1845/46				**4035.53**	**2762.00**	**3423.00**
1847/48				***1950.01***	**2762.00**	**2590.00**
1869/70				***1588.40***	*2249.81*	**2048.00**
1871/72				***2579.60***	*3653.74*	**3326.00**
1872/73				***817.47***	*1157.86*	**1054.00**
1874/75	**1475.20**			**6679.64**	**9147.00**	**7214.00**
1875/76				***1802.46***	*2553.00*	**2324.00**
1898/99				**4628.62**		
1900/01					**4233.00**	***3853.30***
1904/05						
1905/06				***3482.07***	**4932.00**	***4489.60***
1906/07				564.83	800.03	*728.26*
1907/08				209.80	297.16	*270.50*
1908/09				603.57	854.90	*778.21*
1909/10				1383.18	1959.14	*1783.41*
1910/11				2832.00	4011.24	*3651.44*
1911/12				150.38	213.00	*193.89*
1912/13				1383.18	**1287.00**	*1171.56*
1913/14				643.27	*911.13*	*829.40*
1914/15				422.84	*598.91*	*545.18*
1915/16				643.27	*911.13*	*829.40*
1916/17				955.61	**996.00**	*906.66*
1917/18	*1224.86*	**1394.62**		2689.39	**4446.00**	*4047.19*
1918/19	*44.34*	**50.48**		116.03	*164.35*	*149.60*
1919/20	*302.14*	**344.02**		1004.84	*1423.26*	*1295.59*
1920/21	*449.67*	**511.99**		1441.69	*2042.01*	*1858.84*
1921/22	*178.91*	**203.71**		603.57	*854.90*	*778.21*
1922/23	*204.71*	**233.08**		643.27	*911.13*	*829.40*
1923/24	*178.91*	**203.71**		177.42	*251.30*	*228.76*
1924/25	*449.67*	**511.99**		527.56	*747.23*	*680.21*
1925/26	*14.16*	**16.12**		98.66	*139.74*	*127.20*
1926/27	20.96	**122.22**		146.42	95.00	*86.48*
1927/28	198.52	**167.57**		214.02	3297.00	*3001.26*
1928/29	518.26	**511.99**		201.56	235.00	215.00
1929/30	208.15	**253.67**		177.42	495.00	704.00
1930/31	430.46	**437.42**		143.28	235.00	266.00
1931/32	1557.60	**1515.81**		4616.00	5943.00	6156.00
1932/33	174.17	**335.72**		201.56	539.00	345.00
1933/34	390.82	**597.67**	302.60	1052.00	1159.00	831.00
1934/35	232.22	**245.26**	145.85	318.00	882.00	441.00
1935/36	14.73	**36.86**	37.81	123.00	**48.16**	46.00
1936/37	232.22	**204.45**	160.86	189.36	**188.12**	131.00
1937/38	739.15	**549.81**	216.51	495.26	**1434.61**	1783.00
1938/39	801.46	**672.47**	267.06	710.97	**1089.45**	660.00
1939/40	82.13	**119.29**		727.00	**1025.97**	869.00
1940/41	286.03	**204.45**		337.21	**217.45**	114.00
1941/42	166.89	**196.65**		461.99	**2457.32**	1448.00
1942/43	147.12	**152.51**		127.00	**105.37**	122.00
1943/44	835.92	**609.89**		2245.00	**5102.00**	5458.00
1944/45	286.03	**245.26**		143.28	**143.61**	56.00
1945/46	136.46	**145.60**		338.00	**963.10**	475.00
1946/47	286.03	**609.89**		291.00	**291.64**	106.00
1947/48	52.98	**426.76**		239.71	**1089.45**	2136.00
1948/49	*25.80*	**29.38**		14.00	**65.51**	24.00
1949/50	*1346.97*	**1533.66**		2459.00	**2325.19**	1478.00
1950/51	*238.17*	**271.18**		125.00	**407.29**	556.00
1951/52	*193.58*	**220.41**		95.00	**291.64**	145.00
1952/53	*245.96*	**280.05**		58.00	**63.41**	194.00
1953/54	*208.02*	**236.85**		1403.00	**3415.69**	4755.00
1954/55	*146.42*	**166.71**		9.00	**48.16**	21.00
1955/56	*110.37*	**125.67**		40.00	**54.33**	*49.46*
1956/57	*311.94*	**355.18**		597.00	**1025.97**	*933.94*
1957/58	*146.42*	**166.71**		49.00	**188.12**	132.54
1958/59	*68.98*	**78.54**		23.00	**143.61**	89.44
1959/60	*88.69*	**100.98**		72.00	**95.42**	48.94
1960/61	*269.96*	**307.37**		202.00	**236.08**	112.83
1961/62	*72.63*	**82.70**		307.00	**152.60**	152.59
1962/63	*159.35*	**181.43**		402.00	**286.61**	389.57

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Great Fish River - Regions Q1, Q2, Q3, Q7 & Q9

Primary site	Q2H002	Q1H001	Q3H005	Q7H005	Q9H012	Q9H018
River	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**	**Gt Fish**
Catchment area (km^2)	**1713**	**9091**	**10830**	**19134**	**23067**	**29745**
Supplementary sites	Q2H001	-	Q3H003	Q7H001 Q7H002 Q7H003 Q7H004	Q9H001 Q9H003	Q9H006 Q9H010
Hydrological year						
1963/64	*99.28*	**113.04**		32.00	**58.13**	213.62
1964/65	*68.98*	**78.54**		23.00	**168.80**	82.19
1965/66	*51.34*	**58.45**		151.00	**190.07**	396.76
1966/67	*329.42*	**375.08**		247.00	**287.13**	167.60
1967/68	*230.48*	**262.42**		62.00	**149.06**	183.57
1968/69	*159.35*	**181.43**		141.00	**80.37**	195.00
1969/70	*81.86*	**93.21**		95.00	**287.13**	**2681.38**
1970/71	*127.64*	**145.33**		1181.00	**2906.00**	**2906.00**
1971/72	*68.70*	**78.22**		112.00	**80.37**	**60.42**
1972/73	*164.44*	**187.23**		95.00	**169.20**	**101.00**
1973/74	**1438.78**	**2545.44**	**5700.00**	5765.00	**9231.00**	**9053.37**
1974/75	**89.36**	**88.14**	**150.51**	**45.00**	**58.38**	**114.00**
1975/76	**162.31**	**182.91**	**13.31**	**176.00**	**1328.90**	*1209.70*
1976/77	**157.63**	**105.23**	**39.58**	**76.00**	**370.29**	*337.07*
1977/78	**1.38**	**22.82**	**40.43**	**33.00**	**32.53**	**279.01**
1978/79	**13.08**	**27.64**	**142.19**	**119.00**	**490.06**	**614.83**
1979/80	**105.00**	**56.24**	**109.60**	**24.00**	**13.89**	**20.13**
1980/81	**172.92**	**88.14**	**220.97**	**20.64**	**32.34**	**118.78**
1981/82	**148.43**	**89.98**	**23.37**	**61.12**	**46.46**	**54.65**
1982/83	**186.40**	**115.25**	**494.81**	**475.29**	**1967.90**	**919.12**
1983/84	**14.08**	**26.51**	**443.19**	**247.05**	**84.88**	**144.67**
1984/85	**671.26**	**584.11**	**50.40**	**312.83**	**60.05**	**220.20**
1985/86	**245.26**	**324.86**	**175.11**	**345.35**	**254.59**	**864.27**
1986/87	**26.13**	**40.79**	**374.52**	**33.97**	**31.20**	**88.60**
1987/88	**139.43**	**108.79**	**239.63**	**189.06**	**256.23**	**311.88**
1988/89	**362.41**	**232.67**	**66.82**	**193.04**	**111.88**	**430.22**
1989/90	**149.95**	**172.92**	**39.05**	**381.01**	**1390.00**	**1328.60**
1990/91	**0.85**	**42.27**	**45.02**	**25.43**	**19.96**	**22.36**
1991/92	**33.18**	**46.84**	**190.10**	**165.57**	**117.23**	**280.07**
1992/93	**0.27**	**33.96**	**52.54**	**193.71**	**118.68**	**107.14**
1993/94	**173.97**	*198.08*	**54.23**	**126.79**	**82.21**	**171.66**
1994/95	**0.26**	*0.29*	**94.84**	**692.42**	**1089.08**	**616.57**
1995/96	**50.97**	*58.04*	**60.46**	**66.55**	**34.61**	**160.73**
1996/97	**63.67**	*72.50*	**43.80**	**132.80**	**289.76**	**489.71**
1997/98	**16.88**	*19.22*	**72.20**	**146.84**	**87.92**	**100.92**
1998/99	**2.12**	*2.41*	**124.27**	**49.91**	**32.31**	**87.25**
1999/00	**50.41**	*57.39*	**26.35**	**77.91**	**62.35**	**203.00**
2000/01	**161.70**	*184.11*		**337.66**	**1009.62**	**866.67**
Correlation-r^2	0.81	0.81			0.79	0.88
Multiplier-linear	0.88	1.14			1.42	0.91
Site	*Q1H001*	*Q2H002*			*Q7H005*	*Q9H012*

Note:

1260.78	Systematic site data
1260.78	Systematic supplementary site data
1260.78	Historic and palaeoflood data
1260.78	Correlated data
1260.78	Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Regions Q1, Q3, Q4, Q6 & Q8

Primary site	**Q1R001**	**Q1H013**	**Q1H012**	**Q3H004**	**Q4H004**
River	**Gt Brak**	**Lt Brak**	**Teebus**	**Pauls**	**Tarka**
Catchment area (km^2)	**4324.00**	**2445.00**	**1567.00**	**872**	**671**
Supplementary sites	Q1H002	Q1H003 Q1H008 Q1H010	Q1H006	Q3H001	
Hydrological year					
1918/19					
1919/20					
1920/21	339.84				
1921/22	110.45				
1922/23	201.07				
1923/24					
1924/25	**147.00**				
1925/26	**130.00**				
1926/27	**46.00**	432.94	8.10	41.06	
1927/28	**68.00**	134.04	36.53	49.84	
1928/29	**136.00**	114.14	204.70	149.53	
1929/30	**78.00**	574.11	53.81	54.52	
1930/31	**49.00**	650.82	44.83	23.08	
1931/32	**607.00**	859.29	266.89	283.20	
1932/33	**316.00**	201.65	192.92	24.19	
1933/34	**376.00**	574.11	164.20	215.80	
1934/35	**118.00**	574.11	78.19	34.83	
1935/36	**21.00**	37.76	25.37	11.95	
1936/37	**107.00**	314.20	63.52	65.14	
1937/38	**36.00**	432.94	44.83	283.20	
1938/39	**148.00**	731.42	91.62	149.53	
1939/40	**125.00**	337.92	53.81	53.52	
1940/41	**47.00**	1240.38	57.60	31.72	
1941/42	**176.00**	501.61	96.29	84.96	
1942/43	**93.00**	164.23	53.81	23.08	
1943/44	**304.00**	1189.77	155.14	184.08	
1944/45	**15.00**	65.48	30.67	145.85	
1945/46	**181.00**	0.00	53.81	184.08	
1946/47	**68.00**	574.11	73.92	67.40	
1947/48	**127.00**			132.25	
1948/49	**56.00**				
1949/50	**533.00**				
1950/51	**82.00**				
1951/52	**41.00**				
1952/53	**316.00**				
1953/54	**283.00**				
1954/55	**34.00**				
1955/56	**46.00**				
1956/57	**53.00**				
1957/58	**87.00**				
1958/59	**83.00**				
1959/60	**57.00**				
1960/61	**65.00**				
1961/62	**115.00**				
1962/63	**93.00**				
1963/64	**41.00**				
1964/65	**15.00**				
1965/66	**109.00**				
1966/67	**672.00**				**28.50**
1967/68	**18.00**				**12.30**
1968/69	**44.00**				**22.60**
1969/70	**233.00**				**11.70**
1970/71	**86.00**				**9.85**
1971/72	**46.00**				**7.29**
1972/73	**43.00**				**20.56**
1973/74	**1200.00**			**2500.00**	**170.60**
1974/75	**169.00**				**7.26**
1975/76	**286.00**			**42.26**	**226.47**

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Regions Q1, Q3, Q4, Q6 & Q8

Primary site	**Q1R001**	**Q1H013**	**Q1H012**	**Q3H004**	**Q4H004**
River	**Gt Brak**	**Lt Brak**	**Teebus**	**Pauls**	**Tarka**
Catchment area (km^2)	**4324.00**	**2445.00**	**1567.00**	**872**	**671**
Supplementary sites	Q1H002	Q1H003 Q1H008 Q1H010	Q1H006	Q3H001	
Hydrological year					
1976/77	**111.00**		**10.30**	**14.75**	**76.43**
1977/78	**38.00**		**26.68**	**7.73**	**4.53**
1978/79	**120.00**		**45.26**	**27.65**	**14.15**
1979/80	**45.00**		**41.32**	**0.13**	**4.91**
1980/81	**180.00**		**84.83**	**12.84**	**52.27**
1981/82	**145.00**	**0.01**	**49.03**	**10.10**	**8.28**
1982/83	**371.00**	**0.01**	**62.52**	**90.90**	**45.63**
1983/84	**172.00**	**13.75**	**53.08**	**1.88**	**0.00**
1984/85	**103.00**	**0.03**	**115.97**	**750.87**	**3.81**
1985/86	**88.00**	**77.44**	**84.58**	**81.94**	**169.30**
1986/87	**48.00**	**130.58**	**47.84**	**3.40**	**8.41**
1987/88	**174.00**	**2.79**	**232.45**	**204.42**	
1988/89	**58.00**	**0.10**	**100.30**	**55.45**	
1989/90	**37.00**	**7.39**	**96.31**	**102.10**	
1990/91	**37.00**	**0.02**	**57.83**	**0.52**	
1991/92	**170.00**	**2.30**	**79.32**	**0.60**	
1992/93	**119.00**	**2.15**	**127.74**	**35.63**	
1993/94	**91.00**	**5.34**	**163.60**	**7.95**	
1994/95	**23.00**	**0.40**	**30.11**	**0.49**	
1995/96	**67.00**		**102.27**	**24.00**	
1996/97	**32.00**		**49.40**	**42.22**	
1997/98	**33.00**		**66.54**	**1.47**	
1998/99	**41.00**		**95.90**	**0.48**	
1999/00	**145.00**		**219.91**	**3.40**	
2000/01			**44.64**	**16.43**	
Correlation-r^2					
Multiplier-linear					
Site					

Note:

1260.78	Systematic site data
1260.78	Systematic supplementary site data
<u>1260.78</u>	Historic and palaeoflood data
<u>1260.78</u>	Correlated data
<u>1260.78</u>	Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Regions Q1, Q3, Q4, Q6 & Q8

Primary site	**Q4H003**	**Q4R002**	**Q6H003**	**Q8H010**	**Q8H008**
River	**Vlekpoort**	**Tarka**	**Baviaans**	**Lt Fish**	**Lt Fish**
Catchment area (km^2)	**1300**	**3623**	**814.00**	**808**	**1512**
Supplementary sites	Q4H002		Q6H001 Q6H002	Q8H001 Q8H004 Q8H005	Q8H002
Hydrological year					
1918/19			69.93		
1919/20			720.76		
1920/21			637.95		
1921/22			380.31		
1922/23			134.34	642.86	*759.93*
1923/24			156.42	79.98	*94.54*
1924/25			336.15	140.14	*165.66*
1925/26			17.48	95.72	*113.15*
1926/27			272.97		
1927/28			496.86		
1928/29			737.32		
1929/30			369.27	22.94	*27.11*
1930/31			177.89	243.52	128.57
1931/32			969.19	1555.73	1674.52
1932/33			637.95	22.94	19.41
1933/34			564.34	186.18	152.12
1934/35			69.93	22.94	26.52
1935/36			101.21	22.94	59.77
1936/37			272.97	329.15	197.15
1937/38			177.89	532.29	650.93
1938/39				54.23	106.70
1939/40				38.05	59.77
1940/41				46.03	16.95
1941/42				300.86	232.24
1942/43				22.94	24.82
1943/44				735.43	197.15
1944/45				532.29	134.20
1945/46				228.60	12.40
1946/47				432.01	134.20
1947/48					
1948/49					
1949/50					
1950/51					
1951/52					
1952/53					
1953/54					
1954/55					
1955/56		**33.00**			
1956/57		**221.00**		32.02	*37.85*
1957/58		**53.00**		85.61	30.78
1958/59		**88.00**		23.10	5.17
1959/60	27.50	***29.00***		33.95	72.58
1960/61	74.80	***103.00***		146.66	342.59
1961/62	84.10	***83.00***		80.91	25.12
1962/63	82.50	***158.00***		99.48	338.39
1963/64	12.20	***46.00***		4.23	*5.00*
1964/65	**64.47**	**29.00**		93.44	*110.46*
1965/66	**41.09**	**55.00**		32.02	*37.85*
1966/67	**211.57**	**155.00**		37.94	*44.85*
1967/68	**3.93**	**19.00**		55.73	*65.88*
1968/69	**158.96**	**100.00**		37.94	*44.85*
1969/70	**51.07**	**204.00**		10.25	*12.12*
1970/71	**72.67**	**184.00**		250.57	*296.20*
1971/72	**46.67**	**66.00**		79.05	*93.45*
1972/73	**12.37**	**56.00**		28.31	*33.46*
1973/74	**119.50**	**21.00**	158.73	1485.49	*1755.99*
1974/75	**16.60**	**29.00**	0.05	19.83	*23.44*
1975/76	**68.46**	**367.00**	156.75	113.12	*133.72*
1976/77	**25.35**	**108.00**	30.39	51.88	*61.33*

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Regions Q1, Q3, Q4, Q6 & Q8

Primary site	**Q4H003**	**Q4R002**	**Q6H003**	**Q8H010**	**Q8H008**
River	**Vlekpoort**	**Tarka**	**Baviaans**	**Lt Fish**	**Lt Fish**
Catchment area (km^2)	**1300**	**3623**	**814.00**	**808**	**1512**
Supplementary sites	Q4H002		Q6H001 Q6H002	Q8H001 Q8H004 Q8H005	Q8H002
Hydrological year					
1977/78	**18.36**	**33.00**	9.49	1.46	*1.73*
1978/79	**10.98**		29.68	118.74	**346.75**
1979/80	**40.10**	**37.00**	17.28	10.74	**1.12**
1980/81	**58.77**	**291.00**	**32.89**	51.88	**29.46**
1981/82	**29.17**	**37.00**	**36.27**	37.55	**20.65**
1982/83	**28.04**	**262.00**	**142.72**	195.57	**545.11**
1983/84	**12.30**	**17.00**	**5.16**	25.21	**5.75**
1984/85	**17.11**	**110.00**	**56.52**	44.48	**106.69**
1985/86	**29.94**	**242.00**	**107.77**	44.48	**166.93**
1986/87	**27.67**	**49.00**	**31.42**	46.94	**17.68**
1987/88	**54.53**	**86.00**	**173.08**	**90.84**	**129.75**
1988/89	**23.93**	**42.00**	**81.20**	**124.88**	**101.28**
1989/90	**26.56**	**40.00**	**165.83**	**226.61**	**528.24**
1990/91	**26.20**	**139.00**	**70.42**	**3.82**	**0.54**
1991/92	**20.63**	**24.00**	**220.74**	**29.74**	**24.32**
1992/93		**18.00**	**184.93**	**34.59**	**11.45**
1993/94		**181**	**366.77**	**84.97**	**124.95**
1994/95		**16**	**30.93**	**43.07**	**401.79**
1995/96		**192**	**61.01**	**24.92**	**19.75**
1996/97		**55**	**14.63**	**133.21**	**365.81**
1997/98		**77**	**86.59**	**22.29**	**85.73**
1998/99		**16**	**62.87**	**12.08**	**9.05**
1999/00		**151**	**7.81**	**16.47**	**49.04**
2000/01			**199.72**	**47.55**	**198.57**
Correlation-r^2					0.85
Multiplier-linear					1.1821
Site					**Q8H010**

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Region Q9

Primary site	**Q9H030**	**Q9H002**	**Q9R001**	**Q9H004**	**Q9H011**	**Q9H029**
River	**Koonap**	**Koonap**	**Kat**	**Kat**	**Kat**	**Kat**
Catchment area (km^2)	**246**	**1245**	**258**	**404**	**539**	**1036**
Supplementary sites	Q9H014					Q9H008
Hydrological year						
1874/75		**2655.00**				
1880/81		**680.00**				
1921/22						69.37
1922/23						333.32
1923/24						20.20
1924/25						0.00
1925/26						5.10
1926/27		**67.02**		**20.12**		44.04
1927/28		**243.00**		**55.27**		246.87
1928/29		**332.00**		**0.00**		134.40
1929/30		**1019.00**		**57.91**		115.65
1930/31		**1782.00**		**55.27**	**28.82**	103.37
1931/32		**1019.00**		**252.25**	**171.66**	364.93
1932/33		**113.00**		**34.35**	**13.47**	170.38
1933/34		**273.16**		**124.77**	**86.54**	388.25
1934/35		**135.63**		**144.87**	**122.98**	257.35
1935/36		**18.56**		**5.55**	**0.27**	38.32
1936/37		**97.14**		**24.47**	**67.12**	134.40
1937/38		**1499.60**		**293.85**	**456.29**	257.35
1938/39		**206.27**		**51.94**	**82.91**	103.37
1939/40		**141.55**		**134.65**	**151.14**	103.37
1940/41		**13.65**		**110.70**	**371.29**	42.93
1941/42		**113.00**		**34.35**	**11.72**	57.05
1942/43		**87.12**		**45.67**	**19.39**	37.52
1943/44		**206.27**		**88.80**	**59.72**	141.36
1944/45		**5.03**		**3.48**	**11.72**	18.20
1945/46		**30.16**		**6.76**	**1.26**	27.67
1946/47		**87.12**		**252.25**	**146.07**	170.38
1947/48		**714.65**		**323.39**	**387.95**	493.27
1948/49		**206.27**		**69.29**	**74.68**	41.02
1949/50		**538.76**		**160.76**	**93.04**	134.40
1950/51		**135.63**		**69.29**	**150.36**	170.38
1951/52		**40.31**		**51.94**	**74.68**	103.37
1952/53		**113.00**		**160.76**	**173.46**	93.02
1953/54		**1154.89**		**445.87**	**587.23**	364.93
1954/55		**15.54**		**16.17**	**40.04**	41.02
1955/56		**8.40**		**24.47**	**20.95**	41.02
1956/57		**812.75**		**219.57**	**472.22**	308.18
1957/58		**8.98**		**12.62**	**20.95**	41.02
1958/59		**43.95**		**0.00**	**106.70**	170.38
1959/60		**32.75**		**20.12**	**104.96**	57.05
1960/61		**64.05**		**18.06**		31.52
1961/62		**126.95**		**69.29**		141.36
1962/63		**59.15**		**42.73**		27.67
1963/64	40.62	**108.29**		**183.26**		232.46
1964/65	9.06	**9.56**				22.69
1965/66	0.03	**134.93**				128.85
1966/67	16.66	**46.71**				53.98
1967/68	0.77	**25.00**				77.21
1968/69	6.76	**0.05**				214.09
1969/70	51.17	**197.00**				554.66
1970/71	56.31	**2598.00**	**163.00**			387.19
1971/72	13.12	**29.12**	**39.00**			
1972/73	0.62	**7.34**	**8.00**			
1973/74	74.10	**1587.00**	**192.00**			
1974/75	8.40	**12.53**	**11.00**			
1975/76	73.62	**1758.00**	**294.00**			
1976/77	28.21	**45.71**	**65.00**			
1977/78	14.07	**28.34**	**33.00**			
1978/79	40.24	**19.15**	**72.00**			
1979/80	7.04	**31.36**	**13.00**			
1980/81	19.62	**23.73**	**36.00**			
1981/82	15.18	**6.91**	**12.00**			

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Region Q9

Primary site	Q9H030	Q9H002	Q9R001	Q9H004	Q9H011	Q9H029
River	Koonap	Koonap	Kat	Kat	Kat	Kat
Catchment area (km^2)	246	1245	258	404	539	1036
Supplementary sites	Q9H014					Q9H008
Hydrological year						
1982/83	13.20	11.13	6.00			
1983/84	31.34	12.53	7.00			
1984/85	13.13	17.69	21.00			
1985/86	79.55	269.86	365.00			
1986/87	29.62	43.64	49.00			
1987/88	13.57	15.26	23.00			
1988/89	46.53	15.37	22.00			
1989/90	66.78	276.22	91.00			
1990/91	12.02	6.77	29.00			
1991/92	14.74	30.33	29.00			33.99
1992/93	80.40	0.64	60.00			37.36
1993/94	24.78	36.42	42.00			81.87
1994/95	11.86	40.35	18.00			17.44
1995/96	27.28	50.92	45.00			73.76
1996/97	60.76	100.87	109.00			110.66
1997/98	31.58	19.10	19.00			32.67
1998/99	3.12	5.97	14.00			12.51
1999/00	44.14	78.05				227.80
2000/01	75.58	302.78				149.80
Correlation-r^2						
Multiplier-linear						
Site						

Note:

1260.78 Systematic site data

1260.78 Systematic supplementary site data

1260.78 Historic and palaeoflood data (printed underlined)

1260.78 Correlated data (printed underlined)

1260.78 Correlated historic and palaeoflood data (printed underlined)

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Great Fish River Tributaries- Region Q9

Primary site	**Q9H019**	**Q9H013**	**Q9H017**
River	**Balfour**	**Kap**	**Blinkwater**
Catchment area (km^2)	**76**	**46**	**226**
Supplementary sites	Q9H007		
Hydrological year			
1927/28	42.46		
1928/29	11.37		
1929/30	24.95		
1930/31	11.37		
1931/32	4.16		
1932/33	1.08		
1933/34	6.00		
1934/35	35.17		
1935/36	4.06		
1936/37	3.00		
1937/38	23.58		
1938/39	20.86		
1939/40	3.49		
1940/41	2.48		
1941/42	1.55		
1942/43	1.99		
1943/44			
1944/45			
1945/46			
1946/47			
1947/48			
1948/49			
1949/50			
1950/51			
1951/52			
1952/53			
1953/54			
1954/55			
1955/56			
1956/57			
1957/58			
1958/59			
1959/60			
1960/61			
1961/62			
1962/63		**52.19**	
1963/64		**62.73**	
1964/65		**14.95**	**0.01**
1965/66		**19.97**	**18.04**
1966/67		**41.53**	**1.35**
1967/68		**10.54**	**11.87**
1968/69		**12.99**	**3.90**
1969/70		**127.61**	**54.92**
1970/71		**211.29**	**281.08**
1971/72	**0.77**		**44.99**
1972/73	**7.82**		**1.13**
1973/74	**51.44**		**158.40**
1974/75	**4.12**		**10.65**
1975/76	**90.30**		**218.89**
1976/77	**20.74**		**78.49**
1977/78	**19.73**		**13.44**
1978/79	**10.90**	**0.91**	**34.11**
1979/80	**3.27**	**3.44**	**0.61**
1980/81	**6.47**	**22.84**	**8.65**
1981/82	**3.18**	**2.68**	**0.01**
1982/83	**4.80**	**1.32**	**0.00**
1983/84	**5.11**	**2.56**	**11.87**
1984/85	**5.57**		**1.21**
1985/86	**32.46**	**53.41**	**147.20**
1986/87	**20.03**	**5.17**	**5.50**
1987/88	**12.29**	**6.40**	**1.86**

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Great Fish River Tributaries- Region Q9

Primary site	**Q9H019**	**Q9H013**	**Q9H017**
River	**Balfour**	**Kap**	**Blinkwater**
Catchment area (km^2)	**76**	**46**	**226**
Supplementary sites	Q9H007		
Hydrological year			
1988/89	**18.56**	**0.50**	**5.03**
1989/90	**51.71**	**60.16**	**79.63**
1990/91	**10.38**	**0.08**	**2.64**
1991/92	**12.52**	**2.99**	**2.65**
1992/93	**36.79**		**0.00**
1993/94	**18.70**		**18.61**
1994/95	**4.43**		**0.16**
1995/96	**19.19**		**28.89**
1996/97	**12.10**		**15.93**
1997/98	**37.37**		**1.24**
1998/99	**5.74**		**1.92**
1999/00	**37.63**		**91.45**
2000/01	**20.13**		**28.29**
Correlation-r^2			
Multiplier-linear			
Site			

Note:	**1260.78**	Systematic site data
	1260.78	Systematic supplementary site data
	<u>**1260.78**</u>	Historic and palaeoflood data
	<u>*1260.78*</u>	Correlated data
	<u>***1260.78***</u>	Correlated historic and palaeoflood data

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Kieskamma River Catchment - Region R1

Primary site	R1H014	R1H001	R1H003	R1H005	R1H013	R1H015
River	Tyume	Tyume	Kieskamma	Kieskamma	Kieskamma	Kieskamma
Catchment area (km^2)	70.00	238.00	266.00	482.00	1515.00	2530.00
Supplementary sites		-		R1H017		
Hydrological year						
1874/75			693.00	***966.69***	***1850.52***	***2474.97***
1917/18			584.00	***824.46***	***1601.91***	***2156.80***
1921/22						
1922/23						
1923/24						
1924/25						
1925/26						
1926/27						
1927/28	*3.02*	11.78	6.94	*9.34*	*35.75*	*98.67*
1928/29	*42.75*	166.67	60.14	*80.96*	*309.71*	*854.84*
1929/30	*7.58*	29.54	40.04	*53.90*	*206.21*	*569.15*
1930/31	*13.34*	51.99	80.91	*108.91*	*416.65*	*1150.00*
1931/32	*16.29*	63.51	75.20	*101.23*	*387.28*	*1068.92*
1932/33	*10.57*	41.21	40.04	*53.90*	*206.21*	*569.15*
1933/34	*13.34*	51.99	36.96	*49.76*	*190.35*	*525.40*
1934/35	*16.29*	63.51	32.73	*44.06*	*168.57*	*465.27*
1935/36	*11.11*	43.33	20.63	*27.77*	*106.24*	*293.22*
1936/37	*5.77*	22.49	21.54	*28.99*	*110.92*	*306.16*
1937/38	*14.50*	56.52	32.73	*44.06*	*168.57*	*465.27*
1938/39	*28.48*	111.05	26.62	*35.83*	*137.08*	*378.34*
1939/40	*16.29*	63.51	22.48	*30.27*	*115.79*	*319.59*
1940/41	*13.90*	54.21	32.73	*44.06*	*168.57*	*465.27*
1941/42	*24.86*	96.92	16.56	*22.30*	*85.30*	*235.43*
1942/43	*12.21*	47.60	17.90	*24.10*	*92.19*	*254.45*
1943/44	*16.29*	63.51	20.63	*27.77*	*106.24*	*293.22*
1944/45	*10.57*	41.21	8.24	*11.10*	*42.45*	*117.16*
1945/46	*4.13*	16.09	20.63	*27.77*	*106.24*	*293.22*
1946/47	*36.19*	141.08	24.47	*32.94*	*126.00*	*347.77*
1947/48	*50.61*	197.31	235.67	*317.23*	*1213.59*	*3349.63*
1948/49	*5.34*	20.82	*6.37*	8.57	*32.79*	*90.50*
1949/50	*10.57*	41.21	*16.37*	22.04	240.17	*662.90*
1950/51	*44.45*	173.31	*55.15*	74.23	392.39	*1083.04*
1951/52	*8.53*	33.24	*52.25*	70.33	86.32	*238.24*
1952/53	6.36	22.49	*114.30*	153.86	242.48	*669.26*
1953/54	6.52	150.15	*21.82*	29.37	392.39	*1083.04*
1954/55	9.88	48.08	*18.14*	24.42	17.36	*47.92*
1955/56	4.32	34.05	*21.82*	29.37	31.91	*88.07*
1956/57	7.14	65.46	*87.34*	117.56	445.29	*1229.04*
1957/58	2.42	5.66	*14.72*	19.81	4.93	*13.59*
1958/59	6.71	65.46	*93.15*	125.39	307.27	*848.08*
1959/60	7.50	93.35	*27.94*	37.61	138.27	*381.64*
1960/61	13.83	11.28	*17.93*	24.14	85.17	*235.09*
1961/62	47.03	134.19	*39.57*	53.27	250.23	*690.66*
1962/63	60.70	39.87	*78.87*	106.17	304.78	*841.23*
1963/64	103.82	267.46	*190.35*	256.23	557.19	*1537.91*
1964/65	9.86	16.32	*44.72*	60.20	24.23	*66.87*
1965/66	24.22	25.67	*18.99*	25.56	114.93	*317.23*
1966/67	27.92	33.13	*44.29*	59.61	274.80	*758.47*
1967/68	39.64	42.35	*114.30*	153.86	349.97	*965.96*
1968/69	11.38	25.17	*25.36*	34.14	87.51	*241.55*
1969/70	88.44	433.20	*251.80*	338.94	2771.50	2680.65
1970/71	51.71	153.35	*220.68*	297.05	1413.53	2250.37
1971/72	32.56	48.37	*61.86*	83.28	145.00	915.93
1972/73	10.55	14.36	*15.46*	20.80	31.50	45.48
1973/74	53.30	39.27	*9.08*	12.22	32.54	1402.58
1974/75	18.36	*71.57*	*8.76*	11.79	21.54	54.26
1975/76	56.22	*219.18*	*213.11*	*286.86*	1097.40	2728.19
1976/77	36.05	*140.55*	*14.00*	*18.85*	72.10	880.54
1977/78	27.85	5.96	*13.70*	*18.44*	70.53	856.94

APPENDIX B ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Kieskamma River Catchment - Region R1

Primary site	**R1H014**	**R1H001**	**R1H003**	**R1H005**	**R1H013**	**R1H015**
River	**Tyume**	**Tyume**	**Kieskamma**	**Kieskamma**	**Kieskamma**	**Kieskamma**
Catchment area (km^2)	**70.00**	**238.00**	**266.00**	482.00	**1515.00**	**2530.00**
Supplementary sites		-		R1H017		
Hydrological year						
1978/79	**35.62**	**36.30**	*136.29*	*183.45*	**701.80**	**2398.71**
1979/80	**2.74**	**1.23**	*2.22*	**2.99**	**18.08**	**11.93**
1980/81	**51.44**	*200.55*	*58.26*	**78.43**	**68.52**	**345.60**
1981/82	**21.05**	*82.08*	*7.23*	**9.73**	**16.88**	**12.95**
1982/83	**4.98**	*19.41*	*6.76*	**9.10**	**13.41**	**134.04**
1983/84	**29.01**	*113.09*	*7.07*	**9.52**	**166.14**	**379.29**
1984/85	**31.40**	*122.44*	*15.36*	**20.67**	**62.35**	**66.75**
1985/86	**131.76**	*513.68*	***227.81***	**318.56**	**1156.29**	**3056.90**
1986/87	**28.77**	*112.18*	*19.74*	**26.57**	*58.40*	**161.19**
1987/88	**28.97**	*112.94*	*20.51*	**27.61**	*20.84*	**57.53**
1988/89	**13.61**	*53.08*	*16.01*	**21.55**	*12.03*	**33.20**
1989/90	**54.69**	*213.23*	*113.81*	**153.20**	*1134.33*	**3130.86**
1990/91	**31.12**	*121.33*	*27.10*	**36.48**	*6.31*	**17.41**
1991/92	**22.85**	*89.09*	*12.70*	**17.09**	*73.16*	**201.93**
1992/93	**52.02**	*202.81*	*17.86*	**24.05**	*9.16*	**25.29**
1993/94	**40.61**	*158.31*	*23.91*	**32.19**	*215.03*	**593.51**
1994/95	**15.57**	*60.69*	*25.36*	**34.14**	*168.20*	**464.25**
1995/96	**38.27**	*149.21*	*115.35*	155.27	*165.12*	**455.75**
1996/97	**40.61**	*158.31*	*255.50*	343.93	*573.69*	**1583.44**
1997/98	**16.46**	*64.18*	*54.09*	72.82	*18.67*	**51.53**
1998/99	**10.57**	*41.21*	*12.51*	16.85	*10.33*	**28.51**
1999/00	**127.05**	*495.31*	*143.52*	193.19	*408.43*	**1127.30**
2000/01	**31.90**	*124.35*	**89.38**	120.31	*335.87*	**927.03**
Correlation-r^2	0.58	0.58	SQR	0.75	0.89	0.89
Multiplier-linear	0.26	3.90	0.74	0.26	0.36	2.76
Site	**R1H001**	**R1H014**	**R1H005**	**R1H013**	**R1H015**	**R1H013**

Note:

- **1260.78** Systematic site data
- 1260.78 Systematic supplementary site data
- **1260.78** Historic and palaeoflood data
- *1260.78* Correlated data
- ***1260.78*** Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Buffalo-,Nahoon- and Gqunube River Catchments - Regions R2 & R3

Primary site	R2H001	R2H005	R2H010	R2R001	R2H012	R2H006	R2H007
River	Buffalo	Buffalo	Buffalo	Buffalo	Mgqakwebe	Mgqakwebe	Zele
Catchment area (km^2)	29	411	668	913	15	119	82
Supplementary sites		-		R2H003 R2H002			
Hydrological year							
1847/48		785.00	1072.11	1625.11			
1863/64		412.00	562.69	852.92			
1874/75		595.00	812.62	1231.77			
1905/06		944.00	0.00	1863.70			
1921/22							
1922/23		0.00	0.00	1935.53			
1923/24							
1924/25							
1925/26							
1926/27							
1927/28							
1928/29							
1929/30							
1930/31							
1931/32							
1932/33							
1933/34		0.00	0.00	450.71			
1934/35		0.00	0.00	934.85			
1935/36		0.00	0.00	19.17			
1936/37		0.00	0.00	240.79			
1937/38							
1938/39							
1939/40							
1940/41							
1941/42							
1942/43							
1943/44							
1944/45							
1945/46							
1946/47							
1947/48		947.55	0.00	1658.00	48.90	214.96	164.60
1948/49		1.84	0.00	2.00	0.59	2.58	1.49
1949/50		116.34	0.00	337.00	10.97	48.20	72.01
1950/51		819.93	0.00	434.00	95.02	417.69	134.82
1951/52		0.00	0.00	114.00	4.22	18.53	16.46
1952/53		0.00	0.00	255.00	20.09	88.32	75.99
1953/54		0.00	0.00	1900.00	43.12	189.56	163.09
1954/55		38.99	0.00	76.00	4.86	21.35	18.37
1955/56		11.83	0.00	31.00	3.43	15.06	12.95
1956/57		202.10	0.00	586.00	35.65	156.71	134.82
1957/58		30.44	9.85	19.00	4.60	20.22	17.40
1958/59		81.97	582.05	860.00	22.35	98.25	84.53
1959/60		12.07	14.39	68.00	0.08	98.25	84.53
1960/61		17.00	26.18	36.00	8.62	89.61	77.10
1961/62		62.62	112.01	236.00	10.11	39.42	33.92
1962/63	17.82	123.27	201.47	825.00	14.52	48.20	90.28
1963/64	83.64	233.13	902.27	1673.00	23.73	121.89	133.06
1964/65	3.04	7.74	13.54	22.00	1.19	0.91	12.03
1965/66	7.11	29.02	35.20	249.00	4.00	10.45	8.89
1966/67	12.78	84.40	103.65	191.48	16.07	50.75	39.12
1967/68	10.98	185.88	508.17	1270.00	7.71	77.10	75.27
1968/69	3.56	61.45	57.13	30.00	18.59	40.81	26.85
1969/70	57.41	1516.90	0.00	3494.10	26.38	171.41	137.48
1970/71	52.80	146.93	195.74	1340.90	33.72	139.54	124.56
1971/72	15.65	230.35	359.18	232.98	9.79	85.55	61.93
1972/73	11.80	73.23	19.35	33.00	6.26	14.77	30.34
1973/74	21.24	150.20	0.00	373.02	52.56	29.38	33.11
1974/75	4.41	79.83	30.53	49.00	3.32	60.46	17.88
1975/76	26.79	869.70	447.41	201.00	23.56	50.50	141.51
1976/77	5.68	86.21	76.96	62.00	7.30	14.92	35.46
1977/78	22.19	210.88	38.69	188.00	15.16	77.33	72.29
1978/79	44.62	621.20	0.00	887.00	28.10	126.95	118.93
1979/80	1.43	3.90	5.33	4.00	0.40	2.51	5.60

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Buffalo-,Nahoon- and Gqunube River Catchments - Regions R2 & R3

Primary site	**R2H001**	**R2H005**	**R2H010**	**R2R001**	**R2H012**	**R2H006**	**R2H007**
River	**Buffalo**	**Buffalo**	**Buffalo**	**Buffalo**	**Mgqakwebe**	**Mgqakwebe**	**Zele**
Catchment area (km^2)	**29**	**411**	**668**	**913**	**15**	**119**	**82**
Supplementary sites		-		R2H003 R2H002			
Hydrological year							
1980/81	**18.38**	*0.00*	**134.68**	**202.00**	**19.43**	**46.33**	**10.38**
1981/82	**1.17**	*0.00*	**9.75**	**13.00**	**0.34**	**5.30**	**5.65**
1982/83	**3.40**	*0.00*	**26.12**	**61.00**	**2.75**	**21.29**	18.32
1983/84	**5.93**	*0.00*	**212.02**	**453.00**	**4.28**	**33.83**	29.10
1984/85	**22.53**	*0.00*	**100.45**	**122.00**	**12.27**	**33.41**	28.75
1985/86	**63.03**	*0.00*	**2021.90**	**2849.00**	**25.78**	**150.27**	129.30
1986/87	**6.47**	*0.00*	**89.01**	**142.00**	**11.83**	**29.10**	25.04
1987/88	**20.59**	*0.00*	**158.73**	**283.00**	**12.45**	**49.42**	42.52
1988/89	**5.93**	**57.11**	**94.19**	**109.00**	**5.78**	**24.25**	20.86
1989/90	**17.35**	**584.97**	**967.35**	**1303.00**	**19.43**	**137.88**	118.63
1990/91	**2.53**	**3.29**	**4.62**	**14.00**	**4.12**	**3.48**	3.00
1991/92	**6.97**	**73.08**	**141.64**	**230.00**	**9.56**	**47.57**	40.93
1992/93	**3.32**	**37.27**	**45.79**	**45.00**	**13.10**	**23.85**	20.52
1993/94	**15.27**	**175.89**	**201.10**	**327.00**	**16.65**	**64.35**	55.36
1994/95	**26.75**	**66.50**	**114.12**	**174.00**	**10.65**	**27.02**	23.25
1995/96	**11.80**	**76.22**	**86.04**	**114.00**	**8.27**	**62.01**	53.36
1996/97	**17.82**	**215.10**	**261.51**	**521.00**	**13.45**	**67.78**	58.32
1997/98	**16.15**	**112.07**	**137.91**	**286.00**	13.14	**57.77**	49.70
1998/99	**17.52**	**89.52**	**118.24**	**192.00**	8.03	**35.30**	30.37
1999/00	**29.39**	**359.47**	**230.73**	*0.00*	19.13	**84.08**	72.34
2000/01	**6.79**	**88.85**	**198.87**	*0.00*	11.29	**49.61**	42.69
Correlation-r^2		0.85	0.83	0.83	0.64	0.81	0.81
Multiplier-linear		0.73	0.66	1.52	0.23	1.16	0.86
Site		*R2H010*	*R2R001*	*R2H010*	*R2H006*	*R2H007*	*R2H006*

Note:

1260.78	Systematic site data
1260.78	Systematic supplementary site data
1260.78	Historic and palaeoflood data
1260.78	Correlated data
1260.78	Correlated historic and palaeoflood data

APPENDIX B **ASSEMBLED ANNUAL MAXIMUM FLOOD DATA**

Buffalo-,Nahoon- and Gqunube River Catchments - Regions R2 & R3

Primary site	R2H008	R2H009	R2H015	R2H016	R3H001	R3R001
River	Quencwe	Ngqokweni	Yellowwoods	Zwelitsha	Gqunube	Nahoon
Catchment area (km^2)	61	103	198	7	500	473.00
Supplementary sites			R2H011			
Hydrological year						
1946/47	5.86	7.59	10.24			
1947/48	229.16	254.24	343.09			
1948/49	0.63	0.82	1.10			
1949/50	21.11	10.56	14.26			
1950/51	135.68	175.70	237.11			
1951/52	3.60	4.66	6.29			
1952/53	6.73	8.71	11.76			
1953/54	27.59	35.72	48.21			
1954/55	1.40	0.28	0.37			
1955/56	0.63	6.06	8.17			
1956/57	135.68	199.91	12.70			
1957/58	5.05	0.05	0.28			
1958/59	63.32	136.81	192.83			
1959/60	44.86	0.09	62.84			
1960/61	12.61	0.08	13.59			
1961/62	44.86	58.09	39.69			
1962/63	121.05	0.02	123.29			
1963/64	51.46	293.47	209.67			
1964/65	6.13	0.28	6.13			
1965/66	0.01	0.01	16.31			
1966/67	18.14	22.10	17.51		407.13	662.00
1967/68	26.12	19.28	78.38		177.74	289.00
1968/69	36.81	122.91	131.28		66.42	108.00
1969/70	176.47	422.18	742.74		1374.54	2235.00
1970/71	255.00	265.85	135.29		271.22	441.00
1971/72	70.13	1.83	92.01		110.70	180.00
1972/73	13.40	22.91	94.36		4.47	72.00
1973/74	96.83	66.33	27.92		139.47	111.00
1974/75	7.63	8.79	14.68		48.09	34.00
1975/76	159.84	87.27	204.77		485.60	267.00
1976/77	18.80	58.31	32.63		74.05	318.00
1977/78	82.29	57.79	123.82		170.67	203.00
1978/79	160.17	90.08	402.87		722.51	1129.47
1979/80	0.47	5.53	1.41		1.49	52.52
1980/81	53.78	20.65	27.32		40.84	59.00
1981/82	0.70	3.52	0.27		0.09	6.00
1982/83	22.64	3.66	7.96		190.61	487.00
1983/84	72.15	5.62	38.86		0.75	18.00
1984/85	22.42	6.23	13.85		111.63	130.00
1985/86	159.66	204.99	590.00		278.32	1525.00
1986/87	21.15	21.18	28.59		57.95	119.00
1987/88	68.66	25.63	6.05	3.35	61.28	182.00
1988/89	102.47	2.97	9.34	0.30	8.18	6.00
1989/90	104.69	132.66	321.14	7.25	405.62	780.00
1990/91	1.38	1.30	1.43	0.29	1.60	5.00
1991/92	29.59	24.43	36.39	5.50	54.10	48.00
1992/93	2.14	18.96	10.60	1.47	1.30	4.00
1993/94	70.50	32.88	63.94	5.83	121.07	267.00
1994/95	37.84	32.73	46.04	2.60	199.34	250.00
1995/96	35.23	25.36	50.57	0.36	72.31	174.00
1996/97	82.24	67.78	75.66	4.35	263.93	383.38
1997/98	30.07	46.51	77.08	3.21	129.10	313.18
1998/99	22.69	24.17	62.59	8.46	105.26	111.68
1999/00	149.89	17.72	75.66	1.14	159.09	146.67
2000/01	11.65	84.19	65.81	6.77	107.96	112.36
Correlation-r^2	0.57	0.57	0.53			
Multiplier-linear	0.77	1.30	1.35			
Site	R2H009	R2H008	R2H009			

Note:

1260.78 Systematic site data

1260.78 Systematic supplementary site data

1260.78 Historic and palaeoflood data

1260.78 Correlated data

1260.78 Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Kei River Catchment - Region S

Primary site	**S2H001**	**S3R001**	**S3H002**	**S3H006**	**S3H003**	**S3H004**	**S3H005**
River	**Indwe**	**Klipplaat**	**Klaas Smits**	**Klaas Smits**	**Black Kei**	**Black Kei**	**Oxkraal**
Catchment area (km^2)	**1139**	**603**	**796**	**2170**	**240**	**1413**	**462**
Supplementary sites	S2R001				S3H001		
Hydrological year							
1946/47	**233.53**		**1.93**				
1947/48	**183.60**		**261.13**		28.64		
1948/49	**366.46**		**93.38**				
1949/50	**150.38**		**905.98**		51.65		
1950/51	**121.38**		**71.96**		15.65		
1951/52	**60.60**				1.42		
1952/53	**94.11**						
1953/54	**225.31**				63.60		
1954/55	**165.42**				8.62		
1955/56	**174.51**				28.64		
1956/57	**292.55**		**98.13**		121.16		
1957/58	**303.59**	**4.00**	**98.13**		6.07		
1958/59	**355.13**	**358.00**	**93.38**				
1959/60	**374.39**	**50.00**	**150.71**	**838.63**			
1960/61	**159.00**	**46.00**	**42.47**				
1961/62	**428.00**	**22.00**	**103.22**				
1962/63	**304.00**	**32.00**	**143.90**		**18.44**		
1963/64	**87.90**	**41.00**	**48.91**		**13.89**	**4.11**	**1.19**
1964/65	**178.00**	**12.00**	**52.25**	**10.30**	**2.78**	**92.11**	**77.11**
1965/66	**275.00**	**36.00**	**125.26**	**66.35**	**5.55**	**114.36**	**173.96**
1966/67		**78.00**	**157.53**	**119.57**	**6.55**	**96.96**	**154.64**
1967/68		**102.00**	**55.68**	**113.33**	**23.10**	**8.63**	**49.40**
1968/69	483.00	**5.00**	**179.92**	**136.54**	**6.57**	**347.78**	**225.85**
1969/70	129.00	**168.00**	**113.83**	**224.83**	**5.97**	**425.88**	**372.12**
1970/71	253.00	**315.00**	**424.53**	**145.22**	**37.47**	**216.07**	**301.21**
1971/72	528.00	**46.00**	**98.13**	**117.03**	**4.78**	**49.6**	**85.12**
1972/73	462.00	**5.00**	**26.97**	**74.09**		**107.3**	**98.34**
1973/74	373.00	**507.00**	**542.64**	**107.06**	**57.24**	**222.24**	**179.42**
1974/75	147.00	**6.00**	**19.79**	**9.55**	**0.11**	**24.92**	**120.08**
1975/76	189.00	**533.00**	**271.54**	**298.16**		**159.41**	**476.00**
1976/77	341.00	**63.00**	**422.73**	**340.56**		**89.23**	**229.06**
1977/78	578.00	**23.00**	**19.94**	**41.38**	**5.63**	**33.04**	**55.79**
1978/79	12.00	**103.00**	**34.13**	**80.43**	**8.91**	**47.35**	**77.00**
1979/80	59.00	**48.00**	**26.27**	**43.53**	**0.45**	**79.58**	**53.99**
1980/81	64.00	**29.00**	**41.92**	**58.60**	**2.91**	**88.22**	**30.24**
1981/82		**22.00**	**14.10**	**322.99**	**0.87**	**37.07**	**33.96**
1982/83		**17.00**	**11.64**	**12.68**	**4.77**	**51.06**	**254.63**
1983/84		**11.00**	**20.56**	**44.66**	**1.96**	**97.54**	**27.97**
1984/85		**32.00**	**47.33**	**196.95**	**17.55**	**176.88**	**432.25**
1985/86		**1070.00**	**67.85**	**73.39**	**11.49**	**191.76**	**516.69**
1986/87		**52.00**	**21.73**	**24.02**	**3.15**	**19.48**	**74.86**
1987/88		**17.00**	**86.01**	**66.06**	**0.47**	**62.57**	**36.77**
1988/89		**13.00**	**146.82**	**96.35**	**5.47**	**74.93**	**79.17**
1989/90		**131.00**	**42.77**	**68.77**	**4.81**	**31.97**	**21.74**
1990/91		**18.00**	**22.53**	**22.67**	**2.73**	**112.09**	**27.15**
1991/92		**48.00**	**99.86**	**64.70**	**16.98**	**110.82**	**41.07**
1992/93		**37.00**	**13.58**	**13.23**	**1.91**	**64.19**	**4.35**
1993/94		**26.00**	**13.33**	**73.18**	**26.30**	**142.31**	**60.78**
1994/95		**16.00**	**5.17**	**2.38**	**0.50**	**14.32**	**63.79**
1995/96		**33.00**	**107.86**	**168.42**		**93.02**	
1996/97		**268.00**		**145.37**		**155.76**	
1997/98		**17.00**		**8.13**		**115.23**	
1998/99	49.00	**23.00**		**83.02**		**99.37**	
1999/00				**49.95**		**74.23**	
2000/01				**24.87**		**72.14**	
Correlation-r^2							
Multiplier-linear							
Site							

Note:

1260.78	Systematic site data
1260.78	Systematic supplementary site data
1260.78	Historic and palaeoflood data
1260.78	Correlated data
1260.78	Correlated historic and palaeoflood data

APPENDIX B

ASSEMBLED ANNUAL MAXIMUM FLOOD DATA

Kei River Catchment - Region S

Primary site	S5H002	S6H001	S6H002	S6H003	S7H001	S7H004
River	Tsomo	Kubusi	Kubusi	Toise	Gcuwa	Great Kei
Catchment area (km^2)	2359	90	488	215	724	20174
Supplementary sites						
Hydrological year						
1874/75						10794.00
1930/31						5970.00
1946/47			0.20			
1947/48		139.81	450.10			
1948/49		6.59	2.13			
1949/50		29.41	43.12			
1950/51		15.08	45.39			
1951/52		24.47	35.77		14.84	
1952/53		17.39	52.18		282.14	
1953/54		68.05	339.70		87.15	
1954/55		18.16			104.86	
1955/56		2.33			11.00	
1956/57		63.90	17.16		296.90	
1957/58		2.97	16.13		63.22	
1958/59		13.41	27.75		879.91	2830.00
1959/60		16.65	26.46		12.62	
1960/61		16.40	24.70		77.14	
1961/62		27.98	37.55		22.06	
1962/63		32.23	23.96		79.60	2699.00
1963/64	3.61	51.86	34.61	2.18	93.23	
1964/65	165.50	5.50	6.95	3.28	1.80	
1965/66	248.91	12.23	19.81	6.21	20.82	
1966/67	437.14	0.68	25.85	25.35	28.89	
1967/68	31.57	31.73	47.92	36.67	10.11	
1968/69	236.03	3.66	6.38	7.31	31.27	
1969/70	420.40	77.19	10.91	230.42	66.58	
1970/71	386.52	75.99	137.00	227.02	75.15	
1971/72	1003.14	40.88	121.00	61.26	41.69	
1972/73	53.31	6.90	14.32	20.58	22.63	
1973/74	248.27	34.69	67.63	61.35	60.93	
1974/75	83.44	7.42	14.53	3.03	5.30	
1975/76	2337.30	58.96	313.00	282.20	42.60	
1976/77	1822.75	43.86	57.05	31.63	266.68	
1977/78	41.20	48.62	106.50	51.37	339.24	
1978/79		68.23	191.30	160.57	329.00	
1979/80		1.67	3.35	18.86	7.28	
1980/81	93.50	43.16	66.97	18.43	130.47	
1981/82	17.92	1.92	1.38	1.34	9.40	
1982/83	14.61	4.62	9.09	15.55	73.75	
1983/84	14.61	7.42	11.60	15.95	4.84	
1984/85	246.68	32.15	56.69	68.63	104.22	
1985/86	891.01	166.35	840.00	59.61	9.80	
1986/87	33.77	8.90	27.93	10.61	21.61	
1987/88	93.82	7.58	36.04	44.60	11.57	
1988/89	144.27	8.08	59.49	27.78	32.82	
1989/90	111.20	29.89	100.40	46.50	39.44	
1990/91	81.20	4.53	2.19	30.03		407.26
1991/92	50.14	8.95	2.72	25.47		452.12
1992/93	6.95	1.88	0.50	13.43	27.07	85.14
1993/94	109.73	29.97	2.65	32.33	8.75	446.14
1994/95	232.96	3.60		1.82		263.01
1995/96	933.97	15.37		25.88		502.94
1996/97	117.19	46.11		50.51		701.22
1997/98	291.52	11.32		113.67	199.44	860.06
1998/99	66.77	21.04		20.59	41.94	428.91
1999/00	107.38	29.49		48.44	649.55	1764.29
2000/01	68.33	13.16		52.08	47.56	767.94
Correlation-r^2						
Multiplier-linear						
Site						

Note:

1260.78 Systematic site data
1260.78 Systematic supplementary site data
1260.78 Historic and palaeoflood data
1260.78 Correlated data
1260.78 Correlated historic and palaeoflood data

Appendix C

Catchment Characteristics for Sites Selected

APPENDIX C1: TOPOGRAPHICAL CATCHMENT CHARACTERISTICS - GIS

Station	River	Total Catchment Area (km2)	Perimeter (km)	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Mean Catchment Slope (%)	Standard River Slope - 1085 (m/m)	Stream Length (km)	Mean Annual Precipitation- MAP (mm)
J1H006	Brand	372	106	280	1611	496	14.76	0.0068	28.7	401
J1H010	Touws	2898	327	480	2146	900	13.88	0.0034	121.4	314
J1H012	Groot	5556	459	280	2223	927	15.02	0.0045	178.8	275
J1H015	Bok	9	14	1032	2100	1535	55.33	0.2091	4.6	549
J1H016	Smalblaar	33	26	881	2100	1264	22.72	0.0536	12.9	535
J1H017	Sand	250	73	186	1205	359	11.59	0.0061	30.3	351
J1H018	Touws	5867	476	260	2146	796	14.84	0.0038	173.0	306
J1H019	Groot	12490	699	180	2223	824	14.88	0.0042	216.9	296
J1R003	Buffels	4030	334	580	1720	101	11.68	0.0052	105.7	262
J1R004	Brand	251	80	330	1611	543	16.50	0.0151	27.9	452
J2H005	Huis	265	83	458	2320	984	30.99	0.0369	24.3	356
J2H006	Boplaas	26	27	458	1920	961	28.19	0.0786	10.3	378
J2H007	Joubert	37	30	478	1869	870	27.12	0.0920	11.0	361
J2R006	Gamka	17081	772	368	2320	832	8.26	0.0045	211.1	222
J3H002	Traka	3011	310	684	1726	897	6.32	0.0039	107.9	225
J3H005	Klip	93	48	460	1313	694	24.96	0.0139	17.1	653
J3H012	Groot	687	145	460	2058	1028	24.46	0.0156	55.6	370
J3H014	Grobbelaars	150	56	540	2106	977	32.13	0.0257	20.0	443
J3H016	Wilge	33	31	660	1916	1170	38.04	0.0688	13.4	506
J3H017	Kandalaars	348	87	280	1399	552	18.30	0.0120	32.4	454
J3H020	Meul	35	28	600	2040	873	19.49	0.0661	11.8	426
J3R001	Kammanasie	1526	266	344	1930	779	18.91	0.0055	110.3	537
J3R002	Olifants	5229	461	433	2080	899	11.75	0.0034	174.8	307
J4H002	Gourits	43500	1406	120	1493	460	13.14	0.0031	334.2	293
J4H003	Weyers	94	48	104	1040	440	28.92	0.0210	18.4	555
J4H004	Langtou	101	48	104	1040	440	25.23	0.0207	21.1	500
K3H001	Kaaimans	47	38	79	1535	536	39.99	0.0228	21.4	758
K3H002	Rooi	1	5	360	922	591	6.17	0.2707	2.1	850
K3H003	Maalgate	142	53	132	1420	366	17.07	0.0151	20.1	801
K3H004	Malgas	34	27	201	1492	601	39.67	0.0478	10.7	797
K3H005	Touws	78	42	140	1188	569	35.46	0.0283	18.1	670
K4H001	Hoekraal	112	52	20	1480	442	26.11	0.0216	25.1	762

APPENDIX C1: TOPOGRAPHICAL CATCHMENT CHARACTERISTICS - GIS

Station	River	Total Catchment Area (km2)	Perimeter (km)	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Mean Catchment Slope (%)	Standard River Slope - 1085 (m/m)	Stream Length (km)	Mean Annual Precipitation-MAP (mm)
K4H002	Karatara	23	20	251	1367	655	42.32	0.0581	8.0	850
K4H003	Diep	72	37	220	1100	535	26.87	0.0223	15.4	686
K5H001	Gouna	86	48	84	910	339	18.06	0.0252	14.7	850
K5H002	Knysna	142	61	203	1435	592	30.84	0.0196	24.7	791
K6H001	Keurbooms	161	66	320	1440	709	30.75	0.0155	31.6	667
K6H002	Keurbooms	760	187	20	1595	586	33.24	0.0086	71.7	716
K7H001	Bloukrans	59	40	60	1638	534	37.10	0.0318	18.5	845
K8H001	Kruis	26	25	221	1300	669	50.60	0.0404	11.5	800
K8H002	Elands	35	30	223	1202	582	20.87	0.0330	10.7	797
L1H002	Sout	3664	334	1020	1840	1331	8.33	0.0051	81.9	300
L2H003	Buffels	1161	169	1191	2181	1522	11.52	0.0076	41.4	390
L2H004	Buffels	5627	432	955	2181	1312	7.72	0.0034	125.7	326
L3R001	Groot	20580	817	792	1965	1087	5.16	0.0023	264.2	225
L6H001	Heuningklip	1293	200	480	1325	724	6.19	0.0044	70.2	283
L6H002	Heuningklip	677	130	606	983	751	2.57	0.0109	27.5	295
L7H006	Groot	29491	1179	100	2181	985	7.54	0.0021	499.6	286
L8H005	Kouga	1627	252	480	1325	848	29.91	0.0057	97.1	572
L8R001	Kouga	3890	395	100	2181	794	31.15	0.0032	189.6	521
L9H003	Gamtoos	34063	1356	40	2181	948	10.52	0.0023	531.5	317
L9R001	Loerie	145	62	38	820	305	19.35	0.0201	17.8	646
M1H004	Elands	393	125	80	1193	467	21.18	0.0086	66.5	540
M1H012	Swartkops	918	154	40	1370	450	23.53	0.0076	78.8	527
M1R001	Swartkops	264	95	137	1370	602	33.03	0.0100	55.5	506
N1R001	Sundays	3668	297	778	2474	1397	14.66	0.0093	101.0	400
N2H007	Sundays	13438	620	280	2474	945	9.48	0.0041	297.7	350
N2H008	Riet	344	103	260	920	599	9.67	0.0091	59.3	368
N2R001	Sundays	16828	733	238	2474	884	9.63	0.0038	326.8	355
N3H002	Voel	1585	233	340	2040	848	13.65	0.0052	119.5	401
P1H003	Bushmans	1476	231	281	960	561	12.50	0.0034	84.3	492
P3H001	Kariega	578	137	80	820	374	11.42	0.0040	90.6	522
P4H001	Kowie	576	120	41	840	349	12.69	0.0056	83.7	549
Q1H001	Great Fish	9085	554	980	2373	1349	8.40	0.0037	143.4	399

APPENDIX C1: TOPOGRAPHICAL CATCHMENT CHARACTERISTICS - GIS

Station	River	Total Catchment Area (km2)	Perimeter (km)	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Mean Catchment Slope (%)	Standard River Slope - 1085 (m/m)	Stream Length (km)	Mean Annual Precipitation-MAP (mm)
Q1H012	Teebus	1571	186	1120	2080	1383	8.45	0.0050	53.9	437
Q1H013	Little Brak	2457	292	1060	2280	1378	8.76	0.0045	112.3	383
Q1R001	Great Brak	4325	381	1051	2080	1330	7.23	0.0177	97.9	416
Q2H002	Great Fish	1714	267	980	2373	1428	11.84	0.0070	94.2	395
Q3H004	Pauls	877	148	922	2120	1430	17.21	0.0107	67.2	400
Q3H005	Great Fish	10837	570	900	2373	1473	9.10	0.0038	176.5	397
Q4H003	Vlakpoort	1310	217	1120	2120	1350	7.34	0.0040	86.7	427
Q4H004	Tarka	664	119	1146	2352	1543	19.41	0.0085	54.4	498
Q4R002	Tarka	3622	355	1002	2352	1392	12.21	0.0037	113.0	459
Q6H003	Baviaans	809	143	640	1920	1205	24.52	0.0128	60.3	496
Q7H005	Great Fish	19240	865	421	2373	1265	11.43	0.0023	416.5	418
Q8H008	Little Fish	1506	220	680	2000	1227	16.87	0.0058	111.3	446
Q8H010	Little Fish	807	133	987	2000	1361	16.98	0.0106	42.8	413
Q9H002	Koonap	1249	184	565	2360	1151	23.21	0.0089	82.2	543
Q9H004	Kat	406	107	600	1960	1054	21.22	0.0130	29.0	707
Q9H011	Kat	542	119	560	1960	1025	21.76	0.0132	34.1	697
Q9H012	Great Fish	23071	971	302	2373	1197	11.45	0.0021	507.0	422
Q9H013	Kap	45	38	260	840	482	19.90	0.0199	20.9	550
Q9H017	Blinkwater	228	69	480	1380	819	20.48	0.0270	16.0	579
Q9H018	Great Fish	29748	1056	40	2373	1084	12.27	0.0018	683.8	445
Q9H019	Balfour	76	37	620	1820	1019	28.45	0.0540	12.1	723
Q9H029	Kat	1037	167	440	1960	888	20.30	0.0157	72.5	632
Q9H030	Koonap	251	84	1000	2315	1448	27.14	0.0405	20.1	626
Q9R001	Kat	259	79	748	1960	1103	20.09	0.0171	17.2	738
R1H001	Tyume	240	75	540	1800	872	15.95	0.0150	36.6	640
R1H003	Kieskamma	271	74	640	1920	981	22.84	0.0172	22.9	787
R1H013	Kieskamma	1524	202	264	1920	719	15.24	0.0043	114.2	625
R1H014	Tyume	71	37	702	1800	1205	22.02	0.1004	10.1	797
R1H015	Kieskamma	2521	295	20	1920	571	14.40	0.0028	231.3	578
R2H001	Buffalo	29	23	540	1340	954	24.09	0.1083	5.8	1000
R2H005	Buffalo	415	103	360	1340	621	12.48	0.0063	35.0	744
R2H006	Mgqakwebe	121	62	400	1260	588	10.76	0.0102	31.1	752

APPENDIX C1: TOPOGRAPHICAL CATCHMENT CHARACTERISTICS - GIS

Station	River	Total Catchment Area (km2)	Perimeter (km)	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Mean Catchment Slope (%)	Standard River Slope - 1085 (m/m)	Stream Length (km)	Mean Annual Precipitation- MAP (mm)
R2H007	Zele	84	41	460	920	617	11.25	0.0177	17.1	660
R2H008	Quencwe	62	37	460	1120	718	16.54	0.0234	16.8	810
R2H009	Mgqokweni	80	40	381	620	519	5.99	0.0079	20.4	500
R2H010	Buffalo	674	139	320	1340	566	10.04	0.0052	49.2	655
R2H012	Mgqakwebe	16	17	560	1260	756	19.98	0.0320	5.7	968
R2H015	Yellowwoods	203	87	320	900	547	7.41	0.0075	44.9	620
R3H001	Gqunube	507	121	200	860	540	11.84	0.0069	67.0	634
R3R001	Nahoon	472	110	143	720	421	8.73	0.0071	61.3	629
S2H001	Indwe	1137	188	1040	2100	1379	12.42	0.0051	92.7	582
S3H002	Klaas Smits	809	150	1220	2085	1500	11.16	0.0056	47.4	500
S3H003	Black Kei	324	92	1320	2341	1697	15.71	0.0112	46.9	514
S3H004	Black Kei	1409	224	1034	2341	1393	11.16	0.0069	118.5	503
S3H005	Oxkraal	469	103	1060	1895	1378	16.02	0.0064	48.7	518
S3H006	Klaas Smits	2186	229	1060	2120	1396	11.38	0.0038	98.0	502
S3R001	Klipplaat	602	131	1180	2000	1481	16.65	0.0048	60.6	638
S5H002	Tsomo	2373	358	780	2502	1323	16.18	0.0028	192.5	670
S6H001	Kubusi	91	44	800	1660	1042	14.46	0.0153	20.0	768
S6H002	Kubusi	488	111	660	1660	883	10.18	0.0030	80.3	691
S6H003	Toise	216	67	760	1456	1006	14.29	0.0091	41.0	635
S7H001	Gcuwa	724	135	540	1200	849	9.91	0.0044	76.4	611
S7H004	Great Kei	18799	790	160	2502	1191	14.43	0.0033	410.3	563

APPENDIX C2: VEGETATION TYPES

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Vegetation Types						
				Karoo & Karroid Types	False Karoo Types	False Sclerophyllous & Sclerophyllous Bush Types	Pure & False Grassveld Types	False Bushveld Types	Temparate and Transitional Forest and Scrub Types	Coastal Tropical Forest Types & Tropical Bush and Savanna Types (Bushveld)
J1H006	Brand	372	401	71		29				
J1H010	Touws*	2898	314	31	37	32				
J1H012	Groot*	5556	275	66	21	13				
J1H015	Bok*	9	549			100				
J1H016	Smalblaar*	33	535		34	66				
J1H017	Sand	250	351	90		10				
J1H018	Touws*	5867	306	45	25	31				
J1H019	Groot	12490	296	58	21	22				
J1R003	Buffels	4030	262	68	29	4				
J1R004	Brand*	251	452	57		43				
J2H005	Huis*	265	356	43		57				
J2H006	Boplaas*	26	378	41		60				
J2H007	Joubert*	37	361	61		39				
J2R006	Gamka	17081	222	87	8	5				
J3H002	Traka	3011	225	93		7				
J3H005	Klip*	93	653	1	15	64				21
J3H012	Groot*	687	370	56		45				
J3H014	Grobbelaar	150	443	31	29	40				
J3H016	Wilge	33	506	8		92				
J3H017	Kandelaars	348	454	40	26	28				5
J3H020	Meul*	35	426	43	23	34				
J3R001	Kammanas	1526	537	11	32	55				2
J3R002	Olifants	5229	307	72	10	18				
J4H002	Gourits	43500	293	69	13	17				
J4H003	Weyers	94	555			77			23	
J4H004	Langtou*	101	500			85			15	
K3H001	Kaaimans	47	758			7				93
K3H002	Rooi*	1	850							100
K3H003	Maalgate	142	801						37	63
K3H004	Malgas	34	797			6			1	93
K3H005	Touws	78	670			5				95
K4H001	Hoekraal	112	762			5				95
K4H002	Karatara	23	850							100
K4H003	Diep*	72	686			12				88
K5H001	Gouna*	86	850							100
K5H002	Knysna	142	791			1				99
K6H001	Keurbooms	161	667			81				19
K6H002	Keurbooms	760	716			17				83
K7H001	Bloukrans	59	845							100
K8H001	Kruis	26	800			6				94
K8H002	Elands	35	797			17				83
L1H002	Sout	3664	300	98	2					
L2H003	Buffels	1161	390		57		42			

APPENDIX C2: VEGETATION TYPES

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Vegetation Types						
				Karoo & Karroid Types	False Karoo Types	False Sclerophyllous & Sclerophyllous Bush Types	Pure & False Grassveld Types	False Bushveld Types	Temparate and Transitional Forest and Scrub Types	Coastal Tropical Forest Types & Tropical Bush and Savanna Types (Bushveld)
L2H004	Buffels	5627	326	37	51		11			
L3R001	Groot	20580	225	79	17		4			
L6H001	Heuningkli	1293	283	97		3				
L6H002	Heuningkli	677	295	100						
L7H006	Groot	29491	286	82	12	3	3			
L8H005	Kouga	1627	572			92				8
L8R001	Kouga	3890	521	16	1	79				3
L9H003	Gamtoos+c	34063	317	73	11	13	2			
L9H003	Gamtoos	34063	317	73	11	13	2			
L9R001	Loerie	145	646	1		99				
M1H004	Elands*	393	540	34		66				
M1H012	Swartkops*	918	527	28		72				
M1R001	Swartkops*	264	506	11		89				
N1R001	Sundays	3668	400	7	31		62			
N2H007	Sundays	13438	350	50	27		23			
N2H008	Riet*	344	368	100						
N2R001	Sundays	16828	355	52	29		19			
N3H002	Voel	1585	401	36	57		8			
P1H003	Bushmans*	1476	492	14	55	31				
P3H001	Kariega*	578	522	25		26				49
P4H001	Kowie*	576	549	29		38				33
Q1H001	Great Fish	9085	399		76		24			
Q1H012	Teebus	1571	437		70		30			
Q1H013	Little Brak	2457	383		72		28			
Q1R001	Great Brak	4325	416		77		23			
Q2H002	Great Fish	1714	395		69		31			
Q3H004	Pauls*	877	400	2	50		48			
Q3H005	Great Fish	10837	397		74		26			
Q4H003	Vlekpoort	1310	427		81		19			
Q4H004	Tarka	664	498		13		63	1	24	
Q4R002	Tarka	3622	459		58		37	1	4	
Q6H003	Baviaans	809	496	4	35		43	8	10	
Q7H005	Great Fish	19240	418	2	69		26	1	2	
Q8H008	Little Fish	1506	446	2	15		65	8	6	4
Q8H010	Little Fish	807	413	1	18		81			
Q9H002	Koonap	1249	543	8				30	62	
Q9H004	Kat	406	707	38				24	38	
Q9H011	Kat	542	697	47				18	35	
Q9H012	Great Fish	23071	422	4	65		27	1	2	
Q9H013	Kap*	45	550	1		99				
Q9H017	Blinkwater*	228	579	29				9	62	
Q9H018	Great Fish	29748	445	12	53		22	7	5	1
Q9H019	Balfour*	76	723	76					24	

APPENDIX C2: VEGETATION TYPES

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Vegetation Types						
				Karoo & Karroid Types	False Karoo Types	False Sclerophyllous & Sclerophyllous Bush Types	Pure & False Grassveld Types	False Bushveld Types	Temparate and Transitional Forest and Scrub Types	Coastal Tropical Forest Types & Tropical Bush and Savanna Types (Bushveld)
Q9H029	Kat	1037	632	47				21	32	
Q9H030	Koonap	251	626	1				3	96	
Q9R001	Kat	259	738	31				30	39	
R1H001	Tyume	240	640	7				33	60	
R1H003	Keiskamma	271	787	21					79	
R1H013	Keiskamma	1524	625	33				30	37	
R1H014	Tyume	71	797	1					99	
R1H015	Keiskamma	2521	578	42				26	22	9
R2H001	Buffalo*	29	1000						100	
R2H005	Buffalo	415	744	19					40	42
R2H006	Mgqakweb	121	752	10					46	45
R2H007	Zele	84	660	14					26	61
R2H008	Quencwe*	62	810	14					61	24
R2H009	Mgqokwen	80	500	17						83
R2H010	Buffalo	674	655	27					25	48
R2H012	Mgqakweb	16	968						100	
R2H015	Yellowwoo	203	620	4					8	89
R2R001	Buffalo	923	645	22					20	58
R3H001	Gqunube	507	634	10					23	67
R3R001	Nahoon	472	629	25						75
S2H001	Indwe	1137	582				41	26	32	
S3H002	Klaas Smit	809	500				30	70		
S3H003	Black Kei*	324	514				65	5	30	
S3H004	Black Kei	1409	503				34	59	7	
S3H005	Oxkraal	469	518				41	44	15	
S3H006	Klaas Smit	2186	502				22	78		
S3R001	Klipplaat	602	638				10	24	65	
S5H002	Tsomo	2373	670				18		82	
S6H001	Kubusi	91	768						100	
S6H002	Kubusi	488	691	6					94	
S6H003	Toise	216	635						100	
S7H001	Gcuwa	724	611	3					97	
S7H004	Great Kei	18799	563	10			13	38	39	

APPENDIX C3: SOIL TEXTURE (TYPES)

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Soil Type						
				Loamy Sand-Sandy Loam (BC)	Sandy Loam (B/C)	Loamy Sand (C)	Sand-Loamy Sand (C)	Sandy Clay Loam-Sandy Clay (D)	Sandy Clay Loam (D)	Sandy Loam-Sandy Clay Loam (D)
J1H006	Brand	372	401	58			42			
J1H010	Touws*	2,898	314	80			20			1
J1H012	Groot*	5,556	275	16			20			64
J1H015	Bok*	9	549	100						
J1H016	Smalblaar*	33	535	100						
J1H017	Sand	250	351	26			74			
J1H018	Touws*	5,867	306	78			22			1
J1H019	Groot	12,490	296	50			21			29
J1R003	Buffels	4,030	262				12			88
J1R004	Brand*	251	452	39			61			
J2H005	Huis*	265	356	24			76			
J2H006	Boplaas*	26	378				100			
J2H007	Joubert*	37	361				100			
J2R006	Gamka	17,081	222	9		63	10			17
J3H002	Traka	3,011	225	2		55	43			
J3H005	Klip*	93	653				99		1	
J3H012	Groot*	687	370				100			
J3H014	Grobbelaars	150	443				100			
J3H016	Wilge	33	506				100			
J3H017	Kandelaars*	348	454				100			
J3H020	Meul*	35	426				100			
J3R001	Kammanasie	1,526	537				80		20	
J3R002	Olifants	5,229	307	22		32	47			
J4H002	Gourits	43,500	293	23		29	32		1	15
J4H003	Weyers	94	555	65			35	0		
J4H004	Langtou*	101	500	49			51			
K3H001	Kaaimans	47	758	31			69			
K3H002	Rooi*	1	850	100						
K3H003	Maalgate	142	801	86			14			
K3H004	Malgas	34	797	55			45			
K3H005	Touws	78	670	15			85			
K4H001	Hoekraal	112	762	58			42			
K4H002	Karatara	23	850	29			71			
K4H003	Diep*	72	686	14			86			
K5H001	Gouna*	86	850	100						
K5H002	Knysna	142	791	43			57			
K6H001	Keurbooms*	161	667				100			
K6H002	Keurbooms	760	716	29			71			
K7H001	Bloukrans	59	845	100						
K8H001	Kruis	26	800	39			61			
K8H002	Elands	35	797	32			68			
L1H002	Sout	3,664	300	100						
L2H003	Buffels	1,161	390	100						

APPENDIX C3: **SOIL TEXTURE (TYPES)**

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Soil Type						
				Loamy Sand-Sandy Loam (BC)	Sandy Loam (B/C)	Loamy Sand (C)	Sand-Loamy Sand (C)	Sandy Clay Loam-Sandy Clay (D)	Sandy Clay Loam (D)	Sandy Loam-Sandy Clay Loam (D)
L2H004	Buffels	5,627	326	94		6				
L3R001	Groot	20,580	225	48		49	3			
L6H001	Heuningklip	1,293	283				100			
L6H002	Heuningklip	677	295				100			
L7H006	Groot	29,491	286	43		35	21	1		
L8H005	Kouga	1,627	572	1			66	33		
L8R001	Kouga	3,890	521				85	1	14	
L9H003	Gamtoos	34,063	317	37		30	29	1	2	
L9R001	Loerie	145	646	33			67			
M1H004	Elands*	393	540	17			83			
M1H012	Swartkops*	918	527	27			58	15		
M1R001	Swartkops*	264	506				51	49		
N1R001	Sundays	3,668	400	95			5			
N2H007	Sundays	13,438	350	37		1	62			
N2H008	Riet*	344	368				100			
N2R001	Sundays	16,828	355	32		1	65	3		
N3H002	Voel	1,585	401	27		73				
P1H003	Bushmans*	1,476	492					100		
P3H001	Kariega*	578	522					43	57	
P4H001	Kowie*	576	549					72	28	
Q1H001	Great Fish	9,085	399	49				51		
Q1H012	Teebus	1,571	437					100		
Q1H013	Little Brak	2,457	383	63				37		
Q1R001	Great Brak	4,325	416	21				79		
Q2H002	Great Fish	1,714	395	95				5		
Q3H004	Pauls*	877	400	100						
Q3H005	Great Fish	10,837	397	57				43		
Q4H003	Vlekpoort	1,310	427	51	3			46		
Q4H004	Tarka	664	498	8	92					
Q4R002	Tarka	3,622	459	55	24			21		
Q6H003	Baviaans	809	496	64	36					
Q7H005	Great Fish	19,240	418	56	11		4	28		
Q8H008	Little Fish	1,506	446	86			14			
Q8H010	Little Fish	807	413	100						
Q9H002	Koonap	1,249	543		100					
Q9H004	Kat	406	707	3	97					
Q9H011	Kat	542	697	2	98					
Q9H012	Great Fish	23,071	422	54	10		12	25		
Q9H013	Kap*	45	550					100		
Q9H017	Blinkwater*	228	579		100					
Q9H018	Great Fish	29,748	445	49	19		11	21		
Q9H019	Balfour*	76	723		100					
Q9H029	Kat	1,037	632	6	94					

APPENDIX C3: SOIL TEXTURE (TYPES)

Site	River	Catchment Area (km^2)	Mean Annual Precipitation-MAP (mm)	Soil Type						
				Loamy Sand-Sandy Loam (BC)	Sandy Loam (B/C)	Loamy Sand (C)	Sand-Loamy Sand (C)	Sandy Clay Loam-Sandy Clay (D)	Sandy Clay Loam (D)	Sandy Loam-Sandy Clay Loam (D)
Q9H030	Koonap	251	626		100					
Q9R001	Kat	259	738	5	95					
R1H001	Tyume	240	640	50	50					
R1H003	Keiskamma	271	787		99					1
R1H013	Keiskamma	1,524	625	44	44				1	12
R1H014	Tyume	71	797		100					
R1H015	Keiskamma	2,521	578	32	26				29	12
R2H001	Buffalo*	29	1000							100
R2H005	Buffalo	415	744		1				18	81
R2H006	Mgqakwebe	121	752						27	73
R2H007	Zele	84	660							100
R2H008	Quencwe*	62	810		6					94
R2H009	Mgqokweni*	80	500						82	18
R2H010	Buffalo	674	655		1				44	55
R2H012	Mgqakwebe*	16	968							100
R2H015	Yellowwoods*	203	620						74	26
R2R001	Buffalo	923	645						53	46
R3H001	Gqunube	507	634						87	13
R3R001	Nahoon	472	629						100	
S2H001	Indwe	1,137	582		27			73		
S3H002	Klaas Smits	809	500		92			8		
S3H003	Black Kei*	324	514		100					
S3H004	Black Kei	1,409	503		100					
S3H005	Oxkraal	469	518		100					
S3H006	Klaas Smits	2,186	502		97			3		
S3R001	Klipplaat	602	638		94					6
S5H002	Tsomo	2,373	670		59			41		
S6H001	Kubusi	91	768		12					88
S6H002	Kubusi	488	691		9					91
S6H003	Toise	216	635		23					77
S7H001	Gcuwa	724	611	6	92				2	
S7H004	Great Kei	18,799	563	11	64			13	1	10

APPENDIX C4: BASE GEOLOGY

Site	River	Catchment Area (km^2)	Mean Annual Precipitation- MAP (mm)	Intercalated assemblage- compact sedimentary/ extrusive rocks	Intercalated arenaceous and argillaceous strata	Assemblage of tillite, shale and sandstone	Base Geology Principally arenaceous strata	Compact sedimentary strata	Porous unconsolidated and consolidated sedimentary strata	Acid and intermediate extrusives	Basic / Mafic lavas
J3H002	Traka	3011	225		49	49	1				
J1H006	Brand	372	401		73		27				
J1H010	Touws*	2898	314		88		12				
J1H012	Groot*	5556	275		73	22	5				
J1H015	Bok*	9	549				100				
J1H016	Smalblaar*	33	535		22		78				
J1H017	Sand	250	351		87		13				
J1H018	Touws*	5867	306		87		13				
J1H019	Groot	12490	296		80	10	11				
J1R003	Buffels	4030	262		70	30					
J1R004	Brand*	251	452		61		39				
J2H005	Huis*	265	356		32		66		2		
J2H006	Boplaas*	26	378		6		72		23		
J2H007	Joubert*	37	361				38		62		
J2R006	Gamka	17081	222		84	14	2				
J3H005	Klip*	93	653		14		86				
J3H012	Groot*	687	370		62	8	28		2		
J3H014	Grobbelaars	150	443				40		60		
J3H016	Wilge	33	506		15		85				
J3H017	Kandelaars*	348	454		55		45				
J3H020	Meul*	35	426				27		74		
J3R001	Kammanasie	1526	537		36		64				
J3R002	Olifants	5229	307		46	28	19	5	1		
J4H002	Gourits	43500	293		67	12	15	4	2		
J4H003	Weyers	94	555		36		64				
J4H004	Langtou*	101	500				93		7		
K3H001	Kaaimans	47	758				85		15		
K3H002	Rooi*	1	850				100				
K3H003	Maalgate	142	801				38		19	44	
K3H004	Malgas	34	797				89		11		
K3H005	Touws	78	670				98		2		
K4H001	Hoekraal	112	762				64		24	12	
K4H002	Karatara	23	850				100				
K4H003	Diep*	72	686				100				
K5H001	Gouna*	86	850				100				
K5H002	Knysna	142	791				100				
K6H001	Keurbooms*	161	667				100				
K6H002	Keurbooms	760	716				100				
K7H001	Bloukrans	59	845				100				
K8H001	Kruis	26	800				100				
K8H002	Elands	35	797				100				
L1H002	Sout	3664	300	100							
L2H003	Buffels	1161	390	100							
L2H004	Buffels	5627	326	100							
L3R001	Groot	20580	225	100							

APPENDIX C4: BASE GEOLOGY

Site	River	Catchment Area (km^2)	Mean Annual Precipitation- MAP (mm)	Intercalated assemblage- compact sedimentary/ extrusive rocks	Intercalated arenaceous and argillaceous strata	Assemblage of tillite, shale and sandstone	Base Geology Principally arenaceous strata	Compact sedimentary strata	Porous unconsolidated and consolidated sedimentary strata	Acid and intermediate extrusives	Basic / Mafic lavas
L6H001	Heuningklip	1293	283		28	72					
L6H002	Heuningklip	677	295		40	60					
L7H006	Groot	29491	286		86	11	3	1			
L8H005	Kouga	1627	572				100				
L8R001	Kouga	3890	521				100				
L9H003	Gamtoos+corr (	34063	317		75	9	15	1			
L9H003	Gamtoos	34063	317		75	9	15	1			
L9R001	Loerie	145	646				43	31	26		
M1H004	Elands*	393	540		36		64				
M1H012	Swartkops*	918	527		18		71	11			
M1R001	Swartkops*	264	506				98	2			
N1R001	Sundays	3668	400		100						
N2H007	Sundays	13438	350		93	7					
N2H008	Riet*	344	368		96	4					
N2R001	Sundays	16828	355		89	11					
N3H002	Voel	1585	401		100						
P1H003	Bushmans*	1476	492		74	26					
P3H001	Kariega*	578	522		100						
P4H001	Kowie*	576	549		100						
Q1H001	Great Fish	9085	399		100						
Q1H012	Teebus	1571	437		100						
Q1H013	Little Brak	2457	383		100						
Q1R001	Great Brak	4325	416		100						
Q2H002	Great Fish	1714	395		100						
Q3H004	Pauls*	877	400		100						
Q3H005	Great Fish	10837	397		100						
Q4H003	Vlekpoort	1310	427		100						
Q4H004	Tarka	664	498		100						
Q4R002	Tarka	3622	459		100						
Q6H003	Baviaans	809	496		100						
Q7H005	Great Fish	19240	418		100						
Q8H008	Little Fish	1506	446		100						
Q8H010	Little Fish	807	413		100						
Q9H002	Koonap	1249	543		100						
Q9H004	Kat	406	707		100						
Q9H011	Kat	542	697		100						
Q9H012	Great Fish	23071	422		97	3					
Q9H013	Kap*	45	550		100						
Q9H017	Blinkwater*	228	579		100						
Q9H018	Great Fish	29748	445		95	5					
Q9H019	Balfour*	76	723		100						
Q9H029	Kat	1037	632		100						
Q9H030	Koonap	251	626		100						
Q9R001	Kat	259	738		100						
R1H001	Tyume	240	640		100						

APPENDIX C4: BASE GEOLOGY

Site	River	Catchment Area (km^2)					Base Geology				
			Mean Annual Precipitation-MAP (mm)	Intercalated assemblage-compact sedimentary/ extrusive rocks	Intercalated arenaceous and argillaceous strata	Assemblage of tillite, shale and sandstone	Principally arenaceous strata	Compact sedimentary strata	Porous unconsolidated and consolidated sedimentary strata	Acid and intermediate extrusives	Basic / Mafic lavas
R1H003	Keiskamma	271	787		100						
R1H013	Keiskamma	1524	625		100						
R1H014	Tyume	71	797		100						
R1H015	Keiskamma	2521	578		100						
R2H001	Buffalo*	29	1000		100						
R2H005	Buffalo	415	744		100						
R2H006	Mgqakwebe	121	752		100						
R2H007	Zele	84	660		100						
R2H008	Quencwe*	62	810		100						
R2H009	Mgqokweni*	80	500		100						
R2H010	Buffalo	674	655		100						
R2H012	Mgqakwebe*	16	968		100						
R2H015	Yellowwoods*	203	620		100						
R2R001	Buffalo	923	645		100						
R3H001	Gqunube	507	634		100						
R3R001	Nahoon	472	629		100						
S2H001	Indwe	1137	582		100						
S3H002	Klaas Smits	809	500		100						
S3H003	Black Kei*	324	514		100						
S3H004	Black Kei	1409	503		100						
S3H005	Oxkraal	469	518		100						
S3H006	Klaas Smits	2186	502		100						
S3R001	Klipplaat	602	638		100						
S5H002	Tsomo	2373	670		95						5
S6H001	Kubusi	91	768		100						
S6H002	Kubusi	488	691		100						
S6H003	Toise	216	635		100						
S7H001	Gcuwa	724	611		100						
S7H004	Great Kei	18799	563		99						1

Appendix D

Statistical Properties of Data Series

APPENDIX D STATISTICAL PROPERTIES OF DATA SETS

ANALYSIS OF SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Data: Period Start	Data: Period End	Data: Length (years)	Data (N)	Natural data: Q_{med} (m^3/s)	Natural data: Q_m (m^3/s)	Natural data: SD (m^3/s)	Natural data: COV	Natural data: g (skew)	Log-transformed data: Q_m	Log-transformed data: Q_{ml} (m^3/s)	Log-transformed data: SD	Log-transformed data: COV	Log-transformed data: g (skew)
1	K3H001	Kaaimans	47	758	1960	2001	41	41	23.2	34.3	30.3	0.88	1.02	1.316	20.7	0.419	0.32	-0.23
1	K3H002	Rooi	1	850	1960	2001	41	41	1.3	1.5	1.0	0.67	1.74	0.026	1.1	0.259	10.04	0.08
1	K3H003	Maalgate	142	801	1960	2001	41	41	43.3	70.2	70.9	1.01	1.36	1.640	43.7	0.418	0.26	0.10
1	K3H004	Malgas	34	797	1960	2001	41	41	44.1	59.0	54.5	0.92	2.01	1.619	41.6	0.372	0.23	0.00
1	K3H005	Touws	78	670	1960	2001	41	41	37.1	91.5	168.0	1.84	3.58	1.533	34.1	0.616	0.40	0.18
1	K4H001	Hoekraal	112	762	1959	2001	42	42	39.7	72.6	80.0	1.10	2.15	1.618	41.5	0.494	0.31	-0.18
1	K4H002	Karatara	23	850	1962	2001	39	39	25.4	39.2	41.3	1.05	2.67	1.449	28.1	0.334	0.23	0.70
1	K4H003	Diep	72	686	1960	2001	41	41	9.0	32.0	52.8	1.65	2.86	1.036	10.9	0.687	0.66	-0.04
1	K5H001	Gouna	86	850	1961	1984	23	23	73.7	125.2	124.9	1.00	0.59	1.625	42.1	0.715	0.44	-1.04
1	K5H002	Knysna	142	791	1961	2001	40	40	40.2	82.2	135.5	1.65	3.13	1.566	36.8	0.533	0.34	0.47
1	K7H001	Bloukrans	59	845	1961	2001	40	40	79.2	99.8	82.5	0.83	1.43	1.845	70.1	0.391	0.21	-0.22
1	K8H001	Kruis	26	800	1960	2001	41	41	49.8	57.9	36.9	0.64	0.82	1.672	46.9	0.294	0.18	-0.12
1	K8H002	Elands	35	797	1961	2001	40	40	28.2	61.6	95.0	1.54	3.12	1.483	30.4	0.525	0.35	-0.24
2	J3H012	Groot	687	370	1912	1997	85	83	81.3	175.9	228.4	1.30	1.90	1.803	63.5	0.748	0.42	-0.64
2	J3R001	Kammanas	1526	537	1911	2001	90	84	37.0	166.7	448.0	2.69	4.45	1.576	37.7	0.653	0.41	0.75
2	J3R002	Olifants	5229	307	1923	2001	78	78	197.1	349.2	425.9	1.22	4.03	2.324	211.1	0.459	0.20	-0.37
2	J2H005	Huis	265	356	1954	2001	47	47	7.7	15.1	34.3	2.27	6.03	0.826	6.7	0.524	0.63	0.28
2	J2H006	Boplaas	26	378	1954	2001	47	47	1.6	3.2	6.3	1.94	5.08	0.113	1.3	0.473	4.18	0.15
2	J2H007	Joubert	37	361	1954	2001	47	47	1.1	1.6	1.7	1.09	1.51	-0.107	0.8	0.487	-4.55	-0.24
2	J3H005	Klip	93	653	1925	1947	22	22	29.0	60.7	84.8	1.40	3.03	1.483	30.4	0.542	0.37	-0.17
2	J3H014	Grobbelaa	150	443	1966	2001	35	35	15.8	23.4	23.2	0.99	2.31	1.198	15.8	0.397	0.33	-0.06
2	J3H016	Wilge	33	506	1966	2001	35	35	1.6	4.8	12.4	2.60	4.95	0.010	1.0	0.634	61.74	0.34
2	J3H017	Kandelaars	348	454	1968	2001	33	33	14.6	41.0	65.4	1.60	2.00	0.907	8.1	0.926	1.02	-0.45
2	J3H020	Meul	35	426	1974	2001	27	27	3.3	20.9	39.7	1.90	2.15	0.643	4.4	0.773	1.20	0.58
2	J3H002	Traka	3011	225	1912	1923	11	11	193.4	442.9	501.0	1.13	1.57	2.403	252.8	0.500	0.21	-0.06
2	J4H003	Weyers	94	555	1964	2001	37	37	49.4	68.2	59.9	0.88	1.57	1.662	46.0	0.421	0.25	-0.38
2	J4H004	Langtou	101	500	1966	1997	31	31	5.9	23.0	36.6	1.59	2.45	0.810	6.5	0.783	0.97	-0.07
2	K6H001	Keurbooms	161	667	1961	2001	40	40	6.9	46.7	128.6	2.75	3.93	0.870	7.4	0.811	0.93	0.42
2	K6H002	Keurbooms	760	716	1960	2001	41	41	48.3	184.0	462.5	2.51	3.97	1.619	41.6	0.741	0.46	0.18
2	L8H005	Kouga	1627	572	1989	2001	12	12	44.6	201.2	478.8	2.38	3.35	1.788	61.3	0.568	0.32	1.63
2	L8R001	Kouga (In)	3890	521	1961	2001	40	32	103.0	647.2	851.7	1.32	2.13	2.062	115.3	0.830	0.40	0.04
2	L9R001	Loerie	145	646	1969	2001	32	32	23.5	204.9	540.1	2.64	3.59	1.470	29.5	0.803	0.55	0.83
2	M1H004	Elands	393	540	1965	2001	36	27	95.1	316.0	479.6	1.52	1.74	1.592	39.1	1.164	0.73	-0.28
2	M1R001	Swartkops	264	506	1926	2002	76	66	16.5	79.0	152.2	1.93	3.06	1.115	13.0	0.990	0.89	-0.22
2	M1H012	Swartkops	918	527	1965	2001	36	25	34.0	263.4	680.3	2.58	1.40	1.572	37.3	1.161	0.74	-0.30
5	S2H001	Indwe	1137	582	1946	1981	35	33	207.2	241.2	140.5	0.58	0.56	2.273	187.6	0.262	0.12	-0.46
5	S3R001	Klipplaat	602	638	1958	1999	41	41	34.5	106.7	198.2	1.86	3.45	1.615	41.2	0.568	0.35	0.57
5	S3H002	Klaas Smit	809	500	1959	2001	42	38	72.0	121.1	148.5	1.23	3.49	1.792	62.0	0.465	0.26	-0.20
5	S3H003	Black Kei	324	514	1947	1995	48	39	6.1	16.0	24.2	1.51	2.78	0.812	6.5	0.510	0.63	0.20
5	S3H004	Black Kei	1409	503	1963	2001	38	38	90.7	105.4	86.4	0.82	2.04	1.872	74.5	0.325	0.17	-0.27
5	S3H005	Oxkraal	469	518	1963	1995	32	32	77.1	138.6	142.4	1.03	1.42	1.885	76.7	0.467	0.25	-0.38
5	S5H002	Tsomo	2373	670	1963	2001	38	36	110.5	312.4	506.8	1.62	2.83	2.079	119.9	0.644	0.31	-0.17
5	S6H001	Kubusi	91	768	1947	2001	54	54	17.0	28.9	32.5	1.13	2.34	1.201	15.9	0.495	0.41	-0.23
5	S6H002	Kubusi	488	691	1946	1994	48	46	35.2	84.0	147.6	1.76	3.78	1.489	30.8	0.748	0.50	-0.53
5	S6H003	Toise	216	635	1963	2001	38	38	28.9	51.4	67.4	1.31	2.27	1.410	25.7	0.467	0.33	-0.09
5	S7H001	Gcuwa	724	611	1951	2001	50	45	41.9	106.4	171.6	1.61	3.05	1.637	43.4	0.599	0.37	0.09
5	S7H004	Great Kei	18799	563	1990	2001	11	11	452.1	607.2	442.8	0.73	1.92	2.683	481.7	0.331	0.12	-0.80

APPENDIX D STATISTICAL PROPERTIES OF DATA SETS

ANALYSIS OF SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Data: Period Start	Data: Period End	Data: Period Length (years)	Data (N)	Natural data: Q_{med} (m^3/s)	Natural data: Q_m (m^3/s)	Natural data: SD (m^3/s)	Natural data: COV	Natural data: g (skew)	Log-transformed data: Q_m	Log-transformed data: Q_{ml} (m^3/s)	Log-transformed data: SD	Log-transformed data: COV	Log-transformed data: g (skew)
6	J4H002	Gourits	43500	293	1911	2000	89	45	791.0	1112.4	1942.0	1.75	3.67	2.857	718.8	0.641	0.22	-0.47
6	J2R006	Gamka	17081	222	1923	2000	77	57	214.0	574.7	1018.2	1.77	3.66	2.174	149.3	0.741	0.34	-0.23
6	J1R003	Buffels	4030	262	1922	1991	69	42	86.1	214.1	851.0	3.97	4.45	1.943	87.7	0.708	0.36	0.18
6	J1R004	Brand	251	452	1964	1999	35	22	13.5	34.5	36.5	1.06	0.88	1.263	18.3	0.526	0.42	0.12
6	J1H006	Brand	372	401	1937	1967	30	30	28.9	48.4	44.5	0.92	1.45	1.487	30.7	0.464	0.31	-0.52
6	J1H015	Bok	9	549	1973	2001	28	28	3.3	3.8	2.8	0.72	1.26	0.467	2.9	0.351	0.75	-0.57
6	J1H016	Smalblaar	33	535	1973	2000	27	27	3.9	6.3	6.2	0.98	1.83	0.626	4.2	0.392	0.63	0.17
6	J1H017	Sand	250	351	1980	2000	20	20	25.1	60.6	97.8	1.61	2.93	1.405	25.4	0.588	0.42	0.24
6	J1H010	Touws	2898	314	1938	2001	63	41	27.3	78.4	266.9	3.40	5.97	1.369	23.4	0.493	0.36	0.99
6	J1H018	Touws	5867	306	1938	2001	63	41	37.0	138.0	577.9	4.19	6.16	1.423	26.5	0.556	0.39	0.69
6	J1H012	Groot	5556	275	1963	2000	37	37	27.1	178.9	829.5	4.64	5.99	1.291	19.6	0.754	0.58	0.60
6	J1H019	Groot	12490	296	1963	2000	37	37	68.1	400.0	1801.3	4.50	5.98	1.682	48.1	0.755	0.45	0.47
6	L1H002	Sout	3664	300	1917	1988	71	60	149.1	298.6	406.9	1.36	2.56	2.004	101.0	0.486	0.24	0.16
6	L2H004	Buffels	5627	326	1923	1983	60	49	276.7	425.0	384.5	0.90	0.95	2.238	173.1	0.552	0.25	-1.00
6	L3R001	Groot (In)	20580	225	1916	1999	83	79	109.6	286.6	446.7	1.56	3.61	2.084	121.2	0.613	0.29	-0.19
6	L6H002	Heuningkli	1293	283	1963	1986	23	23	137.4	181.8	155.9	0.86	3.67	1.956	90.3	0.546	0.28	0.30
6	L6H001	Heuningkli	677	295	1927	2001	74	72	35.7	84.3	199.6	2.37	2.41	1.464	29.1	0.514	0.35	-0.51
6	L7H006	Groot	29491	286	1927	2001	74	74	256.0	360.5	445.2	1.23	3.20	2.207	161.1	0.544	0.25	-0.35
6	L9H003	Gamtoos	34063	317	1931	2001	70	70	149.4	529.7	963.3	1.82	3.05	2.188	154.1	0.674	0.31	0.30
6	P1H003	Boesmans	1476	492	1956	2001	45	45	19.0	54.6	101.4	1.86	2.39	1.012	10.3	0.551	0.54	0.41
6	P3H001	Kariega	578	522	1969	2001	32	29	1.7	53.1	154.0	2.90	3.25	0.539	3.5	1.046	1.94	0.30
7	L2H003	Buffels	1161	390	1925	1993	68	65	44.7	76.6	94.9	1.24	2.66	1.621	41.8	0.475	0.29	-0.09
7	N1R001	Sundays	3668	400	1904	2001	97	81	113.0	275.3	483.5	1.76	3.67	1.995	98.9	0.599	0.30	-0.03
7	N2H007	Sundays	13438	350	1921	2001	80	79	159.8	301.0	434.0	1.44	2.35	2.082	120.7	0.537	0.26	-0.07
7	N2H008	Riet	344	368	1978	2001	23	22	15.1	20.6	21.1	1.03	1.31	1.125	13.3	0.451	0.40	0.02
7	N3H002	Voel	1585	401	1921	1992	71	37	129.1	204.6	256.5	1.25	2.29	1.957	90.5	0.539	0.28	-0.31
7	N2R001	Sundays	16828	355	1914	1990	76	15	697.3	1176.4	1899.1	1.61	0.73	2.754	568.0	0.608	0.22	-0.69
7	P4H001	Kowie	576	549	1968	2001	33	32	8.2	132.5	232.0	1.75	1.81	1.098	12.5	1.227	1.12	-0.21
7	Q2H002	Gt Fish	1714	395	1917	2001	84	84	160.5	244.0	315.7	1.29	2.65	2.040	109.6	0.474	0.23	-0.26
7	Q1H001	Gt Fish	9085	399	1917	2001	84	84	177.2	274.6	385.6	1.40	3.69	2.157	143.5	0.452	0.21	0.08
7	Q3H005	Gt Fish	10837	397	1933	2000	67	33	109.6	309.6	975.5	3.15	5.60	2.036	108.5	0.502	0.25	1.09
7	Q7H005	Gt Fish	19240	418	1905	2001	96	96	197.6	547.7	970.0	1.77	3.32	2.349	223.3	0.595	0.25	0.07
7	Q9H012	Gt Fish	23071	422	1905	2001	96	96	286.9	913.2	1528.8	1.67	2.97	2.519	330.1	0.643	0.26	0.12
7	Q9H018	Gt Fish	29748	445	1905	2001	96	96	324.5	905.3	1525.7	1.69	2.99	2.554	357.7	0.618	0.24	0.11
7	Q1R001	Gt Brak	4325	416	1920	2000	80	79	93.0	145.9	176.1	1.21	3.57	1.976	94.5	0.392	0.20	0.32
7	Q1H013	Lt Brak	2457	383	1926	1995	69	35	130.6	284.2	355.0	1.25	1.02	1.316	20.7	0.869	0.66	-0.95
7	Q1H012	Teebus	1571	437	1926	2001	75	46	63.0	85.6	60.0	0.70	1.43	1.829	67.4	0.263	0.14	0.39
7	Q3H004	Pauls	877	400	1926	2001	75	49	41.1	129.2	366.9	2.84	5.95	1.440	27.6	0.888	0.62	-0.67
7	Q4H004	Tarka	664	498	1966	1987	21	20	12.3	43.1	65.5	1.52	1.93	1.110	12.9	0.548	0.49	0.68
7	Q9H030	Koonap	251	626	1963	2001	38	38	22.2	30.4	24.2	0.80	0.72	1.227	16.9	0.337	0.27	-0.04
7	Q9H002	Koonap	1249	543	1926	2001	75	75	59.1	260.9	498.9	1.91	2.81	1.799	63.0	0.814	0.45	-0.53
7	Q9R001	Kat	259	738	1977	1999	22	22	33.0	65.1	86.2	1.33	2.41	1.552	35.6	0.469	0.30	0.44
7	Q9H004	Kat	406	707	1926	1964	38	38	55.3	97.0	105.4	1.09	1.49	1.512	32.5	0.422	0.28	0.03
7	Q9H011	Kat	542		1930	1960	30	30	84.7	137.0	157.8	1.15	1.59	1.778	60.0	0.498	0.28	-0.15
7	Q9H029	Kat	1037	632	1921	2001	80	59	103.4	134.9	127.1	0.94	1.42	1.943	87.8	0.415	0.21	-0.07
7	Q9H019	Balfour	76	723	1927	2001	74	52	11.4	17.0	40.5	2.38	3.30	1.001	10.0	0.549	0.55	0.04
7	Q9H013	Kap	45	550	1962	1992	30	22	11.8	32.6	51.4	1.58	2.49	0.960	9.1	0.731	0.76	-0.11

APPENDIX D STATISTICAL PROPERTIES OF DATA SETS

ANALYSIS OF SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Data				Natural data					Log-transformed data				
					Period			Data (N)	Q_{med} (m^3/s)	Q_m (m^3/s)	SD (m^3/s)	COV	g (skew)	Q_m	Q_{ml} (m^3/s)	SD	COV	g (skew)
					Start	End	Length (years)											
7	Q9H017	Blinkwater	228	579	1964	2001	37	37	10.6	37.4	67.5	1.80	2.29	0.778	6.0	0.813	1.04	-0.16
8	R1H014	Tyume	71	797	1927	2001	74	74	17.4	27.9	26.2	0.94	2.11	1.279	19.0	0.363	0.28	0.08
8	R1H001	Tyume	240	640	1927	2001	74	74	63.5	96.7	100.5	1.04	2.46	1.785	61.0	0.399	0.22	-0.08
8	R1H003	Kieskamma	271	787	1927	2001	74	74	26.0	56.7	65.0	1.15	1.84	1.519	33.0	0.453	0.30	0.20
8	R1H013	Kieskamma	1524	625	1927	2001	74	74	131.5	269.6	423.0	1.57	3.65	2.067	116.6	0.599	0.29	-0.18
8	R1H015	Kieskamma	2521	578	1927	2001	74	74	418.7	697.2	798.4	1.15	1.85	2.521	332.1	0.619	0.25	-0.60
8	R2H001	Buffalo	29	1000	1961	2001	40	40	15.3	18.5	18.6	1.00	1.90	1.068	11.7	0.446	0.42	-0.26
8	R2H005	Buffalo	415	744	1922	2001	79	59	89.2	222.5	346.4	1.56	2.32	1.949	88.9	0.657	0.34	-0.40
8	R2H010	Buffalo	674	655	1922	2001	79	59	136.3	290.9	466.4	1.60	2.69	2.042	110.3	0.690	0.34	-0.45
8	R2R001	Buffalo	923	645	1922	2001	79	59	231.5	473.7	711.7	1.50	2.39	2.257	180.8	0.699	0.31	-0.52
8	R2H012	Mgqakweb	16	968	1947	2001	54	54	11.6	15.7	16.2	1.04	2.76	0.957	9.1	0.372	0.39	-0.14
8	R2H006	Mgqakweb	121	752	1947	2001	54	54	48.8	68.4	70.5	1.03	2.72	1.612	40.9	0.406	0.25	-0.43
8	R2H007	Zele	84	660	1947	2001	54	54	41.7	58.1	46.3	0.80	0.81	1.584	38.4	0.416	0.26	-0.56
8	R2H008	Quencwe	62	810	1946	2001	55	55	30.1	57.1	62.3	1.09	1.36	1.329	21.3	0.720	0.54	-0.86
8	R2H009	Ngqokweni	80	500	1946	2001	55	55	22.1	59.0	88.8	1.50	2.23	1.090	12.3	1.093	1.00	-1.13
8	R2H015	Yellowwoo	203	620	1946	2001	55	55	38.9	92.1	145.0	1.57	2.83	1.465	29.2	0.798	0.54	-0.74
8	R3H001	Gqunube	507	634	1966	2001	35	35	110.7	183.6	271.8	1.48	3.13	1.770	58.9	0.435	0.25	-0.22
8	R3R001	Nahoon	472	629	1966	2001	35	35	174.0	320.8	465.3	1.45	2.82	2.241	174.0	0.681	0.30	-0.68

APPENDIX D STATISTICAL PROPERTIES OF DATA SETS

ANALYSIS OF HISTORICAL AND SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Data				Natural data					Log-transformed data				
					Period			Data (N)	Q_{med} (m^3/s)	Q_m (m^3/s)	SD (m^3/s)	COV	g (skew)	Q_m	Q_{ml} (m^3/s)	SD	COV	g (skew)
					Start	End	Length (years)											
2	J3H012	Groot	687	370	1884	2001	117	84	81	176	237	1.35	1.91	1.803	64	0.75	0.42	-0.63
6	J4H002	Gourits	43500	293	1848	2000	152	48	791	1112	1485	1.33	4.00	2.857	719	0.62	0.22	-0.56
2	J3R002	Olifants	5229	307	1897	2001	104	80	197	349	420	1.20	3.61	2.324	211	0.46	0.20	-0.37
6	J2R006	Gamka	17081	222.2	1921	2000	79	78	214	575	955	1.66	3.51	2.174	149	0.74	0.34	-0.25
6	J1R003	Buffels	4030	262.1	1897	1991	94	43	86	214	648	3.03	6.78	1.943	88	0.64	0.33	0.20
6	L7H006	Groot	29491	285.9	1896	2001	105	74	256	361	531	1.47	3.94	2.207	161	0.55	0.25	-0.27
2	L8H005	Kouga	1627	572.2	1931	2001	70	12	45	201	584	2.90	3.31	1.788	61	0.60	0.34	1.58
2	L8R001	Kouga (In)	3890	521.2	1931	2001	70	33	103	647	1018	1.57	2.53	2.062	115	0.85	0.41	0.06
6	L9H003	Gamtoos	34063	317.2	1847	2001	154	77	149	530	1055	1.99	3.72	2.188	154	0.74	0.34	-0.35
2	M1H012	Swartkops	918	526.9	1853	2001	148	33	34	263	451	1.71	2.34	1.572	37	1.07	0.68	-0.13
7	N2H007	Sundays	13438	349.7	1866	2001	135	79	160	301	480	1.60	2.28	2.082	121	0.55	0.26	-0.02
7	N2R001	Sundays	16828	354.6	1866	1990	124	17	697	1176	994	0.84	1.94	2.754	568	0.42	0.15	-0.30
6	P1H003	Boesmans	1476	491.6	1892	2001	109	45	19	55	155	2.85	6.35	1.012	10	0.54	0.53	0.55
7	P4H001	Kowie	576	549	1888	2001	113	33	8	133	216	1.63	1.80	1.098	13	1.22	1.11	-0.20
7	Q2H002	Gt Fish	1714	394.6	1874	2001	127	85	161	244	321	1.31	2.59	2.040	110	0.48	0.23	-0.25
7	Q3H005	Gt Fish	10837	397.3	1874	2000	126	33	110	310	511	1.65	10.24	2.036	109	0.43	0.21	0.42
7	Q7H005	Gt Fish	19240	417.7	1819	2001	182	103	198	548	1036	1.89	3.70	2.349	223	0.59	0.25	0.16
7	Q9H012	Gt Fish	23071	421.5	1819	2001	182	103	287	913	1462	1.60	3.54	2.519	330	0.62	0.25	0.23
7	Q9H018	Gt Fish	29748	445.3	1905	2001	96	96	324	905	1376	1.52	3.38	2.554	358	0.59	0.23	0.20
7	Q9H002	Koonap	1249	543	1874	2001	127	77	59	261	455	1.74	3.61	1.799	63	0.66	0.36	0.44
8	R1H003	Kieskamma	271	787.2	1874	2001	127	76	26	57	98	1.72	3.77	1.519	33	0.48	0.31	0.36
8	R1H013	Kieskamma	1524	625	1874	2001	127	76	132	270	419	1.56	3.09	2.067	117	0.61	0.29	-0.18
8	R1H015	Kieskamma	2521	578	1874	2001	127	76	419	697	705	1.01	1.94	2.521	332	0.61	0.24	-0.64
8	R2H005	Buffalo	415	743.6	1847	2001	154	63	89	222	249	1.12	3.28	1.949	89	0.60	0.31	-0.57
8	R2H010	Buffalo	674	655	1847	2001	154	63	136	291	336	1.15	3.53	2.042	110	0.60	0.29	-0.31
8	R2R001	Buffalo	923	644.8	1847	2001	154	63	231	474	515	1.09	3.28	2.257	181	0.65	0.29	-0.61
5	S7H004	Great Kei	18799	563.4	1874	2001	127	15	452	607	1098	1.81	7.04	2.683	482	0.27	0.10	1.64

ANALYSIS OF PALAEOFLOOD AND SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Data				Natural data					Log-transformed data				
					Period			Data (N)	Q_{med} (m^3/s)	Q_m (m^3/s)	SD (m^3/s)	COV	g	Q_m	Q_{ml} (m^3/s)	SD	COV	g
					Start	End	Length (years)											
6	J4H002	Gourits	43500	293	-1000	2000	3000	46	791	1112	1995	1.79	4.03	2.857	719	0.64	0.22	-0.46
6	J1R003	Buffels	4030	262.1	-1000	1991	2991	43	86	214	309	1.44	3.02	1.943	88	0.49	0.25	0.07
6	L7H006	Groot	29491	285.9	100	2001	1901	74	256	361	455	1.26	3.36	2.207	161	0.54	0.25	-0.34
7	N2H007	Sundays	13438	349.7	-6000	2001	8001	79	160	301	456	1.52	4.22	2.082	121	0.54	0.26	-0.06
7	N2R001	Sundays	16828	354.6	-6000	1990	7990	17	697	1176	1875	1.59	0.54	2.754	568	0.49	0.18	-0.79

Appendix E

Log-Pearson Derived Flood Growth Curves

APPENDIX E LOG PEARSON TYPE 3 DERIVED FLOOD GROWTH CURVES

ANALYSIS OF SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Q_T/Q_{ml}^{NCAPA} for various return periods -T (year)											
					2	5	10	20	50	100	200	500	1000	2000	5000	10000
1	K3H001	Kaaimans	47	758	1.21	2.66	3.93	5.36	7.53	9.38	11.11	14.40	16.89	19.58	23.45	26.62
1	K3H002	Rooi	1	850	1.24	2.05	2.69	3.36	4.34	5.16	5.94	7.33	8.40	9.56	11.24	12.63
1	K3H003	Maalgate	142	801	1.07	2.43	3.77	5.44	8.28	10.98	13.89	19.62	24.58	30.47	39.88	48.44
1	K3H004	Malgas	34	797	1.00	2.06	3.00	4.09	5.80	7.32	8.85	11.72	14.05	16.66	20.62	24.02
1	K3H005	Touws	78	670	0.96	3.25	6.32	11.06	21.08	32.67	47.29	80.96	115.58	162.38	249.27	340.10
1	K4H001	Hoekraal	112	762	1.03	2.63	4.20	6.13	9.27	12.15	15.00	20.68	25.25	30.40	38.20	44.88
1	K4H002	Karatara	23	850	0.92	1.83	2.78	4.04	6.34	8.73	11.67	17.48	23.22	30.63	43.78	57.03
1	K4H003	Diep	72	686	1.01	3.80	7.54	13.26	24.96	37.97	53.31	88.41	122.15	165.64	241.85	317.02
1	K5H001	Gouna	86	850	1.99	6.10	9.52	12.87	16.97	19.74	21.38	24.96	26.73	28.24	29.89	30.89
1	K5H002	Knysna	142	791	0.91	2.70	5.06	8.75	16.76	26.36	39.34	69.34	102.37	149.27	241.79	344.58
1	K7H001	Bloukrans	59	845	1.03	2.15	3.10	4.15	5.72	7.03	8.26	10.55	12.27	14.12	16.77	18.92
1	K8H001	Kruis	26	800	1.01	1.77	2.36	2.97	3.84	4.54	5.18	6.34	7.19	8.09	9.35	10.37
1	K8H002	Elands	35	797	1.05	2.80	4.55	6.72	10.26	13.50	16.67	23.03	28.09	33.77	42.27	49.51
2	J3H012	Groot	687	370	1.20	4.38	7.81	12.01	18.56	24.12	30.11	38.50	45.12	51.88	60.94	67.81
2	J3R001	Kammanas	1526	537	0.99	3.87	8.85	18.62	45.97	87.46	162.14	355.66	632.51	1110.18	2295.79	3933.17
2	J3R002	Olifants	5229	307	1.07	2.47	3.69	5.05	7.05	8.72	10.50	13.04	15.09	17.25	20.25	22.63
2	J2H005	Huis	265	356	0.94	2.71	4.85	7.98	14.26	21.23	29.89	48.90	68.06	93.50	139.84	187.51
2	J2H006	Boplaas	26	378	1.41	3.59	5.94	9.08	14.76	20.51	27.03	40.45	52.76	67.95	93.44	117.65
2	J2H007	Joubert	37	361	1.35	3.35	5.26	7.54	11.16	14.38	17.48	23.57	28.31	33.56	41.30	47.78
2	J3H005	Klip	93	653	1.04	2.89	4.84	7.35	11.62	15.69	19.85	28.35	35.40	43.55	56.19	67.29
2	J3H014	Grobbelaar	150	443	1.01	2.17	3.21	4.43	6.36	8.07	9.78	13.02	15.63	18.55	22.95	26.71
2	J3H016	Wilge	33	506	1.52	5.47	11.20	20.79	42.87	70.64	108.90	202.32	307.72	460.77	769.89	1120.26
2	J3H017	Kandelaars	348	454	1.44	7.64	16.76	30.70	57.99	86.34	115.05	181.85	237.12	301.57	401.51	488.62
2	J3H020	Meul	35	426	0.84	4.16	10.62	24.33	65.68	132.04	246.84	594.22	1094.47	1981.67	4247.95	7453.24
2	J3H002	Traka	3011	225	1.01	2.64	4.34	6.51	10.24	13.83	17.62	25.28	31.82	39.50	51.66	62.56
2	J4H003	Weyers	94	555	1.06	2.29	3.31	4.41	5.98	7.26	8.38	10.50	11.99	13.54	15.68	17.35
2	J4H004	Langtou	101	500	1.02	4.59	9.93	18.66	37.69	59.99	87.09	152.13	216.77	302.33	456.52	612.49
2	K6H001	Keurbooms	161	667	0.88	4.57	11.72	26.54	69.67	136.21	245.28	565.85	1002.03	1740.42	3521.09	5902.38
2	K6H002	Keurbooms	760	716	0.95	4.13	9.19	18.04	39.20	66.43	103.73	198.11	304.18	458.13	767.74	1116.27
2	L8H005	Kouga	1627	572	0.71	2.40	5.67	13.08	38.53	86.23	189.92	545.33	1196.98	2617.15	7321.96	15884.76
2	L8R001	Kouga (In)	3890	521	0.99	4.97	11.67	23.70	52.83	90.37	140.51	269.57	411.19	613.35	1010.96	1448.04
2	L9R001	Loerie	145	646	0.78	4.21	11.86	30.34	95.69	217.56	463.28	1318.09	2769.92	5732.35	14696.13	29565.67
2	M1H004	Elands	393	540	1.31	11.35	32.74	75.83	187.99	336.97	525.03	1042.48	1580.22	2319.81	3698.64	5127.08
2	M1R001	Swartkops	264	506	1.09	6.95	17.49	36.59	81.88	138.02	206.66	383.18	560.28	797.16	1226.78	1661.92
2	M1H012	Swartkops	918	527	1.99	17.01	48.49	110.93	270.45	478.66	736.78	1438.09	2152.92	3121.77	4897.63	6707.75
5	S2H001	Indwe	1137	582	1.24	1.99	2.48	2.94	3.52	3.94	4.34	4.85	5.23	5.59	6.06	6.40
5	S3R001	Klipplaat	602	638	0.88	2.85	5.67	10.39	21.44	35.68	57.92	106.70	166.41	256.26	446.05	671.08
5	S3H002	Klaas Smit	809	500	1.17	2.82	4.36	6.20	9.10	11.69	14.63	19.09	22.94	27.20	33.52	38.85
5	S3H003	Black Kei	324	514	1.35	3.73	6.49	10.36	17.79	25.69	36.16	55.11	74.39	99.11	142.36	185.14
5	S3H004	Black Kei	1409	503	1.19	2.18	2.93	3.71	4.78	5.63	6.52	7.74	8.70	9.70	11.06	12.13
5	S3H005	Oxkraal	469	518	1.23	2.87	4.30	5.91	8.28	10.24	12.35	15.35	17.76	20.30	23.82	26.61

APPENDIX E LOG PEARSON TYPE 3 DERIVED FLOOD GROWTH CURVES

ANALYSIS OF SYSTEMATIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Q_T/Q_{ml}^{NCAPA} for various return periods -T (year)											
					2	5	10	20	50	100	200	500	1000	2000	5000	10000
5	S5H002	Tsomo	2373	670	1.04	3.52	6.49	10.65	18.34	26.16	36.01	52.71	68.57	87.63	118.45	146.62
5	S6H001	Kubusi	91	768	1.11	2.80	4.44	6.41	9.57	12.40	15.64	20.58	24.84	29.58	36.61	42.54
5	S6H002	Kubusi	488	691	0.90	3.39	6.25	9.94	16.05	21.58	27.84	37.14	44.91	53.23	65.01	74.44
5	S6H003	Toise	216	635	1.28	3.13	4.95	7.19	10.89	14.33	18.38	24.79	30.53	37.12	47.27	56.15
5	S7H001	Gcuwa	724	611	0.98	3.17	5.93	10.02	18.20	27.21	39.44	62.05	85.49	115.92	169.82	223.68
5	S7H004	Great Kei	18799	563	1.11	1.92	2.43	2.88	3.40	3.74	4.05	4.41	4.65	4.86	5.11	5.28
6	J4H002	Gourits	43500	293	0.86	2.71	4.65	7.04	10.88	14.27	18.06	23.65	28.30	33.28	40.35	46.04
6	J2R006	Gamka	17081	222	1.18	4.72	9.41	16.33	29.78	43.95	62.27	94.04	124.77	162.20	223.49	280.05
6	J1R003	Buffels	4030	262	1.33	5.41	11.60	22.10	46.41	76.84	122.75	218.45	329.19	487.02	798.04	1141.63
6	J1R004	Brand	251	452	0.98	2.75	4.80	7.65	13.03	18.67	26.05	39.16	52.28	68.82	97.20	124.75
6	J1H006	Brand	372	401	1.10	2.50	3.66	4.89	6.61	7.97	9.36	11.23	12.67	14.12	16.05	17.50
6	J1H015	Bok	9	549	1.08	2.00	2.65	3.27	4.07	4.65	5.21	5.92	6.44	6.94	7.57	8.03
6	J1H016	Smalblaar	33	535	0.98	2.12	3.23	4.61	6.92	9.13	11.80	16.18	20.24	25.07	32.82	39.89
6	J1H017	Sand	250	351	0.95	3.07	5.84	10.10	19.07	29.43	44.11	72.74	103.95	146.35	225.59	308.99
6	J1H010	Touws	2898	314	1.11	3.16	6.11	11.22	23.78	40.90	69.20	136.01	224.12	366.22	693.32	1115.54
6	J1H018	Touws	5867	306	1.31	4.18	8.37	15.56	32.97	56.12	93.38	178.22	285.89	453.36	821.47	1275.21
6	J1H012	Groot	5556	275	0.84	4.01	10.04	22.65	60.13	119.55	230.13	526.34	961.49	1727.56	3668.50	6393.85
6	J1H019	Groot	12490	296	0.87	4.10	9.96	21.62	54.23	102.95	181.29	404.04	700.71	1193.90	2359.97	3892.58
6	L1H002	Sout	3664	300	1.67	4.37	7.34	11.37	18.80	26.42	35.18	53.41	70.35	91.50	127.38	161.87
6	L2H004	Buffels	5627	326	1.93	4.62	6.56	8.35	10.43	11.80	12.62	14.34	15.19	15.92	16.73	17.22
6	L3R001	Groot (In)	20580	225	1.04	3.32	5.92	9.44	15.73	21.95	28.46	42.26	54.00	67.84	89.76	109.40
6	L6H002	Heuningkli	1293	283	0.41	1.22	2.25	3.80	6.98	10.60	15.19	25.49	36.11	50.45	77.11	105.08
6	L6H001	Heuningkli	677	295	4.14	10.32	15.75	21.74	30.39	37.38	43.25	54.75	62.60	70.61	81.38	89.62
6	L7H006	Groot	29491	286	1.27	3.44	5.56	8.12	12.15	15.71	19.02	25.66	30.68	36.13	44.01	50.48
6	L9H003	Gamtoos	34063	317	1.01	3.93	8.36	15.96	33.92	56.94	88.97	168.90	260.09	393.80	666.65	978.66
6	P1H003	Boesmans	1476	492	2.58	7.92	14.99	26.08	50.09	78.79	117.19	206.04	302.91	439.47	706.50	1000.45
6	P3H001	Kariega	578	522	1.37	11.23	36.14	98.38	315.98	704.40	1404.20	3786.10	7380.15	14012.85	31608.95	57200.21
7	L2H003	Buffels	1161	390	1.08	2.68	4.28	6.26	9.55	12.62	15.78	22.05	27.25	33.24	42.51	50.66
7	N1R001	Sundays	3668	400	1.20	3.80	6.94	11.37	19.81	28.65	38.63	60.27	80.13	104.81	146.36	185.87
7	N2H007	Sundays	13438	350	1.28	3.59	6.11	9.43	15.29	21.06	27.22	39.98	51.04	64.22	85.35	104.56
7	N2H008	Riet	344	368	1.00	2.39	3.79	5.55	8.54	11.39	14.42	20.43	25.59	31.66	41.30	49.98
7	N3H002	Voel	1585	401	1.35	3.65	5.92	8.68	13.10	17.05	20.79	28.31	34.08	40.43	49.73	57.45
7	N2R001	Sundays	16828	355	2.17	6.14	9.71	13.62	19.10	23.37	26.67	33.35	37.56	41.68	46.92	50.73
7	P4H001	Kowie	576	549	1.10	11.05	34.90	87.75	240.41	462.59	831.94	1668.66	2692.36	4199.48	7236.44	10620.92
7	Q2H002	Gt Fish	1714	395	1.44	3.48	5.38	7.61	11.07	14.10	17.50	22.56	26.85	31.53	38.35	44.00
7	Q1H001	Gt Fish	9085	399	1.12	2.71	4.34	6.42	10.03	13.53	17.82	24.96	31.65	39.65	52.59	64.45
7	Q3H005	Gt Fish	10837	397	0.81	2.37	4.72	8.93	19.81	35.33	62.04	128.27	219.78	373.68	746.10	1250.37
7	Q7H005	Gt Fish	19240	418	1.02	3.27	6.06	10.15	18.23	27.02	38.82	60.38	82.47	110.86	160.56	209.66
7	Q9H012	Gt Fish	23071	422	1.03	3.66	7.21	12.73	24.37	37.79	56.67	93.07	132.24	184.72	281.09	380.66
7	Q9H018	Gt Fish	29748	445	1.00	3.37	6.46	11.14	20.76	31.62	46.63	75.01	105.03	144.67	216.29	289.19

APPENDIX E LOG PEARSON TYPE 3 DERIVED FLOOD GROWTH CURVES

ANALYSIS OF SYSTEMATIC RECORDS																
Region	Site	River	Catchment Area (km^2)	MAP (mm)	Q_T/Q_{ml}^{NCAPA} for various return periods -T (year)											
					2	5	10	20	50	100	200	500	1000	2000	5000	10000
7	Q1R001	Gt Brak	4325	416	0.95	2.10	3.26	4.77	7.42	10.06	13.40	19.11	24.67	31.53	43.06	54.06
7	Q1H013	Lt Brak	2457	383	8.30	33.48	59.12	87.74	127.08	156.34	184.25	218.29	241.57	262.61	286.99	302.86
7	Q1H012	Teebus	1571	437	1.05	1.80	2.43	3.15	4.29	5.31	6.49	8.35	10.00	11.91	14.88	17.51
7	Q3H004	Pauls	877	400	1.25	5.77	11.37	18.78	31.10	42.09	54.28	71.90	86.10	100.85	120.90	136.27
7	Q4H004	Tarka	664	498	1.34	4.21	8.32	15.28	31.89	53.69	88.38	166.32	264.00	414.28	740.41	1137.57
7	Q9H030	Koonap	251	626	1.53	2.93	4.11	5.42	7.39	9.07	10.94	13.73	16.09	18.68	22.49	25.68
7	Q9H002	Koonap	1249	543	1.18	4.98	9.69	16.06	27.08	37.38	49.34	67.57	83.09	100.02	124.39	144.19
7	Q9R001	Kat	259	738	0.92	2.41	4.15	6.68	11.72	17.32	25.05	39.77	55.53	76.68	115.79	156.67
7	Q9H004	Kat	406	707	2.21	5.03	7.75	11.09	16.64	21.82	27.99	37.87	46.85	57.30	73.67	88.26
7	Q9H011	Kat	542		1.43	3.68	5.94	8.74	13.39	17.70	22.77	30.77	37.90	46.04	58.49	69.32
7	Q9H029	Kat	1037	632	1.06	2.36	3.55	4.97	7.23	9.27	11.61	15.23	18.40	21.98	27.40	32.07
7	Q9H019	Balfour	76	723	1.24	3.61	6.35	10.14	17.21	24.53	33.96	50.45	66.66	86.77	120.63	152.88
7	Q9H013	Kap	45	550	1.29	5.19	10.58	18.88	35.89	54.77	80.34	127.17	174.97	235.93	341.34	443.90
7	Q9H017	Blinkwater	228	579	1.95	9.05	19.65	36.74	73.15	114.72	172.07	278.98	389.51	531.79	779.78	1022.50
8	R1H014	Tyume	71	797	1.07	2.19	3.19	4.37	6.25	7.96	9.94	13.03	15.78	18.93	23.77	28.01
8	R1H001	Tyume	240	640	1.10	2.37	3.51	4.84	6.91	8.75	10.85	14.04	16.80	19.89	24.51	28.44
8	R1H003	Kieskamm	271	787	0.97	2.38	3.89	5.89	9.53	13.21	17.90	26.04	34.01	43.90	60.59	76.55
8	R1H013	Kieskamm	1524	625	1.04	3.23	5.70	9.01	14.89	20.67	27.75	39.42	50.22	62.93	83.00	100.96
8	R1H015	Kieskamm	2521	578	1.15	3.39	5.53	7.98	11.58	14.53	17.63	21.88	25.17	28.50	32.93	36.27
8	R2H001	Buffalo	29	1000	1.04	2.40	3.62	5.02	7.16	9.00	11.03	14.04	16.55	19.28	23.21	26.44
8	R2H005	Buffalo	415	744	1.15	3.80	6.70	10.43	16.67	22.40	29.03	39.17	47.90	57.53	71.65	83.37
8	R2H010	Buffalo	674	655	1.17	4.06	7.30	11.46	18.43	24.81	32.15	43.29	52.78	63.17	78.25	90.63
8	R2R001	Buffalo	923	645	1.20	4.13	7.33	11.34	17.83	23.58	30.01	39.47	47.27	55.59	67.27	76.58
8	R2H012	Mgqakweb	16	968	1.35	2.73	3.90	5.21	7.17	8.84	10.68	13.38	15.65	18.11	21.68	24.63
8	R2H006	Mgqakweb	121	752	1.28	2.67	3.79	4.96	6.58	7.87	9.20	11.01	12.41	13.84	15.77	17.25
8	R2H007	Zele	84	660	1.16	2.42	3.38	4.35	5.64	6.62	7.59	8.86	9.80	10.73	11.92	12.80
8	R2H008	Quencwe	62	810	1.47	4.78	7.84	11.15	15.62	18.95	22.16	26.14	28.93	31.50	34.59	36.67
8	R2H009	Ngqokweni	80	500	1.59	8.43	15.98	24.40	35.56	43.39	50.43	58.38	63.38	67.57	71.97	74.51
8	R2H015	Yellowwoo	203	620	1.25	4.83	8.70	13.37	20.45	26.30	32.41	40.70	47.00	53.24	61.29	67.17
8	R3H001	Gqunube	507	634	2.42	5.47	8.20	11.35	16.17	20.34	24.98	31.87	37.66	43.98	53.16	60.75
8	R3R001	Nahoon	472	629	0.90	2.90	4.86	7.12	10.42	13.10	15.87	19.59	22.43	25.24	28.89	31.57

APPENDIX E LOG PEARSON TYPE 3 DERIVED FLOOD GROWTH CURVES

ANALYSIS OF SYSTEMATIC & HISTORIC RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Q_T/Q_{ml}^{NCAPA} for various return periods -T (year)											
					2	5	10	20	50	100	200	500	1000	2000	5000	10000
2	J3H012	Groot	687	370	1.54	5.65	10.13	15.66	24.33	31.75	39.77	51.10	60.08	69.30	81.71	91.18
6	J4H002	Gourits	43500	293	1.13	3.34	5.48	7.96	11.69	14.79	18.09	22.69	26.32	30.05	35.08	38.94
2	J3R002	Olifants	5229	307	1.02	2.36	3.54	4.85	6.78	8.39	10.12	12.58	14.57	16.65	19.56	21.87
6	J2R006	Gamka	17081	222.2	0.83	3.30	6.52	11.22	20.23	29.60	41.57	62.08	81.67	105.28	143.47	254.72
6	J1R003	Buffels	4030	262.1	1.03	3.66	7.31	13.14	25.82	40.90	62.73	106.25	154.63	221.35	348.09	483.44
6	L7H006	Groot	29491	285.9	1.24	3.45	5.70	8.49	13.07	17.26	21.35	29.60	36.12	43.42	54.30	63.52
2	L8H005	Kouga	1627	572.2	0.75	2.69	6.62	15.80	48.56	111.92	252.98	754.06	1698.16	3806.72	10996.74	24427.38
2	L8R001	Kouga (In)	3890	521.2	1.03	5.42	13.04	27.08	62.06	108.31	171.60	337.61	524.42	796.31	1343.15	1957.06
6	L9H003	Gamtoos	34063	317.2	1.06	4.13	7.97	13.33	23.13	32.84	42.64	64.16	81.85	102.32	133.92	161.46
2	M1H012	Swartkops	918	526.9	1.00	7.69	21.69	50.30	127.51	234.77	380.64	789.04	1246.94	1913.23	3243.59	4718.54
7	N2H007	Sundays	13438	349.7	1.32	3.82	6.64	10.46	17.43	24.46	32.20	48.47	62.99	80.65	109.66	136.64
7	N2R001	Sundays	16828	354.6	1.35	2.93	4.28	5.77	7.95	9.77	11.42	14.53	16.81	19.22	22.61	25.32
6	P1H003	Boesmans	1476	491.6	2.37	7.22	13.81	24.44	48.36	78.02	119.54	217.97	330.44	494.88	830.77	1216.63
7	P4H001	Kowie	576	549	1.04	10.18	31.85	79.53	216.41	414.74	743.38	1485.55	2391.39	3722.62	6400.50	9380.67
7	Q2H002	Gt Fish	1714	394.6	1.45	3.52	5.46	7.74	11.32	14.47	18.01	23.32	27.82	32.77	40.01	46.03
7	Q3H005	Gt Fish	10837	397.3	0.85	2.05	3.38	5.21	8.70	12.41	17.36	26.40	35.74	47.89	69.56	91.45
7	Q7H005	Gt Fish	19240	417.7	0.93	2.96	5.54	9.40	17.26	26.07	38.20	61.09	85.28	117.24	175.03	233.96
7	Q9H012	Gt Fish	23071	421.5	0.86	2.96	5.83	10.39	20.27	31.99	48.96	82.82	120.54	172.68	272.05	378.58
7	Q9H018	Gt Fish	29748	445.3	0.84	2.72	5.17	8.90	16.65	25.51	37.92	61.83	87.58	122.17	185.98	252.30
7	Q9H002	Koonap	1249	543	0.91	3.48	7.48	14.57	32.07	55.50	93.19	178.37	285.17	448.90	801.43	1226.15
8	R1H003	Kieskamma	271	787.2	0.98	2.58	4.44	7.10	12.30	17.98	25.68	40.05	55.14	75.03	111.02	147.84
8	R1H013	Kieskamma	1524	625	1.07	3.35	5.95	9.44	15.70	21.86	29.46	42.01	53.66	67.41	89.19	108.72
8	R1H015	Kieskamma	2521	578	1.09	3.12	4.99	7.07	10.05	12.43	14.88	18.16	20.64	23.12	26.34	28.71
8	R2H005	Buffalo	415	743.6	0.95	2.76	4.48	6.46	9.40	11.83	14.40	17.97	20.76	23.62	27.46	30.40
8	R2H010	Buffalo	674	655	0.98	2.94	5.03	7.68	12.13	16.25	21.06	28.53	35.08	42.42	53.40	62.71
8	R2R001	Buffalo	923	644.8	0.93	2.88	4.81	7.06	10.44	13.25	16.22	20.33	23.55	26.82	31.19	34.51
5	S7H004	Great Kei	18799	563.4	1.06	1.88	2.82	4.19	7.00	10.26	14.98	24.62	35.77	51.87	84.55	122.16

ANALYSIS OF SYSTEMATIC & PALAEOFLOOD RECORDS

Region	Site	River	Catchment Area (km^2)	MAP (mm)	Q_T/Q_{ml}^{NCAPA} for various return periods -T (year)											
					2	5	10	20	50	100	200	500	1000	2000	5000	10000
6	J4H002	Gourits	43500	293	1.24	3.93	6.75	10.24	15.85	20.82	26.39	34.64	41.50	48.88	59.36	67.82
6	J1R003	Buffels	4030	262.1	2.04	5.34	8.90	13.62	22.10	30.58	41.25	59.42	76.87	98.14	133.27	166.12
6	L7H006	Groot	29491	285.9	0.62	1.68	2.73	3.98	5.98	7.74	9.39	12.70	15.20	17.94	21.89	25.15
7	N2H007	Sundays	13438	349.7	0.79	2.21	3.76	5.82	9.47	13.06	16.92	24.91	31.86	40.16	53.51	65.67
7	N2R001	Sundays	16828	354.6	7.54	17.25	24.61	31.81	40.90	47.37	53.46	60.89	66.05	70.83	76.57	80.50

Appendix F

Flood Record of the Gourits River-3000BP to Present

Paper presented at the 7th South African Hydrological Symposium in Port Elizabeth - 23 to 27 September 2003

FLOOD RECORD OF THE GOURITS RIVER-3 000BP TO PRESENT

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Summary

A current WRC pilot project in the eastern Cape (Catchment regions J to S) to derive a robust flood estimation methodology using palaeoflood, historical and systematic data yielded significant flood records for several rivers with that of the Gourits River being the most significant. The paper will describe the gathering of the data, the compilation of the data set and interpretation and application of the data for the Gourits River. The oldest flood on this record is dated at 3 000BP, using luminescence techniques on the palaeoflood sediments, with the discharge estimated at 26 000m^3/s. The flood record of the Gourits River is placed in context regarding the climate over the period and the relevance of the data for flood estimation.

Using the Gourits data and the compiled data sets from the other sites in the Gamtoos, Sundays, Great Fish and Kei river basins and regions P and R, the methodology proposed using index floods and growth curves for flood estimation is presented.

1. INTRODUCTION

The estimation of flood magnitudes for engineering design and planning projects associated with river works and developments impacted by rivers is often characterised by a degree of uncertainty. The selection of an appropriate level of risk and designing for that risk requires the estimation of a flood peak or in flood attenuation studies the full flood hydrograph associated with that risk. During the past two decades southern Africa has been ravaged by several floods. The most notable are that of Natal in 1987, the Orange river in 1988, the December 1995 floods in Pietermaritzburg where a 147 people lost their lives, the floods from January to March 1996 in the north eastern areas of South Africa, the November 1996 floods in the eastern Cape and the floods of February and March 2000 that effected the Limpopo-, Mpumalanga and Eastern Cape provinces in South Africa and caused severe devastation in Mozambique.

When estimating flood peaks and their associated risk of occurrence the practioners have a wide choice of methods available for use. The methods are generally grouped in the following categories;

- Deterministic methods that derive the flood peaks by transforming rainfall data to runoff. This relies on the analysis of rainfall statistics that are generally longer than flow records to provide the risk information and characteristics obtained for the catchment of interest.
- Empirical methods that use observed flood data to provide estimates of flood magnitudes for various probabilities of occurrence (risk). The most notable method at present is the RMF method proposed by Kovacs (1988) and currently used extensively in Dam Safety.
- Statistical methods. This consists of analysing flood peak data fitting appropriate statistical distributions to data.

Experience has shown that the results from these methods can vary significantly and subjective choice or selection of the adopted frequency analysis results may subject future tenants to more frequent flooding than anticipated or may lead to costly engineering works or retrofitting in the case of dams.

The results of flood frequency estimations using various methods for the Great Fish River at Elands Drift Dam is summarised in Table 1 below.

Table 1: Elands Drift Dam – Estimated flood peaks (m^3/s)-Catchment Area=16 864km^2

Method	Return Period-T (years)						
	2	5	10	20	50	100	200
Statistical	293	863	1423	2126	2943	3713	4596
Rational	466	977	1380	1805	2419	2938	3472
DRH	923	1434	1801	2160	2679	3098	3541
SUH	787	1223	1535	1841	2284	2641	3019
MIPI	350	852	1345	1933	2856	3666	4572
TR137					7030	8222	9449
Recommended	295	865	1420	2130	2940	3710	4600
Std Flood	251		1316	1890	2743	3458	4215
Data	190	610	1850	2500	4100	5060	6030

Note:

- Statistical is based on the average values for several distribution, using data from Q7H002/3/4/5 downstream (Catchment Area = 19134km2). The record from 1921 to 2000 did not include historical floods or the 1974 flood.
- DRH refers to direct runoff hydrograph
- SUH refers to synthetic unit hydrograph
- MIPI refers to Midgley Pitman (HRU, 1972)
- TR137 refers to regional maximum flood (RMF) method proposed by Kovacs (1988).
- Std Flood refers to the standard design flood as proposed by Alexander (2002).

Most of the methods used in South Africa with the possible exception of the RMF method and the recently introduced Standard Flood (Alexander, 2002) is the long period that has elapsed since the various methods were developed in the 1970's and early 1980's. Since the time that the methods have been developed and the present;

- South Africa has experienced several large floods,
- The systematic period of observation has added a further 15-20 years of record,
- The inclusions of historical and palaeoflood data in statistical analysis of flood peaks has gained acceptance and could increase the observation period by 50-150 years in South Africa. Palaeoflood data could increase the period by up to 10 000 years.

Taking all the above into account the WRC commissioned a pilot study to investigate the use of index floods and growth curves to develop a robust method to estimate flood peaks and their associated probabilities using the longer systematic record, historical flood information and palaeoflood information. The requirement for such a investigation was promoted by Alexander (1990) and the Committee of State Road Authorities in their guidelines TR25 (1994)

The study area selected was catchment management area 15 (Figure 1) that included drainage regions, K, L, M, N, P and Q. Drainage areas J, R and S were included to ensure that any regionalisation for the pilot area is complete. The choice of study area was determined by the reasonable availability of systematic data, the long recorded written history of the area and the relatively arid climate of the area would provide better information and sites for palaeoflood hydrology.

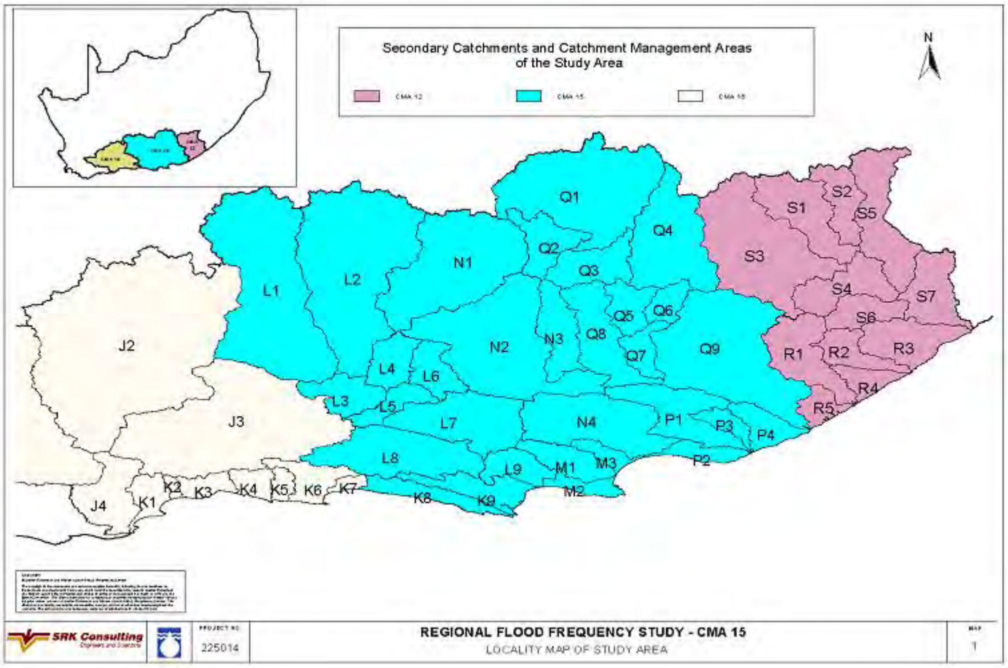

Figure 1: Study area-Catchment Management Area no. 15.

2. DATA GATHERING

The data gathered for the pilot study consisted of gathering the annual maximum flood peaks from the systematic data at the various gauging sites and obtaining historical and palaeoflood data and information. The methods and aspects of each of the data sets are expanded upon below and the process as applied to the Gourits River is discussed.

2.1 Systematic data

Systematic data for the pilot study area was obtained from the Hydrological Information System (HIS) data base held by DWAF. The data was supplied in text file format and then converted to an Excel file format for screening and checking. The data requested were for gauging stations and dams and included stations that are closed. The following aspects prevented the direct use of the data in several instances;

- Limited range of the gauging structure. This resulted in the annual maximum flood peaks at many stations being truncated at the limit. Fortunately the actual flood level is still recorded by the recorder.
- Gaps in the record. This was often due to flood damage to a station and loss of the recorder charts. The directorate of hydrology and their regional offices however frequently conducted field surveys to establish the maximum flood levels attained by the floods. Using the surveys, slope-area or bridge calculations were used to estimate the peak discharges. These surveys were done at most gauging stations that experienced floods that exceeded the stations gauging capacity with the purpose of using that information to extend the calibration of the gauging station above the discharge table limits.
- Short period of observation. Stations damaged during floods were never opened again or were closed due to poor locations, conditions that are not considered advantages for calibration of the station, operational reasons or were replaced by another station.
- Stations located downstream of dams. The data from these sites are of little value for the study of floods. The record for the dam was rather used after routing the inflows to the dam, to obtain a record of flows at a dam. Should the capacity of a dam be small relative to the mean annual runoff the data may still have some value.

The systematic data for the Gourits River was taken from DWAF gauging stations J4H001 for the period 1911 to 1931 and J4H002 and J2H005 for the period 1963 to 2000. The discharge tables for both sites were limited and were extended using the 1981 flood peaks and surveyed flood levels. Site J4H001 does not have any gaps but sites J4H002/5 had several gaps in the record due to damage by flooding and equipment failure.

2.2 Historical data

Historic flood data is any information relating to flood events outside the systematic record. These could include flood levels and peaks and quantative information such as “the flood was the largest since 1819”. Sources for historic information were;

- DWAF files and library. The correspondence and calibration files of the gauging stations were consulted for references to historical floods and to obtain the surveyed flood levels of floods not recorded by the instrumentation. The information in the files was also used for the extension of the discharge tables. The library contains old Irrigation Department reports that referenced flood events.
- The South African Weather service publications, the most notable being Caloceum (Viljoen, 1990).
- Newspapers held by the various libraries. The dates provided by Viljoen (1990) provided a starting point for the newspaper searches.
- The National Archives in Cape Town and Port Elizabeth. Old Department of Public Works files for the Cape Colony and district council files contained several bridge plans and references to floods.
- The South African railways, National roads and the Cape Provincial Administration bridge plans showed flood levels and river sections that could be used to estimate flood peaks.
- Articles and books.

Historic data for the Gourits River was obtained from the Cape Argus reporting on the flooding in May 1885, railway bridge plans obtained from the archives in Cape Town and the bridge plans for the bridge between Albertina and Herbertsdale from the Cape Provincial administration. The historic data obtained were the flood levels at the railway bridge (same area as J4H001) in 1849, 1869 and 1885 and flood levels at the Herbertsdale bridge (J4H002) for the floods of 1932, a flood prior to 1955 and 1961 floods.

2.3 Palaeoflood data

Palaeoflood hydrology is the study of ‘past or ancient flow events that occurred before direct measurement by modern hydrological procedures’ (Baker 2000, p. 359). The principal objective of the technique is to provide information on the peak discharge and recurrence of past floods that occurred up to 10 000 years ago. Before this time the prevailing hydroclimatic conditions that produced floods were probably dissimilar to that of today and therefore cannot be incorporated into the present-day flood record. Usually the palaeoflood records cover periods of hundreds to thousands of years (Zawada 1997; Baker 2000).

Palaeoflood hydrology can provide information on the following aspects of a rivers flooding behaviour:

- Identifying one or several floods that were larger than modern or historical flood records indicate. This can be used to verify the representivity of the modern and historical flood record in terms of magnitude and recurrence of floods;
- bracketing of periods in which no floods of a certain magnitude occurred;
- verification of the regional maximum flood, and
- testing the validity of the probable maximum flood of a river. This is of particular interest to high hazard developments such as nuclear related facilities.

The development of various palaeoflood techniques has occurred during the last 30 years in response to the observation that many flood records of rivers, which are based on modern hydrological measurements and even reliable historical records are still comparatively short. Because palaeoflood hydrology is not dependent on human recording of floods and is based on erosional and depositional features produced by floods it can extend the period of flood record considerably. Palaeoflood hydrology should therefore be viewed not as an alternative methodology but as a suite of techniques that complement the hydrological analysis of flooding rivers.

Palaeoflood hydrology is a multidisciplinary method and therefore comprises several techniques. These include:

- relating the maximum particle size analysis to a measure of flood magnitude such as flow competency (stream power values);
- using botanical evidence as a proxy indicator of past floods, and
- using slack-water sediments as proxy indicators of palaeostage, and therefore discharge.

In South Africa several palaeoflood investigations have been done (Smith and Zawada, 1990 (primarily a palaeocompetence investigation); Boshoff et al., 1993; Zawada, 1994; Hattingh and Zawada, 1995; Zawada, 1995; Zawada et al., 1996) that focussed on using slack-water sediments in stable bedrock-controlled reaches as this method has been shown to provide the most accurate information on past floods (Baker, 2000). For this investigation on the palaeoflood hydrology of the Gourits, Sundays, Great Fish and Great Kei Rivers, bedrock-controlled reaches that favour slack-water deposition were selected as preferred palaeoflood sites.

A detailed review of the methodology of palaeoflood hydrology using slack-water sediments in South Africa and internationally with an extensive bibliography is given in Zawada (1997). The following is a brief overview of slack-water sediments and their application in identifying palaeofloods since these were primarily used in the palaeoflood study on southern and eastern Cape rivers.

Slack-water sediments represent the most accurate palaeoflood evidence for reconstructing the magnitude and recurrence frequency of floods that are hundreds to thousands of years old. The technique is dependent on recognising slack-water sediments, which are usually fine grained and deposited from heavily sediment-laden flood waters at sites that experience sudden reductions of flow regime. Each successive flood with a stage capable of inundating previously accumulated slack-water sediment will deposit a new layer on top of the previous one. Smaller floods will deposit sediments as insets that exhibit an on lapping relationship with the existing slack-water sediments. The maximum elevation of the slack-water sediment is assumed to indicate the peak stage of the flood. This, together with hydraulic modelling of stable bedrock-controlled cross sections, can yield accurate estimates of palaeodischarge. Applying sedimentological, stratigraphic and chronostratigraphic techniques such as radiocarbon and luminescence dating, to the slack-water sediments, can furnish a catalogue of dated, flow modelled palaeoflood events.

Slack-water sediments form by suspension settling in regions of flow reductions across a wide spectrum of physiographic or geomorphic settings. These include back-flooded tributary mouths, downstream of abrupt channel expansions, upstream of channel constrictions (back-water effects), bedrock caves or alcoves along the channel or valley wall in which flow detachment and ponding occurs. For the southern and eastern Cape rivers palaeoflood study, the mouths of back-flooded tributaries were focussed on.

2.3.1 Gourits river palaeoflood data

Site A on the Gourits River is at the Jan Muller Bridge on the 1:50 000 top cadastral sheet 3321DC Langberg with the GPS coordinates: S33° 54” 39,00’ E 21° 39’15.9” (Figure 2).

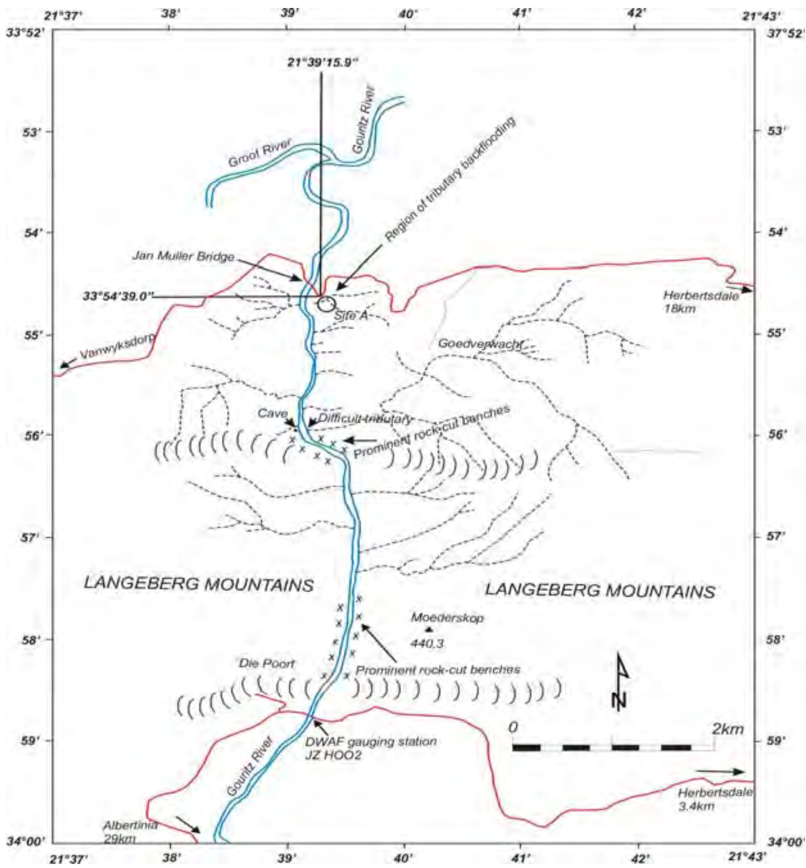

Figure 2- Position of Site A and associated area of tributary back flooding, cave site and 'difficult tributary', which contains an extensive sequence of slack-water sediments deposited by the Gourits River in the Langberg Mountains, southern Cape. The position of the 'cave' and 'difficult tributary' sites are also indicated.

On the western side of the bridge on the rock face through which the Herbertsdale-Willomore road passes through is a silver painted mark that was placed here by the Roads Department to indicate the maximum water level of the 1981 flood. The stage of this flood above channel base is 15,721 m (14,233 m above the Jan Muller bridge deck).

Site A comprises a thick sequence of flood-related slack-water sediments deposited on the eastern bank of the Gourits River that have choked the unnamed tributary of the Gourits. The Gourits River at site A is bedrock controlled and flows through a well-defined incised channel comprising black to dark-grey shale (slate like in places), siltstone and thin sandstone of the Gydo Formation, Bokkeveld Group of the Cape Supergroup. Immediately downstream of the Jan Muller Bridge the bedrock is exposed after which it is covered with a boulder bar of up to 3 m thick. The slack-water sediments on the eastern bank of the Gourits (Figure 3) occupies an area of approximately 0,1 km^2. Sediments extend from the side of the Gourits up to a moderately well defined break in slope in the slack-water sequence (Figure 3) which was interpreted as the uppermost position for the 1981 flood (Figure 3). The surveyed position for this feature is 14,793 m above the channel base, which is 0,928 m or 5,9% less than the 1981 flood (15,721 m) as observed by the Department of Roads. This relatively small difference indicates the close parity that can occur between the observed maximum flood stage and optimum sites of slack-water deposition. This observation was also confirmed in flume tank experiments of slack-water deposition by Kochel and Ritter (1987).

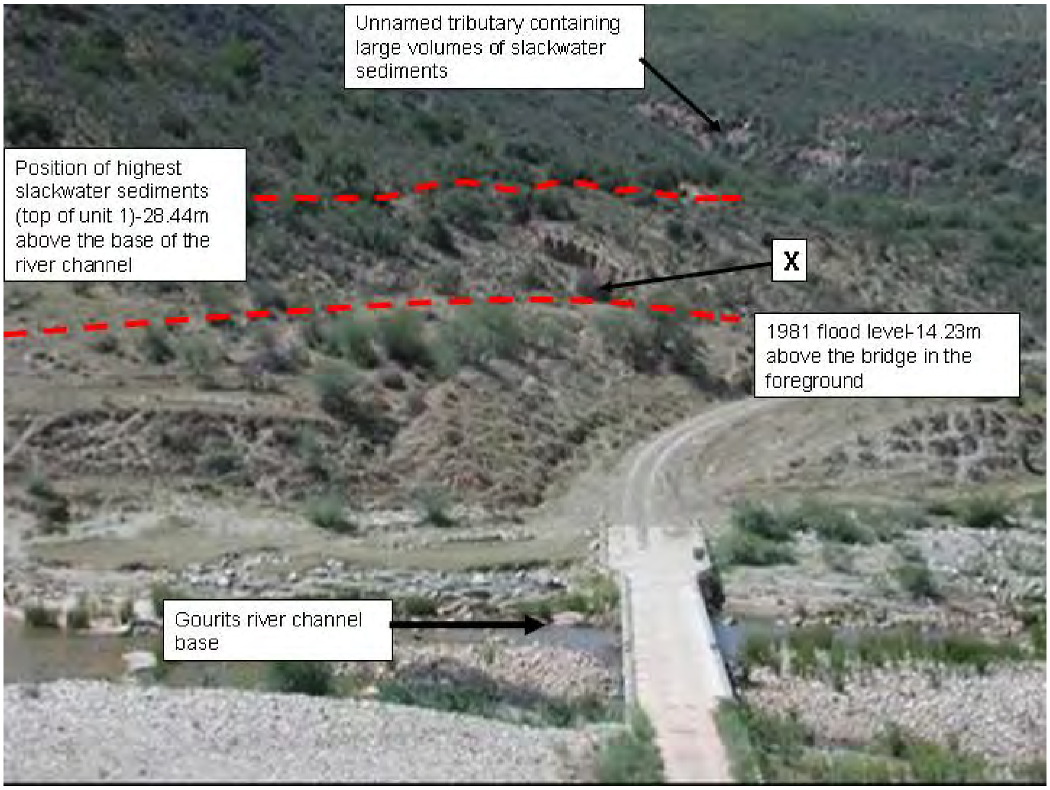

Figure 3 – View of the Gourits River at site A with the Jan Muller bridge in the foreground. Note the position of the 1981 flood level and the associated slack-water sediments in the middle of the photograph. Above the 1981 flood level indicated by X is an outcrop comprising mainly non-flood related colluvial sediments (unit 3). Overlying these sediments are inclined fine-grained flood related slack-water sediments (unit 1), which are positioned 28,44 m above the base of the Gourits River. Of interest is the tributary in the background to the right that contains large volumes of slack-water sediments, which were not examined in detail.

The 1981 sediments comprise light-grey, very fine-grained sand that for the most part is apparently massive. The sediments are distinctly non-indurated and are comparatively easy to excavate. The unconsolidated and non-indurated nature of the

1981 flood sediments results in the poor development of vertical exposure and their considerable reworking by wind, rain and local stream runoff. Closer to the Gourits River channel margin some exposures show ripple lamination and climbing-ripple lamination, the latter indicating high rates of vertical accretion as ripples migrated during flooding. It seems from site A that the 1981 flood smothered much of the pre-existing stratigraphy.

At site A a stratigraphy that is located higher than the 1981 flood level is present. The 1981 flood level laps up against this. The following stratigraphic section at site A was compiled (section) and is described below from top to bottom and is also illustrated in Figure 4.

Unit 1: Variable thickness (40 – 90 cm) but has a maximum thickness of 90 cm, comprising very fine-grained, light-grey apparently structure less sand. The sediments are very similar to the 1981 slackwater sediments except that unit 1 is more indurated.

PKZ 1 sample was taken from unit 1 at 20 cm from the base for luminescence dating (Figure 3). An age of 3000 ±200 years was obtained for sample PKZ 1.

Unit 1 is interpreted as a slack-water deposit that was deposited by the Gourits River. Its similarity to the 1981 flood sediments is striking. There is no evidence of colluvial sedimentation such as coarse-grained beds and isolated clasts. The more indurated nature of unit 1 compared to the lower 1981 flood sediments indicates that unit 1 is older (perhaps considerably more so) than the lower-lying 1981 flood sediments. However, no evidence of pedogenesis was noted from this unit. The luminescence date of 3000 ±200 years is therefore significant as it supports the above macroscopic description and interpretation of these suspected palaeoflood sediments.

Unit 2: 1 – 7 cm thick gravel, comprising angular, schist, quartzite, quartz clasts 2 – 4 cm in size. Most are less than 5 cm. The basal contact of unit 2 appears to be gradational.

Unit 2 is interpreted as a non-flood related interval probably related to the underlying colluvially deposited unit 3 as evidenced from the lower gradational contact. The angular nature of the clasts indicates that they were sourced locally probably from the adjacent hill slope.

Unit 3: Unit 3 is at least 125 cm thick. The basal contact was not observed but extends to below the high water position for the 1981 flood (the 1981 slackwater sediments lap up against unit 3 (Figure 3). Unit 3 comprises brown to reddy-brown, very indurated (much harder than unit 1) very fine-grained sand with approximately a less than 10% clay (visually estimated). Unit 3 contains isolated, scattered or ‘floating’ subrounded clasts 3 – 15 cm in size. Lenses of gravel 10 – 15 cm wide occur containing gravel clasts 3 – 5 mm in size. A rhizocretion occurs towards the base of unit 3. Unit 3 contains small (1 mm) size carbonate blebs.

PKZ 2 sample was taken from unit 3 at 47 cm below the base of unit 2 for luminescence dating. An age of 85 200 ±790 years was obtained for unit 3.

Unit 3 was interpreted prior to the luminescense dating results as a colluvially deposited unit of considerable age that has undergone some pedogenesis. The rhizocretions, carbonate blebs, reddy-brown colour and highly indurated nature indicates that unit 3 is of a considerable age. The luminescence date of 85 200 ±790 years therefore supports the above macroscopic description and interpretation. The colluvial nature of unit 3 is indicated by the pebble and boulder clasts set in a silt – sandy matrix, and was probably deposited as a mud flow.

Significant palaeoflood information has been obtained from the Jan Muller Bridge palaeoflood site. In particular, importance is attached to the palaeoflood indicated in unit 1 and the luminescence date of 3 000 ±200 years. In terms of a flood stage this flood is 12,72 m higher than the 1981 flood stage and was deposited by a flood approximately 3000 years ago. The palaeoflood stage of unit 1 (28,44 m above the Gourits channel base) corresponds to a modelled palaeodischarge of 26 000 m^3/s. A range of discharges is provided due to a range of differing roughness coefficients, which are assumed to occur during flooding. In terms of the palaeodischarge modelling, the lower estimate is regarded as the more reliable. To put the unit 1 palaeoflood into perspective the 1981 flood had a discharge of 11 400 cumecs at Mullershoop (bridge immediately downstream of Die Poort at gauging station J2H002) (Figure 2).

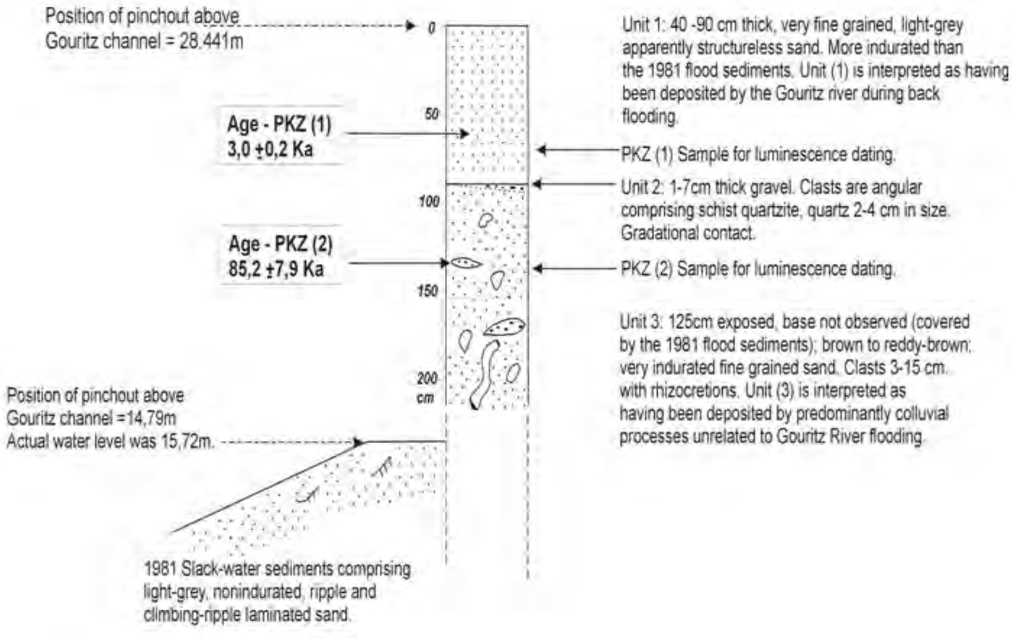

Figure 4 – Slack-water stratigraphy of the Gourits River at site A. Note the difference in stage between the 1981 flood and the top of unit 1, which is interpreted an on older palaeoflood.

Although texturally the sediments of unit 1are almost identical to the 1981 slack-water sediments, which strongly suggests that unit 1 is a palaeoflood slackwater unit that was deposited by the Gourits River, the following issues require clarification:

The unit 1 flood may have been generated when the channel infill of the Gourtiz River was much more extensive perhaps containing several meters of sediment. This would have the effect of increasing the flood stage. This condition indicates that the hydroclimatic regime of the Gourits was different to that of today. However, even if this was the case and that channel infill resulted in increasing the position of the base of the channel from 89,42 m to 100 m the modelled palaeodischarge would be approximately 20 000 – 23 000 m^3/s (Figure 5). This would still indicate the existence of a very large flood that occurred approximately 3 000 years ago. It is likely though that a flood of this magnitude would be sufficiently competent to scour considerable volumes of fluvial sediment and is likely to have removed all the sediment down to the current position of the channel bedrock. It is not considered likely that the base of the channel has been lowered significantly through bedrock erosion in approximately 3000 years.

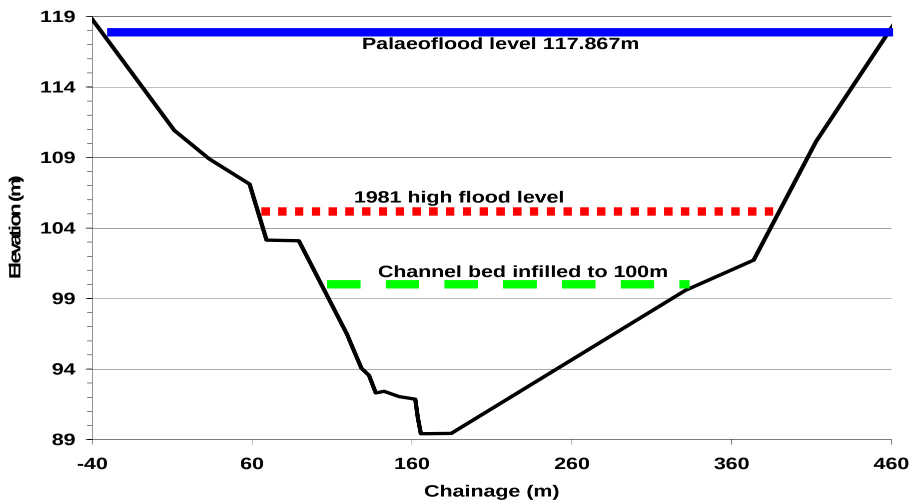

Figure 5:Cross-section of the Gourits River at the Jan Muller palaeoflood site. Note the position of the 1981 flood level compared to the inferred palaeoflood level for unit 1.

A further observation regarding the flood behaviour of the Gourits River was made approximately 3 km downstream of the Jan Muller Bridge palaeoflood site where the river passes into a narrow, quartzite bedrock controlled reach. The downstream end of the reach at Die Poort was observed where the Herbertsdale – Albertinia road crosses the Gourits. Where the river leaves the Die Poort well defined rock-cut benches are present. The quartzite is smooth and exhibits a prominent knick point. The level of this knick point is close to the 1981 flood level (Figure 6). A possible interpretation of this feature is that it was formed by the relatively common (geologically speaking) occurrence of floods similar to the 1981 flood. This implies that the 1981 flood level cannot be regarded as a catastrophic flood and rather the palaeoflood discharge for unit 1 of approximately 26 000 m^3/s should be regarded as a catastrophic flood for the Gourits River.

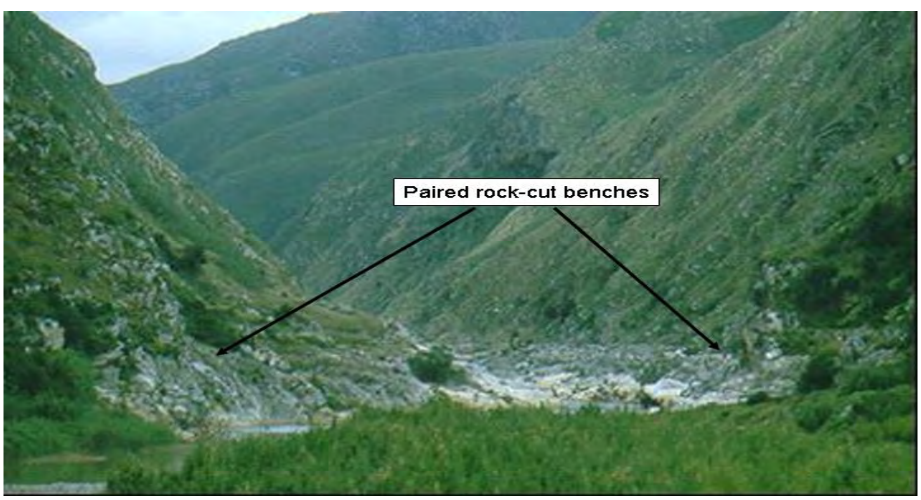

Figure 6: View looking upstream in the Gourits River as the river leaves the bedrock confined reach of the Langeberg Mountains at Die Poort. Note the pair of well defined rock-cut benches below which the quartzite is conspicuously smooth. It is suggested that this feature formed not as the result of one large flood event but comparatively frequent floods of a similar size to the 1981 flood discharge.

Partial confirmation of the existence of large palaeofloods occurring in the Gourits River is present at the confluence of the Gourits and Valse River approximately 50 km downstream of the Jan Muller bridge site. The Valse River site was studied in an earlier preliminary investigation (Zawada, 1996). At this site a sequence of interbedded fine-grained slackwater sediments with no-flood deposited breccia is present. Radiocarbon dating of bone from an intermediate slackwater deposited unit and the immediately underlying non-flood deposited breccia yielded the following respective un-calibrated ages, 2 730 ±60 years and 2 710 ±60. These ages correspond to respective calibrated dates of 889 (823) 804 B.C. and 843 (816) 799 B.C. where the date in brackets is regarded as the more likely date. The significance of this palaeoflood information at the Valse River site is three fold:

- The age of the palaeoflood is in the same age range as that obtained for the slack-water sediments from the Jan Muller bridge site.
- The stage of the Valse River palaeoflood sites is approximately 17,3 m. Although no corresponding palaeodischarge was obtained this stage is considered to represent a large flood in view of the wide cross-section of the Gourits.
- Although discharge modelling is required, there appears to be partial corroboration of a large flood occurring in the Gourits River at about 2800 – 3200 years B.P.

2.3.2 Palaeoflood data for other sites in Study Area

The available palaeoflood data for several other sites in the study area are summarised below;

- Buffels river-J1: Previous palaeoflood investigations concluded that the 1981 floods on the Buffels River was the largest flood to have occurred. The total period of observation could thus be taken to between 100 and 200 years.
- Groot (Gamtoos) river-L7: Evidence of a large flood of 4400m3/s (100BC) was found in a cave site on the Groot River. The analysis could thus take the total period of observation as approximately 2000 years for the Groot River. Unfortunately no palaeoflood evidence could be found in the Gamtoos River due to floodplain development. The large flood on the Groot River cannot be extrapolated to the Gamtoos River due to the significant contribution of the Kouga River to floods in the Gamtoos River.
- Sundays river-N2: Downstream of Darlington Dam two palaeofloods events were identified. The oldest event of 8000m3/s was dated as 8000BP. The second event estimated as 6130m3/s and dated as 7100BP. The total period of observation could thus be taken as approximately 8000 years.
- Great Fish river-Q9: Palaeoflood data located did not provide any evidence of flooding greater than the floods of 1874 and 1974. One relic feature approximately 4m higher than the 1974 flood
- Great Kei river-S7: No palaeoflood data that indicated floods larger than the 1874 flood was identified in the area around the Kei Bridges.

2.3.3 Relevance of Palaeoflood Data

In placing the approximately 3 000 year old Gourits river palaeoflood and the other palaeoflood sites information into a climatic context with respect to the present climate, Jerardino (1995) noted the occurrence of three distinct Neoglacial episodes that occurred during the past 5 000 years, between 4 500 and 4 000 B.P., between 3 000 and 2 000 B.P. and during the last 1 000 years in southern South America and southern Africa. The middle Neoglacial episode that occurred between 3 000 and 2 000 B.P. was the most marked and was characterised by glacial advance in southern Chile, an average temperature decline of 1-3º with a marked increase in precipitation. In strong support of this contention, Talma and Vogel (1992) identified a marked cooling episode between 3 100 and 2 500 years B.P. based on an oxygen isotope temperature record of a speleothem at Cango Caves, in the southern Cape. Jerardino (1995) presented further evidence in support of this cooling period such as a buried organic-rich palaeosol that indicated a wet episode and yielded a radiocarbon age of 3 080 ±60 years old and palynological evidence from Cecilia Cave from Table Mountain that indicated cooler and wetter conditions were present around 3 000 years B.P. In conclusion it appears that the Gourits River palaeoflood can be placed into a palaeoclimatic context in which there is evidence that the flood producing system could have generated the Gourits River flood. Jerardino (1995) ascribed this climatic variation to minor northward latitudinal shifts of frontal systems and probably strong atmospheric circulation together with significant polar expansions into the Benguela current. Of importance is the observation that the short-term, low amplitude climatic change at around 3 000 – 2 000 years B.P. and its effect on the magnitude of generated floods should be viewed as part of the current flood series for the Gourits River.

2.4 Data Set Compilation

The data sets compiled for the study consisted of the systematic data using annual maximum flood peaks, historical flood peaks and palaeoflood data. The historical and or palaeoflood data need not be from the site being analysed provided it is from the general vicinity.

2.4.1 Gourits River

The Gourits River data set shown in Figure 7 below was compiled from the systematic data obtained from the original returns for gauging station J4H001 and the HIS data and correspondence files for J4H002. Only water levels were recorded in the natural river section at J4H001 and the station was calibrated using the surveyed sectional information and a DWAF backwater programme. The historical and palaeoflood data was then added to the data set.

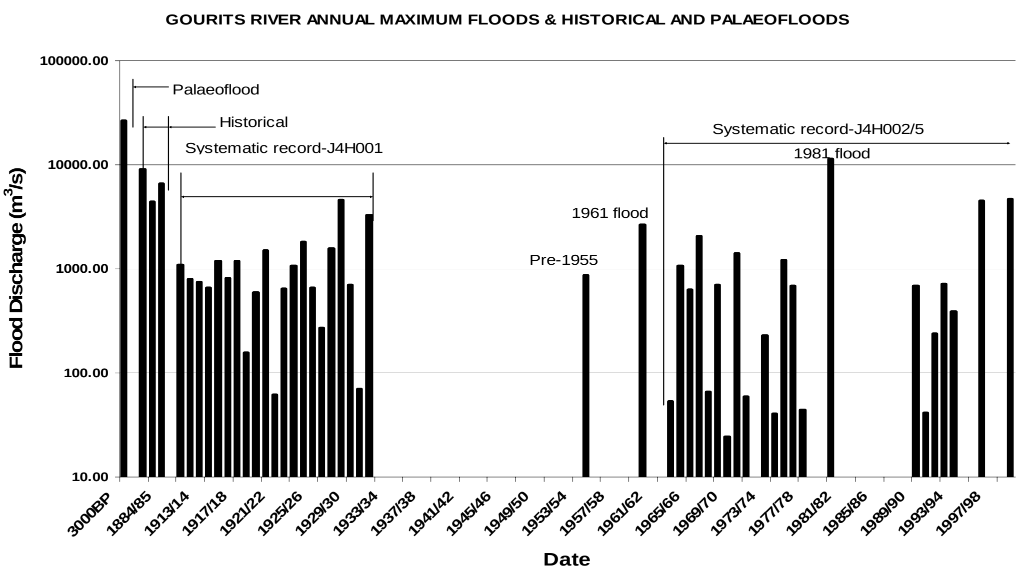

Figure 7: Gourits river annual maximum, historical and palaeoflood flood peaks at J4H002. Catchment area 43451km².

The following should be noted;

- The systematic period is 1911 to 2000,
- Historical period is from 1849 to 1911 and
- The palaeoflood period is 3000 years before present.
- There are two threshold values or double truncated sets, i.e. the historical and palaeoflood.

2.4.2 Pilot Area Data Summary

The data sets for the other rivers were compiled using same procedures as for the Gourits River and the data sets are summarised for the various regions in Table 2 below. The initial selection included all possible candidate sites. After checking the data quality and other factors such as period of observation and location the available sites were reduced to 122. The reduction did not necessarily mean that sites were discarded. Several sites such as J4H001, J4H002 and J4H005 on the Gourits River, Q7H001, Q7H002 and Q7H005 on the Great Fish River and L7H002, L7H004 and L7H006 on the Groot (Gamtoos) River were combined to provide one long systematic record. This was applied to all stations that qualified.

TABLE 2: SUMMARY OF ANNUAL MAXIMUM FLOOD DATA – CMA 15

Region	River Basin	All sites		Selected Sites		Maximum Period
		Total	Density (km^2/site)	Total	Density (km^2/site)	
J	Gourits	63	725	27	1693	1000BC-2000
K3-K9	South Coast	25	246	15	410	1959-2000
L	Gamtoos	25	1393	13	2678	100BC-2000
M	Swartkops	5	526	3	877	1854-2000
N	Sundays	28	759	5	4250	6000BC-2000
P	Boesmans, Kariega, Kowie	7	760	3	1774	1874-2000
Q	Great Fish	73	414	25	1210	1819-2000
R	Kieskamma, Buffalo	39	203	18	441	1848-2000
S	Great Kei	30	683	13	1576	1874-2000
Total		**299**	**584**	**122**	**1431**	

All regions with the exception of region K now have periods of observation longer than 100 years.

3. Analysis methodology

The analysis of the assembled data sets attempt to derive methods to estimate (1) the index flood using relevant catchment characteristics and (2) determine the growth factors for various flood probabilities.

Although this has been attempted before using the systematic record the motivation for the inclusion of historic and palaeoflood data are:

- The extension of the short period of observation for the systematic record.
- The micro (decadal) cyclic climatic variations as shown in Figure 5 and discussed by Kelly et. al (2002) for the USA indicate that short record periods for systematic records may only cover a relatively dry or wet period and as such can not be considered representative of the climatic system that impacts on the specific river.
- The inclusion of historic and palaeoflood data and their impact on flood estimation has gained wider acceptance and much research on their inclusion has been undertaken and is being undertaken.
- In South Africa the floods of 1981, 1984, 1988, 1996 and 2000 provided systematic records with so called outlier values. The inclusion of historic data where available actually showed these outlier values, although extreme, are not out of character for the specific rivers. If the period of observation was longer more flood values of the same order of magnitude would have formed part of the record.

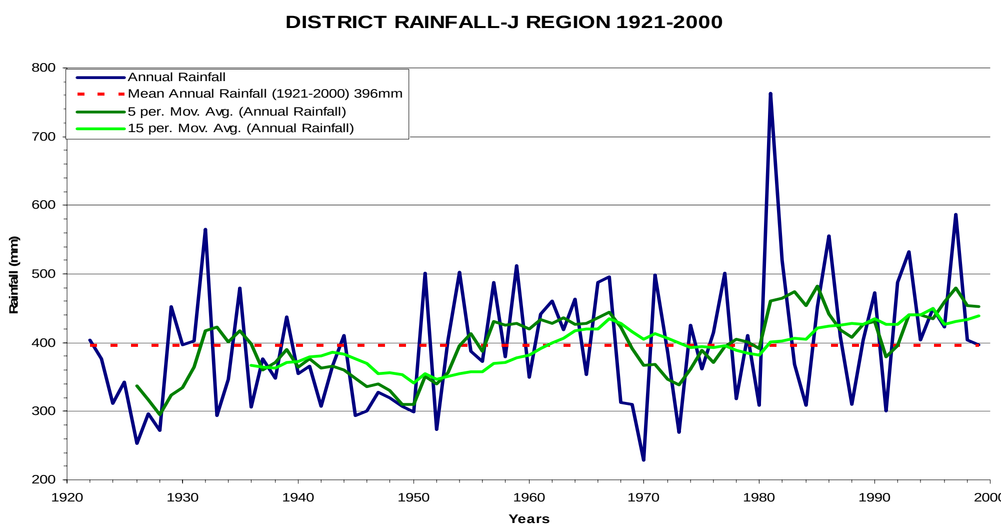

Figure 5. Micro Climatic Variation, based on Annual Rainfalls for Region J4

The annual regional rainfall data would suggest that there are cycles and that rainfall on average is increasing. The high rainfall periods indicated in Figure 5 also correspond to know periods of flooding such as 1928 to 1932, 1953 to 1955, 1967-1974, 1981 to 1983 and 1996 to 2000. A more general observation is the steady increase in the MAP.

The general form of the proposed method is:

$$Q_T = K_t Q_I$$

Where: Q_T is at estimated flood for the T-year event,
K_t is the multiplier for the T-year event related to a region and possibly MAP and
Q_I is the estimated index flood value.

The generic approach to analysing and interpreting the data is demonstrated using the presented Gourits River data.

3.1. Index Flood

The index flood is a flow value for the site of interest that is used as the scaling value for use with the growth factor. The index flood maybe derived from the mean annual flood, median flood value or the mean annual flood based on the log-transformed data. These values are typically related to catchment characteristics to provide a method to determine the index flood for ungauged sites. Catchment characteristics that typically are used include area, river length, river slope, catchment slope, soils, geology, vegetation, mean annual rainfall, 1-day 2 year rain and drainage density. The systematic record length is however very important and is demonstrated in Figure 9 below for the data obtained for the Great Fish River.

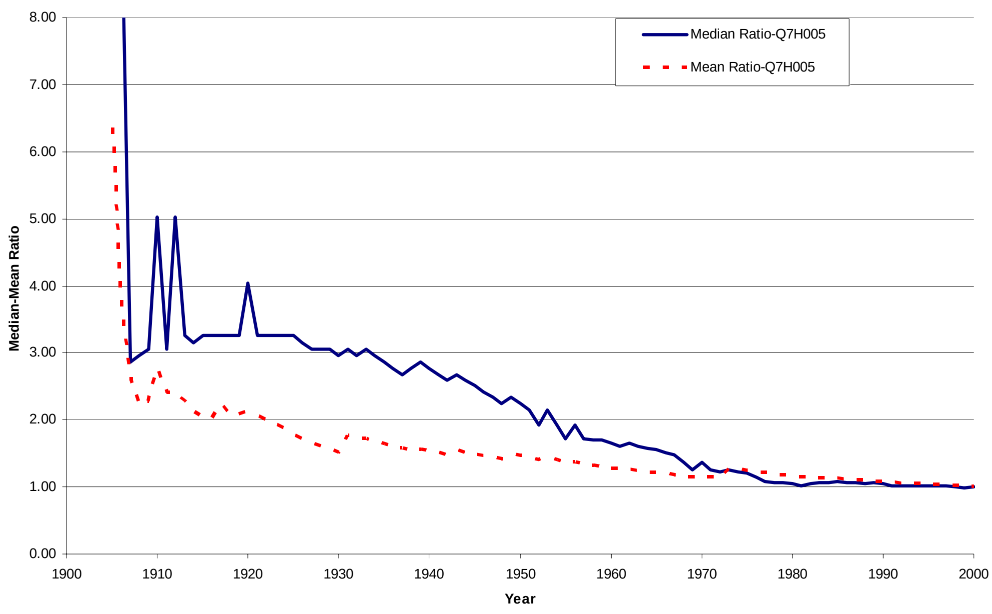

Figure 9: Variation in the median and mean flood estimates expressed as ratios (the total record value is the base) for the change in record length from 1905 to 2000, Great Fish River (Q7H005).

For the specific record shown above a twenty year record still resulted in an over estimation of the median flood peak by a factor of 3 and the mean annual flood by a factor of 1.87. The estimation of the median and mean only really starts to stabilise after a 60 plus year record. Depending on when the data capture starts these values maybe underestimated. The Great Fish River systematic record started with the floods of 1905 and the period 1905 to 1944 was characterised by flooding. The 1974 flood did cause a slight rise in the estimated mean but did not effect the median estimate. From the above and the results from provisional correlations the mean annual flood (Q_{mean}) would seem to the more appropriate value to use as the index flood. The length of the data set used to estimate the Q_{mean} is thus important. Longer records provide better estimates.

To achieve the objectives of simplicity and robustness when estimating index flood for a ungauged catchment the number of catchment variables must be carefully considered and site that have a sufficiently long period of observation must be used. McPherson (1983) had developed the Catchment Parameter method that utilised the catchment area, river length, MAP and catchment slope. The inclusion of more catchment characteristics such soil and vegetation characteristics was proposed but never pursued. The method briefly consisted of a determination of a lumped catchment parameter-M.

$$M = MAP(i\frac{\sqrt{A}}{L})^{1/2}$$

Where :MAP = mean annual precipitation (mm)
i = mean catchment slope (%)
L = length of the longest water course (km)
A = catchment area (km^2)

The M values were calculated for each of the catchments. The Q_{mean} and A for the catchments were then plotted on a logarithmic graph and points with similar M values were then joined. This resulted in lines of equal slopes for several M values. The index flood or the mean annual flood is then read off a log-log graph using the site M value. The previous study recommended that regionalisation should refine the method. The regionalisation currently being undertaken includes MAP, soils and vegetation.

3.2. Growth Curves

The provisional growth curves being deduced will use the using the Log-Pearson Type 3 distribution which has been found to be the most suitable for South Africa (Alexander, 2000). The General Extreme Value distribution using probability weighted moments is another candidate (van Bladeren, 1993). The intention is to extend the application of the distribution derived growth curves to the rarer events such as the 50-year to the 200-year event and beyond.

3.3. Analysis of Gourits River floods

The analysis of the Gourits River data is shown provide an indication of the methodology that was applied to the other sites.

The Gourits River data was split into four data sets;

- Set 1: The data for J4H002 from 1963 to 2000. It included the 1981 flood. Seven anomalous low values were excluded.
- Set 2: The data for J4H002 and J4H001 were combined and included the intermediate flood peaks of 1955 and 1961. Total period 1911 to 2000. Nine anomalous low values were excluded.
- Set 3: Set 3 plus the three historical floods that occurred in 1848/49, 1868/69 and 1884/85. The lowest historical value was selected as the high threshold value.
- Set 4: Set 2 plus the palaeoflood of 3000BP. The three historical values could not be included due to the unknown flood regime in the period between the palaeoflood and the first historical flood.

The observed data in Figure 10 was plotted using the Cunnane plotting position for both the systematic record from 1963 to 2000 and the full record (all the data we have) for the period 1048BC to 2000. The historical data was plotted using the procedure described by Alexander (1990) and the single palaeoflood peak was plotted using the Cunnane plotting position.

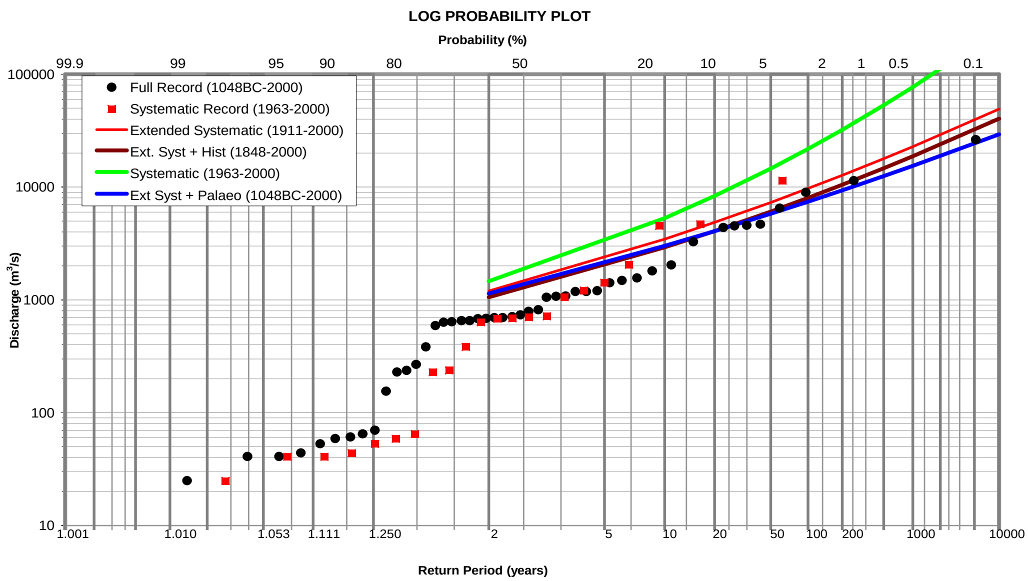

Figure 9: Gourits River (J4H002) Flood probability analysis for 4 data sets.

The estimated flood peaks in Figure 10 indicate that as the period of observation increases, the estimates are closer to the actual record. The inclusion of historical and palaeoflood greatly improve the estimates at the tail end of the data.

The data used for each of the estimates are summarised in Table 3.

TABLE 3: SUMMARY OF DATA FOR THE FOUR DATA SETS

Data Set	Gauged Period		Historical/Palaeo Flood Period		Total Record Length (years)
	Data	Length (years)	Data	Length (years)	
1	15	37	0	0	37
2	36	89	0	0	89
3	36	89	3	64	151
4	36	89	1	3048	3091

The impact of the additional data on the statistical properties is shown in Table 4. The longer record available from data sets 3 and 4 decreased the coefficient of variation (COV) and the skewness (g) for the log transformed data used in the Log Pearson distribution. The g for the untransformed data increased and the COV decreased. The impact of these changes are clear from the estimated flood frequencies summarised in Table 5.

TABLE 4: IMPACT OF ADDITIONAL DATA ON STATISTICAL PROPERTIES

Data Set	Untransformed Data					Log Transformed data				
	Median (m3/s)	Mean (m3/s)	SD	COV	g	Mean	Mean (m3/s)	SD	COC	G
1	1055	1770	2445	1.38	2.92	2.999	998	0.445	0.148	0.624
2	867	1454	1691	1.16	3.51	2.989	975	0.374	0.125	0.299
3	1074	1277	1562	1.22	4.03	2.944	879	0.353	0.12	0.372
4	1055	1299	1323	1.02	4.36	2.963	918	0.355	0.12	0.159

TABLE 5: IMPACT ON ESTIMATED LP3 FLOOD ESTIMATES.

Data Set	Flood Peak (m3/s) for various Return Periods-T (years)								
	2	10	20	50	100	200	500	1000	10000
1	1463	5287	8320	14552	21772	32140	52981	76601	250246
2	1201	3461	4866	7303	9703	12704	17834	22801	49171
3	1055	2917	4069	6058	8015	10461	14647	18705	40319
4	1140	3004	4064	5799	7417	9352	12490	15376	29284

The results from data sets 2, 3 and 4 are in close agreement with the observed total record.

DWAF are currently using the McPherson (1983) approach to estimate the mean annual flood and provisional growth values related to MAP (van der Spuy and Rademeyer, 1997). The growth values for the 20- and 50-years events (this is the limit of their growth values) for the Gourits River is 4.05 and 6.39 respectively. From tables 4 and 5 the values for the same events are 3.85 and 5.50. The growth values for the other events are 7.03 (100-year), 8.86 (200-year) and 14.57 (1000-year).

4. Conclusions and further studies

The data period including historical data maybe extended by up to 180 years and if palaeoflood data included this maybe taken to 3000 and even 8000 years. The spatial distribution of the palaeoflood sites at this stage is reasonable, but more sites would be advantageous.

For the estimation of the index flood the length of the records used would be important if the method is to remain robust. The method as proposed by McPherson (1983) will be adjusted to be applicable to the regions that are identified in the pilot study area. At present it would seem that three or possibly four regions would be identified for the estimation of the index flood.

Growth curves for the regions will be derived using the four data set analysis as shown for the Gourits River above. The derived growth curves would be linked to the regions and the catchment MAP as currently used by DWAF. The growth curve values can now be extended to probabilities be yond the 100- and 200-year event with a greater degree of certainty.

The study has provided well interrogated annual maximum flood peak data sets for the pilot study area and catchment characteristic data. The study has also provided data that maybe used to update the Regional Maximum Flood region and the regional “k” values.

Further work and studies that need to be undertaken are;

- Extending the study to other areas of South Africa to ensure that the momentum is maintained,
- The collections of palaeoflood data be expanded upon to ensure that full use is made of the method to ensure that the final growth curve values are applicable over a wider range of flood risk estimates.
- Study be undertaken to investigate the palaeo-climate over the past 10 000 years to confirm the applicability of the palaeoflood data in flood studies.
- Data that becomes available from continuous flow modelling work be included in the data sets. These data sets must however be verified.
- Expanding and improving the analysis of the data.
- The use of non-parametric methods of analysis of the data sets be included in future studies.
- Developing methods to deal with multiple censured data.
- The data generated in this study be used for further studies relating to storm losses and flood hydrographs.

5. Acknowledgements

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Appendix G

Determining of the Economic Viability of Newly Derived Flood Level Information

Assessment of Flood Damages using the Methodology Proposed

Report by the Free State University

DETERMINING OF THE ECONOMIC VIABILITY OF NEWLY DERIVED FLOOD LEVEL INFORMATION

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1 INTRODUCTION

The main purpose of this section is first to discuss appropriate methodology to determine potential flood damages by using a flood damage simulation model, after which the potential flood damages with original and newly derived flood level information be determined. Hence, results from these two information sets will be weighed against each other to determine the economic viability of newly derived flood level information. Lastly, the necessary conclusion and recommendation will be made.

2 FLOOD DAMAGE MODELLING

The loss function concept is fundamental for the determination of flood damage (Smith and Greenaway, 1988) and no alternative approach to determine flood damage could be tracked down. The loss function approach was presented by White and applied by the US Army Corps of Engineers (Flood Damage Analysis Package, User's Manual, 1988), and it forms the basis for the National Flood Insurance Program in urban areas (Smith and Greenaway, 1988).

Statutory planning is usually based on spatial information as contained on maps and plans. As a result, spatial information systems are becoming increasingly more essential for the co-ordination of floodplain planning. In this way data on *inter alia* the river geomorphology, which is necessary for the implementation of sustainable local and regional environmental plans, can be stored (Tané and Xingzhao, 1993).

It is possible to create water level and overflow maps with hydrological simulation models and when integrated with digital terrain models (DTM) and other GIS databases, like infrastructure, land use and population density, it becomes possible to provide the basis for impact-of-flood calculations.

After the development of a suitable DTM for the study area, the land use database is chosen. In situ and/or remote sensing surveys can be used with this purpose. Once the land use pattern is known, it is possible to draw up suitable loss functions for identified land-uses in the study area. As loss functions for different flood afflicted areas in South Africa become available, it becomes possible to choose from a databank of loss functions to determine the negative impacts of floods.

Numerical flood models should be used by engineers or hydrologists to provide hydraulic data required by flood damage simulation models (FDSM). Topographic data for numerical flood models usually consist of a river network and cross sectional profiles of the floodplain which can be exported from FDSM.

Examples of numerical flood models[1] which use cross sections to describe the topography are HEC-RAS, XP-SWMM, MIKE 11 and WSPRO (Van Bladeren, 1998). Mike 11 and XP-SWMM are dynamic models while HEC-RAS and WSPRO are steady state models. The difference between dynamic models and steady state models lies in the absence of the time dimension in steady state models. A dynamic model enables a hydrograph as input while a steady state model allows only a specific discharge as input. Dynamic models should be used when duration of inundation is required by the loss functions in FDSM.

The topographic data that are exported from FDSM should be converted into a format supported by the numerical flood model with which the simulation is to be done. FDSM then integrates the hydraulic data from the numerical flood model with the original topographic data. Finally hydraulic data, for example the average depth of inundation, are calculated for each cultivated field and these results are then used to determine flood damage.

Coupling environments can be categorised in isolated-, loose-, tight-, and integrated environments (Wolff-Piggott, 1994). Isolated and loosely coupled systems are based on a file transfer method where the user is expected to exchange the files from the one system to the other. With tight coupling the file transfer is performed automatically by the software and in an integrated system the GIS and hydrological model have been developed as a single software system.

According to De Vantier and Veldman (1993) connections with GIS can be expected in the hydrologic engineering field since large parts of hydrological analyses are linked to processes on the surface of the earth. Spence *et al*. (1995) supports this statement and adds that GIS can bring a spatial context to hydrological models that lacked in the past. The authors are of the opinion that the input data to hydrological models should also be enhanced, seeing that the models become more complex and describe more physical processes. The output data from hydrological models are complex the large volume of data makes it difficult to relate the results directly to locations (Muller and Rungoe, 1995). GIS can therefore provide the input data for hydrological models and it can make the process of analysing the output data more efficient.

An interface with the Mike 11 hydraulic simulation model was developed as an example system to demonstrate the coupling between the FDSM and a numerical flood model. The interface entails two processes. The output file from the FDSM must first be converted into an acceptable format for Mike 11 and then the output file of Mike 11 must be converted into the format required by the FDSM. This interface can be categorised as an isolated system. The software that converts the input- and output data is independent of both models. It is therefore possible to create interfaces between the FDSM and other numerical flood models as well.

---

[1] Also known as backwater packages

An additional module is also available with which topographic data can be extracted from the DTM to be used with numerical flood models. With this module the river network and cross sections can be digitised on the screen. The module provides functions to add, select or delete cross sections and a profile of a selected cross section can also be displayed. The user may choose any of the themes from the model to be displayed in the background while he is digitising. The module also enables the user to define the different channels of the river network. The exporting process is fully automatic and is activated by the clock of a button.

The river is represented by a network configuration as a system of interconnected branches. The network consists of centre lines representing the different channels. A centre line can be defined as a line connecting the points with maximum water speed in the cross sections (Tchoukanski, 1996). Chainages are calculated for the connections of centre lines and for the intersections between cross sections and centre lines. Chainages are calculated from the beginning of each line and starts at zero for all channels.

The following rules must be taken into consideration during the digitising process:

- Centre lines must be directed downstream.
- Cross sections must be taken from left to right over a centre line when looking downstream.
- Cross sections are not allowed to cross each other.
- Cross sections must cross a centre line, but are not allowed to cross more than one centre line.
- Cross sections should be approximately perpendicular to the centre line.
- Cross sections should extend far enough to cover the highest elevation expected to be reached by the flood.
- Cross sections should not extend beyond the boundary of the DTM.

The output data are saved into two files. The first file describes the river network and gives the chainages where the different channels connect. The second file describes the cross sections and consists of three parts (Figure 1). The different parts are delimited with a line that contains only a ‘0’. The first past gives the section id, chainage of the section on the centre line of a channel in meters, and the channel name of each cross section. The second part gives the section id, surface id, the distance in meters from the starting point of the section and the x-, y-, and z- co-ordinates of three points for each cross section. These three points include the starting point and ending point of the cross section as well as the point on which the section crosses the centre line of a channel. The last part of the file describes the profile of each cross section. The x-, y-, and z- co-ordinates are given for regular points along the line. The user determines the intervals between the points, and for this example a distance of 33m was taken. The cross sections in the output file will be in the same order in which they were digitised.

```
  1,  26452.950,MAIN
  2,  25678.560,MAIN
  3,  25051.370,MAIN
0
  1,  1,  0.000,      -60480.41009,  -42760.42602,   10.194
  1,  1,  3334.375,   -57359.47412,  -43934.22909,   3.629
  1,  1,  3922.329,   -56809.15573,  -44141.20719,   24.641
  2,  1,  0.000,      -60537.26579,  -42914.74836,   15.304
  2,  1,  3352.527,   -57665.97439,  -44645.38992,   4.278
  2,  1,  3461.496,   -57572.64692,  -44701.64210,   12.054
  3,  1,  0.000,      -60585.99918,  -43085.31545,   15.613
  3,  1,  3420.693,   -57914.20798,  -45221.35680,   3.742
  3,  1,  3993.179,   -57467.05759,  -45578.84421,   9.549
0
  1,  1,  0.000,      -60480.41009,  -42760.42602,   10.194
  1,  1,  33.000,     -60449.52247,  -42772.04304,   9.873
  1,  1,  66.000,     -60418.63486,  -42783.66006,   7.591
  1,  1,  99.000,     -60387.74724,  -42795.27708,   7.218
  1,  1,  132.000,    -60356.85962,  -42806.89410,   7.530
  ...
  1,  1,  3922.329,   -56809.15573,  -44141.20719,   24.641
  2,  1,  0.000,      -60537.26579,  -42914.74836,   15.304
  2,  1,  33.000,     -60509.00274,  -42931.78362,   10.215
  2,  1,  66.000,     -60480.73969,  -42948.81888,   8.746
  2,  1,  99.000,     -60452.47664,  -42965.85414,   8.312
  2,  1,  132.000,    -60424.21360,  -42982.88941,   9.605
  ...
  2,  1,  3461.496,   -57572.64692,  -44701.64210,   12.054
  3,  1,  0.000,      -60585.99918,  -43085.31545,   15.613
  3,  1,  33.000,     -60560.22397,  -43105.92220,   13.051
  3,  1,  66.000,     -60534.44875,  -43126.52895,   13.059
  3,  1,  99.000,     -60508.67353,  -43147.13570,   11.517
  3,  1,  132.000,    -60482.89831,  -43167.74245,   8.988
  ...
  3,  1,  3993.179,   -57467.05759,  -45578.84421,   9.549
```

Figure 1: The output file from the FDSM

A stream network together with profiles of cross sections is represented in the output file of the FDSM and it is then expected of the numerical flood model to provide the hydraulic information for each cross section in return. Two programs are available for the interface between the FDSM and Mike 11. The first program, Arc2Mike, does the conversion from the output file of FLODSIM (Figure 1) into a format supported by Mike 11 (Figure 2). The second program, Mike2Arc, converts the Mike 11 output file (Figure 3) into the format of FLODSIM’s input file (Figure 4). The input and output files of Mike 11 will be described in the remainder of this paragraph.

Cross-sectional data can be read from a text file into the database of Mike 11 (DHI, 1995:2-14). The text files may exist in several formats. The format used for the interface is described in Figure 1. The cross sections are specified by a number of x-z co-ordinates where x is the distance from the beginning of the section and z is the corresponding bed elevation. A maximum number of 300 points are allowed for each cross section DHI, 1995:2-9). The cross sections of the input file may be in any order and will be sorted in Mike 11 by channel name and chainage.

Chatty	*Topographical identification*
MAIN	*River or channel name*
26.453	*Chainage in kilometers*
Co-ordinates	*Explanatory text*
1 -57359.47 -43934.23	*Horizontal co-ordinates*
Profile 121	*Number of x-z co-ordinates*
0.00 10.19	*x1 z1*
33.00 9.87	*x2 z2*
66.00 7.59	*x3 z3*
99.00 7.21	*x4 z4*
132.00 7.53	*x5 z5*
...	
3922.00 24.64	*x121 z121*
********************	*End of the first cross-section*
Mfolozi	*Topographical identification*
MAIN	*River or channel name*
25.679	*Chainage in kilometers*
Co-ordinates	*Explanatory text*
1 -57665.97 -44645.39	*Horizontal co-ordinates*
Profile 107	*Number of x-z co-ordinates*
0.00 15.30	*x1 z1*
33.00 10.22	*x2 z2*
66.00 8.75	*x3 z3*
99.00 8.31	*x4 z4*
132.00 9.61	*x5 z5*
165.00 8.76	*x6 z6*

Figure 2: The input file of Mike 11

The results of the simulation can be written to a text file (DHI, 1995:2-14). A summary or time series can be given for each cross section. The summary file only gives the minimum and maximum water level of the flood for each cross section. This file can be used when durations are not needed as is the case with the Orange River. A file containing a time series is illustrated by Figure 2 and Mike2Arc can convert these files into the format used by the FDSM. With this file water levels are given over time intervals, for example every hour during the total duration of the simulation. The interval can be defined in Mike 11. The channel name and chainage (in kilometres) identify the cross sections. The first cross section in Figure 2 is for example 51 metres from the beginning of the main channel. The minimum distance allowed between two cross sections can be defined in Mike 11 (DHI, 1995:2-22). If the distance between two cross sections is longer than the defined distance Mike 11 will generate a cross section at the required position. Hydraulic parameters at these additional cross sections will be calculated by interpolating between the specified cross sections. The results of the cross sections that were generated by Mike 11 will also be shown in the output file.

```
+------------------------------------------------------------------------------------------+
! DATA FILE: MFOLOZI.RDF     BOUNDARY FILE: 10.BSF                                          !
! PARAMETER: 10-1.RRF        CALCULATED : 12-JAN-1998, 16:10                                !
+-----------------+------------------------------------------------------------------------+
!                  MAIN      MAIN      MAIN      MAIN      MAIN                             !
!  HOURS:MIN                                                                                !
!                  0.051     0.231     0.411     0.566     0.721                            !
+-----------------+------------------------------------------------------------------------+
1998  1  1  0  0   12.83     12.67     12.46     12.16     11.77
1998  1  1  1  0   13.05     12.88     12.63     12.28     11.84
1998  1  1  2  0   13.21     13.04     12.79     12.40     11.91
1998  1  1  3  0   13.35     13.18     12.89     12.47     11.97
1998  1  1  4  0   13.47     13.29     12.98     12.53     12.02
1998  1  1  5  0   13.58     13.39     13.06     12.58     12.07
```

Figure 3: The output file of Mike 11

The two elevations at which the water will be for longer than two critical periods can be determined with Mike2Arc (Figure 3). This is done by determining the duration of the water at levels from the flood peak downward with an interval declared by the user. The required elevation will then be the first elevation at which the duration is longer than the critical period. In the case of sugarcane the critical periods would be the periods (for winter and summer) that the plant could be inundated before it is destroyed.

Two input files are required by Mike2Arc namely the output file from FLODSIM and the output file from Mike 11. The output file from the FDSM is necessary to identify the original cross sections. Only the original cross sections will be included in the input file of FDSM.

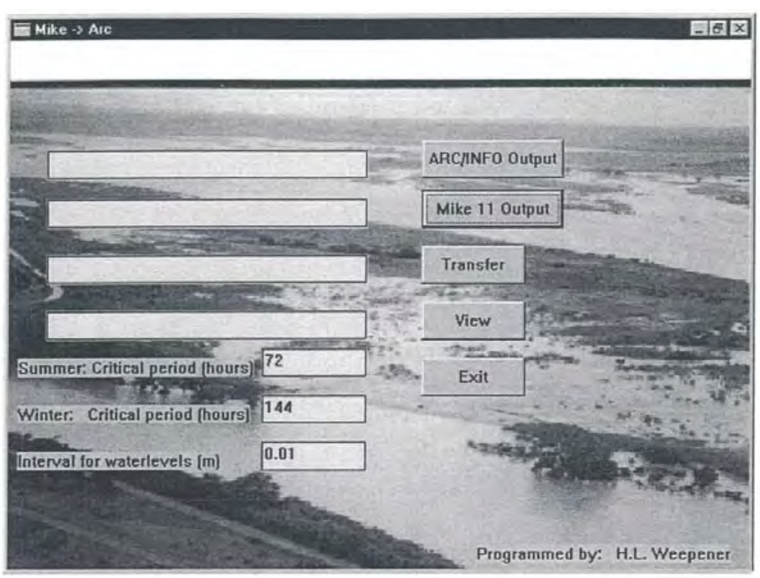

Figure 4: The front page of Mike2Arc

An engineer or hydrologist should process hydraulic data for the FDSM with a numerical flood model. Topographic data for numerical flood models usually consist of a river network and cross sectional profiles of the floodplain which can be exported from the FDSM.

The FDSM contains a module with which a water grid can be created from the hydraulic data and cross sections. For the purposes of this document a water grid will be defined as a grid representing the elevation of water for specific floods over the floodplain. The values in the cells of the water grid are acquired by interpolating between the water levels at adjacent cross sections.

The input file required by FDSM must consist of at least three columns namely the channel name, chainage and flood peak of each cross section. Any number of additional fields may be added after the flood peak when additional data are required by the loss functions. The same calculations, which are done on the flood peak, will also be done on the additional fields. Sugarcane may for example only be inundated for a certain period before it would be damaged. This period will differ between winter and summer. Two additional fields were therefore added to the input file for the Mfolozi river. These two fields represent respectively the elevation at which the water would stay for the critical periods of the winter and summer.

Channel name	*Chainage*	*Flood peak*	*Summer*	*Winter*
MAIN,	51.00,	15.36,	14.23,	13.22
MAIN,	411.00,	14.56,	13.57,	12.81
MAIN,	721.00,	13.58,	12.50,	11.93
MAIN,	1196.00,	13.02,	11.80,	11.03
MAIN,	1682.00,	12.83,	11.72,	11.01
MAIN,	2196.00,	12.70,	11.68,	10.99
MAIN,	2665.00,	12.55,	11.62,	10.98
MAIN,	3144.00,	12.08,	11.35,	10.86

Figure 5: Input file for FLODSIM

The values of hydraulic data in the input file will be appended to the attributes of corresponding cross sections. When the hydraulic attributes of the cross sections are known, water grids are created by interpolating between the attributes of adjacent cross sections. The linear interpolation method of the “tinlattice” command was used. Extra vertices were inserted into the cross sections in order to optimise the triangulation process of the “creattin” command. The average distance between cross sections was calculated to determine the distance at which the points should be inserted.

The average depth of inundation for each cultivated field is usually needed in the loss functions for different crops. The depth of inundation of fields is calculated by taking the average of the cells within cultivated fields after the elevation of the water grids have been subtracted from the elevations of the DEM. This will only be done for flooded areas. There are sometimes areas that are lower than the water level, but cannot be reached by the water. An example would be when a levee lies between the area and the water. A program was written to determine the flooded areas.

3 A TYPICAL FLOOD DAMAGE SIMULATION MODEL

As a starting point a database has to be developed. Several alternative methods were investigated to create specific databases. After the creation of the databases, the modelling process starts by choosing between the different databases that were developed with several techniques. A DTM is essential for flood damage modelling and can be created in several different ways (as was discussed above).

After a suitable DTM was created, a land use database has to be established. The user can choose between an *in situ*- or a remote sensed database. Loss functions that were developed specifically for the land use in the area of investigation are utilised and the next step will be to choose loss functions from the databank. With the interface between FLODSIM and MIKE 11 (Arc2Mike and Mike 2 Arc), it is possible to obtain hydraulic data from MIKE 11 with reference to specific scenarios that were drawn up with the FDSM.

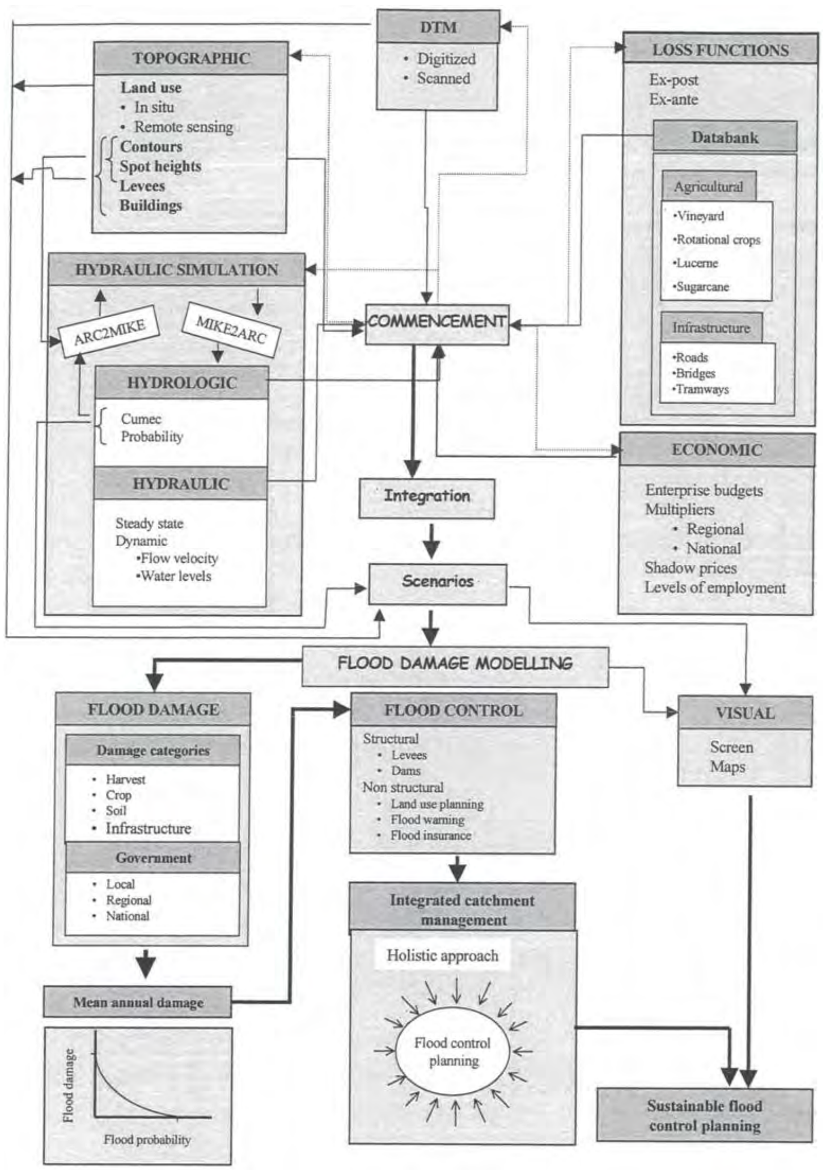

Figure 6: A Typical FLODSIM Simulation – Source: du Plessis, 1998

After this, the economic database is chosen. The economic database consists of enterprise budgets, multipliers (regional and national) shadow prices and employment rate. Information from enterprise budgets is used to calculate the total direct flood damage. With the total direct flood damage known, it is possible to calculate the secondary results of floods by using suitable multipliers. When flood damage is calculated from a national viewpoint, the under- and over supply of agricultural commodities are of importance. To make sure that the real economic value of the various agricultural commodities is reflected, it is necessary to make some shadow price adaptations. The employment rate of the South African economy is also of importance, seeing that floods have a stimulating effect on the local economy when it does not function at full employment level (du Plessis en Viljoen, 1995).

After the database has been specified in the FDSM, it is possible to set up several scenarios by manipulating the topographical, hydrological, hydraulic and economic data. Flood damage can then be calculated for a specific scenario from a local, regional and a national point of view. Scenarios can also be shown visually on the screen or on maps. Maps are essential for floodplain planning and the depth and duration of overflows, as well as floodlines and flood areas can be shown. These are especially essential for flood management plans. A difference is being made between harvest, crop, soil and infrastructure damage. When the flood damage for floods with different probabilities of occurrence is known, it is possible to calculate the mean annual damage (MAD).

Structural and non-structural control measures can only be evaluated adequately if the MAD is known. Traditionally, flood damage modelling calculated only structural and non-structural control measures. This gave rise to the escalation of flood damage and the non-optimal utilisation of floodplains. Additional aspects also have to be considered, so that especially local authorities can be in the position to formulate sustainable long-term flood management plans. For this purpose, a holistic approach to integrated catchment area management is necessary.

4 EMPIRICAL RESULTS

For the purpose of this study it was decided to use the Chatty River at Port Elizabeth as pilot study. The main reason for this is because the research team already has most information (as discussed above) readily available for simulation purposes.

Land-uses in the floodplain of the Chatty River consist mainly out of informal settlements. The discussion of loss functions for the Chatty River falls outside the scope of this report. However, this has been discussed in detail in Du Plessis *et al*., 1998 for the interested reader.

Next, the direct primary flood damages will be discussed first, which were determined by using the original flood level information (provided by SRK Consulting). After this discussion, the direct primary flood damages were determined by using the newly derived flood level information (provided by SRK

Consulting). Lastly these two data set were compared with each other, after which the necessary conclusions and recommendation will be made.

4.1 Flood damage for Chatty with original flood level estimation

After the above procedures were followed and implemented for the Chatty River study area, it was possible to determine the potential flood damages for simulated floods, using the original flood level estimations (received from SRK Consulting). Table 4.1 summaries the results. The mean annual flood damage (MAD) for the Chatty River (2002) determined with the original flood level information equals R4,617 million.

Table 4.1: Flood Damage for the Chatty River, with original flood level estimation, 2002

Flood	Probability	Flood Damage (R)
2	50.00%	6,020,055
5	20.00%	6,187,198
10	10.00%	6,348,885
20	5.00%	6,512,452
50	2.00%	6,512,452
100	1.00%	6,512,452
200	0.50%	7,084,339
500	0.20%	7,462,108
1000	0.10%	7,734,425
5000	0.02%	8,558,735
10000	0.01%	9,206,586
MAD		**4,616,674**

4.2 Flood Damage for Chatty with new derived growth curves

New hydraulic information was received from SRK to determine the direct flood damages. Table 4.2 summaries results received from the new high flood levels using the new derived flood peaks. The mean annual flood damage (MAD) for the Chatty River (2002), using the newly derived growth curves equals R4,622 million.

Table 4.2: Flood Damage for the Chatty River, with new flood levels using the newly derived flood peaks, 2002

Flood	Probability	Flood Damage (R)
2	50.00%	6,020,055
5	20.00%	6,187,198
10	10.00%	6,348,885
20	5.00%	6,512,452
50	2.00%	6,729,953
100	1.00%	6,897,664
200	0.50%	7,061,234
500	0.20%	7,247,481
1000	0.10%	7,352,533
5000	0.02%	7,606,187
10000	0.01%	7,683,985
MAD		**4,622,390**

4.3 Comparison between information sets

When the newly derived flood peak information is used to determine the direct flood damages, it is interesting when results are compared with the original flood level estimation. There is no difference in flood damages for floods smaller than the 50 year floodline. Flood damages for the 50 and 100 year floodline suddenly increase when using the newly derived flood peak information (Table 4.2). For floods, bigger than the 100 years flood, flood damages decrease when using the newly derived flood peak information. When comparing the differences of flood damages of individual floodlines with each other, the differences seem to be quite significant (20 per cent in the case of the 10 000 floodline). There is only a 5 per cent difference in flood damage for the 100 year floodline between the two data sets (Figure 7). However, there is only a 0.12 per cent difference in the MAD, which is not at all a significant difference (Table 4.2).

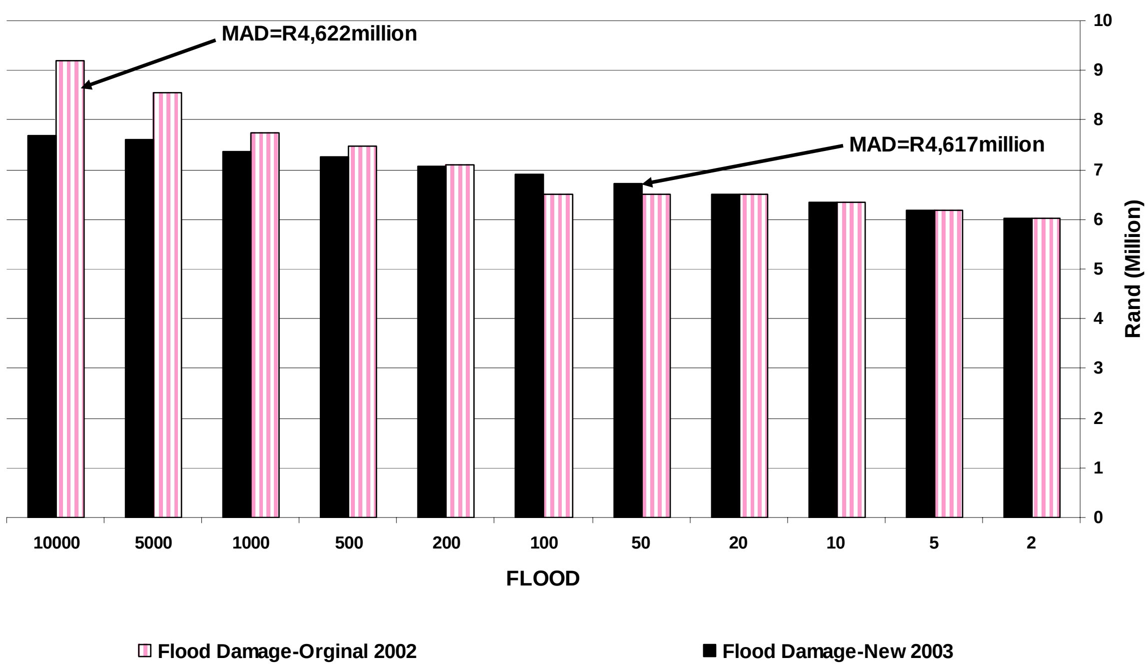

Figure 7: Comparison between the original flood peak estimation and the newly derived flood peak information

An unique procedure has been developed by SRK and Watees Consulting (Pty) Ltd to add value to flood hydraulics, flood hydrological and flood damage information, namely:

- From the flood hydraulics (flood depth and duration of inundation) information it is possible to formulate appropriate evacuation plans which will guide disaster management in proactive evacuation plans which will guide disaster management in proactive planning. The 100 year floodline can be used as a guideline for evacuation plans.

- From the flood hydrological information (this is when the probability of floods are added to the flood hydraulic information) it is possible to formulate appropriate and sustainable development policy for the disaster management component.
- It is possible to execute a flood damage risk assessment by using the flood damages to formulate appropriate flood prevention and mitigation strategies. In this case, the MAD plays a crucial role in the formulation of optimum prevention and mitigation strategies.

Bearing the above-mentioned procedures in mind and information required to execute all the assessments, the following conclusions can be made:

- Flood hydraulics is used for the formulation of evacuation plans and very little differences exist between the original and newly derived flood level information. It can therefore be concluded that evacuation plans will not change significantly when using either approaches.
- The probability did not change, hence no changes are foreseen when development policies are formulated.
- Notwithstanding the changes in individual flood damages, the MAD between the two data sets only differ with 0.2 per cent and will not influence the optimum prevention and mitigation strategy.

4.4 Conclusions and recommendation

When using the newly derived flood levels to determine flood damages it can be concluded that very little to no differences exist for smaller floods when results are compared with the original flood level information. Differences only appear in floods bigger than the 20 year floodline. The 50 and 100 year floodline indicates a slight increase in flood damages, while all the flood damages for floods bigger than the 100 year floodline decrease when using the new derived flood level information. This information does not indicate any trend, not does it give from an economic point of view any useful information for planning purposes.

It is therefore only when the hydraulic information is integrated with unique risk assessment procedures, that useful conclusions can be made. There is no significant difference in the results when using it for planning purposes. In other words, when using the newly derived flood level information, it will not change evacuation plans, development policies nor will it change the optimal prevention and mitigation strategies when the flood damages are calculated with the new data set.

Hence, the additional effort, costs and information required to generated hydraulic information needs to be weighted against its benefits. In this case it seems that no additional benefits from an economic and sustainable development point of view will be gathered.

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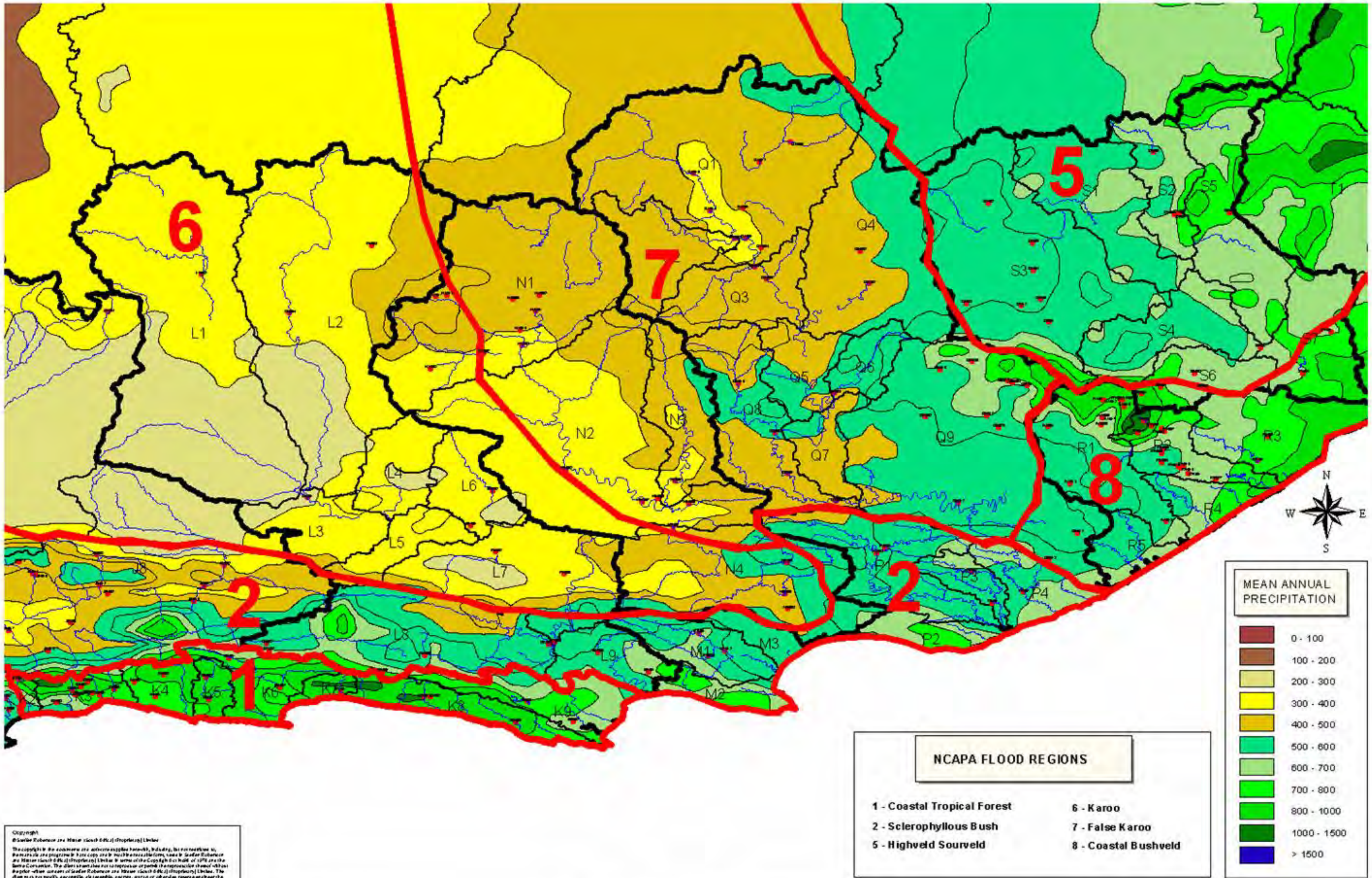

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