The Augmentation of Water Supply to the Central Area of Namibia and the Cuvelai

WATER RESOURCES YIELD ASSESSMENT OF THE KUNENE RIVER AND DROUGHT ANALYSES

NOVEMBER 2014

AECOM

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LIST OF ABBREVIATIONS

AMSL	above mean sea level
ARMA	Auto-regressive Moving Average
CAN	Central Area of Namibia
DSL	dead storage level
Epupa	Feasibility Study for the Lower Cunene Hydropower Scheme
FSL	full supply level
LCL	lower confidence limit
LCE	GABHIC Study by Coba consultants
MAP	mean annual precipitation
MAR	mean annual runoff
MAE	mean annual evaporation
UCL	upper confidence limit
WRYM	Water Resources Yield Model
WRYM-MF	Water Resources Yield Model Management Framework
YRC	yield-reliability characteristics

LIST OF UNITS

km^2	square kilometre
m^3	cubic metre
m^3/s	cubic metre per second
million m^3/a	million cubic metre per annum
r	correlation coefficient

1 INTRODUCTION

The Ministry of Agriculture, Water and Forestry (Namibia) appointed **Lund Consulting Engineers CC / Seelenbinder Consulting Engineers JV** to undertake ***The Augmentation of Water Supply to the Central Area of Namibia and the Cuvelai*** Prefeasibility Study.

AECOM SA (Pty) Ltd in association with Hydrological Assessment Monitoring and Management cc (HAMM cc) was appointed as sub-consultant to the JV for statistical analyses to establish correlations between drought occurrences of existing and potential surface water resources as well as to determine the yield in the Kunene River at Ruacana.

1.1 SCOPE OF THIS REPORT

The objective of this report is to assess:

- The extent of the correlation between droughts in the Okavango River and Kunene River.
- The extent of the correlation between droughts in the Okavango River and the three dams in the Central Area of Namibia (CAN), namely Von Bach, Swakoppoort and Omatako dams.
- The yield in the Kunene River at Ruacana under various development scenarios.

The foremost concern on acceptance of this assignment was the availability of hydro-meteorological data. The hydro-meteorological data prerequisites for statistical and yield analyses are quite stringent, and inadequacies and paucity of the data could limit the type of analyses and confidence in the results.

1.2 STUDY AREA

This Study area comprises of the Kunene River, Okavango River and the three CAN dams, namely Omatako, Von Bach and Swakoppoort.

The Kunene River originates in the Angola highlands to the northern border with Namibia. It then flows west along the border until it reaches the Atlantic Ocean.

The Okavango River is the fourth-longest river system in southern Africa. It originates in Angola, where it is known as the Cubango River. Further south it forms part of the border between Angola and Namibia, and then flows into Botswana, discharging into a swamp in the Okavango Delta.

Windhoek, which is the largest industrial and financial centre in Namibia, relies mainly on three major dams, the Von Bach and Swakoppoort dams on the Swakop River and the Omatako Dam, for its water supply. Future planning to provide sufficient security of water supply for Windhoek is based on the integrated use of the three dams together with groundwater in the Windhoek aquifer and the conjunctive use with the groundwater resources of the Karst Area.

2 HYDRO-METEOROLOGICAL DATA

The water resource yield assessment was undertaken using hydro-meteorological data mainly supplied by Lund Consulting, but supplemented by other sources, and comprises of:

- Observed and normalised hydro-meteorological data provided for the CAN dams and the Okavango by Lund Consulting;
- Research rainfall and stream flow data based on satellite imagery on the Okavango River by University of Grahamstown, South Africa, provided by Prof. DA Hughes (Denis A. Hughes, n.d.);
- The report and stream flow data in the GABHIC report (GABHIC, 2005) which used the Epupa stream flow data ((PJTC), 1990) for yield and hydropower analyses;
- LCE Report (Engineers, 1992);
- Personal communication with Mr Willem van Wyk from AECOM who is currently involved with the rehabilitation of the Calueque Dam (van Wyk, 2014).

Further details in this regard are provided in the remainder of this section.

2.1 RAINFALL DATA

2.1.1 Background

Namibia is the driest country in southern Africa. Rainfall in Namibia is low, unpredictable, unreliable, erratic and spatially unevenly distributed across the country. The mean annual precipitation (MAP) decreases from more than 600 mm/a in the Zambezi (Caprivi) Region in the extreme north-east to less than 50 mm/a towards the south and west. The country-wide average rainfall is approximately 270 mm.

2.1.2 Rainfall data requirements

The availability of rainfall data for hydrological analyses is critical. Rainfall data have the advantage that it is generally more economical and straightforward to collect than stream flow data. Also rainfall data are not impacted by land-use changes and infrastructure development as is the case with stream flow data. In the absence of satisfactory periods of stream flow data, rainfall records can be used to extend and patch these stream flow records, using a rainfall/runoff model.

Rainfall and stream flow data alike, are used to derive statistical correlations between different datasets and locations. It is expected that the correlation between rainfall data from various locations be more reliable than what is obtained from stream flow data with no man-made impact and probably fewer observation and instrumentation errors, as explained in the previous paragraph.

The various sources of rainfall data for the study area are discussed in the remainder of this section.

2.1.3 Available rainfall data in the Okavango

The scarcity of data in the Okavango motivated the Okavango Study (Denis A. Hughes, n.d.) where rainfall estimates were derived from satellite imagery. This Study derived monthly time series of rainfall data over the **Okavango River Basin** at 23 locations for the period from 1959 to 2002 to supplement the extremely limited observed hydrological parameters, such as precipitation and run-off, in the Okavango River. The derived MAPs range from 460 mm in northern Namibia/Botswana, increasing to 1 800 mm in Angola with the highest rainfall in the Upper Northern Regions of Angola.

This data was analysed to determine its value for use in this study, but excluded after evaluation for statistical analyses, since it was found that the stream flow time series derived from this satellite rainfall displayed some serial correlation, which is not the seen in the observed stream flow data. The serial correlations are discussed in more detail in **Section 2.3.3**.

2.1.4 Available rainfall data in the CAN

a) ***Rainfall data at the CAN dams***

Even though observed rainfall data at the three CAN dams were available, the records were short and incomplete. The only complete rainfall records with adequate length for analyses were the catchment rainfall. This data were therefore used in the statistical analyses and a summary of the catchment data used is provided in **Table 2.1** and the time series are provided in **Appendix B**.

Table 2.1: Summary of the characteristics of the catchment rainfall of the CAN dams

Location	Period	MAP mm	Description	Comments
Swakoppoort Dam	1923 - 2012	308	Normalised catchment rainfall	Catchment rainfall data complete and stationary
Von Bach Dam	1923 - 2012	345	Normalised catchment rainfall	Catchment rainfall data complete and stationary
Omatako Dam	1923 - 2012	355	Normalised catchment rainfall	Catchment rainfall data complete and stationary

2.1.5 Available rainfall data in the Kunene River

There are no readily available observed rainfall data in the Kunene River catchment in Angola where the bulk of the stream flows are generated.

2.1.6 Summary of rainfall data used

The scope of this study was limited to the use of available and complete data, and not to generate or patch any data. Unfortunately, the observed time series of rainfall data obtained for use in this study contain many periods of incomplete data. Most of the rainfall data were therefore excluded from the statistical analyses for this study. The use of rainfall data for statistical analyses was therefore limited to the catchment rainfall data from the CAN dams.

Also, a complete time series of monthly rainfall data covering the modelling period representative of the rainfall at a dam is a pre-requisite to model rainfall directly onto the exposed surface area of major dams for calculation of net evaporation from the dam. Absence of such rainfall data, compelled the use of the net monthly average evaporation from the surface area of these dams as published in the GABHIC Study (GABHIC, 2005). Net evaporation is the monthly average evaporation minus the rainfall on the exposed surface area of the relevant dam. See **Section 2.2** for more details.

No rainfall data, *per se*, was therefore directly included to model evaporation losses from the Gove and Calueque dams in the Kunene River.

2.2 EVAPORATION

Evaporation rates in Namibia decrease from more than 2 600 mm/a in the south, to 1 680 mm/a in the north-east and coastal areas due to higher cloud cover and cool and humid conditions in the south-western regions.

It was mentioned in the previous section that net monthly evaporation at Gove Dam and Calueque Dam in the Kunene River were sourced from the GABHIC Study (GABHIC, 2005) as there are no observed readily available meteorological data. The net mean monthly evaporation is summarised in **Table 2.2**. It is shown that the estimated potential net evaporation rate at Gove Dam is far more favourable than that at Calueque Dam with the net MAE at Calueque four times higher than at Gove Dam.

Table 2.2: Net mean monthly evaporation (mm)

Location	Net mean evaporation (mm)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Gove Dam	68	40	0	0	0	0	0	52	52	52	68	68	400
Calueque	159	116	116	73	58	58	116	116	159	160	160	159	1 450

2.3 RUNOFF

2.3.1 Background

The Okavango and Kunene rivers are the only perennial rivers in the study area and are located on the national borders with Angola and the short border with Botswana in the Caprivi.

The headwaters of the **Okavango River** in Angola are responsible for the greater portion of the runoff in the Okavango River and are largely natural with very little impact from human activities. Few dams have been constructed on these rivers and there has been little artificial channelling of the rivers.

The **Kunene River** basin is also largely undeveloped with some infrastructure developments, which serve mainly as balancing dams for hydropower and irrigation activities. The three dams are at Matala, Gove and Calueque in Angola, with a weir and hydro-electric scheme near the falls at Ruacana. The potential for future hydro-electric schemes downstream of the Ruacana Falls are also under investigation by other studies. The incremental contribution of run-off between Calueque and Ruacana was found to be negligible by previous studies

(LCE Report) and likewise no adjustment in runoff had been applied between these two sites.

In the interior of Namibia, surface water is available only in the summer months when rivers are in flood after exceptional rainfalls. Otherwise, surface water is restricted to a few large storage dams retaining and damming of these seasonal floods and runoff. The inflow records of the three major dams that supply water to Windhoek and the Cuvelai area, the Von Bach and Swakoppoort dams on the Swakop River and the Omatako Dam, the so-called **CAN dams**, were obtained for statistical analyses. These inflow records show many consecutive months of no flow.

2.3.2 Stream flow data requirements

Natural monthly stream flow records are used in yield analyses as a basis for determining the historical sequence of inflows to reservoirs within the water resources system under consideration, and thereby allow for the behaviour of the system to be simulated under various development scenarios. Complete natural stream flow records with sufficient overlapping periods between the different sites are a pre-requisite for correlation analyses.

2.3.3 Stream flow data in Okavango River

As discussed in **Section 2.1.3**, the lack of hydrological data in the upper Okavango in Angola, necessitates consideration of all available information and data for use in this study.

a) ***Data derived from Satellite Imagery***

The University of Grahamstown derived rainfall data from satellite images (Denis A. Hughes, n.d.) using advanced scientific technology to extend the rainfall data time series spatially and temporally. Subsequently, this rainfall data was used in the Pitman rainfall-runoff model **(Pitman, 1973)** to generate stream flow data. The use of satellite data to generate rainfall records from satellite data is an innovative approach. Research during the early 1990's showed reasonable results for the inland parts of South Africa, but in general it was agreed that satellite rainfall data overestimated the true rainfall. Subsequent improved technologies yielded superior satellite images to generate improved rainfall data.

Serial correlation analyses of the modelled annual runoff at Mukwe in the Okavango River are illustrated graphically in **Appendix D.1**. These analyses show significant memory at annual lags of one, six and seven consecutive years with the annual lag at the second consecutive year at 0.29, nearly exceeding the upper confidence limit of 0.298.

This is in complete contrast to the absence of any significant memory in all the available observed records of the region which is shown in **Appendix D** and discussed in more detail in **Section 3.2.2**.

The impact of this significant memory will be to overestimate the stream flow as it is in actual fact purely random. This stream flow data obtained from the satellite study were therefore excluded.

b) ***Observed stream flow data***

Observed daily stream flow records supplied by Lund Consulting at Rundu and Mukwe in the Okavango River were the only stream flow data available and were used for statistical analyses. The observed stream flow record from Dirico was also obtained from an unknown source and included in the analyses. The aggregated monthly stream flow records are shown in **Appendix C**.

2.3.4 Inflow data of the CAN dams

The recorded and normalised stream flow records obtained for the three dams that supplies water to the central area of Namibia and the Cuvelai, namely Swakoppoort Dam with a full supply capacity (FSC) of 63.5 million m^3, Omatako with a FSC of 43.5 million m^3, and von Bach Dams with a FSC of 48.6 million m^3, were supplied by Lund Consulting. The normalised sequence refers to the fact that the five highest runoff year's values were normalised with the preceding and subsequent years to account for possible estimation errors.

2.3.5 Stream flow data in the Kunene River

The observed stream flow gauging station at Ruacana has only 12 years (1961-1972) data that could be considered as reliable, due to uncertainties in the upstream flow regime after the building of the Gove Dam and inconsistent recording at Ruacana. The Epupa Study ((PJTC), 1990) extended and naturalised this record through correlation with the stream flow record at Ruacana.

Natural stream flow data were sourced from the GABHIC report (GABHIC, 2005) which in turn used the aggregated data from the Epupa Study ((PJTC), 1990). Previous studies disaggregated the naturalised inflow at Calueque Dam to create incremental stream flow records at both Calueque Dam and Gove Dam. Uncertainty exists regarding the breakdown of the cumulative stream flow into incremental run-off at Gove and Calueque dams. No rainfall records in Angola were available and thus prevented any extension of these stream flow records.

2.3.6 Extension of annual stream flow records at Rundu, Mukwe, Dirico and Ruacana

Observed and extended stream flow records in the Kunene and Okavango rivers were sourced as follows:

- The Kunene River in Angola for the period 1933 - 1971;
- The Cubango River at Dirico from 1959 - 2003;
- The Cubango/Okavango River at Rundu cover the period 1945 - 2008; and
- The Cubango/Okavango River at Mukwe from 1949 - 2007.

One of the objectives of this report was to compute cross correlations between different locations to assess differences or similarities of low flow periods. The initial analyses showed fairly good cross correlations in the Okavango and Kunene between sites, albeit for different, rather short periods, which complicates useful comparison.

The annual stream flow records were extended backwards in time to a common starting period of 1933/34 with multiple linear regression (MLR) software, developed by HAMM cc to compute basic statistics and cross correlations. This enabled the derivation of a statistical model for each of Rundu, Mukwe, Dirico and a new record for Ruacana for the complete period from 1933/4 to 2008/9 based on the record used in the GABHIC (2005) report.

1. This software uses the backward elimination technique, which displays the development of the multiple linear model at each step. The user controls the inclusion or exclusion of independent variables in the model by supplying a t-value. The square of the correlation coefficient as well as the standard errors of estimate and t-values for the intercept and each independent variable are computed, as well as an F-value which indicates the probability of a sufficient model. Tables for t-values and F-values are published in statistical text books. A high F-value is an indication of a plausible model.

Although a multiple regression model for each site was successfully fitted, the best or robust models were found to be a simple straight line for each gauging site. **Table 2.3** summarizes the linear regression results and the annual stream flows are provided in **Appendix D**.

Table 2.3: Linear regression results used to extend stream flow records

Dependable variable	Intercept	Coefficient	Independent variable	r^2	F-value
Rundu	1 591.52	0.972	Calueque LCE	0.928	321
Mukwe	5 356.76	0.856	Rundu	0.932	222
Dirico	726.38	0.386	Mukwe	0.715	108
Ruacana extended	-2 031.22	1.322	Rundu	0.949	812

2.3.7 Stream flow data used in this study

The time-series of monthly incremental natural stream flow data for the Kunene and Okavango rivers are presented in **Appendix D** and a summary of the data is provided in **Table 2.4**.

Table 2.4: Summary of natural runoff characteristics for incremental catchments

Location of (in)flow record	Period	Natural / observed	Incremental MAR (million m³/a)	Comments
Gove Dam (GABHIC, 2005)	1945 - 1994	Natural	1 469.00	Complete and stationary
Calueque (GABHIC, 2005)	1945 - 1994	Natural	3 523.00	Complete and stationary
Calueque LCE data (Engineers, 1992)	1933 - 1987	Natural	3 866.00	Not analysed
Von Bach Dam	1970 - 2012	Near natural	15.50	Complete
Omatako Dam	1981 - 2012	Near natural	24.40	Complete
Swakoppoort	1977 - 2012	Near natural	19.16	Complete
Mukwe	1949 - 2007	Daily observed and monthly	9 219.00	Gaps. Intact for 1945 - 1983
Rundu	1945 - 2012	Daily observed and monthly	5 286.00	Gaps. Intact for 1945 to 1989
Dirico	1959 - 2002	Observed annual	4 317.00	Only annual data available

3 SERIAL AND CROSS CORRELATION ANALYSES

3.1 INTRODUCTION

This section describes the serial and cross correlations at and between the catchments of the Okavango, Kunene river catchments as well as the central area of Namibia (CAN) using complete, readily available hydro-meteorological data. Stationary complete natural stream flow data and / or rainfall data with sufficient length and overlapping periods of data, including dry and wet periods, are a pre-requisite for these analyses. The study area is unfortunately characterised by a paucity of rainfall and stream flow data and data availability is discussed in detail in the previous section (**Section 2**).

For the statistical analyses, a data set comprising of ***stream flow*** and ***catchment rainfall data*** were selected, as follows:

- Stream flow in the Cubango (Okavango) River at Rundu;
- Stream flow in the Cubango (Okavango) River at Mukwe;
- Stream flow in the Cuito River, a tributary of the Cubango at Dirico;
- Stream flow in the Kunene at Ruacana (GABHIC, 2005);
- Catchment rainfall data for the Von Bach Dam;
- Catchment rainfall for Omatako Dam; and
- Catchment rainfall for Swakoppoort Dam.

General statistics of the records used are given in **Table 3.1.**

Forecasting for water supply purposes has a long term focus; for that reason annual time series were analysed to determine the correlations, be it serial or cross, at and between selected sites.

The CAN dams are situated in an area of very low rainfall and consequently have low runoff from their catchments. Rainfall in the catchments is highly seasonal with prolonged periods of low runoff. Soil moisture storage in the catchments becomes depleted very soon after rain storms. It is known that soil moisture plays a very important part in regulating the amount of runoff from a catchment. The extremity of the climate and runoff regime is succinctly summarised by the runoff statistics and cross correlations depicted in **Table 3.1.**

Table 3.1 : Basic statistics of the hydro-meteorological records used for the statistical analyses

Location	River / region	Observed record period	Statistics for period	Statistics		
				MAR (million m³) or MAP (mm)	SD	CV
Rundu stream flow	Okavango	1945 - 2012	1945 - 1995	5 263	1 976	0.38
Dirico stream flow	Okavango	1959 - 2002	1945 - 1995	4 489	809	0.18
Mukwe stream flow	Okavango	1949 - 2008	1945 - 1995	9 537	1 977	0.21
Cumulative Ruacana (GABHIC, 2005) stream flow	Kunene	1945 - 1995	1945 - 1995	4 992	2 650	0.53
Cumulative Ruacana stream flow extended	Kunene	N/A	1945 - 1995	4 924	2611	0.53
Omatako catchment rainfall	Central Namibia	1923 - 2012	1945 - 1995	356	133	0.70
Swakoppoort catchment rainfall	Central Namibia	1923 - 2012	1945 - 1995	308	112	0.37
Von Bach Dam catchment rainfall	Central Namibia	1923 - 2012	1945 - 1995	345	117	0.34
Omatako recorded inflow	Central Namibia	1970 - 2012	1970 - 2012	24	28	1.15
Swakoppoort Dam recorded inflow	Central Namibia	1970 - 2012	1970 - 2012	19	31	1.61
Von Bach Dam recorded inflow	Central Namibia	1977 - 2012	1977 - 2012	16	20	1.30

3.2 SERIAL CORRELATION

3.2.1 Methodology

Serial correlation, also referred to as auto correlation, is an important technique to determine whether there is 'memory' in a time series. Another way of describing serial correlation is that it depicts the correlation of the stream flow or rainfall with itself over successive time intervals.

Serial correlation, together with other statistical functions such as the partial autocorrelation function, provides guidance towards fitting autoregressive-moving-average (ARMA) type stochastic models. The greater the 'memory' of the process the greater will be the possibility to do successful forecasting of the process.

The serial correlation analyses were applied to the full available record period of data as overlapping of records at the different sites are not considered for this type of analyses.

3.2.2 Results

Table 3.2 lists the serial correlations of the annual stream flow and rainfall data in the Kunene and Okavango rivers for the overlapping years of record. These serial correlations are shown graphically in **Appendix D.** It is shown that the serial correlation never exceeds the upper 95% confidence level (UCL) or lower 95% confidence level (LCL) which very clearly indicates that the selected rivers and rainfall analysed are random in nature. Although some serial correlations on these graphs appear to reveal a weak seven year cycle, it falls within the 95% confidence limits, implying that the serial correlation of all the stations is statistically insignificant.

The serial correlations for the stream flow and catchment rainfall for the period 1981 to 2007 are shown in **Table 3.3**. These serial correlations are also shown graphically in **Appendix D.**

Table 3.2: Serial correlation of stream flow data at specific sites in the Okavango and Kunene rivers

Lag (year)	Rundu	Dirico	Mukwe	Ruacana (Extended)	Ruacana (GABHIC 2005)	UCL	LCL
0	1.000	1.000	1.000	1.000	1.000	0.277	-0.277
1	0.112	0.195	0.251	0.112	0.003	0.277	-0.277
2	0.052	0.060	0.176	0.052	0.038	0.277	-0.277
3	-0.006	-0.062	0.030	-0.006	0.044	0.277	-0.277
4	-0.193	-0.092	-0.084	-0.193	-0.131	0.277	-0.277
5	-0.045	-0.006	-0.002	-0.045	-0.015	0.277	-0.277
6	-0.070	0.163	-0.004	-0.070	-0.096	0.277	-0.277
7	0.138	0.263	0.210	0.138	0.106	0.277	-0.277
8	-0.012	0.157	0.103	-0.012	0.003	0.277	-0.277
9	0.039	0.058	0.043	0.039	0.087	0.277	-0.277
10	-0.195	-0.049	-0.104	-0.195	-0.177	0.277	-0.277
11	-0.147	-0.136	-0.151	-0.147	-0.047	0.277	-0.277
12	-0.038	-0.092	0.008	-0.038	-0.057	0.277	-0.277
13	-0.073	-0.017	-0.016	-0.073	-0.102	0.277	-0.277
14	0.184	-0.123	0.227	0.184	0.230	0.277	-0.277
15	0.104	0.171	0.126	0.104	0.034	0.277	-0.277
16	0.183	0.002	0.099	0.183	0.154	0.277	-0.277

It is shown that the serial correlations of the CAN dams do not exceed the upper 95% confidence level (UCL) or lower 95% confidence level (LCL). The CAN rainfall and inflows, similar to that of the Kunene River and Okavango River display no serial correlation, and can therefore be regarded as random in nature.

The serial correlation analysis confirms the finding of fitting an ARMA (0,0) model in the Kunene River (see **Section 4.2.2**) as the most appropriate fit. This is also an indication that the stream flow data are random in time. The fitting of the ARMA (0,0) model on the Kunene River annual stream flow data and disaggregated to monthly data, is discussed in **Section 4** in more detail.

Table 3.3: Serial correlation for the period 1981 to 2007

Lag (year)	Swakoppoort Dam rainfall	Swakoppoort Dam inflow	Omatako Dam rainfall	Omatako Dam inflow	von Bach Dam rainfall	von Bach Dam inflow	UCL	LCL
0	1.000	1.000	1.000	1.000	1.000	1.000	0.370	-0.370
1	-0.047	-0.132	-0.077	-0.236	-0.255	-0.222	0.370	-0.370
2	-0.013	0.071	-0.211	-0.294	0.055	0.176	0.370	-0.370
3	-0.025	-0.039	0.052	0.118	0.055	-0.054	0.370	-0.370
4	0.239	0.075	-0.152	-0.172	-0.265	-0.043	0.370	-0.370
5	0.037	-0.182	-0.238	-0.219	0.113	0.009	0.370	-0.370
6	-0.240	-0.189	0.066	0.506	-0.204	-0.050	0.370	-0.370
7	-0.029	-0.105	0.053	-0.180	0.120	-0.132	0.370	-0.370
8	-0.125	0.056	0.004	-0.064	-0.019	-0.008	0.370	-0.370
9	0.187	0.251	0.154	0.196	-0.023	0.110	0.370	-0.370
10	-0.295	-0.311	-0.055	-0.124	-0.074	-0.200	0.370	-0.370
11	0.061	0.105	-0.079	-0.093	-0.050	0.044	0.370	-0.370
12	-0.088	0.094	-0.059	0.106	-0.030	-0.017	0.370	-0.370
13	0.024	-0.025	0.063	-0.114	-0.122	-0.087	0.370	-0.370
14	-0.120	-0.187	-0.034	-0.037	0.129	-0.136	0.370	-0.370

3.3 CROSS CORRELATION

3.3.1 Methodology

The significant statistical cross correlation between different data sets provides a means of successfully fitting statistical or other types of models to extend short records and to transpose information of droughts from one place to other places. The square of the correlation coefficient indicates the variance which can be declared in a statistical equation. Thus a 0.9 correlation coefficient (r) indicates that only 81% of the variance (r^2) of the dependant variable can be declared.

Cross correlations were determined between annual stream flow records and rainfall records, for a 50 year overlapping period between 1945 and 1994 and also from 1981 to 2007 to include the CAN dams in the analyses.

3.3.2 Results

The cross-correlations between the Okavango, Kunene steam flow and CAN rainfall are given **Table 3.4**. The unusual high correlation in Table 3.4 between

Rundu in the Okavango River, and previously derived records for Calueque/Ruacana (0.98 to 1.0) in the Kunene River is suspect as these records were derived from correlation with the longer stream flow record at Rundu. There is no correlation between the CAN rainfall and the Okavango stream flow data, which is depicted by cross-correlation between 0.09 and 0.33.

The annual statistics at Dirico and Mukwe display an unusually low coefficient of variation (CV) of 0.18 and 0.20 respectively which means that the Okavango River flows do not vary that much between years which is an indication of a perennial river. It originates in a high rainfall region in Angola.

The Kunene River is in an adjacent catchment to the west of the Okavango origin, where the rainfall is reported to be lower. This should instil some caution towards transposing the Okavango River stream flow to the Kunene River without verification.

This concern is partly addressed by using Rundu with a coefficient of variation of 0.37 (indicating more variability in stream flow) and previously derived records at Ruacana by the Study (GABHIC, 2005) with a CV of 0.54. Since all the stream flow time series indicate randomness, it is wise to study different lengths and severity of dry spells by means of stochastic processes.

Table 3.4: Annual cross correlations (r) of variables for the 50 year hydrological period 1945 to 1994

Site	Rundu stream flow	Dirico stream flow	Mukwe stream flow	Ruacana stream flow (extended)	Ruacana (GABHIC 2005) stream flow	Omatako catchment rainfall	Swakoppoort catchment rainfall	Von Bach catchment rainfall
Rundu stream flow	1.00	0.80	0.93	1.00	0.98	0.26	0.10	0.11
Dirico stream flow	0.80	1.00	0.82	0.80	0.79	0.32	0.17	0.20
Mukwe stream flow	0.94	0.82	1.00	0.93	0.91	0.33	0.17	0.19
Ruacana extended stream flow	1.00	0.80	0.93	1.00	0.98	0.26	0.10	0.11
Ruacana (GABHIC 2005) stream flow	0.98	0.79	0.91	0.98	1.00	0.25	0.09	0.09
Omatako catchment rainfall	0.26	0.32	0.33	0.26	0.25	1.00	0.76	0.78
Swakoppoort catchment rainfall	0.10	0.17	0.17	0.10	0.09	0.76	1.00	0.84
von Bach catchment rainfall	0.11	0.20	0.19	0.11	0.09	0.78	0.84	1.00

Table 3.5: Cross correlation matrix (r) for the 27 year hydrological period 1981 to 2007

Site	Rundu	Mukwe	Swakopoort catchment rainfall	Swakopport Dam inflow	Omatako Catchment Rainfall	Omatako Dam inflow	Von Bach catchment rainfall	Von Bach Dam inflow
Rundu	1.000	0.777	0.299	0.132	0.283	-0.073	0.353	0.124
Mukwe	0.777	1.000	0.344	0.122	0.260	0.005	0.385	0.208
Swakopoort catchment rainfall	0.299	0.344	1.000	0.701	0.630	0.287	0.679	0.715
Swakopport Dam inflow	0.132	0.122	0.701	1.000	0.587	0.530	0.535	0.846
Omatako catchment rainfall	0.283	0.260	0.630	0.587	1.000	0.584	0.673	0.607
Omatako Dam inflow	-0.073	0.005	0.287	0.530	0.584	1.000	0.376	0.446
Von Bach catchment rainfall	0.353	0.385	0.679	0.535	0.673	0.376	1.000	0.567
Von Bach Dam inflow	0.124	0.208	0.715	0.846	0.607	0.446	0.567	1.000

The time series of observed dam inflow records stretch from 1981 to date. The available records of the Okavango / Cubango River at Rundu and Mukwe restricted the cross correlation analysis period to 2007. It was found that there is almost no correlation between the CAN Dams and streamflow in the Cubango River. The cross correlation table shows the annual correlation coefficient with any one of the dams and the Okavango River is very small, with the von Bach catchment the highest at 0.385 (variance of 0.15). The correlation between these dams with their own catchment rainfall is also unexpectedly low.

3.4 DROUGHT FLOWS

Drought flows were derived through low flow analyses. Initially, the worst low stream flow hydrological year (annual total) on record was calculated. The next step was to calculate the worst two consecutive low stream flow years on record. This process was repeated, increasing the drought period up to the worst 13 consecutive low stream flow years on record.

Drought flows were calculated for stream flow on the Kunene River at Gove Dam, Ruacana (GABHIC, 2005), Ruacana (Extended Annual record), (Cubango / Okavango River at Rundu, Dirico, Mukwe and Mohembo.

The drought analyses were done for both the full record period of the records as well as the overlapping period of 1945 to 1995.

3.4.1 Results

Appendix D contains a table with the hydrological year droughts. **Appendix D.2** shows the droughts for the total observed period and **Appendix D.4** compares these droughts over the overlapping period of 1945 to 1995.

It is shown that the worst recorded droughts in Central Namibia are in the early 1920's and the 1990's. The 1980's to early 2000's shows the worst droughts in the Okavango River on record. The earliest stream flow records for the Okavango River only started in 1945.

However, if one compares the overlapping data period (1954 to 1995) of the three regions, the Okavango and Kunene show its worst droughts since the early 1990's with indications that the drought was still ongoing in 1995. The CAN dams shows droughts during the midd-1950's to mid-1960's, which indicate that the correlation between the droughts in central Namibia is independent of the droughts in the Okavango.

It is difficult to come to any conclusion with regards to the correlation between the Kunene River with the Okavango and CAN dams since the Kunene River has very little observed data, and most of its data were derived through correlation with the observed stream flow in the Okavango River.

4 STOCHASTIC VALIDATION AND VERIFICATION TESTS FOR THE KUNENE RIVER CATCHMENT

4.1 BACKGROUND

The primary objective of using stochastically generated stream flows is to provide alternative realistic time series sequences that can be analysed in the same manner as the historical stream flow sequence. However, before the end user can place their confidence in results obtained from such sequences, it is first necessary to provide confirmation that the sequences are in fact realistic and plausible.

In the hydrological analysis undertaken as part of this study, a detailed stochastic stream flow analysis was undertaken, including verification and validation testing of generated stochastic sequences. Based on the results of this analysis it was found that the natural historical runoff time-series data sets have been well prepared and that results of the stochastic stream flow analysis could be considered to be acceptable.

4.2 GENERATION OF STOCHASTIC STREAM SLOW DATA

The firm yield value derived from a single historic stream flow sequence can be very misleading and depends, to a large extent, on the period of record and severity of the critical period. In order to assess the yield from a system, it is normal practice to extend a stream flow record using a rainfall/run-off model to extend the various measured stream flow records to produce longer records that spans the record period of the measured rainfall.

The historic firm yield drops significantly as the period of record increases. It should be noted that as a record becomes longer, the historic firm yield will never increase. The yield can either remain constant or decrease, depending on the location of the critical period in the record.

A single historic firm yield value can, however, be very misleading. Even though the recorded record length has been extended and contains the worst drought sequence in memory, it is not possible to relate the historic firm yield to a specific risk of failure or reliability directly from the record without additional analyses. As water resource systems become more complex and capital intensive, it is increasingly important to estimate the likely risk of failure associated with specific yield values. To achieve this, it is necessary to generate stream flow sequences stochastically, which can be used to derive reliability and risk of failure information associated with various system yields.

As the need for information on reliability grows, the use of stochastic stream flow sequences is becoming increasingly popular in water resource studies. It is no longer satisfactory to say that the yield from a system is 20 million m^3/a. Such a figure could for example indicate 20 million m^3/a with a risk of failure of either once in every 10 years or once in every 200 years. Clearly the reliabilities of the two yields are completely different, hence the need to be more specific and to relate each yield value to a particular reliability.

The major objective of using stochastic generation software is to provide alternative realistic stream flow sequences that can be analysed in the same manner as the historic stream flow sequence. One of the main problems associated with the use of generated stream flow sequences concerns the validity of such sequences. Before the end user can place his/her confidence in results based on stochastically generated stream flow sequences, it is first necessary to provide confirmation that the stochastic stream flow sequences are in fact realistic and plausible.

Two different classes of tests are used in the checking procedure, namely verification tests and validation tests. Verification involves resampling various statistics from the generated sequences to ensure that the model can reproduce the statistics from the historic sequence with reasonable accuracy. Tests of the mean and standard deviation are two examples of verification tests.

Validation tests involve testing certain features of the stochastically generated flows that were not involved directly in the generation of the stream flows. Tests in this category include various storage checks such as maximum deficit, duration of maximum deficit, minimum run-sums and yield-capacity checks.

The STOMSA model, included in the Water Resources Yield Model Management Framework (WRYM-MF), was used for the generation and testing of stochastic stream flow sequences. The STOMSA incorporates three programs and these are ANNUAL, CROSSYR and GENTST-programs.

The ANNUAL-program (Mark 5, named ANLMK5) was used in the stochastic analysis of stream flow data and selects the distribution for modelling annual stream flows which selects the appropriate ARMA(p,q) model.

The CROSSYR-program, CRSMK5 was used to compute the inter-dependence between the annual stream flow residuals from the various stations.

GENTST generates 201 replicate sets of stream flow sequences, each as long as the original historical sample which is 50 years (1945 to 1994). Each of the 201 sequences for each gauge is re-sampled and its basic statistics computed.

4.2.1 Verification and validation tests

A natural incremental stream flow record at Calueque Dam and at Gove Dam was obtained from the GABHIC Study (GABHIC, 2005).

a) ***Monthly and annual means***

The first and most basic verification test carried out on the stochastically generated stream flow sequences involves comparing the monthly and annual means of each stochastic stream flow sequence with those of the historic stream flow record. The test is based on 201 stochastically generated stream flow sequences, each of the same length as the historic stream flow sequence. The mean annual run-off (MAR) of each sequence is calculated together with the 12 monthly averages. The results are then displayed in the form of box plots with the historic values indicated by arrowheads. The acceptability criteria require that the annual historic means are generally between the 25th percentile and the 75th percentile limits of the stochastically generated stream flows.

b) ***Monthly and annual standard deviations***

The second verification test carried out involves the assessment of the monthly and annual standard deviations (SDs) of the generated and historic stream flow sequences.

The annual SDs are particularly important in water resource studies where reservoir yield calculations are involved. The yield from a reservoir will be considerably greater for a low annual SD compared to that obtained when the SD of the annual totals is high.

The results are also then displayed in the form of box plots with the historic values indicated by arrowheads. The acceptability criteria require that the annual historic means are generally between the 25th percentile and the 75th percentile limits of the stochastically generated stream flows.

c) ***Minimum run-sums***

Minimum run-sums are usually given for a particular time period such as 12 months, 24 months, 36 months etc. The 12-month minimum run-sum for a given sequence is the lowest flow to occur during the complete sequence for 12 consecutive months. This is a validation test since the run-sum characteristics of the historic stream flow sequence are not used in any way to generate the stochastic stream flow sequences.

It is sometimes found that the historic minimum run-sums are greater or less than the maximum or minimum simulated values respectively. When examining the minimum run-sum results, however, the general lengths of critical period experienced in the catchment area (also a function of reservoir storage) should be taken into account. If, for example, the average historical critical periods experienced in a given catchment are in the order of two years, it is more important to produce realistic 12 month, 24 month and 36 month minimum run-sums. Obviously it is desirable to match the minimum run-sums for all durations. This is often not achieved, however, in these cases more significance should be placed on the minimum run-sums most appropriate to the given catchment area.

d) ***Maximum deficit and deficit durations***

The maximum deficit and deficit duration tests are validation tests where a given draft expressed as a percentage of the MAR is applied to a semi-infinite reservoir starting full. Three tests are undertaken, the maximum deficit test, the duration of maximum deficit test and the duration of longest depletion test. The results are again simply a variation on the presentation of the results depicted in the minimum run-sum plots and the yield-capacity diagrams.

The maximum deficit test provides a record of the minimum reservoir storage required for each sequence to provide an uninterrupted supply for requirements of 40%, 50%, 60%, 70% and 80% of each generated MAR. The duration of maximum deficit test records the duration in months of the drought event causing the maximum deficit. The duration is the period from full supply to maximum deficit and back to full supply. The maximum duration is obviously the total record length (= 50 years or 600 months in this case).

The third and final test in this set is the duration of the longest depletion that again can be equal to the total record length. The depletion is given in months and does not necessarily tie in with the drought event causing the maximum deficit although in many cases the same event causes both maximum deficit and longest depletion.

e) ***Yield-capacity***

The yield-capacity test is a storage based validation test and is simply the minimum reservoir capacity required to meet a given yield for each of the 201 stochastically generated sequences. This test is simply a different form of presenting the results derived from the minimum run-sum test with the variation that the yields are expressed as percentages of the historical MAR, whereas in the minimum run-sum test, the drafts are a function of the generated MAR. The results are expressed in terms of the historic MAR and yields of 20%, 40%, 60%, 80% and 100% of the MAR are used. The yield-capacity test assumes that there are no evaporation losses from the reservoir surface.

The yield-capacity test is a most useful visual validation test, because it summarises so much of the behaviour of both the historical stream flows and of the generated stream flows. Ideally the stochastic points (indicated by the small squares) should show a reasonable spread around the values obtained from the historic stream flow sequence. This is assuming that the historic record contained periods of average severity as would be expected from the available record length. In such cases historic values should also be reasonably close to the median values of the stochastic stream flow sequences. If the results from the historic record are considerably lower than the median values from the stochastic sequences or even outside the range of generated values, it would indicate that the recorded data contain a period of extreme severity. In such cases the critical period in question should be carefully examined for possible errors.

4.2.2 Results

A summary of the results for the Gove and Calueque dam's inflow records are given in **Table 4.1**. It shows that the natural stream flow data performed adequately when subjected to the verification and validation tests.

The log normal 2 (LN2) distribution were fitted to both the stream flow records for modelling annual stream flows and the ARMA(0,0) model for generation of stochastic stream flow.

Table 4.1 Results of the verification and validation tests for the Kunene River catchments

Catchment	MAR ($10^6 m^3$)	Monthly and annual means	Annual STD	N-month run sums				Yield capacity
				N-month run sums	Max deficit	Duration of max deficit	Duration of longest depletion	
Gove Dam	1 469	Good	Good	Good	Good	Good	Good	Fair
Calueque Dam	4 992	Good	Good	Good	Good	Fair	Good	Good

4.2.3 Conclusions

The log normal 2 (LN2) distribution was fitted to both the incremental natural stream flow records at Gove and Calueque dams. This implies that no inter-dependence between the annual stream flow residuals exists. This is consistent with the statistical tests done (see **Section 1**) as these tests show the variables are completely random (stochastic).

In the stochastic checks the historic values are usually positioned between the 25% and 75% limits suggested by the stochastic sequences. The monthly tests for the shorter periods (less than 5 months) were generally unsatisfactorily, but good to very good for the longer monthly periods.

The stochastic model used in this study is considered to be one of the most reliable models available and has been thoroughly tested over the years in southern Africa. It should also be remembered that no stochastic model is perfect, particularly one in which stochastic sequences are generated simultaneously at multiple sites. No model is capable of producing perfect results at all gauges and any possible errors or anomalies should be judged individually to ensure that they are not data errors or large enough to have a significant influence on the overall results.

Based on the experience gained during previous simulations of stochastic stream flows in this system as well as other parts of Southern Africa, these results are considered to be acceptable

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5 YIELD ANALYSES OF THE KUNENE RIVER SYSTEM

5.1 MAJOR DAMS IN THE KUNENE RIVER

Two important dams were constructed in Angola in the Kunene River during the late 1960's early 1970's mainly for power generation purposes

The **Gove Dam** with a gross full storage of 2 574 million m³ is an embankment dam and is the uppermost dam in the Kunene River in Huambo Province, Angola. The purpose of the dam is to regulate stream flow. Construction of Gove Dam began in 1969 and was completed in 1975.

Downstream, in Angola close to the Namibian border, **Calueque Dam** with a gross storage of 475 million m³/a with future plans to raise it to 1 430 million m³ capacity was constructed in 1974. It was never completed due to the ongoing war. Calueque Dam was severely damaged in 1988.

Storage at Matala Dam is regarded as negligible as it serves only as a balancing dam for abstraction. A summary of the physical characteristics is provided in **Table 5.1** and **Table 5.2** to show the relationship between elevation, storage capacity and surface area for Gove and Calueque dams, respectively.

The reduction in the storage capacity of Calueque Dam is based on sediment volumes derived in the Epupa Study ((PJTC), 1990) and used in the (GABHIC, 2005) Study.

Table 5.1: Physical characteristics of the Gove Dam

Elevation (amsl)	Gross storage capacity (million m^3)	Surface area (km^2)	Notes
1 590	**2 5741**	**178.2**	**Full supply level**
1 585	1 786.4	136.9	-
1 580	1 197.6	98.6	-
1 575	781.6	67.7	-
1 570	486.4	50.4	-
1 565	270.8	35.9	-
1 560	**138.5**	**17.0**	**Lowest draw down / dead storage**
1 555	67.1	11.5	-
1 550	21.8	6.6	-
1 545	2.6	1.1	-
1 541	**0.0**	**0.0**	**Bottom of reservoir**

Table 5.2: Physical characteristics of the Calueque Dam

Elevation (m AMSL)	Storage capacity	Surface area (km^2)	Notes
	Gross (million m^3)		
1 102.5	**1 809**	**431.1**	**-**
1 101.5	1 430	390.0	-
1 100.0	920	279.8	-
1 098.0	475	175.0	**Full supply level**
1 097.5	394	151.3	**-**
1 095.0	123	70.1	**-**
1 092.5	17	19.3	**-**
1 092.0	13	10.0	**Lowest draw down / dead storage**
1 090.0	0	0.0	**Bottom of reservoir**

5.2 WATER USE IN THE KUNENE RIVER CATCHMENT

Some of the water requirements that have been included in the system analyses are given in **Table 5.3**. The total consumptive use from the Kunene River is approximately 10% of the 4 992 million m³/a runoff in the Kunene River. Future water use is uncertain, but indications are that the water requirements will probably double to 20% of the MAR. The current water use can be summarised in **Table 5.3**.

Table 5.3: Present and future water use in the Kunene River catchment

Region	User	Present use		Future use	
		million m³/a	m³/s	million m³/a	m³/s
Upper Kunene requirements	Abstraction downstream of Gove	43.42	1.38	43.42	1.38
	Matala abstraction	214.21	6.79	380.00	12.0
	Total Upper Kunene	**257.63**	**8.17**	**423.42**	**13.38**
Lower Kunene requirements	Calueque supply to Namibia	94.61	3.00	189.22	6.0
	Calueque to Angola (Domestic)	1.58	0.05	47.54	1.5
	Calueque Irrigation	132.45	0.05	380.00	12.0
	Total Lower Kunene	**228.64**	**3.1**	**616.76**	**19.5**
Total abstractions for the Kunene down to Calueque Dam		**486.27**	**11.27**	**1 040.18**	**32.88**

5.3 MONTHLY ABSTRACTION RATES FOR DOMESTIC AND IRRIGATION REQUIREMENTS

The water requirements in the Kunene River system are mainly for irrigation (GABHIC, 2005) and the seasonal distribution derived in the Epupa Study were used for all requirements except where it was explicitly stated that the water are for domestic use or hydropower. The monthly irrigation pattern is given as a percentage of annual requirements in **Table 5.4**.

Table 5.4: Monthly irrigation pattern (as a percentage of annual requirements)

Location	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Irrigation	14.0	9.5	7.9	4.7	2.2	1.4	4.7	7.9	9.2	13.7	11.2	13.6
Domestic requirements	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333

5.4 MODEL CONFIGURATION

5.4.1 Model selection and description

The yield analysis of the Kunene River at Ruacana was undertaken using **Version 3.2.8** of the **Water Resources Yield Model Modelling Framework (WRYM-MF)** system. The model was developed by the South African Department of Water and Sanitation for the purpose of modelling complex water resource systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating large water resource schemes.

The WRYM uses a sophisticated network solver to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system's long- and short-term yields. Analyses are undertaken based on a monthly time-step and for constant development levels, which means that the system configuration and modelled use characteristics remain unchanged over the simulation period. The major strength of the model lies in the fact that it allows for the configuration of most water resource system networks using basic building blocks. A system network and the relationships between its elements are therefore defined by means of input data, rather than by fixed algorithms embedded in the source code of the model.

5.4.2 The system network

The WRYM was configured on the basis of available hydrological data. For the Kunene system, this comprises of incremental inflow records at the two major dams, namely Gove and Calueque dams, as well as the location of in-catchment water users to develop a representative system network model to determine the yield of the Kunene River at Ruacana under various development scenarios. For the purposes of these analyses, it was assumed that there are no incremental inflows between Calueque and Ruacana.

A schematic diagram of the WRYM system network model for the Kunene River system is provided in **Figure A.1** of **Appendix A**.

5.4.3 Operating rules

The purpose of the yield analyses was simply to assess the potential of the Kunene River at Ruacana under various development scenarios. A summary of the physical layout and operation of the Kunene system is provided below:

- Water will be released for power generation and irrigation from Gove Dam to Calueque Dam via the Kunene River with a constant monthly release pattern.
- All user requirements upstream of Calueque Dam will have access to this water. Where applicable the monthly irrigation requirement pattern for abstraction was used.
- Calueque Dam will supply its full requirement.
- Calueque Dam will release water for power generation at Ruacana.
- The yield at Ruacana will be determined after all upstream users' water requirements have been satisfied.
- No specific releases will be made for environmental considerations (minimum stream flow of 50 m^3/s). Compliance with these considerations have, however, been reported on for the historical runs.

Deviations from the discussions for the various scenarios are discussed under each scenario description (see **Section 6.1**).

5.5 YIELD ANALYSIS PROCEDURE

The WRYM model was used to undertake yield analyses in the Kunene River. The yield at Ruacana was determined by imposing a single (variable) target abstraction (or target draft) on the system at Ruacana and assessing the modelled behaviour of the system under target draft and the scenario in question.

Furthermore, all analyses were undertaken on the following basis:

- The analysis period spans 50 years from the 1945 to the 1994 hydrological year (i.e. October 1945 to September 1995). Long-term stochastic yield analyses based on 201 50-year stochastically generated stream flow sequences.

- Both historical and stochastic long-term yield analyses were undertaken with all dams assumed to be full at the start of the analysis period.

6 YIELD ANALYSIS SCENARIOS AND RESULTS

6.1 DEVELOPMENT SCENARIOS

The main objective of the yield analyses was to determine the yield at Ruacana under various development scenarios. Compliance with the environmental requirements which was taken as a minimum stream flow of 50 m^3/s was monitored. The objectives were achieved by analysing defined scenarios using the WRYM-MF, aimed at assessing the performance of the Kunene River system in a variety of situations.

An overview of the selected scenarios is provided below, with the details in **Table 6.1**.

Scenario 1: Present day water requirements before rehabilitation of Calueque Dam and the 1:50 year return period (98% assurance of supply) yield released from Gove Dam on top of the user requirements between Gove and Calueque dams.

Scenario 2: Scenario 1, but with Calueque Dam rehabilitated.

Scenario 3: Optimised Scenario 2 where Gove Dam only releases water when required to minimise spills from Calueque Dam.

Scenario 4: Scenario 2, but with additional abstraction from Calueque Dam.

Scenario 5: Scenario 2, but with even more additional abstractions in the Upper and Lower Kunene River.

Table 6.1: Details of the selected scenarios for yield analyses

Description	Property	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
		million m³/a	m³/s	million m³/a	m³/s	million m³/a	m³/s	million m³/a	m³/s	million m³/a	m³/s
Calueque Dam	FSC²	10.00	-	475.00	-	475.0	-	475.00	-	475.0	-
	Dead Storage	none	-	13.00	-	13.00	-	13.00	-	13.00	-
Gove Dam	FSC²	2 574.0	-	2 574.0	-	2 574.0	-	2 574.0	-	2 574.0	-
	Dead Storage	138.50	-	138.50	-	138.50	-	138.50	-	138.50	-
Upper Kunene requirements	Gove Releases	1 209.0	38.31	1 209.0	38.31	1 439.34	45.61	1 209.0	38.31	1 209.0	38.31
	Gove requirements	43.42¹	1.38	43.42¹	1.38	43.42¹	1.38	43.42¹	1.38	43.42¹	1.38
	Matala abstraction	214.21¹	6.79	214.21¹	6.79	214.21¹	6.79	214.21¹	6.79	380.00¹	12.04
Lower Kunene requirements	Calueque supply to Namibia	94.61¹	3.00	94.61¹	3.00	94.61¹	3.00	189.22¹	6.00	189.22¹	6.00
	Calueque to Angola (Domestic)	1.58¹	0.05	1.58¹	0.05	1.58¹	0.05	31.60¹	1.00	47.54¹	1.51
	Calueque Irrigation	132.45¹	4.20	132.45¹	4.20	132.45¹	4.20	225.00¹	7.13	380.00¹	12.04
TOTAL abstractions/ releases for Upper Kunene River		257.63	8.17	257.63	8.17	257.63	8.17	257.63	8.17	423.42	13.42
TOTAL abstractions/ releases at Calueque Dam and downstream of Calueque Dam		228.64	7.25	228.64	7.25	228.64	7.25	445.82	14.13	616.76	19.55
TOTAL abstractions		486.27	15.42	486.27	15.42	486.27	15.42	703.45	22.30	1 040.18	32.97

¹ Irrigation requirement pattern used

² Full supply capacity

The Gove Dam releases are constant with the exception of **Scenario 3** where the system has been optimised and the average Gove releases are 1 439 million m³/a with the Gove Dam release ranging from minimum 608 million m³/a to a maximum of 3 250 million m³/a.

6.2 YIELD RESULTS AT GOVE DAM

The 1:50 year yield from Gove for a 2 574 million m³ Gove Dam with a lowest drawdown of 138.5 million m³ described in the above table, and a constant release pattern, were determined to establish realistic water releases to Calueque Dam from Gove Dam. The yield depicts the available yield after the full present day requirements between Gove and Calueque was provided. The yield results for Gove Dam are shown graphically in **Appendix C.1** and summarised in **Table 6.2**.

Table 6.2: Historical and stochastic yield results at Gove Dam

Units	HFY Gove	1:20	1:50	1:100	1:200
million m³/a	1 205.60	1 316.00	1 209.00	1 144.00	1 090.00
m³/s	38.23	41.73	38.31	36.28	34.56

These analyses show that the HFY at Gove Dam is very close to the 1:50 year yield.

6.3 YIELD RESULTS AT RUACANA

The results of the yield analyses at Ruacana are summarised in **Table 6.3** and graphically illustrated in **Appendix C**. **Figure 6.1** illustrates the scenario yields graphically.

Scenario 1 and Scenario 2 differs only with regards to the rehabilitation of Calueque Dam. It is shown that the yield increases with approximately 2.5 times at Ruacana, i.e. the yield is 573 million m³/a before rehabilitation and increases to 1 410 million m³/a after rehabilitation of Calueque Dam.

Analyses from Scenario 2 and Scenario 4 show that coordinated releases from Gove Dam can increase the yield by a further 1.4 times from 1 410 million m³/a to 2 040 million m³/a.

The results from Scenario 4 and 5 show that proposed future abstractions have a significant impact on the water available at Ruacana.

Only Scenario 4, with maximum regulation of the stream flow in the Kunene River and minimisation of spills, complies with the minimum environmental requirement of 50 m³/s. The minimum stream flow downstream of Ruacana is equal to the firm yield given in **Table 6.3**.

Table 6.3: Historical and stochastic yield results at Ruacana for various return periods and assurances of supply

Scenario	Units	HFY Calueque	1:20 year (95%)[1]	1:50 year (98%)[1]	1:100 year (99%)[1]	1:200 year (99.5%)[1]
1	million m³/a	573	609	602	none	none
	m³/s	18.17	19.31	19.09	none	none
2	million m³/a	1 410	1 516	1 422	1 159	896
	m³/s	44.71	48.07	45.09	36.75	28.41
3	million m³/a	2 040	2 495	2 255	2 064	1 980
	m³/s	64.69	79.12	71.51	65.45	62.79
4	million m³/a	1 171	1 276	1 183	920	648
	m³/s	37.13	40.46	37.51	29.17	20.55
5	million m³/a	716.00	821.00	731.00	560.00	345.00
	m³/s	22.70	26.03	23.18	17.76	10.94

[1]Assurance of supply is given in brackets

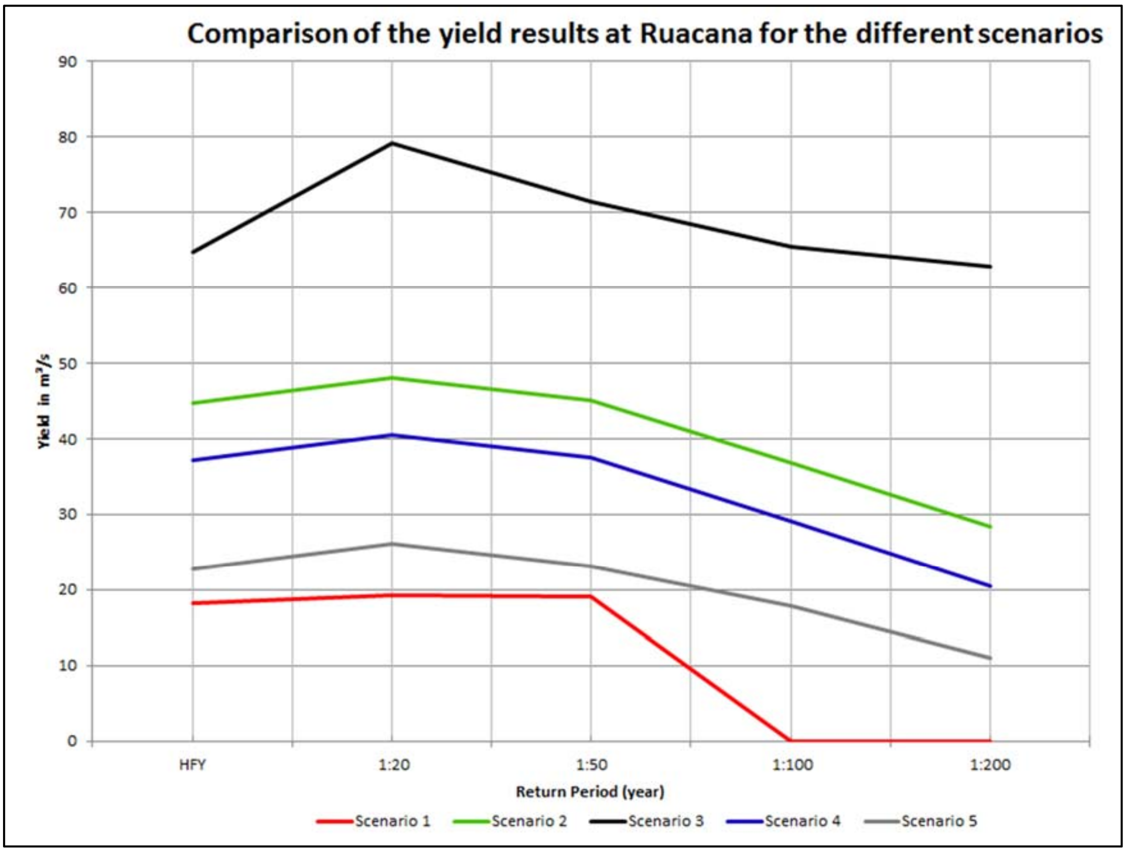

Figure 6.1: Comparison of the yield at Ruacana for various development scenarios

Environmental flows are non-consumptive and will constitute the yield plus the spills from Calueque Dam. Only Scenario 4 complies with the minimum stream flow requirement of 50 m^3/s downstream of the Ruacana Falls as it provides maximum regulation of the stream flow in the Kunene River and minimisation of spills. Unfortunately this is not the only factor to meet environmental requirements with optimisation leading to increased flow regulation. The minimum stream flow is equal to the firm yield for all the scenarios.

7 CONCLUSIONS

Data availability

Namibia is a water scarce country with the central rivers ephemeral, sporadic and consequently unreliable. The Kunene and the Okavango rivers which border Angola, however, have large volumes available with an average MAR of approximately 5 000 and 10 000 million m³/a, respectively.

The largest challenge for this study was the lack of reliable data. The importance of observed data is vital in managing water resources. The data available to this study proved to be inadequate with a low confidence in some of the records. It is however acknowledged that there are many problems with international data acquisition.

Whilst the Okavango River has observed stream flow at Mukwe and Rundu, stream flow data in the Kunene River are limited to a few years of observed stream flow data, regulated and impacted upon by upstream development and water use. Rainfall data in the Kunene River catchment are non-existent. No usable rainfall data were also to be found in the Okavango River catchment.

Many assumptions on stream flow, water use, disaggregation of stream flow between the catchments of Gove and Calueque dams, and dam operation were made by previous studies in the Kunene River. This stream flow data used for analyses are the best available, but results should be used with consideration to such uncertainties in data.

Serial correlation

The serial correlation analysis showed no correlation at any of the CAN dams or at the gauging stations on the Okavango / Cubango River. The annual stream flows are therefore regarded as completely random in nature.

Cross correlation

It was found that there is no cross correlation between the CAN dams and the Okavango River. The good cross correlation found between the stream flow records of the Okavango and Kunene rivers should be treated with caution. The reason for this good correlation is because the Kunene River data were derived from stream flow data in the Okavango. No conclusion can be drawn with regards to the correlation between the Kunene and Okavango river.

Droughts

It is shown that for the overlapping record period (1945 to 1995) the worst droughts in the Okavango and Kunene catchments were in the early 1980's, with the drought not completely broken in 1995. During this period the worst drought at the CAN dams was found to be in the 1950's and 1960's. This confirms the lack of correlation displayed by the cross correlation analyses.

Yield analyses in the Kunene River

The disaggregated stream flow data from the GABHIC Study (GABHIC, 2005) were found to be stationary, even though the cumulative stream flow sequences are not stationary. The ARMA (0,0) model was successfully fitted to the incremental inflow record at Gove and Calueque dams producing satisfactory validation and verification tests. Great care was taken with the validation and verification tests to ensure that the stochastic model fitted are acceptable. Stochastically sequences were subsequently generated and analysed.

Yields in the Kunene River from this and the GABHIC (2005) Study were compared with some improvised adjustments to compensate for differences in scenarios. Scenario 2 from this study and the results from the GABHIC (2005) Study showed similar results with only a 3% difference in yield at Gove Dam. The 98% (1:50 year) yield of Calueque Dam obtained by this study, however, was approximately 29% lower than that of the GABHIC (2005) Study.

The difference in results can be ascribed to the methodology used in this study. This study analysed 201 stochastic stream flow records with similar statistics to the historical stream flow record. This methodology is regarded as superior to counting the number of months with failures in one historical record.

It is shown that yield at Ruacana can be more than doubled if releases from Gove Dam are optimised and spills minimised. This would require improved cooperation between Namibia and Angola regarding operation of Gove and Calueque dams, and subsequent stream flow regulation.

The critical period for the yield analyses of Calueque Dam is relatively short and only lasted eight months during 1958. The reason for this is that Calueque Dam is a small dam relative to its MAR, and also supported by the much larger Gove Dam. It was found that the critical period of Gove Dam was six and a half years from May 1954 to December 1960, which supports the drought analyses that showed the droughts at Gove Dam from the late 1940's to 1960 for a 6-year drought period.

The best available information was used for the system analyses and the stochastic model was successfully fitted for confidence in the yield results.

8 RECOMMENDATIONS

It is recommended that:

- Data collection, and particularly rainfall data collection, be given a high priority by the respective Governments (Namibia and Angola) to improve confidence in future hydro-meteorological studies.
- Attention should be paid to improving cooperation between respective Governments leading to optimised water use in the Kunene River.
- The results are accepted as the best estimate of the yield of the Kunene River at Ruacana. The confidence in the stream flow data, which is used to derive the yield at Calueque Dam is, however, very low.

9 APPROVAL

This report has been read and approved for submission to the Director: Infrastructure Development of the Department of Water Affairs and Forestry for concurrence. I support the recommendations set out in the report and submit it to the Deputy Permanent Secretary of the Department of Water Affairs and Forestry for endorsement.

(V. SLINGER) 04/03/2016

DEPUTY DIRECTOR: INFRASTRUCTURE DEVELOPMENT **DATE**

I endorse the recommendations set out in the report and submit it to the Permanent Secretary of the Ministry of Agriculture, Water and Forestry for approval.

07/03/2016

DEPUTY PERMANENT SECRETARY: DWAF **DATE**

The recommendations in this report have been decided upon as follows:

PERMANENT SECRETARY 07-03-2016 Republic of Namibia Ministry of Agriculture, Water & Forestry

07/03/2016

PERMANENT SECRETARY

DATE

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Appendix A

Schematic WRYM diagram of the Kunene River system

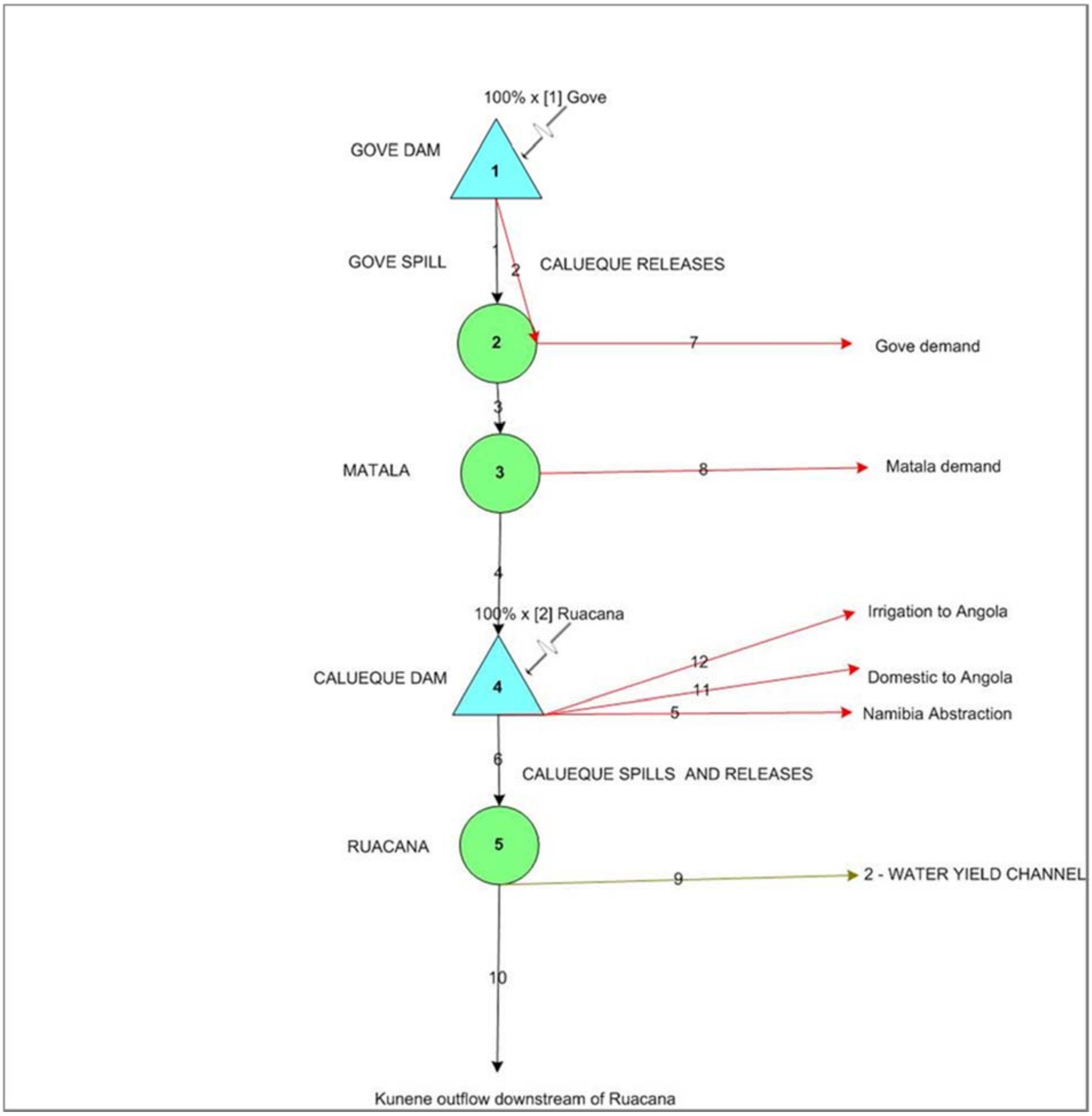


Figure A.1: WRYM schematic diagram for the Kunene River system

Appendix B

Rainfall data

Monthly normalised catchment rainfall (mm) for Omatako

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1923	11.2	10.1	21.6	34.9	47.4	123.5	1.7	0.0	0.0	0.0	0.0	0.0	250.4
1924	14.5	5.1	19.7	75.7	50.5	81.6	63.6	2.5	0.0	7.4	0.0	0.0	320.5
1925	3.8	8.2	34.5	76.0	20.7	58.3	81.4	9.5	13.2	0.0	0.0	2.5	308.1
1926	11.1	39.9	156.3	91.5	36.5	37.2	82.3	0.0	0.0	0.0	0.0	0.0	454.6
1927	22.1	22.7	62.5	92.3	74.2	180.7	104.1	0.0	0.0	0.0	0.0	2.4	561.0
1928	0.0	22.4	2.7	64.3	77.8	90.6	8.5	0.0	0.0	0.0	0.0	6.9	273.1
1929	46.0	12.0	2.1	28.0	59.9	12.8	12.9	0.0	0.0	0.0	0.0	0.0	173.8
1930	6.1	15.7	30.2	126.7	85.9	74.2	7.8	0.0	0.0	0.0	0.0	0.1	346.7
1931	2.8	23.1	42.7	19.6	12.7	68.1	3.2	11.7	0.0	0.0	0.0	0.0	183.9
1932	34.3	16.2	35.3	14.9	35.9	26.8	5.6	0.0	0.0	0.3	0.0	0.0	169.2
1933	0.2	17.5	41.7	112.0	80.0	58.4	20.7	0.0	0.0	0.0	0.0	0.0	424.4
1934	13.9	52.4	109.9	116.3	50.1	32.6	19.6	0.1	0.0	0.0	0.0	3.9	398.9
1935	0.9	22.5	81.4	160.8	32.2	133.2	28.4	43.1	0.0	0.0	0.0	0.0	502.5
1936	4.1	15.8	59.9	89.1	139.0	36.1	30.0	0.2	0.0	0.0	0.0	0.0	374.2
1937	16.7	23.9	66.3	127.3	62.1	26.9	68.3	25.7	2.6	0.2	0.0	0.0	420.0
1938	9.7	55.0	29.1	56.0	6.7	155.1	23.8	12.3	0.0	0.4	0.6	3.7	352.2
1939	34.6	25.7	53.1	97.5	76.3	38.1	39.1	0.0	1.3	0.0	0.0	1.3	367.1
1940	3.6	9.4	47.6	43.8	58.4	30.3	9.9	0.8	0.4	0.0	0.0	0.0	204.1
1941	13.4	0.0	15.8	25.8	172.5	143.0	50.1	0.0	0.0	0.9	0.0	0.5	422.1
1942	14.2	21.2	115.3	18.7	32.3	16.5	15.2	0.0	0.0	0.0	0.3	0.0	233.7
1943	0.4	3.8	98.0	121.6	58.3	46.9	0.0	0.0	0.0	0.0	0.0	0.7	329.5
1944	4.9	28.9	23.9	88.6	50.7	51.7	9.5	0.2	0.0	0.0	0.0	0.0	258.3
1945	0.2	98.6	73.2	18.3	24.3	12.3	17.7	0.0	0.0	0.0	0.0	16.8	261.3
1946	3.7	4.9	63.5	86.2	128.6	70.9	38.8	0.0	0.4	0.0	0.0	0.0	397.1
1947	0.1	3.9	48.2	69.1	64.5	26.8	0.7	3.0	0.0	3.7	0.0	0.0	220.0
1948	2.0	32.7	10.3	51.0	21.0	171.1	43.8	0.0	0.0	0.0	0.0	0.0	331.8
1949	0.6	14.6	19.0	139.0	154.3	101.1	64.2	12.7	0.0	0.0	0.1	0.1	505.6
1950	0.0	55.7	99.1	26.2	90.0	36.9	32.1	7.8	0.0	0.0	0.0	7.7	355.6
1951	11.1	25.0	58.9	30.3	66.7	3.2	3.0	0.0	0.9	0.0	0.0	0.8	199.8
1952	7.6	22.2	33.0	32.5	192.3	68.4	34.5	4.7	0.0	0.0	0.0	3.4	398.6
1953	35.1	18.7	69.3	142.1	206.3	171.3	19.3	0.0	0.0	0.0	0.0	1.1	663.1
1954	4.7	25.1	93.8	68.5	101.3	50.2	37.8	0.4	3.9	0.0	0.0	0.0	385.7
1955	16.9	18.1	35.5	105.5	144.0	110.4	22.0	0.0	0.0	0.0	0.0	2.9	455.2
1956	3.8	23.0	17.1	106.9	87.7	59.4	1.4	0.0	0.0	0.0	0.0	0.5	299.7
1957	9.7	86.1	39.7	105.0	42.3	57.2	19.9	0.0	0.0	0.0	0.0	1.5	361.5
1958	3.3	5.7	21.5	42.4	86.2	18.2	32.5	1.5	0.0	0.0	0.0	0.6	211.9
1959	0.3	12.6	13.1	29.8	174.0	17.6	22.6	33.7	0.0	0.0	0.0	0.3	304.1
1960	2.4	21.3	13.9	6.9	32.9	89.5	39.1	28.4	2.6	0.0	0.0	0.1	237.0
1961	0.4	40.6	4.2	24.8	94.0	4.9	11.5	0.0	0.0	0.0	18.5	0.0	198.9
1962	25.0	7.2	8.1	117.4	17.9	58.5	54.1	1.0	0.0	0.0	0.0	0.6	289.9
1963	5.5	137.4	49.0	20.8	46.6	32.2	6.1	0.0	0.0	0.0	0.0	0.0	297.7
1964	3.0	8.4	10.1	46.6	89.7	86.6	108.1	0.0	0.0	0.0	0.0	0.5	353.0
1965	1.0	42.0	0.6	145.0	103.1	34.4	41.1	0.0	0.5	0.0	0.0	45.4	413.2
1966	0.5	18.1	107.1	40.6	150.0	42.1	14.1	11.2	0.0	0.0	0.0	0.0	383.6
1967	0.3	122.8	113.0	87.6	23.4	185.7	10.7	22.6	0.0	0.0	0.0	0.0	566.0
1968	0.0	51.6	14.8	63.0	136.4	55.4	9.1	0.0	0.0	0.0	0.1	0.0	330.3
1969	0.0	37.0	19.4	83.6	80.5	37.2	6.3	0.0	0.0	0.0	0.0	0.0	264.2
1970	20.9	5.3	54.7	48.4	210.9	23.1	30.1	1.5	3.2	0.0	0.0	0.0	398.1
1971	0.1	7.2	22.2	70.4	12.8	129.8	41.4	0.0	0.0	0.0	0.0	0.0	283.7
1972	4.9	8.3	9.4	26.7	41.2	125.8	15.1	0.0	0.0	0.1	0.0	0.0	231.5
1973	10.6	12.1	28.5	124.7	143.6	20.2	46.9	0.0	0.5	0.0	0.0	0.4	387.5
1974	10.2	49.2	18.0	122.0	70.6	110.8	38.9	10.7	0.0	0.0	0.0	0.0	430.3
1975	0.5	17.6	16.3	258.3	150.5	127.9	19.5	0.0	0.1	0.0	0.0	0.0	590.6
1976	11.0	0.0	15.2	82.1	255.2	47.3	50.6	1.5	0.0	0.0	0.0	0.6	463.3
1977	12.3	18.4	58.9	219.5	234.5	74.5	23.5	3.7	0.0	0.0	7.3	0.0	652.5
1978	2.3	12.4	48.0	69.6	267.9	8.4	5.2	8.1	1.3	0.0	1.0	4.9	429.1
1979	9.4	71.1	34.1	28.6	56.1	111.4	4.7	0.0	0.0	0.0	0.3	37.5	353.2
1980	2.7	13.1	29.3	46.0	91.2	16.2	20.9	0.0	0.0	0.0	0.0	0.0	219.3
1981	0.4	7.5	5.1	29.6	97.2	71.6	35.4	0.9	0.0	0.0	0.0	0.4	248.0
1982	2.9	7.9	79.8	65.9	9.1	28.9	16.6	7.2	17.1	0.0	0.0	0.0	235.3
1983	8.1	44.3	114.7	24.8	101.8	55.6	82.9	4.1	0.0	0.0	0.0	0.0	436.1
1984	3.2	20.2	5.6	108.7	141.6	46.9	15.6	0.0	0.0	0.0	0.0	0.0	341.7
1985	14.4	22.9	56.1	63.5	117.2	103.0	25.5	0.0	2.4	0.0	0.0	2.3	407.4
1986	16.2	3.6	32.8	8.5	120.6	24.2	39.5	1.6	0.0	0.0	0.0	0.2	247.2
1987	26.5	10.4	24.6	99.5	26.8	11.5	22.5	1.9	0.0	0.0	0.0	0.0	223.9
1988	4.1	23.5	100.2	66.7	134.6	1.9	37.2	6.6	0.0	0.0	0.0	0.0	374.7
1989	3.4	5.8	11.6	155.0	47.2	97.1	30.2	0.0	0.0	0.0	0.0	0.0	350.3
1990	5.5	30.5	72.5	117.4	138.3	40.9	0.0	0.0	0.0	0.0	0.0	23.2	428.2
1991	3.5	21.0	64.5	33.5	44.0	61.5	0.0	0.0	0.0	0.0	0.0	6.0	234.0
1992	1.5	8.0	4.0	117.0	154.0	50.0	26.0	0.0	0.0	0.0	0.0	0.8	361.3
1993	55.5	40.0	6.4	85.1	101.3	63.8	30.5	3.2	0.7	0.1	0.5	4.4	391.5
1994	0.0	20.9	8.4	4.5	33.9	106.7	20.8	11.6	0.0	0.0	0.0	2.3	209.1
1995	0.6	9.1	1.4	83.4	72.4	11.5	6.9	0.1	0.0	7.3	0.0	0.0	192.7
1996	1.0	5.9	102.0	162.5	91.0	155.0	0.0	0.0	0.0	0.0	0.0	12.0	529.4
1997	26.5	2.0	90.0	87.9	98.0	62.0	28.1	0.0	0.0	0.0	0.0	0.0	394.5
1998	5.1	4.9	43.3	55.4	16.3	72.9	0.0	7.5	0.0	0.0	0.0	0.0	205.4
1999	2.0	250.4	54.0	46.2	73.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2	426.7
2000	13.5	3.1	12.7	64.0	69.4	28.9	123.6	8.5	0.0	0.0	0.5	12.2	336.4
2001	0.3	13.4	5.6	51.1	39.3	46.2	16.5	0.0	0.0	0.0	0.0	0.0	172.4
2002	13.5	47.4	40.5	62.0	18.1	2.5	64.3	0.0	0.0	0.0	0.2	4.9	253.4
2003	0.0	6.1	14.6	94.5	85.2	33.2	35.9	0.0	0.0	0.0	0.0	0.0	269.5
2004	17.8	59.6	20.5	57.4	27.6	10.0	4.1	0.0	0.0	0.0	0.0	0.0	197.0
2005	10.4	23.8	8.8	219.6	170.6	77.2	59.0	3.4	0.0	0.0	0.0	11.3	584.1
2006	30.2	30.6	79.6	91.0	37.2	96.4	18.8	0.0	0.0	0.0	0.0	0.0	383.8
2007	3.2	32.8	32.2	107.4	175.2	95.2	12.6	3.4	0.0	0.0	0.0	0.0	462.0
2008	11.6	101.0	29.8	99.2	121.2	62.4	15.2	5.0	4.0	0.0	0.0	7.4	456.8
2009	9.6	41.0	76.2	162.0	142.8	40.2	31.4	35.6	0.0	0.0	0.0	0.0	539.0
2010	0.0	57.8	39.4	280.8	139.8	135.2	123.8	1.8	2.4	1.0	0.0	7.0	789.0
2011	0.4	93.0	63.6	233.6	285.6	83.2	14.8	0.0	0.0	0.0	0.2	0.0	774.4
2012	0.0	0.0	2.6	0.0	25.2	54.0	0.2	4.4	0.0	0.0	0.4	0.0	86.8
AVERAGE	**8.7**	**29.4**	**42.5**	**82.3**	**90.8**	**63.9**	**29.0**	**4.1**	**0.6**	**0.2**	**0.3**	**2.7**	**355.5**

Monthly normalised catchment rainfall (mm) for Von Bach Dam

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1923	2.2	6.4	12.5	21.4	26.8	83.4	3.9	0.0	0.0	0.0	0.0	0.0	156.6
1924	22.8	7.2	11.7	54.3	55.3	93.8	63.0	4.3	0.0	8.8	0.0	0.0	321.0
1925	0.5	7.5	20.0	61.1	11.1	25.8	43.6	17.4	11.6	0.0	0.0	1.7	200.2
1926	10.5	16.6	113.9	35.6	19.4	45.3	97.5	0.0	0.0	0.0	0.0	0.4	339.0
1927	14.8	38.8	43.0	117.9	35.9	126.8	40.4	0.1	0.0	0.0	0.0	4.9	422.5
1928	0.0	11.1	7.7	36.9	57.6	80.9	4.5	0.0	0.0	0.0	0.0	8.1	206.8
1929	27.9	0.3	2.5	32.0	50.8	17.4	7.3	0.0	0.0	0.0	0.0	0.0	138.2
1930	8.2	18.4	38.3	115.7	70.5	94.8	2.6	0.0	0.0	0.0	0.0	0.2	348.6
1931	0.9	28.1	35.1	12.0	33.8	92.0	3.6	22.1	0.0	0.0	0.0	0.0	227.4
1932	31.7	8.5	41.6	17.6	35.5	32.9	5.6	0.0	0.0	0.5	0.0	0.0	173.9
1933	0.5	12.3	74.3	193.5	115.5	96.6	43.7	0.2	0.1	0.0	0.0	0.0	536.6
1934	8.7	95.7	72.0	86.4	54.1	23.6	11.3	5.2	0.0	0.0	0.0	3.9	360.9
1935	0.4	17.9	63.1	181.5	21.8	66.7	25.6	35.4	0.0	0.0	0.0	0.0	412.4
1936	1.3	14.4	41.6	113.0	116.2	51.5	18.2	0.3	0.0	0.0	0.0	0.0	356.5
1937	11.1	35.0	78.4	136.4	78.9	36.0	83.0	34.2	2.5	0.2	0.0	0.0	495.7
1938	4.0	94.4	42.4	45.6	6.7	170.4	15.2	3.5	0.0	0.0	0.6	1.2	384.0
1939	36.9	18.4	48.9	103.7	36.2	89.8	23.1	0.0	1.0	0.0	0.0	1.0	358.9
1940	1.6	8.3	60.9	60.4	48.5	24.7	11.4	0.0	1.5	0.0	0.0	0.0	217.1
1941	13.3	0.1	4.6	22.2	213.0	113.5	42.8	0.0	0.0	0.0	0.0	3.4	412.8
1942	13.3	16.8	78.8	43.8	26.1	25.0	59.8	0.1	0.0	0.0	1.2	0.8	265.8
1943	0.0	12.3	63.9	129.3	31.4	64.4	0.0	0.0	0.0	0.0	0.0	0.1	301.4
1944	2.1	14.2	25.4	57.6	47.2	26.2	17.8	3.0	0.0	0.0	0.0	0.0	193.4
1945	0.8	78.4	96.5	24.2	14.8	8.7	19.5	0.0	0.0	0.0	0.0	0.1	243.0
1946	3.5	11.3	79.9	74.2	115.8	123.8	48.7	0.0	0.5	0.0	0.0	1.8	459.5
1947	2.4	20.7	36.7	114.4	84.8	24.6	10.6	3.7	0.0	4.3	0.0	0.0	302.3
1948	2.9	33.4	12.3	78.0	55.5	222.7	88.2	0.0	0.0	0.0	0.0	0.0	493.1
1949	8.9	19.2	15.3	116.9	171.2	263.3	82.4	20.2	0.3	0.0	0.1	0.5	698.2
1950	0.1	39.7	64.5	25.6	84.0	62.1	60.4	13.5	0.0	0.0	0.0	6.7	356.5
1951	19.2	19.7	48.2	12.8	109.0	5.5	18.3	0.0	1.5	0.0	0.0	0.5	234.8
1952	19.0	49.3	18.1	31.1	225.7	66.4	13.3	6.8	0.0	0.0	0.0	1.9	431.6
1953	31.5	29.9	37.5	123.0	100.9	137.3	42.2	1.4	0.0	0.0	0.0	2.7	506.3
1954	8.2	10.9	75.1	76.6	78.7	74.6	70.0	0.0	10.8	0.0	0.0	0.3	405.2
1955	21.0	49.2	13.5	117.4	134.2	130.3	20.5	0.8	0.0	1.7	0.0	3.6	492.1
1956	2.4	23.8	16.3	98.0	85.5	56.8	11.2	1.9	0.0	0.6	0.9	2.6	299.9
1957	16.8	92.9	52.1	129.8	64.8	52.2	8.8	1.1	0.0	0.0	0.0	0.3	418.8
1958	0.2	33.3	20.9	60.5	76.3	21.7	18.1	0.6	0.0	0.0	0.0	0.7	232.1
1959	0.0	25.2	21.7	24.7	177.4	14.9	15.7	19.4	0.0	0.0	0.0	1.4	300.3
1960	13.5	12.6	12.1	20.2	76.1	73.4	19.3	18.8	10.5	0.0	0.0	0.1	256.6
1961	0.1	25.1	16.9	38.6	119.5	8.5	8.4	0.0	0.0	0.0	18.1	0.0	235.1
1962	22.2	5.8	13.0	176.6	16.3	75.4	51.0	3.6	0.0	0.0	0.1	0.6	364.7
1963	15.1	122.8	23.4	17.8	59.5	31.4	8.1	0.3	0.0	0.0	0.2	0.0	278.6
1964	2.0	15.1	19.6	56.9	65.2	97.9	75.7	0.0	0.0	0.0	0.0	4.1	336.5
1965	3.9	36.7	0.2	148.2	77.7	42.4	31.3	0.0	0.6	0.0	0.0	50.2	391.3
1966	4.0	14.9	82.7	79.5	105.7	52.9	11.1	10.0	0.0	0.0	0.1	9.4	370.2
1967	0.0	79.0	60.0	80.1	34.7	170.9	12.0	49.0	0.8	0.0	0.0	0.0	486.4
1968	0.3	82.9	30.0	29.9	104.2	54.5	29.6	1.3	0.0	0.0	0.2	0.0	332.8
1969	0.7	17.0	26.1	85.2	57.3	55.8	8.3	0.0	0.0	0.0	0.0	0.0	250.3
1970	51.2	5.0	37.2	67.7	184.2	43.3	34.2	20.3	2.2	0.0	0.0	0.0	445.2
1971	1.3	8.1	13.4	62.4	22.4	217.7	46.4	0.0	0.0	0.0	0.0	0.0	371.6
1972	1.8	7.2	9.8	37.4	51.0	96.0	25.9	0.0	0.0	0.2	0.0	0.0	229.3
1973	28.6	11.5	30.8	169.7	133.1	40.7	67.1	0.0	1.1	0.0	0.0	0.0	482.7
1974	15.7	68.9	46.6	73.2	59.3	135.5	36.7	17.6	0.0	0.0	0.0	0.0	453.6
1975	0.1	9.2	34.1	255.9	153.0	136.4	12.3	6.9	0.0	0.0	0.0	0.0	607.9
1976	16.7	13.3	18.1	49.4	236.7	42.9	44.2	3.6	0.0	0.0	0.0	0.1	425.0
1977	10.8	3.6	49.1	192.3	165.6	44.6	14.5	4.0	0.0	0.0	6.2	0.0	490.7
1978	0.0	9.8	10.0	60.6	175.8	5.4	11.0	11.1	1.2	0.3	0.4	6.3	291.6
1979	11.4	50.2	14.0	31.1	98.3	155.8	3.8	0.0	0.0	0.0	1.7	13.2	379.5
1980	0.8	12.3	18.7	7.9	52.6	56.3	12.3	0.0	0.0	0.0	0.0	0.0	160.9
1981	0.0	1.0	0.3	39.9	90.2	49.7	14.5	0.0	0.3	0.0	0.0	8.0	203.8
1982	8.8	10.5	76.6	127.3	5.4	38.4	17.7	8.8	16.9	0.0	0.0	0.0	310.5
1983	15.0	24.3	97.1	23.7	69.6	67.5	60.3	0.6	0.0	0.0	0.0	0.0	358.0
1984	13.9	3.1	8.1	53.2	95.3	43.2	24.3	0.0	0.0	0.0	0.0	0.0	241.1
1985	22.8	27.5	20.3	75.5	86.1	113.3	50.8	0.0	0.8	0.0	0.0	3.8	400.7
1986	29.4	11.9	41.3	6.7	147.2	16.7	42.6	1.1	0.0	0.0	0.0	0.2	297.1
1987	19.1	17.3	25.7	159.4	55.7	18.0	64.0	3.4	0.0	0.0	0.0	0.0	362.6
1988	3.5	18.9	65.0	68.6	134.8	28.8	21.5	8.3	0.0	0.0	0.0	0.0	349.4
1989	0.0	0.0	2.8	110.2	47.5	102.6	24.1	0.0	0.0	0.0	0.0	0.0	287.3
1990	2.1	17.0	60.9	151.0	163.3	35.4	0.0	0.0	0.0	0.0	0.0	27.6	457.2
1991	77.0	44.0	111.5	19.0	28.0	69.0	0.0	0.0	0.0	0.0	0.0	5.0	353.5
1992	0.0	0.0	3.0	91.0	82.5	66.5	17.0	0.0	0.0	0.0	0.0	0.0	260.0
1993	27.5	29.0	29.0	99.0	125.4	52.4	20.3	2.6	1.3	0.0	0.0	0.8	387.3
1994	0.0	20.9	8.4	4.5	33.9	106.7	20.8	11.6	0.0	0.0	0.0	2.3	209.1
1995	0.6	9.1	1.4	83.4	72.4	11.5	6.9	0.1	0.0	7.3	0.0	0.0	192.7
1996	0.0	15.0	40.0	106.0	87.5	59.5	9.0	0.0	0.0	0.0	0.0	0.0	317.0
1997	0.0	0.0	136.5	31.5	7.0	63.5	0.0	0.0	0.0	0.0	0.0	0.0	238.5
1998	0.0	20.3	73.2	44.4	29.1	63.8	0.4	12.2	1.8	0.0	0.0	0.0	245.2
1999	3.9	65.5	88.1	29.2	125.5	0.3	15.8	12.1	0.0	0.0	0.0	0.0	340.4
2000	5.0	0.0	13.8	70.2	89.5	96.1	193.5	92.5	0.0	0.0	0.0	1.1	561.7
2001	0.0	10.1	0.4	33.9	76.9	93.0	15.1	0.0	0.5	0.0	0.0	0.0	229.9
2002	22.1	7.7	10.4	36.3	99.4	6.8	111.6	0.0	0.0	0.0	0.0	0.0	296.0
2003	6.9	39.6	3.4	66.1	64.4	34.9	11.1	0.0	0.0	0.0	0.0	2.1	228.5
2004	22.3	83.2	0.0	49.1	16.5	87.9	28.0	0.0	0.0	0.0	0.0	0.0	287.0
2005	17.7	0.4	7.6	90.1	205.8	75.4	116.8	2.2	0.0	0.0	0.0	0.0	516.0
2006	4.3	11.6	58.8	56.2	29.0	18.8	20.4	0.0	0.0	0.0	0.0	0.0	199.1
2007	9.4	2.8	48.4	116.2	219.6	103.6	7.2	6.8	0.0	1.6	0.6	0.0	516.2
2008	11.2	40.2	49.0	86.6	233.0	44.4	3.8	1.4	0.0	0.0	0.0	14.0	483.6
2009	9.8	12.4	45.0	203.4	16.4	67.2	8.0	0.8	0.0	0.0	0.0	0.4	363.4
2010	0.8	61.0	29.4	185.0	84.0	135.4	156.0	3.0	0.0	0.0	0.0	3.0	657.6
2011	0.0	2.8	11.6	140.8	144.6	68.8	5.8	0.0	0.0	0.0	0.0	0.4	374.8
2012	1.8	21.8	67.2	17.6	38.6	41.2	0.0	0.0	0.0	0.0	0.0	0.0	188.2
AVERAGE	**9.8**	**25.1**	**37.7**	**77.8**	**84.7**	**69.6**	**31.1**	**5.7**	**0.8**	**0.3**	**0.3**	**2.2**	**345.1**

Monthly normalised catchment rainfall (mm) for Swakoppoort Dam

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1923	2.0	8.1	11.7	28.3	34.5	64.2	3.3	0.0	0.0	0.0	0.0	0.0	152.0
1924	15.9	0.4	6.8	43.4	49.6	93.7	57.5	8.4	0.0	4.4	0.0	0.0	280.1
1925	1.3	5.8	12.3	55.8	23.9	59.5	53.8	3.9	8.4	0.0	0.0	2.6	227.1
1926	2.6	12.9	95.6	47.1	20.6	37.0	67.0	0.0	0.0	0.0	0.0	1.9	284.7
1927	9.5	31.8	19.6	74.8	46.3	80.1	34.6	0.0	0.0	0.0	0.0	2.5	299.3
1928	0.0	3.4	16.7	38.4	49.9	89.2	1.4	0.0	0.3	0.0	0.0	4.6	204.0
1929	23.3	6.6	5.6	21.7	22.3	17.7	8.7	0.0	0.0	0.0	0.0	0.0	105.9
1930	5.0	13.3	37.6	112.1	75.1	84.3	0.0	0.0	0.0	0.0	0.0	0.5	328.0
1931	1.2	11.0	27.5	15.5	23.1	67.6	2.6	32.2	0.0	0.0	0.0	0.0	180.6
1932	47.8	1.7	13.8	19.2	47.2	25.5	1.6	0.0	0.0	0.4	0.0	0.0	157.1
1933	0.6	7.7	43.1	164.5	101.7	92.4	40.4	1.3	0.0	0.0	0.0	0.0	451.6
1934	5.5	55.8	45.6	79.7	48.3	20.5	17.9	17.4	0.0	0.0	0.0	7.7	298.5
1935	0.8	10.9	30.8	116.0	18.8	66.6	17.7	42.7	0.0	0.0	0.0	0.0	304.4
1936	0.2	10.4	51.2	149.8	96.6	55.5	1.0	0.0	0.0	0.0	0.0	0.0	364.6
1937	8.8	28.8	58.7	150.2	34.0	9.9	41.5	33.0	0.9	0.0	0.0	0.1	365.8
1938	0.0	97.0	36.1	28.4	67.4	162.1	7.0	4.4	1.1	0.0	0.8	0.0	404.3
1939	25.3	26.5	32.4	84.2	61.6	54.3	14.0	0.0	0.5	0.0	0.0	2.0	300.8
1940	9.9	6.7	44.1	64.5	28.6	33.6	3.9	0.0	0.0	0.0	0.0	0.0	191.2
1941	25.8	0.0	0.9	12.4	213.9	107.3	60.0	0.5	0.1	0.0	0.1	5.0	426.0
1942	7.2	11.2	105.3	26.2	20.1	42.8	115.4	0.0	0.0	0.0	0.9	2.6	331.6
1943	0.3	11.1	76.7	133.6	19.6	11.4	0.0	0.1	0.0	0.0	0.0	0.3	253.0
1944	1.2	20.0	13.7	59.0	21.6	15.1	0.0	1.6	0.0	0.0	0.0	0.0	132.2
1945	0.0	51.3	89.7	4.0	7.0	9.0	12.2	0.0	0.0	0.0	0.0	0.0	173.3
1946	0.0	4.6	65.6	65.6	89.4	107.2	35.9	2.9	1.3	0.0	0.0	0.1	372.6
1947	1.7	0.2	23.4	69.8	57.7	6.5	6.6	0.0	0.0	6.6	0.0	0.0	172.4
1948	2.0	38.5	17.9	47.1	35.4	141.0	80.4	0.0	0.0	0.0	0.0	0.0	362.1
1949	6.3	30.3	2.3	109.8	157.4	199.1	91.0	3.1	1.3	0.0	0.0	0.2	600.8
1950	0.0	26.1	35.5	19.7	66.4	18.9	42.2	9.3	3.2	0.0	0.0	0.2	221.5
1951	14.2	15.8	48.1	8.1	174.8	7.5	9.1	0.2	0.8	0.0	0.0	0.4	279.0
1952	18.7	52.2	4.8	18.2	234.7	61.2	14.8	17.2	0.0	0.0	0.0	1.0	422.8
1953	13.9	10.0	64.6	84.2	80.1	182.0	44.1	0.0	0.0	0.0	0.0	3.9	482.8
1954	26.3	32.7	65.5	72.5	69.7	37.6	57.1	0.0	11.1	0.0	0.0	0.0	372.5
1955	13.8	48.7	8.3	105.6	118.1	159.5	18.0	0.6	0.0	1.8	0.0	1.6	475.9
1956	1.0	21.3	4.5	98.3	63.9	83.8	12.3	3.6	0.0	0.1	0.0	1.6	290.3
1957	20.9	69.2	23.2	113.6	38.4	37.7	12.1	1.0	0.0	0.0	0.0	0.2	316.3
1958	0.0	10.9	12.1	37.4	77.4	19.3	24.5	0.1	0.0	0.0	0.0	0.0	181.6
1959	0.2	18.2	16.9	27.3	113.2	25.5	17.7	13.7	0.1	0.0	0.0	4.8	237.5
1960	2.0	13.1	17.1	26.8	53.9	57.0	29.4	20.5	8.2	0.1	0.0	0.5	228.6
1961	0.1	29.3	11.2	26.0	121.2	4.1	7.8	0.0	0.0	0.0	14.0	0.0	213.7
1962	15.3	3.3	9.0	160.9	15.4	78.1	55.4	5.0	0.0	0.0	0.5	1.5	344.4
1963	8.3	63.1	27.4	12.0	60.2	45.9	17.8	0.0	0.0	0.0	0.5	0.0	235.2
1964	6.7	10.5	11.6	63.7	70.5	117.1	65.9	0.0	0.0	0.0	0.0	3.1	349.1
1965	2.9	18.6	2.8	103.1	69.0	74.2	40.2	0.0	2.0	0.0	0.0	26.7	339.4
1966	17.2	0.9	82.9	78.9	117.0	77.9	16.4	6.5	0.0	0.0	0.0	1.3	399.0
1967	0.0	80.1	41.4	52.0	38.8	110.2	7.7	30.4	0.1	0.0	0.0	0.0	360.7
1968	0.3	78.5	19.7	21.5	84.7	59.8	16.1	0.0	0.0	0.0	0.2	0.0	280.7
1969	0.0	10.0	17.3	85.5	58.6	13.7	6.1	0.0	0.0	0.0	0.0	0.0	191.1
1970	26.7	2.2	37.1	61.9	167.5	36.7	18.3	8.2	0.3	0.0	0.0	0.0	358.7
1971	0.0	3.4	11.1	95.8	25.3	199.8	57.2	0.0	0.0	0.0	0.0	0.0	392.6
1972	3.6	25.8	8.0	23.1	40.4	93.8	16.4	0.0	0.0	0.2	0.0	0.1	211.4
1973	21.8	3.9	16.8	163.1	104.4	74.9	34.1	0.0	0.6	0.0	0.0	2.6	422.2
1974	14.5	60.8	15.8	39.6	37.6	149.5	23.8	6.6	0.0	0.0	0.0	0.0	348.3
1975	6.3	10.8	15.0	245.3	125.2	182.0	20.8	0.0	0.0	0.0	0.1	0.0	605.5
1976	12.4	0.3	8.4	47.9	221.7	55.7	53.0	5.7	0.0	0.0	0.0	0.1	405.2
1977	6.8	2.3	60.8	170.6	119.2	70.8	12.9	3.7	0.0	0.0	1.1	0.0	448.4
1978	0.0	10.6	10.3	63.6	167.4	6.4	21.6	9.9	6.8	4.4	0.1	6.8	307.7
1979	9.4	35.4	31.7	20.8	83.2	90.3	4.7	0.0	0.0	1.9	2.0	6.6	285.9
1980	3.6	11.6	41.7	15.5	28.9	53.0	10.9	0.0	0.0	0.0	0.0	0.0	165.1
1981	0.1	0.0	0.2	22.2	92.6	55.1	23.4	0.4	0.0	0.0	0.0	6.1	200.0
1982	0.1	5.4	59.6	95.1	10.1	29.5	13.9	1.1	18.7	0.0	0.0	0.0	233.4
1983	5.7	25.0	72.0	14.9	71.8	57.5	84.9	8.4	0.0	0.0	0.0	0.0	340.2
1984	12.7	5.0	1.3	65.4	128.0	38.3	25.7	0.0	0.0	0.0	0.0	0.0	276.3
1985	15.0	31.7	26.0	89.7	79.7	111.8	27.9	0.2	1.7	0.0	0.0	0.9	384.5
1986	22.2	6.6	23.0	4.9	155.7	20.7	52.9	1.1	0.0	0.5	0.0	0.0	287.7
1987	22.9	9.2	18.5	180.1	58.6	9.3	45.6	8.0	0.0	0.0	0.0	0.0	352.2
1988	2.2	32.4	62.4	89.4	98.9	21.8	23.9	4.5	0.0	0.0	0.0	0.0	335.4
1989	0.0	0.4	2.4	157.9	87.8	115.0	44.6	0.0	0.1	0.0	0.1	0.0	408.4
1990	5.0	16.2	24.4	105.9	51.1	44.3	0.0	0.0	0.0	0.0	0.0	4.2	251.1
1991	29.0	78.4	50.6	14.0	27.0	25.2	0.0	0.0	0.0	0.0	0.0	0.0	224.2
1992	2.5	0.0	0.0	100.3	93.4	57.4	22.1	0.0	0.0	0.0	0.0	0.0	275.7
1993	26.5	1.4	10.7	55.8	66.0	53.0	22.8	2.1	0.6	0.4	0.1	0.8	240.2
1994	0.0	20.9	8.4	4.5	33.9	106.7	20.8	11.6	0.0	0.0	0.0	2.3	209.1
1995	0.6	9.1	1.4	83.4	72.4	11.5	6.9	0.1	0.0	7.3	0.0	0.0	192.7
1996	0.0	0.0	72.5	212.6	163.9	49.5	43.2	0.0	0.0	0.0	0.0	0.0	541.7
1997	5.0	0.0	118.8	0.0	13.1	9.1	17.0	0.0	0.0	0.0	0.0	0.0	163.0
1998	0.0	17.9	64.4	39.1	25.6	56.1	0.3	10.7	0.8	0.0	0.0	0.0	214.9
1999	3.4	57.6	77.5	25.7	110.4	0.2	13.9	10.6	0.0	0.0	0.0	0.0	299.3
2000	4.4	0.0	12.1	61.8	78.7	84.6	170.3	81.4	0.0	0.0	0.0	1.0	494.3
2001	0.0	12.3	1.5	49.8	109.2	94.3	15.2	0.6	0.0	0.0	0.0	0.0	282.9
2002	2.8	22.1	16.6	39.6	76.6	11.2	124.4	0.0	0.0	0.0	0.0	7.5	300.8
2003	18.7	38.4	5.0	182.1	52.0	62.8	28.1	0.0	0.0	0.0	0.0	0.3	387.4
2004	41.4	67.6	4.8	89.5	88.4	90.7	43.3	0.4	0.0	0.0	0.0	0.0	426.1
2005	18.4	24.2	11.3	275.7	125.7	110.9	89.3	0.0	0.0	0.0	0.0	1.0	656.5
2006	12.0	9.2	16.0	109.0	47.2	15.0	3.6	0.2	0.0	0.0	0.0	0.0	212.2
2007	3.0	13.2	1.2	23.6	152.4	61.8	68.2	22.8	0.0	0.0	0.0	0.0	346.2
2008	2.0	34.4	35.6	36.6	172.8	29.8	1.2	1.6	0.6	0.0	0.0	1.0	315.6
2009	4.2	2.4	18.6	53.8	56.8	7.0	3.2	2.4	1.2	0.0	0.0	0.0	149.6
2010	0.0	26.6	33.0	160.4	73.0	97.6	88.6	0.8	0.0	0.0	0.0	3.0	483.0
2011	0.4	1.0	15.2	37.4	88.2	80.0	2.2	0.0	0.0	0.0	0.0	0.0	224.4
2012	2.4	1.0	9.4	15.6	6.0	83.6	0.0	1.4	0.0	0.0	0.0	0.0	119.4
AVERAGE	**8.1**	**20.6**	**29.3**	**72.0**	**76.5**	**63.8**	**29.9**	**5.2**	**0.8**	**0.3**	**0.2**	**1.3**	**308.1**

Appendix C

Stream flow data

Monthly incremental stream flow data (million m³) at Gove Dam

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1945	23.4	102.8	213.7	169.4	46.8	85.2	61.3	45.6	32.0	25.3	17.3	15.1	837.7
1946	37.8	46.9	187.7	535.0	624.1	359.3	251.0	176.7	130.1	105.8	79.6	46.0	2579.9
1947	26.3	17.9	49.3	107.4	291.5	184.8	85.4	90.1	64.2	47.0	27.7	15.8	1007.3
1948	14.9	19.0	9.1	22.9	81.4	248.4	157.7	75.3	58.7	43.8	26.2	9.6	767.0
1949	6.8	9.7	20.1	115.8	243.8	403.7	144.9	80.4	56.6	29.3	11.4	7.0	1129.5
1950	7.4	8.1	73.0	159.9	518.5	578.6	736.6	398.6	237.0	162.4	107.7	58.6	3046.4
1951	52.0	79.5	135.4	147.6	242.8	188.2	74.2	72.8	57.5	47.0	30.0	13.2	1140.0
1952	24.4	57.7	77.7	104.2	120.3	292.7	285.6	164.2	115.0	89.6	61.6	33.2	1426.1
1953	30.4	44.9	68.9	276.5	611.6	872.7	541.5	336.8	213.0	163.7	114.0	60.4	3334.5
1954	38.1	38.1	42.9	64.8	45.9	66.9	57.8	62.0	41.4	32.9	19.5	8.2	518.5
1955	11.5	28.9	82.3	307.0	244.8	222.2	238.6	179.3	105.9	80.2	53.3	25.7	1579.6
1956	12.8	15.1	13.6	47.8	100.6	205.2	122.8	65.5	47.3	28.7	13.2	6.8	679.6
1957	14.5	27.4	97.1	114.6	57.2	147.7	67.5	37.0	31.2	20.6	13.2	6.6	634.7
1958	6.5	9.8	62.3	115.1	159.7	147.2	127.7	103.2	69.4	47.0	25.8	9.5	883.0
1959	6.5	8.9	59.7	123.8	202.8	190.6	121.2	135.5	88.3	62.6	39.6	12.0	1051.4
1960	7.1	18.8	45.8	130.9	214.3	450.2	562.3	321.2	176.7	120.4	79.4	43.0	2170.2
1961	57.8	90.9	603.3	383.8	200.4	292.1	312.6	202.3	148.3	117.7	87.9	55.0	2552.1
1962	48.5	78.3	155.6	279.7	543.2	822.0	455.0	242.4	202.1	146.7	101.7	65.0	3140.2
1963	69.2	98.0	61.4	118.6	138.6	237.7	156.0	100.5	83.0	71.1	52.5	30.7	1217.1
1964	36.3	35.1	67.6	165.6	369.1	803.3	392.5	237.8	162.6	122.1	87.3	58.2	2537.5
1965	49.6	44.5	152.8	296.2	179.4	290.6	140.5	112.8	93.6	77.7	59.7	43.6	1541.0
1966	33.4	31.6	63.8	77.0	85.0	127.4	222.0	145.7	82.2	57.2	37.9	22.8	986.1
1967	33.3	154.7	392.6	651.2	279.0	329.7	238.6	180.9	134.1	99.6	65.2	35.3	2594.1
1968	32.3	67.5	83.4	135.7	321.9	650.2	302.8	191.9	139.7	104.4	68.1	37.9	2135.7
1969	77.1	149.1	218.4	324.2	393.4	522.6	177.2	179.3	140.0	107.5	72.6	40.2	2401.5
1970	57.5	77.8	84.2	155.7	235.6	284.0	213.0	113.9	79.9	53.5	30.7	20.2	1406.0
1971	15.3	19.3	25.6	29.3	23.6	50.4	79.4	49.0	33.4	23.6	11.3	2.6	362.8
1972	0.4	13.2	73.3	214.1	156.4	194.3	213.7	109.8	66.1	44.5	33.3	10.8	1129.8
1973	12.3	17.9	36.8	36.4	32.9	96.7	159.7	80.3	54.0	38.2	23.9	11.9	601.0
1974	13.3	23.1	74.4	232.5	497.0	479.8	202.2	144.2	105.2	77.4	50.9	23.2	1922.9
1975	12.3	27.6	46.7	129.0	203.1	356.1	316.4	253.1	145.7	108.1	74.4	46.8	1719.3
1976	34.3	39.9	91.2	137.3	119.0	202.3	279.5	157.7	106.1	80.8	53.7	30.8	1332.6
1977	22.3	30.4	59.7	50.5	77.3	218.6	250.1	166.8	115.9	91.2	65.9	44.0	1192.5
1978	31.2	39.7	74.1	145.6	506.6	779.6	249.3	184.5	139.9	118.4	87.5	52.1	2408.4
1979	41.8	83.1	93.0	141.6	218.5	166.3	82.6	74.6	60.4	47.0	27.1	12.6	1048.4
1980	9.8	6.2	17.8	79.5	187.6	431.6	224.2	110.2	88.8	71.2	48.5	21.4	1296.7
1981	9.9	16.9	22.9	76.7	236.5	266.4	218.9	158.0	105.9	79.7	47.1	22.2	1261.1
1982	12.2	28.3	39.1	102.7	123.6	185.9	99.6	82.0	68.9	50.7	28.8	11.9	833.7
1983	16.6	44.5	213.2	644.3	412.6	637.3	524.2	264.9	180.6	139.5	101.4	60.9	3239.9
1984	61.0	79.2	128.1	140.4	88.5	180.6	225.1	160.7	117.8	93.2	63.3	29.8	1367.6
1985	26.2	15.3	11.2	42.2	138.4	340.9	193.8	113.6	84.7	65.8	44.3	20.2	1096.7
1986	36.3	56.9	78.4	95.6	131.4	203.9	99.9	77.9	64.2	52.7	31.2	19.4	947.7
1987	16.9	26.4	31.0	118.1	196.0	220.0	251.7	219.7	124.8	97.1	67.4	40.5	1409.5
1988	27.3	56.9	178.8	271.2	146.6	125.7	208.5	214.2	123.6	91.0	61.0	27.2	1532.0
1989	9.6	4.5	8.0	100.6	171.1	181.0	226.9	120.7	84.7	62.7	41.7	18.3	1029.6
1990	13.2	36.8	115.6	147.9	79.6	137.6	92.9	66.8	53.2	37.0	24.6	7.8	812.9
1991	12.4	47.1	130.4	287.4	329.6	368.0	176.9	120.9	104.3	86.9	61.4	33.6	1758.8
1992	26.8	22.1	29.8	48.3	50.5	122.2	80.4	93.9	73.3	43.2	25.8	15.1	631.4
1993	9.3	18.8	75.9	76.7	67.5	69.4	50.4	59.8	49.3	33.7	9.6	6.2	526.5
1994	6.2	9.1	30.6	32.6	62.8	202.9	140.6	87.1	68.0	46.9	21.1	3.3	711.2
AVERAGE	**25.9**	**42.5**	**96.1**	**170.2**	**216.2**	**304.4**	**217.9**	**144.4**	**100.2**	**74.9**	**49.8**	**27.0**	**1469.4**

Monthly stream flow data (million m³) at Rundu

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1945	85	151	626	952	454	328	438	284	158	128	112	89	3804
1946	101	146	344	864	1531	1693	1304	805	420	327	268	200	8003
1947	143	109	137	358	563	1308	576	408	266	191	148	108	4316
1948	92	101	125	83	204	663	1063	540	239	185	147	104	3546
1949	66	52	95	212	640	1237	1274	492	235	169	106	69	4646
1950	48	34	124	408	777	1713	1819	1671	795	498	366	245	8498
1951	171	192	471	536	720	1080	588	347	224	178	150	108	4766
1952	87	131	329	400	440	711	1312	928	404	302	238	164	5446
1953	119	131	228	489	1168	1803	2099	1354	667	476	371	264	9168
1954	178	157	229	288	318	335	373	336	212	153	132	94	2804
1955	50	94	178	678	1117	888	941	886	405	280	213	149	5878
1956	108	87	120	123	347	631	915	437	217	156	114	78	3332
1957	72	103	234	582	414	421	633	304	144	126	103	78	3217
1958	56	54	145	363	596	693	656	519	300	203	149	101	3836
1959	65	53	140	367	628	886	727	524	372	243	182	123	4309
1960	69	61	170	291	581	1124	1652	1378	651	400	291	196	6865
1961	129	139	465	1547	1291	1137	1327	911	478	366	289	204	8283
1962	149	174	321	886	1161	2175	1873	1248	663	501	390	270	9810
1963	201	241	630	560	622	863	825	418	271	236	204	145	5216
1964	105	109	177	514	903	1367	1465	936	449	345	268	189	6826
1965	142	113	306	717	1129	1112	1202	551	338	278	218	154	6260
1966	139	104	123	208	230	449	683	770	363	243	184	128	3623
1967	93	190	1040	1847	1862	1431	1057	683	472	359	294	208	9536
1968	136	133	297	521	943	1434	1923	931	471	371	304	221	7686
1969	166	252	507	617	1172	1541	1128	660	405	330	264	181	7222
1970	125	126	184	476	747	988	689	450	252	203	161	116	4516
1971	91	79	77	217	205	237	380	405	209	149	124	88	2260
1972	69	69	118	370	496	576	679	510	243	181	136	92	3539
1973	64	96	154	236	200	250	709	586	252	179	139	105	2970
1974	76	101	137	546	847	1786	1226	682	376	270	206	140	6391
1975	100	83	192	310	566	1101	1375	1141	532	356	272	190	6218
1976	152	125	290	467	523	631	1026	926	388	282	219	151	5180
1977	124	107	222	294	233	624	943	915	420	312	248	183	4624
1978	142	121	267	371	688	1844	1739	766	450	352	296	215	7250
1979	159	176	423	473	678	932	597	365	232	187	146	105	4473
1980	83	72	77	179	438	1032	1478	640	312	251	201	141	4903
1981	94	80	124	187	460	1197	987	807	390	288	208	140	4962
1982	98	90	198	284	510	651	755	424	259	211	158	107	3746
1983	77	103	350	1029	1703	1523	1788	1215	559	416	329	239	9331
1984	175	218	422	596	476	542	843	799	408	314	246	168	5206
1985	116	114	110	102	311	879	1341	631	319	241	191	136	4488
1986	95	178	316	379	471	753	753	412	243	200	163	112	4075
1987	101	99	173	237	609	780	1020	983	479	327	254	180	5241
1988	132	131	364	884	876	594	620	879	468	314	237	162	5663
1989	103	68	49	132	583	718	900	787	327	242	184	131	4224
1990	90	105	276	625	520	466	644	372	216	172	136	97	3720
1991	61	101	327	663	1189	1398	1165	569	334	280	231	161	6479
1992	134	120	153	213	268	436	537	421	306	218	146	110	3062
1993	91	85	194	465	352	425	364	295	213	176	119	62	2840
1994	53	54	128	186	201	553	907	503	280	202	153	92	3313
1995	59	63	120	265	262	499	654	340	201	158	124	91	2836
1996	72	47	104	213	336	588	695	491	265	171	134	98	3213
1997	65	71	75	279	653	1039	998	464	227	191	147	96	4305
1998	62	73	139	293	561	1080	1566	750	355	278	211	153	5520
1999	108	56	230	708	480	482	788	659	343	246	188	127	4415
2000	86	59	64	159	470	1188	1521	1208	466	200	225	186	5831
2001	59	64	159	470	1188	1521	1208	466	200	225	186	140	5886
2002	64	159	470	1188	1521	1208	466	200	225	186	140	102	5929
2003	159	470	1188	1521	1208	466	200	225	186	140	102	183	6049
2004	249	502	959	1129	730	377	276	212	140	94	86	168	4923
2005	322	766	1046	690	579	299	228	179	123	78	78	293	4682
2006	1340	1784	1475	1339	780	188	0	0	57	143	127	239	7471
2007	384	885	1035	1526	853	396	300	244	173	110	125	200	6231
2008	380	435	630	860	911	468	314	236	170	135	200	674	5413
AVG.	**137**	**176**	**322**	**546**	**695**	**902**	**946**	**633**	**331**	**246**	**195**	**157**	**5286**

Shaded data are incomplete data

Monthly stream flow data (million m³) at Mukwe

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1949	294	252	380	498	754	1358	1676	1055	687	529	456	368	8307
1950	288	232	389	692	863	1811	2020	2210	1322	989	781	601	12198
1951	487	526	742	897	1025	1428	1124	816	578	510	466	388	8986
1952	349	398	627	721	786	1064	1592	1551	975	785	645	525	10018
1953	441	441	590	790	1244	2068	3425	1971	1240	990	827	670	14697
1954	543	474	606	757	822	922	934	885	725	612	510	430	8219
1955	375	411	526	867	1367	1498	1370	1436	1004	804	655	530	10842
1956	451	398	461	456	631	980	1272	994	651	546	495	418	7754
1957	395	414	564	922	963	1040	1138	888	626	513	472	407	8344
1958	344	332	480	734	852	1186	1127	1092	797	627	524	431	8526
1959	360	319	450	710	876	1266	1178	1037	845	683	563	457	8744
1960	366	337	500	623	815	1261	1829	1901	1238	915	720	556	11061
1961	444	413	693	1490	1714	1548	1656	1495	1012	851	709	579	12604
1962	488	479	633	1070	1332	1494	1631	1778	1268	1270	1049	728	13221
1963	560	583	983	1012	1062	1262	1407	1253	1041	886	640	490	11180
1964	419	402	494	711	1105	1654	1861	1556	1069	810	683	554	11318
1965	451	366	569	925	1412	1577	1830	1149	802	659	566	470	10774
1966	438	379	415	559	651	919	1125	1274	886	717	566	437	8365
1967	374	460	1135	1782	953	2267	1725	1316	977	786	645	516	12936
1968	411	380	565	740	1213	1934	1248	1664	1009	836	704	571	11274
1969	498	570	797	929	1304	2052	1784	1140	808	694	618	515	11709
1970	430	411	574	1009	1228	1609	1272	1006	685	577	511	430	9742
1971	385	375	400	559	567	755	944	929	693	562	480	404	7053
1972	367	332	393	614	749	856	972	980	641	507	450	381	7240
1973	336	366	472	640	667	766	1011	1231	781	621	496	418	7806
1974	378	396	457	752	1072	2173	1911	1303	896	735	574	463	11110
1975	397	352	502	624	889	1408	1872	1749	1118	836	656	518	10920
1976	458	399	551	739	867	1008	1237	1560	906	706	566	463	9461
1977	424	369	539	768	810	1079	1502	1634	995	751	609	496	9976
1978	447	422	562	684	881	1640	818	1422	911	716	615	509	9629
1979	431	444	695	761	977	1522	1165	927	691	566	501	427	9107
1980	367	323	353	470	714	1331	1938	1378	841	688	563	460	9423
1981	387	336	394	458	637	1451	1554	1398	882	724	555	435	9212
1982	372	344	501	588	702	1089	1487	1175	677	553	476	401	8365
1983	357	374	581	1097	1992	1903	1774	1845	965	729	628	518	12764
1984	424	446	670	879	881	942	1177	1323	875	730	599	473	9418
1985	400	378	417	424	608	1136	1828	1260	836	666	533	441	8928
1986	410	472	607	686	740	995	1094	811	605	506	460	388	7773
1987	367	339	478	532	804	1118	1267	1424	958	723	569	483	9061
1988	415	392	621	1072	1392	1215	1069	1280	930	668	508	412	9974
1989	367	332	384	413	714	1063	1124	1302	769	604	478	398	7949
1990	349	338	540	791	955	892	986	812	535	463	419	356	7436
1991	325	384	580	884	1304	1667	1585	1062	654	550	496	398	9888
1992	334	338	384	426	544	633	889	844	645	521	424	351	6333
1993	334	321	434	829	822	865	786	653	463	418	391	333	6649
1994	290	267	367	414	411	755	1067	908	551	456	390	330	6207
1995	287	268	341	473	503	735	910	651	420	387	362	297	5635
1996	250	227	308	467	583	920	1098	905	581	432	377	324	6472
1997	278	275	296	504	795	1197	1392	945	571	467	416	345	7482
1998	297	288	392	577	748	1336	1984	1501	794	589	467	371	9343
1999	320	276	397	939	888	917	1015	1161	796	602	433	336	8078
2000	270	216	239	335	537	1231	1908	2139	1056	775	569	442	9719
2001	354	299	436	494	636	1086	1401	1201	812	632	515	404	8269
2002	336	284	420	571	888	1365	1042	976	685	537	433	344	7881
2003	276	274	438	1029	1833	1611	1913	1545	989	809	602	475	11795
2004	402	362	496	600	980	1364	1800	642	0	68	208	0	6923
2005	362	496	600	980	1364	1800	642	0	68	208	0	113	6634
2006	496	600	980	1364	1800	642	0	68	208	0	113	336	6608
2007	600	980	1364	1800	642	0	68	208	0	113	336	448	6560
AVG	**387**	**384**	**538**	**765**	**947**	**1266**	**1364**	**1197**	**780**	**631**	**527**	**433**	**9219**

Shaded data are incomplete data

Annual stream flow in million m³									
Year	Extension of Ruacana	Rundu	Mukwe	Dirico	Year	Extension of Ruacana	Rundu	Mukwe	Dirico
1933	2 889.09	3 722.99	8 542.52	4 022.94	1968	8 126.76	7 686.12	11 274.43	6 321.43
1934	4 781.61	5 154.98	9 767.88	4 495.80	1969	7 513.12	7 221.80	11 709.08	4 723.22
1935	5 621.30	5 790.34	10 311.56	4 705.61	1970	3 937.19	4 516.05	9 741.72	5 119.81
1936	10 475.86	9 463.58	13 454.75	5 918.57	1971	955.82	2 260.17	7 053.03	4 185.75
1937	7 516.39	7 224.28	11 538.57	5 179.12	1972	2 645.71	3 538.83	7 240.27	3 855.26
1938	3 736.48	4 364.18	9 091.19	4 234.67	1973	1 894.06	2 970.09	7 805.56	4 026.56
1939	2 681.09	3 565.61	8 407.85	3 970.97	1974	6 415.54	6 391.31	11 109.52	5 938.84
1940	4 410.55	4 874.22	9 527.63	4 403.09	1975	6 186.01	6 217.64	10 920.29	5 671.28
1941	2 432.01	3 377.14	8 246.58	3 908.73	1976	4 814.27	5 179.69	9 460.96	4 290.29
1942	3 889.27	4 479.79	9 190.12	4 272.85	1977	4 080.40	4 624.41	9 975.51	4 191.14
1943	4 604.42	5 020.92	9 653.16	4 451.53	1978	7 551.01	7 250.48	9 628.55	5 747.32
1944	7 362.32	7 107.70	11 438.82	5 140.62	1979	3 880.54	4 473.18	9 106.60	4 408.98
1945	2 996.21	3 804.05	8 611.88	4 049.71	1980	4 448.07	4 902.61	9 423.49	4 780.26
1946	8 545.65	8 003.08	12 205.00	5 436.29	1981	4 526.93	4 962.28	9 212.33	4 083.39
1947	3 672.95	4 316.11	9 050.05	4 218.80	1982	2 919.34	3 745.88	8 364.77	4 005.39
1948	2 654.65	3 545.60	8 390.73	3 964.36	1983	10 300.33	9 330.77	12 763.88	5 624.64
1949	4 108.99	4 646.04	8 306.68	3 931.93	1984	4 849.66	5 206.47	9 417.71	4 295.25
1950	9 199.32	8 497.68	12 198.29	5 433.70	1985	3 900.56	4 488.33	8 927.81	4 905.30
1951	4 267.16	4 765.72	8 986.44	4 194.25	1986	3 354.42	4 075.09	7 773.45	4 193.12
1952	5 166.83	5 446.46	10 018.11	4 592.37	1987	4 895.86	5 241.44	9 061.18	3 843.76
1953	10 085.35	9 168.11	14 696.63	6 397.81	1988	5 452.88	5 662.91	9 974.27	3 482.52
1954	1 673.99	2 803.58	8 219.30	3 898.21	1989	3 551.60	4 224.29	7 948.70	3 628.95
1955	5 737.52	5 878.28	10 842.49	4 910.50	1990	2 885.64	3 720.39	7 436.19	3 583.84
1956	2 372.81	3 332.34	7 754.46	3 718.83	1991	6 531.78	6 479.26	9 888.38	4 527.45
1957	2 219.97	3 216.70	8 343.97	3 946.32	1992	2 015.83	3 062.23	6 333.09	3 527.28
1958	3 038.07	3 835.72	8 526.43	4 016.73	1993	1 721.57	2 839.58	6 649.11	3 838.51
1959	3 663.98	4 309.32	8 744.15	4 341.59	1994	2 347.14	3 312.92	6 207.31	2 995.52
1960	7 040.96	6 864.54	11 061.17	4 832.70	1995	1 717.35	2 836.39	5 634.66	3 383.38
1961	8 915.84	8 283.19	12 603.65	5 970.77	1996	2 215.38	3 213.22	6 472.10	3 314.67
1962	10 933.58	9 809.92	13 221.16	5 722.23	1997	3 657.97	4 304.78	7 482.37	3 145.52
1963	4 862.14	5 215.92	11 179.51	4 706.88	1998	5 264.24	5 520.17	9 342.99	3 253.41
1964	6 990.61	6 826.45	11 318.45	4 186.16	1999	3 803.60	4 414.97	8 078.27	3 368.05
1965	6 241.43	6 259.57	10 773.95	4 202.11	2000	5 675.23	5 831.15	9 718.51	3 583.84
1966	2 757.09	3 623.12	8 364.94	3 841.67	2001	5 747.67	5 885.97	8 269.22	3 405.75
1967	10 571.65	9 536.07	12 935.75	5 271.12	**Average**	**5 374.78**	**5 603.81**	**10 157.82**	**4 585.41**

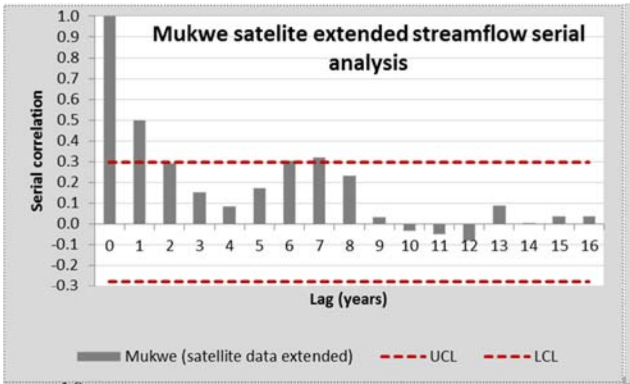
LEGEND of formula for extension of stream flow
f(x) = 1591.52+0.9715*LCE_Calueque
f(x) = -2031.2172 + 1.3216*Rundu
f(x) = 26.38+0.3859*Mukwe
f(x) = 1591.52+0.9715*Mukwe
f(x) = 5356.76+0.8557*Rundu
Many gaps

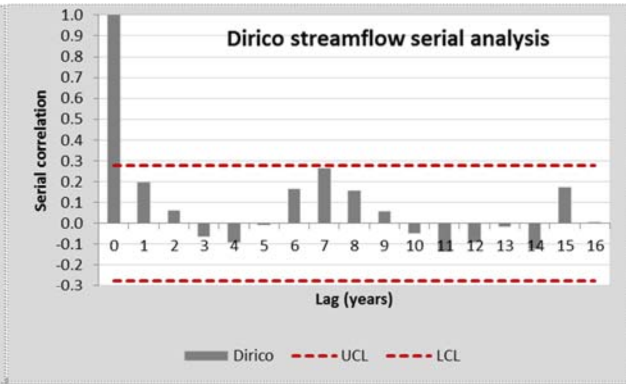
Annual recorded inflow at the CAN dams in million m³			
Year	**Omatako Dam**	**Swakoppoort Dam**	**von Bach Dam**
1964			
1965			
1966			
1967			
1968			
1969			
1970			30.9
1971			30.6
1972			10.6
1973			119.5
1974			7.6
1975			29.6
1976			5.2
1977		6.2	18.5
1978		0.1	3.4
1979		2.1	7.6
1980		0.8	3.5
1981	12.8	2.6	2.4
1982	5.8	2.6	16.3
1983	22.1	18.1	15.1
1984	54.4	27.7	9.9
1985	16.2	29.1	21.9
1986	10.8	14.5	7.1
1987	15.1	51.9	22.7
1988	18.7	25.4	24.9
1989	16.5	6.7	4.0
1990	32.8	0.6	5.3
1991	1.0	2.0	1.7
1992	23.2	19.1	9.6
1993	66.8	9.5	15.5
1994	0.3	0.2	0.4
1995	6.8	1.5	1.4
1996	35.3	46.9	22.3
1997	2.5	1.0	3.7
1998	4.1	1.3	8.0
1999	112.4	33.7	14.0
2000	6.3	16.7	7.5
2001	0.2	6.8	5.3
2002	4.4	2.0	0.9
2003	10.0	22.0	20.2
2004	14.8	11.7	9.8
2005	54.6	58.6	46.6
2006	5.5	1.6	1.2
2007	42.1	50.4	21.7
2008	27.3	25.0	19.3
2009	8.4	9.4	3.8
2010	100.2	170.9	51.3
2011	48.3	11.0	5.6
2012	0.2	0.5	0.0
AVERAGE	**24.4**	**19.2**	**15.5**

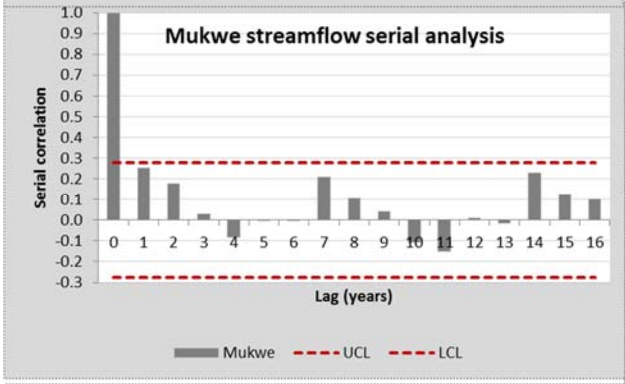
Appendix D

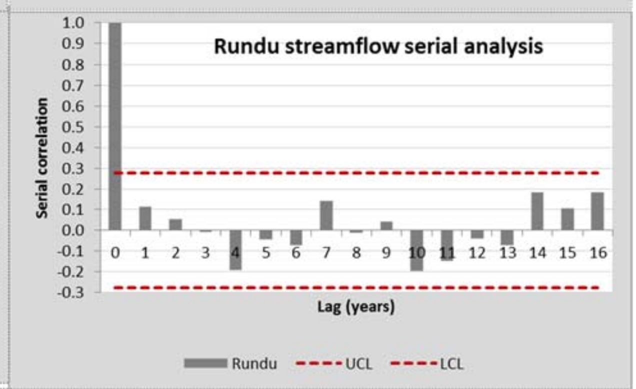
Statistical analyses

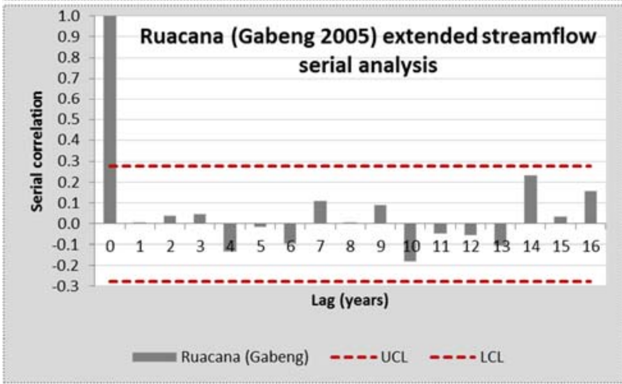
Appendix D.1: Serial correlations for the Okavango and Kunene rivers

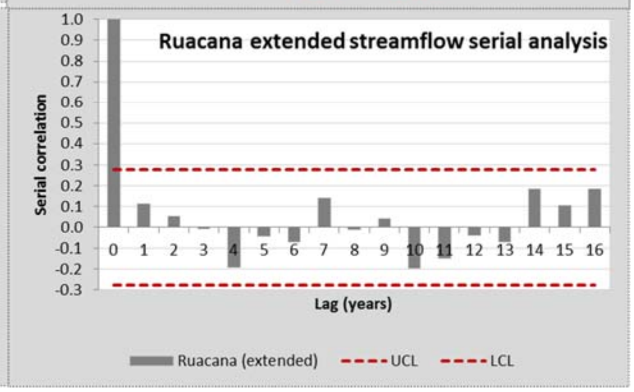




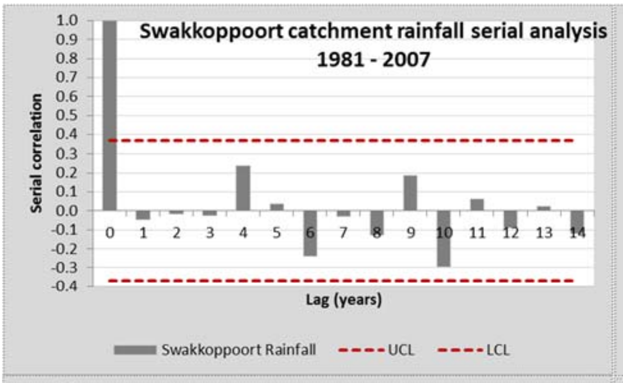


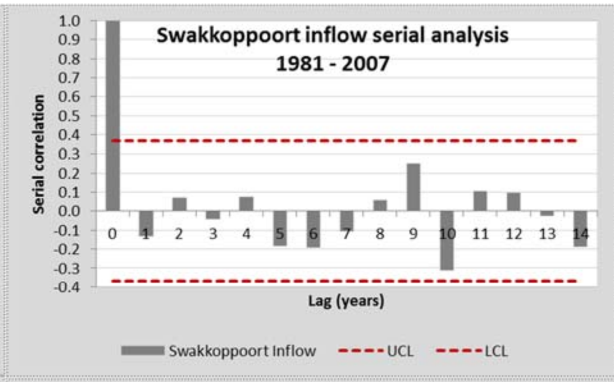


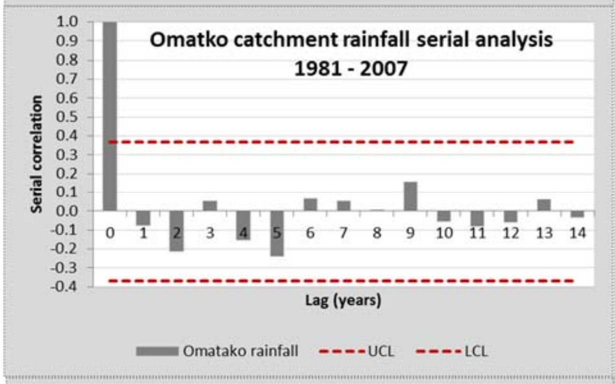


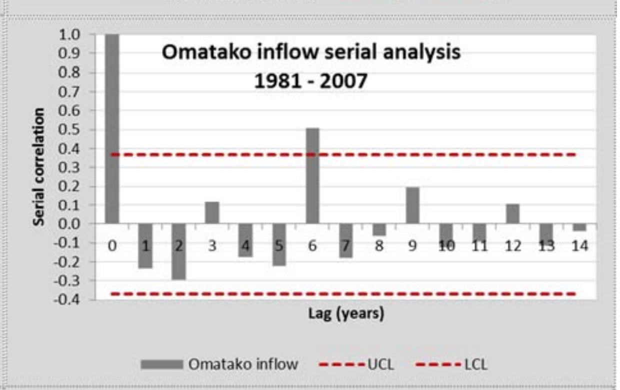


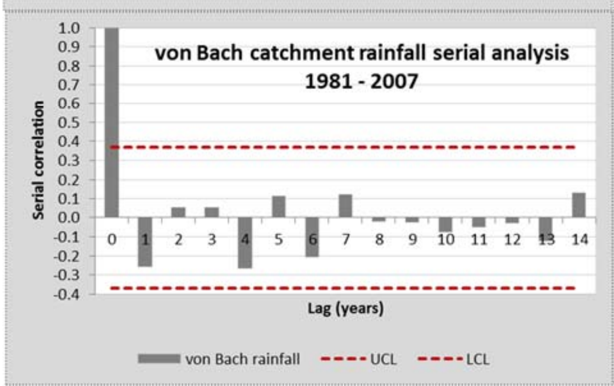
Appendix D.2: Serial correlations for the CAN dams for 1981 to 2007

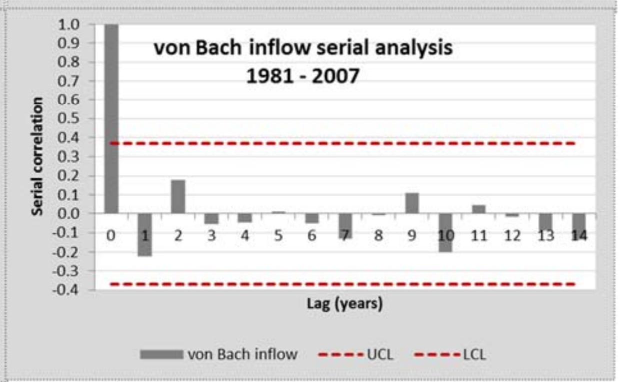












Appendix D.3: Historical worst droughts for full record period

Okavango River at Dirico. Annual record Oct 1933 to Sep 2003. Mean = 4 390 million m³/a													
	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1994-1995	1994-1996	1994-1997	1994-1998	1994-1999	1994-2000	1994-2001	1994-2002	1994-2003	1992-2002	1992-2003	1990-2002	1990-2003
Total period runoff	2 995.00	6 378.00	9 692.00	12 838.00	16 091.00	19 459.00	23 043.00	26 449.00	30 071.00	33 815.00	37 436.00	41 923.00	45 544.00
Incremental annual	2 995.00	3 383.00	3 314.00	3 146.00	3 253.00	3 368.00	3 584.00	3 406.00	3 622.00	3 744.00	3 621.00	4 487.00	3 621.00
Incremental as % of MAR	68.20	77.10	75.50	71.70	74.10	76.70	81.60	77.60	82.50	85.30	82.50	102.20	82.50
Okavango River at Mukwe. Annual record Oct 1933 to Sep 2009. Mean = 9 359 million m³/a													
Worst historic drought	1995-1996	1994-1996	1994-1997	1992-1996	1992-1997	1992-1998	1992-1999	1990-1998	1989-1998	1989-1999	1989-2000	1986-1998	1990-2003
Total period runoff	5 635.00	11 842.00	18 314.00	24 825.00	31 297.00	38 779.00	48 122.00	56 103.00	64 052.00	73 395.00	81 474.00	90 862.00	99 391.00
Incremental annual	5 635.00	6 207.00	6 472.00	6 511.00	6 472.00	7 482.00	9 343.00	7 981.00	7 949.00	9 343.00	8 079.00	9 388.00	8 529.00
Incremental as % of MAR	60.20	66.30	69.20	69.60	69.20	79.90	99.80	85.30	84.90	99.80	86.30	100.30	91.10
Cubango / Okavango River at Mohembo. Annual record Oct 1959 to Sep 2003. Mean = 4 317 million m³/a													
Worst historic drought	1994-1995	1994-1996	1994-1997	1994-1998	1994-1999	1994-2000	1994-2001	1994-2002	1994-2003	1992-2002	1992-2003	1990/2002	1990-2003
Total period runoff	2 995.00	6 378.00	9 692.00	12 838.00	16 091.00	19 459.00	23 044.00	26 449.00	30 071.00	33 815.00	37 436.00	41 927.00	45548.00
Incremental annual	2 995.00	3 383.00	3 314.00	3 146.00	3 253.00	3 368.00	3 585.00	3 405.00	3 622.00	3 744.00	3 621.00	4 491.00	3621.00
Incremental as % of MAR	69.40	78.40	76.80	72.90	75.40	78.00	83.00	78.90	83.90	86.70	83.90	104.00	83.90
Cunene River at Gove Dam. Annual record Oct 1933 to Sep 1972. Mean = 1 776 million m³/a													
Worst historic drought	1971-1972	1954-1956	1954-1957	1954-1958	1954-1959	1953-1959	1951-1958	1951-1959	1951-1960	1949-1959	1947-1958	1947-1959	1947-1960
Total period runoff	663.00	1834.00	2749.00	3 883.00	5 218.00	6 623.00	8 084.00	9 419.00	11 181.00	13 966.00	15 632.00	16 967.00	18729.00
Incremental annual	663.00	1171.00	915.00	1 134.00	1 335.00	1 405.00	1 461.00	1 335.00	1 762.00	2 785.00	1 666.00	1 335.00	1762.00
Incremental as % of MAR	37.30	65.90	51.50	63.90	75.20	79.10	82.30	75.20	99.20	156.80	93.80	75.20	99.20
Cunene River at Calueque (LCE Report). Annual record Oct 1933 to Sep 1987. Mean = 3 866 million m³/a													
Worst historic drought	1971-1972	1980-1982	1980-1983	1979-1983	1971-1976	1971-1977	1971-1978	1970-1978	1973-1982	1973-1983	1971-1982	1971-1983	1970-1983
Total period runoff	804.00	2 533.00	4 602.00	6 777.00	10 378.00	13 649.00	16 118.00	19 704.00	22 572.00	24 641.00	26 284.00	28 353.00	31 939.00
Incremental annual	804.00	1 729.00	2 069.00	2 175.00	3 601.00	3 271.00	2 469.00	3 586.00	2 868.00	2 069.00	1 643.00	2 069.00	3 586.00
Incremental as % of MAR	20.80	44.70	53.50	56.30	93.10	84.60	63.90	92.80	74.20	53.50	42.50	53.50	92.80
Cunene River at Ruacana (BKSA3 Report). Annual record Oct 1945 to Sep 1994. Mean = 4 992 million m³/a													
Worst historic drought	1971-1972	1992-1994	1992-1995	1956-1960	1954-1959	1954-1960	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1983-1995	1982-1995
Total period runoff	1 211.00	3 773.00	6 185.00	11 165.00	14 720.00	18 248.00	23 597.00	28 163.00	31 337.00	35 062.00	39 508.00	50 555.00	53 382.00
Incremental annual	1 211.00	2 562.00	2 412.00	4 980.00	3 555.00	3 528.00	5 349.00	4 566.00	3 174.00	3 725.00	4 446.00	11 047.00	2 827.00
Incremental as % of MAR	24.30	51.30	48.30	99.80	71.20	70.70	107.20	91.50	63.60	74.60	89.10	221.30	56.60
Cunene River at Ruacana (Extended record). Annual record Oct 1933 to Sep 2009. Mean = 4 967 million m³/a													
Worst historic drought	1971-1972	1971-1973	1971-1974	1992-1996	1992-1997	1992-1998	1992-1999	1992-2000	1989-1998	1989-1999	1989-2000	1986-1998	1985-1998
Total period runoff	956.00	3 602.00	5 496.00	7 802.00	10 018.00	13 675.00	18 939.00	22 744.00	26 645.00	31 909.00	35 713.00	40 348.00	44 248.00
Incremental annual	956.00	2 646.00	1 894.00	2 306.00	2 216.00	3 657.00	5 264.00	3 805.00	3 901.00	5 264.00	3 804.00	4 635.00	3 900.00
Incremental as % of MAR	19.20	53.30	38.10	46.40	44.60	73.60	106.00	76.60	78.50	106.00	76.60	93.30	78.50
Von Bach Dam catchment rainfall. Annual record Oct 1923 to Sep 2012. Mean annual precipitation = 345 mm													
Worst HY drought	1929-09/30	1928-09/30	1980-09/83	1929-09/33	1928-09/33	1927-09/33	1923-09/30	1925-09/33	1923-09/32	1923-09/33	1923-09/34	1923-09/35	1992-09/05
Total period rainfall	138.00	345.00	675.00	888.00	1 095.00	1 517.00	1 784.00	2 056.00	2 360.00	2 534.00	3 071.00	3 431.00	3 792.00
Incremental annual	138.00	207.00	330.00	213.00	207.00	422.00	267.00	272.00	304.00	174.00	537.00	360.00	361.00
Incremental as % of MAP	40.00	60.00	95.65	61.74	60.00	122.32	77.39	78.84	88.12	50.43	155.65	104.35	104.64

Swakoppoort Dam catchment rainfall. Annual record Oct 1923 to Sep 2012. Mean annual precipitation = 308 mm													
Worst HY drought	1929-09/30	1944-09/46	1943-09/46	1929-09/33	1928-09/33	1927-09/33	1923-09/30	1925-09/33	1923-09/32	1923-09/33	1923-09/34	1923-09/35	1923-09/36
Total period rainfall	106.00	305.00	558.00	772.00	976.00	1 275.00	1 553.00	1 787.00	2 062.00	2 219.00	2 670.00	2 969.00	3 273.00
Incremental annual	106.00	199.00	253.00	214.00	204.00	299.00	278.00	234.00	275.00	157.00	451.00	299.00	304.00
Incremental as % of MAP	34.42	64.61	82.14	69.48	66.23	97.08	90.26	75.97	89.29	50.97	146.43	97.08	98.70
Omatako Dam catchment rainfall. Annual record Oct 1923 to Sep 2012. Mean annual precipitation = 354 mm													
Worst HY drought	2012-09/13	1931-09/33	1931-09/34	1929-09/33	1928-09/33	1928-09/34	1998-09/05	1956-09/64	1956-0965	1956-09/66	1994-09/05	1993-09/05	1992-09/05
Total period rainfall	87.00	353.00	684.00	874.00	1 145.00	1 477.00	1 861.00	2 201.00	2 554.00	2 967.00	3 187.00	3 578.00	3 939.00
Incremental annual	87.00	266.00	331.00	190.00	271.00	332.00	384.00	340.00	353.00	413.00	220.00	391.00	361.00
Incremental as % of MAP	24.58	75.14	93.50	53.67	76.55	93.79	108.47	96.05	99.72	116.67	62.15	110.45	101.98


Rundu
Dirico
Mukwe
Mohembo
Gove
Calueque
Ruacana (Gabeng,
Ruacana
Von Bach
Swakoppoor
Omataku Da
Drought

Appendix D.5: Historical worst droughts for overlapping record period (1945 to 1995)

Okavango River at Rundu. Annual record Oct 1945 to Sep 1995. Mean = 5 311 million m³/a

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1971-1972	1971-1973	1971-1974	1970-1974	1954-1959	1954-1960	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1971-1983	1970-1983
Total period runoff	2 260	5 799	8 769	13 285	19 067	23 376	29 302	34 543	38 618	43 106	48 313	56 517	61 033
Incremental Annual	2 260	3 539	2 970	4 516	5 782	4 309	5 926	5 241	4 075	4 488	5 207	8 204	4 516
Incremental as % of MAR	43	67	56	85	109	81	112	99	77	85	98	154	85

Okavango River at Dirico. Annual record Oct 1945 to Sep1995. Mean = 4 512 million m³/a

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1994-1995	1993-1995	1992-1995	1987-1991	1990-1995	1989-1995	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1983-1995	1982-1995
Total period runoff	2 995	6 834	10 361	14 539	18 473	22 102	25 584	29 428	33 620	38 526	42 821	48 445	52 451
Incremental Annual	2 995	3 839	3 527	4 178	3 934	3 629	3 482	3 844	4 192	4 906	4 295	5 624	4 006
Incremental as % of MAR	66	85	78	93	87	80	77	85	93	109	95	125	89

Okavango River at Mukwe. Annual record Oct 1945 to Sep 1995. Mean = 9 615 million m³/a

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1994-1995	1993-1995	1992-1995	1991-1995	1990-1995	1992-1998	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1983-1995	1982-1995
Total period runoff	6 208	12 857	19 190	29 078	44 464	38 779	54 438	63 499	71 273	80 201	89 618	102 383	110 748
Incremental Annual	6 208	6 649	6 333	9 888	15 386	-5 685	15 659	9 061	7 774	8 928	9 417	12 765	8 365
Incremental as % of MAR	65	69	66	103	160	-59	163	94	81	93	98	133	87

Kunene River at Ruacana (GABHIC, 2005). Annual record Oct 1945 to Sep 1995. Mean = 4 992 million m³/a

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1971-1972	1992-1994	1992-1995	1956-1960	1954-1959	1954-1960	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1983-1995	1982-1995
Total period runoff	1 211	3 773	6 185	11 165	14 720	18 248	23 597	28 163	31 337	35 062	39 508	50 555	53 382
Incremental Annual	1 211	2 562	2 412	4 980	3 555	3 528	5 349	4 566	3 174	3 725	4 446	11 047	2 827
Incremental as % of MAR	24	51	48	100	71	71	107	91	64	75	89	221	57

Kunene River at Ruacana (Extended record). Annual record Oct 1945 to Sep 1995. Mean = 4 988 million m³/a

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1971-1972	1971-1973	1971-1974	1970-1974	1954-1959	1954-1960	1988-1995	1987-1995	1986-1995	1985-1995	1984-1995	1971-1983	1970-1983
Total period runoff	956	3 602	5 496	9 433	15 042	18 706	24 508	29 404	32 758	36 658	41 507	50 317	54 254
Incremental Annual	956	2 646	1 894	3 937	5 609	3 664	5 802	4 896	3 354	3 900	4 849	8 810	3 937
Incremental as % of MAR	19	53	38	79	112	73	116	98	67	78	97	177	79

Omatako Dam catchment rainfall. Annual record Oct 1945 to Sep 1995. Mean annual precipitation = 352 million m³/a

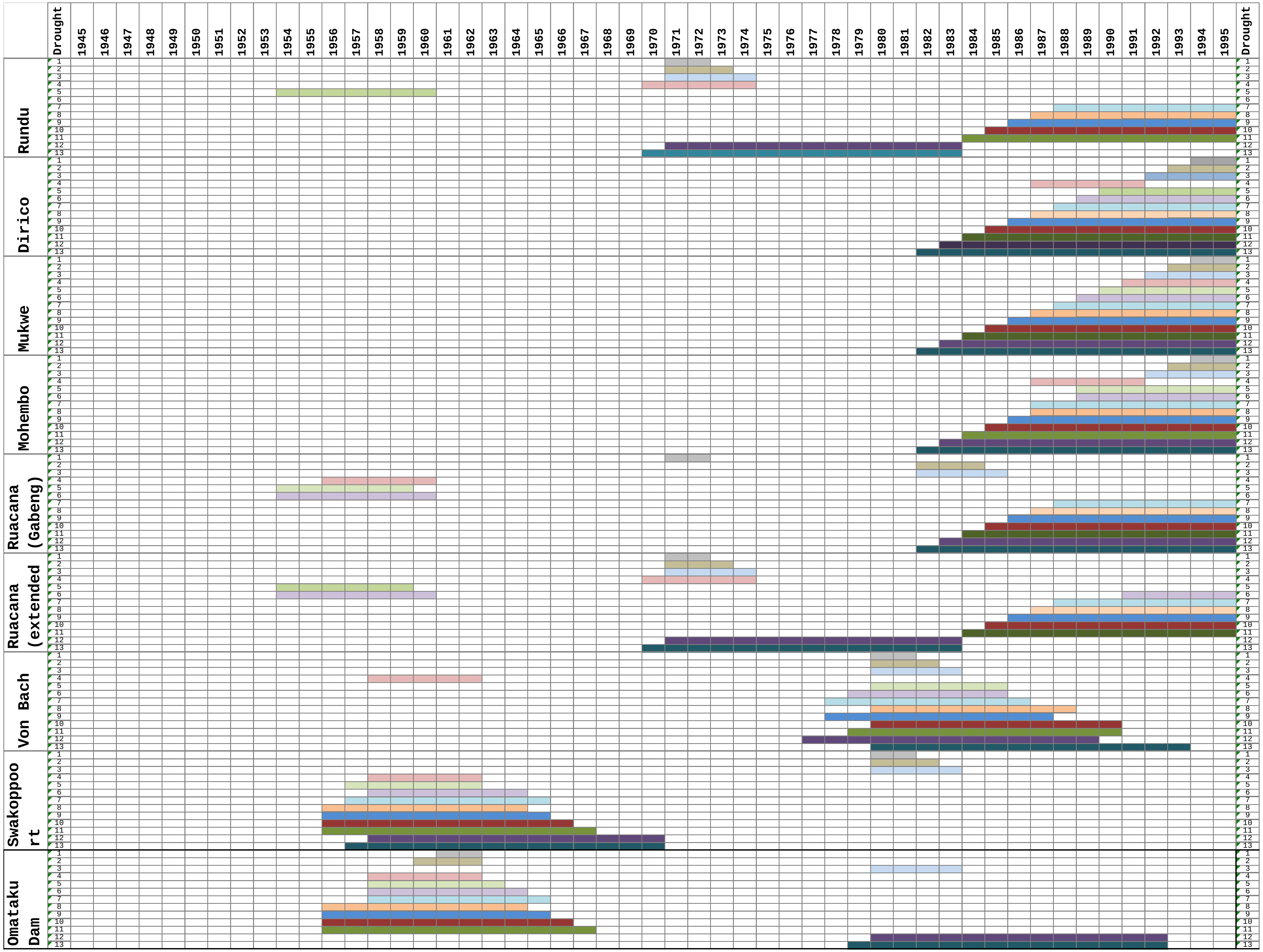
	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst historic drought	1961-09/62	1960-09/62	1980-09/83	1958-09/62	1958-09/63	1958-09/64	1958-09/65	1956-09/64	1956-09/65	1956-09/66	1956-09/67	1980-09/92	1979-09/92
Total period rainfall	199	436	703	952	1 242	1 539	1 892	2 201	2 554	2 967	3 350	3 746	4 099
Incremental Annual	199	237	267	249	290	297	353	309	353	413	383	396	353
Incremental as % of MAP	57	67	76	71	82	84	100	88	100	117	109	113	100

Von Bach Dam catchment rainfall. Record Oct 1945 to Sep 1995. Mean annual precipitation = 360 mm

	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst HY drought	1980-09/81	1980-09/82	1980-09/83	1958-09/62	1980-09/85	1979-09/85	1978-09/85	1980-09/88	1978-09/87	1980-09/90	1979-09/90	1978-09/90	1980-09/93
Total period rainfall	161	365	675	1024	1274	1654	1945	2335	2643	2971	3351	3643	4042

Incremental Annual	161	204	310	349	250	380	291	390	308	328	380	292	399
Incremental as % of MAP	44.7222222	56.6666667	86.1111111	96.9444444	69.4444444	105.555556	80.8333333	108.333333	85.5555556	91.1111111	105.555556	81.1111111	110.833333
Swakoppoort Dam catchment rainfall. Record Oct 1945 to Sep 1995. Mean annual precipitation = 317 mm													
	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst HY drought	1980-09/81	1980-09/82	1980-09/83	1958-09/62	1957-09/62	1958-09/64	1957-09/64	1956-09/64	1956-09/65	1956-09/66	1956-09/67	1958-09/70	1957-09/70
Total period rainfall	165	365	598	861	1178	1441	1757	2048	2397	2736	3135	3361	3677
Incremental Annual	165	200	233	263	317	263	316	291	349	339	399	226	316
Incremental as % of MAP	52.0504732	63.0914826	73.5015773	82.9652997	100	82.9652997	99.6845426	91.7981073	110.094637	106.940063	125.867508	71.2933754	99.6845426
Omatako Dam catchment rainfall. Record Oct 1945 to Sep 1995. Mean annual precipitation = 352 mm													
	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year
Worst HY drought	1961-09/62	1960-09/62	1980-09/83	1958-09/62	1958-09/63	1958-09/64	1958-09/65	1956-09/64	1956-09/65	1956-09/66	1956-09/67	1980-09/92	1979-09/92
Total period rainfall	199	436	703	952	1242	1539	1892	2201	2554	2967	3350	3746	4099
Incremental Annual	199	237	267	249	290	297	353	309	353	413	383	396	353
Incremental as % of MAP	56.5340909	67.3295455	75.8522727	70.7386364	82.3863636	84.375	100.284091	87.7840909	100.284091	117.329545	108.806818	112.5	100.284091

Appendix D.6: Worst droughts on record for overlapping period of record (1945 – 1995)



Appendix E

Yield results

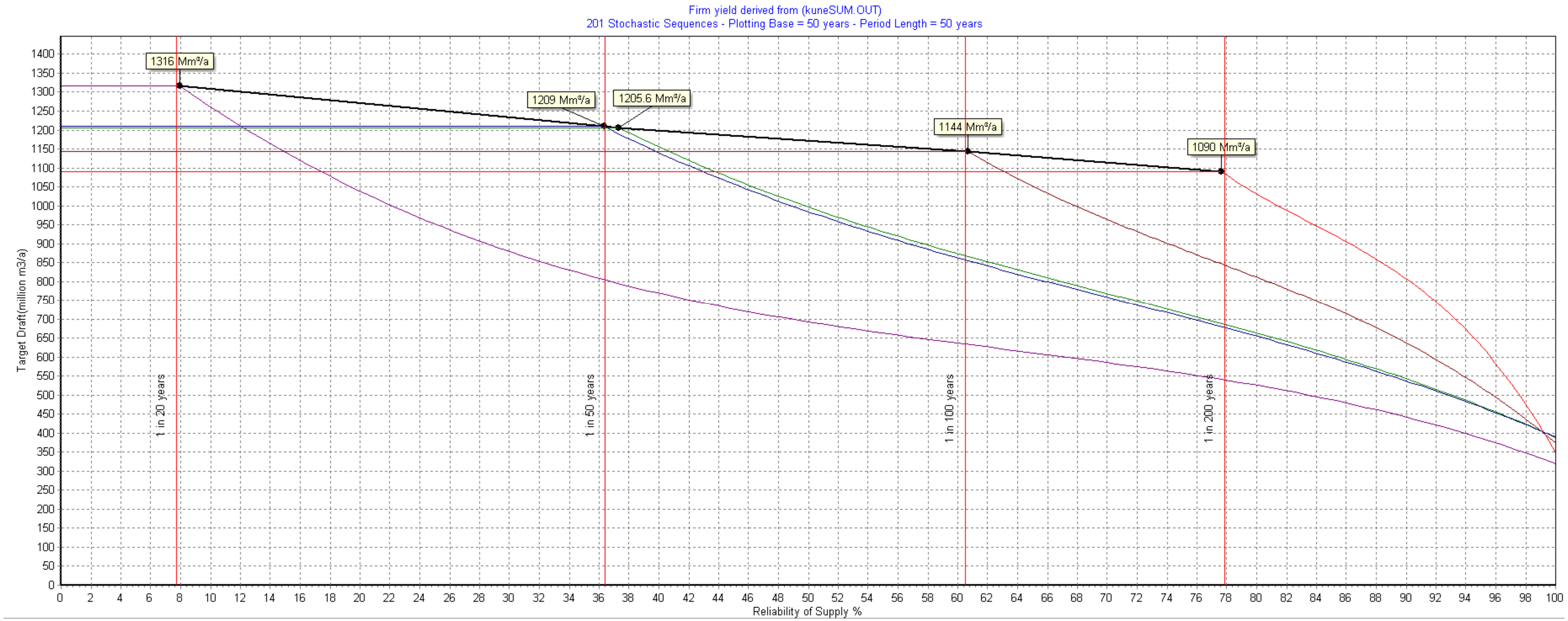


Figure E.1: Stochastic yield results for Gove Dam

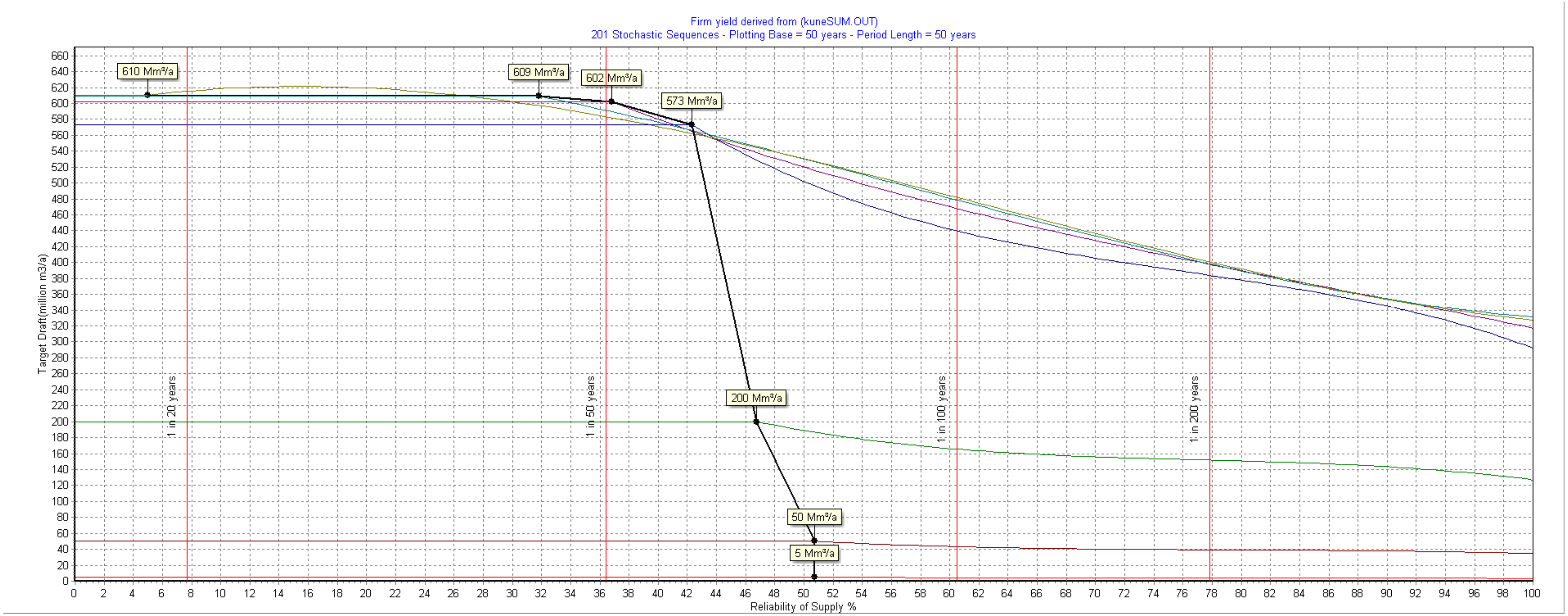


Figure E.2: Stochastic yield results – Scenario 1: Calueque Dam yield

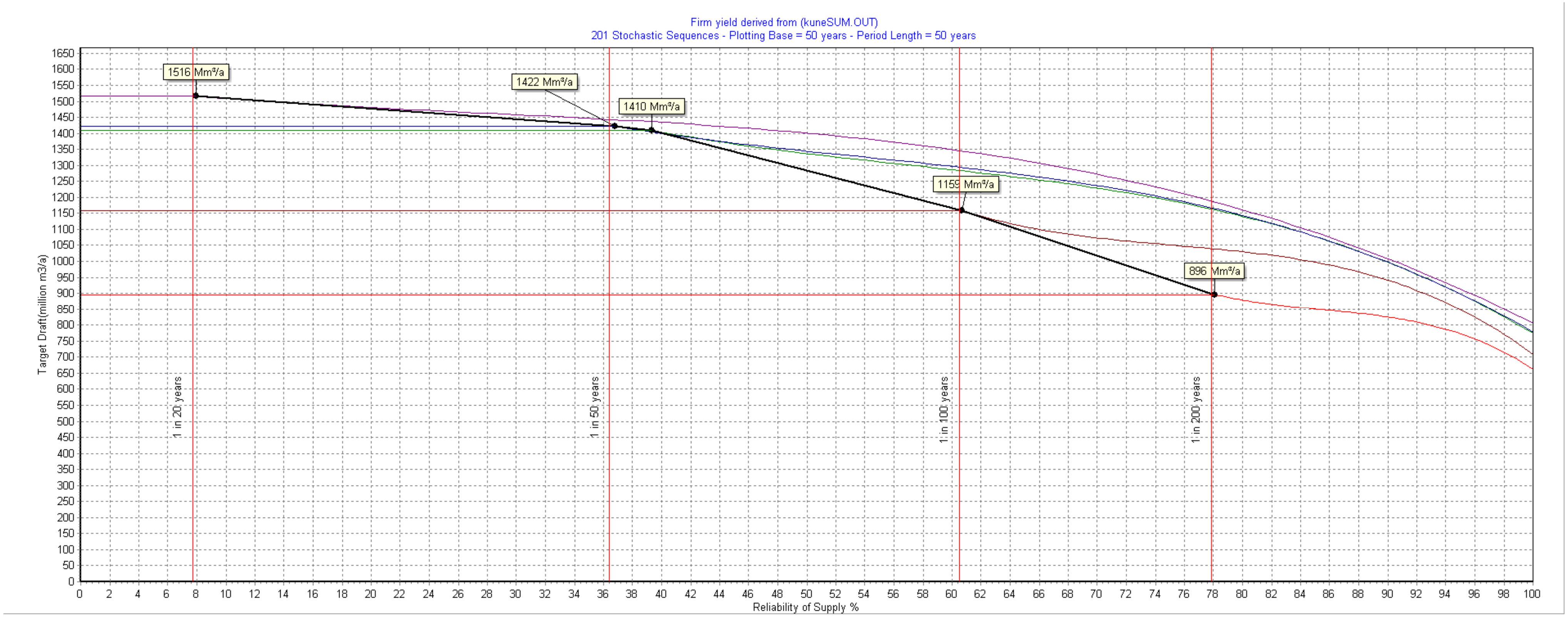


Figure E.3: Stochastic yield results – Scenario 2: Calueque Dam yield

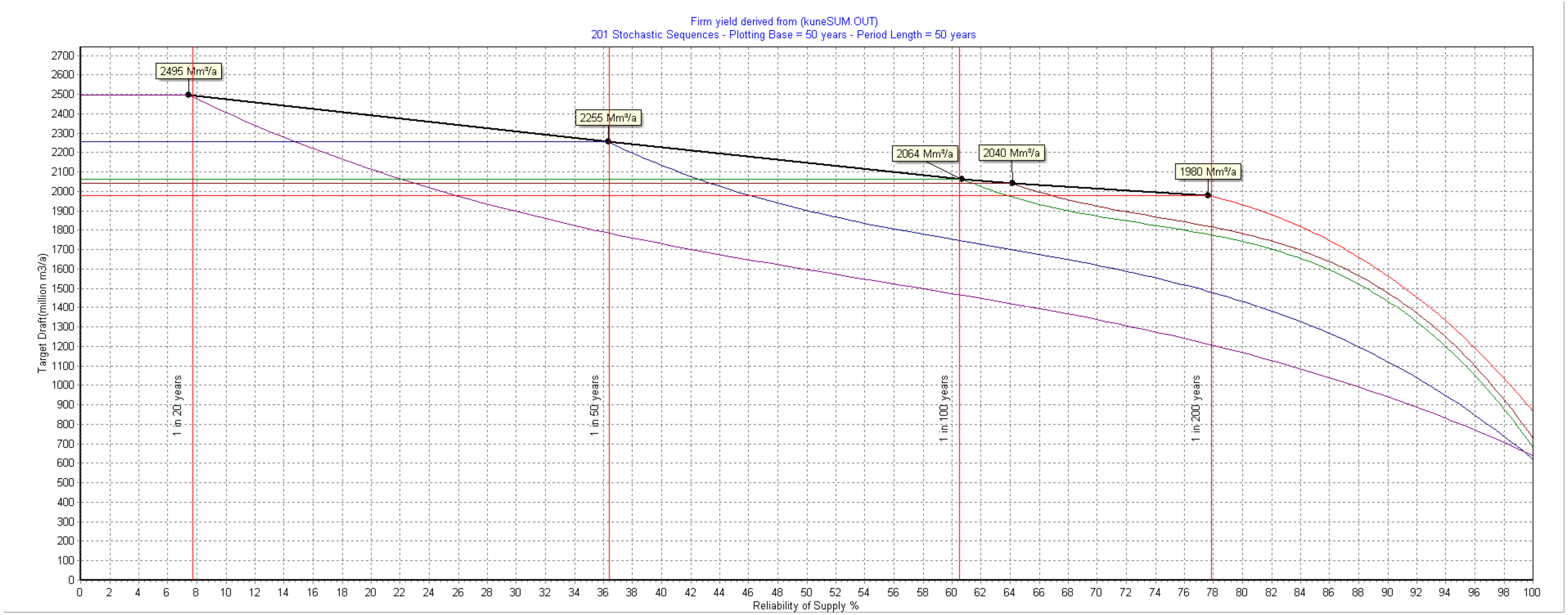


Figure E.4: Stochastic yield results – Scenario 3: Calueque Dam yield

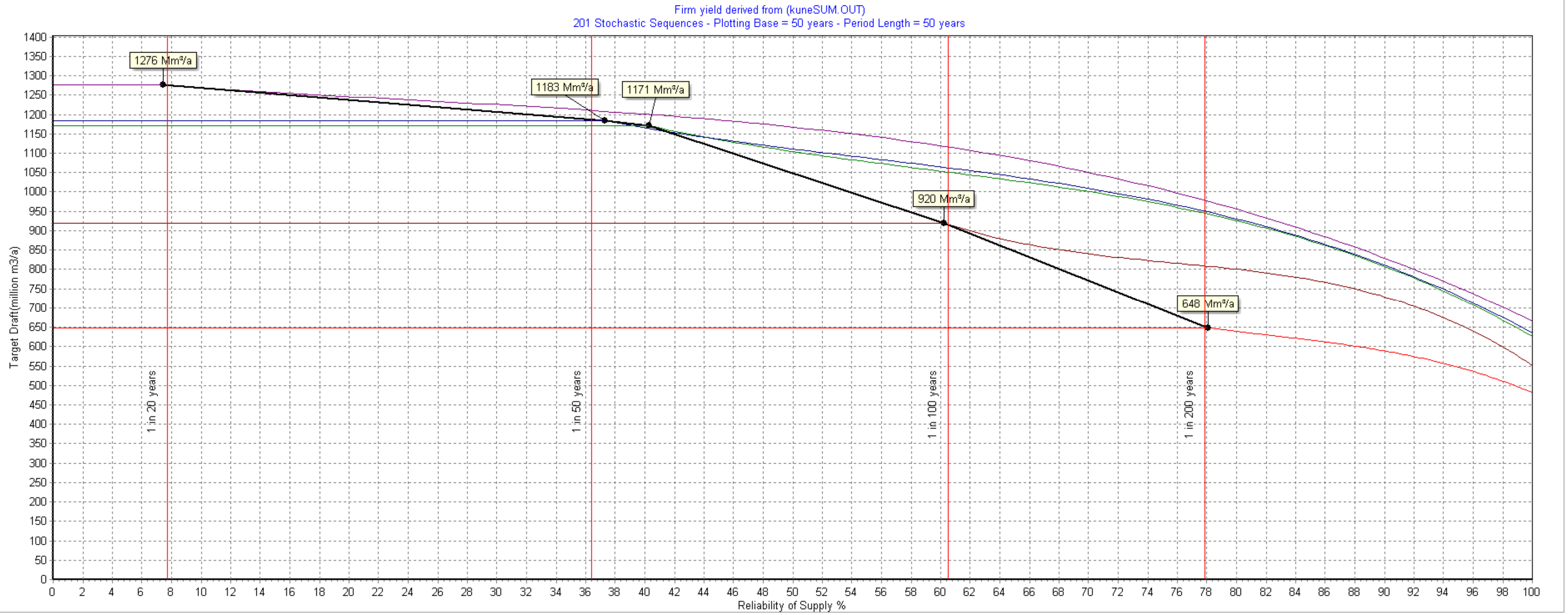


Figure E.5: Stochastic yield results – Scenario 4: Calueque Dam yield

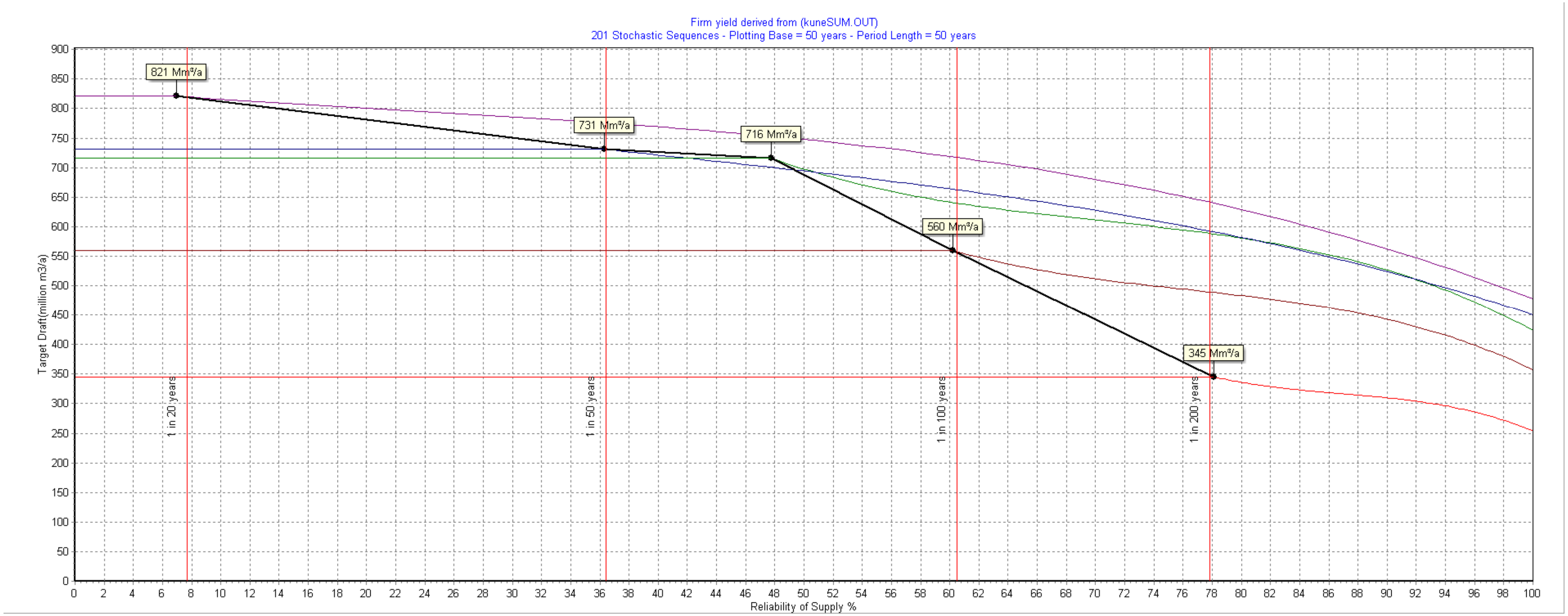


Figure E.6: Stochastic yield results – Scenario 5: Calueque Dam yield