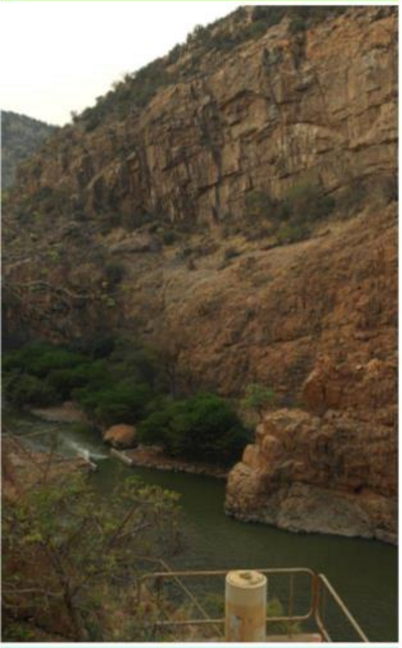
water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

REPORT NO: PWMA 01/000/00/02914/7





THE DEVELOPMENT OF THE LIMPOPO WATER MANAGEMENT AREA NORTH RECONCILIATION STRATEGY

YIELD ANALYSIS (WRYM)

FINAL

MARCH 2016

W79_2014/J02173

Project Name:	***Limpopo Water Management Area North Reconciliation Strategy***
Report Title:	***Yield Analysis (WRYM)***
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DWS Report No.:	***P WMA 01/000/00/02914/7***
DWS Contract No.	***WP 10768***
PSP Project Reference No.:	***60326619***
Status of Report:	***Final***
Date:	***March 2016***

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Limpopo Water Management Area North Reconciliation Strategy

Date: March 2016

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EXECUTIVE SUMMARY

The Department of Water and Sanitation (DWS) identified the need for the Limpopo Water Management Area (WMA) North Reconciliation Strategy to ensure sustainable water supply up to 2040 in the area. Limpopo WMA North refers to the Limpopo WMA as defined in the first National Water Resources Strategy (NWRS-1, 2004). The reconciliation strategy must a) address growing water demands as well as water quality problems experienced in the Study Area, b) identify resource development options and c) provide reconciliation interventions, both structural and administrative or regulatory.

The objective of this yield assessment task and report is to configure the WRYM and undertake yield analyses for the major dams in the Study Area, using the updated hydrology which covers the Study period of 1920 to 2010 hydrological years (i.e. October 1920 to September 2011).

The Historical Firm Yield (HFY) analyses were conducted for the each of the major dams in the Study Area, with and without the Environmental Water Requirements (EWRs) imposed on the systems. Long-term stochastic yield analyses were also conducted to evaluate the assurance of supply of each of these dams. ***Figure i*** *provides the historical and stochastic yield results (at different assurance of supply) of the major dams that were analysed in the Study Area. The results are given with and without the EWRs – which have a significant impact on the yield. The impact of implementing the EWR on the 1:50 year yield is illustrated in* ***Figure ii****, with the largest being on the Glen Alpine Dam.*

The considerable impact of releasing the desktop EWR is shown in ***Figure ii****, with a reduction in yield at Glen Alpine Dam of 80% and around 46% for Doorndraai and 44% for Nzhelele dams respectively.*

Based on the yield analyses undertaken and resulting rational yield results obtained as part of the Limpopo North Reconciliation Strategy*, it is concluded that the WRYM has successfully been configured and used to determine both historical and long term stochastic sub-system yields for the Mogalakwena, Sand and Nzhelele catchments and the models have been configured for the Matlabas and Lephalala river catchments.*

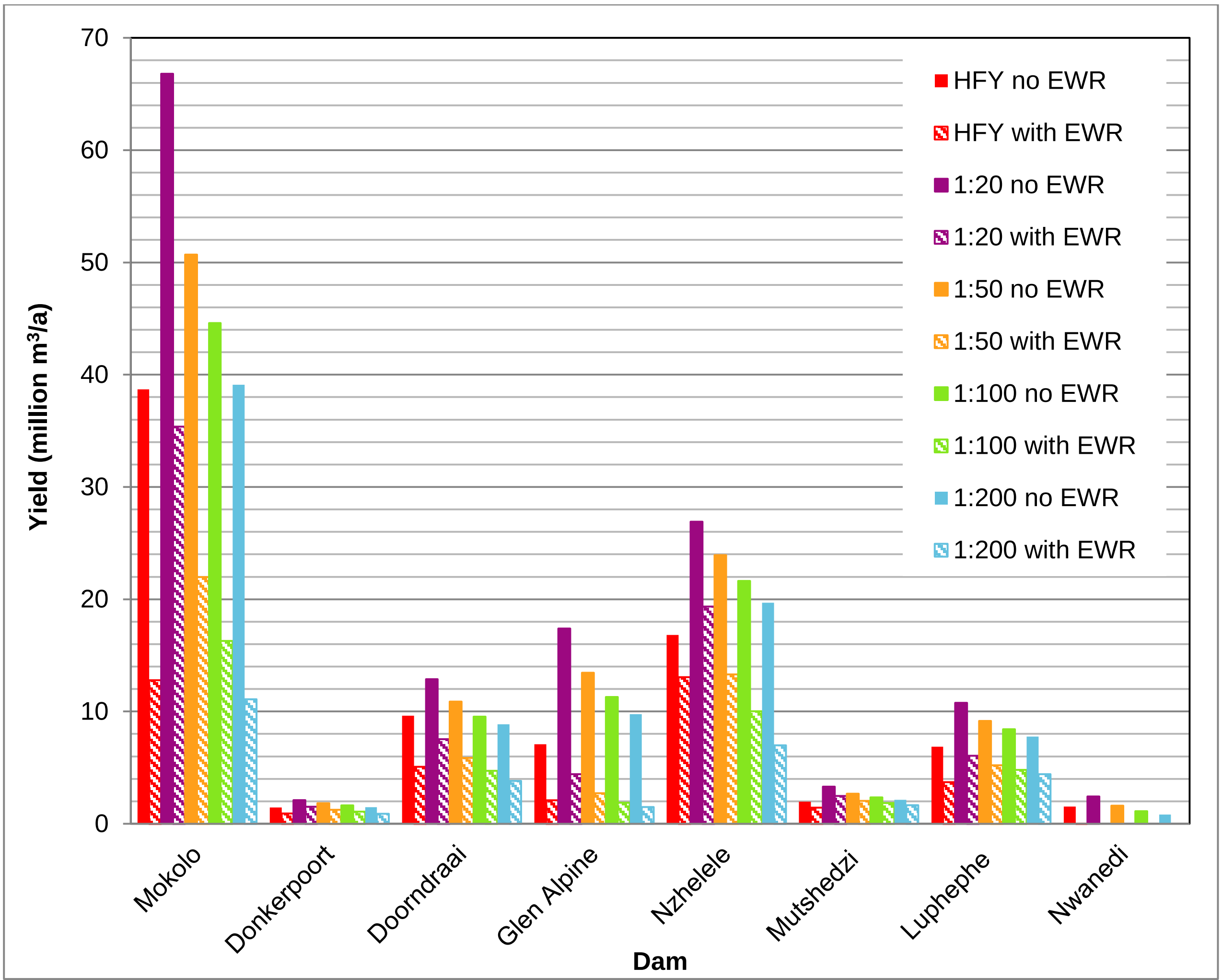

Figure i **Overview of the historic and stochastic yields with and without EWR (in million m³/a)**

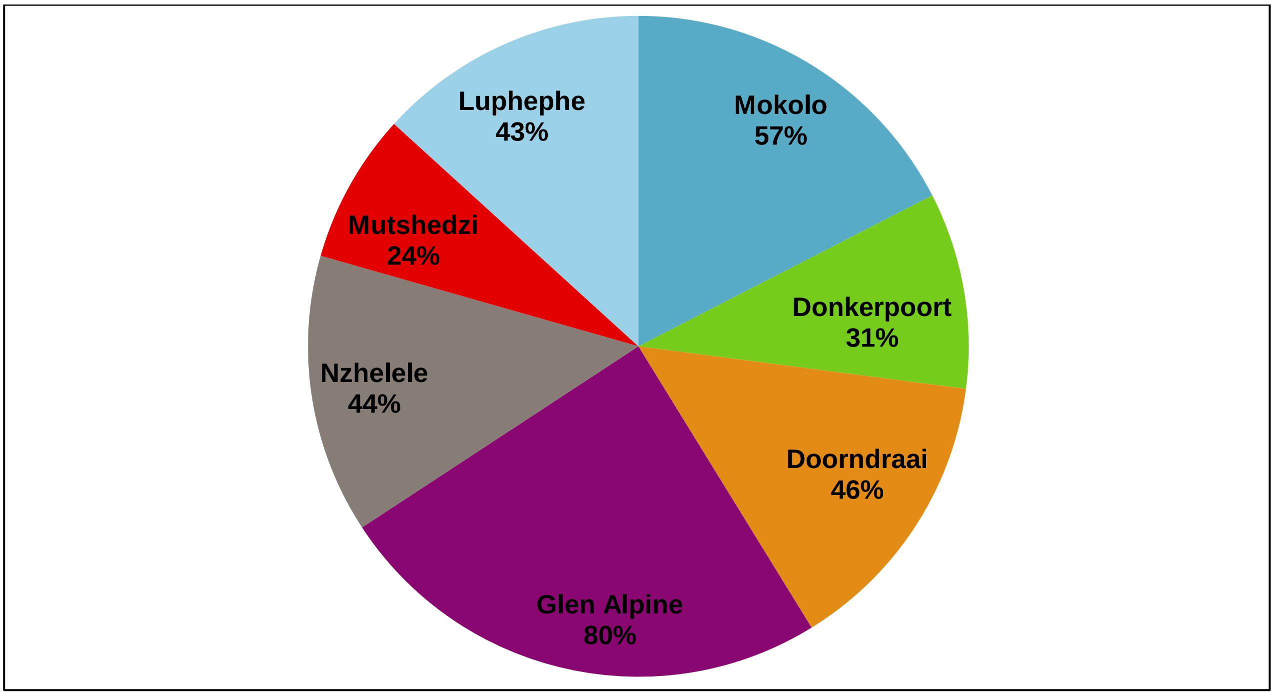

Figure ii **Reduction of the 1:50 year yield as a result of the EWR**

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AECOM	AECOM SA (Pty) Ltd
CV	Coefficient of Variance
DM	District Municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Ecological condition
EI	Ecological Importance
ES	Ecological Sensitivity
EWR	Environmental water requirements
FSC	Full Supply Capacity
HFY	Historical Firm Yield
IAP	Invasive Alien Plant
IWR	Institute for Water Research
LM	Local Municipality
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NWRS-1	National Water Resource Strategy First Edition
NWRS-2	National Water Resource Strategy Second Edition
PES	Present Ecological State
PSP	Professional Service Provider
RI	Recurrence Interval
RSA	Republic of South Africa
SD	Standard Deviation
SFRA	Stream Flow Reduction Activity
STOMSA	Stochastic Model of South Africa
S-pan	Symons pan
SQ	Sub-quaternary reach
WCWDM	Water Conservation and Water Demand Management
WMA	Water Management Area
WRMF	Water Resources Modelling Framework
WRPM	Water Resources Planning Model
WRSM2000	Water Resource Simulation Model of 2000
WRYM	Water Resources Yield Model
WULA	Water Use License Application
YRC	Yield-reliability curve

LIST OF UNITS

m^3	cubic meter
m^3/a	cubic meter per annum
m^3/s	cubic meter per second
km^2	square kilometre
mm	millimetre

1 INTRODUCTION

1.1 APPOINTMENT OF PROFESSIONAL SERVICE PROVIDER (PSP)

The Department of Water and Sanitation (DWS), then Department of Water Affairs (DWA) appointed **AECOM SA (Pty) Ltd** in association with three sub-consultants **Hydrosol**, **Jones and Wagener** and **VSA Rebotile Metsi Consulting** with effect from 1 March 2014 to undertake the **Limpopo Water Management Area North Reconciliation Strategy**.

1.2 BACKGROUND TO THE PROJECT

The DWS (then DWA) identified a need for the development of the Limpopo Water Management Area (WMA) North Reconciliation Strategy. The Limpopo WMA North refers to the Limpopo WMA described in the first edition of the *National Water Resource Strategy* (NWRS-1) published in 2004. The 19 initial WMAs were consolidated into nine WMAs during 2012 and acknowledged in the second edition of the *National Water Resource Strategy* (NWRS-2) of 2013. The newly defined Limpopo WMA also includes the original Crocodile (West) and Marico WMA as well as the Luvuvhu River catchment, previously part of the Luvuvhu and Letaba WMA. However, these additional areas will not be part of this Reconciliation Strategy.

The Limpopo WMA North comprises of six main river catchments; Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele and are shown in **Figure 1.1**. The very small Nwanedi River catchment forms part of the Nzhelele River catchment. Most of these river catchments rely on their own water resources and are managed independently from neighbouring catchments. This implies that some river catchments require separate and independent reconciliation strategies whilst others need integrated water management reconciliation strategies.

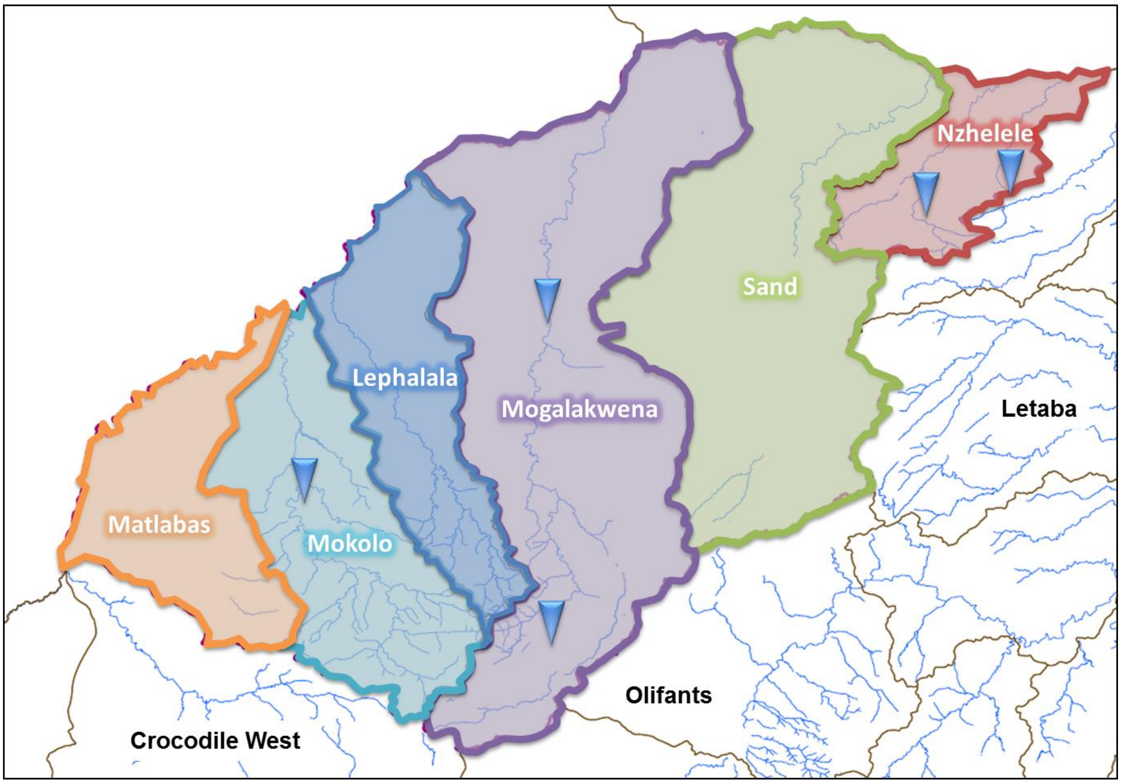

Figure 1.1 Overview of the catchments of the Limpopo WMA North

The main urban areas within the WMA include Mokopane, Polokwane, Mookgophong, Modimolle, Lephalale, Musina and Louis Trichardt. Approximately 760 rural communities are scattered throughout the WMA, mostly concentrated in the central region. The main economic activities are irrigation and livestock farming as well as expanding mining operations due to the vast untapped mineral resources in the area. The water resources, especially surface water resources, are heavily stressed due to the present levels of development. It is crucial that water supply is secured and well managed.

The most western area of the Limpopo WMA North, the Matlabas River catchment, is a dry catchment with no significant dams and with a low growth potential for land-use development.

The large Mokolo Dam, in the Mokolo River catchment, supplies water to the Matimba Power Station, Medupi Power Station, Grootegeluk Coal Mine, the Lephalale Local Municipality (LM) as well as a number of downstream irrigators. The dam is able to meet the bulk of the current requirements but will in future rely on transfers from other WMAs to meet the water requirements at a sufficiently high assurance of supply.

The middle reaches of the Lephalala River catchment have a high conservation value with irrigation activities dominant in the remainder of the catchment. Irrigation in this area is supplied by surface water and alluvial aquifer abstraction.

The bulk of the water resources in the Mogalakwena River catchment have been fully developed. The Doorndraai Dam is over-allocated. Additional water to support the rapid expanding mining activities in the vicinity of Mokopane needs to be augmented by transfers from the Flag Boshielo Dam in the adjacent Olifants

River Catchment. Glen Alphine Dam presently supplies water to emerging farmers, who has not yet taken up their full allocated quota, and is expected to supply the growing domestic requirements in future.

Groundwater resources in the Mogalakwena and the Sand river catchments have been extensively utilised, and possibly over-exploited by the dominating irrigation sector. The expanding urban and industrial requirements of Polokwane and Makhado LMs, currently supplied by Albasini Dam, rely heavily on water transfers from adjacent WMAs. This includes transfers from the Ebenezer Dam, Dap Naude Dam, Flag Boshielo Dam and Nandoni Dam in the Olifants WMA.

Domestic and irrigation water in the small but highly developed Nzhelele River catchment is supplied through the Mutshedzi Dam Regional Water Supply Scheme and the Nzhelele Dam Regional Water Supply Scheme as well as extensively from groundwater resources. The inflows to the Mutshedzi and Nzhelele dams have been reduced as a result of afforestation upstream of these dams. The area is in deficit due to the over-allocation and over development of irrigation.

The Sand and Nzhelele river catchments have high coal mining potential but the availability of local water resources may limit future mining development.

1.3 STUDY AREA

The Limpopo WMA North is the most northern WMA in South Africa and refers to the area described as the Limpopo WMA in NWRS-1. Refer to **Figure 1.2** for the location and general layout of the study area. The areas indicated in grey show the additional catchment and WMA areas included in the Limpopo WMA as per NWRS-2 and which do not form part of the study area for this reconciliation strategy.

The Limpopo WMA North forms part of the internationally shared Limpopo River Basin which also includes sections of Botswana, Zimbabwe and Mozambique. The Limpopo River forms the entire length of the northern international border between South Africa and Botswana and Zimbabwe before flowing into Mozambique and ultimately draining into the Indian Ocean. The dry Limpopo WMA North is augmented with transfers from the adjacent Letaba, Olifants and Crocodile West river catchments. No transfers are currently made from the Limpopo WMA North to other WMAs.

The main rivers in the study area, which form the six major catchment areas, are the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele rivers. These rivers, together with other smaller tributaries, flow northwards and discharge into the Limpopo River.

The climate over the study area is temperate and semi-arid in the south to extremely arid in the north. Mean annual rainfall ranges from 300 mm to 700 mm with the potential evaporation well in excess of the rainfall. Rainfall is seasonal with most rainfall occurring in the summer with thunderstorms. Runoff is low due to the prevalence of sandy soils in the most of the study area, however, loam and clay soils are also found.

The topography is generally flat to rolling, with the Waterberg on the south and the Soutpansberg in the north-east as the main topographic features. Grassland and sparse bushveld shrubbery and trees cover most of the terrain.

The southern and western parts of the WMA are mainly underlain by sedimentary rocks, whilst metamorphic and igneous rocks are found in the northern and eastern parts. With the exception of some alluvium deposits and dolomites near Mokopane and Thabazimbi, these formations are mostly not of high water bearing capacity. The mineral rich Bushveld Igneous Complex extends across the south-eastern part of the WMA, and precious metals are mined at various localities throughout the area. Large coal deposits are found in the north-west.

Several wildlife and nature conservation areas have been proclaimed in the WMA, of which the Nylsvley Nature Reserve, Mapungubwe National Park and the Marekele National Park are probably the best known.

1.4 MAIN OBJECTIVES OF THE STUDY

The main objective of the study is to formulate a water resource reconciliation strategy for the entire Limpopo WMA North up to 2040. The reconciliation strategy must a) address growing water demands as well as water quality problems experienced in the catchment, b) identify resource development options and c) provide reconciliation interventions, structural and administrative/ regulatory. To achieve these objectives, the following aspects are included in the study:

- Review of all available information regarding current and future water requirements projections as well as options for reconciliation;
- Determine current and future water requirements and return flows and compile projection scenarios;
- Configure the system models (WRSM2000 rainfall-runoff catchment model, also known as the Pitman Model, the Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM)) in the study area at a quaternary catchment scale, or smaller, where required, in a manner that is suitable for allocable water quantification. This includes updating the hydrological data and accounting for groundwater surface water interaction;
- Assess the water resources and existing infrastructure and incorporate the potential for Water Conservation and Water Demand Management (WCWDM) and water reuse as reconciliation options; and
- Develop a preliminary short-term reconciliation strategy followed by a final long-term reconciliation strategy.

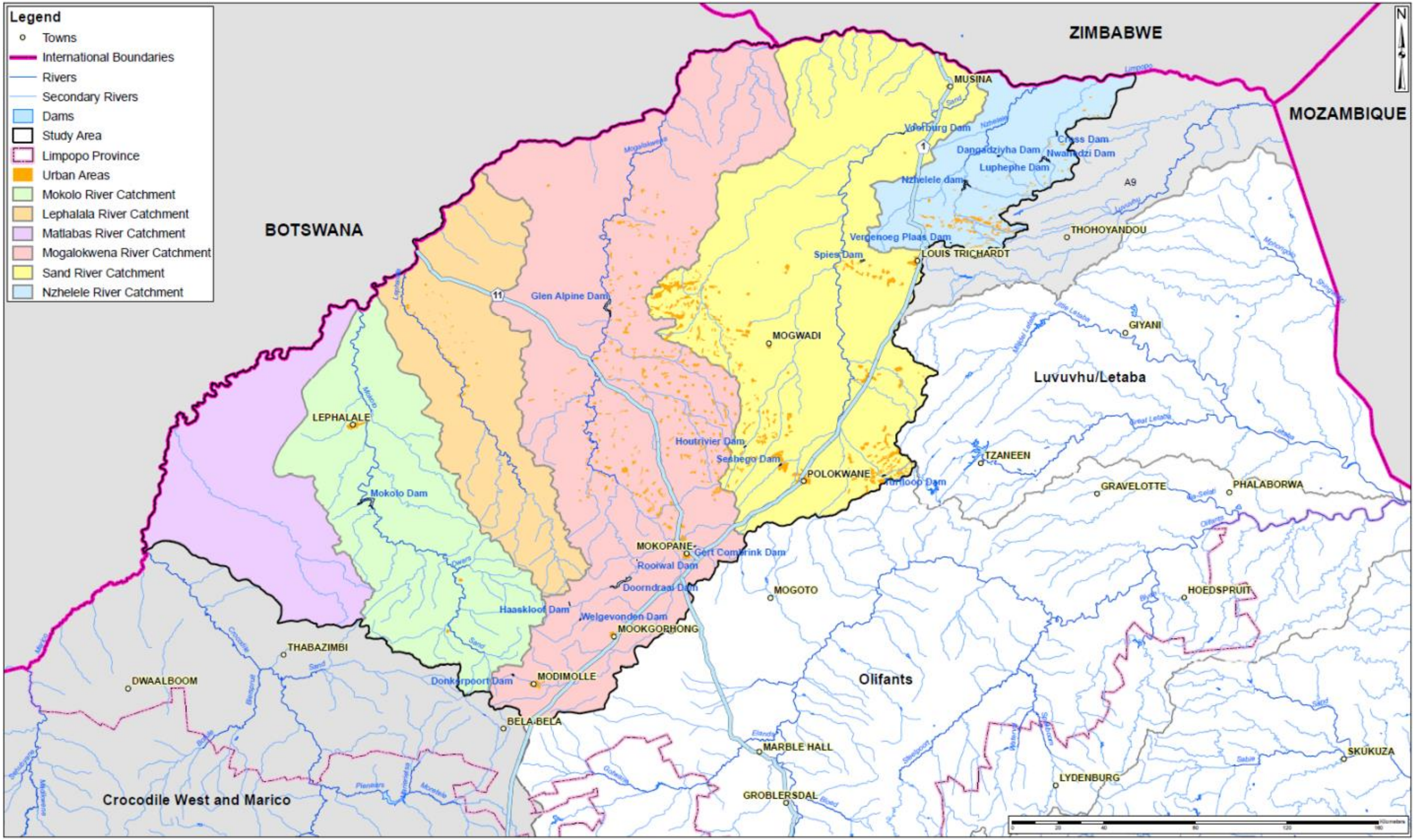

Figure 1.2 General layout of the study area

1.5 PURPOSE AND STRUCTURE OF THE DOCUMENT

The objective of this task and report is to configure the WRYM and undertake yield analyses at the major dams in the Study Area using the updated hydrology which covers the Study period of 1920 to 2010 hydrological years (i.e. October 1920 to September 2011). The *yield analysis* report includes the following sections:

- An introduction to the document, a description of the Study Area including background and context of the Study, as well as the purpose and structure of the document **(this section)**;
- A summary of the available hydro-meteorological data used in the yield analysis, including rainfall, evaporation and streamflow, as well as a discussion on the interaction between groundwater and surface water **(Section 2)**;
- Water requirements and return flows, including those related to streamflow reduction activities, irrigation activities, mining, power generation, urban centres and the ecology (**Section 3**);
- The physical components of the system including impoundments and irrigation (**Section 4**);
- The configuration of the WRYM, model description, operating rules for the system and the system yield definition as applied in this study (**Section 5**);
- Results obtained from the yield analysis both historical and stochastic (**Section 6**);
- The information repository accompanying this document (**Section 7**);
- Conclusions and recommendations from the results of the yield analysis (**Section 8**);
- References (**Section 9**).

1.6 SUB-DIVISION OF THE STUDY AREA IN DEFINED INCREMENTAL SUB-CATCHMENTS

The study area was divided into a total of 112 smaller sub-quaternary catchments to provide for detailed system modelling. The subdivision of quaternaries was based on the physical features and layout of the catchments such as the position of the main rivers and their tributaries, locations of waterbodies and flow gauging stations as well as the locations of water abstraction and return flows.

A summary of the incremental streamflow records per quaternary and sub-quaternary catchments, together with their sequence order is included in the parameter file, the *PARAM.DAT-file* and is shown in **Table F.1** Selected Johnson-Transform distributions and values of associated model parameters for quaternary / sub-quaternary catchmentsin **Appendix F**. This file contains the statistical properties of the natural streamflow and is discussed in more detail in **Section 2.3.2**.

2 HYDRO-METEOROLOGICAL DATA

Hydro-meteorological data provide the basis for the assessment of the yield of a water resources system. The level of confidence that can be placed on the results of such assessments is largely dependent on the quality or integrity of the available data. The updated hydro-meteorological data used in the yield analysis were obtained from the hydrological analysis undertaken as part of this Study. More details can be found in the report "*Limpopo Water Management Area North Reconciliation Strategy: Hydrological Analysis*". The following paragraphs of this Section describe the hydro-meteorological data used for the analysis of the six river systems of the Limpopo WMA North. It also provides the rationale on how these configurations were derived as well as how they were applied in the WRYM. These data sets cover the Study period of 91 years for the 1920 to the 2010 hydrological years (i.e. October 1920 to September 2011) and include the following:

- Rainfall (see **Section 2.1**)
- Evaporation (see **Section 2.2**)
- Streamflow (see **Section 2.3**)

2.1 RAINFALL

Rainfall data were included in the WRYM to calculate irrigation water requirements (see **Section 3.2**) as well as to allow for the direct rainfall on waterbodies. This includes the rainfall on major dams, small storage dams and weirs (as described in **Section 4.1**).

A set of data files, one for each of the 112 sub-catchments for a period of 91 years from 1920 to 2010 (hydrological years), were created with monthly historical rainfall in units of mm, referred to as *.RAN-files. The files were created based on data from the rainfall analysis, which was conducted as part of this Study, which are:

- Representative quaternary catchment rainfall files, containing monthly historical rainfall data expressed as a percentage of mean annual precipitation (MAP), referred to as *.SEC-files;
- Quaternary catchment MAPs, which were determined during the hydrological analysis based on information from the *Water Resources of South Africa 1990* publications, also known as WR90, (WRC, 1994). These are summarised in **Table B.1** in **Appendix B**.

Listings of the resulting *.RAN-files per quaternary catchment in the Limpopo WMA North, are attached with this document in a DVD. In this regard it should be noted that the rainfall data shown for a particular quaternary catchment were assumed to apply to all sub-quaternary catchment areas located inside the quaternary in question.

Traditionally, the *.RAN-files are used in yield analyses to define *point* rainfall data, since the intention is to model, specifically, the impact of rainfall on the surface area of major dams. However, in the case of the Limpopo WMA North, the hydrological response of the system is influenced to a large degree by the presence of a large number of small water bodies (as discussed in **Section 4.1**) and the predominant water use of irrigation (see **Section 3.2**). Consequently, it was decided that the *.RAN-files would be used in the yield analysis to define *catchment* rainfall instead of point rainfall, since the former is more representative of the rainfall that occurs on the water bodies and irrigated areas that are scattered over the various catchment areas in the system.

2.2 EVAPORATION

While rainfall and streamflow data are generally modelled in yield analyses as monthly time-series to incorporate the variability of these data on a monthly and annual basis, this is not the case with evaporation data. The latter is known not to vary significantly from one year to the next i.e. evaporation in, for example, one October-month is similar to evaporation in the next October-month. Therefore, it is generally considered to be acceptable to model evaporation simply by applying 12 average monthly evaporation values over the standard hydrological year, from October to September, for the particular area in question.

Evaporation data were used in WRYM to calculate:

- Evapo-transpiration from irrigated crops (see **Section 3.2**)
- Evaporation losses from the surface area of impoundments in the catchment, including the major dams, small storage dams and weirs (as described in **Section 4.1**).

Evaporation losses from water bodies are defined in the WRYM by means of 12 monthly *lake evaporation* values which were calculated for each of the quaternary catchments in the Study Area based on *Symons pan* (or S-pan) data and a set of S-pan-to-lake evaporation conversion factors (which is common to all catchment areas in South Africa). These were obtained from the hydrological analysis conducted as part of this study based on information from the WR90 publications (WRC, 1994) and are presented both in **Table B.3** in **Appendix B** and **Table 2.1**. The resulting lake evaporation data values are shown in **Table B.2** in **Appendix B**. In this regard it should be noted that the monthly and annual evaporation for a particular quaternary catchment were assumed to apply to all sub-quaternary catchment areas located inside the relevant quaternary.

Table 2.1 S-pan-to-lake evaporation conversion factors (WR90 (WRC,1994)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0.81	0.82	0.83	0.84	0.88	0.88	0.88	0.87	0.85	0.83	0.81	0.81

2.3 STREAMFLOW DATA

2.3.1 Historical streamflows

Streamflow data provide a critical input to water resources studies and are used in the process of calibrating the WRSM2000 rainfall-runoff model and used as the basis for generating natural streamflow time-series. These processes are discussed in detail in the *Hydrological Analysis* report which forms part of this Study.

Natural streamflow time-series, also referred to as a *.INC-file, was generated for all the 122 defined quaternary and sub-quaternary catchments in the Limpopo WMA North, for a period of 91 years from 1920 to 2010 (hydrological years), as part of the hydrological analysis of the Study. The results are presented on a separate DVD which is attached with this document. The statistical characteristics are presented in **Appendix B**, including the natural mean annual runoff (MAR), standard deviation (SD), coefficient of variance (CV) as well as the name of the associated WRYM data input file.

2.3.2 Stochastic streamflows

With the growing need to attach reliability to information and particularly the assurance of supply associated with the calculated yield, the use of stochastic flow sequences is increasingly becoming popular in water resources studies. It is no longer acceptable to report on a single number, such as the yield from a system of 10 million m^3/a. The assurance of supply attach to this figure is unknown and could be anything from once in every 10 years to once in every 200 years. The application for different sectors are certainly different for the various water use sectors as power supply need a high assurance of supply (1: 200) but it would not be cost-effective to plan for irrigation with such a high assurance.

The major objective of using stochastic generation software is to provide a range of plausible flow sequences with the same inherent statistical properties as the natural historical streamflow record for analysis, similar to the analysis of one single natural historical flow sequence. It is critical that the stochastically generated flow sequences need to be validated through the existing validation and verification tests in the *Stochastic Model of South Africa* (STOMSA) to ensure that these synthetic stochastic flow sequences are in fact realistic and plausible.

The statistical generation and analysis of stochastic stream flows was undertaken in this Study using the *STOMSA*, which incorporates Mark 7.1 of the *ANNUAL* and *CROSSYR* programs, both are being used extensively in South Africa for such purposes. These analyses are based on the statistical properties of the natural historical streamflow sequences for the sub-catchments in the Study Area.

Each stochastic sequence covers the period 1920 to 2010 (hydrological years). Subsequent to the cross correlation analysis, STOMSA was used to create the statistical parameter file called the *PARAM.DAT-file*, which summarises the results of the statistical analyses, including the marginal distribution and serial correlation parameters as well as the ß-matrix of the cross correlation. The *PARAM.DAT-file* provides direct input data to the WRYM and generates at runtime the stochastic streamflow sequences for stochastic yield and planning analysis. Included in the *PARAM.DAT-file* is control information for the verification and validation testing. A combined *PARAM.DAT* file was created for the entire Study Area including the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele catchments.

The file contains parameters for all 122 quaternary and sub-quaternary catchments in the Limpopo WMA North. The marginal distribution of a streamflow sequence provides a measure of the relationship between its annual total flows. The appropriate distribution for modelling annual flows is selected using the so-called *Hill Algorithm* (HILL, HILL and HOLDER, 1976). The *Hill algorithm* is based on the Johnson Transform Suite, which uses the first four moments of the marginal distribution to classify the type of distribution function as one of the following:

- 2-parameter Log-normal (LN2);
- 3-parameter Log-normal (LN3);
- 3-parameter Bounded (SB3);
- 4-parameter Bounded (SB4).

The Log-normal (LN) and Bounded (SB) distribution functions are defined as shown in **Equations 2.1** and **2.2**, respectively. More information in this regard is provided in the document Stochastic Modelling of Streamflow (BKS, 1986):

$$y = y + \delta * Ln(x - \xi), \qquad where\ x > \xi \tag{2.1}$$

$$y = y + \delta * \frac{Ln(x - \xi)}{\lambda + x - \xi}, \qquad where\ \lambda > x > \xi \tag{2.2}$$

It should be noted that each of the above distributions has its strengths and weaknesses with the result that careful checking is undertaken by the program to ensure that realistic and meaningful results are produced. A summary of the selected Johnson-Transform distributions and the values of the associated model parameters, as determined by STOMSA for the quaternary and sub-quaternary catchments, are provided in **Table F.1** of **Appendix F**.

The Johnson-Transform parameters are applied in STOMSA to transform the annual total flows of each streamflow sequence to normalised flow residuals to ensure that the data exhibit zero mean and unit variance. This transformation is undertaken by means of the linear stochastic difference equation models of time-series, called ARMA (Φ, Θ), which are defined as follows (BKS, 1986):

$$xt - \Phi 1 * xt - 1 - \Phi 2 * xt - 2 = at - \Theta 1 * at - 1 - \Theta 2 * at - 2 \tag{2.3}$$

Any one of the eight ARMA models may be selected, based on a set of standard selection criteria applied in STOMSA. These models are ARMA(0,0), ARMA(0,1), ARMA(1,0), ARMA(1,1), ARMA(0,2), ARMA(1,2), ARMA(2,0) and ARMA(2,1).

A summary of the selected ARMA distributions and the values of the associated model parameters, as determined by STOMSA, are provided in **Table F.2**.

2.4 GROUNDWATER SURFACE WATER INTERACTION

The interaction of groundwater and surface water was explicitly modelled in the rainfall-runoff modelling with the WRSM2000 and generation of the incremental natural historical runoff time-series discussed in **Section 2.3**. This involved the application of the *Groundwater-Surface Water Interaction Model (GWSWIM),* developed by groundwater specialist Karim Sami. This has been incorporated as a sub-model into the *WRSM2000 rainfall-runoff* model (as mentioned in **Section 2.3**). More information in this regard is provided in the *Hydrological Analysis* report of this Study. The effects of groundwater-surface water interaction were already incorporated in the generated flows using the *WRSM2000* and subsequently *STOMSA* and were therefore implicitly accounted for in the resulting yield analysis as described in this report.

The groundwater-surface water interaction was simulated in the WRSM2000. Natural historical streamflow records per management unit were generated that included and excluded the groundwater abstractions. **Table B.5** in **Appendix B** provides a summary per sub-catchment of the MARs with, and without present day (2010) groundwater abstractions.

3 WATER REQUIREMENTS AND RETURN FLOWS

3.1 INTRODUCTION

This Section provides detailed information on the water requirements and return flows in the Study Area and explains in detail how these were included in the WRYM for the purpose of the yield analysis. In all cases, the information provided is representative of the 2010-development level (2010 hydrological year, which covers the period from October 1920 to September 2011). The purpose of modelling water requirements and return flows in the yield analysis is to estimate the impact of such developments on the water resource capability (yield) of the system at the development 2010 level in question. More information on the yield analysis is provided in **Section 6**.

3.2 IRRIGATION

Irrigation is extensively practised throughout the Study Area. The 2010 irrigation crop area in the Limpopo WMA North was found to be more than 650 km^2 (approximately 1% of the total gross catchment area of the Study Area of 60 782 km^2), corresponding to an annual water requirement of around 457 million m^3 from both groundwater and surface water sources. This includes irrigation from boreholes, small storage dams, weirs and run-of-river schemes. Of the total crop area that is irrigated, more than 20% of the area (152 km^2) is sourced directly from the Limpopo River and amounts to an annual water requirement of 118 million m^3. The irrigation areas per quaternary and the corresponding requirements in million m^3/a are presented in **Tables C.2** and **C.3** of **Appendix C**.

The irrigated areas and the crop types were obtained from the Validation and Verification Study (DWA, 2013b), also referred to as the *V&V Study*. This information was used as part of the analysis of the water users and their impact on the water resource.

A summary of the irrigated areas and water requirements at the 2010-development level supplied from groundwater and surface water, such as dams, rivers and schemes, as well as from groundwater, is provided in **Table 3.1** and **Table 3.2** for each river catchment in the study area. A clear distinction is made throughout this study between the irrigation water requirements from water resources fed by runoff generated in the Study Area (excluding the Limpopo River catchment) as modelled in the WRYM and the irrigation water requirements supplied from the Limpopo River main stem.

The WRYM is used to simulate irrigation requirements and return flows by means of an irrigation block sub module. A total of 124 irrigation blocks were configured for the catchments, including five (5) in the Matlabas, 30 in the Mokolo, ten (10) in the Lephalala, 35 in the Mogalakwena, 30 in the Sand and 11 in the Nzhelele. More information on the modelling of irrigation areas are given in **Section 4.2**.

To be consistent with the hydrological analysis of the study, the Irrigation Block, incorporating the *"Type 2" (SAPWAT-based)* irrigation model, was used for the purpose of modelling irrigation water requirements and return flows in the yield analysis of the Limpopo WMA North catchment.

Table 3.1 Summary of irrigated areas in the Limpopo WMA North at the 2010-development level

River catchment	Irrigated area (km^2)									
	Surface water			Groundwater			Scheme	Total		
	Catchments(1)	Limpopo(2)	Total	Catchments(1)	Limpopo(2)	Total	Catchments(1)	Catchments(1)	Limpopo(2)	Total
Matlabas	2.6	2.6	5.2	1.9	0.3	2.2	-	4.5	2.9	7.4
Mokolo(3)	81.1	-	81.1	9.5	-	9.5	-	101.4	-	101.4
Lephalala	52.6	0.0	52.6	30.4	22.2	52.6	-	63.7	22.2	83.0
Mogalakwena	43.5	4.6	48.1	58.1	16.8	74.9	10.9	112.5	21.4	133.9
Sand	27.5	27.9	55.4	243.5	0.0	243.5	-	271	27.9	298.9
Nzhelele	2.5	8	10.5	5.6	0.1	5.7	25.2	33.3	8.1	41.5
TOTAL	**209.7**	**43.3**	**253**	**329.8**	**36.4**	**366.2**	**46.9**	**586.3**	**79.7**	**666.1**

Note: (1) Area supplied from sources fed by runoff generated in the Study Area only.
(2) Area supplied by the Limpopo River main stem and associated Nzhelele aquifers.
(3) From the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" Study (DWA, 2007).

Table 3.2 Summary of irrigation requirements in the Limpopo WMA North at the 2010-development level

River catchment	Irrigation water requirements (million m^3/a)									
	Surface water			Groundwater			Scheme	Total		
	Catchments(1)	Limpopo(2)	Total	Catchments(1)	Limpopo(2)	Total	Catchments(1)	Catchments(1)	Limpopo(2)	Total
Matlabas	0.6	1.8	2.4	2.0	0.3	2.3	-	2.6	2.1	4.7
Mokolo(3)	30.9	0.0	30.9	3.2	0.0	3.2	6.1	40.2	0.0	40.2
Lephalala	38.5	4.4	42.9	0.7	26.2	26.9	-	39.2	30.6	69.8
Mogalakwena	25.4	6.1	31.5	43.2	16.8	60.0	7.9	76.5	22.9	99.4
Sand	9.9	43.7	53.6	126.8	41.3	168.1	-	136.7	85.0	221.6
Nzhelele	0.8	5.7	6.5	3.8	0.1	3.9	18.7	23.3	5.8	29.1
TOTAL	**106.2**	**61.7**	**167.9**	**179.7**	**84.7**	**264.4**	**32.7**	**318.5**	**146.4**	**464.8**

Note: (1) Area supplied from sources fed by runoff generated in the Study Area only.
(2) Area supplied by the Limpopo River main stem and associated Nzhelele aquifers.
(3) From the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" Study (DWA, 2007).

3.3 RETURN FLOWS

The return flows from of irrigation are calculated within the irrigation blocks in the WRYM. The return flow channel from the irrigation block does not only calculate the water returned to the system as a result of irrigation, but also calculates a certain component of the runoff as a result of rainfall on the area under irrigation. Table 3.3 presents a summary of each of these combined elements which contribute to the total return flow from the irrigation block sub-modules in the Limpopo North WMA.

Table 3.3 Annual average irrigation return flows per quaternary catchment at the 2010-development level

Catchment/ quaternary	Average annual irrigation return flows (million m^3/a)			
	Surface water	Groundwater	Scheme	Total
Matlabas Total	0.19	0.19	0.00	0.38
Mokolo Total	2.53	0.27	0.53	3.33
Lephalala Total	3.25	1.90	0.00	5.15
Mogalakwena Total	2.42	4.17	0.58	7.17
Sand Total	3.67	13.38	0.00	17.05
Nzhelele Total	0.69	0.42	1.78	2.89
Limpopo WMA North	**12.75**	**20.34**	**2.89**	**35.98**

Return flow factors for all the quaternary catchments were calibrated and calculated during the hydrology analysis to be consistent with the specified return flows determined by the *Validation and Verification Study*. The irrigation application efficiencies and the return flows per quaternary, both as a percentage of supply and volumes for all quaternary catchments in the study area are given in Table C.4 and Appendix C.

3.4 DOMESTIC WATER USERS

Water users, other than irrigation and the ecology were modelled as point source abstractions from dams and run-of-river. These water users are represented in the WRYM by means of min-max channels, which are defined by 12 monthly flow values in units of m^3/s. A total list of all domestic water users in the study area is given in Table C in Appendix C indicating the source of water (groundwater or surface water) and the quaternary catchment from where it is sourced.

3.5 LIVESTOCK WATERING

Other water users sector included in the WRYM by means of min-max channels defined by 12 monthly flow values, are livestock and game farming water use. A summary of the monthly average flows (in m^3/s) and the annual totals (in million m^3) for all the quaternary catchments is given in Table C.7 in Appendix C.

3.6 STREAMFLOW REDUCTION ACTIVITIES

Two types of streamflow reduction activities (SFRAs) occur in the Study Area, namely afforestation and invasive alien plants (IAP) vegetation. A set of four data files for each incremental sub-catchment in a water resource system network, were defined to account for these water users. These files are listed below, where the "*" represents the name of the sub-catchment in question. This file contains the names of these files and the directories where they are stored and referenced in the *PARAM.DAT* file.

- The *.INC-file, which contains monthly naturalised or natural simulated incremental runoff (in million m³);
- The *.RAN-file, which contains monthly point rainfall at the node (in mm);
- The *.IRR-file, which contains streamflow reductions due to alien vegetation inside the catchment (in million m³);
- The *.AFF-file, which contains streamflow reductions due to afforestation inside the catchment (in million m³).

A summary of the reduction in runoff from natural runoff volumes as a result of the mentioned SFRAs is provided in **Appendix C**, **Table C.**.

3.7 ECOLOGICAL WATER REQUIREMENTS

The ecological water requirements (EWR) are an important non-consumptive water requirement that must be included in yield analyses to determine the impact of these requirements on the yield of an individual dam and/or the water resource in total. The releases for EWR are legal obligations to ensure that the upstream catchment delivers its equitable and fair share for maintaining the health of the downstream river in terms of water quantity.

All approved and signed-off EWR results from previous Reserve assessments, including desktops for Water Use License Applications (WULAs), were sourced from the Reserve database files curated by the Directorate Reserve Requirements (D: RR). Apart from the Mokolo and Matlabas catchments, no high level Reserve information (i.e. Rapid, Intermediate or Comprehensive level) for the Limpopo WMA North is available.

Furthermore, desktop information on the ecological categories is available from the Desktop PESEIS (2012) assessment conducted per sub-quaternary reach for the country under the leadership of DWS and the Water Research Commission (DWS, 2014a). The information obtained from these assessments, e.g. a Present Ecological State (PES) and Recommended Ecological Category (REC), can be used as a first level desktop assessment to set the Ecological category for the Reserve determination. The Ecological Category (EC) is derived from the *maximum* of the Ecological Importance (EI) and Ecological Sensitivity (ES). The REC is obtained through scaling the PES category according to the EC. The REC was calculated as follows:

- If the derived EC is high, then the REC is half a category better than the PES;

- If the derived EC is very high, then the REC is a full category better than the PES; and
- If the derived EC is moderate or low, then the REC is equal to the PES.

Even though there are some signed-off desktop reserve assessments available, the natural streamflow data were updated as part of this study (See *Hydrological Analysis Report* (PWMA 01/000/00/02914/3)) and this necessitated the update of the existing desktop EWR determinations. The Desktop Rapid Reserve module of the Grahams town Institute for Water Research (IWR) model, *SPATSIM version 2.0.12.6* were used together with the derived ECs and the REC as explained in the previous paragraph.

The EWRs were not included in the initial yield analyses and therefore must be accounted for as a non-consumptive water requirement that impact on the yields of the different systems when running the WRPM or other scenarios of the WRYM. A supporting document to the yield analysis report titled "*Reserve Requirements Scenarios"* is attached and submitted with this document.

Table 3.4 lists the details of the input to the *SPATSIM* model, i.e. natural runoff and calculated REC as well as the resulting calculated EWRs at various dams and outlets of rivers just upstream of the confluence with the Limpopo River. The EWR comprise of a maintenance component as well as a drought component. The maintenance component has both a high flow (freshets) and low flow component, whilst the drought component (at desktop level) only comprises of a low flow component that ensures only survival of the biota in the river during drought conditions. Turfloop and Houtrivier dams have a very small MAR and EWR with only a high flow component, the low flow component is zero. Together with the extremely small MARs, these EWRs were regarded as insignificant and therefore no yield analysis was done including the EWR at these two dams. The Matlabas River has no storage and therefore no desktop EWRs were calculated for this river. The rule curves used in the yield analyses are represented in Appendix C, Tables C10 to C18.

The cumulative natural streamflow record (including borehole abstractions) and the REC of the quaternary catchment of the dams were used to set the EWR for the upstream catchment that need to be released from the dam. Also, the EWR were calculated using the cumulative streamflow and the EC at the outlet of the river upstream of the confluence with the Limpopo River to ensure that the lawful EWR of the river bypass other water users and reach the main stem of the Limpopo River. These EWRs at the outlets of the five main rivers (excluding the Matlabas River) where analyses are envisaged, will however, only be included and used in the WRPM.

Table 3.4 Desktop ecological water requirements for the Limpopo River

Dam name	SQ[1]	Quaternary catchment	MAR[2] million m³/a	PES[3]	EI4	ES5	REC6	Ecological water requirements in million m3/a (% of MAR)			
								Total EWR	Maintenance high flow	Maintenance low flow	Drought low flow
Mokolo[7]	Mokolo	A42F	35.160	-	-	-	C	48.51 (23%)	-	-	-
Donkerpoort	Little Nyl	23.1% of A61A1	5.349	D	High	High	CD	1.009 (18.87%)	0.410 (7.67 %)	0.599 (11.20 %)	0.407 (7.61 %)
Doorndraai	Sterk	Only A61H	38.108	D	High	High	CD	7.306 (19.17%)	2.817 (7.39%)	4.489 (11.78%)	3.075 (8.07%)
Glen Alpine	Mogalakwena	A62A to A62J	204.041	C	Medium	Medium	C	42.982 (21.07%)	20.599 (10.10%)	22.383 (10.97%)	10.582 (5.19%)
Turfloop	Turfloop	10.05% of A71B	0.605	D	Medium	Low	D	0.068 (11.23%)	0.068 (11.23%)	0.000 (0.00%)	0.000 (0.00%)
Houtrivier	Hout	16.2% of A71E	0.378	D	Medium	Very low	D	0.043 (11.46%)	0.043 (11.46%)	0.000 (0.00%)	0.000 (0.00%)
Mutshedzi	Nzhelele	31.8% of A80A	15.552	E	Medium	High	D	2.123 (13.65 %)	1.346 (8.65%)	0.777 (4.99%)	0.380 (2.45%)
Nzhelele	Nzhelele	A80C	73.404	D	Medium	Medium	CD	12.825 (17.47%)	6.577 (8.96%)	6.248 (8.51%)	1.711 (2.33%)
Luphephe	Luphephe	100% of A80H1	21.374	C	High	Very high	B	7.284 (34.08%)	0.270 (10.62%)	5.014 (23.46%)	1.002 (4.69%)
Nwanedi	Nwanedi	100% of A80H2	9.459	B	High	Very high	A	4.338 (45.86%)	1.449 (15.31%)	2.889 (30.54%)	0.000 (0.00%)
Nzhelele[8]	Nzhelele	A80G	105.403	C	High	High	CD	18.448 (17.50%)	9.418 (8.93%)	9.030 (8.57%)	5.556 (5.27%)
Nwanedi[8]	Nwanedi	A80J	34.596	D	High	Very high	C	7.423 (21.46 %)	3.373 (9.75%)	4.050 (11.71%)	1.970 (5.69%)
Sand[8]	Sand/Limpopo	A71K	81.040	C	High	High	CD	11.576 (14.28%)	8.868 (10.94%)	2.707 (3.34%)	0.424 (0.52%)
Mogalakwena[8]	Mogalakwena	A63D	229.222	C	Moderate	Moderate	C	48.659 (21.23%)	22.817 (9.95%)	25.841 (11.27%)	12.368 (5.40%)
Mokolo[8]	Mokolo	A42J	275.953	D	High	High	CD	47.679 (17.28%)	25.174 (9.12%)	22.506 (8.16%)	13.710 (4.97%)

[1]SQ: Sub-quaternary reach

[2]MAR: Mean Annual Runoff

[3]PES: Present Ecological State derived from PESEIS (2012)

[4]EI: Ecological Importance

[5]ES: Ecological Sensitivity

[6]REC: Derived through rules explained to get the Recommended Category

[7]Mokolo (DWA, 2007)

[8]At outlet of the main river for inclusion in the WRPM

4 PHYSICAL SYSTEM COMPONENTS

4.1 IMPOUNDMENTS

Only ten of the large dams in the study area have a capacity's greater than 5 million m³. These dams are the Mokolo, Nzhelele, Doorndraai, Glen Alpine, Luphephe, Dikgale, Houtrivier, Rooiwal, Nwanedi and Gert Combrink dams and are located in the Mokolo, Mogalakwena, Nzhelele and Sand catchments.

Ten dams, that include the smaller Turfloop, Donkerpoort and Mutshedzi dams, were selected and included as stand-alone dams based on their strategic importance in the study area for yield analyses and the dam names are ***in bold*** in **Table 4.1**. There are numerous smaller dams scattered throughout the Study Area and used for irrigation and stock watering. It should be noted that the results from the *Mokolo Study* (DWA, 2007) was found to be of high resolution and integrity and therefore accepted without change.

Where a large number of small dams are located within a catchment, it is considered impractical to model each dam individually. The dams were grouped according to similar geographic, topographic and type of water users to form a single representative network element, referred to as a *dummy dam*. The process of combining individual dams into a dummy dam must be undertaken in such a way that the impact of the dummy dam mimics the combined impact of the individual dams that it represents. For the purpose of this Study, small storage dams and weirs located in a single tributary catchment and supplying water to a defined set of water users, were combined into a dummy dam. In this regard, consideration must always be given to the possibility of simulating the larger key dams individually, as was the case with the dams as listed in **Table 4.1**. Finally, it should be noted that the behaviour of *dummy dams* is modelled in the WRYM system network based on the same principles as applied for major dams.

For the major DWS dams, survey information was obtained from DWS while information on the smaller dams was obtained from the *Validation and Verification Study (DWA, 2013b)*. This information was collected and collated as part of the *Hydrological Analysis* of the study.

Table 4.1 presents the characteristics of the major dams within the Study Area. **Appendix D** shows a summary of all dummy dams.

4.2 IRRIGATION AREAS

Information on the modelling of irrigation areas within the context of the WRYM representative network is provided in **Table C** of **Appendix C**. This includes the Irrigation Block number associated with each irrigation area and the particular source of water (either as *dummy dam*, discussed previously in **Section 4.1**, run-of-river, or groundwater). Furthermore, the WRYM number of the supply and return flow channels that route water from the source to the irrigation block and return it back to the system, are shown. The abstraction node is also provided.

Table 4.1 Information on major dams

Dam name	Quaternary	WRYM No.	FSC (million m^3)	DSV (million m^3)	FSA (km^2)
Mokolo[1]	A42F	-	145.9	0.55	8.29
Nzhelele	A80C	4	51.2	0	5.44
Doorndraai	A61H	75	44.2	0	5.61
Glen Alpine	A62J	128	18.9	0	4.61
Luphephe	A80H	33	14.8	0	1.42
Dikgale[2]	A71E	-	8.3	0	2.78
Houtrivier	A71E	34	7.5	0	1.59
Rooiwal	A61J	76	6.8	0	2.27
Nwanedi	A80H	34	5.3	0	0.57
Gert Combrink	A61F	63	5.1	0	2.57
Turfloop Dam	A71B	29	3.3	0	0.72
Cross	A80J	42	2.6	0	0.66
Donkerpoort	A61A	23	2.4	0	0.56
Mutshedzi	A80A	2	2.2	0	0.40
Haaskloof	A61H	68	2.0	0	0.44
Seshego[2]	A71A	-	2.6	0	0.74
Voorbrug[2]	A71K	-	1.3	0	0.5
Welgevoden[2]	A61H	-	1.2	0	0.28
Limpopo WMA North			**325.6**	**0.55**	**39.45**

1 As in the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" Study (DWA, 2007)

2 Dams that were not modelled explicitly but were lumped with other upstream smaller dams

5 CONFIGURATION OF THE WATER RESOURCES YIELD MODEL (WRYM)

5.1 INTRODUCTION

5.1.1 Overview of the WRYM

The yield analysis of the Study Area was undertaken using the WRYM. The WRYM was developed by DWS for the purpose of modelling complex water resources systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country's water resources.

DWS has developed a software system for the structured storage and utilisation of hydrological and water resource system network model information. The system, referred to as the Water Resources Modelling Framework (WRMF), serves as a user friendly interface with the Fortran-based WRYM and substantially improves the performance and ease of use of the model. It incorporates the WRYM data storage structure in a database and provides users with an interface which allows for system configuration and run result interpretation within a Microsoft Windows environment.

The WRYM uses a sophisticated network solver in order 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 resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels, i.e. the system configuration and modelled demands remain unchanged over the simulation period. The major strength of the model lies in the fact that it enables the user to configure most water resource system networks using basic building blocks, which means that the configuration of a system network and the relationships between its elements are defined by means of input data, rather than by fixed algorithms embedded in the complex source code of the model.

5.1.2 Development of a representative system network model

Developing a representative network model for a water resource system involves a process whereby the modeller creates a synthetic representation of reality, in the form of a schematic diagram. This is achieved by indicating the connectivity between, and nature of, the various components that make up the system in question. This process of synthesis, however, always implies a trade-off between the need to simulate the behaviour of individual system components at a sufficient level of detail, on the one hand, and practical modelling limitations on the other.

The process of developing a representative system network model therefore includes three main aspects:

- the identification of physical system features,
- assessing the appropriate spatial resolution; and
- the lumping and aggregation of system components until the appropriate spatial resolution is achieved.

These aspects are discussed below.

a) ***Identification of physical system features***

The process of identifying the physical features of the Study Area for the purpose of the hydrological analysis involved a visual study of Google Earth images covering the whole of the Study Area. In order to enhance these images, the location and extent of the main land-use activity in the catchment, which is irrigation, was plotted on the images as polygons, together with polygons representing water bodies. This spatial information was obtained from the *V&V Study* (DWA, 2013b).

b) ***Spatial resolution***

In general, previous system analysis studies focused mainly on determining the yield of systems consisting of one of more dams. It was therefore sufficient to analyse the water availability and use of relative large catchments on a regional level. However, in this Study emphasis was on detailed simulation of local catchments and tributaries in order to reflect the impacts water users (or groups of water users) have on one another and the local water availability.

Within this context, the following aspects were considered in the definition of the WRYM system network model:

- The resolution was dictated by the system layout and not by pre-defined modelling units;
- Each quaternary catchment was represented by a node or a number of nodes in the network;
- Users receiving water from tributaries and from the main stream of the river were modelled separately in order to evaluate local availability;
- Local hydrological and climatic conditions;
- The location of small dams and water use abstractions.

c) ***Aggregation of system components***

In cases where a large number of similar system elements are located within a catchment it is generally considered to be impractical to model each element individually. It was therefore inevitable that certain system elements had to be combined and simulated as single network elements in the yield analysis of the Study Area. This is of particular importance in the case of the irrigation demands, as well as impoundments. In this regard, the following overriding principles were followed:

- Water abstractions of the same type that have access to the same surface flow were grouped and represented by a single system component;
- Farm dams located in tributary catchments were combined to form a single dummy dam in the network model;

- The process of combining individual system elements was undertaken in such a way that the impact of the resulting element mimics, as closely as possible, the combined impact of the individual elements that it represents.

5.2 MODEL DESCRIPTION

Six new river configurations were set-up separately using version 4 of the WRYM, viz. the Matlabas, Mokolo, Lephalala, Mogalakwena, Sand and Nzhelele catchments. The schematic diagrams of the WRYM configurations are included in **Appendix A**. It should be noted that these diagrams are representative of the base scenario; the 2010 development level without EWRs. Therefore the network definition of other scenarios can be built from this scenario by the inclusion or exclusion of a particular system element or land-use development.

It is important to note that even though the hydro-meteorological data were extended, sensitivity analyses indicated that the yield of the Mokolo Dam which is defined by the critical period, i.e. the worst drought on record, did not impact on this. The results from the Mokolo Study (DWA, 2007) were therefore accepted and the yields were not re-analysed.

This section provides details on the configuration of the WRYM for the Study Area, particularly with regard to the:

- selected basic run control settings;
- modelled sub-catchment areas;
- incremental runoffs;
- irrigation areas;
- operating rule definition;
- The determination of the system yield.

5.2.1 Run control settings

Run control settings in the WRYM are used to define general information on how the system will be analysed for a particular model run. For the yield analysis of the six configurations, this includes the following:

- An analysis period of 91 years from the 1920 to the 2010 hydrological year (i.e. October 1920 to September 2011). This corresponds with the selected Study period as well as with the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study;
- The long-term stochastic yield analyses were undertaken using the *PARAM.DAT*-file developed as part of the stochastic streamflow analysis and based on 201, 91-year stochastically generated streamflow sequences; and
- The short-term stochastic yield analyses were undertaken based on 501, 5-year stochastically generated streamflow sequences; the results of these analyses are short term yield-reliability characteristics that are required as input to the following planning analyses with the WRPM. This will be discussed in detail in the WRPM Report (P WMA 01/000/00/02914/7).

5.2.2 Sub-catchment and incremental runoffs

Information on the modelling of sub-catchments and incremental runoff within the context of the representative WRYM network model is provided in **Appendix E** and is based on the updated and extended hydro-meteorological data sets developed during the hydrological analysis of the Study. The information includes a description of the network elements, node numbers and catchment areas associated with the sub-catchment in question, as well as the reference number (i.e. the management unit number), in the sequence as listed in the *PARAM.DAT-file* as well as the routing percentage (percentage of run-off, rainfall and SFRs the associated hydrological data file set.

It should be noted that such a data file set is defined for each sub-quaternary catchment in the system and includes four time-series data files that cover the Study period of 91 years from 1920 to 2010 (hydrological years). These are:

- The *.INC-file, which contains monthly historical natural incremental runoff volumes (in units of million m^3);
- The *.IRR-file, which contains monthly historical diffuse irrigation water requirements (in units of million m^3);
- The *.AFF-file, which contains monthly historical reductions in runoff due to commercial forestry and in-catchment alien vegetation (in units of million m^3);
- The *.RAN-file, which contains monthly historical rainfall (in units of mm).

5.2.3 Operating rules

The system operating rules adopted for this Study Area are similar to the operating rules used for the Mokolo River system (DWA, 2007), and are as follows:

- Yield from the system is supplied from the live storage of the major dams and is not supported by controlled releases made from the small dams located in the catchment upstream of the dam nor is it supported by upstream major dams. This implies that even if a dam fails to meet the system demand no water will be released from upstream, even if there is water available.
- The supply of water to irrigators from small dams upstream of major dams is dictated purely by the local availability of water and the modelled requirement of the user in question. Controlled curtailments are therefore not applied.
- The yield as determined for the major dams represents the total available water resource of the system and can be used for the purpose of developing an allocation strategy for all of the existing and possible future water users supported from the dam in question.

As a rule, no defined system operating rule exists for the dams and other abstractions and they are operated by experience, water availability and practicality.

Operating rules were implemented in the WRYM configuration of the representative river catchment systems by means of the WRYM penalty structure mechanism. Penalties are dimensionless values assigned by the system analyst and are used by the WRYM as a basis for determining appropriate flow routing solutions. The penalty structures applied in the yield analysis of the six river catchment area systems are shown on the system schematic diagrams of **Appendix A**.

5.2.4 Monthly abstraction patterns

The yield is not only a function of the target draft imposed on a dam, but is also impacted by the monthly pattern of abstractions and releases. The monthly abstraction pattern for the dams where yield analyses were conducted was allocated according to the current user type, i.e. domestic or irrigation from the dam in question.

It can be seen in **Table 5.1** that Donkerpoort Dam, which is exclusively used for domestic purposes, has a constant monthly abstraction pattern and Glen Alpine Dam, which is exclusively an irrigation dam, has a large monthly variation in its abstraction pattern, with less water abstracted during the dry winter months when the requirement is low.

Table 5.1 Monthly abstraction pattern as % of the target draft

Dam	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Donkerpoort	8.498	8.202	8.498	8.498	7.708	8.498	8.202	8.498	8.202	8.498	8.498	8.202
Doorndraai	9.286	6.871	7.245	7.245	11.565	10.391	9.082	7.891	5.544	6.871	7.092	10.918
Glen Alpine	9.821	12.840	16.185	14.661	9.651	5.108	5.813	6.025	6.110	5.574	3.753	4.459
Turfloop	8.451	8.451	8.451	8.451	7.042	8.451	8.451	8.451	8.451	8.451	8.451	8.451
Hourivier	8.451	8.451	8.451	8.451	7.042	8.451	8.451	8.451	8.451	8.451	8.451	8.451
Nzhelele	10.527	11.799	13.847	12.651	10.095	5.744	3.922	5.938	5.558	5.259	6.701	7.958
Mutshedi	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333	8.333
Luphephe	9.150	16.792	25.189	25.591	17.999	0.352	0.352	0.352	0.754	1.156	1.156	1.156
Nwanedi	9.150	16.792	25.189	25.591	17.999	0.352	0.352	0.352	0.754	1.156	1.156	1.156

5.2.5 Ecological water requirements

Yield analyses were done to show the impact of the EWR on the yield. Desktop EWRs were included in the systems operated as described in **Section 5.2.3.** EWRs were only included in the setups downstream of the major dams because reduced abstraction from run-of-river to give priority to the EWR and releases from farm dams is not regarded as a practical option. The EWR releases can only be managed at major dams where there are storage and river outlets.

The EWRs were calculated using the EC of the SQ at the dam and the cumulative natural flow record (with borehole abstractions) of the upstream catchment to ensure that the upstream catchment delivers its equitable and fair share for maintaining the health of the downstream river in terms of water quantity.

Yield analyses for stand-alone dams i.e. at dams where there are no major upstream dams, were conducted with the supply of the EWR a priority over the historical firm yield (HFY) yield. The HFY with EWR included, was calculated for stand-alone dams.

However some of these river systems have major dams upstream of a major dam that influences the yield of the downstream major dam, for example the yield of Glen Alpine Dam is impacted on by the upstream Donkerpoort and Doorndraai dams. In these instances the HFY (with EWR) was placed as a requirement on the upstream dam(s) and the EWR was returned to the river at the node just downstream of the dam. The EWR were therefore available to all downstream users.

The EWR at the most downstream dam were calculated using the EWR based on the EC at the SQ of the relevant dam and the cumulative flow of the upstream catchment, but excluding the flow of the upstream major dams where EWR were included. The EWR at the most downstream dam were implemented with priority over the yield.

Yield analyses with EWR at Glen Alpine Dam, which is used exclusively for irrigation, were however adapted to suit its current operating rule. Glen Alpine Dam releases water to the farm dams downstream in the Mogalakwena River with the farm dams spilling until the most downstream dam is full. Irrigation occurs from these farm dams on the mainstream river. Generally farm dams do not have the capability to release the EWR. It was found that Glen Alpine Dam has no yield with EWR if the system was run in the conventional manner. Therefore the EWR were released from Glen Alpine Dam with the yield channel downstream of the Glen Alpine EWR, i.e. the yield channel could use the EWR. The motivation behind this is that the EWR released from Glen Alpine Dam will be trapped in the downstream farm dams and therefore will not benefit the ecology of the remainder of the Mogalakwena and the Limpopo River.

5.2.6 System yield

a) ***Definition***

The yield from the major dams were calculated without differentiating between the different water sectors, i.e. the total yield from the major dams were not split according to the different types of users, i.e. domestic, irrigation, mining, and industry to provide managers the opportunity to allocate the entire resource according to new priorities within the context of the enormous growth in water requirements expected as a result of the developments planned for in the Study Area.

This was achieved by imposing a single (variable) target draft on the dam in order to evaluate its behaviour in various supply situations. For this purpose, the yield channel-type of the WRYM was used.

b) ***Determination***

The yield results presented in this report are based on two distinct types of analyses. The *first* is a historical firm yield (HFY) analysis which is undertaken by analysing the WRYM system based on the time-series of monthly historical natural incremental runoff volumes contained in the *.INC-files (as discussed in

Section 6.2), which cover the period of 91 years from the hydrological years 1920 to 2010, i.e. October 1920 to September 2011.

The HFY is determined by means of an iterative process and is defined as the maximum annual target draft that can be supplied from the system without a failure. However, while the HFY provides a reasonable indication of the water resource capability of the system it does not show the likelihood (or probability) that the water volume in question could be supplied in future without failure, since it is possible that a longer and more intense dry period may in future occur that is more severe than any period covered by the historical record.

The *second* type of analyses is the long-term stochastic yield analyses of 201, 91-year stochastically generated time-series of incremental monthly natural runoff streamflow sequences. These 201 time-series, or sequences, are generated by the WRYM at run-time based on the statistical parameters contained in the *PARAM.DAT* file, developed as part of the stochastic streamflow analysis of the Study (as discussed in Section 6.3).

The results of long-term stochastic yield analyses include the assurance of supply associated with each of the target drafts analysed under a particular scenario, which, in turn, may be used to derive the yield-reliability characteristics (YRC) curve. This curve provides a graphical representation of the relationship between yield and reliability of supply and is used as a basis for allocating a system's water resources to a group of users with varying requirements in terms of assurance. Generally, the assurance characteristics of a particular target draft are expressed in terms of its recurrence interval (RI), which is defined as the average time period between failures. For example, if the RI is shown as "1:200" years, this implies, on average, one failure every 200 years, or a risk of failure of 0.5% (1 ÷ 200) in any given year. This can also be expressed as an annual assurance of supply of 99.5% (100% – 0.5%)

5.2.7 WRYM system configuration testing

Great care was taken to ensure that the network configuration definition input into the WRYM was correct and accurately represented the intended configuration and reality. This included four main processes which are discussed below:

- Extensive checking was undertaken to verify that the sub-catchment hydrology data was applied correctly in the WRYM system. This involved comparing simulated node inflows with the net runoffs contained in the associated sub-catchment hydrology data sets;
- Simulated model results were checked against the known physical characteristics of system components, such as the full supply, dead storage and bottom levels of dams;
- The system network connectivity was checked by undertaking mass balances at each node in the system to ensure that the defined linkages in the system definition are correct;

- Simulated model results were checked to ensure that the behaviour of the system does reflect the intended operating rules, including the following situations:
  - When dams / dummy dams are full
  - When dams / dummy dams are empty
  - During drawdown events
  - When supply priorities control the flow of water.

6 YIELD ANALYSIS RESULTS

6.1 INTRODUCTION

The purpose of this Study was to conduct yield analyses at the nine major dams, excluding Mokolo Dam listed in **Table 6.1** (as discussed in **Section 5.2.6**). These dams were chosen largely because of their size, but also for their strategic value to provide for the growing requirements of existing and new water users.

6.2 HISTORICAL FIRM YIELD (HFY)

6.2.1 Historical firm yield without consideration to the EWR

Summarised in **Table 6.1** are the results from the historical firm yield (HFY) analyses without the EWR requirement imposed on the system. These HFY analyses were carried out using the naturalised historical inflow sequence (see **Section 5.2.6**) with no direct water requirements imposed on the dam and the upstream catchment at the 2010 hydrological year development level. These HFY analyses show the available yield under present day (2010) conditions and the corresponding critical period when the dam fails. The critical period is dynamic and could change with increased water requirements or a change in full supply of the dam in question. The yields in the table are without releases to the ecology in the form of EWRs.

Table 6.1 Summary of historical yield analysis (without EWR)

Dam name	Quaternary	MAR(1)	FSC	HFY(2)	Storage as % of MAR	Yield/ Storage
		(million m^3/a)	(million m^3)	(million m^3/a)	(%)	(%)
Mokolo(3)	A42F	209.4	145.9	38.7	0.7	27
Donkerpoort	A61A1	5.3	2.4	1.44	0.5	60
Doorndraai	A61H	38.1	44.2	9.64	1.2	22
Glen Alpine	A62J	204.0	18.9	7.09	0.1	38
Turfloop	A71B	0.6	3.3	0.01	5.5	0
Houtrivier	A71E	0.4	7.5	0.06	18.8	1
Nzhelele	A80C	73.4	51.2	16.81	0.7	33
Mutshedzi	A80A	15.5	2.2	1.98	0.1	90
Luphephe	A80H1	21.4	14.8	6.87	0.7	46
Nwanedi	A80H2	9.5	5.3	1.54	0.6	29

Notes: (1) Mean Annual Runoff simulated in the WRSM2000 model with active groundwater abstractions.
(2) HFY based on an analysis of 91 years from the 1920 to the 2010 hydrological years.
(3) From "Updating the Hydrology and Yield Analysis of the Mokolo River Catchment"

Comparison of results with those obtained from previous studies is an integral part in the process of evaluating results. Yield results from previous studies (the *All Towns Studies*) were obtained from scenarios that closely resemble the operating and yield determination principle as used in this study, and is summarised in Table 6.2.

Table 6.2 Comparison of results with previous studies

Dam name	Historic firm yield			Yield / storage		
	This study	Previous studies	Difference	This study	Previous studies	Difference
	(million m^3/a)		(%)	(million m^3)		(%)
Mokolo(3)	-	38.7	-	-	-	-
Donkerpoort	1.44	0.97	32	60	41	31.7
Doorndraai	9.64	5.10	47	22	12	45.5
Glen Alpine	7.09	7.80	-10	38	41	-7.9
Turfloop	0.01	-(2)	-(2)	-(2)	-(2)	-(2)
Houtrivier	0.06	0.60	-900	1	8	-700.0
Nzhelele	16.81	16.25	3	33	32	3.0
Mutshedzi	1.98	2.60	-31	92	120	-30.4
Luphephe	6.87	5.90	14	46	40	13.0
Nwanedi	1.54	2.44	-58	29	46	-58.6

Notes: (1) Historic firm yield based on an analysis of 91 years from the 1920 to the 2010 hydrological years.
(2) Yield analysis could not be conducted due to the dams failing under natural conditions.
(3) As per "Updating Hydrology and Yield Analysis of the Mokolo River Catchment" Study (DWA, 2007)

6.2.2 Historical firm yield with EWR

The yield analyses described in the previous section were repeated, but with the EWRs imposed on the individual dams. EWRs were always assigned the highest priority of water allocation, even higher that the yield in the WRYM set-ups. Whenever a downstream dam was influenced by an upstream dam, the HFY of the downstream dam was abstracted from the upstream dams and its EWR were released and returned to the system at the node downstream of the dam. The impact of the EWRs on the yields of the dams is shown in Table 6.3.

Table 6.3 Summary of historical yield analysis (with EWR) and impact of the EWR on the historical firm yield

Dam	Quat	MAR[1] (million m³/a)	FSC (million m³)	HFY[1] With no EWR (million m³/a)	HFY[1] With full EWR (million m³/a)	% reduction in HFY as result of EWR
Mokolo[3]	A42F	209.4	145.9	38.7	12.8	67
Donkerpoort	A61A1	5.3	2.4	1.4	0.93	34
Doorndraai	A61H	38.1	44.2	9.6	5.1	47
Glen Alpine	A62J	204.0	18.9	7.1	2.1	70
Turfloop	A71B	0.6	3.3	0.01	-	-
Houtrivier	A71E	0.4	7.5	0.06	-	-
Nzhelele	A80C	73.4	51.2	16.8	13.06	22
Mutshedzi	A80A	15.5	2.2	2.0	1.46	27
Luphephe	A80H1	21.4	14.8	6.9	3.72	46
Nwanedi	A80H2	9.5	5.3	1.5	0.01	99

Notes: (1) *Mean annual runoff simulated in the WRSM2000 model with active groundwater abstractions.*
(2) *HFY based on an analysis of 91 years from the 1920 to the 2010 hydrological years.*
(3) *As per "Updating Hydrology and Yield Analysis of the Mokolo River Catchment"* (DWA, 2007).

6.3 STOCHASTIC YIELD ANALYSIS

6.3.1 Stochastic yield analysis

The long-term stochastic yield analyses are based on 201, 91-year synthetically generated streamflow sequences. The results from the stochastic yield analyses are summarised in **Table 6.4** and the importance of conducting these analyses is discussed in **Section 2.3.2**.

The long-term stochastic analyses could not be done for the Turfloop Dam. This was because of the long periods of no flow in the Sand River that even though Turfloop Dam which is a large dam relative to its mean annual runoff (MAR), i.e. a 6 MAR dam, it has an insignificant yield in comparison to the intended WRYM application scale.

6.3.2 Stochastic yield analyses with ecological water requirements

The impact of including the desktop EWR (see **Section 3-4** for more detail) is shown in **Table 6.5**. The yield analyses could not be done for some of the smaller dams, i.e. Turfloop, Houtrivier and Nwanedi dams because of their insignificant yields if the EWRs are placed as a water requirement on these dams.

Table 6.4 Summary of long-term stochastic yield results with no EWR (in million m^3/a)

Dam	HFY(1)	Stochastic yield (million m^3/a), at indicated RI(2) of failure (annual assurance of supply)			
		1:200 (99.5%)	1:100 (99%)	1:50 (98%)	1:20 (95%)
Mokolo	38.7	39.10	44.60	50.70	66.80
Donkerpoort	1.44	1.49	1.64	1.83	2.11
Doorndraai	9.64	8.87	9.55	10.89	12.87
Glen Alpine	7.09	9.75	11.30	13.45	17.40
Turfloop(3)	0.01	-	-	-	-
Houtrivier(3)	0.06	0.01	0.04	0.13	0.26
Nzhelele	16.81	19.68	21.64	23.92	26.91
Mutshedzi	1.98	2.12	2.35	2.69	3.30
Luphephe	6.87	7.77	8.42	9.17	10.78
Nwanedi	1.54	0.81	1.11	1.62	2.43

Notes: (1) HFY based on an analysis of 91 years from the 1920 to the 2010 hydrological years.
(2) Recurrence interval of failure, in years based on a long-term stochastic yield analysis of 201 91-year generated streamflow sequences.
(3) Yield analysis could not be conducted due to the extreme low yields.

Table 6.5 Summary of long-term stochastic yield results with full EWR (in million m^3/a)

Dam	HFY(1)	Stochastic yield at indicated risk of failure (annual assurance of supply)			
	Full EWR	1:200 (99.5%)	1:100 (99%)	1:50 (98%)	1:20 (95%)
Mokolo	12.8	11.1	16.3	22.0	35.4
Donkerpoort	0.93	0.90	1.10	1.26	1.54
Doorndraai	5.1	3.82	4.72	5.89	7.55
Glen Alpine	2.1	1.51	1.88	2.74	4.42
Turfloop(3)	-	-	-	-	-
Houtrivier(3)	-	-	-	-	-
Nzhelele	13.06	6.99	10.03	13.33	19.35
Mutshedzi	1.46	1.67	1.86	2.05	2.49
Luphephe	3.72	4.42	4.81	5.23	6.08
Nwanedi	0.01	-	-	-	-

Notes: (1) HFY based on an analysis of 91 years from the 1920 to the 2010 hydrological years.
(2) Recurrence interval of failure, in years based on a long-term stochastic yield analysis of 201 91-year generated streamflow sequences.
(3) Yield analysis could not be conducted due to the extreme low yields.

6.4 SUMMARY OF RESULTS

Figure 6.1 shows the historical and stochastic yield of the dams that were analysed in the Limpopo WMA North. The corresponding yields with the impact of releasing the desktop EWRs (with pattern in the same colour as yield) are included to show the impact of the EWRs on the yield.

The considerable impact of releasing the desktop EWR from the major dams selected for yield analyses is shown in Figure 6.2. It is shown that there is a reduction in yield of 80% at Glen Alpine Dam, 46% at Doorndraai Dam and a 44% at Nzhelele Dam.

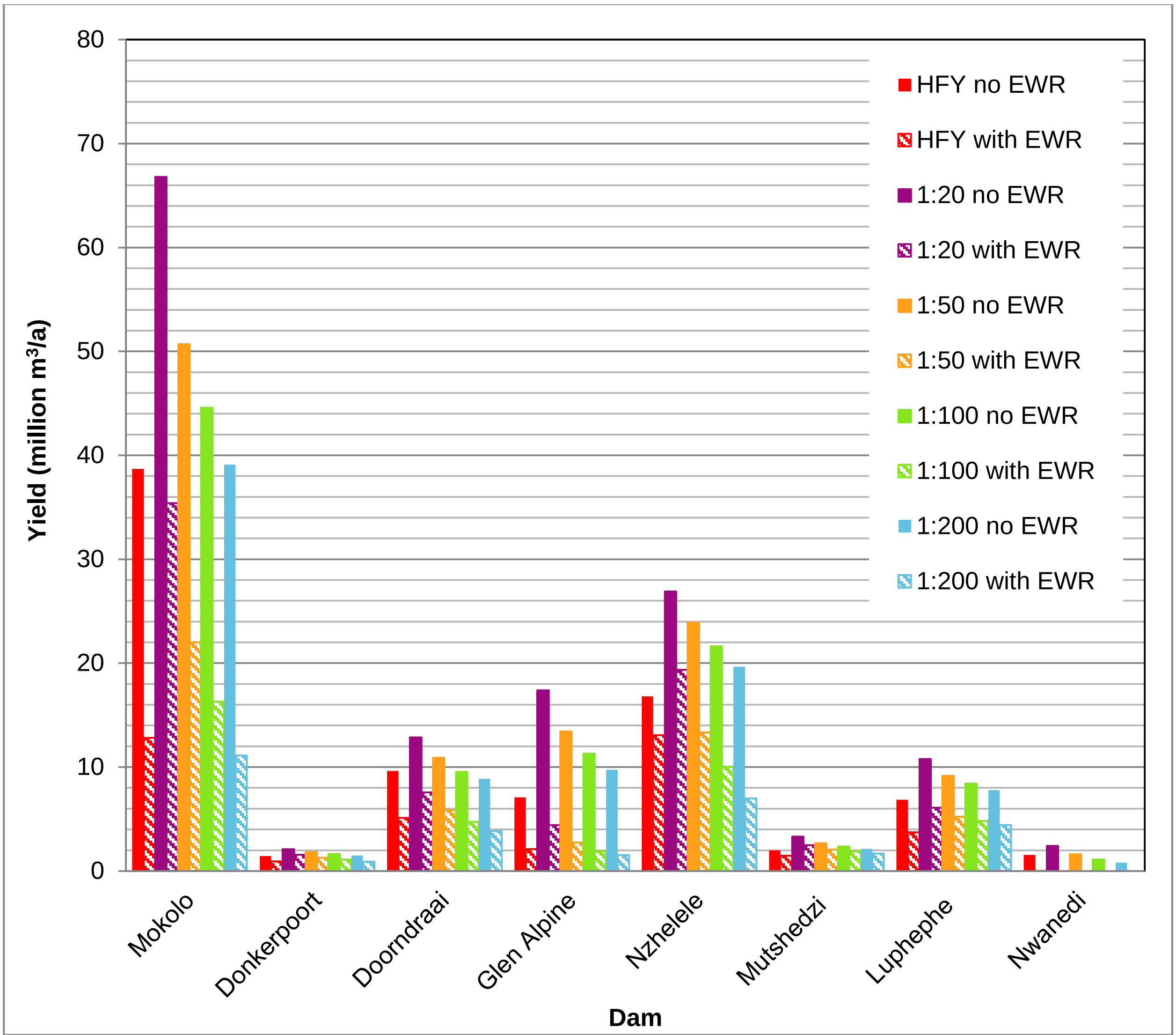

Figure 6.1 Overview of the historic and stochastic yields with and without EWR (in million m³/a)

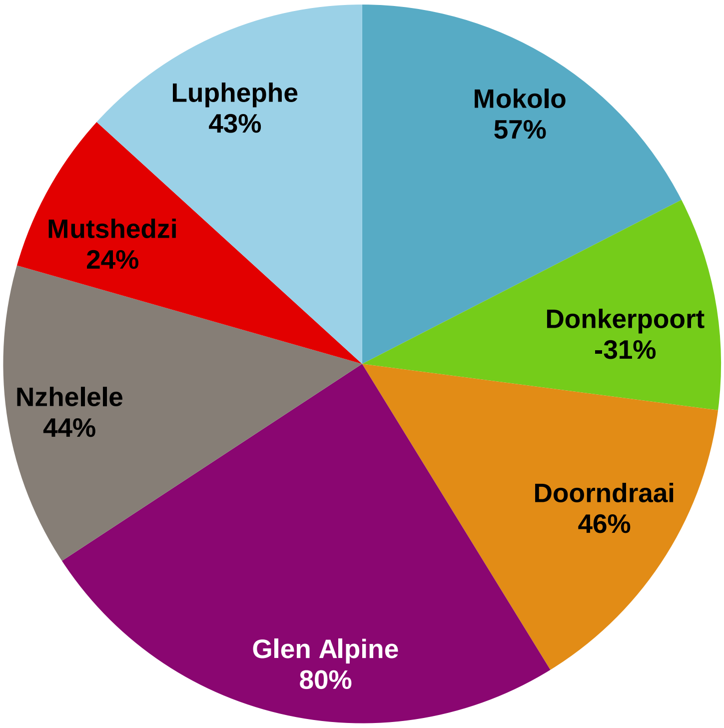

Figure 6.2 Reduction of the 1:50 year yield as a result of the EWR

7 INFORMATION REPOSITORY

The electronic data directory structure used for this purpose is as follows:

- [1. Documentation];
- [2. Hydro-meteorological Data]:
  - [2.1 Rainfall];
  - [2.2 Streamflow].
- [3. Stochastic Streamflow Analysis]:
  - [3.1 Stochastic Streamflow Testing];
  - [3.2 PARAM.DAT-file].
- [4. Desktop IFR Rule Curves];
- [5. WRYM System Configuration];
  - [5.1 WRYM Text Data Files];
    - [5.1.1 Matlabas]
    - [5.1.2 Mokolo]
    - [5.1.3 Lephalala]
    - [5.1.4 Mogalakwena]
    - [5.1.5 Sand]
    - [5.1.6 Nzhelele]
  - [5.2 WRYM-IMS Study Export File].
- [6. Graphics]:
  - [6.1 Maps];
  - [6.2 WRYM System Schematic Diagrams];
  - [6.3 Long-term YRCs].

The file naming conventions adopted are summarised in **Table 7.1**.

Table 7.1 File naming conventions for the yield analysis information repository[1]

Directory		Units	File name structure		Example
No.	**Name / description**		**Name**	**Extension**	
1	**Documentation**				
This report, *Yield Analysis (WRYM) and Reserve requirements.*		N/A	DWS Report No.	PDF	LNRS_Yield Analysis.PDF
2	Hydro-meteorological Data				
2.1	Monthly representative quaternary and sub-quaternary catchment rainfall data	mm	Catchment No.	RAN	A41A.RAN
2.2	Monthly incremental natural streamflow data for quaternary and sub-quaternary catchments	million m^3	Catchment No.	INC	A41A.INC
3	**Stochastic Streamflow Analysis**				
3.1	Quaternary catchment stochastic streamflow testing data files	Various	Catchment No.	ANS; COR; INC; PIN; PIN2; RNK; YER.	Gntstmk5.PIN
	Quaternary catchment stochastic streamflow testing results	N/A	Catchment No. and test type	CGM	A41A_NMR.CGM
3.2	PARAM.DAT-file	N/A	PARAM*	DAT	PARAMK7.DAT
4	**Desktop IFR Rule Curves**				
Quaternary catchment desktop IFR rule curves[2]		million m^3	Catchment No.	TXT	A41E.TXT
5	**WRYM System Configuration**				
5.1	WRYM Text Data Files				
5.1.1 to 5.1.6	Catchment name	N/A	*F* and Catchment No.	AFF; DAT; INC; IRR; RAN.	MATF01.DAT
5.2	WRYM-IMS Study Export File	N/A	Study name	ZIP	LNRS.ZIP
6	**Graphics**				
6.1	Maps	N/A	Figure No.	PDF	Figure A-1.PDF
6.2	WRYM system schematic diagrams	N/A	Figure No.	EMF	Figure B-1.EMF
6.3	Long-term YRCs	N/A	Figure No.	EMF	Figure G-1.EMF

Notes: (1) Provided electronically with this report.

(2) Derived by application of the Spatial and Time-series Information Modelling (SPATSIM) Decision Support System (DSS) from the Rhodes University's Institute for Water Research (IWR).

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

With the exception of Doorndraai Dam, the HFYs which are represented as grey blocks in **Figure 6.1** are generally more conservative than the 200 year yield as a drought exceeding the severity of a 200 year drought were recorded during the historical period. The drought periods in the Limpopo WMA North, considering intensity and length, were the 1920s, early 1950s, 1960s and 1990s, with the 1960s drought generally the critical drought.

The Mokolo and Nzhelele dams are both 0.7 MAR dams. However, Mokolo Dam is nearly three times the size of Nzhelele Dam, which is the second largest dam in the Limpopo WMA North. It is therefore plausible that the yield of Mokolo Dam is close to three times that of Nzhelele Dam. Although Nzhelele Dam is only slightly larger than Doorndraai Dam, the yield results from Nzhelele Dam show nearly double the yield of Doorndraai Dam. This can be explained by the fact that the Nzhelele Dam is a 0.7 MAR dam relative to the 1.2 MAR Doorndraai Dam. Donkerpoort, Mutshedzi and Nwanedi dams show the lowest yields in the Limpopo WMA North (see **Figure** 6.1 for more details).

The considerable impact of releasing the desktop EWR is shown in **Figure 6.2**, with a reduction in yield at Glen Alpine Dam of 80% and around 46% for Doorndraai and 44% for Nzhelele dams respectively.

Based on the yield analyses undertaken and resulting rational yield results obtained as part of the *Limpopo North Reconciliation Strategy*, it is concluded that the WRYM has successfully been configured and used to determine both historical and long term stochastic sub-system yields for the Mogalakwena, Sand and Nzhelele river catchments and the models have been configured for the Matlabas and Lephalala river catchments.

8.2 RECOMMENDATION

The considerable decrease in the yield of these dams caused by the implementation of the desktop EWRs must be considered when any high level ecological Reserve determination is done.

It is recommended that the yields developed at the current development level, as documented in this report, be used to calculate the water balances to be used in the reconciliation strategy.

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Appendix A

Network diagrams

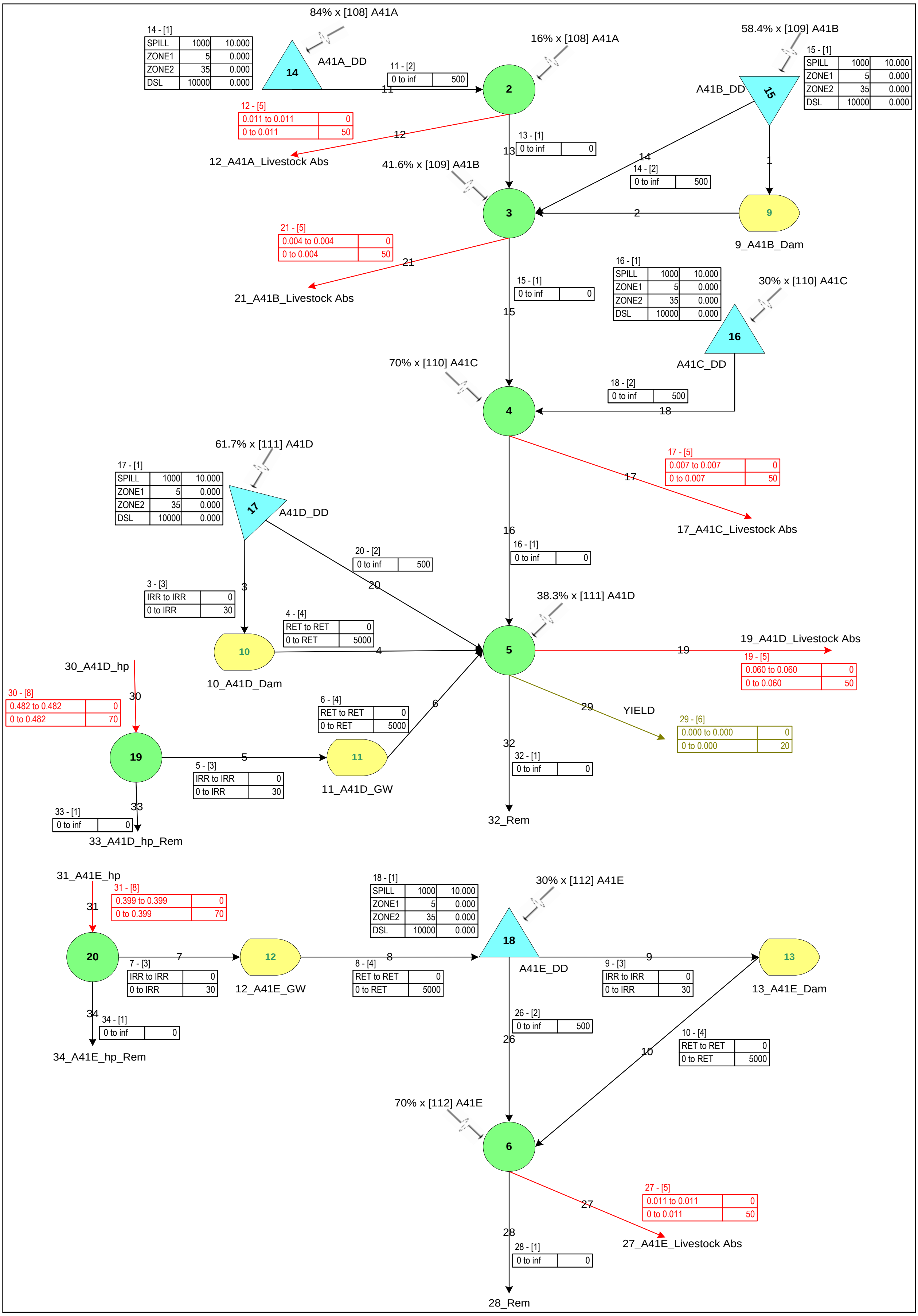

Figure A.1 WRYM schematic diagram: Matlabas catchment

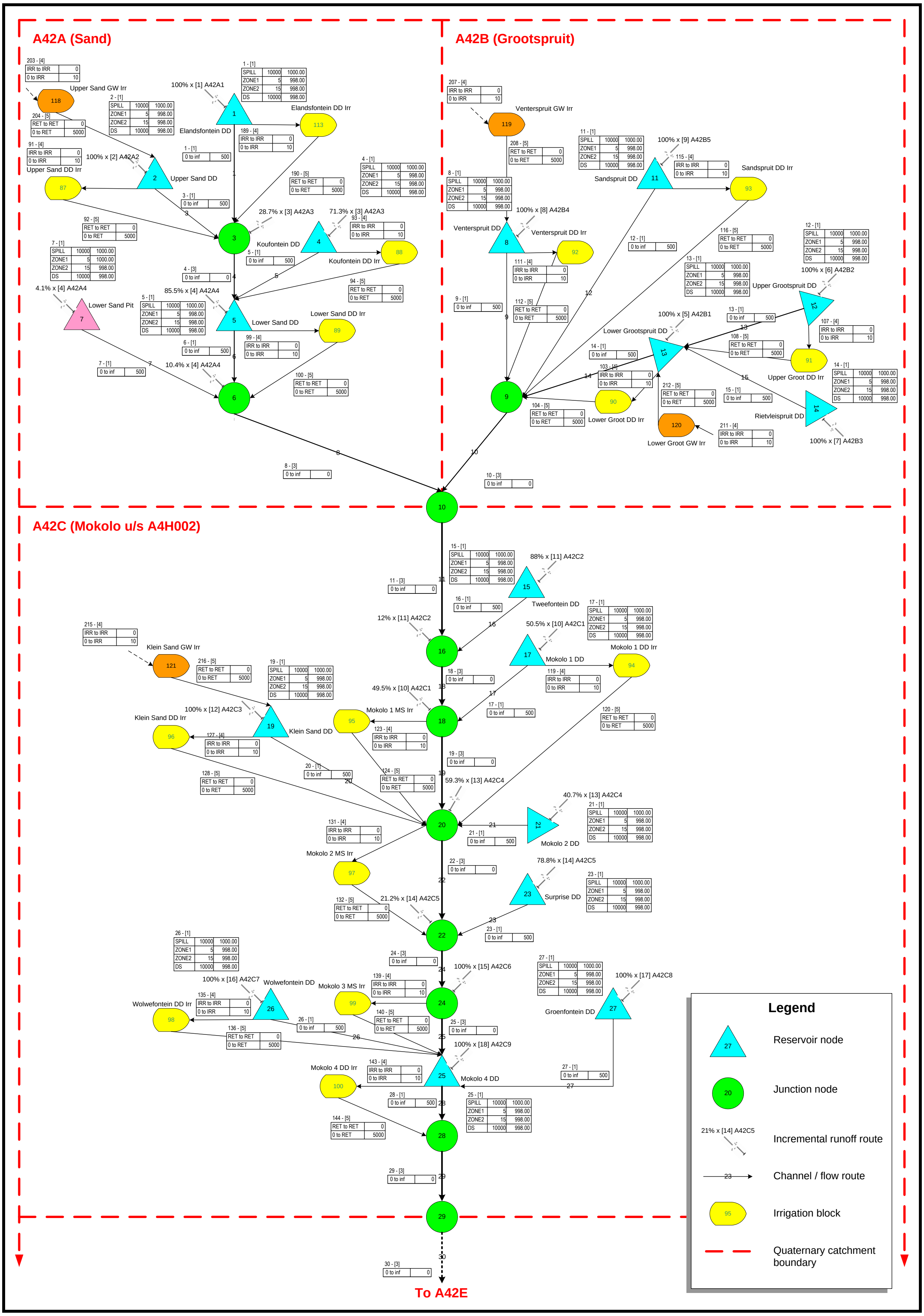

Figure A.2 WRYM schematic diagram: Mokolo catchment for quaternary catchments A42A to A42C

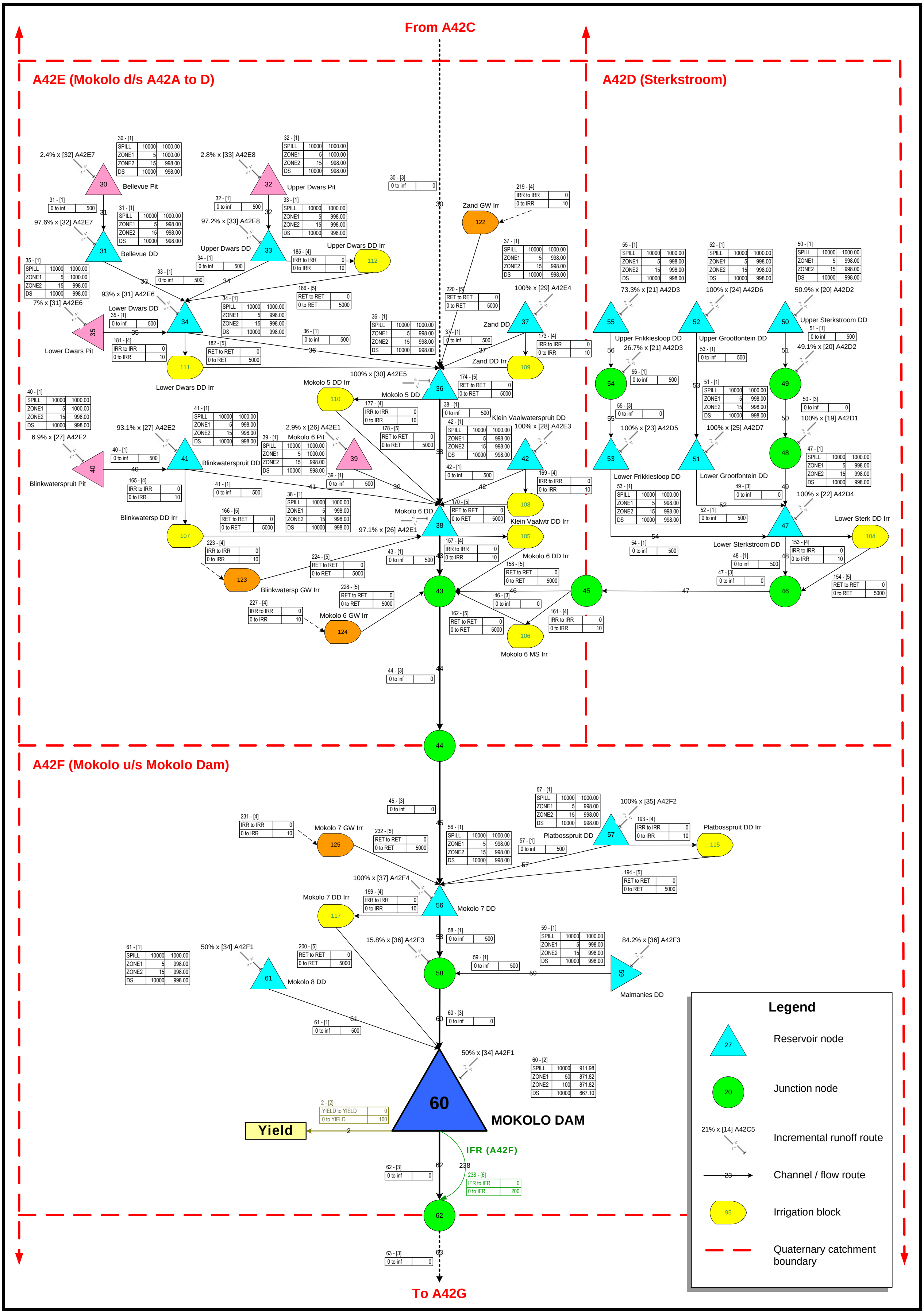

Figure A.3 WRYM schematic diagram: Mokolo catchment for quaternary catchments A42D to A42F (down to Mokolo Dam)

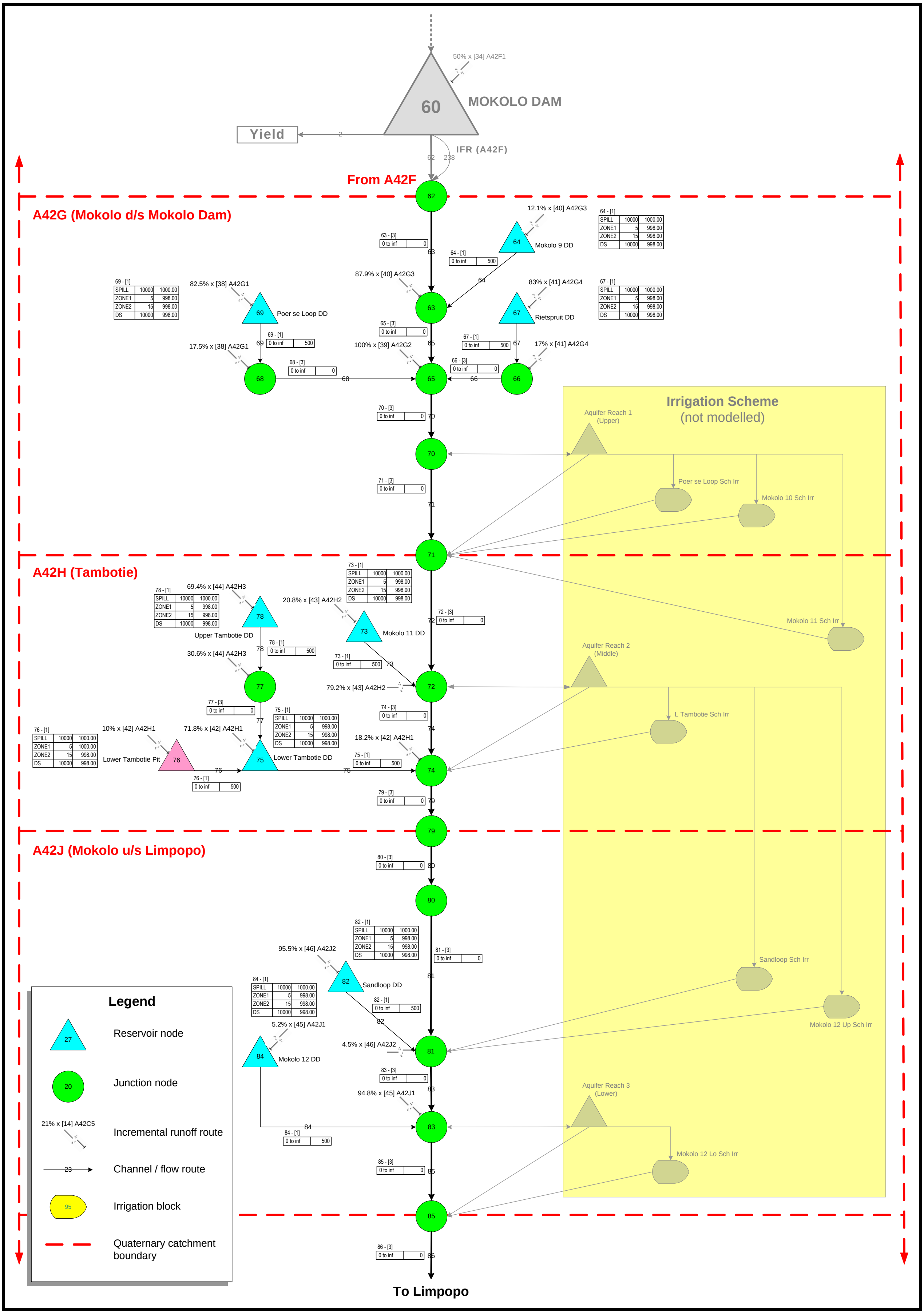

Figure A.4 WRYM schematic diagram: Mokolo catchment for quaternary catchments A42G to A42J

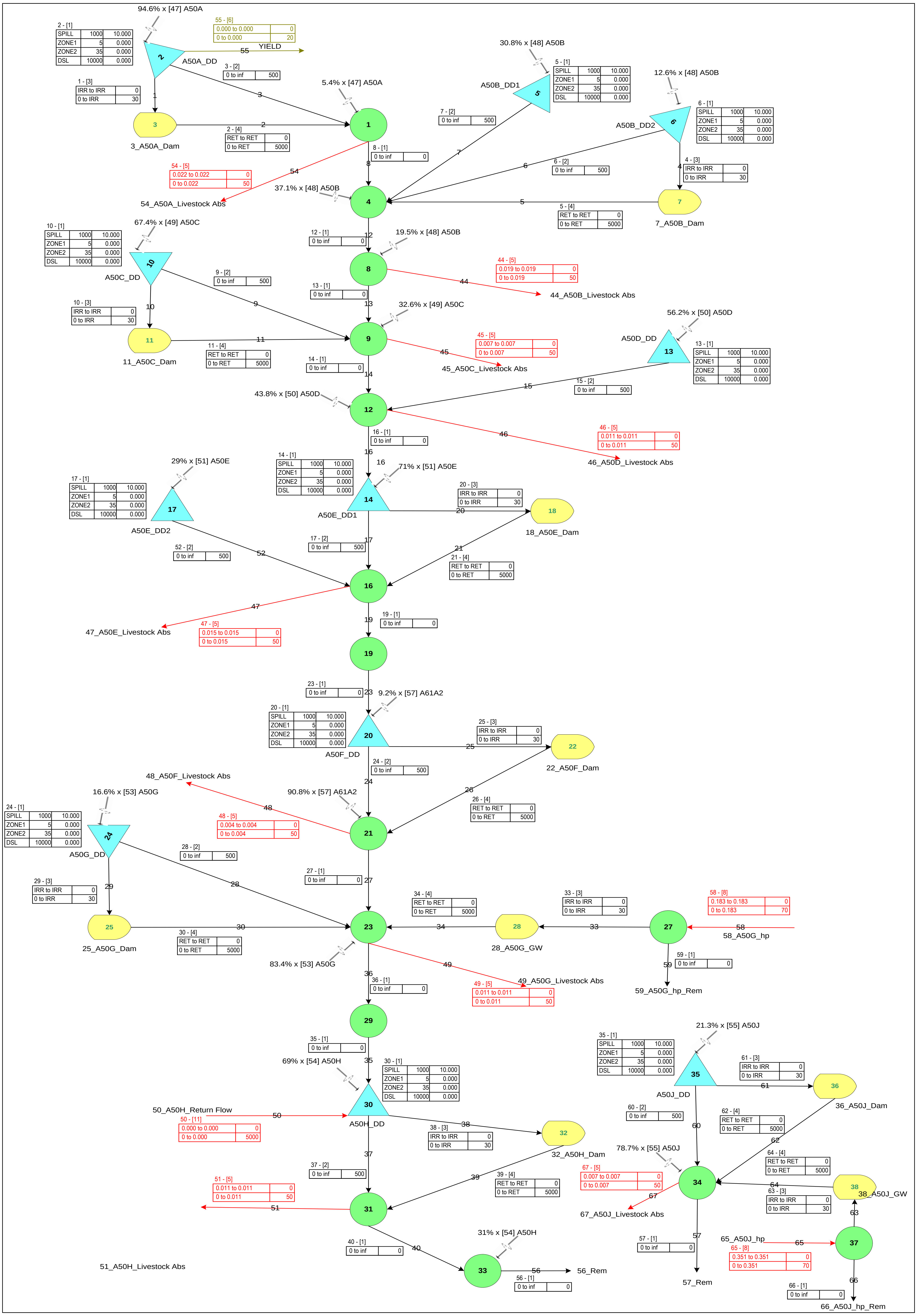

Figure A.5 WRYM schematic diagram: Lephalala catchment

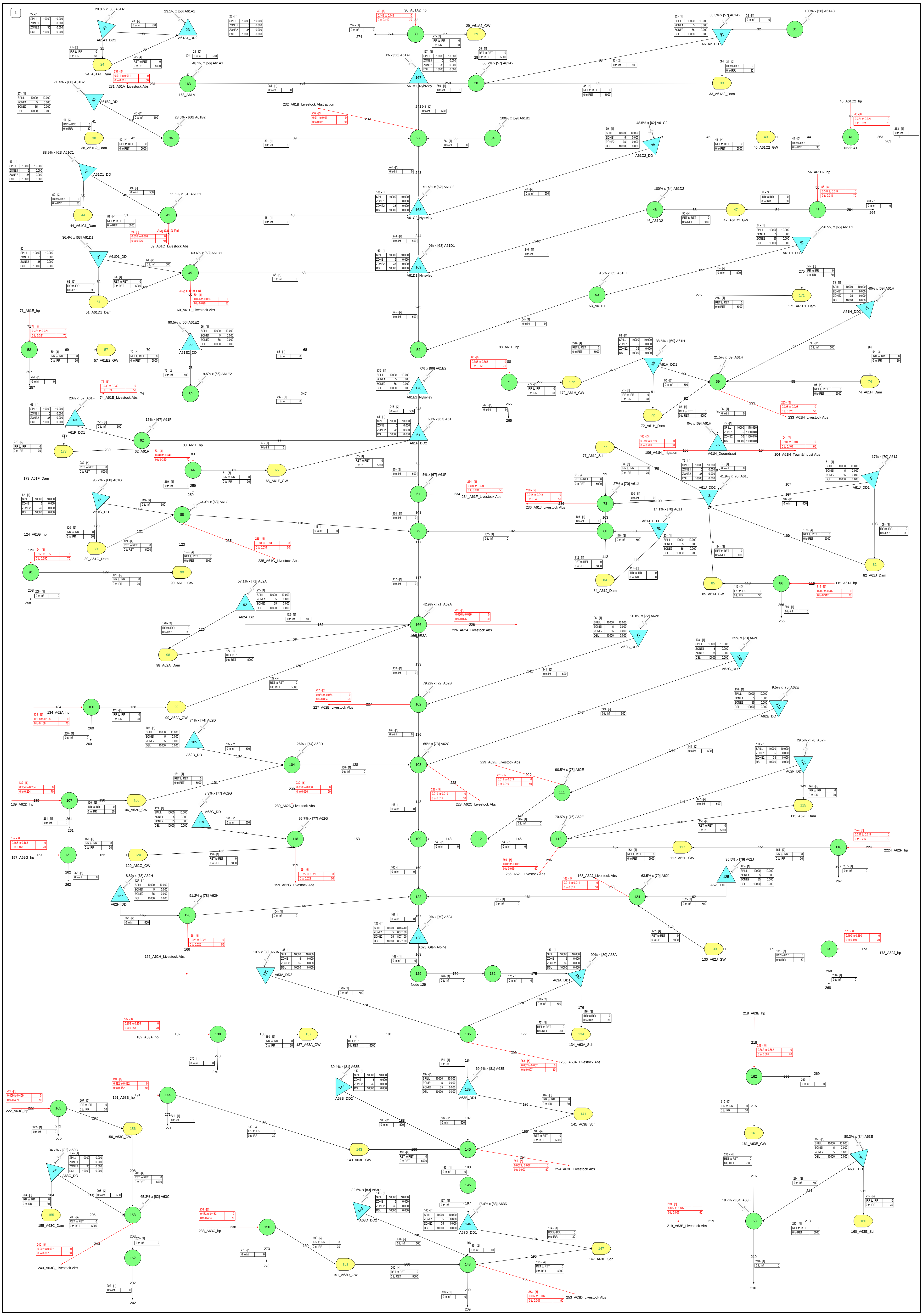

Figure A.6 WRYM schematic diagram: Mogalakwena catchment

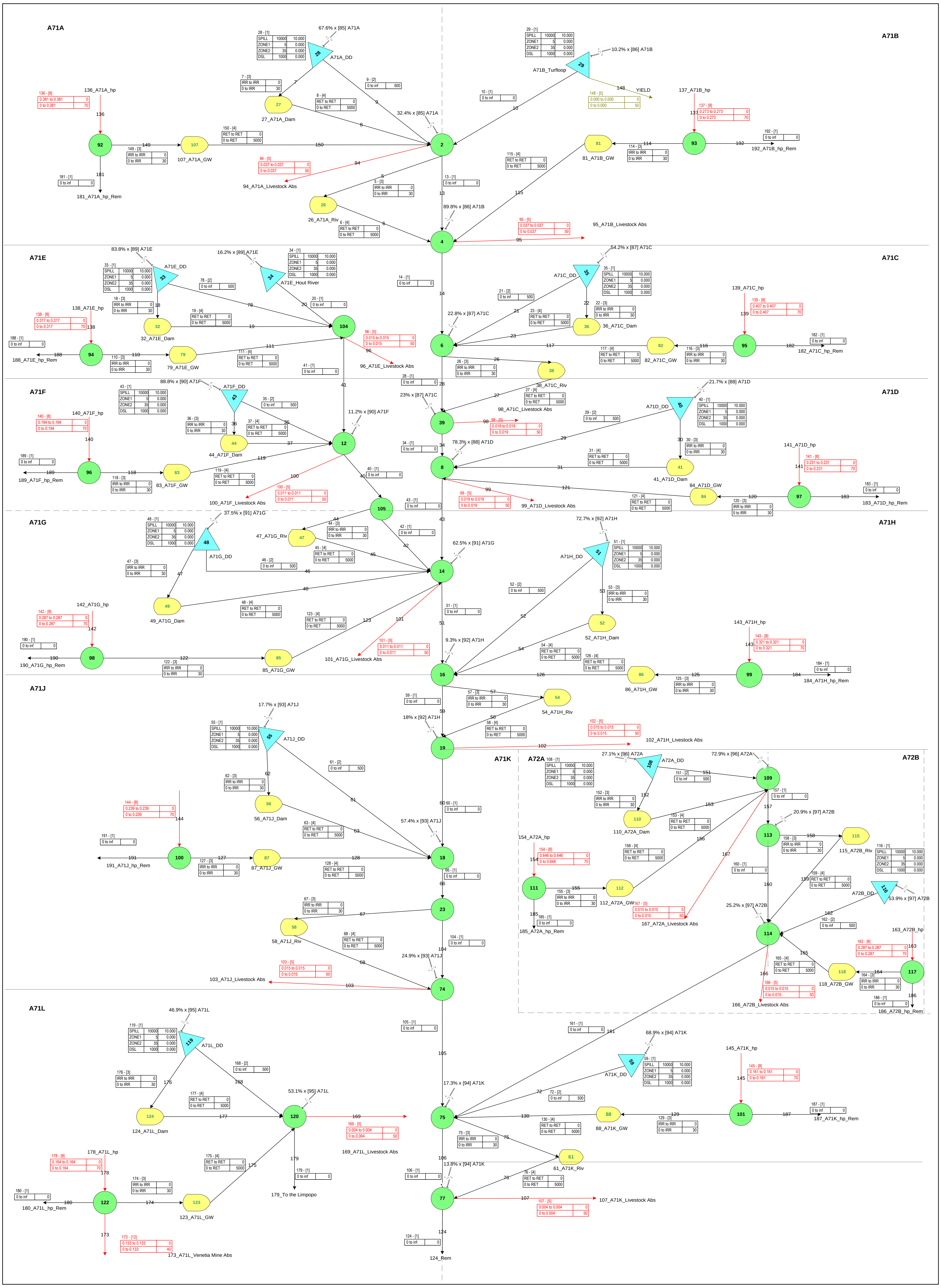

Figure A.7 WRYM schematic diagram: Sand catchment

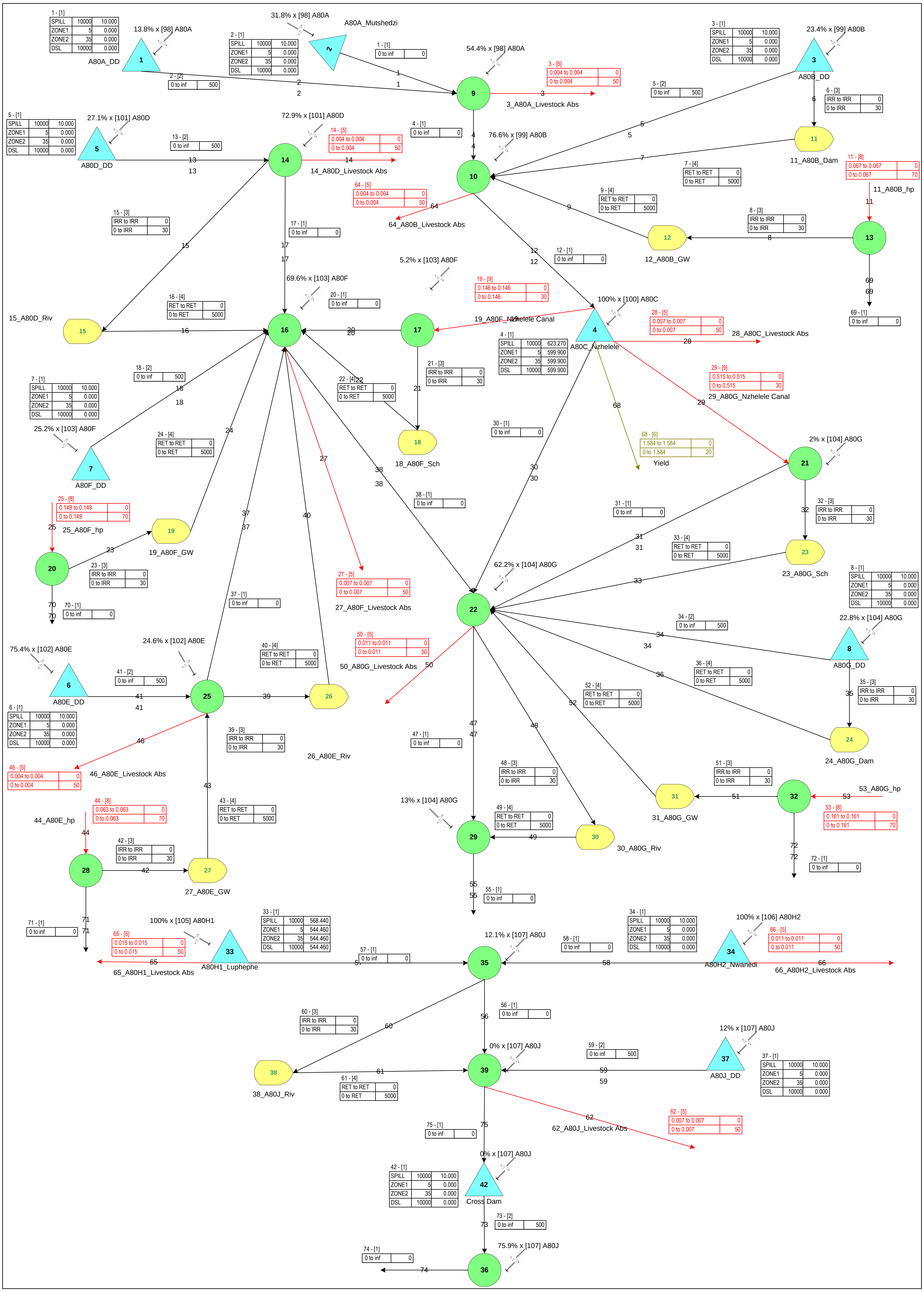

Figure A.8 WRYM schematic diagram: Nzhelele catchment

Appendix B

Hydro-meteorological data

Table B.1 Summary of quaternary catchment MAPs

Catchment	Rainfall zone	Quaternary	MAP (mm)(1)	MAP (mm)(2)
			1920 - 1989	1920 - 2010
Matlabas	A4A	A41A	625	617
		A41B	587	579
	A4B	A41C	512	510
		A41D	492	490
		A41E	438	436
Mokolo	A4C	A42A	640	643
		A42B	660	662
		A42C	656	658
	A4D	A42D	667	669
		A42E	605	597
		A42F	577	570
	A4E	A42G	551	545
		A42H	518	516
		A42J	428	428
Lephalala	A5A	A50A	654	662
		A50B	599	607
		A50C	593	601
	A5B	A50D	558	556
		A50E	517	515
		A50F	496	494
	A5C	A50G	435	431
		A50H	407	403
		A50J	391	387
Mogalakwena	A6A	A61A	629	633
		A61B	625	629
		A61C	608	612
	A6B	A61D	630	629
		A61E	615	614
		A61H	636	635
	A6C	A61F	597	595
		A61G	585	583
		A61J	631	629
	A6D	A62A	610	613
		A62B	529	531
		A62C	478	480
		A62D	489	491

Catchment	Rainfall zone	Quaternary	MAP (mm)(1) 1920 - 1989	MAP (mm)(2) 1920 - 2010
Mogalakwena	A6E	A62E	460	464
		A62F	478	482
		A62G	437	441
		A62H	439	443
		A62J	450	454
	A6F	A63A	433	431
		A63B	394	392
		A63C	378	376
		A63D	412	410
		A63E	358	357
Sand	A7A	A71A	468	466
		A71B	450	448
		A71C	418	416
		A71D	390	388
		A71H	491	489
	A7B	A71E	421	422
		A71F	400	401
		A71G	427	428
		A72A	465	466
	A7C	A71J	396	396
		A71K	305	305
		A71L	288	288
		A72B	344	344
Nzhelele	A8A	A80A	938	939
		A80B	659	659
		A80C	576	576
		A80D	622	622
		A80E	622	622
		A80F	388	388
	A8B	A80G	333	330
		A80H	621	616
		A80J	292	290

Notes: (1) From the Water Resources of South Africa 1990 publications (WRC, 1990).
(2) As applied in the WRYM yield analysis of this study

Table B.2 S-pan evaporation data

Quaternary		Average S-pan evaporation for indicated month (mm)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Matlabas	A41A	208	194	194	193	160	152	119	101	83	94	126	172	1 796
	A41B	208	194	194	193	160	152	119	101	83	94	126	172	1 796
	A41C	220	204	204	203	169	160	126	107	88	99	133	181	1 894
	A41D	226	210	210	209	174	164	129	109	90	102	137	186	1 946
	A41E	226	210	210	209	174	164	129	109	90	102	137	186	1 946
Mokolo	A42A	191	193	187	181	146	148	113	106	85	95	134	170	1 748
	A42B	200	197	196	185	150	152	115	108	86	97	137	174	1 797
	A42C	193	194	189	182	148	149	115	107	85	96	135	171	1 765
	A42D	200	199	194	185	149	152	116	108	87	98	137	175	1 799
	A42E	197	199	193	186	152	152	116	107	86	97	136	174	1 795
	A42F	211	209	207	196	159	160	118	110	87	101	139	182	1 879
	A42G	214	210	209	199	161	162	120	112	88	102	140	185	1 901
	A42H	214	212	209	201	164	163	120	112	87	102	140	185	1 910
	A42J	225	223	220	212	172	170	123	114	89	106	143	192	1 989
Lephalala	A50A	197	183	183	182	152	143	112	95	79	88	119	162	1 695
	A50B	203	188	188	187	156	147	116	98	81	91	123	167	1 745
	A50C	203	188	188	187	156	147	116	98	81	91	123	167	1 745
	A50D	214	199	199	198	165	156	122	104	86	96	130	176	1 845
	A50E	220	204	204	203	169	160	126	107	88	99	133	181	1 894
	A50F	220	204	204	203	169	160	126	107	88	99	133	181	1 894
	A50G	226	210	210	209	174	164	129	109	90	102	137	186	1 946
	A50H	226	210	210	209	174	164	129	109	90	102	137	186	1 946
	A50J	221	205	219	220	183	177	137	114	93	100	140	186	1 995
Mogalakwena	A61A	188	174	186	187	155	151	117	97	79	85	119	158	1 696
	A61B	188	174	186	187	155	151	117	97	79	85	119	158	1 696
	A61C	192	179	190	191	159	154	119	99	80	87	121	162	1 733
	A61D	192	178	190	190	158	154	119	99	80	87	121	161	1 729
	A61E	192	178	190	191	159	154	119	99	80	87	122	161	1 732
	A61F	199	185	197	198	164	160	124	103	83	90	126	167	1 796
	A61G	199	185	197	198	164	160	124	103	83	90	126	167	1 796
	A61H	188	174	186	187	155	151	117	97	79	85	119	158	1 696
	A61J	193	180	191	192	160	155	120	100	81	88	122	162	1 744
	A62A	199	185	197	198	164	160	124	103	83	90	126	167	1 796
	A62B	205	190	202	203	169	164	127	105	86	93	129	172	1 845
	A62C	210	195	208	209	173	168	130	108	88	95	133	176	1 893
	A62D	210	195	208	209	173	168	130	108	88	95	133	176	1 893
	A62E	210	195	208	209	173	168	130	108	88	95	133	176	1 893
	A62F	205	190	202	203	169	164	127	105	86	93	129	172	1 845

Quaternary		Average S-pan evaporation for indicated month (mm)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Mogalakwena	A62G	205	190	202	203	169	164	127	105	86	93	129	172	1 845
	A62H	210	195	208	209	173	168	130	108	88	95	133	176	1 893
	A62J	216	200	213	214	178	173	134	111	90	98	136	181	1 944
	A63A	216	200	213	214	178	173	134	111	90	98	136	181	1 944
	A63B	221	205	219	220	183	177	137	114	93	100	140	186	1 995
	A63C	221	205	219	220	183	177	137	114	93	100	140	186	1 995
	A63D	227	210	224	225	187	182	141	117	95	103	143	190	2 044
	A63E	214	205	218	213	174	174	142	134	110	124	152	185	2 045
Sand	A71A	188	180	192	187	152	152	124	117	97	109	133	162	1 793
	A71B	177	170	181	177	144	144	118	111	91	103	126	153	1 695
	A71C	177	170	181	177	144	144	118	111	91	103	126	153	1 695
	A71D	177	170	181	177	144	144	118	111	91	103	126	153	1 695
	A71E	193	185	197	193	157	157	128	121	100	112	137	167	1 847
	A71F	188	180	192	187	152	152	124	117	97	109	133	162	1 793
	A71G	162	155	165	161	131	131	107	101	83	94	115	140	1 545
	A71H	162	155	165	161	131	131	107	101	83	94	115	140	1 545
	A71J	188	180	192	187	152	152	124	117	97	109	133	162	1 793
	A71K	209	200	213	208	169	169	138	131	108	121	148	180	1 994
	A71L	214	205	218	213	174	174	142	134	110	124	152	185	2 045
	A72A	198	190	202	198	161	161	131	124	102	115	141	171	1 894
	A72B	204	195	208	203	165	165	135	127	105	118	144	176	1 945
Nzhelele	A80A	146	140	149	146	118	118	97	91	75	85	103	126	1 394
	A80B	151	145	154	151	123	123	100	95	78	88	107	130	1 445
	A80C	167	160	170	166	135	135	111	104	86	97	118	144	1 593
	A80D	151	145	154	151	123	123	100	95	78	88	107	130	1 445
	A80E	151	145	154	151	123	123	100	95	78	88	107	130	1 445
	A80F	183	175	186	182	148	148	121	114	94	106	129	158	1 744
	A80G	198	190	202	198	161	161	131	124	102	115	141	171	1 894
	A80H	183	175	186	182	148	148	121	114	94	106	129	158	1 744
	A80J	198	190	202	198	161	161	131	124	102	115	141	171	1 894

Table B.3 Lake evaporation data

Quaternary		Lake evaporation for indicated month (mm)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Matlabas	A41A	168	159	161	162	141	134	96	88	71	78	102	139	1 499
	A41B	168	159	161	162	141	134	96	88	71	78	102	139	1 499
	A41C	178	167	169	171	149	141	102	93	75	82	108	147	1 581
	A41D	183	172	174	176	153	144	104	95	77	85	111	151	1 625
	A41E	183	172	174	176	153	144	104	95	77	85	111	151	1 625
Mokolo	A42A	155	158	155	152	128	130	92	92	72	79	109	138	1 460
	A42B	162	162	163	155	132	134	93	94	73	81	111	141	1 500
	A42C	156	159	157	153	130	131	93	93	72	80	109	139	1 473
	A42D	162	163	161	155	131	134	94	94	74	81	111	142	1 502
	A42E	160	163	160	156	134	134	94	93	73	81	110	141	1 498
	A42F	171	171	172	165	140	141	96	96	74	84	113	147	1 569
	A42G	173	172	173	167	142	143	97	97	75	85	113	150	1 588
	A42H	173	174	173	169	144	143	97	97	74	85	113	150	1 594
	A42J	182	183	183	178	151	150	100	99	76	88	116	156	1 661
Lephalala	A50A	160	150	152	153	134	126	91	83	67	73	96	131	1 415
	A50B	164	154	156	157	137	129	94	85	69	76	100	135	1 457
	A50C	164	154	156	157	137	129	94	85	69	76	100	135	1 457
	A50D	173	163	165	166	145	137	99	90	73	80	105	143	1 540
	A50E	178	167	169	171	149	141	102	93	75	82	108	147	1 581
	A50F	178	167	169	171	149	141	102	93	75	82	108	147	1 581
	A50G	183	172	174	176	153	144	104	95	77	85	111	151	1 625
	A50H	183	172	174	176	153	144	104	95	77	85	111	151	1 625
	A50J	179	168	182	185	161	156	111	99	79	83	113	151	1 667
Mogalakwena	A61A	152	143	154	157	136	133	95	84	67	71	96	128	1 417
	A61B	152	143	154	157	136	133	95	84	67	71	96	128	1 417
	A61C	156	147	158	160	140	136	96	86	68	72	98	131	1 448
	A61D	156	146	158	160	139	136	96	86	68	72	98	130	1 444
	A61E	156	146	158	160	140	136	96	86	68	72	99	130	1 447
	A61F	161	152	164	166	144	141	100	90	71	75	102	135	1 500
	A61G	161	152	164	166	144	141	100	90	71	75	102	135	1 500
	A61H	152	143	154	157	136	133	95	84	67	71	96	128	1 417
	A61J	156	148	159	161	141	136	97	87	69	73	99	131	1 457
	A62A	161	152	164	166	144	141	100	90	71	75	102	135	1 500
	A62B	166	156	168	171	149	144	103	91	73	77	104	139	1 541
	A62C	170	160	173	176	152	148	105	94	75	79	108	143	1 581
	A62D	170	160	173	176	152	148	105	94	75	79	108	143	1 581
	A62E	170	160	173	176	152	148	105	94	75	79	108	143	1 581
	A62F	166	156	168	171	149	144	103	91	73	77	104	139	1 541
	A62G	166	156	168	171	149	144	103	91	73	77	104	139	1 541
	A62H	170	160	173	176	152	148	105	94	75	79	108	143	1 581

Quaternary		Lake evaporation for indicated month (mm)												
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Mogalakwena	A62J	175	164	177	180	157	152	109	97	77	81	110	147	1 624
	A63A	175	164	177	180	157	152	109	97	77	81	110	147	1 624
	A63B	179	168	182	185	161	156	111	99	79	83	113	151	1 667
	A63C	179	168	182	185	161	156	111	99	79	83	113	151	1 667
	A63D	184	172	186	189	165	160	114	102	81	85	116	154	1 708
	A63E	173	168	181	179	153	153	115	117	94	103	123	150	1 709
Sand	A71A	152	148	159	157	134	134	100	102	82	90	108	131	1 498
	A71B	143	139	150	149	127	127	96	97	77	85	102	124	1 416
	A71C	143	139	150	149	127	127	96	97	77	85	102	124	1 416
	A71D	143	139	150	149	127	127	96	97	77	85	102	124	1 416
	A71E	156	152	164	162	138	138	104	105	85	93	111	135	1 543
	A71F	152	148	159	157	134	134	100	102	82	90	108	131	1 498
	A71G	131	127	137	135	115	115	87	88	71	78	93	113	1 291
	A71H	131	127	137	135	115	115	87	88	71	78	93	113	1 291
	A71J	152	148	159	157	134	134	100	102	82	90	108	131	1 498
	A71K	169	164	177	175	149	149	112	114	92	100	120	146	1 666
	A71L	173	168	181	179	153	153	115	117	94	103	123	150	1 709
	A72A	160	156	168	166	142	142	106	108	87	95	114	139	1 582
	A72B	165	160	173	171	145	145	109	110	89	98	117	143	1 625
Nzhelele	A80A	118	115	124	123	104	104	79	79	64	71	83	102	1 165
	A80B	122	119	128	127	108	108	81	83	66	73	87	105	1 207
	A80C	135	131	141	139	119	119	90	90	73	81	96	117	1 331
	A80D	122	119	128	127	108	108	81	83	66	73	87	105	1 207
	A80E	122	119	128	127	108	108	81	83	66	73	87	105	1 207
	A80F	148	144	154	153	130	130	98	99	80	88	104	128	1 457
	A80G	160	156	168	166	142	142	106	108	87	95	114	139	1 582
	A80H	148	144	154	153	130	130	98	99	80	88	104	128	1 457
	A80J	160	156	168	166	142	142	106	108	87	95	114	139	1 582

Table B.4 Summary of historical natural incremental runoff data

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file	Statistic		
			MAR (million m^3/a)	SD (million m^3/a)	CV
Matlabas	A41A	A41A.inc	18.8	23.8	1.26
	A41B	A41B.inc	8.7	11.2	1.29
	A41C	A41C.inc	11.3	20.1	1.78
	A41D	A41D.inc	11.3	22.1	1.95
	A41E	A41E.inc	5.7	11.7	2.04
Matlabas			**55.8**	**88.8**	**1.59**
Mokolo	A42A1	A42A1.inc	8.0	6.9	0.87
	A42A2	A42A2.inc	9.5	8.2	0.87
	A42A3	A42A3.inc	1.1	1.0	0.95
	A42A4	A42A4.inc	5.8	5.3	0.92
	A42B1	A42B1.inc	2.8	2.4	0.86
	A42B2	A42B2.inc	11.2	9.7	0.86
	A42B3	A42B3.inc	2.2	1.9	0.86
	A42B4	A42B4.inc	3.8	3.3	0.86
	A42B5	A42B5.inc	6.9	5.9	0.86
	A42C1	A42C1.inc	3.5	3.0	0.85
	A42C2	A42C2.inc	2.1	1.8	0.85
	A42C3	A42C3.inc	20.7	17.6	0.85
	A42C4	A42C4.inc	1.0	0.8	0.85
	A42C5	A42C5.inc	1.2	1.0	0.85
	A42C6	A42C6.inc	1.6	1.4	0.85
	A42C7	A42C7.inc	2.8	2.4	0.86
	A42C8	A42C8.inc	1.9	1.6	0.86
	A42C9	A42C9.inc	2.3	1.9	0.87
	A42D1	A42D1.inc	7.0	6.0	0.86
	A42D2	A42D2.inc	3.0	2.6	0.86
	A42D3	A42D3.inc	1.4	1.2	0.86
	A42D4	A42D4.inc	13.4	11.5	0.86
	A42D5	A42D5.inc	4.6	4.0	0.86
	A42D6	A42D6.inc	2.2	1.9	0.86
	A42D7	A42D7.inc	11.5	9.8	0.86
	A42E1	A42E1.inc	9.2	11.4	1.24
	A42E2	A42E2.inc	4.1	5.0	1.24
	A42E3	A42E3.inc	2.7	3.3	1.24
	A42E4	A42E4.inc	1.5	1.8	1.24
	A42E5	A42E5.inc	2.0	2.4	1.24
	A42E6	A42E6.inc	5.3	6.6	1.24
	A42E7	A42E7.inc	3.7	4.6	1.24
	A42E8	A42E8.inc	15.3	18.9	1.24
	A42F1	A42F1.inc	8.2	10.3	1.26
	A42F2	A42F2.inc	1.7	2.2	1.26

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file	Statistic		
			MAR (million m^3/a)	SD (million m^3/a)	CV
	A42F3	A42F3.inc	9.6	12.0	1.26
	A42F4	A42F4.inc	14.8	18.6	1.26
	A42G1	A42G1.inc	13.0	19.4	1.50
	A42G2	A42G2.inc	2.7	4.1	1.50
	A42G3	A42G3.inc	4.8	7.2	1.50
	A42G4	A42G4.inc	12.8	19.2	1.50
	A42H1	A42H1.inc	13.0	18.0	1.40
	A42H2	A42H2.inc	3.8	5.3	1.40
	A42H3	A42H3.inc	10.1	14.0	1.40
	A42J1	A42J1.inc	4.1	4.8	1.17
	A42J2	A42J2.inc	2.3	2.6	1.17
Mokolo			**276.0**	**304.5**	**1.10**
Lephalala	A50A	A50A.inc	32.3	22.3	0.69
	A50B	A50B.inc	34.8	24.7	0.71
	A50C	A50C.inc	14.6	16.6	1.13
	A50D	A50D.inc	20.4	21.3	1.05
	A50E	A50E.inc	19.0	16.6	0.87
	A50F	A50F.inc	9.5	8.5	0.89
	A50G	A50G.inc	4.1	6.5	1.60
	A50H	A50H.inc	2.7	4.6	1.66
	A50J	A50J.inc	3.8	6.3	1.65
Lephalala			**141.3**	**127.4**	**0.90**
Mogalakwena	A61A1	A61A1.inc	10.3	5.6	0.55
	A61A2	A61A2.inc	8.0	5.0	0.63
	A61A3	A61A3.inc	4.5	2.4	0.53
	A61B1	A61B1.inc	6.6	5.7	0.87
	A61B2	A61B2.inc	14.8	11.5	0.77
	A61C1	A61C1.inc	3.3	2.6	0.80
	A61C2	A61C2.inc	2.1	2.9	1.37
	A61D1	A61D1.inc	3.1	3.7	1.18
	A61D2	A61D2.inc	4.6	8.0	1.73
	A61E1	A61E1.inc	2.2	2.8	1.28
	A61E2	A61E2.inc	4.4	9.0	2.04
	A61F	A61F.inc	17.2	26.7	1.55
	A61G	A61G.inc	18.0	29.2	1.62
	A61H	A61H.inc	38.1	25.6	0.67
	A61J	A61J.inc	17.8	23.0	1.29
	A62A	A62A.inc	13.4	18.7	1.40
	A62B	A62B.inc	10.6	18.2	1.72
	A62C	A62C.inc	2.7	5.9	2.16
	A62D	A62D.inc	4.0	7.4	1.85
	A62E	A62E.inc	3.7	7.5	2.02

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file	Statistic		
			MAR (million m^3/a)	SD (million m^3/a)	CV
Mogalakwena	A62F	A62F.inc	3.6	9.5	2.65
	A62G	A62G.inc	2.3	5.2	2.23
	A62H	A62H.inc	4.1	8.2	2.00
	A62J	A62J.inc	4.5	9.3	2.06
	A63A	A63A.inc	6.0	25.3	4.19
	A63B	A63B.inc	4.1	16.6	4.02
	A63C	A63C.inc	3.0	11.1	3.75
	A63D	A63D.inc	2.3	9.4	4.04
	A63E	A63E.inc	3.5	13.4	3.79
Mogalakwena			**223.0**	**329.4**	**1.48**
Sand	A71A	A71A.inc	9.1	25.9	2.85
	A71B	A71B.inc	6.1	19.2	3.17
	A71C	A71C.inc	7.0	22.1	3.15
	A71D	A71D.inc	2.9	11.0	3.75
	A71E	A71E.inc	2.4	7.2	3.04
	A71F	A71F.inc	1.4	4.3	3.11
	A71G	A71G.inc	2.9	8.6	3.00
	A71H	A71H.inc	7.3	24.5	3.33
	A71J	A71J.inc	10.3	46.4	4.52
	A71K	A71K.inc	9.7	48.1	4.94
	A71L	A71L.inc	5.0	38.7	7.69
	A72A	A72A.inc	7.7	14.5	1.88
	A72B	A72B.inc	4.8	18.6	3.85
Sand			**76.6**	**289.0**	**3.77**
Nzhelele	A80A	A80A.inc	48.6	46.6	0.96
	A80B	A80B.inc	16.1	19.6	1.22
	A80C	A80C.inc	8.7	11.4	1.31
	A80D	A80D.inc	7.0	8.8	1.24
	A80E	A80E.inc	13.7	16.6	1.21
	A80F	A80F.inc	2.9	8.1	2.85
	A80G	A80G.inc	5.6	15.7	2.79
	A80H1	A80H1.inc	21.4	18.5	0.87
	A80H2	A80H2.inc	9.5	12.0	1.27
	A80J	A80J.inc	2.3	5.9	2.56
Nzhelele			**135.7**	**163.2**	**1.20**
Limpopo WMA North			**908.4**	**1302.3**	**1.43**

Table B.5 Summary comparison of historical natural incremental runoff with and without active groundwater abstractions data

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file(1)	MAR-GW(2) (million m^3/a)	MAR(3) (million m^3/a)
Matlabas	A41A	A41A.inc	18.8	18.8
	A41B	A41B.inc	8.7	8.7
	A41C	A41C.inc	11.3	11.3
	A41D	A41D.inc	11.3	11.2
	A41E	A41E.inc	5.7	5.7
Matlabas			**55.8**	**55. 7**
Mokolo	A42A1	-	-	8.3
	A42A2	-	-	9.8
	A42A3	-	-	1.2
	A42A4	-	-	6.2
	A42B1	-	-	2.9
	A42B2	-	-	11.6
	A42B3	-	-	2.2
	A42B4	-	-	3.9
	A42B5	-	-	7.1
	A42C1	-	-	3.6
	A42C2	-	-	2.1
	A42C3	-	-	21.0
	A42C4	-	-	1.0
	A42C5	-	-	1.2
	A42C6	-	-	1.7
	A42C7	-	-	2.8
	A42C8	-	-	1.9
	A42C9	-	-	2.3
	A42D1	-	-	7.1
	A42D2	-	-	3.0
	A42D3	-	-	1.4
	A42D4	-	-	13.5
	A42D5	-	-	4.7
	A42D6	-	-	2.3
	A42D7	-	-	11.6
	A42E1	-	-	9.3
	A42E2	-	-	4.1
	A42E3	-	-	2.68
	A42E4	-	-	1.49
	A42E5	-	-	1.98
	A42E6	-	-	5.36
	A42E7	-	-	3.73
	A42E8	-	-	15.33
	A42F1	-	-	8.40
	A42F2	-	-	1.76

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file(1)	MAR-GW(2) (million m^3/a)	MAR(3) (million m^3/a)
Mokolo	A42A1	-	-	9.81
	A42F4	-	-	15.19
	A42G1	-	-	13.27
	A42G2	-	-	2.79
	A42G3	-	-	4.91
	A42G4	-	-	13.13
	A42H1	-	-	13.17
	A42H2	-	-	3.85
	A42H3	-	-	10.26
	A42J1	-	-	10.18
	A42J2	-	-	5.61
Mokolo			**276.0**	**276.0**
Lephalala	A50A	A50A.inc	32.3	32.3
	A50B	A50B.inc	34.8	34.8
	A50C	A50C.inc	14.6	14.6
	A50D	A50D.inc	20.4	20.4
	A50E	A50E.inc	19.0	19.0
	A50F	A50F.inc	9.5	9.5
	A50G	A50G.inc	4.1	4.1
	A50H	A50H.inc	2.7	2.8
	A50J	A50J.inc	3.8	4.8
Lephalala			**141.3**	**142.3**
Mogalakwena	A61A1	A61A1.inc	10.3	10.4
	A61A2	A61A2.inc	8.0	8.9
	A61A3	A61A3.inc	4.5	4.5
	A61B1	A61B1.inc	6.6	6.6
	A61B2	A61B2.inc	14.8	15.0
	A61C1	A61C1.inc	3.3	3.3
	A61C2	A61C2.inc	2.1	3.8
	A61D1	A61D1.inc	3.1	3.4
	A61D2	A61D2.inc	4.6	7.1
	A61E1	A61E1.inc	2.2	2.2
	A61E2	A61E2.inc	4.4	8.6
	A61F	A61F.inc	17.2	19.5
	A61G	A61G.inc	18.0	19.9
	A61H	A61H.inc	38.1	39.9
	A61J	A61J.inc	17.8	19.6
	A62A	A62A.inc	13.4	14.2
	A62B	A62B.inc	10.6	11.8
	A62C	A62C.inc	2.7	4.0
	A62D	A62D.inc	4.0	4.5
	A62E	A62E.inc	3.7	3.7
	A62F	A62F.inc	3.6	4.7

Catchment	Quaternary or sub-quaternary	Associated WRYM data input file(1)	MAR-GW(2) (million m^3/a)	MAR(3) (million m^3/a)
Mogalakwena	A61A1	A62G.inc	2.3	2.6
	A62H	A62H.inc	4.1	4.1
	A62J	A62J.inc	4.5	4.6
	A63A	A63A.inc	6.0	6.2
	A63B	A63B.inc	4.1	4.1
	A63C	A63C.inc	3.0	3.0
	A63D	A63D.inc	2.3	2.4
	A63E	A63E.inc	3.5	3.5
Mogalakwena			**223.0**	**246.2**
Sand	A71A	A71A.inc	9.1	10.3
	A71B	A71B.inc	6.1	7.3
	A71C	A71C.inc	7.0	8.2
	A71D	A71D.inc	2.9	3.9
	A71E	A71E.inc	2.4	3.7
	A71F	A71F.inc	1.4	2.3
	A71G	A71G.inc	2.9	4.1
	A71H	A71H.inc	7.3	8.1
	A71J	A71J.inc	10.3	10.9
	A71K	A71K.inc	9.7	9.8
	A71L	A71L.inc	5.0	7.5
	A72A	A72A.inc	7.7	7.8
	A72B	A72B.inc	4.8	4.8
Sand			**76.6**	**88.6**
Nzhelele	A80A	A80A.inc	48.6	49.4
	A80B	A80B.inc	16.1	16.6
	A80C	A80C.inc	8.7	9.6
	A80D	A80D.inc	7.0	7.0
	A80E	A80E.inc	13.7	14.1
	A80F	A80F.inc	2.9	2.9
	A80G	A80G.inc	5.6	5.8
	A80H1	A80H1.inc	21.4	22.0
	A80H2	A80H2.inc	9.5	10.3
	A80J	A80J.inc	2.3	2.4
Nzhelele			**135.7**	**140.0**

Note: (1) The MARs are calculated for the period 1920-2010 hydrological years.
(2) The natural MAR with active groundwater abstractions.
(3) The natural MAR without groundwater abstractions.

Appendix C

Water requirements and return flows

Table C.1 Summary of total domestic water requirements (2010-development level)

Quaternary	Demand centre	Source	Surface water source		Groundwater source	Total (million m^3/a)
			Quantity (million m^3/a)	Location	Quantity (million m^3/a)	
A42C	Vaalwater	GW	-	-	0.47	0.47
A42E	Vaalwater	GW	-	-	0.35	0.35
A42H	Lephalale town	Mokolo Dam and GW	5.00	A42F	0.03	5.03
Mokolo Total			**5.00**		1.01	**6.01**
A50G	Villages	GW	-	-	1.27	1.27
A50H	Villages	GW	-	-	1.70	1.70
Lephalala Total			**0.00**		2.98	**2.98**
A61A	Modimolle	Donkerpoort Dam and GW	2.05	A61A	0.07	2.12
A61B	Modimolle	Donkerpoort Dam and GW	0.87	A61A	0.03	0.90
A61D	Mookgopong	Welgevonden Dam and GW	0.49	A61H	1.01	1.50
A61E	Mookgopong	Doorndraai Dam and GW	0.41	A61H	0.24	0.66
A61F	Mokopane	Doorndraai Dam and GW	3.25	A61H	2.81	6.06
A61G	Villages	Doorndraai Dam and GW	0.14	A61H	2.23	2.36
A61J	Villages	Doorndraai Dam and GW	0.58	A61H	0.37	0.95
A62A	Villages	GW	-	-	0.34	0.34
A62B	Villages	GW	-	-	1.45	1.45
A62C	Villages	GW	-	-	1.24	1.24
A62D	Villages	GW	-	-	0.46	0.46
A62E	Villages	Hout River Dam (Mathala Dam) and GW	0.13	A71E	0.66	0.79
A62F	Villages	GW	-	-	1.88	1.88
A62G	Villages	GW	-	-	0.86	0.86
A63A	Villages	GW	-	-	0.24	0.24
A63B	Villages	GW	-	-	0.28	0.28
A63D	Villages	GW	-	-	0.50	0.50
Mogalakwena Total			**7.94**		**14.83**	**22.77**

Quaternary	Demand centre	Source	Surface water source		Groundwater source	Total (million m^3/a)
			Quantity (million m^3/a)	Location	Quantity (million m^3/a)	
A71A	Polokwane	Transfers (Ebenezer Dam, Dap Naude Dam and Olifantspoort weir) and GW	-	B81A, B81B and B52D	1.9	1.9
A71B	Mankweng	Transfers	-	B81A	13.1	13.1
A71C	Villages		-	-	9.2	9.2
A71E	Villages	Hout River (Mathala Dam) and GW	0.3	-	2.3	2.6
A71F	Villages	Transfers (Ebenezer & Dap Naude Dams and Olifantspoort Weir) and GW		B81A, B81B and B52D	1.3	1.3
A71G	Villages	GW	-	-	0.4	0.4
A71H	Louis Trichardt	Transfers (Nandoni Dam) and GW	-	A91F	2.2	2.2
A71K	Musina	Limpopo River / Sand Aquifer and GW	10.4	A71K		10.4
A72A	Villages	GW	-	-	1.5	1.5
Sand Total			**10.7**		**32.0**	**42.6**
A80A	Siloam & Dzanani	Mutshedzi Dam, Tshifiri / Murunwa Weir and GW	1.3	A80A	0.7	2.0
A80B	Makhado town	Mutshedzi Dam and GW	1.0	A80A	0.4	1.4
A80C	Villages	Mutshedzi Dam and GW	0.2	A80A	0.9	1.1
A80E	Villages	Mutshedzi Dam and GW	0.3	A80A	0.1	0.5
A80F	Villages	Mutshedzi Dam and GW	0.1	A71K, A80A	0.1	0.2
A80G	Villages	Limpopo River/Sand Aquifer, Mutshedzi Dam and GW	0.2	A80A	0.2	0.4
A80H	Villages	Mutshedzi Dam and GW	0.0	A80A	1.5	1.6
A80J	Villages	GW	-	-	0.6	0.6
Nzhelele Total			**3.2**		4.6	**7.7**
Limpopo WMA North			**26.8**		55.3	**82.1**

Note: (1) Only GW supply quantities > 0.1 million m^3/a shown

(2) Transfer supplies not modelled in the WRSM2000

Table C.2 Irrigation areas per quaternary catchment for the different water sources (2010-development level)

River catchment	Irrigated area (km^2)						
	Modelled surface water(1)	Ground-water(2)	Modelled ground-water(1)	Scheme(2)	Modelled scheme(1)	Total(2)	Modelled total(1)
A41A	0.0	0.3	0.0	0.0	0.0	0.3	0.0
A41B	0.1	0.0	0.0	0.0	0.0	0.1	0.1
A41C	0.0	0.0	0.0	0.0	0.0	2.6	0.0
A41D	0.5	1.5	1.6	0.0	0.0	2.0	2.0
A41E	2.0	0.4	0.4	0.0	0.0	2.3	2.4
Matlabas	**2.6**	**2.2**	**1.9**	**0.0**	**0.0**	**7.4**	**4.5**
A42A	18.1	1.4	1.4	0.0	0.0	19.5	19.5
A42B	14.6	1.3	1.3	0.0	0.0	15.9	15.9
A42C	17.1	3.1	3.1	0.0	0.0	20.2	20.2
A42D	4.4	0.1	0.1	0.0	0.0	4.5	4.5
A42E	18.5	1.9	1.9	0.0	0.0	20.3	20.3
A42F	8.6	1.5	1.5	0.0	0.0	10.1	10.1
A42G	0.0	0.0	0.0	0.8	0.8	0.8	0.8
A42H	0.0	0.0	0.0	1.9	1.9	1.9	1.9
A42J	0.0	0.2	0.2	8.1	8.1	8.3	8.3
Mokolo	**81.1**	**9.5**	**9.5**	**10.7**	**10.7**	**101.4**	**101.4**
A50A	12.3	0.0	0.0	0.0	0.0	12.3	12.3
A50B	1.8	0.0	0.0	0.0	0.0	1.8	1.8
A50C	2.1	0.0	0.0	0.0	0.0	2.1	2.1
A50D	0.0	0.1	0.0	0.0	0.0	0.1	0.0
A50E	12.9	0.0	0.0	0.0	0.0	12.9	12.9
A50F	0.3	0.0	0.0	0.0	0.0	0.3	0.3
A50G	1.9	0.7	0.7	0.0	0.0	2.6	2.6
A50H	15.4	19.1	0.0	0.0	0.0	34.5	15.4
A50J	5.8	10.5	10.5	0.0	0.0	16.3	16.3
Lephalala	**52.6**	**30.4**	**11.2**	**0.0**	**0.0**	**83.0**	**63.7**
A61A	3.0	1.6	1.6	0.0	0.0	4.6	4.6
A61B	0.4	0.3	0.0	0.0	0.0	0.7	0.4
A61C	2.1	3.6	3.6	0.0	0.0	5.7	5.7
A61D	0.3	3.4	3.4	0.0	0.0	3.7	3.7
A61E	0.1	10.1	10.1	0.0	0.0	10.2	10.2
A61F	0.6	3.0	3.0	0.0	0.0	3.6	3.6
A61G	0.8	0.5	0.5	0.0	0.0	1.3	1.3
A61H	22.4	1.1	1.1	0.0	0.0	23.5	23.5
A61J	8.2	2.1	2.1	3.3	3.4	13.7	13.7
A62A	2.4	0.5	0.5	0.0	0.0	2.9	2.9
A62B	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A62C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A62D	0.0	0.8	0.8	0.0	0.0	0.8	0.8
A62E	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A62F	0.2	3.5	3.6	0.0	0.0	3.8	3.8
A62G	0.0	0.0	0.0	0.0	0.0	0.0	0.0

River catchment	Irrigated area (km²)						
	Modelled surface water(1)	Ground-water(2)	Modelled ground-water(1)	Scheme(2)	Modelled scheme(1)	Total(2)	Modelled total(1)
A62H	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A62J	0.0	0.5	0.5	0.0	0.0	0.5	0.5
A63A	0.0	20.3	20.3	1.5	1.5	21.8	21.8
A63B	0.0	2.1	2.2	3.8	3.9	6.0	6.0
A63C	1.9	3.9	1.5	0.0	0.0	8.6	3.4
A63D	0.0	2.7	2.7	2.2	2.2	4.9	4.9
A63E	1.2	14.7	0.6	0.0	0.0	17.8	1.8
Mogalakwena	**43.5**	**74.9**	**58.1**	**10.9**	**10.9**	**133.9**	**112.5**
A71A	2.7	41.9	41.9	0.0	0.0	44.6	44.6
A71B	0.0	10.0	10.1	0.0	0.0	10.0	10.1
A71C	2.9	33.9	33.9	0.0	0.0	36.7	36.8
A71D	0.3	8.2	8.2	0.0	0.0	8.6	8.6
A71E	0.4	15.2	15.2	0.0	0.0	15.6	15.6
A71F	1.0	16.0	16.0	0.0	0.0	17.0	17.0
A71G	0.7	19.6	19.6	0.0	0.0	20.2	20.2
A71H	0.5	2.0	2.0	0.0	0.0	2.4	2.4
A71J	4.5	21.0	21.0	0.0	0.0	25.5	25.5
A71K	0.6	3.4	3.4	0.0	0.0	3.9	3.9
A71L	12.6	38.4	38.4	0.0	0.0	78.9	51.0
A72A	1.0	28.2	28.2	0.0	0.0	29.2	29.2
A72B	0.4	5.7	5.8	0.0	0.0	6.1	6.2
Sand	**27.5**	**243.5**	**243.5**	**0.0**	**0.0**	**298.9**	**271.0**
A80A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A80B	0.8	0.4	0.4	0.0	0.0	1.1	1.1
A80C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A80D	0.1	0.0	0.0	0.0	0.0	0.1	0.1
A80E	0.1	1.4	1.4	0.0	0.0	1.5	1.5
A80F	0.0	0.4	0.4	5.6	5.6	6.0	6.0
A80G	0.3	3.4	3.4	19.7	19.7	25.0	23.3
A80H	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A80J	1.1	0.1	0.0	0.0	0.0	7.6	1.1
Nzhelele	**2.5**	**5.7**	**5.6**	**25.2**	**25.2**	**41.5**	**33.3**
Total LNRS	**209.7**	**366.2**	**329.8**	**46.9**	**46.9**	**666.0**	**586.3**

Note: (1) Irrigation areas as modelled in the WRYM (i.e. total areas less the areas that source irrigation water from the Limpopo River, and irrigation areas that source water from groundwater that are less than 0.3 km² in areal extent)

(2) Total areas under irrigation within the study area.

Table C.3 Annual average irrigation water requirements per quaternary catchment (2010-development level)

Catchment / quaternary		Average annual irrigation requirement (million m³/a)					
		Supplied by sources fed from study area runoff				Supplied from Limpopo River	Total
		Surface water	Ground-water	Scheme	Total		
Matlabas	A41A	0.0	0.2	0.0	0.2	0.0	0.2
	A41B	0.1	0.0	0.0	0.1	0.0	0.1
	A41C	0.0	0.0	0.0	0.0	0.0	0.0
	A41D	0.6	1.8	0.0	2.4	0.0	2.4
	A41E	0.0	0.0	0.0	0.0	2.1	2.1
Matlabas Total		**0.6**	**2.0**	**0.**	**2.6**	**2.1**	**4.7**
Mokolo[(1)]	A42A	7.3	0.5	0.0	7.9	0.0	7.9
	A42B	5.6	0.4	0.0	5.9	0.0	5.9
	A42C	5.8	1.0	0.0	6.8	0.0	6.8
	A42D	1.2	0.0	0.0	1.2	0.0	1.2
	A42E	7.3	0.7	0.0	8.0	0.0	8.0
	A42F	3.8	0.6	0.0	4.4	0.0	4.4
	A42G	0.0	0.0	0.4	0.4	0.0	0.4
	A42H	0.0	0.0	0.8	0.8	0.0	0.8
	A42J	0.0	0.0	4.9	4.9	0.0	4.9
Mokolo Total		**30.9**	**3.2**	**6.1**	**40.2**	**0.0**	**40.2**
Lephalala	A50A	8.4	0.0	0.0	8.4	0.0	8.4
	A50B	1.3	0.0	0.0	1.3	0.0	1.3
	A50C	1.3	0.0	0.0	1.3	0.0	1.3
	A50D	0.0	0.1	0.0	0.1	0.0	0.1
	A50E	10.8	0.0	0.0	10.9	0.0	10.9
	A50F	0.3	0.0	0.0	0.3	0.0	0.3
	A50G	1.6	0.6	0.0	2.2	0.0	2.2
	A50H	14.7	0.0	0.0	14.7	18.2	32.9
	A50J	0.0	0.0	0.0	0.0	12.4	12.4
Lephalala Total		**38.5**	**0.7**	**0.0**	**39.2**	**30.6**	**69.8**
Mogalakwena	A61A	2.1	1.1	0.0	3.2	0.0	3.2
	A61B	0.3	0.2	0.0	0.5	0.0	0.5
	A61C	1.3	2.3	0.0	3.6	0.0	3.6
	A61D	0.2	2.2	0.0	2.4	0.0	2.4
	A61E	0.1	8.8	0.0	8.8	0.0	8.8
	A61F	0.2	1.2	0.0	1.4	0.0	1.4
	A61G	0.5	0.3	0.0	0.8	0.0	0.8
	A61H	14.9	0.7	0.0	15.7	0.0	15.7
	A61J	3.7	1.0	1.5	6.2	0.0	6.2
	A62A	2.1	0.5	0.0	2.6	0.0	2.6
	A62B	0.0	0.0	0.0	0.0	0.0	0.0

Catchment / quaternary		Average annual irrigation requirement (million m^3/a)					
		Supplied by sources fed from study area runoff				Supplied from Limpopo River	Total
		Surface water	Ground-water	Scheme	Total		
	A62C	0.0	0.0	0.0	0.0	0.0	0.0
	A62D	0.0	0.6	0.0	0.6	0.0	0.6
	A62E	0.0	0.0	0.0	0.0	0.0	0.0
	A62F	0.2	2.3	0.0	2.4	0.0	2.4
	A62G	0.0	0.0	0.0	0.0	0.0	0.0
	A62H	0.0	0.0	0.0	0.0	0.0	0.0
	A62J	0.0	0.3	0.0	0.3	0.0	0.3
	A63A	0.0	17.4	1.3	18.7	0.0	18.7
	A63B	0.0	1.5	2.7	4.2	0.0	4.2
	A63C	0.0	0.0	0.0	0.0	5.6	5.6
	A63D	0.0	2.9	2.4	5.3	0.00	5.3
	A63E	0.0	0.0	0.0	0.0	17.2	17.2
Mogalakwena Total		**25.4**	**43.2**	**7.9**	**76.6**	**22.9**	**99.4**
Sand	A71A	2.0	32.3	0.0	34.3	0.0	34.3
	A71B	0.0	6.8	0.0	6.8	0.0	6.8
	A71C	2.0	23.6	0.0	25.6	0.0	25.6
	A71D	0.2	5.4	0.0	5.7	0.0	5.7
	A71E	0.1	5.3	0.0	5.4	0.0	5.4
	A71F	0.4	6.1	0.0	6.5	0.0	6.5
	A71G	0.3	9.6	0.0	9.9	0.0	9.9
	A71H	0.3	1.0	0.0	1.3	0.0	1.3
	A71J	3.3	15.4	0.0	18.7	0.0	18.7
	A71K	0.5	3.1	0.0	3.6	0.0	3.6
	A71L	0.0	0.0	0.0	0.0	84.9	84.9
	A72A	0.5	15.0	0.0	15.5	0.0	15.5
	A72B	0.2	3.2	0.0	3.4	0.0	3.4
Sand Total		**9.9**	**126.8**	**0.0**	**136.7**	**84.9**	**221.6**
Nzhelele	A80A	0.0	0.0	0.0	0.0	0.0	0.0
	A80B	0.4	0.2	0.0	0.6	0.0	0.6
	A80C	0.0	0.0	0.0	0.0	0.0	0.0
	A80D	0.1	0.0	0.0	0.1	0.0	0.1
	A80E	0.1	0.8	0.0	0.9	0.0	0.9
	A80F	0.0	0.3	4.0	4.3	0.0	4.3
	A80G	0.2	2.5	14.7	17.4	1.3	18.7
	A80H	0.0	0.0	0.0	0.0	0.0	0.0
	A80J	0.0	0.0	0.0	0.0	4.5	4.5
Nzhelele Total		**0.8**	**3.8**	**18.7**	**23.3**	**5.8**	**29.1**
Limpopo WMA North		**106.2**	**179.7**	**32.6**	**318.5**	**146.3**	**464.8**

Note: (1) As in the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" study

(DWA, 2007).

Table C.4 Irrigation application efficiencies and return flows

Catchment/ quaternary		Application efficiency (as a %)	Return flows (as % of supply)
Matlabas	A41A	-	-
	A41B*	75	-
	A41C	-	11
	A41D	82	7
	A41E	87	14
Mokolo[1]	A42A	83	8
	A42B	83	8
	A42C	83	9
	A42D	84	8
	A42E	84	8
	A42F	85	7
	A42G	88	6
	A42H	71	14
	A42J	84	8
Lephalala	A50A	84	9
	A50B	84	9
	A50C	85	9
	A50D	90	-
	A50E	86	6
	A50F	86	6
	A50G	83	9
	A50H	87	7
	A50J	88	7
Mogalakwena	A61A	81	6
	A61B	86	6
	A61C	87	9
	A61D	83	7
	A61E	86	7
	A61F	87	7
	A61G	90	5
	A61H	84	8
	A61J	85	8
	A62A	85	8
	A62B	-	-
	A62C	-	-
	A62D	83	6
	A62E	-	-

Catchment/ quaternary		Application efficiency (as a %)	Return flows (as % of supply)
	A62F**	89	10
	A62G	75	12
Mogalakwena	A61A	-	-
	A62J	93	4
	A63A	88	6
	A63B	88	8
	A63C	87	7
	A63D	84	7
	A63E	88	7
Sand	A71A	83	8
	A71B	88	8
	A71C	87	9
	A71D	86	8
	A71E	85	12
	A71F	83	8
	A71G	85	9
	A71H	80	10
	A71J	92	5
	A71K	89	6
	A71L***	86	7
	A72A	87	10
	A72B	87	7
Nzhelele	A80A	68	-
	A80B	69	14
	A80C	66	-
	A80D	67	17
	A80E	-	11
	A80F	91	4
	A80G	89	11
	A80H	-	-
	A80J	87	-
Limpopo WMA North		**83**	**9**

Note: (1) As in the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" study (DWA, 2007).

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Table C.5 Annual average irrigation return flows per quaternary catchment at the 2010-development level

Catchment/ Quaternary		Average annual irrigation return flows (million m^3/a)			
		Surface water	Groundwater	Scheme	Total
Matlabas	A41A	-	-	-	0.0
	A41B	0.0	0.0	0.0	0.0
	A41C	-	-	-	0.0
	A41D	0.1	0.2	0.0	0.2
	A41E	0.1	0.0	0.0	0.2
Matlabas Total		**0.2**	**0.2**	**0.0**	**0.4**
Mokolo[1]	A42A	0.6	0.0	0.0	0.6
	A42B	0.4	0.0	0.0	0.5
	A42C	0.5	0.1	0.0	0.6
	A42D	0.1	0.0	0.0	0.1
	A42E	0.6	0.1	0.0	0.6
	A42F	0.3	0.1	0.0	0.4
	A42G	0.0	0.0	0.0	0.0
	A42H	0.0	0.0	0.1	0.1
	A42J	0.0	0.0	0.4	0.4
Mokolo Total		**2.5**	**0.3**	**0.5**	**3.3**
Lephalala	A50A	0.8	0.0	0.0	0.8
	A50B	0.1	0.0	0.0	0.1
	A50C	0.1	0.0	0.0	0.1
	A50D	-	-	-	0.0
	A50E	0.7	0.0	0.0	0.7
	A50F	0.0	0.0	0.0	0.0
	A50G	0.1	0.1	0.0	0.2
	A50H	1.1	1.3	0.0	2.4
	A50J	0.3	0.5	0.0	0.8
Lephalala Total		**3.3**	**1.9**	**0.0**	**5.2**
Mogalakwena	A61A	0.1	0.1	0.0	0.2
	A61B	0.0	0.0	0.0	0.0
	A61C	0.1	0.2	0.0	0.3
	A61D	0.0	0.2	0.0	0.2
	A61E	0.0	0.6	0.0	0.6
	A61F	0.0	0.1	0.0	0.1
	A61G	0.0	0.0	0.0	0.0
	A61H	1.2	0.1	0.0	1.2
	A61J	0.3	0.1	0.1	0.5
	A62A	0.2	0.0	0.0	0.2
	A62B	-	-	-	0.0
	A62C	-	-	-	0.0

Catchment/ Quaternary		Average annual irrigation return flows (million m^3/a)			
		Surface water	Groundwater	Scheme	Total
	A62D	0.0	0.0	0.0	0.0
Mogalakwena	A61A	-	-	-	0.0
	A62F	0.0	0.2	0.0	0.3
	A62G	0.0	0.0	0.0	0.0
	A62H	-	-	-	0.0
	A62J	0.0	0.0	0.0	0.0
	A63A	0.0	1.1	0.1	1.2
	A63B	0.0	0.1	0.2	0.3
	A63C	0.2	0.2	0.0	0.4
	A63D	0.0	0.2	0.2	0.4
	A63E	0.2	1.0	0.0	1.2
Mogalakwena Total		**2.4**	**4.2**	**0.6**	**7.2**
Sand	A71A	0.2	2.7	0.0	2.9
	A71B	0.0	0.6	0.0	0.6
	A71C	0.2	2.1	0.0	2.3
	A71D	0.0	0.4	0.0	0.5
	A71E	0.0	0.6	0.0	0.6
	A71F	0.0	0.5	0.0	0.5
	A71G	0.0	0.9	0.0	0.9
	A71H	0.0	0.1	0.0	0.1
	A71J	0.2	0.7	0.0	0.9
	A71K	0.0	0.2	0.0	0.2
	A71L	2.9	2.8	0.0	5.7
	A72A	0.1	1.5	0.0	1.6
	A72B	0.0	0.2	0.0	0.2
Sand Total		**3.7**	**13.4**	**0.0**	**17.1**
Nzhelele	A80A	-	-	-	0.0
	A80B	0.0	0.0	0.0	0.1
	A80C	-	-	-	0.0
	A80D	0.0	0.0	0.0	0.0
	A80E	0.0	0.1	0.0	0.1
	A80F	0.0	0.0	0.2	0.2
	A80G	0.2	0.3	1.6	2.1
	A80H	-	-	-	0.0
	A80J	0.5	0.0	0.0	0.5
Nzhelele Total		**0.7**	**0.4**	**1.8**	**2.9**
Limpopo WMA North		**12.8**	**20.3**	**2.9**	**36.0**

Note: (1) As in the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" study (DWA, 2007).

Table C.6 Information on modelled irrigation areas in the WRYM

Quaternary / Quinary		Irrigation block no.	Source of water		Supply channel No.	Return flow channel no.	Figure no.
			Description	Node no.			
Matlabas	A41A	-		-	-	-	B-1
	A41B	9	Dummy Dam	15	1	2	B-1
	A41C	-		-	-	-	B-1
	A41D	10	Dummy Dam	17	3	4	B-1
		11	Groundwater	19	5	6	B-1
	A41E	12	Groundwater	20	7	8	B-1
		13	Dummy Dam	18	8	10	B-1
Mokolo[(1)]	A42A	-	-	-	-	-	-
	A42B	-	-	-	-	-	-
	A42C	-	-	-	-	-	-
	A42D	-	-	-	-	-	-
	A42E	-	-	-	-	-	-
	A42F	-	-	-	-	-	-
	A42G	-	-	-	-	-	-
	A42H	-	-	-	-	-	-
	A42J	-	-	-	-	-	-
Lephalala	A50A	3	Dummy Dam	2	1	2	B-2
	A50B	7	Dummy Dam	6	4	5	B-2
	A50C	11	Dummy Dam	10	10	11	B-2
	A50D	-		-	-	-	B-2
	A50E	18	Dummy Dam	14	20	21	B-2
	A50F	22	Dummy Dam	20	25	26	B-2
	A50G	25	Dummy Dam	24	29	30	B-2
		28	Groundwater	27	33	34	B-2
	A50H	32	Dummy Dam	30	38	39	B-2
	A50J	36	Dummy Dam	35	61	62	B-2
		38	Groundwater	37	63	64	B-2
Mogalakwena	A61A1	24	Dummy Dam	22	21	22	B-3
	A61A2	33	Dummy Dam	32	34	35	B-3
		29	Groundwater	30	27	28	B-3
	A61A3	-		-	-	-	B-3
	A61B1	-		-	-	-	B-3
	A61B2	38	Dummy Dam	37	41	42	B-3
	A61C1	44	Dummy Dam	43	50	51	B-3
	A61C2	40	Groundwater	41	44	45	B-3
	A61D1	51	Dummy Dam	50	62	63	B-3
	A61D2	47	Groundwater	48	54	55	B-3
	A61E1	171	Dummy Dam	54	275	276	B-3
	A61E2	57	Groundwater	58	69	70	B-3
	A61F	65	Groundwater	66	81	82	B-3
		173	Dummy Dam	63	279	280	B-3

Quaternary / Quinary		Irrigation block no.	Source of water		Supply channel No.	Return flow channel no.	Figure no.
Mogalakwena	A61G	89	Dummy Dam	87	120	121	B-3
		90	Groundwater	91	122	123	B-3
	A61H	74	Dummy Dam	73	94	95	B-3
		72	Groundwater	68	91	92	B-3
		172	Groundwater	71	277	278	B-3
	A61J	77	Dummy Dam	76	98	99	B-3
		82	Dummy Dam	81	108	109	B-3
		85	Groundwater	86	113	114	B-3
		77	Dummy Dam	76	98	99	B-3
	A62A	98	Dummy Dam	92	126	127	B-4
		99	Groundwater	100	128	129	B-4
	A62B	-		-	-	-	B-4
	A62B	-		-	-	-	B-4
	A62D	106	Groundwater	107	130	131	B-4
	A62E	-		-	-	-	B-4
	A62F	115	Dummy Dam	114	149	150	B-4
		117	Groundwater	116	151	152	B-4
	A62G	120	Groundwater	121	155	156	B-4
	A62H	-		-	-	-	B-4
		-		-	-	-	B-4
	A62J	130	Groundwater	131	171	172	B-4
	A63A	134	Dummy Dam	133	176	177	B-5
	A63A	137	Groundwater	138	180	181	
	A63B	141	Dummy Dam	139	185	186	B-5
	A63B	143	Groundwater	144	189	190	B-5
	A63C	155	Dummy Dam	154	207	208	B-5
		156	Groundwater	165	204	205	B-5
	A63D	151	Groundwater	150	199	200	B-5
		147	Dummy Dam	146	194	195	B-5
	A63E	160	Dummy Dam	159	212	213	B-5
		161	Groundwater	161	215	216	B-5
Sand	A71A	26	Run-of-river	2	5	6	B-6
		27	Dummy Dam	28	7	8	B-6
		107	Groundwater	92	149	150	
	A71B	81	Groundwater	93	114	115	B-6
	A71C	36	Dummy Dam	35	22	23	B-6
		38	Run-of-river	6	26	27	B-6
		82	Groundwater	95	116	117	B-6
	A71D	41	Dummy Dam	40	30	31	B-6
		84	Groundwater	97	120	121	B-6
	A71E	32	Dummy Dam	33	18	19	B-6
		79	Groundwater	94	110	111	B-6
	A71F	44	Dummy Dam	43	36	37	B-6
		83	Groundwater	96	118	119	B-6

Quaternary / Quinary		Irrigation block no.	Source of water		Supply channel No.	Return flow channel no.	Figure no.
Sand	A71G	47	Run-of-river	105	44	45	B-6
		49	Dummy Dam	48	47	48	B-6
		85	Groundwater	98	122	123	B-6
	A71H	52	Dummy Dam	51	53	54	B-6
		54	Run-of-river	16	57	58	B-6
		86	Groundwater	99	125	126	B-6
	A71J	56	Dummy Dam	55	62	63	B-6
		58	Groundwater	23	67	68	B-6
		87	Run-of-river	100	127	128	B-6
	A71K	61	Run-of-river	75	75	76	B-6
		88	Groundwater	101	120	121	B-6
	A71L	123	Groundwater	122	174	175	B-6
		124	Dummy Dam	119	176	177	B-6
	A72A	110	Dummy Dam	108	152	153	B-6
		112	Groundwater	111	155	156	B-6
	A72B	115	Run-of-river	113	158	159	B-6
		118	Groundwater	117	164	165	B-6
Nzhelele	A80A	-		-	-	-	B-7
	A80B	11	Dummy Dam	3	6	7	B-7
		12	Groundwater	13	8	9	B-7
	A80C	-		-	-	-	B-7
	A80D	15	Run-of-river	14	15	16	B-7
	A80E	26	Run-of-river	25	39	40	B-7
		27	Groundwater	28	42	43	B-7
	A80F	18	Run-of-river	17	21	22	B-7
		19	Groundwater	20	23	24	B-7
	A80G	23	Run-of-river	21	32	33	B-7
		24	Dummy Dam	8	35	36	B-7
		31	Groundwater	32	51	52	B-7
	A80H1	-		-	-	-	B-7
	A80H2	-		-	-	-	B-7
	A80J	38	Run-of-river	35	60	61	B-7

Note: *(1) As in the “Updating the Hydrology and Yield Analysis in the Mokolo River Catchment” study (DWA, 2007).*

Table C.7 Summary of livestock water requirements per quaternary catchment

Catchment		Water requirement	Water requirement (m^3/s)												
Name	Quaternary	(million m^3/a)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Avg
Matlabas	A41A	0.30	0.011	0.012	0.011	0.011	0.012	0.011	0.008	0.007	0.008	0.007	0.007	0.008	0.009
	A41B	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A41C	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A41D	1.45	0.060	0.062	0.060	0.060	0.066	0.060	0.031	0.030	0.031	0.030	0.030	0.031	0.046
	A41E	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
Matlabas		**2.3**													
Mokolo	A42A	0.24	0.004	0.004	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.008
	A42B	0.24	0.004	0.004	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.008
	A42C	0.30	0.007	0.008	0.011	0.012	0.011	0.011	0.012	0.011	0.008	0.007	0.008	0.007	0.009
	A42D	0.18	0.004	0.004	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.006
	A42E	0.42	0.007	0.008	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.013
	A42F	0.18	0.004	0.004	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.006
	A42G	0.18	0.004	0.004	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.006
	A42H	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A42J	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Mokolo		**2.0**													
Lephalala	A50A	0.54	0.022	0.023	0.022	0.022	0.025	0.022	0.012	0.011	0.012	0.011	0.011	0.012	0.017
	A50B	0.42	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.007	0.008	0.013
	A50C	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A50D	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A50E	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
	A50F	0.06	0.004	0.004	0.004	0.004	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.002
	A50G	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A50H	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A50J	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006

Catchment		Water requirement	Water requirement (m^3/s)												
Name	Quaternary	(million m³/a)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Avg
Lephalala		**2.5**													
Mogalakwena	A61A	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A61B	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A61C	0.60	0.026	0.027	0.026	0.026	0.029	0.026	0.012	0.011	0.012	0.011	0.011	0.012	0.019
	A61D	0.60	0.026	0.027	0.026	0.026	0.029	0.026	0.012	0.011	0.012	0.011	0.011	0.012	0.019
	A61E	0.72	0.030	0.031	0.030	0.030	0.033	0.030	0.015	0.015	0.015	0.015	0.015	0.015	0.023
	A61F	0.78	0.034	0.035	0.034	0.034	0.037	0.034	0.015	0.015	0.015	0.015	0.015	0.015	0.025
	A61G	0.78	0.034	0.035	0.034	0.034	0.037	0.034	0.015	0.015	0.015	0.015	0.015	0.015	0.025
	A61H	0.66	0.026	0.027	0.026	0.026	0.029	0.026	0.015	0.015	0.015	0.015	0.015	0.015	0.021
	A61J	1.08	0.045	0.046	0.045	0.045	0.049	0.045	0.023	0.022	0.023	0.022	0.022	0.023	0.034
	A62A	0.60	0.026	0.027	0.026	0.026	0.029	0.026	0.012	0.011	0.012	0.011	0.011	0.012	0.019
	A62B	0.78	0.034	0.035	0.034	0.034	0.037	0.034	0.015	0.015	0.015	0.015	0.015	0.015	0.025
	A62C	0.42	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.007	0.008	0.013
	A62D	0.72	0.030	0.031	0.030	0.030	0.033	0.030	0.015	0.015	0.015	0.015	0.015	0.015	0.023
	A62E	0.48	0.019	0.019	0.019	0.019	0.020	0.019	0.012	0.011	0.012	0.011	0.011	0.012	0.015
	A62F	0.42	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.007	0.008	0.013
	A62G	0.54	0.022	0.023	0.022	0.022	0.025	0.022	0.012	0.011	0.012	0.011	0.011	0.012	0.017
	A62H	0.66	0.026	0.027	0.026	0.026	0.029	0.026	0.015	0.015	0.015	0.015	0.015	0.015	0.021
	A62J	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A63A	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A63B	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A63C	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A63D	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A63E	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
Mogalakwena		**11.5**													

Catchment		Water requirement	Water requirement (m^3/s)												
Name	Quaternary	(million m³/a)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Avg
Sand	A71A	0.90	0.037	0.039	0.037	0.037	0.041	0.037	0.019	0.019	0.019	0.019	0.019	0.019	0.029
	A71B	0.90	0.037	0.039	0.037	0.037	0.041	0.037	0.019	0.019	0.019	0.019	0.019	0.019	0.029
	A71C	0.42	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.007	0.008	0.013
	A71D	0.42	0.019	0.019	0.019	0.019	0.020	0.019	0.008	0.007	0.008	0.007	0.007	0.008	0.013
	A71E	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
	A71F	0.30	0.011	0.012	0.011	0.011	0.012	0.011	0.008	0.007	0.008	0.007	0.007	0.008	0.009
	A71G	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A71H	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
	A71J	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
	A71K	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A71L	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A72A	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
	A72B	0.36	0.015	0.015	0.015	0.015	0.016	0.015	0.008	0.007	0.008	0.007	0.007	0.008	0.011
Sand		**5.2**													
Nzhelele	A80A	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A80B	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A80C	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A80D	0.06	0.004	0.004	0.004	0.004	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.002
	A80E	0.13	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	A80F	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
	A80G	0.24	0.011	0.012	0.011	0.011	0.012	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.008
	A80H	0.60	0.026	0.027	0.026	0.026	0.029	0.026	0.012	0.011	0.012	0.011	0.011	0.012	0.019
	A80J	0.18	0.007	0.008	0.007	0.007	0.008	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.006
Nzhelele		**1.8**													
Total		**25.3**													

Table C.8 Streamflow reduction due to invasive alien plants and forestry per quaternary / sub quaternary

Quaternary	Invasive alien plants	Forestry
A50A	0.8	-
A50B	0.1	-
A50C	0.3	-
Lephalala	**1.2**	**0.0**
A61A_1	0.1	-
A61A_2	0.0	-
A61B_1	0.0	-
A61B_2	0.2	-
A61C_1	0.0	-
A61C_2	0.0	-
A61D_1	0.1	-
A61F	0.7	-
A61G	0.1	-
A61H	1.1	-
A61J	0.2	-
A62A	0.1	-
Mogalakwena	**2.6**	**-**
A71A	0.3	-
A71B	0.1	-
A71C	0.3	0.1
A71D	0.0	-
A71E	0.1	-
A71F	0.0	-
A71G	0.1	-
A71H	0.1	0.1
Sand	**1.0**	**0.2**
A80A	-	1.9
A80B	0.3	0.1
A80C	0.1	-
A80E	0.6	-
A80G	0.1	-
A80H_1	0.8	-
A80H_2	0.4	-
Nzhelele	**2.1**	**2.0**
Total	**6.9**	**2.2**

Note: Data only provided for quaternaries and sub-quaternaries where SFRAs had a significant effect.

Table C.9 Rule Curve for Donkerpoort Dam

Desktop Ver. 2 Data are given in million m^3 per month **Donkerpoort** **Dam**
Summary of IFR Rule curves for: A61A1
Determination based on specific parameters from SPATSIM database
Regional Type: Lowveld ERC = C/D

Total ecological Reserve (Low and high flow)

Month	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	0.990
Oct	0.076	0.073	0.068	0.058	0.048	0.038	0.033	0.030	0.029	0.029
Nov	0.114	0.110	0.101	0.087	0.069	0.052	0.041	0.036	0.034	0.034
Dec	0.239	0.199	0.162	0.126	0.080	0.059	0.047	0.042	0.041	0.041
Jan	0.163	0.145	0.125	0.103	0.073	0.056	0.045	0.040	0.040	0.040
Feb	0.543	0.434	0.339	0.250	0.140	0.097	0.071	0.061	0.059	0.059
Mar	0.188	0.181	0.166	0.140	0.108	0.079	0.059	0.050	0.047	0.047
Apr	0.141	0.135	0.123	0.103	0.081	0.062	0.049	0.043	0.041	0.041
May	0.088	0.085	0.078	0.067	0.055	0.045	0.039	0.037	0.036	0.036
Jun	0.086	0.083	0.077	0.067	0.055	0.046	0.039	0.036	0.034	0.034
Jul	0.083	0.080	0.073	0.063	0.052	0.043	0.037	0.034	0.033	0.033
Aug	0.079	0.076	0.070	0.061	0.051	0.042	0.036	0.033	0.032	0.031
Sep	0.071	0.068	0.062	0.054	0.044	0.036	0.032	0.030	0.029	0.029

Reserve flows without high flows

Oct	0.070	0.067	0.062	0.054	0.045	0.037	0.032	0.029	0.028	0.028
Nov	0.077	0.074	0.069	0.061	0.051	0.042	0.035	0.032	0.031	0.031
Dec	0.083	0.080	0.074	0.064	0.053	0.043	0.037	0.035	0.034	0.034
Jan	0.089	0.086	0.081	0.071	0.059	0.047	0.040	0.037	0.037	0.037
Feb	0.098	0.094	0.087	0.076	0.062	0.051	0.044	0.041	0.040	0.040
Mar	0.098	0.095	0.088	0.078	0.065	0.053	0.045	0.041	0.040	0.040
Apr	0.093	0.089	0.083	0.072	0.059	0.049	0.042	0.039	0.037	0.037
May	0.088	0.085	0.078	0.067	0.055	0.045	0.039	0.037	0.036	0.036
Jun	0.086	0.083	0.077	0.067	0.055	0.046	0.039	0.036	0.034	0.034
Jul	0.083	0.080	0.073	0.063	0.052	0.043	0.037	0.034	0.033	0.033
Aug	0.079	0.076	0.070	0.061	0.051	0.042	0.036	0.033	0.032	0.031
Sep	0.071	0.068	0.062	0.054	0.044	0.036	0.032	0.030	0.029	0.029

Natural Flow Duration curves

Oct	0.265	0.229	0.177	0.161	0.146	0.130	0.114	0.104	0.094	0.078
Nov	0.572	0.421	0.328	0.270	0.224	0.187	0.156	0.125	0.104	0.073
Dec	1.513	0.702	0.515	0.421	0.374	0.307	0.260	0.208	0.135	0.114
Jan	1.290	0.920	0.764	0.634	0.484	0.385	0.333	0.281	0.229	0.120
Feb	1.695	1.082	0.822	0.645	0.530	0.468	0.406	0.317	0.218	0.161
Mar	1.472	0.910	0.764	0.655	0.520	0.468	0.426	0.317	0.239	0.146
Apr	0.936	0.759	0.629	0.556	0.484	0.421	0.385	0.276	0.234	0.140
May	0.707	0.588	0.499	0.452	0.369	0.338	0.296	0.229	0.192	0.125
Jun	0.541	0.463	0.380	0.333	0.291	0.270	0.239	0.192	0.156	0.120
Jul	0.437	0.369	0.307	0.276	0.244	0.224	0.203	0.166	0.140	0.109
Aug	0.338	0.286	0.244	0.218	0.198	0.172	0.166	0.135	0.120	0.094
Sep	0.265	0.208	0.182	0.166	0.151	0.140	0.130	0.114	0.094	0.083

Table C.10 Rule Curve for Doorndraai Dam

Desktop Ver.2 Data are given in million m^3 per month **Doorndraai Dam**
Summary of IFR Rule curves for: A61H
Determination based on specific parameters from SPATSIM database
Regional Type: Foothill ERC= C/D

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.543	0.539	0.530	0.513	0.483	0.436	0.375	0.308	0.253	0.231
Nov	1.109	1.093	1.058	0.992	0.884	0.737	0.572	0.429	0.339	0.313
Dec	1.368	1.346	1.299	1.213	1.075	0.888	0.680	0.500	0.388	0.355
Jan	3.451	2.864	2.372	1.928	1.295	1.012	0.749	0.564	0.469	0.448
Feb	1.107	1.027	0.950	0.865	0.731	0.630	0.518	0.421	0.360	0.343
Mar	1.396	1.245	1.113	0.984	0.779	0.660	0.527	0.410	0.338	0.317
Apr	0.701	0.695	0.683	0.658	0.616	0.551	0.463	0.369	0.292	0.261
May	0.524	0.521	0.513	0.498	0.471	0.429	0.371	0.307	0.254	0.233
Jun	0.507	0.504	0.497	0.483	0.457	0.416	0.360	0.298	0.247	0.226
Jul	0.530	0.527	0.523	0.513	0.496	0.465	0.416	0.348	0.272	0.225
Aug	0.502	0.499	0.492	0.478	0.453	0.413	0.357	0.295	0.244	0.224
Sep	0.498	0.495	0.488	0.474	0.448	0.408	0.353	0.292	0.243	0.222

Reserve flows without high flows

Oct	0.513	0.509	0.501	0.485	0.458	0.416	0.359	0.298	0.249	0.229
Nov	0.588	0.581	0.567	0.541	0.498	0.439	0.373	0.315	0.279	0.268
Dec	0.645	0.637	0.621	0.591	0.543	0.478	0.406	0.343	0.304	0.293
Jan	0.699	0.687	0.661	0.617	0.552	0.477	0.406	0.356	0.331	0.325
Feb	0.717	0.709	0.691	0.657	0.604	0.531	0.450	0.380	0.337	0.324
Mar	0.615	0.608	0.594	0.566	0.521	0.459	0.389	0.329	0.291	0.280
Apr	0.563	0.558	0.549	0.532	0.502	0.455	0.393	0.326	0.272	0.249
May	0.524	0.521	0.513	0.498	0.471	0.429	0.371	0.307	0.254	0.233
Jun	0.507	0.504	0.497	0.483	0.457	0.416	0.360	0.298	0.247	0.226
Jul	0.530	0.527	0.523	0.513	0.496	0.465	0.416	0.348	0.272	0.225
Aug	0.502	0.499	0.492	0.478	0.453	0.413	0.357	0.295	0.244	0.224
Sep	0.498	0.495	0.488	0.474	0.448	0.408	0.353	0.292	0.243	0.222

Natural Flow Duration curves

Oct	1.170	1.120	1.080	1.070	1.050	1.040	1.030	1.020	1.000	0.940
Nov	17.440	4.960	1.770	1.240	1.110	1.090	1.070	1.050	1.030	0.980
Dec	23.180	10.620	5.900	2.160	1.410	1.140	1.110	1.090	1.060	0.890
Jan	23.260	13.170	9.450	4.480	1.780	1.320	1.120	1.080	1.060	0.760
Feb	22.360	14.100	6.510	3.020	1.350	1.150	1.090	1.070	1.050	0.760
Mar	10.230	6.290	2.170	1.390	1.210	1.160	1.100	1.090	1.060	1.010
Apr	3.390	1.670	1.440	1.200	1.140	1.130	1.110	1.070	1.050	0.990
May	1.710	1.170	1.120	1.100	1.080	1.070	1.060	1.060	1.040	0.770
Jun	1.180	1.100	1.090	1.080	1.070	1.060	1.060	1.050	1.030	0.800
Jul	1.120	1.090	1.080	1.070	1.070	1.060	1.050	1.050	1.030	0.800
Aug	1.100	1.070	1.060	1.060	1.060	1.050	1.040	1.040	1.020	0.890
Sep	1.110	1.060	1.050	1.040	1.040	1.030	1.030	1.020	1.010	0.830

Table C.11 Rule Curve for Glen Alpine Dam

Desktop Ver. 2 Data are given in million m^3 per month **Glen Alpine Dam**

Summary of IFR Rule curves for: A62J

Determination based on specific parameters from SPATSIM database

Regional Type: Lowveld ERC= C

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	2.387	2.291	2.086	1.765	1.392	1.070	0.866	0.769	0.736	0.736
Nov	4.892	4.696	4.273	3.577	2.709	1.905	1.363	1.105	1.035	1.035
Dec	10.250	8.396	6.698	5.019	2.952	2.027	1.474	1.251	1.223	1.223
Jan	6.870	6.006	5.110	4.087	2.726	1.922	1.410	1.209	1.209	1.209
Feb	28.757	22.754	17.532	12.660	6.630	4.299	2.903	2.342	2.270	2.270
Mar	7.310	7.007	6.356	5.281	3.943	2.703	1.867	1.470	1.362	1.362
Apr	4.864	4.643	4.176	3.441	2.587	1.853	1.385	1.164	1.088	1.088
May	2.853	2.722	2.450	2.041	1.594	1.233	1.013	0.910	0.872	0.868
Jun	2.757	2.642	2.403	2.037	1.617	1.255	1.015	0.891	0.840	0.826
Jul	2.689	2.563	2.306	1.928	1.519	1.184	0.972	0.864	0.818	0.803
Aug	2.539	2.434	2.215	1.879	1.496	1.165	0.945	0.831	0.784	0.772
Sep	2.327	2.222	2.003	1.675	1.317	1.027	0.851	0.768	0.737	0.734

Reserve flows without high flows

Oct	2.274	2.184	1.992	1.691	1.341	1.040	0.848	0.758	0.726	0.726
Nov	2.732	2.636	2.430	2.090	1.667	1.275	1.011	0.885	0.851	0.851
Dec	2.886	2.773	2.529	2.132	1.662	1.261	1.020	0.924	0.911	0.911
Jan	3.380	3.266	3.015	2.584	2.029	1.512	1.183	1.053	1.053	1.053
Feb	4.063	3.901	3.549	2.980	2.304	1.727	1.382	1.243	1.225	1.225
Mar	3.425	3.303	3.041	2.609	2.070	1.571	1.235	1.075	1.032	1.032
Apr	3.097	2.971	2.704	2.284	1.795	1.375	1.108	0.982	0.938	0.938
May	2.853	2.722	2.450	2.041	1.594	1.233	1.013	0.910	0.872	0.868
Jun	2.757	2.642	2.403	2.037	1.617	1.255	1.015	0.891	0.840	0.826
Jul	2.689	2.563	2.306	1.928	1.519	1.184	0.972	0.864	0.818	0.803
Aug	2.539	2.434	2.215	1.879	1.496	1.165	0.945	0.831	0.784	0.772
Sep	2.327	2.222	2.003	1.675	1.317	1.027	0.851	0.768	0.737	0.734

Natural Flow Duration curves

Oct	6.040	5.170	4.520	4.140	3.500	2.770	2.360	1.960	1.780	1.620
Nov	38.050	14.240	7.930	5.900	5.110	4.140	3.650	2.850	2.330	1.600
Dec	57.380	28.180	18.970	11.790	8.390	6.880	5.510	4.390	2.980	2.020
Jan	73.990	44.370	29.160	24.220	12.200	8.780	7.130	4.940	3.920	2.360
Feb	144.710	49.460	30.700	18.770	12.370	10.390	6.590	4.920	3.920	2.480
Mar	104.360	38.680	23.540	15.430	11.300	9.650	6.320	4.550	3.820	2.830
Apr	34.010	22.570	17.890	13.910	9.260	7.580	5.880	4.170	3.420	2.450
May	19.290	15.290	11.440	9.380	7.050	5.820	4.540	3.580	2.940	2.170
Jun	13.370	9.960	8.480	7.320	5.680	4.670	3.750	2.890	2.490	1.880
Jul	9.750	7.760	7.060	6.290	5.340	4.020	3.400	2.580	2.240	1.770
Aug	7.800	6.670	5.640	5.210	4.280	3.490	2.750	2.300	2.050	1.680
Sep	6.380	5.610	4.890	4.380	3.450	2.650	2.290	1.980	1.820	1.540

Table C.12 Rule Curve for Houtrivier Dam

Desktop Ver. 2 Data are given in million m^3 per month **Houtrivier Dam**

Summary of IFR Rule curves for: A71E

Determination based on specific parameters from SPATSIM database

Regional Type: Lowveld ERC= D

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.009	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.004	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Reserve flows without high flows

Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Natural Flow Duration curves

Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.075	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.250	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C.13 Rule Curve for Luphephe Dam

Desktop Ver. 2 Data are given in million m^3 per month **Luphephe Dam**

Summary of IFR Rule curves for: A80H1

Determination based on specific parameters from SPATSIM database

Regional Type: E.Escarp ERC= B

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.408	0.407	0.403	0.396	0.382	0.355	0.311	0.246	0.167	0.108
Nov	0.497	0.495	0.490	0.480	0.461	0.427	0.370	0.289	0.193	0.121
Dec	0.718	0.715	0.707	0.692	0.662	0.610	0.525	0.404	0.260	0.154
Jan	1.183	1.102	1.028	0.957	0.877	0.744	0.627	0.462	0.271	0.129
Feb	2.987	2.687	2.427	2.194	1.710	1.340	1.020	0.800	0.530	0.200
Mar	1.270	1.191	1.119	1.048	0.970	0.835	0.713	0.537	0.327	0.160
Apr	0.750	0.748	0.741	0.726	0.696	0.641	0.550	0.415	0.252	0.100
May	0.521	0.520	0.515	0.505	0.486	0.448	0.385	0.289	0.171	0.082
Jun	0.450	0.450	0.446	0.438	0.422	0.391	0.338	0.257	0.156	0.080
Jul	0.417	0.417	0.414	0.407	0.393	0.366	0.319	0.244	0.151	0.079
Aug	0.392	0.392	0.389	0.381	0.367	0.339	0.291	0.218	0.128	0.059
Sep	0.362	0.361	0.358	0.351	0.336	0.309	0.262	0.191	0.104	0.039

Reserve flows without high flows

Oct	0.365	0.364	0.361	0.354	0.342	0.319	0.280	0.223	0.155	0.103
Nov	0.385	0.384	0.381	0.373	0.359	0.334	0.292	0.232	0.161	0.108
Dec	0.454	0.452	0.447	0.438	0.421	0.391	0.341	0.270	0.186	0.124
Jan	0.602	0.598	0.590	0.575	0.547	0.499	0.422	0.313	0.186	0.093
Feb	0.748	0.744	0.736	0.718	0.685	0.627	0.532	0.396	0.235	0.116
Mar	0.689	0.687	0.679	0.665	0.637	0.586	0.503	0.383	0.241	0.134
Apr	0.601	0.600	0.594	0.582	0.558	0.515	0.443	0.337	0.209	0.100
May	0.521	0.520	0.515	0.505	0.486	0.448	0.385	0.289	0.171	0.082
Jun	0.450	0.450	0.446	0.438	0.422	0.391	0.338	0.257	0.156	0.080
Jul	0.417	0.417	0.414	0.407	0.393	0.366	0.319	0.244	0.151	0.079
Aug	0.392	0.392	0.389	0.381	0.367	0.339	0.291	0.218	0.128	0.059
Sep	0.362	0.361	0.358	0.351	0.336	0.309	0.262	0.191	0.104	0.039

Natural Flow Duration curves

Oct	1.100	0.870	0.770	0.680	0.610	0.580	0.500	0.430	0.340	0.110
Nov	2.520	1.430	1.100	0.890	0.740	0.640	0.570	0.500	0.350	0.220
Dec	2.750	1.950	1.570	1.270	1.090	0.980	0.820	0.620	0.400	0.190
Jan	9.000	4.680	2.670	1.890	1.460	1.140	0.990	0.780	0.520	0.190
Feb	13.080	6.870	5.080	2.530	1.710	1.340	1.020	0.800	0.530	0.200
Mar	8.040	4.270	3.410	2.290	1.610	1.280	1.090	0.870	0.560	0.160
Apr	3.790	2.440	1.810	1.470	1.270	1.120	0.990	0.760	0.550	0.100
May	1.960	1.440	1.260	1.130	1.020	0.900	0.820	0.620	0.490	0.100
Jun	1.140	1.040	0.960	0.910	0.850	0.760	0.720	0.590	0.420	0.100
Jul	0.980	0.900	0.850	0.820	0.780	0.730	0.660	0.540	0.400	0.080
Aug	0.880	0.810	0.790	0.760	0.730	0.670	0.600	0.470	0.430	0.070
Sep	0.850	0.750	0.720	0.680	0.660	0.620	0.540	0.450	0.340	0.060

Table C.14 Rule Curve for Mutshedzi Dam

Desktop Ver. 2 Data are given in million m^3 per month **Mutshedzi Dam**
Summary of IFR Rule curves for: A80A
Determination based on specific parameters from SPATSIM database
Regional Type: E.Foothill ERC= D

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.057	0.056	0.054	0.051	0.046	0.037	0.026	0.013	0.000	0.000
Nov	0.060	0.059	0.056	0.051	0.044	0.033	0.016	0.003	0.000	0.000
Dec	0.117	0.115	0.110	0.100	0.085	0.064	0.041	0.021	0.009	0.000
Jan	0.546	0.451	0.369	0.293	0.186	0.134	0.085	0.051	0.034	0.030
Feb	1.818	1.513	1.259	1.034	0.680	0.537	0.378	0.240	0.155	0.109
Mar	0.611	0.533	0.466	0.404	0.307	0.261	0.210	0.165	0.137	0.129
Apr	0.433	0.429	0.420	0.403	0.372	0.325	0.263	0.195	0.140	0.118
May	0.162	0.161	0.159	0.155	0.149	0.138	0.123	0.107	0.093	0.088
Jun	0.145	0.144	0.141	0.134	0.123	0.105	0.080	0.052	0.029	0.020
Jul	0.130	0.129	0.128	0.124	0.117	0.104	0.084	0.057	0.026	0.007
Aug	0.093	0.092	0.090	0.085	0.077	0.063	0.045	0.024	0.007	0.001
Sep	0.070	0.069	0.068	0.064	0.057	0.047	0.033	0.018	0.006	0.000

Reserve flows without high flows

Oct	0.052	0.051	0.050	0.047	0.042	0.034	0.024	0.013	0.000	0.000
Nov	0.045	0.044	0.042	0.039	0.033	0.024	0.015	0.003	0.000	0.000
Dec	0.055	0.054	0.051	0.047	0.039	0.029	0.018	0.008	0.002	0.000
Jan	0.101	0.098	0.092	0.081	0.066	0.047	0.030	0.018	0.012	0.010
Feb	0.182	0.179	0.173	0.162	0.144	0.120	0.094	0.071	0.056	0.052
Mar	0.191	0.190	0.186	0.179	0.168	0.153	0.136	0.121	0.112	0.109
Apr	0.181	0.180	0.178	0.173	0.165	0.153	0.136	0.119	0.104	0.098
May	0.162	0.161	0.159	0.155	0.149	0.138	0.123	0.107	0.093	0.088
Jun	0.145	0.144	0.141	0.134	0.123	0.105	0.080	0.052	0.029	0.020
Jul	0.130	0.129	0.128	0.124	0.117	0.104	0.084	0.057	0.026	0.007
Aug	0.093	0.092	0.090	0.085	0.077	0.063	0.045	0.024	0.007	0.001
Sep	0.070	0.069	0.068	0.064	0.057	0.047	0.033	0.018	0.006	0.000

Natural Flow Duration curves

Oct	0.262	0.192	0.138	0.090	0.067	0.038	0.029	0.013	0.000	0.000
Nov	0.390	0.262	0.186	0.141	0.067	0.038	0.016	0.003	0.000	0.000
Dec	1.155	0.717	0.496	0.378	0.298	0.224	0.131	0.067	0.038	0.000
Jan	5.469	2.522	1.402	0.909	0.675	0.570	0.432	0.266	0.166	0.054
Feb	13.030	5.546	3.008	2.544	1.328	0.989	0.714	0.435	0.282	0.109
Mar	7.130	5.120	4.250	2.627	1.632	1.267	1.002	0.707	0.339	0.208
Apr	4.755	4.240	2.410	1.869	1.491	1.242	1.056	0.666	0.435	0.211
May	1.933	1.619	1.459	1.309	1.232	1.123	0.870	0.525	0.362	0.154
Jun	1.286	1.174	1.046	0.966	0.870	0.736	0.547	0.346	0.237	0.080
Jul	0.874	0.774	0.685	0.624	0.534	0.448	0.317	0.230	0.109	0.029
Aug	0.586	0.464	0.419	0.368	0.317	0.275	0.198	0.112	0.038	0.019
Sep	0.371	0.298	0.250	0.205	0.173	0.131	0.096	0.051	0.022	0.000

Table C.15 Rule Curve for Nwanedi Dam

Desktop Ver. 2 Data are given in million m3 per month **Nwanedi Dam**

Summary of IFR Rule curves for: A80H2

Determination based on specific parameters from SPATSIM database

Regional Type: E.Escarp ERC= A

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.223	0.222	0.219	0.214	0.204	0.185	0.150	0.070	0.010	0.000
Nov	0.232	0.231	0.228	0.222	0.211	0.190	0.157	0.060	0.010	0.000
Dec	0.373	0.371	0.366	0.357	0.338	0.300	0.253	0.150	0.050	0.000
Jan	0.707	0.655	0.609	0.490	0.400	0.340	0.290	0.230	0.090	0.000
Feb	2.071	1.856	1.400	0.620	0.520	0.360	0.320	0.240	0.090	0.000
Mar	0.776	0.725	0.679	0.620	0.560	0.440	0.320	0.260	0.100	0.000
Apr	0.409	0.408	0.403	0.393	0.375	0.340	0.282	0.197	0.090	0.000
May	0.302	0.302	0.299	0.292	0.279	0.254	0.211	0.147	0.068	0.000
Jun	0.270	0.270	0.267	0.261	0.250	0.228	0.190	0.132	0.061	0.000
Jul	0.245	0.245	0.243	0.238	0.229	0.210	0.176	0.123	0.057	0.000
Aug	0.231	0.230	0.228	0.223	0.213	0.195	0.162	0.100	0.052	0.000
Sep	0.216	0.215	0.213	0.208	0.199	0.181	0.150	0.080	0.030	0.000

Reserve flows without high flows

Oct	0.206	0.205	0.203	0.198	0.188	0.171	0.141	0.070	0.010	0.000
Nov	0.200	0.199	0.196	0.191	0.181	0.164	0.134	0.060	0.010	0.000
Dec	0.237	0.236	0.233	0.226	0.214	0.193	0.158	0.108	0.050	0.000
Jan	0.336	0.334	0.329	0.319	0.301	0.270	0.220	0.150	0.068	0.000
Feb	0.467	0.464	0.458	0.446	0.422	0.360	0.311	0.213	0.090	0.000
Mar	0.405	0.403	0.398	0.388	0.367	0.332	0.273	0.187	0.086	0.000
Apr	0.330	0.329	0.326	0.318	0.302	0.274	0.226	0.156	0.072	0.000
May	0.302	0.302	0.299	0.292	0.279	0.254	0.211	0.147	0.068	0.000
Jun	0.270	0.270	0.267	0.261	0.250	0.228	0.190	0.132	0.061	0.000
Jul	0.245	0.245	0.243	0.238	0.229	0.210	0.176	0.123	0.057	0.000
Aug	0.231	0.230	0.228	0.223	0.213	0.195	0.162	0.100	0.052	0.000
Sep	0.216	0.215	0.213	0.208	0.199	0.181	0.150	0.080	0.030	0.000

Natural Flow Duration curves

Oct	0.470	0.430	0.410	0.380	0.340	0.310	0.150	0.070	0.010	0.000
Nov	0.700	0.460	0.430	0.370	0.330	0.260	0.180	0.060	0.010	0.000
Dec	1.040	0.530	0.470	0.410	0.380	0.300	0.260	0.150	0.050	0.000
Jan	3.980	1.530	0.740	0.490	0.400	0.340	0.290	0.230	0.090	0.000
Feb	6.000	3.020	1.400	0.620	0.520	0.360	0.320	0.240	0.090	0.000
Mar	3.520	1.490	0.880	0.620	0.560	0.440	0.320	0.260	0.100	0.000
Apr	1.470	0.710	0.640	0.580	0.520	0.450	0.340	0.270	0.090	0.000
May	1.040	0.600	0.560	0.520	0.470	0.420	0.340	0.230	0.100	0.000
Jun	0.640	0.540	0.520	0.490	0.450	0.400	0.320	0.170	0.110	0.000
Jul	0.530	0.510	0.490	0.470	0.430	0.380	0.310	0.130	0.080	0.000
Aug	0.490	0.470	0.460	0.440	0.400	0.350	0.290	0.100	0.060	0.000
Sep	0.460	0.440	0.430	0.400	0.370	0.310	0.210	0.080	0.030	0.000

Table C.16 Rule Curve for Houtrivier Dam

Desktop Ver. 2 Data are given in million m^3 per month **Nzhelele Dam**

Summary of IFR Rule curves for: A80C

Determination based on specific parameters from SPATSIM database

Regional Type: E.Foothill ERC= C/D

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.559	0.551	0.536	0.505	0.452	0.369	0.260	0.141	0.044	0.000
Nov	0.557	0.546	0.522	0.476	0.402	0.301	0.187	0.088	0.026	0.000
Dec	0.789	0.773	0.739	0.677	0.576	0.441	0.290	0.160	0.079	0.055
Jan	2.876	2.403	1.994	1.604	1.049	0.759	0.490	0.299	0.203	0.180
Feb	9.068	7.570	6.317	5.197	3.436	2.697	1.876	1.166	0.725	0.410
Mar	3.132	2.744	2.408	2.091	1.587	1.322	1.024	0.765	0.604	0.556
Apr	2.187	2.164	2.117	2.026	1.866	1.619	1.290	0.933	0.644	0.527
May	0.981	0.974	0.959	0.929	0.875	0.790	0.675	0.548	0.444	0.402
Jun	0.927	0.917	0.897	0.855	0.780	0.659	0.493	0.308	0.156	0.095
Jul	0.889	0.882	0.869	0.842	0.792	0.705	0.567	0.375	0.160	0.025
Aug	0.733	0.725	0.707	0.670	0.604	0.498	0.353	0.191	0.058	0.005
Sep	0.620	0.613	0.597	0.565	0.508	0.418	0.295	0.159	0.049	0.004

Reserve flows without high flows

Oct	0.537	0.530	0.515	0.485	0.434	0.355	0.249	0.134	0.041	0.000
Nov	0.497	0.487	0.465	0.424	0.357	0.266	0.164	0.075	0.019	0.000
Dec	0.533	0.522	0.499	0.456	0.388	0.296	0.193	0.105	0.049	0.033
Jan	0.711	0.691	0.648	0.574	0.465	0.338	0.220	0.136	0.094	0.084
Feb	1.049	1.031	0.993	0.922	0.808	0.654	0.483	0.335	0.243	0.215
Mar	1.089	1.076	1.049	0.997	0.912	0.795	0.665	0.551	0.481	0.460
Apr	1.053	1.045	1.027	0.993	0.933	0.840	0.717	0.583	0.475	0.431
May	0.981	0.974	0.959	0.929	0.875	0.790	0.675	0.548	0.444	0.402
Jun	0.927	0.917	0.897	0.855	0.780	0.659	0.493	0.308	0.156	0.095
Jul	0.889	0.882	0.869	0.842	0.792	0.705	0.567	0.375	0.160	0.025
Aug	0.733	0.725	0.707	0.670	0.604	0.498	0.353	0.191	0.058	0.005
Sep	0.620	0.613	0.597	0.565	0.508	0.418	0.295	0.159	0.049	0.004

Natural Flow Duration curves

Oct	2.210	1.890	1.660	1.420	0.980	0.750	0.560	0.220	0.140	0.000
Nov	2.980	2.100	1.730	1.450	0.900	0.630	0.490	0.220	0.090	0.000
Dec	5.830	4.050	2.970	2.260	1.660	1.450	1.050	0.690	0.250	0.080
Jan	20.990	10.780	6.670	4.270	3.370	2.680	2.140	1.610	0.900	0.220
Feb	48.100	22.250	12.410	10.700	6.020	4.350	3.290	2.220	1.330	0.410
Mar	33.810	22.560	17.770	12.320	7.280	5.540	4.570	3.120	1.730	0.860
Apr	22.590	17.310	11.160	8.810	7.240	5.640	4.410	3.100	1.840	0.850
May	11.040	8.660	7.700	6.580	5.670	4.890	4.210	2.410	1.600	0.610
Jun	7.320	6.290	5.680	4.950	4.220	3.710	2.840	1.850	1.120	0.290
Jul	5.240	4.570	4.080	3.640	3.010	2.490	1.870	1.210	0.640	0.100
Aug	3.770	3.300	2.840	2.530	2.040	1.740	1.280	0.870	0.390	0.080
Sep	2.690	2.450	2.080	1.730	1.400	1.170	0.930	0.540	0.230	0.020

Table C.17 Rule Curve for Houtrivier Dam

Desktop Ver. 2 Data are given in million m^3 per month **Turfloop Dam**

Summary of IFR Rule curves for: A71B

Determination based on specific parameters from SPATSIM database

Regional Type: Lowveld ERC= D

Total ecological Reserve (Low and high flow)

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.022	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.010	0.008	0.006	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.097	0.055	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.019	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Reserve flows without high flows

Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Natural Flow Duration curves

Oct	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.036	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dec	0.080	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jan	0.193	0.081	0.026	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Feb	0.121	0.055	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar	0.045	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jun	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix D

Impoundments

Table D.1 Modelled dummy dam information

Dam name	Quaternary	WRYM no	FSC (million m^3)	DSV (million m^3)	FSA (km^2)
A41A_DD	A41A	14	1.3	0.0	1.2
A41B_DD	A41B	15	0.3	0.0	0.3
A41C_DD	A41C	16	0.0	0.0	0.0
A41D_DD	A41D	17	1.3	0.0	1.6
A41E_DD	A41E	18	1.1	0.0	1.1
Sub-Total Matlabas			**4.0**	**0.0**	**4.3**
A50A_DD	A50A	2	4.7	0.0	2.3
A50B_DD1	A50B	5	0.9	0.0	0.5
A50B_DD2	A50B	6	0.6	0.0	0.3
A50C_DD	A50C	10	1.6	0.0	0.9
A50D_DD	A50D	13	0.8	0.0	0.5
A50E_DD1	A50E	14	2.3	0.0	0.6
A50E_DD2	A50E	17	0.3	0.0	0.3
A50F_DD	A50F	20	0.3	0.0	0.2
A50G_DD	A50G	24	0.2	0.0	0.1
A50H_DD	A50H	30	3.4	0.0	2.7
A50J_DD	A50J	35	3.3	0.0	2.7
Sub-Total Lephalala			**18.3**	**0.0**	**11.1**
A61A1_DD1	A61A1	22	1.0	0.0	0.3
A61A1_Nylsvley	A61A1	167	51.4	0.0	68.5
A61A2_DD	A61A2	32	0.1	0.0	0.2
A61B2_DD	A61B2	37	0.4	0.0	0.5
A61C1_DD	A61C1	43	1.2	0.0	0.4
A61C2_DD	A61C2	39	1.2	0.0	0.4
A61C2_Nylsvley	A61C3	168	12.8	0.0	17.0
A61D1_DD	A61D1	50	1.4	0.0	0.5
A61D1_Nylsvley	A61D1	169	1.9	0.0	2.5
A61E1_DD	A61E1	54	1.3	0.0	0.3
A61E2_DD	A61E2	56	1.3	0.0	0.3
A61E2_Nylsvley	A61E2	170	2.8	0.0	5.0
A61F_DD1	A61F	63	5.1	0.0	2.6
A61G_DD	A61G	87	3.2	0.0	0.8
A61H_DD2	A61H	73	6.8	0.0	2.3
A61J_DD1	A61J	81	4.8	0.0	2.4
A61J_DD2	A61J	76	6.8	0.0	2.3
A61J_DD3	A61J	83	2.4	0.0	0.6
A62A_DD	A62A	92	1.8	0.0	0.6
A62B_DD	A62B	95	0.0	0.0	0.0
A62C_DD	A62C	108	0.0	0.0	0.0

Dam name	Quaternary	WRYM no	FSC (million m^3)	DSV (million m^3)	FSA (km^2)
A62D_DD	A62D	105	0.7	0.0	0.2
A62E_DD	A62E	110	0.0	0.0	0.0
A62F_DD	A62F	114	0.4	0.0	0.3
A62G_DD	A62G	119	0.0	0.0	0.0
A62H_DD	A62H	127	0.0	0.0	0.0
A62J_DD	A62J	125	0.1	0.0	0.1
A63A_DD1	A63A	133	0.1	0.0	0.2
A63A_DD2	A63A	136	0.1	0.0	0.2
A63B_DD1	A63B	139	1.2	0.0	1.3
A63B_DD2	A63B	142	0.1	0.0	0.2
A63C_DD	A63C	154	2.7	0.0	2.8
A63D_DD1	A63D	146	0.3	0.0	0.6
A63D_DD2	A63D	149	0.3	0.0	0.5
A63E_DD	A63E	159	7.1	0.0	8.3
Sub-Total Mogalakwena			**108.8**	**0.0**	**108.0**
A71A_DD	A71A	28	4.7	0.0	1.3
A71C_DD	A71C	35	9.8	0.0	2.4
A71D_DD	A71D	40	0.2	0.0	0.1
A71E_DD	A71E	33	2.0	0.0	2.4
A71F_DD	A71F	43	4.6	0.0	2.1
A71G_DD	A71G	48	1.7	0.0	0.3
A71H_DD	A71H	51	3.8	0.0	1.1
A71J_DD	A71J	55	0.3	0.0	0.0
A71K_DD	A71K	59	9.5	0.0	0.8
A71L_DD	A71L	119	6.0	0.0	0.8
A72A_DD	A72A	108	1.7	0.0	1.1
A72B_DD	A72B	116	0.0	0.0	0.1
Sub-Total Sand			**44.2**	**0.0**	**12.5**
A80A_DD	A80A	1	0.1	0.0	0.0
A80B_DD	A80B	3	0.1	0.0	0.0
A80D_DD	A80D	5	0.1	0.0	0.0
A80E_DD	A80E	6	0.0	0.0	0.0
A80F_DD	A80F	7	0.0	0.0	0.0
A80G_DD	A80G	8	2.2	0.0	0.7
A80J_DD	A80J	37	0.0	0.0	0.8
Sub-Total Nzhelele			**2.5**	**0.0**	**1.5**
Limpopo WMA North			**177.9**	**0.0**	**137.3**

Appendix E

Modelled incremental runoff catchments

Table E.1 Modelled sub-catchment areas and incremental runoffs in the WRYM

	Quaternary/ sub-quaternary	Descrip-tion	Area (km^2)	Order in param.dat file	% area	Figure no.
Matlabas	A41A	RV14	515	108	84	B-1
		NOD2	98	108	16	B-1
	A41B	RV15	210	109	58	B-1
		NOD3	150	109	42	B-1
	A41C	RV16	236	110	30	B-1
		NOD4	550	110	70	B-1
	A41D	RV17	642	111	62	B-1
		NOD5	398	111	38	B-1
	A41E	RV18	245	112	30	B-1
		NOD6	571	112	70	B-1
Mokolo[(1)]	A42A	-	-	-	-	-
	A42B	-	-	-	-	-
	A42C	-	-	-	-	-
	A42D	-	-	-	-	-
	A42E	-	-	-	-	-
	A42F	-	-	-	-	-
	A42G	-	-	-	-	-
	A42H	-	-	-	-	-
	A42J	-	-	-	-	-
Lephalala	A50A	RV2	284	47	95	B-2
		NOD1	16	47	5	B-2
	A50B	RV5	126	48	31	B-2
		RV6	52	48	13	B-2
		NOD4	152	48	37	B-2
		NOD8	80	48	20	B-2
	A50C	RV10	246	49	67	B-2
		NOD9	119	49	33	B-2
	A50D	RV13	361	50	56	B-2
		NOD12	281	50	44	B-2
	A50E	RV14	450	51	71	B-2
		RV17	184	51	29	B-2
	A50F	RV20	34	52	9	B-2
		NOD21	340	52	91	B-2
	A50G	RV24	106	53	17	B-2
		NOD23	533	53	83	B-2
	A50H	RV30	444	54	69	B-2
		NOD33	199	54	31.0	B-2
	A50J	RV35	225	55	21.3	B-2
		NOD34	830	55	78.7	B-2

	Quaternary/ sub-quaternary	Descrip-tion	Area (km^2)	Order in param.dat file	% area	Figure no.
Mogalakwena	A61A1	RV22	48	56	28.8	B-3
		RV23	39	56	23.1	B-3
		NOD163	81	56	48.1	B-3
	A61A2	RV32	48	57	33.3	B-3
		NOD28	96	57	66.7	B-3
	A61A3	NOD31	73	58	100.0	B-3
	A61B1	NOD34	120	59	100.0	B-3
	A61B2	RV37	175	60	71.4	B-3
		NOD36	70	60	28.6	B-3
	A61C1	RV43	151	61	88.9	B-3
		NOD42	19	61	11.1	B-3
	A61C2	RV39	93	62	48.5	B-3
		RV168	99	62	51.5	B-3
	A61D1	RV50	52	63	36.4	B-3
		NOD49	91	63	63.6	B-3
	A61D2	NOD46	317	64	100.0	B-3
	A61E1	RV54	112	65	90.5	B-3
		NOD53	12	65	9.5	B-3
	A61E2	RV56	388	66	90.5	B-3
		NOD59	41	66	9.5	B-3
	A61F	RV63	159	67	20.0	B-3
		NOD62	119	67	15.0	B-3
		RV61	478	67	60.0	B-3
		NOD67	40	67	5.0	B-3
	A61G	RV87	904	68	96.7	B-3
		NOD88	31	68	3.3	B-3
	A61H	RV73	236	69	40.0	B-3
		NOD69	127	69	21.5	B-3
		RV68	227	69	38.5	B-3
	A62A	RV92	246	71	57.1	B-4
		NOD166	185	71	42.9	B-4
	A62A	RV92	246	71	57.1	B-4
		NOD166	185	71	42.9	B-4
	A62B	RV95	149	72	20.8	B-4
		NOD102	567	72	79.2	B-4
	A62C	RV108	136	73	35.0	B-4
		NOD103	252	73	65.0	B-4
	A62D	RV105	355	74	74.0	B-4
		NOD104	125	74	26.0	B-4
	A62E	RV110	60	75	9.5	B-4
		NOD111	567	75	90.5	B-4
	A62F	RV114	184	76	29.5	B-4
		NOD113	441	76	70.5	B-4

	Quaternary/ sub-quaternary	Descrip-tion	Area (km^2)	Order in param.dat file	% area	Figure no.
Mogalakwena	A62G	RV119	18	77	3.3	B-4
		NOD118	521	77	96.7	B-4
	A62H	RV127	77	78	8.8	B-4
		NOD126	802	78	91.2	B-4
	A62J	RV125	342	79	36.5	B-4
		NOD124	595	79	63.5	B-4
	A63A	RV136	142	80	10.0	B-5
		RV133	1278	80	90.0	B-5
	A63B	RV139	1047	81	69.6	B-5
		RV142	458	81	30.4	B-5
	A63C	RV154	463	82	34.7	B-5
		NOD153	871	82	65.3	B-5
	A63D	RV146	129	83	17.4	B-5
		RV149	612	83	82.6	B-5
	A63E	RV159	1600	84	80.3	B-5
		NOD158	392	84	19.7	B-5
Sand	A71A	RV28	782	85	67.6	B-6
		NOD2	375	85	32.4	B-6
	A71B	RV29	91	86	10.2	B-6
		NOD4	801	86	89.8	B-6
	A71C	RV35	730	87	54.2	B-6
		NOD6	307	87	22.8	B-6
		NOD39	310	87	23.0	B-6
	A71D	RV40	196	88	21.7	B-6
		NOD8	706	88	78.3	B-6
	A71E	RV33	756	89	83.8	B-6
		RV34	146	89	16.2	B-6
	A71F	RV43	613	90	88.8	B-6
		NOD12	77	90	11.2	B-6
	A71G	RV48	332	91	37.5	B-6
		NOD14	553	91	62.5	B-6
	A71H	RV51	650	92	72.7	B-6
		NOD16	83	92	9.3	B-6
		NOD19	161	92	18.0	B-6
	A71J	RV55	160	93	17.7	B-6
		NOD18	519	93	57.4	B-6
		NOD74	225	93	24.9	B-6
	A71K	RV59	1165	94	68.9	B-6
		NOD75	293	94	17.3	B-6
		NOD77	233	94	13.8	B-6
	A71L	RV119	828	95	46.9	B-6
		NOD120	937	95	53.1	B-6

	Quaternary/ sub-quaternary	Descrip-tion	Area (km^2)	Order in param.dat file	% area	Figure no.
Sand	A72A	RV108	359	96	27.1	B-6
		NOD109	964	96	72.9	B-6
	A72B	RV116	684	97	53.9	B-6
		NOD113	265	97	20.9	B-6
		NOD114	320	97	25.2	B-6
Nzhelele	A80A	RV1	40	98	13.80	B-7
		RV2	93	98	31.80	B-7
		NOD9	158	98	54.40	B-7
	A80B	RV3	60	99	23.40	B-7
		NOD10	195	99	76.60	B-7
	A80C	RV3	298	100	100.00	B-7
	A80D	RV5	35	101	27.10	B-7
		NOD14	94	101	72.90	B-7
	A80E	RV6	189	102	75.40	B-7
		NOD25	62	102	24.60	B-7
	A80F	RV7	124	103	25.20	B-7
		NOD16	342	103	69.60	B-7
		NOD17	26	103	5.20	B-7
	A80G	RV8	284	104	22.80	B-7
		NOD21	25	104	2.00	B-7
		NOD22	775	104	62.20	B-7
		NOD29	162	104	13.00	B-7
	A80H1	RV33	156	105	100.00	B-7
	A80H2	RV34	113	106	100.00	B-7
	A80J	RV37	106	107	12.00	B-7
		NOD35	107	107	12.10	B-7
		NOD36	670	107	75.90	B-7

Note: *(1) As in the "Updating the Hydrology and Yield Analysis in the Mokolo River Catchment" study (DWA, 2007).*

Table E.2 Summary of sub-catchments

Catchment		Incremental catchment area (km^2)(1)		No. in param.dat file
No.	Name	Gross(2)	Net(3)	
A42A1	Elandsfontein	186	186	1
A42A2	Upper Sand	221	221	2
A42A3	Koufontein	26	26	3
A42A4	Lower Sand	140	140	4
A42B1	Lower Grootspruit	55	55	5
A42B2	Upper Grootspruit	218	218	6
A42B3	Rietvleispruit	42	42	7
A42B4	Ventersspruit	74	74	8
A42B5	Sandspruit	134	134	9
A42C1	Mokolo 1	66	66	10
A42C2	Tweefontein	40	40	11
A42C3	Klein Sand	390	390	12
A42C4	Mokolo 2	18	18	13
A42C5	Surprise	22	22	14
A42C6	Mokolo 3	31	31	15
A42C7	Wolwefontein	52	52	16
A42C8	Groenfontein	35	35	17
A42C9	Mokolo 4	43	43	18
A42D1	Middle Sterkstroom	81	81	19
A42D2	Upper Sterkstroom	35	35	20
A42D3	Upper Frikkiesloop	16	16	21
A42D4	Lower Sterkstroom	154	154	22
A42D5	Lower Frikkiesloop	53	53	23
A42D6	Upper Grootfontein	26	26	24
A42D7	Lower Grootfontein	132	132	25
A42E1	Mokolo 6	212	212	26
A42E2	Blinkwaterspruit	93	93	27
A42E3	Klein Vaalwaterspruit	61	61	28
A42E4	Zand	34	34	29
A42E5	Mokolo 5	45	45	30
A42E6	Lower Dwars	123	123	31
A42E7	Bellevue	85	85	32
A42E8	Upper Dwars	352	352	33
A42F1	Mokolo 8	244	244	34
A42F2	Platbosspruit	51	51	35
A42F3	Malmanies	285	285	36
A42F4	Mokolo 7	442	442	37
A42G1	Poer se Loop	469	469	38
A42G2	Mokolo 10	99	99	39
A42G3	Mokolo 9	174	174	40

Catchment		Incremental catchment area (km^2)[1]		No. in param.dat file
No.	**Name**	**Gross[2]**	**Net[3]**	
A42G4	Rietspruit	464	464	41
A42H1	Lower Tambotie	511	511	42
A42H2	Mokolo 11	149	149	43
A42H3	Upper Tambotie	397	397	44
A42J1	Mokolo 12	1 179	668	45
A42J2	Sandloop	633	359	46
Mokolo		**8 392**	**7 607**	
A50A	Lephalala	300	300	47
A50B	Lephalala	409	409	48
A50C	Melk	365	365	49
A50D	Lephalala	642	642	50
A50E	Lephalala	633	633	51
A50F	Lephalala	374	374	52
A50G	Lephalala	821	639	53
A50H	Lephalala	1945	643	54
A50J	Lephalala	1255	1055	55
Lephalala		**6 744**	**5 060**	
A61A1	Little Nyl	168	168	56
A61A2	Little Nyl	143	143	57
A61A3	Little Nyl	73	73	58
A61B1	Nyl	120	120	59
A61B2	Nyl	245	245	60
A61C1	Nyl	170	170	61
A61C2	Nyl	421	192	62
A61D1	Nyl	143	143	63
A61D2	Nyl	317	317	64
A61E1	Nyl	124	124	65
A61E2	Nyl	429	429	66
A61F	Mogalakwena	796	796	67
A61G	Mogalakwena	935	935	68
A61H	Sterk	590	590	69
A61J	Sterk	825	825	70
A62A	Mokamole	431	431	71
A62B	Mogalakwena	716	716	72
A62C	Mogalakwena	388	388	73
A62D	Klein Mogalakwena	607	480	74
A62E	Mogalakwena	627	627	75
A62F	Mogalakwena	625	625	76
A62G	Mogalakwena	632	539	77
A62H	Seepabana	879	879	78
A62J	Mogalakwena	937	937	79

Catchment		Incremental catchment area (km²)(1)		No. in param.dat file
No.	**Name**	**Gross(2)**	**Net(3)**	
A63A	Mogalakwena	1 943	1 420	80
A63B	Mogalakwena	1 505	1 505	81
A63C	Mogalakwena	1 334	1 334	82
A63D	Mogalakwena	1 331	741	83
A63E	Mogalakwena	1 992	1 992	84
Mogalakwena		**19 446**	**17 884**	
A71A	Sand	1 157	1 157	85
A71B	Diep	892	892	86
A71C	Sand	1 347	1 347	87
A71D	Sand	902	902	88
A71E	Hout	902	902	89
A71F	Brakspruit	690	690	90
A71G	Hout	885	885	91
A71H	Sand	1 024	894	92
A71J	Sand	1 175	905	93
A71K	Sand	1 691	1 691	94
A71L	Sand	1 765	1 765	95
A72A	Brak	1 926	1 323	96
A72B	Brak	1 571	1 269	97
Sand		**15 927**	**14 622**	
A80A	Nzhelele	291	291	98
A80B	Nzhelele	255	255	99
A80C	Mufungudi	298	298	100
A80D	Mutamba	129	129	101
A80E	Mutamba	250	250	102
A80F	Nzhelele	638	491	103
A80G	Nzhelele	1 246	1 246	104
A80H1	Luphephe	156	156	105
A80H2	Nwanedi	113	113	106
A80J	Nwanedi	883	883	107
Nzhelele		**4259**	**4112**	
A41A	Motlhabatsi	692	613	108
A41B	Mamba	358	359	109
A41C	Matlabas	1 111	785	110
A41D	Matlabas	1 913	1 040	111
A41E	Matlabas	1 940	816	112
Matlabas		**6 014**	**3 613**	
Limpopo WMA North		**60 782**	**52 898**	

Notes: *(1) From WR2005.*

(2) Total incremental area of the sub-catchment in question.

(3) Excludes the catchment area of pans, which do not contribute to runoff in the river system.

Appendix F

Stochastic streamflow analysis

Table F.1 Selected Johnson-Transform distributions and values of associated model parameters for quaternary / sub-quaternary catchments

Catchment, quaternary or sub-quaternary		Selected distribution	Johnson Transform parameters			
			Γ	δ	λ	ξ
Matlabas	A41A	LN3	-1.82608	0.8370554	1.00000	1.13964
	A41B	LN3	-1.22487	0.8589615	1.00000	0.57517
	A41C	LN3	-1.63628	0.9347748	1.00000	0.00000
	A41D	LN3	-1.53436	0.8981890	1.00000	0.00000
	A41E	LN3	-1.07119	0.9560750	1.00000	0.00000
Mokolo	A42A1	SB4	1.64730	0.8221306	40.91767	0.96342
	A42A2	SB4	1.63401	0.8183343	48.18272	1.15951
	A42A3	SB4	1.57389	0.7985110	5.41659	0.14279
	A42A4	SB4	1.55333	0.8445582	30.69358	0.00000
	A42B1	SB4	1.58705	0.8091972	13.93082	0.34356
	A42B2	SB4	1.60864	0.8157572	56.23871	1.34014
	A42B3	SB4	1.51678	0.7868760	10.17347	0.27787
	A42B4	SB4	1.57932	0.8065029	18.61717	0.46854
	A42B5	SB4	1.61331	0.8181538	34.55610	0.81204
	A42C1	SB4	1.50843	0.7993395	16.39748	0.43322
	A42C2	SB4	1.46009	0.7858653	9.56318	0.26751
	A42C3	SB4	1.53514	0.8100187	98.26279	2.44840
	A42C4	SB4	1.45774	0.7929108	4.36537	0.11463
	A42C5	SB4	1.43473	0.7749331	5.29106	0.15257
	A42C6	LN3	-0.02109	1.1135122	1.00000	0.12186
	A42C7	SB4	1.46802	0.7851984	12.64048	0.33795
	A42C8	SB4	1.35339	0.7481166	7.92294	0.25632
	A42C9	SB4	1.22209	0.7147612	8.99471	0.29529
	A42D1	SB4	1.03591	0.6982963	27.75576	0.00000
	A42D2	SB4	1.03437	0.6980269	11.92083	0.00000
	A42D3	SB4	1.01868	0.6898601	5.41885	0.00000
	A42D4	SB4	1.04072	0.7010158	52.89851	0.00000
	A42D5	SB4	1.04110	0.7006586	18.25891	0.00000
	A42D6	SB4	1.04213	0.7021125	8.88465	0.00000
	A42D7	SB4	0.96390	0.6266174	43.55596	0.34466
	A42E1	SB4	1.30852	0.5604884	53.10378	0.00000
	A42E2	SB4	1.45118	0.6164104	24.90785	0.00000
	A42E3	SB4	1.44896	0.6165211	16.31803	0.00000
	A42E4	SB4	1.43570	0.6106907	9.04152	0.00000
	A42E5	SB4	1.45486	0.6182782	12.08200	0.00000
	A42E6	SB4	1.33192	0.5687127	30.96311	0.00000
	A42E7	SB4	1.44787	0.6152446	22.71165	0.00000

Catchment, quaternary or sub-quaternary		Selected distribution	Johnson Transform parameters			
			Γ	δ	λ	ξ
Mokolo	A42E8	SB4	1.31611	0.5631825	88.07758	0.00000
	A42F1	SB4	1.33157	0.5573712	48.28095	0.00000
	A42F2	SB4	1.45348	0.6061032	10.65307	0.00000
	A42F3	SB4	1.32564	0.5553565	56.26810	0.00000
	A42F4	SB4	1.33636	0.5592896	87.41174	0.00000
	A42G1	SB4	1.23776	0.4300730	75.74064	0.34489
	A42G2	SB4	1.31313	0.4503115	16.60146	0.05854
	A42G3	SB4	1.26784	0.4364525	28.39207	0.12795
	A42G4	SB4	1.23645	0.4290537	74.90569	0.34505
	A42H1	SB4	1.62928	0.5285758	108.38040	0.00000
	A42H2	SB4	1.66147	0.5413543	32.02517	0.00000
	A42H3	SB4	1.64591	0.5350141	84.85722	0.00000
	A42J1	LN3	-0.67460	0.8776719	1.00000	0.22817
	A42J2	LN3	-0.14414	0.8750807	1.00000	0.13351
Lephalala	A50A	SB4	1.63591	0.8391115	149.93187	6.29882
	A50B	SB4	1.83081	0.8644770	183.49478	6.92964
	A50C	LN3	-1.99510	0.9986159	1.00000	2.10258
	A50D	LN3	-2.04810	0.8985649	1.00000	2.65945
	A50E	LN3	-2.56480	1.722661	1.00000	2.48273
	A50F	LN3	-1.63925	1.485068	1.00000	1.93594
	A50G	LN3	-0.59790	0.8153934	1.00000	0.00000
	A50H	LN3	-0.18069	0.7005291	1.00000	0.00000
	A50J	LN3	-0.48928	0.7139349	1.00000	0.00000
Mogalakwena	A61A1	LN3	-4.37019	1.9861755	1.00000	0.00000
	A61A2	LN3	-3.14276	1.6587957	1.00000	0.00000
	A61A3	LN3	-1.77276	1.5852607	1.00000	0.81032
	A61B1	SB4	1.06543	0.6213247	26.38688	0.44055
	A61B2	SB4	1.18895	0.7288584	57.58237	1.68011
	A61C1	LN3	-1.45008	1.5104767	1.00000	0.00000
	A61C2	SB4	1.94178	0.6396026	23.61598	0.00000
	A61D1	SB4	1.97104	0.7283699	28.21226	0.00000
	A61D2	SB4	1.19234	0.4129564	46.66815	0.00000
	A61E1	LN3	-0.03771	0.8316766	1.00000	0.10101
	A61E2	LN3	-1.96524	0.9662308	1.00000	0.00000
	A61F	SB4	1.49910	0.5160649	139.21169	0.00000
	A61G	SB4	1.55087	0.5133914	155.64042	0.00000
	A61H	SB4	1.06209	0.4959560	123.81486	12.02698
	A61J	SB4	1.81553	0.6789751	161.57917	0.00000
	A62A	SB4	1.46936	0.5341701	104.35964	0.00000

Catchment, quaternary or sub-quaternary		Selected distribution	Johnson Transform parameters			
			Γ	δ	λ	ξ
Mogalakwena	A62B	SB4	1.44572	0.4573081	104.67883	0.00000
	A62C	SB4	1.31775	0.5093983	37.46469	0.00000
	A62D	SB4	1.64700	0.4876903	42.77016	0.00000
	A62E	LN3	-0.38766	0.8849318	1.00000	0.00000
	A62F	LN3	0.09845	0.5302301	1.00000	0.00000
	A62G	LN3	0.13061	0.6780496	1.00000	0.00000
	A62H	LN3	-0.45929	0.8910069	1.00000	0.19816
	A62J	LN3	-0.54263	0.8798937	1.00000	0.10443
	A63A	LN3	-0.25567	0.5340034	1.00000	0.00000
	A63B	LN3	0.05963	0.4823708	1.00000	0.00000
	A63C	LN3	0.00899	0.5862986	1.00000	0.00000
	A63D	LN3	0.26054	0.5177083	1.00000	0.00000
	A63E	LN3	0.07172	0.5043382	1.00000	0.00000
Sand	A71A	LN3	-0.42820	0.5798073	1.00000	0.00000
	A71B	LN3	-0.11163	0.5480934	1.00000	0.00000
	A71C	LN3	-0.27355	0.5891444	1.00000	0.00000
	A71D	LN3	-0.15018	0.5982169	1.00000	0.00000
	A71E	LN3	-0.22172	0.7128966	1.00000	0.00000
	A71F	LN3	0.14228	0.6872406	1.00000	0.00000
	A71G	LN3	-0.31373	0.7297204	1.00000	0.00000
	A71H	LN3	-0.21626	0.5257149	1.00000	0.00000
	A71J	LN3	-0.17000	0.5154440	1.00000	0.00000
	A71K	LN3	-0.25484	0.5982196	1.00000	0.00000
	A71L	LN3	-0.74208	0.4698894	1.00000	0.00000
	A72A	LN3	-1.15679	0.8835174	1.00000	0.00000
	A72B	LN3	-0.04170	0.5876290	1.00000	0.00000
Nzhelele	A80A	LN3	-3.66796	1.557715	1.00000	0.00000
	A80B	LN3	-2.09205	0.9255735	1.00000	0.00000
	A80C	LN3	-1.66573	0.9639132	1.00000	0.00000
	A80D	LN3	-1.55388	1.972992	1.00000	0.51248
	A80E	LN3	-2.75340	1.2267211	1.00000	0.00000
	A80F	LN3	-0.08740	0.8010069	1.00000	0.00000
	A80G	LN3	-0.29194	0.5946104	1.00000	0.00000
	A80H1	LN3	-3.60485	1.2996270	1.00000	0.00000
	A80H2	SB4	2.20881	0.7406320	112.40792	0.00000
	A80J	LN3	0.03309	0.8331027	1.00000	0.00000

Table F.2 Selected ARMA distributions and values of associated model parameters for quaternary/sub-quaternary catchments

Catchment, quaternary or sub-quaternary		ARMA parameters			
		Φ1	Φ2	Θ1	Θ2
Matlabas	A41A	-0.00076	0.72285	0.24735	0.73658
	A41B	-0.00864	0.72176	0.23880	0.74505
	A41C	0.00000	0.00000	0.00000	0.00000
	A41D	0.00000	0.00000	0.00000	0.00000
	A41E	0.00000	0.00000	0.00000	0.00000
Mokolo	A42A1	0.15998	0.33140	0.00000	0.00000
	A42A2	0.15976	0.33076	0.00000	0.00000
	A42A3	0.15752	0.32571	0.00000	0.00000
	A42A4	0.24782	0.40641	0.00000	0.00000
	A42B1	0.16777	0.32475	0.00000	0.00000
	A42B2	0.16780	0.32538	0.00000	0.00000
	A42B3	0.16807	0.32321	0.00000	0.00000
	A42B4	0.16617	0.32639	0.00000	0.00000
	A42B5	0.16788	0.32489	0.00000	0.00000
	A42C1	0.13706	0.33512	0.00000	0.00000
	A42C2	0.13488	0.33424	0.00000	0.00000
	A42C3	0.13597	0.33619	0.00000	0.00000
	A42C4	0.13621	0.33513	0.00000	0.00000
	A42C5	0.13950	0.33322	0.00000	0.00000
	A42C6	0.14912	0.34246	0.00000	0.00000
	A42C7	0.12556	0.34252	0.00000	0.00000
	A42C8	0.12690	0.33392	0.00000	0.00000
	A42C9	0.12531	0.34142	0.00000	0.00000
	A42D1	0.00000	0.00000	0.00000	0.00000
	A42D2	0.00000	0.00000	0.00000	0.00000
	A42D3	0.00000	0.00000	0.00000	0.00000
	A42D4	0.00000	0.00000	0.00000	0.00000
	A42D5	0.00000	0.00000	0.00000	0.00000
	A42D6	0.00000	0.00000	0.00000	0.00000
	A42D7	0.00000	0.00000	0.00000	0.00000
	A42E1	0.09218	0.15936	0.00000	0.00000
	A42E2	0.00000	0.00000	0.00000	0.00000
	A42E3	0.00000	0.00000	0.00000	0.00000
	A42E4	0.00000	0.00000	0.00000	0.00000
	A42E5	0.00000	0.00000	0.00000	0.00000
	A42E6	0.08890	0.16654	0.00000	0.00000
	A42E7	0.00000	0.00000	0.00000	0.00000
	A42E8	0.09058	0.16265	0.00000	0.00000

Catchment, quaternary or sub-quaternary		ARMA parameters			
		Φ1	Φ2	Θ1	Θ2
Mokolo	A42F1	0.08006	0.17551	0.00000	0.00000
	A42F2	0.00000	0.00000	0.00000	0.00000
	A42F3	0.08301	0.17201	0.00000	0.00000
	A42F4	0.08069	0.17593	0.00000	0.00000
	A42G1	0.00000	0.00000	0.00000	0.00000
	A42G2	0.00000	0.00000	0.00000	0.00000
	A42G3	0.00000	0.00000	0.00000	0.00000
	A42G4	0.00000	0.00000	0.00000	0.00000
	A42H1	0.00000	0.00000	0.00000	0.00000
	A42H2	0.00000	0.00000	0.00000	0.00000
	A42H3	0.00000	0.00000	0.00000	0.00000
	A42J1	0.00000	0.00000	0.00000	0.00000
	A42J2	0.00000	0.00000	0.00000	0.00000
Lephalala	A50A	-0.15995	0.00000	0.00000	0.00000
	A50B	0.00000	0.00000	0.00000	0.00000
	A50C	-0.05479	0.27020	0.00000	0.00000
	A50D	0.00000	0.00000	0.00000	0.00000
	A50E	0.00000	0.00000	0.00000	0.00000
	A50F	0.00000	0.00000	0.00000	0.00000
	A50G	0.86164	0.00000	1.12235	-0.12235
	A50H	0.00000	0.00000	0.00000	0.00000
	A50J	0.00000	0.00000	0.00000	0.00000
Mogalakwena	A61A1	0.40160	0.00000	0.49799	-0.36675
	A61A2	0.31810	0.00000	0.45612	-0.39663
	A61A3	0.41098	0.00000	0.47951	-0.36691
	A61B1	0.52477	0.00000	0.58538	-0.31396
	A61B2	0.59194	0.00000	0.64391	-0.30711
	A61C1	0.00000	0.00000	0.00000	0.00000
	A61C2	0.00000	0.00000	0.00000	0.00000
	A61D1	0.00000	0.00000	0.00000	0.00000
	A61D2	0.00000	0.00000	0.00000	0.00000
	A61E1	0.00000	0.00000	0.18122	-0.27045
	A61E2	0.00000	0.00000	0.00000	0.00000
	A61F	0.00000	0.00000	0.00000	0.00000
	A61G	0.00000	0.00000	0.00000	0.00000
	A61H	-0.23854	0.00000	0.00000	0.00000
	A61J	0.00000	0.00000	0.00000	0.00000
	A62A	0.00000	0.00000	0.00000	0.00000
	A62B	0.00000	0.00000	0.00000	0.00000
	A62C	0.00000	0.00000	0.00000	0.00000

Catchment, quaternary or sub-quaternary		ARMA parameters			
		Φ1	Φ2	Θ1	Θ2
Mogalakwena	A62D	0.00000	0.00000	0.00000	0.00000
	A62E	-0.69272	0.00000	-0.73877	-0.34360
	A62F	0.00000	0.00000	0.00000	0.00000
	A62G	0.00000	0.00000	0.00000	0.00000
	A62H	-0.67543	0.00000	-0.71373	-0.37189
	A62J	-0.67813	0.00000	-0.73732	-0.37759
	A63A	0.00000	0.00000	0.00000	0.00000
	A63B	0.00000	0.00000	0.00000	0.00000
	A63C	0.00000	0.00000	0.00000	0.00000
	A63D	0.00000	0.00000	0.00000	0.00000
	A63E	0.00000	0.00000	0.00000	0.00000
Sand	A71A	0.00000	0.00000	0.00000	0.00000
	A71B	0.00000	0.00000	0.00000	0.00000
	A71C	0.00000	0.00000	0.00000	0.00000
	A71D	0.00000	0.00000	0.00000	0.00000
	A71E	0.00000	0.00000	0.00000	0.00000
	A71F	0.00000	0.00000	0.00000	0.00000
	A71G	0.00000	0.00000	0.00000	0.00000
	A71H	0.00000	0.00000	0.00000	0.00000
	A71J	0.00000	0.00000	0.00000	0.00000
	A71K	0.00000	0.00000	0.00000	0.00000
	A71L	0.00000	0.00000	0.00000	0.00000
	A72A	0.00000	0.00000	0.00000	0.00000
	A72B	0.00000	0.00000	0.00000	0.00000
Nzhelele	A80A	0.14055	0.00000	0.00000	0.00000
	A80B	0.27303	0.00000	0.00000	0.00000
	A80C	0.00000	0.00000	0.00000	0.00000
	A80D	0.34047	0.00000	0.00000	0.00000
	A80E	0.36961	0.00000	0.00000	0.00000
	A80F	0.69950	0.00000	0.50087	0.00000
	A80G	0.00000	0.00000	0.00000	0.00000
	A80H1	0.00000	0.00000	0.00000	0.00000
	A80H2	1.03891	-0.18302	0.99338	0.00000
	A80J	0.19219	0.33543	0.00000	0.00000

Appendix G

Long-term yield-reliability characteristics curves

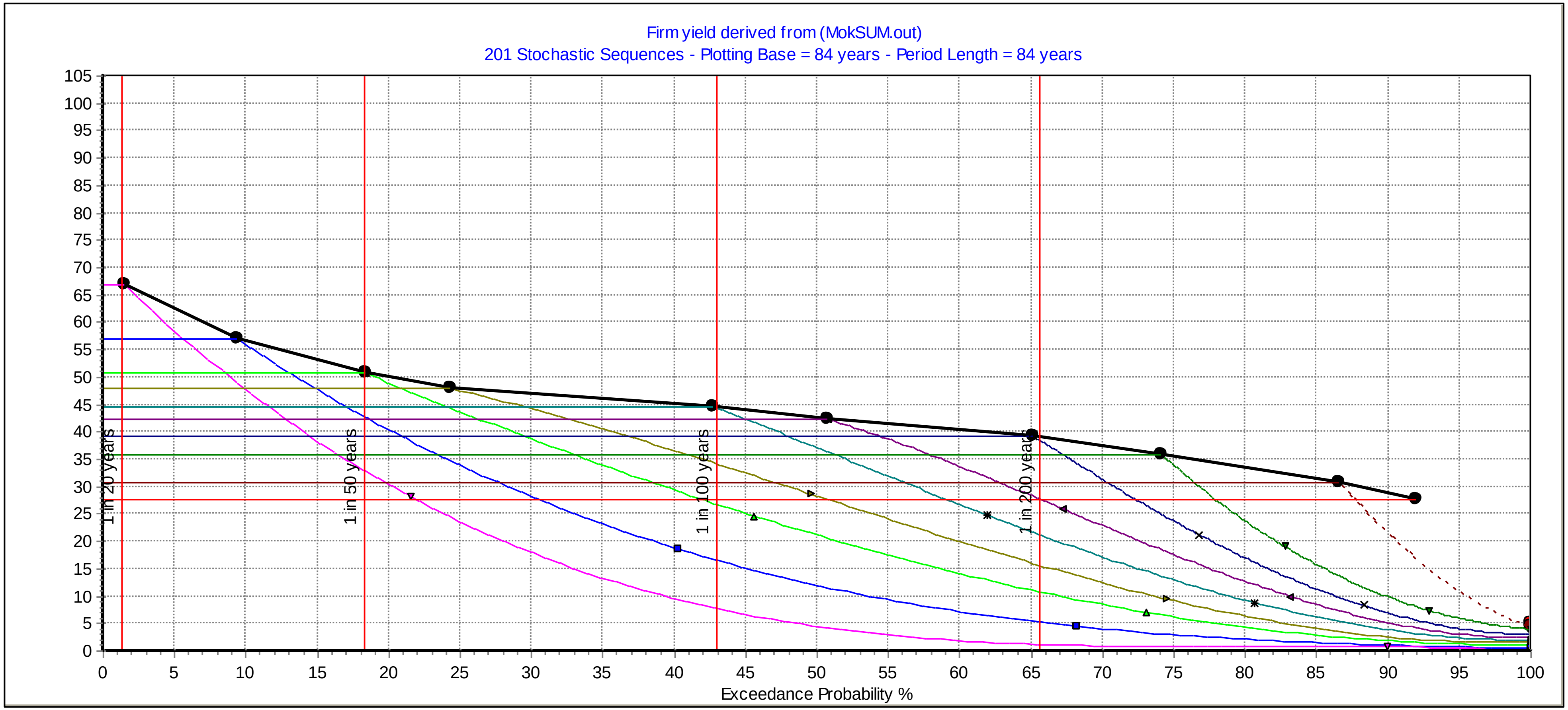

Figure G.1 Long-term yield-reliability characteristics curve: Mokolo Dam (from Mokolo Study (DWA, 2007)

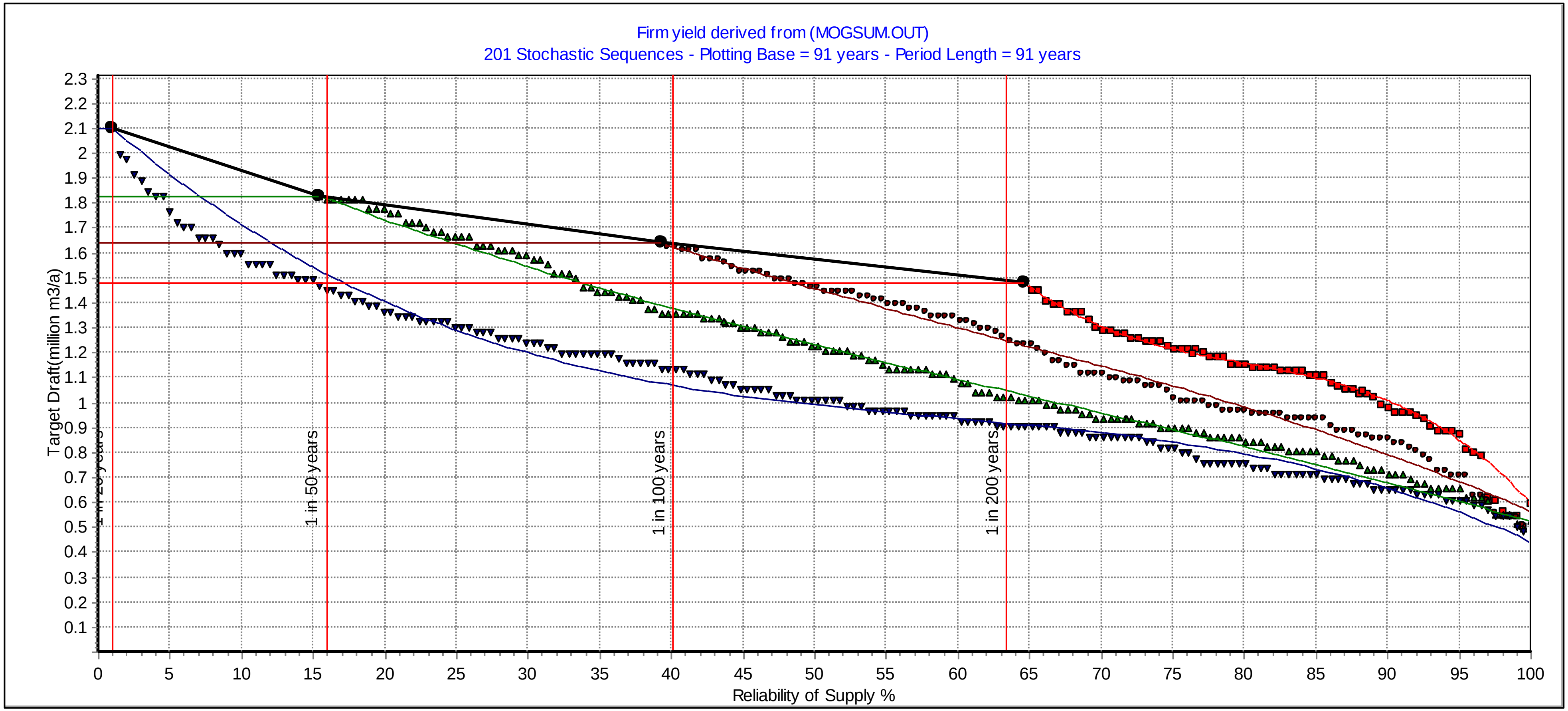

Figure G.2 Long-term yield-reliability characteristics curve: Donkerpoort Dam

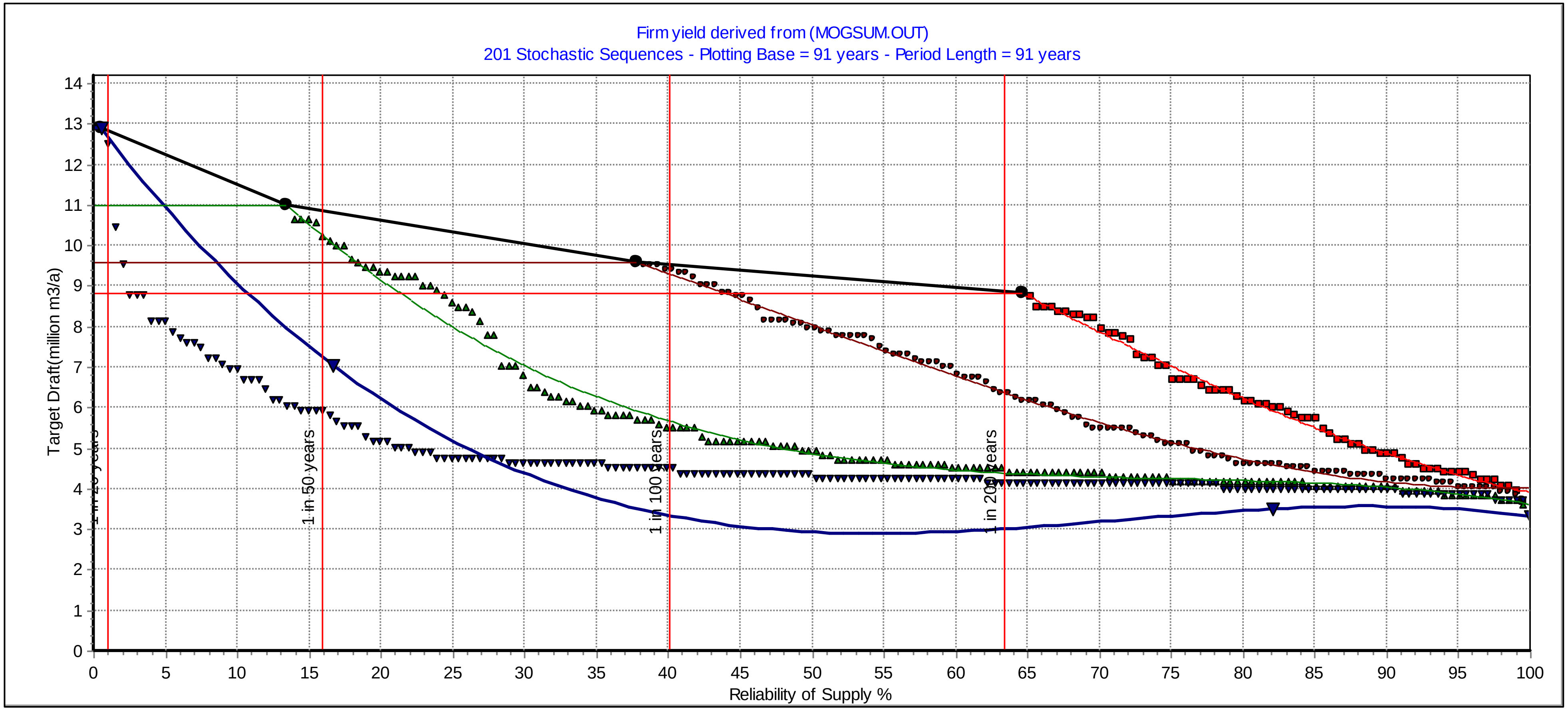

Figure G.3 Long-term yield-reliability characteristics curve: Doorndraai Dam

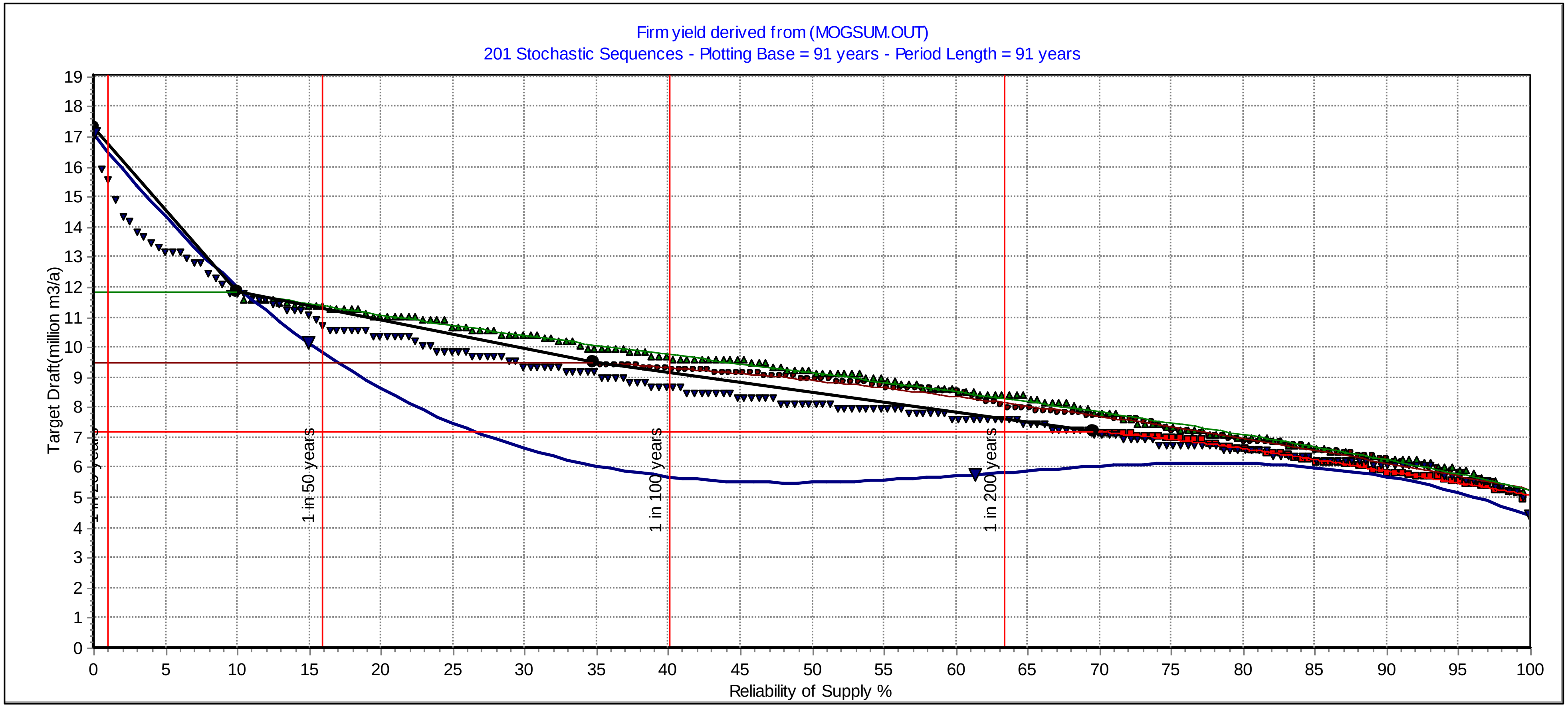

Figure G.4 Long-term yield-reliability characteristics curve: Glen Alpine Dam

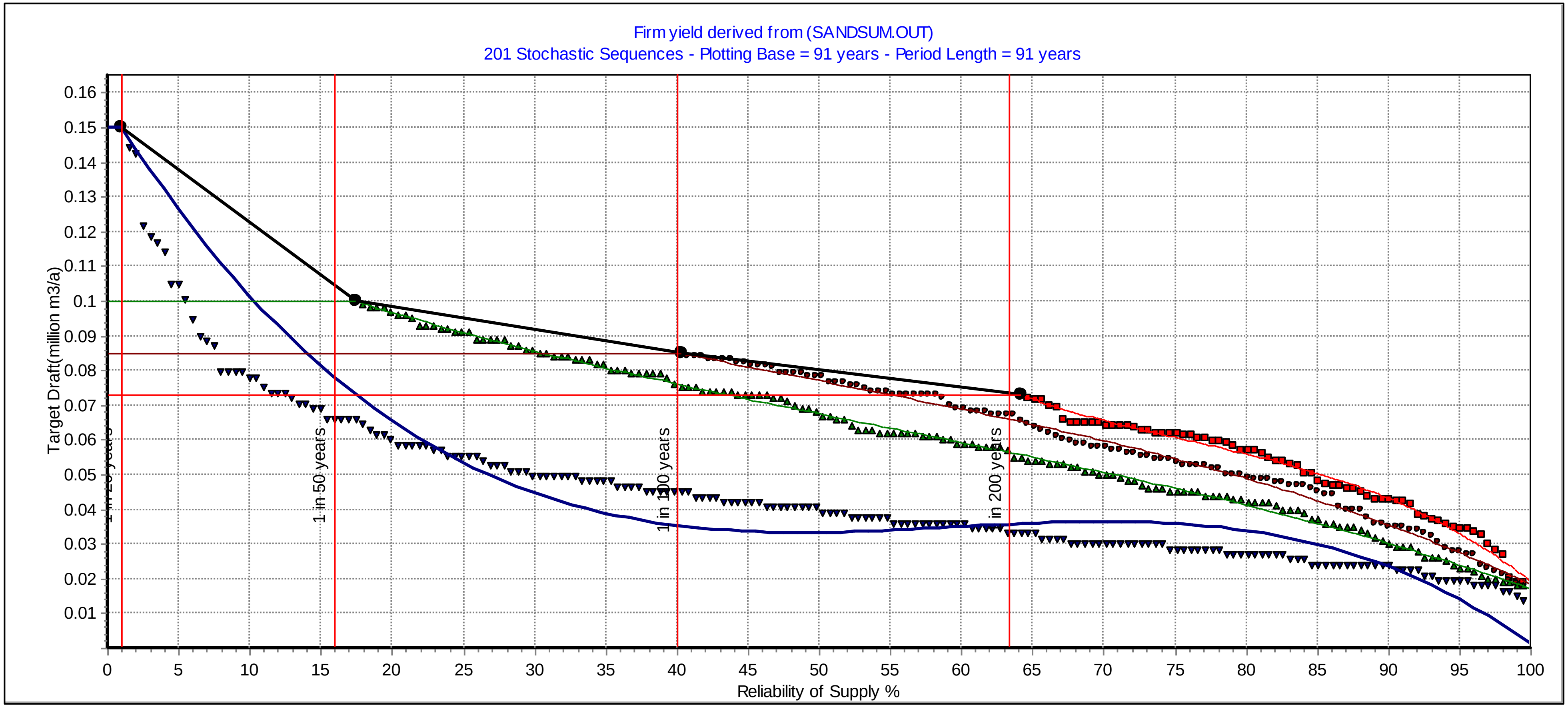

Figure G.5 Long-term yield-reliability characteristics curve: Turfloop Dam

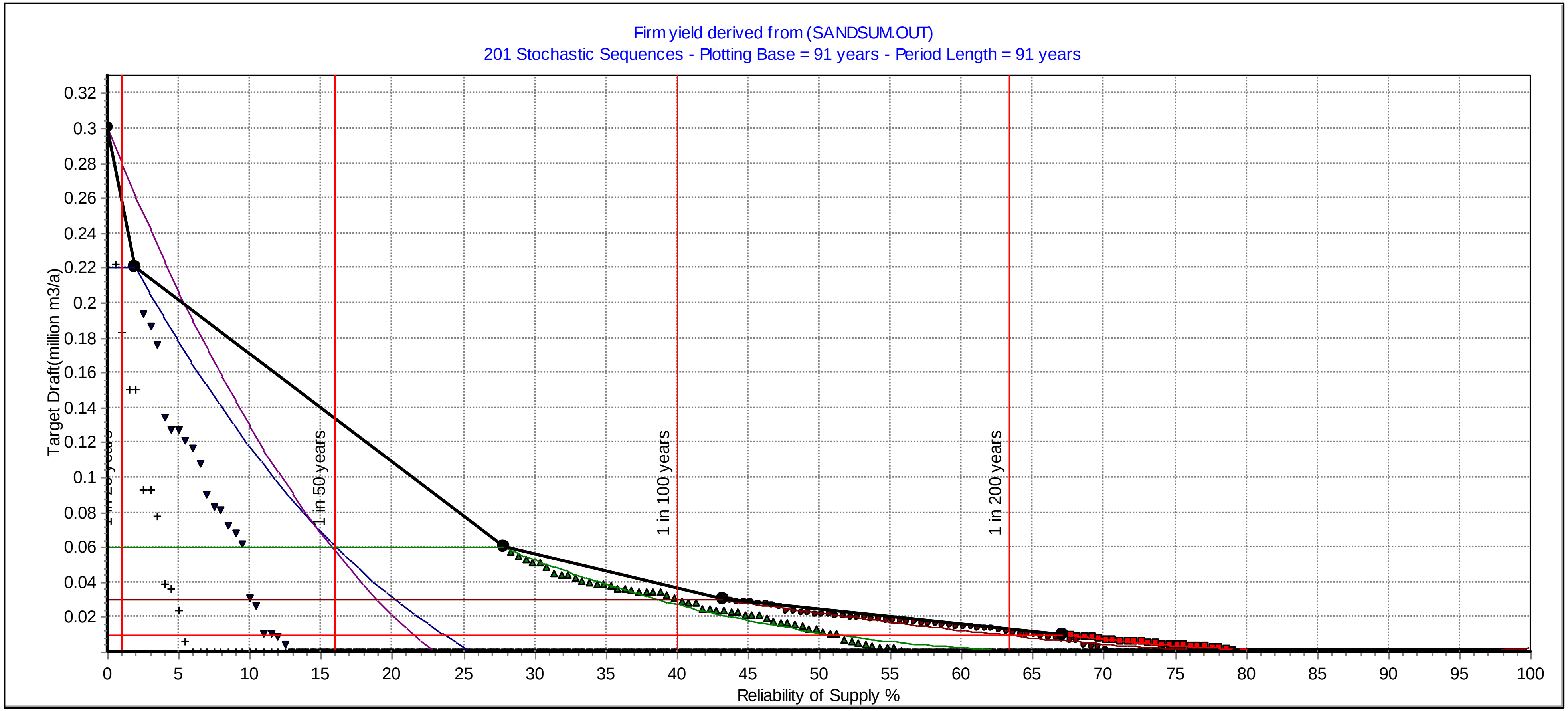

Figure G.6 Long-term yield-reliability characteristics curve: Houtrivier Dam

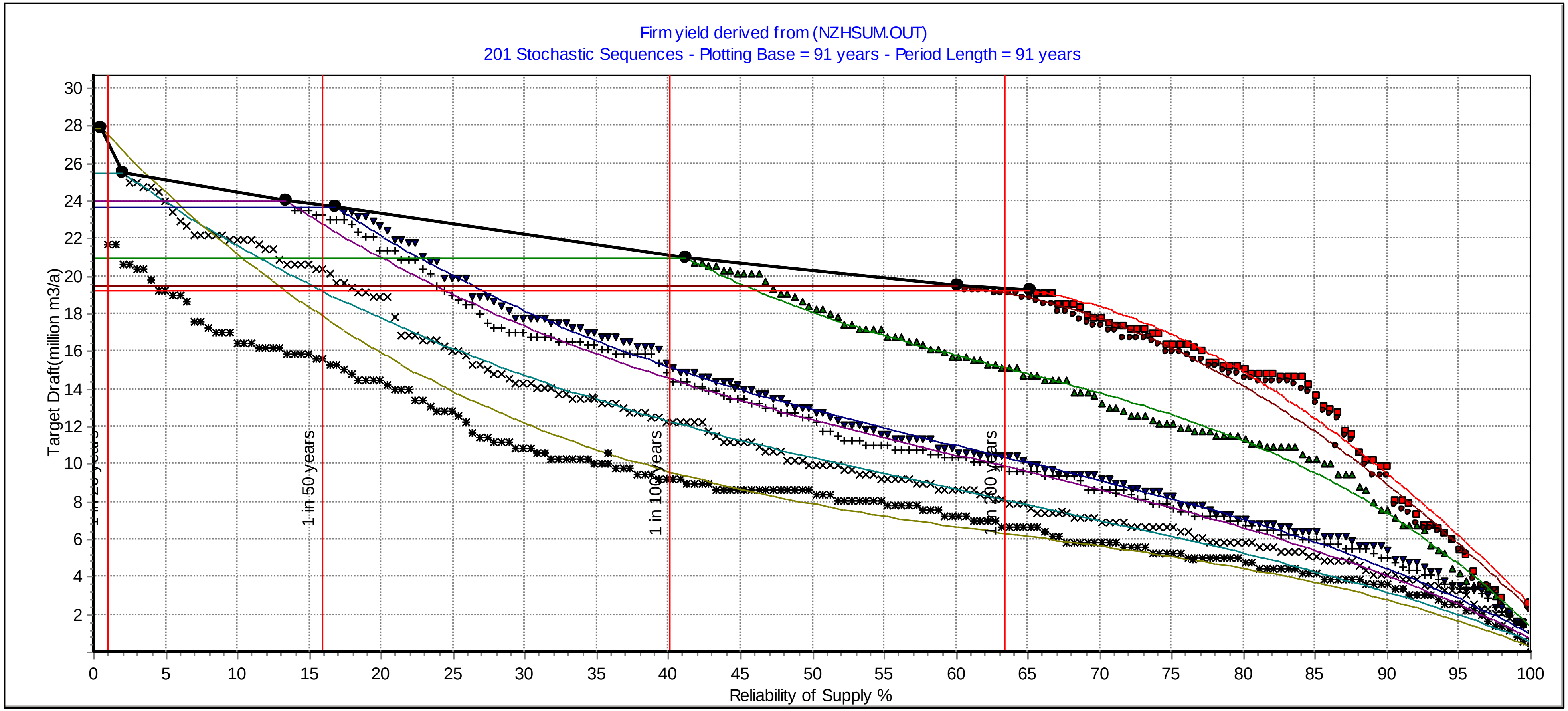

Figure G.7 Long-term yield-reliability characteristics curve: Nzhelele Dam

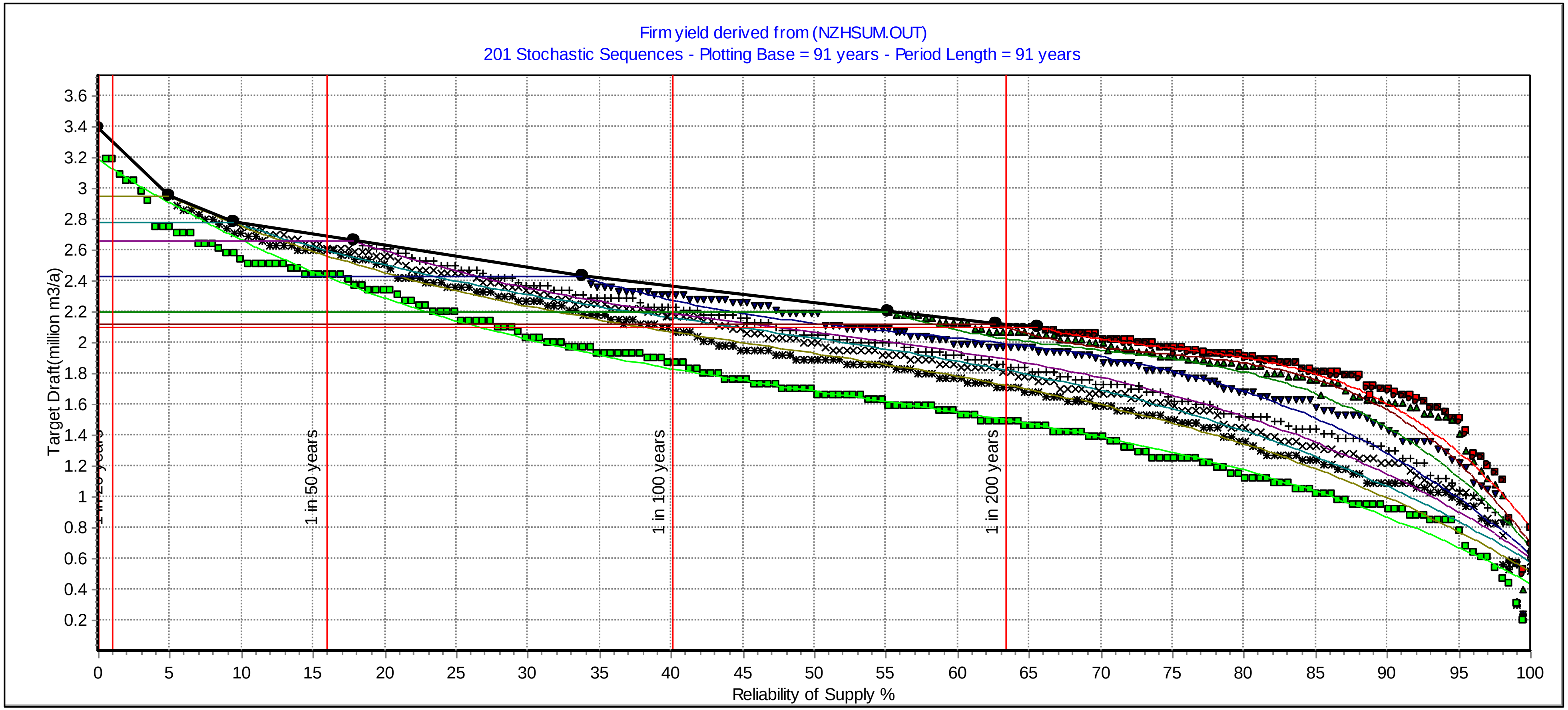

Figure G.8 Long-term yield-reliability characteristics curve: Mutshedzi Dam

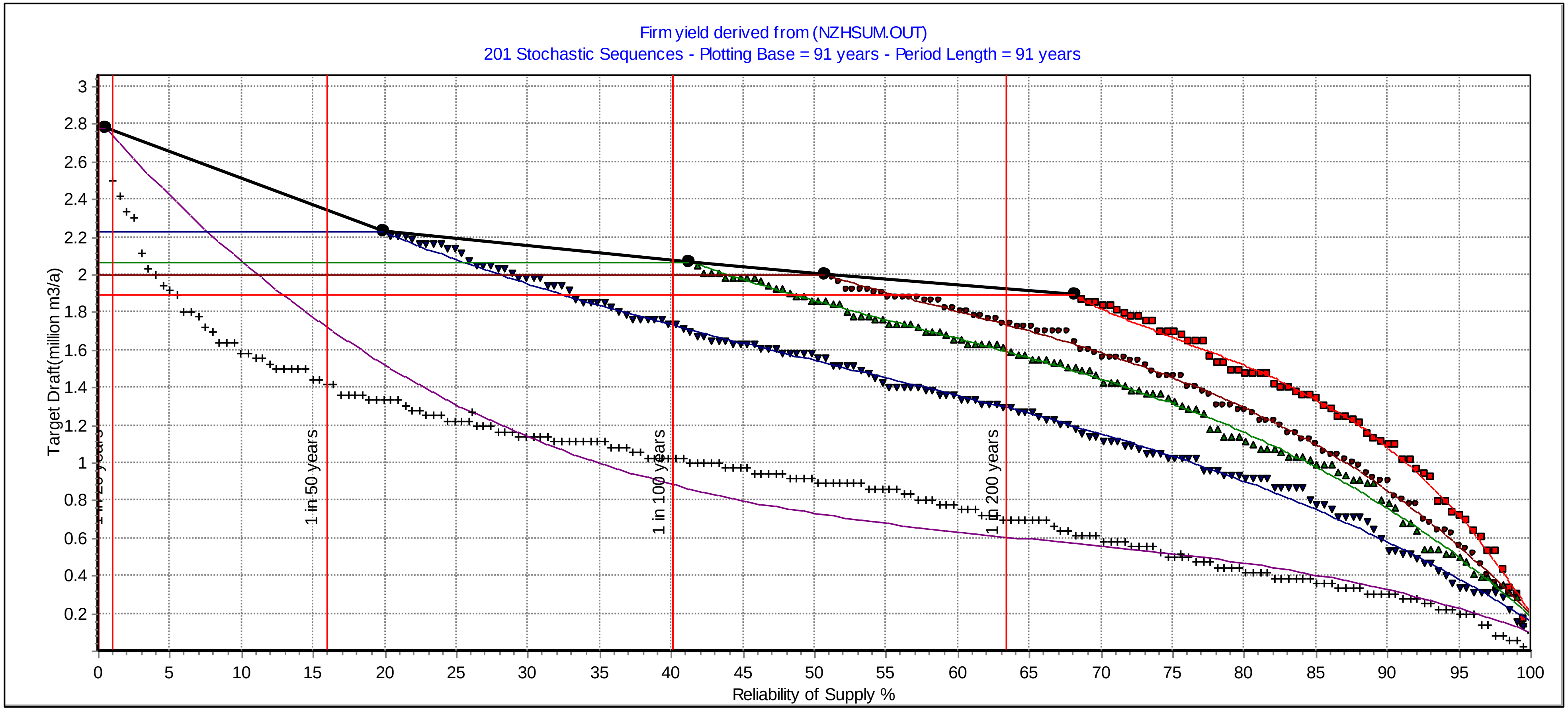

Figure G.9 Long-term yield-reliability characteristics curve: Nwanedi Dam

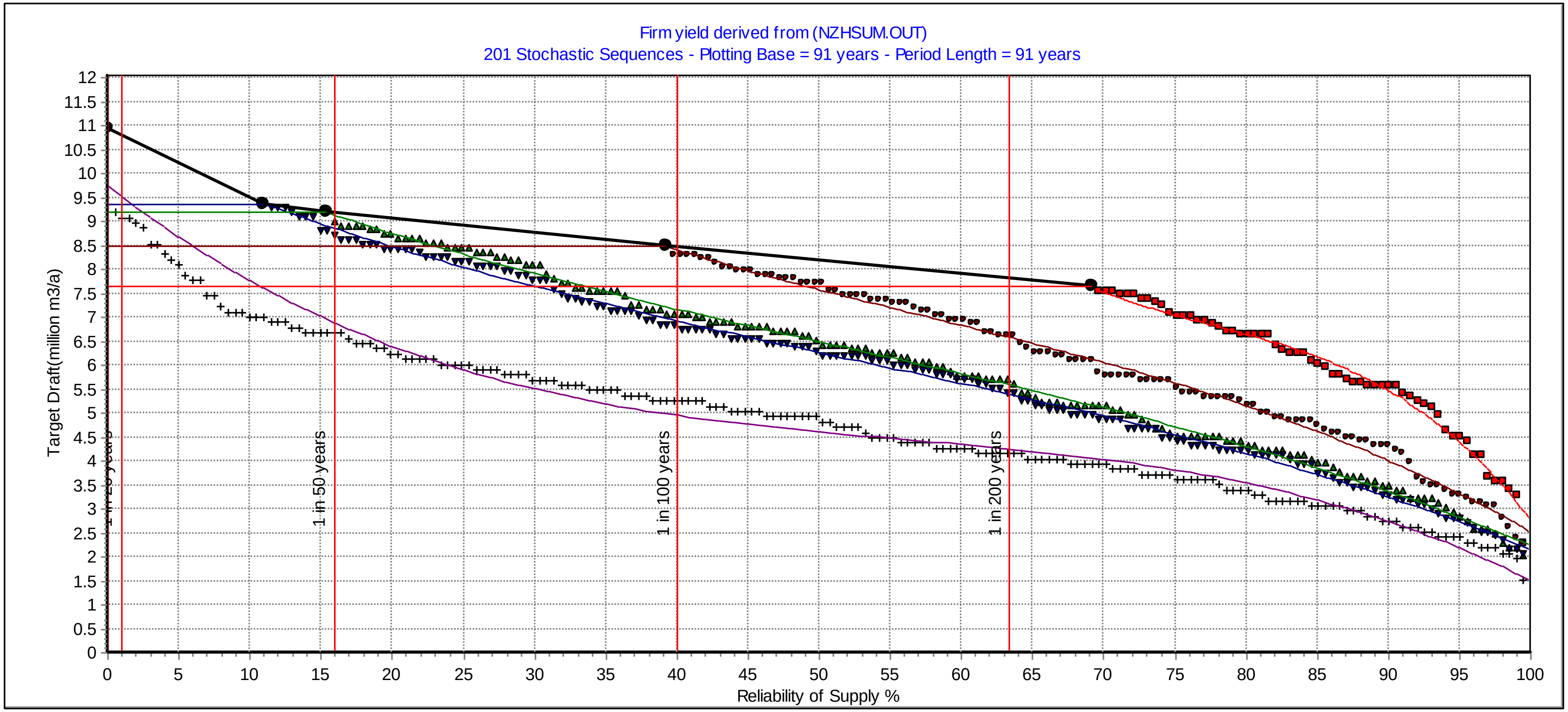

Figure G.10 Long-term yield-reliability characteristics curve: Luphephe Dam

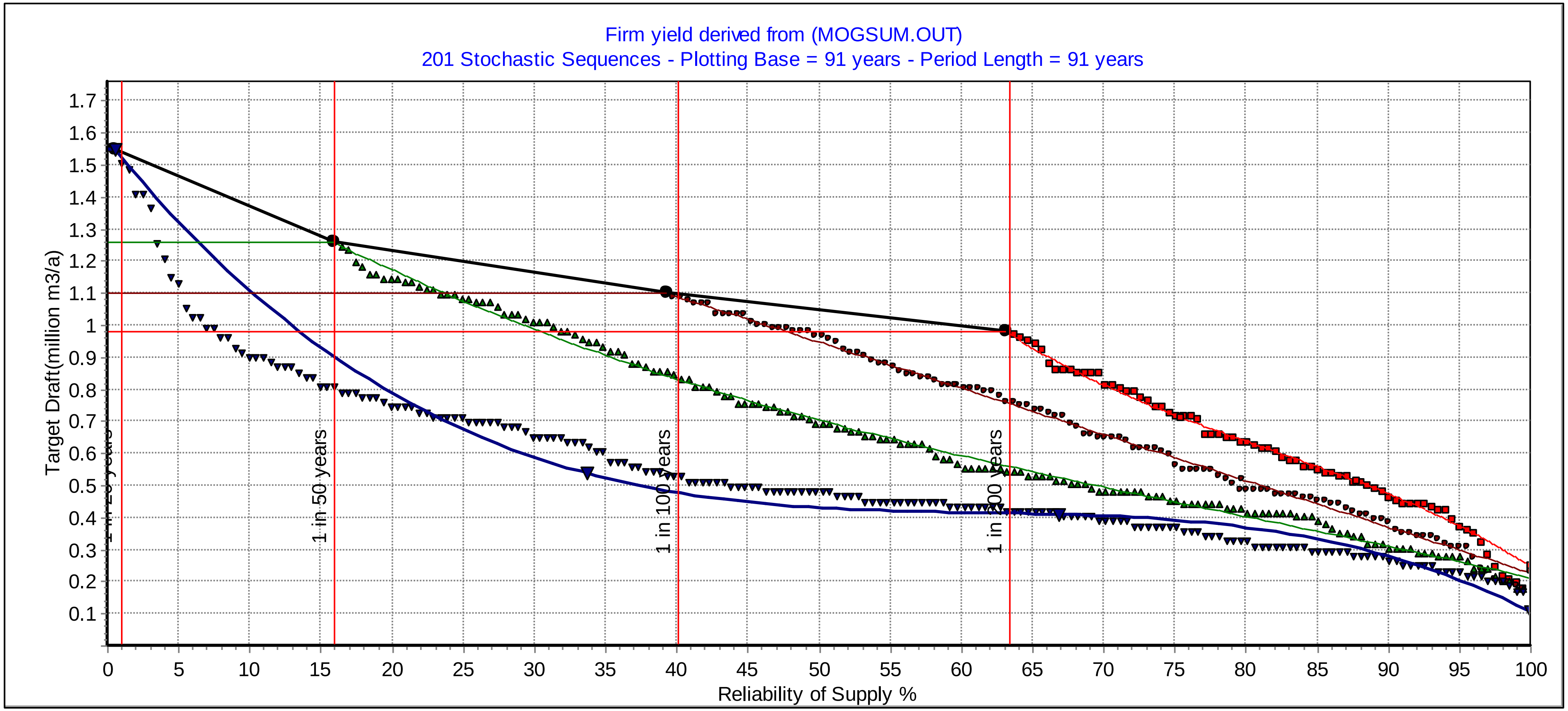

Figure G.11 Long-term yield-reliability characteristics curve with EWR: Donkerpoort Dam

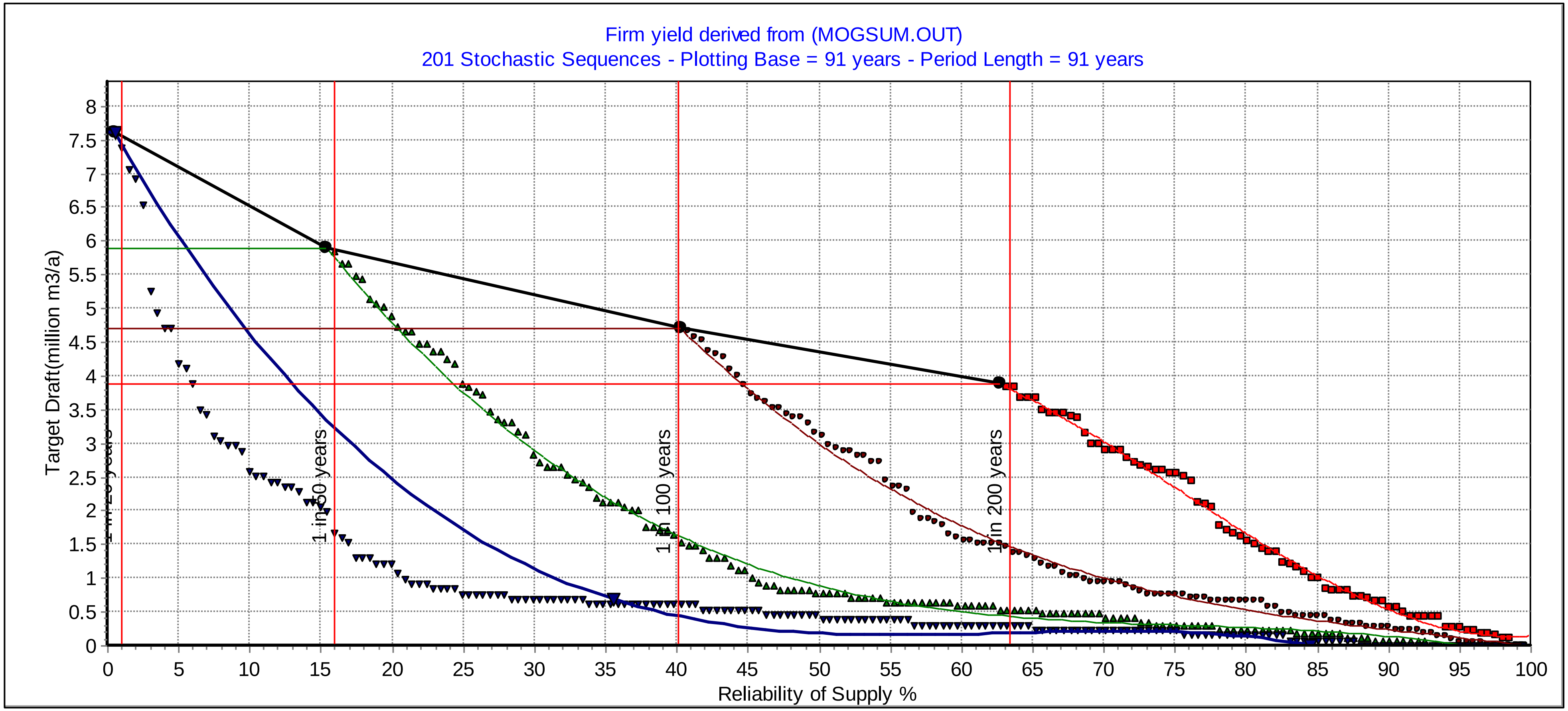

Figure G.12 Long-term yield-reliability characteristics curve with EWR: Doorndraai Dam

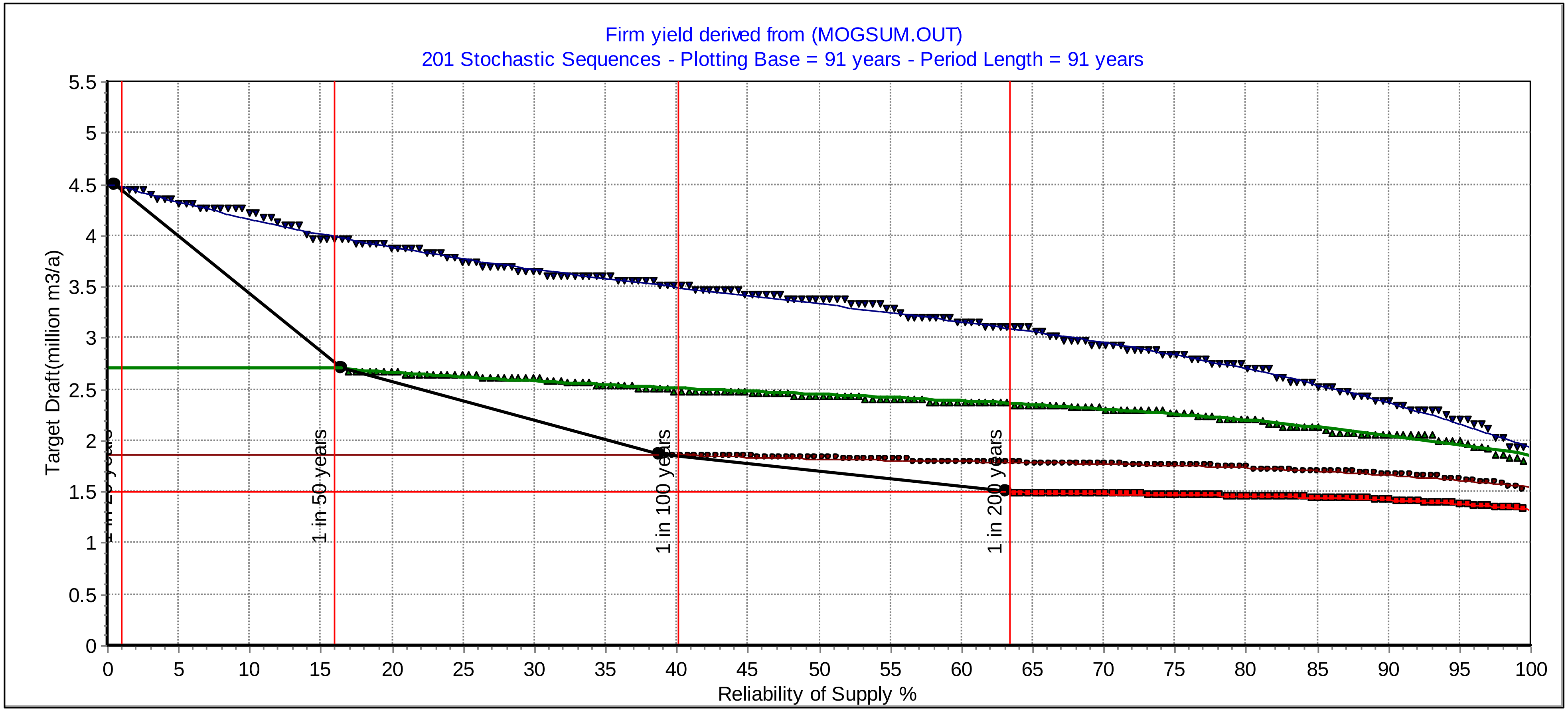

Figure G.13 Long-term yield-reliability characteristics curve with EWR: Glen Alpine Dam

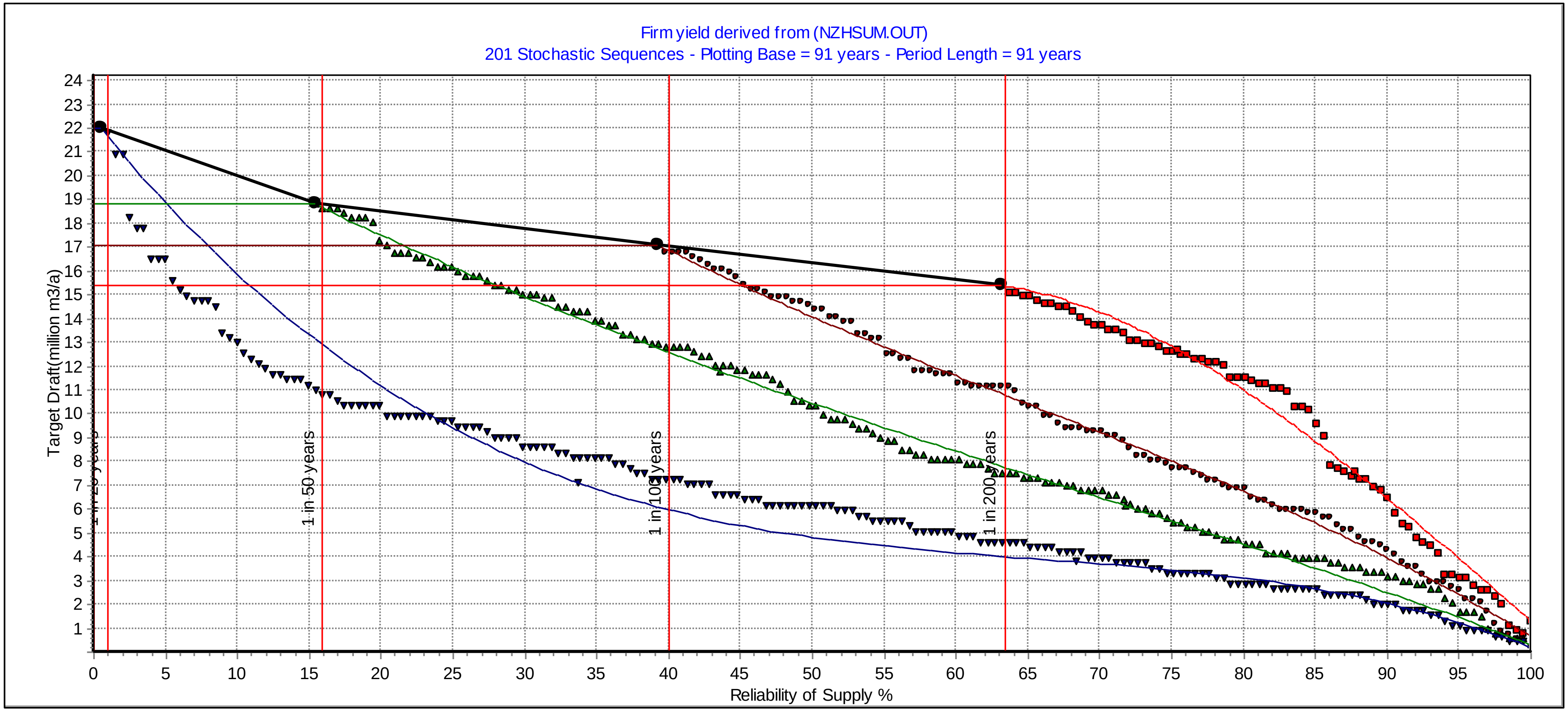

Figure G.14 Long-term yield-reliability characteristics curve with EWR: Nzhelele Dam

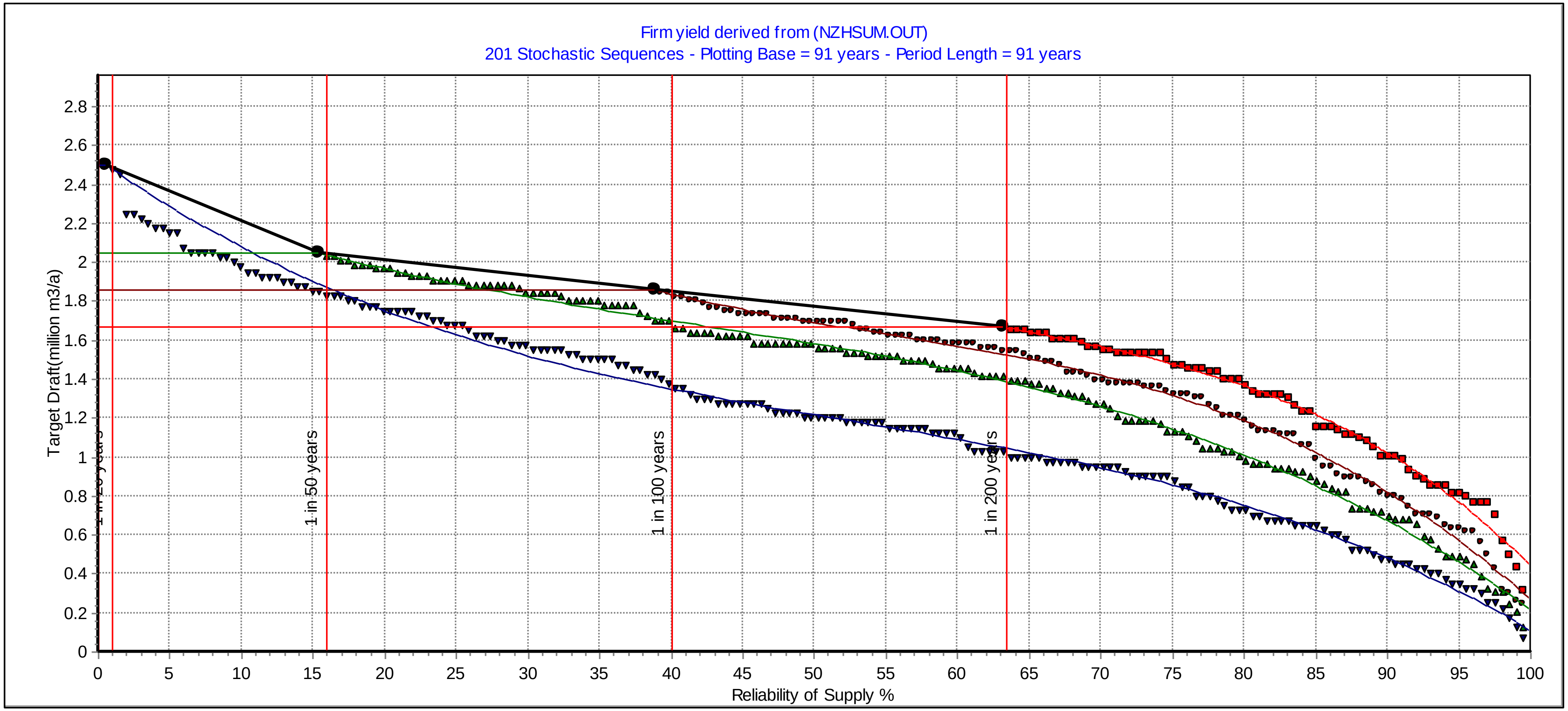

Figure G.15 Long-term yield-reliability characteristics curve with EWR: Mutshedzi Dam

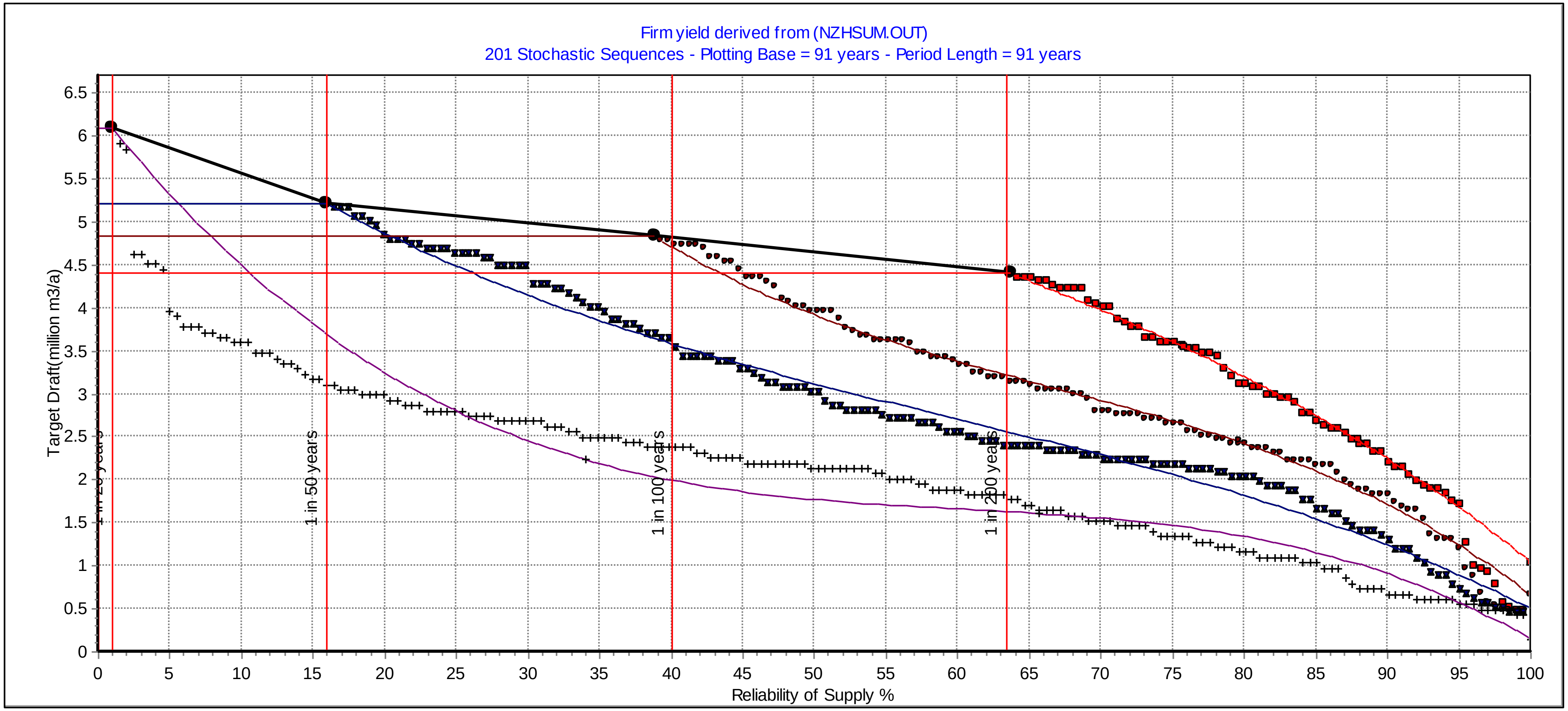

Figure G.16 Long-term yield-reliability characteristics curve with EWR: Luphephe Dam