DWS report number: P WMA 03/X22/00/6718/5

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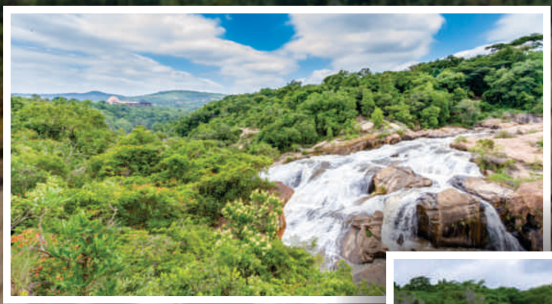
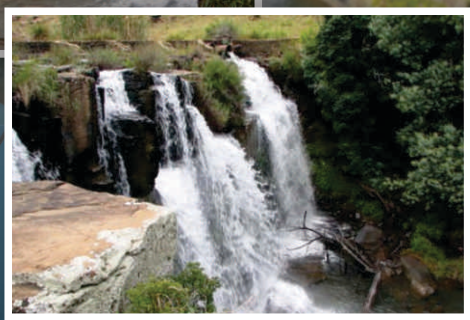
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY STUDY FOR THE MBOMBELA MUNICIPAL AREA

Water Resources Analysis Report



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FEBRUARY 2021

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water & sanitation

Department:
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CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WATER RESOURCES ANALYSIS REPORT (FINAL)

FEBRUARY 2020

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CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WATER RESOURCES ANALYSIS REPORT

(FINAL)

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LIST OF STUDY REPORTS

Report Name	Report Number	DWS Report Number
Inception	1	P WMA 03/X22/00/6718
Economic Growth and Demographic Analysis	2	P WMA 03/X22/00/6818
Water Requirements and Return Flows	3	P WMA 03/X22/00/6918
Water Conservation and Water Demand Management	4	P WMA 03/X22/00/6718/4
Water Resources Analysis	5	P WMA 03/X22/00/6718/5
Infrastructure and Cost Assessment	6	
Updated Reconciliation Strategy	7	
Executive Summary: Updated Reconciliation Strategy	8	

Title:	**Water Resources Analysis Report**
Authors:	**Study Team**
Project Name:	**Continuation of Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area**
DWS Report No:	**P WMA 03/X22/00/6718/5**
Status of Report:	**Final Report**
First Issue:	**February 2020**

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LIST OF ABBREVIATIONS AND ACRONYMS

BBR	Bushbuckridge
BJE	Black Jills Engineers Pty Ltd.
CoM	City of Mbombela
DARDLEA	Department of Agriculture, Rural Development, Land & Environmental Affairs
DM	District Municipality
DWA	Department of Water Affairs (now DWS)
DWAF	Department of Water Affairs and Forestry (now DWS)
DWS	Department of Water and Sanitation
EWR	Ecological Water Requirement
FSC	Full Supply Capacity
GRA	Groundwater Resource Assessment
GRIP	Groundwater Resource Information Project
HFY	Historic Firm Yield
IAPs	Invasive Alien Plants
IB	Irrigation Board
ISDP	Internal Strategic Development Plan
IUCMA	Inkomati-Usuthu Catchment Management Agency
IWAAS	Inkomati Water Availability Assessment Study
iX	iX Engineers Pty Ltd.
JV	Joint Venture
KLP	Klipkopje, Longmere, Primkop Dams
LM	Local Municipality
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MEA	Mean Annual Evaporation
NGIS	National Groundwater Monitoring Network
NGS	National Groundwater Strategies
NWRP	National Water Resource Planning
PSP	Professional Services Provider
SDIP	Service Delivery Implementation Plan
S-Pan	Simons Pan
StraSC	Strategy Steering Committee
TSG	Technical Support Group
V&V	Validation and Verification
WAP	Water Allocation Plan
WfW	Working for Water
WReMP	Water Resources Modelling Platform
WRP	WRP Consulting Engineers Pty Ltd.
WRPM	Water Resources Planning Model
WRSM	Water Resources Simulation Model
WRYM	Water Resources Yield Model

WSA	Water Service Authority
WSDP	Water Services Development Plan
WSP	Water Services Provider
WSS	Water Supply Scheme
WTW	Water Treatment Works
WWTW	Waste Water Treatment Works
WUA	Water User Association

LIST OF UNITS AND SYMBOLS

ha	Hectare
l/c/d	Litres per Capita per Day
km^2	Square Kilometres
Mℓ/d	Mega Litres per Day
m^3/a	Cubic Metres per Annum
mcm/a	Million Cubic Metres per Annum
$m^3/ha/a$	Cubic Metres per Hectare per Annum
$m^3/km^2/a$	Cubic Metres per Square Kliometre per Annum
million m^3/a	Million Cubic Metre per Annum
m^3/s	Cubic Metres per Second
%	Percentage

EXECUTIVE SUMMARY

Introduction

The Continuation of Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area (this Study) followed on the *Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area (DWA, 2014)*. The overall objective of this Study was to systematically update, improve, and extend the Water Resource Reconciliation Strategy to cover the entire Crocodile (East) and Sabie Sub-Catchments, in order for the Strategy to remain relevant, technically sound, economically viable, socially acceptable and sustainable. The objective of this report was to determine the water resources availability at the required assurance of supply in the Study Area.

Overview of Study Area

The Study Area includes both the Crocodile (East) and the Sabie Sub- Catchments, which form part of the Ehlanzeni District Municipality (DM). The focus of this study was on the City of Mbombela Local Municipality (CoM LM) (centre of the Study Area), former Umjindi LM (South), which was recently amalgamated with the CoM LM, and Bushbuckridge (BBR) LM (North). The remainder of the Study Area incorporates parts of the Emakhazeni LM (West), Thaba Chweu LM (North-West) and Nkomazi LM (South-East), which are situated and form part of the Crocodile (East) and Sabie Sub- Catchments.

The confluence of the Crocodile (East) River and Sabie River, which are the main rivers in the Study Area, is in neighbouring Mozambique. These two rivers are both trans-boundary waterways and are therefore governed by an international treaty stating the minimum flows that are required to flow into the neighbouring country Mozambique.

The two largest dams in the Study Area are the Inyaka Dam in BBR LM, Kwena Dam in the Thaba Chweu LM, as well as smaller dams in the CoM LM such as Witklip Dam, Longmere Dam, Klipkopjes Dam, Primkop Dam and Da Gama Dam.

Background and Approach

This report provides an overview and summary of the water resources of the Study Area. The report summarises the hydrology used to determine the water resources availability as well as documenting the updates carried out to the water resources models used, including updated current water requirements and projections, environmental water requirements (EWRs), infrastructure components and operating rules. Water resources analyses were undertaken to determine the capability in terms of yield of the existing water resources. Both historical and stochastic yield analyses were undertaken and yields are therefore quoted in terms of assurance of supply. Furthermore, scenario analyses were undertaken including an assessment of the current situation as well as future possibilities of water augmentation options.

Hydrology

The hydrology developed as part of the Inkomati Water Availability Assessment Study (IWAAS) (DWAF, 2009) has been used in the water resources analyses Task of this Study. The hydrology covers a period from 1920 to 2004 and has been produced for 140 delineated quinary catchments. During the execution of this work, the Inkomati Usuthu Catchment Management Agency (IUCMA) carried out a Study to update and extend the IWAAS hydrology to cover the historical period 1920 to 2016. Unfortunately, the results of the hydrology update were not available in time to be incorporated into this Study. The following Table provides a summary of the hydrological data used per tertiary catchment.

Table i: Hydrology Summary

Major River	Tertiary Catchment	IWAAS (maint.) MAR (million m^3/annum)
Sand	X32	135.96
Sabie	X31	526.68
Sabie	X33	12.51
Kaap	X23	204.22
Crocodile	X21	467.24
Crocodile	X22	359.38
Crocodile	X24	106.62

Water Requirements

Water requirements determined as part of a previous Task of this Study were used in this water resources analyses Task. The following Table provides a summary of the water requirements per user sector used.

Table ii: Water Requirement Summary

User	Catchment	2018 Requirement (million m^3/annum)
Urban	Sabie/Sand	65.86
Urban/industrial	Crocodile	62.59
Irrigation	Sabie/Sand	125.8
Irrigation	Crocodile	466.6
Afforestation	Sabie/Sand	89.7
Afforestation	Crocodile	157.5

User	Catchment	2018 Requirement (million m^3/annum)
Alien vegetation	Sabie/Sand	31.6
Alien vegetation	Crocodile	32
EWR	Sabie	18.5% of natural flows
EWR	Sand	30.8% of natural flows
EWR	Crocodile	12.5% of natural flows
International obligation	Crocodile	37

Infrastructure

The main infrastructure components located in the Study Area weren simulated in the water resources models. These include major dams, smaller farms dams lumped together as dummy dams as well as potential future dams. The potential future infrastructure options assessed are the Boschjeskop and Mountain View Dams in the Crocodile Catchment, the Dingleydale and New Forest Dams in the Sand Catchment and the raising of Primkop Dam in the White River catchment. The inter-catchment transfer linkages were also included in the simulations, namely, the transfer from the Lomati River for Barberton and the supply from the Sabie River to Nsikazi North. The transfer from the Sabie catchment to the north into the Sand catchment was also included.

Operating Rules

Operating rules in the form of drought restriction rules and dam release rules were obtained from the IUCMA and were included in the analyses. The rules were tested to ascertain their suitability and impact on the users' assurance of supply. The results indicate that the existing drought restriction rules for the Crocodile and Sabie systems are not providing sufficient water to the users at an adequate assurance.

Alternative drought restriction rules were produced using the results from the short-term yield analyses undertaken in the catchments. The results of the simulations using the alternative rule show an improved supply to users, as well as an improved use of dam resources.

The results of the raised Primkop simulation highlight the need to revisit the release rules for the White River Dams should this intervention occur. The typical approach to release rules is to store water in the upstream Dams (in this case Klipkopje Dam) for as long as possible in order to capture the most river runoff in the downstream dams.

Water Resources Yields

The Water Resources Yield Model (WRYM) has been used to determine the yield capabilities of the various dams and systems. The yields were compared with previous study results. Both historic, short and long term stochastic yield analyses were undertaken. The following Tables provide a summary of the yield analyses results.

Table iii: Yield Results Summary

Dam/System	Historic Firm Yield (million m^3/annum)	1 in 50 year (98%) Long Term Stochastic Yield (million m^3/annum)
Witklip Dam	8.1	8.6
Klipkopje, Longmere, Primkop Dams	14.0	15.9
Kwena Dam	49.5	-
Crocodile System	186.7	184.7
Inyaka Dam	21.3	24.1
Potential Boschjeskop	31.2	-
Potential Mountain View	78.1	-
Potential New Forest	19.6	-
Potential Dingleydale	20.6	-

In order to determine the water resources capabilities of the system at various assurance of supply levels, stochastic yield analyses are undertaken. In addition, varying starting storage levels of the dams are analysed ranging from 100% to 10% in order to incorporate the dam storage levels into the determination of the water resources capabilities. This is referred to as the short term yield capabilities of the system, or short term curves.

Table iv: Short Term Yield Results: Witklip Dam

	Yield million m^3/annum at indicated Recurrence Interval					
Starting storage (as % of live FSC)	1:200	1:100	1:50	1:20	1:10	1:4
100	8.39	8.89	9.55	10.50	11.91	13.97
80	7.66	8.45	8.94	9.96	11.43	13.53
60	6.96	7.62	8.04	9.28	10.42	12.95
40	6.30	6.59	7.00	7.92	8.96	10.93
20	4.85	5.22	4.59	6.27	6.92	8.19
10	3.59	3.90	4.29	4.66	4.97	5.85

Table v: Short Term Yield Results: Klipkopje, Longmere, Primkop Dams

	Yield million m³/annum at indicated Recurrence Interval					
Starting storage (as % of live FSC)	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	15.54	16.18	17.47	19.14	21.11	24.60
80	14.65	15.96	17.24	18.13	20.11	23.84
60	13.11	14.18	15.56	15.27	19.19	23.01
40	11.00	11.76	12.88	11.79	17.43	20.14
20	8.80	9.74	10.75	11.79	12.58	14.03
10	6.40	6.74	7.45	8.30	9.18	10.72

Table vi: Short Term Yield Results: Crocodile System

	Yield million m³/annum at indicated Recurrent Intervals					
Starting storage (as % of live FSC)	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	185.83	194.90	209.10	227.91	252.82	298.77
80	169.45	178.58	203.83	228.75	237.50	287.73
60	157.31	181.49	193.57	200.83	240.83	275.39
40	108.65	131.39	185.96	222.98	235.31	242.72
20	96.66	117.77	128.32	118.23	126.18	148.54
10	33.00	35.53	38.57	43.00	47.70	52.75

Table vii: Short Term Yield Results: Inyaka Dam

	Yield million m³/annum at indicated Recurrent Intervals					
Starting storage (as % of live FSC)	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	33.84	36.58	39.22	44.25	49.89	62.37
80	28.84	32.54	34.50	39.86	47.13	57.48
60	23.55	25.71	28.27	34.59	42.06	51.27
40	15.79	19.16	23.21	28.76	34.42	4.02
20	6.79	8.98	13.52	18.88	24.70	35.34
10	2.00	4.27	6.18	10.77	13.55	16.84

Scenario Analysis

The Water Resources Planning Model (WRPM) has been used to undertake scenario analyses for the various systems. The existing drought restriction operating rules based on dam levels were configured into the WRPM in order to assess their impacts on the users. Alternative operating rules using the short term yield capabilities of the systems were then analysed with the WRPM. The WRPM results highlight, for most of the systems, the poor assurance of supply that the majority of users in the catchments are exposed to. The water resources availability is too low compared with the existing requirements on the systems.

Groundwater

A desktop groundwater assessment has been undertaken as part of this Task whereby all information from previous groundwater assessments has been summarised. The IUCMA is currently undertaking a more detailed Study on groundwater availability for further use in the Study Area. The general outcome from most of the previous studies is that further use of groundwater resources should be undertaken with caution as it is believed that abstracting additional groundwater will result in a reduction in the surface water availability due to the groundwater-surface water interactions.

Conclusions and Recommendations

It can be concluded from the water resources analyses work undertaken, that the assurance of supply to water users in the Sabie and Crocodile catchments is well below the typical levels that are provided for in other catchments in the country. The imbalance between water resources availability and water allocations/requirements is unprecedented. For the Sabie catchment, the yield for Inyaka Dam including the EWR releases is not sufficient to supply the existing urban requirements, without any future growth on the system or the reinstatement of unused irrigation allocations. The Crocodile catchment can accommodate some growth in domestic requirements, however, this is at the expense of the irrigators who will obtain their water at an even lower level of assurance as the urban requirements grow. It is recommended that augmentation of water resources in the Sabie and Crocodile system in the form of new dams be fast tracked in order to supply the growing urban demands in the area, as well as to provide an improved assurance of supply to the existing irrigators.

1 INTRODUCTION

1.1 Background to this Study

The Department of Water and Sanitation (DWS) commissioned a study on the development of a Water Reconciliation Strategy for Mbombela Municipal Area (2013-2015) to inform the planning and implementation of water resource management interventions necessary to reconcile future water requirements and water use patterns up to a period of thirty years.

For the Reconciliation Strategy for the Mbombela Municipal Area, referred to as the Strategy hereafter, to be implemented, and for the Strategy to remain relevant to properly fulfil its purpose into the future it has to be dynamic. Hence, the water balance has to be continuously monitored and the developed Strategy has to be regularly updated and maintained. This would ensure that planned intervention options identified for implementation will also be revised where necessary to consider any changes that may have potential impacts on the projected water balance.

The DWS commissioned the Implementation and Continuation of the Water Reconciliation Strategy for the Mbombela Municipal Area, referred to as this Study, to facilitate a process to maintain the relevance of the Strategy.

1.2 Objectives of this Study

The overall objective of the Study was to systematically update and improve the Strategy in order for the Strategy to remain technically sound, economically feasible, as well as socially and environmentally acceptable and sustainable. In addition to the Mbombela Municipal Area, smaller towns in the neighbouring catchments were also considered at a desktop level of detail, namely Machadodorp, Waterval Boven, Dullstroom, Sabie, Graskop, Malelane, Hectorspruit and Komatipoort, which is an extension of the footprint of the 2015 Strategy.

This report provides an overview and summary of the water resources of the Study Area. The report summarises the hydrology used to determine the water resources availability as well as documenting the updates carried out to the water resources models used, including updated current water requirements and projections, environmental water requirements (EWRs), infrastructure components and operating rules. Water resources analyses were undertaken to determine the capability in terms of yield of the existing water resources. Both historical and stochastic yield analyses were undertaken and yields are therefore quoted in terms of assurance of supply. Furthermore, scenario analyses were undertaken including an assessment of the current situation as well as future possibilities of water augmentation options. The results of this water resources analyses Task were used as inputs in the formulation of the Final Strategy prepared for the Study Area.

1.3 Study Area

The Study Area included both the Crocodile (East) and the Sabie Sub- Catchments, which form part of the Ehlanzeni District Municipality (DM) as illustrated in the Study Area map in **Figure 1.1**. The focus of this study was on the City of Mbombela (CoM) Local Municipality (LM) (centre of the Study Area), former Umjindi LM (South), which was recently amalgamated with the CoM LM, and Bushbuckridge (BBR) LM (North). The remainder of the Study Area incorporated parts of the Emakhazeni LM (West), Thaba Chweu LM (North-West) and Nkomazi LM (South-East), which are situated and form part of the Crocodile (East) and Sabie Sub- Catchments.

Two major water courses traverse the two Sub- Catchments in the Study Area, which are the Crocodile (East) River and the Sabie River. The Crocodile (East) River, originates at Dullstroom and joins the Lunsklip River before entering the Kwena Dam from which it flows through the Schoemanskloof Mountains. The Crocodile (East) River joins with a major tributary, the Elands River, which originates at Machadodorp and flows through Waterval Boven before its confluence with Ngodwana River. The Crocodile and Elands rivers have their confluence at Montrose. The river meanders through the catchment from West to East, where it joins with smaller tributaries such as the Nels River, Wit River, Kaap River and Nsikazi River. The Crocodile River finally merges with the Komati River close to Komatipoort, where it becomes the Inkomati River. A major tributary of the Sabie River is the Sand River, which has its origin on the border of Thaba Chweu LM and BBR LM and the Marite River, which is regulated by releases from the Inyaka Dam. The Sabie River impounds the Corumana Dam in Mozambique, which is upstream of the confluence with the Sabie River and the Inkomati River within Mozambique, where it discharges into the Indian Ocean as the Inkomati River to the north of the City of Maputo, Mozambique.

There are two major dams in the Study Area, which are the Inyaka Dam in BBR LM, Kwena Dam in the Thaba Chweu LM, as well as smaller dams in the CoM LM such as Witklip Dam, Longmere Dam, Klipkopje Dam, Primkop Dam and Da Gama Dam.

The Sappi Ngodwana Mill is a major industrial water user in the Crocodile (East) Sub-catchment, which abstracts water from the Ngodwana Dam, on the Ngodwana River, and obtains additional water supply from former irrigation licenses. Other major industrial water users are the TSB Malelane sugar mill in Nkomazi LM in the Lower Crocodile (East) Tertiary Catchment and smaller mining operations in the former Umjindi LM.

The largest water user in the Crocodile (East) Sub-Catchment is the irrigation sector (467 million m^3/annum), followed by commercial afforestation (158 million m^3/annum). The shared watercourses with Mozambique are regulated by an international water sharing agreement (IIMA, 2002).

There are water transfers from the neighbouring Lomati Catchment to support the towns of Barberton and Shiyalongubo. There is also a transfer from the Sabie Sub- Catchment to the Crocodile (East) Sub-Catchment to support the Nsikazi North demand centre.

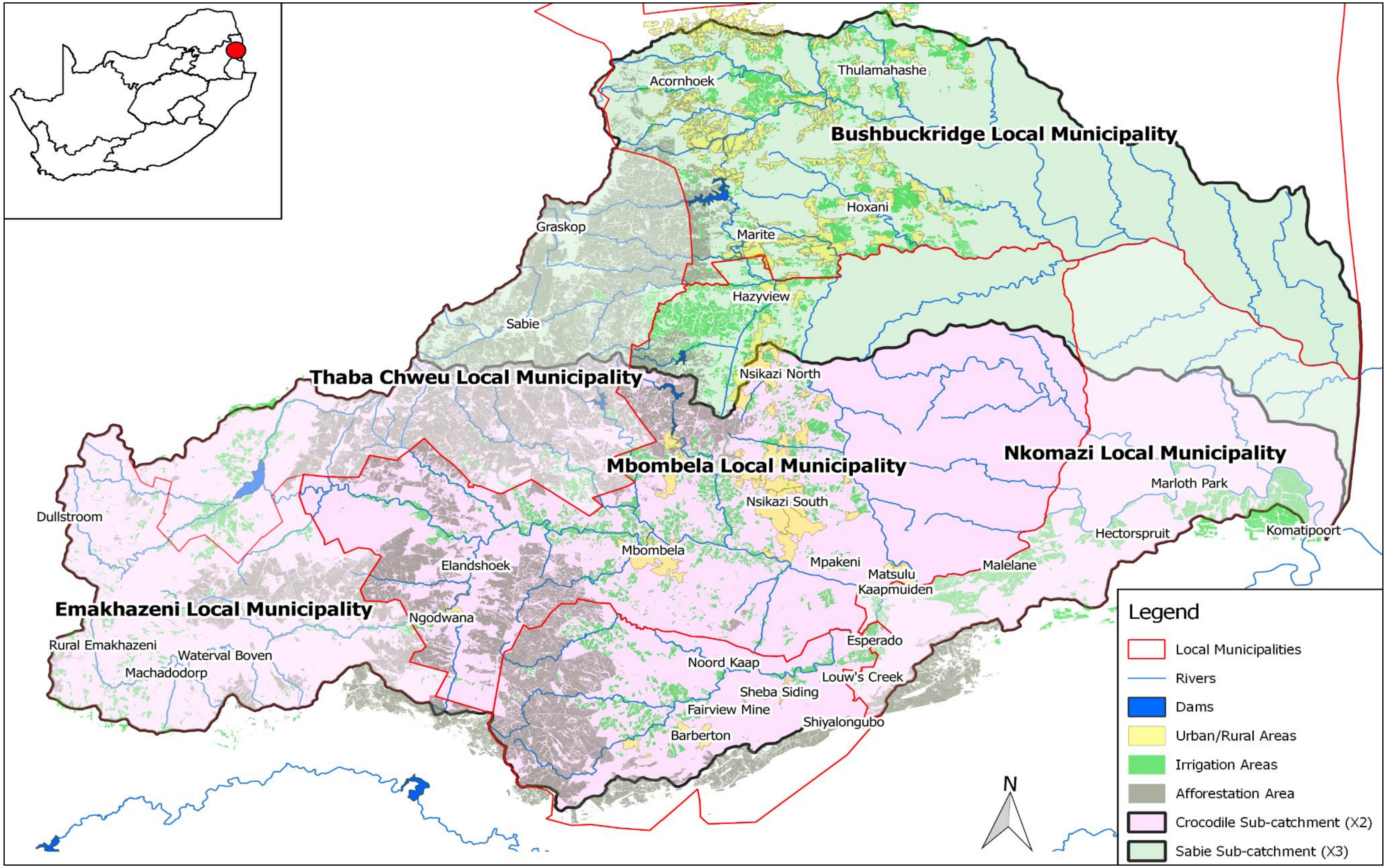


Figure 1.1: Map of the Study Area

1.4 Purpose and Structure of this Report

This report provides an overview and summary of the water resources of the study area. The purpose of this report was to:

- Summarise the hydrology used to determine the water resources availability in the Study area.
- Document the updates carried out to the water resources models as part of this study including updated current water requirements and projections, environmental water requirements (EWRs) infrastructure components and operating rules.
- Present the water resources capability in terms of yield of the various existing water resources.
- Document and describe scenarios undertaken and analysed of the current situation as well as future possibilities of water augmentation options.

The report is structured as follows:

- **Section 1** provides a formal overview of the Study Area, this strategy and the purpose and structure of this report.
- **Section 2** presents an overview of previous water resources studies were undertaken in the Study area over the past ten years and that are relevant to the work undertaken as part of this task.
- **Section 3** provides a summary of all the related aspects that have an effect on the water resources such as, hydrological and climate data, water resources infrastructure, water requirements including Environmental Water Requirements and operating rules.
- **Section 4** presents the yield analyses that were undertaken in the study area, both the approach and the results.
- **Section 5** covers the scenario planning analyses that were undertaken.
- **Section 6** provides an overview of the Groundwater assessment that was undertaken.
- **Section 7** contains the conclusions and recommendations to this report.
- **Section 8** provides updated information and additional scenario analyses results relating to information provided by the IUCMA subsequent to the completion of the initial work.
- **Section 9** indicates the study references.

2 OVERVIEW OF PREVIOUS WATER RESOURCES STUDIES

2.1 IWAAS

Though previous hydrological studies had been undertaken in the Crocodile East and Sabie/Sand River catchments, the Inkomati Water Availability Assessment Study (IWAAS) has been selected as the point of departure of this Section outlining previous studies. The IWAAS (DWAF, 2009) was completed in 2009, and covered the entire Crocodile East, Sabie/Sand and Komati Catchments. Detailed rainfall-runoff calibrations using the WRSM2000/Pitman Model were carried out, and the hydrology was produced for the hydrological years dating 1920-2004. A complete landuse assessment was undertaken in order to produce the hydrology.

The DWS standard Water Resources Yield Model (WRYM) was configured and yield analyses were undertaken for the major dams in the catchments. The IWAAS was considered a comprehensive study, and all future study results are compared with the IWAAS as a reference.

2.2 IWAAS Maintenance

Following the IWAAS which was completed in 2009, a “Maintenance” Study took place which was completed in 2012 (DWA, 2012). Some changes and updates were made to the hydrology. The review of the IWAAS hydrology of the Crocodile East catchment was prompted by data errors related to S-pan and A-pan evaporation in some X22 sub-catchments and all X23 sub-catchments. The hydrological record period remained 1920 – 2004 in the Maintenance Study.

2.3 Mbombela Reconciliation Strategy Phase 1

The Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area (DWA, 2014) purely focused on the CoM LM and its demand centres. The water resources information quoted in the Strategy resulted from the IWAAS, and it appears that no updated water resources analyses were undertaken. Confirmation was obtained from the Phase 1 Study Team, which stated that the bulk of the water balances were undertaken using spreadsheets, and water resources modelling was not carried out (Mallory, 2018).

2.4 Sabie and Sand River Reconciliation Strategy

The Water Reconciliation Strategy of the Schemes in the Sabie and Sand River System in the Bushbuckridge LM was completed in 2016, (DWS, 2016). The water balances presented in the Strategy relate to water allocations and Water Treatment Works (WTW) Capacities, and it does not appear that specific water resources analyses were undertaken as part of the Study.

2.5 Classification Study

The Determination of Water Resource Classes and Associated Resource Quality Objectives in the Inkomati Water Management Area, known as the Classification Study (DWA, 2014b) produced recommended EWRs for the Study Area. An assessment of the Study, and subsequent communication with the Study Team, determined that water resources analyses was carried out using the Water Resources Modelling Platform (WReMP). It was stated that the model configuration base of the IWAAS had been adjusted to a finer resolution of detail due to the necessity to add additional nodes for environmental flow assessment purposes. It was recommended that the previous version of the WRYM (developed in the IWAAS) was better suited for the Reconciliation Study and that the Classification WReMP configuration be ignored (Mallory, 2018). The final Gazetted EWRs from the Classification Study have, however, been used in this Study.

2.6 White River Specific Studies

Operating rules for water supply and drought management of the White River System were developed in 2015 (IUCMA, 2015). Only the White River Dams of Klipkopje, Longere and Primkop were focused on, as well as the Witklip Dam. The WReMP was used to develop the operating rules. The results provided guidance as to varying dam levels at which various size restrictions are required for the domestic and irrigation sectors.

A brief hydrological update was carried out on the White River Catchment upstream of Primkop Dam, specifically quaternary catchments X22G and X22H (IUCMA, 2017). The hydrological update was undertaken for the IUCMA and was completed in 2017. It was stated that the IWAAS configuration was improved on with more accurate information. The hydrology was extended to cover the period 1920 to 2015 (hydrological years). The operation of the catchment was documented in the report.

2.7 Crocodile East & Kaap Hydrology Updates

In a parallel process to this Reconciliation Strategy update, a Study was undertaken to update the hydrology of the entire Crocodile East Catchment, including the Kaap River (IUCMA, 2019d). The IWAAS hydrology was updated to cover the period 1920 to 2016. Unfortunately, the final hydrology was not completed in time for use in this Study and it was agreed that the hydrology should be included in further Reconciliation Strategy updates at a later stage. The Validation and Verification of landuse in the catchment has not been completed, and the hydrology update has therefore been based on assumptions related to the landuse.

Prior to the acceptance and further use of the updated hydrology, it is recommended that the following take place:

- Verification of stochastic hydrology;
- Updated assessment of landuse including farm dams;
- Configuration of updated information and hydrology into the WRYM;
- Yield checks of major dams and comparisons / explanations with previous IWAAS results.

2.8 Water Allocation Plans

During the finalization of the Water Resources Task documented in this report, it was brought to the attention of the Study Team that the IUCMA had prepared Water Allocation Plans (WAPs) for both the White River (IUCMA, 2019b) and Kaap (IUCMA, 2019c) catchments. The updated hydrology was used in the WAPs. The WAPs present various scenarios to assist with rectifying the low assurance of supply to users in the catchments. The WReMP was used to assess the scenarios.

3 ASPECTS IMPACTING WATER RESOURCES

3.1 Hydrology

3.1.1 Catchment Delineation and Natural Flows

The catchments included in this Study are summarised in **Table 3.1** to **Table 3.4**. The quinary catchment delineations were maintained since the original IWAAS hydrology subdivisions. **Figure 3.1** presents a map of the catchments and sub-catchment delineations. In total, there are 140 sub-catchments. The Mean Annual Runoffs provided in the Tables are as per the IWAAS Maintenance Study (DWA, 2012) and cover the time period 1920 to 2004.

Table 3.1: Sand River Hydrology

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km^2)	IWAAS (maint.) MAR (million m^3/annum)
Sand	X32	X32A	X32A1	37.9	12.96
			X32A2	72.2	13.86
		X32B	X32B1	54.1	9.99
		X32C	X32C1	15.9	1.45
			X32C2	13.1	0.98
			X32C3	10.9	1.16
			X32C4	57.5	4.21
			X32C5	66.6	4.53
			X32C6	59.2	3.13
			X32C7	18.1	0.89
		X32D	X32D1	62.0	22.39
			X32D2	35.9	5.40
		X32E	X32E1	28.3	6.39
			X32E2	51.2	6.86
		X32F	X32F1	65.2	4.20
			X32F2	14.2	1.07
			X32F3	26.1	2.06
			X32F4	57.5	2.64
		X32G	X32G1	198.3	7.42
			X32G2	112.2	3.94
			X32G3	28.9	0.94
		X32H	X32H1	199.7	4.87
			X32H2	281.5	7.59
		X32J	X32J1	232.9	4.71
			X32J2	110.9	2.23
			X32J3	7.4	0.08
Total					**135.96**

Table 3.2: Sabie River Hydrology

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km²)	IWAAS (maint.) MAR (million m³/annum)
Sabie	X31	X31A	X31A1	174	80.24
			X31A2	55.7	16.62
		X31B	X31B1	198	76.81
		X31C	X31C1	54	31.50
			X31C2	99.5	38.78
		X31D	X31D2	99.5	22.46
			X31D3	89.9	17.06
		X31E	X31E1	97.9	38.09
			X31E2	80.0	33.15
			X31E3	35.8	8.64
		X31F	X31F1	92.6	41.26
		X31G	X31G1	115.8	26.33
			X31G2	10.3	2.65
			X31G3	41.6	6.98
		X31H	X31H1	45.3	16.77
			X31H2	16.0	3.54
		X31J	X31J1	153.7	26.99
		X31K	X31K1	80.2	2.64
			X31K2	100.4	2.50
			X31K3	50.5	3.00
			X31K4	260	6.74
		X31L	X31L1	66.9	3.24
			X31L2	69.7	3.84
			X31L3	158.4	4.76
		X31M	X31M1	214.9	3.88
			X31M2	141.9	2.95
			X31M3	357.1	5.28
	X33	X33A	X33A1	166.8	1.97
			X33A2	434.8	4.12
		X33B	X33B1	317.2	2.95
		X33C	X33C1	178.5	1.24
		X33D	X33D1	311.1	2.24
Total					**539.19**

Table 3.3: Kaap River Hydrology

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km2)	IWAAS (maint.) MAR (million m^3/annum)
Kaap	X23	X23A	X23A1	51.6	15.89
			X23A2	75.2	18.69
		X23B	X23B1	33.9	2.91
			X23B2	97.3	5.64
			X23B3	97.9	5.81
		X23C	X23C1	81.3	24.91
		X23D	X23D1	98.4	22.55
			X23D2	83.4	11.63
		X23E	X23E1	86.7	14.72
			X23E2	93.7	13.26
		X23F	X23F1	142.6	9.25
			X23F2	167	8.21
		X23G	X23G1	75.9	7.99
			X23G2	149.2	10
		X23H	X23H1	81.3	6.26
			X23H2	110.2	9.51
			X23H3	30	3.37
			X23H4	11	0.44
			X23H5	73.5	4.32
Total					**195.36**

Table 3.4: Crocodile East River Hydrology

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km2)	IWAAS (maint.) MAR (million m^3/annum)
Crocodile	X21	X21A	X21A1	124.9	19.2
			X21A2	139.3	17.5
		X21B	X21B1	76.7	13.4
			X21B2	115.8	12.4
			X21B3	185.8	16.6
		X21C	X21C1	162.4	23.5
			X21C2	92.7	9.9
			X21C3	55.9	5.9
		X21D	X21D1	147.9	16.9
			X21D2	71.3	6.4
		X21E	X21E1	209	30.3
			X21E2	136.1	25.7
		X21F	X21F1	206.5	26
			X21F2	190.1	24.9

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km2)	IWAAS (maint.) MAR (million m³/annum)
		X21G	X21G1	132.9	13.7
			X21G2	214.5	25.6
		X21H	X21H1	146.1	39.4
			X21H2	82.8	20.2
		X21J	X21J1	312	53.6
			X21J2	42.6	7.9
		X21A	X21K1	111.7	29.4
			X21K2	106.6	23.9
			X21K3	26.9	5
Crocodile	X22	X22A	X22A1	208.2	56.31
			X22A2	43.1	9.61
		X22B	X22B1	131.2	32.61
			X22B2	95.5	20.18
		X22C	X22C1	46.3	3.24
			X22C2	114.5	13.02
			X22C3	205.4	18.07
		X22D	X22D1	41	11.04
			X22D2	97.3	26.56
			X22D3	136.2	29.26
		X22E	X22E1	16	5.82
			X22E2	48.3	13.95
			X22E3	88.6	19.49
		X22F	X22F1	105.9	9.63
			X22F2	106.5	9.66
		X22G	X22G1	77	23.44
			X22G2	30.5	7.8
		X22H	X22H1	66.2	10.3
			X22H2	90.2	10.65
			X22H3	43.8	3.07
		X22J	X22J1	104.5	8.87
			X22J2	135.4	10.19
		X22K	X22K1	102.7	5.79
			X22K2	156.4	13.91
			X22K3	75.8	9.38
Crocodile	X24	X24A	X24A1	89.3	4.9
			X24A2	159.2	5.9
		X24B	X24B1	35.2	2.1
			X24B2	117.4	6.3
			X24B3	182.4	4.6
		X24C	X24C1	258.9	11.4
			X24C2	26.8	1.3

Major River	Tertiary Catchment	Quaternary Catchment	Quinary Catchments	Area (km2)	IWAAS (maint.) MAR (million m^3/annum)
		X24D	X24D1	25.2	3.5
			X24D2	276.6	18.3
		X24E	X24E1	139.1	4.9
			X24E2	387	9.6
		X24F	X24F1	262.1	7.4
		X24G	X24G1	620	15.3
		X24H	X24H1	672.5	10.2
			X24H2	97	0.9
Total					**955.75**

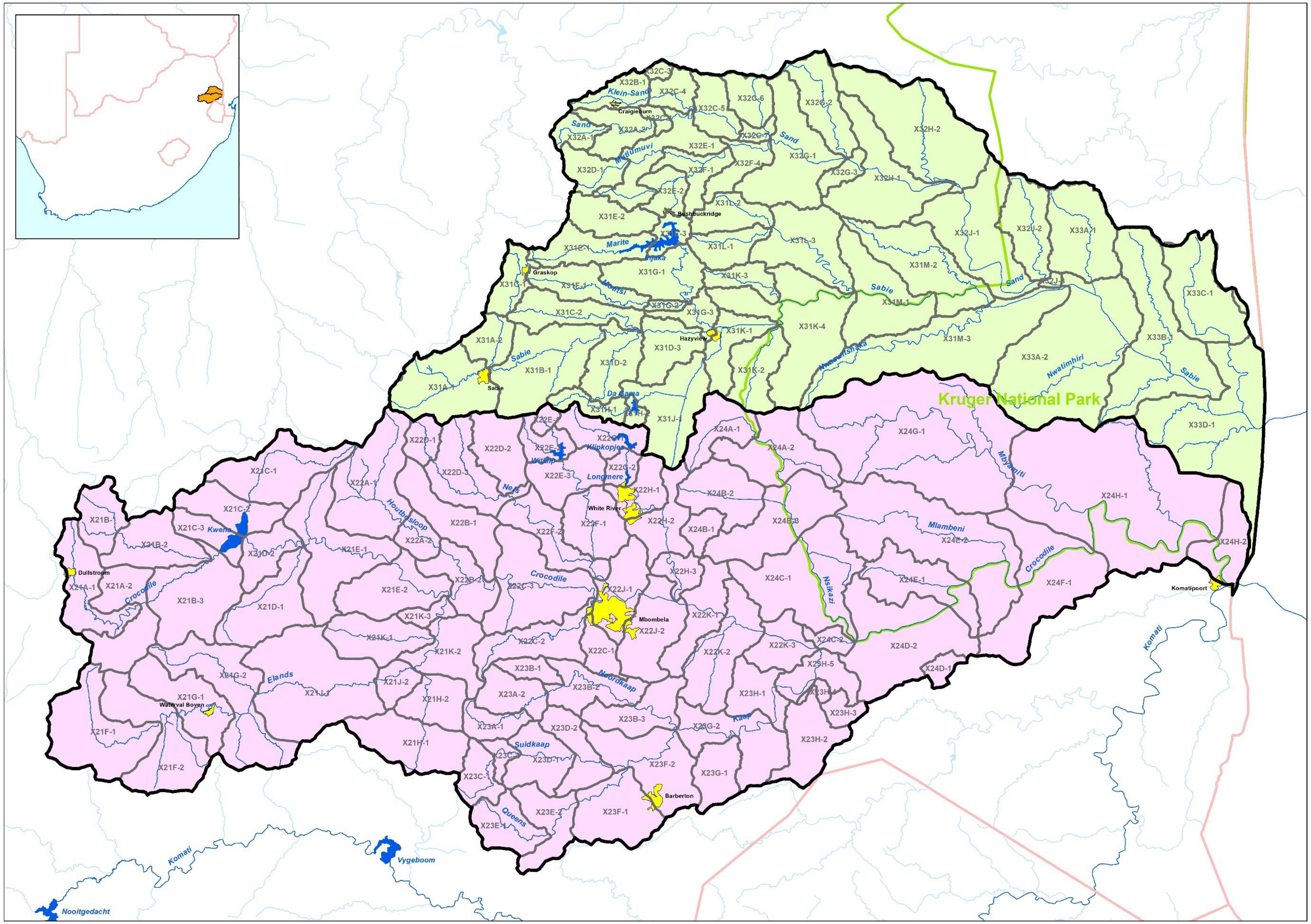


Figure 3.1: Sub-catchments simulated in the Study Area

3.1.2 Rainfall

Each of the 140 sub-catchments have an associated rainfall file. This file represents the rainfall over the historical period (1920 to 2004). **Table 3.5** provides a summary of the Mean Annual Precipitation (MAP) for each sub-catchment. The rainfall data was collected and collated as part of the hydrology assessment of the IWAAS (DWAF, 2009). Detailed evaluation and patching of the rainfall took place as part of that Study.

Table 3.5: Mean Annual Precipitation per sub-catchment (1920-2004)

Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)
X21A1.RAN	793.6	X23A1.RAN	1171.2	X31A1.RAN	1216.9
X21A2.RAN	743.4	X23A2.RAN	1054.5	X31A2.RAN	1243.1
X21B1.RAN	809.0	X23B1.RAN	947.7	X31B1.RAN	1267.7
X21B2.RAN	711.0	X23B2.RAN	816.3	X31C1.RAN	1451.1
X21B3.RAN	666.9	X23B3.RAN	823.7	X31C2.RAN	1220.4
X21C1.RAN	810.3	X23C1.RAN	1126.5	X31D2.RAN	999.9
X21C2.RAN	721.4	X23D1.RAN	871.3	X31D3.RAN	917.5
X21C3.RAN	702.6	X23D2.RAN	742.1	X31E1.RAN	1294.7
X21D1.RAN	757.4	X23E1.RAN	1045.3	X31E2.RAN	1336.0
X21D2.RAN	698.1	X23E2.RAN	989.9	X31E3.RAN	1022.5
X21E1.RAN	830.3	X23F1.RAN	870.3	X31F1.RAN	1337.8
X21E2.RAN	928.7	X23F2.RAN	785.0	X31G1.RAN	985.6
X21F1.RAN	747.8	X23G1.RAN	986.6	X31G2.RAN	1079.0
X21F2.RAN	767.0	X23G2.RAN	838.9	X31G3.RAN	857.6
X21G1.RAN	776.2	X23H1.RAN	879.8	X31H1.RAN	1240.1
X21G2.RAN	808.4	X23H2.RAN	917.6	X31H2.RAN	937.5
X21H1.RAN	1073.2	X23H3.RAN	1018.4	X31J1.RAN	884.5
X21H2.RAN	1051.8	X23H4.RAN	693.6	X31K1.RAN	699.2
X21J1.RAN	911.6	X23H5.RAN	796.0	X31K2.RAN	636.1
X21J2.RAN	968.0	X24A1.RAN	778.3	X31K3.RAN	843.5
X21K1.RAN	1085.3	X24A2.RAN	676.3	X31K4.RAN	645.4
X21K2.RAN	1034.7	X24B1.RAN	807.8	X31L1.RAN	790.9
X21K3.RAN	972.2	X24B2.RAN	772.7	X31L2.RAN	823.1
X22A1.RAN	1001.7	X24B3.RAN	639.2	X31L3.RAN	684.7
X22A2.RAN	908.5	X24C1.RAN	725.5	X31M1.RAN	582.8
X22B1.RAN	999.1	X24C2.RAN	775.7	X31M2.RAN	613.5
X22B2.RAN	917.5	X24D1.RAN	987.3	X31M3.RAN	542.1
X22C1.RAN	853.1	X24D2.RAN	795.5	X32A1.RAN	1265.5
X22C2.RAN	990.3	X24E1.RAN	700.6	X32A2.RAN	983.5
X22C3.RAN	918.7	X24E2.RAN	629.1	X32B1.RAN	966.1
X22D1.RAN	1208.6	X24F1.RAN	659.5	X32C1.RAN	834.5

Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)	Rainfall file name	MAP (mm)
X22D2.RAN	1216.7	X24G1.RAN	594.6	X32C2.RAN	789.8
X22D3.RAN	1107.6	X24H1.RAN	561.1	X32C3.RAN	872.5
X22E1.RAN	1300.1	X24H2.RAN	473.1	X32C4.RAN	832.6
X22E2.RAN	1179.8			X32C5.RAN	761.6
X22E3.RAN	1054.4			X32C6.RAN	705.8
X22F1.RAN	929.7			X32C7.RAN	698.8
X22F2.RAN	931.7			X32D1.RAN	1299.6
X22G1.RAN	1104.3			X32D2.RAN	886.1
X22G2.RAN	1042.6			X32E1.RAN	1055.3
X22H1.RAN	1000.6			X32E2.RAN	833.3
X22H2.RAN	904.8			X32F1.RAN	746.0
X22H3.RAN	801.3			X32F2.RAN	788.5
X22J1.RAN	795.6			X32F3.RAN	799.2
X22J2.RAN	823.2			X32F4.RAN	677.5
X22K1.RAN	788.7			X32G1.RAN	672.3
X22K2.RAN	851.5			X32G2.RAN	662.2
X22K3.RAN	967.9			X32G3.RAN	655.1
				X32H1.RAN	629.1
				X32H2.RAN	645.2
				X32J1.RAN	593.1
				X32J2.RAN	591.0
				X32J3.RAN	544.1
				X33A1.RAN	563.9
				X33A2.RAN	530.0
				X33B1.RAN	524.3
				X33C1.RAN	483.4
				X33D1.RAN	468.5

3.2 Water Resources Infrastructure

3.2.1 Large Reservoirs

Table 3.6 provides a summary of the large storage reservoirs simulated explicitly in the Study Area.

Table 3.6: Large Reservoirs located in the Study Area

Major River	Quaternary Catchment	Reservoir	Full Supply Capacity (million m^3)	Users Supplied
Sabie	X31E	Maritsane Dam	2	Domestic
Sabie	X31E	Inyaka Dam	125	Domestic
Sabie	X31H	Da Gama Dam	13.6	Irrigation
Sand	X32C	Acornhoek	0.1	Irrigation/ Domestic
Sand	X32C	Edinburgh Dam	3.3	Irrigation/ Domestic
Sand	X32F	Orinico Dam	1.9	Irrigation
Croc	X21C	Kwena	158.9	Irrigation/ Domestic/ Industrial
Croc	X21H	Ngodwana	10	Irrigation/ Domestic/ Industrial
Croc	X22E	Witklip	12.7	Irrigation/ Domestic
Croc	X22G	Klipkopje	11.9	Domestic
Croc	X22G	Longmere	4.3	Irrigation/ Domestic
Croc	X22H	Primkop	2	Irrigation/ Domestic
Croc	X23H	Manders	1	Irrigation
Croc	X24D	Spago	2.3	Irrigation/ Domestic

3.2.2 Farm Dams

106 additional lumped “dummy” dams are included in the water resources systems models, to represent groupings of farm dams per quinary catchment. **Table 3.7** provides a summary of these.

Table 3.7: Dummy dams in the Study Area

Major River	Tertiary Catchment	Number of Dummy Dams	Combined Full Supply Capacity (million m^3)
Croc	X21	18	14.04
Croc	X22	22	17.77
Croc	X23	18	9.01
Croc	X24	12	14.25
Sabie	X31	24	24.73
Sand	X32	12	5.18
	Total	106	84.98

3.2.3 Canals and Transfers

There are several canal systems which from part of the White River system (IUCMA, 2015).

These are as follows:

- The Kruisfontein Canal transfers water from upstream of the Witklip Dam into the upper reach of the White River. This water then flows into the Klipkopje Dam. The capacity of this transfer is 0.33 m^3/s. Water is only diverted via this canal if the storage in the Witklip Dam is above 70% of the dam's full supply capacity.
- The White River canal is concrete lined and sources water from the Longmere Dam and supplies the town of White River and irrigators surrounding White River.
- The Ranch Karino and Curlews are two concrete lined canals which branch off from a short section of unlined canal diverted at the Haig weir. They provide water to irrigators.
- The Manchester canal diverts water from the Manchester Dam to supply irrigators within the Manchester Irrigation Board. More recently some of these irrigators' allocations were transferred to domestic use which is pumped from the canal and supplied to Karino.
- Downstream of the Witklip Dam, an upper canal, referred to as the Left Bank canal, diverts water to irrigators as well as the allocation of 0.75 million m^3/annum to White River supplied from Witklip Dam. The lower canal, referred to as the Right Bank Canal, diverts water only to irrigators.

The Champagne, Edinburgh, Dingleydale and New Forest irrigation schemes in the Sand River catchment are supplied by means of diverting run-of-river flows into canals. Some of these systems are in a state of disrepair and need refurbishment, mostly related to the distribution canals and outlet works from the dams. For example, the Champagne canal system is clogged with sand and cannot be used. **Figure 3.2** provides an indication of the locations.

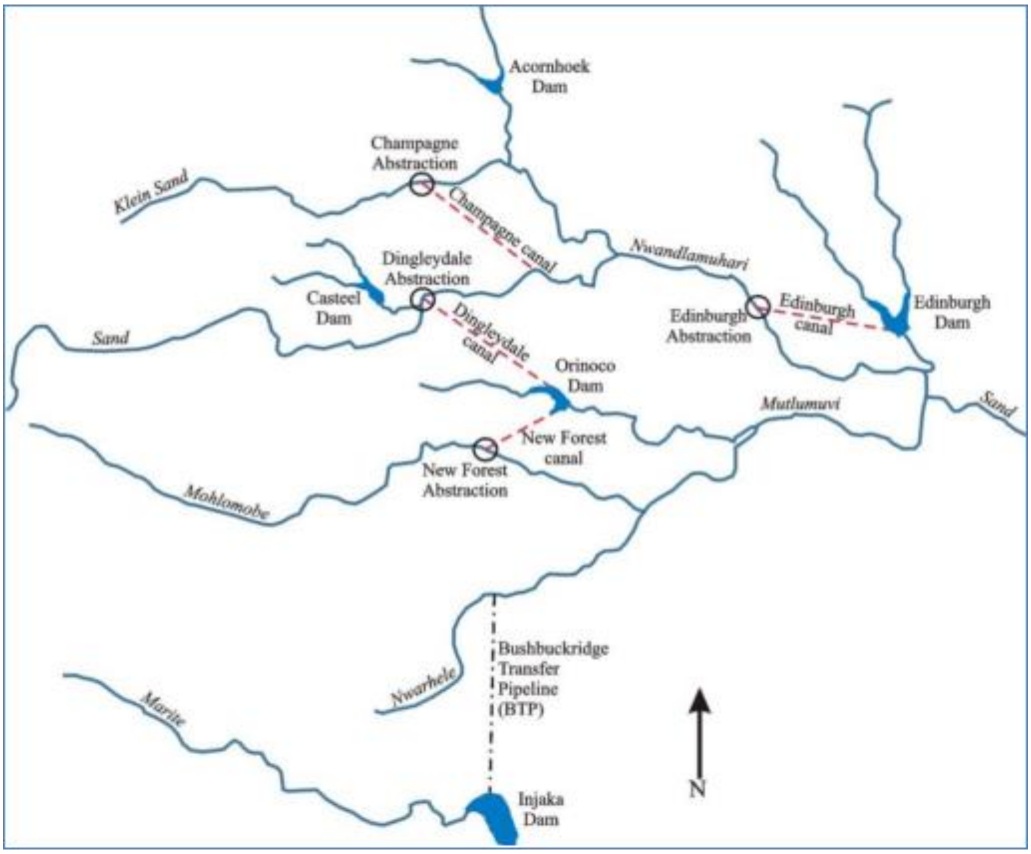


Figure 3.2: Locality of Sabie canals (from IWAAS (DWAF, 2009))

There is a transfer from the Crocodile River to Primkop Dam which supports an allocation of 0.836 million m^3/annum for Emoyeni from the Crocodile River. In addition, part of the White River domestic area is supplied via a transfer from the Nelspruit WTW, abstracting from the Crocodile River.

Barberton has as its source of bulk raw water supply the Lomati River. Water is released from the Lomati Dam which is located in the headwaters of the Lomati River, a major tributary of Komati River. Water is pumped from the dam into the Saddleback tunnel, from where it gravitates via Rimer's Creek to a weir which acts as the balancing reservoir supplying the Rimer's Creek Water Treatment Works which is situated on the southern outskirts of Barberton. The permitted size of this transfer is 2.787 million m^3/annum. (DWAF, 2008).

3.2.4 Potential New Dams

An assessment was undertaken to determine the additional yields that could be contributed by possible new dams in the Study area that were investigated in previous Studies. Two of these dams (Strathmore and Montrose dams) have already been eliminated as viable options in previous Studies as a result of their costs and/or impact on the environment as well as, in the case on Strathmore, its location nearby an existing Epsom Salt Mine. Four new dams were included as part of the water resources analyses Task. These are Boschjeskop and Mountain View Dams in the Crocodile catchment and New Forest and Dingleydale in the Sand catchment. In addition, the raising of Primkop Dam has also been included in the assessment.

Figure 3.3 provides a locality map of the new infrastructure investigated. The table thereafter provides a summary of the characteristics of the new dams. The references for the information sources are provided in the notes following the Table.

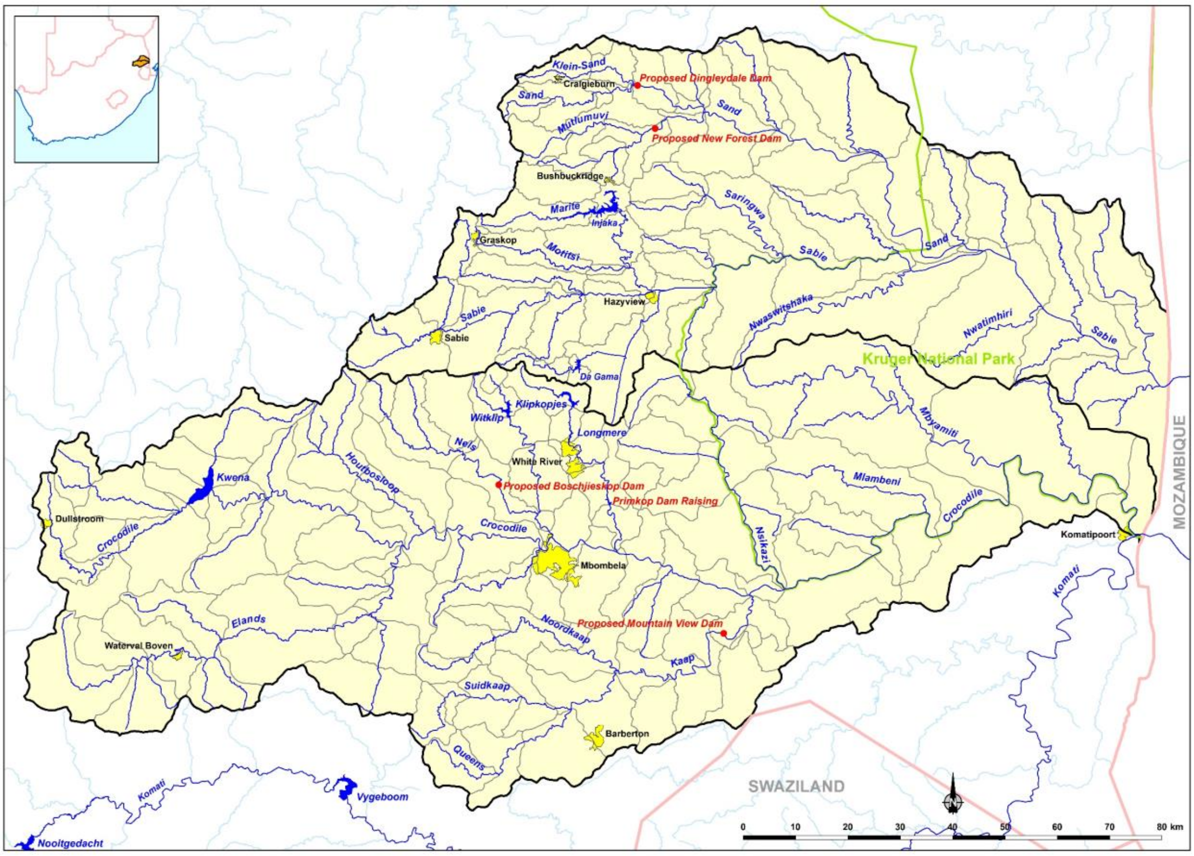


Figure 3.3: Locations of potential new dam sites

Table 3.8: Characteristics of potential new dams

Dam		Lev 1	Lev 2	Lev 3	Lev 4	Full
Mountain View[1]	Height[3]	10.0	30.0	50.0	60.0	74.0
	Volume[4]	2.3	17.3	60.7	100.4	184.8
	Area[5]	0.4	1.3	3.2	4.7	7.2
Boschjeskop[1]	Height[3]	10.0	20.0	30.0	40.0	50.0
	Volume[4]	2.1	13.1	37.1	75.6	130.5

Dam		Lev 1	Lev 2	Lev 3	Lev 4	Full
	Area(5)	0.5	1.7	3.1	4.7	6.3
Dingleydale(2)	Height(3)	10.7	17.5	24.2	26.3	34.99
	Volume(4)	0.5	4.6	16.3	22.1	62.5
	Area(5)	0.4	2.0	3.6	4.1	6.1
New Forest(2)	Height(3)	10.8	18.1	21.2	27.4	42.2
	Volume(4)	0.6	5.1	9.3	20.4	82.0
	Area(5)	0.3	1.7	2.2	3.4	6.2

Note (1): Reference (DWA, 2008)

Note (2): Reference (DWA, 1990)

Note (3): Height units in meters, Note (4): Volume units in million cubic meters, Note (5): Area units in square kilometers

3.3 Water Requirements

The water requirements used in the water resources analyses task were mostly sourced from the water requirements assessment and update completed as part of this Study (DWS, 2018). Updated information of 2018 actual use for some of the major domestic users was obtained from the CoM and was also included. The following sub-sections provide a summary of the water requirements per user sector.

3.3.1 Urban and Industrial Demands

The water requirement task of this Study undertook to update current use and future water requirements for the urban demand centres included in the Study area. The future requirement projections were determined by considering both population growth determined from the demographic assessment (DWS, 2018a) as well as the projected improvement in level of services supplied to the users.

When undertaking water resources analyses, it is important to locate users at their points of abstraction. An assessment was undertaken to determine the locations of the existing WTWs and these were configured into the model. Each user is provided with a unique channel number which can be referenced on the network schematic diagrams presented in **Appendix A**. **Table 3.9** provides a summary of the domestic and industrial demands included in the water resources analyses. It should be noted that these projected requirements may exceed the conditions of the existing allocations, as it is important to plan for future growth without the limitation of the allocation.

Table 3.9: Urban and industrial projected water requirements per year indicated

Demand	Channel no.	Requirement (million m³/annum)				
		2018	2025	2030	2035	2040
Dullstroom	604	0.85	1.10	1.20	1.30	1.40
Machadodorp	605	0.95	1.20	1.40	1.50	1.60
Watervalboven	606	0.95	1.10	1.20	1.30	1.40
Sappi Ngodwana	600	0.75	0.96	1.14	1.35	1.59
Elandshoek	200	0.11	0.14	0.16	0.17	0.19
CoM: Nelspruit WTW, part to Rocky drift*	601	17.00	22.28	26.26	30.24	34.22
White River from Witklip Dam*	803	0.28	0.40	0.48	0.56	0.64
White River from Longmere Dam*	607	1.60	2.10	2.51	2.91	3.32
Karino, Tekwane West*	805	0.92	1.10	1.23	1.35	1.48
Emoyeni, Tekwane North*	804	0.30	0.46	0.58	0.70	0.82
Nsikazi South*	641	25.00	27.97	30.11	32.26	34.40
Barberton, Emjindini	811	5.39	6.05	6.56	7.02	7.51
Shiba Siding	810	0.11	0.15	0.18	0.19	0.21
Matsulu	608	6.49	7.50	8.25	8.98	9.76
Malelane	609	0.73	0.82	0.90	0.90	0.99
Marloth Park	610	0.92	1.04	1.12	1.19	1.26
Hectorspruit	813	0.25	0.25	0.28	0.40	0.42
Nsikazi North	817	10.44	11.63	12.51	13.13	13.75
Sabie	819	1.78	1.78	1.78	1.79	1.79
Graskop	1646	0.83	0.91	0.97	1.04	1.10
Hazyview	1647	1.61	2.09	2.47	2.70	2.84
Hoxani	1605	14.20	16.00	17.20	18.20	19.20
Marite	829	3.40	3.90	4.30	4.60	4.80
Acornhoek (own resources)	1606	5.15	7.15	7.85	9.95	10.95
Thulamahashe (own resources)	1608	3.45	4.65	5.45	6.05	6.65
BBR Transfer pipeline to Acornhoek and Thulamahashe	1000	25.0	25.0	25.0	25.0	25.0

Note *: These requirements were updated subsequent to the water requirements Task with additional information received and therefore will not correspond with DWS, 2018b

3.3.2 Irrigation

Until the Validation and Verification of water use in the Study Area is completed, the IWAAS is still the most reliable source of irrigation water requirements to be included in the water resources assessment. The following Tables summarise the irrigation water requirements used in this Study.

Table 3.10: Summary of Irrigation: Sabie/Sand catchment

Type	Area (km^2)	Volume (million m^3/annum)	Model methodology	Model references
Sabie Irrigation Board	20.63	10.9	Min-max	1624
White Waters Irrigation Board	27.84	15.6	Min-max	1622, 1623
Diffuse[(1)] (Sabie)	79.1	63.11	Irrigation blocks	1113, 1114, 1115, 1116, 1117, 1118, 1123, 1135, 1136, 1137, 1138
Diffuse (Sand)	24.65	17.06	Irrigation blocks	1124, 1126, 1127, 1128, 1129, 1134, 1130, 1131, 1132, 1133

Note (1): Irrigation taking place outside a formal irrigation board, normally on tributaries, is referred to as diffuse irrigation

Table 3.11: Summary of Irrigation: Crocodile catchment

Type	Area (km^2)	Volume (million m^3/annum)	Model methodology	Model references
Elands Irrigation Board	15.17[(1)] 27.04[(2)]	7.9[(1)] 20.8[(2)]	Specified demand Irrigation blocks	622 215, 216
Upper Croc diffuse	9.1	4.3	Irrigation blocks	202, 204, 205, 206, 207, 211
Upper Croc diffuse	3.5	1.5	Specified demand	620
Crocodile Irrigation Board	282.86	312.9[(3)]	Min-Max: WRYM Master Control: WRPM	621, 624, 625, 627, 628, 636, 637, 638, 639, 645
Sand River IB Avalon & Gradely Farms	59.3	10.8	Min-Max: WRYM Master Control: WRPM	283
White River IB, Ranch Karino & Curlews		8.4	Min-Max: WRYM Master Control: WRPM	291, 297
Manchester & Good Hope IBs		4.0	Min-Max: WRYM Master Control: WRPM	626
Middle Croc diffuse	33.72	20.2	Irrigation blocks	217, 221, 222, 225
Middle Croc diffuse	8.2	4.93	Specified demand	623
Kaap Upper & Lower IBs	54.2	36.1	Specified demand Irrigation blocks	629, 630, 631, 632, 633, 634, 635
Kaap Diffuse	43.8	55.6		240, 242, 243, 247

Notes:
1 Reference IWAAS Appendices
2 Reference IWAAS Report Table
3 See update in Chapter 8

3.3.3 Streamflow Reduction Activities

Afforestation

Each of the 140 quinary catchments have an associated afforestation file representing the reduction in streamflow as a result of afforestation in the catchment. **Table 3.12** presents a summary of the totals (per tertiary) catchment of the areas and use from afforestation.

Table 3.12: Afforestation per Tertiary Catchment

Tertiary	Area (km^2)	Streamflow reduction (million m^3/a)
X21	587	51.6
X22	900	65.8
X23	443	39.7
X24	11	0.4
X31	797	85.8
X32	56	3.9
X33	0	0
Total	**2794**	**247.11**

Alien Vegetation

Alien vegetation is a streamflow reduction activity. The approach to simulate the impacts of alien vegetation is similar to afforestation, whereby a time series file representing the reduction of runoff resulting from alien plants is subtracted from the natural flow file. **Table 3.13** summarises the impacts of alien vegetation per tertiary catchment.

Table 3.13: Alien Vegetation per Tertiary Catchment

Tertiary	Area (km^2)	Streamflow reduction (million m^3/a)
X21	89.1	10.1
X22	122.1	17.1
X23	69	4.4
X24	14.9	0.4
X31	182.6	29.9
X32	33.1	1.7
X33	0	0.0
Total	**510.8**	**63.63**

3.3.4 Environmental Water Requirements

Due to the fact that a Classification Study has been undertaken in the Study Area (DWA, 2014b), it was originally believed that the Environmental Water Requirements (EWRs) would be readily available, and that their incorporation into the systems model had already taken place. This was not the case and the following regarding the EWRs was determined:

- The standard WRYM was not used in the Classification Study, and therefore the EWRs needed to be configured into the WRYM, including their locations and structures;
- Two Gazettes were published (January 2016 and November 2017) relating to the EWRs. The former is titled "Proposed Classes of Water Resources and Resource Quality Objectives for the Catchments of the Inkomati" and the latter "Proposed Reserve Determination of Water Resources for the Inkomati River Catchment". Both these Gazettes contain fundamental errors relating to the natural flows at each EWR site, and it is unclear the extent of the errors relating to the EWR structures. Neither of the two documents could therefore be used as a source of EWR information.
- As a result of the above, the EWR Specialist who worked on the Classification Study was contacted in order to provide the raw data that should have been published in the Gazettes. The Specialist was able to provide a spreadsheet, however, not all the required information could be obtained.

Considering the above, an attempt was made as part of this Study to produce correct EWR structures and to configure these into the models for further assessment. EWR structures are based on the cumulative natural flow that occurs from the catchments upstream of the EWR site. There are seven EWR sites in the Crocodile River, as presented in **Table 3.14** and eight on the Sabie/Sand as presented in

Table 3.15. The reader will note that these tables provide different information to that provided in the Water requirements Report (DWS, 2018b) of this Study. This is a result of the errors in the Gazetted information as mentioned previously. The errors were not picked up during the Water requirements Task.

Table 3.14: Crocodile EWRs

EWR	Site Name	Category	MAR upstream of EWR site (million m^3/annum)	Ecological Reserve (% of NMAR)
EWR1	Valyspruit	A/B	15.6	24.3
EWR2	Goedehoop	B	76.1	30.9
EWR3	Poplar Creek	B/C	194.1	37.2

EWR	Site Name	Category	MAR upstream of EWR site (million m³/annum)	Ecological Reserve (% of NMAR)
EWR4	KaNyamazane	C	819.3	26.1
EWR5	Malelane	C	1089.2	22.3
EWR6	Nkongoma	C	1137.5	12.5
EWR7	Honeybird	C	179.3	16.4

Table 3.15: Sabie EWRs

EWR	Site Name	Category	MAR upstream of EWR site (million m³/annum)	Ecological Reserve (% of NMAR)
EWR1	Upper Sabie	B/C	132.0	35.8
EWR2	Aan de Vliet	C	261.7	27.3
EWR3	Kidney	A/B	493.7	30.8
EWR4	Mac Mac	B	65.8	45.4
EWR5	Marite	B/C	156.4	21.7
EWR6	Mutlumuvi	C	45.0	26.0
EWR7	Upper Sand	C	28.9	20.4
EWR8	Lower Sand	B	133.6	18.5

Further to the EWRs, an International Obligation exists for the Crocodile River. The information was obtained from the IWAAS (DWAF, 2009) and the requirement is that a minimum of 51 million m^3/annum (1.6 m^3/s) crosses the border into Mozambique (see update in Chapter 8). If the EWR requirement at EWR Site 6 is more than the international requirement, then it is assumed that the requirement is met.

3.4 Operating Rules

Operating rules exist in two forms, namely:

- Reservoir release rules dictating at what levels releases should be made; and
- Drought restriction rules dictating when to reduce supply to users.

Two release rules were found to be used in the Study area, both occurring in the White River System. Water is released from the Klipkopje Dam to the Longmere Dam when the Longmere Dam drops to below about 60% (IUCMA, 2017). Furthermore, water is transferred via the Kruisfontein canal from the catchment upstream of Witklip Dam to the catchment upstream of Klipkopje Dam until Witklip Dam drops to 70%. Below that level the transfer is stopped.

Three sets of restriction rules were sourced for the White River (IUCMA, 2015), Inyaka and

Kwena Dam users (IUCMA, 2019a). **Table 3.16** provides a summary of these rules.

Table 3.16: Drought restriction rules for indicated systems

Dam	User sector	Storage (% full)	Restriction (% of allocation)
Witklip	Irrigation	>60	0
		40-60	30
		20-40	50
		<20	70
White River	Irrigation	>100	0
		90-99.9	10
		80-90	20
		70-80	30
		60-70	40
		50-60	50
		40-50	60
		30-40	70
		20-30	80
		10-20	90
		0-10	100
Witklip & White River	Domestic	>30	0
		20-30	5
		10-20	10
		<10	20
Kwena	Irrigation	>70	0
		55-70	35
		11-55	60
		<10	100
Kwena	Domestic	>60	0
		40-60	10
		20-40	20
		<20	30
Kwena	Industrial	<10	10
Inyaka	Irrigation	>65	0
		20-65	40
		<20	60
Inyaka	Domestic	>60	0
		40-60	10
		20-40	20
		<20	30

See also additional information relating to operating rules provided in Chapter 8.

4 WATER RESOURCES YIELDS

4.1 Results from previous studies

Water resources yield analyses were undertaken/quoted in previous water resources studies. Relevant results are presented in **Table 4.1** with the study references also indicated.

Table 4.1: Yield Results from previous Studies

Dam/system	Yield (million m^3/annum)	Study	Comment
Inyaka Dam	57.8	Water Reconciliation Strategy Update for the Schemes in the Sabie and Sand River System (DWS, 2016)	Reference source: White Paper on development of Inyaka Dam
Inyaka Dam	41.9	IWAAS (DWAF, 2009)	Historic firm yield, excluding EWR
Inyaka Dam	50.5	IWAAS (DWAF, 2009)	1 in 50 year assurance long term yield, excluding EWR
Inyaka Dam	21.4	IWAAS (DWAF, 2009)	Historic firm yield, including EWR
Witklip Dam	8.1	IWAAS (DWAF, 2009)	Historic firm yield
Witklip Dam	9.9	Operating Rules of the White River System (IUCMA, 2015)	1 in 50 year yield
Klipkopje/Longmere/ Primkop Dams	13.8	IWAAS (DWAF, 2009)	Historic firm yield
Klipkopje/Longmere/ Primkop Dams	15.6	IWAAS (DWAF, 2009)	1 in 50 year assurance long term yield
Klipkopje/Longmere Dams	8.0	Operating Rules of the White River System (IUCMA, 2015)	Historic firm yield
Klipkopje/Longmere Dams	8.2	Operating Rules of the White River System (IUCMA, 2015)	1 in 50 year yield
Primkop Dam	3.4	Operating Rules of the White River System (IUCMA, 2015)	Historic firm yield
Primkop Dam	4.4	Operating Rules of the White River System (IUCMA, 2015)	1 in 50 year yield
Kwena Dam	48.6	IWAAS (DWAF, 2009)	Historic firm yield, including EWR
Crocodile System	264	Inkomati Water Management Area: Internal Strategic Perspective (ISP, 2004)	Yield at 98% assurance of supply (1 in 50 year)
Crocodile System	446	Progressive Realisation of the IncoMaputo Agreement (PRIMA, 2011)	Yield at 90% assurance of supply (1 in 10 year)

Important aspects to note from **Table 4.1** are as follows:

- The White Paper on Inyaka Dam quotes a higher yield than that obtained in the IWAAS in which a detailed hydrological assessment was done. It should therefore be noted that the allocations presented in the White Paper are related to a higher yield than is available.
- Inyaka Dam yield is halved when the EWR is included downstream of the Dam.
- The total yield available from the White River Dams is about 22 million m^3/annum.
- The Crocodile system yield supplied by the incremental unregulated river-runoff and supported by releases from Kwena Dam far exceeds the yield of the dam alone. This highlights the importance of operational control, monitoring and cooperation among water users and institutions involved in water abstraction and supply.

Most of yield analyses have taken the typical approach of abstracting a demand from various individual dams, or in some cases a combination of dams, and determining the maximum demand that can be supplied by the dam over the historical hydrological period, typically referred to as the Historic Firm Yield (HFY). Further stochastic analyses were undertaken in some cases in order to provide yield results at an associated risk or assurance of supply.

It is important to note that, in the Crocodile catchment, merely considering the yield of the Kwena Dam is not satisfactory. The result will continuously show a severe imbalance between the dam yield and the current requirements or allocations from the dam. The reason for this is the positions of where the users are located along the river, downstream of the dam. The physical locations of the abstraction points allow many of the users access to an additional resource, the incremental runoff from tributary sub-catchments that contribute to Crocodile River flows downstream of the dam. This highly temporal varying flow provides limited firm supply on its own, however, in combination with releases from Kwena Dam (when operated as a system) the yield benefits are substantial as shown in the previous results as well as in subsequent sections.

4.2 Yield analysis methodology

Due to the individual catchment characteristics and current approach to operation, varying yield analyses methodologies were utilized for the various catchments. These are described in the following sub-sections. The Water Resources Yield Model (WRYM) developed by the DWS and applied countrywide was applied to carry out long term historical and stochastic yield analysis as well as short term analysis to determine the yield available for a range of initial dam storages. A brief description of what the terminology relating to the yield analyses is as follows:

- Historic Firm Yield: The maximum volume of water that can be abstracted from a resource over the historical observed time period (1920-2004) such that the resource is able to provide the abstracted volume in full each and every year.
- Long Term Yield at various Recurrence Intervals: 201 natural hydrological time series' (known as stochastic sequences) of 85 year record length are analysed in order to determine the system behavior under different hydrological conditions. The analyses allow for some sequences to fail (not supply the abstraction in full) and the results are quoted in assurance of supply depending on how many sequences fail.
- Short Term Yield at various Recurrence Intervals: 501 natural hydrological time series' (known as stochastic sequences) of 5 year record length are analysed in order to determine the system behavior under different hydrological conditions. In this case the resource's starting storage condition is considered as additional yield is available when the resource is fuller compared with when it starts lower.

More information on yield analyses as well as additional terminology such as assurance of supply, recurrence interval etc. can be found in Basson *et. al*, 1994.

The following sub-sections presenting the yield analyses results include a comparison of the available yield at various assurance of supply levels with the required demands on the systems. The typical approach in South Africa is to provide urban/domestic users at a 98% assurance of supply level (1 in 50 year risk of failure) and irrigators at a 90% assurance of supply level (1 in 10 year risk of failure). In severely stressed systems, it is sometimes not possible to supply users at these criteria, and a 75% assurance of supply level (1 in 4 year risk of failure) is sometimes used for irrigators.

It will be noted that the assurance criteria of these demands differ per subsystem. This is a result of the demands compared with the resources of each sub-system, as well as the different system layouts considering the dam location compared with that of the users. In each sub-system, iterative analyses were undertaken in order to obtain the following criteria:

- The dam should be utilized and should not be over protected such that users are severely restricted whilst water remains in the dam;
- If possible, the selected user assurance criteria should not be violated, ie. the users should not be restricted more than what their user criteria allows for.

The user assurance criteria for each sub-system presented is therefore the final result of the iterative analyses which provides the most efficient use of the system considering the above two criteria.

The WRYM base model configuration was from the IWAAS and this was updated as per the information provided in Section 3 of this report.

4.2.1 White River

The White River system consists of the Witklip, Klipkopje, Longmere and Primkop Dams. The relevant quinary catchments contributing to the White River resources include X22 E1, E2, E3, F1, G1, G2, H1, H2 and H3 as presented in locality **Figure 4.1**.

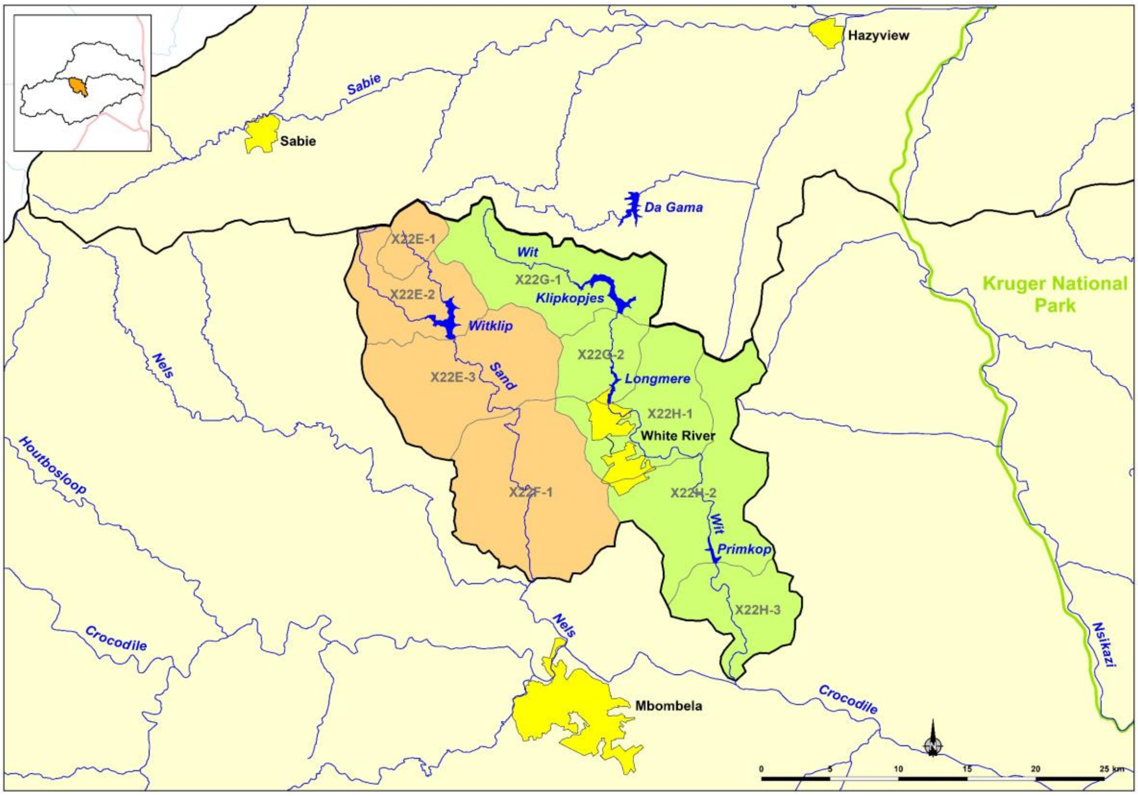


Figure 4.1: White River system

While specific drought restriction rules were developed for the system in 2015 (IUCMA, 2015), information received (IUCMA, 2019a) indicates the operation of the White River

System is interlinked with the Crocodile system, as the current approach is to restrict users in the Crocodile River "and its tributaries" equally. For this reason, restrictions for the White River users are dependent on the storage in Kwena Dam (in the Crocodile River) regardless of the levels of their own dams' storages. However, in reality, past studies have indicated that the White River resources are more in balance with the demands than in the case in the Crocodile River system. It was therefore decided to keep the system separate for the purposes of yield analyses which will allow for more flexibility when undertaking planning scenarios later. Additional information received from the IUCMA indicated that from May 2020 onwards, the White River System will be restricted separately from the Crocodile System using its own resources as the trigger mechanism.

Table 4.2 provides a summary of the users forming part of the White River system, in terms of their current use and water source. References for the information are provided in the notes that follow the Table.

Table 4.2: Water users of the White River Resources

Type	User	Use (million m^3/annum)	Resource
Domestic	City of Mbombela for White River	0.31*	Witklip Dam via White River WTW (0.75 million m^3/a allocation)
Irrigation	Sand River, Avalon and Gradely Farms	10.8**	Witklip Dam
Domestic	City of Mbombela for White River	1.61*	Klipkopje Dam supporting Longmere Dam via WR Country Estate WTW (1.25 million m^3/a allocation)
Irrigation	White River, Ranch Karino and Curlews	8.4**	Klipkopje Dam supporting Longmere Dam
Domestic	City of Mbombela for Emoyeni	0.32*	Primkop Dam via Emoyeni WTW (0.28 million m^3/a allocation)
Irrigation	Manchester, Good Hope	4.0**	Primkop Dam
		25.44	

* Raw water abstractions (2018) obtained from City of Mbombela.

** Reported as part of the Operating Rules of the White River System (IUCMA, 2015).

For the purposes of the yield analyses of the White River System, the system was further subdivided into two sub-systems, namely, the Witklip Dam and the combination of the Klipkopje, Longmere and Primkop (KLP) Dams. The WRYM was used to determine the HFYs of the two sub-systems, with the following results:

- Witklip Dam: HFY: 8.1 million m^3/annum
- Klipkopje/Longmere/Primkop Dams: HFY: 14 million m^3/annum.

The above results are in line with those obtained in the IWAAS and presented in **Table 4.1**. The slight difference in the KLP System yield could be a result of the incorporated operating rule (as described in **Section 3.4**) whereby Klipkopje Dam releases water to Longmere Dam when Longmere Dam reaches 60% of its storage capacity.

A combined system HFY was also determined by including the transfer through the Kruisfontein canal with a result of 22.2 million m^3/annum as the total HFY.

The HFY of a system is usually a conservative figure given the length of the historical period (84 years from 1920 to 2003 hydrological years) and the fact that the maximum yield abstracted only allows the system to fail once. The yield is dependent on the critical period (series of years with low rainfall) observed in the historical period, which in all likelihood will not be repeated in the future. In order to determine the water resources capabilities of the system at various assurance of supply levels, stochastic yield analyses are undertaken.

The long term curves resulting from the long term stochastic yield analyses are presented in **Figure 4.2** and **Figure 4.3**. These results will be taken forward to and used in the water balance plots to be presented in the Reconciliation Strategy. The curve shows the firm yield line (in black) and the base yield lines (in colour) at various assurance of supply levels. The long term yield at the various assurance of supply is read off on the Y-axis from the intersection point of the assurance lines (1 in x years) and the firm yield line. Further information on interpreting a long term curve can be found in Basson *et. al*, 1994.

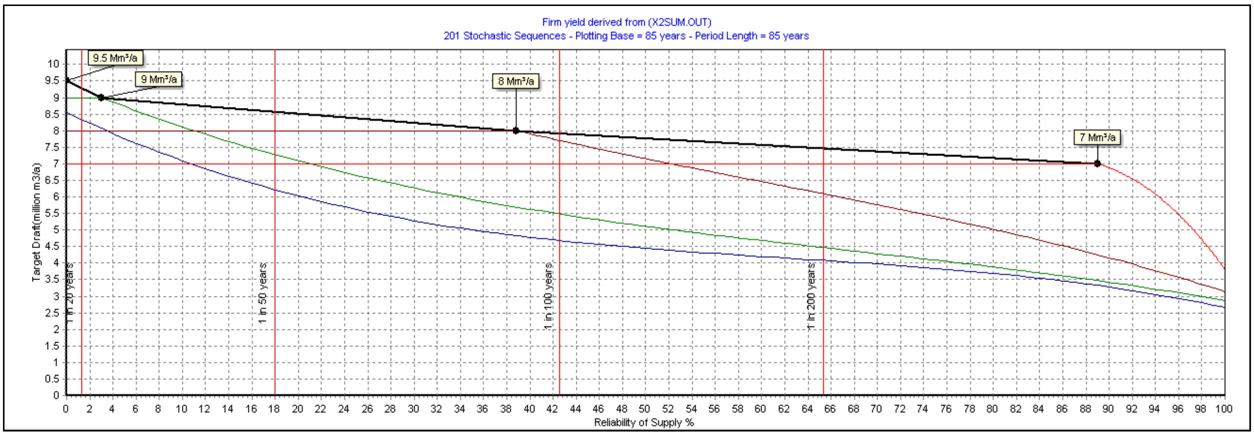


Figure 4.2: Long Term Curve: Witklip Dam

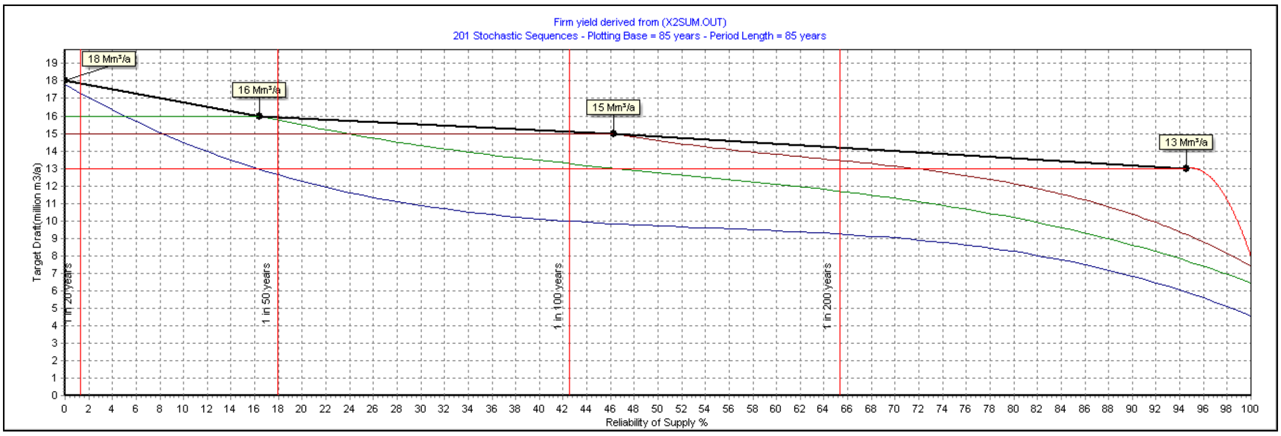


Figure 4.3: Long Term Curve: KLP system

For short term stochastic analyses varying starting storage levels of the dams are analysed ranging from 100% to 10% in order to incorporate the dam storage levels into the determination of the water resources capabilities. This is referred to as the short term yield capabilities of the system, or short term curves.

Two sets of short term curves were produced for the White River System, one for Witklip Dam and one for the combined KLP Dams. **Table 4.3** and **Table 4.4** provide the results of the analyses and the curves are provided in **Appendix B**.

Table 4.3: Short term yield capabilities of Witklip Dam

	Yield million m^3/annum at indicated Recurrence Interval (2)					
Starting storage (as % of live FSC(1))	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	8.39	8.89	9.55	10.50	11.91	13.97
80	7.66	8.45	8.94	9.96	11.43	13.53
60	6.96	7.62	8.04	9.28	10.42	12.95
40	6.30	6.59	7.00	7.92	8.96	10.93
20	4.85	5.22	4.59	6.27	6.92	8.19
10	3.59	3.90	4.29	4.66	4.97	5.85

(1): Full Supply Capacity

(2) Recurrence Interval of a failure in supply, for example one's in ten years indicated as 1:10

Table 4.4: Short term yield capabilities of combined KLP Dams

	Yield million m^3/annum at indicated Recurrence Interval (2)					
Starting storage (as % of live FSC(1))	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	15.54	16.18	17.47	19.14	21.11	24.60
80	14.65	15.96	17.24	18.13	20.11	23.84

60	13.11	14.18	15.56	15.27	19.19	23.01
40	11.00	11.76	12.88	11.79	17.43	20.14
20	8.80	9.74	10.75	11.79	12.58	14.03
10	6.40	6.74	7.45	8.30	9.18	10.72

(1): Full Supply Capacity

(2) Recurrence Interval of a failure in supply, for example one's in ten years indicated as 1:10

The short term yield results are compared with the current demands on the sub-systems. The demands at an appropriate assurance, the determination of which is described in Section 4.2, are placed on the curves in order to determine whether or not the system is able to supply the demands considering the starting storages of the dams. This is indicated in **Figure 4.4** and **Figure 4.5** which provide the firm yield lines at the various starting storage levels for the Witklip and KLP Dam systems respectively. The assurance criteria of the urban and irrigation demands are indicated on the figures, and are represented by the various bars. The system is unable to provide the demand at the storage level indicated where the bars cross above the firm yield lines. It is at this point that a restriction on the demand will be required.

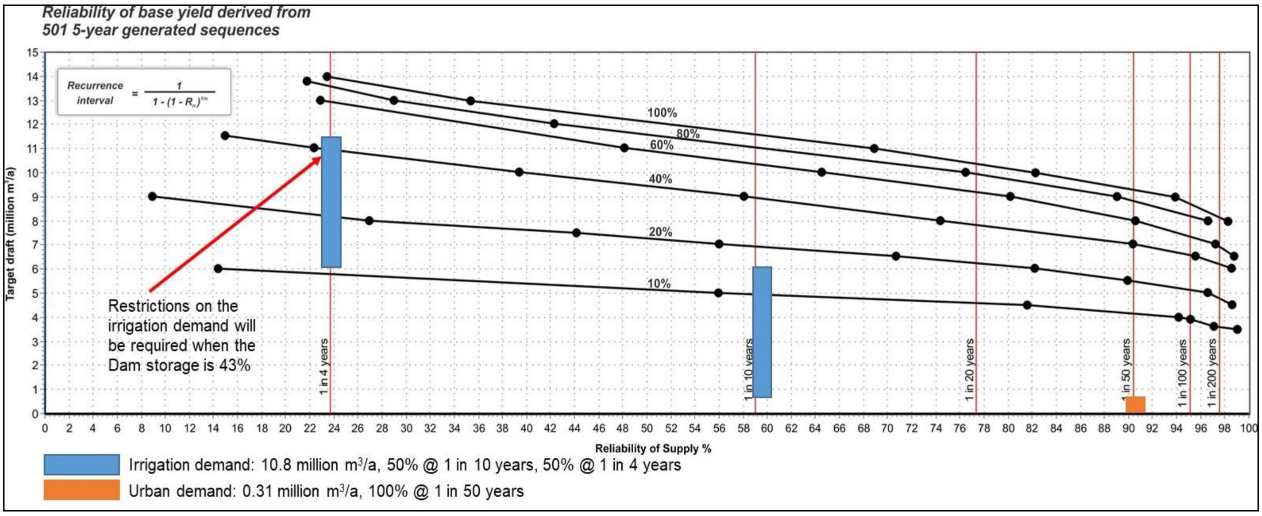


Figure 4.4: Short Term firm yields and required demands: Witklip Dam

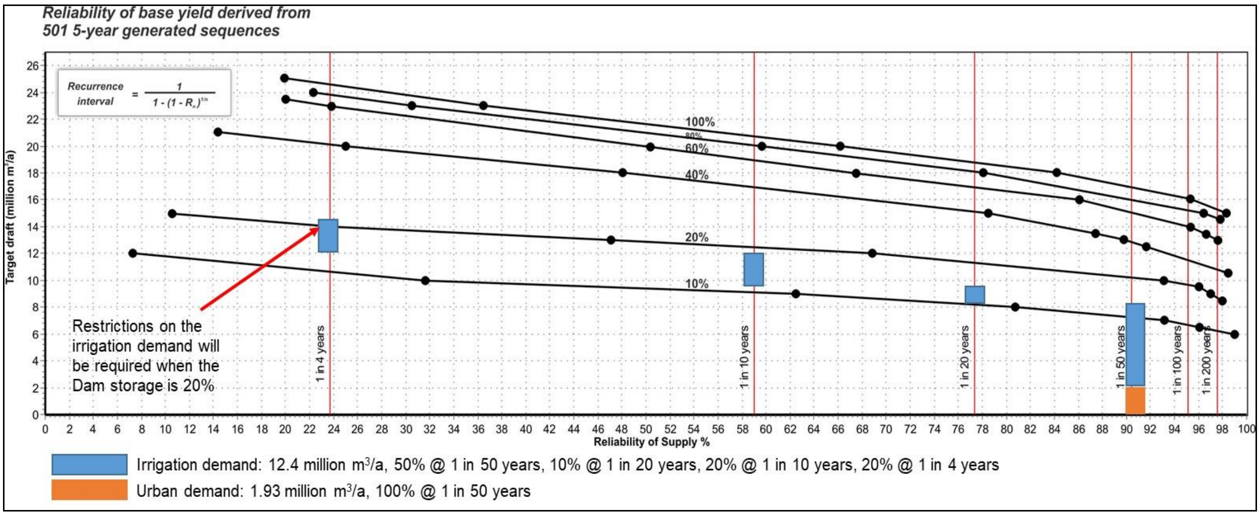


Figure 4.5: Short Term firm yields and required demands: KLP System

The results of the short term yield assessment indicate that the Witklip Dam users require restrictions when the Dam drops to about 43%, whereas the KLP system Dams can drop as low as 20% prior to restrictions being required.

4.2.2 Crocodile River System

The Crocodile system contains just one major dam, Kwena Dam, which is located in the upper reaches of the catchment. The system provides water to a number of users distributed along a lengthy stretch of river downstream of the Dam. **Figure 4.6** presents a locality of the main users along the Crocodile River.

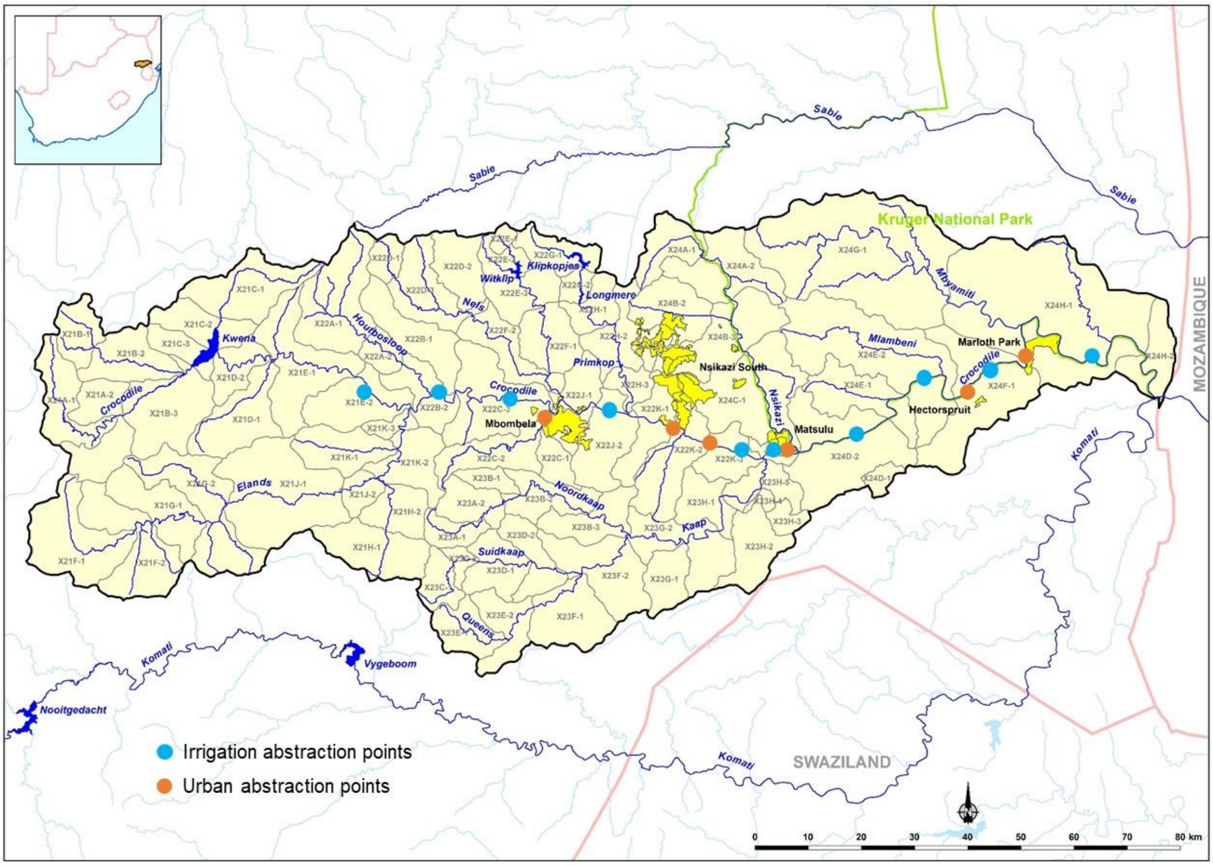


Figure 4.6: Locations of abstraction points along the Crocodile River

The yield of the Crocodile River System is directly affected by the size of abstraction and location of the users in the system as mentioned in the opening paragraph of this Chapter. The dynamics of the incremental runoff that adds to the water availability of the users were considered when assessing the system capabilities. A yield analyses of Kwena Dam alone was undertaken in order to compare with previous results, and to ascertain the impact of the updated Classification EWR that was included into the model as part of this Study. The result obtained was a HFY for Kwena Dam of 49.5 million m^3/a. This is in line with the IWAAS yield obtained of 48.6 million m^3/annum as presented in **Table 4.1**. The slight difference is likely to be a result of the differing EWRs included for the two analyses.

The users along the Crocodile River that have access to the storage in Kwena Dam are presented in **Table 4.5**. The current use/allocation is presented in the Table.

Table 4.5: Water users of the Crocodile River Resources

Type	User	Use (million m^3/annum)
Irrigation	Crocodile Irrigation Board (divided into 10 individual point abstractions based on location)	312.90*

Type	User	Use (million m^3/annum)
Domestic	City of Mbombela for Nelspruit, including Rocky Drift	17.50**
Domestic	City of Mbombela for Emoyeni from Crocodile and Karino	0.95**
Domestic	City of Mbombela for Nsikazi South	25.40**
Domestic	City of Mbombela for Matsulu	6.26**
Domestic	Malelane	0.75***
Domestic	Hectorsspruit	0.22***
Domestic	Marloth Park	0.95***
Total		364.93

* IWAAS Water Requirements Report, see update in Chapter 8

** Raw water abstractions (2018) obtained from City of Mbombela

*** Water Requirements determined as part of this Study (DWS, 2018)

It is clear that the yield of Kwena Dam of 49.5 million m^3/annum is far lower than the demands on the dam of 364.9 million m^3/annum. A system yield (historic firm) was therefore determined using the following approach:

- A representative yield node was configured into the model;
- All the user requirements were abstracted from their physical locations and were joined to the yield node;
- The yield channel was placed on the yield node;
- The HFY of 22.2 million m^3 was abstracted (removed) from the White River Resources, and these were not added to the yield node;
- The abstractions were scaled downwards based on the current operation of the system (irrigators restricted prior to domestic users) until the point that the Kwena Dam just fails once in the historic time period.

The result was obtained at a level of 90% domestic demand supplied and 45% irrigation demand supplied which equates to a HFY of the Crocodile system of 186.7 million m^3/annum. Comparing that with the yield of Kwena Dam alone implies that the flows from incremental runoff provide an additional 137.2 million m^3/a to the system yield.

The long term curve resulting from the long term stochastic yield analysis is presented in **Figure 4.7**. These results will be taken forward to and used in the water balance plots to be presented in the Reconciliation Strategy.

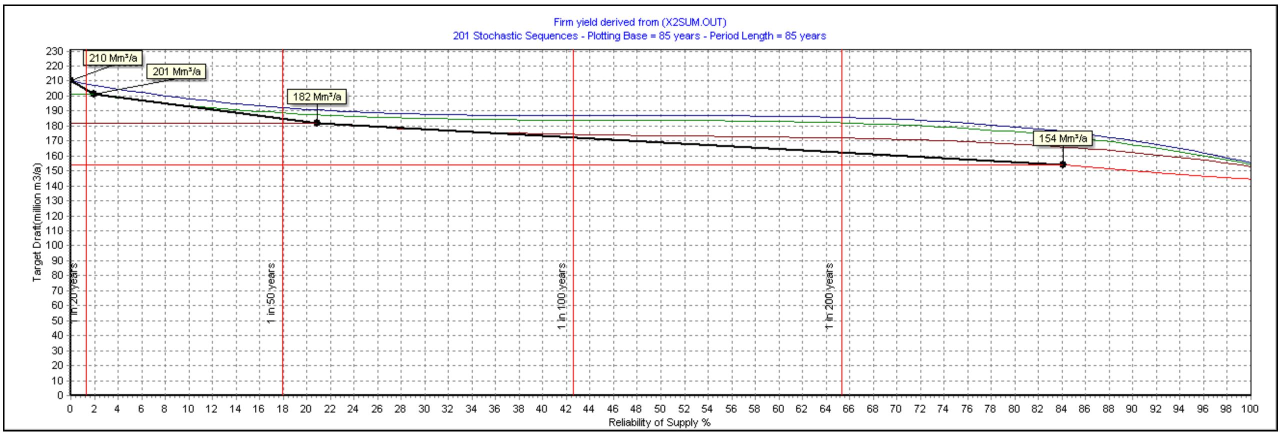


Figure 4.7: Long Term curve: Crocodile System

The short term stochastic yield analyses were carried out for varying starting storages of Kwena Dam. In order to remove the benefit of the White River incremental such that the White River remain a separate sub-catchment, varying yields were removed from the White River resources in accordance with the 1 in 50 year assurance Short Term Yields obtained from that system. The demands on the Crocodile were systematically scaled downwards in accordance with the existing drought restriction operating rule in order to determine the short term yields. **Table 4.6** provides the short term yield results for the Crocodile River System. The curves are provided in **Appendix B**.

Table 4.6: Short term yield capabilities of Crocodile system

	Yield million m^3/annum at indicated Recurrent Intervals (2)					
Starting storage (as % of live FSC(1))	**1:200**	**1:100**	**1:50**	**1:20**	**1:10**	**1:4**
100	185.83	194.90	209.10	227.91	252.82	298.77
80	169.45	178.58	203.83	228.75	237.50	287.73
60	157.31	181.49	193.57	200.83	240.83	275.39
40	108.65	131.39	185.96	222.98	235.31	242.72
20	96.66	117.77	128.32	118.23	126.18	148.54
10	33.00	35.53	38.57	43.00	47.70	52.75

(1): Full Supply Capacity

(2) Recurrence Interval of a failure in supply, for example one's in ten years indicated as 1:10

The short term yield results are compared with the current demands on the sub-system as indicated in **Figure 4.8** which provides the firm yield lines of the full system at the various starting storage levels of Kwena Dam.

Based on the short-term results the system is not able to supply the water requirements at the assigned assurance levels even if the Kwena Dam's storage is 100%. This confirms the low assurance of supply observed by previous studies. The short-term yield curves provide the initial base information required for drought restriction rules, however, due to the large deficit between supply and demand, alternatives were considered as presented in **Section 5.3.2**.

A comparison of the respective graphs and yield results for the two White River Subsystems with the Crocodile System indicates that the users from the White River System can be supplied at a higher level of assurance (lower restrictions) than users from the Crocodile River System based on the water availability.

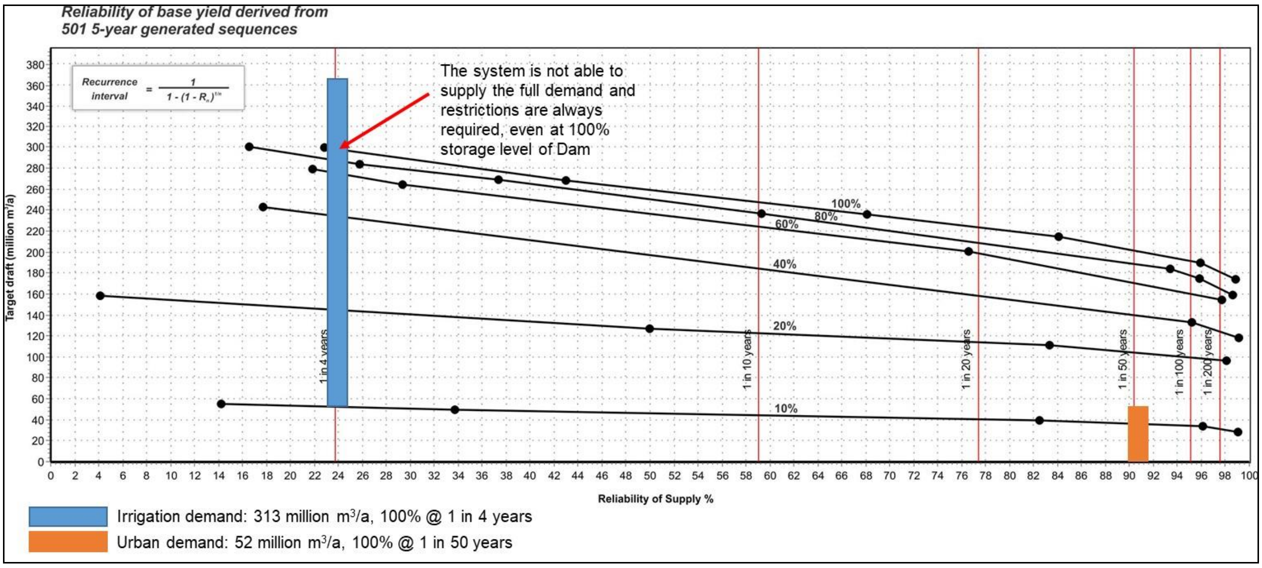


Figure 4.8: Short Term firm yields and required demands: Crocodile system

4.2.3 Sabie/Sand River

The Inyaka Dam is the main water resource infrastructure in the Sabie River, and supplies users both in the Sabie catchment as well as the Sand catchment through the Bushbuckridge Transfer Pipeline. The HFY of Inyaka Dam was determined in the IWAAS to be 41.9 million m^3/a without an EWR on the dam, and 21.4 million m^3/a including an EWR. It should be noted that the White Paper on the development of Inyaka Dam indicates a dam yield of 57.8 million m^3/a. It should therefore be noted that the allocations presented in the White Paper are related to a higher yield than is available, especially if one it to consider releases for the EWR. A summary of the existing use/allocation from the dam is provided in **Table 4.7**.

Table 4.7: Water users of the Inyaka Dam resources

Type	User	Use (million m³/annum)	Comments
Domestic	Acornhoek and Thulamahashe	25.0	Limited by the size of the Bushbuckridge Transfer Pipeline
Domestic	Marite	3.50	2018 requirement
Domestic	Hoxani	14.45	2018 requirement
Domestic	Nsikazi North, (City of Mbombela)	10.62	2018 requirement
Domestic	Hazyview	1.69	2018 requirement
Irrigation	Lawful Allocations in X31G, Marite	14.12	Information received from IUCMA & DARDLEA, most of these are currently dormant
		69.4	

The EWR as determined and Gazetted through the Classification process (DWA, 2014b) was incorporated in the analyses for this Study, and the HFY was determined to be 21.3 million m³/annum, which is almost identical to the IWAAS result.

The long term curve resulting from the long term stochastic yield analysis is presented in **Figure 4.9**. These results will be taken forward to and used in the water balance plots to be presented in the Reconciliation Strategy.

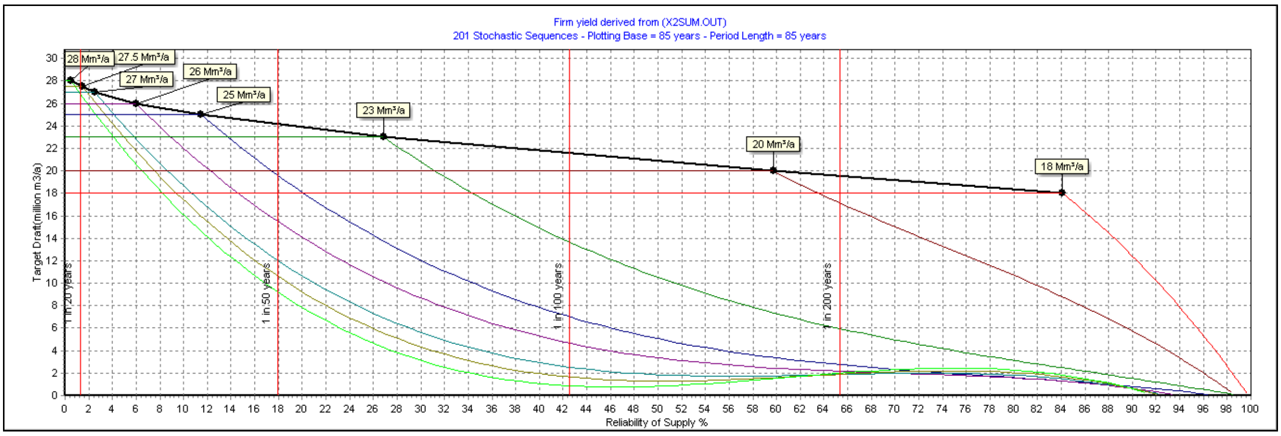


Figure 4.9: Long Term curve: Inyaka Dam

The short term yield capabilities determined for Inyaka Dam at the various starting storage levels of the dam are presented in **Table 4.8**. The curves are provided in **Appendix B**.

Table 4.8: Short term yield capabilities of Inyaka Dam

Starting storage (as % of live FSC(1))	Yield million m^3/annum at indicated Recurrent Intervals (2)					
	1:200	1:100	1:50	1:20	1:10	1:4
100	33.84	36.58	39.22	44.25	49.89	62.37
80	28.84	32.54	34.50	39.86	47.13	57.48
60	23.55	25.71	28.27	34.59	42.06	51.27
40	15.79	19.16	23.21	28.76	34.42	47.02
20	6.79	8.98	13.52	18.88	24.70	35.34
10	2.00	4.27	6.18	10.77	13.55	16.84

(1): Full Supply Capacity

(2) Recurrence Interval of a failure in supply, for example one's in ten years indicated as 1:10

Figure 4.10 represents the comparison of the firm yields obtained at the various starting storages of the Inyaka Dam with the water requirements to be supplied from the system. The figure indicates the water requirements significantly exceed the system supply capability at the assigned assurance levels. This is also reflected in the comparison of the 1 in 50 year long term yield (24 million m^3/annum) with the current domestic water requirements of 55 million m^3/annum, indicating a shortfall of 56%. Scenarios analyses were carried out to evaluate a range of drought restriction rules as described in **Section 5.4**.

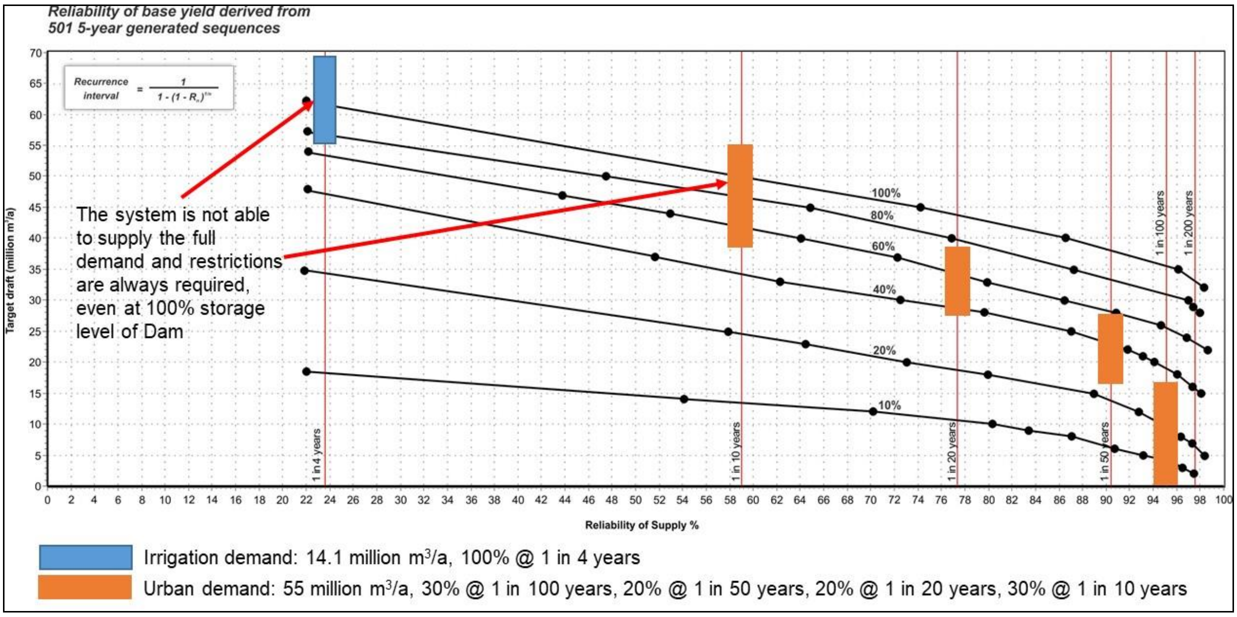


Figure 4.10: Short Term firm yields and required demands: Inyaka Dam

4.2.4 Minor Dams in Study Area

Yield analyses have previously been undertaken for minor dams falling within the Study Area as part of the IWAAS. The results are presented in **Table 4.9.**

Table 4.9: HFYs of minor dams within the Study Area

Dam	System	User	HFY (million m^3/annum)
Ngodwana	Crocodile (Elandspruit)	Sappi & Irrigation	21.0
Da Gama	Sabie (Whitewaters)	Whitewaters Irrigation Board	10.3
Edinburgh	Sand	Thulamahashe & irrigation	2.29
Orinoco	Sand	Irrigation	0.34
Acornhoek	Sand	Acornhoek (domestic)	0.33

4.3 Potential New Dams

Due to the severity of the deficits in the Study area, new dams will be required in order to provide the existing users with a more reliable assurance of supply as well as to augment future growth in water requirements. The new dams that were assessed as part of this water resources analysis Task have been described in Section 3.2.4. The following subsections provide the yield analyses results.

4.3.1 Crocodile River System

The approach to determine the yield of the new dams on the Crocodile system involved two analyses as a result of the dynamics of the river runoff and dam operation already described in previous sections. The first analyses involved determining the yield at the new dam sites, by undertaking a HFY with the yield channel at the dam. It should be noted that this yield is not the total additional yield that the new dam will add to the system, as its existence will impact on runoff previously available to users downstream. The impact on those users was assessed and a net yield has therefore been determined. A second approach to determining the yield was also undertaken in order to find the maximum benefit that the new dam would have on the system. The approach involved a similar analyses as described in **Section 4.2.2** whereby the existing user demands were scaled at their point of abstraction until a level that both the Kwena Dam and the new dam were no longer able to supply the demands. This approach allows for maximum use of the river runoff with the dams augmenting the supply in low flow times. **Table 4.10** provides a summary of the yield analyses results of the new dams.

Table 4.10: Yield benefit of new dams: Crocodile system

Yield Analyses approach	Dam	Boschjeskop	Mountain View
1	HFY (million m^3/annum): Yield channel at dam	39.8	51
	Impact on downstream users (million m^3/annum)	-15.7	-15.7
	Net HFY of new dam	24.1	35.3
2	Existing system yield / supply to users: 186.7 million m^3/annum	-	-
	Existing percentage per user sector: 90% domestic, 45% irrigation	-	-
	New system yield / supply to users (million m^3/annum)	217.9	264.8
	Percentage per user sector including new dam	90% domestic 55% irrigation	90% domestic 70% irrigation
	Net benefit of new dam (million m^3/annum)	31.2	78.1

4.3.2 Sabie/Sand River System

Two potential new dam sites have previously been determined in the Sand River System. The dams would augment the supply to the Bushbuckridge domestic demand. HFY analyses were undertaken on the two new dams, including releases for the existing EWR downstream in the system. The results are as follows:

- Dingleydale Dam: HFY 20.6 million m^3/annum.
- New Forest Dam: HFY 19.6 million m^3/annum.

4.3.3 Raised Primkop Dam

The possibility of raising Primkop Dam appears to be the City of Mbombela's preferred option for short term relief to the system with a Terms of Reference for the Feasibility Study being released in late 2019. It has not yet been ascertained as to what height the Dam could be raised to, and therefore the resulting increased capacity of the Dam is unknown. The Water Allocation Plan (IUCMA, 2019b) contained a curve of yield for various capacities of the Primkop Dam. This curve was confirmed as part of this Study and the following yield results were obtained:

- Additional HFY: Dam capacity: 8 million m^3: 1.2 million m^3/annum.
- Additional HFY: Dam capacity: 30 million m^3: 5.9 million m^3/annum.

The results are dependent on the operating rule selected between the three Dams, Klipkopje, Longmere and Primkop, as well as where the additional abstraction will take place. This will need to be further investigated as part of the Feasibility Study to be undertaken by the CoM.

5 WATER RESOURCES SCENARIO ANALYSES

5.1 Overview and methodology

The purpose of the Water Resource Planning Model (WRPM) is to undertake analysis for both operational and development planning in an integrated manner. This analysis approach provides the benefit that the implications of system operations (inclusive of drought restriction rules) on development planning decisions are duly taken into consideration.

This is particularly important for scheduling of future water resource developments to ensure set risk criteria are achieved in systems with different user sectors with different assurance requirements (criteria) – as is the case in the Crocodile River System.

The short term yield characteristics, as presented in the previous Chapter, were configured into the WRPM to analyse the behaviour of the systems and to evaluate if the restrictions:

- protect the system from unintended (uncontrolled) supply failures;
- provide full utilisation of the available water (storage in dams); and
- achieve optimal utilisation considering the availability constraints highlighted in the previous chapter.

The WRPM has additional capabilities to the WRYM in that it performs projection analysis by considering growing demands over time and implements dynamically changing operating rules as opposed to a fixed set of restriction rule levels.

An integrated WRPM system was configured containing both the Crocodile River and Sabie River systems including the relevant inter-catchment linkages. The results are, however, presented for the respective sub-systems for ease of reference. The results are provided in the form of boxplots showing the simulated behaviour of selected system elements for 1000 stochastic hydrological sequences indicating the projected probability and risks for the various scenarios described below. Graphical results are given in three main forms, namely:

- Reservoir storage plots;
- User supply plots; and
- Restriction plots.

Conclusions are drawn from the results in terms of the system's behavior resulting from the specific conditions assigned with each varying scenario assessed. **Figure 5.1** provides an example of a boxplot including the probability distribution levels. Further details of interpreting a boxplot as well as analyses results are provided in **Appendix C**.

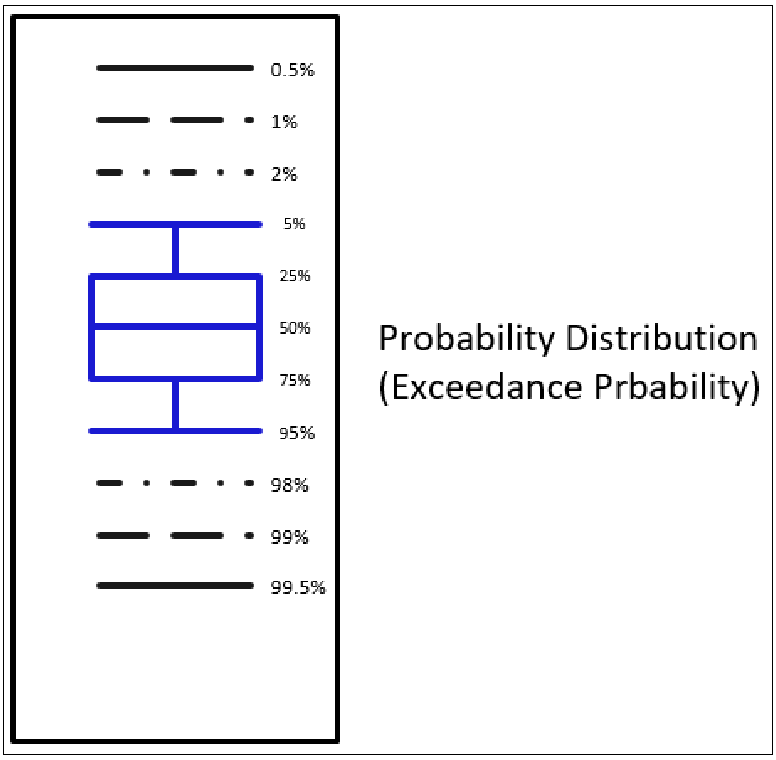


Figure 5.1: Boxplot legend to be applied to all results

5.2 White River Sub-system

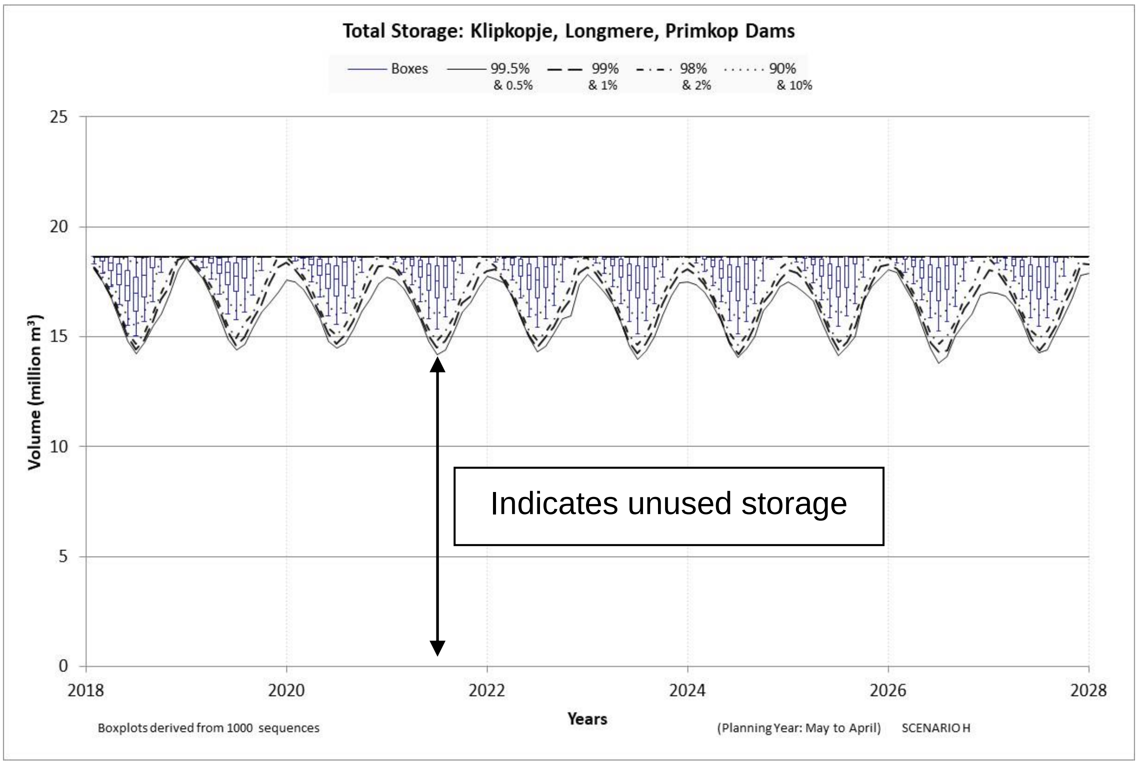
As presented is **Section 4.2.1**, the White River sub-system is further broken down into the individual sub-catchments of Witklip Dam and the combination of Klipkopje, Longmere and Primkop (KLP) Dams.

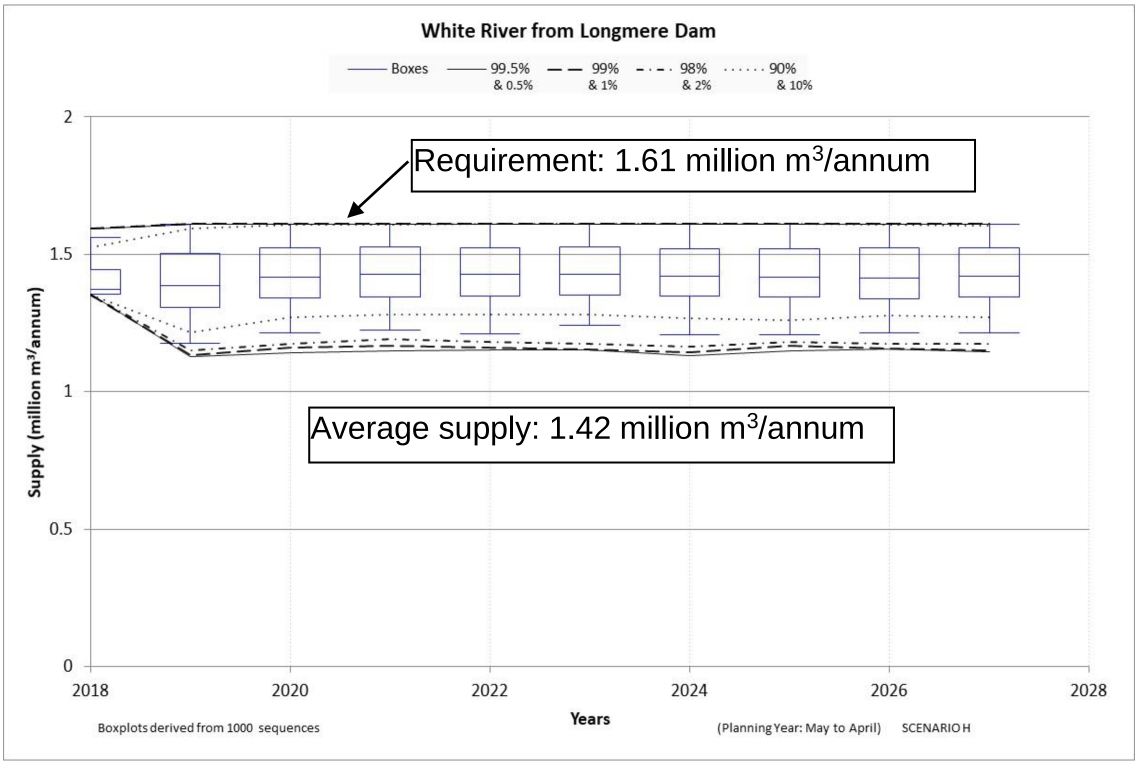
Three scenarios were undertaken to analyse the White River subsystem; namely:

- Scenario A: The existing operating rule;
- Scenario B: An operating rule driven by the short term yield capabilities without releases for the EWR; and
- Scenario C: Scenario B with releases for the EWR.

5.2.1 Scenario A

Figure 5.2 provides plots of output from Scenario A, applying the existing drought restriction operating rule which restricts users in the White River System identically to those in the Crocodile System and is dependent on the storage of Kwena Dam. The existing operating rule is described in Section 3.4. For this scenario, only the current (2018) demands were placed on the system and growth in demands was not considered.


Total Storage: Klipkopje, Longmere, Primkop Dams
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Volume (million m³)
25
20
15
10
5
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO H
Indicates unused storage


White River from Longmere Dam
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/annum)
2
1.5
1
0.5
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO H
Requirement: 1.61 million m³/annum
Average supply: 1.42 million m³/annum

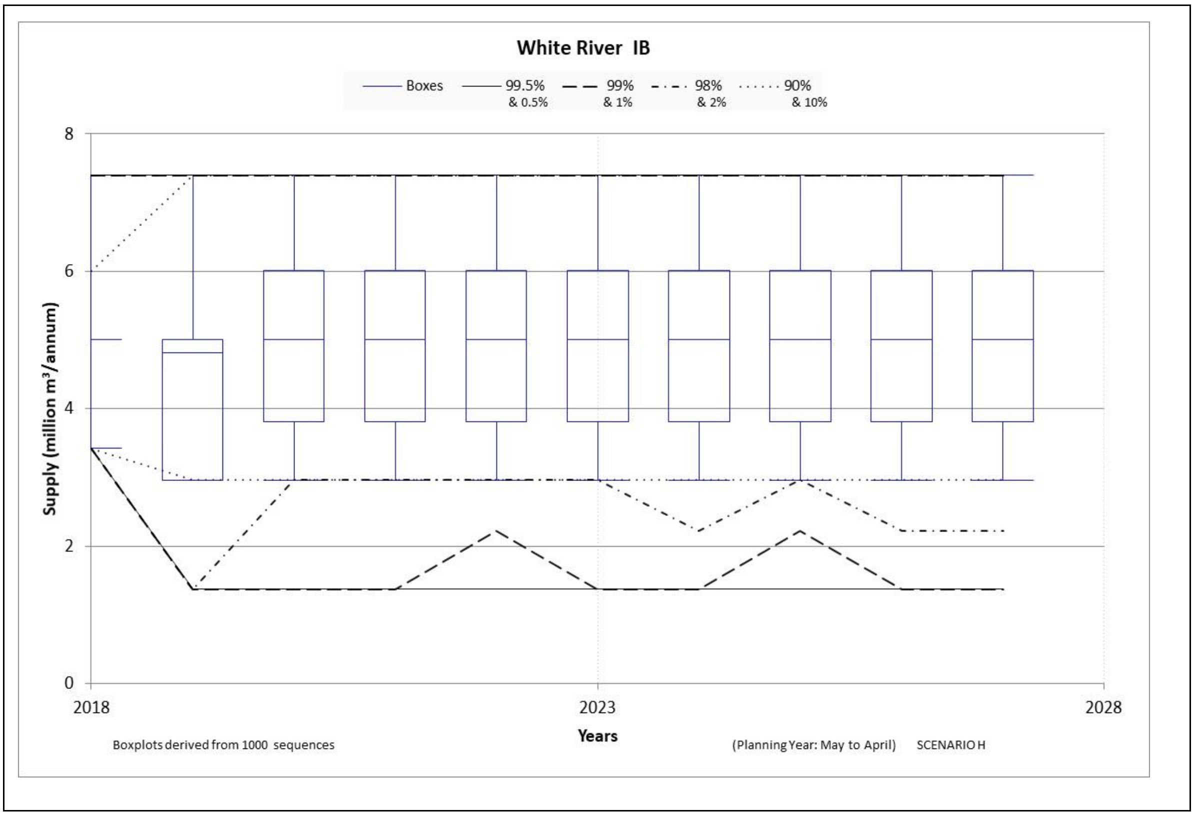
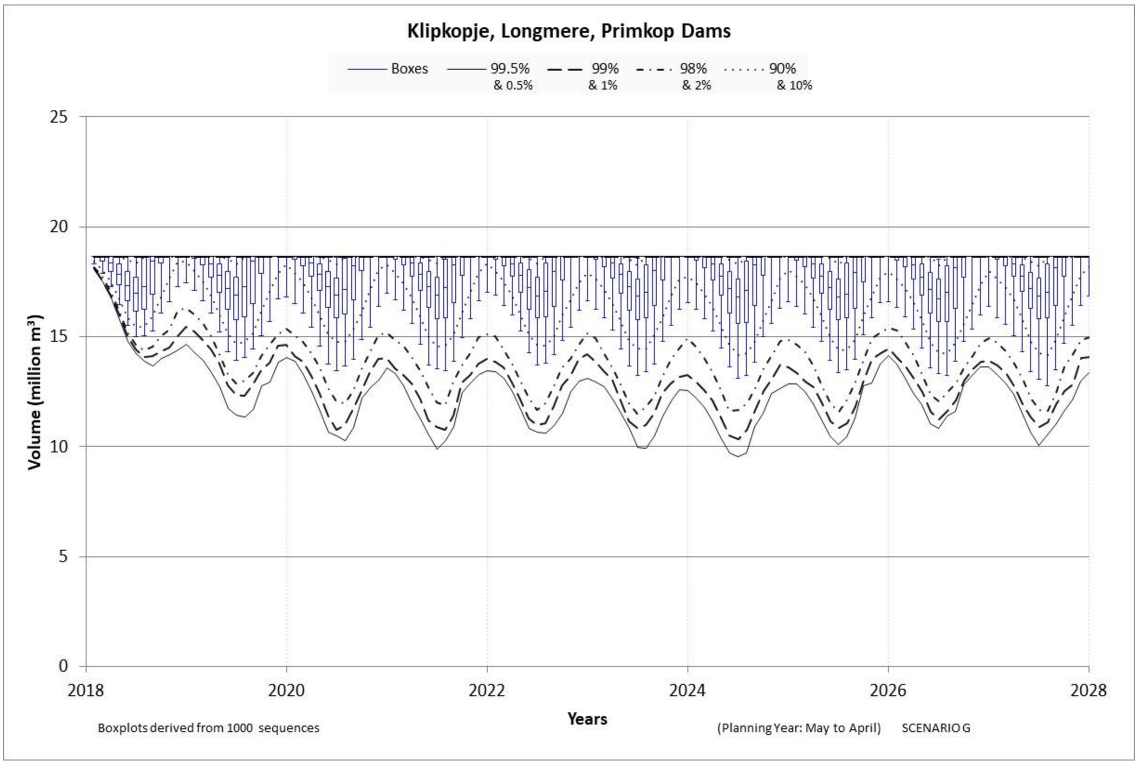


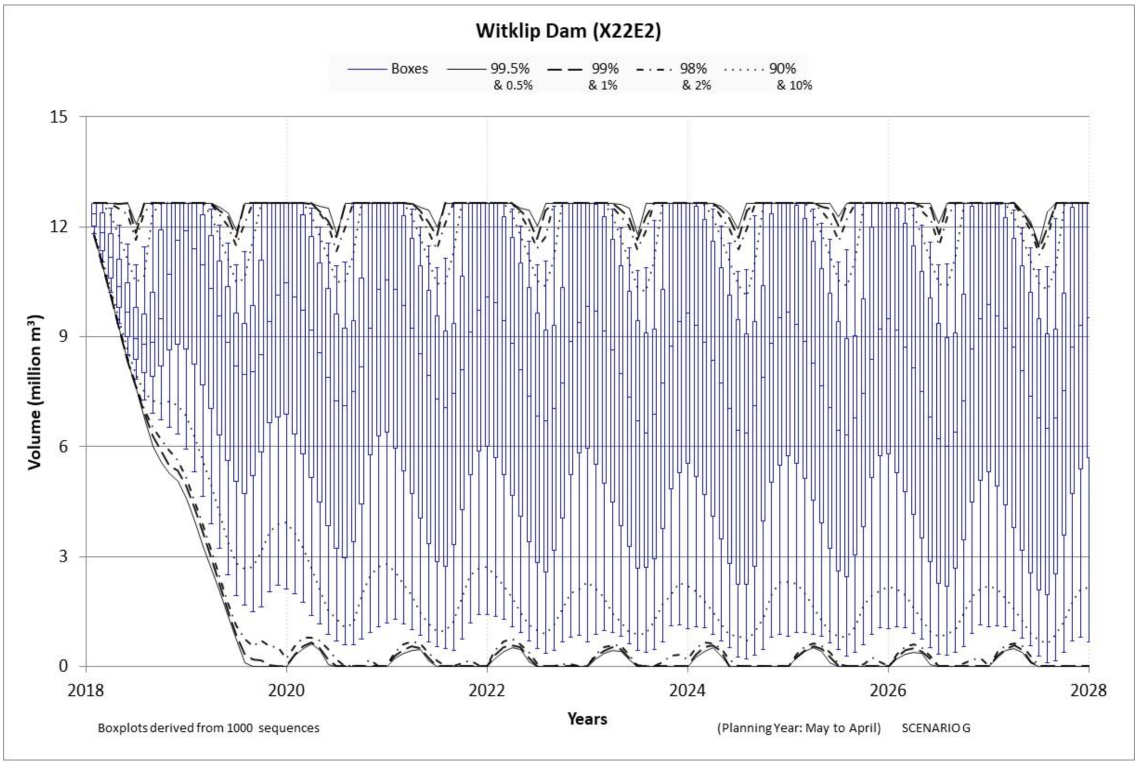
Figure 5.2: Results from Scenario A: White River System

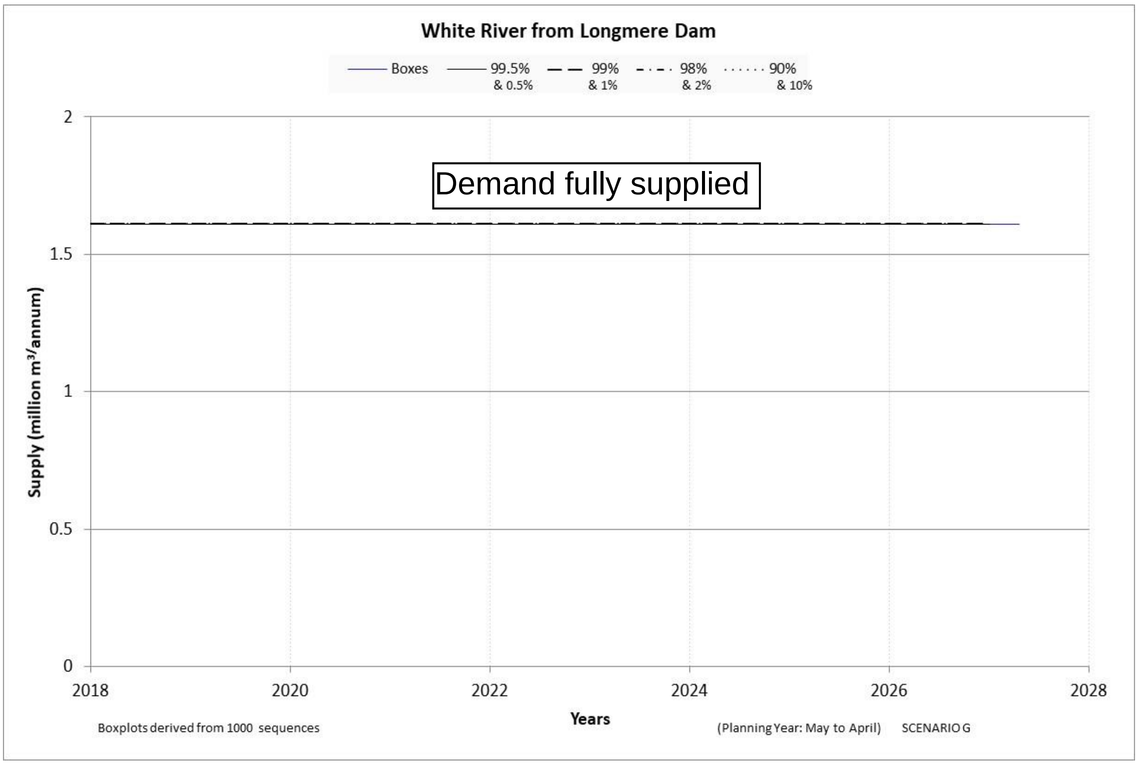
The results show that linking the White River restrictions to the Kwena Dam storage is not an efficient way to operate the White River system. The KLP System is left with unused excess storage due to the strict implementation of restrictions on the users. The domestic users of White River are restricted in excess of a satisfactory criteria for the urban sector and on average only obtain approximately 88% of their required demand each year. Similarly, the irrigators are supplied at a very low assurance level albeit similar to the Crocodile System irrigators.

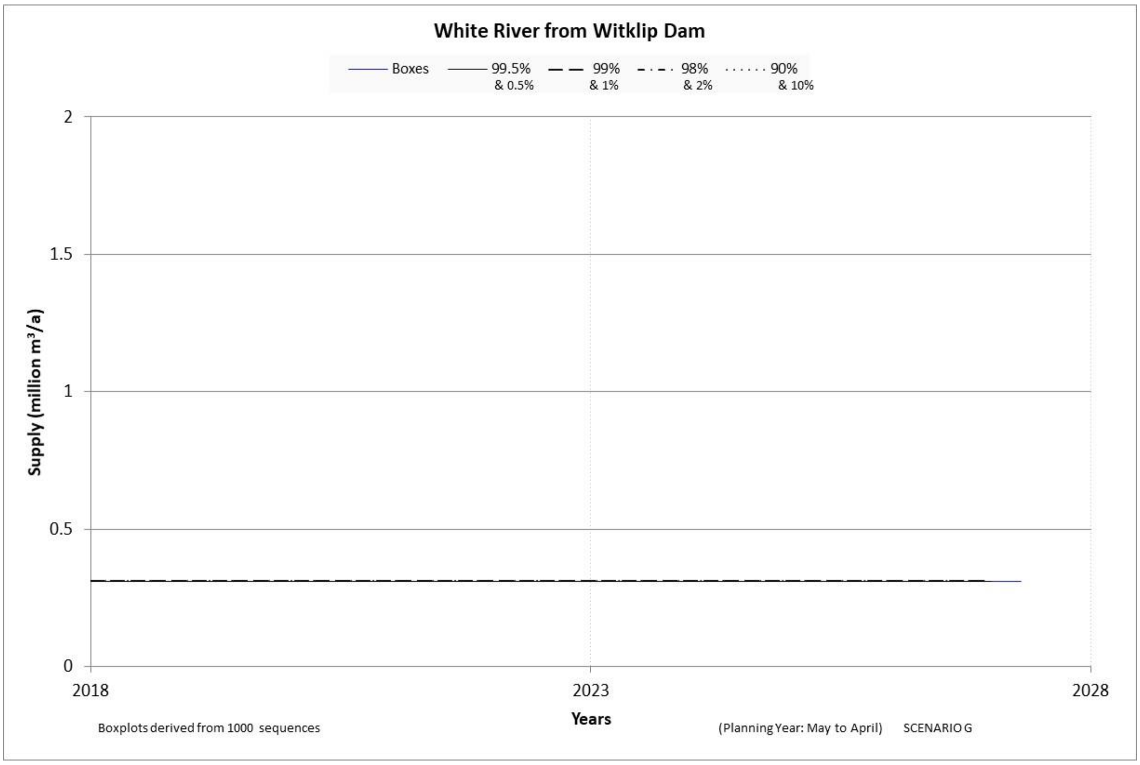
5.2.2 Scenario B

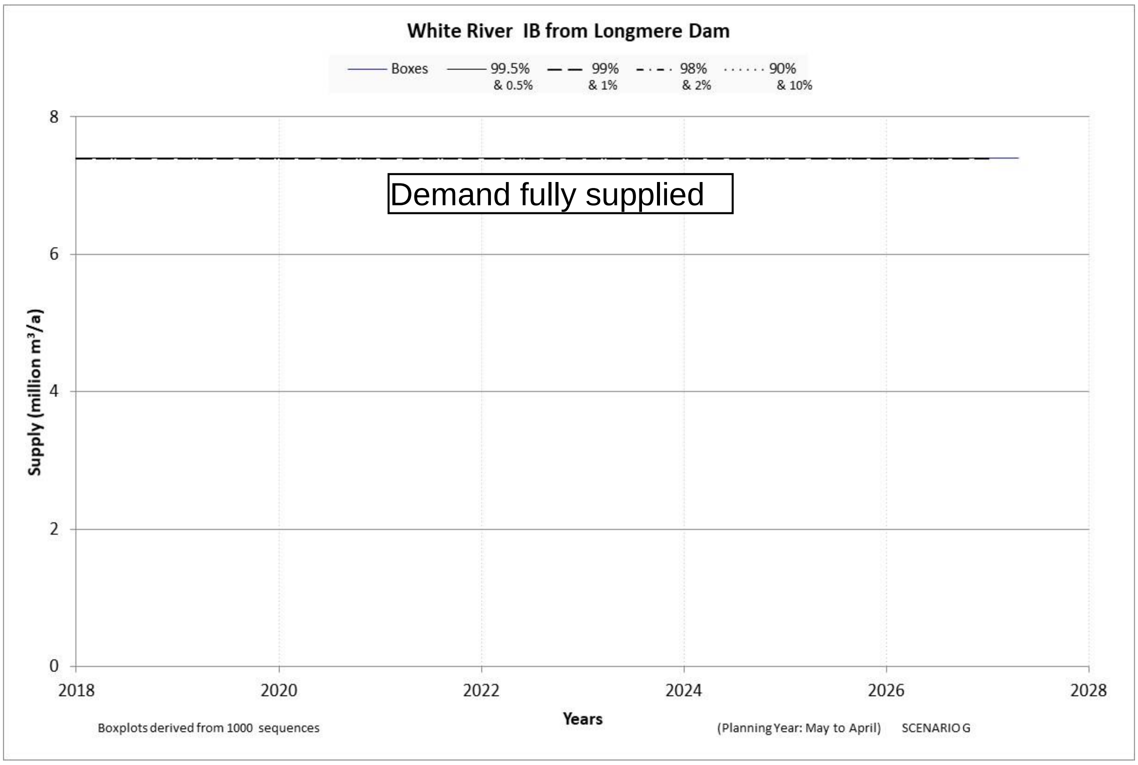
The following figures provide plots resulting from Scenario B. In this scenario, an operating rule driven by the short term yield capabilities of the systems has been included. This rule allows for the model to make a decision on the selected decision date (1 May) each year at the time where the dam storages are at their highest levels as a result of the preceding rainy season. The user requirements at their specified assurance of supply criteria are then compared with the short term yield capabilities of the system and a decision is made whether their full requirement can be supplied, or whether a restriction on their use should be applied for the following year.


Klipkopje, Longmere, Primkop Dams
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Volume (million m³)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

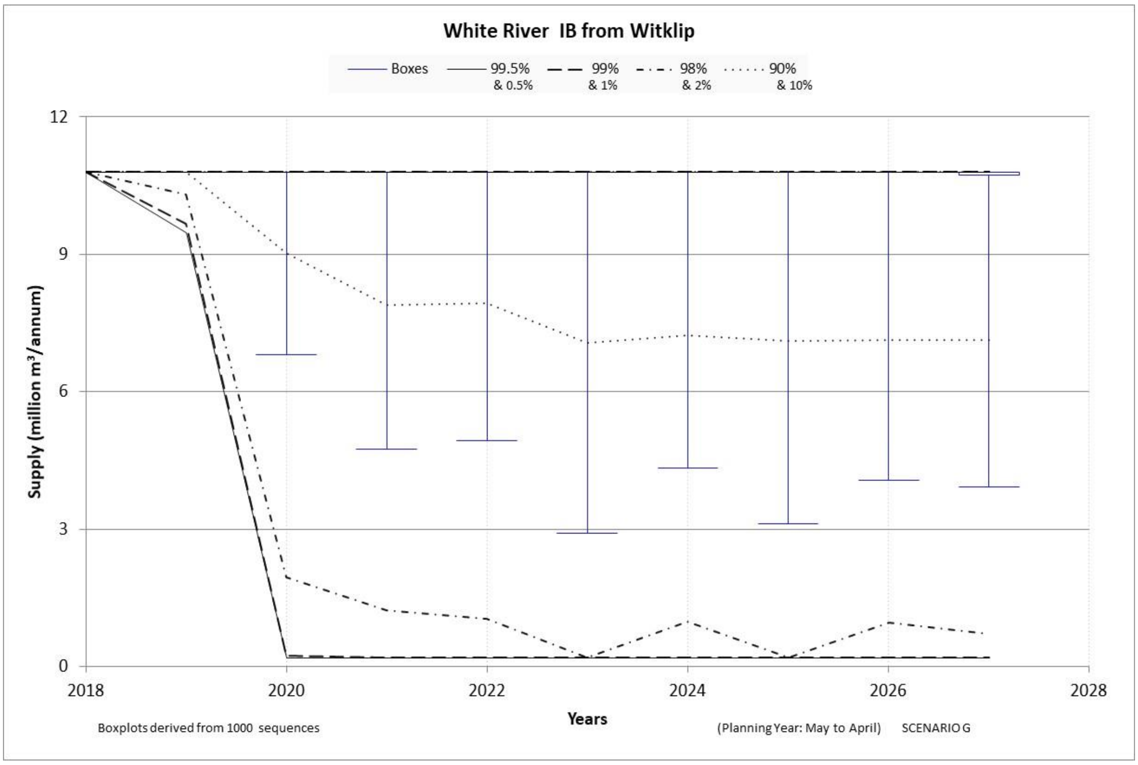

Witklip Dam (X22E2)
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Volume (million m³)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G


White River from Longmere Dam
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Demand fully supplied
Supply (million m³/annum)
0
0.5
1
1.5
2
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G


White River from Witklip Dam
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
0
0.5
1
1.5
2
2018
2023
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G



White River IB from Longmere Dam
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Demand fully supplied
Supply (million m³/a)
8
6
4
2
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G



White River IB from Witklip
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/annum)
12
9
6
3
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

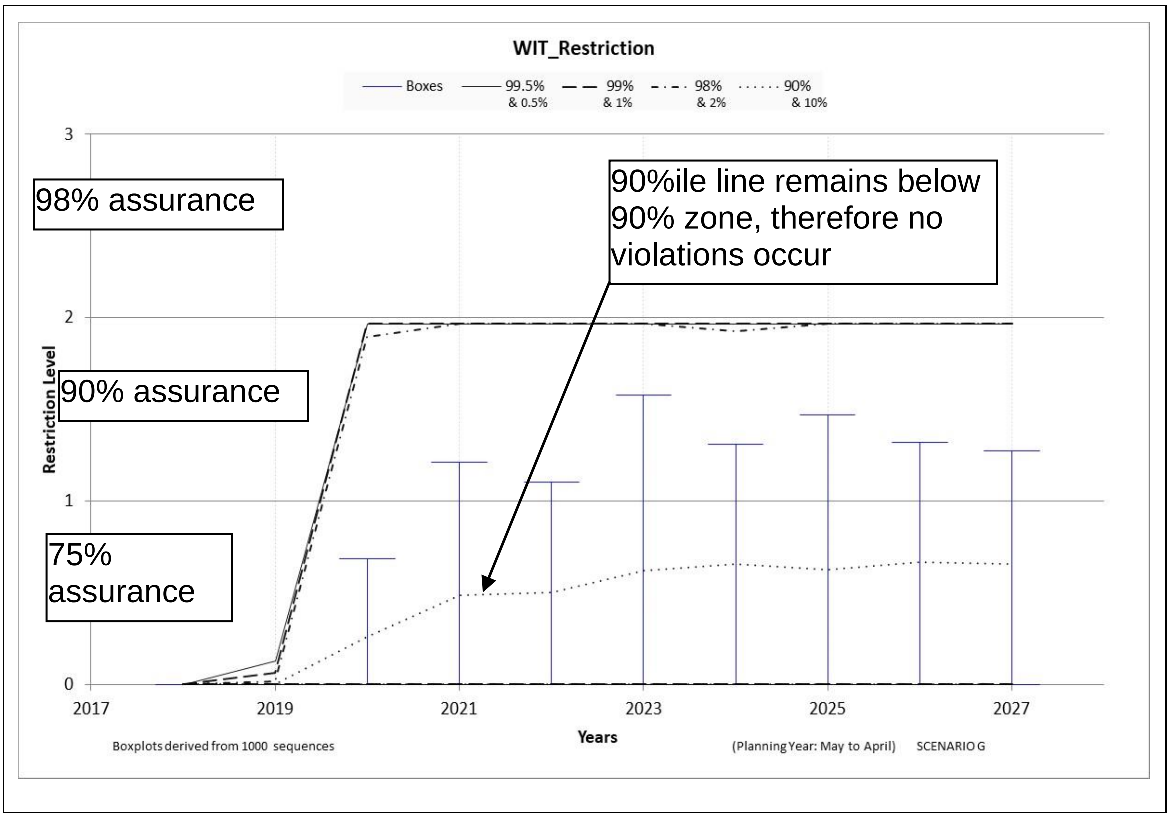


Figure 5.3: Results from Scenario B: White River System

It is evident from the KLP plots resulting from Scenario B, that there is surplus water in that sub-system. The users are provided their allocations in full and restrictions are not required. This is in line with the short term yield plot including the system demands presented in **Figure 4.5** which shows that the dams are able to drop to 20% storage level prior to any restriction of users being required due to the balance between yield and demand on that system, also shown in the Long Term Yield results.

The demands on the Witklip Dam are heavily weighted towards irrigation with 10.8 million m^3/annum required for irrigation allocations compared with only 0.3 million m^3/a currently used for domestic purposes. The results show that the irrigators are restricted first, while the urban demand is fully supplied at all times. This is achieved by placing the irrigation demands at the lower assurance criteria levels. The assurance criteria is not violated under these criteria. **Figure 5.4** provides a simplified operating rule curve for the Witklip Dam sub-system obtained from the WRPM result of simulating the operating rule driven by the short term yield. It should be noted that this rule curve is extracted from results of the 2018 demand level. The rule curve would differ slightly as the domestic demands on the system grow such that the curve always protects the higher assurance criteria users. This is automatically simulated in the WRPM under the growth projection scenario.

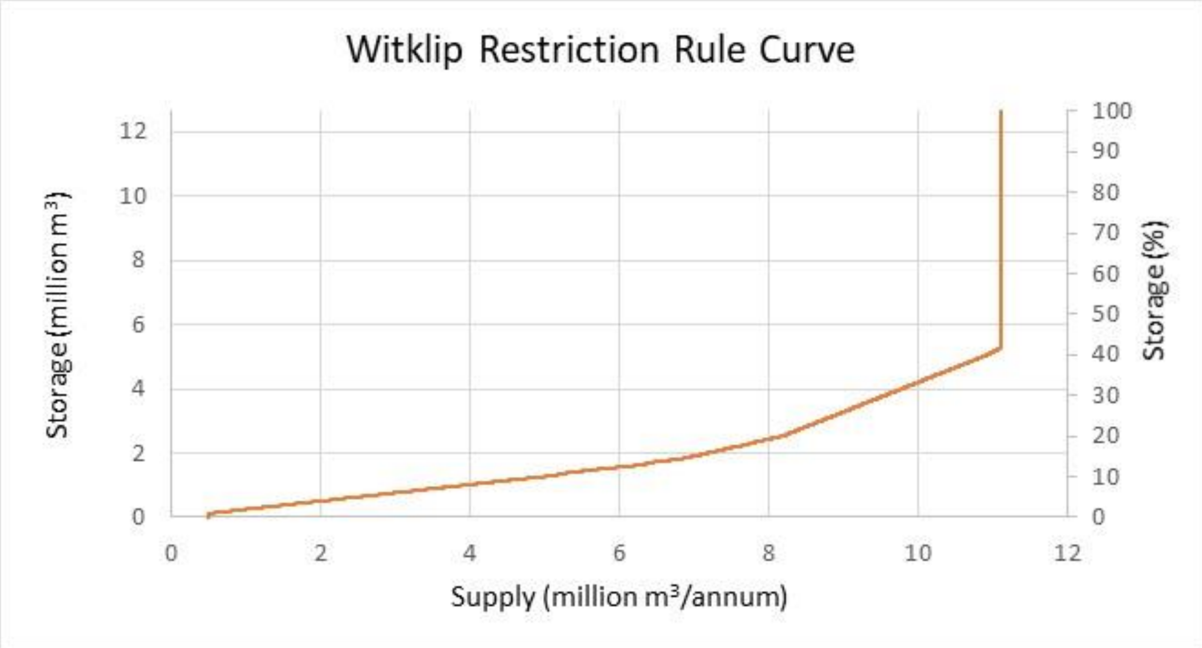


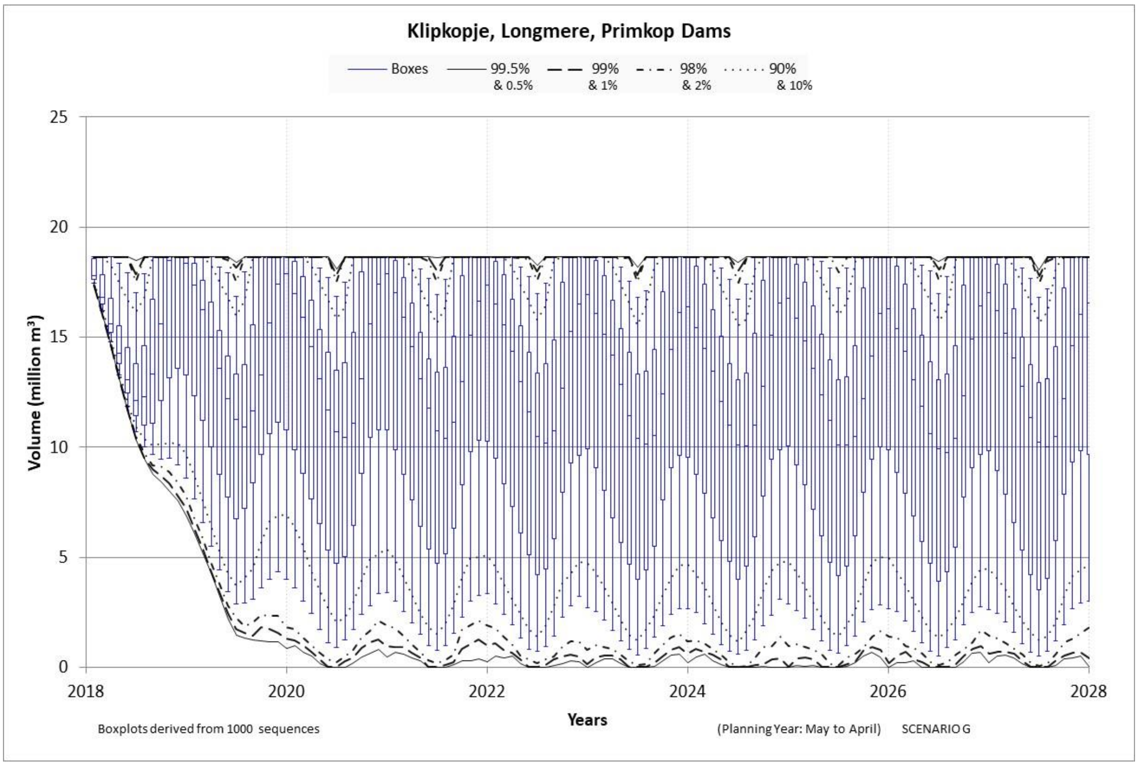
Figure 5.4: Witklip Dam Restriction Rule Curve based on 2018 demand level

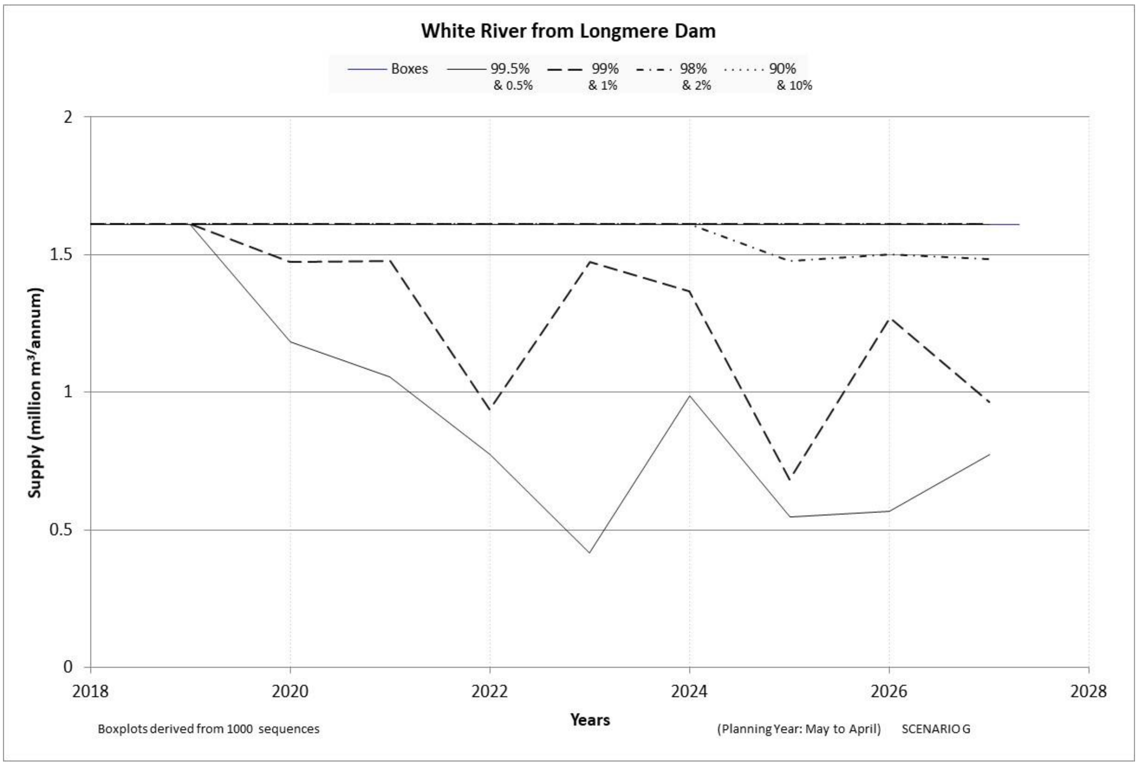
5.2.3 Scenario C

As a result of the evident surplus in availability in the KLP Dam sub-system observed as an outcome of Scenario B, a further scenario was undertaken in order to allow the KLP Dams to contribute some surplus towards the EWR on the Crocodile River. The criteria set was to obtain a result such that the irrigators on the KLP Dam sub-system have a similar assurance criteria as the Witklip Dam irrigators of 50% of the demand at a 1 in 4 year assurance and 50% of the demand at a 1 in 10 year assurance level.

The EWR was placed on the system downstream of Primkop Dam. The EWR was determined by scaling the Crocodile EWR site 3 which is located shortly after the White River and Crocodile River confluence. A balance was obtained by using an EWR of 50% of the requirements based on the relationship of the natural hydrological flows.

The following figures provide the result of the scenario.


Klipkopje, Longmere, Primkop Dams
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Volume (million m³)
25
20
15
10
5
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G


White River from Longmere Dam
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/annum)
2
1.5
1
0.5
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G

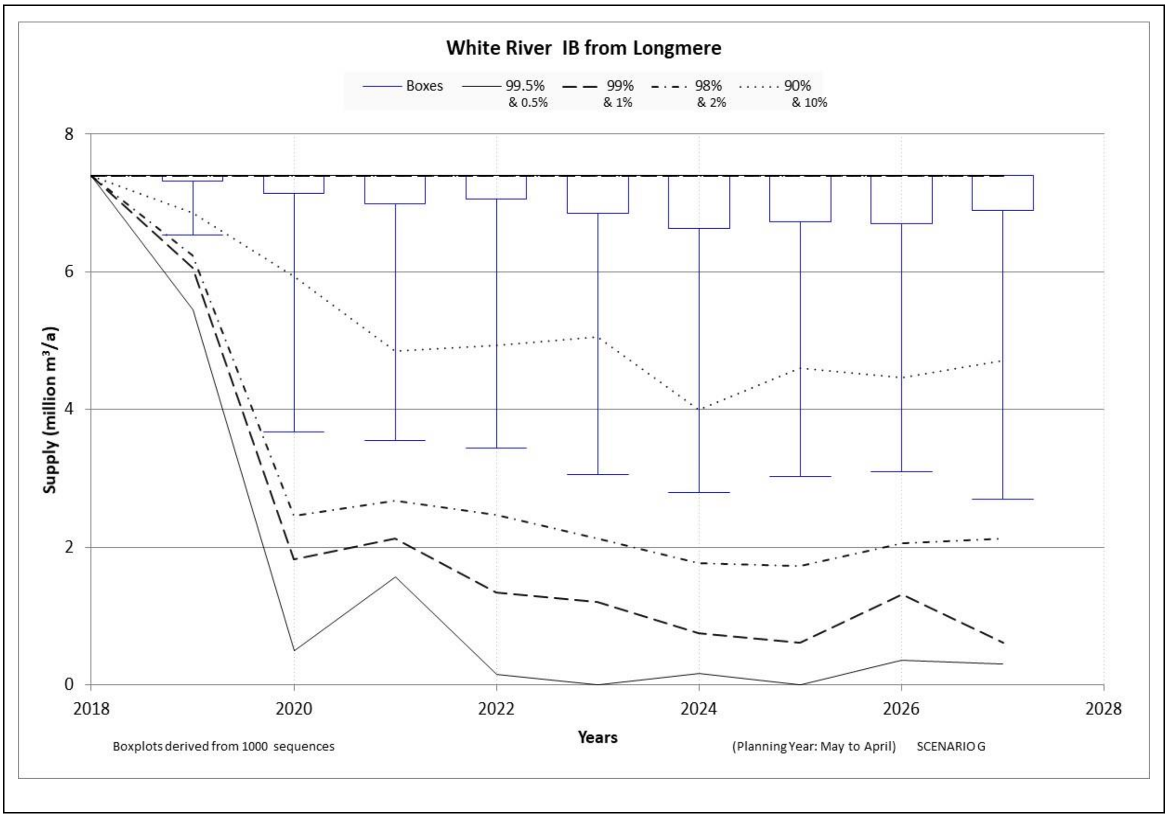


Figure 5.5: Results from Scenario C: White River System

The results show an improved utilization of the KLP System is observed while the water users are supplied at a more similar assurance criteria to the same user groups in other sub-systems. The results indicate that a balance should still be sought between EWR releases and user supply as the irrigation demand is starting to fail at the 1 in 4 year recurrence interval. Further refinement can be undertaken if agreement is reached from users of the system to allow for releases in order to support the Crocodile EWR. The preliminary analyses was undertaken in order to determine the impact. The implication of the EWR releases on the Crocodile River System are illustrated in Section 5.3.3.

5.3 Crocodile system

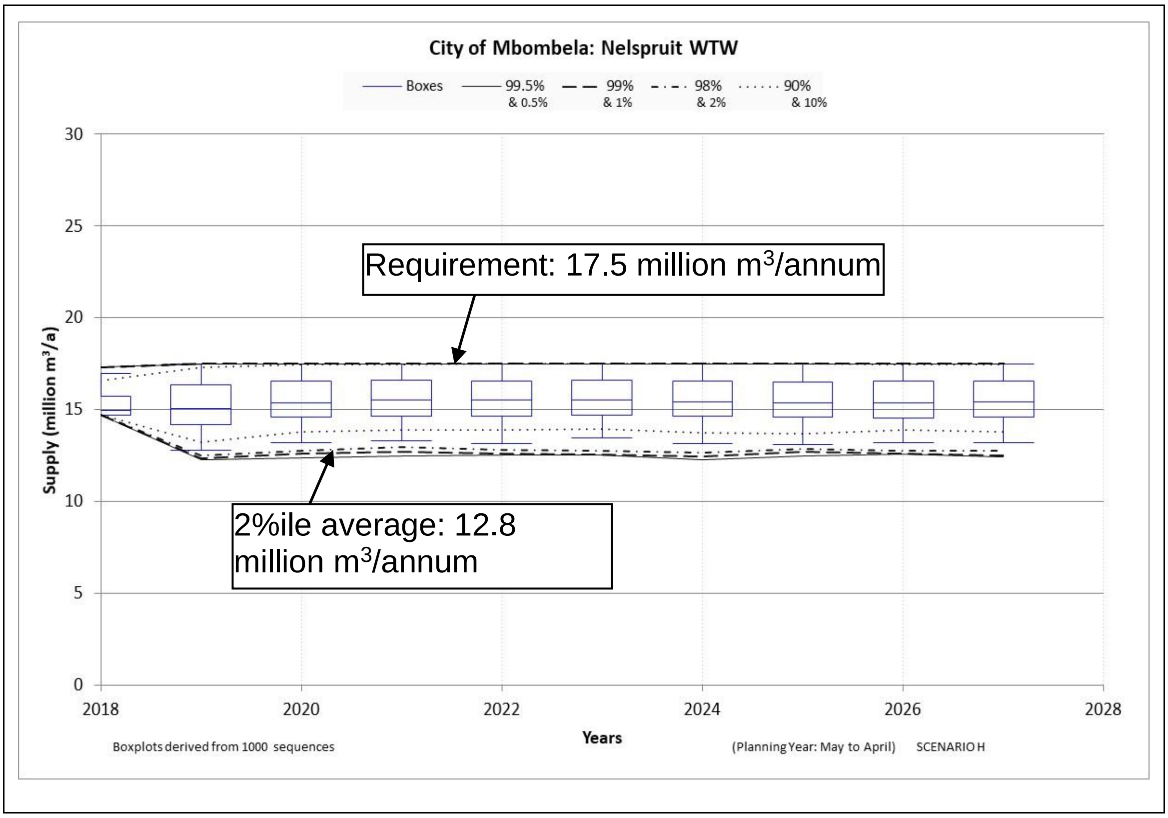
Five scenarios were formulated to analyse the Crocodile River system; namely:

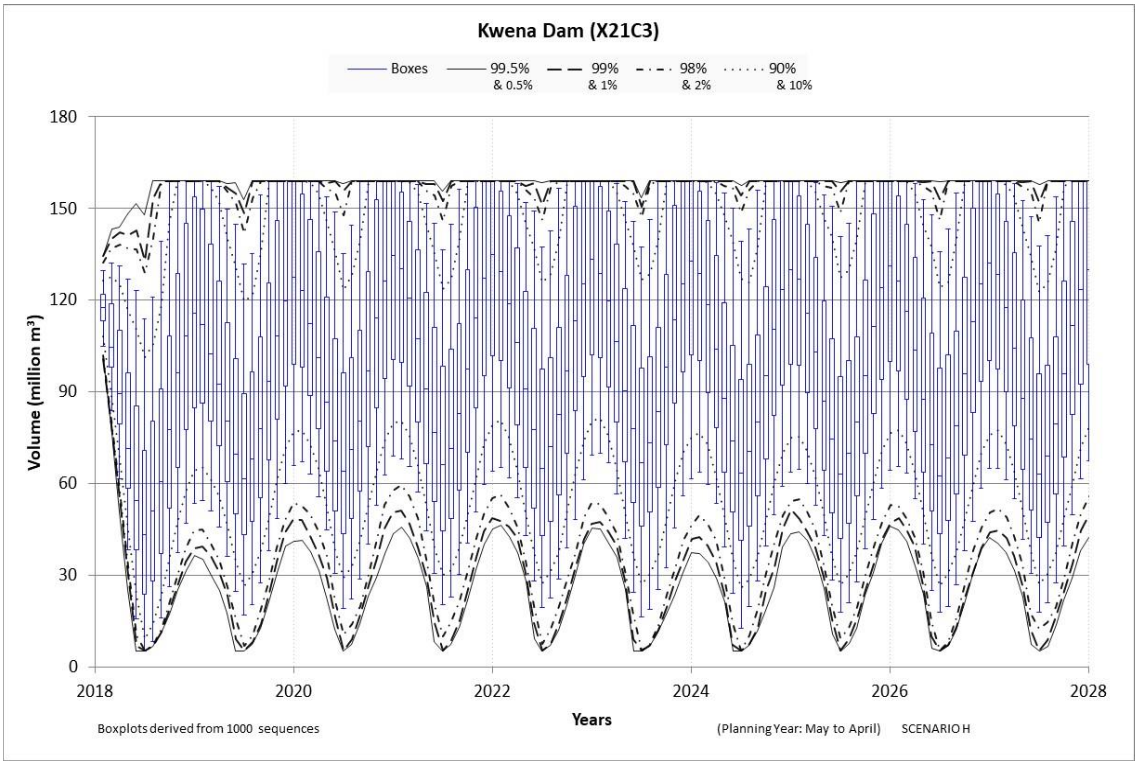
- Scenario A: The existing operating rule;
- Scenario A_{relax}: Scenario A with restrictions lifted when surplus river runoff occurs in system downstream of Kwena Dam;
- Scenario B: The operating rule driven by the short term yield capabilities;
- Scenario B_{adjust}: Scenario B with adjusted short term yield curves at the higher dam storage levels to allow users to obtain 100% allocation in times of high system storage;

- Scenario C: Scenario B_{adjust} with releases from the KLP Dams for the EWR.

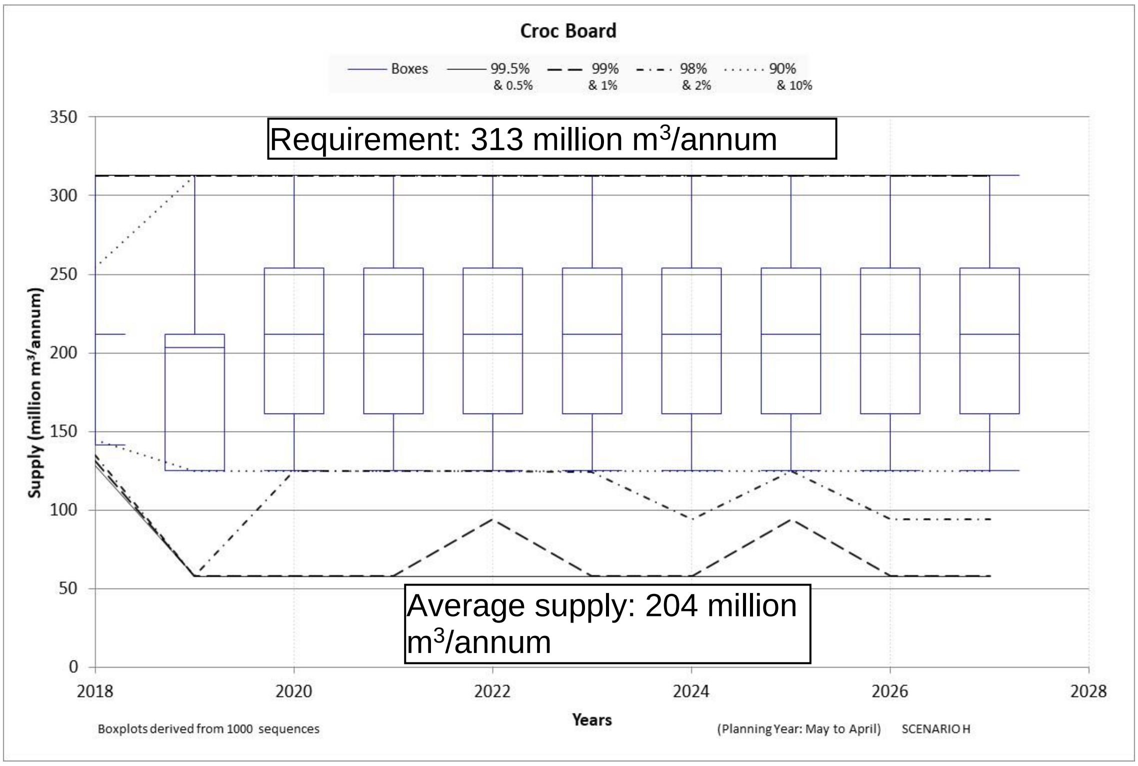
5.3.1 Scenario A and Scenario A_{relax}

The following figures provide the results obtained from analyzing the system using the WRPM including the existing operating rule as described in Section 3.4. The rule restricts users (both domestic and irrigators) differently depending on the storage level of Kwena Dam. The model has been configured to make the decision to restrict users on two occasions in the year, 1 November and 1 May each year.



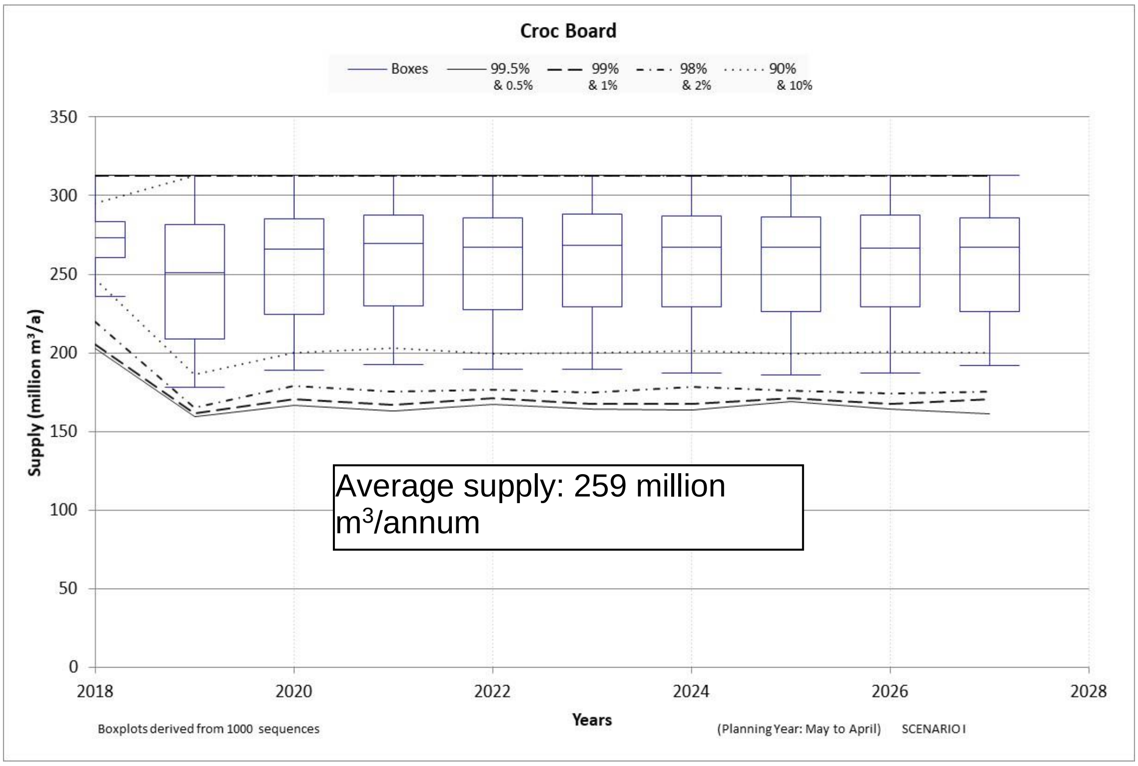


Kwena Dam (X21C3)
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Volume (million m³)
180
150
120
90
60
30
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO H



Croc Board
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Requirement: 313 million m3/annum
Average supply: 204 million m3/annum
Supply (million m³/annum)
350
300
250
200
150
100
50
0
2018
2020
2022
2024
2026
2028
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO H

Scen A



Scen A_{relax}

Figure 5.6: Results from Scenario A and A_{relax}: Crocodile River System

The results show that the operating rule is effective as the rule protects the storage in Kwena Dam and the dam only nearly empties at the 98% assurance criteria level which is the standard criteria for domestic users. However, the results also shows that the assurance of supply to the domestic users (in this case abstraction at the Nelspruit WTW) and the irrigators of the Crocodile Irrigation Board is far lower than what a reasonable expectation of an assurance criteria for those sectors would be. The urban example of the resulting supply through the Nelspruit WTW shows the two percentile probability average of 12.8 million m^3/annum, which is only 73 percent of the requirement of 17.5 million m^3/annum. The irrigation only receives 204 million m^3/annum on average as a supply, whereas the requirement is 313 million m^3/annum.

A comparison of the Crocodile Irrigation Board supply for Scenario A and Scenario A_{relax} shows that the Board is supplied better if the users are allowed to benefit from river flows that may occur during restriction conditions. The improvement on the average supply is 55 million m^3/annum. It should be noted that this is a simulation and therefore the ideal case, and would likely be less in reality due to operational inefficiencies. Continuous monitoring and cooperating operation of the system is required to achieve this benefit.

5.3.2 Scenario B and Scenario B_{adjust}

The following figures provide plots resulting from Scenario B and Scenario B_{adjust}. In these scenarios, an operating rule driven be the short term yield capabilities of the system has been included. This rule allows for the model to make a decision on the selected decision date (1 May) each year at the point where the dam storage is at its highest levels as a result of the preceding rainy season. The user requirements at their specified assurance of supply criteria are then compared with the short term yield capabilities of the system and a decision is made whether their full requirement can be supplied, or whether a restriction on their use should be applied for the following year.

As presented in **Section 4.2.2**, the Crocodile system is not able to provide the existing demand on the system at the required assurance of supply level, and the yield availability from the system requires that the irrigators be permanently restricted. A second operating rule was assessed in Scenario B_{adjust} in order to allow the irrigators to obtain their full allocation when the Kwena Dam level is at 100% on the decision date. In order to do this, the 100% starting storage short term curves was adjusted as indicated by the red line in **Figure 5.7**.

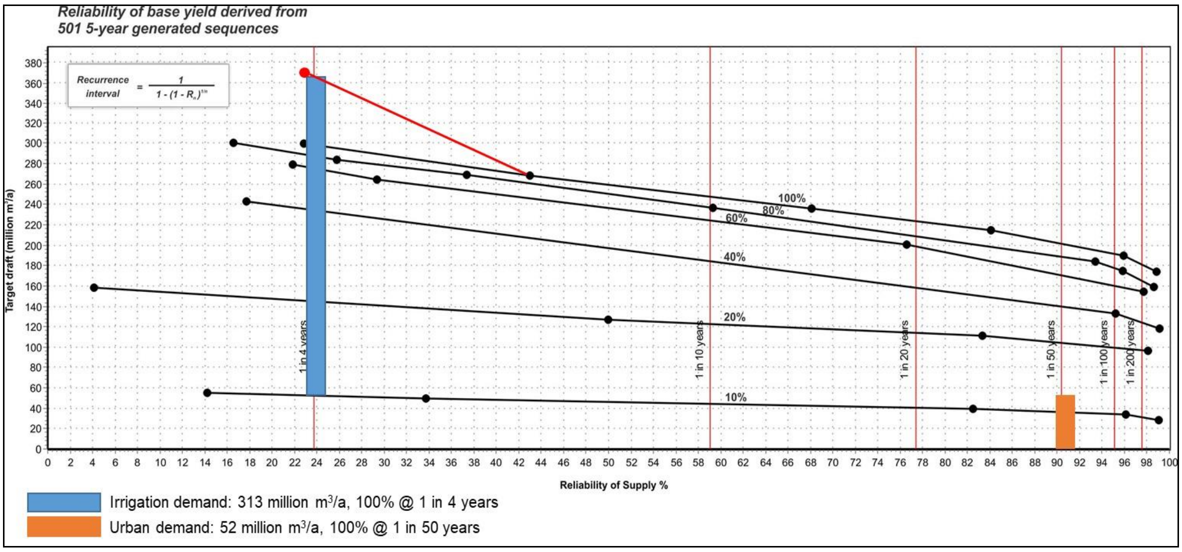
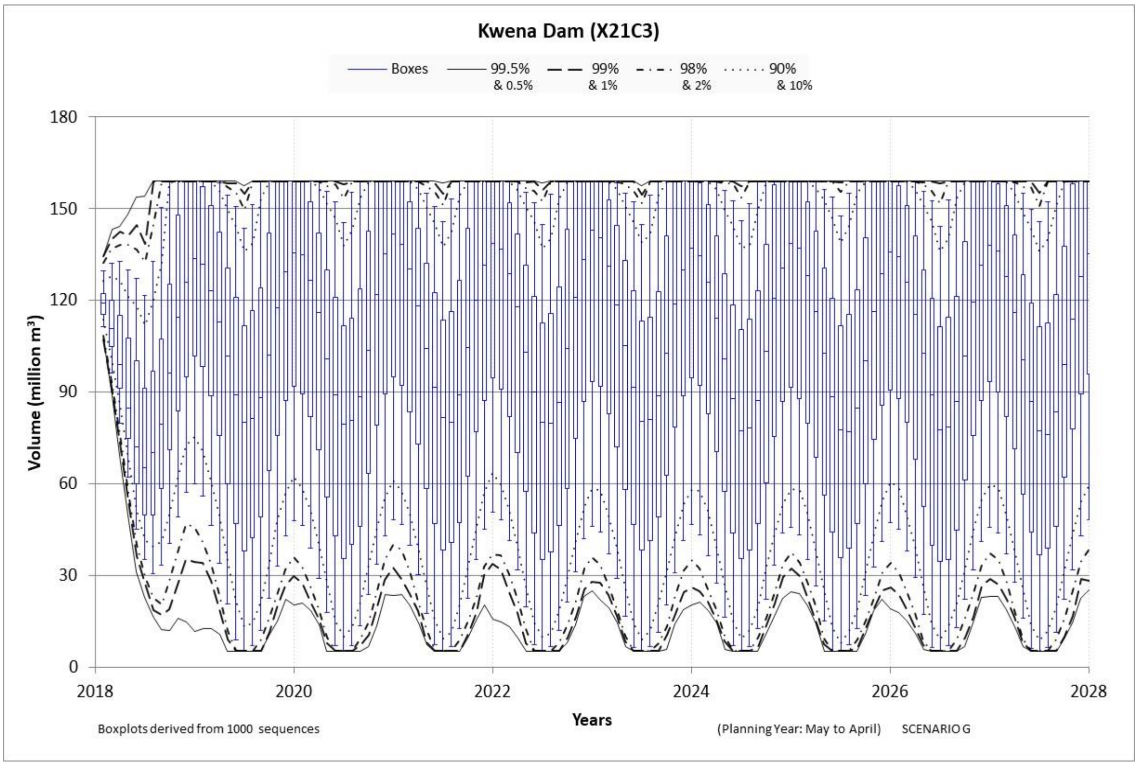
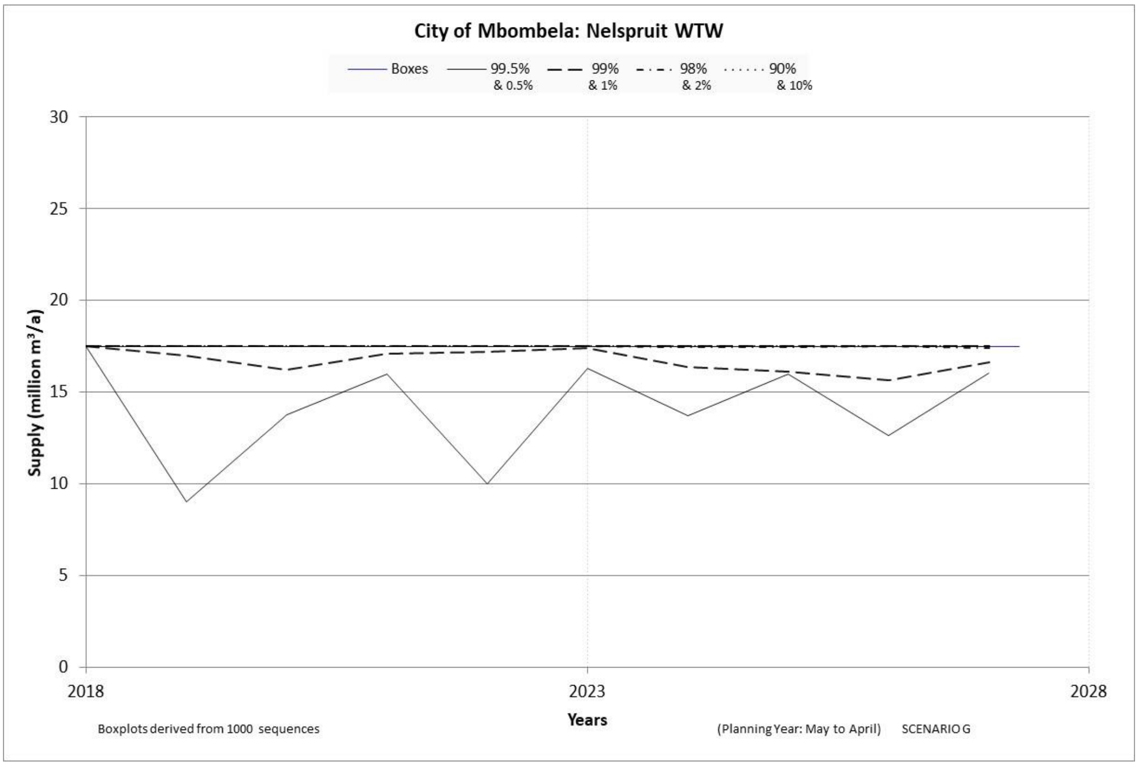


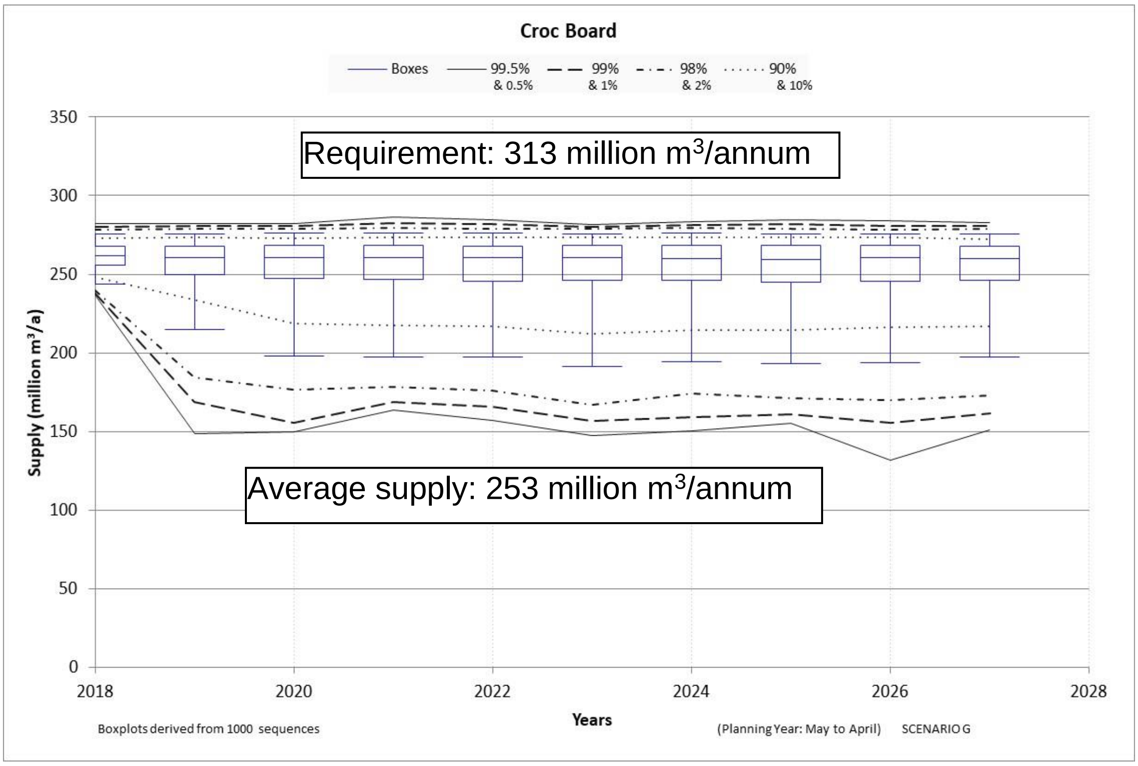
Figure 5.7: Adjustment to Crocodile system short term curves



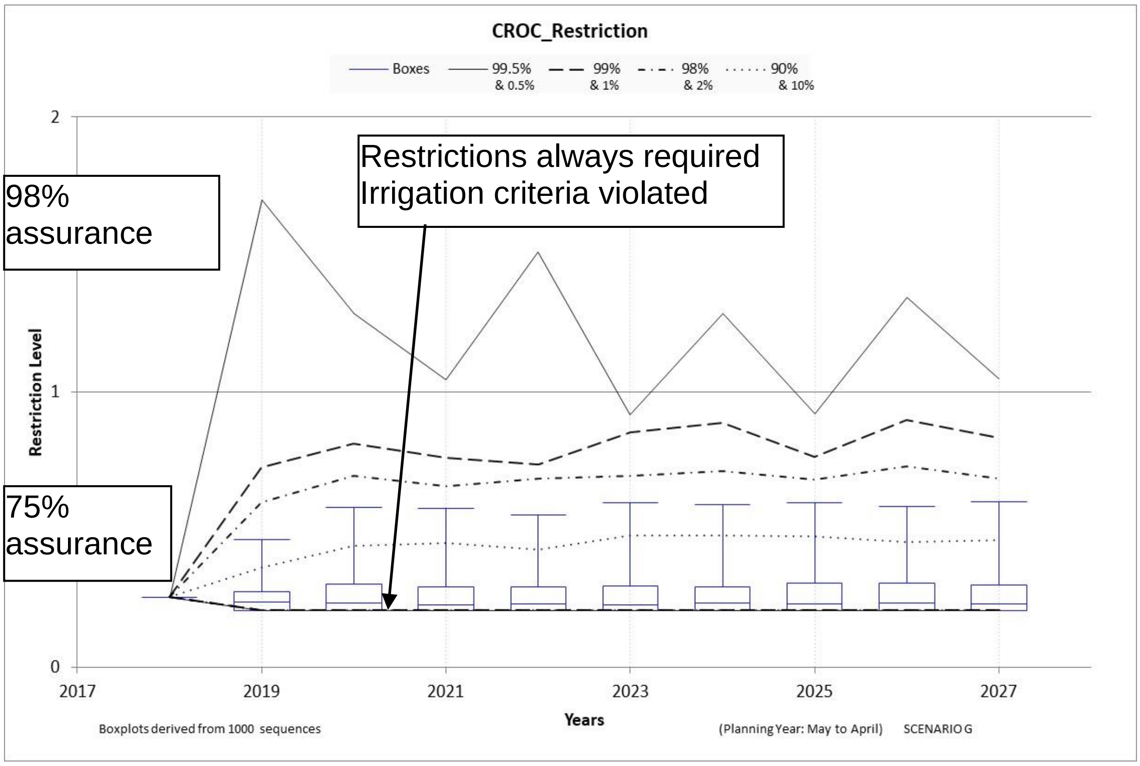
Scenario B



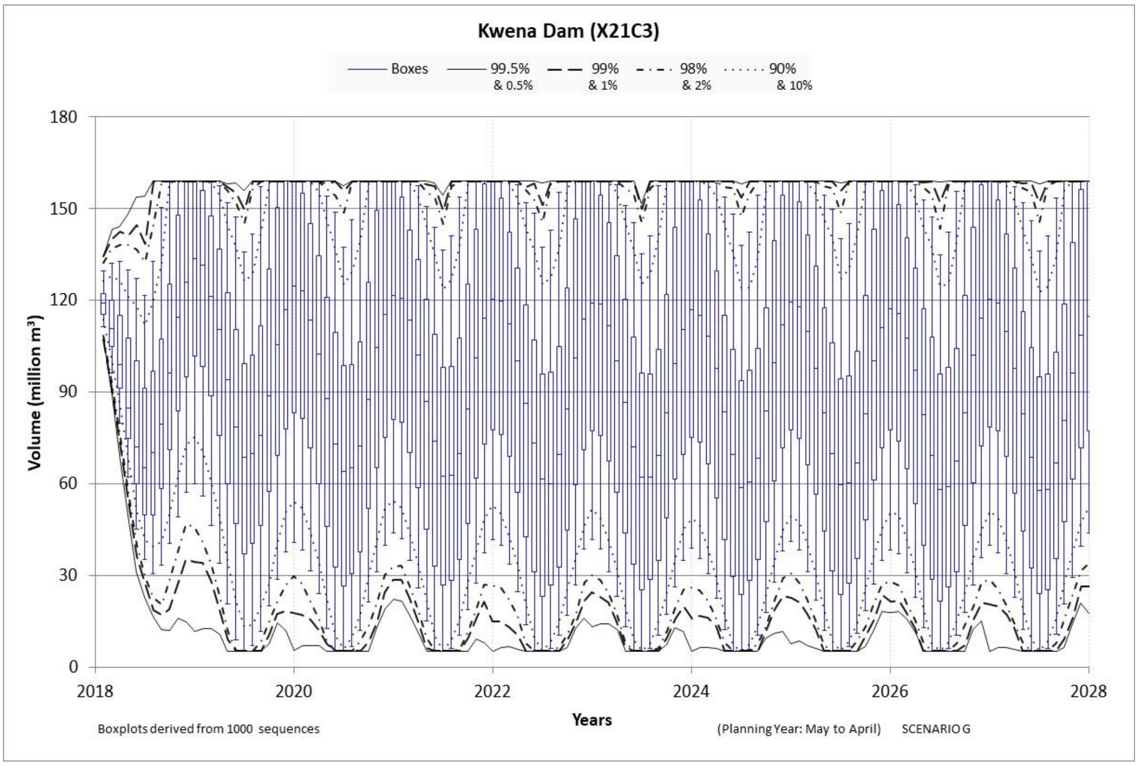
Scenario B



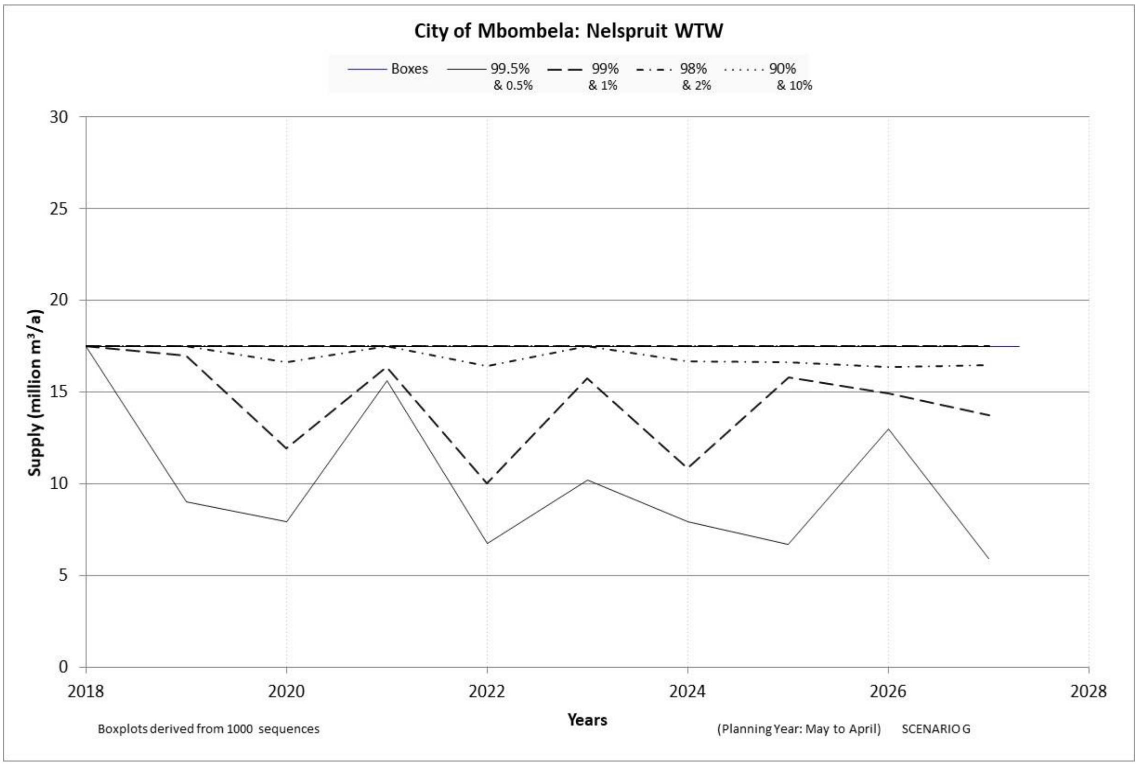
Scenario B



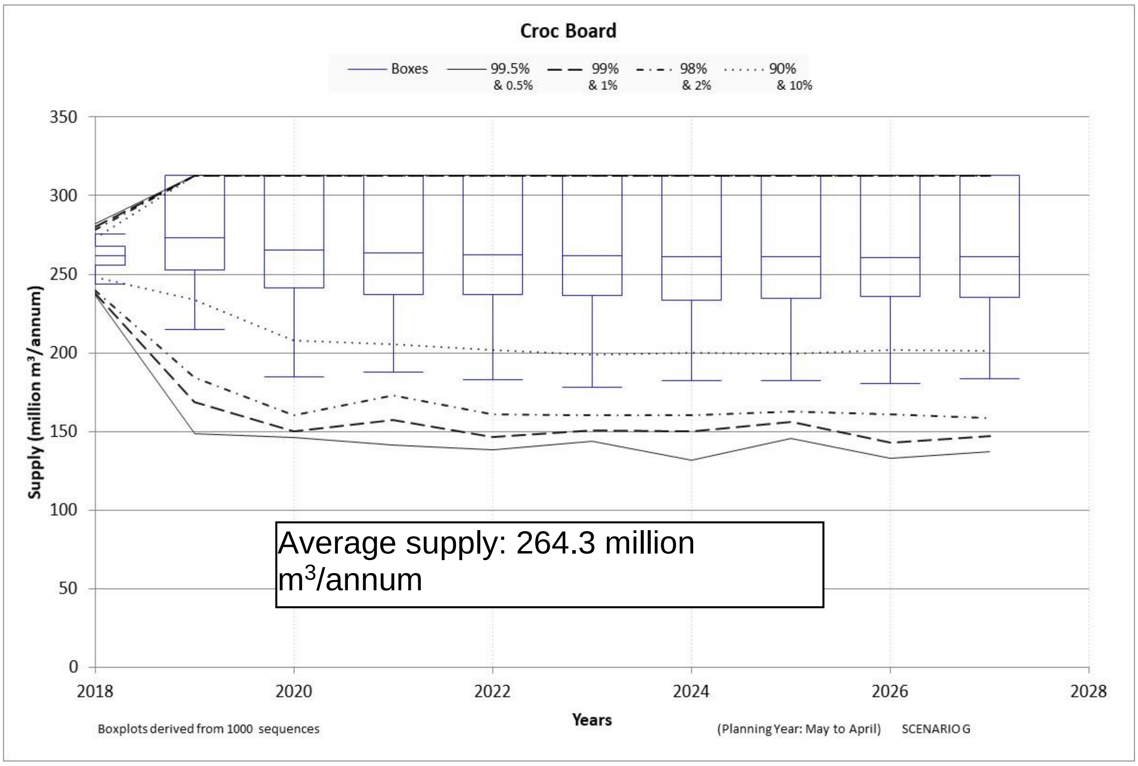
Scenario B



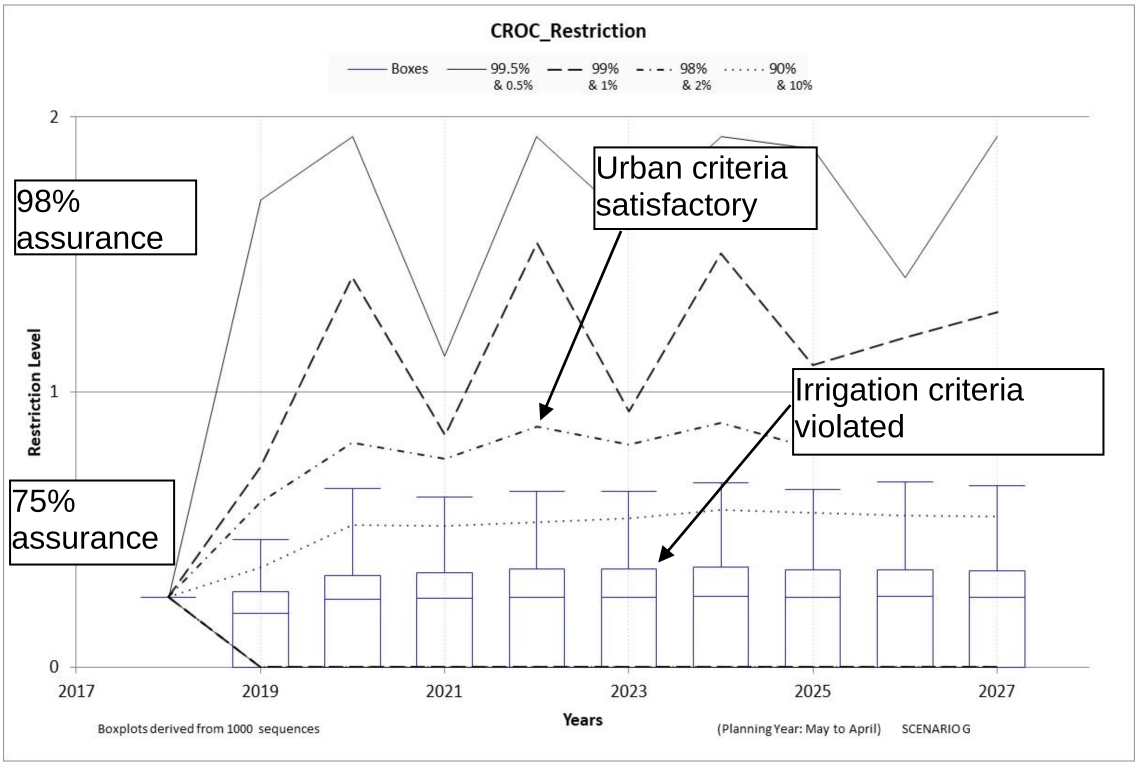
Scenario B_adjust



Scenario B_adjust



Scenario B_{adjust}



Scenario B_{adjust}

Figure 5.8: Results from Scenario B and B_{adjust}: Crocodile River System

The results of Scenario B indicate that the irrigation sector is always under restrictions and never receive their full allocation of 313 million m^3/annum. The average supply over the simulation period is 253 million m^3/annum. The urban demand specified at the higher assurance criteria of 98% is, however, fully supplied as a result of the severe restrictions placed on the irrigation sector. The Kwena Dam plot indicates that the Dam empties at the 5% probability line. This is a higher risk than one would usually allow for a dam supplying domestic users. However, it should be noted that this occurs as a result of a large portion of the system yield occurring from river runoff downstream of the dam as highlighted in **Section 4.2.2**. While the dam has been allowed to run lower than the norm, and the result still indicates that the domestic users are satisfactorily supplied at their required assurance level of 98%.

The results of Scenario B_{adjust} show that the irrigation is now no longer restricted at all times, and they are able to obtain their full allocation for part of the time when the Kwena Dam is full. The average supply over the simulation period increases to 264.3 million m^3/annum in this scenario. However, what the result also shows is that, by allowing the irrigators to take more water at the higher dam storage levels, they are more frequently restricted when the storage levels drop. The domestic supply is also slightly worse in Scenario B_{adjust} however, again it is still within the 98% assurance of supply criteria level and users are not restricted more often than allowed for.

Figure 5.9 provides a simplified operating rule curve for the Crocodile system obtained from the WRPM result of simulating the operating rule with the adjusted short term yield curves (Scenario B_{adjust}). The curve shows that the full demand on the system (363 million m^3/annum) is only allowed for at a storage level of the dam of 100% on the decision date. Thereafter, the system is able to supply demands as per the X-axis dependent on the storage level in the dam indicated on the Y-axis. This simplified curve is applicable to the 2018 demands on the system only, and would require adjustment as the domestic demands on the system grow. The plot also presents dots which indicate supply applicable to storage levels of Current operating rule curve.

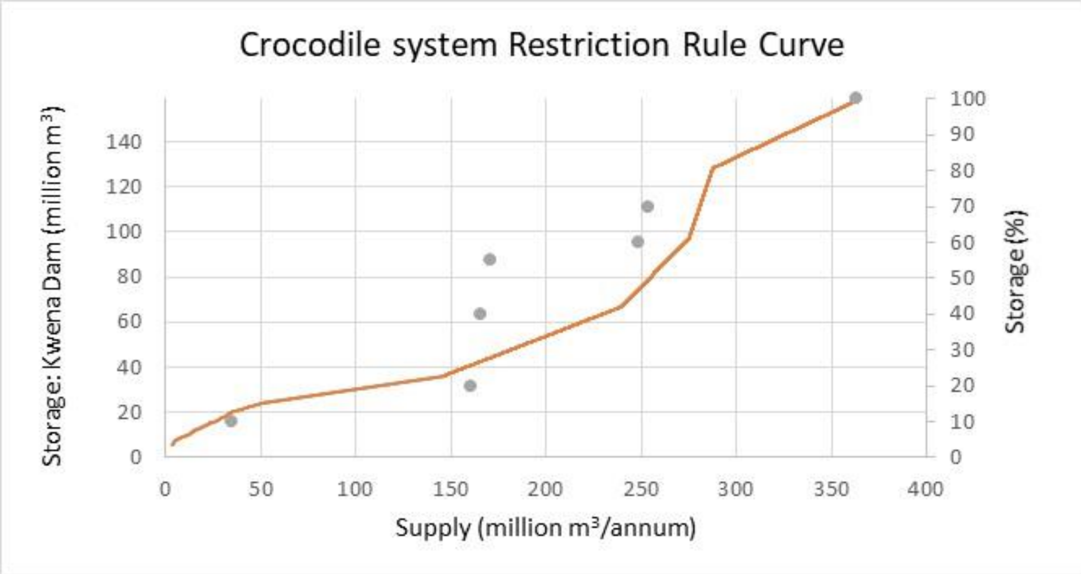
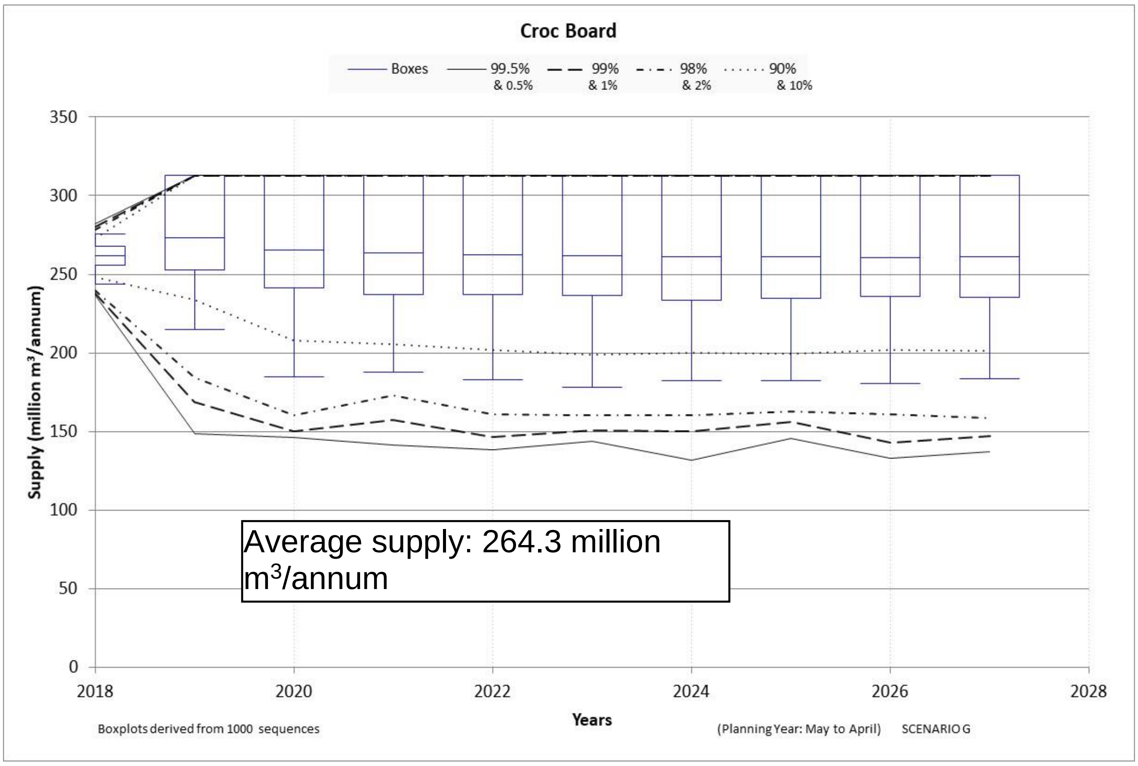


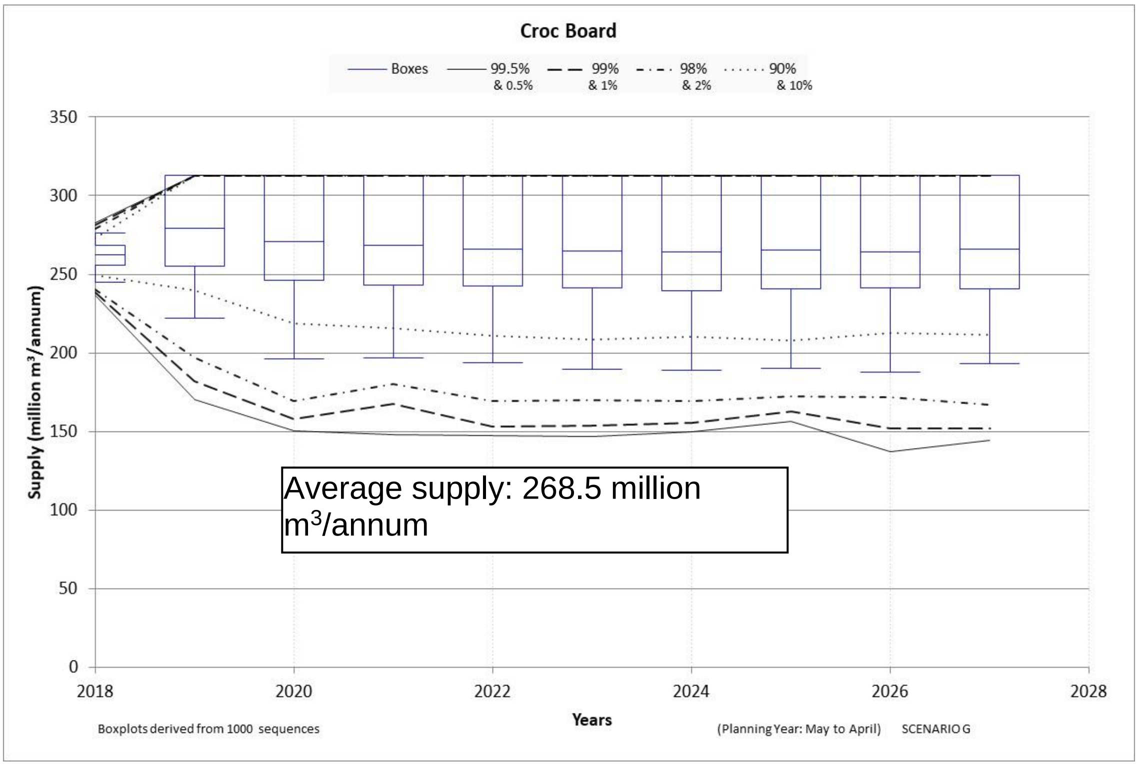
Figure 5.9: Crocodile System restriction rule curve based on 2018 demand level

5.3.3 Scenario C

Scenario C shows the benefit of releasing some water from the KLP dams for the EWR specified on the Crocodile River. In this case, the KLP sub-system irrigators were allowed a similar assurance criteria as all the other irrigators in the system. The KLP dams are utilized more. Though very slight, the plots show a benefit to Crocodile irrigators when releasing a partial EWR from the KLP dams.



No KLP release



Some KLP release

Figure 5.10: Results from Scenario C: Crocodile River System

5.4 Sabie/Sand River System

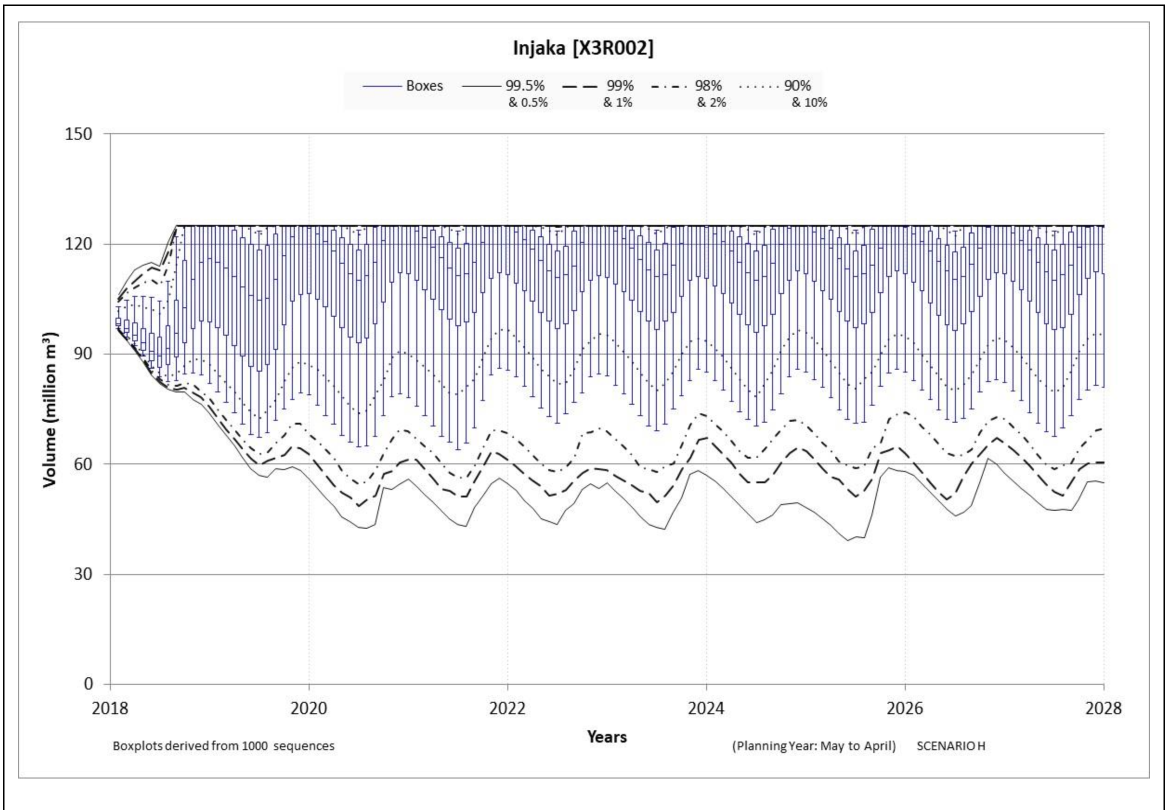
The scenarios undertaken to analyse the Sabie/Sand River system are as follows:

- Scenario A: The existing operating rule
- Scenario B: The operating rule driven by the short term yield capabilities;
- Scenario B_{adjust}: Scenario B with an adjusted yield curve to make better use of the Inyaka Dam storage.

It is important to note that the analyses of Sabie/Sand system were undertaken without the irrigation allocations in place. Most of these allocations currently lie dormant. **Section 4.2.3** showed the severe deficits in current availability resulting from the EWR implementation on Inyaka Dam compared with the existing allocations and requirements from the Dam. The irrigation allocations will not be ignored, and will be included on future water balance plots.

5.4.1 Scenario A

The following figures provide the results from analyzing the system using the WRPM including the existing operating rule as described in **Section 3.4**. The rule restricts users depending on the storage level of Inyaka Dam. The model has been configured to make the decision to restrict on two occasions in the year, 1 November and 1 May each year.



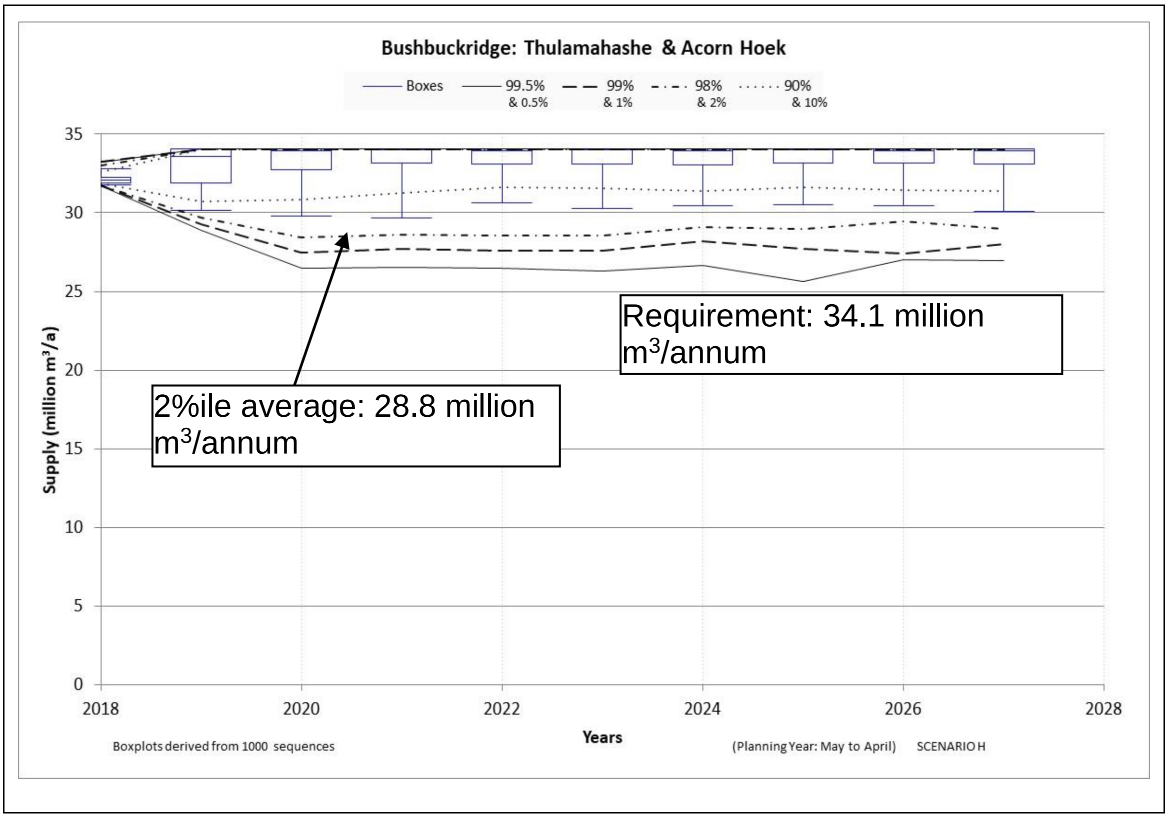


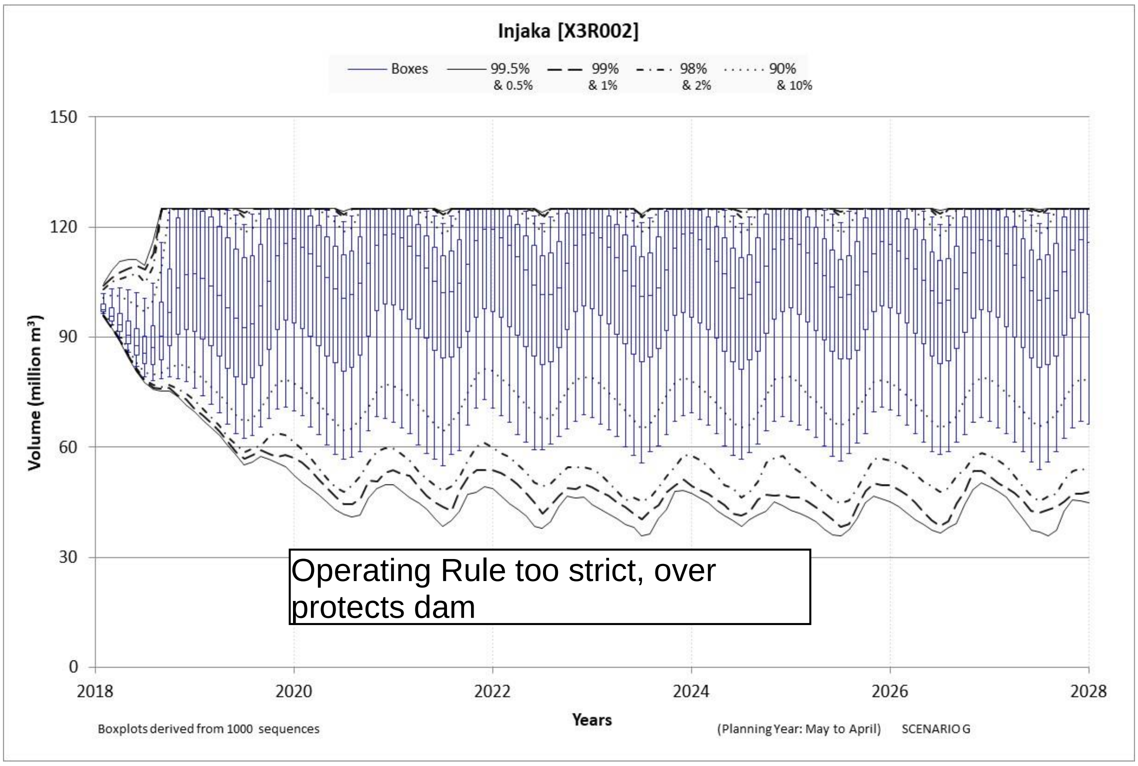
Figure 5.11: Results from Scenario A: Sabie/Sand River System

The results show that the existing operating rule is too stringent and does not allow for sufficient use of the dam storage. This is indicated by the fact that that users are restricted too heavily and the dam is protected at a higher level than is required. There is a 2% risk that the urban demand will only obtain 85% of its requirement on average. The results highlight the need to relook at the operating rule in order to make better use of the dam.

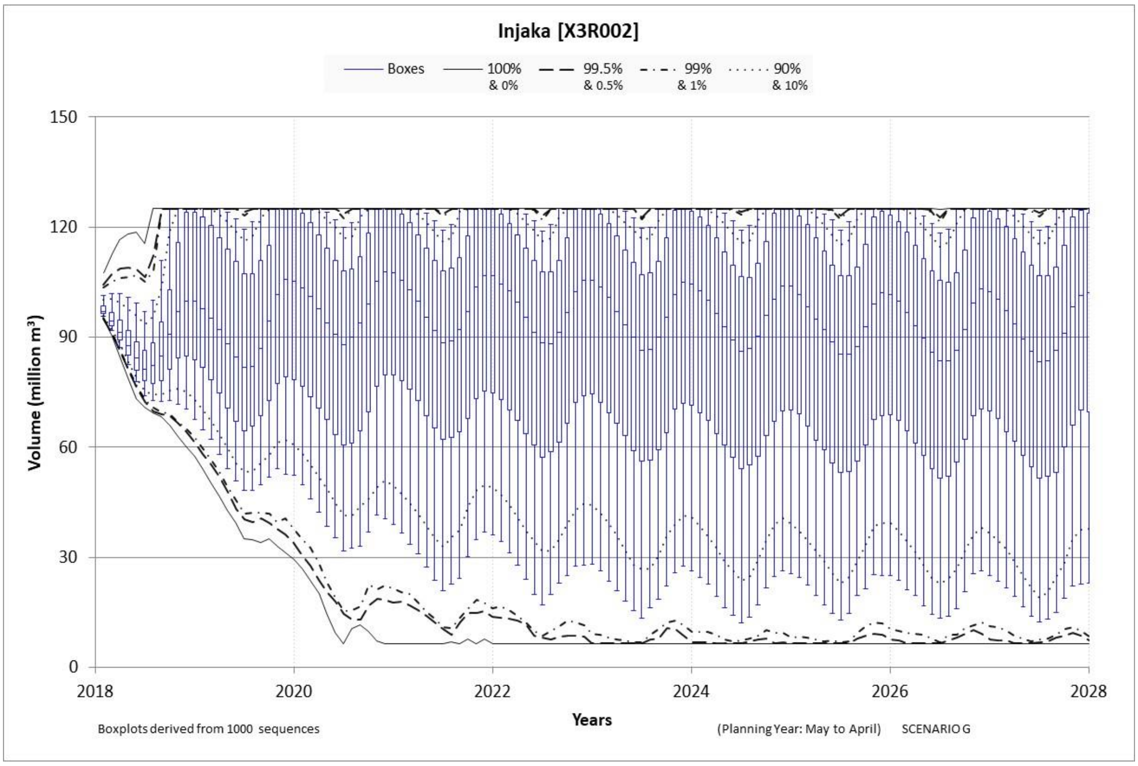
5.4.2 Scenario B and Scenario B_{adjust}

The following figures provide plots resulting from Scenario B and Scenario B_{adjust}. In these scenarios, an operating rule driven be the short term yield capabilities of the system has been included. This rule allows for the model to make a decision on the selected decision date (1 May) each year at the point where the dam storage is at its highest levels as a result of the preceding rainy season. The user requirements at their specified assurance of supply criteria are then compared with the short term yield capabilities of the system and a decision is made whether their full requirement can be supplied, or whether a restriction on their use should be applied for the following year.

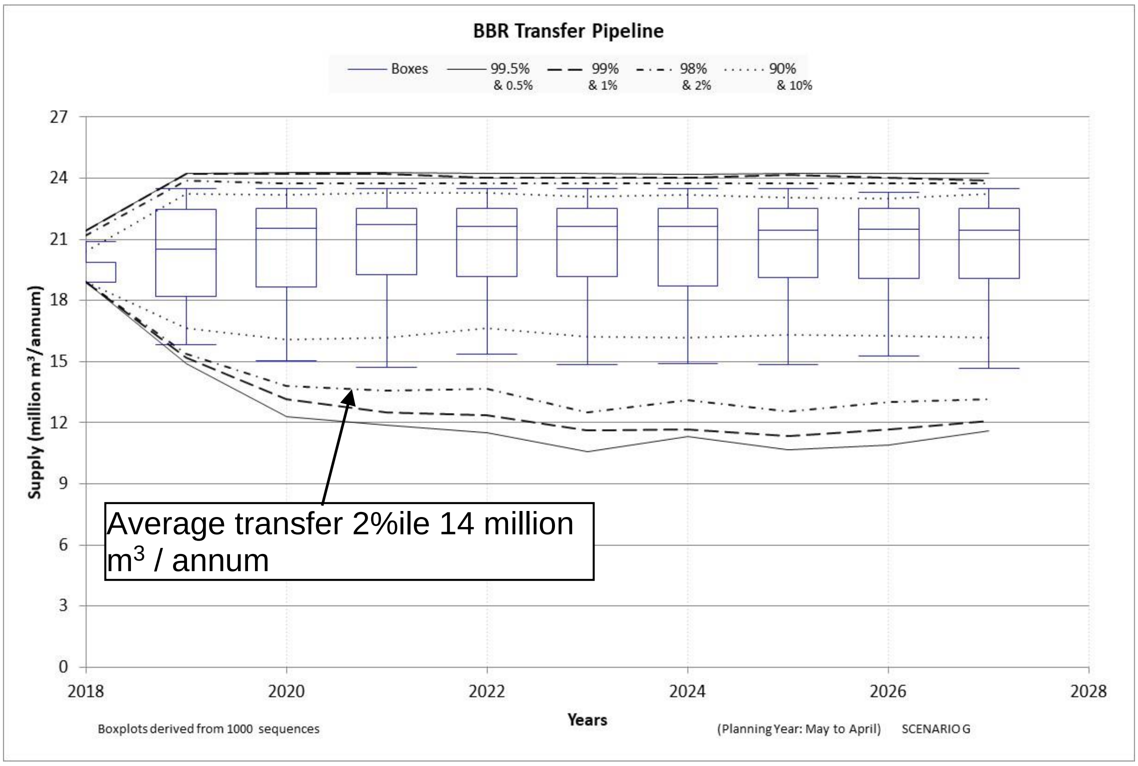
As presented in **Section 4.2.3**, the Inyaka Dam is not able to provide the existing demand on the system at the required assurance of supply level, and the yield availability from the system requires that both the irrigators and the domestic sector be permanently restricted.



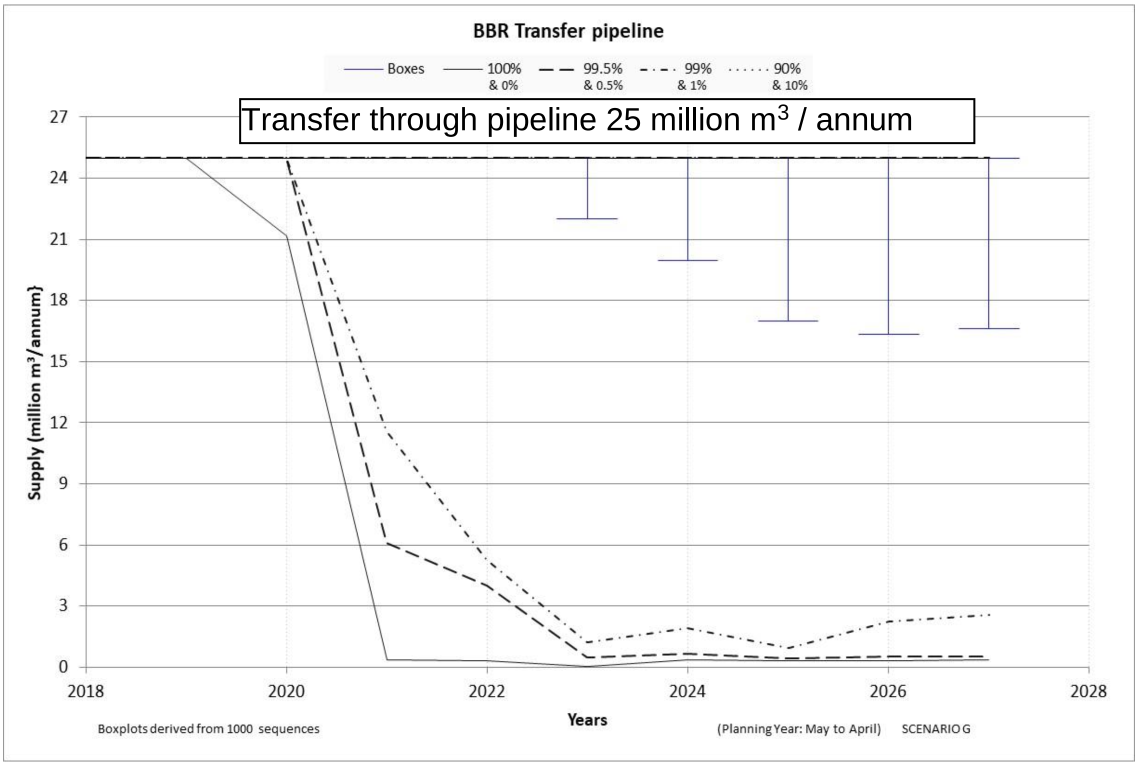
Scenario B



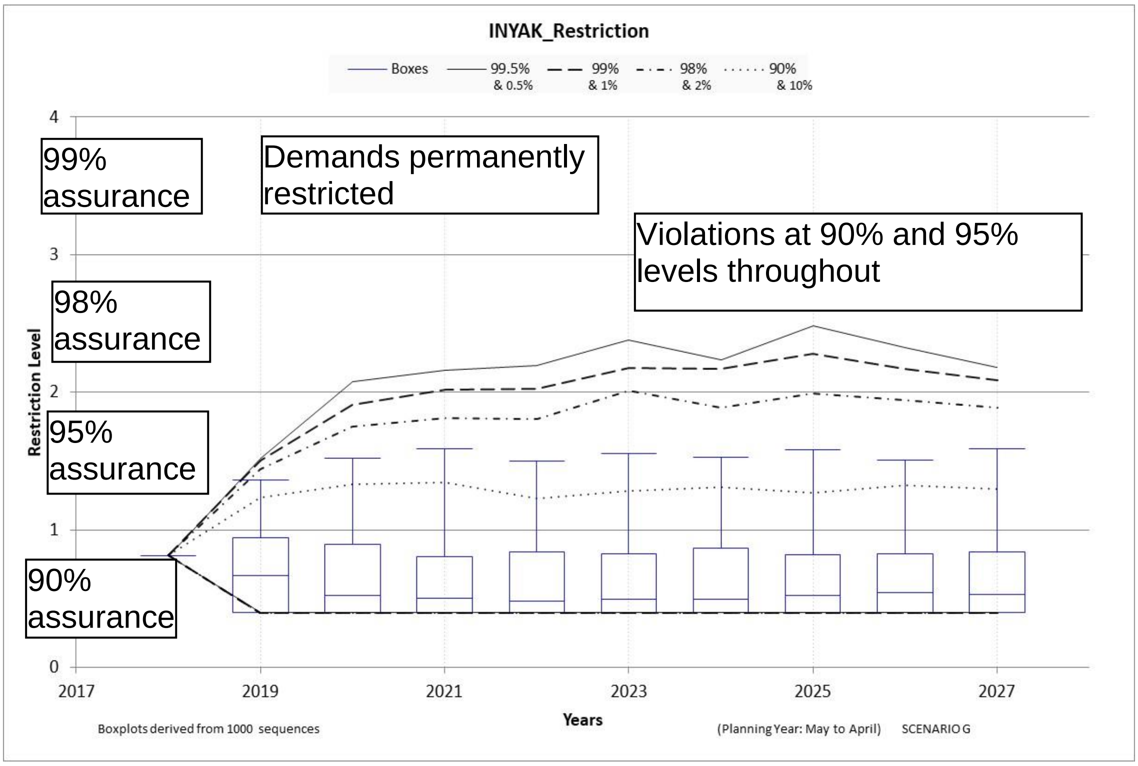
Scenario B_{adjust}



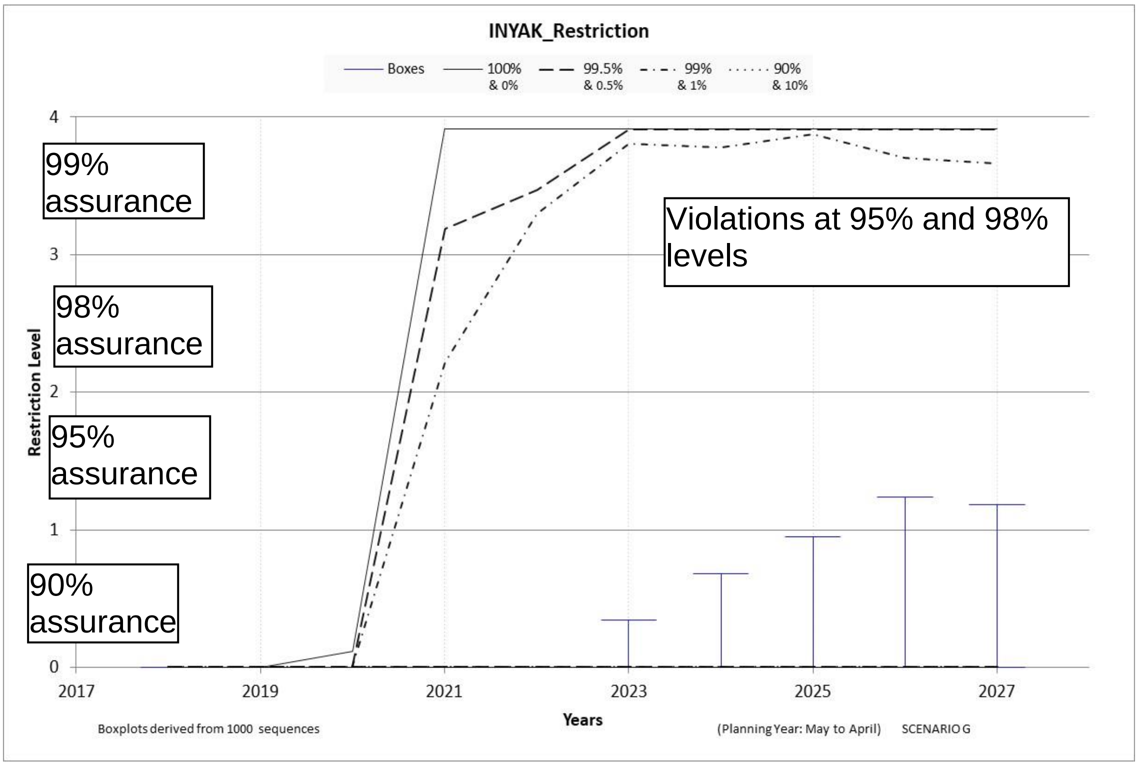
Scenario B



Scenario B_{adjust}



Scenario B



Scenario B_{adjust}

Figure 5.12: Results from Scenario B and B_{adjust}: Sabie/Sand River System

The results of Scenario B show that the Dam is not fully utilized under the operating rule linked to the short term curves. Users are restricted severely and the supply is not satisfactory. The short term curves were then scaled upwards to allow for a better utilization of the dam. The curves were adjusted as per **Figure 5.13**.

The Inyaka dam storage plot resulting from Scenario B_{adjust} shows a better utilization of the dam storage. The supply to the domestic sector is improved, however, still shows restrictions in excess of the required users' assurance of supply criteria.

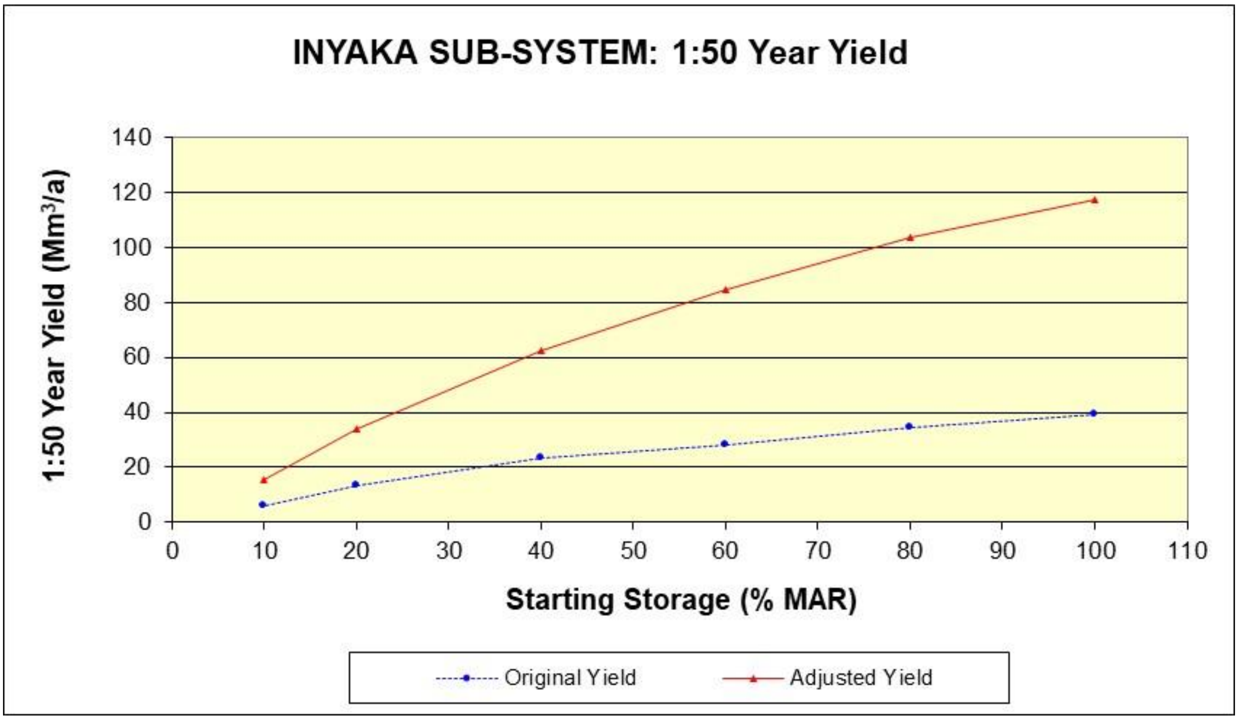
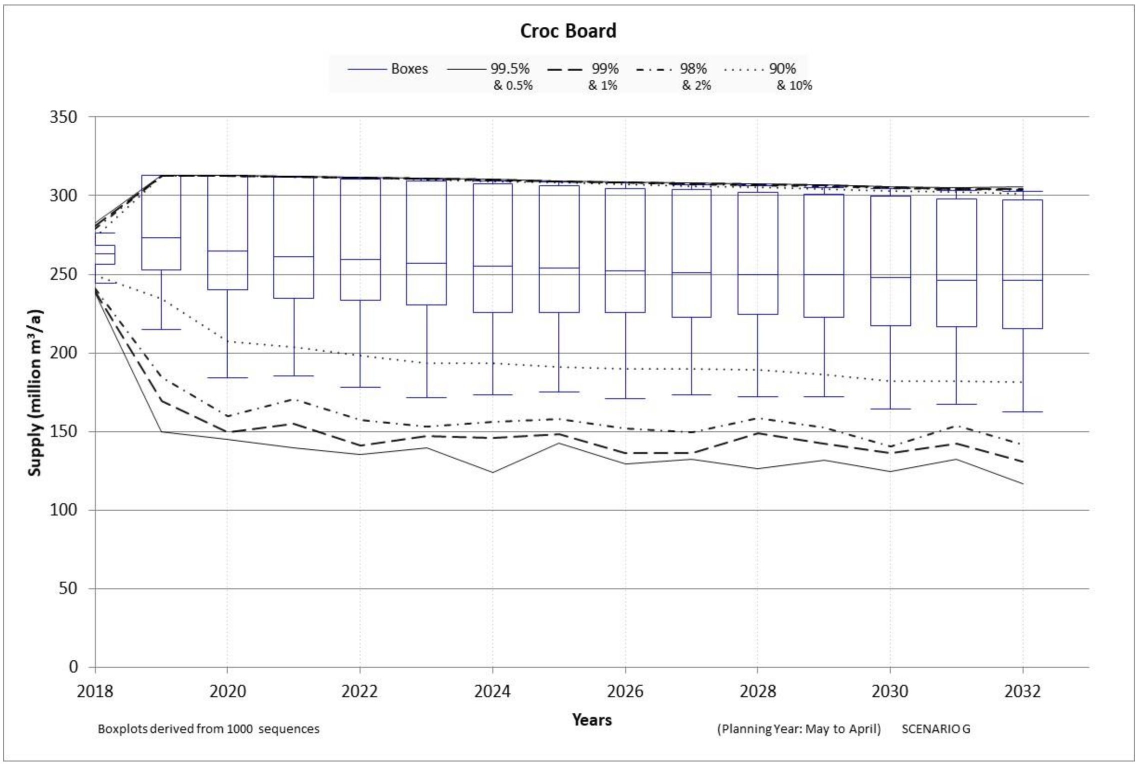
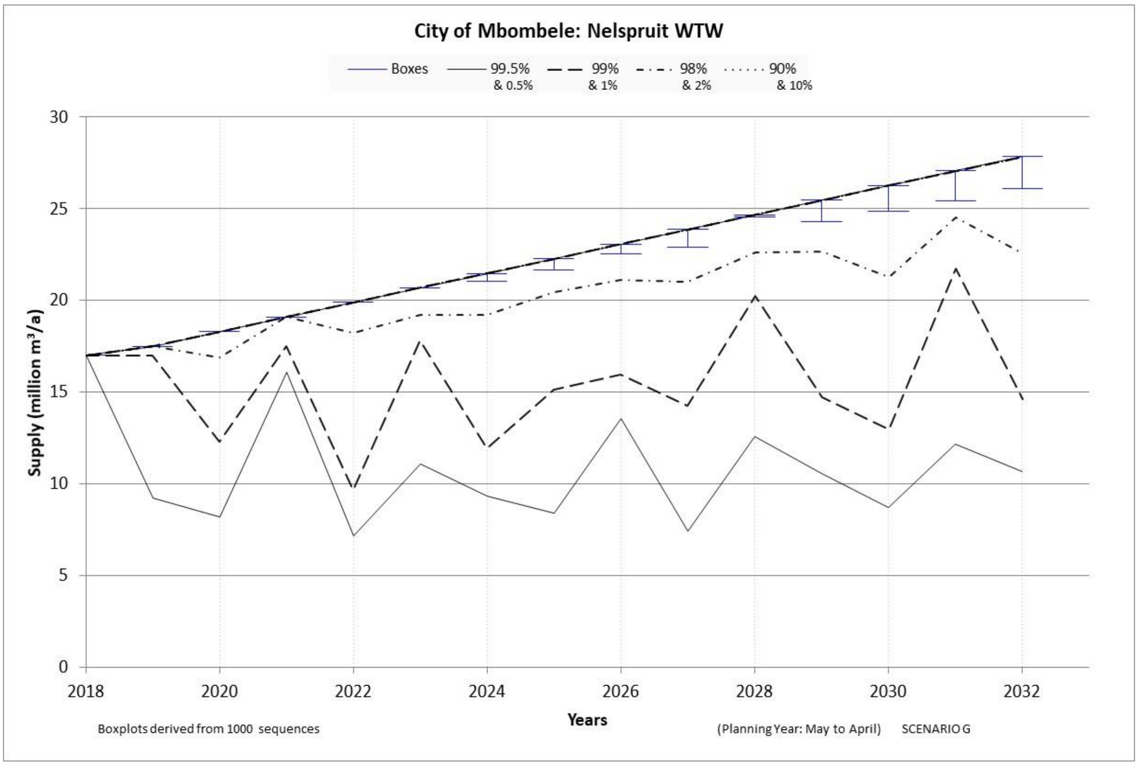


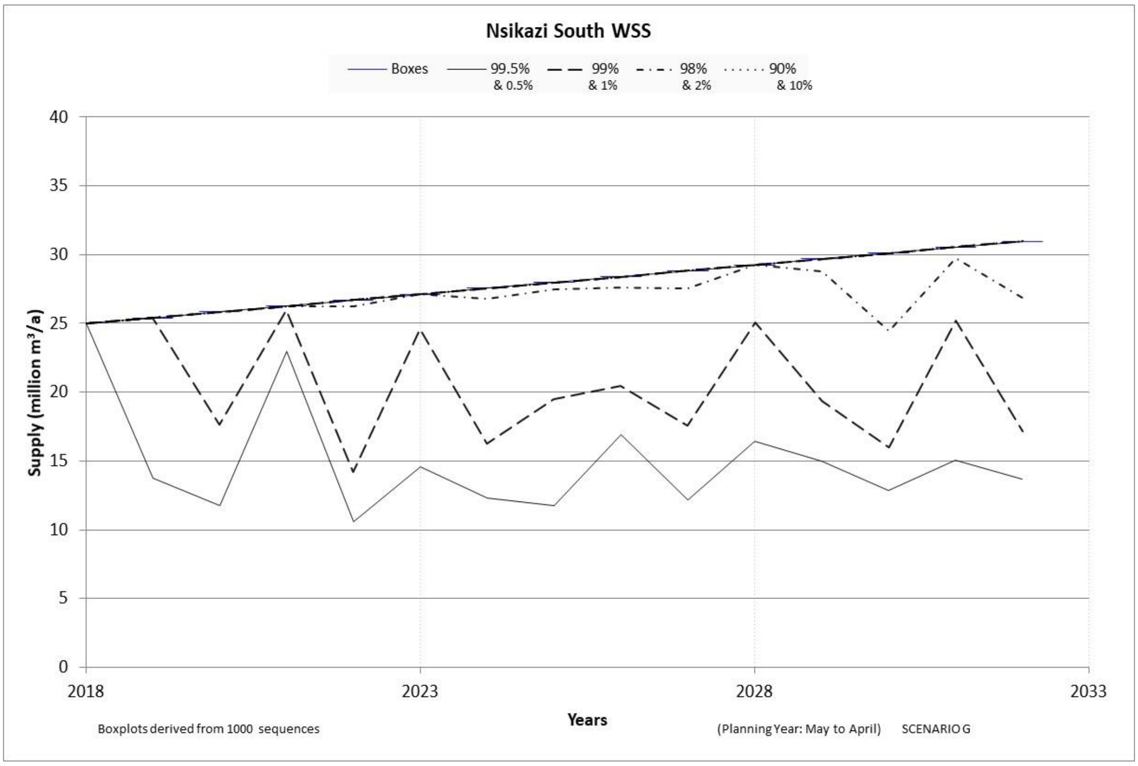
Figure 5.13: Scaled 1 in 50 year yield characteristics for Inyaka Dam

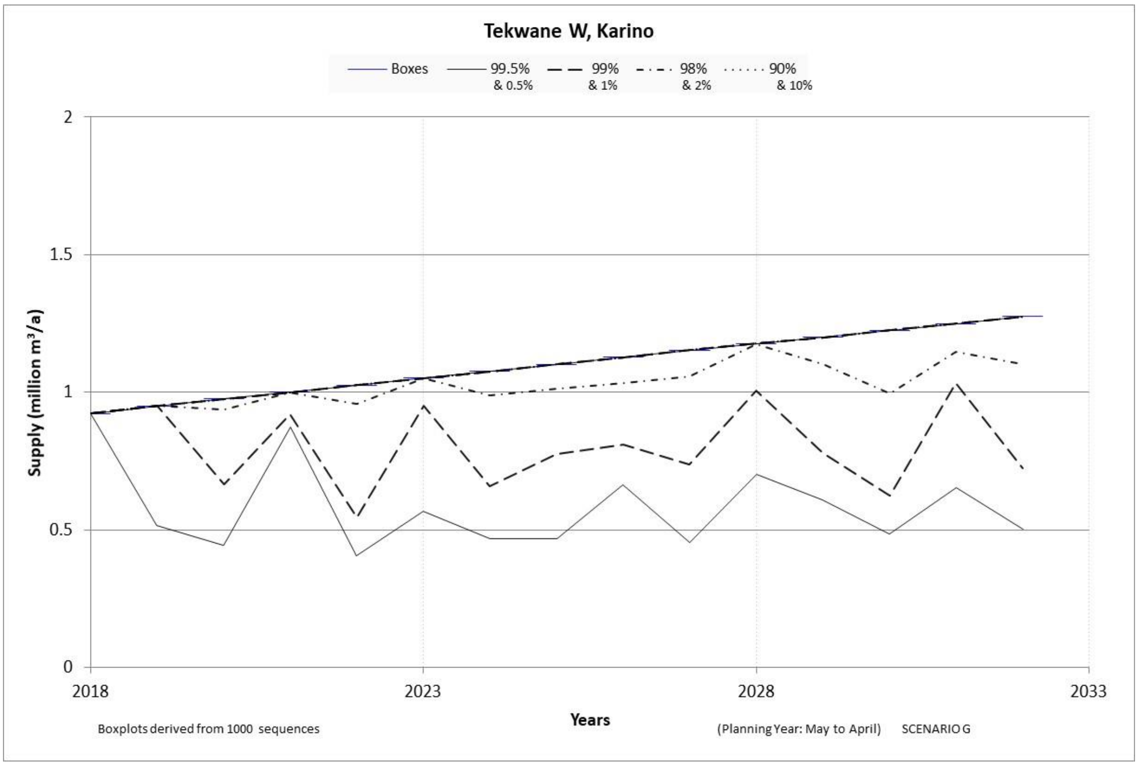
5.5 Growth Scenario

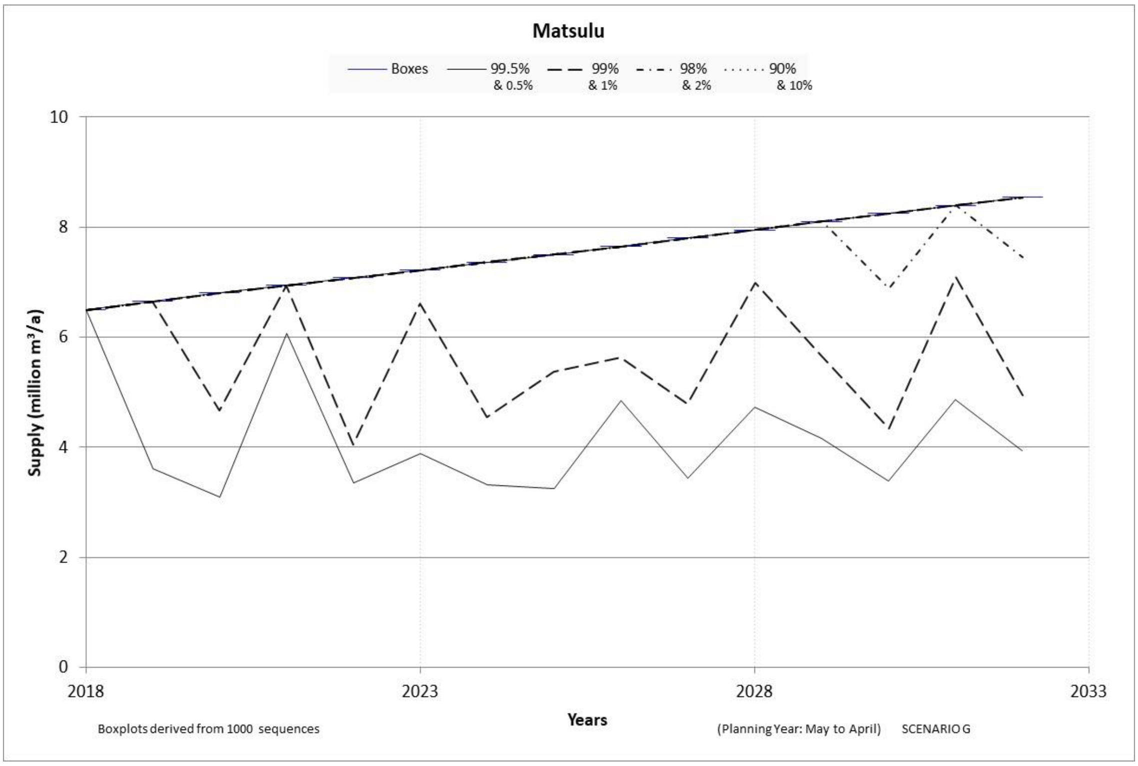
A WRPM scenario was undertaken including the projected growth in demands of the various users. This was carried out in order to determine whether the short term yield curve operating rules protect the dams sufficiently as the demands grow. The simulation period was selected to be 15 years as it is assumed that further augmentation will be in place by that time. The results of the growth scenario are presented in the following plots.

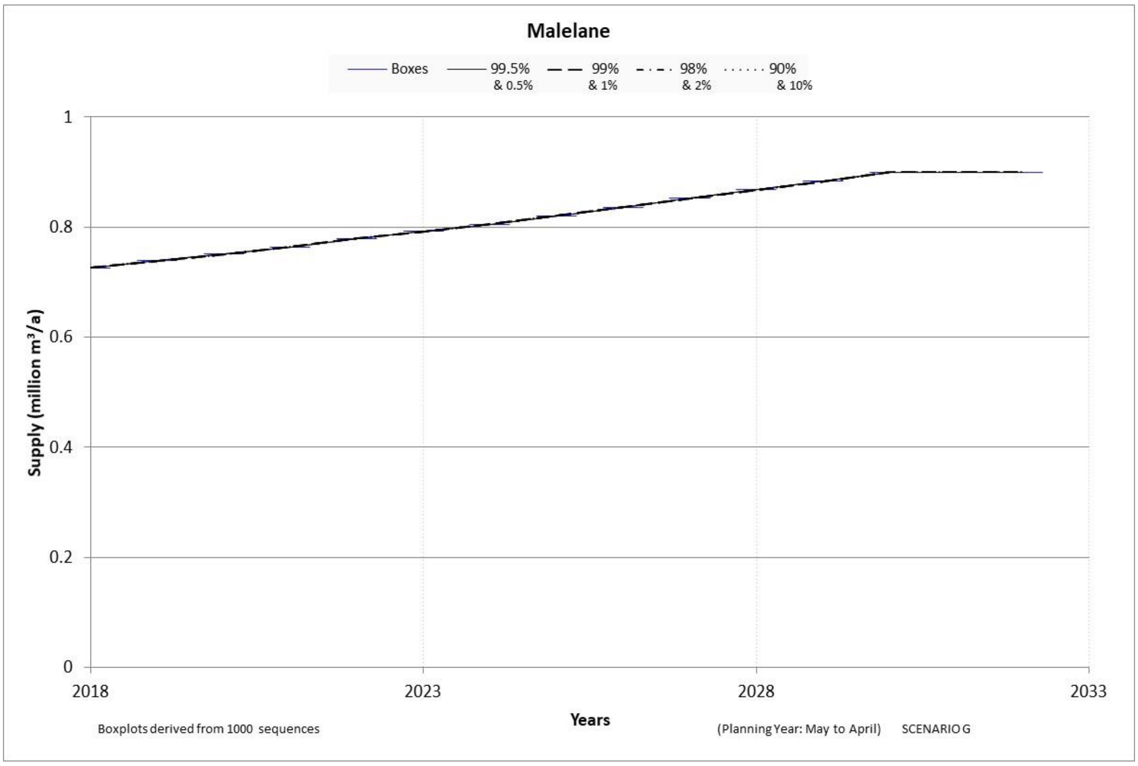

Croc Board
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
350
300
250
200
150
100
50
0
2018
2020
2022
2024
2026
2028
2030
2032
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

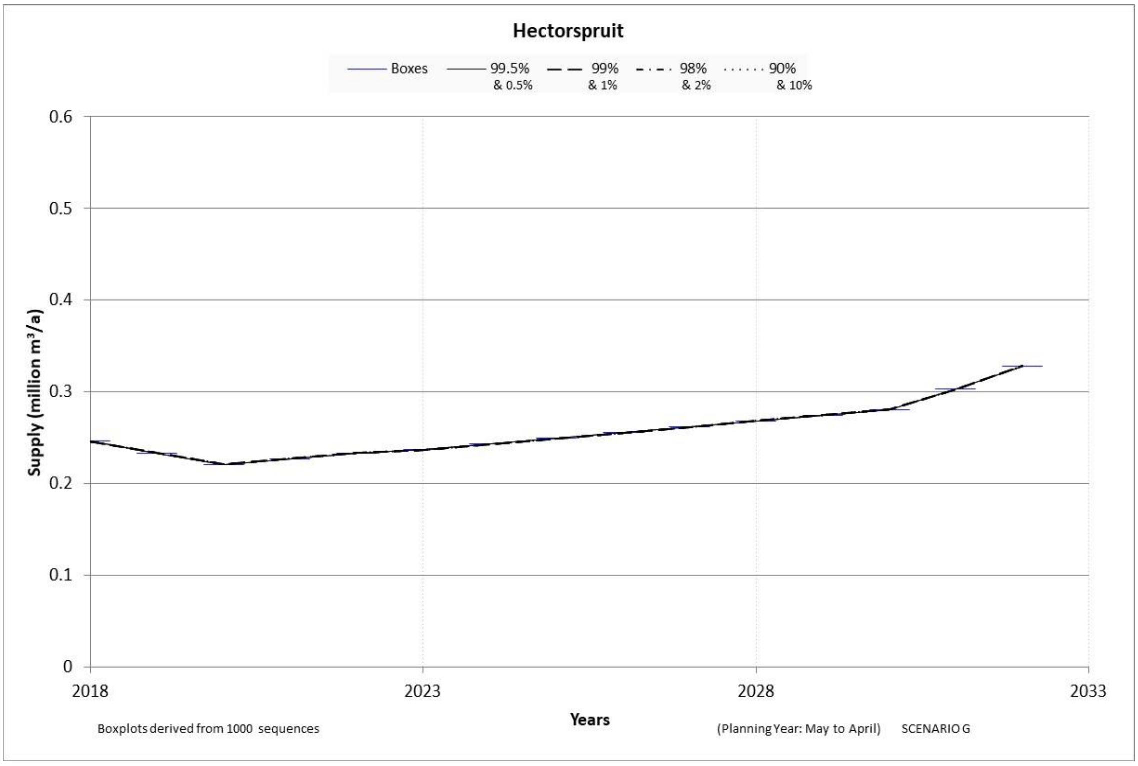

City of Mbombele: Nelspruit WTW
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
30
25
20
15
10
5
0
2018
2020
2022
2024
2026
2028
2030
2032
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

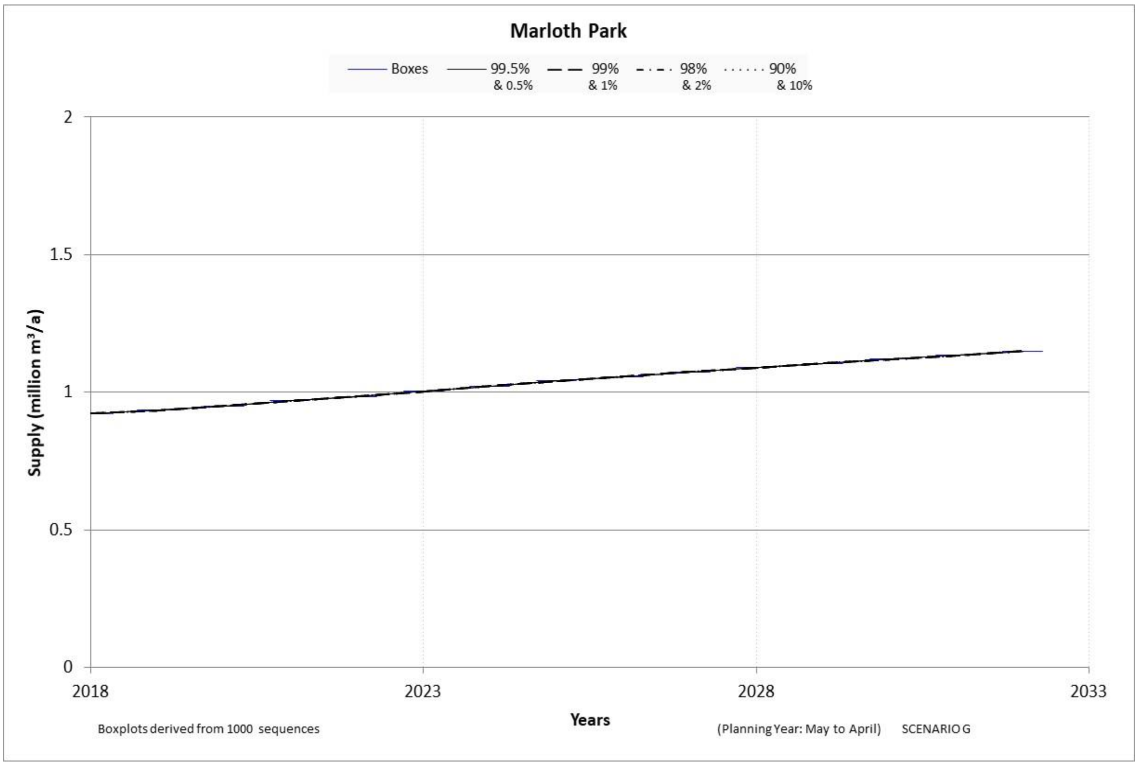

Nsikazi South WSS
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G


Tekwane W, Karino
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

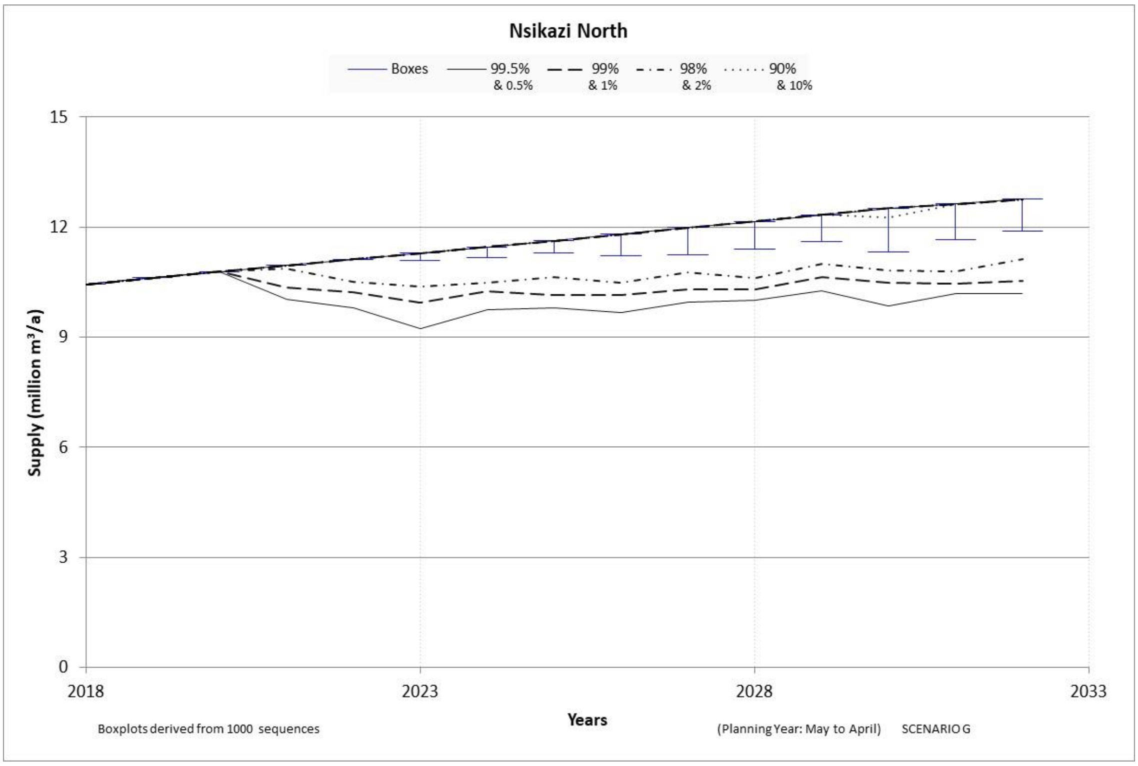

Matsulu
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
10
8
6
4
2
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

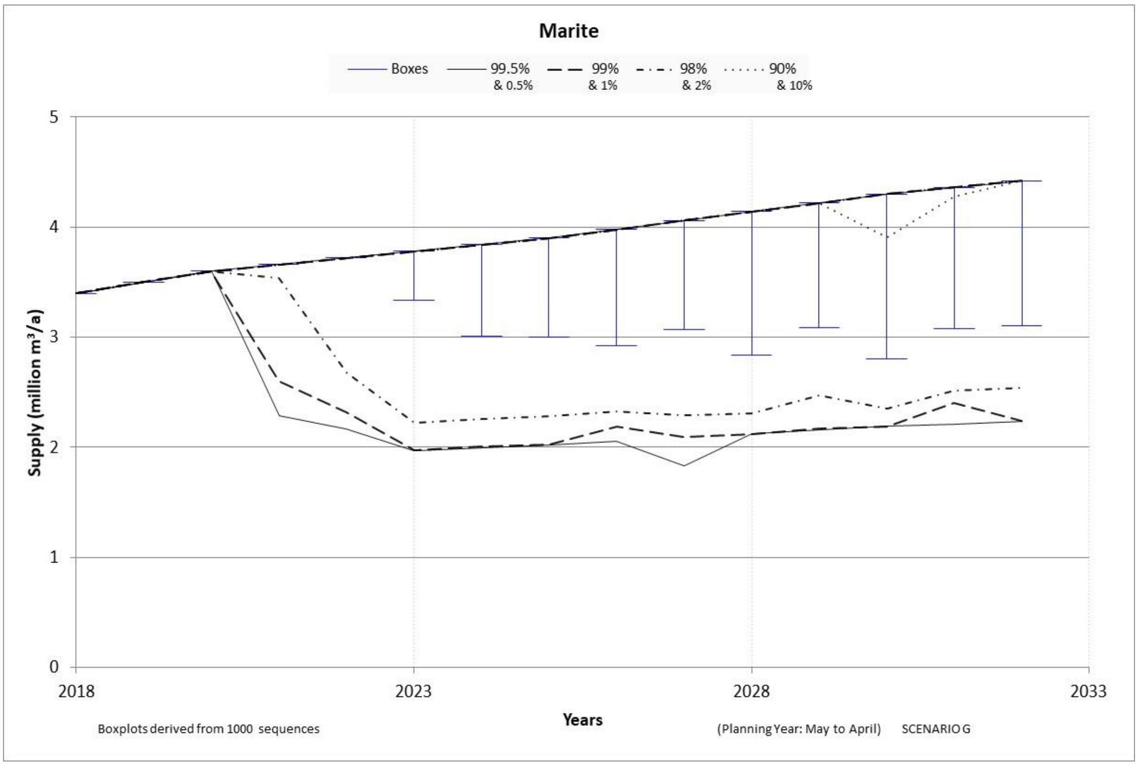

Malelane
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
1
0.8
0.6
0.4
0.2
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

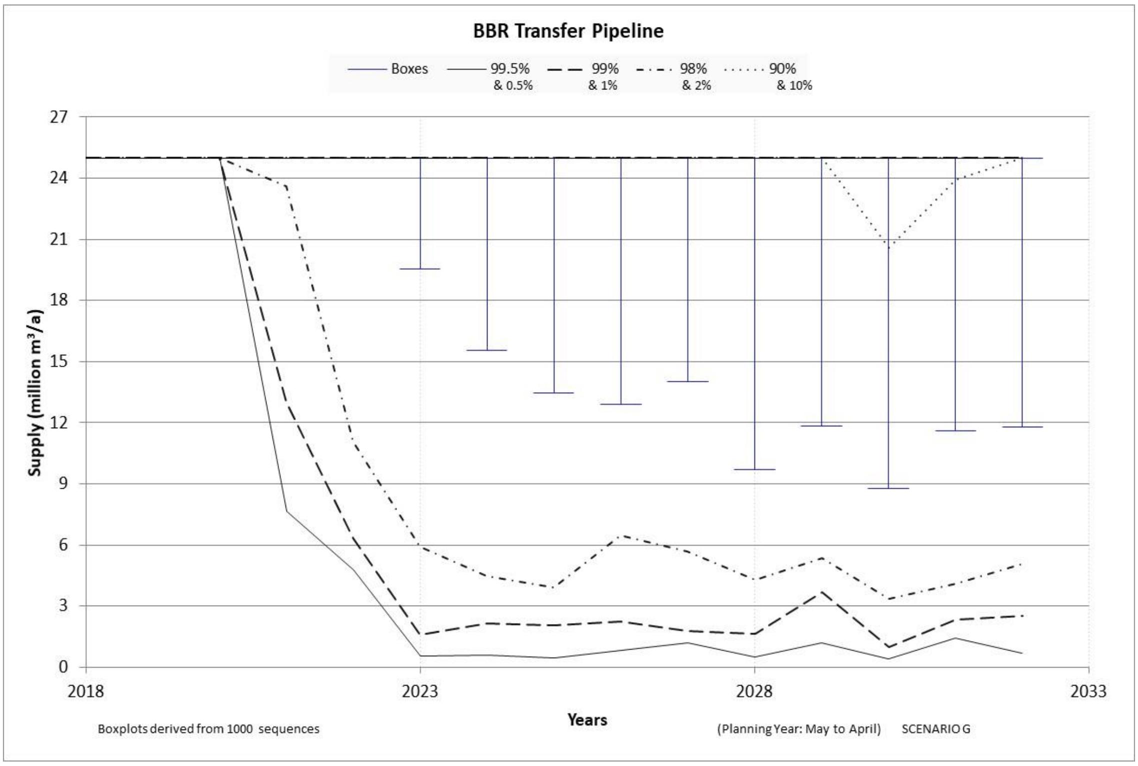

Hectorspruit
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
0.6
0.5
0.4
0.3
0.2
0.1
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G

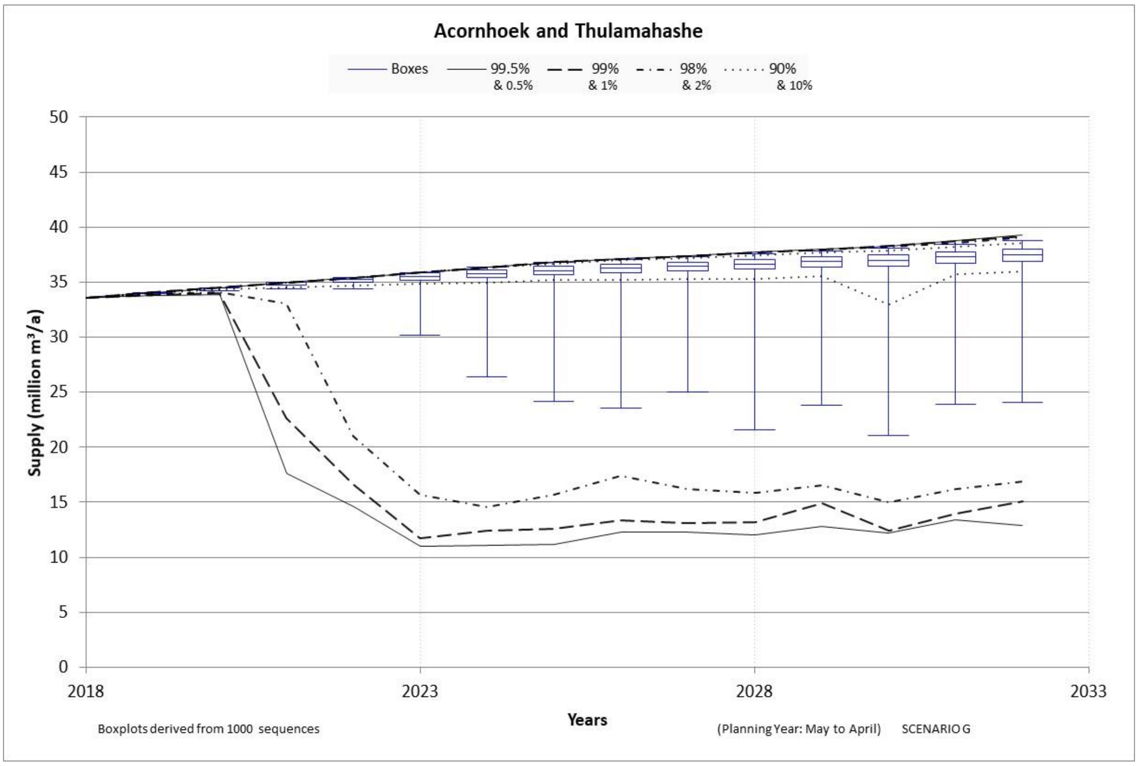

Marloth Park
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
2
1.5
1
0.5
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G

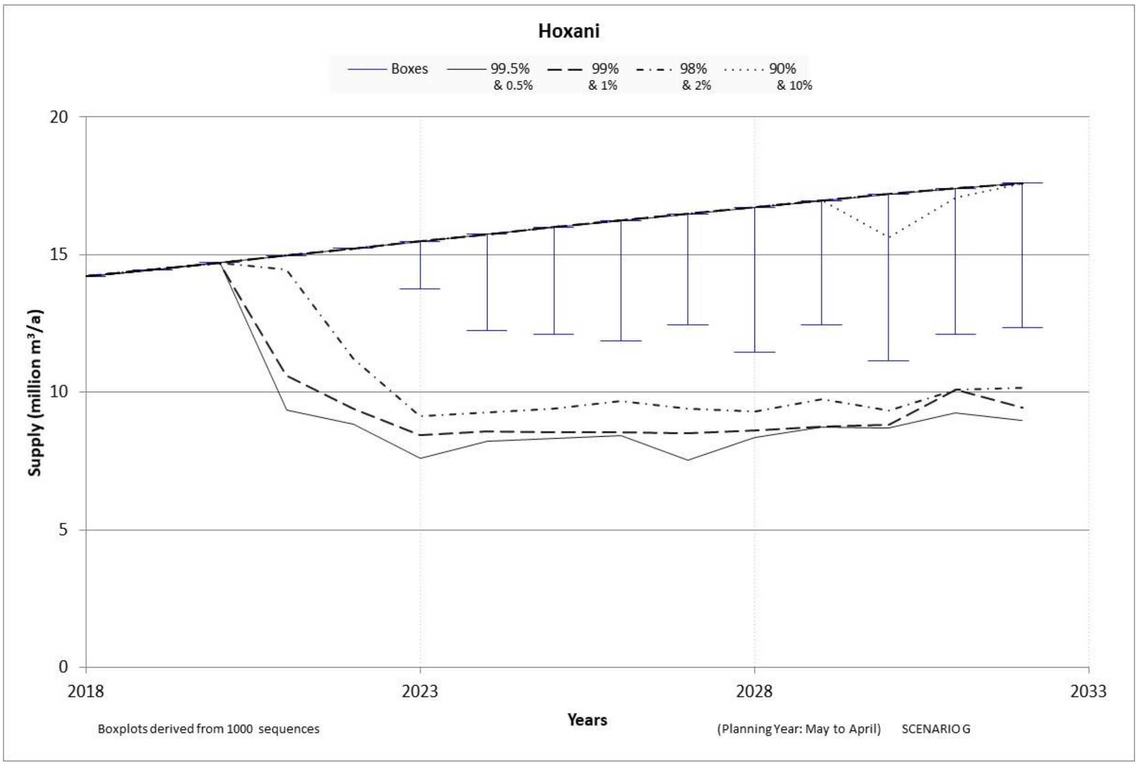
For the Crocodile system, the short term curve operating rule is protecting the urban demands over the projection period by applying greater restrictions to the irrigators as the time period goes on. It is evident that the trend of the Crocodile Irrigation Board supply plot is decreasing over the time period, indicating the higher restrictions required to protect the system in the future. The CoM Nelspruit WTW supply shows deficits at the 95% probability start to occur from the year 2024. The operating rule should be revisited at this time based on the level that the actual demands have achieved by then.



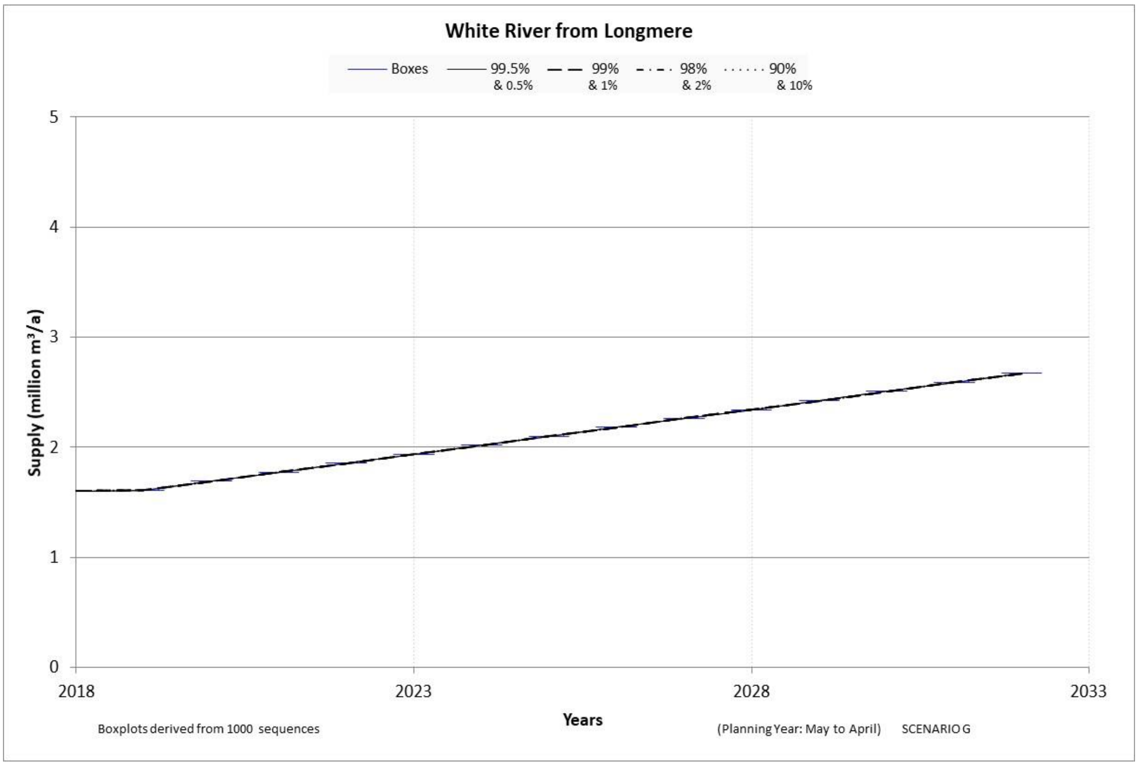

Marite
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
5
4
3
2
1
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G

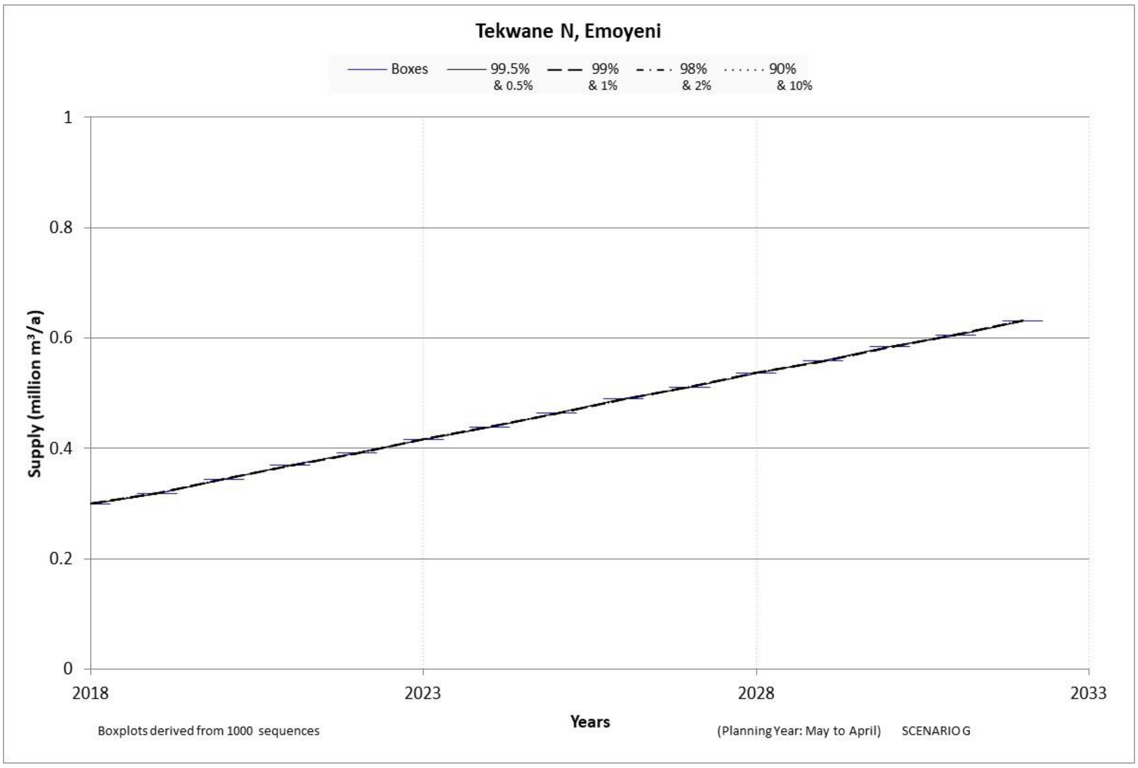

BBR Transfer Pipeline
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
27
24
21
18
15
12
9
6
3
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G

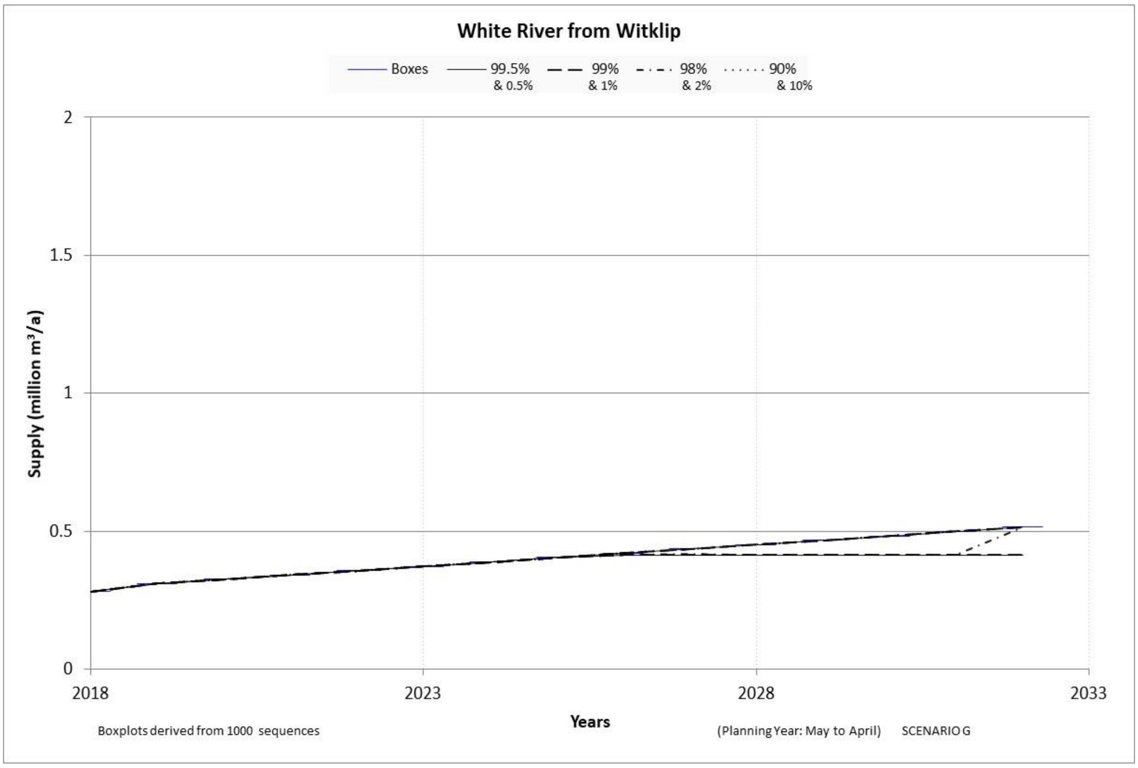

Acornhoek and Thulamahashe
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G


Hoxani
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April) SCENARIO G

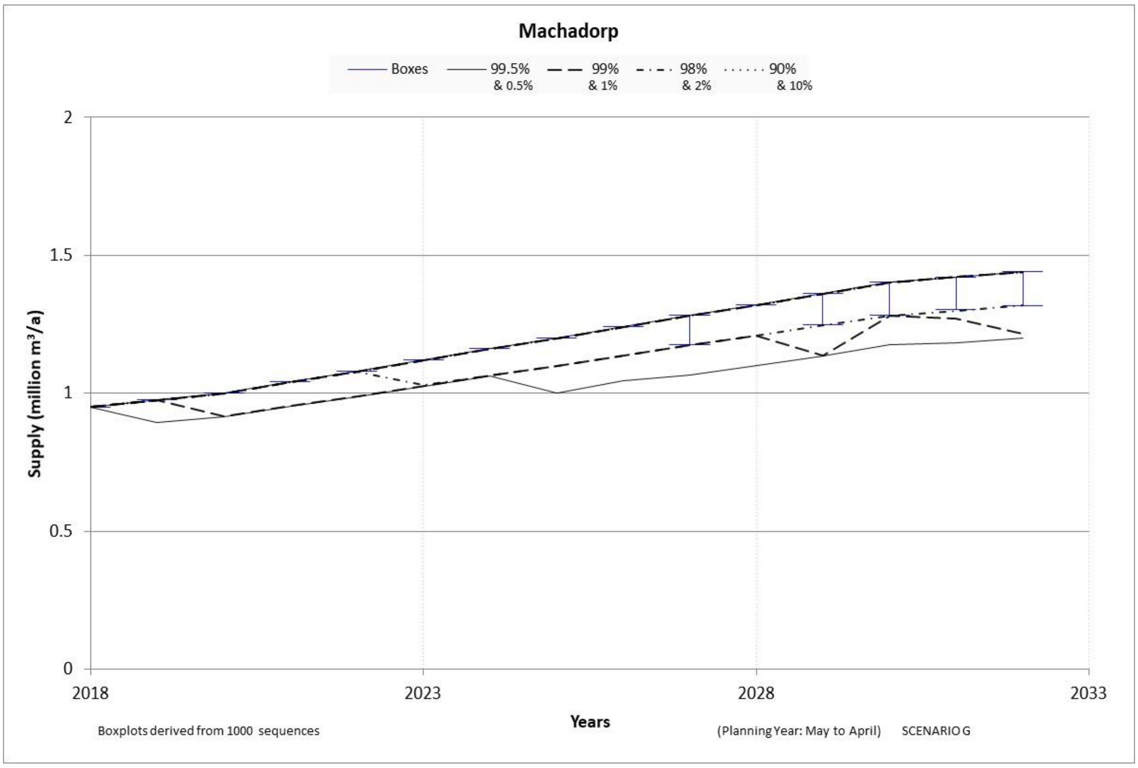
The results of the Sabie/Sand domestic supply areas are similar to the non-growth scenario whereby the Bushbuckridge and Nsikazi North areas relying on Inyaka Dam all show unsatisfactory deficits in supply. The operating rule is protecting the dam by applying severe restrictions to the users. This scenario was again undertaken without the irrigation demands on the dam.







The White River domestic demands are supplied satisfactorily and the system shows a surplus exists in the Klipkopje, Longmere and Primkop Dams.


Machadorp
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
2
1.5
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2018
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2028
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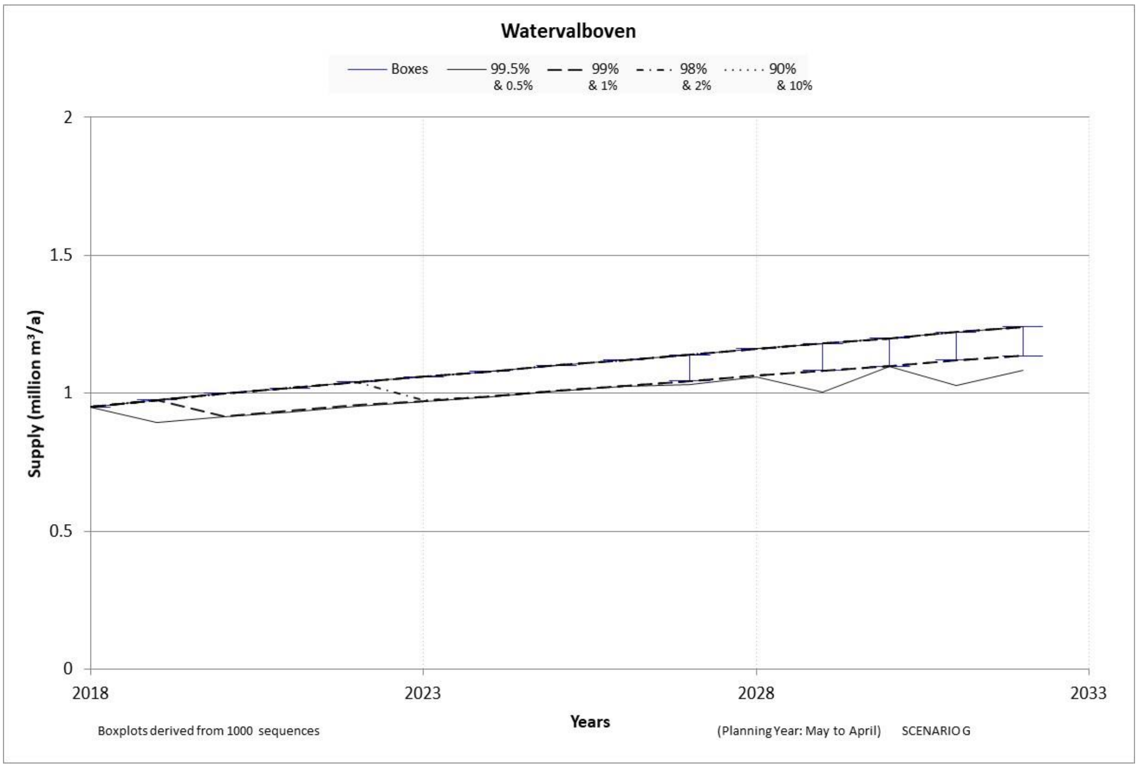
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G


Watervalboven
Boxes
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90% & 10%
Supply (million m³/a)
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2018
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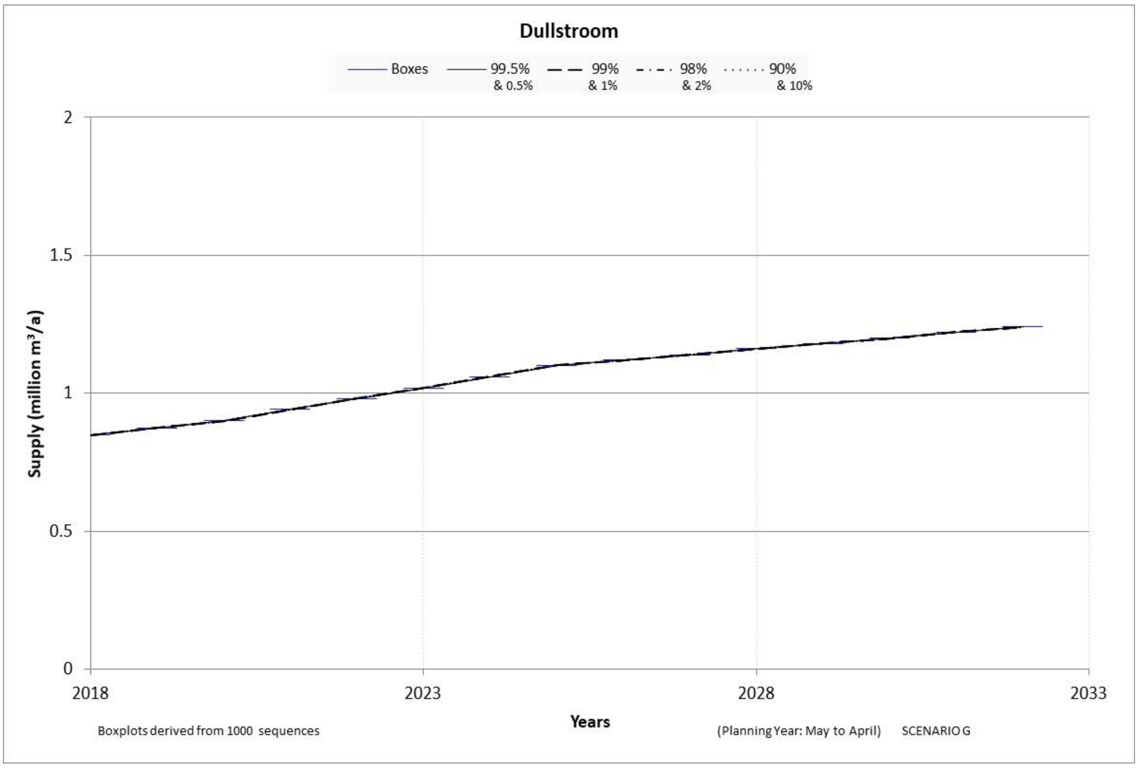
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G


Dullstroom
Boxes
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Supply (million m³/a)
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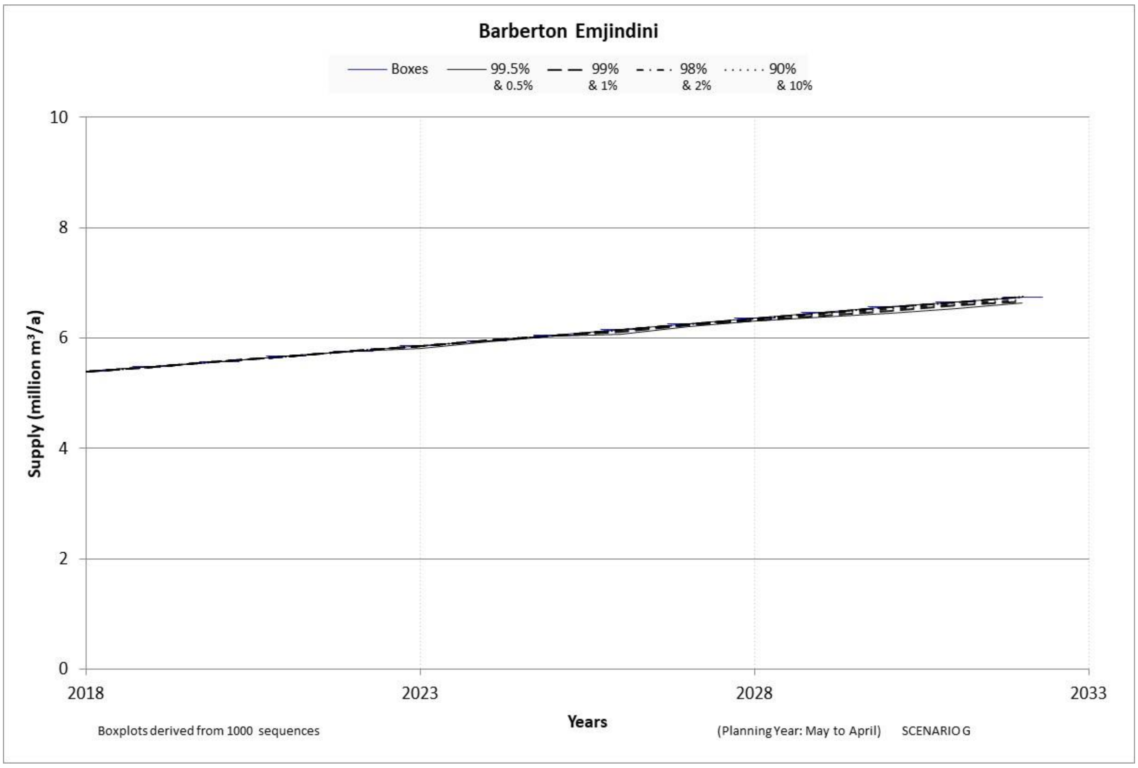
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G


Barberton Emjindini
Boxes
99.5% & 0.5%
99% & 1%
98% & 2%
90% & 10%
Supply (million m³/a)
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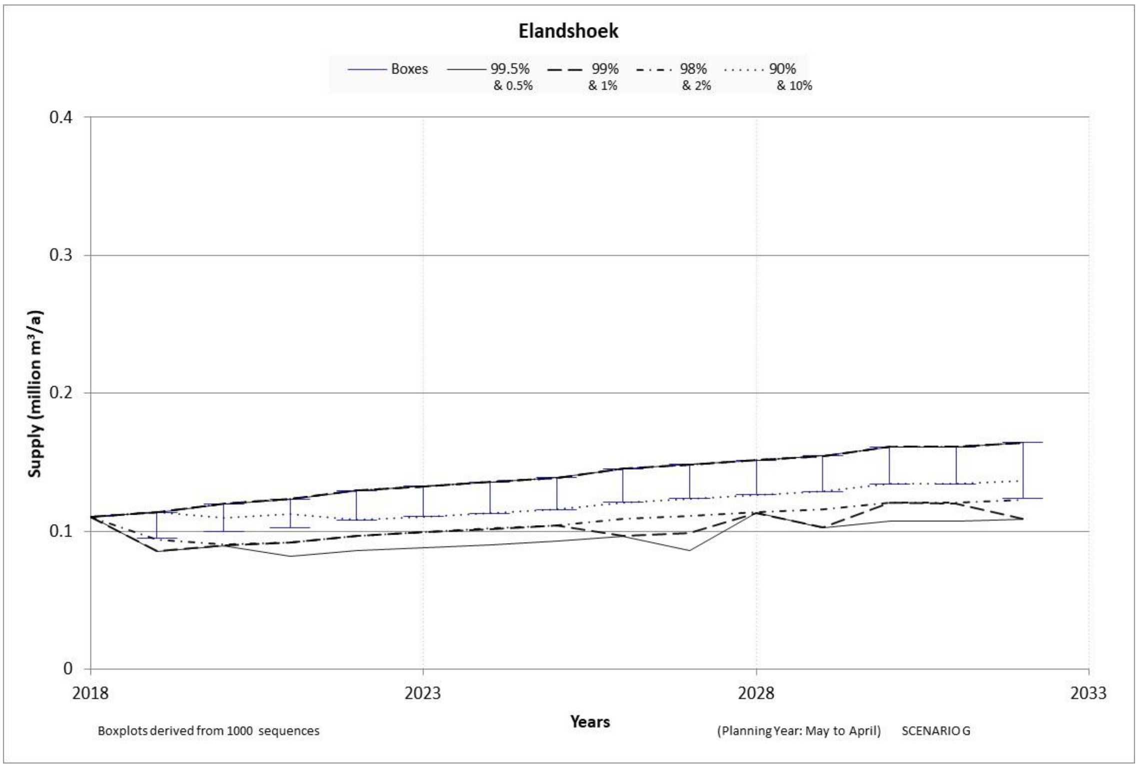
6
4
2
0
2018
2023
2028
2033
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO G



Most of the smaller domestic areas in the Crocodile are satisfactorily supplied over the projection period, except for the towns in the Elandspruit catchment, Machadodorp, Watervalboven and Elandshoek, which show deficits in supply.

Figure 5.14: WRPM Results: growth scenario

6 GROUNDWATER

This Chapter presents an overview of the information gathered relating to the groundwater use, registration and potential in the Study Area. Relevant existing sources were reviewed, such as:

- All Towns Reports;
- Groundwater Resource Information Project (GRIP);
- Groundwater Resource Assessment (GRA) II;
- Inkomati Water Availability Assessments (IWAAS);
- National Groundwater Monitoring Network (NGIS);
- National Groundwater Strategies (NGS); and
- Service delivery implementation plan (SDIP)

A summary of the current reported groundwater use, registration and potential obtained from the All Towns Reports and iWAAS study is indicated in **Table 6.1**.

Table 6.1: Summary of All Towns Reports and IWAAS

Local Municipality	Supply Area	Current use	Registered	Un-registered	Total Potential	Remarks / Recommendation	Reference
		(Million m^3/a)					
Nkomazi	Louisville	0.14	-[a]	0.14	-	Potential for conjunctive use, establish groundwater monitoring program, and Determine pollutant hazard domestic and agricultural	DWA (2011g)
	Malelane	-	-	-	0.0		DWA (2011h)
	Komatipoort	-	-	-	0.0		DWA (2011f)
	Marloth Park	-	-	-	0.0		DWA (2011i)
	Hectorspruit	-	-	-	0.0		DWA (2011d)
	Kaapmuiden	0.16	-	0.16	-		
		-	-	-	-	Requirements not growing/ monitor quality	DWS (2016)
Thaba Chweu	Thaba Chweu Cluster[1]	2.55	3.34	-	4.25	Groundwater levels and quality to be monitored monthly	DWA (2011)
Emakhazeni	Dullstroom	-	-	-	low		DWA (2011n)
	eNtokozweni (Machadodorp)	0.67[2]	0.49	0.18	5.9[3]		DWA (2011o)
	Wateral Boven (Emgwenya)	0.67[2]	0.49	0.18	moderate	Groundwater not a viable resource option due to its impact on the Elands River baseflow	DWA (2011p)
Mbombela	Mbombela City (Nelspruit)	-	-	-	-	Nelspruit has not GW entitlement, White River is supplemented by GW sources/-	DWA (2011k)
		0.12	-	-	low	western part of municipality higher potential, however the reliability of drilling a higher yield borehole is between 40% - 60%	DWA (2014) & DWA (2014c)
	Barberton (previously Umjindi LM)	-	-	-	low	Very low potential, therefore not an option for long-term augmentation	DWA (2011c)
	Hazyview	-	-	0.001	10.5[4]	Potential for conjunctive use	DWA (2011b)

Local Municipality	Supply Area	Current use	Registered	Un-registered	Total Potential	Remarks / Recommendation	Reference
	Matsulu	N/A[b]	N/A	N/A	N/A	Remote villages make use of groundwater not official use is registered/ there is potential for conjunctive GW use	DWA (2011j)
	Nsikazi South	N/A	N/A	N/A	low	there is potential for conjunctive GW use	DWA (2011m)
	Nsikazi North	N/A	N/A	N/A	low	there is potential for conjunctive GW use	DWA (2011l)
	Kaapsehoop	0.003	-	-	low		DWA (2011k)
Bushbuckridge	Hoxane	N/A	N/A	N/A	low	Before bulk supply scheme installed some remote villages made use of GW, however supply was intermittent and inadequate/ there is some potential for conjunctive use	DWA (2011e)
		N/A	N/A	N/A	low	-	DWS (2016b)

Notes: a No GW volume recorded
b Known that there is GW use, however no information on the volume
1 Thaba Chweu Cluster consist of Sabie, Graskop, Pilgrim’s Rest, Matibidi, Ponieskrantz, Coromandel, Blyde Forestry Station, Morgenzon Forestry Station, Hebron, Roodewal Sam Mill, Glory Hill, Brodal, Simile, Tweefontein Forestry Station, Harmony Hill, Hendriksdaal, Polapark, Rural Thaba Chweu Ward 10, Rural Thaba Chweu Ward 11, Rural Thaba Chweu Ward 4, Rural Thaba Chweu Ward 5, Draaikraal, Boshoek, Emshinini and Badfontein
2 Assmang Chrome major user with some irrigation use and livestock watering, no domestic/urban use is made by Machadodorp
3 Entire X21F Catchment
4 Entire Sabie Catchment

In addition to the All Towns and iWAAS reports, the five year reliable water and sanitation service delivery implementation plan (SDIP) was reviewed to determine the potential borehole yields at different sites throughout the Local Municipalities. Bushbuckridge LM is shown in **Figure 6.1**, City of Mbombela and former Umjindi in **Figure 6.2**, Thaba Chweu in **Figure 6.3** and Nkomazi in **Figure 6.4**. There are a significant number of borehole sites which do not have any yield attributes, indicated as white dots with black borders. The maps further show dry boreholes as grey dots and boreholes with different yields ranging from very low to very high indicated as red, orange, green and blue dots, respectively. The data is further summarized in small bar charts, however, the green dot (3-5 l/s) on the map legend is indicated as a yellow bar chart. The boreholes which were classified in terms of their yield are either very low or low yielding boreholes, with only a few boreholes indicating promising yields. Groundwater use is indicated with a light blue color.

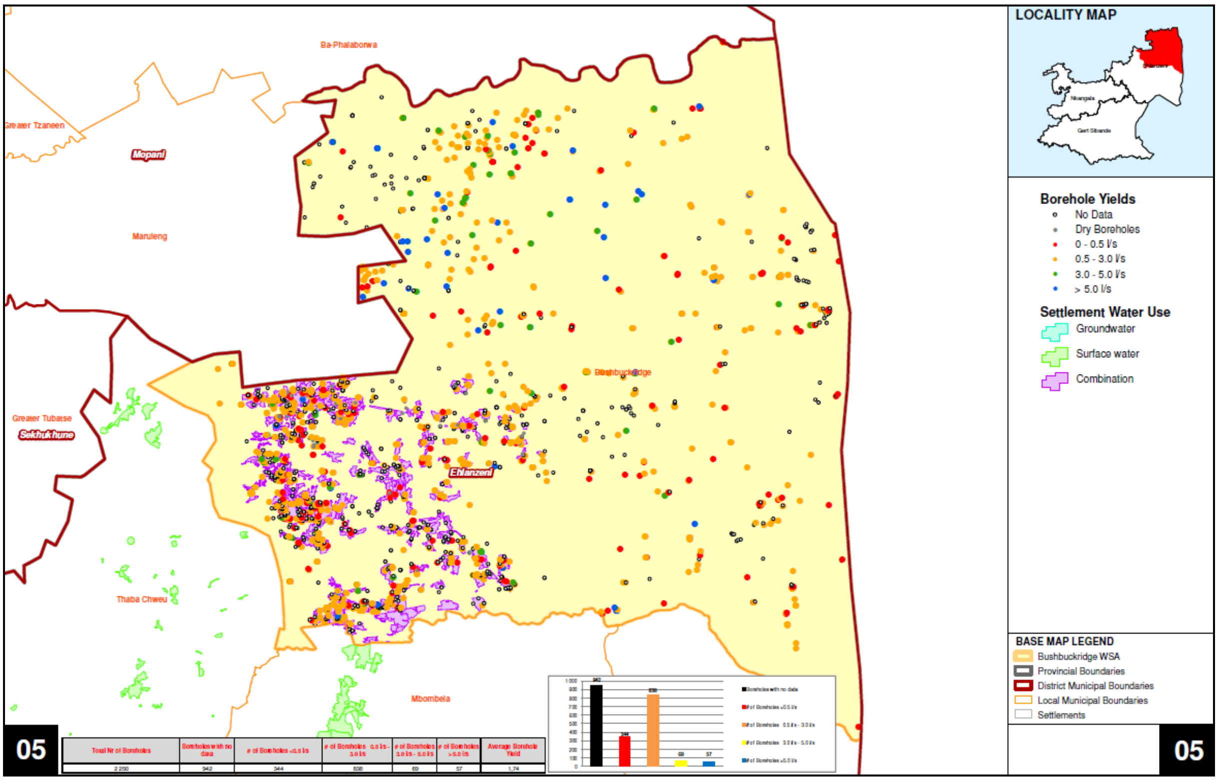


Figure 6.1: Borehole yields for the Bushbuckridge LM (ISDP) (MISA, 2017)

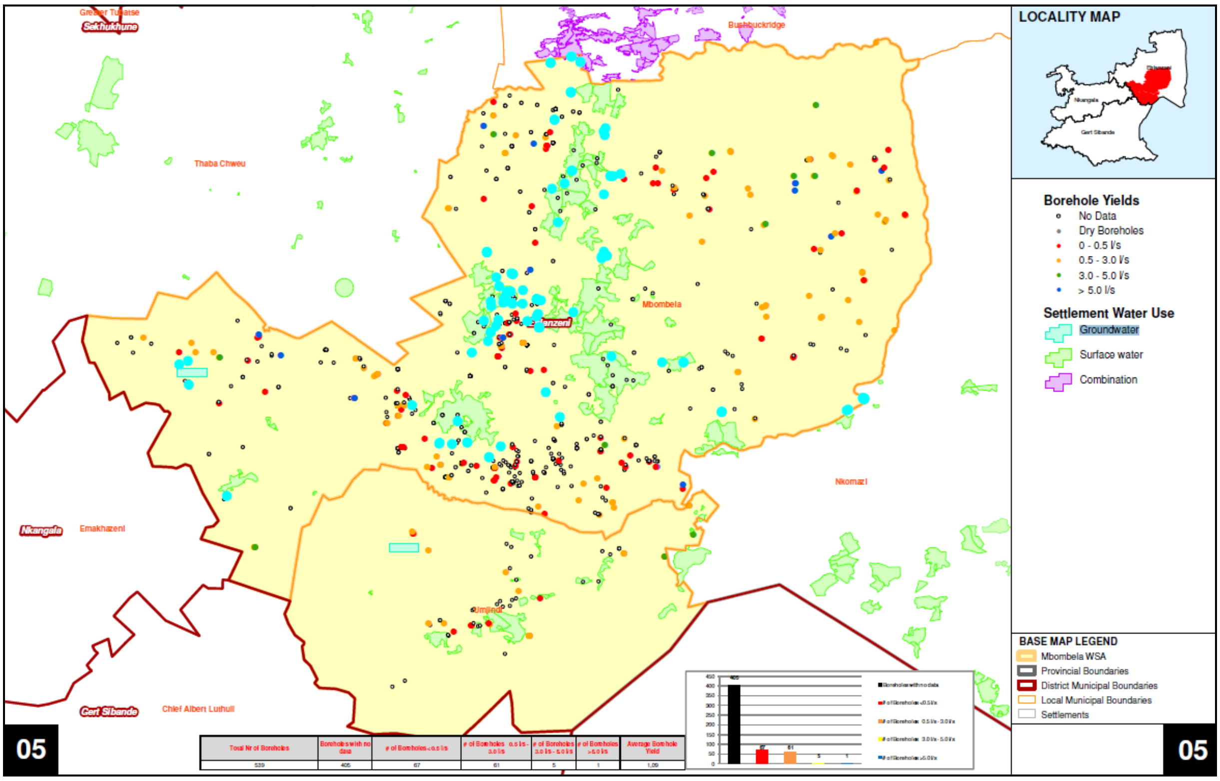


Figure 6.2: Borehole yields for the City of Mbombela LM (ISDP) (MISA, 2016)

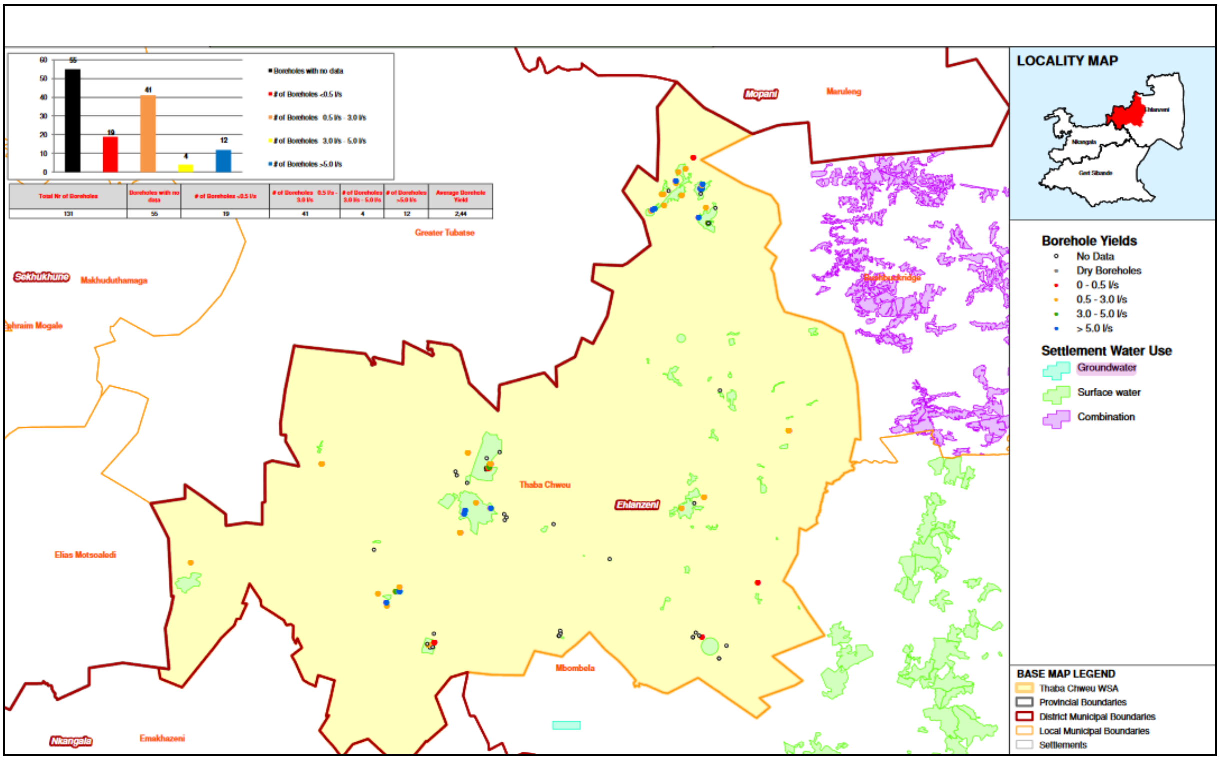


Figure 6.3: Borehole yields for the Thaba Chweu LM (ISDP) (MISA, 2016b)

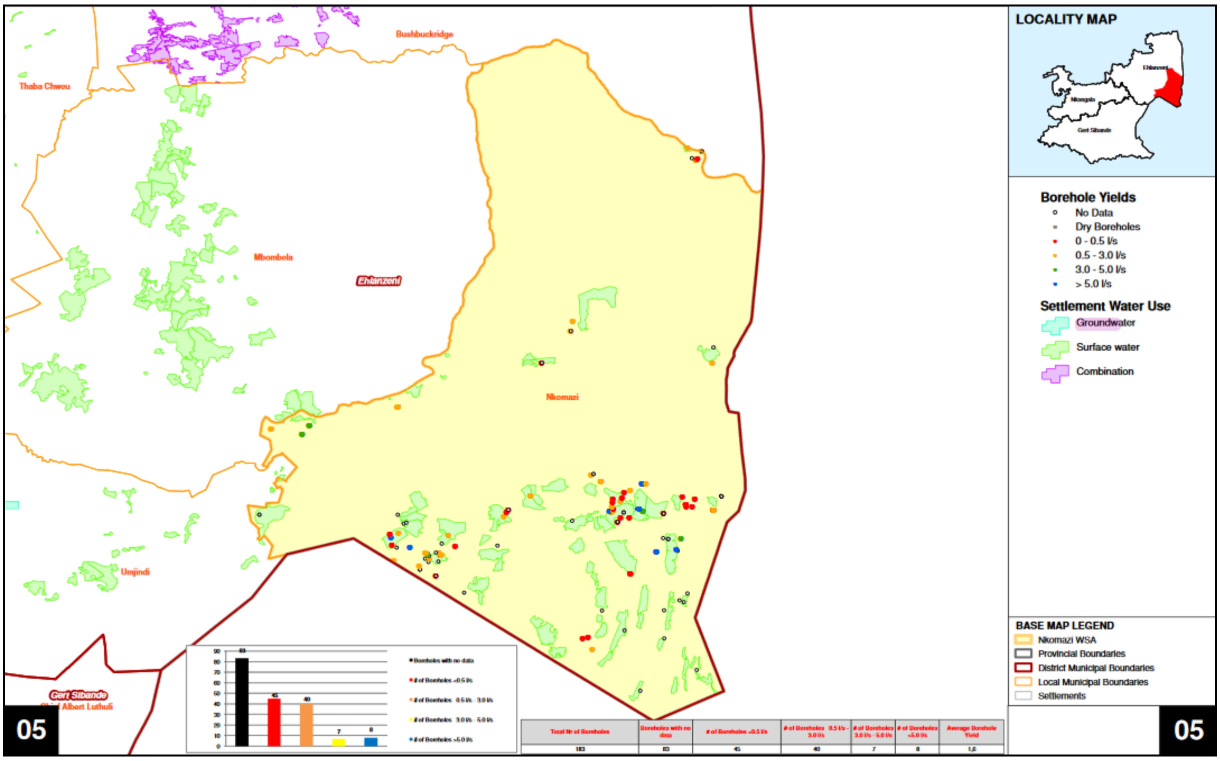


Figure 6.4: Borehole yields for the Nkomazi LM (ISDP) (MISA, 2016c)

The groundwater occurrence is very low, however, needs further investigation, according to the Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area - current and future water requirements and water resources report (DWA, 2014). A geological map for the Mbombela Municipal Area is shown in **Figure 6.5** (DWA, 2014). In the western part of the municipality, which is dolomitic, it is expected that there are borehole yields in excess of 5 l/s. The main concern is that the abstraction of the groundwater, might have a severe impact on the baseflow of the rivers, and therefore requires a more detailed study.

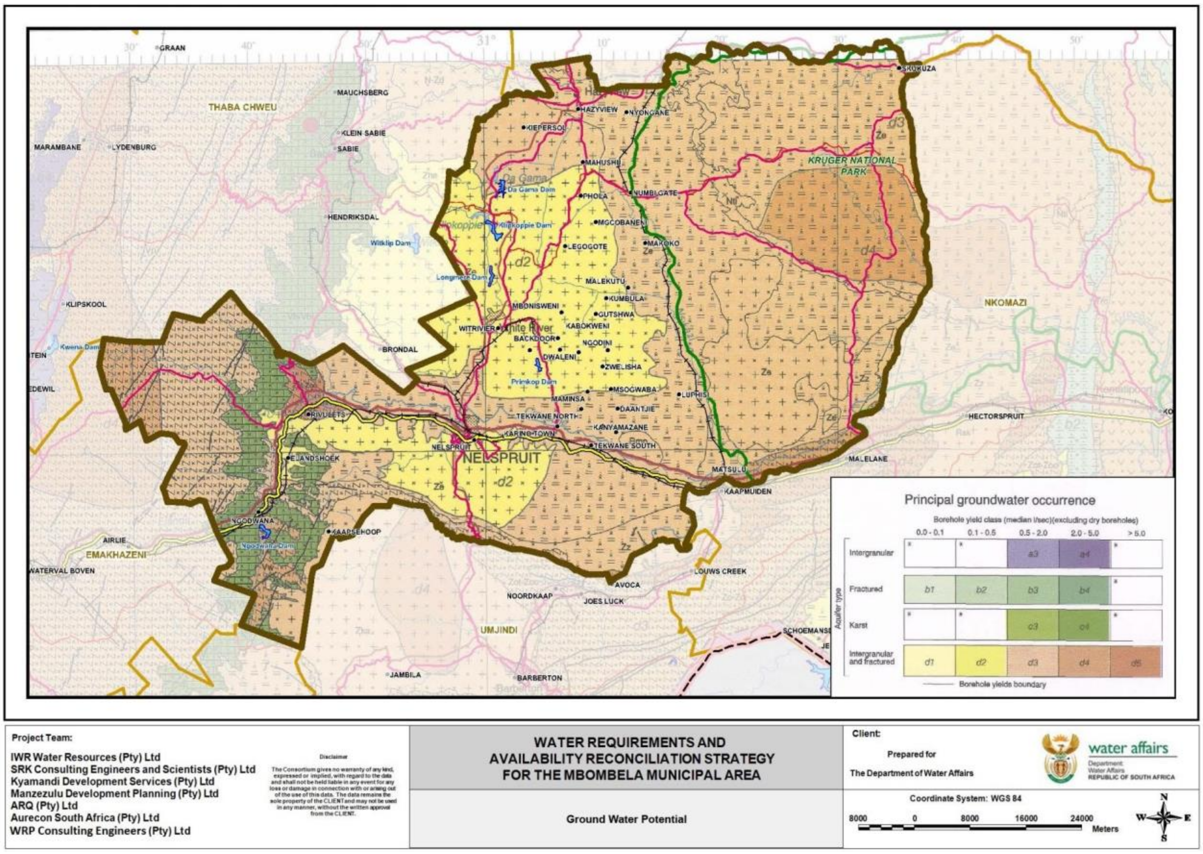


Figure 6.5: Principal groundwater occurrence according to geology (DWA, 2014)

Additional information was found for the Study Area in the National Groundwater Strategies (NGS) (DWS, 2016c). The document describes the process in which the groundwater monitoring system is going to be established as well as the current shortfall in groundwater and its use. It is highlighted that at the time of compiling the NGS little information on the current use and development potential is available. The latest NGS indicates that the total registered groundwater use is 41.52 Mm^3/a for the entire Inkomati-Usuthu Catchment, which equates to about 2% of the total use in the catchment (DWS, 2016c)

GIS datasets were made publicly available during the GRA II study. The average groundwater exploitation potential for the Study Area in m^3/km^2/annum is shown in **Figure 6.6.** According to the classification, Thaba Chweu LM has the highest groundwater potential whereas Emakhazeni LM has a fairly low potential followed by Nkomazi and Bushbuckridge LMs. In the upper portions of the Mbombela LM there appears to be an intermediate potential for groundwater, however, the concern regarding groundwater use and its impact on the surface water baseflow should be investigated in greater detail (DWAF, 2005).

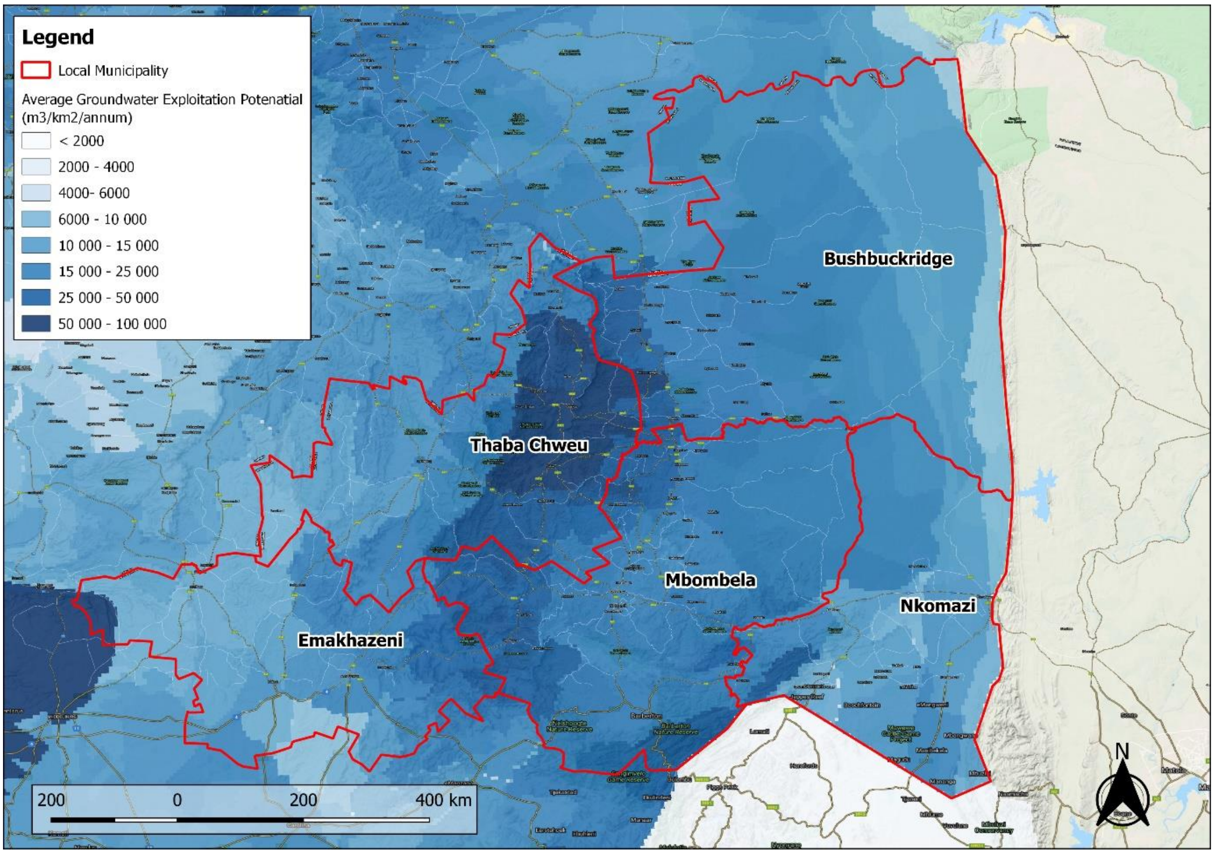


Figure 6.6: Average Groundwater Exploitation Potential in m³/km²/annum (GRA II study, DWAF, 2005)

Borehole data was received from the BBR and CoM LM with labels, indicating if the boreholes are operational (in-use) or not- operational, as well as if the boreholes are blocked, dry-dilled, destroyed, unused, already tested or still to be tested. This data is shown as maps in **Figure 6.7** and **Figure 6.8** respectively. There are many boreholes in BBR LM which are unused, destroyed, not working and blocked. These boreholes could be rehabilitated to supplement the local water supply infrastructure. In CoM LM there are many boreholes which are non-operational for unknown reasons. The cause of the non-operational boreholes should be investigated, and their rehabilitation could assist in supporting the local water supply infrastructure.

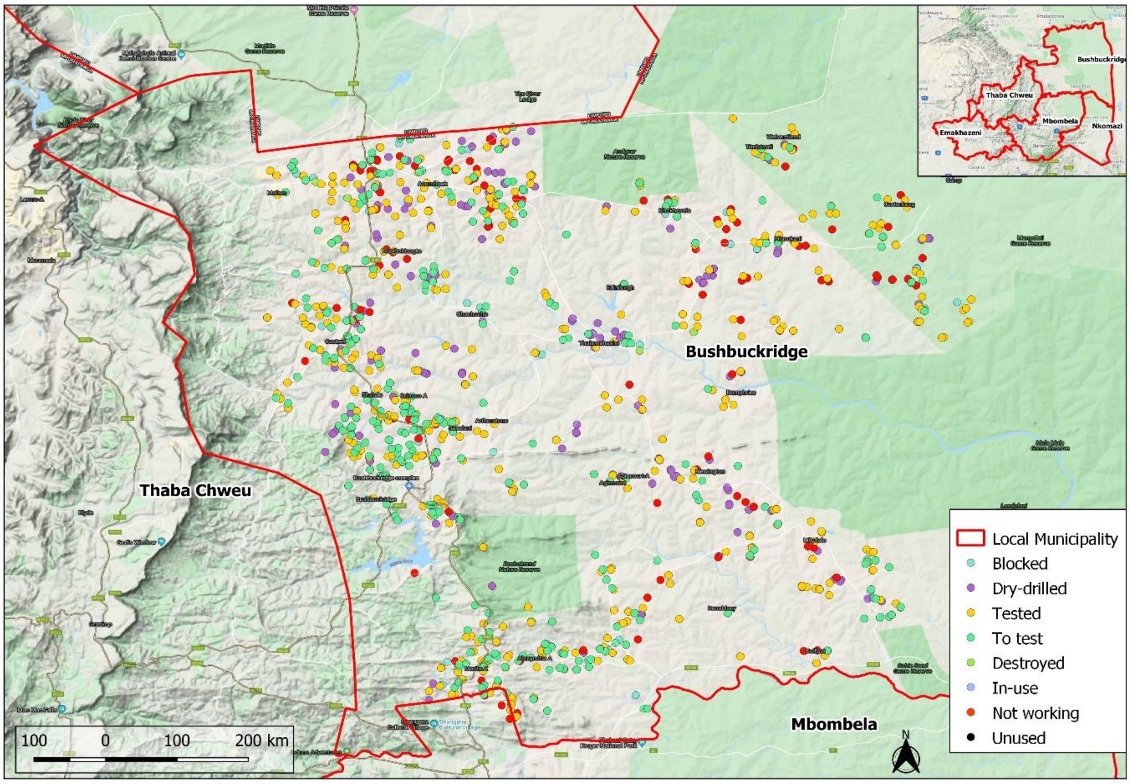


Figure 6.7: Borehole information for Bushbuckridge LM

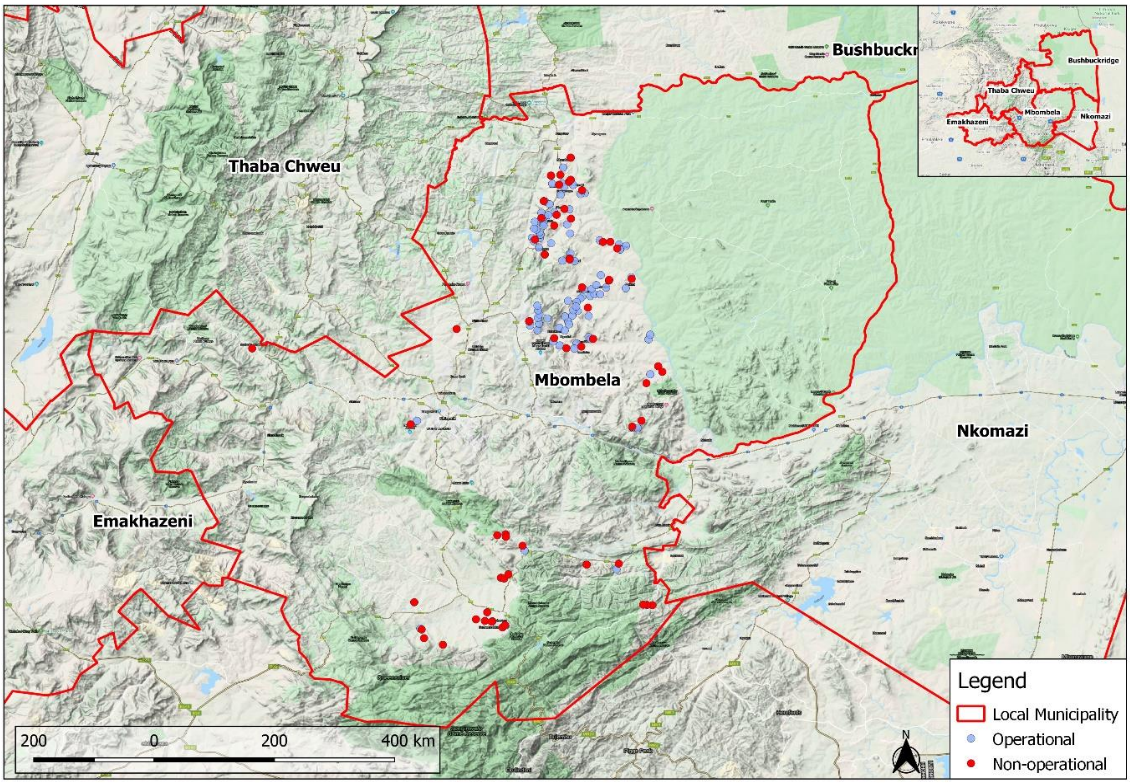


Figure 6.8: Borehole information for Mbombela LM

Musa et al. (2015) published a paper proposing the use of groundwater for drought mitigation by simulating groundwater movement throughout the Crocodile (East) River Catchment. They concluded that groundwater is a viable option for the Kaap and Lower Crocodile, however, that the groundwater is not the best option for the Middle Crocodile, City of Mbombela (Nelspruit) and White River, due to high river flow reductions and drawdown during drought conditions (Musa et al., 2015).

There is potential for artificial recharge in the dolomitic strata on the Crocodile (East) River and in the sandy alluvial aquifers in the Sand River, a tributary of the Sabie River. No additional details were found on the exact location of such sites and details of ongoing investigations. This information was sourced through personal communication with Mr. Karim Sami, a hydrogeologist at WSM Leshika.

The IUCMA recently (October 2019) initiated a detailed groundwater study to determine the extent of groundwater resources in the Study Area. This study has been long required and will provide results that will assist in the finalization of the Reconciliation Strategy update.

7 CONCLUSIONS AND RECOMMENDATIONS

This report has outlined the work undertaken to determine the water resources availability of the Crocodile and Sabie/Sand River Catchments for later use in the water balances to be presented in the updated Reconciliation Strategy. The main objective of the Task was to update the DWS standard water resources models (WRYM and WRPM) which, after initial configuration during the IWAAS (DWAF, 2009), have not been maintained for use in the catchment area. Updated water requirements were configured into the models as well as improvements in the configurations in order to mimic the behavior of the catchment. The hydrology and landuse components of the models were not changed as part of this Task. From the work undertaken, it can be concluded that:

- The catchments included in the Study area fall upstream of the Kruger National Park which is an environmentally sensitive area. EWRs were set for the catchments and these need to be provided for. Supplying the EWRs have an impact on the yield available for other users in the catchment.
- The yield of Kwena Dam alone cannot be used for the water availability in the Crocodile catchment. Additional water resources are available if the inflow from the tributaries downstream of the Kwena Dam are considered. The additional yield available, presented as a catchment yield, has been determined as part of this Task.
- The White River catchment has a small surplus of water available considering the current requirements in the catchment. This water could be used for the future growth of the White River domestic area, or to contribute partly to the EWR on the Crocodile by making releases for this purpose.
- The Crocodile catchment is able to provide water to the existing users, however, the assurance of supply for the irrigators when considering their allocations as a demand on the system is very low compared with the typical assurance usually provided to irrigators. Water resources augmentation is required to allow for growth in the CoM LM.
- The Sabie/Sand catchment is in a severe deficit and, given that the main use from the catchment is for the domestic sector, urgent intervention is required to augment the supply in the catchment. There is currently not sufficient water available to reinstate the irrigation use from Inyaka Dam.
- The current operating rules applied to the system are not efficient and restrict users beyond their acceptable assurance of supply criteria. If the White River

system continues to be restricted based on Kwena Dam storage, the White River dams will not be properly utilized.

- Implementing dynamic operating rules for the system which are driven by the short term yield capabilities and assessed on an annual basis based on the existing demands and storage state of the dams will provide users with an improved supply, on average, as well as make better use of the dam storages and river runoff in the catchments.
- The Crocodile catchment requires a high level of management in order to make efficient use of the available water resources.
- The majority of groundwater studies undertaken in the past have concluded that further use of groundwater resources should be undertaken with caution as it is believed that abstracting additional groundwater will result in a reduction in the surface water availability due to the groundwater-surface water interactions.

The final Reconciliation Strategy will provide the overall recommendations resulting from this Study. Recommendations for further consideration resulting from the work undertaken in this Task are as follows:

- The White River system be managed separately and operating rules for the system should be dependent on the storage of the White River Dam and not on the Kwena Dam. An appropriate contribution towards the Crocodile EWR should be developed and implemented in the White River system.
- The approach to system operation should be similar to that implemented with success in most of the larger catchments in South Africa whereby annual analyses are undertaken using risk based methodologies, dynamic operating rules driven by short term yield and actual demands on the system.
- The Validation and Verification of water use in the catchment be completed and realistic water requirements, especially for the irrigation sector, be incorporated into the water resources models.
- River flows and abstractions should be monitored throughout the system in order to benefit from river runoff. Liaison and communication between users and the Catchment Managers should be undertaken weekly in order to improve the management and operation of the system.
- Augmentation of water resources in the Sabie and Crocodile system in the form of new dams be fast tracked in order to supply the growing urban

demands in the area, as well as to provide an improved assurance of supply to the irrigators.

- Irrigation allocations on the Sabie River currently not utilized should only be revitalized once a new dam has been built in order to supply the additional requirements.
- In the time period leading up to the construction of a new dam in the Crocodile system, the growing demands in the urban sector should be supplied at the required assurance criteria. In order to do this, higher restrictions will be required in the irrigation sector. This will only be acceptable if the urban sector is seen to be managing its demand level to the best of its ability by implementing water conservation and water demand management activities and reducing water losses.

Finally, it should be noted that, having assessed the water resources analyses results produced in the Task, the situation of the water resources availability in the Crocodile and Sabie catchments is unprecedented. The models are showing an imbalance between water allocations and availability which is resulting in water users being supplied at a much lower assurance than would typically be the case in other catchments. However, it is further noted that those users exist, irrigators are irrigating and the domestic sector is growing. It could be that the model is providing results that are not mimicked in reality. Possible reasons for this are as follows:

- The model is simulating what the environment and international obligations require as per official agreements. It may be that these are not adequately being released for in reality which would indicate more water remains in the system than the simulations project for.
- The model has simulated an irrigation requirement for the Crocodile Irrigation Board according to their allocation of 313 million m^3/annum. It is possible that not all this water is used on an annual basis and that some farmers are no longer irrigating as per their allocations. This again would result in the model providing more conservative results than those observed in reality.

In order to ascertain if the above possibilities are a reality, comparisons of the EWRs required by the Gazette and the actual flows past these sites should be undertaken. Furthermore, the actual abstractions from users should be monitored and it should be established if there is a significant difference between actual use and allocations.

8 MODEL UPDATES AND IUCMA SCENARIO

8.1 Background

This water resources draft report was presented to the Technical Support Group in March 2020. At the meeting, the IUCMA provided further information to refine the analyses as well as made a request for further scenarios to be undertaken. This sub-section provides a summary of the updated information received and the additional scenario results.

The two main uncertainties that existed after the initial results had indicated the severe system deficits at acceptable assurance of supply were as follows:

- Was the Crocodile Irrigation Boards' actual use significantly lower than the allocation figure used in the scenario analyses?
- Were the EWR and cross border flows that were simulated in the model being released in reality?

Clarity was sought at the meeting, and further information was subsequently sent which is summarized as follows.

- The confirmed allocation value for the Crocodile irrigation Board is 304 million m^3/annum, which is slightly lower than the 313 million m^3/annum which was used for the original analyses. It was stated that the allocation should be used in the scenarios as this is what is lawful. On average, however, due to the system deficits and restrictions, the irrigators usually obtain approximately 60% of their allocation. This is equivalent to 182 million m^3/annum.
- The cross border flow of 51 million m^3/annum (1.6 m^3/s) previously used was not correct. The IUCMA clarified that the only obligation for the Crocodile contribution to the cross border flow is 37 million m^3/annum (1.17 m^3/s).
- The drought restriction rule linked to the storage of Kwena Dam was clarified and updated. The restrictions are issued based on the level of Kwena Dam for the Crocodile Main River and its tributaries, except the White River System, which uses different operating rules. However, during excessive flows, there are target flows at Karino (8 m^3/s) and Riverside (5 m^3/s), at which users can abstract up to their full allocations and store the water even if restriction rules are in place. The location of these gauges are presented in **Figure 8.1**.
- Although it was stated at the meeting that the Sabie system was presently not adhering to the Gazetted EWRs, it was confirmed that these should be included in all scenarios as the intention was to start making the correct

releases. To date, only 0.6 m^3/s was released for the international obligation contribution from the Sabie.

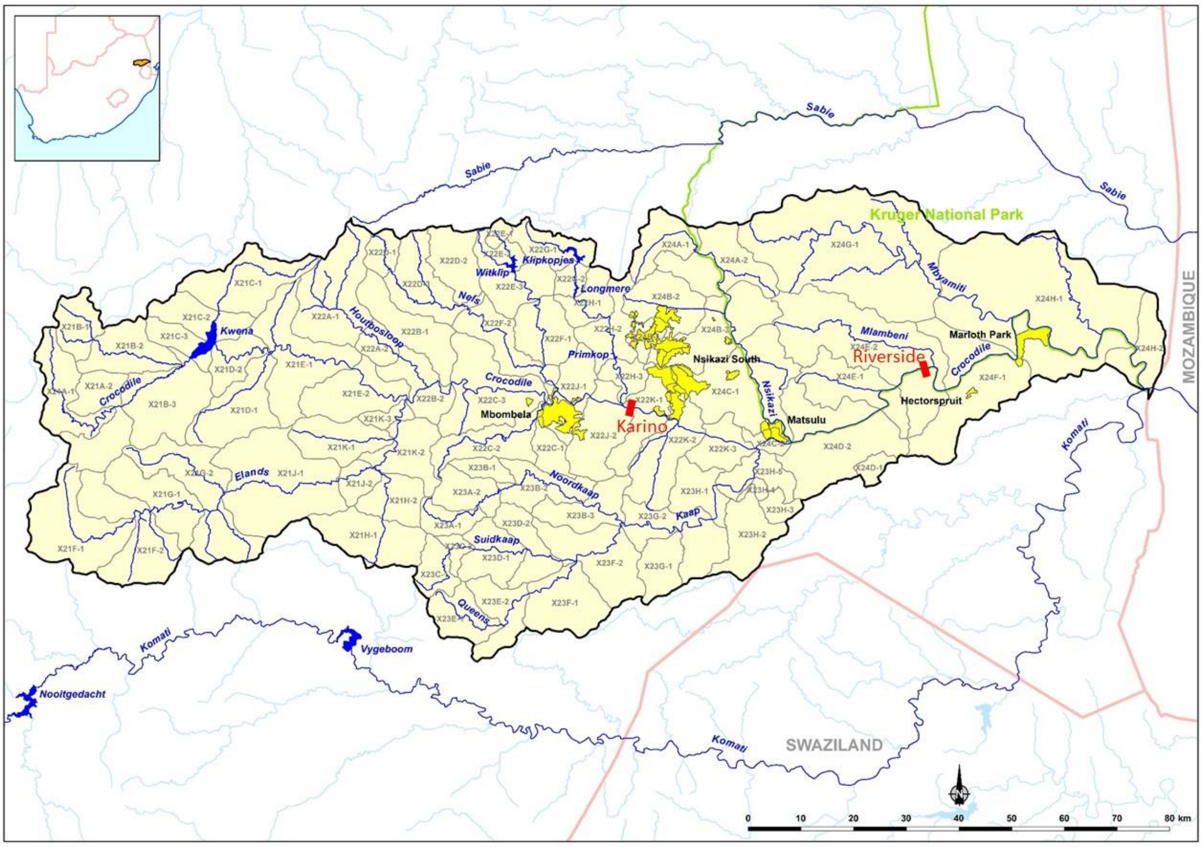


Figure 8.1: Locations of gauges used to trigger restriction rule relaxation

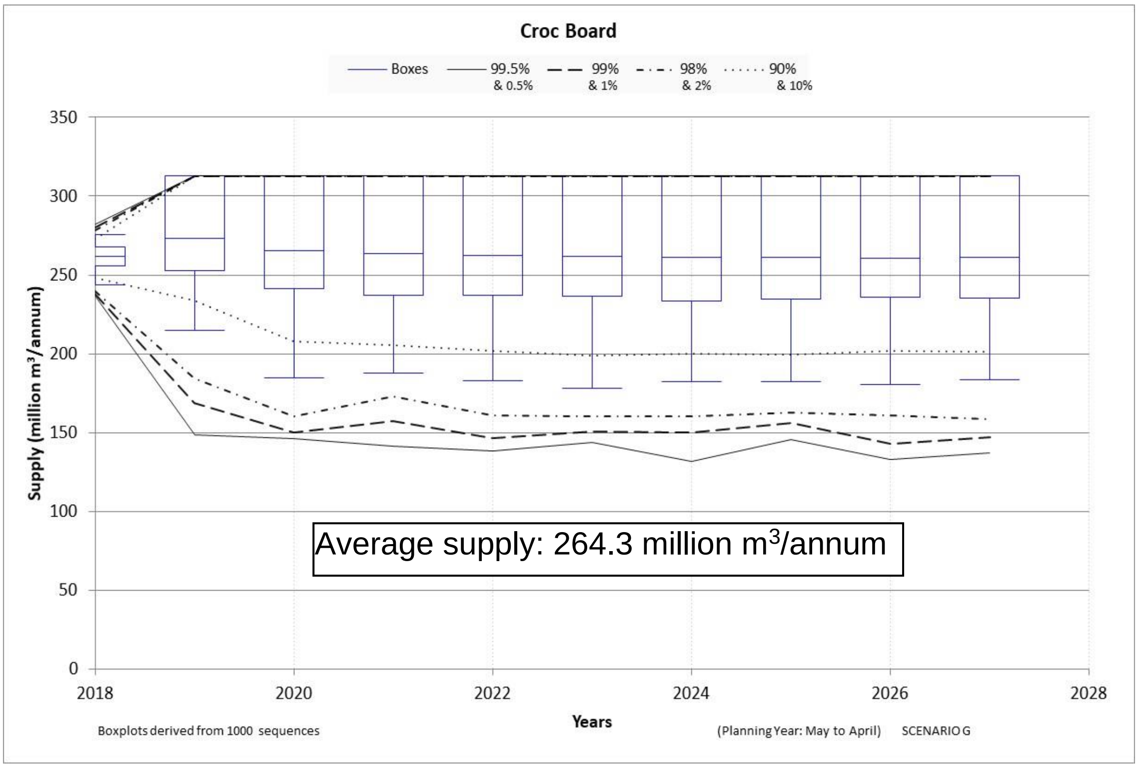
8.2 Defined Scenarios

Three additional scenarios were undertaken in order to account for the new information received. These are described as follows:

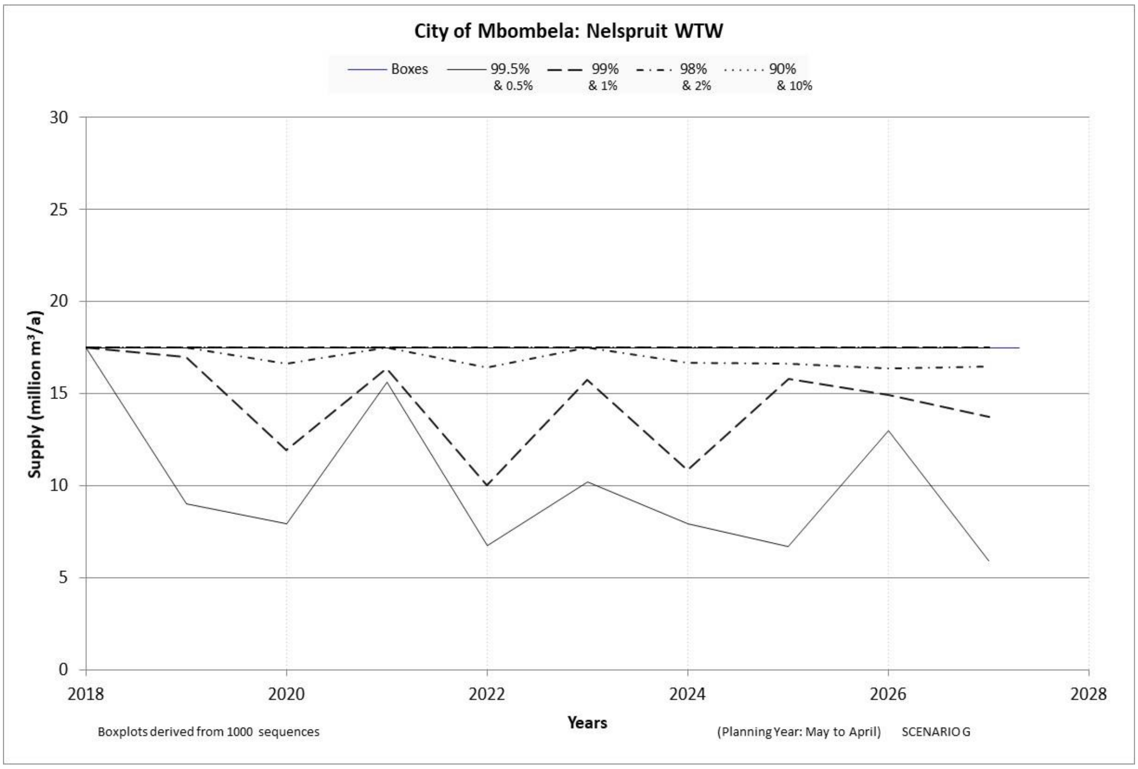
- Scenario D: Previous scenario B_{adjust} with cross border flow reduced from 1.6 m^3/s to 1.17 m^3/s.
- Scenario E: Previous scenario B_{adjust} without any cross border flow on in order to confirm if the Gazetted EWR accounts for the cross border flow requirement.
- Scenario F: Scenario D with the Crocodile Irrigation Board allocation reduced to 304 million m^3/a.

8.3 Scenario Results

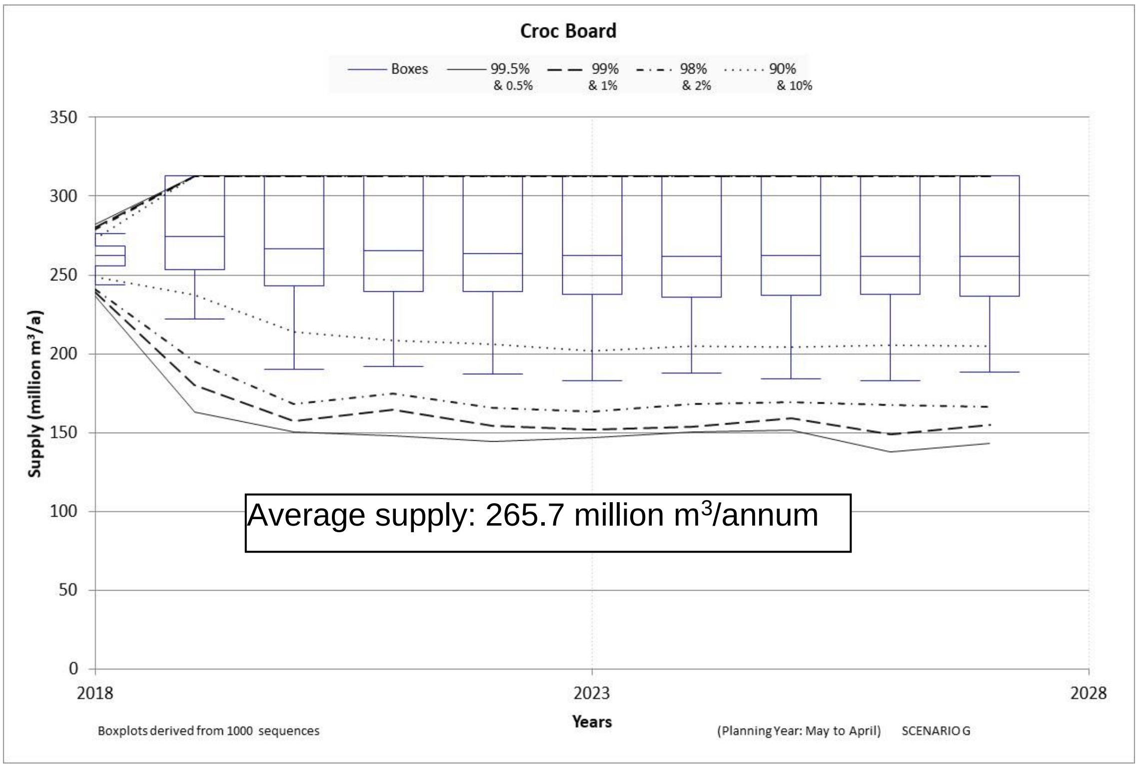
The following figures show a comparison between the Crocodile Irrigation Board supply and the City of Mbombela supply between the two scenarios Scenario B_{adjust} and Scenario D.



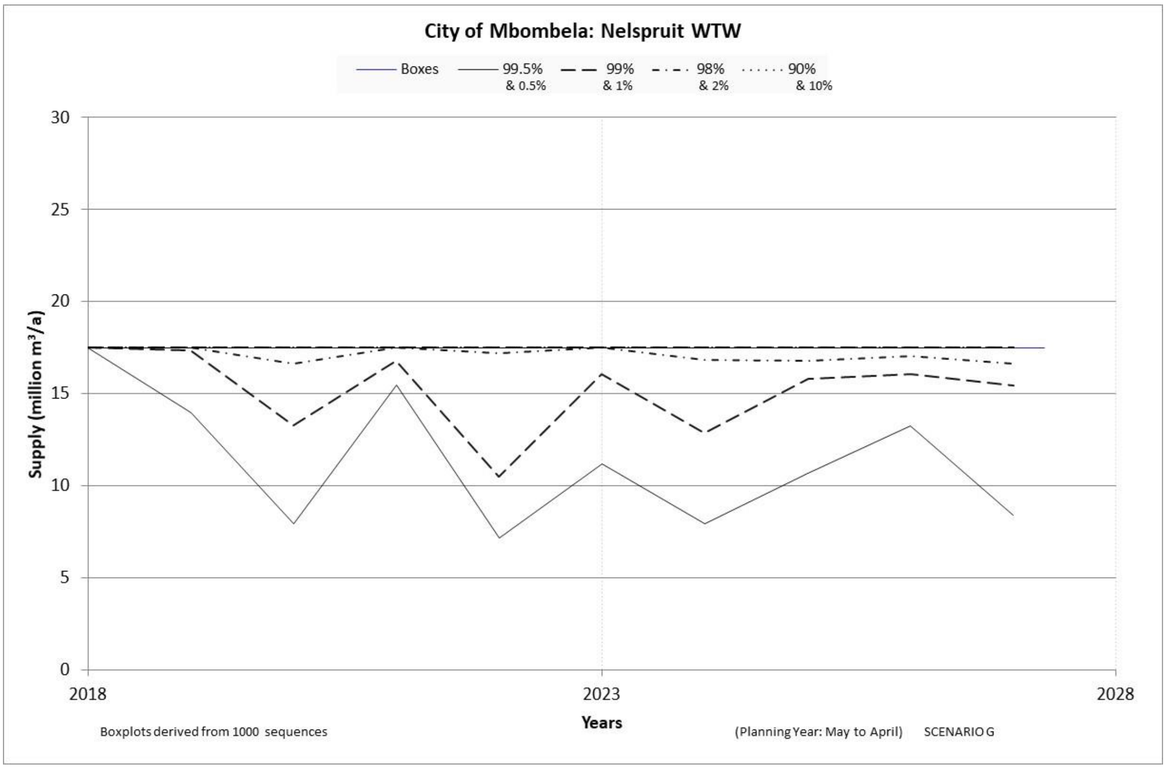
Scenario B_{adjust}



Scenario B_{adjust}

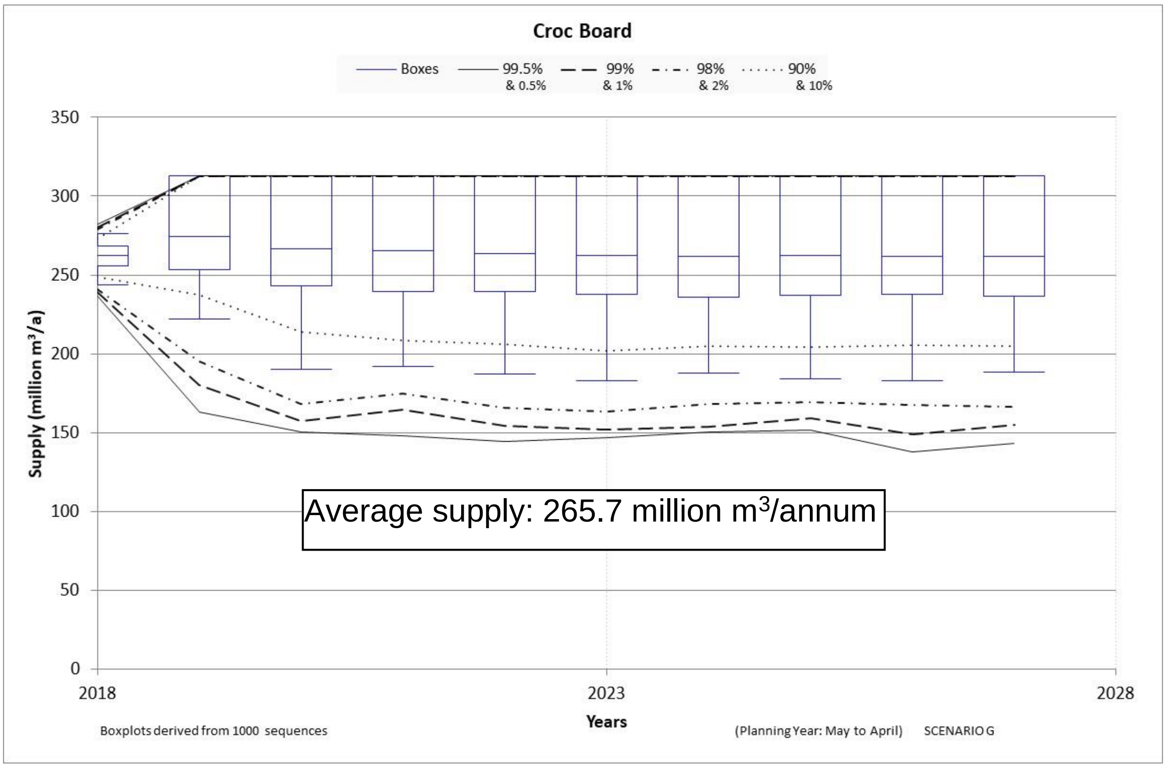


Scenario D

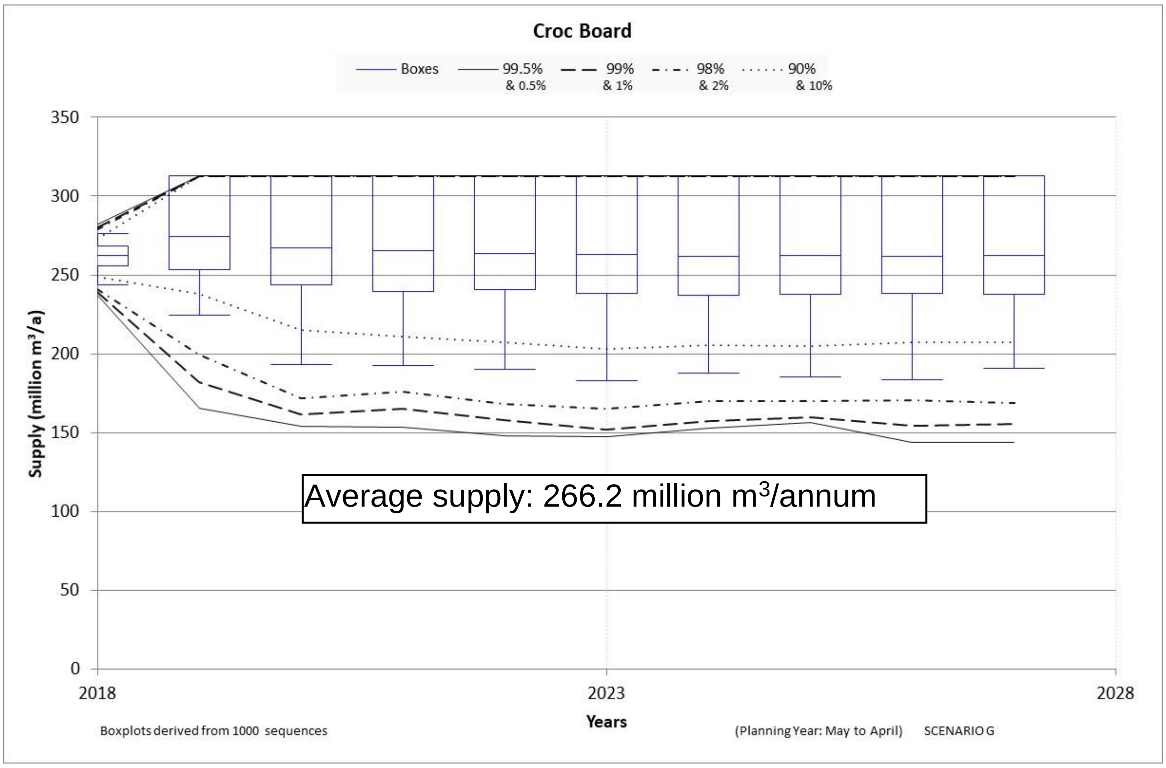


Scenario D

The results for the two scenarios are almost identical, with only a slight increase in average supply to the irrigation board. This shows that, reducing the cross border flows from the previous incorrect figure of 51 million m^3/annum to the correct figure of 37 million m^3/annum does not have a significant impact on the results. The reason for this is due to the fact that the EWR is the same in both cases, and the EWR is driving the releases. This was confirmed with Scenario E, the results of which are shown in the following figures.



Scenario D

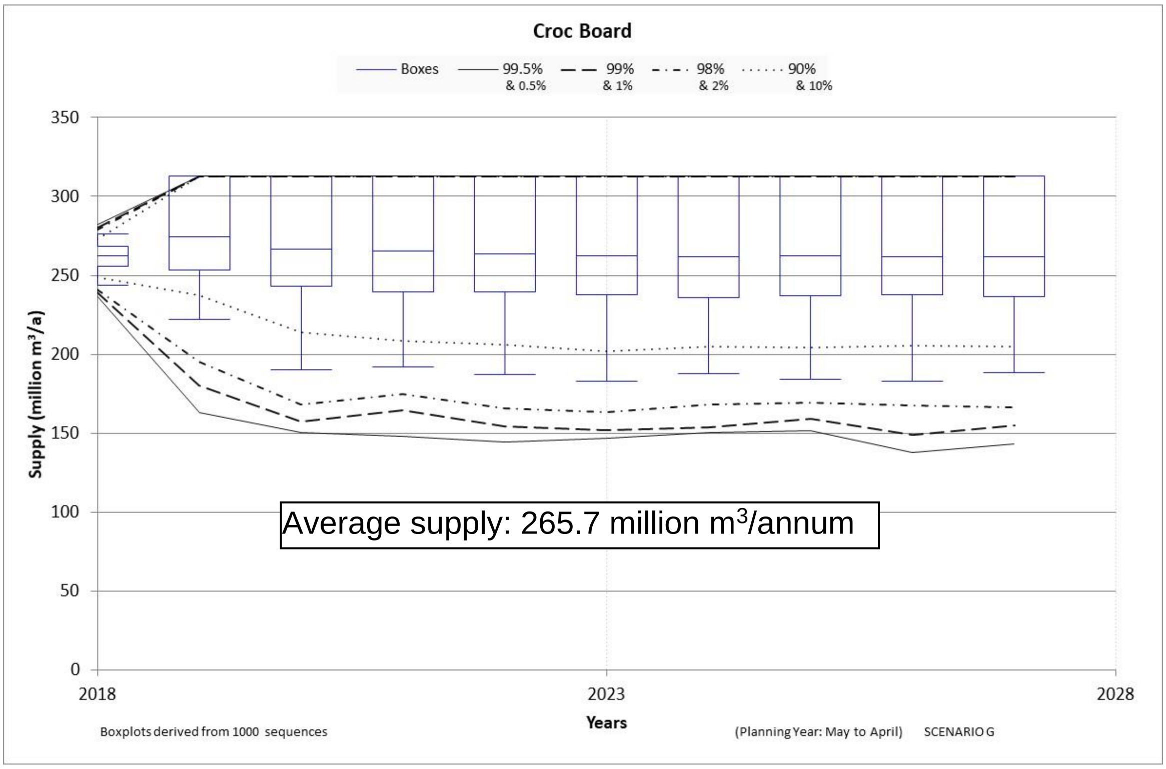


Scenario E

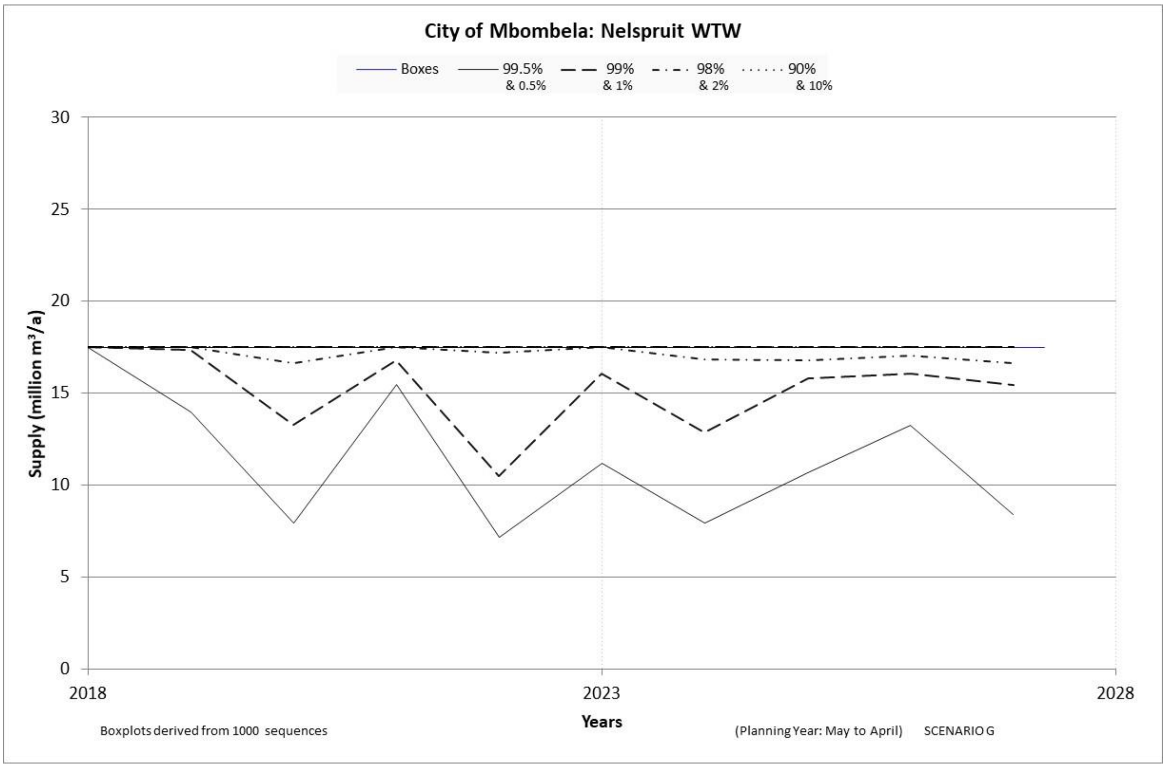
The result of Scenario E shows only a very small increase in average supply to the irrigators if the cross border flow is not included in the simulation, and only the EWR is included. This is expected as the EWR is driving the flows.

Scenario F saw a corrected value assigned to the Crocodile irrigation Board of 304 million m^3/annum. The comparison of results between Scenario D and Scenario F are presented in the following figures.

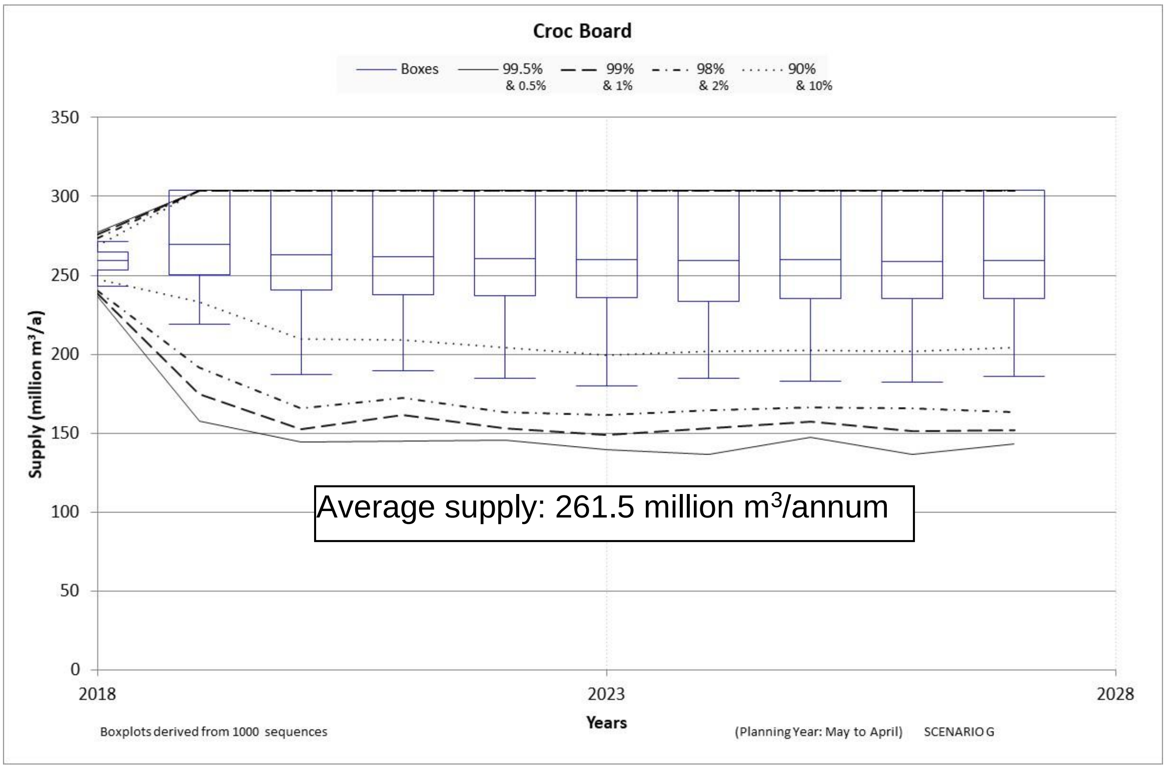
The average supply to the Crocodile Irrigation Board's irrigators under conditions of Scenario F is 261.5 million m^3/annum, whereas their allocation is 304 million m^3/annum. This equates to an 86% supply which is higher than the current average of 60% supply. This indicates that the supply to the irrigators can be improved with an adjusted operating rule.



Scenario D

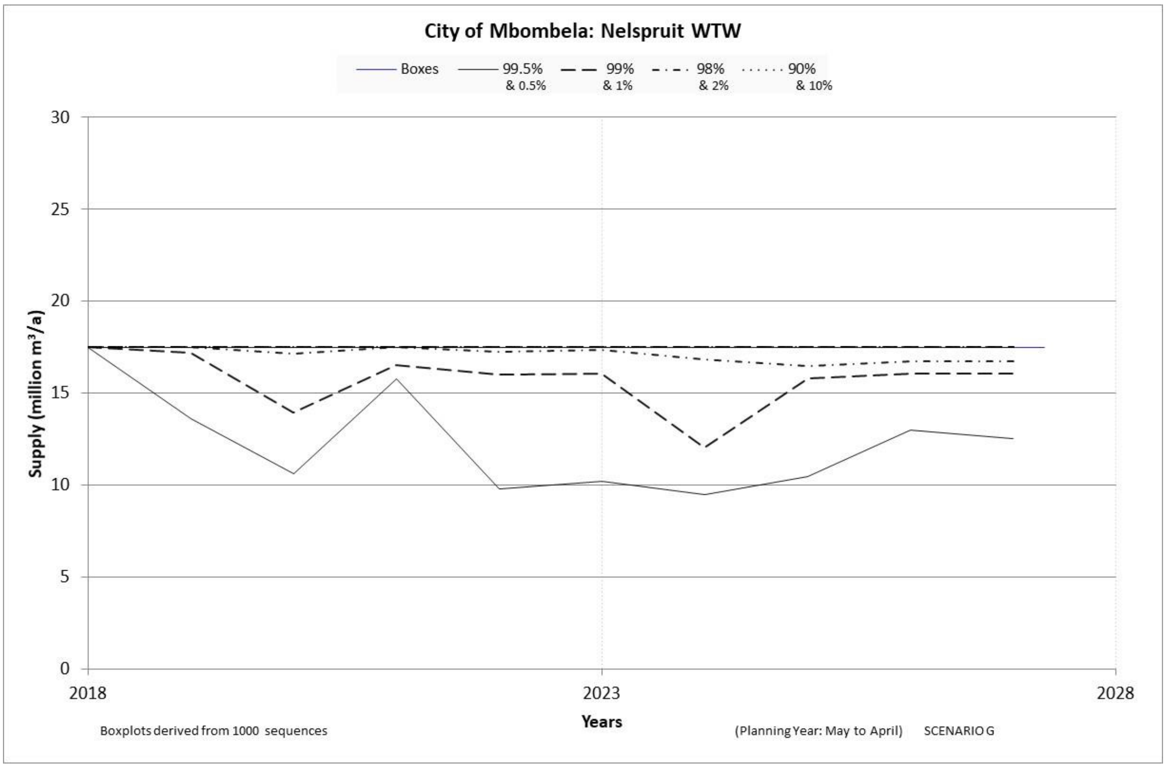


Scenario D



Average supply: 261.5 million m^3/annum

Scenario F



Scenario F

The results of the simulations were reviewed to assess whether the Sabie cross border flows were being met by the EWR releases included in the scenarios. It was found that this is the case and that the EWRs are much larger than the cross border flow requirement of 0.6 m^3/s.

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DWA (2011g) Ehlanzeni District Municipality: Reconciliation Strategy for Louisville Water Supply Scheme area – Nkomazi Local Municipality compiled by Water for Africa (Pty) Ltd in association with Aurecon and Water Geoscience Consulting in 2011, for the Department of Water Affairs Directorate: Water Resource Planning Systems, Pretoria, South Africa.

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DWA (2011m) Ehlanzeni District Municipality: Reconciliation Strategy for Nsikazi South Water Supply Scheme area – Mbombela Local Municipality compiled by Water for Africa (Pty) Ltd in association with Aurecon and Water Geoscience Consulting in 2011, for the Department of Water Affairs Directorate: Water Resource Planning Systems, Pretoria, South Africa.

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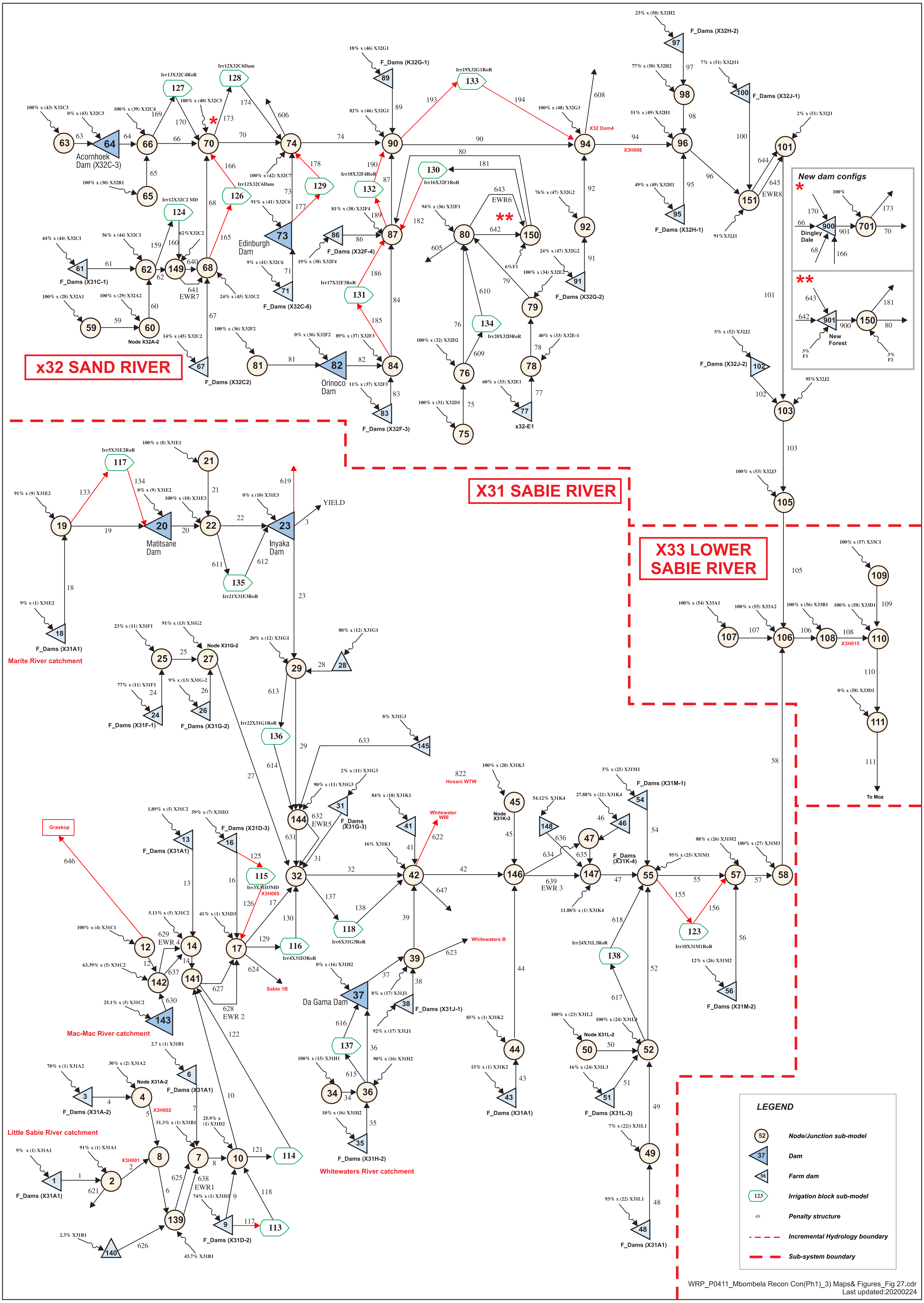
APPENDIX A

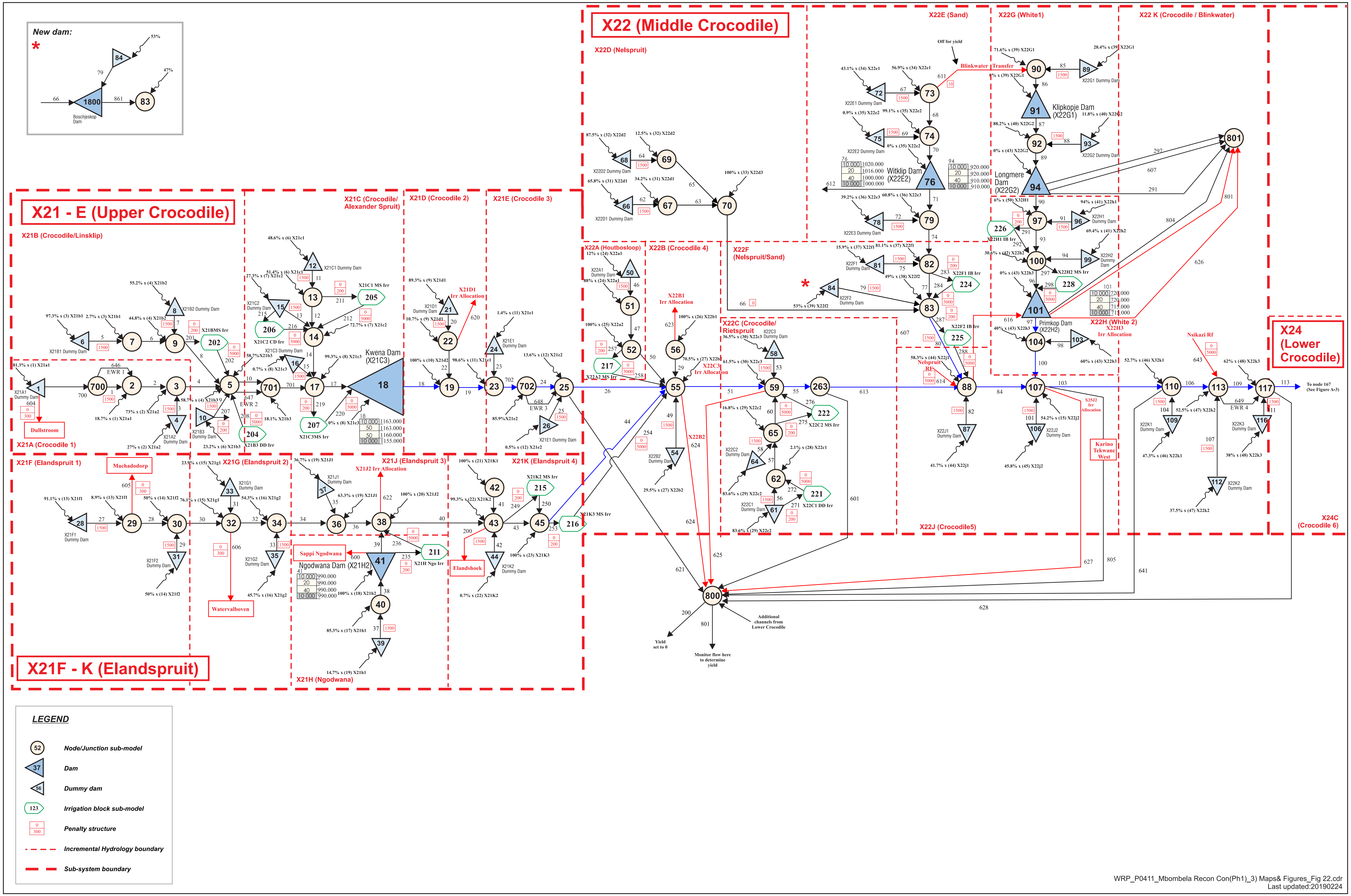
WRYM & WRPM NETWORK DIAGRAMS



CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRYM Schematic Diagram: Sabie/Sand River

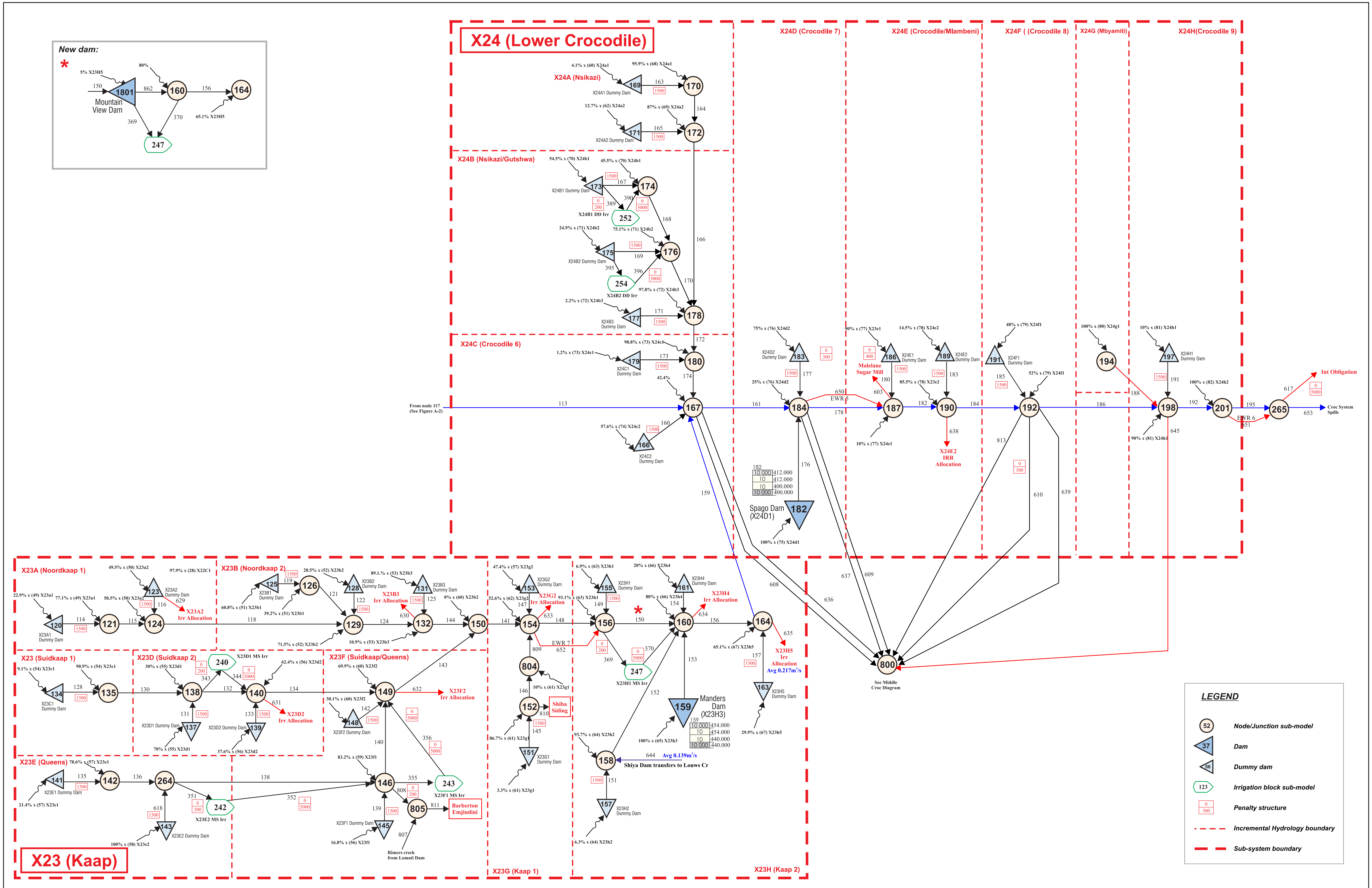
A-1



water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA
iX engineers
Infrastructure Excellence
wrp

CONTINUATION OF WATER REQUIREMENTS
AND AVAILABILITY RECONCILIATION
STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRYM Schematic Diagram: Upper Crocodile/Middle Crocodile River **A-2**



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Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

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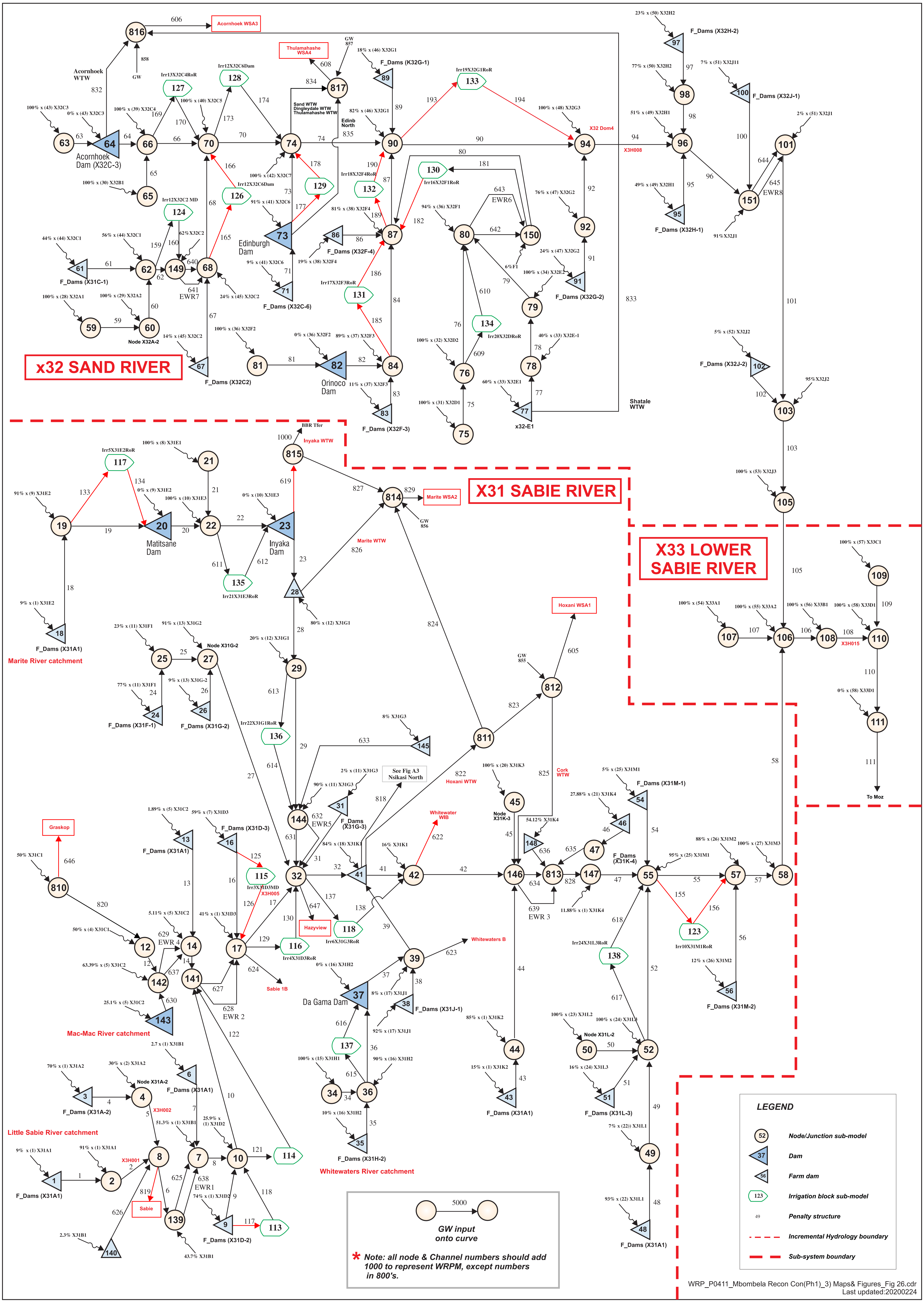
Infrastructure Excellence

CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRYM Schematic Diagram: Kaap/Lower Crocodile River

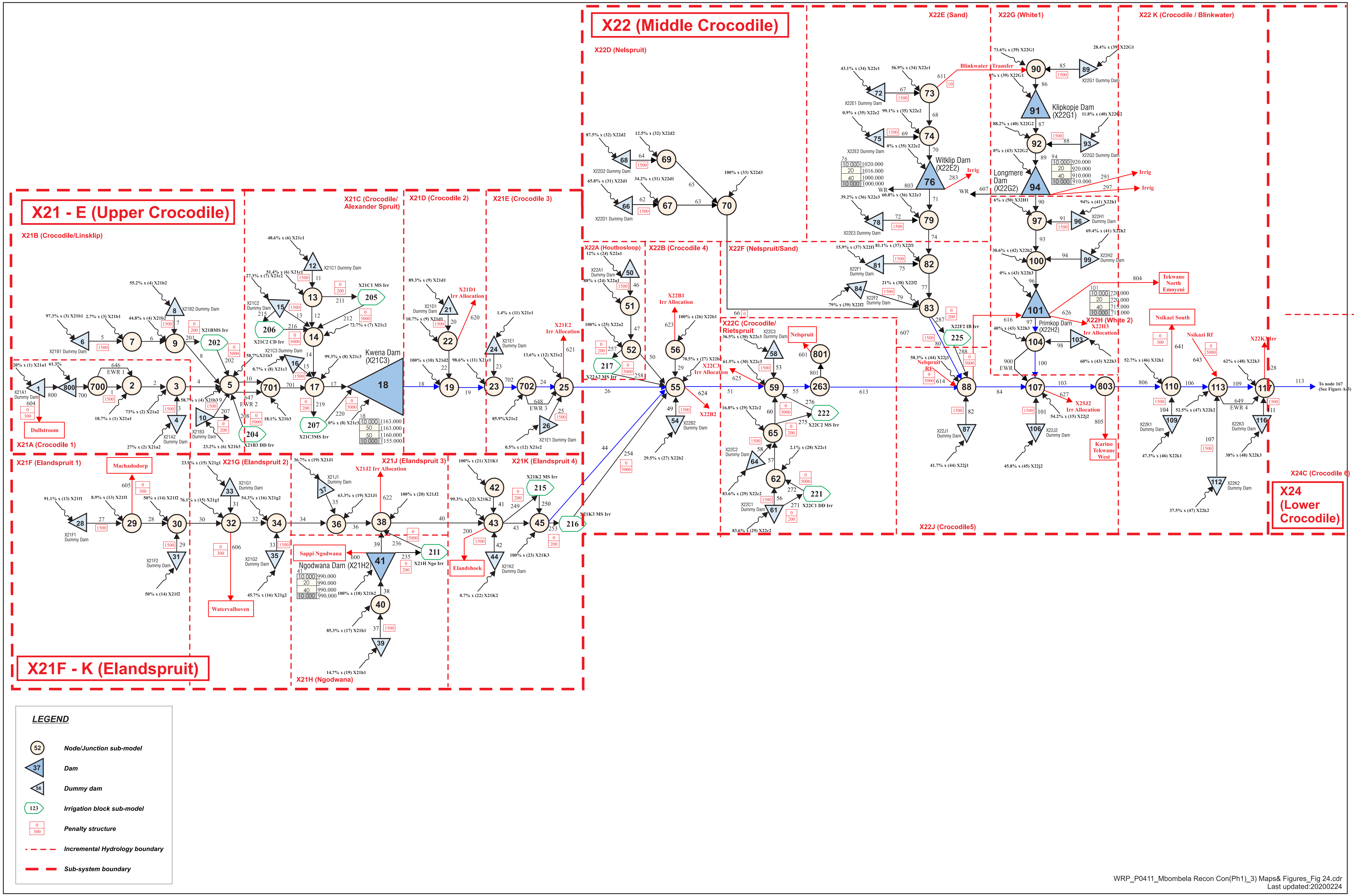
A-3



CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRPM Schematic Diagram: Sabie/Sand River

A-1



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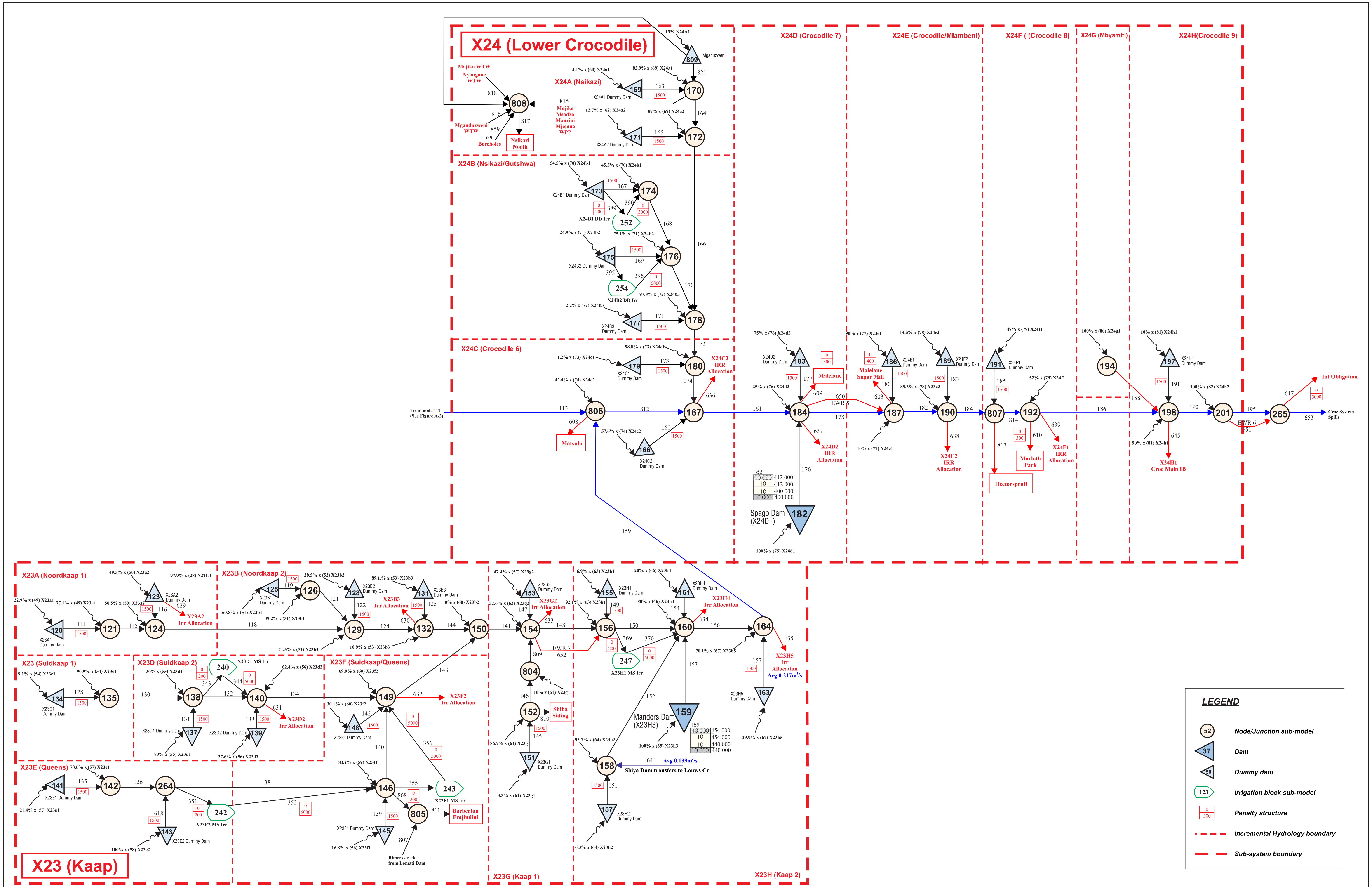
CONTINUATION OF WATER REQUIREMENTS AND AVAILABILITY RECONCILIATION STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRPM Schematic Diagram: Upper Crocodile/Middle Crocodile River **A-2**



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CONTINUATION OF WATER REQUIREMENTS
AND AVAILABILITY RECONCILIATION
STRATEGY FOR THE MBOMBELA MUNICIPAL AREA

WRPM Schematic Diagram: Kaap/Lower Crocodile River

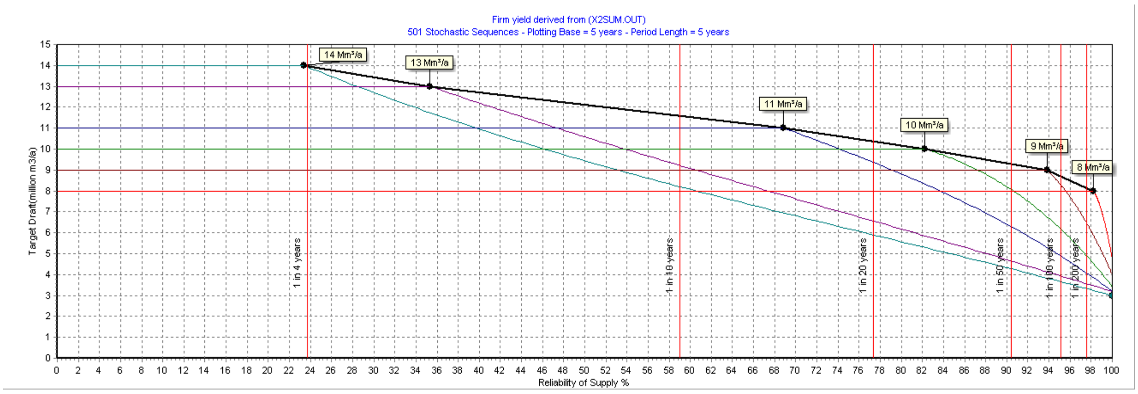
A-3

APPENDIX B

SHORT TERM YIELD CURVES

Witklip Dam

100%



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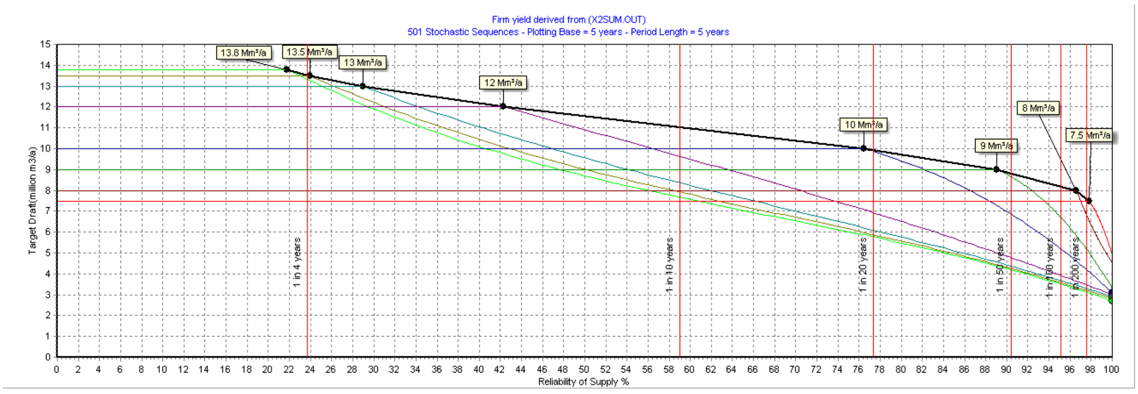

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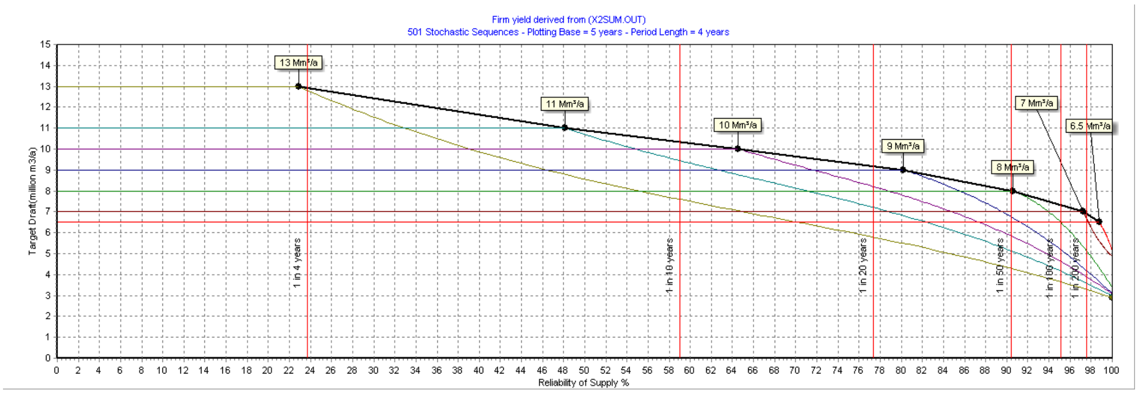

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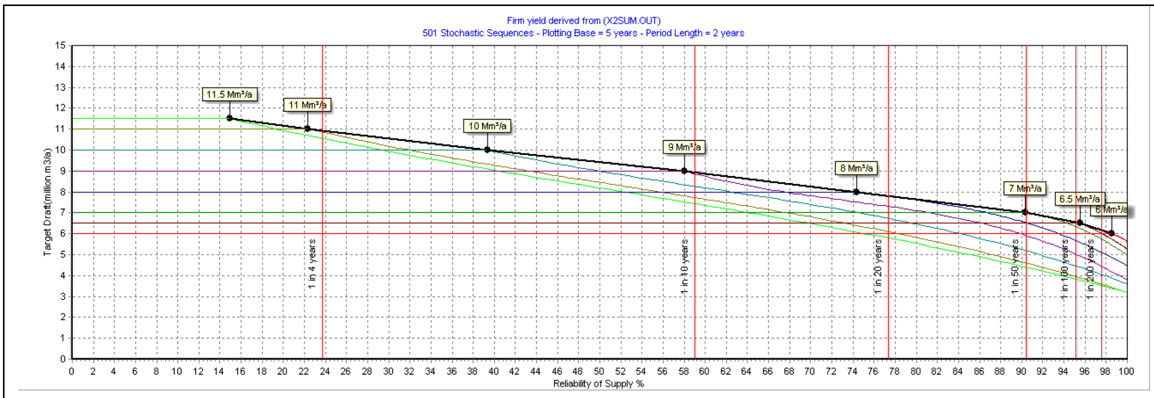
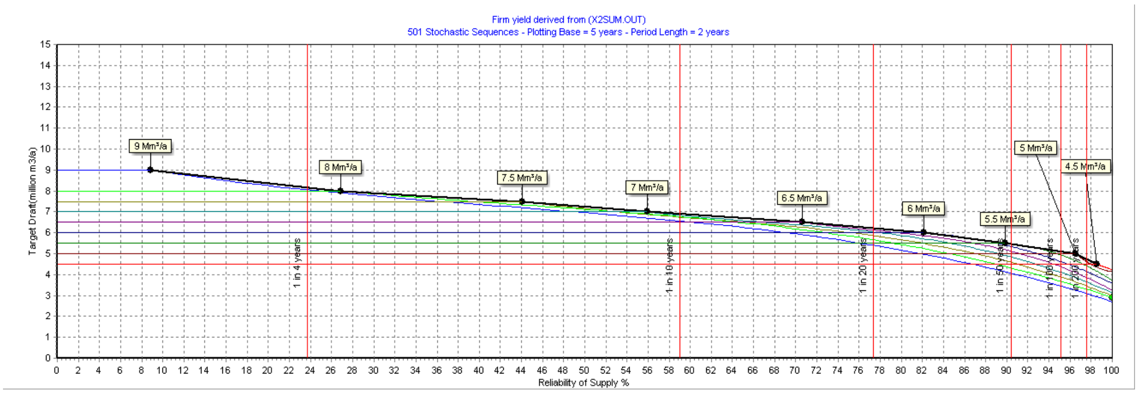
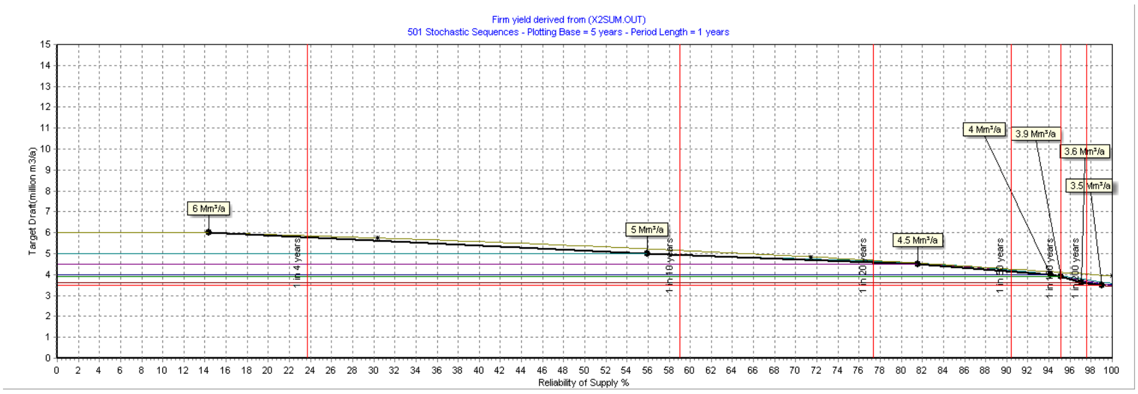

Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 2 years
Target Draft(million m3/a)
Reliability of Supply %
11.5 Mm³/a
11 Mm³/a
10 Mm³/a
9 Mm³/a
8 Mm³/a
7 Mm³/a
6.5 Mm³/a
6 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

20%

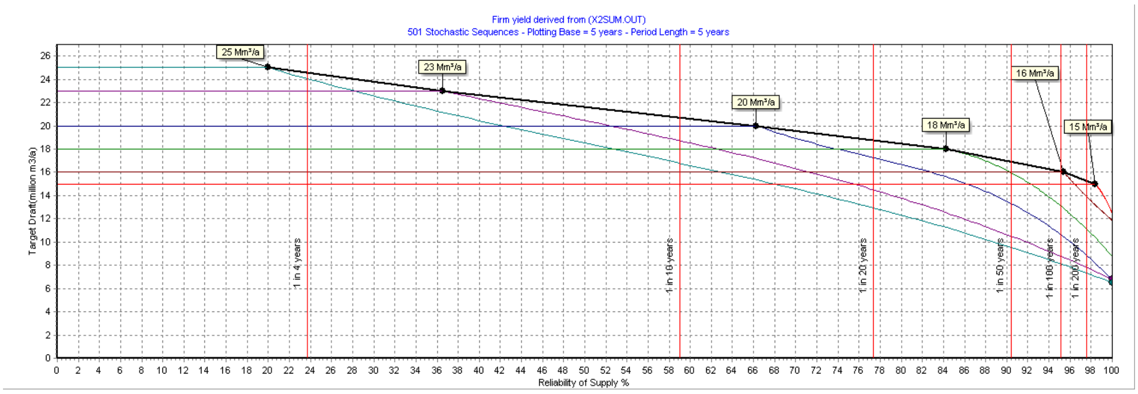

Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 2 years
Target Draft(million m3/a)
Reliability of Supply %
9 Mm³/a
8 Mm³/a
7.5 Mm³/a
7 Mm³/a
6.5 Mm³/a
6 Mm³/a
5.5 Mm³/a
5 Mm³/a
4.5 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

10%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 1 years
Target Draft(million m3/a)
Reliability of Supply %
6 Mm³/a
5 Mm³/a
4.5 Mm³/a
4 Mm³/a
3.9 Mm³/a
3.6 Mm³/a
3.5 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

Klipkopje, Longmere, Primkop System

100%



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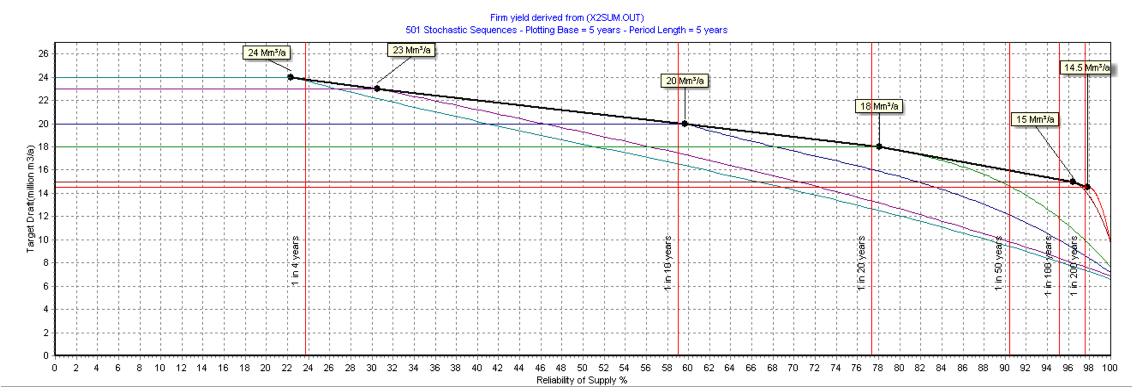

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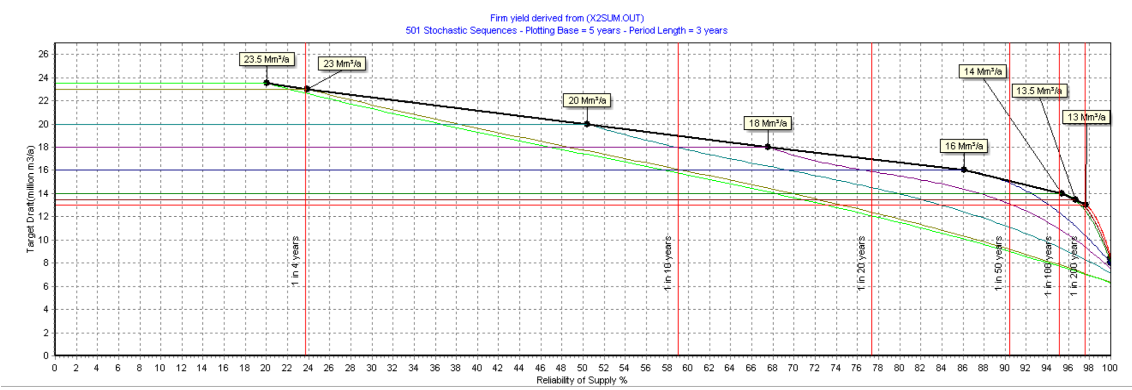

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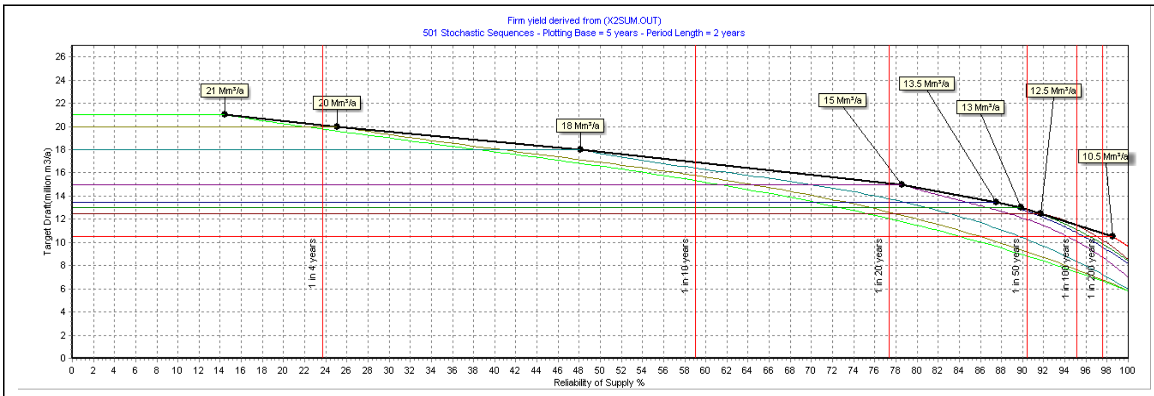
Firm yield derived from (X2SUM.OUT)
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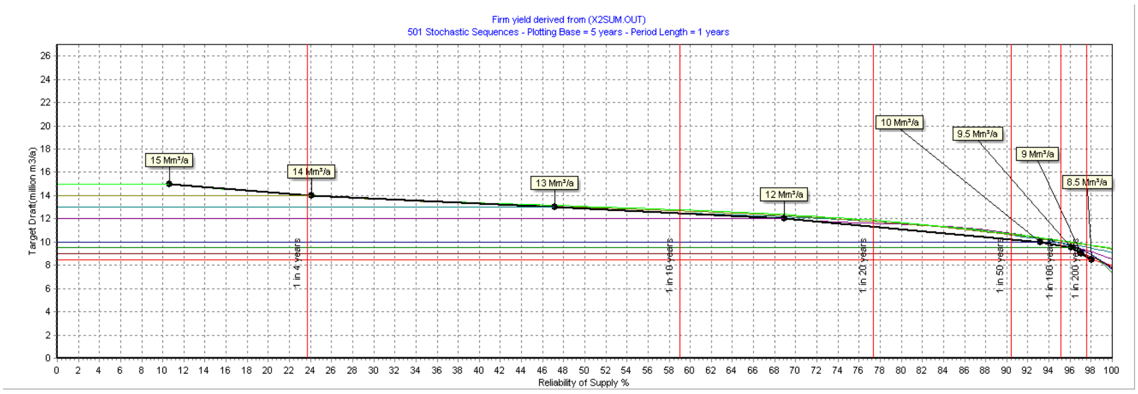
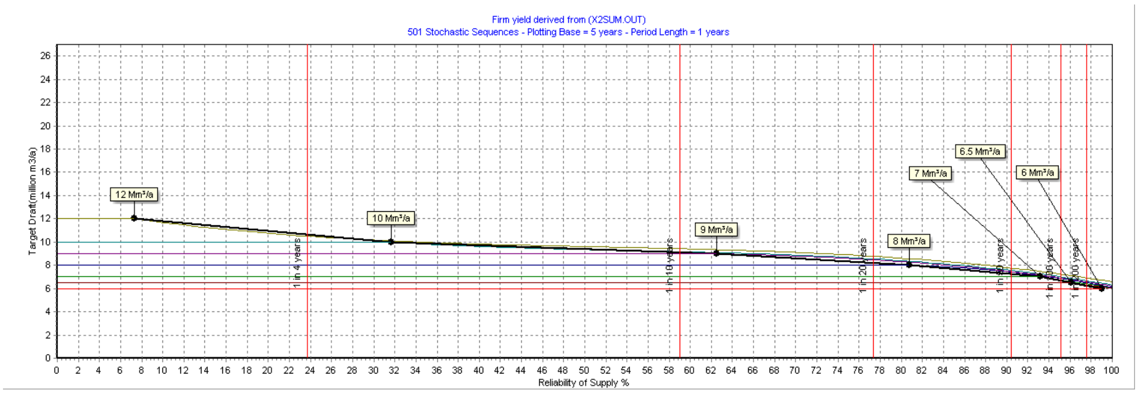
21 Mm³/a
20 Mm³/a
18 Mm³/a
15 Mm³/a
13.5 Mm³/a
13 Mm³/a
12.5 Mm³/a
10.5 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

20%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 1 years
15 Mm³/a
14 Mm³/a
13 Mm³/a
12 Mm³/a
10 Mm³/a
9.5 Mm³/a
9 Mm³/a
8.5 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

10%


Firm yield derived from (X2SUM.OUT)
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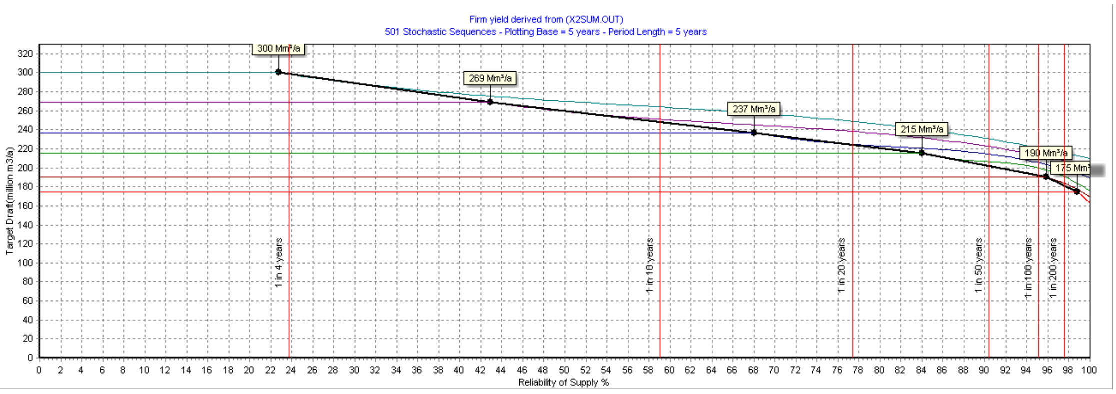
12 Mm³/a
10 Mm³/a
9 Mm³/a
8 Mm³/a
7 Mm³/a
6.5 Mm³/a
6 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

Crocodile System

100%



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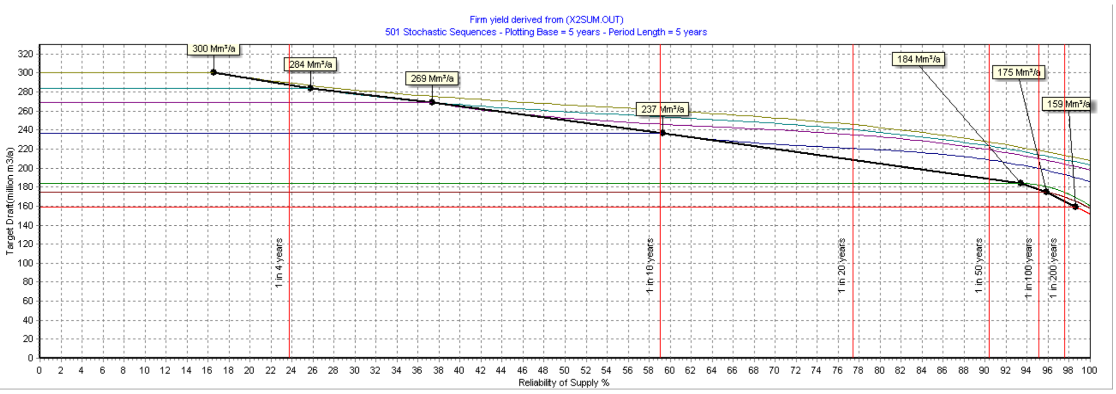

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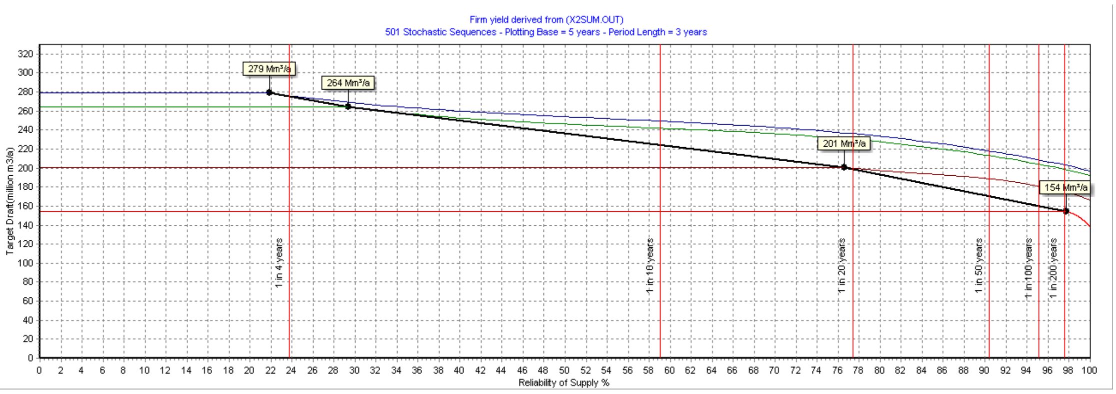

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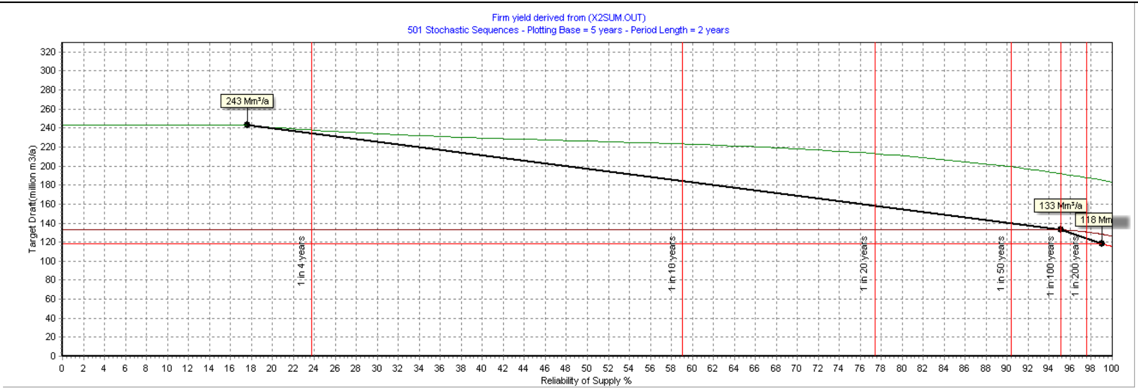
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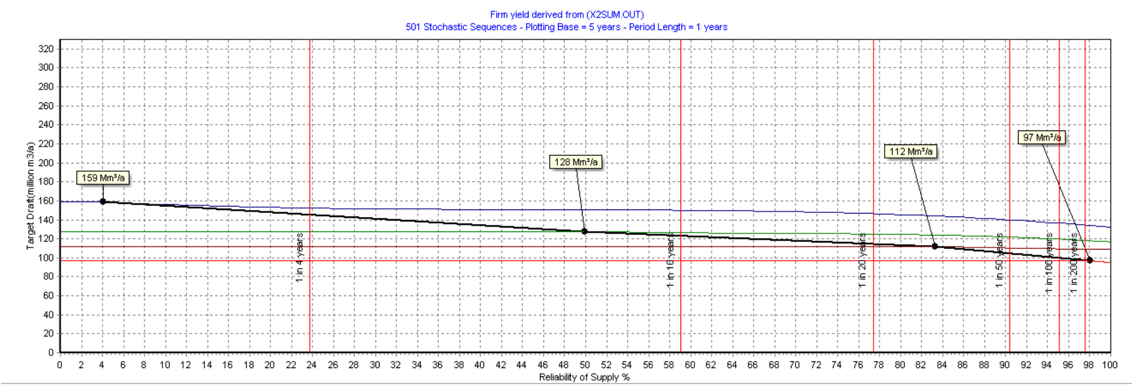
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 2 years
243 Mm³/a
133 Mm³/a
118 Mm
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

20%


Firm yield derived from (X2SUM.OUT)
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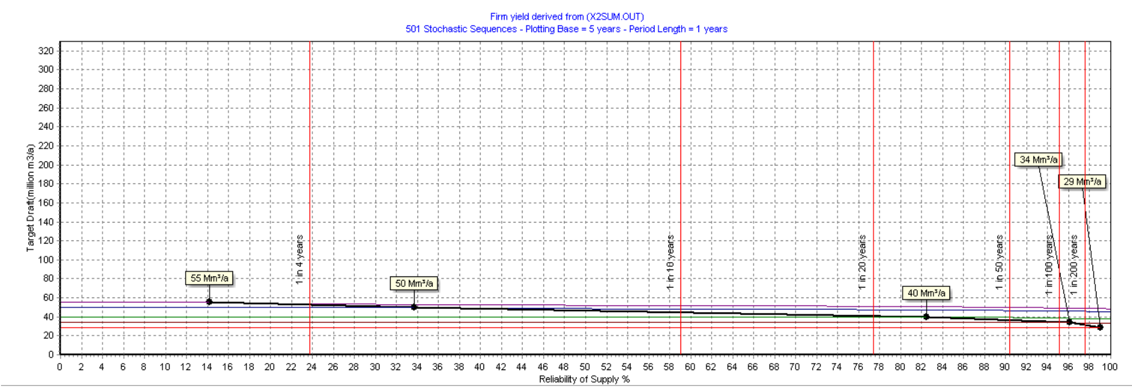
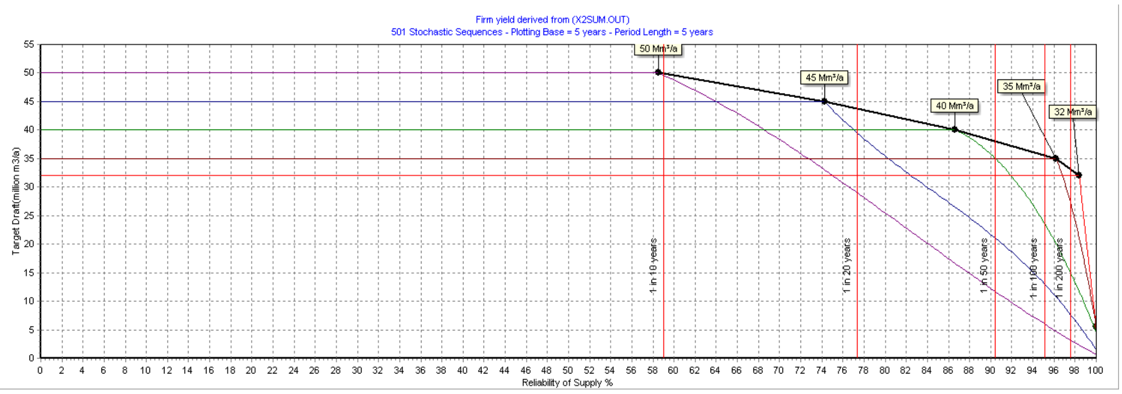
159 Mm³/a
128 Mm³/a
112 Mm³/a
97 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

10%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 1 years
55 Mm³/a
50 Mm³/a
40 Mm³/a
34 Mm³/a
29 Mm³/a
1 in 4 years
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
Target Draft(million m3/a)
Reliability of Supply %

Inyaka Dam

100%



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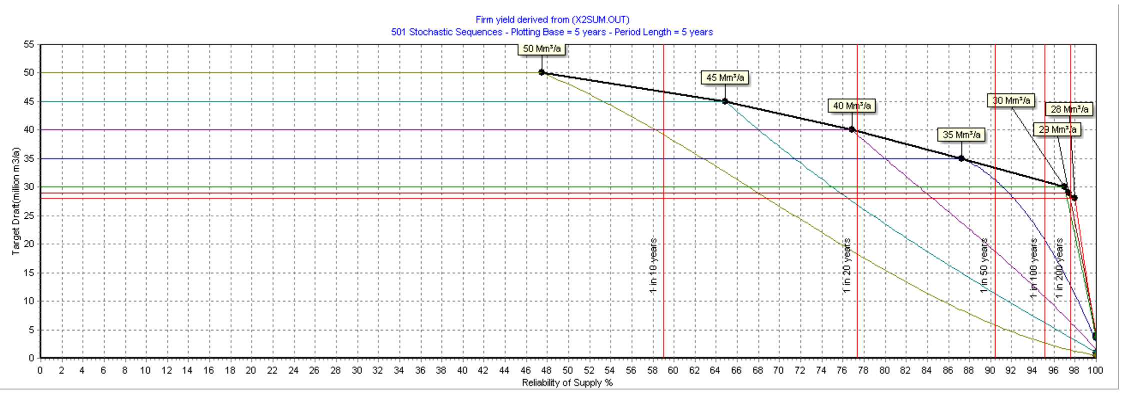
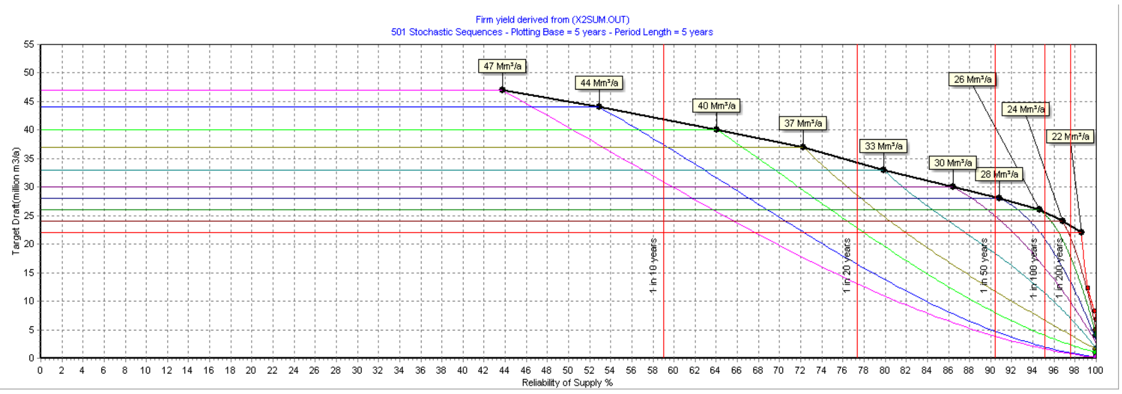
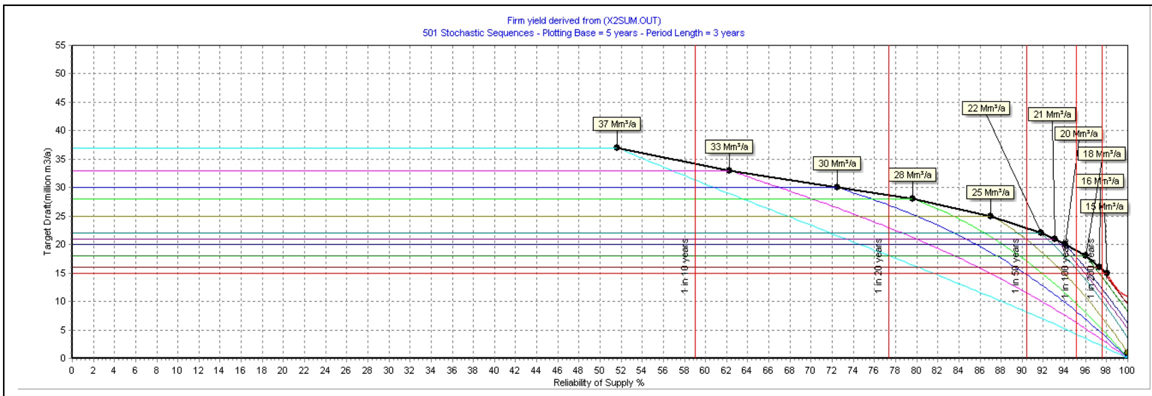


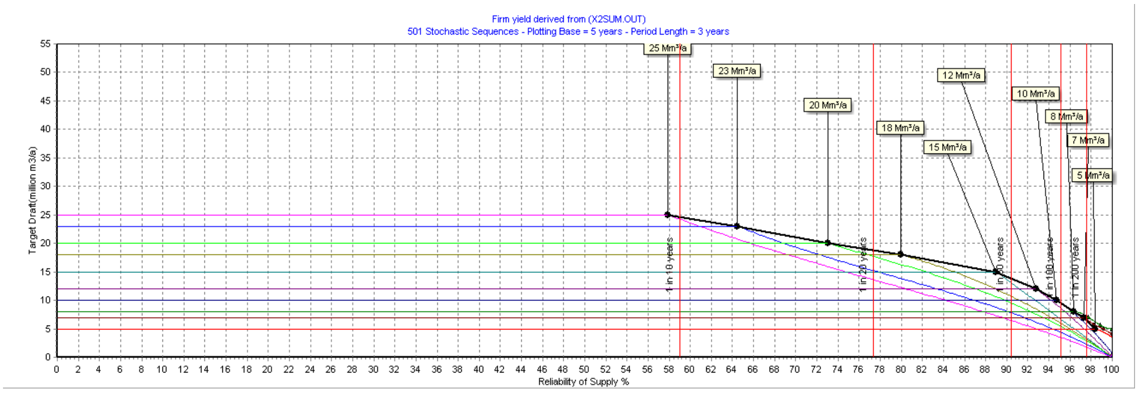
60%



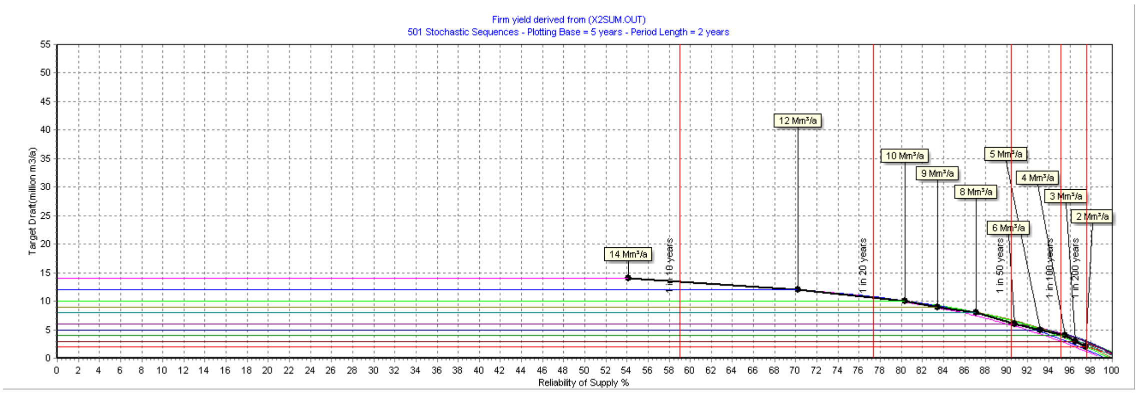
40%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 3 years
Target Draft(million m3/a)
Reliability of Supply %
37 Mm³/a
33 Mm³/a
30 Mm³/a
28 Mm³/a
25 Mm³/a
22 Mm³/a
21 Mm³/a
20 Mm³/a
18 Mm³/a
16 Mm³/a
15 Mm³/a
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

20%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 3 years
Target Draft(million m3/a)
Reliability of Supply %
25 Mm³/a
23 Mm³/a
20 Mm³/a
18 Mm³/a
15 Mm³/a
12 Mm³/a
10 Mm³/a
8 Mm³/a
7 Mm³/a
5 Mm³/a
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

10%


Firm yield derived from (X2SUM.OUT)
501 Stochastic Sequences - Plotting Base = 5 years - Period Length = 2 years
Target Draft(million m3/a)
Reliability of Supply %
14 Mm³/a
12 Mm³/a
10 Mm³/a
9 Mm³/a
8 Mm³/a
6 Mm³/a
5 Mm³/a
4 Mm³/a
3 Mm³/a
2 Mm³/a
1 in 10 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years

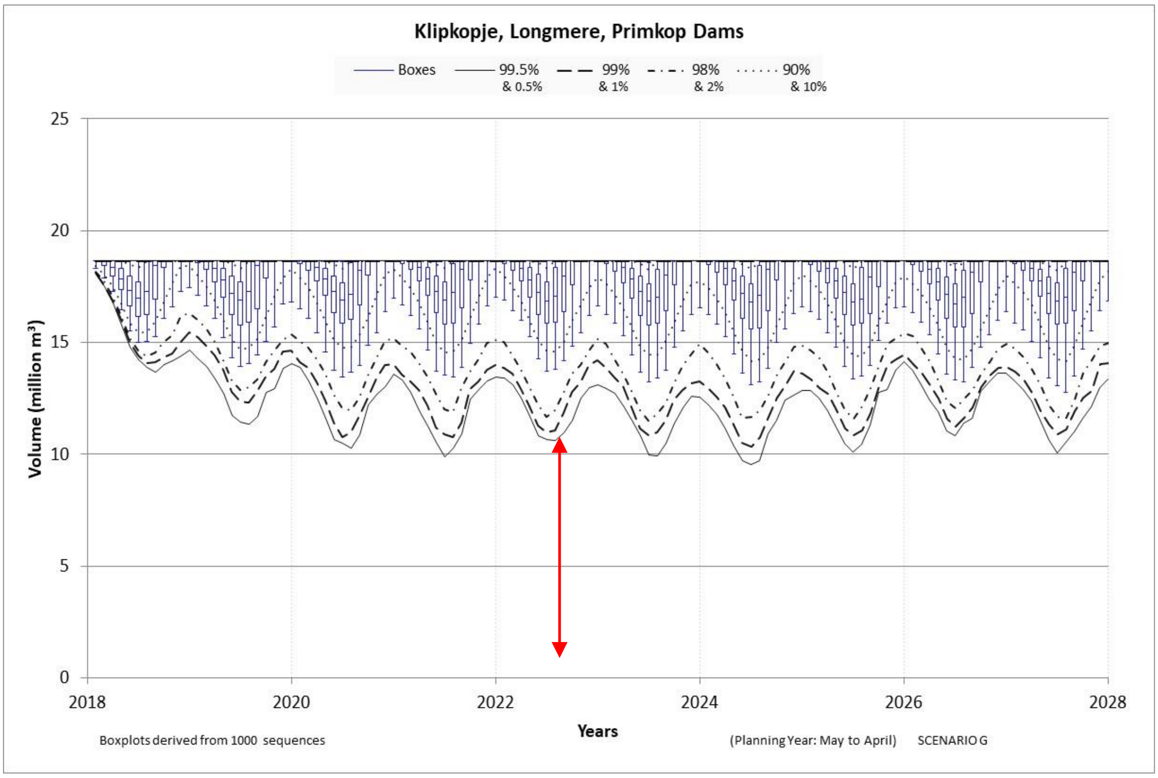
APPENDIX C

INTERPRETING WRPM OUTPUT

Results obtained from the WRPM are often difficult to understand. This Appendix provides a guide to interpreting the boxplot output.

Reservoir Plots

Example of an underused reservoir:



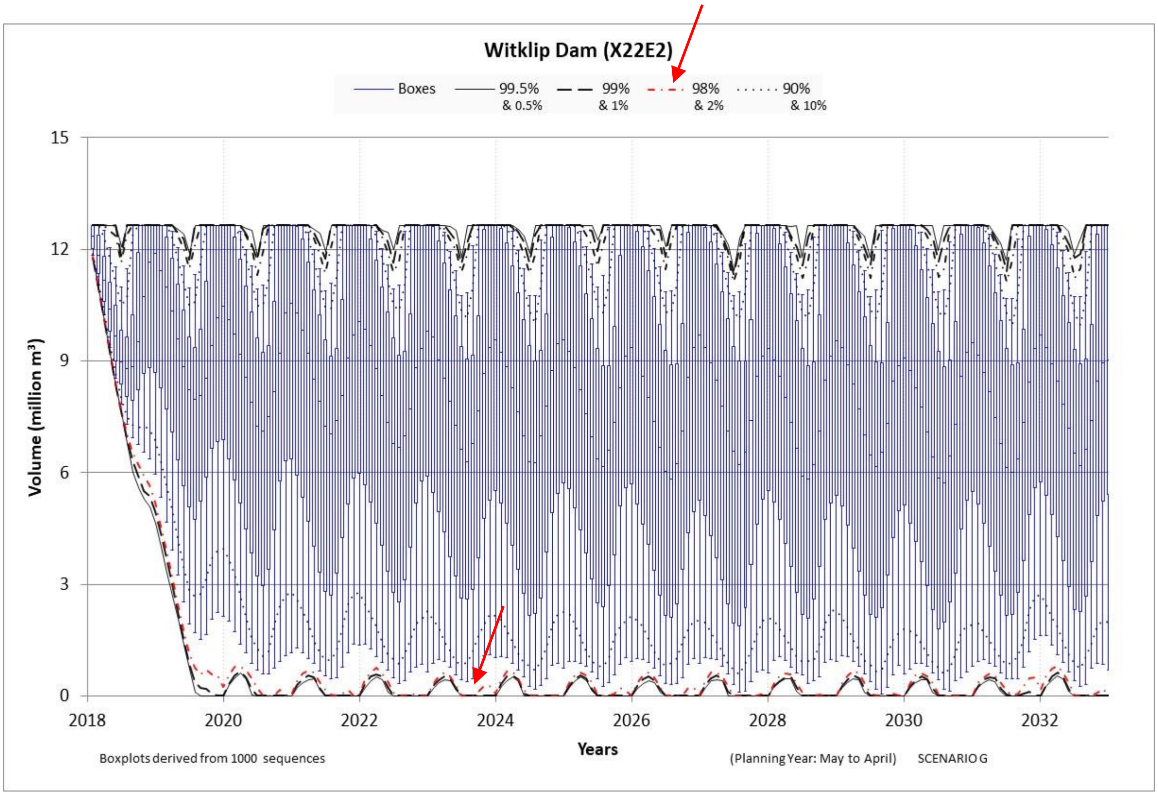
White space between the lowest dam storage and the X-axis indicates the dam is not utilised sufficiently. This could be a result of the following:

- If the demands from the dam are supplied in full, the dam has surplus storage available for other users;
- If the demands from the dam are not supplied in full, the dam has been overprotected by the operating rule and the rule is too strict.

Example of a failing reservoir:

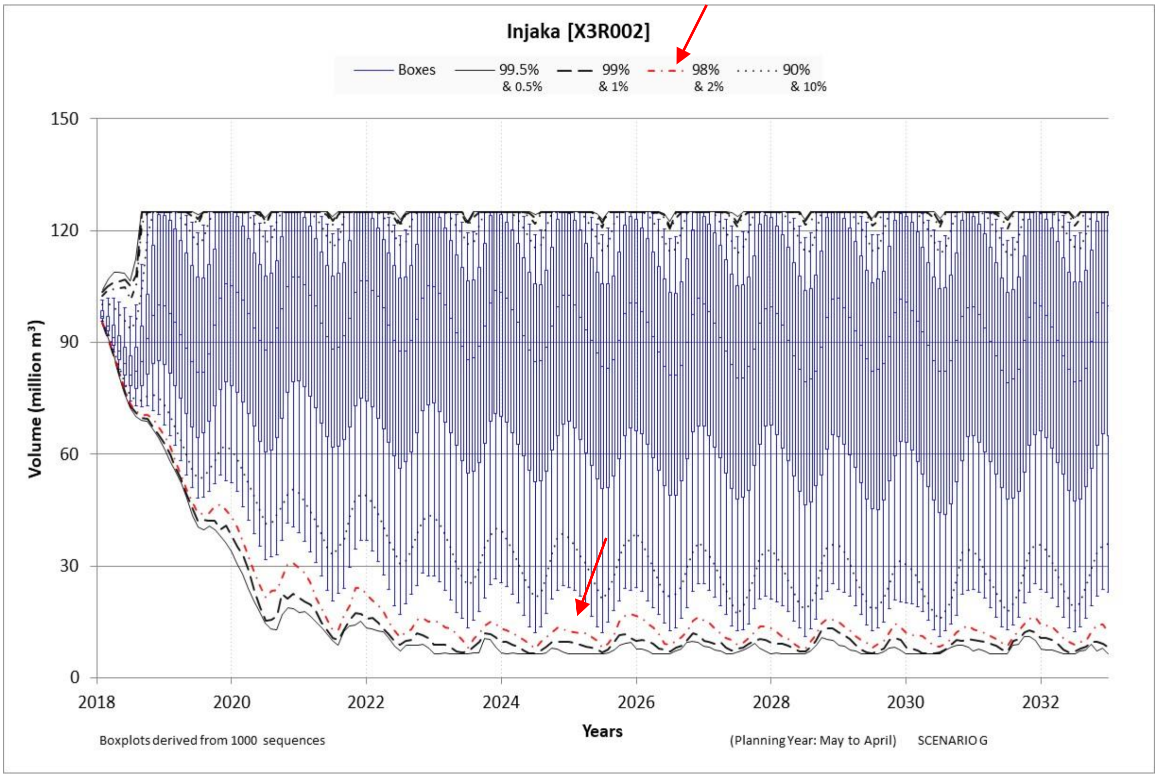
Various criteria can be set to define a reservoir failure depending on the user assurance of supply requirements. Typically, for the domestic sector, the defined criteria is that one would not want to see the reservoir emptying at the 98% assurance level.

Example of failing reservoir



Reservoir is emptying at 98% probability which is unacceptable if the users are urban. If the users are from the irrigation sector the reservoir behavior would still be satisfactory.

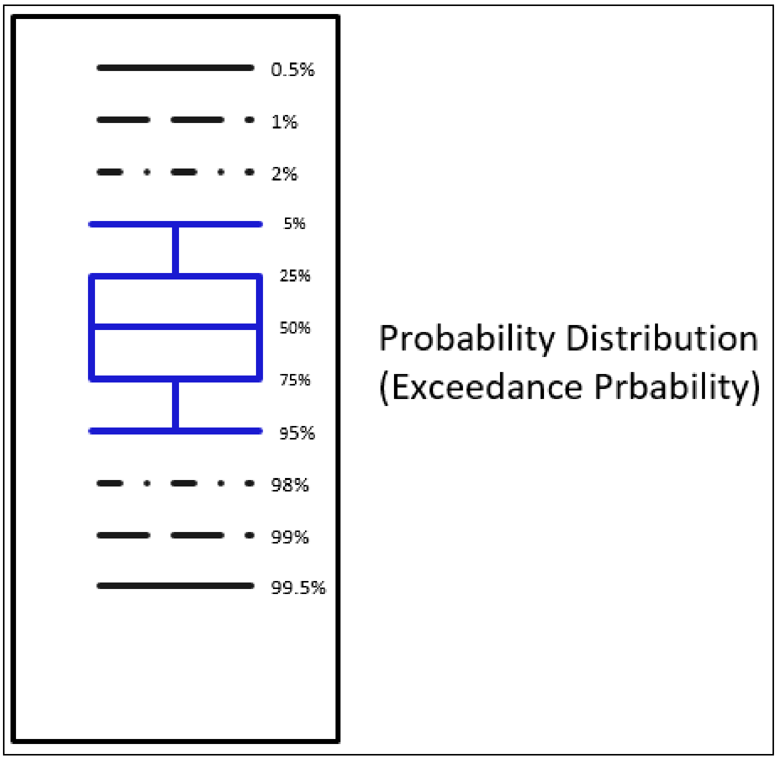
Example of a reservoir adhering to criteria of not emptying at 98% probability



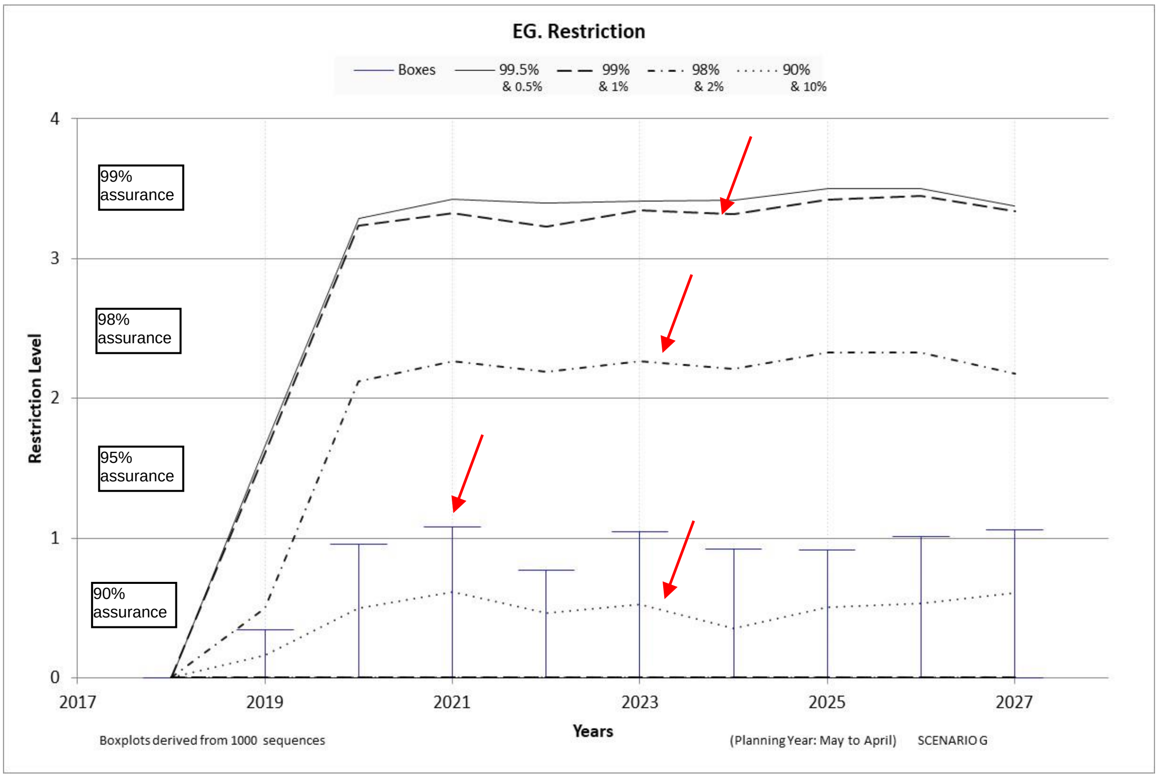
98% line remains just above the empty level throughout simulation period. This means that the restriction rule is protecting the dam at that level.

Restriction plots

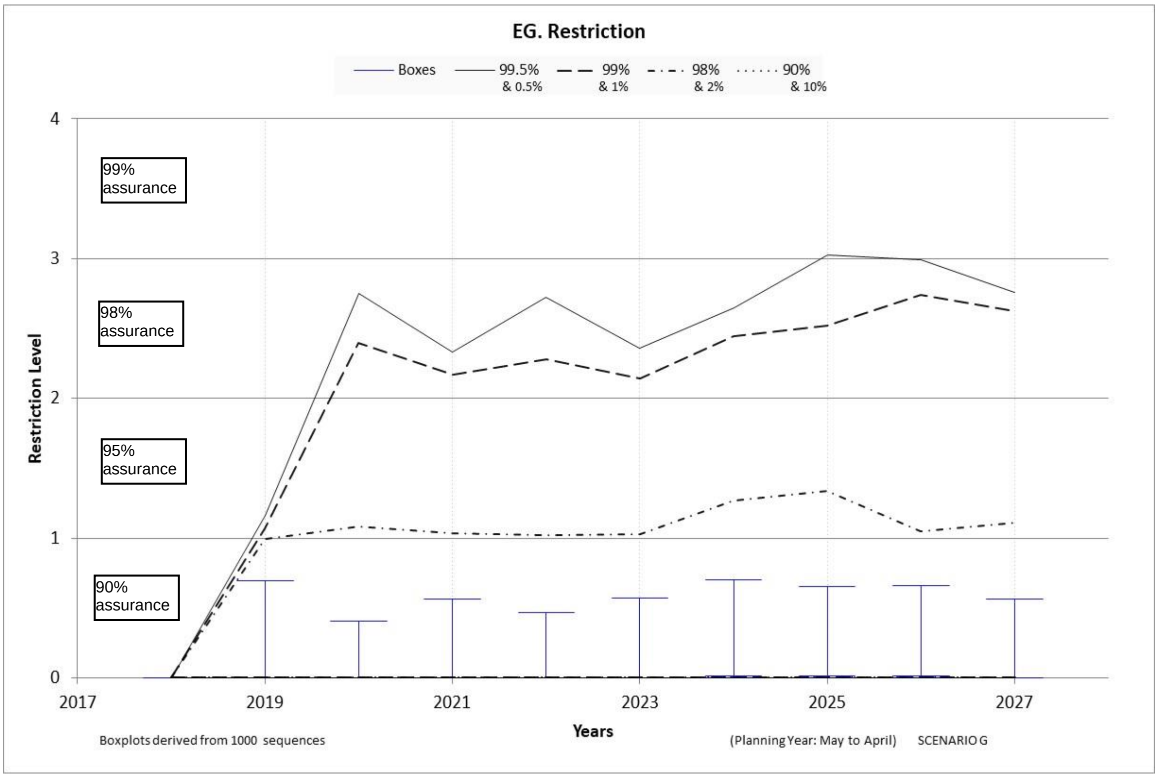
Restriction plots are the main guide to determine whether a not a water resource system is in deficit. The plot shows when users are restricted greater than their satisfactory level of assurance criteria. When this occurs, the risk of non-supply to users is too great, and an intervention is required. Restriction plots vary per system, and it is important to interpret the results based on each specific system's unique requirements. The specific assurance criteria levels should be known. A violation occurs when the specific probability line enters the "zone" level as indicated on the Y-axis that is the same as the line, indicated by the boxplot key.



Example of restriction plot where violations occur at all levels. In this example, level 1 is set at a 1 in 10 year assurance criteria (90%), level 2 is at a 1 in 20 year assurance criteria (95%), level 3 is at a 1 in 50 year assurance criteria (98%) and level 4 is at a 1 in 100 year assurace criteria (99%).



The next plot shows that restrictions have occurred at all levels, however, they are satisfactory as they do not enter the specific zone.



Supply plots

Supply plots are typically assessed for the main users of a system in order to determine the supply to the users for a specific scenario. The plot is interpreted by reading the probability of supply for the various lines. For example, in the following plot, there is a 98% probability that the supply through the Nelspruit WTW will be on average 16.9 million m^3/annum over the projection period.