water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

P WMA 03/A31/00/6110/3

Support to the Implementation and Maintenance of the Reconciliation Strategy of the Crocodile West Water Supply System

WATER RESOURCES PLANNING MODEL ANALYSIS

DECEMBER 2012

W07_2013/J01330_04

Title:	***Water Resources Planning Model Analyses***
Authors:	*JH Schroder* *JD Rossouw*
Project Name:	*Support to the Implementation and Maintenance of the Reconciliation Strategy of the Crocodile West Water Supply System*
DWAF Report No:	*P WMA 03/A31/00/6110/3*
Status of Report:	*Final*
BKS Report No:	*J01330/03*
First Issue:	*November 2012*
Final Issue:	*December 2012*

PROFESSIONAL SERVICE PROVIDER

Approved for the PSP by:

....	....
JD Rossouw (BKS)	*PG van Rooyen (WRP)*
Study Leader	*Deputy Study Leader*

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Directorate: National Water Resource Planning

Approved for the Department of Water Affairs and Forestry:

....	....
JA van Rooyen	*T Nditwani*
Director: NWRP	*Study Manager*

List of study reports and other relevant documents

This Study

REPORT NAME	REPORT NR
Inception Report	P WMA 03/A31/00/6110/1
Water Quality Modelling	P WMA 03/A31/00/6110/2
Water Resources Planning Model Analyses	**P WMA 03/A31/00/6110/3**
Crocodile West River Reconciliation Strategy 2012	P WMA 03/A31/00/6110/4

SUPPORT TO THE IMPLEMENTATION AND MAINTENANCE OF THE RECONCILIATION STRATEGY OF THE CROCODILE WEST WATER SUPPLY SYSTEM

WATER RESOURCES PLANNING MODEL ANALYSES

EXECUTIVE SUMMARY

The Water Resources Planning Model (WRPM) has been configured, tested and used to perform water balances and scenario analyses for the Crocodile West River catchment. The ability to simulate water quality (salinity) has been added.

Water balances were revised and calculated every six months with the WRPM. The results were presented to the Strategy Steering committee, and used to assist with the updating of the Reconciliation strategy and to keep it relevant. To revise the water balance, water requirement projections were updated based on actual water supply figures, where available. This included water requirements both inside the catchment, as well as the proposed transfer of water to the Lephalale area. Water requirements for the Lephalale area for coal fired power generation and mining developments have fluctuated significantly over the past three years. This is due to economic conditions as well as state policy on power development, in particular the transition to more renewable generation sources. However, the uncertainty and associated large range in possible water requirement projections for the area has reduced for the short to medium term, and currently two development scenarios are currently considered which take into account both the need to transition away from coal fired power, as well as the practical realities of meeting growth in power requirements.

The WRPM has been updated in a phased manner as new information became available, and as refinements to the system configuration were incorporated, which included the phased addition of water quality (salinity) modeling. The water balance was thus updated accordingly. The phased water balances calculated, have shown a surplus volume of water available in the catchment, available primarily in the upstream dams in the catchment that receive the majority of the return flows. This surplus volume is however not unlimited and depending on the water requirement projection scenario considered for Lephalale, was either greater than the transfer volume needed, or too little. The most recent water balance indicated that the surplus volume of water in the Crocodile River catchment would be insufficient to meet all the growth in water requirements in the Lephalale area. The shortfall projected is, however, small, and only temporary in nature.

The water balance needs to continue to be updated to reflect changes in the volume or timing of water requirement growth. In particular mining and domestic water requirements projections need to be updated to accommodate the current socio-economic environment. The ability to simulate water quality (salinity) will also allow the possible build up of salts associated with re-use of effluent to be investigated.

SUPPORT TO THE IMPLEMENTATION AND MAINTENANCE OF THE RECONCILIATION STRATEGY OF THE CROCODILE WEST WATER SUPPLY SYSTEM

WATER RESOURCES PLANNING MODEL ANALYSES

TABLE OF CONTENTS

Page

APPENDICES

<u>List of Tables</u>

<u>List of Figures</u>

List of Acronyms and Abbreviations

CWMS	Crocodile West Modelling Study
DWA	Department of Water Affairs
EWR	Ecological Water Requirements
LM	Local Municipality
MM	Metro Municipality
RWQOs	Resource Water Quality Objectives
SIPs	Strategically Import Projects
SSC	Strategy Steering Committee
WC/WDM	Water conservation and water demand management
WQT	Water Quality Model
WRPM	Water Resources Planning Model

1. INTRODUCTION

1.1 DESCRIPTION OF STUDY AREA

The study area covers the Crocodile West River catchment, which forms the major part of the Crocodile West and Marico Water Management Area, but excludes the Marico River catchment. It extends northwards from the Witwatersrand catchment divide in central Johannesburg (where the Crocodile River originates), to the confluence of the Crocodile and Marico rivers. The catchment area includes part of the Gauteng, North West and Limpopo Provinces.

From the confluence of the Crocodile and Marico rivers, the river is known as the Limpopo River, which forms the northern border of South Africa with Botswana and then with Zimbabwe, before flowing into Mozambique where it discharges into the Indian Ocean. The Limpopo River basin thus is an international basin, shared by South Africa, Botswana, Zimbabwe and Mozambique. The total catchment area is approximately 29 000 km^2. A locality map is included as **Figure 1**.

1.2 BACKGROUND AND PURPOSE OF THE STUDY

The Reconciliation Strategy for the Crocodile West Water Supply System was developed and published in 2008 by the Department of Water Affairs (DWA) to ensure sufficient water can be made available to supply the current and future water requirements of the urban, industrial, mining and irrigations users in the system The Strategy primarily focused on the quantitative reconciliation of the water requirements with the available resources and also considering water quality where it impacts on the water balance.

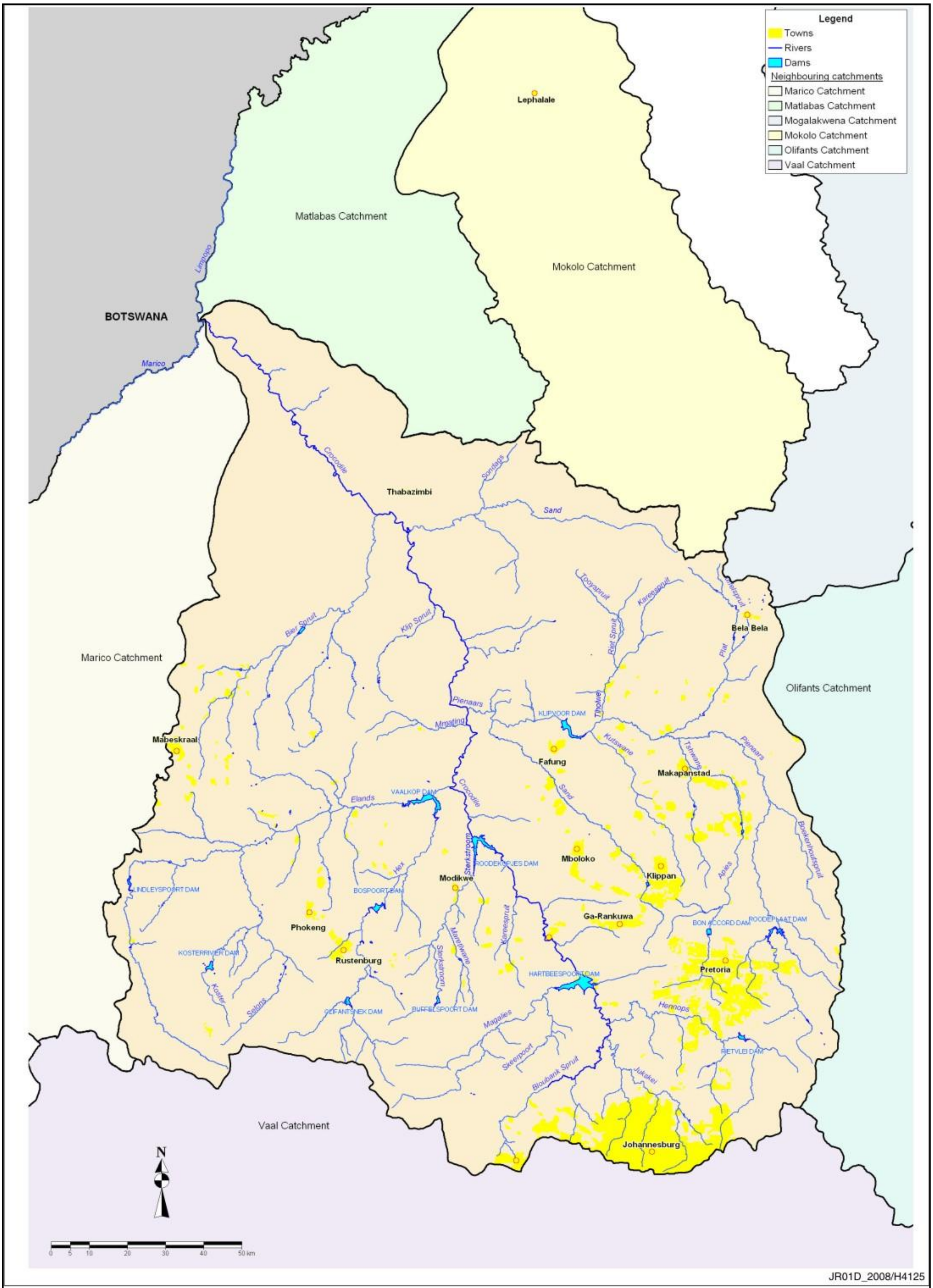
DWA recognized that the successful implementation of the strategy require continuous monitoring, review and revision to ensure its relevance in a changing environment where both short term economic swings and evolving long term development planning has to be accommodated.

This study, *Support to the Implementation and Maintenance of the Reconciliation Strategy of the Crocodile West Water Supply System*, therefore, provides the administrative, technical and organisational support for DWA and the collaborating institutions represented on the Strategy Steering Committee.

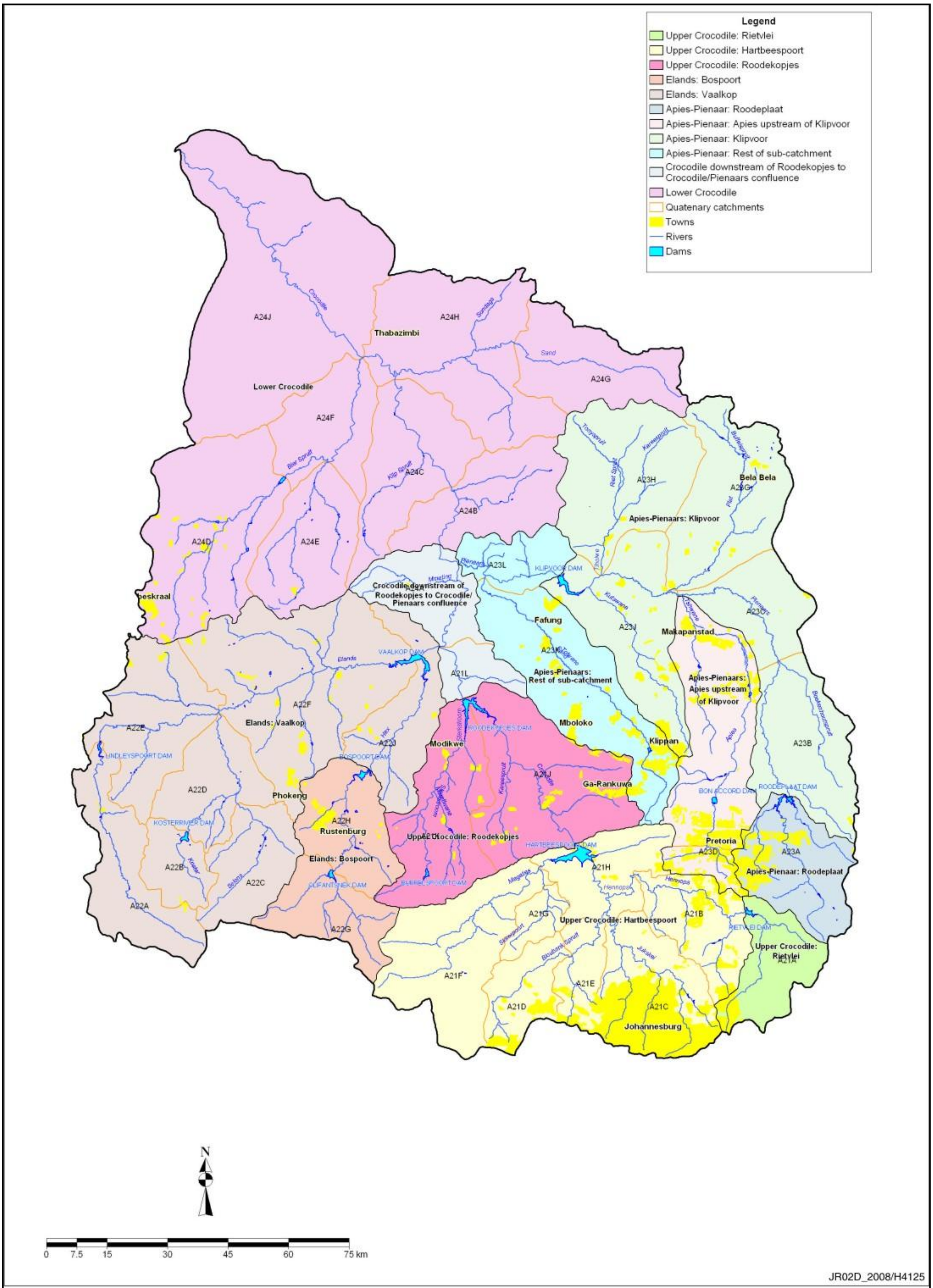
Water balances were determined for the period 2005 to 2030 at 5-year intervals to facilitate the development of a robust strategy that would be stable over time. These were done for each of eleven representative sub-areas, as presented in **Figure 2**. A detailed definition of the sub-areas is given in **Appendix A**.

1.3 PURPOSE OF THIS REPORT

The purpose of this report is to summarise the work undertaken by the Water Resources Planning Model.



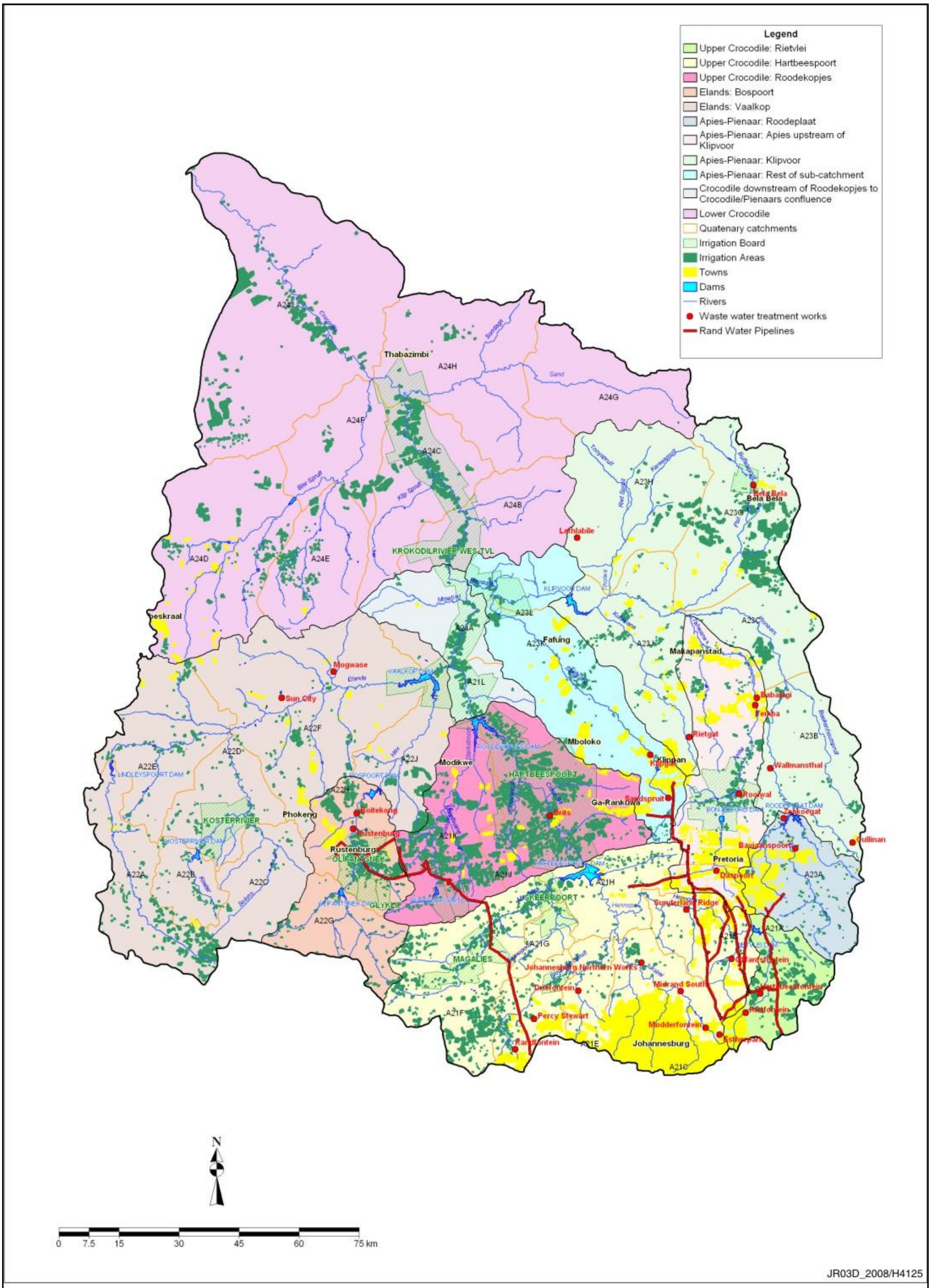
CROCODILE (WEST) RECONCILIATION STUDY **Locality Map** **FIG 1**



CROCODILE (WEST) RECONCILIATION STUDY

Map with sub-catchments split into sub-areas

FIG 2



CROCODILE (WEST) RECONCILIATION STUDY

Map with irrigation boards and areas, Rand Water pipeline and the waste water treatment works

FIG 3

2. SETTING UP, CALIBRATION AND TESTING OF THE WRPM

2.1 WORK CONDUCTED PREVIOUSLY

2.1.1 Crocodile West Modelling Study (CWMS)

The Water Resources Yield Model (WRYM) was configured and used to analyse the Crocodile West River System as part of the Crocodile West Modelling Study (DWAF, 2009). More information on the WRYM configuration as well as the yield analyses including short-term curves developed for the Water Resources Planning Model (WRPM) is available in the WRYM Analyses Report (DWAF report no. P WMA 03/000/00/2708).

2.1.2 Crocodile West Reconciliation Strategy (CWRS)

Building on the work conducted as part of the CWMS, the Water Resources Planning Model (WRPM) configuration was initiated as part of *The Development of a Reconciliation Strategy for the Crocodile West Water Supply System*. The population of the WRPM data files was completed up to the point of model testing. Some difficulties were experienced at the time, as some of the functionality of new features had not yet been finalised in the WRPM. This included the new F17.dat type irrigation blocks not being able to be included in the allocation procedure. Some errors in the allocation procedure itself also needed to be resolved. This was discussed with the model developers. However at the time of the Reconciliation Strategy study contract coming to and end, a solution to the WRPM error had not yet been found. The completion of the WRPM testing was thus left to the next phase of the Reconciliation Strategy. Recommendations were made for completion of the WRPM testing. These recommendations together with a write up of the work conducted in configuring the WRPM data files is summarised in the WRPM Analyses Report (DWAF, 2009), Report no. P WMA 03/000/00/3708.

2.2 COMPLETION OF THE SETTING UP OF THE WRPM

Once this study, *Support to the Implementation and Maintenance of the Reconciliation Strategy of the Crocodile West Water Supply System* commenced, the error in the code of the WRPM allocation procedure had been resolved by the model developers. The WRPM configuration testing could thus be finalised, and scenarios analysed using the WRPM.

2.3 TESTING OF THE WRPM

Due to the size of the Crocodile West River System and the level of detail at which the system was configured and simulated (sub-quaternary catchments), a rigorous testing and error solving process was conducted. Testing included scenario analyses with the WRYM and WRPM to confirm similar results, and to test the allocation procedure of the WRPM.

Once the system was tested and running and the allocation procedure confirmed to be operational, the following phased process was adopted to perform the scenario analyses, update the water balance, and improve on the functionality of the model configuration.

3. PHASED APPROACH WITH THE WRPM

3.1 RATIONALE

As the WRPM configuration that was tested utilised the WRYM data files with 2003 development level information as a starting point, the catchment development level information and the water requirements and needed to be updated in the WRPM. Further to this, the F17.DAT input data file containing irrigation functionality of the WRPM needed to be updated. Although the irrigation could be included in the WRPM, the irrigation requirements included in the F17.DAT data file could not be curtailed as part of the allocation procedure. As irrigation is a major water use in the catchment, this was required to be resolved.

The phased approach was adopted for two reasons:

1. To change one variable/dataset at a time so that any changes in results could be understood and assigned to an influencing factor. This is an important quality control mechanism for a complex catchment such as the Crocodile West River system.
2. To update the WRPM and determine the water balance for each Strategy Steering Committee meeting. As the changes and update of the WRPM and information included therein took time to gather and include, the water balances were determined in phases as the WRPM was being refined and updated over time.

3.2 WATER REQUIREMENT UPDATES

3.2.1 Assurance of supply criteria

The different water user categories and associated assurance of supply criteria adopted for the Crocodile West River catchment is presented in **Table 2.1**.

Table 2.1 Assurance of supply criteria and user priority classification for water supply in the Crocodile

User Sectors	User priority classification (assurance of supply)		
	Low (90 %)	Medium (99 %)	High (99.5 %)
	Proportion of water demand supplied (%)		
Domestic	20	30	50
Industry, Mining, Power	0	30	70
Irrigation *	100	0	0
Restriction levels:	**1**	**2**	**3**

The assurance of supply of irrigation was set at 90% (1:10 years failure), which corresponds with the 70/30 rule for irrigation.

3.2.2 Urban and domestic water requirements

During the Reconciliation Strategy Study by the DWA, a number of water requirement scenarios were developed. The strategy adopted the high water requirement scenario with medium water conservation and water demand management (WC/WDM) savings as the preferred planning scenario. The medium WC/WDM scenario assumed a 15% saving in water requirements achieved over 5 years for the large metro's (Johannesburg and Tshwane), as per the Vaal Reconciliation Strategy. Similar WC/WDM savings were also assumed for the other municipalities in the Crocodile West River Catchment.

As part of this study, *Support to the Implementation and Maintenance of the Reconciliation Strategy of the Crocodile West Water Supply System,* domestic water requirement projections were updated by obtaining recent actual water supply/treated figures from the municipalities and Magalies Water. The water requirement projections were updated by using the current volumes as the base point, and adjusting the projections up or down accordingly.

Further to this information obtained directly from the municipalities and Magalies Water, information contained in other recent study reports was sourced. This included the *The Development of a Reconciliation Strategy for All Towns in the Northern Region*, as well as the *Consolidation of Feasibility studies in the Bojanala Platinum District Municipality Study*. Data was updated in the WRPM as it was obtained.

The domestic water requirement projections that were included in the WRPM for the final water balance as part of this study are shown per municipality in **Table 2.2**.

The disaggregating of urban water requirements at a municipal level into modelling units is discussed further in **Section 3.4**.

One of the adjustments that were made based on discussions with the City of Tshwane was an increase in the water requirements for the Hammanskraal area that drains to Temba and Babalegi waste water treatment works (WwTW). This increase was due to a planned increase in the level of water services and is to be catered for by the recent license approval for an increased water abstraction from 60 to 120 Mℓ /d at the Temba water treatment works (WTW). The uptake in utilisation of the new license and WTW capacity is assumed to take 5 years.

As can bee seen in **Table 2.2**, some domestic water requirements have been included for areas north and outside of the Crocodile West River catchment in the Limpopo Water Management Area. This includes Modimolle and Mookgopong. The local water resources in these areas are insufficient, and additional grow in water requirements beyond 2010 levels have been assumed to be met by a transfer from the Crocodile West River catchment (by expanding the pipeline to Bela-Bela). No mining water requirements in this area north of the Crocodile West River catchment have been catered for.

Table 2.2 Domestic water requirements included in the water balances for Version 2 of the Reconciliation Strategy

Municipality	Domestic water requirements per municipality (million m^3/a)						
	2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Areas within the Crocodile West River catchment							
Bela-Bela LM	2.9	2.9	3.3	3.6	4.0	4.3	4.5
City of Johannesburg MM	205.6	188.2	204.9	216.4	235.7	247.7	260.3
City of Tshwane MM	269.3	287.7	314.0	343.6	375.6	395.3	416.1
Ekurhuleni MM	84.3	89.7	97.6	103.3	112.4	118.2	124.2
Kgetlengrivier LM	1.3	1.4	1.6	1.7	1.9	2.0	2.2
LM of Madibeng	18.5	18.5	18.5	18.5	18.5	18.6	18.6
Mogale City LM	13.5	14.0	15.6	16.9	18.7	19.7	20.7
Moretele LM	4.4	4.6	4.8	5.1	5.4	5.6	5.8
Moses Kotane LM	11.4	10.0	10.9	11.9	12.8	13.6	14.3
Nokeng tsa Taemane LM	5.3	5.5	5.6	5.8	6.0	6.1	6.2
Randfontein LM	9.2	9.7	10.7	11.3	12.4	13.0	13.7
Rustenburg LM	40.5	39.5	47.4	52.6	54.4	56.3	58.3
Thabazimbi LM	4.6	4.6	4.6	4.7	4.7	4.8	4.8
Areas outside the catchment							
Modimolle LM	1.3	2.4	3.4	4.5	5.5	5.6	5.7
Mookgopong LM	0.8	1.2	1.7	2.1	2.5	2.9	3.3
Total	**673.0**	**679.9**	**744.7**	**801.9**	**870.5**	**913.5**	**958.6**

3.2.3 Mining water requirements

Detailed mining water requirements were obtained from the Rustenburg Joint Water Forum in 2007, along with projected growth in water requirements for the mining sector. An update of these mining water requirements has been requested, but not yet received. The existing available mining water requirement projection was updated where possible, through discussions with Magalies Water. Based on the information provided by Magalies Water on supply to the mining industry, the economic downturn in 2009/2010 and the uncertainty in the mining sector in general, a lag of 5 years was added to the growth projected in 2007. By applying this lag of 5 years, the projected water requirements for 2010 approximately equalled the current 2010/2011 supply volumes as per Magalies Water. The revised mining water requirements are summarised in ***Table 2.3***.

Table 2.3 Mining water requirements included in Version 2 of the Reconciliation Strategy

Source	Mining water requirements (million m^3/a)						
	2010	2015	2020	2025	2030	2035	2040
Supply from Hartbeespoort Dam	18.38	24.9	29.3	30.0	29.7	29.8	29.8
Supply from Vaalkop Dam	34.61	50.7	61.6	62.5	63.8	63.8	63.4

3.2.4 Industrial and power generation water requirements

The current major industrial and power generation water requirements in the Crocodile West River catchment are shown in **Table 2.4**. No growth in these water requirements is expected and was included as such in version 2 of the reconciliation strategy.

Table 2.4 Industry and power generation water requirements

Industry	Source of Water	Water requirement 2012	
		million m^3/a	*Mℓ /d*
Kelvin Power Station	Rand Water & Northern WWTW	10.9 (Northern WwTW)	30.0
Pretoria West Power Station	Tshwane and Daspoort WWTW	5.9 (Daspoort WwTW)	16.0
Rooiwal Power Station	Tshwane and Rooiwal WWTW	17.6 (Rooiwal WwTW)	48.0
NECSA (Pelindaba)	Crocodile River	0.9	2.3
AECI	Rand Water	5	13.7

3.2.5 Irrigation water requirements

No growth of irrigation water requirements was included in Version 2 of the Reconciliation Strategy. The current water requirements were assumed to be at the same level as that determined in the *CWMS Study* Irrigation Assessment Report (Report P WMA 03/000/00/2208. Irrigation is widespread through the catchment. The large water requirements in the irrigation board areas, which form the bulk of the irrigation water requirements, are summarised in **Table *2.5***.

Table 2.5 Major irrigation water requirements in the Crocodile West River catchment

Scheme	Source	Area (km^2)	Requirements (million m^3/a)
Hartbeespoort GWS	Hartbeespoort Dam (canal)	132.0	81.8
Hartbeespoort GWS	Hartbeespoort Dam (old furrows)	16.2	10.0
Hartbeespoort GWS	**Total**	**148.2**	**91.8**
Crocodile West IB	From Roodekopjes Dam	40.2	32.2
Crocodile West IB	From Vaalkop Dam	3.0	2.4
Crocodile West IB	From Klipvoor Dam	70.8	56.6
Crocodile West IB	Boreholes within redline	33.9	27.1
Crocodile West IB	**Total**	**147.9**	**118.4**
Lindleyspoort GWS	Lindleyspoort Dam	15.81	4.8
Koster River IB	Kosterrivier Dam	5.42	1.0
Olifantsnek IB	Olifantsnek Dam	16.61	2.6
Pienaars River GWS	Roodeplaat Dam	7.5	5.5
Warmbad IB	Bischoffs & Warmbaths dams	2.31	1.8
Bon Accord IB	Bon Accord Dam	10.35	11.7

Irrigation water requirements were included in the WRYM as Type 2 irrigation blocks, defined in the F17.DAT file. As mentioned the F17.DAT irrigation blocks can be included and run in the newer versions of the WRPM, but without these irrigation requirements being curtailed. To determine an accurate water balance taking into account the correct assurance of supply for irrigation supplied from the major dams in the catchment, the water requirements needed to be able to be curtailed through inclusion in the allocation procedure. This is usually done through the inclusion of irrigation water requirements as WQT irrigation blocks. As the water quality (salinity) model (WQT) configuration and testing still had to be completed during the study, a different mechanism was needed to be able to model and curtail the irrigation water requirements until the WQT model calibration was completed. To do this, irrigation water requirements placed on the major dams were included as min-max channels with an annual demand equal to the annual average of the variable irrigation block requirements. The seasonal variation in requirements due to crop factors and climate was also built into the min-max channel feature. The first water balance calculated with the WRPM utilised the simplified irrigation requirements that captured the seasonal distribution of the water requirements, but not the climatic variation between years, (i.e. taking rainfall variability into account).

Once the WQT model configuration and calibration was completed, the water quality component of the WRPM could be added, which included changing all irrigation min-max channels to be modelled with the WQT irrigation blocks.

3.2.6 Ecological Water Requirements

The impact of ecological water requirements (EWR) on yield was assessed as part of the *Yield Analyses* Report of the *CWMS*. The overall finding was that the effect of the EWRs on yield is small due to the high volumes of return flows in the catchment. If a significant transfer to Lephalale were to take place in the future, the water would most likely only be abstracted low down in the catchment. As such, EWRs were excluded for the system. Once final classes for the reserve are set during the classification process, the final EWRs can be included in the future.

3.3 WATER AVAILABILITY

3.3.1 Large Dams

There are a number of large dams in the catchment that supply water to the various water users. The yields of these large dams are covered in detail in the *WRYM Analyses Report* of the *CWMS*.

3.3.2 Transfers into the catchment

A significant portion of the urban water supply to the large Metros in the southern part of the catchment is transferred into the catchment by Rand Water. This supply includes the City of Johannesburg MM, the City of Tshwane MM, Rustenburg, Ekurhuleni LM, Mogale City LM, Randfontein LM, and Kungwini LM. The current volume is in the order of 520 million m^3/a. The projected volume of water transferred into the catchment depends on the total growth of domestic water requirements, and how much of this supply is met from local sources, and how much is to be met by Rand Water. The assumed spilt in supply between local sources and water transferred in from the Vaal (Rand Water) is discussed further in **Section 3.5**. The projected transfer in from the Vaal for domestic supply is shown in **Table 2.6**.

Table 2.6: Projected water future transfer voilumes into the Crocodile West River catchment from the Vaal by Rand Water for domestic water supply

	Projected transfers into the Crocodile (million m3/a)						
	2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Rand Water Supply	523	524	577	624	686	725	765

3.3.3 Return flows

Return flows make up a significant portion of the available water in the catchment. Projected Return flow volumes in the catchment based on the revised domestic water requirements are presented in **Table 2.7**.

Table 2.7: Volume of effluent returned to the Crocodile West River from WWTWs

	Volume returned to River System (million m^3/a)						
	2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Return flows	313	321	352	376	408	428	449

3.4 ADDING WATER QUALITY – SALINITY

The configuration and calibration of the WQT (salinity) model for the Crocodile West River catchment was described in detail in the *Task 2: WQT Model Calibration* Report. The WQT suite of data files, calibration parameters, as well as end condition values were adopted to add water quality (salinity) to the WRPM.

In adding the WQT data files to the WRPM, a number of steps were needed. The main steps included:

- Updating node, channel and reservoir numbering in the WQT data files to match the WRPM data files.
- Updating the WQT data files to include the end storage/concentration values from the WQT calibration (these then form the starting values for the WRPM simulations).
- Adding all WQT irrigation block abstraction and return flow channels as demand (master control) channels in the F01.DAT WRPM input file.
- Adding additional variables to the WQT data files required when running the water quality (salinity) sub-model in the WRPM.

Apart from the generic data files updates that were needed to add water quality (salinity) data into the WRPM, a number of smaller scenario and catchment specific updates were required. This included:

- The addition of dolomitic compartments (underground reservoirs) required to calibrate the WQT model in the Upper Crocodile River sub-catchment.
- The splitting of demand centres between different water sources (more on that in **Section 3.4**).
- The inclusion of the sand aquifer functionality (in the F04.DAT input data file) within the water quality (salinity) model of the WRPM.

The inclusion of the sand aquifer required some WRPM code changes as the water quality component of the WRPM had not previously been used with a sand aquifer included in the WRPM. This did result in some further delays as the model developers needed to be requested and approved to incorporate the necessary changes and updates.

3.5 URBAN DEMAND CENTRES AND RETURN FLOWS

As return flows are a very large and important component of the water resource in the Crocodile West River catchment, attention needs to be given to the simulation of return flows when conducting water balances. During the configuration of the WRYM as part of the *CWMS*, a detailed exercise was conducted to calibrate the consumptive use and return flows of urban demand centres based on actual recorded figures. This process and the results thereof are covered in the WRYM report of the CWMS. The relationship between consumptive use and return flows is based on the consumptive use characteristics of the particular water users in the demand centre and climactic parameters. For the purposes of the Crocodile West River catchment, urban demand centres were set up based on drainage regions for ease of calibration, i.e. one demand centre per one wastewater treatment works.

The calibration parameters and required climate data were included in the WRYM through the urban demand centre module, and in the WRPM in the return flow relationship data file (RET.DAT).

One of the challenges in defining the urban demand centres was that the water requirements information at municipal level as per **Table *2.2***, and the drainage basin catchments did not match. Furthermore often water supply in some of the drainage areas was from more than one source. This required some assumptions:

- The urban requirements at a municipal level had to be split into urban demand centre (drainage basin) level.
- A second split of the water requirements into supply from different water sources within each urban demand centre was needed.

This process is also described in the WRYM report of the CWMS, and was done at the then current development level. However, once included in the dynamic WRPM with growth over time, the assumptions of the urban demand centres needed to be revisited due to:

- The growth in water requirements and return flows over time.
- The curtailment of water supply of users linked to the large dams is possible in the WRPM through the short-term allocation procedure, but not the supply from smaller dams and from other sources, such as direct run-of-river abstractions and supply from groundwater.

As the detailed exercise to review spatial growth plans and associated growth in water requirements in the municipalities has not yet been conducted at a catchment level, the growth in water requirements was assumed to be evenly distributed within each municipality, i.e. the split in total municipal requirements between demand centres was kept the same. This assumption, particularly in Tshwane, needs to be revised in future as the location of the growth within the municipality affects the associated return flows and therefore changes the availability of water within the catchment. Once more information is obtained the growth of water requirements and return flows of individual urban demand centres can be refined.

To address the fact that supply from some sources can be curtailed in the WRPM allocation procedure and some cannot, the demand centres were further split. Water supply to urban users from the large dams with associated short-term curves, were included as separate urban demand centres, with the same return flow characteristics as the original demand centre being supplied from multiple water sources. Supply from all other water sources that are not included in the allocation procedure where lumped in a second urban demand centre. The end result was 31 urban demand centres as included in the WRPM schematic **Figure A.1** in **Appendix A**. As a reference the location of the WwTW return flows and other key aspects of the system are shown in the simplified schematic system layout included as **Figure A.2** in **Appendix A**.

The growth of the split urban demand centres was assumed to be as follows:

- For urban demand centres with only one water supply source, all growth was assumed to be met by that resource. Infrastructure, such as water treatment works, would be upgraded as needed.
- For urban demand centres with water supply from multiple sources, growth in supply needed to be assigned to either one or all water sources. In this case, water supply growth in Rustenburg was allocated to the local water resource (Vaalkop Dam) as the Rand Water pipeline is at capacity and assumed not to be expanded in capacity in future. The growth in water supply in Tshwane was allocated to the local water resources (Roodeplaat and Leeukraal dams) up to the capacity of the current water licences. Thereafter water supply growth is to be met by Rand Water (supplied from the Vaal River system).

3.6 CROCODILE WEST RIVER CATCHMENT BASE SCENARIO

The base scenario for the Crocodile West River catchment, also known as the preferred planning scenario, was taken to be the high water requirement projection scenario with water conservation and water demand management (WC/WDM) measures implemented. These are the water requirement projections shown in **Section 3.2**, and in particular, **Table 2.2**. The expected savings of the WC/WDM measures is a 15% reduction in water requirement. The WRPM input data files, including water quality for the Base Scenario, are included in **Appendix B**.

Apart from the Base Scenario, some additional water use scenarios within the Crocodile West River catchment were also tested in the WRPM, and are discussed in **Section 4**.

3.7 LEPHALALE AREA WATER REQUIREMENTS

In the Reconciliation Strategy, surplus water in the Crocodile West River system is earmarked for supply to meet power generating and mining activities requirements in the Lephalale area. This transfer of water is also investigated in the Mokolo-Crocodile Water Augmentation Project, Phase 2 (MCWAP-2).

Water requirement projections for the Lephalale area have fluctuated significantly over the period of the *Maintenance and support to the Implementation of the Crocodile West Reconciliation Strategy*. A number of Lephalale water requirement scenarios have been formulated by the DWA and various role players in an attempt to capture the dynamic factors affecting mining and power production in the country. One of the biggest influencing factors on water requirements in the Lephalale area was the Integrated Development Plan (IDP) which requires the replacement of coal-fired power stations in the medium term with supply from renewable energy. This resulted in a reduction in the number of future coal-fired power stations in the Lephalale area and an associated reduction in projected future water requirements. Sasol's planned Mafuta developments have also been put on hold due to global economics. As such, water requirements reduced significantly from previous projections. This is shown in **Figure 2-1**.

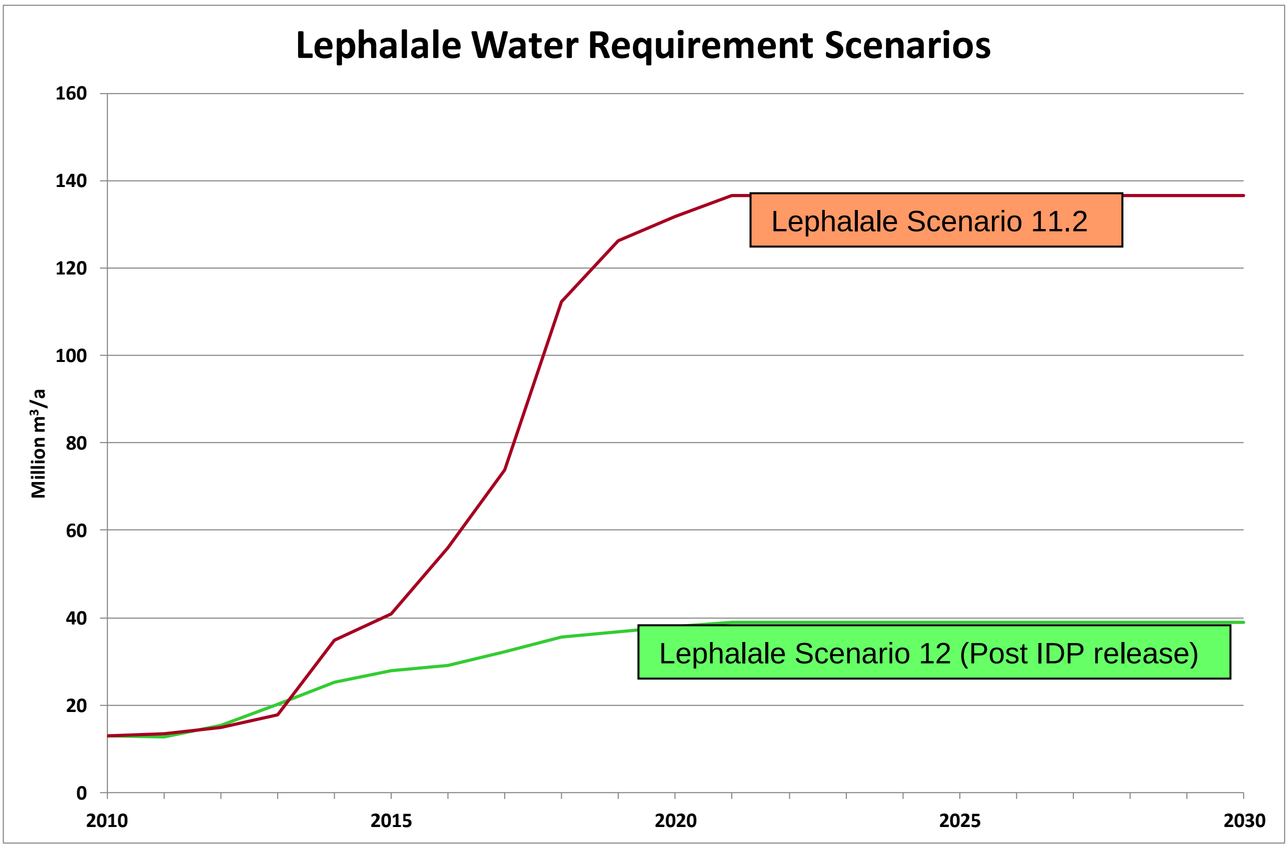


Figure 2-1 Lephalale water requirement scenarios before and after the release of the Integrated Development Plan, stipulating more renewable energy

Subsequently it has become apparent that the possibility of replacing the coal-fired power stations with renewable energy, and nuclear power in particular, is not likely within the timeframe of the IDP, given the time and costs required to develop the nuclear power stations. Some additional coal-fired power stations will still be needed if the growing energy requirements of the country are to be met. Therefore an increase in water requirements was projected, not back to initial estimates made before the IDP, but higher than the scenario with only Matimba and Medupi power stations. Further to this, additional coal is required in Mpumalanga to support existing power production there, and water will be required for this. The current water requirements for the Lephalale area are presented for two different scenarios, Base demand and High demand, in **Figure 2-2**. The main difference between the base and the high demand scenarios for Lephalale is an extra coal-fired power station and an extra phase of coal transfer to Mpumalanga in the high scenario.

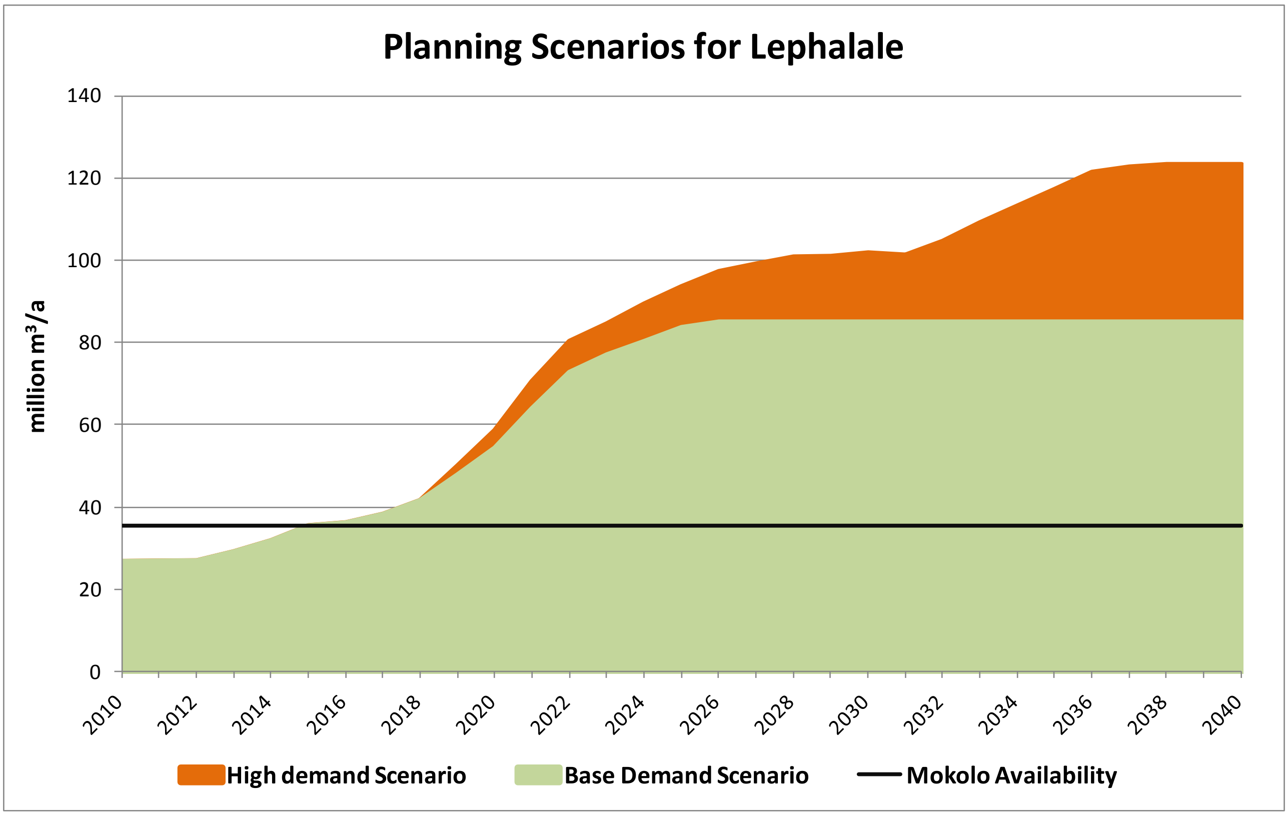


Figure 2-2 Water requirement scenarios for the Lephalale area (2012)

Included in **Figure 2-2** is the water availability from Mokolo Dam. Water requirements in excess of the availability from Mokolo Dam, will need to be met by the MCWAP-2. This transfer from the Crocodile West River catchment to Lephalale appears to be required in 2016. The long-term required volumes transfer is 45 and 80 million m^3/a for the Base and High demand scenarios respectively.

4. CROCODILE WEST WATER BALANCE CALCULATED WITH THE WRPM

4.1 METHODOLOGY

The data files of the WRPM, configured as described in the previous section, are included on a CD attached in **Appendix B**.

The first water balance calculated as part of the Reconciliation Strategy study was conducted using a spreadsheet and reconciling water requirements with water availability. Not only was this a very rigorous exercise due to the complexity of the system, but it also did not take into account the different assurance of supply criteria of the different water users. As such a decision was taken to use the WRPM to conduct further water balances.

The WRPM was used to calculate catchment wide water balances for different scenarios. The motivation for using the WRPM to determine the water balances was that the calculated water balances take into account the specific risk of non-supply criteria for the different water users in the catchment.

To determine the catchment wide water balance, the deficit or surplus at key locations in the catchment was determined. This also included checking the curtailment levels of users from all the large dams, and users downstream of the potential transfer location at

Vlieëpoort in the Lower Crocodile River sub-catchment close to Thabazimbi to the Lephalale area. When determining the surplus in key locations in the catchment, the supply of downstream users was checked. If the supply to downstream users was not acceptable (i.e. violated their supply criteria) then the surplus volume abstracted was reduced, until the supply to downstream users was acceptable. The water balance calculation was iterative and as such was calculated initially for 5-year time slices starting in 2010 and up to 2040. Once the water balances for the 5-year time slices were established a dynamic run was conducted to fill in the gaps.

It must be emphasised that this methodology gives the water balance of the catchment as a whole. Some isolated water shortages from local water resources may occur, and have been noted, where possible. The Reconciliation of All Towns in the Northern Cluster (All Towns Study) initiated by the DWA, was aimed at addressing these smaller localised water shortages. The Reconciliation of the Crocodile West River catchment is focused on the planning at a bigger scale.

4.2 WATER BALANCE CALCULATED FOR SSC MEETING 2 – FEBRUARY 2011

The first water balance using the WRPM was conducted in February 2011, and presented at the Strategy Steering Committee (SSC) meeting 2 on 24 February 2011. This water balance was conducted at the beginning of the phased approach with the WRPM, and the irrigation water requirements had not been included as WQT irrigation blocks yet, and were modelled with min-max type channels. Further to this, the surplus in the catchment was only calculated at two key points, namely Roodeplaat Dam and Hartbeespoort Dam. The surplus determined as presented at the SSC meeting is presented in **Figure 4-1**.

At the time of presenting this water balance there was still a lot of uncertainty about the projected future water requirements in the Lephalale area, and a large window of possible water requirements was presented ranging between the MCWAP Scenario 11.2 and Scenario 12. The possible extent to which the surplus in the Crocodile West River catchment could augment the supply to Lephalale is shown in **Figure 4-2** and **Figure 4-3** for Scenario 11.2 and Scenario 12 respectively.

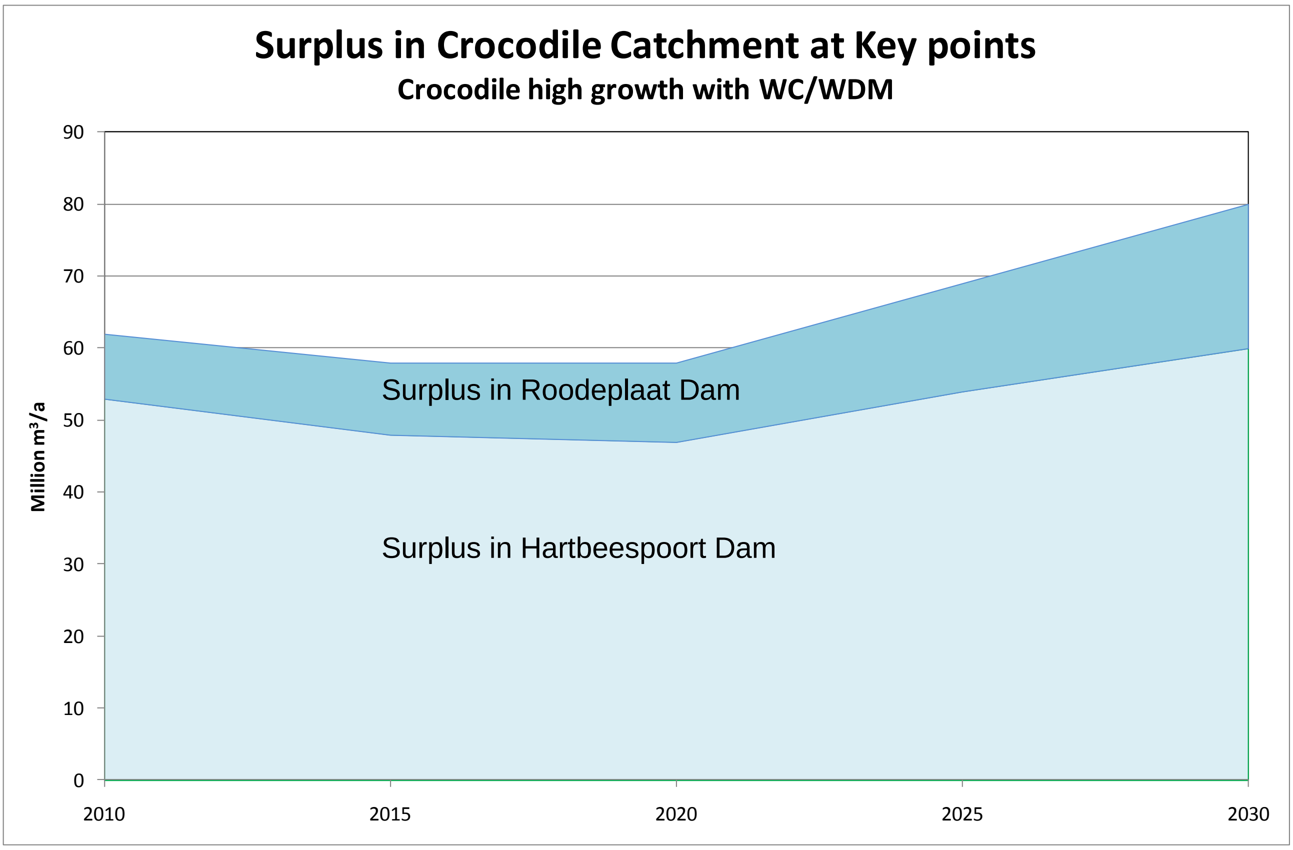


Figure 4-1 Water balance as determined with the WRPM in February 2011

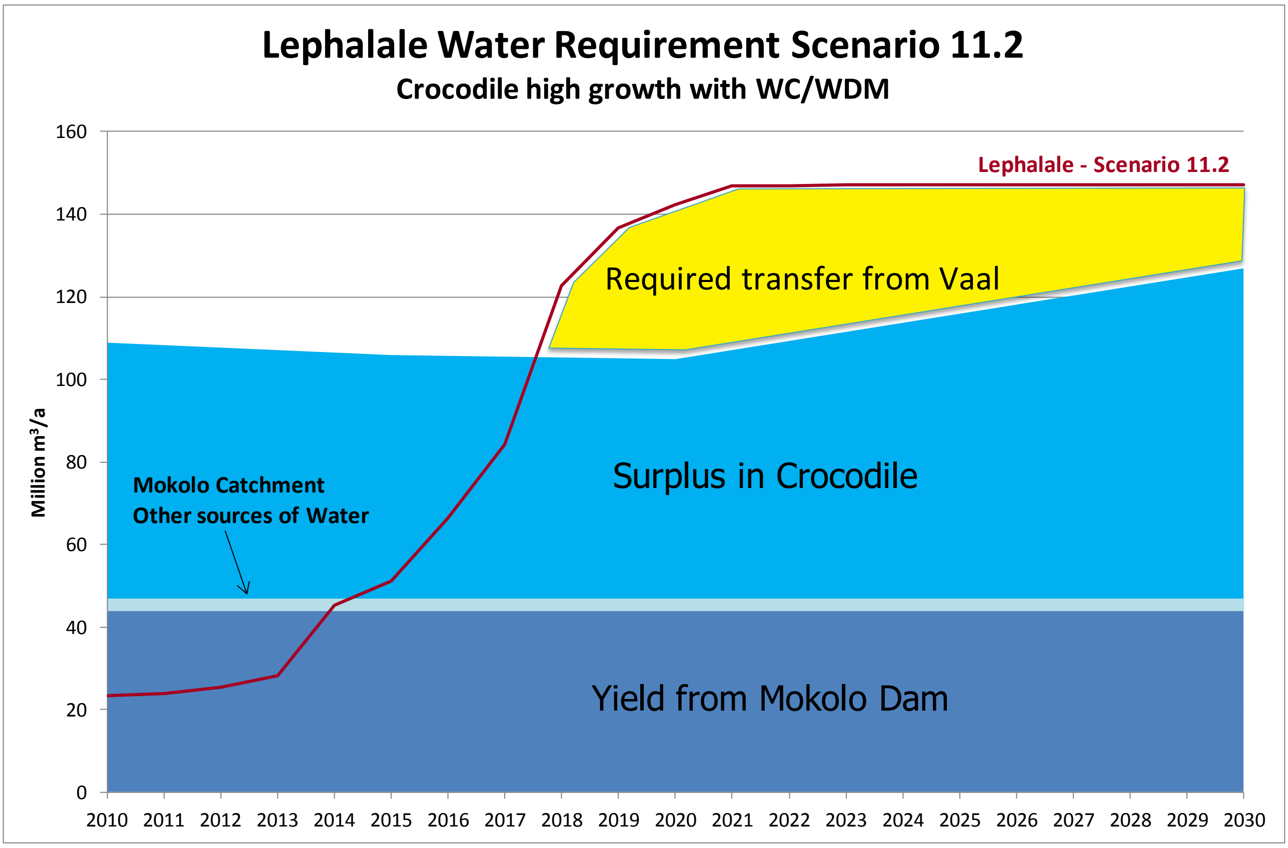


Figure 4-2 Reconciling Lephalale water requirements with Crocodile West River surplus for Lephalale Scenario 11.2

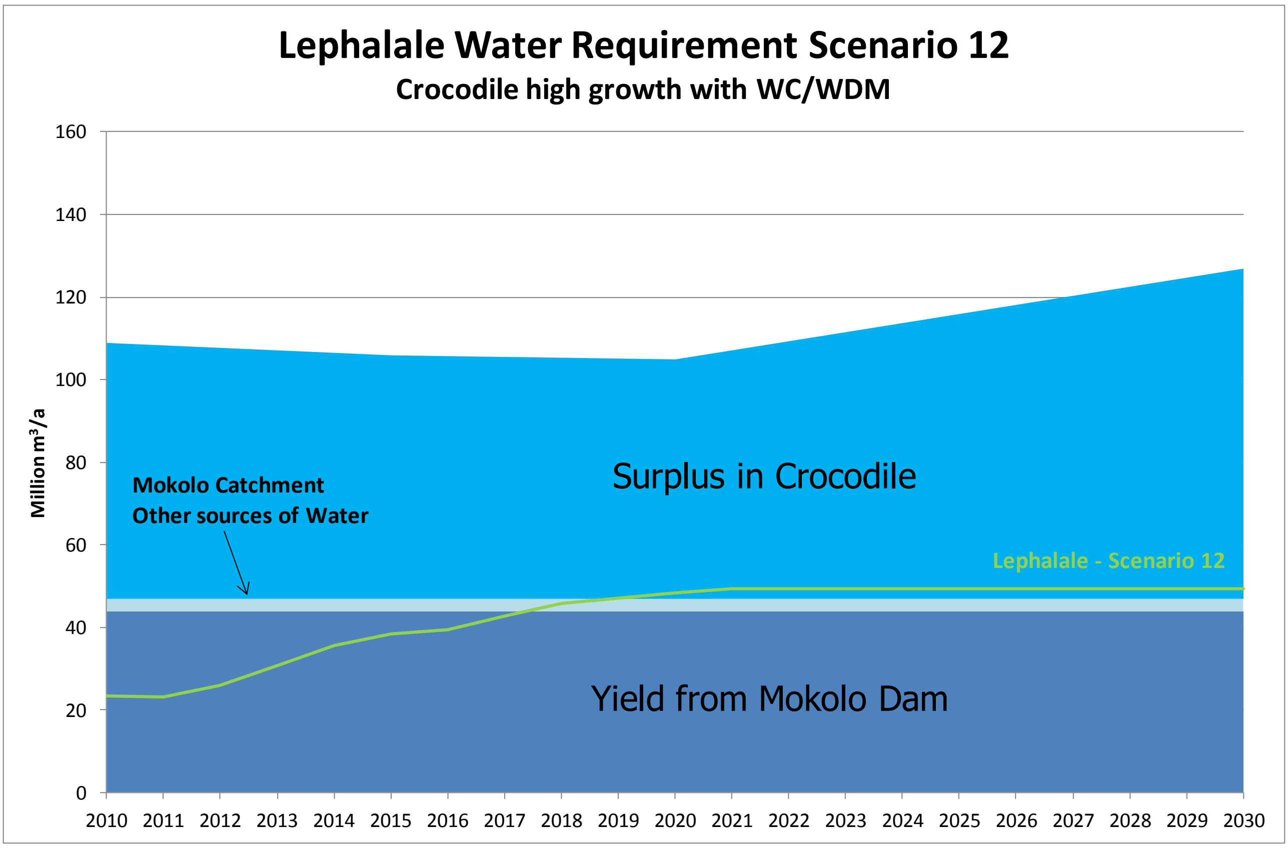


Figure 4-3 Reconciling Lephalale water requirements with Crocodile West surplus for Lephalale Scenario 12

As can be seen from **Figure 4-2** and **Figure 4-3**, the large range in Lephalale water requirement projections at that time indicated that the surplus in the Crocodile West River system may be insufficient to supply the total water requirements at the Lephalale area, with further water to be supplemented from the Vaal River system (Scenario 11.2), or the surplus greater than that required for the Lephalale area (Scenario 12).

4.3 WATER BALANCE CALCULATED FOR SSC MEETING 3 – SEPTEMBER 2011

The water balance as presented at the 3rd SSC meeting included the WQT component for the Upper Crocodile River sub-catchment. This then meant that the Hartbeespoort GWS irrigation was modelled with the WQT irrigation blocks and took into account variability in rainfall. The domestic water requirements for the northern parts of Tshwane were also updated to reflect the planned increase in supply from the expansion at the Temba WTW. This resulted in an increase in the total Tshwane water requirement projection of about 20 million m^3/a.

For the 3rd SSC meeting the surplus water was also determined at three points in the catchment, namely Roodeplaat, Hartbeespoort and Rietvlei dams. The water balance as presented at the 3rd SSC meeting at the end of September 2011 is shown in **Figure 4-4**.

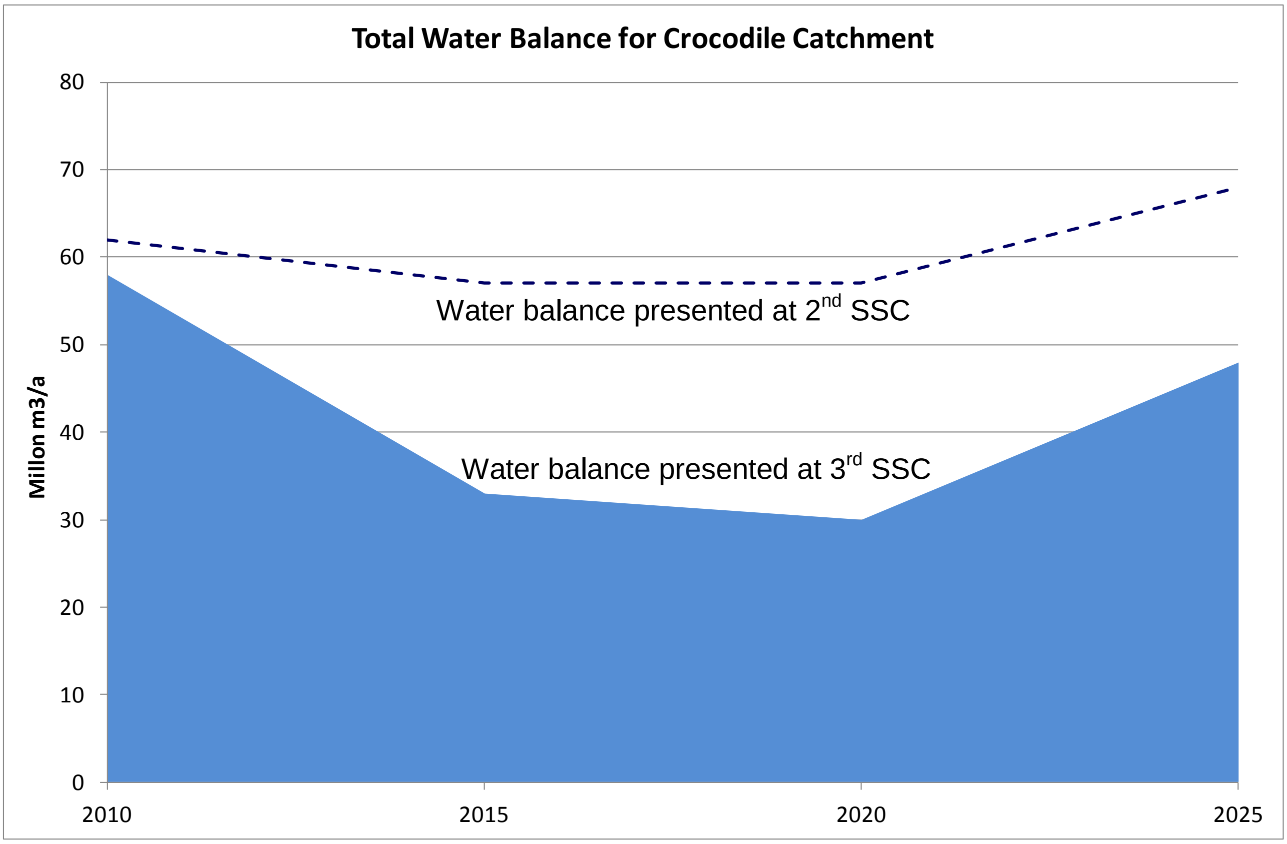


Figure 4-4 Crocodile West water balance presented at the 3rd SSC meeting in September 2011 (previous water balance included as a dotted line)

As a reference the water balance calculated for the 2nd SSC meeting as presented in Section 4.3 is also included on the graph (dotted line). The revised water balance showed:

- A decrease in the surplus projected for the catchment up to 2020, and thereafter the surplus grows again.
- Less surplus than presented at the 2nd SSC meeting.

The following contributed to the changes in the water balance as presented in **Figure 4-4**:

1. The inclusion of the Hartbeespoort and other irrigation in the upper Crocodile West River catchment as WQT irrigation blocks took into account climatic variability. This amplifies the dry years as irrigation requirements are likely to be higher due to less rain and hot conditions. This results in higher water requirements during dry periods.
2. Increased water requirements at the Temba WTW will utilise more of the return flows entering the system upstream of Leeukraal Dam. This water would normally have spilled and ended up in Klipvoor Dam. As such the availability at Klipvoor Dam reduced. This, together with the upstream WQT irrigation block effects resulted in projected violations of supply criteria for the Crocodile West Irrigation Board (CWIB), without the upstream Roodeplaat and Hartbeespoort dams being fully utilised. In other words, abstracting surplus from the upstream dams is not possible with the existing operating rules that no water for irrigation supply to the

Crocodile West Irrigation Board should be released from Hartbeespoort Dam and/or Roodeplaat Dam. This would reduce the spills to Klipvoor and Roodekopjes, and further reduce water availability for the CWIB. In order to maximise the total system yield, a decision was made to determine how much surplus could be abstracted form the upstream dams, while providing just enough of this water as support to Klipvoor and Roodekopjes dams to ensure that the CWIB supply is within the acceptable criteria. This increased the total surplus that could be obtained from the catchment as reflected in the water balance in **Figure *4-4***.

The above 2nd point highlighted that the surplus water in the catchment, generated by large volumes of urban return flows, is stored in the upstream dams in the catchment. The downstream water users, such as the CWIB, only have an allocation from Roodekopjes and Klipvoor dams, and as such do not have direct access to this surplus water in the catchment. The sufficient high assurance of supply to the CWIB and other downstream users has typically been assisted by the fairly reliable spills of water from the upstream dams which have usually in the past been at a full or close to full level.

By increasing the usage of water from the upstream dams through the abstraction of surplus water, the reliability of the spills reduces as the upstream dams are generally operated at lower levels. The decision to provide support to the downstream dams when abstracting surplus water from the upstream dams essentially makes up for the reduced spillage. This does raise the question of possibly revising future operating rules of the system and to operate in a more integrated manner. This information was provided to the *Crocodile West Annual Operating Analysis Study*, also being conducted by the DWA.

For some time the downstream CWIB irrigators have been in disagreement with the idea of supplying water from the Crocodile West River to Lephalale as they felt this would negatively impact their own supply of water. They further did not believe there is surplus water in the Crocodile catchment as they have in recent years had to endure restrictions due to insufficient water availability. The DWA's position had been that the surplus water was upstream in the catchment in dams that the irrigators did not have allocations from. The above exercise in determining the water balance and surplus in the catchment both confirmed this, and also highlighted the DWA's approach that the surplus water in the catchment will not be used for transfer to the Lephalale area if it causes violations in the supply criteria of the water users within the catchment.

A series of graphs that showed the actual and simulated higher water levels in Hartbeespoort and Roodeplaat dams versus the actual and simulated low water levels in Roodekopjes and Klipvoor dams during the 2004/5 dry period was also presented at the 3rd SSC meeting. The presented data assisted a better understanding by the SSC members, including the CWIB representatives. The actual versus simulated 2005 trajectories are provided in **Appendix D**.

4.4 OTHER SCENARIOS ASSESSED FOR SSC MEETING 3 – SEPTEMBER 2011

4.4.1 Tshwane Re-use Scenario

The impacts of Tshwane Metro's planned Water Augmentation Program on the water balance were simulated by including the infrastructure capacity upgrades as envisaged by their program, and the water requirements of the Base Scenario, which Tshwane accepted as the best information currently available on water requirements for the Metro. The program entails significant in-direct re-use of return flows, and this is coupled with a reduction on the demand for water from the Vaal River system. The water balance for the Crocodile West River catchment was re-calculated for the Tshwane Re-use Scenario and is reflected in **Figure 4-5**. As can be seen the re-use interventions of the planned water augmentation program have a significant impact on the water balance, particularly from 2017 onwards when a number of interventions by the Tshwane Metro is planned to come online simultaneously. The timing of these interventions should seriously be reviewed. From around 2025 the water balance is projected to return to a positive state due to the continuation of transfers of water from the Vaal River system by Rand Water into the catchment and projected associated return flows.

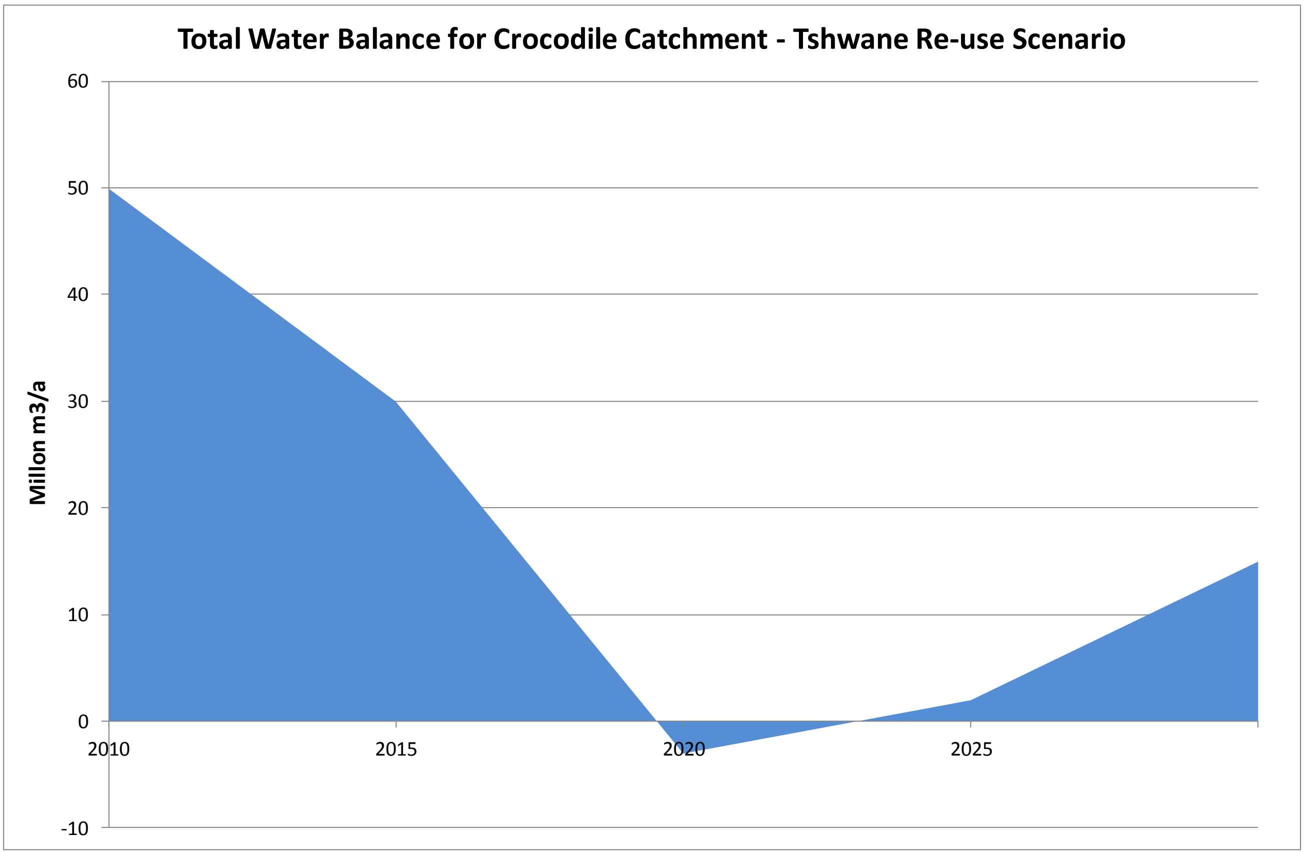


Figure 4-5 Water balance of the Crocodile catchment for the Tshwane Reuse scenario which considers the planned water augmentation program by the City of Tshwane

4.4.2 Magalies Water Scenario

Before calculating the water balance for the Magalies Scenario, the water requirement projections and associated supply anticipated by Magalies Water were compared to those included in the Base Scenario. The water requirement projections in the Rustenburg area linked to Vaalkop Dam were very similar for both scenarios. Water requirement projections linked to Roodeplaat Dam, however, differed significantly. Magalies Water indicated that extensive growth was expected and planned around the Roodeplaat Dam (for the old Nokeng Tsa Tsaemane Municipality). The water requirements for this area included in the Base Scenario projections included a small growth until 2030. The impacts on the water balance for this scenario were therefore focused on the Apies-Pienaars sub-catchment. The results of the water balance indicate that if the growth in water requirements indicated by Magalies Water realise, and are supplied from Roodeplaat Dam, the current surplus would decrease and become a deficit by about 2018, see **Figure 4-6** and **Figure 4-7**.

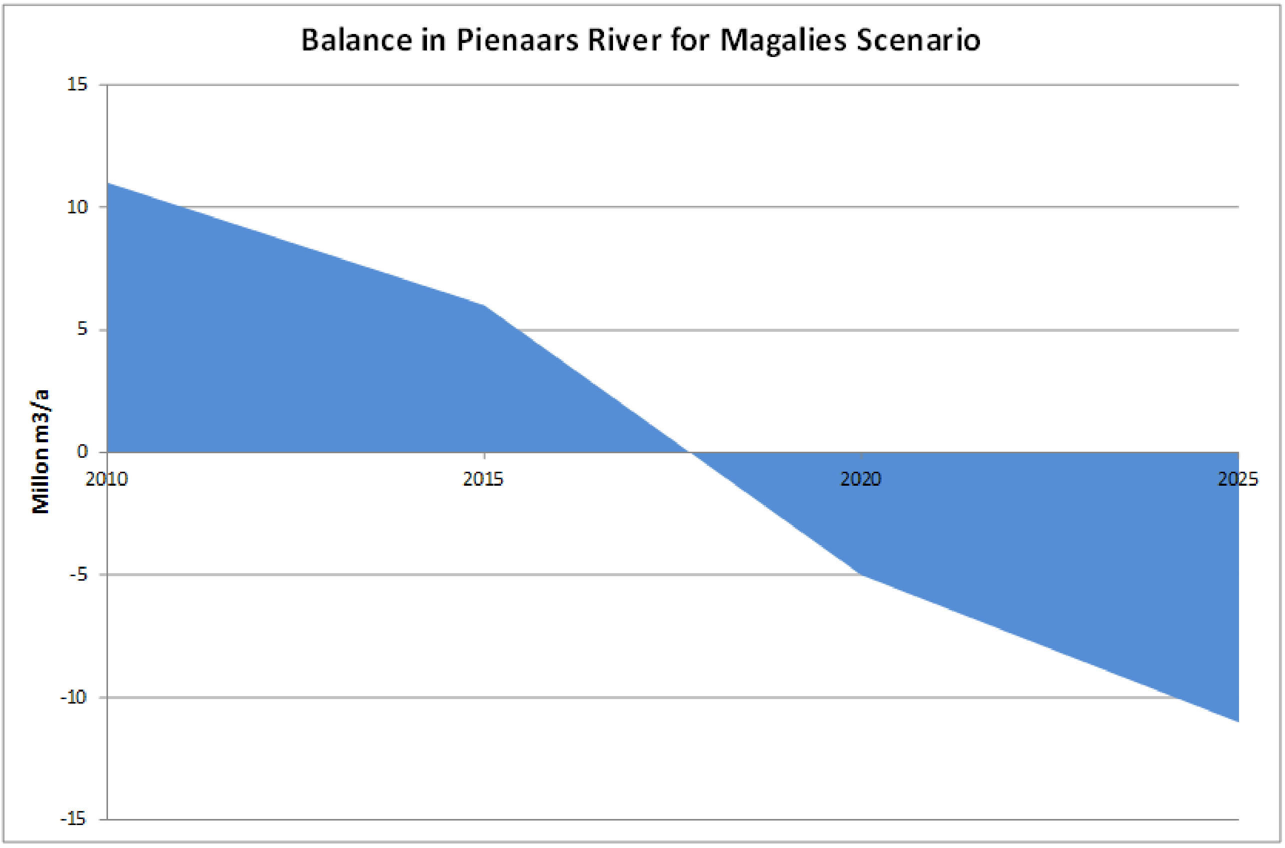


Figure 4-6 Water balance for the Pienaars River catchment due to possible higher water requirements around Roodeplaat Dam

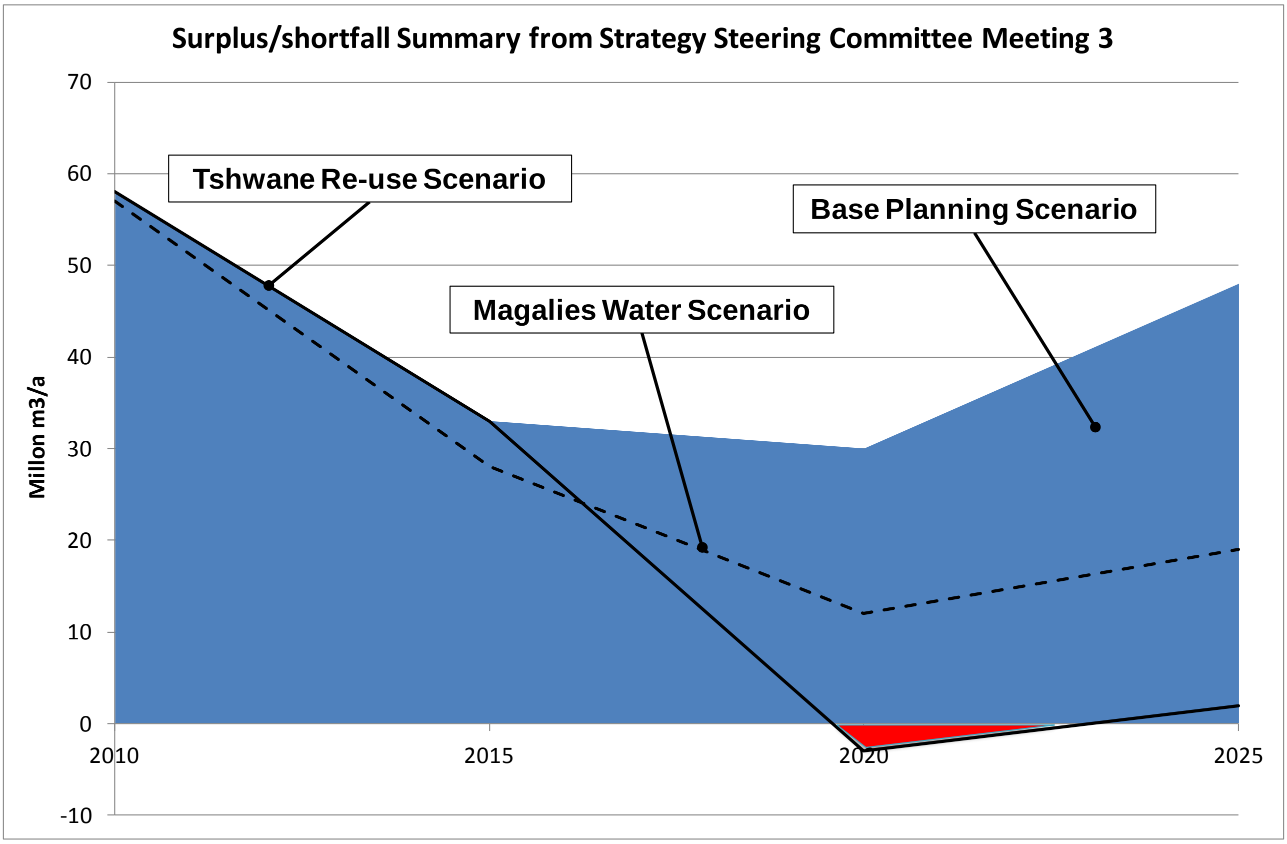


Figure 4-7 **Summary of water balance scenarios using the WRPM and presented at the 3rd SSC meeting**

4.5 WATER BALANCE CALCULATED FOR SSC MEETING 4 – JULY 2012

The final water balance prepared and presented to the 4th SSC meeting in July 2012 were conducted with the WQT component added for the full system. This was done once the problem with the sand aquifers in the WQT model had been resolved by the software developers. All irrigation was modelled with the WQT irrigation blocks and took climatic variability into account. Further to this, the water requirements for Lephalale as presented in **Figure 2-2**, were received and provided more focus on the likely water transfer volumes required from the Crocodile West River, by narrowing the possible window in projections of water requirements and return flows.

The water balance associated with the above is shown in **Figure 4-8**. The water balance as presented at the 3rd SSC meeting is also included in this figure, as a point of reference. The small differences between the two are predominantly due to the addition of the Lower Crocodile sub-catchment WQT files, and inclusion of the CWIB irrigation as WQT irrigation blocks. The boxplots of the dam and curtailment levels for key locations are shown in **Appendix C**, for both the surplus water left in the dams, as well as the surplus abstracted.

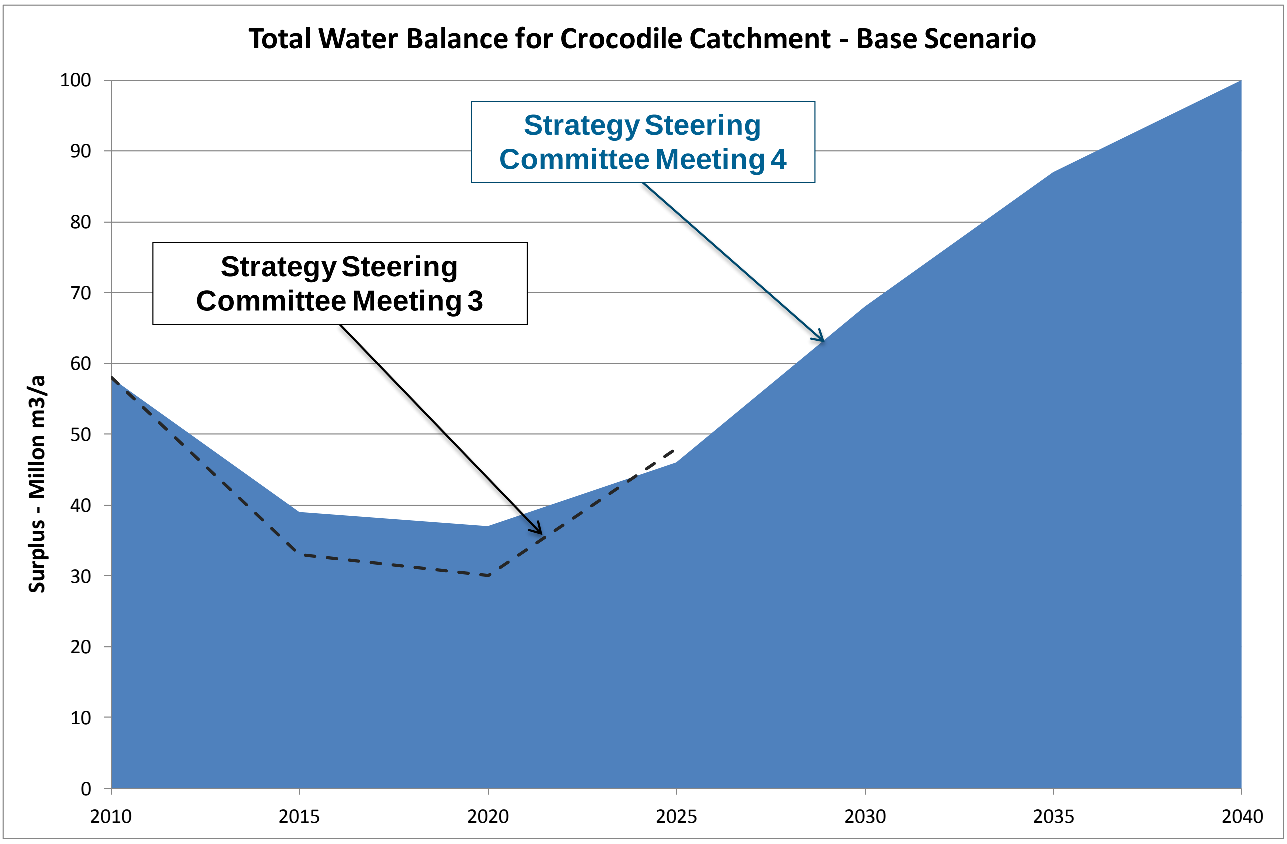


Figure 4-8 Crocodile West water balance as presented at the 4th SSC meeting

The surplus volume of water shown in Figure 4-8 was then compared against the transfer needs for the Lephalale area as shown previously in Figure 2-2. The results of this comparison are shown in **Figure 4-9**. Conveyance losses of 10% were included in the volume of surplus water in the Crocodile West River for transfer to Lephalale. What can be seen in **Figure *4-9*** is that the surplus volume is insufficient to meet the current projected water requirements in the Lephalale area. The shortfall is, however, small and temporary, the volume and duration depending on the specific scenario.

To provide a simpler diagram the shortfall in water needed to meet the Lephalale area water requirement projections from the Crocodile West River system is shown in **Figure *4-10***.

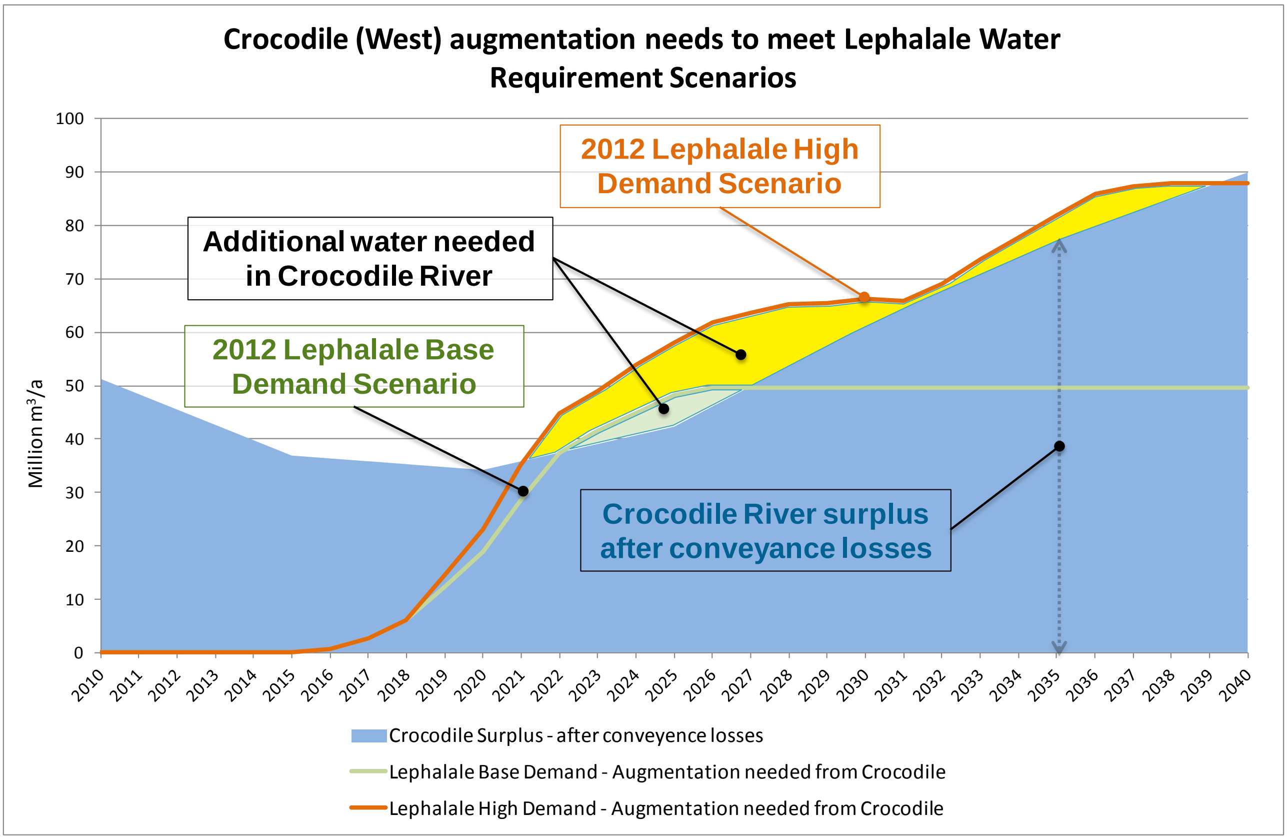


Figure 4-9 Comparison of surplus water in the Crocodile West with additional water required in the Lephalale area

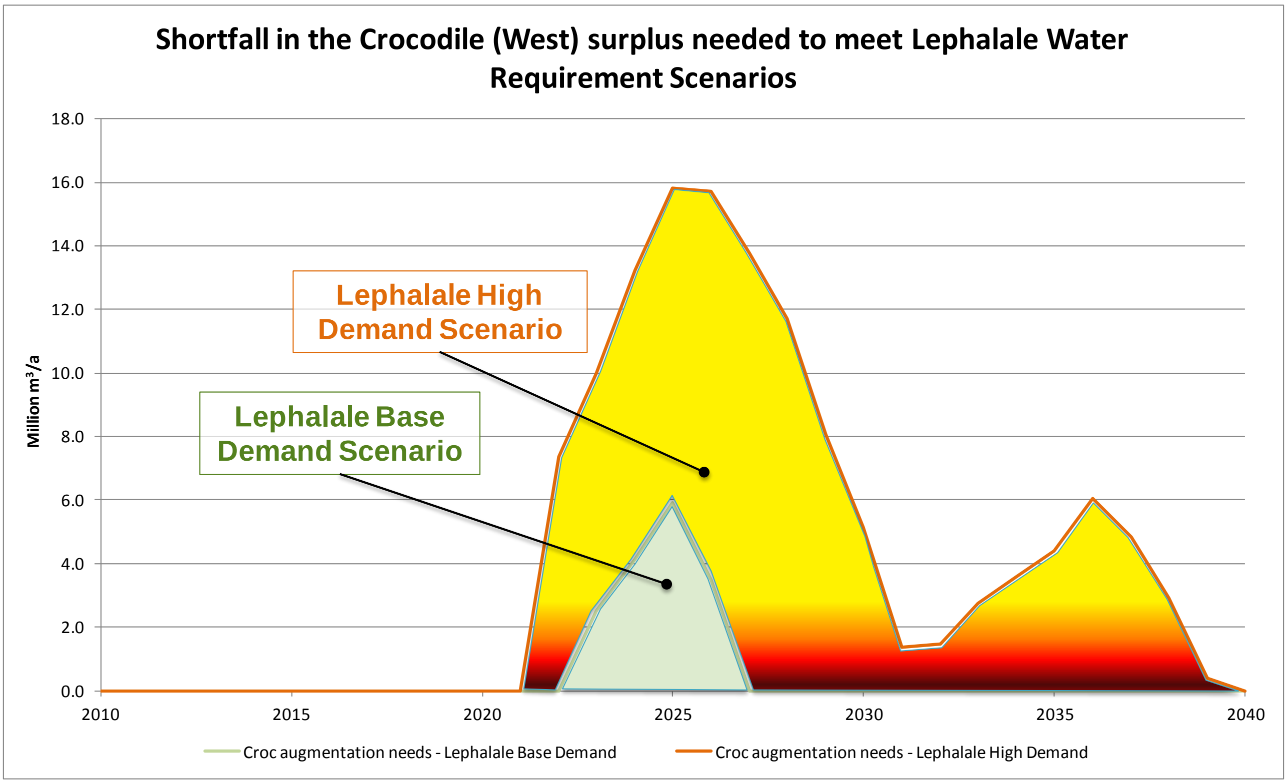


Figure 4-10 Additional water needed in the Lephalale area over and above the surplus in the Crocodile West River system

From Figure 4-10, the additional water needed for the Lephalale area over and above the projected surplus water in the Crocodile ranges between 6 and 16 million m^3/a for the Lephalale Base and High Demand Scenarios respectively. This water is also only needed for a period until the projected return flows increase the surplus water available in the Crocodile West River catchment above the volume of water needed for the Lephalale area. This occurs in 2027 for the Lephalale Base Demand Scenario and 2040 for the Lephalale High Demand Scenario.

Considering the relatively small volumes of additional water needed for Lephalale and the fact that the water is only needed temporarily, various solutions are possible. This includes both infrastructure and demand side measures.

5. WATER QUALITY

As the WQT component of the WRPM had been included for the whole catchment, some water quality (salinity) projection plots were prepared and presented at the 4th SSC meeting. The salinity plots for key resources and locations in the catchment were prepared for the 2012 Crocodile West Base scenario. These boxplots of salinity are included in **Appendix C**. The plots do show a slow increasing trend in the projected salinity levels over the years in Hartbeespoort and Roodeplaat dams due to growing upstream return flows. The increases are, however, small and the salinity (TDS) for Hartbeespoort Dam is expected to range between 300 and 400 mg/ℓ and for Roodeplaat Dam between 200 and 350 mg/ℓ. The increase in average TDS over the projected period from 2010 to 2040 is in the order of 25 mg/ℓ.

An outstanding result of the inclusion of the WQT (salinity) is to plot the possible build up in salts in Roodeplaat Dam. Vaalkop and Bospoort dams are due to re-use of water in a looped system whereby the return flows go back into the system upstream of the abstraction points of the water. This recycles salts and could cause a salt build-up. Proposed re-use programs will need to be rigorously tested for salt build-up.

6. CONCLUSIONS

- The Water Resources Planning Model has been configured, tested and used to conduct water balances and scenario analyses for the Crocodile West River catchment.
- The Water Quality (WQT) salinity model calibration has been completed and the water quality/salinity data files incorporated into the WRPM allowing salinity levels to be simulated.
- Water balances were calculated in a phased manner as the model configuration was refined with additional information and as the WQT data files were added from the top of the system downwards. The water balances were presented to the Strategy Steering Committee members approximately every 6 months at the Strategy Steering Committee meetings.

- The water balance in the Crocodile West River catchment is currently positive (in surplus) with the greater catchment having a surplus of water. Some smaller localised deficits may, however, occur.
- The transfer of treated water by Rand Water into the upper catchment from the Vaal River system to the larger metro areas in the Crocodile West River catchment continues to be the major source of water in the catchment, including the generated return flows.
- One of the key uses of the surplus water in the Crocodile West River catchment is to augment water supply to the Lephalale area's power and mining developments through the future planned Mokolo Crocodile Water Augmentation Project Phase 2 (MCWAP-2).
- Water requirement projections for the Lephalale area's power and mining developments have fluctuated significantly over the past three years and have been influenced by a number of factors, including the release of the Department of Energy's Integrated Development Plan. Recently revised water requirement projections have been received which have narrowed the window in projected water requirements for the Lephalale area and the probable transfer volume of the MCWAP-2.
- Surplus water in the Crocodile West River catchment may not be sufficient to meet the future water requirements for the Lephalale area for a temporary period, and a relatively small additional volume of additional water may need to be sourced.
- If water requirement projections, particularly in the mining sector, grow different to those projected and captured in the water balance scenarios, the shortfall of surplus may be increased or fall away altogether.

7. RECOMMENDATIONS

- Water requirement and return flow projections need to be updated continuously and the water balance revised accordingly.
- Water quality (salinity) needs to be investigated further at key locations were salt build-up due to re-use of water is expected.
- Operating rules of the system need to be reviewed, as more integrated operation of the system may be required in the near future. This should be explored as part of Phase 2 of the Implementation of the Crocodile West Reconciliation Strategy by the DWA.

8. REFERENCES

[1] Department of Water Affairs and Forestry (South Africa). 2008. ***Water requirement and availability scenarios for the Lephalale Area***. DWAF Report Number P WMA 03/000/00/4107. Report by BKS.

[2] Department of Water Affairs and Forestry (South Africa). 2008. ***Groundwater Assessment***. DWAF Report Number P WMA 03/000/00/2507. Report by AGES.

[3] Department of Water Affairs and Forestry (South Africa). 2008. ***Crocodile (West) River Catchment: Hydrological Assessment***. DWAF Report Number P WMA 03/000/00/2307. Report by BKS and Arcus Gibb.

[4] Department of Water Affairs and Forestry (South Africa). 2008. ***Agricultural Assessment***. DWAF Report Number P WMA 03/000/00/2207. Report by Schoeman en Vennote.

[5] Department of Water Affairs and Forestry (South Africa). 2007. ***Vaal River System: Large Bulk Water Supply Reconciliation Strategies: Current and Future Urban Water Requirements and Return-Flows***.

DWAF Report No. P RSA C000/00/4405/01. Report by DMM Development Consultants, Golder Associates Africa, SRK, WRP Consulting Engineers and Zitholele Consulting.

[6] Department of Water Affairs and Forestry (South Africa). 2004. ***Crocodile (West) River Return Flow Analysis Study***. DWAF Report Number P WMA 03/000/00/0504. Report by WRP Consulting Engineers.

[7] Department of Water Affairs (DWA). 2009. ***WRYM Analyses Report***. DWA report no. P WMA 03/000/00/2708).

[8] Department of Water Affairs (DWA). 2009. ***WRPM Analyses Report***. DWA Report no. P WMA 03/000/00/3708.

APPENDICES

Appendix A **:** *WRPM Schematic and System configuration*

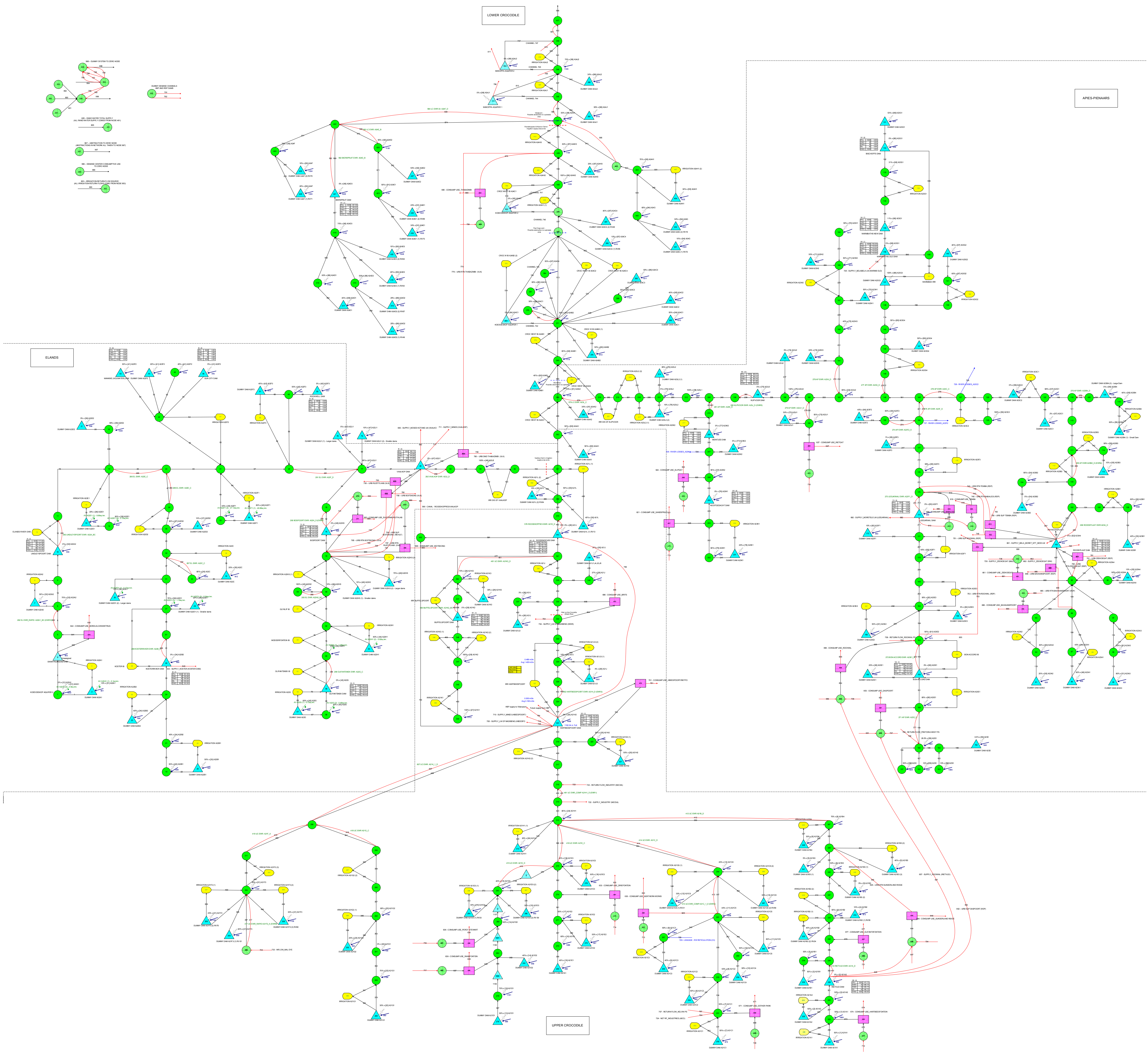
Appendix B **:** *WRPM data files*

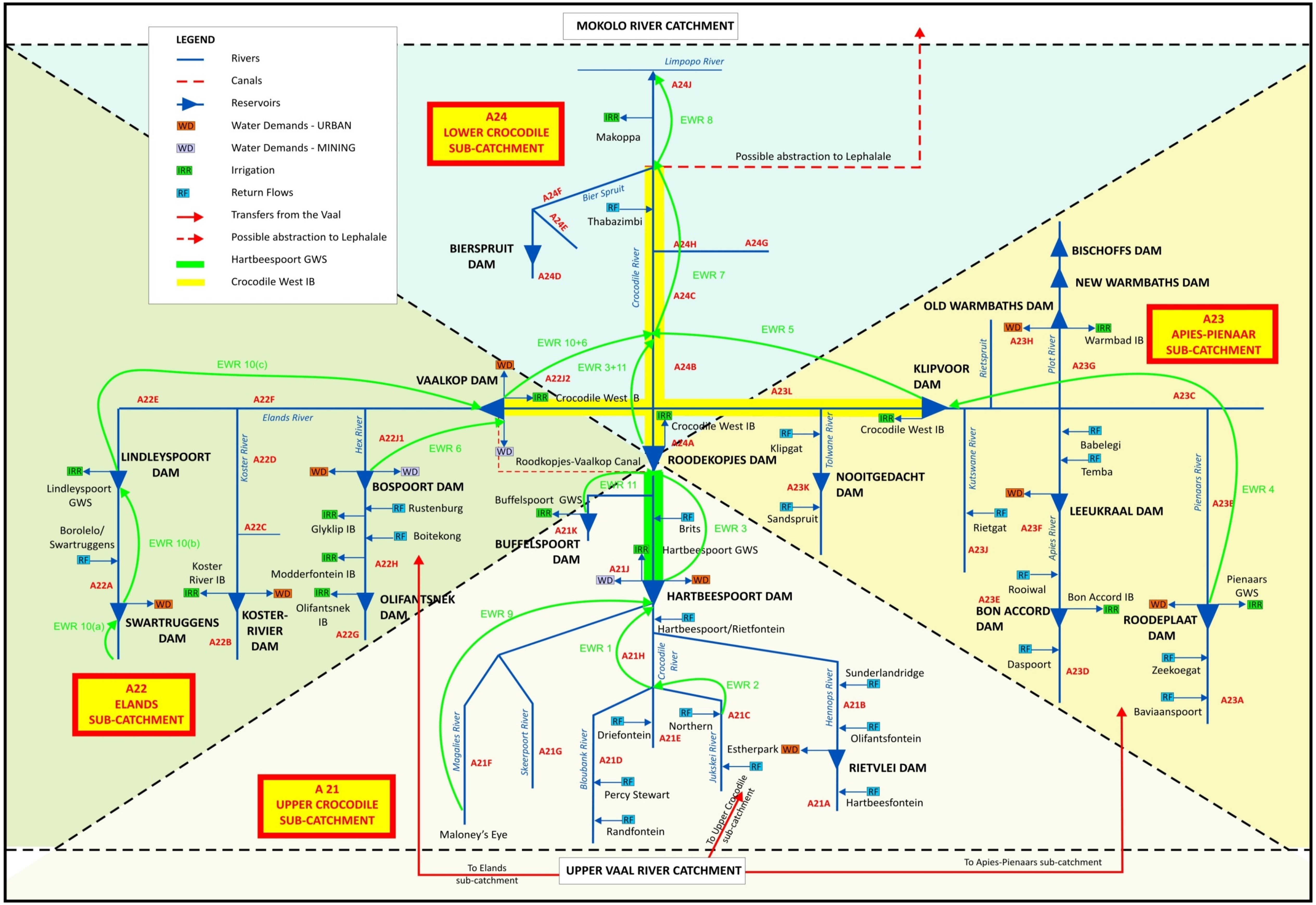
Appendix C **:** *Boxplots for 2012 Base scenario*

Appendix D : *Actual versus simulated 2005 trajectories*

Appendix A

WRPM Schematic and System configuration


LOWER CROCODILE
APIES-PIENAARS
ELANDS
UPPER CROCODILE



MOKOLO RIVER CATCHMENT
LEGEND
Rivers
Canals
Reservoirs
Water Demands - URBAN
Water Demands - MINING
Irrigation
Return Flows
Transfers from the Vaal
Possible abstraction to Lephalale
Hartbeespoort GWS
Crocodile West IB
A24 LOWER CROCODILE SUB-CATCHMENT
A23 APIES-PIENAAR SUB-CATCHMENT
A22 ELANDS SUB-CATCHMENT
A 21 UPPER CROCODILE SUB-CATCHMENT
Limpopo River
Makoppa
EWR 8
Possible abstraction to Lephalale
Bier Spruit
Thabazimbi
BIERSPRUIT DAM
Crocodile River
EWR 7
EWR 5
EWR 10+6
EWR 3+11
EWR 10(c)
VAALKOP DAM
Crocodile West IB
Elands River
Koster River
Hex River
EWR 6
Roodkopjes-Vaalkop Canal
ROODEKOPJES DAM
Klipgat
Tolwane River
KLIPVOOR DAM
Kutswane River
Rietspruit
Plot River
OLD WARMBATHS DAM
NEW WARMBATHS DAM
BISCHOFFS DAM
Warmbad IB
Babelegi
Temba
LEEUKRAAL DAM
Rietgat
Apies River
Pienaars River
EWR 4
LINDLEYSPOORT DAM
Lindleyspoort GWS
Borolelo/ Swartruggens
EWR 10(b)
EWR 10(a)
SWARTRUGGENS DAM
Koster River IB
KOSTER-RIVIER DAM
BOSPOORT DAM
Rustenburg
Glyklip IB
Boitekong
Modderfontein IB
Olifantsnek IB
OLIFANTSNEK DAM
Buffelspoort GWS
EWR 11
BUFFELSPOORT DAM
Brits
EWR 3
Hartbeespoort GWS
NOOITGEDACHT DAM
Sandspruit
HARTBEESPOORT DAM
Hartbeespoort/Rietfontein
EWR 9
EWR 1
EWR 2
Rooiwal
Bon Accord IB
BON ACCORD DAM
Daspoort
Pienaars GWS
RODEPLAAT DAM
Zeekoegat
Baviaanspoort
Magalies River
Skeerpoort River
Bloubank River
Jukskei River
Hennops River
Driefontein
Northern
Sunderlandridge
Olifantsfontein
Estherpark
RIETVLEI DAM
Percy Stewart
Randfontein
Hartbeesfontein
Maloney's Eye
To Upper Crocodile sub-catchment
To Elands sub-catchment
UPPER VAAL RIVER CATCHMENT
To Apies-Pienaars sub-catchment
A24J
A24F
A24E
A24D
A24H
A24G
A24C
A24B
A24A
A22J2
A22J1
A22E
A22F
A22D
A22C
A22A
A22B
A22G
A22H
A23L
A23K
A23H
A23G
A23C
A23J
A23F
A23B
A23E
A23D
A23A
A21K
A21J
A21H
A21F
A21G
A21D
A21E
A21C
A21B
A21A

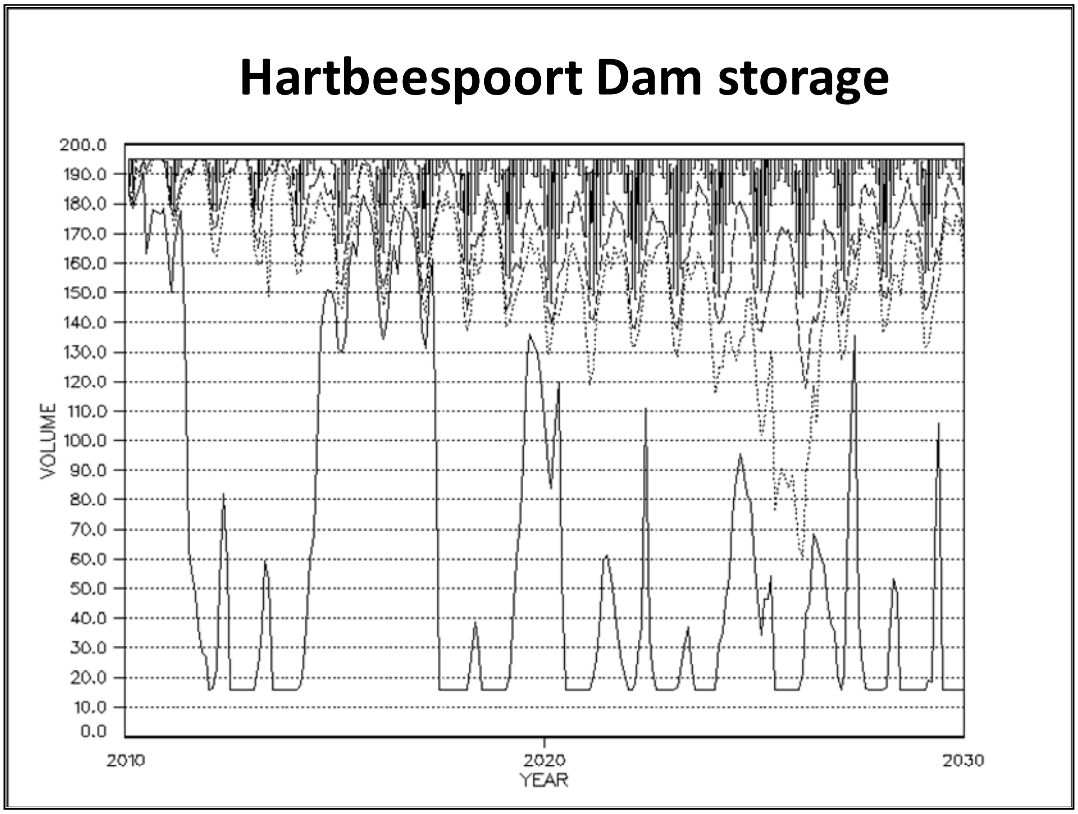
Appendix B

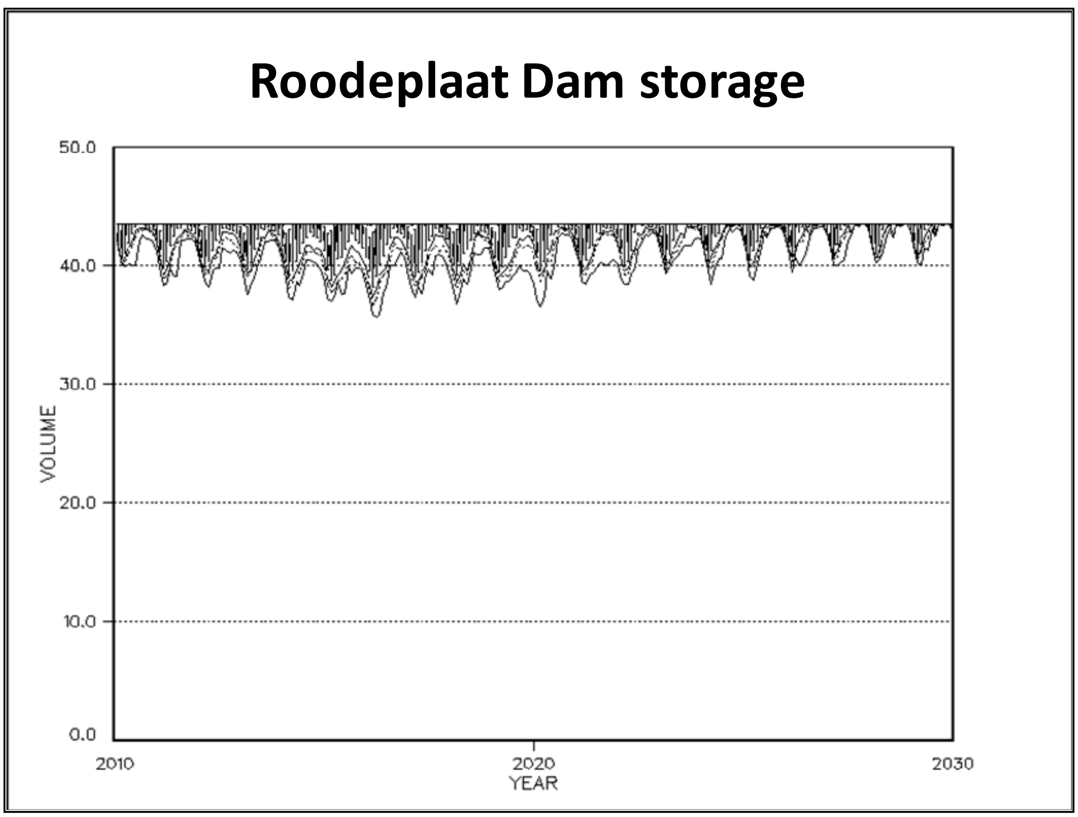
WRPM data files
(CD attached in back cover)

Appendix C

Boxplots for 2012 Base scenario

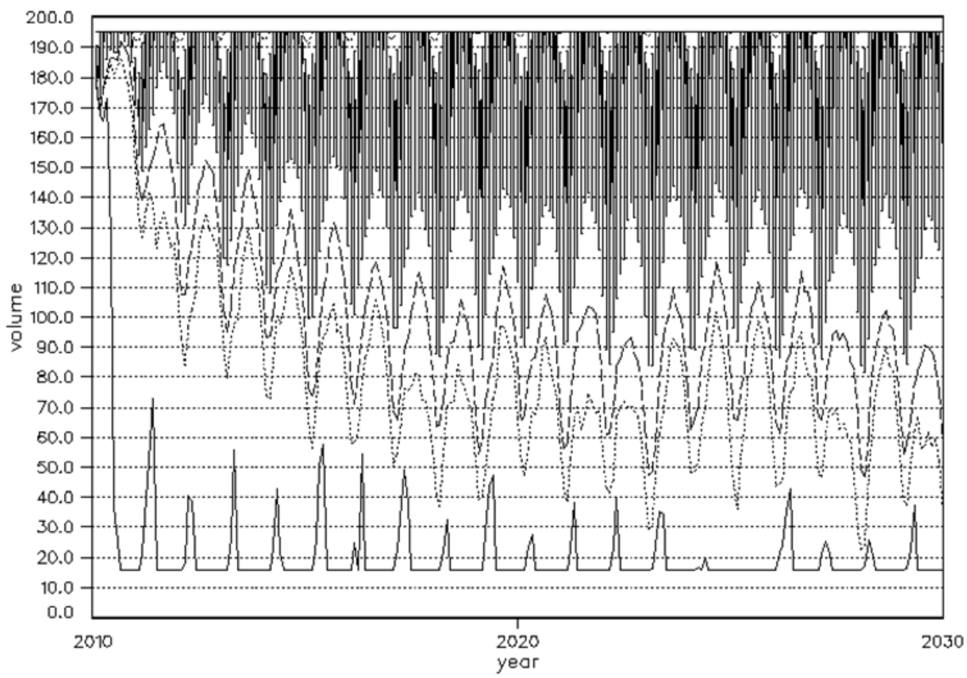
Crocodile West – 2012 Base scenario with NO surplus abstracted (i.e. status quo)



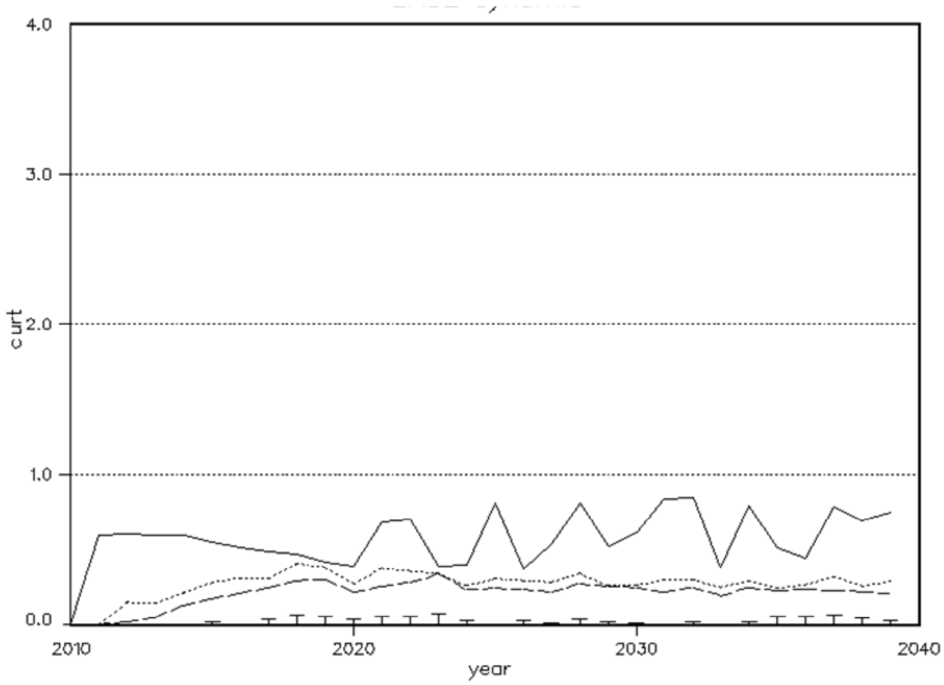


Crocodile West – 2012 Base scenario WITH surplus abstracted

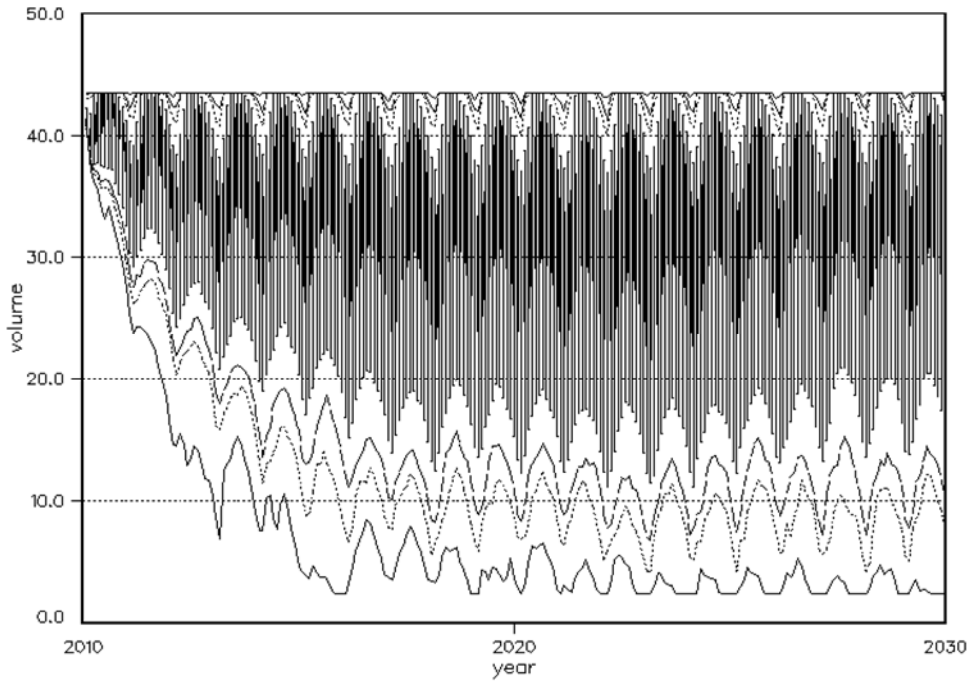
Hartbeespoort Dam storage



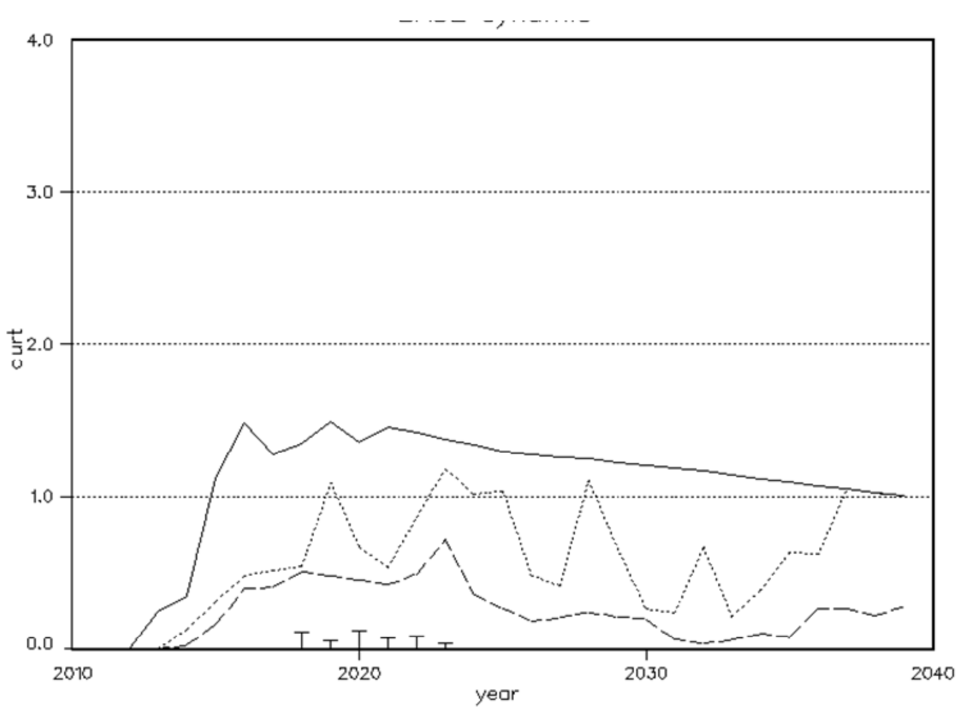
Hartbeespoort restriction levels



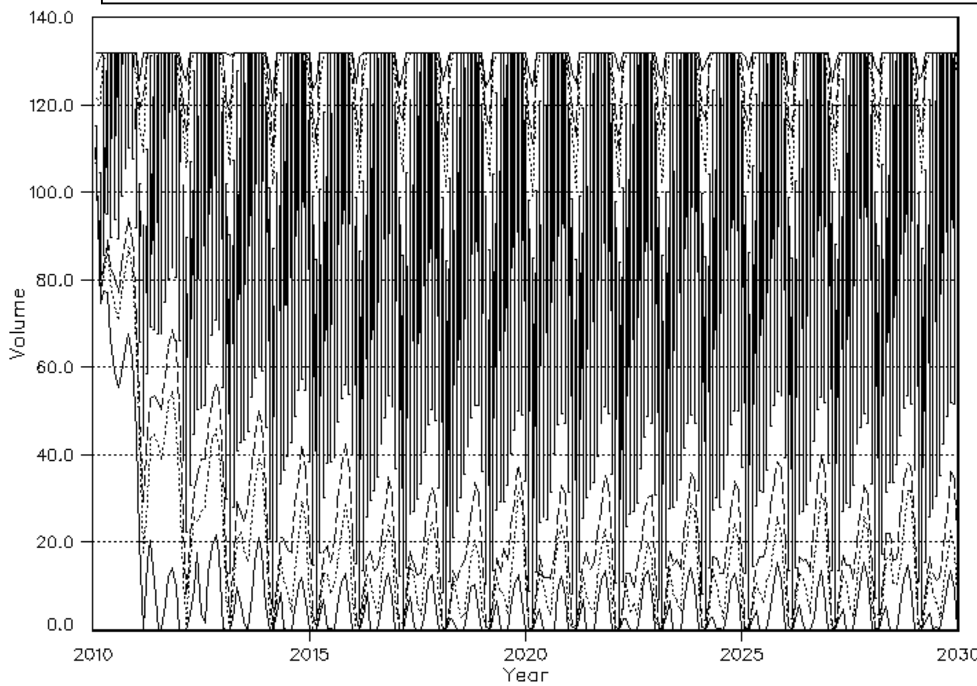
Roodeplaat Dam storage



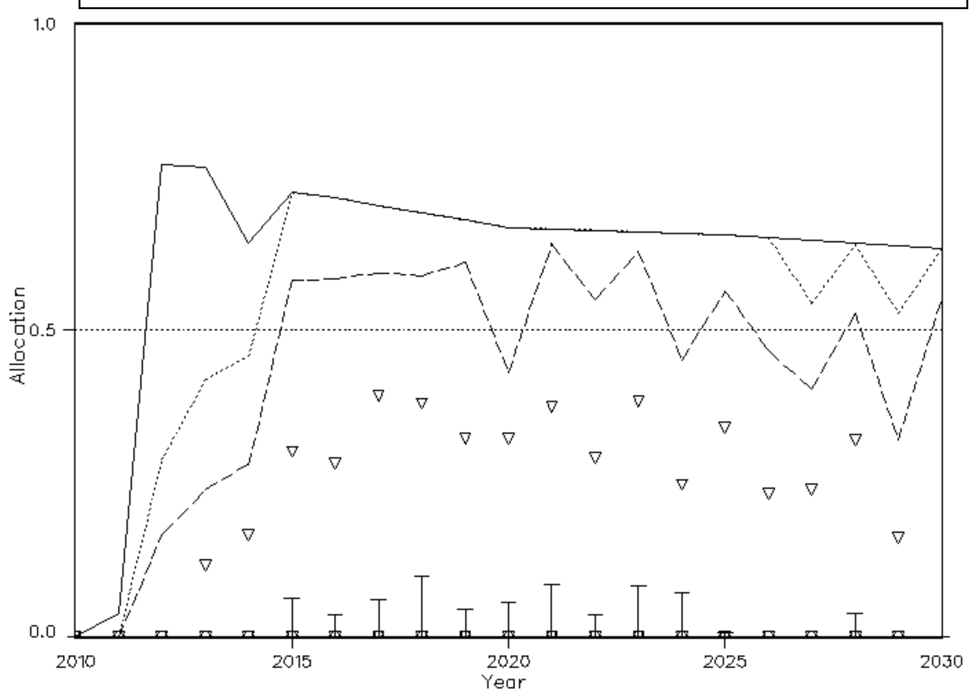
Roodeplaat restriction levels

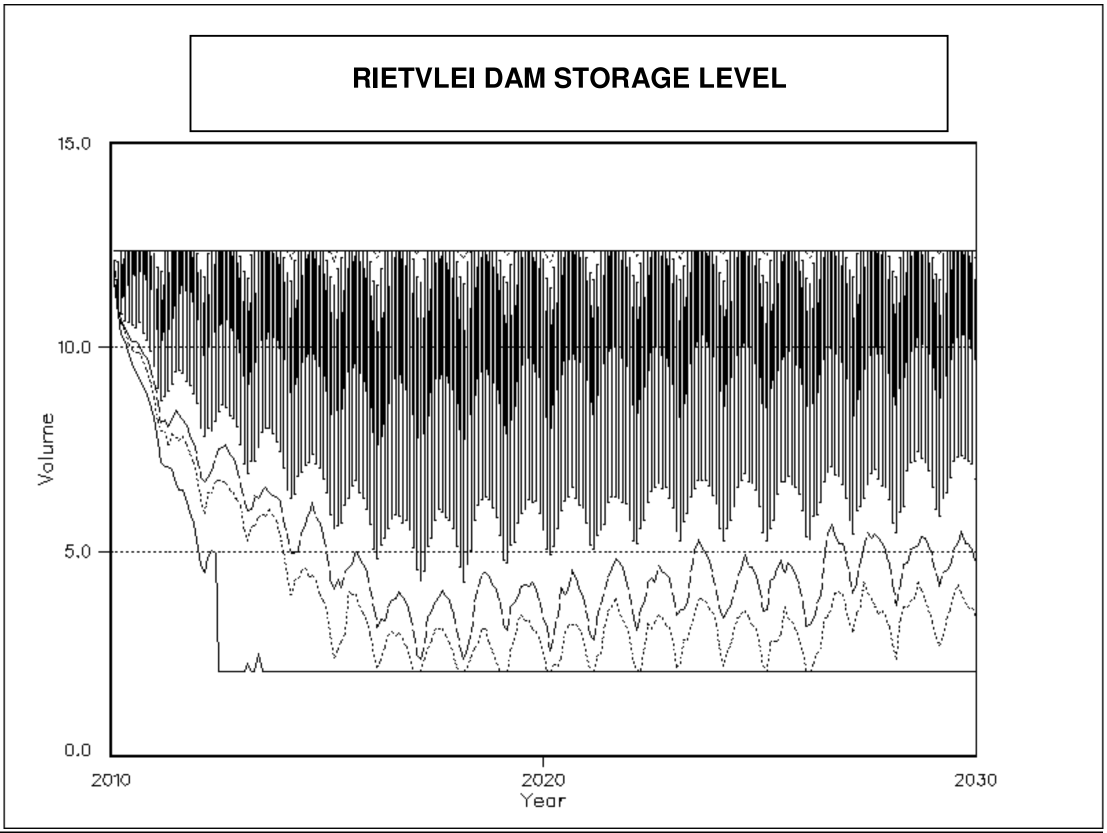


ROODEKOPJES AND KLIPVOOR COMBINED STORAGE LEVEL

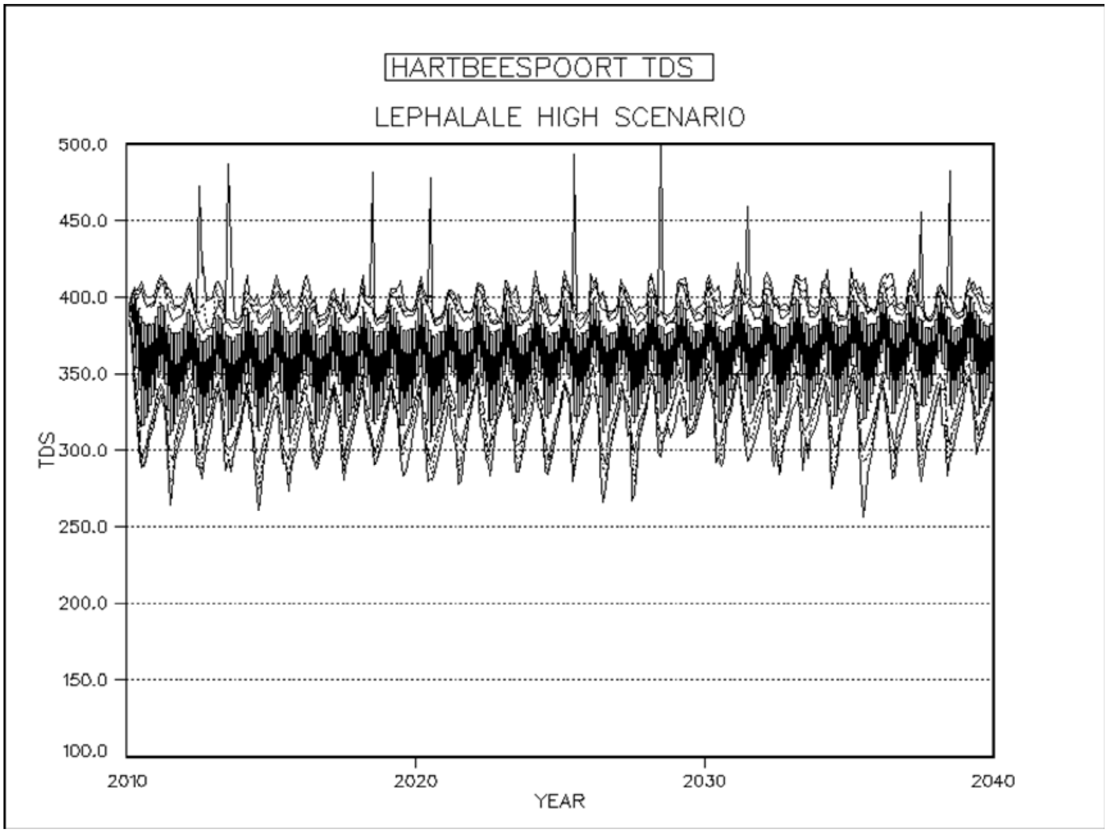


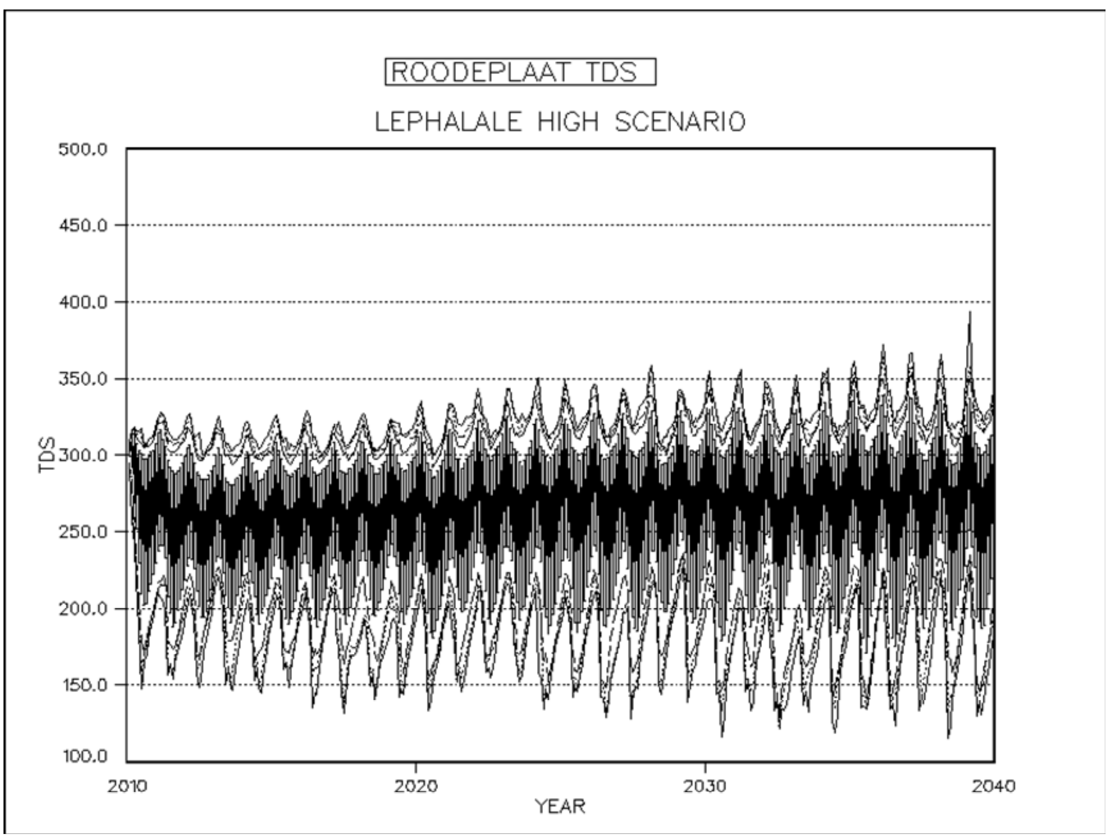
ROODEKOPJES AND KLIPVOOR COMBINED ALLOCATION




RIETVLEI DAM STORAGE LEVEL
15.0
10.0
5.0
0.0
Volume
2010
2020
2030
Year

Water Quality (Salinity) – Crocodile 2012 Base scenario WITH surplus Abstracted

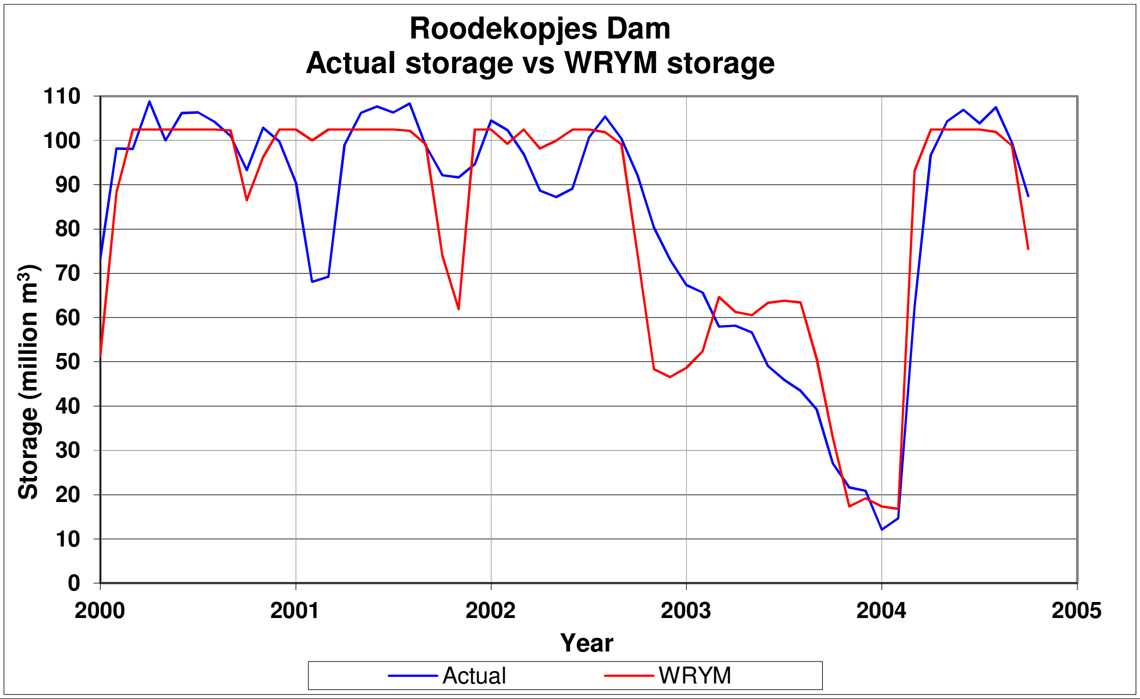


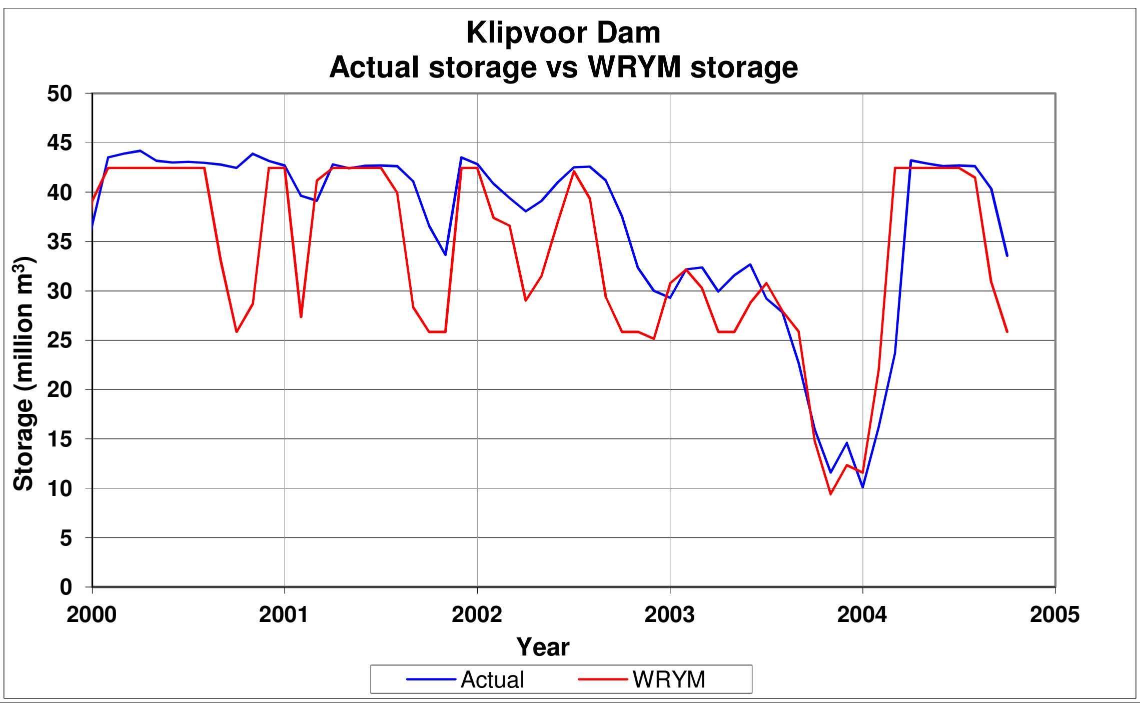


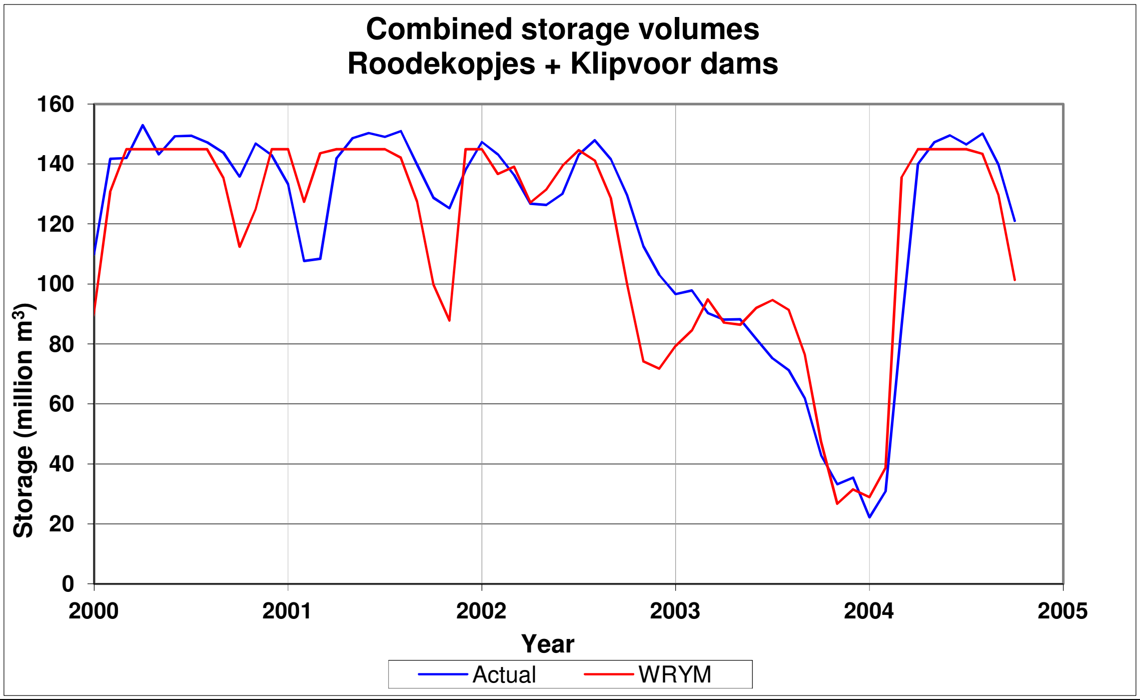
Appendix D

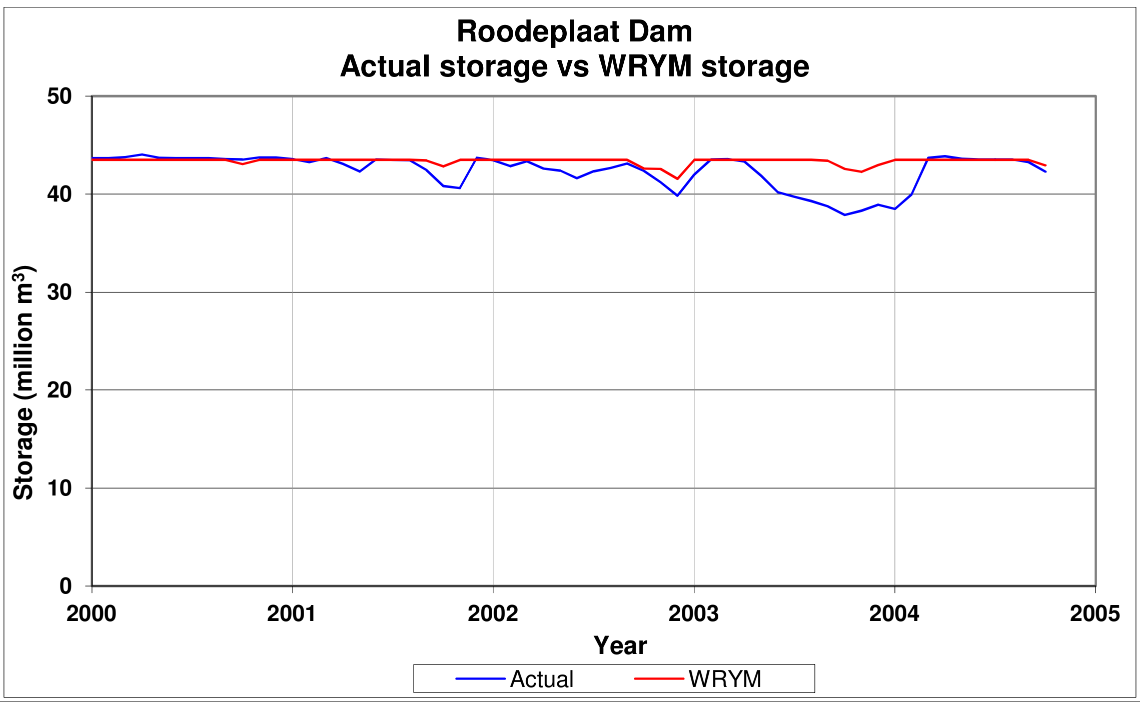
Actual versus simulated 2005 trajectories

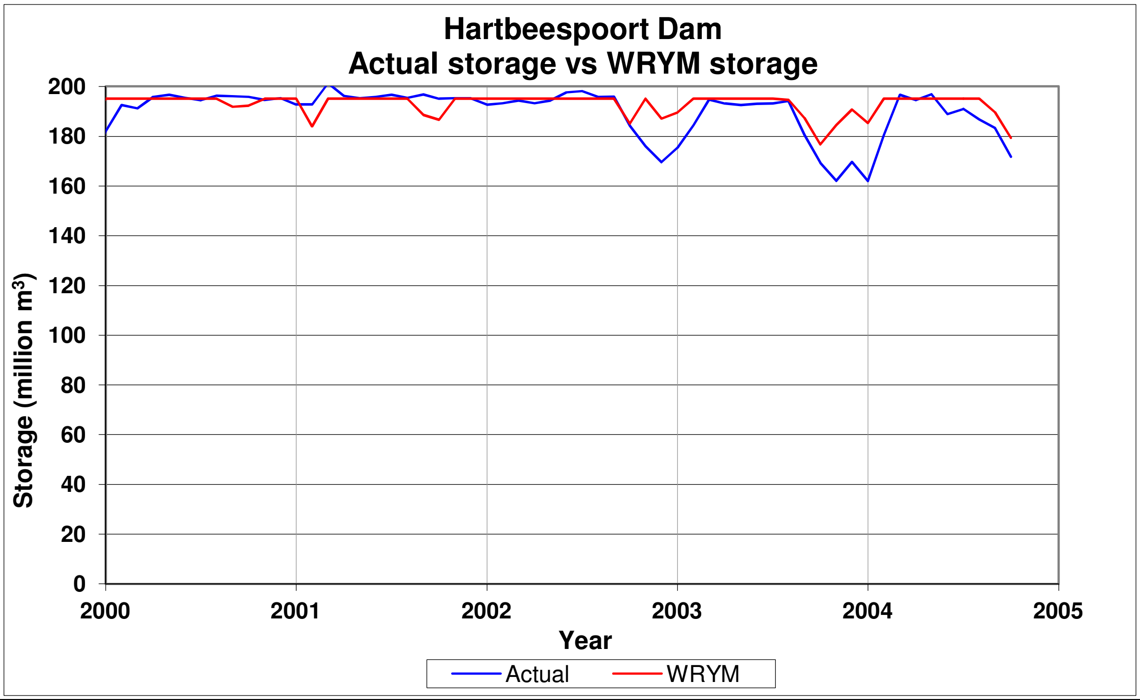
Crocodile West – 2004/2005 drought period actual vs simulated reservoir trajectories






Combined storage volumes
Roodekopjes + Klipvoor dams
160
140
120
100
80
60
40
20
0
Storage (million m³)
2000
2001
2002
2003
2004
2005
Year
Actual
WRYM


Roodeplaat Dam
Actual storage vs WRYM storage
50
40
30
20
10
0
Storage (million m³)
2000
2001
2002
2003
2004
2005
Year
Actual
WRYM



Hartbeespoort Dam
Actual storage vs WRYM storage
Storage (million m3)
200
180
160
140
120
100
80
60
40
20
0
2000
2001
2002
2003
2004
2005
Year
Actual
WRYM