ORANGE - SENQU RIVER COMMISSION
BOTSWANA LESOTHO
ORASECOM
NAMIBIA SOUTH AFRICA
Established 2000

Botswana | Lesotho | Namibia | South Africa

The Orange-Senqu River Commission (ORASECOM)

Sharing the Water Resources of the Orange-Senqu River Basin

Contract No.: P-Z1-EAZ-048/CS/01

Preparation of Climate Resilient Water Resources Investment Strategy & Plan and Lesotho-Botswana Water Transfer Multipurpose Transboundary Project

CORE SCENARIO UPDATE REPORT

Component I and II

February 2020

FINAL REPORT

Report number: ORASECOM 003/2019

FC/03066.cdr

The Preparation of a Climate Resilient Water Resources Investment Strategy & Plan and the Lesotho-Botswana Water Transfer Multipurpose Transboundary project was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the African Development Bank, NEDPAD-IPPF (Infrastructure Project Preparation Facility), the Stockholm International Water Institute (SIWI), the Climate Resilient Infrastructure Development Facility – UK Aid, and the Global Water Partnership-Southern Africa.

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I AND II

CORE SCENARIO UPDATE REPORT

Prepared for

Orange-Senqu River Commission (ORASECOM)

Von Willich LN, C nr Von Willich LN & Lenchen Avenue, Corporate 66 Office Park, Block A

Prepared by

in association with

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I AND II

CORE SCENARIO UPDATE REPORT

ORASECOM Document No.	ORASECOM 003/2019
Date of Publication:	February 2020
Authors:	C Seago, HG Maré and Study Team
Status:	Final Report

APPROVALS

For the Consultants: RMcKenzie

RS McKenzie Study Team Leader

Managing Director: WRP Consulting Engineers

AGMuir

C Muir Deputy Study Team Leader

For ORASECOM: HMolosiwa

C Molosiwa

Executive Secretary: ORASECOM Secretariat

TABLE OF REPORTS

Reports submitted	ORASECOM Report No.[1]
Inception Report Components I and II	ORASECOM 010/2018
Inception Report Components III and IV	ORASECOM 011/2018
Preparation of climate resilient water resources investment strategy & plan Component I	
Core Scenario Update Report Component I	ORASECOM 003/2019
Core Scenario Supporting Report: Water Requirements and Return flows **Component I**	ORASECOM 004/2019
Core Scenario Supporting Report: Water Conservation, Water Demand management and Re-use Report **Component I**	ORASECOM 005/2019
Core Scenario Supporting Report: Ground Water Report **Component I**	ORASECOM 006/2019
Climate Change Report **Component I**	ORASECOM 007/2019
Review and assessment of existing policies, institutional arrangements and structures Component I	ORASECOM 008/2019
Optimized IWRMP Core Scenario economic approach Report Component **I**	ORASECOM 009/2019
Climate Resilient Water Resources Investment Plan Report **Component I**	ORASECOM 010/2019
System analysis Report Component I	ORASECOM 011/2019
Preparation of climate resilient water resources investment strategy & plan Component II	
Roadmap for IWRMP Operationalization Report Component **II**	ORASECOM 012/2019
Roadmap for IWRMP Operationalization Executive Summary	ORASECOM 012A/2019
Roadmap for IWRMP Operationalization: Appendix B Strategic Actions Concept Notes	ORASECOM 012B/2019
Roadmap for IWRMP Operationalization: Appendix C Core Scenario Concept Notes	ORASECOM 012C/2019
Climate Resilience Investment Plan (Brochure)	ORASECOM 012D/2019
Roadmap supporting Report: Strategic actions and TORs (Appendix A to Roadmap Report)	ORASECOM 013/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component III Pre-feasibility Phase	
Pre-feasibility report Phase 1 Report Component **III**	ORASECOM 014/2019
Pre-feasibility report Phase 2 Report Component **III**	ORASECOM 015/2019

Reports submitted	ORASECOM Report No.[1]
Report A Phase 2: Dam on the Makhaleng River	ORASECOM 015A/2019
Report B Phase2: Water Conveyance System	ORASECOM 015B/2019
Report C Phase 2: Environmental and Social Assessment	ORASECOM 015C/2019
Report D Makhaleng River Ecological Water Requirements	ORASECOM 015D/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component IV - Feasibility Phase	
Feasibility Study Interim Report Component IV	ORASECOM 016/2019
Feasibility Study Report Component IV : Volume I – Main Report	ORASECOM 017/2019
Feasibility Study Report Component IV : Volume II - Drawings	ORASECOM 017/2019
Geotechnical Investigation Report for the Dam on the Makhaleng River. Annexure A to Volume I – Main Report	ORASECOM 017A/2019
Survey Report Annexure B to Volume I – Main Report	ORASECOM 017B2019

EXECUTIVE SUMMARY

The Orange-Senqu River basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, as well as a significant portion of South Africa, Botswana and Namibia. The Orange River originates in the Lesotho Highlands and flows in a westerly direction approximately 2 200 km to the west coast of South Africa and Namibia where the river discharges into the Atlantic Ocean

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterised by a high degree of regulation and several major inter-basin transfer schemes to manage the resource availability between areas of relatively abundant precipitation and the areas of greatest water requirements. The infrastructure involves most of the largest water storage reservoirs in Southern Africa as well as the associated transmission infrastructure, transmitting water to more than 250 major demand centers that are in some cases located outside of the Orange-Senqu River basin through intra and inter basin transfers.

The Republic of Botswana is an arid country facing serious water constraints which are exacerbated by the effects of climate change and land use change due to population growth and improved living standards. It is predicted that Botswana will experience chronic water shortages by about 2025, unless major new water sources are developed. Gaborone already relies on long-distance water transfers via the North-South Carrier and its water supply faces many risks including pipeline breakages and normal drought events. The 2015-2016 drought was particularly severe in Botswana and demonstrated the potential impacts of a severe drought compounded by climate change and infrastructure problems. As a consequence, the Governments of Botswana, Lesotho and South Africa signed a memorandum of agreement to undertake a reconnaissance study on a possible transfer scheme from Lesotho to Botswana (the L-BWT) aimed at developing water resources in Lesotho and the necessary conveyance infrastructure (pipelines, canals etc.). The proposed transfer scheme will convey water from Lesotho to Botswana and also supply various users in Lesotho and South Africa on route. This reconnaissance study has identified a number of possible development options which include a new dam on the Makhaleng River in Lesotho and a piped conveyance system to Botswana. The proposed scheme will be capable of providing 150 million m^3/a to Botswana in addition to the water supplied to the various consumers along the route in both Lesotho and South Africa.

Water scarcity is an important challenge in the Orange-Senqu River basin and requires coordinated efforts for the development, management and conservation of the water resources in the basin.

To co-ordinate and facilitate the water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000. This led to the development of a basin level Integrated Water Resources Management (IWRM) Plan adopted in February 2015 by the ORASECOM Member States. The IWRM Plan provides a strategic transboundary water resources management framework and action areas and serves as a guiding and planning tool for achieving the long-term development goals in the basin.

The objective of the current study is to update the Integrated Water Resources Management (IWRM) Plan of 2015 and identify an agreed and updated core scenario which includes the L-BWT project. Furthermore, the project aims to assist the Orange Sengu River Commission (ORASECOM) and the riparian countries in formalising the updated IWRM Plan.

The study is divided into two main components:

- A climate resilient investment plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario (Components I & II of the study); and
- The Lesotho-Botswana Water Transfer Project (Components III & IV of the study)

This report falls under Component I: Climate Resilient Water Resources Investment Plan. The purpose of this report is to describe all the inputs into the Core Scenario, the basis for decision making in the basin. The Core Scenario includes all existing and future water requirements from the basin. It also includes several catchment infrastructure developments that are likely to take place to offset deficits of water demands in the future.

This report contains only summarized information on water requirements, groundwater, water conservation and water demand management and Re-use as well as for water resource system analysis related work.

A water requirement and return flows database in Microsoft Excel Format for modelling purposes was created which contains over 1200 individual model elements, grouped according to region, and sub-catchment. In this Study the water requirements projections were updated and extended until 2050. Two water requirements scenarios were investigated and included in the database i.e. the requirements without Water Conservation/Water Demand Management in place and requirements with Demand Management (WC/WDM) included. **Table i** provide a summary of total water requirements in the Orange/Senqu basin excluding the small systems in the Orange and Vaal catchments.

Table i: Summary of the Orange/Senqu system main water requirements (ORASECOM 2019d)

Description	Water Requirements (million m^3/a)				
	2018	2020	2030	2040	2050
IVRS water requirement	3 978	3 970	4 104	4 341	4 667
Orange River System water requirement (includes Upper Orange but excludes Namibia requirements from the Orange)	3 387	3 372	3 385	3 401	3 422
Greater Bloemfontein system	97	101	126	154	185
Lesotho Water requirements [1]	45	58	162	381	408
Botswana water requirements	55	60	93	105	115
Namibia	142	144	203	395	534

Note 1- Includes the transfer to Botswana

As part of the groundwater study component, an assessment of available hydrogeological data, from existing work already carried out in the basin, was undertaken. The review and evaluation included:

- Assessment of the potential yield of the aquifer systems within each sub-catchment;
- Assessment of the potential volumes of groundwater in storage in each sub-catchment;
- State of current groundwater development and usage per sector within each sub catchment;
- Groundwater quality evaluated according to relevant water sector use standards
- (domestic, livestock, industrial, mining irrigation).
- The vulnerability of groundwater to over abstraction and contamination.
- Assessment of borehole yields (to determine whether aquifers can be economically exploited).
- Analysis of whether abstractions can impact on surface water resources.
- Identification of ecological or environmental limitations on abstraction.

The volume that can be sustainably abstracted is referred to as the Utilizable Groundwater Exploitation Potential, and range from less than 300 $m^3/km^2/a$ to 25000 $m^3/km^2/a$.

The data also shows that the largest volume of remaining allocable groundwater, calculated as Utilizable Groundwater Exploitation Potential minus current legal water use, is found in the Karst aquifers of the Ghaap Plateau in South Africa, where high borehole yields are still possible. From the above it is evident that the Mahikeng local municipality that that was identified as one of the RSA urban/rural centres to receive water from the possible future Lesotho-Botswana transfer, should have sufficient groundwater resources to support their water requirement needs, and should rather develop their groundwater resources. (**Figure i**).

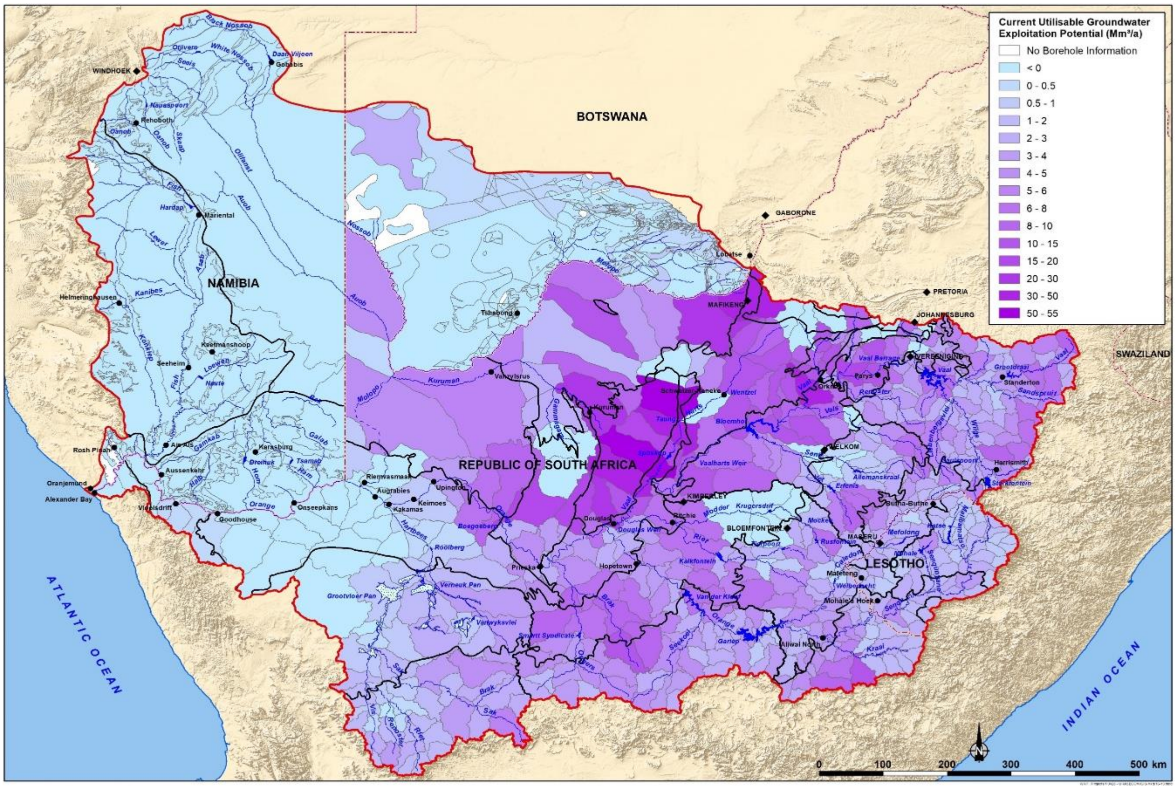


Figure i: Current Utilizable Groundwater Exploitation Potential (million m^3/a)

Groundwater resources are highly stressed in Lower Orange basin, the Middle to lower Vaal.

The Drakensberg Highlands in Lesotho consist of a fractured aquifer of low storage potential, although recharge is high, most is lost as interflow feeding and is not available to boreholes tapping the regional aquifer, consequently the Exploitation potential is lower than the other groundwater regions. The Northeastern Highlands have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the southeastern highlands. Locally, the Northeastern Highland region is moderately stressed by existing abstraction.

Data indicates that for the majority of the Namibian part of the basin, there is little scope for development of large-scale groundwater use schemes for potable use. In Botswana, the aquifers with the highest Utilizable Groundwater Exploitation Potential (UGEP) are Ecca North, Lebung and Lower Transvaal South.

WC/WDM

Municipalities in the IVRS managed to achieve savings of 110.0 million m^3/a of a projected 212 million m^3/a by June 2018, mainly through water restrictions. The actual savings for the IVRS in 2017 and 2018 were 6.4% and 6.7% respectively.

Crocodile (West) River water supply system includes the Northern Johannesburg, Pretoria, Rustenburg, Hammanskraal, etc. areas also receiving water from the IVRS. These municipalities have not achieved their June 2018 targets, although reasonable savings were achieved. The actual savings achieved for the 2017 and 2018 years were 8.2% and 8.9% respectively.

Restrictions of 15% have been implemented in Mangaung Metropolitan Municipality during July 2015, which was increased to 20% in February 2016, due to resources being under stress and care should be taken to distinguish between savings achieved because of WCWDM and the restrictions implemented simultaneously. Actual saving achieved for 2017 and 2018 were 30.4% and 28.7% respectively, which is most probably partly due to the restrictions imposed on the system.

The available data for the Orange River Water Supply System have a low confidence level. Savings of 28.1% and 28.9% were however indicated for the 2017 and 2018 years, which seems optimistic.

Botswana WUC has set NRW targets in its Corporate Strategy 2019 – 2022 and has been forced to reduce consumption in recent years due to the ongoing droughts. The NRW is above 40% in all the southern management centers except Gaborone and Ghanzi. Most significant is the NRW in Lobatse which needs to be addressed to ensure sustainability of water supply services.

Lesotho WASCO has not achieved the set target of 26% NRW and no water use targets have been set. The NRW achieved by WASCO for the 2017/18 year was 36%. The WASCO should embark on a program me to eliminate intermittent supply as it corrupts consumer meter readings, damage infrastructure, increase number of bursts, demotivate staff and impacts on service delivery and willingness to pay.

The improved management of existing water sources including reducing losses, increasing water savings is a key strategic objective of Namibia's National Development Plan. Namibia plans to achieve 100% access to safe drinking water by 2020/21 in the urban areas. No water loss or NRW targets have been set. Initial results indicate low NRW and poor efficiency. The improved management of existing water sources including reducing losses, increasing water savings is a key strategic objective of Namibia's National Development Plan.

It is important to note that the beneficiaries of irrigation water savings depend on the makeup of the irrigation scheme, the location as well as prevailing management goals or policies. In general, savings from schemes sourcing water from smaller tributary rivers do not directly improve the water balance of the Vaal or Orange systems, implying the benefits of the savings are limited to the users receiving water from that source. In these cases, savings (reduced abstraction from the resource) will increase the assurance of supply while expanding irrigated areas will increase the economic activities. Savings from schemes receiving water from the main stem or large dams on the main stem, if not used to expand the irrigation areas, represent a reduction of the water requirement in the overall system water balance.

The Large Bulk Water Reconciliation Strategy for the Orange River, is the only strategy that included large irrigation schemes, making provision for some of the irrigation water use savings to be utilized by other users, which is not necessary from the irrigation sector. Of the total estimated saving of 10% in the ORP, 5% is used by the irrigators for expansion and the remaining 5% saving can be allocated for other purposes. For the rest of the irrigation schemes it was assumed that the irrigation farmers will utilize the savings for expanding of irrigation or improving the assurance of supply.

In South Africa, there are several re-use and recycling, direct or indirect, initiatives that have been incorporated into the various catchment specific reconciliation strategies. In the IVRS, the desalination of AMD will ensure a reduction in water that is needed for dilution purposes; it will reduce demand through reclamation and direct re-use and improve the salinity in the Vaal River system and Orange-Senqu basin, by eventually eliminating the discharge of saline AMD. In Ekurhuleni/ERWAT and the City of Tshwane, substantial volumes of wastewater would be recycled, reused and reclaimed for eventual use for potable and industrial use. A similar situation exists in the Nelson Mandela Bay MM, where wastewater would eventually be reclaimed for use by existing industries as well as new industrial developments in the Coega SEZ. In addition, the NMBMM would in future also be desalinating seawater for potable as well as industrial use.

In Botswana, treated wastewater is used to irrigate lucerne in Lobatse, golf courses in Gaborone, Jwaneng and Orapa, vegetables in Glen Valley and orchards and vegetable gardens at Serowe and Kanye Prisons respectively. WUC plans to develop capacity for greater reuse and recycling by upgrading and improving operations of the Mambo and Lobatse WWTW.

In Lesotho, there is only small-scale re-use by the Agricultural Collage. The previous report recommended that Maseru investigate the possibility to re-use its treated wastewater to irrigate its sports fields and golf course.

The eventual re-use of wastewater and the desalination of seawater could provide substantial volumes of water to all sectors, thereby securing water within the Orange-Senqu River basin. It is thus recommended that all the countries incorporate the re-use of water into its formal respective policies.

The Core Scenario was developed for the Integrated Orange-Senqu System as part of the Support to Phase 3 of the ORASECOM Basin-wide Integrated Water Resources Management Plan. The Core Scenario is the baseline tool that can be used by ORASECOM to undertake management decisions relating to water resources. As a result, the tool should be updated regularly in order to make use of the most recent information available in the basin. The Core Scenario includes a description of the existing or current key elements, conditions and operating rules as applicable to the entire Orange-Senqu Vaal system, as well as the inclusion of possible future developments that is already part of the future water resource related planning by each of the basin counties. Important changes of the previous to the current Core Scenario are highlighted in the following tables.

Table ii: Updates of conditions applying to the Integrated Vaal River System

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial demands imposed on the Integrated Vaal system will be at 2013 development level at the start of the analysis	All the urban/industrial demands imposed on the Integrated Vaal system will be at 2018 development level at the start of the analysis
Use latest demand growth as used for the 2013/14 Vaal AOA and was also adopted in the updated demand data base for ORASECOM Phase lll study. Assume WC/WDM is in place based on latest information from the "Maintenance of the Vaal River Reconciliation Strategy". (DWA, 2014) This reflects the current progress in WC/WDM as taking place in reality.	Use latest demand growth as determined as part of Task 1b1 of this Study and presented in Section 2. Assume WC/WDM is in place based on latest information obtained as part of Task 1b4 of this Study and presented in Section 4. This reflects the potential savings that can be achieved by carrying out WC/WDM in the major urban centers.
Irrigation will be based on 2013 development level. Where irrigation allocations are applicable, the allocated volume will be used as the demand. This condition applies to the start year of the analyses where after the expected growth in irrigation will be included where applicable. In most areas however, irrigation will not be growing.	Irrigation is based on 2018 development level. Where irrigation allocations are applicable, the allocated volume will be used as the demand. This condition applies to the start year of the analyses thereafter the expected growth in irrigation will be included where applicable. In most areas however, irrigation will not be growing.
In the Vaal Reconciliation Strategy study, it was identified that there is a significant amount of unlawful irrigation in the Upper Vaal, partly utilizing the transferred water from Lesotho and the Thukela. The removal of the unlawful irrigation was one of the urgent matters included in the Final Strategy prepared for the Integrated Vaal System. The process has already been put into action and currently 66% of the unlawful irrigation has been removed. For the purpose of the core scenario it will therefore be accepted that these irrigation areas in the Vaal will be at lawful plus 34% at the start of the analyses. It is assumed that further eradication takes place according to the latest information from the "Maintenance of the Vaal River Reconciliation Strategy" (DWA, 2014) study, which is currently in process.	In the Vaal Reconciliation Strategy study, it was identified that there is a significant amount of unlawful irrigation in the Upper Vaal, partly utilizing the transferred water from Lesotho and the Thukela. The removal of the unlawful irrigation was one of the urgent matters included in the Final Strategy prepared for the Integrated Vaal System. The process was put into action and it is assumed that by now the targeted 85% of the unlawful irrigation has been removed. Updated information relating to the success and continual maintenance of eradication and has been sought as part of this Study as well as the ongoing Vaal Reconciliation Strategy Maintenance Study, however, it has not been forthcoming. Due to some unknown's sensitivity analysis will be carried out.
Polihali is built to specification, Fixed transfer from outset, Polihali Dam start to deliver water in 2022	Polihali Dam has been included to start delivery from December 2025 (start storage from November 2023). The inter-reservoir operating rule between Mohale, Polihali and Katse is as per recommended as part of the Determination of the Operating Rule for the Operation of Phase ii Study. The Phase ii operating rule for transfer to the Vaal as recommended in the above-mentioned study still need to be agreed on between Lesotho and the RSA.

Core scenario description (2014)	Adjust / update for this study
	For the purpose of the Core Scenario the following was agreed: From 2018 until 2025 when Polihali Dam transfers start, the current agreed operating rule remain in place. Meaning that the 780 million m^3/a is transferred on a constant basis from Katse to the Vaal. From 2025 onwards the Phase 1 transfer volume is still being transferred on a constant basis of 780 million m^3/a, but the additional yield created by Polihali Dam will only be transferred to the Vaal when its needed by the Vaal system. This last component then represents the only variable part of the transfer volume. Adjustments to the following based on updated information from LHWP Phase 2 Operating Rules Study: Percentage hydrology entering Polihali Dam Katse, Mohale and Polihali evaporation Updated Polihali EWR
Include current and planned neutralizing of mine water outflows. The timing of the planned neutralizing will be according to latest information from the "Implementation of the Vaal River Reconciliation Strategy" (DWA, 2014) study. Desalination of AMD water. The timing of the desalination of the different mine drainage point is according to the latest information from the Maintenance of the Vaal River Reconciliation Strategy study.	Include current neutralization of mine water outflows and planned desalination of Acid Mine Drainage (AMD). All neutralization is currently being undertaken. The timing and details relating to the AMD is as per existing planning targets for desalination of AMDS. The Consultant consulted and established that DWS RSA is currently planning to update the Vaal Integrated Water Quality Strategy (2009) which will include the improvement of the simulated dilution releases. This is likely to be an 18-month study which will also include Scenario analysis of appropriate AMD management options. These results will thus not be available in time for use in the Core Scenario. It is however important to take note of this for future analyses.
Exclude recommendations from the Vaal Reserve study (DWA, 2010) regarding the required flows downstream of Sterkfontein Dam and Douglas Weir for the purpose of the base scenario. These recommendations are not implemented at this stage as it results in a decrease in the Vaal system yield.	Exclude recommendations regarding the required flows downstream of Douglas Weir as these were never implemented. Include recommendations from the Vaal Reserve study (DWA, 2010) relating to releases from Sterkfontein Dam in accordance with natural flow conditions. The Douglas EWR node was excluded from the final Vaal Reserve as published in the Government Gazette.
Botswana-Vaal Gamagara, extend existing Vaal Gamagara transfer scheme to supply water to Botswana, Transfer 5 million m^3/a to Botswana. Expected date for transfers to start is between 2021 & 2023.	Do not include, no longer an option being considered
	Include further Phase of Thukela transfer from about 2040 when Vaal requirements growth exceeds allowable risk of supply criteria based on the current analysis

Table iii: Updates of conditions applying to the Senqu Mohokare River Systems Lesotho

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial and mining demands imposed on the Senqu Mohokare systems will be at 2013 development level at the start of the analysis.	All the urban/industrial and mining demands imposed on the Senqu Mohokare systems will be at 2018 development level at the start of the analysis.
Use latest urban/industrial mining demand growth as used for the Orange Reconciliation and ORASECOM studies.	Use latest urban/industrial mining demand growth as determined as part of Task 1b1 of this Study including reductions as a result of WCWDM initiatives.
Irrigation will be based on 2013 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis	Irrigation will be based on 2018 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis. Irrigation growth planned along the Lower Orange and in Lesotho to be considered.
Include Metolong Dam and Complete water supply distribution system from Metolong Dam and support planned area of supply	Metolong Dam is in place and the demands imposed on the dam are as per updated information obtained as part of this study.
	Inclusion of Further Lowlands phases, Hlotse (105 million m^3) and Ngoajane (36 million m^3) dams, with implementation dates of 2030 and 2035 respectively. (Semongkong Dam was requested to be included by 2040. Unfortunately, not sufficient data on this dam was available to be modelled)
	The implementation of the Lowlands Water Development Project Phase II (Zones 2/3 and Zones 6/7) Goes along with Hlotse and Makhaleng dams
Lesotho Botswana transfer, building of a transfer system taking water from Lesotho to Botswana	Include Makhaleng Dam as per Component iii of this study, site S2 selected for inclusion. Dam to turn on in 2030. A high and a low Transfer option to Botswana will be considered and will start after completion of pipeline assumed to be by 2033.
	The implementation of Lesotho Lowlands Water Supply Scheme in Zones 1 & 2. Goes along with Ngoajane and Hlotse dams
	Implementation of Lesotho Lowlands Water Supply Scheme for Zone 8 and 8 (a) (Mohale's Hoek and Quthing) River runoff supply from the Senqu River (In future might be utilizing releases from hydro-power dams.)
	Include compensation releases from Makhaleng Dam to Verbeeldingskraal Dam if required based on system analyses results

Table iv: Conditions applying to the Integrated Orange River System RSA

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial and mining demands imposed on the Orange system will be at 2013 development level at the start of the analysis.	All the urban/industrial and mining demands imposed on the Orange system will be at 2018 development level at the start of the analysis.
Use latest urban/industrial mining demand growth as used for the Orange Reconciliation and ORASECOM studies.	Use latest urban/industrial mining demand growth as determined as part of Task 1b1 of this Study including reductions as a result of WCWDM initiatives
Irrigation will be based on 2013 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis	Irrigation will be based on 2018 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis. Irrigation growth planned along the Lower Orange and in Lesotho to be taken into account.

Core scenario description (2014)	Adjust / update for this study
The 12 000-ha allocated for use by resource poor farmers. Only include those already developed at 2013 and allow for the expected further development as included in the ORASECOM Phase lll data base	The 12 000-ha allocated for use by resource poor farmers. Only include those already developed at 2018 based on information received from the Regional office as part of Task 1b1 of this study and allow for the expected further development as included in the data base. This is summarized as follows: Free State = 3 000 ha of which 837.6 ha has been taken up Northern Cape = 4 000 ha of which 1671 ha has been taken up Eastern Cape = 5 000 ha of which 2460 ha has been taken up
EWR for Orange as currently released for the river mouth (287.5 million m3/a) which was obtained from the Orange River Replanning Study (ORRS and is referenced as ORRS EWRs). After yield replacement dam, RECs EWR at key sites only, Refinement of EWRs on the Lower Orange to accommodate the required low flows at the estuary	EWR for Orange as currently released for the river mouth (287.5 million m^3/a) which was obtained from the Orange River Replanning Study (ORRS and is referenced as ORRS EWRs) until 2020 after which the “preliminary EWR” will be implemented as according to recommendations from the Lower Orange EWR Study. Final Recommended EWRs (from Lower Orange EWR Study) at Augrabies and Site 5 implemented from 2028 after Noordoewer/Vioolsdrift Dam comes online.
Transfers to the Eastern Cape through the Orange/Fish tunnel based on the latest data from the Orange Annual Operating Analysis as captured in the ORASECOM Phase lll data base. This demand is based on the allocation and scheduled irrigation area and supply to Port Elizabeth and several small towns in the Fish/Sundays sub-system.	Transfers to the Eastern Cape through the Orange/Fish tunnel based on the latest data from the 2018/2019 Orange Annual Operating Analysis as captured in the data base (ORASECOM, 2019d). This demand is based on the allocation and scheduled irrigation area and supply to Port Elizabeth and several small towns in the Fish/Sundays sub-system.
Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in place (Welbedacht to Bloemfontein and Novo Transfer). Only allow the initial proposed increase in Tienfontein Pumping capacity and Novo Transfer capacity according to latest information from Greater Bloemfontein Reconciliation Strategy implementation study (DWA, 2014b).	Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in place (Welbedacht to Bloemfontein and Novo Transfer). Allow the initial proposed increase in Tienfontein Pumping capacity and Novo Transfer capacity according to latest information from The Mangaung Gariep Water Augmentation Project Study. Allow a further increase in Tienfontein pumping in 2040 at the time when shortages in the Bloemfontein subsystem occur.
	Include intervention measures as defined in the Bloemfontein Reconciliation Strategy with timing as determined in the Mangaung Gariep Water Augmentation Project. Included as follows: 2019 increase in Maselpoort WTP capacity from 120 Ml/d to 130 Ml/d 2021 Mockes Dam Storage increase to 12.13 million m^3 2021 Indirect re-use 16.4 million m^3/a 2022 Gariep Phase 1: 32 million m^3/a 2030 Direct re-use 11.7 million m^3/a 2033 Gariep Phase 2: 11 million m^3/a
Utilise Lower Level storage in Vanderkloof Dam	Utilise Lower Level storage in Vanderkloof Dam from May 2019. Though construction has not yet started, information obtained stated that this could be fast tracked under emergency conditions if it was necessary to make use of this storage. The lower level storage volume should therefore be available in the core scenario. The lower level storage will only be utilized between 1 in 50 to 1 in 100-year recurrence intervals and will thus not impact significantly on the generated hydropower.

Core scenario description (2014)	Adjust / update for this study
Construction of Verbeeldingskraal Dam in Upper Orange at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs (Core Option 2)	Construction of Verbeeldingskraal Dam in Upper Orange at same time when shortages start occurring in ORP due to Polihali (May 2032). Implement the REC EWRs
Construction of Noordoewer/Vioolsdrift Dam on Lower Orange at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs	Construction of Noordoewer/Vioolsdrift Dam on Lower Orange to be completed in 2028. Size is set as 650 million m^3 gross storage according to the Noordoewer/Vioosldrift Dam Feasibility Study.
Lesotho Botswana transfer, building of a transfer system taking water from Lesotho to Botswana	Include Makhaleng Dam as per Component iii of this study, site S2 selected for inclusion. Dam to turn on in 2030. A high and a low Transfer option to Botswana will be considered and will start after completion of pipeline assumed to be by 2033.
	Include compensation releases to Verbeeldingskraal Dam if required based on system analyses results
Raising Gariep by 10m at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs (Core Option 1)	To be Included as a scenario variable. Not included in Core Scenario.

Table v: Conditions applying to the Fish River (Namibia) System

IWRMP (ORASECOM PH3) BASELINE	ADJUST FOR THIS STUDY
Complete construction of Neckartal Dam and support to irrigation included	Neckertal Dam and the associated Environmental Releases are on. Releases for hydropower to start in 2021 and Irrigation demand from 2028 after the irrigation scheme was development
Projected demand growth imposed on both Hardap and Naute dams.	Projected demand growth imposed on both Hardap and Naute dams.
Restrictions not imposed on water supply to users from Hardap and Naute dams.	Restrictions not imposed on water supply to users from Hardap and Naute dams.

Core Scenario analyses and results. The start date of the Core Scenario Analyses was set to May 2018. The WRPM was configured to run for 33 years, with the end date of 2050. 1000 stochastic sequences were analyzed with the model, and the results are presented in the form of box and whisker plots. These allow for the assessment of assurances, either risk of failure of dams or risk of non-supply of demands.

The Pre-feasibility Study Phase I recommended that two Lesotho-Botswana transfer volume options be taken forward to Phase II of the Pre-feasibility Study. These two options refer to a high transfer of 186 million m^3/a from Makhaleng Dam and a low transfer of 97 m^3/a. The two Core Scenarios were defined by utilizing these two given transfer volumes. The Two Core Scenarios is identical, with the only difference being the two transfer volumes to Botswana, the high and the low transfer volume as define above. Only the low transfer option allows for irrigation development to be supported from Makhaleng Dam as the yield from Makhaleng Dam is not sufficient when the high transfer option is in place.

WRPM analyses results from the two Core Scenarios were compared as well as with the results produced from the previous Core Scenario. Several sensitivity analyses were carried out in support of the two Core Scenarios. The following sensitivity analyses were carried out.

- Exclude water conservation and water demand management in some of the key large water supply systems. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the final reserve to be imposed on the ORP. The Preliminary Reserve already approved by DWS RSA will then be in place from 2022 to the end of the analysis period. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the option to utilize the Lower Level Storage in Vanderkloof Dam due to its impact on hydro-power generation from Vanderkloof Dam. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the future Hlotse and Ngoajane water supply systems from the Core Scenario with the high Lesotho Botswana transfer in place to determine the impact of these two systems on the water supply to the Greater Bloemfontein system.
- Include the large Noordoewer/Vioolsdrift Dam instead of the medium size Noordoewer/Vioolsdrift Dam, as agreed on for the Core Scenario.
- Determine the change in behaviour for the Makhaleng Dam and transfer system for the low Botswana transfer option, when the Lesotho irrigation is reduced to 40 million m^3/a.
- The results from the Core Scenario with the high Botswana transfer showed that the Lesotho-Botswana transfer was supplied at unacceptable low assurance levels. Include a lower zone in Makhaleng Dam from which water can't be used to support the ORP, but only to support users allocated to Makhaleng Dam and transfer scheme. The purpose of this zone is to adjust the operating rule and thereby increase the assurance of supply to users from Makhaleng Dam.

For detail on the results and the related projection plots the reader is referred to **Section 7** of this report.

Summarized fine-dings, conclusions and recommendations from these analyses are given below per main water supply system.

<u>The Integrated Vaal River System (IVRS)</u>

- The LHWP – IVRS operating rule has a significant impact on the water supply situation in the IVRS. A study recently completed by the Lesotho Highlands Water Commission on the operating rules to be implemented for Phase II of the LHWP was used as the basis for the operating rule used in the Current Core Scenario. This is only one of the recommended operating rules from the study and the two countries (Lesotho and RSA) still need to agree on the final operating rule to be implemented. It is thus important that agreement be obtained on the final operating rule, so that the consequences of the selected operating rule to all parties involved are also known. The final selected LHWP Phase ll operating rule can thus impact on the results from the Current Core Scenario.

- The selected LHWP Phase ll operating rule was agreed with the four basin states to be used for the purpose of the Core Scenario analysis. This rule resulted in a much-improved water supply from the IVRS. The IVRS will however experience possible deficits in supply from 2021 to 2025 before Polihali Dam is in place. Significant deficits are then only again expected by around 2044. The next intervention option which will be the further Phase from the Thukela Transfer system, need to be implemented by then.
- For the IVRS it is crucial that the WC/WDM targets be met as well as the reduction/eliminating of unlawful irrigation in the Upper Vaal. The IVRS will experience significant deficits if these targets are not achieved.
- The planned re-use of return flows in the Crocodile River from the Northern Johannesburg, Pretoria, Rustenburg areas etc. receiving water from the IVRS was assumed to be in place in future. This will reduce the demand imposed on the IVRS. It is however important that DWS RSA check that there will still be sufficient flow available in the Crocodile River System to satisfy the Reserve requirements after the implementation of re-use.
- The Current Core Scenario included the implementation of the desalination and re-use of the Acid Mine Drainage in the Middle Vaal according to the recommended planning from the Vaal Reconciliation Strategy study. DWS RSA is currently in the process to update the Vaal System Integrated Water Quality Strategy, which might result in a change of approach regarding the treatment and use of the Acid Mine Drainage water. This need to be followed up in future, to determine whether significant changes will occur that will impact on water supply from the IVRS.

<u>The Orange River Project (ORP)</u>

- The storage projection plot of the ORP system (Verbeedingskraal Dam included) shows very low storage levels at the 99% and 99.5% exceedance probability levels from about 2030 onwards. This is partly due to the ORP system being overloaded, thus supplying more than the available yield, but also due to the operating rule that allow support from Verbeeldingskraal Dam and compensation releases from Makhaleng Dam once the storage in Gariep and Vanderkloof dams is low. From the future major upstream developments, compensation releases were only made from Makhaleng Dam in support of the ORP. The purposes of the compensation releases are to make good the reduction in yield of the ORP, due to the upstream Makhaleng Dam development. The reduction in ORP yield due to the development of the Hlotse Dam and Ngoajane Dam schemes were not compensated for. Only EWR releases were made from these two dams for the purpose of the Core Scenario.

- The water supply plots from the ORP system show a more positive picture than the storage projection plots, as deficits in the irrigation supply for the first time occurred in 2030 and 2031, then again on a more continuous basis from 2037 onwards. Supply to the urban/industrial/mining component showed deficits from 2044 onwards. The filling up of several future dams around the 2030's such as Noordoewer/Vioolsdrift, Makhaleng and Hlotse dams, is probably the main reason for the deficits experienced in 2030 and 2031.
- When Hlotse and Ngoajane Dams are removed from the Current Core Scenario, the supply from the ORP is acceptable. This means that some compensation needs to be made from Hlotse and Ngoajane Dams, to make up for the reduction in yield at the ORP when these two dams are included in the Core Scenario.
- The medium size Noordoewer/Vioolsdrift Dam is not sufficient to support the significant growth in the Namibia irrigation requirement over the entire projection period, and deficits start to occur from 2043 onwards.
- With the large Noordoewer/Vioolsdrift Dam in place, these irrigation requirements are very well supplied. The supply to the remainder of the ORP system also improved to acceptable levels, when the large Noordoewer/Vioolsdrift Dam is in place.
- The implementation of WC/WDM within the ORP for urban/Industrial/Mining and irrigation use is of high importance, as deficits in water supply will increase significantly and is expected to already start by 2029 if not implemented.
- Not utilizing the Lower Level Storage in Vanderkloof Dam will significantly increase the deficits in the ORP system. Deficits is expected to then start already from 2030 onwards. Its only for droughts with a recurrence interval of 1 in 20 years and higher that Vanderkloof Dam storage drop too low to be able generated hydropower when the Lower Level Storage option is implemented. This can however be improved by adjustments to the operating rules.
- At this stage there is still great uncertainty of what the final Orange River Reserve requirement will be. For this reason, it was regarded as important to carry out a sensitivity analysis on the impact of this Reserve on the water supply from the ORP system. If the current approved preliminary reserve is maintained for the total projection period and not replaced in future by a Reserve with a higher water requirement, the improved positive water supply impact on the system is significant. The ORP dams will operate at much higher storage levels and demands will be fully supplied. The impact of this can however be detrimental on the environmental condition of the river and the river mouth. It is thus very important to carry out the classification study followed by the Reserve determination, to obtain a balance between the ecology and the economy of the area.

Metolong Dam sub-system

- The water requirement projections for Maseru and surrounding areas significantly increased since the previous study in 2014 when the Core scenario was defined for the first time. The Previous Core Scenario thus indicated no deficits for the supply to Maseru. The current Core

Scenario shows deficits to occur already from approximately 2030 onwards. By 2050 the deficits are quite severe.

- It is recommended that the old existing system taking water directly from the Mohokare River be upgraded so that it can again provide a substantial amount of support to the Maseru water supply system. Propper operating rules also need to be developed and implemented to optimise the water supply from the existing water resources.
- Consider also to support Maseru from the Makhaleng Dam and transfer system.

Makhaleng Dam and Transfer Scheme

- The impact of Makhaleng Dam and transfer scheme on the available yield from the ORP is significant, and it is thus important to utilize Makhaleng Dam to also release compensation water in support the ORP. The yield from a 3 MAR Makhaleng Dam is sufficient to support the ORP, as well as to supply the local Lesotho water requirements and transfer to Botswana, but within the limits of the available yield.
- When the high Botswana water requirement needs to be transferred from Makhaleng Dam, there will not be water available for irrigation in Lesotho from Makhaleng Dam.
- With the low Botswana transfer in place, Lesotho will be able to allocate between 40 to 77 million m^3/a for irrigation, depending on the assurance of supply required for irrigation purposes.
- The impact of the Low and High Botswana transfer option on the ORP is almost the same. This is due to the local Lesotho irrigation requirement that is added to the Low Scenario and not to the High Scenario.
- The assurance of supply to users from the Makhaleng to Botswana transfer was found to be unacceptably low, based on the initial analyses carried out. It was found that the assurance of supply is quite sensitive to the operating rule used for Makhaleng Dam. The operating rule was then accordingly adjusted, and the assurance of supply was significantly improved without jeopardizing the water supply assurance available at the ORP. Further improvement in the water supply and related assurance from Makhaleng Dam is still required. It is thus recommended that this be investigated in more detail as part of the feasibility study.

Hlotse Dam sub-system

- The EWR as obtained from the SMEC Report is a very low level EWR, with little information available to be able to model properly. It is thus recommended that a high level EWR be determined as part of the Hlotse Dam Feasibility Phase.
- The results from the Current Core Scenario showed that Hlotse Dam performed well with the EWR (14.4 million m^3/a), irrigation requirement of 46.2 million m^3/a as well as an urban requirement growing from 15.1 to 19.4 million m^3/a by 2050, all imposed on the dam. The demands imposed on the sub-system was supplied at a high assurance level. This indicates that there is some surplus yield available in the Hlotse dam sub-system that can be used to release compensation water in support of the Greater Bloemfontein and or ORP system.

- It is recommended to investigate the possibility of increasing this dam to generate an increased yield that can be used to make good the reduction in yield at the Greater Bloemfontein and ORP systems, caused by the implementation of Hlotse Dam. This can be achieved by means of compensation releases from Hlotse Dam.

Ngoajane Dam sub-system

- The EWR as obtained from the SMEC Report is a very low level EWR with little information available to be able to model properly. It is thus recommended that a high level EWR be determined as part of the Ngoajane Dam Feasibility Phase.
- As for the Hlotse sub-system, results from the Ngoajane sub-system revealed a well-supplied system with no deficits over the entire simulation period. The total water demand that was imposed on the sub-system included 8 million m^3/a for EWR purposes, 6.2 million m^3/a for irrigation and an urban requirement starting at 16.5 million m^3/a and increasing to 23 million m^3/a by 2050. The demands were in general supplied at high assurance levels, which indicates that there might be some surplus yield available in this sub-system.
- It is recommended to investigate the possibility of increasing this dam to generate an increased yield that can be used to make good the reduction in yield at the Greater Bloemfontein and ORP systems, caused by the implementation of Ngoajane Dam.

Neckartal Dam sub-system

- Results from the system analysis of the Current Core Scenario showed that Neckartal Dam will take approximately 10 years to stabilize after inundation started. The dam is expected to be seldom full or spilling (approximately1:20 years).
- Neckartal Dam performed quite well, supplying water for irrigation purposes with a total demand of 90 million m^3/a, EWR requirements with the median demand at approximately 6 million m^3/a and releases of 100 million m^3/a for hydropower generation. The hydropower releases are a non-consumptive demand and is utilised downstream of the dam to supply the irrigation and EWR. All the water requirements imposed on the dam were well supplied at relative high assurances.

Hardap and Naute dams

- Hardap urban requirements were supplied at reasonable assurance levels.
- Irrigation were supplied at acceptable assurance levels, although a bit low.
- No further allocation of water requirements should be imposed on Hardap Dam.
- The assurance of supply to the Naute urban component was a bit low.
- Irrigation supply from Naute Dam was at an acceptable level of assurance.
- The water demand on Naute should not be increased.

Assessment of multipurpose dams. It is quite possible that deficits will be experienced with the updated Core Scenario in place, as more water is removed from the Senqu basin (Polihali Dam) in support of the Integrated Vaal River System, the possible transfer to Botswana

(Makhaleng Dam) as well as due to local developments within Lesotho such as Hlotse and Ngoajane dams.

To be able to overcome the deficit in the ORP or in some places within Lesotho, additional multipurpose dams in Lesotho will be assessed to increase the yield available from the basin. This additional yield can then be used to balance the deficits that might have been created due to the updated Core Scenario components.

Although the development of new dams mainly impacts on users downstream of the dam, some smaller impacts can also be expected on upstream systems. A simple illustration of this would be the following:

- Let's assume there is no water use from the Orange River by the RSA and Namibia as it was many years ago.
- If Lesotho wanted to build a dam in the Senqu under such conditions, this dam would have no impact on downstream users, as there were no users downstream, except for the environment.
- Over and above the environmental releases no additional releases (compensation releases) would then be required from the Lesotho Dam.
- Currently however, the Orange River in the RSA and along the RSA/Namibia border is highly developed, with many users as well as major dams in place.
- Under these conditions any dam build by Lesotho in the upstream catchment will have a significant impact on the water supply downstream and compensation releases from the Lesotho Dam will be required to be able to maintain the existing downstream water balance.

A practical example of such a case can be illustrated by the impact of Polihali and Verbeeldingskraal dams on the available yield from the future Makhaleng Dam in Lesotho. This is a realistic scenario as all three these dams are included in the short to medium term planning horizon of the two countries. Results from the analysis showed that the impact of Verbeeldingskraal and Polihali dams on the available net yield from Makhaleng Dam is relatively small being 11 million m^3/a. This impact is purely as result of the rule/agreement dictating that upstream developments should not impact negatively on existing downstream developments.

Quite a number of scenarios were analyzed as part of this assessment. These scenarios are listed and briefly described in **Table v**.

Table v: Summary of scenarios for historic firm yield analyses

Scenario	Description	Purpose
ORP yield 2013	ORASECOM Phase lll at 2013 development level	HFY of the then existing ORP
2018 Base Scenario	Current system with existing infrastructure and 2018 development level	Determine yield from ORP to compare with the Phase 3 ORP yield result and related yield impact due to increased upstream water requirements.
2030 Base Scenario	As 2018 Base scenario but including future infrastructure developments: Polihali Dam, Verbeeldingskraal Dam, Lower Level storage in Vanderkloof and 2030 development level water requirements.	Determine yield from ORP to confirm whether Verbeeldingskraal and Vanderkloof Lower Level storage were able to balance the ORP yield reduction due to Polihali Dam.
Scenario 2 (2030)	As the 2030 Base Scenario but including the proposed Makhaleng Dam and related transfer to Botswana	Determine yield from ORP and verify whether the proposed Makhaleng Dam can support the Botswana transfer and not reduce the ORP yield.
The purpose of Scenarios 2d to 2h is to determine the impact on yield from upstream dams due to the development of downstream dams		
Sub-scenario 2d (2030)	As Scenario 2 but excluding Polihali, Verbeeldingskraal and Makhaleng Dam.	To determine the HFY at Vanderkloof/Gariep when none of the three dams are in place
Sub-scenario 2e (2030)	As scenario 2d but including a 3 MAR Makhaleng Dam. Makhaleng Dam allowed to support Gariep and Vanderkloof dams to maintain the downstream water balance.	This scenario will provide the HFY available at Makhaleng when the downstream system (ORP) still produces the same HFY as for Scenario 2d
Sub-scenario 2f (2030)	As scenario 2 but excluding Makhaleng Dam. This scenario is in fact the same as the 2030 Base Scenario	This scenario provides the HFY available at Vanderkloof/Gariep when Polihali and Verbeedingskraal dams are in place.
Sub-scenario 2g (2030)	As scenario 2f but including a 3 MAR Makhaleng Dam. Makhaleng Dam allowed to support Gariep and Vanderkloof dams to maintain the downstream water balance.	This scenario will provide the HFY available at Makhaleng when the downstream system (ORP) still produces the same HFY as for Scenario 2f.
Sub-scenario 2h (2030)	As scenario 2g but not allowing Makhaleng Dam to support Gariep and Vanderkloof dams.	This scenario will provide the HFY available at Makhaleng with no support to the ORP and will show the impact of Makhaleng Dam on the yield available from the ORP
Scenario 3 (2030)	As Scenario 2 but including the proposed Hlotse Dam (105 million m^3 gross storage) in the Lesotho Lowlands.	Determine the yield from Hlotse Dam. Determine the impact of the Hlotse Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River
Scenario 3c (2030)	As Scenario 3 but increase Hlotse Dam by 15 million m^3 to gross storage to 120 million m^3	Determine the increase in yield due to the larger Hlotse Dam. Determine the impact of the Hlotse Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River
Scenario 3d (2030)	As Scenario 3c: Supply the expected 2050 demand (urban/rural, irrigation and EWR) from the dam. Use the remaining yield to support users along the Caledon and the ORP.	Determine whether the remaining yield from Hlotse Dam will be able to restore the downstream water balances.

Scenario	Description	Purpose
Scenario 4 (2030)	As Scenario 2 but including the proposed Ngoajane Dam in the Lesotho Lowlands.	Determine the yield from Ngoajane Dam. Determine the impact of the Ngoajane Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River.
Scenario 4c (2030)	As Scenario 4 but increase Ngoajane Dam by 27.3 million m^3 to a gross storage of 63.3 million m^3	Determine the increase in yield due to the larger Ngoajane Dam. Determine the impact of the Ngoajane Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River
Scenario 4d (2030)	As Scenario 4c: Supply the expected 2050 demand (urban/rural, irrigation and EWR) from the dam. Use the remaining yield to support users along the Caledon and the ORP.	Determine whether the remaining yield from Ngoajane Dam will be able to restore the downstream water balances.
Scenario 5 (2030)	Proposed Semonkong Dam	No data was available for this dam
The purpose of Scenario 6a to 6b is to determine the impact of large hydro-power dams on the Senqu River on the yield available from the ORP and Makhaleng Dam.		
Scenario 6a	Senqu B2 and D2 cascade hydropower scheme in combination with sub-scenario 2g Hydro-power releases to provide a base load	Determine the yield impact on the ORP system and the proposed Makhaleng Dam
Scenario 6b	Senqu B2 and D2 cascade hydropower scheme in combination with sub-scenario 2g Hydro-power releases to be aligned with normal monthly flow distribution pattern	Determine the yield impact on the ORP system and the proposed Makhaleng Dam
Scenario 7b	Scenario 2g with Ntoahae Dam (gross storage 2 280 million m^3) included.	Determine the net yield available from Makhaleng Dam when Ntoahae Dam is used to release compensation water in support of the ORP. Reduce compensation releases from Makhaleng Dam to the minimum possible.
Scenario 8b	Scenario 2 with a raised Verbeeldingskraal Dam (14 m raising) included. Gross storage of the raised Verbeeldingskraal Dam is 2 327 million m^3. This is the maximum raising based on the available dam basin characteristics	The purpose of the raising of Verbeeldingskraal Dam is to generate additional yield from the system which can be used to release compensation water in support of Gariep and Vanderkloof dams and thereby reduces the compensation requirements from Makhaleng Dam. This will result in an increase net yield available from Makhaleng Dam.

Results from all the above scenarios are summarized in **Table vi**.

In general, the construction of dams in the upstream parts of a basin impacts much more severely on the yield available from the downstream dams, than what the building of downstream dams will have on the yield of possible future upstream dams. This also depends on the extent of the overall development in the basin, the location of the dams, operating rules used, agreements between users/countries, etc.

- When a 3 MAR Makaleng Dam is in place and the full yield is utilized by Lesotho for their own and or transfer purposes, the impact on the downstream Orange River Project (ORP) is quite significant, reducing the ORP HFY by 252 million m^3/a. The HFY then available from Makaleng Dam is 378 million m^3/a.
- This impact of Makaleng Dam on the ORP can be reduced to zero if Makhaleng Dam is used release compensation water in support of the ORP. Under such conditions there will still be a HFY of between 158 and 188 million m^3/a available from Makhaleng Dam to be utilized by Lesotho at 2030 development level, depending on the specific scenario and operating rule used.

Table vi: Summary of historic firm yield results focused on 2030 development level

Scenario	System and sub-system yield (million m^3/a)						
	ORP	LHWP	Makhaleng	Hlotse	Ngoajane	Total	Net yield increase
ORASECOM IWRMP Phase III	3 252	780	0.0	0.0	0.0	4 032	n.a.
2018 Base Scenario	3 118	780	0.0	0.0	0.0	3 898	n.a.
2030 Base Scenario	3 297	1 171.2	0.0	0.0	0.0	4 468	n.a.
Scenario 2	3 254	1 171.2	200$^{\$}$ (and ± 178 support to the ORP)	0.0	0.0	4 625	(2–2030base)* 158
Sub-scenario 2d	3 336	780	0	0.0	0.0	4 116	
Sub-scenario 2e	3 336	780	199	0.0	0.0	4 315	(2e–2d)* 199
Sub-scenario 2f	3 297	1 171.2	0	0.0	0.0	4 468	
Sub-scenario 2g	3 297	1 171.2	188	0.0	0.0	4 656	(2g – 2f)* 188
Sub-scenario 2h	3 045	1 171.2	378.4	0.0	0.0	4 595	(2h – 2f)* 126
Sub-scenario 2j	3 112	1 171.2	218	0.0	0.0	4 501	(2–2030base)* 33
Scenario 3	3 228	1 171.2	200$^{\$}$	84.6	0.0	4 684	(3 – 2)* 59 (54^{+})
Scenario 3c	3 228	1 171.2	200$^{\$}$	93.9	0.0	4 688	(3c-2)*63 (57.7^{+})
Scenario 3d	3 239	1 171.2	200$^{\$}$	66.3$^{\#}$	0.0	4 677	(3d-2)*51(48^{+})
Scenario 3e	3 211	1 171.2	200$^{\$}$	112.8	0.0	4 695	(3e-2)*70 (62^{+})
Scenario 4	3 209	1 171.2	200$^{\$}$	84.6	30.8	4 696	(4 – 3)*12 (10.5^{+})
Scenario 4b	3 192	1 171.2	200$^{\$}$	112.8	30.8	4 707	(4b-3e)*12 (10^{+})
Scenario 4c	3 204	1 171.2	200$^{\$}$	84.6	38.8	4 699	(4c-3)* 15 (12^{+})
Scenario 4c2	3 187	1 171.2	200$^{\$}$	112.8	38.8	4 710	(4c2-3e)* 15 (13.4^{+})
Scenario 4d	3 220	1 171.2	200$^{\$}$	66.3$^{\#}$	29.2$^{\#}$	4 687	(4d-3d)*10 (8.2^{+})
Scenario 5	No results						
Scenario 6a	3 297	1 171.2	321.9	0.0	0.0	4 790	(6a – 2g)* 134
Scenario 6b	3 297	1 171.2	312.4	0.0	0.0	4 781	(6b – 2g)* 124

Scenario 7b	3 570	1 171.2	188	0.0	0.0	4 929	(7b-2030base)* 461
Scenario 8b	3 415	1 171.2	200$	0.0	0.0	4 786.	(8b-2030base)* 318

Note: *- Net yield increase based on the difference between indicated scenarios
+ Net yield increase when average reduction in supply in the Caledon/Mohokare is included
# 2050 demand imposed on dam – not the yield
$ Target transfer imposed on dam – not yield

- From a system perspective it is better to use Makhaleng Dam to also support the ORP. This approach will result in the system yield being increased by approximately 62 million m^3/a in comparison with the option where Makhaleng Dam is not used to support the ORP.
- The historic firm yield for Hlotse and Ngoajane dams were determined as 84.6 million m^3/a and 30.8 million m^3/a respectively. The net system yield increases due to Hlotse and Ngoajane dams are however only 54 million m^3/a and 10 million m^3/a respectively.
- The inclusion of Hlotse and Ngoajane multipurpose Lesotho Lowland schemes as reflected in scenarios 3 and 4 resulted in a further decrease in yield of 45 million m^3/a for the ORP system, although the large Makhaleng Dam was used to partly support the ORP system.
- The reduction in yield to the Greater Bloemfontein system, Maseru and smaller Lesotho towns along the Mohokare River (-6.4 million m^3/a) brings the total reduction (ORP reduction of 45 million m^3/a included) in yield/water supply to 51.4 million m^3/a for Hlotse and Ngoajane dams combined
- With some increase in storage at both Hlotse and Ngoajane dams of 15 million m^3 and 27.3 million m^3 respectively, the gross yield from the two dams can be increased by 9.3 million m^3/a and 8 million m^3/a, thus a total of 17.3 million m^3/a.
- The analyses carried out as part of this assessment mainly focused on the yield impact of the ORP, Greater Bloemfontein and Maseru sub-systems, and did not include the smaller impacts on river abstractions directly from the Caledon, Orange and Senqu rivers in Lesotho and the RSA. These impacts should be investigated in detail before any of the future schemes are constructed.
- The possible future hydro-power dams on the Senqu River will result in an increase in yield from the ORP system if operated correctly. This can lead to a reduced support from Makhaleng Dam to the ORP, which in turn will increase the net yield available from Makhaleng Dam. The possible increase in the yield was determined for two possible flow pattern release scenarios from the hydro-power dams. An almost stable base flow over the entire year, or a flow pattern that will mimic the natural monthly flow distribution over the year. The increase in yield determined for these two flow release options was 134 million m^3/a and 124 million m^3/a, which can be used to balance the

negative yield impacts and or to make more yield available from Makhaleng Dam for Lesotho's owns usage and or transfers to Botswana and the RSA.

- It is important to note that it is possible to also lower the ORP yield when the possible future hydro-power dams on the Senqu River are not operated correctly, in particular during critical drought periods.

From the assessment of multipurpose dams in Lesotho it is evident that it will be difficult to maintain a positive balance in the downstream water supply schemes with all the developments envisaged for Lesotho in place, which includes major transfers to the RSA and Botswana. It is however not impossible, in particular when the benefit of hydropower dams on the main Senqu River is utilized. This will to a large extend address the deficits on the main Orange and ORP system. Another cost-effective option for the Main Orange and ORP to consider is increasing the storage of Verbeeldingskraal Dam. The DWS RSA study only considered the maximum size at Verbeeldingskraal that will not inundate Lesotho. There is thus scope to increase the storage at this site, when it is agreed between the two counties to also inundate part of Lesotho. The possible combination of dams to be able to maintain a positive water balance with Makhaleng dam in place is given in **Figure 8-9** in **Section 8.4.2** of this report. These options further include increasing the yield available from Makhaleng Dam to support a higher transfer to Botswana as well as larger areas under irrigation within Lesotho.

Increasing the storage of Hlostse and Ngoajane dams will assist to reduce the deficits along the Caledon (Mohokare) River. Providing water from the Makhaleng transfer system to the Greater Bloemfontein and maybe some of the larger towns along the Caledon River experiencing deficits, might solve the Caledon deficits. Decreasing some of the planned Lesotho irrigation schemes to slightly smaller schemes will also contribute to the reduction of deficits along the Caledon/Mohokare River. One would further need to confirm whether all the EWRs along the Caledon and Orange River (final Reserve in Orange) can still be met, once all the planned developments are in place. Taking into account all these possibilities a combination of dams and sub-systems were derived as shown in **Figure 8-10** in **Section 8.4.3** of this report. These possible combinations as given in **Figure 8-10** will be able to maintain a positive water balance in the ORP and ensure a similar water supply to the main users from the Caledon/Mohokare River.

Risk analysis carried out on Makhaleng Dam.

- The net stochastic yield results for Makhaleng Dam based on sub-scenario 2g were determined. This represents the yield available after compensation releases were made in support of Verbeeldingskraal, Gariep and Vanderkloof dams. The historic firm yield for this Makhaleng Dam scenario was determined as 188 million m^3/a and represents a recurrence interval of 1 in 120 years. This means that the historic firm yield represents a relative high assurance which will open the possibility of making more water available for irrigation purposes in Lesotho.

- Based on the results from the 6 selected climate change models natural flow records were generated using the Pitman Model for each of the 6 climate change model results. These updated natural flow records were then included in the WRYM to determine the impact of the changed natural runoff due to climate change on the yield available from Makhaleng Dam. For the Makhaleng sub-system the average impact from the six climate change models natural flow records is relatively small, indicating an increase of 1% above the HFY (from current historic natural flow records) of 378 million m^3/a. The lowest yield was obtained from the CCS climate change model at 345 million m^3/a with the highest yield of 448 million m^3/a from the GFD climate change model.
- It is interesting to note that the range of yield from the six climate change models lies within the range of the stochastic yield results produced for the ORP.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AGRP	Average Groundwater Resource Potential
AMD	Acid mine drainage
AMCOW	African Ministerial Conference on Water
BAS	Best Attainable State
BOT	Build, Operate, Transfer
CSIR	Council for Scientific and Industrial Research
DBOM	Design, Build, Operate and Transfer
DWA	Department of Water Affairs (RSA)
DWAF	Department of Water Affairs and Forestry (RSA)
DWS	Department Water and Sanitation
EC	Electrical conductivity
EFR	Ecological flow requirements
EHI	Estuarine Health Index
EWR	Ecological Water Requirement
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GEP	Groundwater Exploitation Potential
GESI	Global Environmental Sanitation Initiative
GRA II	Groundwater Resources Assessment Phase II
GoL	Government of Lesotho
GRP	Groundwater Resource Potential
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome
IAPP	International Association for Public Participation
IGRAC	International Groundwater Resources Assessment Centre
IPCC	International Panel for Climate Change
IVRS	Integrated Vaal River System
IWRM	Integrated Water Resources Management
JIA	Joint Irrigation Authority
JPTC	Joint Permanent Technical Committee
L-BWT	Lesotho Botswana Water Transfer

LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LOR	Lower Orange River
l/s	Liter per second
MAFS	Ministry of Agriculture and Food Security (Lesotho)
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MCA	Multi-criteria analysis
MC	Management Centre (Botswana)
MEWR	Minerals, Energy and Water Resources (Botswana)
mm/a	Millimeters per annum
m^3/s	Cubic Meters per second
m^3/a	Cubic Meters per annum
MW	Megawatts
NEPAD	New Partnership for Africa's Development
NWA	National Water Act
NAP	National Action Programme
NGO	Non-governmental Organisation
NRW	Non-Revenue Water: This is the difference between the volume of water supplied into the system and the billed authorised consumption.
ORASECOM	Orange Senqu River Commission
ORP	Orange River Project (Gariep and Vanderkloof dams and supply area)
OVTS	Orange Vaal Transfer Scheme
PES	Present Ecological State
PF	Potability Factor
PGEP	Potable Groundwater Exploitation Potential
PPP	Public Private Partnership
PSC	Public Sector Comparator
PWC	Permanent Water Commission
RO	Reverse Osmosis
RQO	Resource Quality Objectives

RSA	Republic of South Africa
SADC	Southern African Development Community
SADC-GIO	Southern African Development Community Groundwater Information Portal
SAP	Strategic Action Programme
SIV	System Input Volume
SOE	State Owned Entities
TCTA	Trans Caledon Tunnel Authority
TDA	Transboundary Diagnostic Analysis
TDS	Total dissolved solids
TTT	Technical Task Team
TOR	Terms of Reference
UGEP	Utilisable Groundwater Exploitation Potential
UN	United Nations
UNDP	United Nations Development Programme
VRS	Vaal River System
WARMS	Water Authorisation and Registration Management System
WASCO	Water and Sanitation Company
WC	Water Conservation
WDM	Water Demand Management
WMA	Water Management Area
WQ	Water Quality
WRYM	Water Resources Yield Model
WRPM	Water Resources Planning Model
WUC	Water Utilities Company
ZAR	South African Rand

1 INTRODUCTION

1.1 Background to the Study Area

The Orange-Senqu River Basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange-Senqu River originates in the Highlands of Lesotho and flows in a westerly direction, approximately 2,200 km to the west coast of South Africa and Namibia, where the river discharges into the Atlantic Ocean. See **Figure 1-1.**

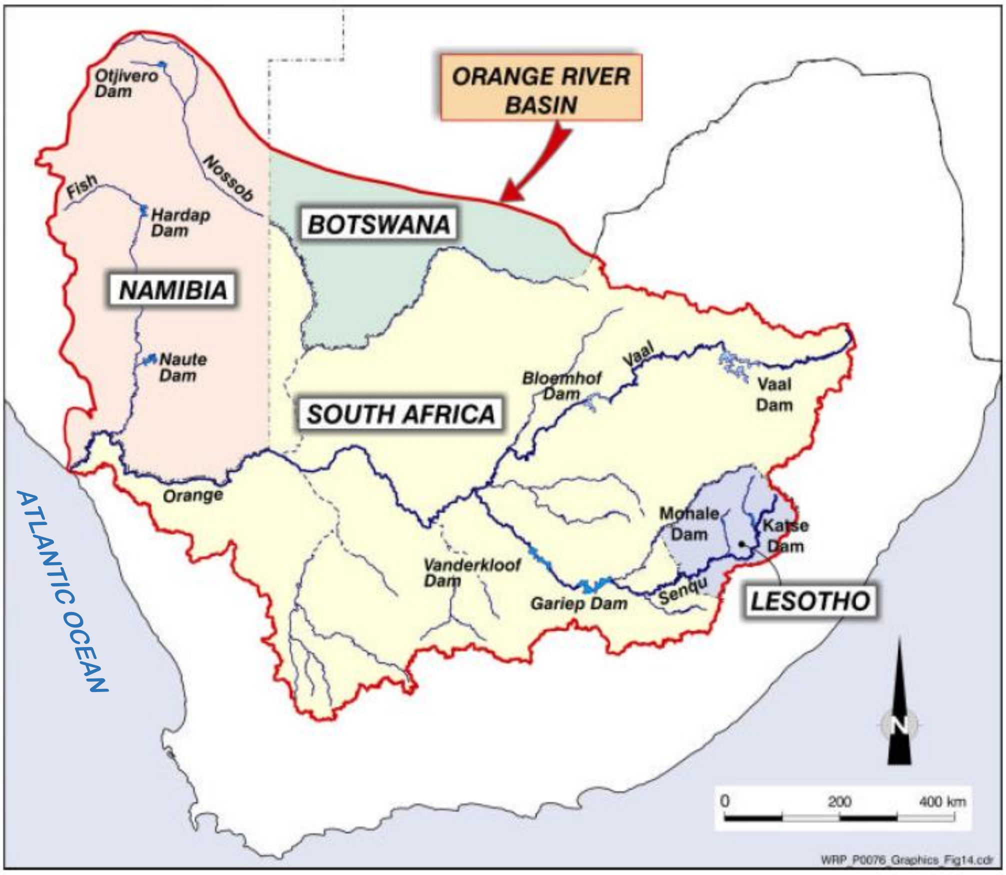


Figure 1-1: Orange-Senqu River Basin

On the part of Lesotho, there are three distinct hydrologically homogenous river basins, where each river basin has its clear source where it originates. These river basins, namely: Senqu, Mohokare and Makhaleng River Basins all flows in the westerly direction and join together outside the border of Lesotho with the Orange River to form one large basin known as the Orange-Senqu River Basin.

It has been estimated that the natural runoff of the Orange-Senqu River Basin is in the order of 11,300 million m^3/a, of which approximately 4,000 million m^3/a originates in the Senqu River Basin in the highlands of Lesotho, 6,500 million m^3/a from the Vaal and Upper Orange River, with approximately 800 million m^3/a from the Lower Orange and Fish River in Namibia. The basin also includes a portion in Botswana and Namibia (north of Fish River) feeding the Nossob and Molopo Rivers.

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen (13) exclusively stretch over the Southern African Development Community (SADC) Member States. The Orange–Senqu is one of these thirteen (13) transboundary water course systems. SADC member states embrace the ideals of utilizing the water resources of these transboundary watercourses for the regional economic integration and for the mutual benefit of the riparian states. The region has demonstrated a great deal of goodwill and commitment towards collaboration on water issues. Thus, SADC has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development.

To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000.

ORASECOM was established by the Governments of four States, namely, South Africa, Lesotho, Botswana and Namibia, for managing the transboundary water resources of the Orange-Senqu River Basin and promoting its beneficial development for the socio-economic wellbeing and safeguarding the basin environment. This led to the development of a basin level Integrated Water Resources Management (IWRM) Plan adopted in February 2015 by the ORASECOM Member States. The IWRM Plan provides a strategic transboundary water resources management framework and action areas and serves as a guiding and planning tool for achieving the long-term development goals in the basin. A key aspect of the transformative approach for strengthening cooperation has been identified as the need for joint project implementation that provides a mutually inclusive transboundary benefit.

The IWRM Plan recommends strategies and measures for promoting sustainable management of the water resources of the basin and defines strategic actions that will ensure and enhance water security, considering the long term socio-economic and environmental demands on the water resources of the basin. The Lesotho to Botswana Water Transfer Scheme, a major component under this study, was not included in the 2015 IWRM Plan as one of the strategic actions but has lately been identified as a priority project.

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterized by a high degree of regulation and major inter-basin transfers to manage the resource availability between the location of relatively abundant precipitation and the location of greatest water requirements. The infrastructure involves water storage and transmission infrastructure, transmitting water to demand centers that are in some cases located outside of the basin through intra and inter basin transfers. Most of the existing infrastructure are those under the Lesotho Highlands Water Project (LHWP) which transfers water to South Africa and those for inter basin transfer to the Vaal Basin.

Figure 1.2 provides approximate values of the natural run-off in the Orange-Senqu River Basin. These figures highlight the variable and uneven distribution of runoff from east to west in the basin. The figures refer to the natural runoff which would have occurred had there been no developments or impoundments in the catchment. The actual runoff reaching the river mouth is considerably less than the natural values and are estimated to be in the order of half the natural values.

The difference is due mainly to the extensive water utilization in the Vaal River Basin, most of which is for domestic and industrial purposes. Several major transfer systems are used to bring water into the Upper Vaal River catchment to support the high-water requirements, in particular those within the Gauteng area as well as for several Power Stations.

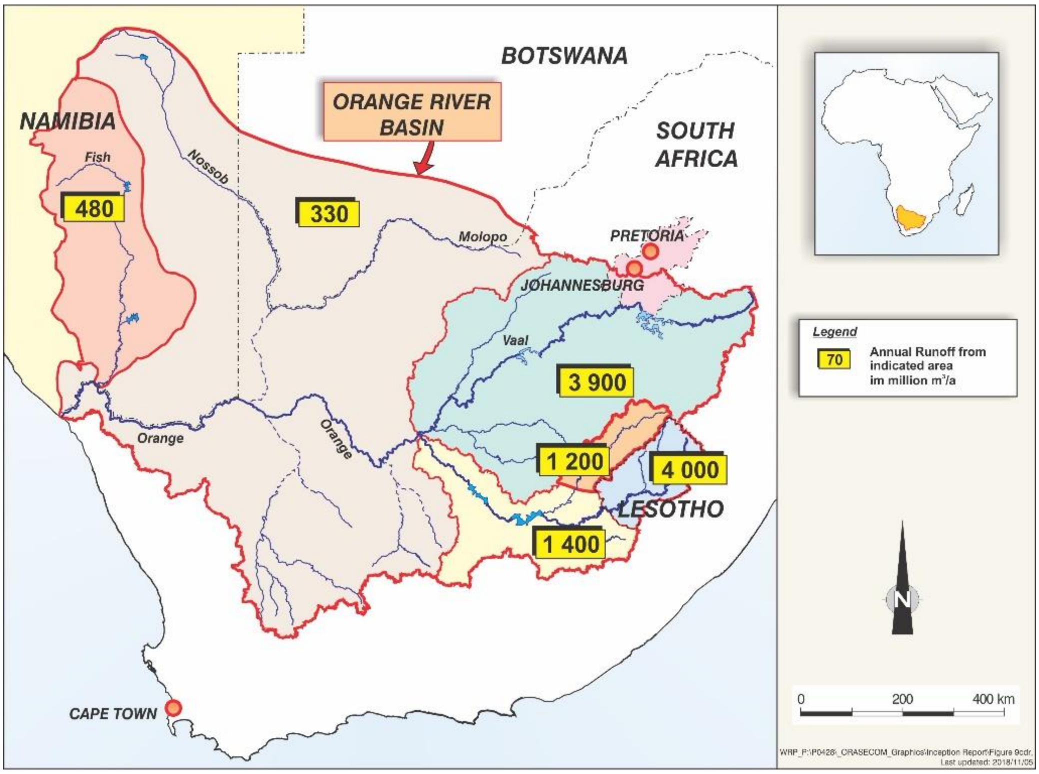


Figure 1-2: Approximate Natural Run-off in the Basin

Large volumes of water are also used to support extensive irrigation and some mining demands along the Orange River downstream of the Orange-Vaal confluence, as well as significant irrigation developments in the Eastern Cape in South Africa, supplied through the Orange-Fish Tunnel. In addition to the water demands, evaporation losses from the Orange

River and the associated riparian vegetation that depend on the river account for 500 to 1,000 Million m^3/a.

As already indicated, there are locations of relatively abundant precipitation and water availability and the locations of greatest water requirements. Water scarcity in locations of greatest need is the main challenge in the basin, and this requires a coordinated joint development, management and conservation of the water resources system. The climate in the basin varies from relatively temperate in the eastern source areas, to hyper-arid in the western areas. As shown in **Figure 1.3**, average annual precipitation decreases from more than 1,000 mm/a in the source areas of the basin to less than 50 mm/a at the river mouth. This varies considerably from year to year. Much of the rainfall occurs as intense storms, which can be highly localized. The temporal and spatial distribution of precipitation within any particular year can be considerable.

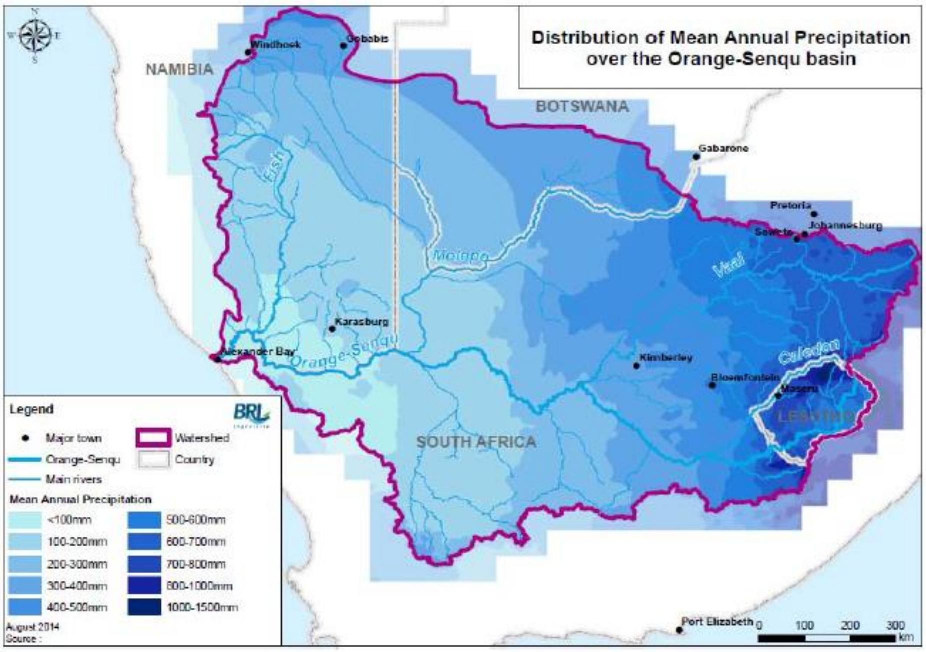


Figure 1-3: Distribution of Mean Annual Precipitation

In **Figure 1.4** it is evident that evaporation increases from south-east to north-west reaching a maximum of more than 1,650 mm/a in the west. Even in the cooler and wetter parts of the basin, evaporation in most cases exceeds precipitation. Temperature and evaporation follow a similar distribution with the coolest temperatures in the Lesotho Highlands and the hottest in the western Kalahari.

It is generally accepted that Southern Africa will be highly impacted by climate change. Consequently, there are concerns around the changes in precipitation and temperature due to climate variability and climate change. This study therefore aims to enhance investment in transboundary water security and to build resilience to climate change into the implementation of the strategic projects and actions described in the IWRM Plan.

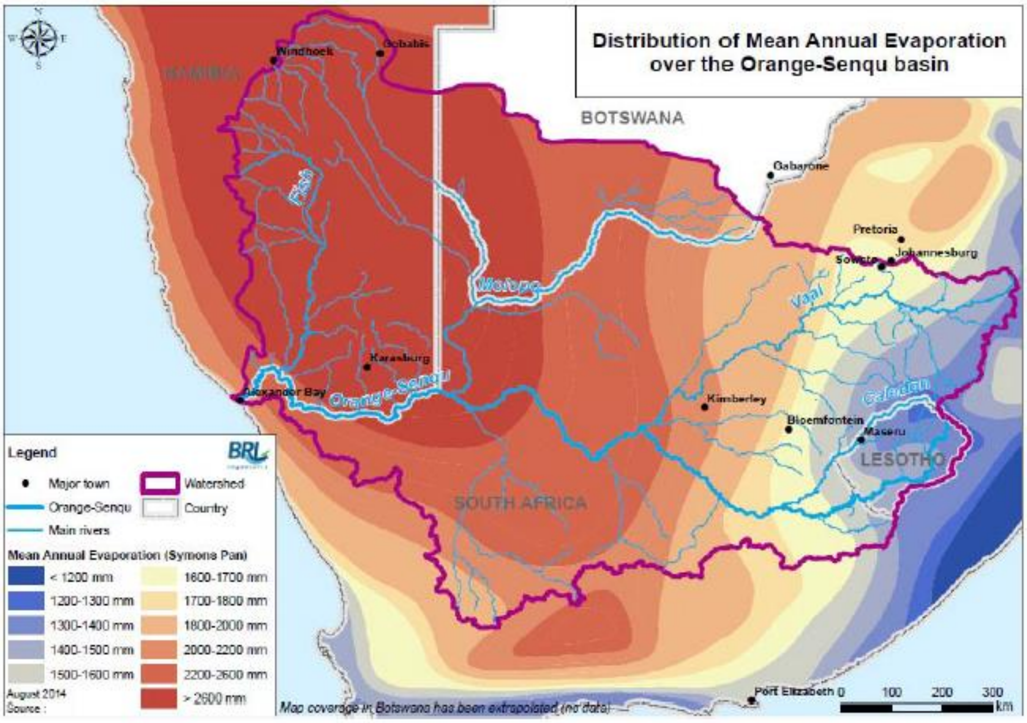


Figure 1-4: Distribution of Mean Annual Evaporation

The Republic of Botswana is an arid country faced with serious water constraints which will worsen with the expected effects of climate change. Botswana will experience chronic water shortages by about 2025, unless major new water sources are developed. Already Gaborone was critically hit by the 2015-2016 drought.

As a consequence, the Governments of Botswana, Lesotho and South Africa, signed a Memorandum of Agreement to undertake a reconnaissance study on the Lesotho to Botswana Water Transfer scheme (L-BWT), which aimed at developing water infrastructure in Lesotho and through South Africa, to convey water to Botswana, at the same time supplying various users in Lesotho and South Africa. This reconnaissance study led to the selection of a technical option which included a new dam on the Makhaleng River in Lesotho and a water conveyance (pipeline) system to Botswana. It was envisaged that eventually 150 million m^3/a will be pumped to Botswana with additional supplies for consumers along the route in Lesotho and South Africa.

1.2 Objective of the Assignment

The objective of the study is to update the IWRM Plan endorsed in 2015 and propose an updated Core Scenario which should include the L-BWT Project, studying at pre-feasibility level the L-BWT Project including the feasibility of the dam, and to assist ORASECOM and the riparian countries in operationalizing the updated IWRM Plan. The objective will therefore be met through three outputs:

- A Climate Resilient Investment Plan for the Orange-Senqu River Basin based on the updated Core Scenario.
- Operationalization Plan for ten (10) priority actions selected from the updated IWRM Plan; and
- Pre-feasibility level report for the L-BWT Project, and the feasibility level report for a new dam, on Makhaleng River in Lesotho.

The study is divided into two distinct parts:

- Preparation of a Climate Resilient Investment Plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015, as Components I & II of the study; and
- The pre-feasibility study of Lesotho-Botswana Water Transfer Project, including the feasibility study of a new dam on Makhaleng River in Lesotho as Components III & IV of the study.

The four components of the study referred to above are:

- Component I: Climate Resilient Water Resources Investment Plan.
- Component II: Operationalisation of the Integrated Water Resources Management Plan.
- Component III: Pre-feasibility study of the Lesotho to Botswana Water Transfer Project.
- Component IV: Feasibility Study of the Dam on Makhaleng River in Lesotho.

1.1.1 Climate Resilient Investment Plan (Components I and II)

The high level of variability in precipitation due to climate variability and change, defines the need to optimize and implement efficient water resources development and management in the basin. The development of new infrastructure to meet increasing water demands, even if technically and environmentally feasible, is both expensive and complex. Economic considerations of water use have been identified as a key part in the planning and optimum use of what will become an increasingly scarce and expensive resource. Projections of future water demand and associated infrastructure development must be based on balanced considerations of economic, social, and environmental factors. The integration of water resources yield analysis, water resources development planning and economic optimization will ensure the development of short, medium- and long-term solutions to address basin water resources needs and development challenges.

The study includes water resource studies in Botswana, Lesotho, Namibian and South Africa. This will include updating of inputs from the Reconciliation Strategy Studies, updating of inputs with more recent results from the Reconciliation Strategy Maintenance Studies as well as other recent water resource related studies conducted in the basin countries. The study will establish comprehensive basin wide analyses which will be integrated with economic analyses to determine the optimized and most efficient development options, as part of setting the long-term development investment strategy and plan for the basin.

Components I & II will thus address the water resources investment plan and the operationalization of the updated IWRM Plan with the following outputs:

- Updated Core Scenario of the IWRM Plan, which would include the Lesotho-Botswana Water Transfer Scheme and any other new projects identified.
- Estimate of the Climate Change Effects on the updated Core Scenario.
- Optimised IWRM Plan Core Scenario through an economic approach.
- Financial Strategy for the Core Scenario.
- Updated Basin Wide Investment Plan approved by ORASECOM, which would include new projects that takes into consideration climate change effects.
- A comprehensive assessment of existing policies, legal and institutional arrangements and structures.
- Selected 10 strategic actions, Terms of Reference and cost estimates for each strategic action: and
- A road map for operationalization of the ten (10) strategic actions contained in the updated Integrated Water Resource Management Plan.

1.1.2 Lesotho-Botswana Water Transfer (L-BWT) Project (Components III and IV)

The south eastern urban complex of Botswana centered around the capital city, Gaborone, has experienced rapidly increasing growth over the last few decades, and is expected to continue doing so. Its water demands have long outstripped local bulk water resources, which are already supplemented by sources in the north-east of the country. The country has experienced several severe drought spells that have, in the recent past, led to water restrictions. Despite several concerted efforts to alleviate the water shortage challenges, indications are that the water sources will not be adequate to meet the growing demand as early as 2025.

The solution for addressing the water security challenges lies in the need for increasing the efficient use of existing water resources, developing additional water resources and improving the management systems based on availability and usage.

A Reconnaissance Study to identify possible water resources was completed in October 2015, which outlined various options of water sources and conveyance routes to supply water from Lesotho to Botswana. The various sources covered by the study include the Lesotho Highlands Water Project, the Makhaleng River and the Orange-Senqu in the south of Lesotho. The preferred supply scheme recommended in the Reconnaissance Study was a dam on the Makhaleng River, and a conveyance system to bring the water from Lesotho, across South Africa to Botswana.

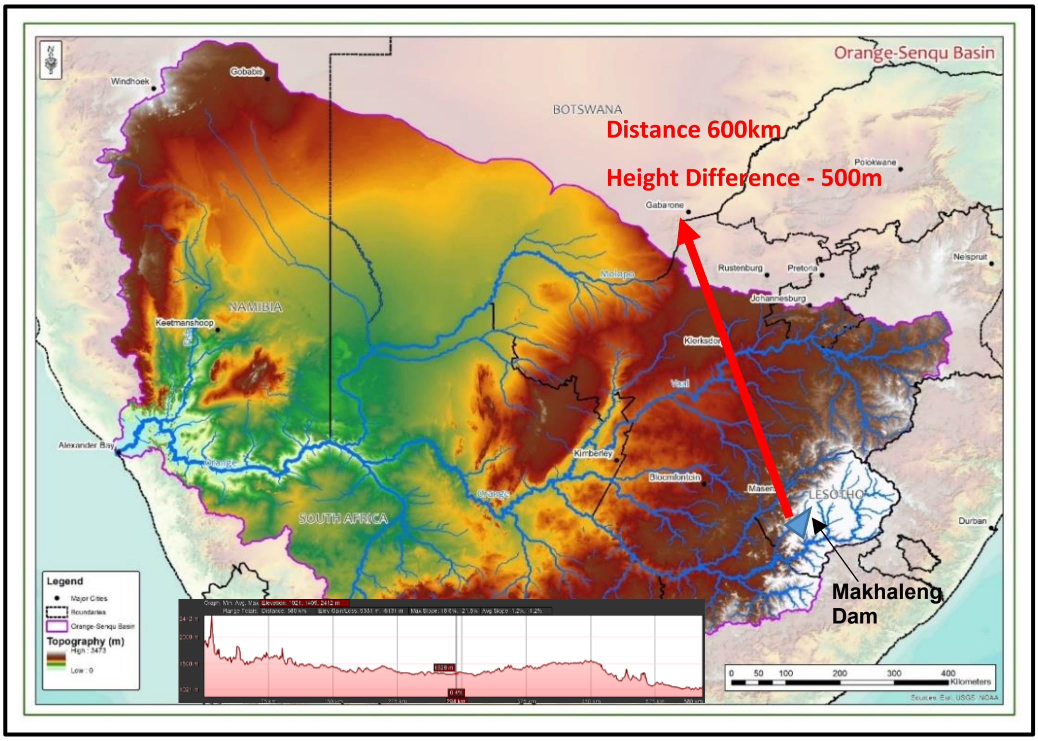


Figure 1.5: Orange Senqu basin topographical map showing the possible Lesotho Botswana Water Transfer Project

A Pre-feasibility Study is required to determine water demands up to 2050 for specified areas in Botswana, Lesotho and South Africa, from available relevant information in all countries, and further investigate suitable dam site(s) by analyzing the Makhaleng catchment hydrology, determining the size of the dam(s) on the basis of topography, geology, yield, sedimentation, hydropower generation and water demands for the specific areas in Botswana, Lesotho and

South Africa. For the conveyance system, the study is only required to investigate pipeline options along the shortest route, to either Gaborone or Lobatse in Botswana, preferably along existing road servitudes.

Depending on the results and recommendations from the Pre-feasibility Study, a Feasibility Study for a new dam on the Makhaleng River will follow, but this depends on a final decision by the State Parties to the project. **Figure 1.5,** is the topographic map of the catchment, showing the Lesotho to Botswana water transfer project stretch and the major topographic features of the two end points of the water transfer scheme.

Components III & IV of the study focus on the Lesotho-Botswana Water Transfer Multipurpose Trans-boundary (L-BWT) Project and address:

<u>Component III - Phase 1 – Initial components of the Pre-feasibility study for Makhaleng Scheme</u>

- Validation of the water requirements for irrigation in Lesotho, the water demand in South Africa along the pipeline route, and the water demand in Botswana.
- Assessment of the water resource, in the Makhaleng catchment.
- Dam site selection; and
- Conveyance route selection.

<u>Component III - Phase 2 - Pre-feasibility of the Makhaleng Scheme</u>

- Pre-feasibility study of a dam on the Makhaleng River.
- Prefeasibility study of the water conveyance pipeline from Makhaleng to Gaborone/Lobatse.
- Assessment of environmental and social impacts.
- Economic assessment of the dam and the Lesotho-Botswana water conveyance pipeline; and
- Multi-Criteria Analysis (MCA) of the options.

<u>Component IV - Feasibility of the Makhaleng Dam (Depending on the outcomes from the Pre-Feasibility Study):</u>

- Hydrological analysis, including climate change effects.
- Feasibility Study of the Makhaleng Dam:
- Economic, Social and Financial analysis update; and
- Preparation of project implementation plan.

1.3 Purpose and Structure of this report

The purpose of this report is to describe all the inputs into the Core Scenario, the basis for decision making in the basin. The Core Scenario includes all existing and future water requirements from the basin. It also includes several catchment infrastructure developments that are likely to take place to offset deficits of water demands in the future. The chapters of this report summarizing the water requirements, water conservation and water demand management and the groundwater are all summaries of separate stand-alone documents detailing the tasks. Chapter 6 provides an overview of the key settings relating to the Core Scenario. The settings included in the 2014 Core Scenario are listed for ease of reference relating to the updates.

This report contains only summarized information on water requirements, groundwater, water conservation and water demand management and Re-use as well as for water resource system analysis related work. Detail information on these specific components of the Core Scenario Report can be found in the following supporting reports:

- Water Requirements and Return flow report
- Groundwater Report
- Water Conservation and Water Demand management and Re-use Report
- System analysis Report

2 UPDATED WATER REQUIREMENTS

2.1 Introduction and Background

The water requirements and return flows task entails updating, verifying and extending the current water requirements projections up to the year 2050, which are summarised according to their respective sub-system in the data base inventory. The data base inventory consists of all the water use and return flow elements in the Orange-Senqu Catchment according to best practice principles and understanding of the physical sub-system layouts, as well as their dependencies.

Two different projections are summarised, indicating water requirements with and without water conservation and water demand management (WC/WDM), thereby, for the latter, reducing the requirements. This intervention is mostly applicable to urban/domestic demands, the same principles could however be applied to irrigation and mining activities. A possible reduction in irrigation water requirements, or increased irrigation efficiency, is expected to result in an increased area being irrigated instead of a net decrease in irrigation requirements, which therefore does not allow additional resources for downstream users.

The water requirements supplied by groundwater sources was indicated where data was available. Groundwater use obtained from authorities and past reports was highly variable in quality. Therefore, the real proportion of groundwater to surface water sources supplying users could not be quantified with great confidence.

The water requirements for the Orange/Senqu Study Area is extensive. For the Orange River System (ORS) and Integrated Vaal River Systems (IVRS) the water requirements and return flows are monitored on a monthly basis by the Department of Water and Sanitation in South Africa, and re- analysed annually to determine necessary restrictions to protect the resource. For the remainder of the Study Area comprising of Lesotho, Botswana and Namibia, existing studies were reviewed to determine the current water requirements, return flows and future projections. Furthermore, stakeholders were engaged to validate the information summarised in the water requirements database.

Previous reports reviewed and information contained within the Data Base Inventory are:

- ORASECOM Phase I and II Water Requirement's (Demand's) Reports
    - Summary of Water Requirements from the Orange River (ORASECOM, 2007c)
    - Water Demand Projections and Synthesis of Planned Infrastructure Investments, Report No. 012/2014 (ORASECOM, 2014a)
- Vaal River Reconciliation and follow up Maintenance studies

  - Vaal River System Large Bulk Water Supply Reconciliation Strategy: Urban Water Requirements and Return Flows, Report No. P RSA C000/00/4406/01 (DWAF, 2007a)
  - Vaal River System Large Bulk Water Supply Reconciliation Strategy: Irrigation Water Use and Return Flows, P RSA C000/00/4406/04 (DWAF, 2007b)
  - Continuation of the Integrated Vaal River system Reconciliation Strategy (Phase 2), Status Report 1 (DWS, 2018d)
- Orange River Reconciliation and follow up Maintenance studies
  - Development of Reconciliation Strategies for Large Bulk Water Supply Systems Orange River: Current and Future Urban/Industrial Water Requirements, Report No. P RSA D000/00/18312/4 (DWA, 2014a)
  - Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Irrigation Demands and Water Conservation/Water Demand Management, Report No. P RSA D000/00/18312/6 (DWA, 2014b)
- All Towns Strategies South Africa
  - All Towns Strategies comprehensive for the RSA completed for larger individual towns or clusters (DWS, 2015b) (DWS, 2011)
- Namibia Water Master Plans
  - Integrated Water Resources Management Plan for Namibia (MAWF, 2010)
- Botswana Water Master Plans
  - Countrywide Comprehensive Assessment of Water and Wastewater Situation, (MMEWR, 2015)
- Lesotho Lowlands Water Supply Report
  - Consulting Services for the Update Details Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme: Final Demand Assessment Report (SMEC, 2017)
- State of Water Resources Report (Lesotho)
  - Ministry of Water: Commissioner of Water: State of Water Resources Report 2016/2017 (LesMW, 2018)

2.2 Data Base Inventory

2.2.1 General

The water requirements data base inventory used for the entire Orange-Senqu River Basin has been developed and improved since the first phase ORASECOM Study. Currently the water requirements data base contains almost 1200 users providing information on surface water requirements off all the users within the basin, as well as the proportional groundwater volumes, where available. The data base provides information on the current water requirements as well as the projected future water requirements until 2050 (ORASECOM, 2019d).

2.2.2 Description of the data base inventory

The data base inventory was established to simplify and summarise the various water user information into a compact spreadsheet, which can be used to monitor projected against actual water requirements (ORASECOM, 2019d). The summary can further be utilised as input to the Water Resources Planning Model (WRPM), as it contains automated functions to group certain elements into the correct input format, to produce a projection growth file.

The data base inventory consists of approximately 1200 elements, grouped according to their main sub-catchments, as follows:

- Lesotho: Senqu, Makhaleng and Caledon
- RSA Orange River System (ORS): Caledon, Upper Orange, Middle Orange and Lower Orange
- RSA Integrated Vaal River System (IVRS): Thukela, Upper Vaal, Riet/Modder, Middle Vaal, Lower Vaal, Komati, Usutu, and Zaaihoek
- Namibia: Nossob, Auob, Fish, Lower Orange River Main Stem
- Botswana: Molopo

The data base was developed within a Microsoft Excel Spreadsheet. For each of the water requirement entries several data elements are included. Element in the data base has a number of characteristics or additional fields, such as:

- Sub-catchment / sub- system
- Resource
- WRPM cannel number
- Channel sub-components
- Description
- Country
- Demand type and WRPM channel type
- Catchment
- Figure number
- WRPM base demand and projection
- Groundwater Contribution and Information Source

2.3 Summary of Water Requirements and Return Flows per Sub-System

2.3.1 Environmental Requirements

The four basin states do not necessarily follow the same methodology to determine or implement environmental water requirements. In most cases however the releases from dams for environmental purposes depends on the flow generated in the upstream catchment for the specific year. This means the EWR at a specific site will be different every year and also vary from month to month. It is therefore difficult to give a single number or volume required per annum for EWR purposes at each of the EWR sites. For this reason, the EWR is not included as fixed values in water requirements summary tables.

The environmental water requirements (EWRs) within the Vaal River System have been determined as part of a EWR classification study of significant water resources in the Upper, Middle, and Lower Vaal Water Management Areas (DWA, 2012a), and the proposed EWRs for the rivers at the EWR sites were published in the Government Gazette No. 42127:1419 (DWS, 2018c) . The obtain agreed balances between the EWR to be imposed on the system and the possible negate economic impacts the implementation of the EWR can impose on the region. This final accepted EWR is the referred to as the Reserve which is then gazetted and implemented according to RSA law. The study concluded that most sites required non-flow related interventions. It was therefore recommended that the determined present flow regime be used as the Reserve in most places in the Vaal System.

The current or initially determined EWR releases for the ORS was derived during the Orange River Replanning Study (ORRS) (DWAF, 1996), and are based on an outdated EWR determination methodology. These releases are made from the Vanderkloof Dam to supply the entire Orange River as well as the Orange River Mouth. The current drought EWR is supplied at a high assurance of 99.5% or 1:200 year (risk of failure) and the normal EWR at a 95% or 1:20 year risk of failure. The normal EWR for Orange as currently released for the river mouth amount to an annual volume of 287.5 million m^3/a and is released according to a fixed monthly distribution pattern. This EWR was found to be insufficient and the environmental conditions in the main river and at the river mouth were deteriorating. The Orange System EWRs were thus updated during Phase II of the ORASECOM Basin wide integrated water resources management plan in 2011 (ORASECOM, 2011a). The EWRs were assessed at intermediate levels for strategic areas of the Orange River basin, the recommendation was made to implement an Ecological Water Resources Monitoring (EWRM) programme. Further work was carried out by DWS RSA for the Lower Orange “Lower Orange EWR Study” (DWS, 2016a). From this study a Preliminary Reserve was determined and agreed on by DWS RSA for EWR sites at Augrabies and Site 5, which provided reasonable flows at the river mouth.

The Preliminary Reserve is expected to be implemented in the next year or two. The final reserve for the Orange River System still needs to be determined.

The environmental requirements for the majority of the Rivers in Namibia have not been considered, due to their ephemeral (mostly dry) nature.

There are no environmental water requirements determined in Botswana as yet, the vegetation is adapted to the arid climatic conditions and due to the ephemeral nature of the Molopo River there is not a major drive to determine EWRs for this area.

The environmental water requirements for the Senqu River in Lesotho were negotiated between the Lesotho Highlands Development Authority (LHDA), and the Governments of Lesotho, South Africa, Namibia, the World Bank, as well as interested and affected parties.

The environmental flows vary between 12% and 18% of the mean annual runoff (MAR) at specific sites along the watercourse (LHDA, 2003).

2.3.2 RSA: Integrated Vaal River System (IVRS)

The IVRS consists of the Main Vaal System with transfers from the Komati, Usutu, Thukela (located in RSA) and Senqu River (located in Lesotho) catchments, as well as significant transfers out of the IVRS to users in the Olifants and Crocodile (West) river catchments (see **Figure 2-1**). The water requirements within the Main Vaal River System substantially exceed the local catchment water supply capability. The IVRS supplies the most populated and economically important areas within RSA, which are located in the Upper and Middle Vaal River, Olifants and upper portion of the Crocodile (West) and Marico catchments. Major power stations, petro-chemical plants, urban developments and strategic industries are located in this supply area.

The Main Vaal Catchment consists of the Upper, Middle and Lower Vaal, and the Vaal River originates in the Mpumalanga Province, in eastern South Africa, near the town of Breyten. The Vaal River is the third largest river in South Africa, with a total length of 1 120 km, flowing through Mpumalanga, Gauteng, Free State and North West provinces.

Vaal Dam and the Vaal Barrage supplies Gauteng, which is South Africa’s economic hub, and supplies users between the Vaal Barrage and Bloemhof Dam by means of releases from Vaal Barrage which is in turn supported by releases from Vaal Dam. The main users downstream of the Vaal Dam are Rand Water, Sasol 1, Midvaal Water Company, Sedibeng Water, irrigation users and other industries along the main river, of which three are large bulk water suppliers. These are Rand Water, which is the largest water supply utility in Africa, Sedibeng Water and Midvaal Water Company. Sasol 1, located in Sasolburg on the border between the Free State and Gauteng provinces, and it is the largest petro-chemical manufacturer in South Africa, using both potable and raw water from the Vaal River, Vaal Dam and Vaal Barrage.

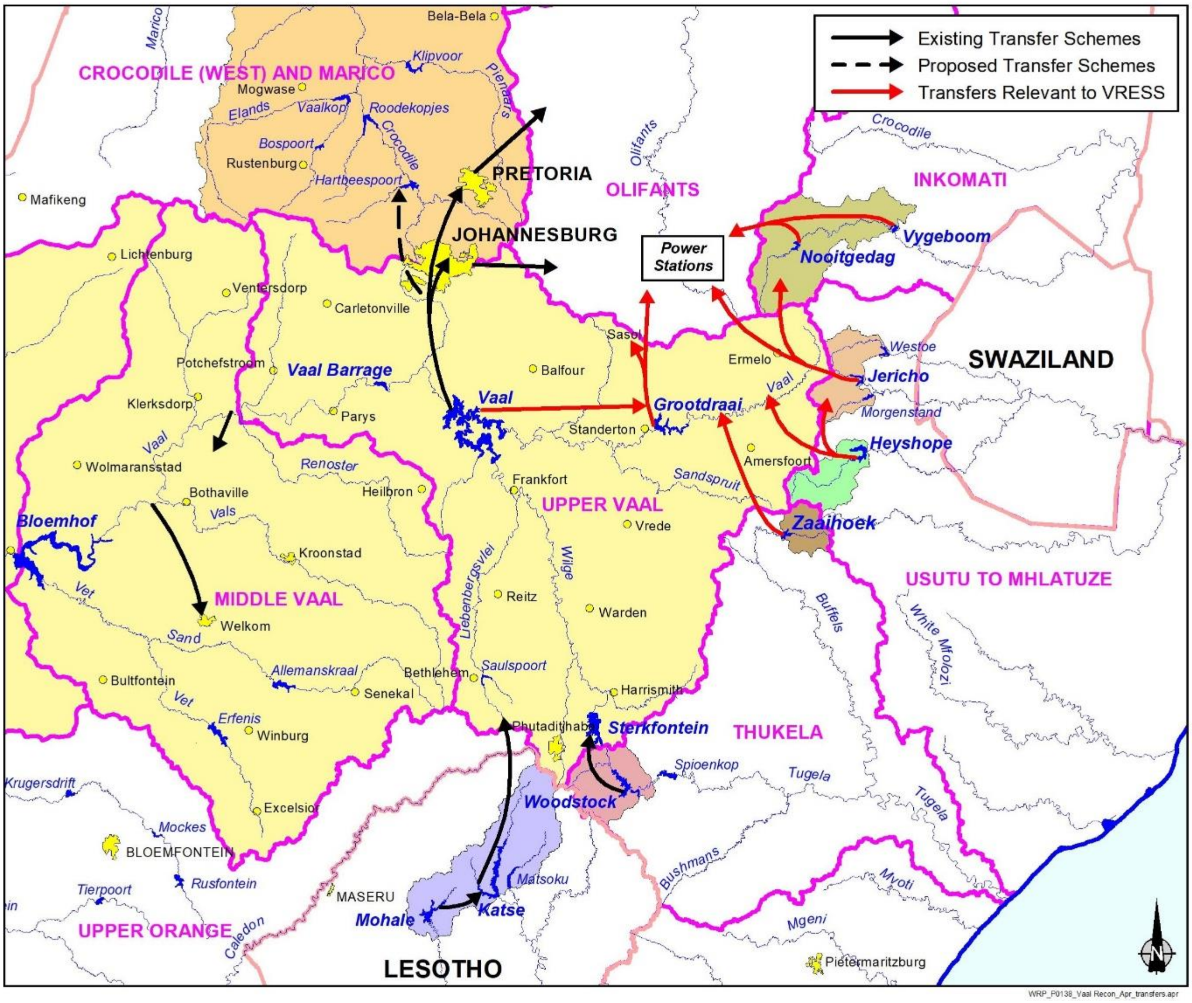


Figure 2-1: Transfers from the Komati, Usuthu Thukela and Lesotho

Bloemhof Dam, located downstream of Vaal Dam, supplies water to the large Vaalharts Irrigation Scheme, as well as diffuse irrigation along the main Vaal River and urban/ industrial users such as Kimberley and the Vaal Gamagara Water Supply Scheme. The Vaalharts Irrigation Scheme covers an area of 39 820 ha in the Northern Cape Province and includes the water supply to six towns. Water is distribution via a 1 176 km long canal system. The total water requirements for the Vaalharts Irrigation Scheme and the Lower Vaal is 542 million m^3/a, for an irrigation area of approximately 39 900 ha. There is a total of 12 smaller irrigation schemes, which receive water from tributaries of the Vaal River System, with the majority of the irrigation schemes located in the Lower Vaal and Middle Vaal catchments Details of these 12 schemes is given in the report “Vaal River System: Large bulk water supply Reconciliation Strategy: Irrigation water use and return flows” (DWAF. 2007b and data base inventory prepared for current ORASECOM study).

Most of the return flows generated in the Vaal River Catchment occur from the southern Gauteng urban and industrial area, which is supplied by Rand Water, as well as from the northern portion of Gauteng flowing into the Crocodile West Catchment. The northern return flows do not contribute to the additional yield available in the Orange-Senqu System. The north and south return flow percentage are 49% and 51% respectively of the total return flow volume of 467 million m^3/a in 2018, compared to 431 million m^3/a in 2014. Other urban/domestic and industrial return flows from Midvaal Water Company, Sedibeng Water, as well as other towns and industries have increased from 65.9 million m^3/a in 2014 to 87.8 million m^3/a in 2018. The mine de-watering volume was approximately 126 million m^3/a in 2018, which increased significantly compared to 93 million m^3/a in 2014. It is estimated that an increase in paved urban areas results in an increased runoff of 100 million m^3/a (DWAF, 2007a) The irrigation return flows in the Vaal decreased from 80 million m^3/a in 2014 to 74 million m^3/a in 2018, due to an increase in water use efficiency (DWAF,2007b).

The imbalance, between demand and supply, of the VRS is the reason for the adjacent transfer schemes from adjacent catchments such as the Komati, Usuthu, Thukela and Senqu River (located in Lesotho) catchments. The Grootdraai Dam in the Vaal Catchment is supported by Heyshope Dam in the Assegaai River and the Zaaihoek Dam in the Slang River, located in the Usuthu and the Tugela Catchments respectively. The Usuthu-Vaal transfer scheme currently consists of 6 pump stations. Furthermore, the Sterkfontein Dam in the upper Wilge River, a tributary of the Vaal River, is supported by transfers from the Woodstock Dam and the Driel Barrage in the Thukela Catchment. Sterkfontein Dam is used to support Vaal Dam, when the water level in the Vaal Dam is very low. The Vaal Dam is supported by Mohale and Katse dams which transfers water to the RSA through a 37 km long delivery tunnel. The two dams are also connected via tunnel.

The water requirements projection with WC/WDM is summarised in **Table 2-1**. The main urban/industrial water requirements, delivered by Rand Water, are expected to increase significantly due to increased urbanisation and economic growth in the Gauteng area. The major industries are expected to have a fairly constant water requirement, however Eskom indicates a gradual decrease in water requirements as the older power plants are decommissioned and the newer power plants have an increase in water use efficiency, as well as the commissioning of more renewable energy sources. Eskom indicates with every annual operating analysis carried out for Integrated Vaal River System that there is a decrease in their requirements and an overall decrease in their long-term projection which reflects the total impact of the decommissioning of older plants, inclusion of newer power plants with an increased water use efficiency as well as the use of renewable energy sources.

Table 2-1: Vaal System Water Requirements and Return Flows Projection with WC/WDM

(ORASECOM, 2019d)

Description	Water Requirements (million m^3/a)				
	2018	2020	2030	2040	2050
Rand Water (1)	1753	1751	1870	2091	2335
Mittal Steel (10)	9	9	10	10	10
ESKOM (8)	318	303	268	218	218
SASOL Sasolburg (Raw water req) (9)	22	23	23	23	23
SASOL Secunda (11)	86	86	89	90	90
Midvaal Water Company	47	47	47	47	47
Sedibeng Water (Balkfontein only)	71	72	76	83	90
Other towns and industries (Vaal)	283	289	327	357	399
Other towns and industries(Zaai)	-23	-23	-21	4	32
Vaalharts/Lower Vaal irrigation (2)	542	542	542	542	542
Diffuse Irrigation and Afforestation (Vaal)	11	11	11	11	11
Diffuse Irrigation and Afforestation (Sub systems)	68	68	68	68	68
Other irrigation in Vaal (3)	452	452	452	452	452
Other irrigation in sup subsystems (3)	25	25	25	25	25
Wetland losses (4)	47	48	50	53	58
Bed losses (5)	267	267	267	267	267
Mooi River (net losses) (6)	14	14	14	14	14
Total Water Requirements	**3991**	**3984**	**4119**	**4354**	**4680**
	Return Flows (million m^3/a)				
Southern Gauteng (Rand Water)	-467	-467	-509	-567	-631
Midvaal Water Company	-1	-1	-1	-1	-1
Sedibeng Water	-3	-3	-3	-3	-4
Other towns and industries	-84	-86	-94	-94	-97
Irrigation (7)	-74	-74	-74	-74	-74
Mine de-watering	-126	-126	-78	-78	-78
Mine Water treated for Re-use	0	0	-50	-50	-50
Increased urban runoff	-111	-113	-129	-150	-178
Total Return Flows	**-865**	**-870**	**-937**	**-1017**	**-1113**
Net Water Requirements	**3126**	**3114**	**3182**	**3337**	**3567**

Notes:

(1) Rand Waters total raw water abstraction includes Sasolburg (urban) as well as the Sasol Secunda (urban) intake of 25 ML/d but excludes Authorised Users (i.e. ESKOM, ISCOR, Sasol Sasolburg (Industrial), Mittal Steel and Small Users (Mining & Industrial)).

(2) Includes distribution losses within Vaalharts canal system and mainstream irrigation along Vaal River from Bloemhof Dam down to Douglas Weir. Distribution losses are estimated to be between 8% to 10% (DWA. 2009b).

(3) "Other irrigation" excludes diffuse irrigation

(4) Includes evaporation losses associated with wetlands as well as bed losses occurring within the Suikerbosrand and Klip rivers (DWA, 2012a)

(5) Vaal Riverbed losses include evaporation and operating losses associated with releases made from Bloemhof Dam (DWA, 2012a)

(6) Mooi River (Wonderfonteinspruit Catchment): Net effect of bed losses and decanting from dolomitic eyes resulting from WQT calibration (DWAF,2009c)

(7) Includes flow contribution resulting from the tailwater component at Efren's Dam (DWA, 2012a) & (DWAF. 2007b)

(8) Includes DWS 3rd Party Users supplied from Eskom conveyance infrastructure as well as from the VRESAP pipeline (i.e. Greylingstad and Burn Stone Mine) (DWAF,2009d)

(9) It is assumed that Sasol's raw water requirements are not supplied through Rand Water, but that the projections of Rand Water include the potable water allocation of 6 Ml/day. Sasol Sasolburg (industrial) is supplied with raw water from the Vaal Dam, Vaal Barrage and the Vaal river, this accounted for roughly 24 million m^3/a in 2018. An additional 2.19 million m^3/a (6 ML/d) in potable water is obtained from Rand Water. Sasol in note 1 is the domestic water requirements, excluding the industrial demands.

(10) Represents Mittal Steels total water requirements (i.e. includes the portion of the demand obtained from Rand Water)

(11) Excludes Sasol Secunda's intake of 25 Ml/d (9.13 million m^3/a) from Rand Water as from start of analysis period until the end of June 2025. A new agreement will then be negotiated between the parties.

2.3.3 RSA: Orange-Senqu River System

The Orange River is the longest river in South Africa, originating in the Highlands of Lesotho as the Senqu River and flows westwards into the Atlantic Ocean. A significant portion of the catchment lies within Botswana and Namibia, as the Molopo River and the Fish River Tributaries respectively. There are a number of major dams in the Orange Senqu System, such as the Katse (gross storage 1 950 million m^3) and Mohale (gross storage 946.90 million m^3) dams in Lesotho, as well as the largest dam in South Africa the Gariep Dam, with a gross storage of 5 342 million m^3, and Vanderkloof Dam, with a gross storage of 3 186 million m^3 in South Africa. Gariep and Vanderkloof Dams combined system is referred to as the Orange River Project and is used to supply all the water requirements along the Orange River up to the river mouth including the environmental requirements at the estuary flowing into the Atlantic Ocean, as well as many transfer schemes to neighbouring catchments. These transfers include the following:

- Current (2018) transfer from the LHWP to IVRS of 780 million m^3.
- Caledon Modder Transfer supports the water supply to Bloemfontein, Mangaung, Botshabelo, Thaba N'chu. Two transfer schemes are used as given below:
  - Novo Transfer Scheme with maximum capacity of 2.2 m^3/s
  - Welbedacht Dam to Bloemfontein with maximum capacity of 1.29 m^3/s.
- Orange-Fish Tunnel transfers water from Gariep Dam to the Fish and Sundays rivers in the Eastern Cape for irrigation and urban/industrial purposes with 2018 transfer volume of 620 million m^3/a of which 93% is used for irrigation and 7% for urban/industrial purposes.
- Orange Riet Transfer abstracts water from the Vanderkloof Dam via the Vanderkloof Main Canal transferring water to the Riet River catchment. The total volume transferred

through the Orange Riet Scheme is 260 million m^3/a of which the bulk is used for irrigation purposes with a small amount for urban use.

- Orange Vaal Transfer Scheme used to mitigate shortages and high salinity issues at Douglas Weir on the Lower Vaal River. The transfer volume ranges from 120 million m^3/a to 142 million m^3/a, depending on the water level and water quality in the Vaal River. This water is mainly used to support irrigation with only about 2.3 million m^3/a used for domestic purposes.
- Transfer from the Lower Orange to Springbok and Kleinsee. (maximum pump capacity of 0.315 m^3/s)
- Possible future transfer from Makhaleng Dam in Lesotho to RSA and Gaborone in Botswana. The total transfer volume is not yet fixed but is expected to be in the order of 186 million m^3/a

Phase 2 of the LHWP is planned to be completed by 2026. This will allow for an additional increase of 460 million m^3/a from the future Polihali Dam via Katse Dam and existing transfer tunnels. Polihali Dam will however capture potential runoff upstream of the Gariep and Vanderkloof dams and thereby significantly reducing the potential inflow to the dams.

Return flows for the ORS are in general small from Urban/Industrial and Mining sectors, except for the Greater Bloemfontein sub-system. Some of the water supply schemes divert water far from the mainstream, thereby almost no return flows return back into the main Orange River. These typically include demand centres such as Kleinsee, Springbok, Pofadder, Aggeneys and Port Nolloth along the Lower Orange with 2018 annual water requirements of 2.0, 6.7, 0.8, 1.0 and 0.6 million m^3/a respectively. The return flows generated by the water supplied via Orange-Fish tunnel transfer from Gariep Dam to eight small towns as well as Port Elizabeth in the Eastern Cape will as such not be available for use in the Orange River. The irrigation sector has significant return flow volume and it is estimated as 200 million m^3/a at 2018 development level, which is currently used by downstream users.

Major transfers to the Riet/Modder Catchment, Vaal River and the Orange-Fish Tunnel to the Fish and Sundays Rivers. The Caledon-Modder transfer supports the water supply to Bloemfontein, Mangaung, Botshabelo, Thaba N'chu and other smaller towns in the Riet Modder Catchment.

Hydropower is generated by releases from the Gariep Dam, Vanderkloof Dam and the Neusberg Hydropower Scheme, which is operational when supplying downstream users.

The water requirements projection with WC/WDM is summarised in **Table 2-2**.

Table 2-2: Orange-Senqu Water Requirements and Return Flows Projection with WC/WDM (ORASECOM, 2019d)

Description	Water Requirements (million m^3/a)				
[(1)]Irrigation Requirements (Inc. net canal losses)	**2018**	**2020**	**2030**	**2040**	**2050**
Upper Orange Irrigation	109	111	109	109	109
From Gariep only	638	646	653	653	653
From Vanderkloof (RSA)	1 382	1 362	1 351	1 353	1 353
From Vanderkloof (Namibia)	55	56	56	272	368
Total Irrigation Demands	**2 183**	**2 174**	**2 169**	**2 387**	**2 483**
Domestic/ Urban Requirements	**Water Requirements (million m^3/a)**				
[(2)]Bloemfontein, Botshabelo, Thaba Nchu	97	101	126	154	185
Upper Orange	11	11	14	17	20
From Gariep Only	77	77	81	84	88
From Vanderkloof (RSA)	87	82	94	102	116
From Vanderkloof (Namibia)	22	20	18	35	37
Total Domestic / Urban Demands	**294**	**292**	**332**	**392**	**446**
Transfer from Katse Dam to Vaal Dam	**780**	**780**	**940**	**1 171**	**1 171**
Total River & Operating requirements	**1 083**	**1 083**	**1 083**	**1 083**	**1 083**
Demand Imposed Gariep & Vanderkloof	**3 343**	**3 325**	**3 335**	**3 581**	**3 697**
Total Orange River Demand	**4 339**	**4 329**	**4 524**	**5 033**	**5 183**

Notes: [(1)] – This represents the net irrigation requirements after the use of irrigation return flows were taken into account.
[(2)] – Bulk of urban/industrial return flows generated from the Greater Bloemfontein System in total 37 million m^3/a at 2018 development level

2.3.4 Namibia: Fish, Nossob, Auob and Lower Orange River

Namibia is located to the north-west of South Africa with a low population density of 3.13 people/km^2, compared to 42.4 people/km^2 in South Africa (population density refers to the average of the entire country). Namibia borders Angola to the north, Botswana to the east and Atlantic Ocean to the west. The entire catchment area of the Orange Catchment in Namibia is approximately 260 000 km^2 or 30% of the entire Orange River basin. The main catchments in Namibia connected to the lower Orange River are the Fisch River, and the Nossob-Molopo river system, as well as the smaller tributaries flowing towards the Lower Orange River main stem. The rivers within Namibia are ephemeral. The only river which occasionally contributes flow to the Orange River is the Fish River Catchments. The water use sectors range from urban, rural, tourism, livestock watering, irrigation and mining, the Fish and Nossob Catchments do not have any large industries.

There are four major irrigation areas within the Orange Catchment, being downstream of the Hardap and Naute dams. These schemes make use of surface runoff from the Fish River Catchment. The Stampriet artesian groundwater basin which underlays the Nossob and Auob

Catchments are used to supply the Stampriet Irrigation Scheme. The fourth irrigation area includes all the Namibia irrigation along the Lower Orange River and include schemes such as the Noordoewer/Vioolsdrif and Aussenkehr irrigation schemes abstracting water directly from the Orange River. The Tandjieskoppe Irrigation Scheme of approximately 1 000 ha irrigation area is planned, however has not yet been implemented. The newly constructed Neckartal Dam was planned to supply irrigation water requirements to a 5 000-ha scheme, which has not yet been constructed. There is major irrigation return flows from the Aussenkehr and Noordoewer/Vioolsdrif irrigation schemes and is expected to be in the order of 9 million m^3/a or 10% of the irrigation requirement (DWS, 2014a).

Mining water requirements for mines at Oranjemund, Rosh Pinah and Skorpion are dependent on water from the Orange River. In addition to the existing mines there is planned mining activities to occur near Noordoewer along the Lower Orange, such as the Haib Copper Mine. The Kudugas project was supposed to be developed, however this has not yet realised, due to the high cost of production.

There are no major return flows from urban demand centres in Namibia towards the Orange River, due to the distance of theses urban and rural demand centres to the Orange River.

The total irrigation, urban/industrial and mining water requirements projection is summarised in **Table 2-3**.

Table 2-3: Namibia Water Requirements Projections (ORASECOM, 2019d)

Description	**Water Requirements (million m^3/a)**				
	2018	**2020**	**2030**	**2040**	**2050**
Irrigation					
Fish	52.8	53.8	112.9	143.8	144.2
Lower Orange Main Stem	54.6	55.6	55.6	208.0	345.0
Nossob/Auob	0.1	0.1	0.1	0.1	0.1
Total Irrigation Water Requirements	**107.5**	**109.5**	**168.6**	**351.9**	**489.4**
Urban					
Fish	2.9	2.9	2.9	2.9	2.9
Lower Orange Main Stem	9.8	10.0	10.3	11.5	12.3
Nossob/Auob	2.0	2.1	2.3	2.5	2.7
Total Urban Water Requirements	**14.7**	**15.0**	**15.4**	**16.9**	**17.9**
Total Mining Water Requirements - Only Lower Orange	**19.5**	**19.2**	**18.8**	**26.2**	**26.8**
Total Water Requirements	**141.7**	**143.6**	**202.9**	**395.0**	**534.1**

2.3.5 Botswana: Molopo River

Botswana has the lowest population density of the four countries of 3 people/km^2, just slightly less than Namibia. The Orange River basin in Botswana forms part of the southern Kgalagadi district, in the Kalahari Desert, there are no large urban centres or industries. The Nossob and Auob tributaries, which originate in Namibia flow into the Main Molopo River. The water requirements are predominantly for urban/rural water users, diffuse irrigation (irrigation that is not part of a defined scheme and normally scattered over the catchment area considered) and stock feeding, as well as some mines.

The topography of the catchment in Botswana dictates that the catchment includes villages such as Lehututu, Tshane and Jwaneng Town and all the villages in South Kgalagadi while towns along the Trans-Kalahari such as Kanye, Lobatse and Kang are not within the catchment boundary. The total catchment area for the Nossob and Molopo Rivers in Botswana is 120 000 km^2. The largest mine in the catchment is the Jwaneng Mine, with a total water requirement of 7.1 million m^3/a, of which 5 million m^3/a is used for the mining operation and 2.1 million m^3/a for domestic purposes. It is estimated that the total industrial water requirements in the largest town of the catchment is approximately 0.001 million m^3/a. The water demands for the villages in the catchment area was calculated in National Water master Plan Update of 2006 and the latest figures are as shown in the Botswana National Water Master Plan Update of 2018 were used. No observed water use data is however available.

The central statistics office of Botswana reported a domestic water consumption of between 0.164 million m^3/a, institutional and industrial water requirement of 0.069 million m^3/a for 2009. There is diffuse irrigation and livestock water requirements, which are supplied by groundwater sources (MMEWA, 2013).

There are currently no major waterborne sanitation systems in the villages, there are however plans to implement such systems, which will drastically increase the water requirements for the area. There are no contributing return flows from Botswana towards the Main Orange River, as there are about no return flows or very small amounts generated in the Botswana parts of the Orange-Senqu basin. Secondly this is an extremely arid area and any return flows just seeps into the soil and/or evaporate. Even during high rainfall periods when significant volumes of runoff is produced, the water is not reaching the Orange River at all, as it disappears in the Kalahari Desert.

The planned Lesotho to Botswana Water Transfer (L-BWT) scheme will address the rapid expansion of the urban complexes. The L-BWT is proposed to deliver water to Lesotho, South Africa and Botswana, from the planned Makhaleng Dam through a 700 km long conveyance pipeline.

The planned transfer volume from Lesotho to Botswana is planned to augment Botswana's water supply by 59 million m^3/a according to the low scenario and 136 million m^3/a for the high scenario, and excludes treatment and conveyance losses (ORASECOM, 2019a).

The future water requirements for Botswana are summarised in **Table 2-4** (ORASECOM, 2019a), containing both Urban and irrigation water requirements.

Table 2-4: Future Botswana Water Requirements and Return Flows (ORASECOM, 2019d)

Description	Water Requirements (million m^3/a)				
	2018	2020	2030	2040	2050
Total Irrigation Water Requirements	10.0	10.0	19.0	19.0	19.0
Total livestock requirements	9.0	9.0	9.0	9.5	9.7
Total Mining Water Requirements	7.6	12.0	13.1	13.2	13.2
Total Urban Water Requirements	28.0	29.0	52.0	63.0	73.0
Total Water Requirements	**54.6**	**60.0**	**93.1**	**104.7**	**114.9**

2.3.6 Lesotho: Senqu/Caledon River

Lesotho has the highest population density of the four basin counties with 71 people/km^2 followed by the RSA with 42.4 people/km^2. Lesotho water requirements are primarily used for urban and rural water supply, with a substantial portion being utilised for industrial applications. The majority of the water is sourced from direct runoff river abstractions and Metolong Dam, with limited use of groundwater resources. A large portion of the runoff generated in Lesotho is exported to South Africa with the current phase 1 LHWP, which transfers a total of 780 million m^3/a to the Vaal Catchment. Phase 2 of the LHWP will allow for an additional volume increase of 460 million m^3/a through the Polihali Dam which is planned to be completed by 2026. Polihali Dam will capture potential runoff upstream of the Gariep and Vanderkloof dams, thereby significantly reducing the potential inflow to the dams.

The Water and Sewage Company (WASCO) in Lesotho supplies water to urban and industrial users which are, Maseru City, followed by Maputsoe, Mafeteng, Mohale'shoek, Quthing, Qacha'snek, Thaba-Tseka, Mokhotlong, Butha-Buthe, Hlotse, Peka, T.Y., Mapoteng, Roma, Morija and Semonkong. WASCO serves approximately 300 000 people, which is 60% of the total urban population in Lesotho. The water supply coverage by WASCO is approximately 49% for all urban centers and 13% with sewer connections. The majority of the water in Maseru is obtained from the Caledon (Mohokare) River and the recently completed Metolong Dam, which is supplemented by the Maqalika off channel storage when the turbidity in the river is too high. The remainder of the 15 town centers obtain their water from direct river abstraction, springs or groundwater sources (WASCO, 2018).

There are some industries located in Lesotho, and supplied by WASCO, ranging from textiles and footwear to electronics, which are based predominately around the capital city of Maseru. Such as Nien Hsing, C&Y, Global Garments and Lesotho Brewing Company, which combined use about 40% of the total potable water produced. The total industrial water use is 60% and domestic water use accounts for 40% of the total potable water production (WASCO, 2018).

Only a small portion of the urban/rural areas have waterborne sanitation located around Maseru, thereby only producing a limited return flow. For 2018 the total return flows from Maseru are estimated to be 7.3 million m^3/a and are expected to increase significantly once the water borne sanitation network is expanded to cover greater parts of Maseru (Metolong Authority, 2018). WASCO has private contracts with sewage trucks to reach out to the outskirts of Maseru.

Lesotho is planning to implement new water supply schemes (Parkman, 2004) (SMEC, 2017) to improve the current lack in water supply to existing users, to make provision for future growth in water use that includes the development of new irrigation schemes as well as a transfer to Gaborone in Botswana (MMEWR, 2015b) with some support to RSA towns on the transfer route. The detailed information on the Lesotho Botswana transfer can be found in the L-BWT report of this Study (ORASECOM, 2019a). Water supply to zone 5 and 6 in Lesotho is planned to benefit from the transfer, as they will receive 9 million m^3/a for urban/Industrial/rural supply purposes. The Makhaleng Dam will support zone 7 downstream of the dam, which does not form part of the L-BWT and will receive an estimated 13 million m^3/a for urban/Industrial/rural through additional infrastructure development. Lesotho plans to support new irrigation development with water from Makhaleng Dam to a maximum of about 107 million m^3/a, but this will depend on the availability of water from Makhaleng Dam. According to current planning, Makhaleng Dam should be in place by 2030.

Two other dams are planned in the Lesotho Lowlands to improve the water supply situation in the Lowlands. These are Hlotse and Ngoajane dams which are both planned to support urban/Industrial/rural as well as new irrigation developments. These dams are located in the Mohokare/Caledon River catchment. Hlotse Dam is targeted to supply 20 million m^3/a for urban/Industrial/rural purposes and 46 million m^3/a for new irrigation developments downstream of the dam. The target date for the completion of Hlotse Dam was given as 2030. Ngoajane Dam is a smaller development and expected to supply 23 million m^3/a to urban/Industrial/rural users with 6 million m^3/a for new irrigation developments.

The current irrigation water requirements in Lesotho are estimated to be 6.7 million m^3/a (ORASECOM 2011c). The latest water resources master plan for Lesotho stated a total irrigation requirement of 151 million m^3/a for the Makhaleng Catchment of which a maximum of 107 million m^3/a can be supported downstream by the planned Makhaleng Dam, 49.19 million m^3/a for the Likhutlong & Ts'ehlanyane catchments, supported by the planned Hlotse Dam, 35.23 million m^3/a for the Senqu Basin and 6.17 million m^3/a for the Khukhune Catchment, supported by the Ngoajane Dam (SMEC, 2017). Most of the existing cultivated areas for crop production in Lesotho is rainfed, due to the high costs involved with lifting the water from rivers to the irrigation areas.

There are a number of diamond mines in Lesotho, in the Butha-Buthe and Mokhotlong district. The largest being the Letseng Mine. In addition to the diamond mines there are also some aggregate mines. The mines use water to wash the raw product, which is recycled a number of times, thereby minimising the overall water requirements.

The current and future water requirements are shown in **Table 2-5**.

Table 2-5: Future Lesotho Water Requirements (ORASECOM, 2019d)

Description	Water Requirements (million m^3/a)				
	2018	2020	2030	2040	2050
Irrigation Requirements					
Caledon	6.7	6.7	52.9	59.1	59.1
Makhaleng	0.0	0.0	0.0	79.0	79.0
Total Irrigation Demands	**6.7**	**6.7**	**52.9**	**138.1**	**138.1**
Domestic/Industrial Requirements					
(1) Caledon	33.1	43.2	93.0	117.8	142.1
Makhaleng	1.6	3.9	10.0	20.1	23.1
Senqu	3.8	4.2	6.1	7.7	8.1
Total Domestic/Industrial Demands	**38.4**	**51.3**	**109.1**	**145.6**	**173.3**
Transfer to Lesotho Botswana and RSA from Makhaleng[1]	**0.0**	**0.0**	**0.0**	**97.0**	**97.0**
Total Water Requirements	**45.2**	**58.1**	**162.0**	**380.7**	**408.4**

Note: (1) – The bulk of the return flows are from Maseru at 2.6 million m^3/a at 2018 development level.

2.4 Assurance of Supply

In arid and semi-arid regions it is generally not economically feasible to develop and operate a water resource system to meet all the demands at all times This means that 100% of the demand cannot be supplied for 100% of the time and shortfalls in the supply will occur from time to time. If shortfalls occur frequently, the supply will have a low assurance while relatively few shortfalls represent a high assurance in supply.

Restrictions in supply during dry periods is one of the few management tools available to operators to cope with the highly variable availability scenarios. It is clear that different types of user groups will require different levels of assurance of supply. Irrigation will typically be supplied at a lower assurance than water for domestic and industrial purposes, and water for strategic industries that generate a high economic benefit from water used. It is also logical to sub-divide the supply to irrigation into different assurance levels, as permanent crops such as export grapes would require a higher assurance than for example a cash crop.

The assurance of water supply is a concept that plays an integral and important part in the supply of water to users within the water supply systems. The approach followed to implement and manage this concept is not necessarily the same in each country as explained in the sub-sections to follow.

2.4.1 Approach followed mainly in the RSA

All the main water supply systems within the RSA as well as many of the smaller water supply systems are based on the principle to supply water to the users at agreed assurance levels. The operating rules developed for these sub-systems include the ability to operate or manage these sub-systems to ensure the supply of water at the required assurance level.

To be able to determine the yield available at different assurance levels, risk analysis are carried out by using a rigorous stochastic streamflow generation model included in both the WRYM and WRPM, that accounts for the statistical characteristics of the rainfall and runoff in multi catchments by maintaining the serial and cross correlation as it was observed historically.

This long-term risk yield curve (also referred to as long-term stochastic yield curve- see **Figure 8-11**) a can be used to determine the yield available at a given risk or assurance as well as for a combination of different assurance requirements. The total demand imposed on the system should not exceed the available yield at the given assurance level to ensure that the resource is not over utilized. When over utilized the resource will not be able to supply the demand imposed on the system at the required assurance.

For operation purposes it is however important to determine the short-term yield characteristics that will provide detail on the short-term yield capability of the system with the system being at a specific storage at the beginning of the analysis or operating year. A storage dam at full supply will for example be able to supply over the short-term (three to five years) a higher yield than in the case when the dam is at 10% storage, at the start of the analysis. Short-term risk yield analyses are carried out using the same method as explained for the long-term risk yield, with the only differences that the analysis period is short, normally 5 years, and is repeated for different starting storage levels.

The operation of sub-systems using the approach described above is thus based on the principle that demands are restricted during severe droughts.

- The objective is to reduce water supply to less essential use to be able to protect the assurance of supply to more essential use.
- The basis on which restrictions are implemented is defined by means of a user priority classification definition and the short-term yield characteristics.

Priority classifications used for the different sub-systems is not always the same as it depends on the yield characteristics of the sub-system, the type of user or combination of users to be supplied from the resource, losses within the system, types of crops or crop combinations that need to be irrigated, the strategic importance of the user etc. Priority classifications are not fixed and can be changed in agreement with the users for various reasons.

In some water supply systems, the assurance of supply to the users is not well defined, resulting in quite a grey area concerning correct operation of the system as well as by when a by how much a resource yield need to be increased to supply users at acceptable levels of assurance. These schemes are normally not operated on a very scientific basis an experience over years are then to a large extent used as guidance in this regard. These schemes very easily run into the problem of zero storage in the dam during critical droughts, with severe negative impacts on the users and the economy in the region.

Transfers are in some cases also linked to a specific assurance level. A good example is the transfer from The LHWP in Lesotho to the IVRS in the RSA. This transfer volume is fixed and represent an assurance of approximately 98% (failure in full supply on average 1 in 50 years).

2.4.2 Approach followed in Namibia

In Namibia the supply of water has been allocated to different users based on a system of priorities allocated to the different consumer categories. These priorities are:

- First priority - Human and livestock
- Second priority - Industries, Commerce and Mining
- Third priority – Agriculture, including irrigation
- Fourth priority – Recreation.
- In the allocation of water priorities, consumers who produce the maximum economic benefit from water use will be considered.

The long-term assurance of supply to the user categories in Namibia has been split into different levels of assurance as follows:

Assurance of supply for long term planning:

Urban (including domestic and industries) 95%

Mines	95%	(assurance is based on stochastic flows)
Irrigation	80%	

The biggest challenge in Namibia is, however, the management of available, and dwindling supplies in the short-term, especially during periods of drought. At the end of each rain season an annual evaluation of all supply sources (dams, boreholes, reclamation) and projected demands for a two year period is carried out, and assuming no inflow into the surface sources (dams) during this two year period, the target is to supply sufficient water to all consumers over this period. Should there be insufficient supplies to bridge this two-year period restrictions on water use is imposed on the system and the required savings obtained through water demand management initiatives such as such as block tariffs, covering swimming pools, no garden watering etc. These are agreed upon between NamWater and the major municipalities which will allow this period to be bridged. The situation is then monitored on a monthly basis and feedback is provided to the major consumers who then take the necessary actions to ensure the required water savings. In 2019, for example, the City of Windhoek is required to show a 15% saving in water consumption to meet the two-year bridging period.

The model currently used by NamWater is their in-house developed CA-Model. This is a computer model, which simulates the hydrological water balance of the Central Area of Namibia (CAN) using a monthly time scale with annual demand/supply inputs. Since the regional hydrology of the CAN is dictated by highly variable rainfall and surface runoff events with high evaporation rates, the CA-Model performs a repeated water balance using a randomized pattern of historic statistical analyses to quantify the security of water supply in terms of statistical probabilities. The CA-Model can also be used to predict the earliest run dry date given current water storages and no future inflows (worst case scenario). The CA-Model has become an invaluable tool for NamWater in the annual water management planning and system optimisation as well as for long-term planning of regional capital investment in bulk infrastructure.

Since its initial development in 1998 and throughout its most recent revisions, the aim of the CA-Model has been to:

- provide a usable tool for assisting with optimizing operation of a complex water supply system
- accurately describe the system's existing and planned infrastructure
- simulate the transfers and losses between water sources and demand centres
- simulate the water balance in the three dams of the Central Area
- account for the stochastic nature of inflow events
- simulate usage of emergency sources.

Depending on how the model is run, its results can include:

- monthly and yearly water balances for the Central Area
- prediction of the run-dry month (first shortfall) in the system assuming no inflows
- shortfall probabilities for the user-defined simulation period
- statistical likelihoods of shortfall magnitudes over the planning period
- optimization of operating rules for the dam storages and transfers
- optimal short-term and long-term operating rules for the system as a whole.

Using the results from the model, the resource managers can take informed decisions regarding possible curtailments at an early stage in any drought event rather than waiting until the situation becomes critical and it is too late to take proper evasive action to avoid severe water restrictions.

2.4.3 Approach followed in Lesotho

Lesotho has adopted a basic water supply of 30 litres per capita per day (30 l/c/d) as a water need for basic healthy livelihood at the domestic water level. However, this demand is occasionally or rarely met, especially in the remote rural areas where water usage may even go as low as 8-15 l/c/d, during low flows and drought periods.

In the urban centres and designated areas of the Water and Sewerage Company (WASCO), the Strategic Plan 2015/2016-2019/2020 (WASCO, 2015), the total national urban household population served is stated as 80,000 out of total national urban households of 431,000. The water sources and condition of the infrastructure have a large impact on the assurance of water supply. However, WASCO (2018) serves approximately 60% of the total urban population of Lesotho. Only 49% of the urban households has water connections within their premises.

The main sources of water in Lesotho are natural springs, groundwater from drilled boreholes (i.e. at household level and at well fields' level); surface water and for some individual's rainwater harvesting facilities like water tanks (e.g.JoJos).

The assurance of supply from water supply systems are normally determined at community (village) level by the Department of Rural Water Supply (DRWS) during the design of the water systems. At the peri-urban and urban levels, Water and Sewerage Company (WASCO) is responsible and at regional levels transboundary schemes, e.g. Lesotho Highlands Water Project and Lesotho-Botswana Water Transfer study are envisaged to provide/determine assurance of supply. These systems are under the auspices of Ministry of Water.

The agreed levels of water supply assurance systems are dependent on:

a) The principle of supplying water mainly for various water use activities e.g. domestic, recreational, industrial, irrigation, hydropower generation and environmental water requirements.

b) Availability of water (yield) through hydro-meteorological assessments spatially and timeously.

c) Quality of water to be supplied within identified water quality standards.

In most cases, these levels are derived from international best practices. The assurance of water supply levels are determined by using stochastic and historical stream flow generation that are derived from historically observed rainfall and runoff data using stochastic, statistical and deterministic models like WEAP, WRYM, WRPM, etc. as well as using already existing storage facilities like dams, and tanks that are mostly precipitation fed.

However, the levels of assurance of water supply are not readily quantified at locations/points of use through water using activities, but at source points/location, thus in terms of availability (yield) and quality for example).

a) In some incidents 100% dependence on the natural springs determines/warrants the assurance level of water supply for the communities.

b) Boreholes are also used to warrant the assurance of water supply for some peri-urban and urban areas. However, WASCO (WASCO, 2018), stipulates that the existing infrastructure, of which most of it is old and obsolete, is struggling to reliably serve the customers. This is an indication that the current status of assurance of supply for some urban and peri-urban areas that are serviced by WASCO are in general low.

c) Transfers are in some cases also linked to a specific assurance level. A good example is the transfer from the LHWP in Lesotho to the IVRS in the RSA. This transfer volume is fixed and represents an assurance of approximately 98% (failure in full supply on average 1 in 50 years).

d) Rainwater harvesting using tanks which is a water storage facility assures the extension of the water supply to the individuals who are in possession of such a system/ facility. The assurance of supply for these systems are in general low.

However, the effects and impacts of climate change in relation to increased occurrence and severity of drought and floods affect all levels of assurance of supply for various water using activities as well as the economy of Lesotho.

The Ministry of Water has the responsibility in the water affairs of the country through its Commission of Water (CoW) in collaboration with the Department of Water Affairs (DWA), the

Department of Rural Water Supply (DRWS) and other parastatals in the allocation of the water resources to the different users. DWA advises CoW on the yields from the water sources, such as surface and groundwater volumes for CoW to assess the supply versus the demand.

During severe droughts, water restrictions are imposed. These restrictions are ably implemented in the urban and peri-urban areas where WASCO is operative. The methods to reduce the water use that are usually used is to impose a ban on hosepipe car-washing, to be followed by lawn watering, garden watering, industrial water use and lastly domestic supply, once the safe yield from the raw water sources are not meeting the full demand.

2.4.4 Approach followed in Botswana

According to the Botswana National Water Master Plan (BNWMP, 2018) a periodic and consistent water balance analysis is recommended to ensure higher reliability of water supply. The water balance analysis is used to promote an efficient development and utilisation of water resources in Botswana. In the context of Botswana and according to the Botswana National Water Master Plan (BNWMP, 2018) water supply reliability refers to the certainty of water supply to meet the set water demand and is expressed in the concept of probability or frequency.

The latest water master plan has adopted the water supply safety at 90% and this figure takes into consideration Botswana's vulnerability to drought which occurs once in 10 years (Botswana National Water Master Plan (2018)

The water balance for the country was based on the following assumptions:

- The annual water supply reliability per dam is 90%
- Groundwater to be sustained without pollution, depletion or reduction in the future
- The Chobe River and Okavango River supply Kasane and Maun respectively
- Sand river supply is small and scattered all over the country and therefore excluded from water availability
- Considering that the water supply is dominated by dams and groundwater, the return flow is not considered

In the case of Botswana, the ModSIM model was used during the Botswana National Master Plan Update (BNWMP, 2018) to model the reliability of water supply and shortage in the future. The model was used to determine the timing of the required future water source developments.

3 GROUNDWATER

3.1 Background

3.1.1 Objective

The objective of the Groundwater Report is the Quantification and mapping of potential groundwater volumes that could be considered in the core scenario, either for new developments or for substitution of surface water resources to obtain an improved utilization of groundwater in the basin.

The report covers:

- Potential quantities and quality groundwater that could be considered in the core scenario either for new developments or for substitution or conjunctive use with of surface water resources in line with spatial unit of analysis utilized by the surface water resource analysis.
- Recommendations on how and where groundwater resources of the basin can be better utilized.
- Identification of constraints, looking at both quantity and quality, such as remaining allocable groundwater, aquifer storage and the impact during droughts, borehole yields, existing infrastructure.

3.1.2 Data sources

The assessment of groundwater resources is based on:

- Assessment of the potential yield of the aquifer systems within each sub-catchment based on recharge and aquifer storage.
- State of current groundwater development and usage per sector within each sub catchment.
- Groundwater quality evaluated according to relevant water sector use standards (domestic, industrial, mining, irrigation, livestock).
- The vulnerability of groundwater to over abstraction and contamination.
- Assessment of borehole yields (to determine whether aquifers can be economically exploited).
- Analysis of whether abstractions can impact on surface water resources.
- Identification of ecological or environmental limitations on abstraction.

Data sources include reports and data held by government departments of the river basin states (e.g. Department of Water Affairs, Authorities, Geological Survey Departments etc.), ORASECOM, SADC Groundwater Information Portal (SADC-GIP), SADC-Groundwater

Management Institute, UNESCO IHP and International Groundwater Resources Assessment Centre (IGRAC).(ORASECOM, 2019e)

3.2 Unit of analysis

For South Africa and Lesotho, the basic unit of evaluation was considered to be the Quaternary catchment, of which 496 exist in Primary catchments C and D covering South Africa and Lesotho. This is consistent with the approach of integrating surface and groundwater resource evaluation. Catchments were overlain over Groundwater regions to further delineate units of analysis; hence many Quaternary catchments are subdivided into units based on variations in geology, physiography and climate, hence integrating hydraulic boundaries with geological boundaries and variations.

For Botswana and Namibia, the Basic unit of analysis was the Litho-Hydrogeological Unit based on the dominant lithology. These were grouped into groundwater regions.

The groundwater regions are shown in **Figure 3-1**. Groundwater regions do not always correlate across borders because of different aquifers being used by different countries. In Namibia, the Stampriet Karoo aquifer is used in the western Kalahari basin (24). In South Africa, the overlying sedimentary Kalahari aquifer is used (23), hence they are mapped as different regions with differing properties. In Botswana, the mapped geology is based on the underlying pre-Kalahari geology.

A summary of groundwater resources per groundwater region is shown in **Table 3-1**. Detailed evaluations per Quaternary catchment are hydro-lithologic unit are given in the Groundwater report. The Utilizable Groundwater Exploitation Potential (UGEP) is an estimate of the maximum volume (m^3) of groundwater that is potentially available for abstraction on an annual basis under pristine aquifer (i.e. no abstraction) and normal rainfall conditions, factoring in a drought index, baseflow, an exploitation factor based on borehole yield, and an acceptable level of drawdown. The Current Utilizable Exploitation Potential is equal to UGEP minus current abstraction.

Figure 3-1 Groundwater Regions, ORASECOM Basin

Table 3-1 Groundwater resources per groundwater region

Groundwater Region	Area (km^2)	Aquifer Recharge (million m^3)	UGEP (million m^3)	Current Use (million m^3)	CUGEP (million m^3)	Potable fraction	% of yields >5 l/s	% of yields >2 l/s	% of yields > 0.5 l/s	80th percentile (l/s)
Southeastern Highveld	45381.74	421.64	300.04	26.33	273.71	0.91	2.6	15	57	1.6
Ghaap Plateau	20217.29	149.69	209.41	33.23	176.18	0.89	25	46.8	77	6
Western Highveld	29891.43	221.38	288.58	148.94	139.64	0.93	3.9	20.5	66.2	2
Eastern Upper Karoo	35943.06	325.65	167.35	29.99	137.36	0.89	22.9	45.1	75	5.14
Central Highveld	13202.02	152.62	192.81	79.09	113.72	0.93	6	25.9	70.6	2.52
South Eastern Highland	22225.9	224.04	116.69	8.14	108.55	0.9	5.7	23.1	62.4	2.5
Northeastern Pan Belt	25108.62	185.25	153.92	46.72	107.19	0.85	2.9	16.7	57.7	1.77
Southeastern Upper Karoo	27568.85	315.28	137.17	43.97	93.2	0.94	12.2	34.9	75.7	3.43
Taung-Prieska Belt	19206.75	120.7	97.36	12.24	85.12	0.85	7.7	25.4	60.5	2.5
Central Pan Belt	41636.37	355.44	180.41	96.05	84.36	0.87	11.2	34.9	70.8	3.4
Northeastern Highland	14793.3	173.17	75.66	6.77	68.89	0.95	5	31.6	68.6	2.98
Northeastern Upper Karoo	18059.16	171.96	78.35	14.55	63.8	0.93	6.8	25.9	65.9	2.53
Western Upper Karoo	31911.5	71.19	65.04	9.35	55.69	0.79	19.3	42.1	77.8	4.5
Eastern Kalahari	49717.18	272.33	142.7	90.39	52.31	0.83	8.5	22.3	59.6	2.14
Drakensberg Highlands	16589.89	155.88	51.8	0.16	51.63	0.92	4.2	23.5	63.6	2.53
Western Kalahari	58006.28	86.7	34.48	4.39	30.1	0.53	1.8	9.9	53.6	1.21
Bushmanland Pan Belt	47017.73	31.12	22.82	5.44	17.38	0.44	12.1	30.9	65.4	3
Bushmanland	54017.52	23.08	17.47	3.36	14.11	0.38	3.7	16.5	50.3	1.59
Namaqualand	5908.89	0.82	0.46	0.22	0.23	0.16	7.3	17.7	60.6	1.6
Far Northwestern Coastal Hinterland	1811.49	0.13	0.04	0.16	-0.12	0.23	7.5	32.2	74	2.88
Western Bankeveld and Bushveld	1088.87	24.61	12.37	14.47	-2.1	1	9.8	26.3	71.9	2.52
West Griqua Land	17950.65	105.73	62.62	68.38	-5.75	0.82	8	24.3	65	2.5
Karst Belt	8028.88	137.41	104.89	148.28	-43.39	0.93	27	50.8	80.3	10
Grand Total	**605283.35**	**3725.82**	**2512.43**	**890.63**	**1621.80**					

Groundwater Region	**Area (km^2)**	**Aquifer Recharge (million m^3)**	**UGEP (million m^3)**	**Current Use (million m^3)**	**CUGEP (million m^3)**	**Potable fraction**	% of yields >5 l/s	% of yields >2 l/s	% of yields > 0.5 l/s	80th percentile (l/s)
Molopo-Nossob	130361.92	31.42	22.30	9.23	13.08	0.55	26.84	45.12	60.23	5.56
Fish River Aroab	70339.44	7.03	3.72	40			1.2	10.7	56.5	
Hochfeld-Dordabis-Gobabis	31561.44	4.19	1.23				0.64	9.2	53.9	
Karas Basement	22219.81	1.26	0.39				0	0	31	
Southern Namib and Naukluft	1986.70	0.76	0							
Stampriet Basin	129557.39	1.16	8.64				2.2	14.2	10.4	
Grand Total		45.82	36.30	49.23	-12.93					

3.3 Groundwater Resources

3.3.1 South Africa and Lesotho

A summary of the groundwater resource potential for each groundwater region is given in **Table 3-1,** in **Section 3.2**.

Large volumes of groundwater (high CUGEP) are available in the South-eastern Highveld, Ghaap Plateau, Western Highveld, Eastern Upper Karoo, Central Highveld, South Eastern Highland, and Northeastern Pan Belt. However, only in the Ghaap Plateau and Eastern Upper Karoo do sufficient boreholes yield greater than 2 l/s to warrant economical abstraction. Over abstraction exists In the Far Northwestern Coastal Hinterland, Western Bankeveld and Bushveld, West Griqua Land and the Karst Belt (largely as a result of localized mine dewatering).

Groundwater resources are highly stressed in Lower Orange basin, the Middle to lower Vaal.

The largest volume of remaining allocable groundwater can be found in the Karst aquifers of the Ghaap Plateau, where high borehole yields are possible.

Generally, groundwater can be used for domestic and stock watering and supply for smaller towns supplied by well fields within the Upper and Lower Orange River basin. It can be assumed that there is in general adequate groundwater resources available in the Upper and Lower Orange River basin to supply towns and communities not connected to the main surface water supply schemes. However, borehole siting should be based on scientific principles, and sound management practices need to be applied to ensure sustainability of the resource.

Groundwater is the most important source for bulk water supply to local towns and rural settlements in the Lower Orange as these towns and settlements are located far from the surface water bulk supply network.

In the Lower Orange area, poor groundwater quality results in a low potability index, which limits the potential for groundwater supply.

Lesotho is underlain by the Northeastern Highland, Drakensberg Highlands and Southeastern Highland groundwater regions. The Drakensberg Highlands consist of a fractured aquifer of low storage potential, although recharge is high, most is lost as interflow feeding and is not available to boreholes tapping the regional aquifer, consequently the Exploitation potential is lower than the other groundwater regions. The Northeastern Highlands have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the southeastern highlands. Locally, the Northeastern Highland region is moderately stressed by existing abstraction.

3.3.2 Botswana and Namibia

A summary of the groundwater resource potential for each groundwater region is given in **Table 3-1**. The CUGEP shows that Namibia already suffers from the over exploitation of groundwater resources and yields are low, whereas groundwater resources still remain in Botswana. High yields warrant the development of the groundwater here locally available.

The ground water assessments carried out as part of this study showed that the Botswana part of the basin is largely underlain by relatively low yielding aquifers with about 13% of the basin underlain by aquifers with a productivity index of more than 60%. (The most productive aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East.

A large part of the basin in Botswana is underlain by aquifers with groundwater of TDS > 1000 mg/l, with about 12% of the basin yielding groundwater which is 60% to 100 % suitable for human consumption. Groundwater with the highest potability index is predominantly found in the basement aquifers (100%), Upper Transvaal East (80%), Lower Transvaal South (77% and Ecca North (72%) with the lowest potability groundwater found in Dwyka North (11% and Ecca South (4%).

In Botswana, the aquifers with the highest Utilisable Groundwater Exploitation Potential (UGEP) are Ecca North, Lebung and Lower Transvaal South. The majority of the basin with exception Ecca North, Lower Transvaal South, Upper Transvaal East and Lebung hydrogeologic units have very little scope for further development of potable groundwater resources. Areas underlain by Archean Gneiss (Goodhope water supply area) and the Olifanthoek North (Tsabong water supply area) are being over abstracted i.e. high to heavily used.

The Namibian part of the basin is largely underlain by low yielding aquifers with most boreholes having yields of less than 1 l/s.

The Namibian part of the basin is dominated by groundwater with a TDS of 1000 mg/l. Elevated nitrates are found in groundwater throughout the basin in Namibia. The Namibia bulk water utility, the Namibia Water Corporation (NamWater) therefore operates small scale reverse osmosis (RO) plants in the basin to treat ground water to potable quality mainly targeting Total Dissolved Solids (TDS). The Stampriet artesian aquifer in Namibia however has fairly good quality water.

Data indicates that for most of the Namibian part of the basin, there is little scope for development of large-scale groundwater use schemes for potable use.

3.4 Data Limitations

There is a significant discrepancy in how the individual countries collect data, which complicates cross-border mapping and results in 'edge effects' at borders, or different classification. These problems can be summarized as:

- The National geological maps are based surficial geology in South Africa, Namibia and Lesotho, and mapped as pre-Kalahari Geology (sub-Kalahari Basement) in Botswana
- The same geological formations have different names across borders, and boundaries do not always align
- Borehole data coverage is dense in South Africa and Namibia, and sparse in Lesotho and the western portion of Botswana, making statistical characterisation difficult
- Low yielding boreholes do not appear to be incorporated into the Botswana and Lesotho databases, resulting in average and median yields being skewed towards higher yields, and resulting in discontinuities at borders
- South Africa manages groundwater based on groundwater management units, which are based on quaternary catchment boundaries, with the exception of the dolomites. Lesotho and Botswana define aquifers based on lithology while Namibia utilises groundwater drainage basins.

3.5 Summary

A brief summary and conclusions from the findings of the groundwater assessment task is given below:

South Africa

- Large volumes of groundwater (high CUGEP) are available in the South-eastern Highveld, Ghaap Plateau, Western Highveld, Eastern Upper Karoo, Central Highveld, South Eastern Highland, and Northeastern Pan Belt.
- Only in the Ghaap Plateau and the dolomites near Mafikeng do sufficient boreholes yield greater than 2 l/s to warrant economical abstraction. The dolomitic compartment near Mafikeng is known as the Grootfontein/Molopo dolomitic compartment (**Figure 3-2)**.

Lesotho

- The Drakensberg Highlands consist of a fractured aquifer of low storage potential, although recharge is high, most is lost as interflow feeding and is not available to boreholes tapping the regional aquifer. In addition, they contribute to groundwater baseflow, hence abstraction would have a significant impact on baseflow

- The North-eastern Highlands GW Region (Lesotho Lowlands) have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the south-eastern highlands. Locally, the North-eastern Highland region is moderately stressed by existing abstraction.

Namibia and Botswana

- Namibia suffers from the over exploitation of groundwater resources and yields are low.
- Groundwater has a TDS greater than 1000 mg/l. Elevated nitrates occur throughout the basin.
- In Botswana. high yields warrant local development of groundwater. The most readily exploitable aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East.
- The highest CUGEP relative to the area is found in Ecca North, Lebung and Lower Transvaal South (**Figure 3-2)**. The Ecca North is a transboundary aquifer shared with Namibia (Stampriet Basin), and the Lower Transvaal South is a dolomitic transboundary aquifer shared with South Africa (Khakea-Bray aquifer). Both these transboundary aquifers are heavily utilised across the border

A large part of the basin in Botswana is underlain by aquifers with groundwater of TDS greater than 1000 mg/l, with about 12% of the basin yielding groundwater which is 60% to 100 % suitable for human consumption

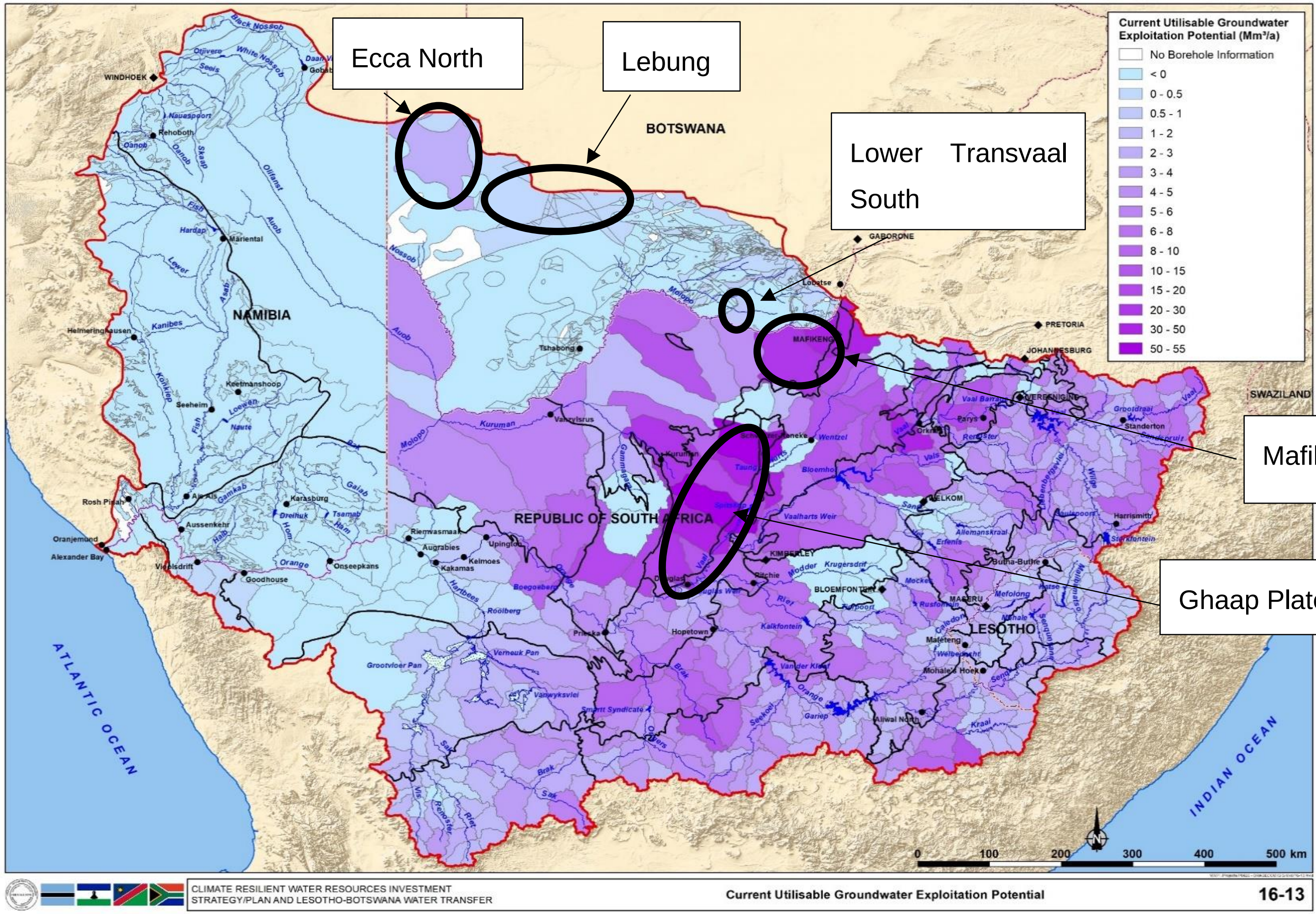


Figure 3-2: Potential zones for large scale groundwater development

4 WATER CONSERVATION WATER DEMAND MANAGEMENT

4.1 Background

The Integrated Water Resources Management (IWRM) plan, adopted in February 2015 (ORASECOM, 2014b) by the ORASECOM Member States, and the National Water Resources Strategy recognize that the Orange-Senqu river basin has for the most part reached its limits in terms of water storage and water transfers and that most of the possible further water developments have a limited economic profitability. Consequently, Water Conservation and Water Demand Management (WC/WDM) measures show the greatest value for money and WC/WDM should therefore be prioritized. WC/WDM is a key strategic intervention to reconcile water requirements with water availability, to enhance long-term water security and protection, to contribute to catchment resilience and climate change adaptation. The purpose of this chapter is as follows:

- To prepare a basin wide investment plan for climate resilient water resources development phased over a period of 30 years, with short, medium and long-term actions and programmes. This plan will build upon the core scenario approved with the IWRM plan of 2015 with greater focus on the potential for the implementation of WC/WDM measures.
- To review the latest estimates of the benefits that can be expected from the implementation of WC/WDM measures in the various sectors, (irrigated agriculture, mining, industry and domestic), and through additional surveys / interviews will assess the potential water savings that could be expected from these users. Irrigated agriculture will in particular be studied in detail to differentiate potential savings according to the type of irrigation system, (gravity or pressurized, pivot, sprinkler, collective or individual, etc.). Potential water savings through the management of irrigated agriculture, in particular irrigation based on actual crop water needs; and to provide details of the progress made with the implementation of WC/WDM, at municipal level, within the large water supply systems (WSS) affecting the study area. The large water supply systems include the Integrated Vaal River WSS, the Crocodile (West) River WSS, the Greater Bloemfontein WSS, the Orange River WSS, Greater Gaborone WSS and the Lesotho WSS. Progress made with the implementation of WC/WDM in the municipal sector within the large water supply systems is provided in this chapter.

4.2 Definitions

The Department of Water and Sanitation (DWS) in South Africa has adopted the collective term of WCWDM, which has been defined in the Water Services Sector Strategy (DWAF, 2004) as follows:

- WC is the minimisation of loss or waste, the care and protection of water resources and the efficient and effective use of water; and
- WDM is the adaptation and implementation of a strategy by a water institution or consumer to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability.

WCWDM can also be defined as follows (Butler and Memon, 2006):

- water conservation means doing less with less and is particularly applicable in drought scenarios and water restrictions (example: take shorter showers; do not irrigate the lawn).
- water efficiency means doing the same (or more) with less (example: fix leaks; use hydraulically efficient toilet pan and cistern design).
- water sufficiency means enough is enough (example: use automatic shut-off of taps; dual flush toilets; careful garden watering).
- water substitution means replace water with something else, say air (example: waterless urinals; vacuum drainage; dry cleaning); and
- water reuse, (example: grey water reuse on-site; shared bath water; groundwater abstraction on-site).

4.3 Urban/Industrial Sector

4.3.1 IVRS

Municipalities in the IVRS managed to achieve savings of 110.0 million m^3/a of a projected 212 million m^3/a by June 2018 mainly through water restrictions. The reduction in demand is positive considering that municipalities in the IVRS exceeded the “high population without WC/WDM” projection by 0.8% in 2016. Ekurhuleni and Midvaal surpassed their 2018 targets. City of Johannesburg and Emfuleni, the major contributors to water loss in the IVRS, have not achieved their targets, and seem unlikely to do so within the next few years, unless significant effort and funds are dedicated to water loss reduction. Most municipalities in the IVRS are category A, B1 or B2 municipalities which are municipalities of economic significance with large budgets, and they should be able to prioritise and implement WC/WDM. The targeted versus the actual savings for the IVRS are summarized in **Table 4-1**.

Table 4-1: IVRS summary of targeted vs actual savings

Year ending	Projected SIV without WDM (X) kl/annum	Projected SIV with WDM (Z) kl/annum	Projected % savings (X – Z) / X * 100	Actual demand (Y) kl/annum	Actual % savings (X - Y) / X * 100
Jun-12	1 355 553 246	1 355 553 246	0.0%	1 350 937 559	0.3%
Jun-13	1 381 188 945	1 328 391 341	3.8%	1 392 562 365	-0.8%
Jun-14	1 407 385 317	1 323 164 904	6.0%	1 420 811 053	-1.0%
Jun-15	1 434 071 521	1 318 268 239	8.1%	1 459 982 952	-1.8%
Jun-16	1 461 309 400	1 316 470 037	9.9%	1 473 100 700	-0.8%
Jun-17	1 488 547 279	1 314 671 835	11.7%	1 392 986 542	6.4%
Jun 18	1 514 433 316	1 302 436 750	14.0%	1 412 547 113	6.7%
Jun-22	1 630 093 995	1 443 086 455	11.5%	-	-

Note: SIV – System input volume (potable water)

4.3.2 CWRWSS

In the Crocodile (West) River water supply system (CWRWSS), most municipalities did not provide water balance data without which no effective WCWDM measures can be implemented or monitored. Water balances for these municipalities were estimated based on the last realistic water balance submitted. These municipalities should be approached to highlight the urgency of implementation and tracking of WC/WDM in the CWRWSS. The results indicate that progress has been made with the reduction of water losses within these municipalities although the data have a very low confidence level. These municipalities have not achieved their June 2018 targets. There is clearly scope for effective metering, billing and cost recovery systems and should be encouraged. The targeted versus the actual savings for the CWRWSS are summarized in **Table 4-2**.

Table 4-2: CWRWSS summary of targeted vs actual savings

Year ending	Projected SIV without WDM (X) (kl/annum	Projected SIV with WDM (Z) (kl/annum)	Projected % savings (X – Z) / X * 100	Actual demand (Y) kl/annum	Actual % savings (X - Y) / X * 100
Jun-13	75 171 987	71 221 843	5.3%	21 810 284	71.0%
Jun-14	77 300 871	71 215 381	7.9%	18 696 180	75.8%
Jun-15	79 442 925	71 572 936	9.9%	75 337 221	5.2%
Jun-16	81 078 966	72 194 677	11.0%	76 169 325	6.1%
Jun-17	82 715 007	72 816 418	12.0%	75 902 630	8.2%
Jun 18	83 961 053	73 189 261	12.8%	76 468 080	8.9%
Jun-22	88 144 534	78 086 454	11.4%		

4.3.3 GBWSS

The **Greater Bloemfontein water supply system** (**GBWSS)** supplies water to the Mangaung Metropolitan Municipality (MMM) and smaller towns in Kopanong and Mantsopa municipalities. The NRW of MMM has increased by 5% in the past year due to the increased SIV. MMM has managed to achieve its water restrictions target. The 15% water restrictions target was well below the WCWDM target which means that additional water restrictions would have been required even if the targets were achieved. Restrictions of 15% have been implemented in MMM during July 2015, which was increased to 20% in February 2016, due to resources being under stress and care should be taken to distinguish between savings achieved because of WCWDM and the restrictions implemented. Municipalities that have not submitted data such as Kopanong and Mantsopa, must be approached to highlight the urgency of implementation and monitoring of WC/WDM in the GBWSS. The targeted versus the actual savings for GBWSS are summarized in **Table 4-3**.

Table 4-3: GBWSS summary of targeted vs actual savings

Year ending	Projected SIV without WDM (X) kl/annum	Projected SIV with WDM (Z) kl/annum	Projected % savings (X – Z) / X * 100	Actual demand (Y) kl/annum	Actual % savings (X - Y) / X * 100
Jun-12	93 987 362	93 441 611	0.6%	80 748 954	14.1%
Jun-13	96 838 705	93 992 315	2.9%	87 052 724	10.1%
Jun-14	99 701 323	94 479 911	5.2%	86 571 262	13.2%
Jun-15	102 650 266	95 167 478	7.3%	82 772 378	19.4%
Jun-16	105 589 723	95 760 163	9.3%	78 782 096	25.4%
Jun-17	108 615 613	96 465 359	11.2%	75 579 381	30.4%
Jun-18	111 358 098	96 871 622	13.0%	79 375 480	28.7%
Jun-22	125 122 413	111 000 600	11.3%		

4.3.4 ORWSS

No data was received from municipalities in the Orange River Water Supply System (ORWSS). The status of water losses and the progress made in terms of WC/WDM within the ORWSS could only be reported on based on estimated values. The available data have low confidence level. The targeted versus actual savings for the ORWSS are summarized in **Table 4-4**. The results indicate that municipalities achieved 28.9% actual savings compared to their targeted 11.6% by June 2018. Municipalities that have not submitted data must be approached to highlight the urgency of implementation and tracking of WC/WDM in the ORWSS.

Table 4-4: ORWSS summary of targeted vs actual savings

Year ending	Projected SIV without WDM (X) kl/annum	Projected SIV with WDM (Z) kl/annum	Projected % savings (X – Z) / X * 100	Actual demand (Y) kl/annum	Actual % savings (X - Y) / X * 100	Savings under or over SIV with WDM
Jun-13	52 886 989	48 348 397	8.6%	32 508 066	38.5%	-15 840 331
Jun-14	54 136 800	49 194 140	9.1%	-	-	-
Jun-15	55 412 934	50 066 206	9.6%	11 844 414	78.6%	-38 221 792
Jun-16	56 157 432	50 214 336	10.6%	40 497 017	27.9%	-9 717 319
Jun-17	56 913 001	50 437 637	11.4%	40 894 883	28.1%	-9 542 753
Jun-18	58 096 888	51 341 133	11.6%	41 297 631	28.9%	-10 043 502
Jun-22	60 856 166	53 656 233	11.8%			

4.3.5 Botswana water supply systems

Botswana WUC has set NRW targets in its Corporate Strategy 2019 – 2022 and has been forced to reduce consumption in recent years due to the ongoing droughts. Water use efficiency is within acceptable international standards, except for Gaborone management center which include industrial and commercial water use. NRW is above 40% in all the southern management centers except Gaborone and Ghanzi. Most significant is the NRW in Lobatse which needs to be addressed to ensure sustainability of water supply services.

4.3.6 Namibia water supply systems

The improved management of existing water sources including reducing losses, increasing water savings is a key strategic objective of Namibia's National Development Plan. Namibia plans to achieve 100% access to safe drinking water by 2020/21 in the urban areas from the current 98.6% (2016) and 95% in the rural areas from the current 84% (2016). No water loss or NRW targets have been set. Initial results indicate low NRW and poor efficiency. The improved management of existing water sources including reducing losses, increasing water savings is a key strategic objective of Namibia's National Development Plan.

4.3.7 Lesotho water supply systems

Lesotho WASCO has not achieved the set target of 26% NRW and no water use targets have been set. The total volume of water produced in 2017/18 was 14 786 732 kiloliters of which 9 424 139 kiloliters was billed, resulting in a NRW of 5 362 593 kiloliters or 36%. The NRW is above WASCO's set target of 28%. The NRW has increased significantly in the past 5 years, however, has decreased by 10% in the past two years. The total estimated population served is 322 861 using an average of 125 liters per capita per day which suggest high efficiency. Of concern is the hours of supply. The WASCO should embark on a program me to eliminate intermittent supply as it corrupts consumer meter readings, damage infrastructure, increase number of bursts, demotivate staff and impacts on service delivery and willingness to pay.

4.4 Mining Sector

4.4.1 South Africa

The reports on Benchmarks for Water Conservation and Demand Management in the Mining Sector (DWS, June 2016) and a Guideline for the Development and Implementation of Water Conservation and Demand Management Plans for the Mining Sector (DWS, June 2016) were published by the South African DWS to promote WCWDM and water use efficiency in the mining sector. The mining sector, as “a significant user of water” is required to implement WCWDM measures and will in future become water use efficient, also within the study area.

4.4.2 Botswana

Figures on water losses in the mining sector is summarised in the Botswana Integrated Water Resources Management & Water Efficiency Plan Volume 2 (May 2013). Water losses varied from very low (around 3%) to around 15 to 20%. These figures need further verification. Debswana managed to reduce water consumption by 33% in the period 2003 to 2008 (target was 50%). It is increasingly difficult to achieve further water consumption gains as the economic interventions have already been implemented.

In order to achieve further savings in the sector, the Botswana National Water Policy (October 2012) on water for mining and industry states that water allocations supporting industry and mining must be integrated within the national management framework to ensure water resource sustainability and maximize benefits in the national interests.

4.4.3 Namibia

Based on the NDP5, Namibia’s mineral resources include diamonds, copper, uranium, lead, zinc, gold dimension stone, and semiprecious stones. Mining contributes 12% to GDP and provide critical direct and indirect linkages for the Namibian economy. Examples of direct and indirect linkages include transport services, power, water, skills, research and development, logistics, communications, financial services and mining inputs and services. Namibia plans to increase its integrated mining industry value chain from 23% in 2015 to 46% by 2021/22. In order to achieve this security of water and uninterrupted power supply are key enablers to attract investments into mineral-based beneficiation and manufacturing.

4.4.4 Lesotho

Mining activities have expanded substantially in the past three decades as new diamond mines have opened currently contributes 9.2% of Lesotho's GDP. By the end of 2018, there were four diamond mines and two sandstone quarries in full production.

Similar to Namibia, water security and power supply are key enablers to develop the mining sector in partnership with stakeholders in an environmentally friendly and sustainable manner for the socioeconomic benefit of the Basotho nation.

4.5 Irrigation Sector

The objective of this subtask was to update or adjust the core scenarios with the WCWDM that can be expected from the irrigation sector based on the latest information available from studies that have been undertaken.

The approach followed included the following sub-components:

- The WC/WDM information from the latest available studies/assessments was reviewed
- The focus was on studies that have been undertaken subsequent to the ORASECOM Integrated Water Resources Management Plan (IWRMP) (ORASECOM, 2014b) as well as the Orange and Vaal Reconciliation Strategies. The Lesotho Ministry of Agriculture and Food Security (MAFS) was in the process of commissioning the Irrigation Master Plan and Investment Framework at the time of draughting this report.
- Based on the assessment and compilation of information, the need was identified to compile a summary of the strategic actions identified from recent studies in the form of a strategy action matrix.

The departure point of the assessment was to summarize the findings and recommendations of the ORASECOM IWRMP (ORASECOM, 2014b). Most recent studies included:

- Large Bulk Water Reconciliation Strategies: Orange River (DWS, 2015a)
- Development and Implementation of Irrigation Water Management Plans to Improve Water Use Efficiency in the Agricultural Sector (DWS 2012-2013)
- Development of a Comprehensive WC/WDM Strategy and Business Plan for the Fish to Tsitsikamma Water Management Area (DWS, 2017b).

The outcome of the findings from the studies are summarized below.

4.5.1 ORASECOM Integrated Water Resources Management Plan

The ORASECOM IWRMP, indicated that the recommendations on irrigation best practices, presented in the report, Phase 2 Work Package 6: The Promotion of WC/WDM in the Irrigation

Sector (ORASECOM, 2011b), should be implemented. The recommendations were of a strategic nature and were summarized into the following themes:

- Legislative and institutional considerations
- Technical considerations
- Best practice demonstration sites
- Water markets
- Illegal water use
- Smallholder irrigation viability

4.5.2 Large Bulk Water Reconciliation Strategies: Orange River

The Department of Water and Sanitation (DWS) of South Africa has together with the member states (Lesotho, Botswana and Namibia) undertaken the Large Bulk Water Reconciliation Strategies: Orange River study. WCWDM in the irrigation sector was addressed by the study and the associated strategic actions that were identified include:

- Limit operational losses through real time monitoring of river flows
- Develop a WC/WDM plan for each irrigation scheme in the Orange River Basin
- Savings target as a 5% nett system savings by 2020
- Introduce mechanism to make savings available to other water users in the system

4.5.3 Water Management Plans

The DWS has, in cooperation with the respective Water User Associations, prepared Water Management Plans for seven schemes located in the Orange-Senqu River Basin:

- Kakamas Water User Association
- Boegoeberg Water User Association
- Sand-Vet Water User Association
- Mooi Government Water Scheme
- Schoonspruit Government Water Scheme
- Lower Sundays River Irrigation Scheme

In addition, DWS undertook a study, “The Development of a Comprehensive Water Conservation and Water Demand Management Strategy and Business Plan for the Fish to Tsitsikamma Water Management Area” (DWS, 2014c) as well as a follow on assessment described in the report “Efficiency of Water Use and Allocations in the Fish and Sundays River Catchment” (DWS, 2017b), in Support of the Water Reconciliation Strategy for the Algoa Water Supply System).

Each of these assessments culminated into recommending specific WC/WDM measures that can be implemented to save water in the respective schemes, the estimated savings and costs.

It is important to note that the beneficiaries of water savings depend on the makeup of the irrigation scheme, the location as well as prevailing management goals or policies. In general, savings from schemes sourcing water from smaller tributary rivers do not directly improve the water balance of the Vaal or Orange systems implying the benefits of the savings are limited to the users receiving water from that source. In these cases, savings (reduced abstraction from the resource) will increase the assurance of supply while expanding irrigated areas will increase the economic activities. Savings from schemes receiving water from the main stem or large dams on the main stem, if not used to expand the irrigation areas, represent a reduction of the water requirement in the overall system water balance.

4.5.4 Strategy Action Matrix for WC/WDM

In conclusion, a Strategy Action Matrix for WC/WDM measures and related interventions in the irrigation sector is provided in **Appendix A**, describing the identified actions, responsibilities and target dates for completion. The table serves as a concise reference against which progress with the implementation of the strategy can be monitored going forward.

5 WATER REUSE

5.1 Background

The availability and quality of water in the Orange-Senqu basin is dependent on the characteristics of the events and activities affecting the water balance. The optimal management of water requires the consideration of water reuse, recycling and reclamation activities as well as the development and utilization of water sources that have previously been considered marginal due to a perception of poor quality or possibly non-economical quantities. For the purpose of this task, these water sources include water that can be recycled, reused or reclaimed for beneficial use and focusses on sources such as naturally occurring non-potable water and water that has been used to fulfil a function in, or results from human endeavors.

The following initiatives attempt to derive value from these previously used or marginal sources:

- Rainwater and fog harvesting.
- Irrigation with treated effluent.
- Recycling of process water.
- Use of brackish groundwater.
- Reclamation of treated municipal or industrial effluent for potable, industrial and irrigation purposes.
- Sea water desalination.
- Reuse of water in the industrial and mining environment; and
- Treatment and utilization of acid mine drainage.

The recycling and reuse of activities affect the naturally occurring in and outflow characteristics of the water balance in the river basin in the following manner:

- Reduction in demand.
- Import of water into the catchment.
- Export of water from the catchment.
- Reduced return flows into water courses and
- An impact on the quality of water (positively or negatively) on the catchment.

The most common activities relevant to this catchment include:

- **Water recycling:** When water is used in a process and then reused in the same process with or without any purification (treatment) or improvement of the water quality.

- **Water reuse**: When water is used, and the return flow is then used again for another purpose. This may include purification to some acceptable level for the secondary use, but the water is not treated to potable standard.
- **Water reclamation:** Water that was previously used for potable or any other purposes is treated up to potable quality standards so that it can again be used for potable purposes
- **Acid mine drainage mitigation:** Acid mine drainage, acid and metalliferous drainage (AMD), or acid rock drainage (ARD) is the uncontrolled discharge of acidic water from abandoned or exhausted mines into the environment. The result of this is pollution of surface and sub-surface water sources. The water can be treated and can augment conventional water resources.

These activities are collectively referred to in this report using the common term “reuse”.

5.2 Summary of Initiatives

The reuse activities in the respective countries are summarized in **Table 5-1**.

Table 5-1: Summary of Re-use, Recycle and Reclamation Initiatives

Reuse activity	Quantum and timelines	Source locations	Discharge locations	Status/Comment
South Africa				
AMD				
Eastern Basin	87 Ml/d partial treatment and discharge - current and ongoing	26°15'6.30"S 28°29'19.78"E	Blesbokspruit	Reuse initiatives to be defined by the LTS – most probably desalination and re-used for potable water or industrial supply
Central Basin	110 Ml/d partial treatment and discharge - current and ongoing	26°13'4.95"S 28°10'59.30"E	Elsburgspruit	
Western Basin	40 Ml/d partial treatment and discharge for next 10 years, thereafter 25 Ml/d	26° 8'3.33"S 27°43'1.32"E	Tweelopiespruit	
Emfuleni Community Sanitation Project				
Leeuwkuil WWTW	32 Ml/d from 2025 onwards	26°40'20.71"S 27°53'45.71"E	Re-used for agricultural purposes on area in proximity of treatment plants	
Sebokeng WWTW	100 Ml/d from 2030 onwards	26°34'27.54"S 27°48'48.23"E	Re-used for agricultural purposes on area in proximity of treatment plants	
Rietspruit WWTW	32 Ml/d from 2020 onwards	26°41'40.02"S 27°45'43.75"E	Re-used for agricultural purposes on area in proximity of treatment plants	Initiative is in the planning phase. Implementation has not commenced.

Reuse activity	Quantum and timelines	Source locations	Discharge locations	Status/Comment
Mangaung MM				
North Eastern WWTW Indirect reuse	45 Ml/d, June 2021 onwards	29° 5'28.46"S 26°19'19.94"E	29° 5'37.77"S 26°20'1.93"E	Treated effluent to be pumped to Mockes dam for indirect reuse purposes
North Eastern WWTW Direct reuse	32 Ml/d, May 2030 onwards	29° 5'28.46"S 26°19'19.94"E	As per source	Treatment effluent to be treated to potable water quality for potable use within the area.
Ekurhuleni/ERWAT				
Olifantsfontein WWTW reuse	17.2 Ml/d, 2025 onwards	25°56'15.35"S 28°12'47.75"E	Industries south of the WWTW	The reuse scheme is to supply non-potable water to industries. The planning of these initiatives was being revised at the time of writing. The transfer of treated effluent to Rietvlei dam is also a possibility and described below under CoTMM initiatives.
Waterval WWTW	68.2 Ml/d, 2030 onwards	26°26'14.24"S 28° 5'53.49"E	Industries north of the WWTW	The reuse scheme is to supply non-potable water to industries. The planning of these initiatives was being revised at the time of writing.
City of Tshwane MM				
Olifantsfontein WWTW reclamation	80 Ml/d by 2025 and additional 40 Ml/d by 2045	25°56'15.35"S 28°12'47.75"E	25°54'21.84"S 28°18'37.39"E	Also refer to the Olifantsfontein reuse scheme described above (ERWAT)
Roodeplaat WTP / Zeekoegat WWTW extension	30 Ml/d in 2020, 30 Ml/d in 2030	25°37'33.50"S 28°19'49.42"E	25°37'13.86"S 28°20'28.74"E	Discharge from WWTW to Roodeplaat dam for indirect use by the WTW.
Nelson Mandela Bay MM				
Uitenhage WWTW reuse	5 Ml/d indefinitely from 2020 onwards	33°46'57.95"S 25°25'36.60"E	33°47'9.38"S 25°25'9.78"E	None of the NMBMM initiatives will impact on the Orange River catchment as the withdrawal rates will remain unchanged.
Fish Water Flats WWTW	30 Ml/d by 2023, 60 Ml by 2024 onwards	33°52'52.37"S 25°36'58.55"E		
New Coega WWTW	20 Ml/d by 2025 increasing to 100 Ml/d by 2033	33°47'52.56"S 25°40'18.15"E	33°47'52.56"S 25°40'18.15"E	
Desalination of Seawater	20 Ml/d by 2030			
Botswana				

Reuse activity	Quantum and timelines	Source locations	Discharge locations	Status/Comment
Glen Valley irrigation project	1.5 Ml/day since 2013	24°36'37.17"S 25°57'49.87"E	203 ha of farmland	Ongoing
Mambo WWTW	Unknown	WWTW	WWTW	Planned
Lobatse WWTW	Unknown	WWTW	WWTW	Planned
Lesotho				
Agricultural Collage	700 kl/d since 2013	WWTP	20 ha fields and grounds for research purposes	Ongoing. No further plans to expand the re-use.

5.3 Conclusion

In this chapter, the status of water recycling, reuse and reclamation initiatives influencing the Orange-Senqu basin has been reviewed and updated as well as having identified future initiatives and trends that could influence the basin in the future. Most of the projects affect the inflow or outflow of water from the catchment, a reduction in demand and reduced wastewater discharges and its associated impacts on the resources' water quality.

In South Africa, there are a number of re-use and recycling, direct or indirect, initiatives that have been, incorporated into the various catchment specific reconciliation strategies. In the IVRS, the desalination of AMD will ensure a reduction in water that is needed for dilution purposes; it will reduce demand through reclamation and direct re-use and improve the salinity in the Vaal River system and Orange-Senqu basin by eventually eliminating the discharge of saline AMD. In Ekurhuleni/ERWAT and the City of Tshwane, substantial volumes of wastewater would be recycled, reused and reclaimed for eventual use for potable and industrial use. A similar situation exists in the Nelson Mandela Bay MM where wastewater would eventually be reclaimed for use by existing industries as well as new industrial developments in the Coega SEZ. In addition, the NMBMM would in future also be desalinating seawater for potable as well as industrial use.

In Botswana, treated wastewater is used to irrigate lucerne in Lobatse, golf courses in Gaborone, Jwaneng and Orapa, vegetables in Glen Valley and orchards and vegetable gardens at Serowe and Kanye Prisons respectively. WUC plans to develop capacity for greater reuse and recycling by upgrading and improving operations of the Mambo and Lobatse WWTW.

In Lesotho, there is only small-scale re-use by the Agricultural Collage. The previous report recommended that Maseru investigate the possibility to re-use its treated wastewater to irrigate its sports fields and golf course.

The eventual re-use of wastewater and the desalination of seawater could provide substantial volumes of water to all sectors, thereby securing water within the Orange-Senqu River basin. It is thus recommended that all the countries incorporate the re-use of water into formal its respective policies.

The findings are discussed in detail in the WCWDM/Reuse report (ORASECOM, 2019c) produced as part of this study.

6 UPDATE OF CORE SCENARIO

6.1 Background to Core Scenario

The Core Scenario was developed for the Integrated Orange-Senqu System as part of the Support to Phase 3 of the ORASECOM Basin-wide Integrated Water Resources Management Plan. The details of the development, configuration and elements included as well as the model simulation results are presented In the Water Resources Modelling, Baseline Scenario, Yield Analysis, Stochastic Verification and Validation Report (ORASECOM, 2014c).

The Core Scenario included operating rules and water requirement projections as per the status in 2014. In addition, the most likely future development and management options of the four basin States which will have an impact on the water resources of the basin were included.

6.2 Approach to Update Information

The Core Scenario is the baseline tool that can be used by ORASECOM to undertake management decisions relating to water resources. As a result, the tool should be updated regularly in order to make use of the most recent information available in the basin. It is not necessary to update all components of the Core Scenario, as some will not have changed. **Table 6-1** presents an overview of the various components included in the Core Scenario, as well as the details of the level of updates required.

Table 6-1: Overview of updates carried out

Core Scenario Input	Update Status	Motivation
Natural Flows (hydrology)	None	Hydrology update was not requested for this study
Rainfall data	None	Hydrology update was not requested for this study
Evaporation data	Possible	Where updated observed data is available
Dam characteristics	Possible	Where updated surveys have occurred and where new dams have been competed, or proposed dams are in a planning stage
Infrastructure capacities	Possible	Where modification to capacities have occurred and new infrastructure has been developed or is planned for
Operating Rules	Possible	Where changes have occurred
Water Requirement Projections	Yes	Adjustment of start base year to 2018 existing requirements and updated projection in requirements obtained from users
Development Options	Yes	Where adjustments to options and timelines have taken place

Reports resulting from studies taking place during the time period after the finalization of the Core Scenario in 2014 were reviewed in order to obtain updated information. The main study reports/documentation consulted were as follows:

- Orange System Annual Operating Analyses carried out during the 2015/2016, 2016/17, 2017/18 and 2018/19 operating years. (DWS,2016b) (DWS,2017) (DWS, 2018)
- Vaal System Annual Operating Analyses carried out during the 2015/2016, 2016/17, 2017/18 and 2018/19 operating years. (DWS,2016c) (DWS, 2018a) (DWS, 2018)
- Vaal River system. Large Bulk Water supply Reconciliation Strategies: Water Resource Analysis (DWAF, 2009)
- Vaal Reconciliation Strategy Maintenance Study (Started January 2018 and ongoing) (DWS, 2018b).
- Update detail designs, and construction supervision of the Lesotho Lowlands Water Supply Scheme, completed in June 2017. (LWC, 2017)
- Noordoewer/Vioolsdrift Dam Feasibility Study, currently ongoing. (PWC,2017)
- Botswana National Water Master Plan Update based on Smart Water Management, completed February 2018. (BNWMP, 2018)
- Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA competed in May 2017. (DWS, 2016a)
- Determination of the Operating Rule for the Operation of Phase ii of the Lesotho Highlands Water Project completed in January 2018. (LHWC,2018)
- Mangaung Gariep Water Augmentation Project completed in August 2018. (MMM,2018)
- Lesotho Water Sector Improvement Project II. Consulting Services for the Update Detail Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme. June 2017. By SMEC International PTY (LTD) for Lesotho Water Commission
  - Final Water Resources Assessment Report
  - Final Demand Assessment Report.

Relevant authorities from the four basin states were approached for updated information relating to development options that the country’s plan to pursue during the time frame ending in 2050.

Using these two sources of information (recent studies and interviews) a list of possible updates to be applied to the 2014 Core Scenario was developed. The list was then workshopped with ORASECOM at the meeting held on 29 January 2019 in order to gain final approval of items that should be included into the updated Core Scenario.

6.3 Core Scenario Updates'

The following Tables provide a summary of the various components included in the Core Scenario. The Tables present how each component was described in the 2014 Core Scenario, and the updated description following this work. The Tables are divided into sections describing items that did not change, and those that did, and into the four main subsystems of the basin, the Vaal, Orange RSA, Senqu Lesotho and Fish River Namibia catchments.

Table 6-2: Conditions applying to the Integrated Vaal River System (no changes)

Restrictions are imposed on demands in the main systems when required, to meet the agreed levels of assurance and to protect the resources from total failure.
Transfer from the LHWP Phase 1 to the Vaal is set equal to 780 million m^3/a according to the current agreement between RSA and Lesotho.
Utilise Crocodile return flows, Large volumes of return flows are generated in the Crocodile catchment with water mainly supplied from the Vaal system. These return flows are currently partly utilized in the Crocodile catchment by existing users but are also earmarked to be transferred to Lephalale to supply Eskom Power Stations and possible coal to liquid plants. After supplying these current and future demands in full, it was estimated that there are still unutilized return flows available in the catchment. Utilise some of this surplus to supply part of the user demands currently met by water from the Vaal system
Operational losses from the Lower Vaal will be in line with the calibration done as part of the Vaal Reserve study. Recent years of observed data indicate the model is accurately simulating these losses. Continuous monitoring of Lower Vaal flows is important to verify these losses.
The Integrated Vaal System is operated to minimize spills into the Orange River. Due to large volumes of water transferred into the IVRS, the cost of the available water in the IVRS is relatively high. Operating rules in the IVRS was thus designed to in general only transfer water into the IVRS when it's really required and to keep the storage in Vaal Dam and Bloemhof Dam relatively low. This will enable the IVRS to capture as much as possible of the local runoff and reduce spills from the most downstream large dam (Bloemhof Dam). Spills results in expensive transferred water to be lost from the IVRS and for economic reasons the system operating rules are thus set to minimize these spills.

Table 6-3: Updates of conditions applying to the Integrated Vaal River System

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial demands imposed on the Integrated Vaal system will be at 2013 development level at the start of the analysis	All the urban/industrial demands imposed on the Integrated Vaal system will be at 2018 development level at the start of the analysis
Use latest demand growth as used for the 2013/14 Vaal AOA and was also adopted in the updated demand data base for ORASECOM Phase lll study. Assume WC/WDM is in place based on latest information from the "Maintenance of the Vaal River Reconciliation Strategy". (DWA, 2014) This reflects the current progress in WC/WDM as taking place in reality.	Use latest demand growth as determined as part of Task 1b1 of this Study and presented in Section 2. Assume WC/WDM is in place based on latest information obtained as part of Task 1b4 of this Study and presented in Section 4. This reflects the potential savings that can be achieved by carrying out WC/WDM in the major urban centers.

Core scenario description (2014)	Adjust / update for this study
Irrigation will be based on 2013 development level. Where irrigation allocations are applicable, the allocated volume will be used as the demand. This condition applies to the start year of the analyses where after the expected growth in irrigation will be included where applicable. In most areas however, irrigation will not be growing.	Irrigation is based on 2018 development level. Where irrigation allocations are applicable, the allocated volume will be used as the demand. This condition applies to the start year of the analyses thereafter the expected growth in irrigation will be included where applicable. In most areas however, irrigation will not be growing.
In the Vaal Reconciliation Strategy study, it was identified that there is a significant amount of unlawful irrigation in the Upper Vaal, partly utilizing the transferred water from Lesotho and the Thukela. The removal of the unlawful irrigation was one of the urgent matters included in the Final Strategy prepared for the Integrated Vaal System. The process has already been put into action and currently 66% of the unlawful irrigation has been removed. For the purpose of the core scenario it will therefore be accepted that these irrigation areas in the Vaal will be at lawful plus 34% at the start of the analyses. It is assumed that further eradication takes place according to the latest information from the "Maintenance of the Vaal River Reconciliation Strategy" (DWA, 2014) study, which is currently in process.	In the Vaal Reconciliation Strategy study, it was identified that there is a significant amount of unlawful irrigation in the Upper Vaal, partly utilizing the transferred water from Lesotho and the Thukela. The removal of the unlawful irrigation was one of the urgent matters included in the Final Strategy prepared for the Integrated Vaal System. The process was put into action and it is assumed that by now the targeted 85% of the unlawful irrigation has been removed. Updated information relating to the success and continual maintenance of eradication and has been sought as part of this Study as well as the ongoing Vaal Reconciliation Strategy Maintenance Study, however, it has not been forthcoming. Due to some unknown's sensitivity analysis will be carried out.
Polihali is built to specification, Fixed transfer from outset, Polihali Dam start to deliver water in 2022	Polihali Dam has been included to start delivery from December 2025 (start storage from November 2023). The inter-reservoir operating rule between Mohale, Polihali and Katse is as per recommended as part of the Determination of the Operating Rule for the Operation of Phase ii Study. The Phase ii operating rule for transfer to the Vaal as recommended in the above-mentioned study still need to be agreed on between Lesotho and the RSA. For the purpose of the Core Scenario the following was agreed: From 2018 until 2025 when Polihali Dam transfers start, the current agreed operating rule remain in place. Meaning that the 780 million m^3/a is transferred on a constant basis from Katse to the Vaal. From 2025 onwards the Phase 1 transfer volume is still being transferred on a constant basis of 780 million m^3/a, but the additional yield created by Polihali Dam will only be transferred to the Vaal when its needed by the Vaal system. This last component then represents the only variable part of the transfer volume. Adjustments to the following based on updated information from LHWP Phase 2 Operating Rules Study: Percentage hydrology entering Polihali Dam

Core scenario description (2014)	Adjust / update for this study
	Katse, Mohale and Polihali evaporation Updated Polihali EWR
Include current and planned neutralizing of mine water outflows. The timing of the planned neutralizing will be according to latest information from the "Implementation of the Vaal River Reconciliation Strategy" (DWA, 2014) study. Desalination of AMD water. The timing of the desalination of the different mine drainage point is according to the latest information from the Maintenance of the Vaal River Reconciliation Strategy study.	Include current neutralization of mine water outflows and planned desalination of Acid Mine Drainage (AMD). All neutralization is currently being undertaken. The timing and details relating to the AMD is as per existing planning targets for desalination of AMDS. The Consultant consulted and established that DWS RSA is currently planning to update the Vaal Integrated Water Quality Strategy (2009) which will include the improvement of the simulated dilution releases. This is likely to be an 18-month study which will also include Scenario analysis of appropriate AMD management options. These results will thus not be available in time for use in the Core Scenario. It is however important to take note of this for future analyses.
Exclude recommendations from the Vaal Reserve study (DWA, 2010) regarding the required flows downstream of Sterkfontein Dam and Douglas Weir for the purpose of the base scenario. These recommendations are not implemented at this stage as it results in a decrease in the Vaal system yield.	Exclude recommendations regarding the required flows downstream of Douglas Weir as these were never implemented. Include recommendations from the Vaal Reserve study (DWA, 2010) relating to releases from Sterkfontein Dam in accordance with natural flow conditions. The Douglas EWR node was excluded from the final Vaal Reserve as published in the Government Gazette.
Botswana-Vaal Gamagara, extend existing Vaal Gamagara transfer scheme to supply water to Botswana, Transfer 5 million m³/a to Botswana. Expected date for transfers to start is between 2021 & 2023.	Do not include, no longer an option being considered
	Include further Phase of Thukela transfer by 2040 when Vaal requirements growth exceeds allowable risk of supply criteria based on the analysis results

Table 6-4: Conditions applying to the Integrated Orange-Senqu River System (no changes)

Restrictions not imposed on Orange System. Failure analyses of Demands and Dams to take place. This is due to the short-term yield capabilities of the system when including all the various intervention options. These short-term yield capabilities have not yet been determined.
EWR releases from Katse and Mohale dams based on Annual Release structure.
Orange/Riet transfer & Orange/Vaal (Douglas) transfer. The current demands with growth are modelled in detail as part of the system, i.e. transfer dependent on requirements considering local resources
Implementation of real time modelling and monitoring in the Orange

Spills from Douglas Weir and contributions from the Lower Orange hydrology are not be used to supply Lower Orange demands prior to Noordoewer/Vioolsdrift Dam coming online, as there is no storage available in the Lower Orange to be able to utilize these flows in practice. Currently the system is operated to release the total downstream requirement from Vanderkloof Dam, without considering any contributions from the Vaal, as the Vaal is operated to minimize spills into the Orange-Senqu River. The Vaal spills and Lower Orange hydrology will however be utilized once the real time modelling and monitoring is in place.
Minimum operating level for Gariep Dam is to be equal to the minimum operating level for releases through the Orange Fish Tunnel.
Hydropower at Gariep and Vanderkloof dams is generated in accordance with downstream demands only as Eskom possible emergency power supply is not linked to hydrological events.
Hydropower is generated at Muela with the water transferred from Lesotho to the RSA. It is however important to note that this is governed by the Treaty between Lesotho and the RSA.

Table 6-5: Updates of conditions applying to the Senqu Mohokare River Systems Lesotho

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial and mining demands imposed on the Senqu Mohokare systems will be at 2013 development level at the start of the analysis.	All the urban/industrial and mining demands imposed on the Senqu Mohokare systems will be at 2018 development level at the start of the analysis.
Use latest urban/industrial mining demand growth as used for the Orange Reconciliation and ORASECOM studies.	Use latest urban/industrial mining demand growth as determined as part of Task 1b1 of this Study including reductions as a result of WCWDM initiatives.
Irrigation will be based on 2013 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis	Irrigation will be based on 2018 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis. Irrigation growth planned along the Lower Orange and in Lesotho to be considered.
Include Metolong Dam and Complete water supply distribution system from Metolong Dam and support planned area of supply	Metolong Dam is in place and the demands imposed on the dam are as per updated information obtained as part of this study.
	Inclusion of Further Lowlands phases, Hlotse (105 million m^3) and Ngoajane (36 million m^3) dams, with implementation dates of 2030 and 2035 respectively. (Semongkong Dam was requested to be included by 2040. Unfortunately, not sufficient data on this dam was available to be modelled)
	The implementation of the Lowlands Water Development Project Phase II (Zones 2/3 and Zones 6/7) Goes along with Hlotse and Makhaleng dams
Lesotho Botswana transfer, building of a transfer system taking water from Lesotho to Botswana	Include Makhaleng Dam as per Component iii of this study, site S2 selected for inclusion. Dam to turn on in 2030. A high and a low Transfer option to Botswana will be considered and will start after completion of pipeline assumed to be by 2033.

Core scenario description (2014)	Adjust / update for this study
	The implementation of Lesotho Lowlands Water Supply Scheme in Zones 1 & 2. Goes along with Ngoajane and Hlotse dams
	Implementation of Lesotho Lowlands Water Supply Scheme for Zone 8 and 8 (a) (Mohale's Hoek and Quthing) River runoff supply from the Senqu River (In future might be utilizing releases from hydro-power dams.)
	Include compensation releases from Makhaleng Dam to Verbeeldingskraal Dam if required based on system analyses results

Table 6-6: Conditions applying to the Integrated Orange River System RSA

Core scenario description (2014)	Adjust / update for this study
All the urban/industrial and mining demands imposed on the Orange system will be at 2013 development level at the start of the analysis.	All the urban/industrial and mining demands imposed on the Orange system will be at 2018 development level at the start of the analysis.
Use latest urban/industrial mining demand growth as used for the Orange Reconciliation and ORASECOM studies.	Use latest urban/industrial mining demand growth as determined as part of Task 1b1 of this Study including reductions as a result of WCWDM initiatives
Irrigation will be based on 2013 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis	Irrigation will be based on 2018 development level allocations or requirements as applicable to the specific area under irrigation, at the start of the analysis. Irrigation growth planned along the Lower Orange and in Lesotho to be considered.
The 12 000-ha allocated for use by resource poor farmers. Only include those already developed at 2013 and allow for the expected further development as included in the ORASECOM Phase lll data base	The 12 000-ha allocated for use by resource poor farmers. Only include those already developed at 2018 based on information received from the Regional office as part of Task 1b1 of this study and allow for the expected further development as included in the data base. This is summarized as follows: Free State = 3 000 ha of which 837.6 ha has been taken up Northern Cape = 4 000 ha of which 1671 ha has been taken up Eastern Cape = 5 000 ha of which 2460 ha has been taken up
EWR for Orange as currently released for the river mouth (287.5 million m3/a) which was obtained from the Orange River Replanning Study (ORRS and is referenced as ORRS EWRs). After yield replacement dam, RECs EWR at key sites only, Refinement of EWRs on the Lower Orange to accommodate the required low flows at the estuary	EWR for Orange as currently released for the river mouth (287.5 million m^3/a) which was obtained from the Orange River Replanning Study (ORRS and is referenced as ORRS EWRs) until 2020 after which the "preliminary EWR" will be implemented as according to recommendations from the Lower Orange EWR Study. Final Recommended EWRs (from Lower Orange EWR Study) at Augrabies and Site 5 implemented from 2028 after Noordoewer/Vioolsdrift Dam comes online.

Core scenario description (2014)	Adjust / update for this study
Transfers to the Eastern Cape through the Orange/Fish tunnel based on the latest data from the Orange Annual Operating Analysis as captured in the ORASECOM Phase lll data base. This demand is based on the allocation and scheduled irrigation area and supply to Port Elizabeth and several small towns in the Fish/Sundays sub-system.	Transfers to the Eastern Cape through the Orange/Fish tunnel based on the latest data from the 2018/2019 Orange Annual Operating Analysis as captured in the data base (ORASECOM, 2019d). This demand is based on the allocation and scheduled irrigation area and supply to Port Elizabeth and several small towns in the Fish/Sundays sub-system.
Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in place (Welbedacht to Bloemfontein and Novo Transfer). Only allow the initial proposed increase in Tienfontein Pumping capacity and Novo Transfer capacity according to latest information from Greater Bloemfontein Reconciliation Strategy implementation study (DWA, 2014b).	Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in place (Welbedacht to Bloemfontein and Novo Transfer). Allow the initial proposed increase in Tienfontein Pumping capacity and Novo Transfer capacity according to latest information from The Mangaung Gariep Water Augmentation Project Study. Allow a further increase in Tienfontein pumping in 2040 at the time when shortages in the Bloemfontein subsystem occur.
	Include intervention measures as defined in the Bloemfontein Reconciliation Strategy with timing as determined in the Mangaung Gariep Water Augmentation Project. Included as follows: 2019 increase in Maselpoort WTP capacity from 120 Ml/d to 130 Ml/d 2021 Mockes Dam Storage increase to 12.13 million m^3 2021 Indirect re-use 16.4 million m^3/a 2022 Gariep Phase 1: 32 million m^3/a 2030 Direct re-use 11.7 million m^3/a 2033 Gariep Phase 2: 11 million m^3/a
Utilise Lower Level storage in Vanderkloof Dam	Utilise Lower Level storage in Vanderkloof Dam from May 2019. Though construction has not yet started, information obtained stated that this could be fast tracked under emergency conditions if it was necessary to make use of this storage. The lower level storage volume should therefore be available in the core scenario. The lower level storage will only be utilized between 1 in 50 to 1 in 100-year recurrence intervals and will thus not impact significantly on the generated hydropower.
Construction of Verbeeldingskraal Dam in Upper Orange at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs (Core Option 2)	Construction of Verbeeldingskraal Dam in Upper Orange at same time when shortages start occurring in ORP due to Polihali (May 2032). Implement the REC EWRs
Construction of Noordoewer/Vioolsdrift Dam on Lower Orange at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs	Construction of Noordoewer/Vioolsdrift Dam on Lower Orange to be completed in 2028. Size is set as 650 million m^3 gross storage according to the Noordoewer/Vioosldrift Dam Feasibility Study.
Lesotho Botswana transfer, building of a transfer system taking water from Lesotho to Botswana	Include Makhaleng Dam as per Component iii of this study, site S2 selected for inclusion. Dam to turn on in 2030. A high and a low Transfer option to Botswana will be considered and will start after completion of pipeline assumed to be by 2033.

Core scenario description (2014)	Adjust / update for this study
	Include compensation releases to Verbeeldingskraal Dam if required based on system analyses results
Raising Gariep by 10m at same time when shortages start occurring in ORP due to Polihali. Implement the REC EWRs (Core Option 1)	To be Included as a scenario variable. Not included in Core Scenario.

Table 6-7: Conditions applying to the Fish River (Namibia) System

IWRMP (ORASECOM PH3) BASELINE	ADJUST FOR THIS STUDY
Complete construction of Neckartal Dam and support to irrigation included	Neckartal Dam and the associated Environmental Releases are on. Releases for hydropower to start in 2021 and Irrigation demand from 2028 after the irrigation scheme was development
Projected demand growth imposed on both Hardap and Naute dams.	Projected demand growth imposed on both Hardap and Naute dams.
Restrictions not imposed on water supply to users from Hardap and Naute dams.	Restrictions not imposed on water supply to users from Hardap and Naute dams.

7 RESULTS OF CORE SCENARIO ANALYSES

7.1 Model Settings

The start date of the Core Scenario Analyses was set to May 2018. The WRPM was configured to run for 33 years, with the end date of 2050. 1000 stochastic sequences were analyzed with the model, and the results are presented in the form of box and whisker plots. These allow for the assessment of assurances, either risk of failure of dams or risk of non-supply of demands.

Results from the stochastic projection or risk analysis are in general expressed in terms of:

- Storage projection plots of the key storage dams in the system, as well as for the total system storage.
- Water supply and deficit plots covering the total analysis period.
- Curtailment plots used to indicate when the curtailment criteria are violated over the analysis period.
- Typical annual or monthly flows in any of the key channels in the system.

To be able to show the risk associated with any of the monthly or annual values, box and whisker plots are used, indicating the exceedance probability of any given value obtained from the results. A typical box plot definition is given in **Figure 7-1.**

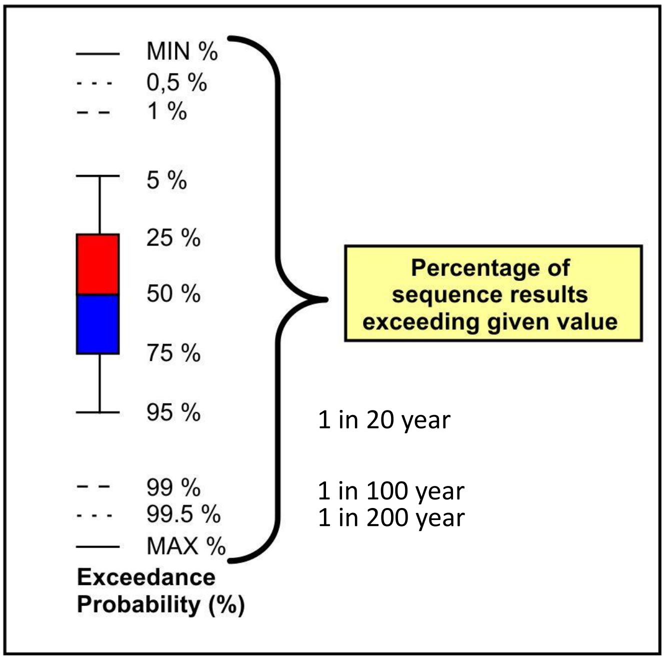
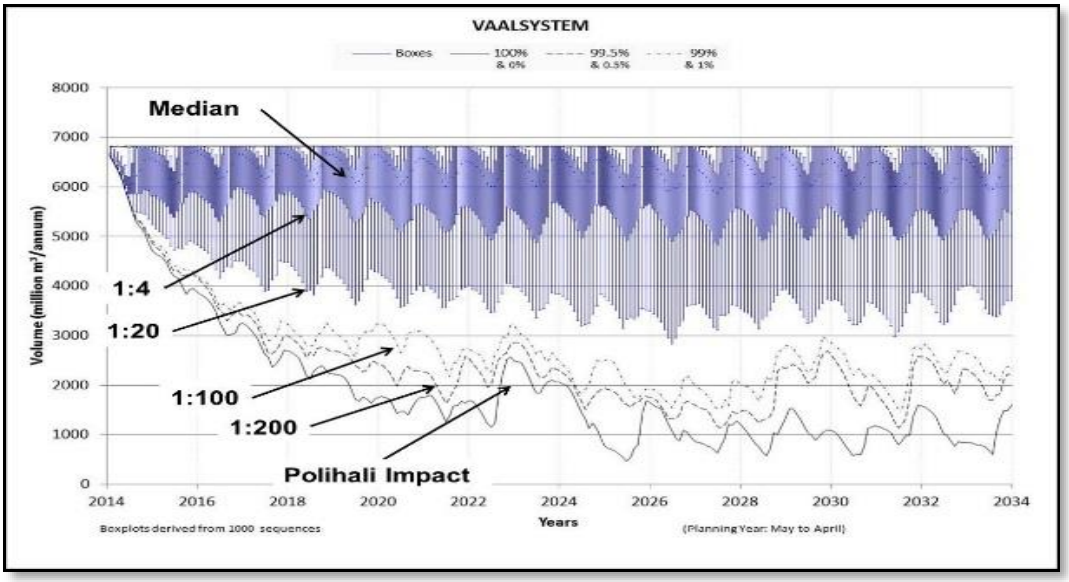


Figure 7-1: Box plot definition

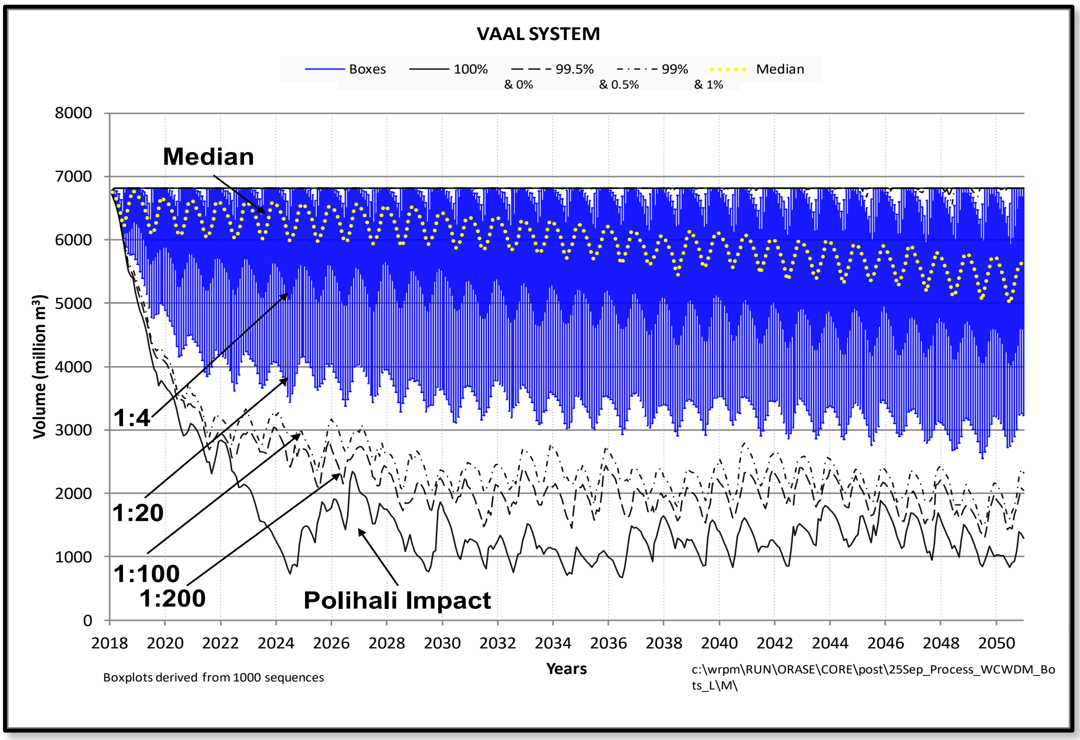
7.2 Results and Comparison with Previous Core Scenario Results

7.2.1 Integrated Vaal River System

The storage projection for the total storage within the Integrated Vaal River System from the previous Core Scenario is compared with that obtained from the updated Core Scenario in **Figure 7-2**.



A



B

Figure 7-2: Vaal System Storage projection for the previous (A) and current (B) Core Scenario

For the updated Core Scenario, it was requested that the projection should be until 2050 which is significantly longer than the projections carried out for the previous Core Scenario. Important differences that were noted include:

- In the previous Core scenario Polihali Dam was expected to be implemented by 2022 while for the current Core Scenario the implementation date is December 2025. This date refers to the time when transfer of water from Polihali Dam will start. The impact of the almost 3 year later starting date is clear from the two projection plots.
- The projected storage from the current Core Scenario is overall lower at almost all the exceedance probabilities than those from the previous Core Scenario. The main reason for this is the difference in operating rule used for the two Core Scenarios. A fixed transfer based on the additional yield from Polihali Dam was assumed to be in place from outset for the previous Core Scenario. Based on a recent study addressing the LHWP Phase II operating rule, the operating rule was adjusted for the purpose of the current Core Scenario. The current Core Scenario allowed the Phase I transfer volume of 780 million m^3/a to be transferred on a constant basis over the entire simulation period, according to the existing rule. The additional yield made available when adding Polihali Dam was for the current Core Scenario kept back in Polihali Dam, and only transferred when requested by the IVRS. This leads to less evaporation losses from the IVRS as well as reduced spills, thus a far more effective use of the water transferred from Polihali Dam.
- The impact of the Polihali scheme on the IVRS storage at the time of the initial transfers to the Vaal, is as significant for the current Core scenario and is a direct result of the changed operating rule as described above.

As part of the Core Scenario analysis restrictions were imposed on the IVRS for both the previous and current core scenarios as described in **Section 2.4.1** according to the methodology used by the RSA. It was therefore possible to produce curtailment plots for the IVRS for both core scenarios. The current operating rules used for the IVRS requires that the water supply system use restrictions on water use during drought periods, to protect the resources from total failure in severe drought events.

The aim of the restriction operating rule is to restrict or curtail the water supply to the low assurance users first, to be able to protect the supply to the high assurance users and to over time be able to supply all the users at their required assurance levels. To be able to model this rule, the WRPM need to know at what assurance each user sector must be supplied. This is defined by means of a priority classification table as given in **Table 7-1**.

Users within the IVRS are supplied according to three different assurance classes, low, medium and high as indicated in **Table 7-1**, representing a 95%, 99% and a 99.5% assurance respectively. From **Table 7-1** it is evident that 50% of the irrigation requirements are supplied at a low assurance of 95%, implying a 5% risk of not receiving its full requirement. This relates to a recurrence interval of 1 in 20 years for the occurrence of restrictions on average.

Table 7-1: Priority Classification Integrated Vaal River System

User Category or Sector	Priority Classification and assurance of Supply (Portion of demand given as a percentage)		
	Low	Medium	High
	1 in 20 year (95%)	1 in 100 year (99%)	1 in 200 year (99.5%)
Irrigation	50	30	20
Domestic	30	20	50
Industrial	10	30	60
Strategic Industries	0	0	100
Losses	0	0	100

Similarly 30% of the irrigation demand requires a medium assurance of supply (99% assurance & 1 in 100 year recurrence interval) and 20% of the irrigation demand will be supplied at a high assurance of 99.5%, relating to a recurrence interval for the occurrence of restrictions of 1 in 200 years on average. The strategic industries typically include water supply to users such as Eskom power stations and Sasol. It is not possible to restrict or curtail losses in a system, as losses will still occur during drought periods, and for this reason the losses were all allocated to the high assurance class.

The WRPM uses these priority classification definitions in combination with the short-term yield assurance characteristics (also referred to as short-term stochastic yield characteristics) to determine when restrictions need to be imposed on a system, as well as the severity of the restrictions that need to be imposed at the time.

The short-term stochastic yield analyses were assessed for a five-year record period. Starting storages of the resources are set at varying levels, and the short-term yields determined are thus applicable to a given starting storage. The results from the short-term stochastic analysis are used as a direct input into the WRPM. This provides the WRPM with the short-term yield characteristics of a particular system at different storage levels. When the total storage in a system is for example at 100%, the system will be able to over the short-term, deliver a significantly higher yield than when the storage is low, say at 20%. The short-term yield characteristics as determined for the related assurance levels for each of the priority classes are then compared with the system demands allocated to the specific priority or assurance class. Based on these comparisons, the WRPM are able to determine when curtailments need to be imposed within a specific priority class and how severe the curtailments need to be, not to exceed the short-term yield available at the related assurance and storage level in the resource, at the specific time.

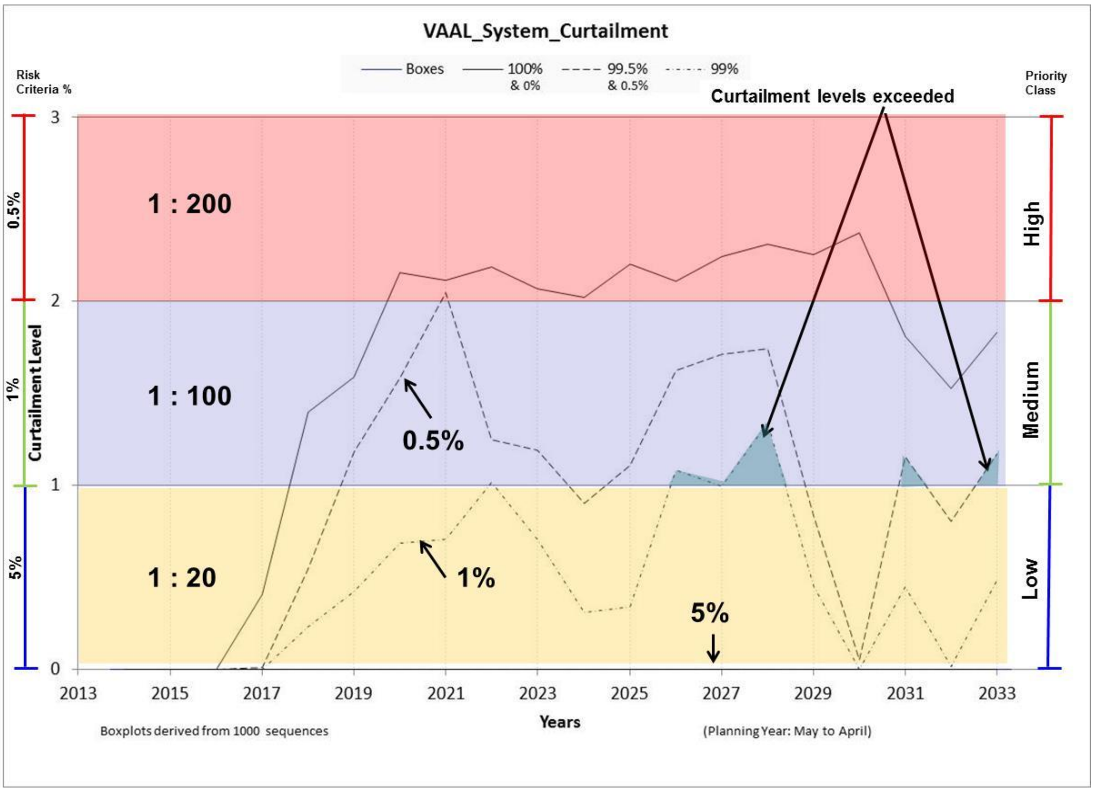
To illustrate the results from the WRPM relating to the restrictions or curtailments that were imposed on a specific system over time, a curtailment plot is generated from the model output. The curtailment plot shows how frequent curtailments were imposed on the system within each of the priority classes. When for example, the low priority class users were curtailed on average more often than only once in 20 years, it means that the system was not able to supply these users at their required assurance of 95%. A 95% assurance implies that the risk of restrictions should not exceed 5%, which also means that on average the restrictions should not occur more often than once in 20 years.

When the curtailment criteria are violated as describe above, it indicates that the current system is no longer able to support the growing demand of the users at the defined or required assurance. At such a time it will be necessary to activate an intervention option to either increase the system yield or to decrease the demands imposed on the system.

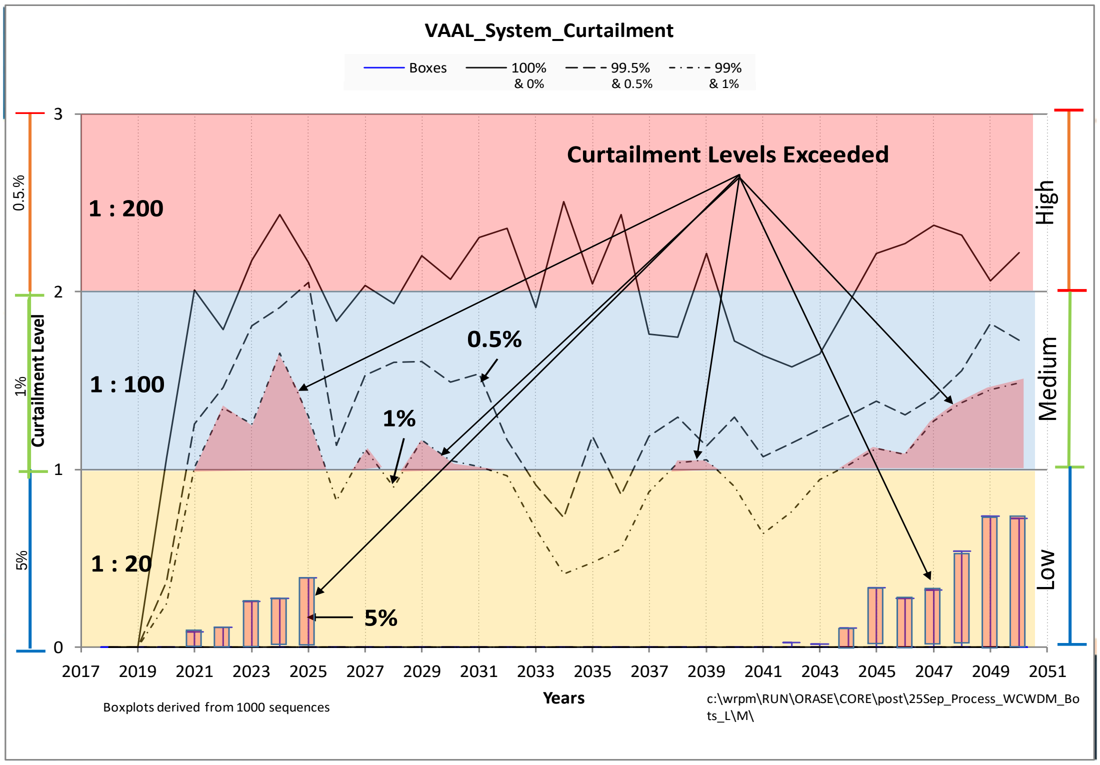
Curtailment plots for the IVRS Core Scenario from the previous and current study are given in **Figure 7-3 A** and **B** respectively. The previous study showed that curtailment levels for the 99% (1 in 100 year) assurance level were slightly exceeded from 2026 to 2028 and again from 2031 and 2033.

The current study Core Scenario analysis showed the exceedance of curtailment levels for the 95% (1 in 20 year) occur from 2021 to 2025 and the 99% (1 in 100 year) assurance level from 2022 to 2025. This is mainly as result of the late implementation of Polihali Dam that was postponed by 3 years. Once Polihali Dam is in place and using the improved operating rules, almost no exceedance of curtailment levels occurred until 2042. This indicate that the next intervention option needs to be in place by 2042. Based on the DWS RSA planning studies this intervention option will be the development of the further phases of the Thukela transfer to Sterkfontein Dam. Sterkfontein Dam is located in the Upper Vaal catchment and releases from this dam will flow into Vaal Dam.

Bloemhof Dam is the most downstream large storage dam in Vaal River. The storage projections for Bloemhof Dam for the Core Scenario from the previous and current study are shown in **Figures 7-4 A** and **B**. From the two projection plots it is clear that the previous study showed much higher storage levels than evident from the current study projection plot. The reason for this significant difference, is the improved operating rule for the Lesotho Highlands/IVRS as used in the current study. These much lower levels will reduce evaporation losses from Bloemhof Dam as well as spills. Spills from Bloemhof Dam is water lost from the IVRS and in general will be a waste of expensive water transferred into the IVRS. The improved LHWP operating rule will thus result in significant savings in losses of expensive water transferred into the IVRS.

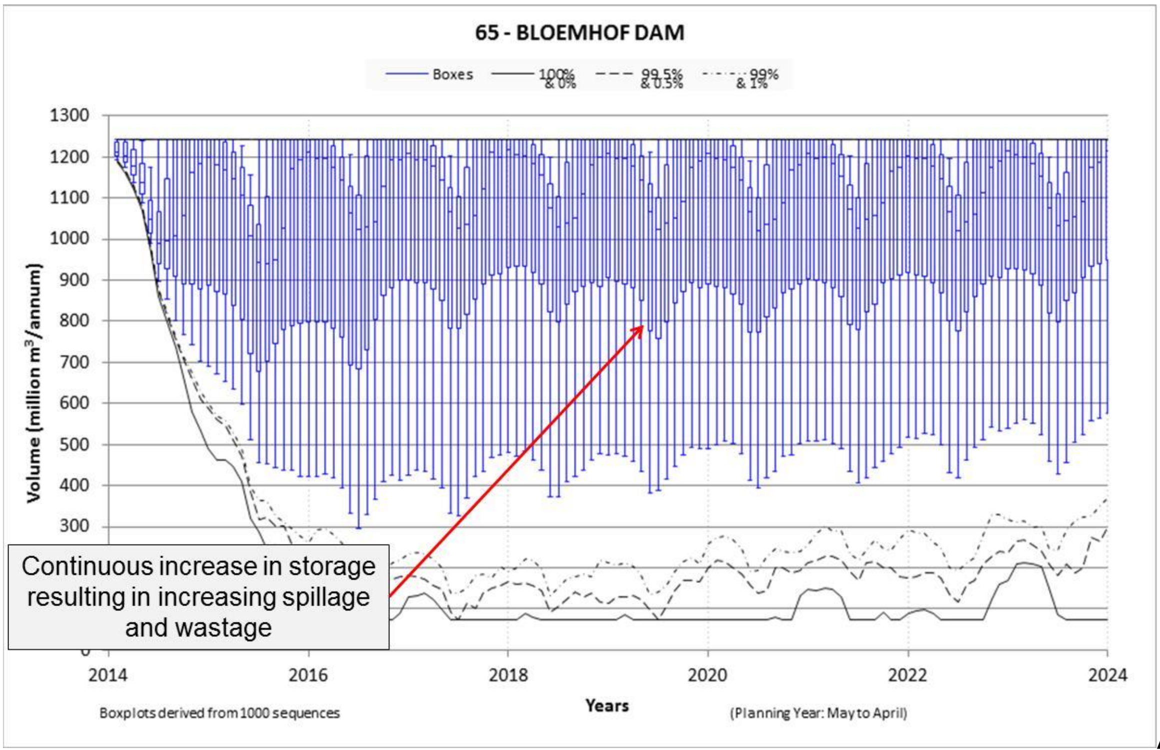


A

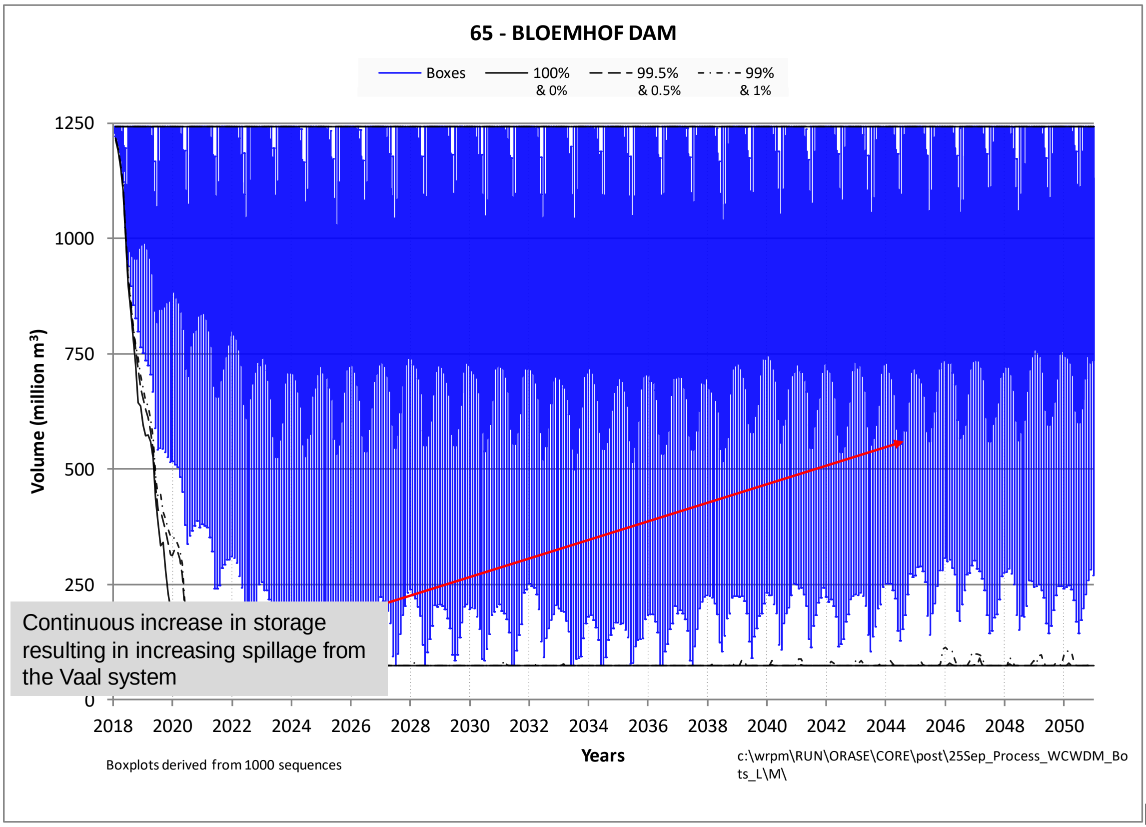


B

Figure 7-3: Vaal System Curtailment Plot for the previous (A) and current (B) Core Scenario



A



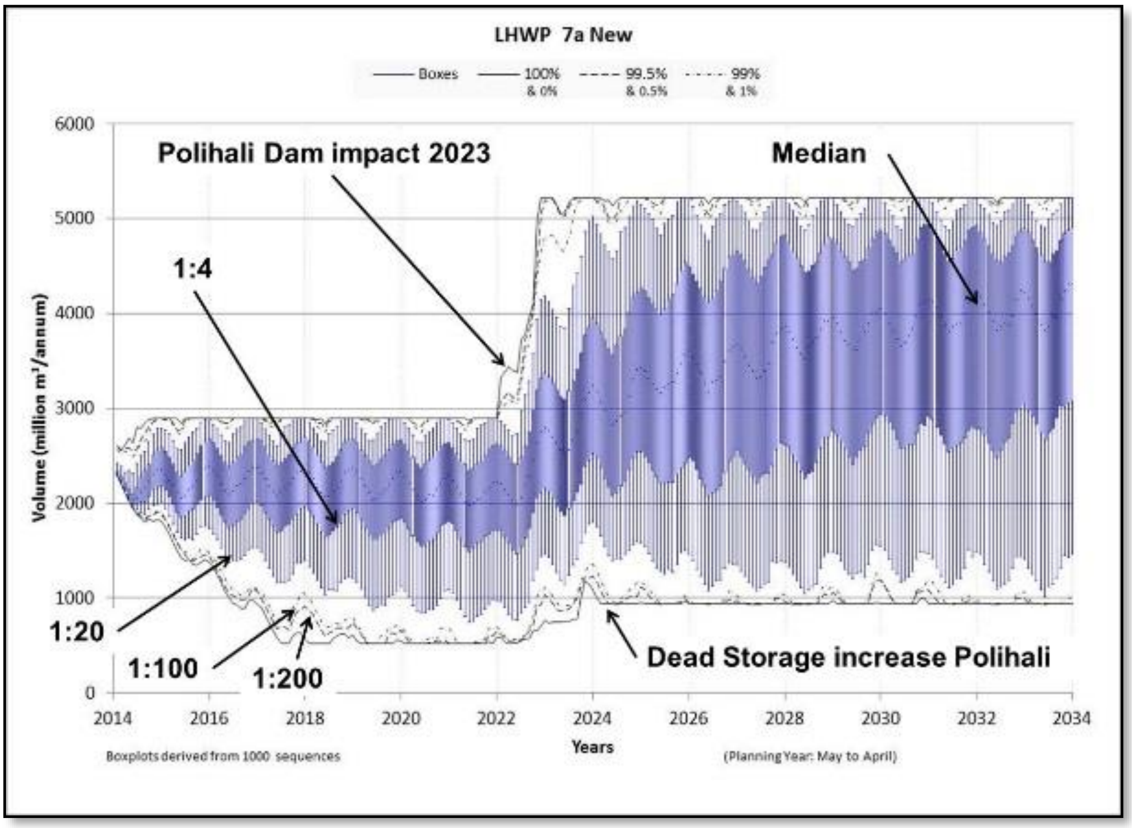
B

Figure 7-4: Bloemhof Dam Storage projection for the previous (A) and current (B) Core Scenario

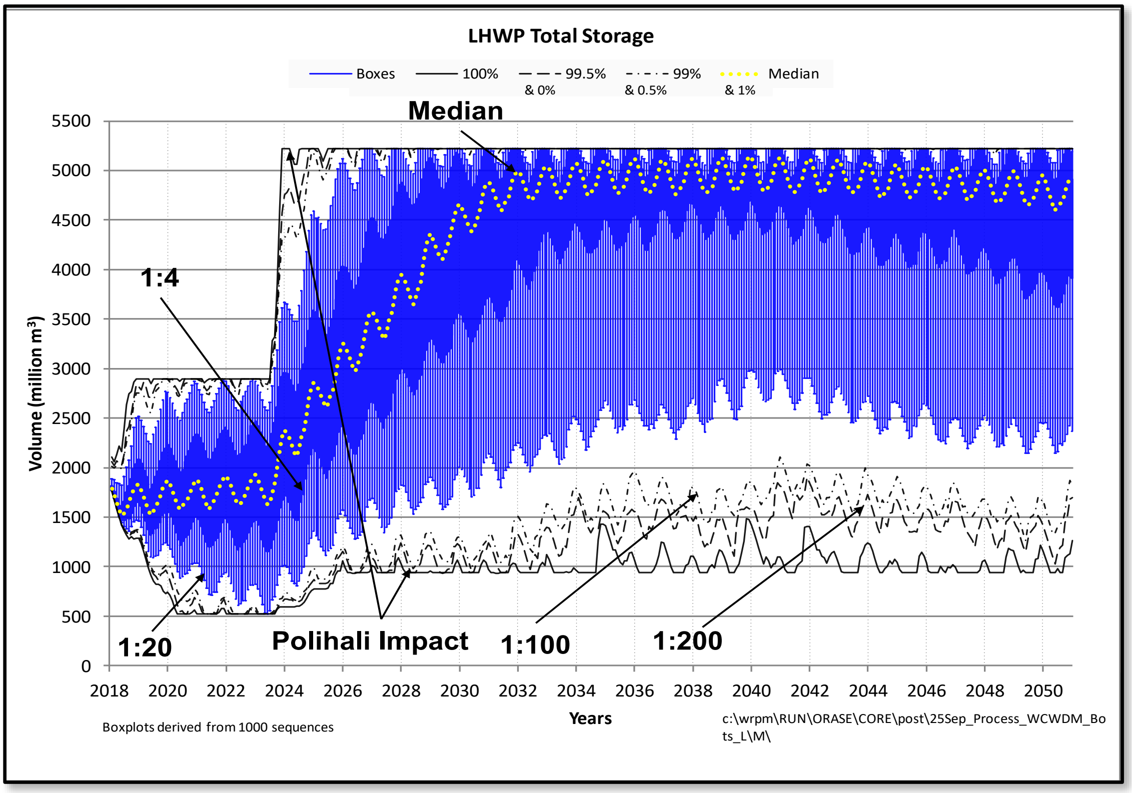
The slow increase in the storage of Bloemhof Dam is as result of increasing return flows from Gauteng and the Middle Vaal.

The LHWP storage plots include the combined storage of Mohale, Katse and Polihali dams. These storage projection plots from the previous and current study are given in **Figures 7-5 A** and **B**. The two storage projection plots differ quite significantly due to the following:

- The LHWP observed starting storage for the previous study was quite higher than the more current 2018 observed starting storage. This resulted in higher storage levels in the initial period as from the previous study until Polihali Dam was introduced. In the previous study Polihali already start inundating water from 2022 onwards, while for the current study it stared in 2023.
- Polihali Dam filled much faster based on the results from the current study versus that obtained from the previous study. This is as result of the improved LHWP operating rule used for the current study. This rule allowed water that would be supplied from Polihali Dam to remain in Polihali until it is requested by the IVRS. Therefore, the higher storage levels in the LHWP system since Polihali Dam was activated, when simulated for the current study according to the improved operating rule.
- The LHWP storage projection from the previous study shows that the 1 in 100 and 1 in 200 year (99% and 99.5% exceedance probabilities) are for most of the time at or close to the minimum operating level. This clearly indicates that the maximum possible was always transferred from the LHWP to the IVRS. This is not the case for the LHWP Phase II as analysed in the current study, as the system is running fairly full since the introduction of Polihali Dam. As previously indicated, this is to the benefit of the IVRS due to reduced evaporation and spills but will also benefit the Senqu and Orange River downstream of Polihali Dam, as spills will occur more frequently from Polihali Dam. This will benefit the hydro-power generation at Polihali Dam but will be a disbenefit for the power generation at Muela.



A



B

Figure 7-5 : LHWP System Storage projection for the previous (A) and current (B) Core Scenario

7.2.2 Greater Bloemfontein Water supply system

The Greater Bloemfontein system is used to support the Bloemfontein and Botshabelo urban demand centers as well as several other towns such as Thaba N'chu, Wepener, Dewetsdorp, Reddersburg, Edenburg, and Excelsior (See **Figure 7.6**).

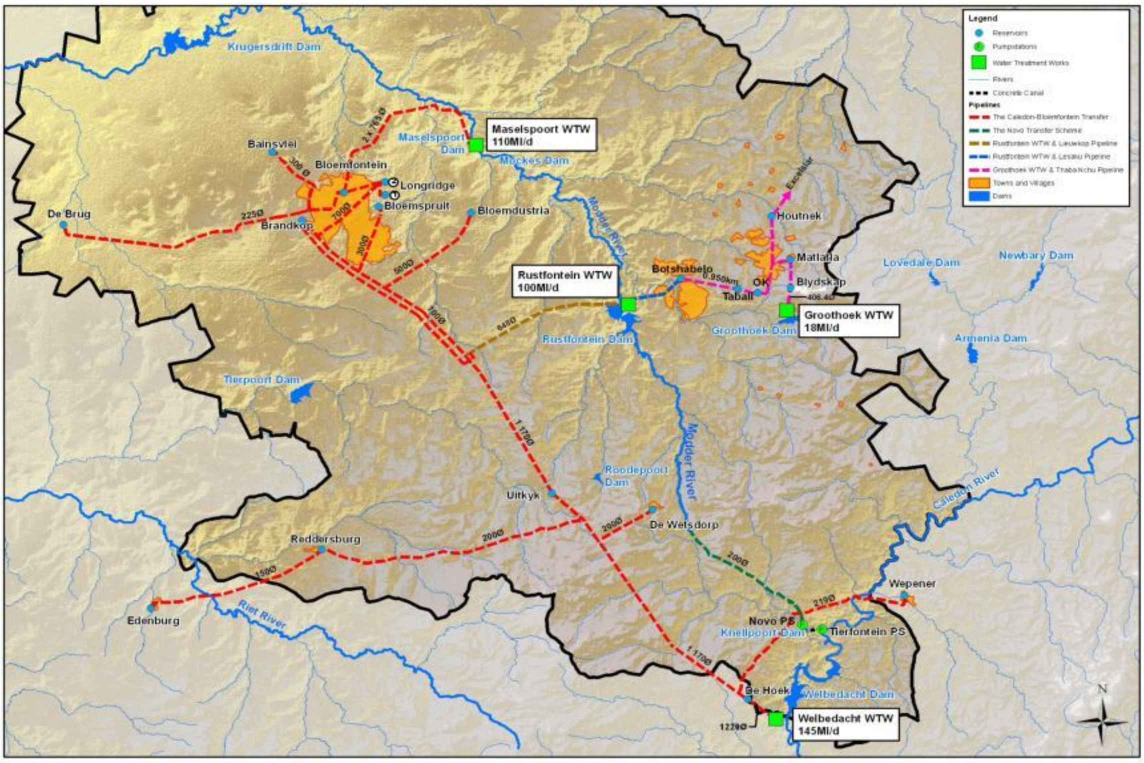
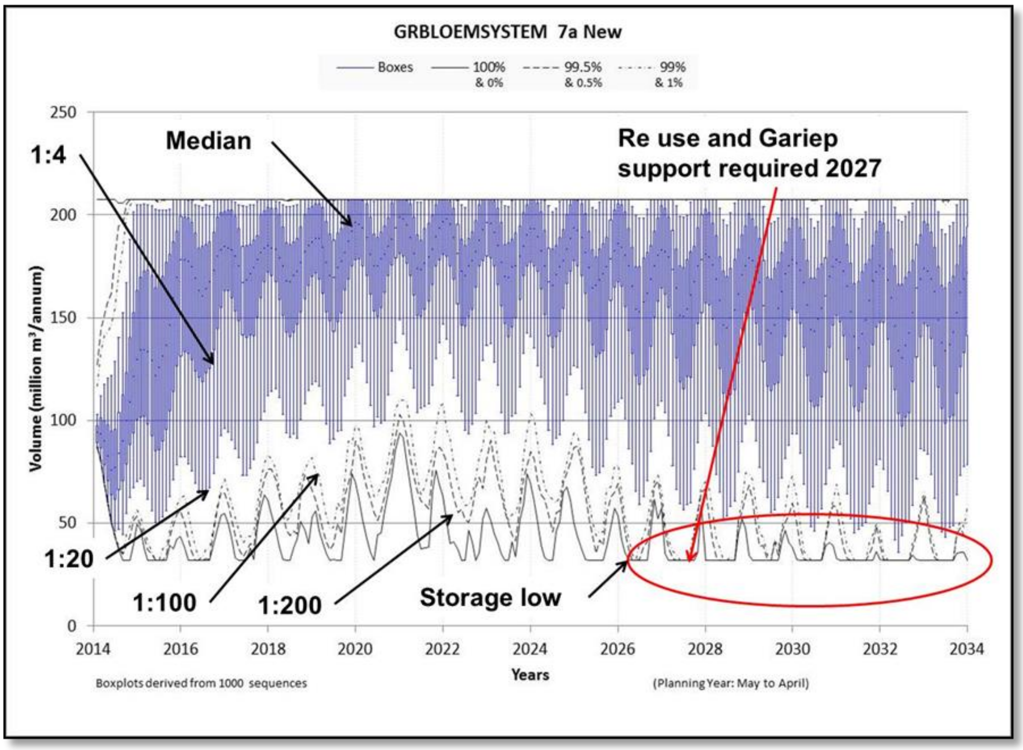


Figure 7-6: Greater Bloemfontein Water Supply System

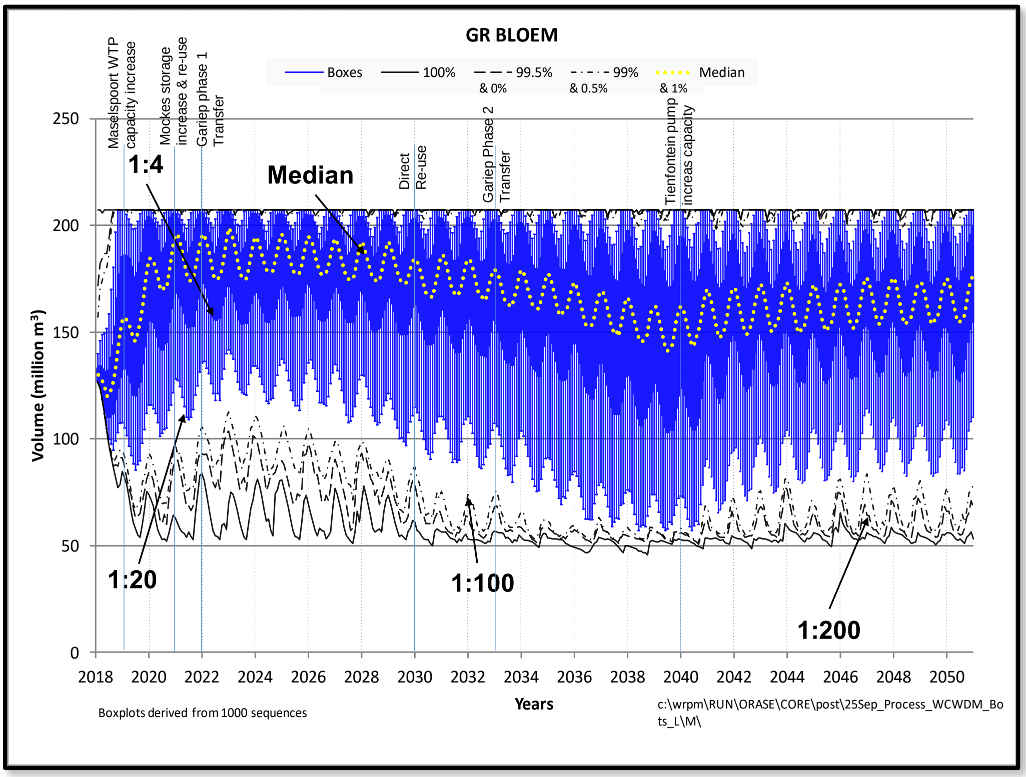
The Greater Bloemfontein water requirements have exceeded the yield capability of its resources for quite some time. DWS RSA did carry out a Reconciliation Strategy (DWA, 2012b) study for this water supply system, but very little of the planned intervention options were put in place. Some of the intervention options also proved impractical after further detailed investigations. The following intervention options formed part of the reconciliation strategy as derived by DWS RSA and need to be implemented in the order as listed.

- WC/WDM actions of which some actions were implemented
- Increase the Tienfontein pumping capacity to 4 m^3/s. This was completed.
- Increase the Welbedacht WTP capacity to 145 Ml/d. (not implemented)
- Pumpstation at Welbedacht Dam with pipeline to Knellpoort Dam to pump water from Welbedacht to Knellpoort Dam. This pipeline was planned as a bi-directional pipeline to also allow flow from Knellpoort Dam to the Welbedacht WTP (not implemented as some practical problems were experienced to install a bi-directional pipeline).
- Increase Tienfontein pump station capacity to 7 m^3/s.
- Implement re-use (not implemented)

- Transfer water from Gariep Dam to Bloemfontein using pump stations and a pipeline (not implemented).



A



B

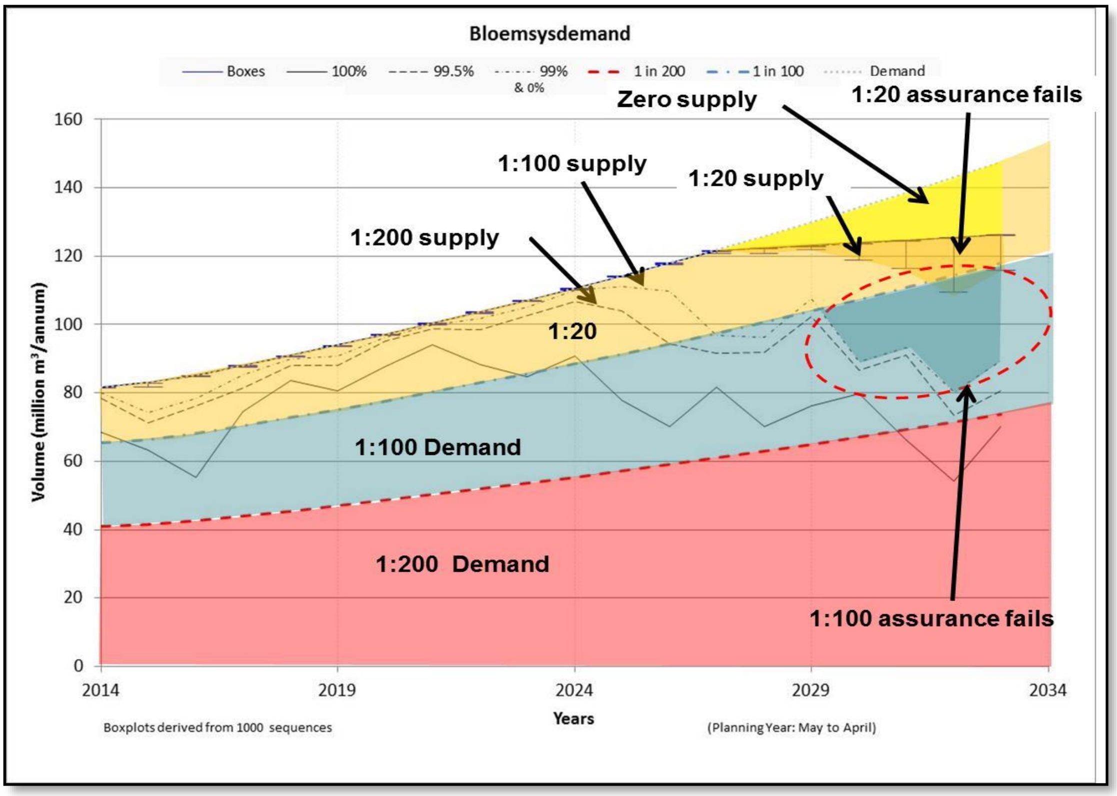
Figure 7-7: :Greater Bloemfontein System Storage projection for the previous (A) and current (B) Core Scenario

Due to the slow implementation process the Mangaung Metropolitan Municipality started their own study with the intention to fast track the Gariep to Bloemfontein pipeline option (MMM, 2018). The intervention options from this study include the following as listed in the order of implementation.

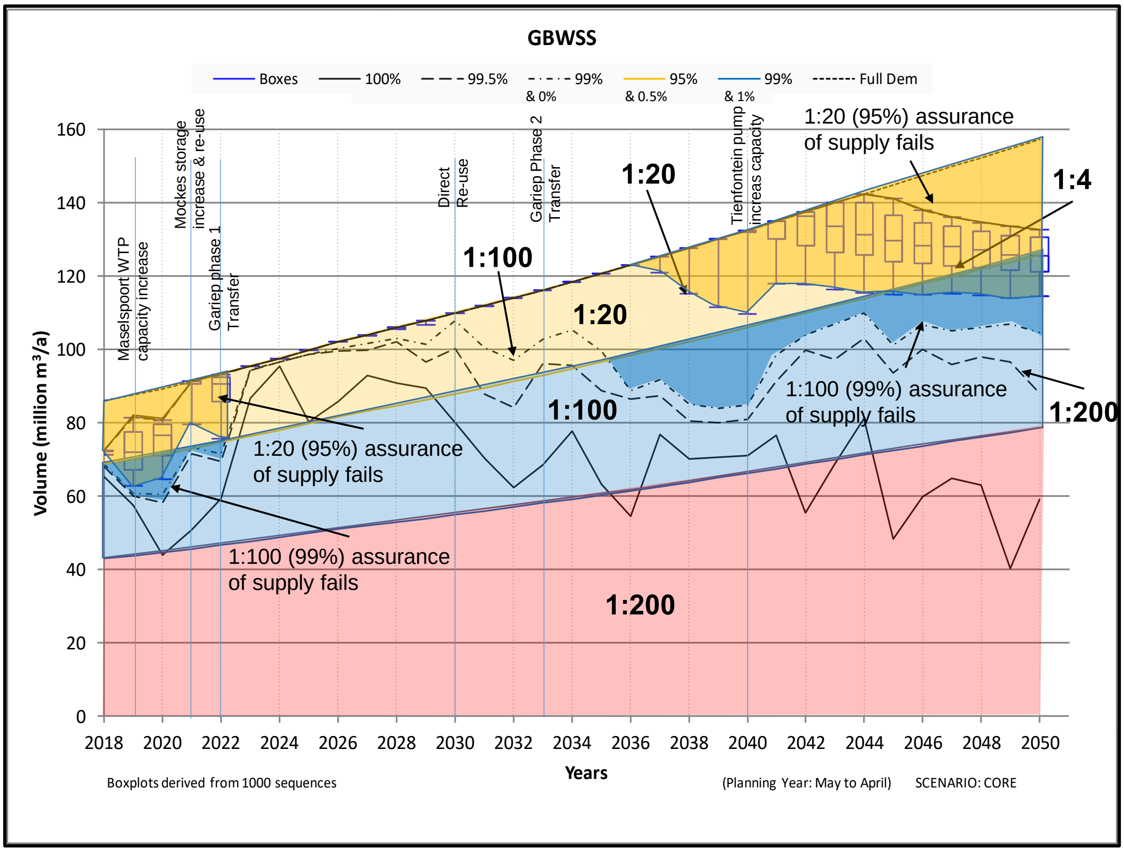
- Increase the Tienfontein pumping capacity to 4 m^3/s as from the DWS reconciliation strategy as this option was almost completed at the time the Mangaung Metro study commenced.
- Continue and improve WC/WDM as it was already in process
- Increase the Maselspoort WTP capacity to 130Ml/d by 2019
- Increase Mockes Dam storage to 12.13 million m^3 by 2021.
- Indirect re-use via Mockes Dam in 2021 – 16.4 million m^3/a
- Gariep to Bloemfontein transfer Phase 1 in 2022– 32 million m^3/a
- Direct/indirect re-use of 11.7 million m^3/a in 2030
- Gariep to Bloemfontein transfer Phase 2 by 2033– 11 million m^3/a
- Increase Tienfontein pump station capacity to 7 m^3/s in 2040 based on the DWS Reconciliation Strategy

The previous Core Scenario and related storage projection was based on the DWS RSA Reconciliation Strategy. At the time of the Phase lll ORASECOM study (previous Core Scenario) the study carried out by Mangaung Metro had not yet started. Results from the Mangaung Metro Study only become available in 2018. As this was the most recent work carried out regarding the Greater Bloemfontein Water Supply System, the intervention options from the Mangang Metro study was used for the updated Core Scenario. The increase of the Tienfontein pump station capacity to 7 m^3/s from the Reconciliation Strategy, was however added.

The difference in the set of intervention options used for the previous and current Core Scenario is the main reason for the differences in the system behavior as obtained from the two Core Scenarios. Both Core Scenarios did show a significant improvement in the total system storage as result of the intervention options introduced over time. The previous Core Scenario indicated that the last intervention option defined in the DWS Reconciliation Strategy need to be implemented by 2027. There was in the meantime a ministerial request that the transfer from Gariep to Bloemfontein be fast tracked and implemented as one of the earlier intervention options. This was taken into account in the Mangaung Metro study in which Phase 1 of the Gariep to Bloemfontein transfer was moved forward to 2022. Based on the results from the Current Core Scenario it seems that the Tienfontein pump station capacity should be implemented earlier than 2040 (See **Figure 7-8B**).



A



B

Figure 7-8: Greater Bloemfontein System demand and supply projection for the previous (A) and current (B) Core Scenario

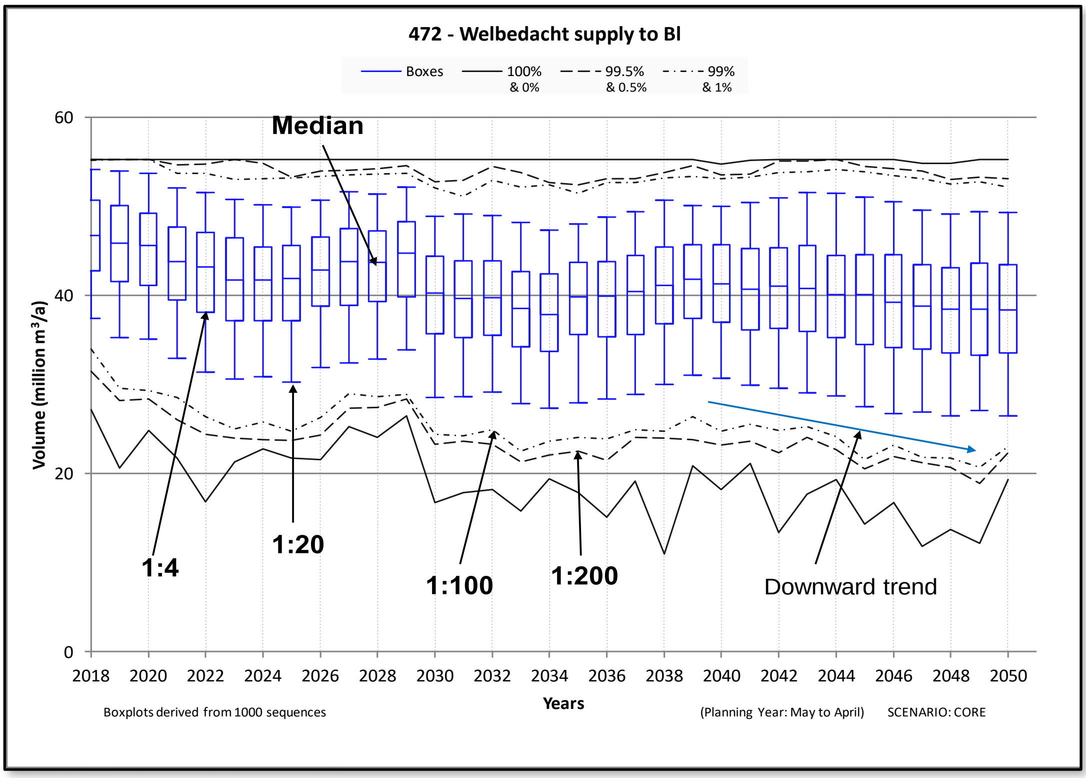
From **Figure 7-8** the Greater Bloemfontein System is currently already experiencing deficits which is confirmed by the restrictions on water use already imposed on the system for several years. Actions to put the recommended intervention options in place are already behind schedule resulting in deficits to continue at least until 2022 if the Gariep pipeline is in place at the planned time. With the new proposed intervention options in place, it is expected that from 2023 onwards the system will be in balance until 2036/37 when deficits in supply are expected to occur again. The previous Core Scenario indicated that deficits were already expected by 2028, about 9 years earlier. The main reasons for these differences include the following:

- Updated information relating to transfer capacities and minimum operating levels in main storage dams.
- Updated water requirement projections from the Mangaung Metro study showing lower future water requirements.
- Different intervention options proposed by the Mangaung Metro study versus those proposed by the Reconciliation Strategy study.
- Lesotho Lowland developments such as the Hlotse and Ngoajane schemes that was not included as part of the Previous Core Scenario.

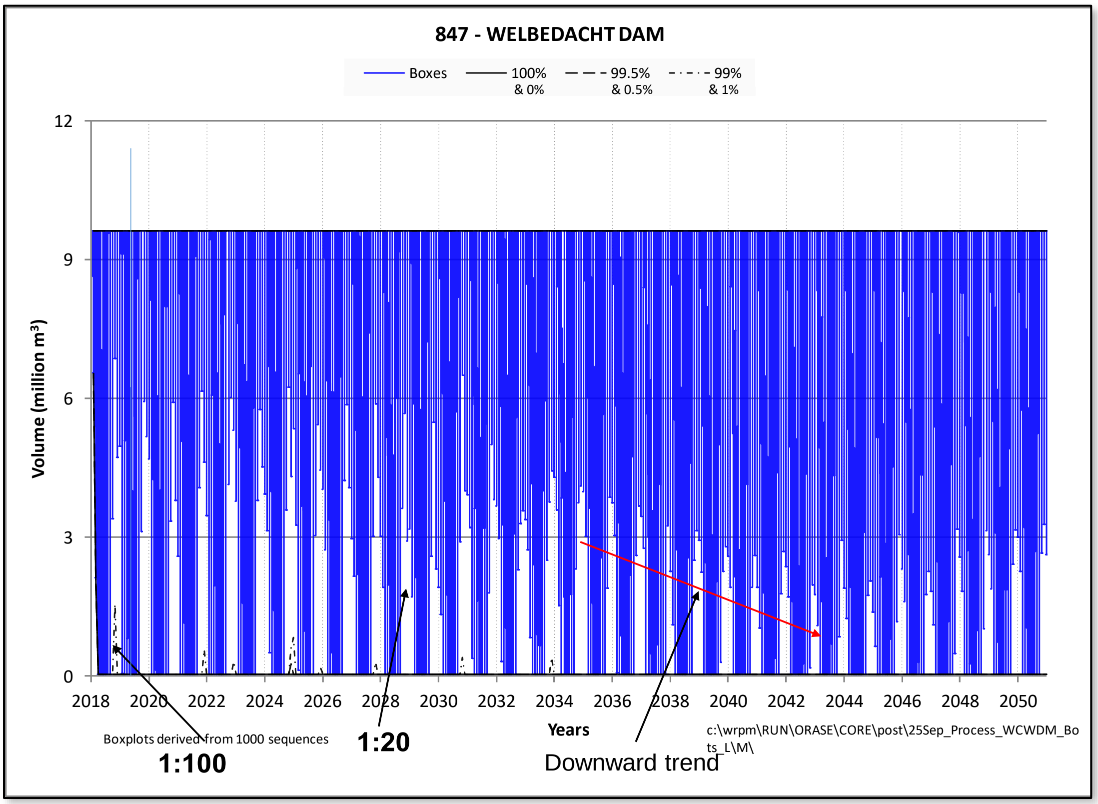
It is interesting to note that the transfer from Welbedacht Dam to Bloemfontein showed a reducing trend from 2040 onwards, similar to the storage in Welbedacht Dam. This is result of the following:

- Due to the limited resources for the Greater Bloemfontein, the WRPM imposes very high restrictions on the system towards the end of the analysis period, resulting in a lower demand imposed on Welbedacht Dam.
- With the lower demand as described above, Welbedacht Dam in general still showed a lower trend in storage, which is the opposite of what is expected when the demand reduces. This reducing storage is as result of the combined impact on Welbedacht Dam inflows due to the increased pumping capacity (7 m^3/s) at the upstream Tienfontein pump-station and increased Lesotho Lowlands developments, such as the Hlotse and Ngoajane schemes.

The Mangaung Metro study suggested that Knellpoort and Rustfontein dams in future be used to only support Botshabelo and Thaba Nchu, while Gariep and Welbedacht be used to support Bloemfontein. The increase in the capacity of the Tienfontein pump capacity to 7 m^3/s however seem to have a negative impact on the supply from Welbedacht Dam to Bloemfontein, which is important to note for future planning purposes. The supply from Welbedacht is further reduced by the development of the Lesotho Lowland schemes in the Caledon River catchment.



A



B

Figure 7-9: Welbedacht Dam storage projection and supply to Bloemfontein

7.2.3 Orange River Project

The Orange River Project (ORP) is the largest water supply system in the Orange Senqu basin and comprises Gariep and Vanderkloof dams and the supply area as highlighted by the magenta strip along the main Orange River, including several transfers as shown in **Figure 7-9**.

Gariep and Vanderkloof dams are the two largest storage dams in the basin with gross storage capacities of 5 198 million m^3 and 3 188 million m^3 respectively. There are several transfers from the ORP to support users in other sub-catchments of which some are located outside the Orange Senqu Basin. There are no transfers in support of the ORP. Upstream of the ORP there are two existing transfers that directly impacts on the ORP yield, the LHWP transfer to the IVRS and the transfers from the Caledon to the Modder River catchment in support of the Greater Bloemfontein Water Supply system. A third transfer scheme is planned to transfer water from Lesotho to Botswana in support of Gaborone. These transfers will increase in future due the increasing water requirements in the IVRS, the Greater Bloemfontein and Gaborone.

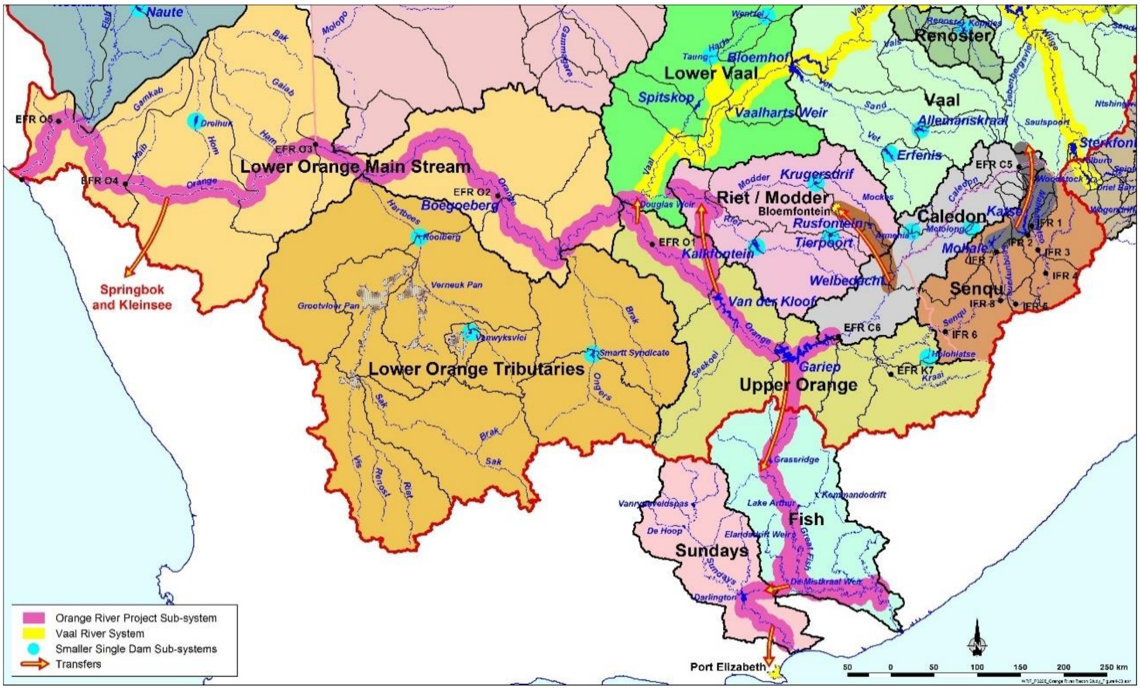


Figure 7-10: Orange River project water supply system and supply area

The largest increase in transfers will be from the LHWP with the implementation of the second phase of the scheme with the construction of Polihali Dam and tunnel to Katse Dam. Current planning is that Polihali Dam will start to inundate water by 2023 and start to transfer in December 2025. The inclusion of Phase II of the Lesotho Highlands transfer system will result in a significant decrease in the yield available from the ORP and relating deficits in water supply to users from the ORP. Several intervention options form part of the reconciliation strategy

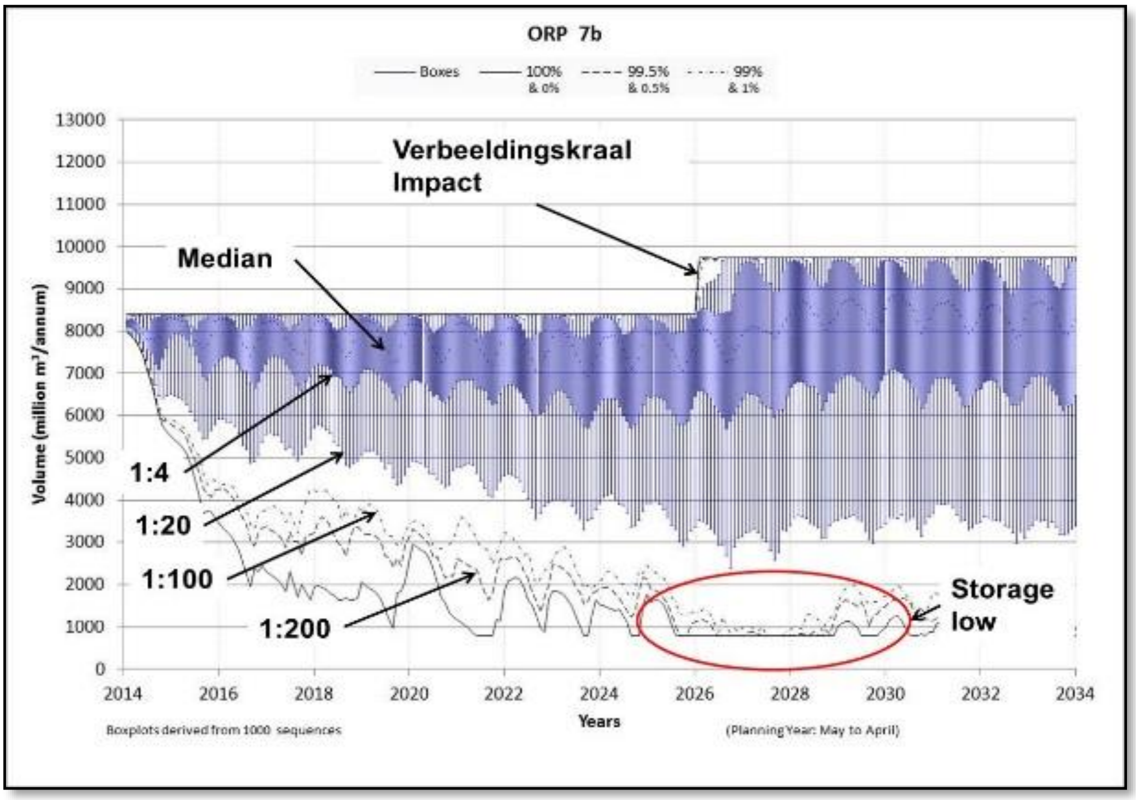
(DWS 2015a) as planned by DWS RSA to maintain a positive water balance in the ORP. These intervention options include the following:

- Utilize the lower level storage in Vanderkloof Dam to increase the ORP yield.
- To implement real time modelling and monitoring to reduce the operational requirements of the ORP.
- Construction of Noordoewer/Vioolsdrift Dam to further reduce operational requirements and to improve the supply of environmental requirements to the river mouth. This dam will also be used to supply water to an increased irrigation area mainly for Namibia.
- Construction of Verbeeldingskraal Dam in the Orange River upstream of Aliwal North. To increase the ORP system yield.

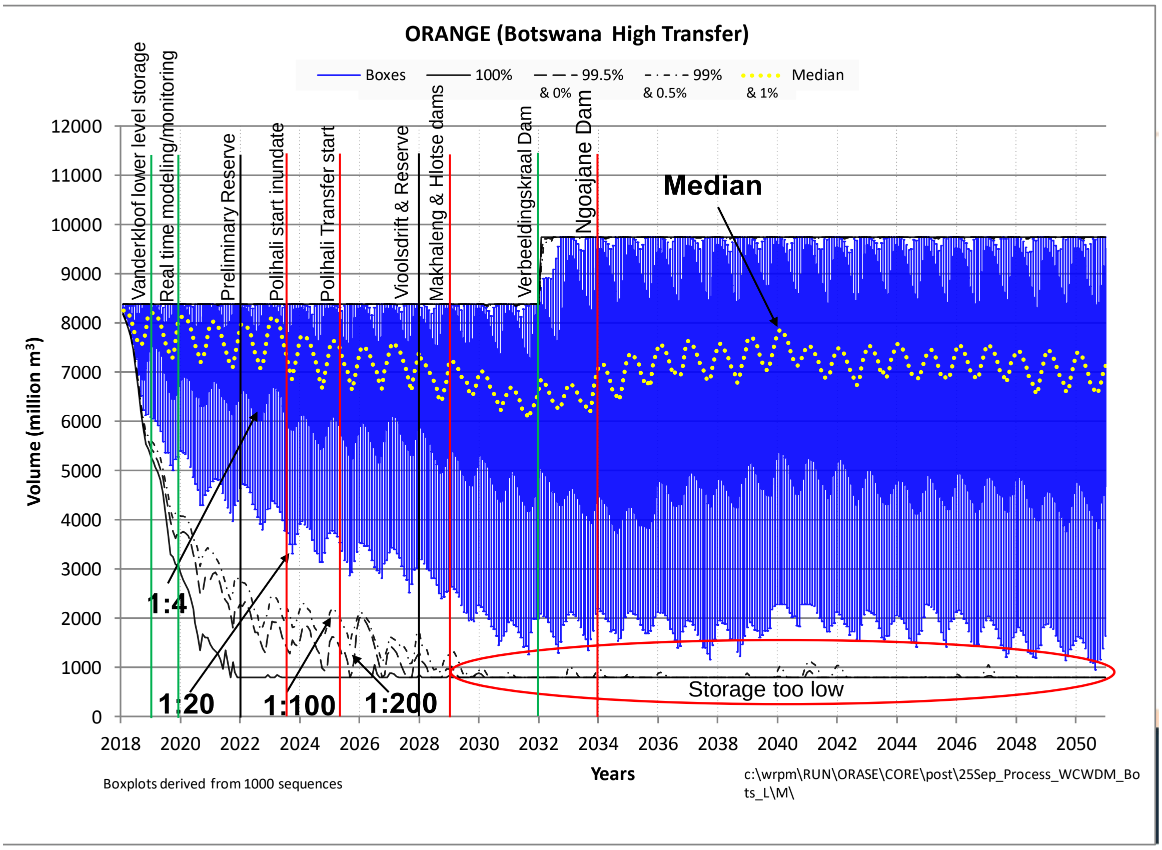
These intervention options were all included in both Core Scenarios. The latest implementation dates of these intervention options are shown on the ORP storage projection plot for the updated Core Scenario in **Figure 7-10B**. The Water conservation and water demand management intervention option was for the updated Core Scenario assumed to be in place for urban/industrial/mining and irrigation users in the RSA, according to the Orange System reconciliation strategy prepared by DWS RSA.

The options indicated by the green lines will result in an increase of the ORP system yield or reducing of some demands imposed on the system. Items indicated by the red lines will result in a reduction in the ORP yield. Those indicated by the black lines will have very little impact on the ORP balance.

Other possible future developments such as Makhaleng Dam and related transfer to Botswana, Hlotse and Ngoajane dams are all developments upstream of the ORP in Lesotho and will result in a decrease in the ORP yield. For the purpose of the Core Scenario, Makhaleng Dam size was increased to a 3 MAR dam, to be able to not only support the Botswana transfer and local Lesotho water requirements, but to also support the ORP to minimize the impact of the Makhaleng Scheme on the ORP. EWR releases were made from all three the Lesotho Lowlands dams. These releases will provide some support the ORP system to enable the ORP to better supply the downstream EWRs.



A



B

Figure 7-11: ORP System Storage projection for the previous (A) and current (B) Core Scenario

When comparing the ORP storage projection plots for the previous Core Scenario and the Current Core Scenario, the following important differences were noted:

- A much longer projection period is available for the Current Core Scenario.
- The Current Core Scenario projection starts 4 years later with a higher demand imposed on the ORP system due to increasing demands.
- Intervention options for the Current Core Scenario were implemented later, specifically Verbeeldingskraal that was in the previous Core Scenario already implemented in 2026 while in the Current Core Scenario is implemented by 2032. This is mainly as result of the late implementation of the LHWP Phase II project in comparison to previous planning schedules.
- From about 2029 onwards the ORP start running empty during severe droughts (See 99% and 99.5% exceedance probability levels) for the entire future projection period. In the previous Core Scenario this occurred over a relative short period from 2026 to 2029, where after the system recovered. The main reason for this, is the new possible future developments in Lesotho and related transfer to Botswana, as well as increased abstraction from the Caledon by towns, but mainly by the Greater Bloemfontein system.
- The storage levels in the ORP at the different exceedance probability levels are significantly lower than those from the Previous Core Scenario. This is as result of the reasons already mentioned in the previous bullet point.

It is important to note that the Preliminary Reserve to be implemented by 2022, was already determined and approved by DWS RSA. The flow requirements for the Preliminary Reserve are thus known and were included in the modeling of the current Core Scenario. The final reserve is to be implemented by 2028 along with Noordoewer/Vioolsdrift Dam. It is important to align the implementation of the final Reserve with Noordoewer/Vioolsdrift Dam implementation, as Noordoewer/Vioolsdrift Dam is essential to enable the correct release volumes and timing for the river mouth EWR. From previous EWR studies on the Orange, a preferred EWR from an ecological point of view was already determined, which was used in the Current Core Scenario as the Reserve. This EWR however, significantly reduce the ORP system yield. It is expected that the final Reserve to be determined will represent a requirement somewhere between the Preliminary Reserve and the preferred ecological Reserve. The preferred ecological requirement included in the Current Core Scenario is thus only an indication of the final Reserve and will still be changed in future.

The simulated water supply to some of the ORP users from the Previous Core Scenario were plotted and include in the ORASECOM Phase III reports. These plots were also included in this report and compared with the water supply to these users as simulated for the Current Core Scenario (See **Figures 7-11, 7-12** and **7-13**).

Channel 1900 (Namakwa Mine and Urban) in the WRPM refer to the combined domestic water requirements of Witbank, Pella, Onseepkans, Pofadder, Aggeneys and Black Mountain Mine, which falls under the Pelladrift Water Board. The water supply to these users for the Previous and Current Core Scenario are shown in **Figure 7-11**.

For the Previous Core Scenario, the water users were supplied at the required assurances without any deficits over the analysis period. The results from the Current Core Scenario analysis showed that for the years 2043 and 44 and again from 2048 onwards, the ORP was not able to adhere to the 99% assurance of supply and some deficits did occur.

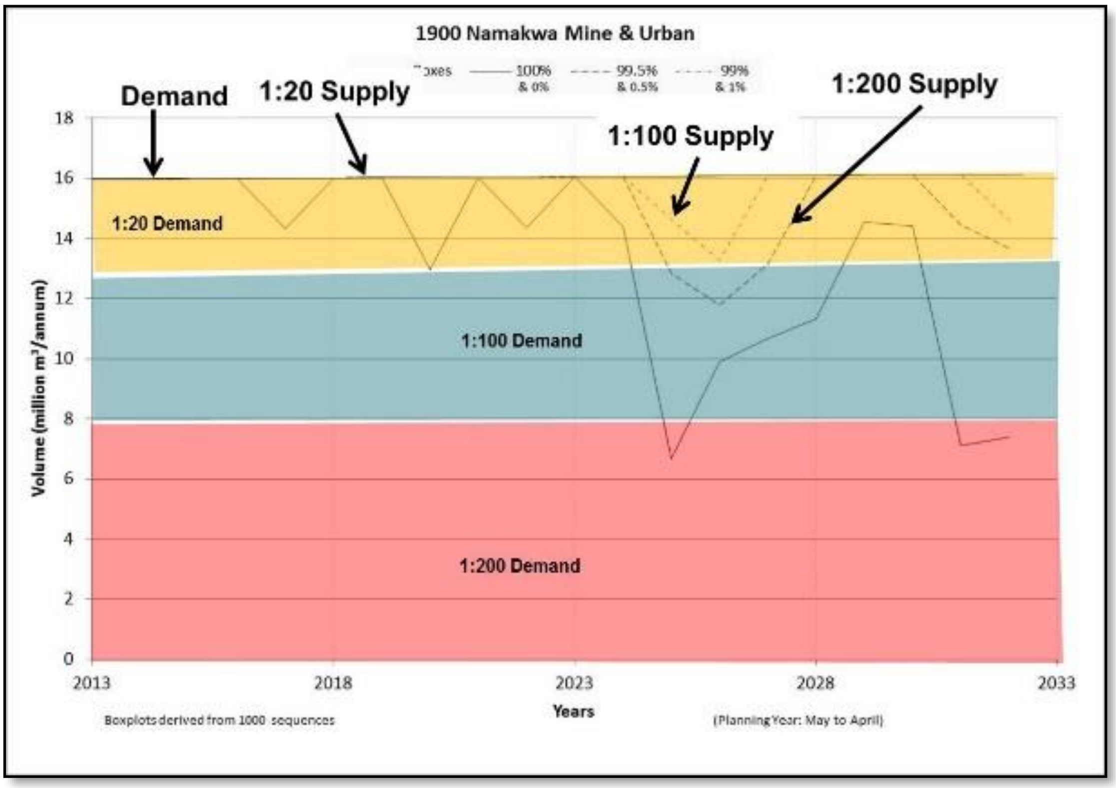
The irrigation supply to the Eastern Cape represents a total water requirement of in the order of 600 million m^3/a and is one of the largest abstractions from the ORP. The simulated water supply to these users for the Previous and Current Core Scenario is given in **Figure 7-12**. The Previous Core Scenario showed no deficits over the simulation period. The Current Core Scenario show deficits occurring for the first time by 2030 at the 95% assurance of supply and from 2036 also at the 99% supply assurance.

These findings are in line with that evident from the storage projection plots.

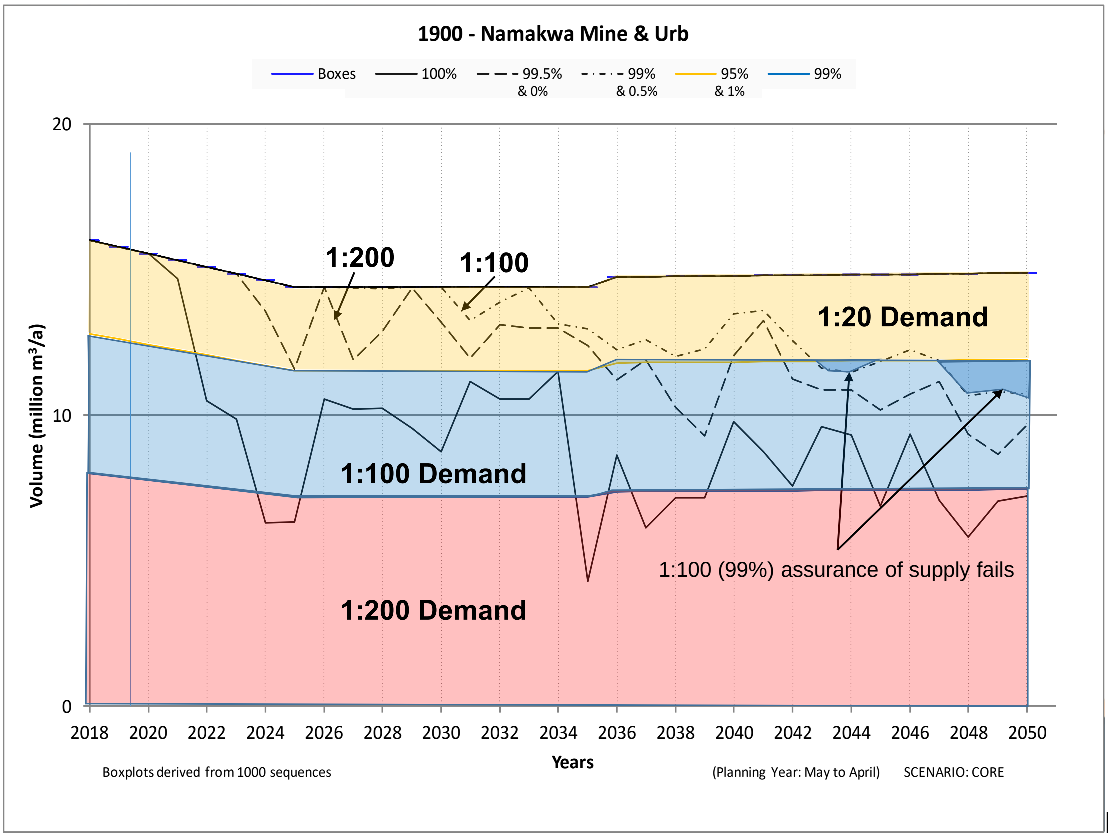
The urban/mining requirement are in general supplied better than irrigation due to the higher priority given to the urban/mining/industrial water requirements.

The water supply to Springbok, Concordia, Kleinsee, Steinkopf and De Beers Mine via Namakwa Water Board is one of the more downstream and larger urban abstractions from the Orange River. The water supply to these users is simulated via channel 1818 in the WRPM and are given for the Previous and Current Core Scenarios in **Figure 7-13**. Both the Previous and Current Core scenario showed some failure in supply at the 99% assurance but was both in general well supplied. **Figure 7-13** represents the last of the projection boxplots for the ORP that was given in the previous Core Scenario analysis report. Several additional projection boxplots showing results from the analysis of the Current Core Scenario regarding the ORP, was added to this section to illustrate some important fine dings.

The medium size future Noordoewer/Vioolsdrift Dam formed part of the Core Scenario. The storage projection of this dam as well as the water supply to some users downstream of the dam are given in **Figure 7-14**. Namibia plan to significantly expand their irrigation supplied from Noordoewer/Vioolsdrift Dam. The irrigation channel representing the growth in irrigation at Noordoewer (Channel 1861) is shown in **Figure 7-14B**. The steep growth in irrigation is clearly evident and failure in the assurance of supply are already seen from 2043 onwards.

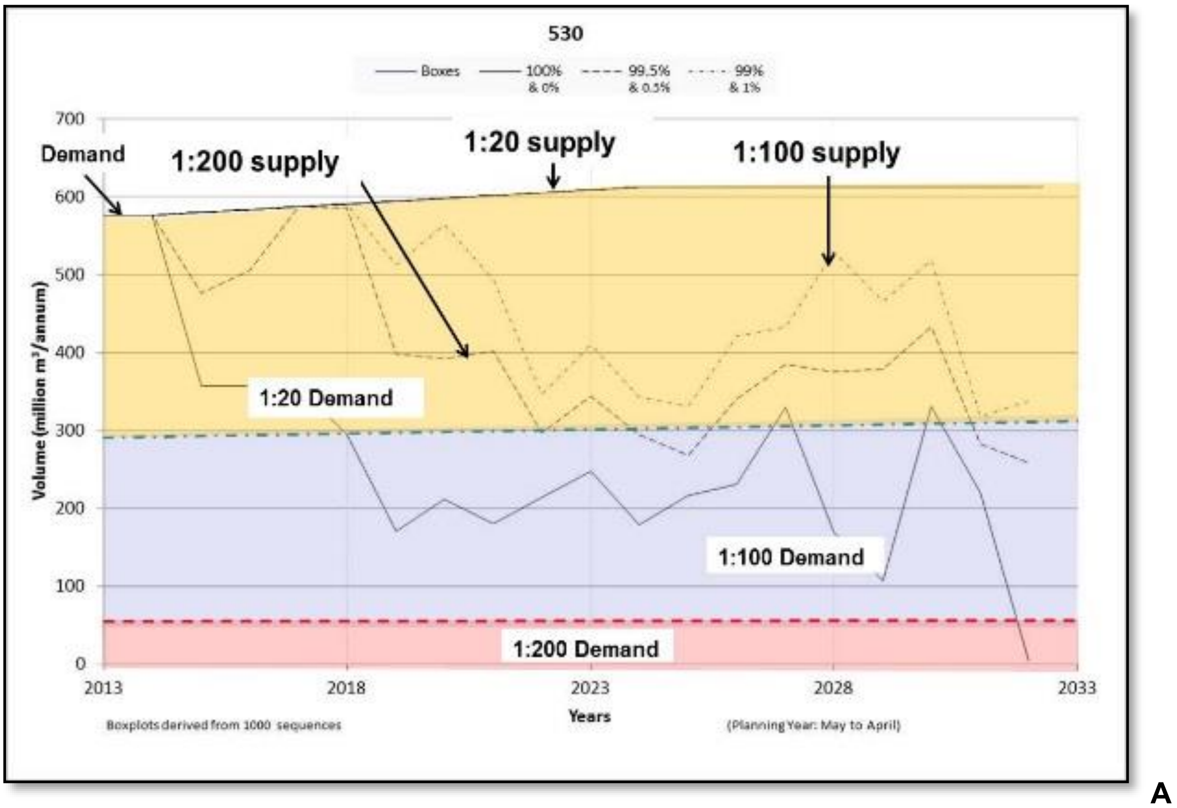


A



B

Figure 7-12: Namakwa urban and mining water supply for the previous (A) and current (B) Core Scenario



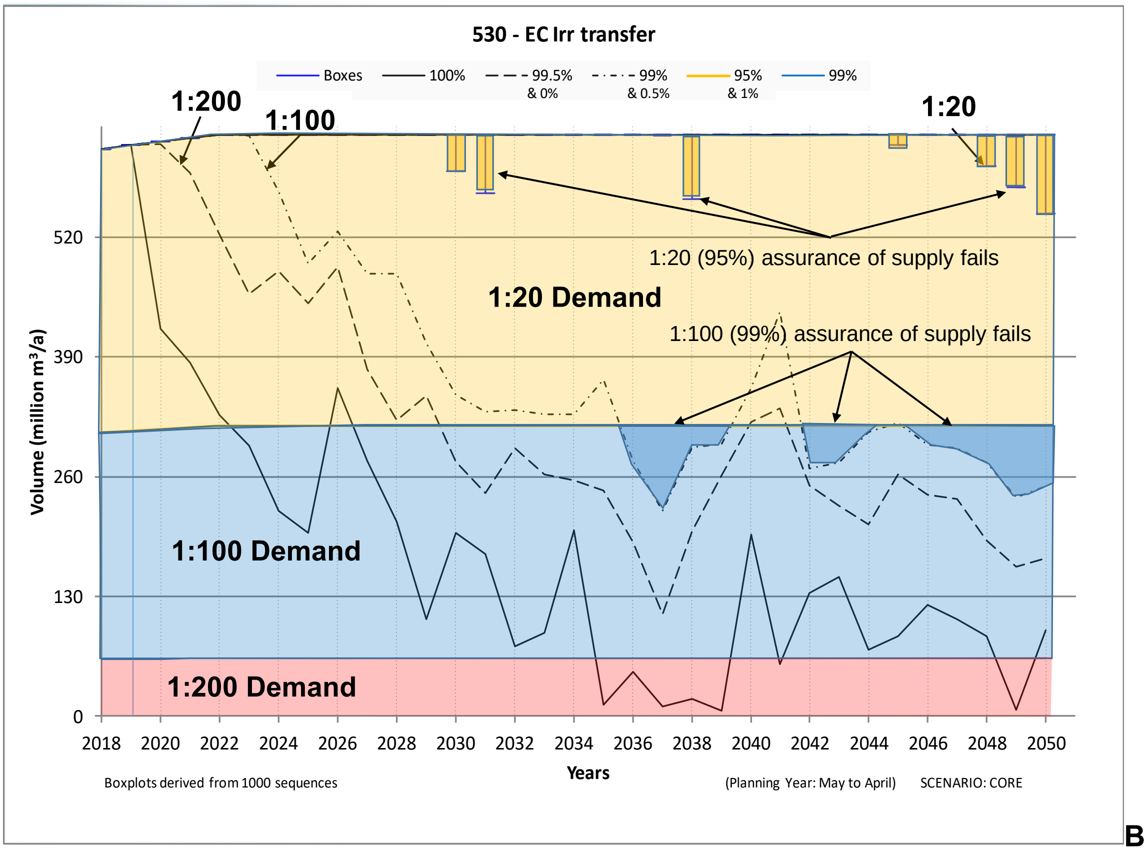


Figure 7-13: Water supply to the Eastern Cape from Gariep Dam for the previous (A) and current (B) Core Scenario

The cause for these failures is a combination of several reasons that include the following:

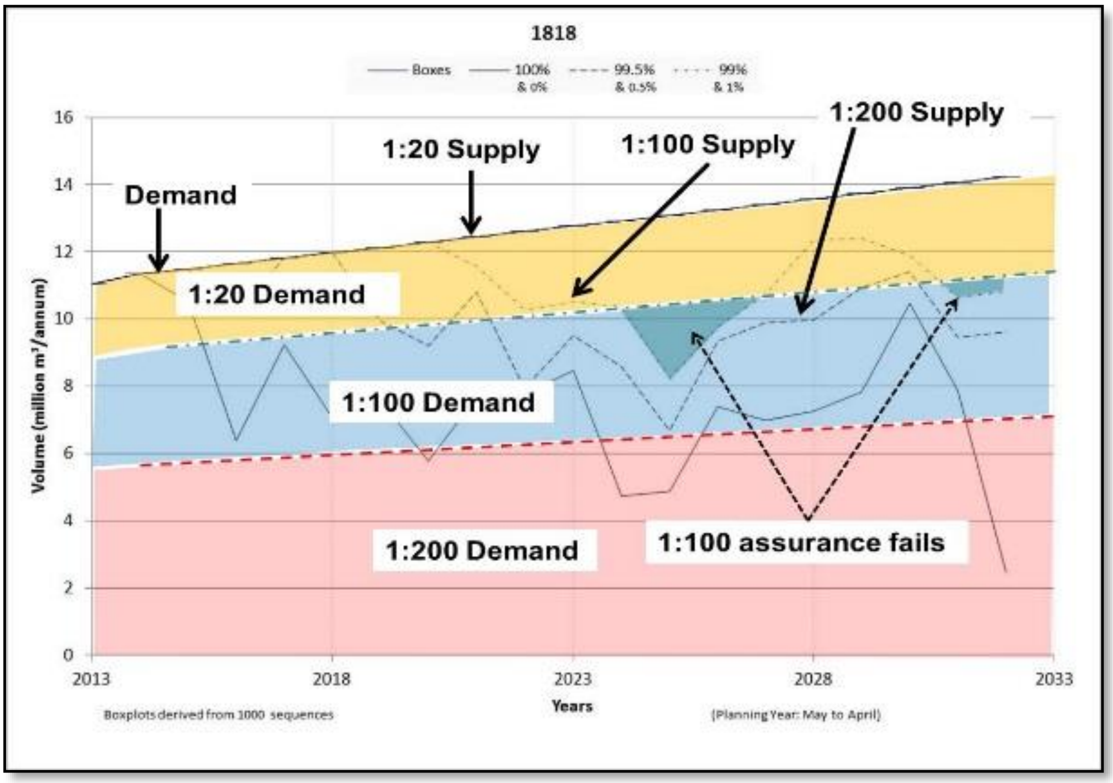
- The Noordoewer/Vioolsdrift Feasibility study is still in process and the proposed increase in irrigation has not yet been finalised.
- The Noordoewer/Vioolsdrift Feasibility study did not take into account the possible Lesotho Lowland developments, that now forms part of the Current Core Scenario
- Namibia wants a large Noordoewer/Vioolsdrift Dam while the RSA only want to allow at maximum a medium size Noordoewer/Vioolsdrift Dam for environmental reasons. These high Namibia irrigation growth projections are aimed more towards the large Noordoewer/Vioolsdrift Dam

Since Noordower/ Vioolsdrift Dam is in place, the supply to the downstream irrigation improved until about 2042, where after the significant increase in irrigation started to result in more deficits in the supply (**Figure 7-14B**).

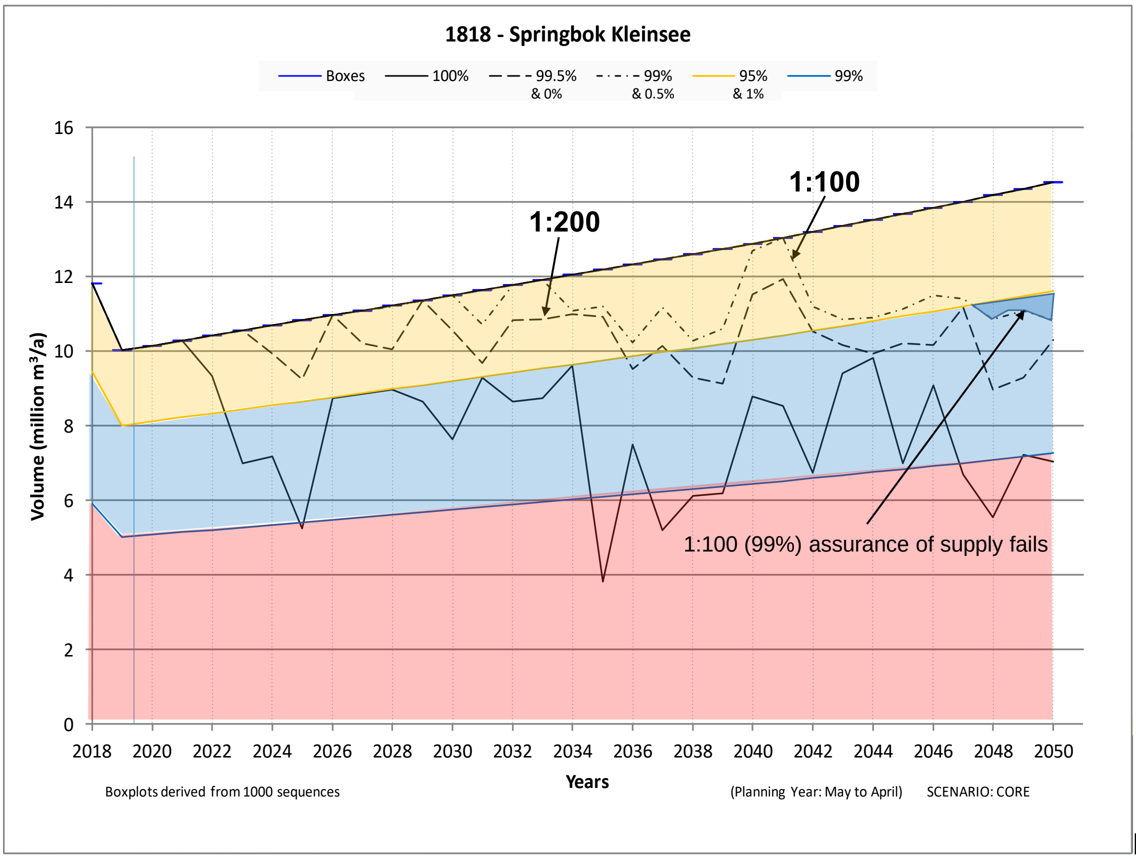
From 2033 onwards the storage projection for Noordoewer/Vioolsdrift Dam start to show a definite decrease in storage levels in comparison with the initial increase in storage. This is due to the significant increase in irrigation and environmental water requirements as well as the operating rule between Noordoewer/Vioolsdrift Dam and the ORP (mainly Vanderkloof Dam).

The operating rule dictates that releases from Vanderkloof Dam to supply the downstream users are firstly to support the users between Vanderkloof and Noordoewer/Vioolsdrift dams. Only when the water available in Noordoewer/Vioolsdrift Dam is not sufficient to support the downstream water requirements, will releases at Vanderkloof Dam be increased to also support the Noordoewer/Vioolsdrift Dam users. It is thus not a problem if the Noordoewer/Vioolsdrift Dam reaches its dead storage level on a fairly frequent basis, as it will be supported by releases from Vanderkloof Dam. In fact, it is beneficial to keep Noordoewer/Vioolsdrift Dam relatively low as it creates storage to capture local runoff.

Due to the higher priority given to urban/industrial/mining use, it is evident from **Figure 7-14C** that the urban requirements for Rosh Pinah and Skorpion mines are better supplied than the irrigation requirements supplied from Noordoewer/Vioolsdrift Dam. The first deficits in supply to the urban requirements supplied from Noordoewer/Vioolsdrift Dam started in 2048 versus 2043 for irrigation requirements.

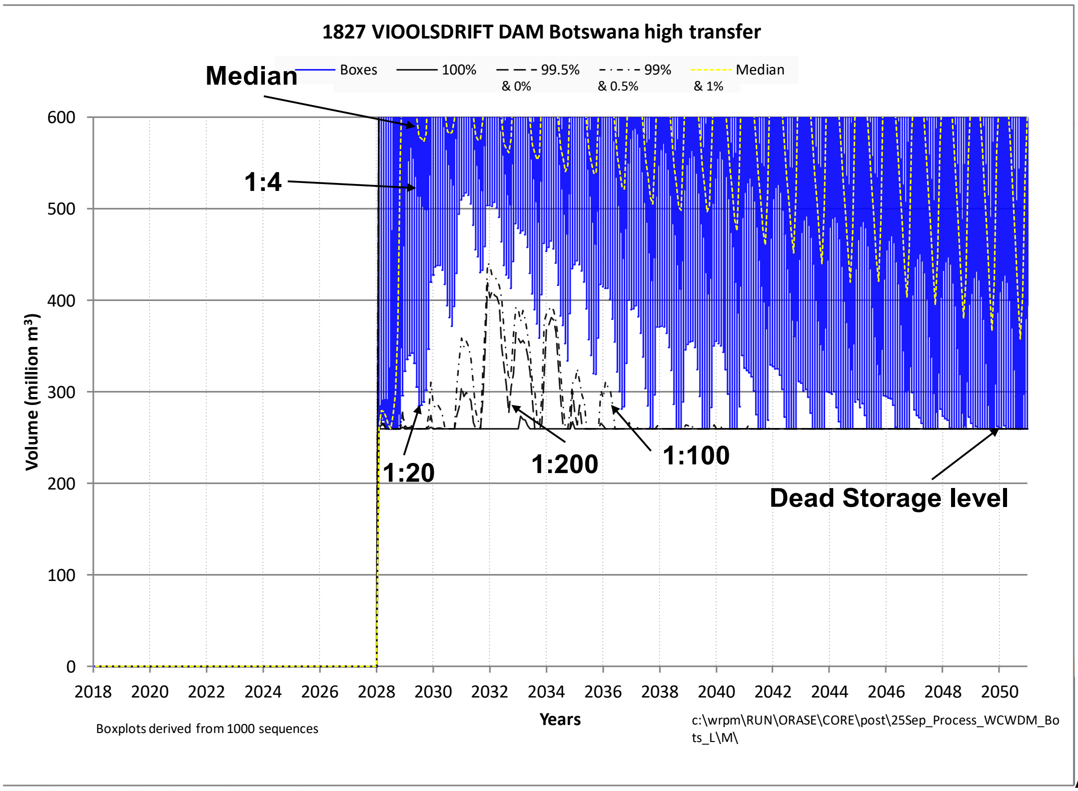


A

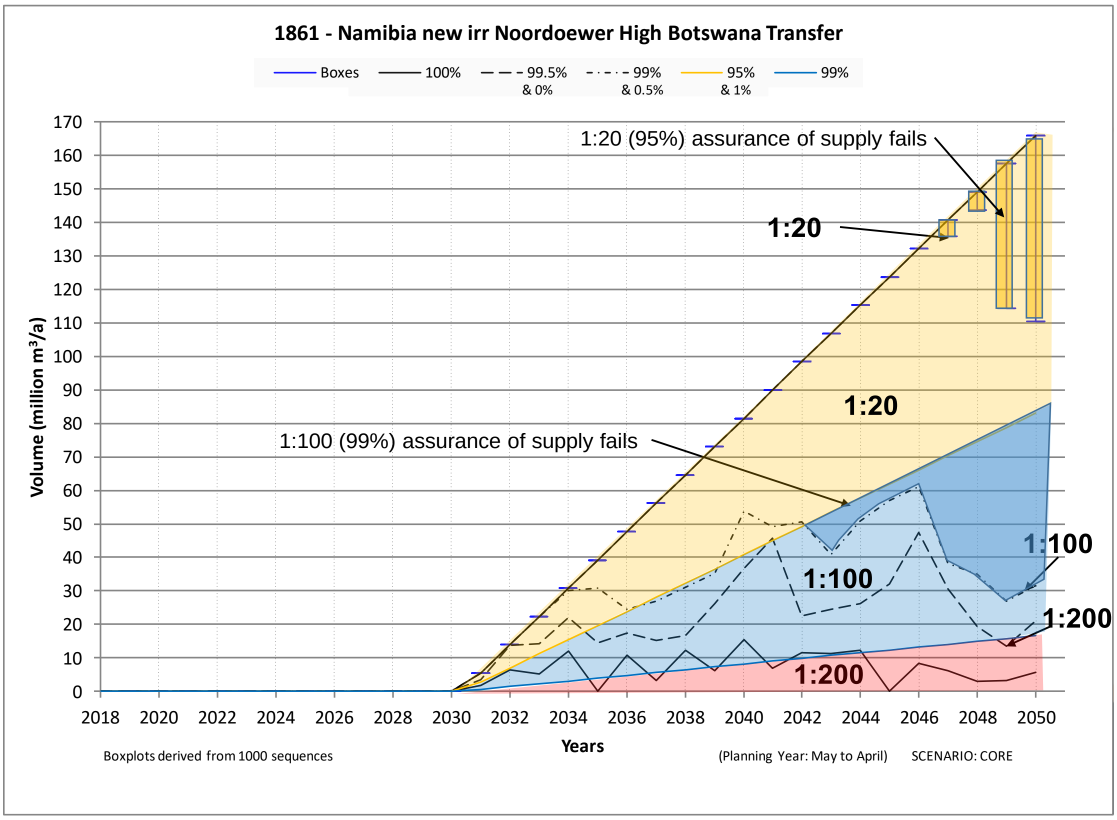


B

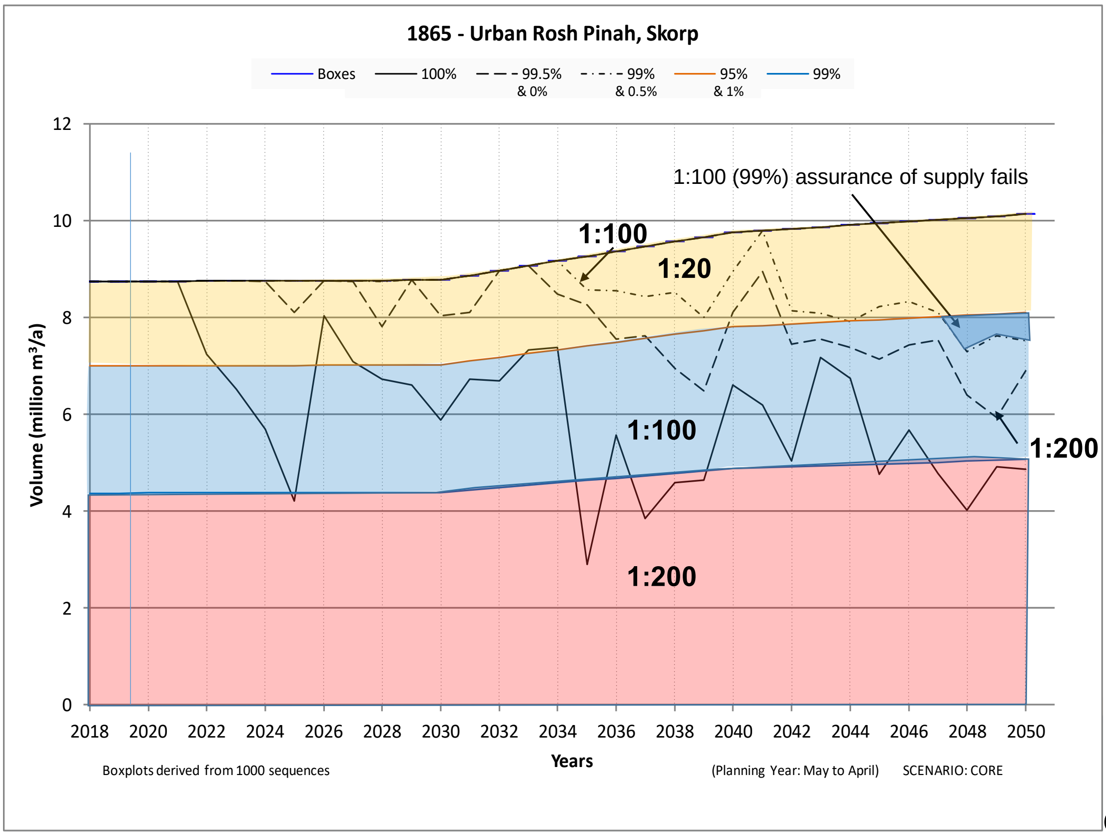
Figure 7-14: Water supply to the Springbok Kleinsee system for the previous (A) and current (B) Core Scenario


1827 VIOOLSDRIFT DAM Botswana high transfer
Boxes
100%
99.5% & 0%
99% & 0.5%
Median & 1%
Median
1:4
1:20
1:200
1:100
Dead Storage level
Volume (million m³)
Years
Boxplots derived from 1000 sequences
c:\wrpm\RUN\ORASE\CORE\post\25Sep_Process_WCWDM_Bots_L\M\

A


1861 - Namibia new irr Noordoewer High Botswana Transfer
Boxes
100%
99.5% & 0%
99% & 0.5%
95% & 1%
99%
1:20 (95%) assurance of supply fails
1:20
1:20
1:100 (99%) assurance of supply fails
1:100
1:100
1:200
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

B



C

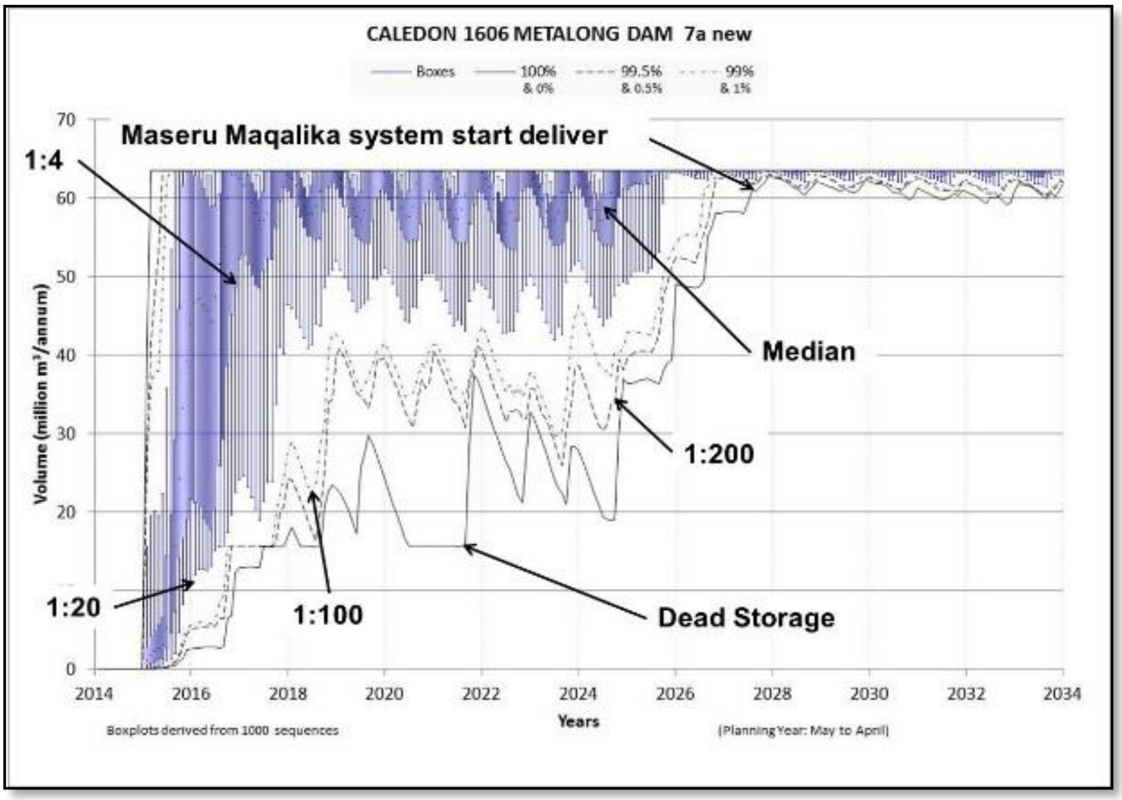
Figure 7-15: Current Core Scenario Noordoewer/Vioolsdrift Dam Storage projection and downstream water supply

7.2.4 Other Important Water Supply Systems

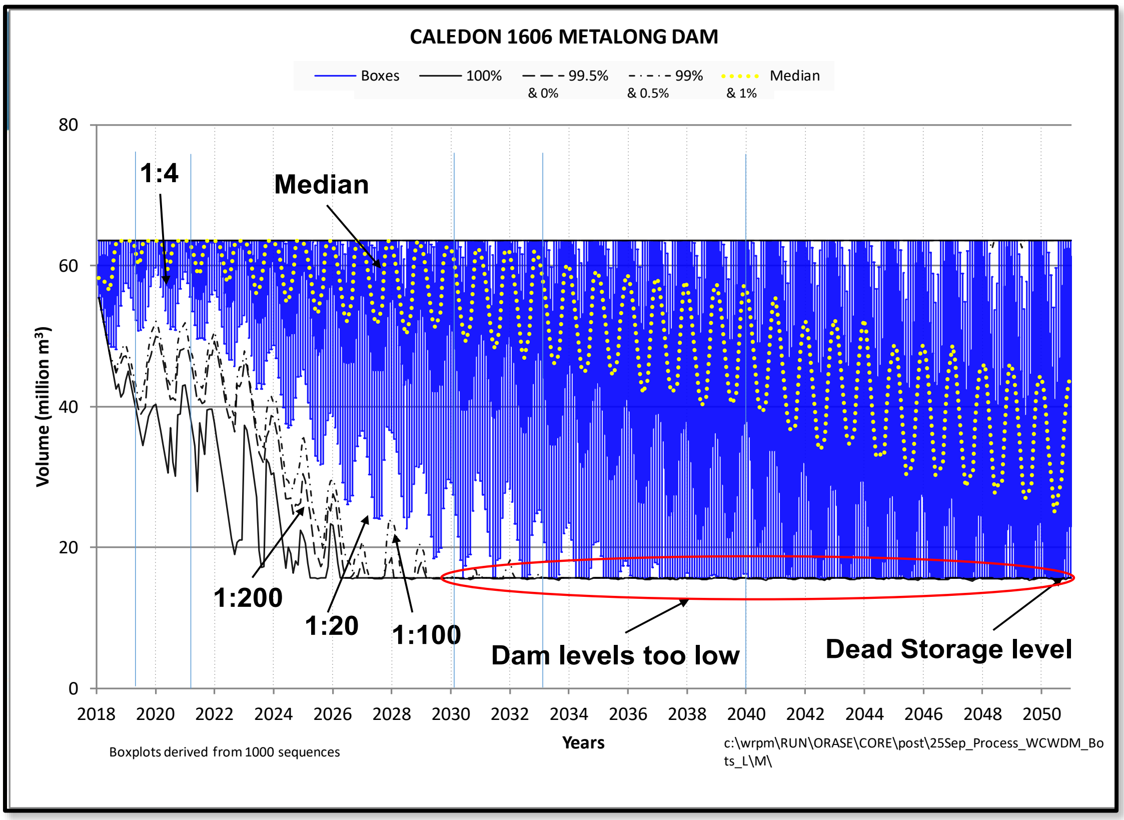
Maseru sub-system

Metolong Dam was completed in 2015 and has since started to supply water to Maseru and other smaller towns and villages in the area. At the time when the previous Core Scenario was analyzed, the water distribution systems were not yet in place and it was expected that the dam would only start to deliver water to the users within the following two years. The existing Maseru river abstraction from the Mohokare (Caledon) River to the Maqalika balancing dam was insufficient to support the growing water needs of Maseru and surrounding areas. Metolong Dam and related distribution system would thus be used also to provide support to these and other areas within Lesotho, bringing relief to the water stressed Maseru water supply system.

For the previous Core Scenario analysis, a specific operating rule was used as provided by Lesotho at the time.



A



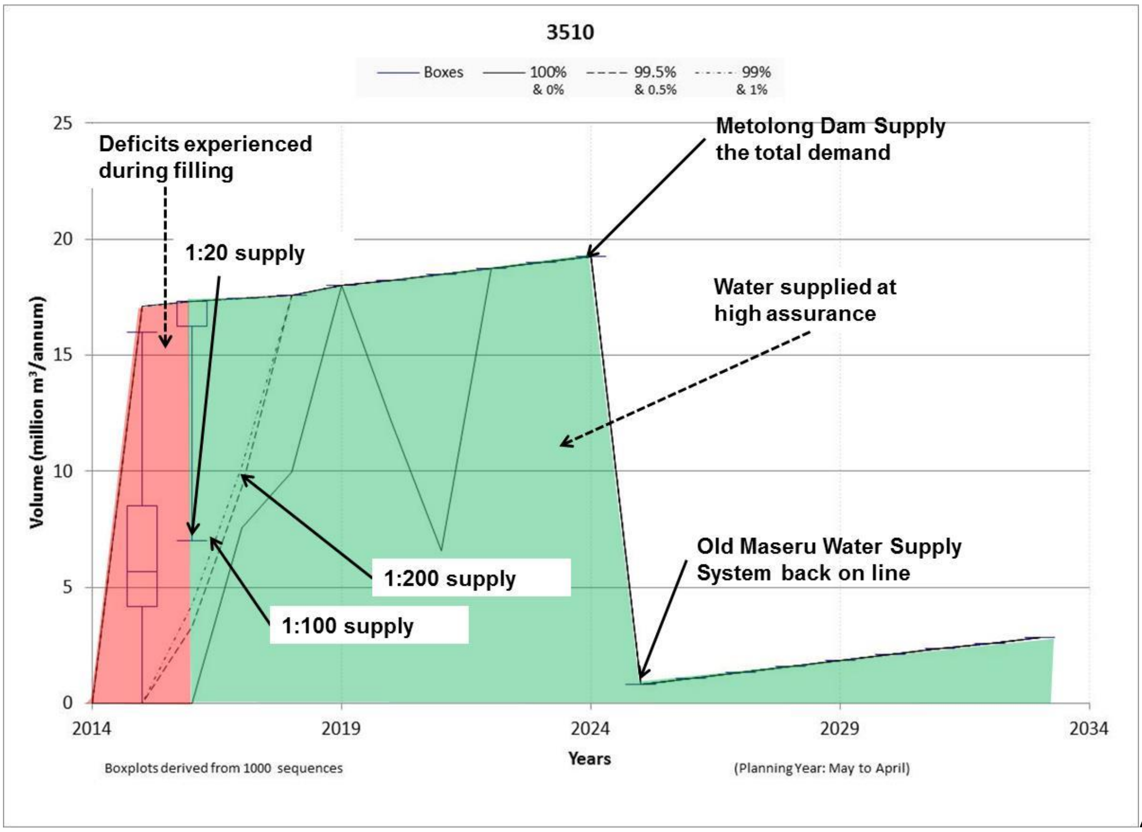
B

Figure 7-16: Metolong Dam storage projection for the previous (A) and current (B) Core Scenario

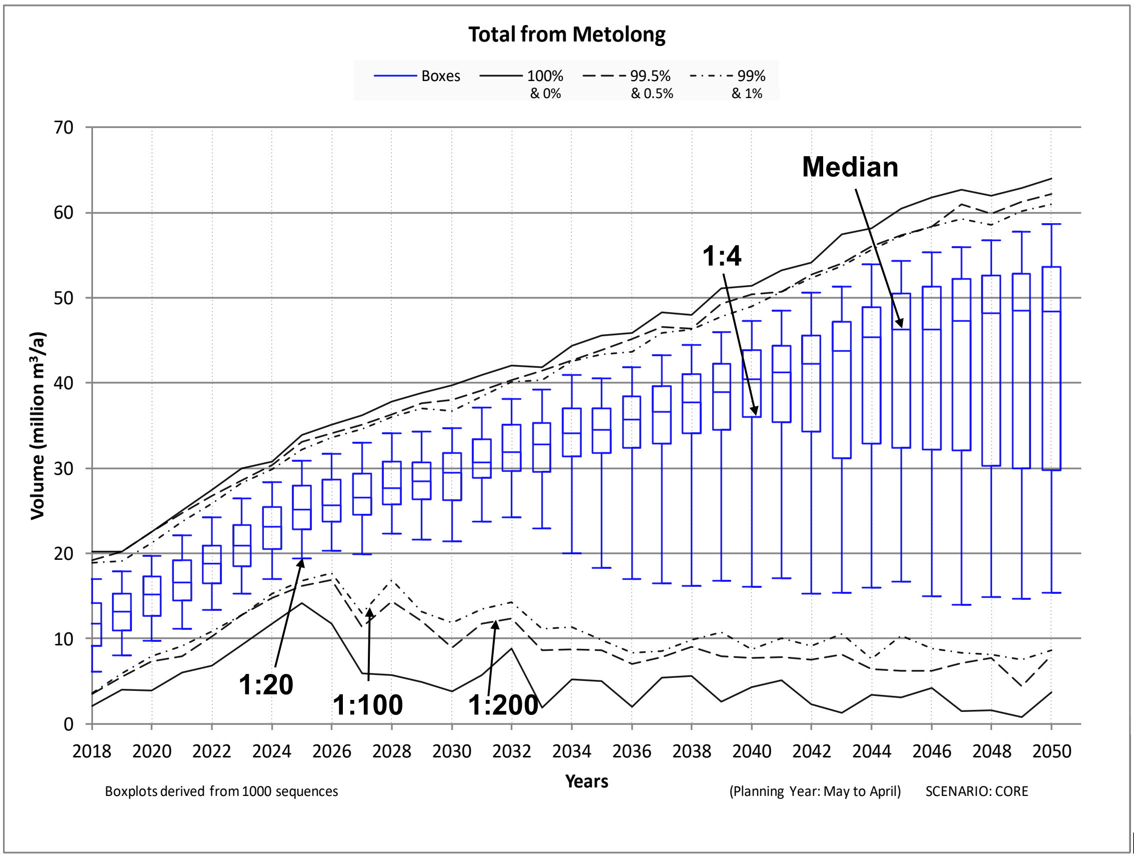
This rule dictated that Maseru will be supplied only from Metolong Dam until May 2025 to allow time for the maintenance and upgrading of the existing old Maseru Water Supply System. From 2025 onwards the old Maseru water system would be re-activated again and only the growth portion of the system demand was then supported from Metolong Dam (**Figure 7-16A**).

In reality this never realized, and Maseru is still being supplied from both resources. Due to water quality problems water is not anymore stored in the off-channel storage of Maqalika Dam. For the purpose of the updated Core Scenario, water was directly abstracted as first priority from the Mohokare (Caledon) River when available, and then supported from Metolong Dam. Metolong Dam is also utilized to support several smaller towns and villages in the area.

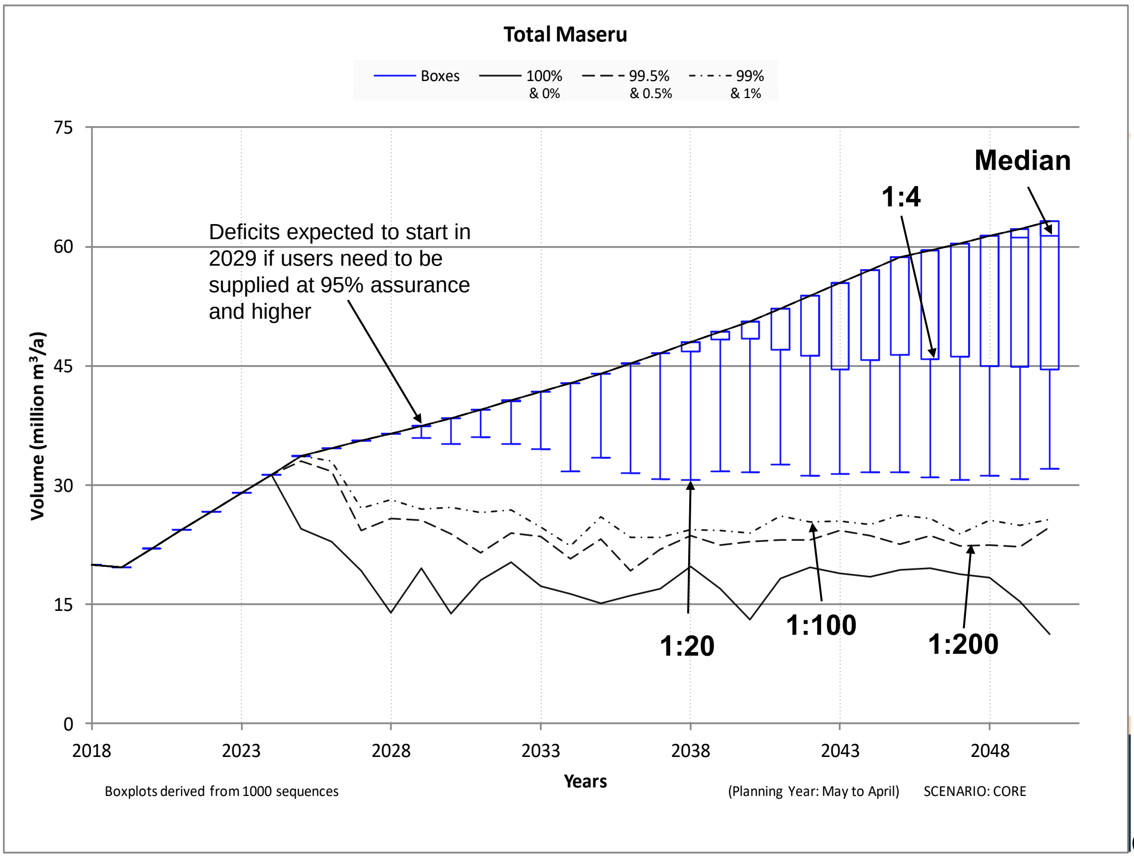
The water requirement projections used for this study is significantly higher than that used for the previous Core Scenario (**Figure 7-17a** versus **7-17b**). From the previous Core Scenario, a maximum of about 19 million m^3/a was supplied from Metolong to Maseru by 2024. The current Core Scenario analysis (**Figure 7-17b**) showed that the median supply from Metolong Dam at 2024 already reached about 24 million m^3/a and increased to almost 49 million m^3/a by 2050. The supply to Maseru (Current Core Scenario) already reached about 32 million m^3/a by 2024 and is supplied with water pumped directly from the Mohokare River and water from Metolong Dam. The difference in operating rule as well as the much higher water requirements resulted in a totally different behavior of Metolong Dam. (See **Figure 7-16A and 16B)**.



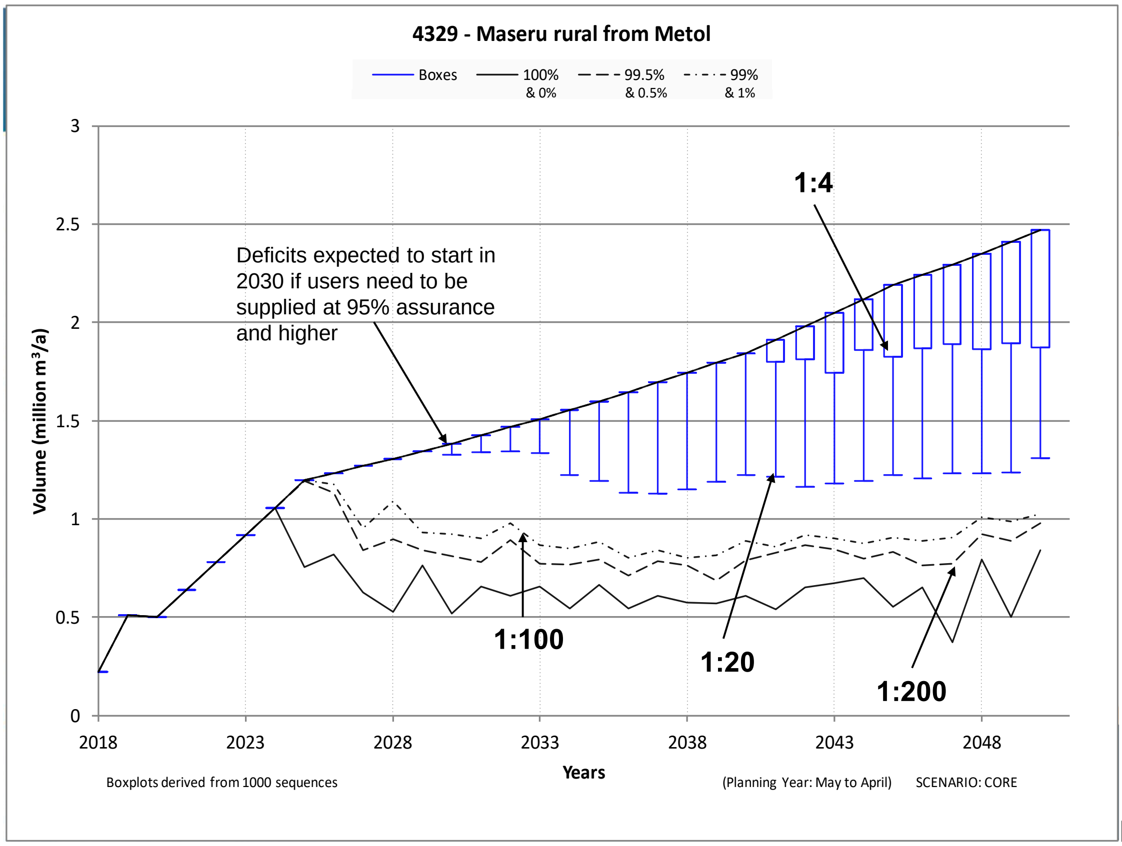
A


Total from Metolong
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Median
1:4
1:20
1:100
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

B


Total Maseru
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Median
1:4
Deficits expected to start in 2029 if users need to be supplied at 95% assurance and higher
1:20
1:100
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

C



D

Figure 7-17: Water supply from Metolong Dam for the previous (A) and current (B, C & D) Core Scenario

The previous Core Scenario analysis indicated that there is surplus water available in the system even beyond 2034, when both resources were used (**Figures 7-16A** and **7-17A**). The updated Core Scenario analysis results show quite the opposite, as it indicated that deficits in water supply will most probably start to occur from 2029/30 onwards (**Figure 7-16B, 7-17C & D**). This is mainly as result of the steep increase in water requirements from 2018 to 2025 as shown in **Figures 7-17C & D**.

Lesotho is planning for the development of three other Lesotho Lowland dams, Makhaleng, Hlotse and Ngoajane dams, to address the significant deficits in water supply in the Lesotho Lowlands. These three water supply schemes were not included in the previous Core Scenario. These water supply schemes do however form part of the updated Core Scenario, and the system analysis results from these schemes are given in **Section 7.3**.

Namibia sub-systems

Since the analysis of the previous Core Scenario Neckartal Dam was completed and started to inundate water in 2018. At the time of the analysis of the previous Core Scenario, it was expected that inundation of Neckartal Dam would already start in 2016, but in reality, it only happened two years later.

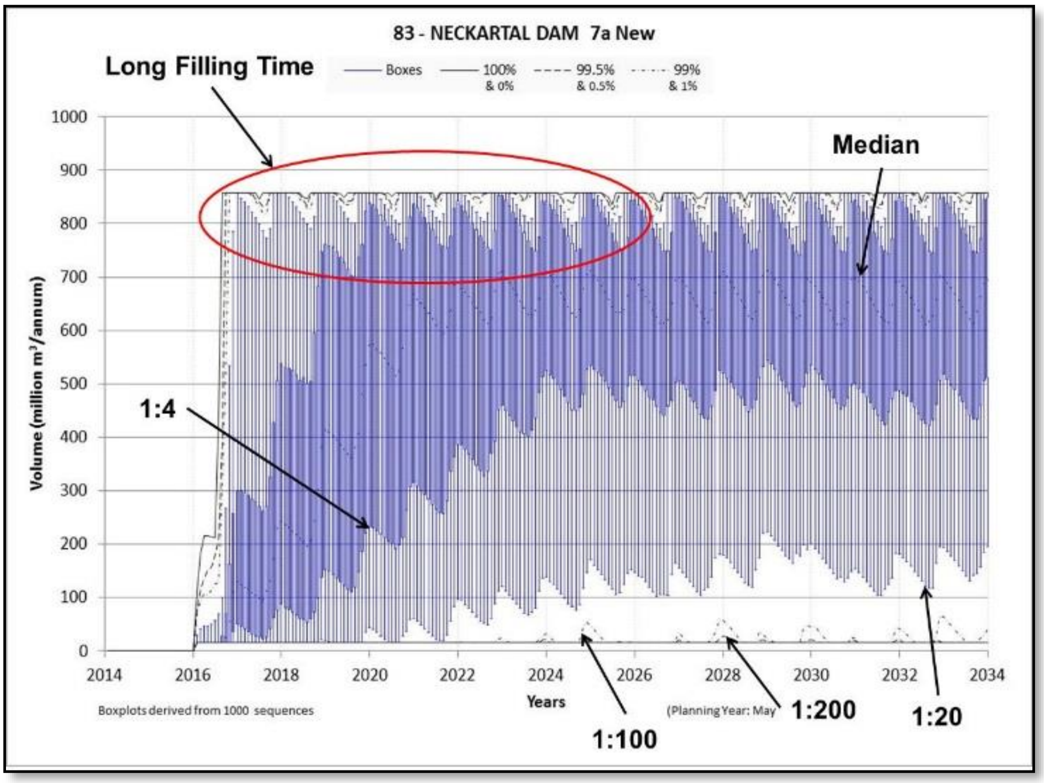
The previous and the current Core Scenario storage projections plots (**Figure 7-18**) show that Neckartal Dam take approximately 10 years to stabilize after inundation started. The dam is expected to seldom be full or spilling (approximately1:20 years). Once the dam stabilized, both projection plots show that the median storage will in general be between 600 to 700 million m^3. For the Current Core Scenario, it was noted that at the higher exceedance probabilities Neckartal Dam performed somewhat better than the previous Core Scenario. The cause of this difference was investigated, and it was found that one of the upstream dummy dams in the previous Fish River WRPM setup did not spill properly. This problem was not evident in the Current Core Scenario and resulted in a slight increase in the simulated inflows into Neckartal Dam.

There are two main differences to be noted between the previous and the current Core Scenario:

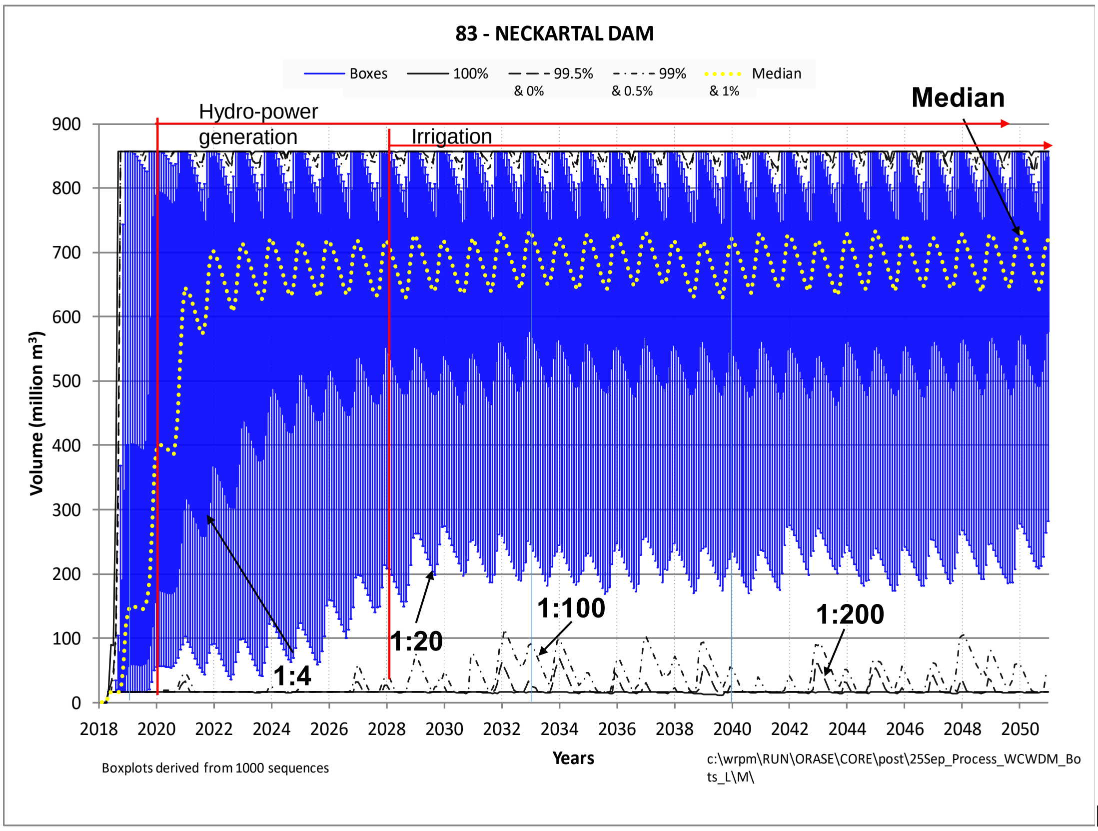
- In the Previous Core Scenario, the irrigation was phased in over a period of eight years, starting a year after inundation.
- For the Current Core Scenario, the irrigation abstractions started eleven years after inundation, thus in 2028/29. This is as result of the slow planning process for the irrigation developments which is currently well behind schedule. For the Current Core Scenario, the irrigation is phased in over a period of seven years.
- The Previous Core Scenario did not include hydro-power generation at Neckartal Dam. The Current Core Scenario do include hydro-power generation at the dam, which is expected to start in 2020. The volume released for hydro-power purposes was taken as 100 million m^3/a based on the installed turbine capacities. The water for the irrigation will be abstracted downstream of Neckartal Dam, with the maximum irrigation requirement expected to be about 90 million m^3/a. The remaining 10 million m^3/a will be used to support part of the EWR downstream of Neckartal Dam.

From **Figure 7-19** it is clear that the expected supply assurance to the irrigation has in fact improved when considering the Current Core Scenario, which is mainly as result of the slightly higher inflows into Neckartal Dam.

The release for hydro-power generation purposes (**See Figure 7-19C**) were in general supplied at fairly high assurances of 99%, after the filling period of the dam.

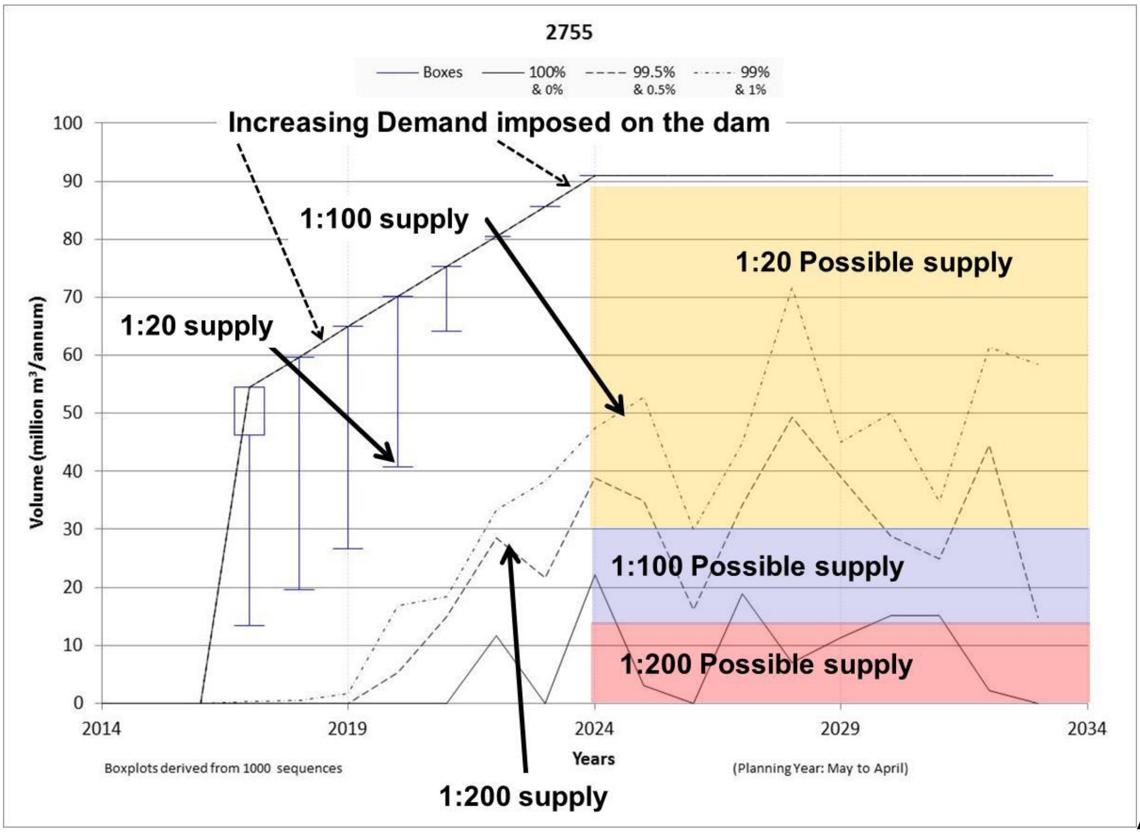


A

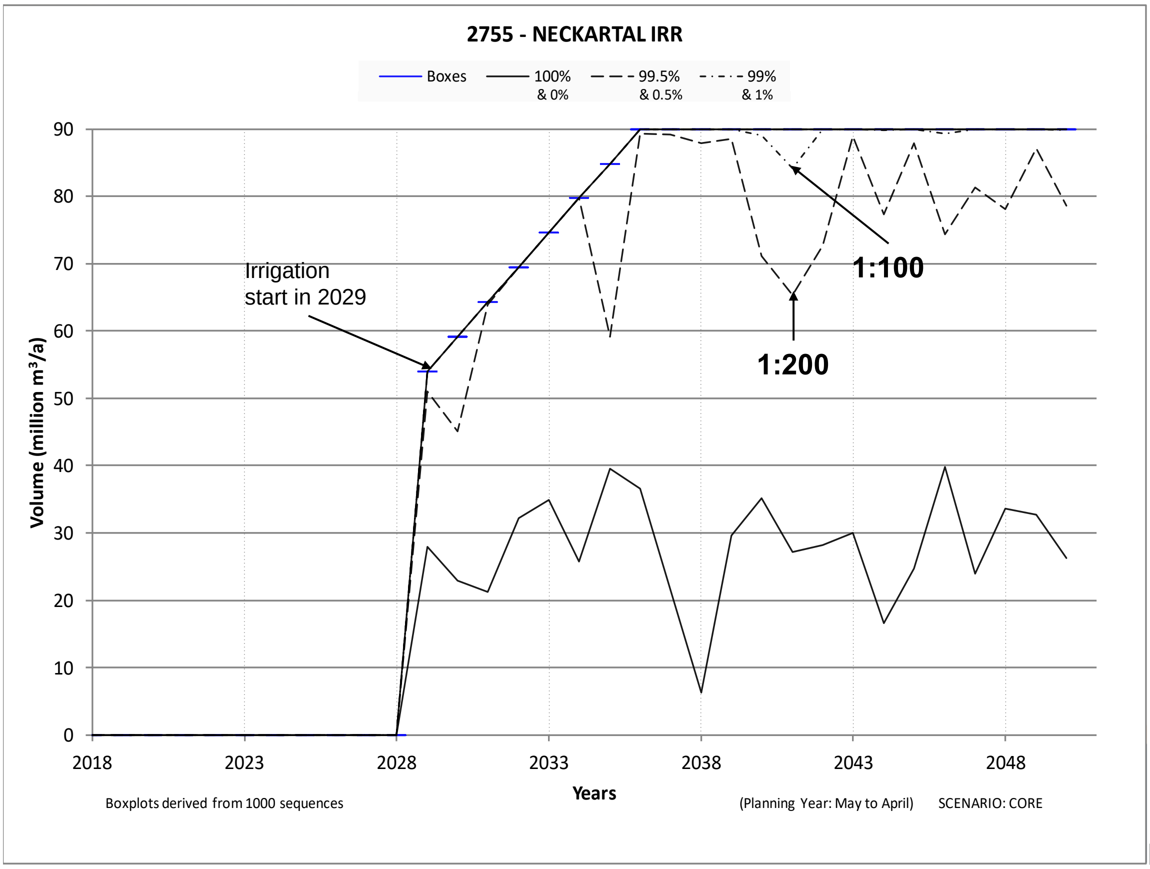


B

Figure 7-18: Neckartal Dam storage projection for the previous (A) and current (B) Core Scenario


2755
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Increasing Demand imposed on the dam
1:100 supply
1:20 supply
1:20 Possible supply
1:100 Possible supply
1:200 Possible supply
1:200 supply
Volume (million m³/annum)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)

A


2755 - NECKARTAL IRR
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Irrigation start in 2029
1:100
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

B

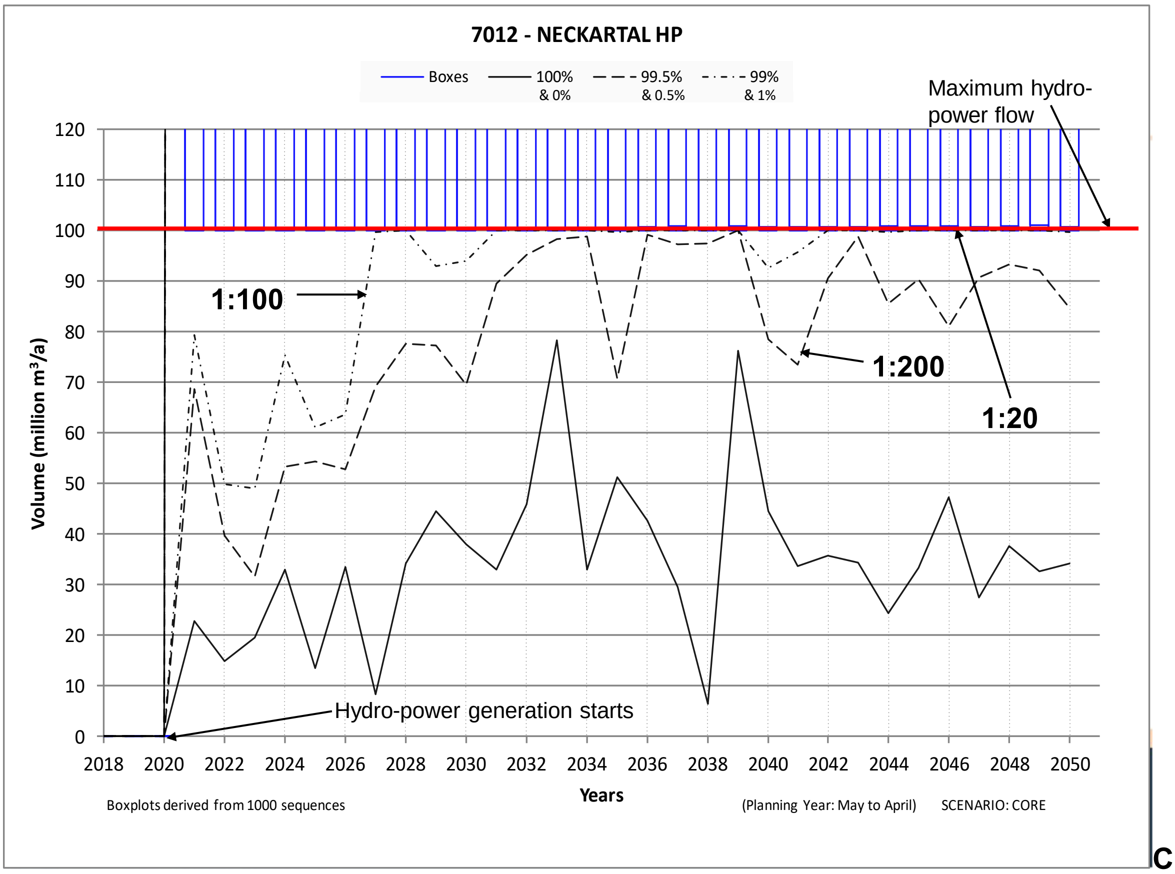


Figure 7-19: Water supply from Neckartal Dam for the previous (A) and current (B & C) Core Scenario

7.3 Results from new developments not included in the previous Core Scenario

7.3.1 Lesotho Botswana Transfer Project

The previous Core Scenario did not include the possible transfer from Makhaleng Dam located in Lesotho, to Gaborone in Botswana. In the ORASECOM Phase III reports this Transfer Scheme was mentioned as a future possibility, but no information was available at the time to be able to model the transfer scheme. Since then a Reconnaissance Study for this transfer scheme was completed followed by the Pre-feasibility Study Phase I (ORASECOM, 2019a), that was recently completed as part the current study. The Pre-feasibility Study Phase I recommended that two transfer volume options be taken forward to Phase II of the Pre-feasibility Study. These two options refer to as a high transfer of 186 million m^3/a from Makhaleng Dam and a low transfer of 97 m^3/a. These transfer volumes to Gaborone include water requirements for domestic use in Lesotho as well as for towns in the RSA along the pipeline route. Detail of the split in water to be supplied to the three countries is given in **Table 7-2**.

Table 7-2: Makhaleng Dam water requirement components

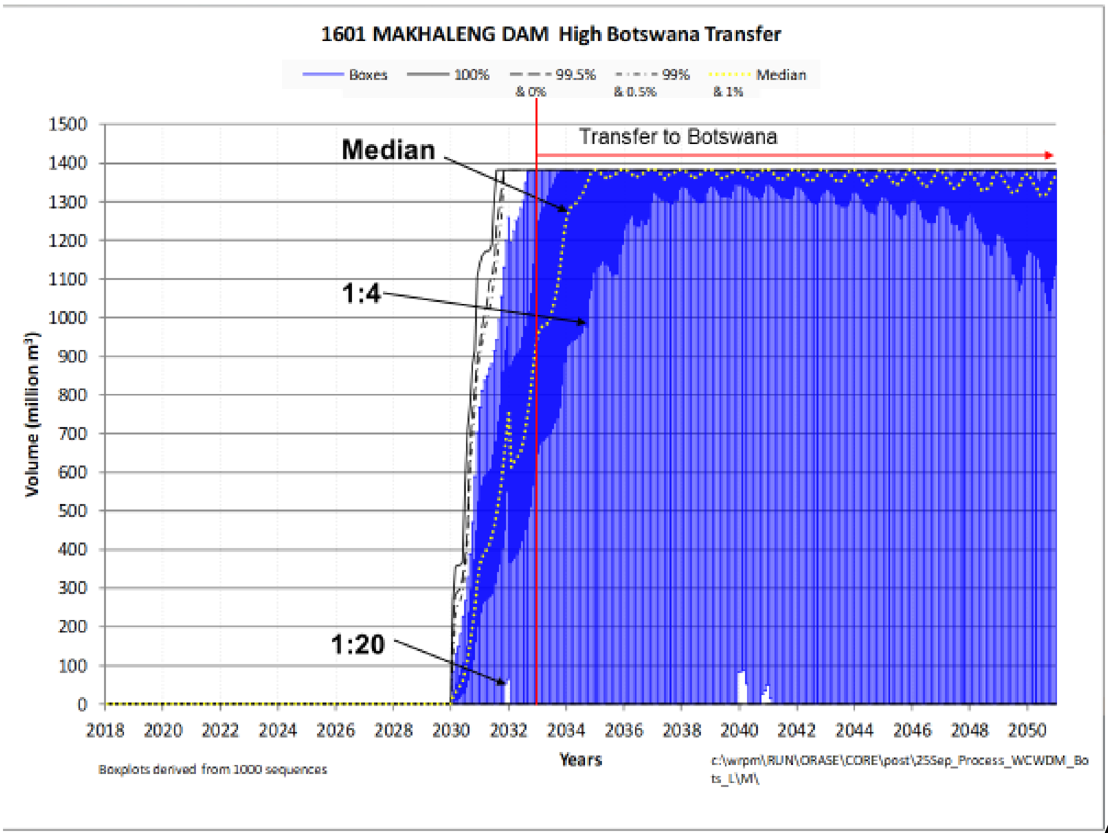
Description and Country	2050 Gross Low Augmentation Water Requirements (million m^3/a)	2050 Gross High Augmentation Water Requirements (million m^3/a)
Lesotho separate pipeline to Zone 7	13	13
Lesotho via the L-BWT pipeline	9	9
South Africa	20	20
Botswana	68	156
Total L-BWT Demand	**97**	**186**
Total Demand (incl. pipeline to Zone 7)	**111**	**199**
Lesotho Irrigation	40 or 77*	0
Total Demand (including irrigation)	**151 or 188***	**199**

Note: *- Irrigation when supplied at a lower assurance

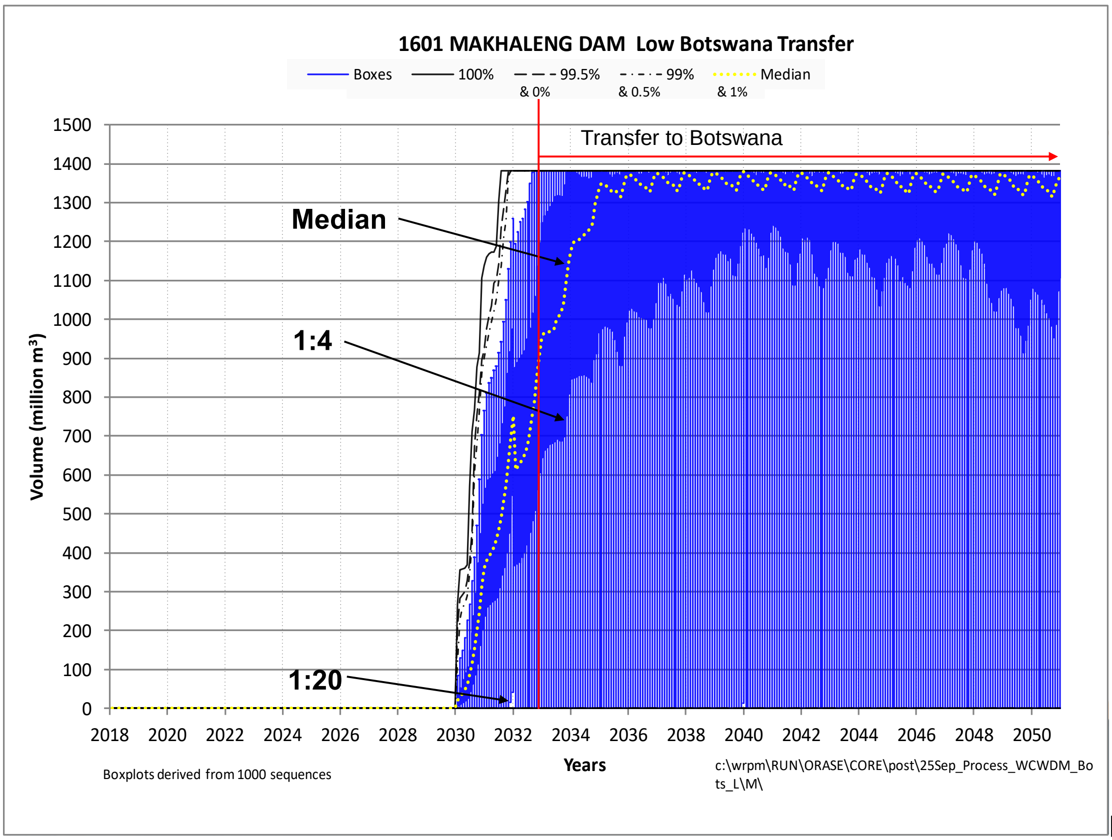
The Makhaleng Dam storage projection pots for the three options are given in **Figure 7-20**. A three MAR Makhaleng Dam at site S2 with a gross storage of 1 382 million m^3 was selected for the Core Scenario analysis, based on the fine dings from the Prefeasibility Phase 1 report (ORASECOM, 2019a) from the current study. Yield analysis results from **Section 8.3** showed that this 3 MAR Makhaleng Dam will result in a decrease in the yield available from the ORP system of 252 million m^3/a, if it is not used to also support the ORP.

The Core Scenario was thus set up to allow Makhaleng Dam to support the ORP, and the following supply priorities was allocated to the different users from Makhaleng Dam.

- Priority 1 – Supply to local Lesotho domestic use.
- Priority 2 – Supply water through the transfer system to Lesotho, RSA and Botswana for urban/industrial/mining use.
- Priority 3 – Releases into the river to supply irrigation developments in Lesotho.
- Priority 4 – Support to the ORP system when the ORP storage reaches very low levels.


1601 MAKHALENG DAM High Botswana Transfer
Boxes
100%
99.5% & 0%
99% & 0.5%
Median & 1%
Transfer to Botswana
Median
1:4
1:20
Volume (million m³)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050
Years
Boxplots derived from 1000 sequences
c:\wrpm\RUN\ORASE\CORE\post\25Sep_Process_WCWDM_Bots_L\M\

A


1601 MAKHALENG DAM Low Botswana Transfer
Boxes
100%
99.5% & 0%
99% & 0.5%
Median & 1%
Transfer to Botswana
Median
1:4
1:20
Volume (million m³)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050
Years
Boxplots derived from 1000 sequences
c:\wrpm\RUN\ORASE\CORE\post\25Sep_Process_WCWDM_Bots_L\M\

B

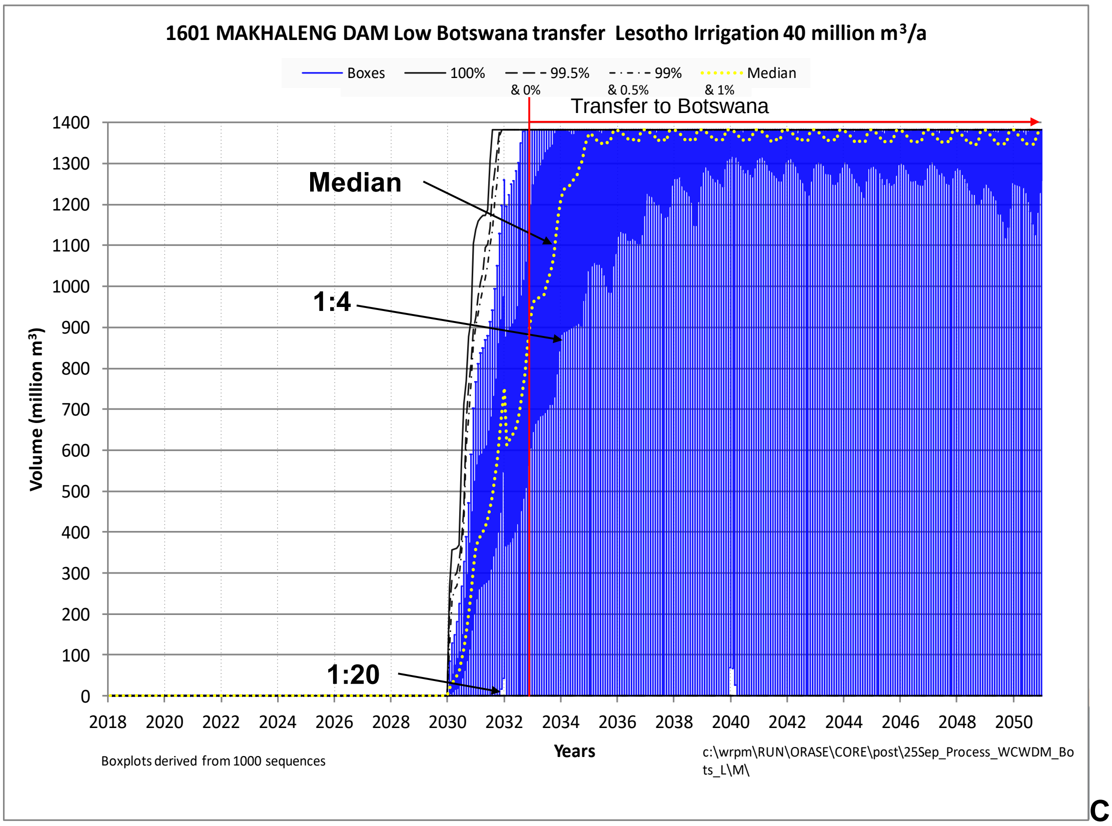
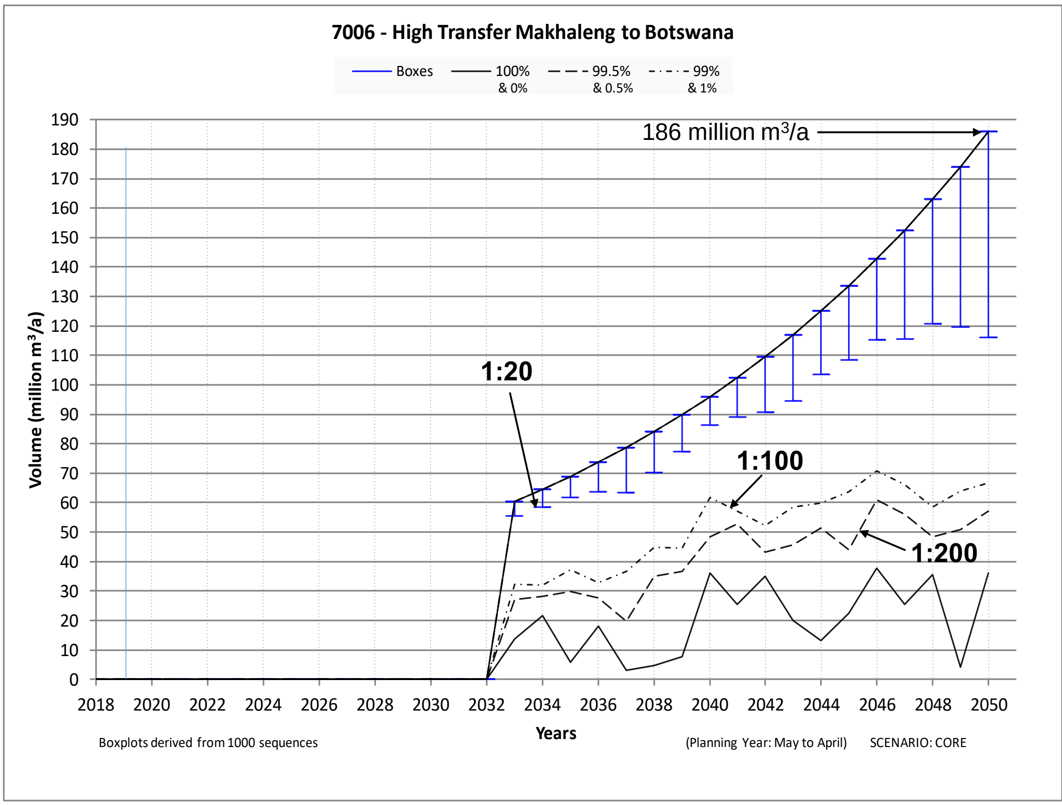


Figure 7-20: Makhaleng Dam storage projections for the high & low Botswana transfers

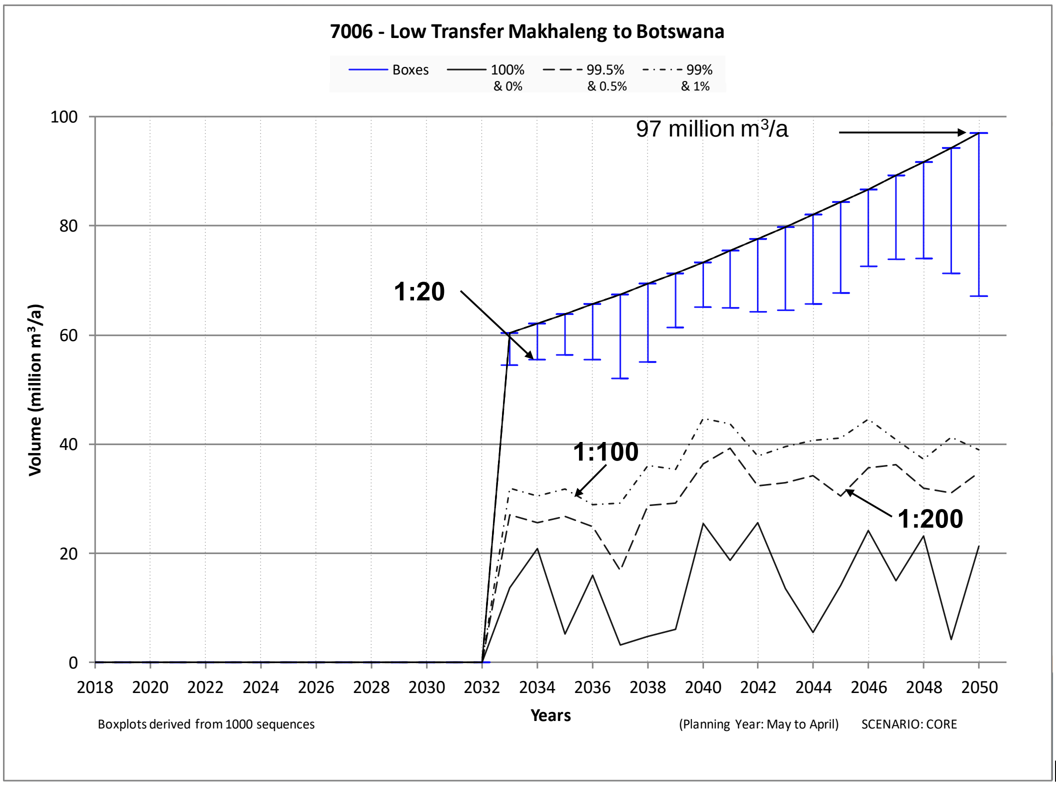
The transfer to Botswana and RSA will start in 2033 as the transfer pipeline will only be completed about 3 years after the completion of the Makhaleng Dam. When the high transfer to Botswana is considered, the yield available from Makhaleng Dam will not be sufficient to also support irrigation developments in Lesotho. The low Botswana transfer will allow for approximately 40 million m^3/a for irrigation development in Lesotho. As irrigation can in general be supplied at lower assurance levels than the supply to urban/industrial users, it is possible to increase the irrigation to about 77 million m^3/a.

The total demand imposed on Makhaleng Dam for the low and high transfer to Botswana is almost similar at 188 million m^3/a and 199 million m^3/a when the higher irrigation requirement is considered. The main difference between the two options is that although the Botswana transfer for both the low and high option start relative low at 60 million m^3/a at 2033 it increases over time to reach the full transfer volume 97 million m^3/a and 186 million m^3/a by 2050 for the two transfer options respectively (See **Figure 7-21A & B**).

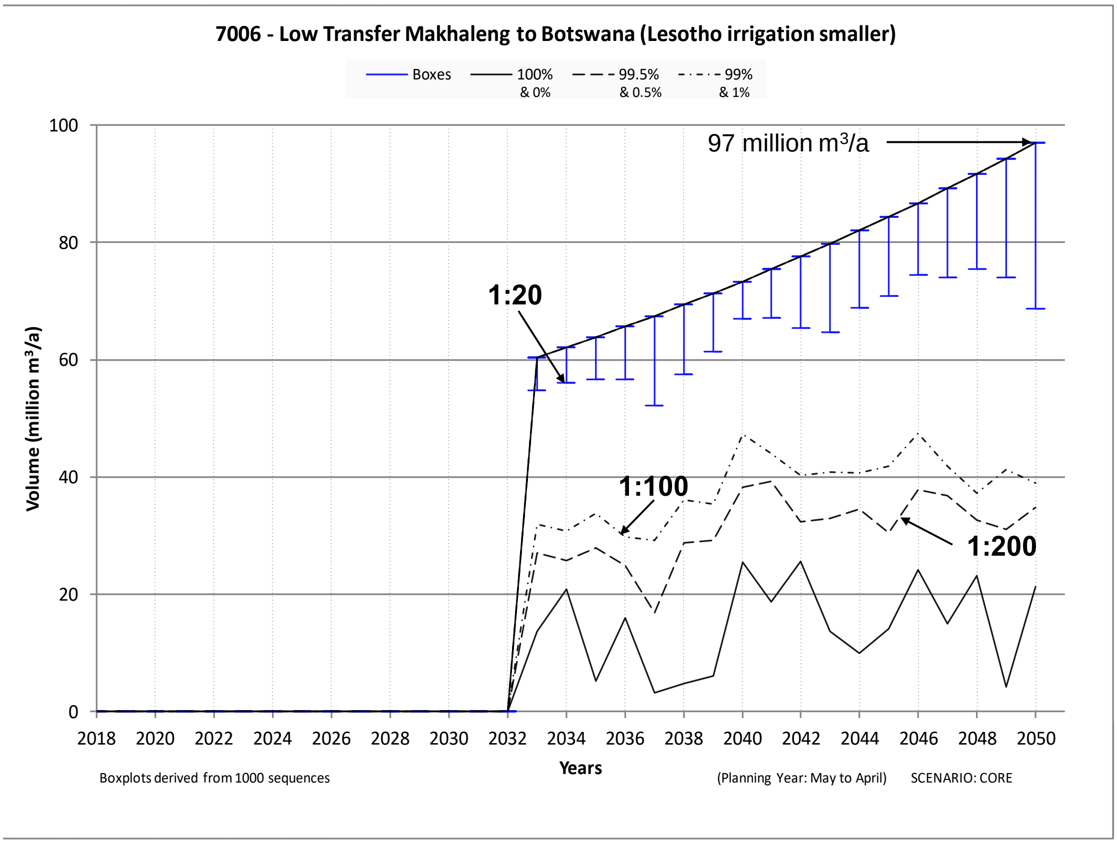
From the Makhaleng Dam storage projection plots it is evident that the dam for all three options analyzed, will for most of the time be relative full as indicated by the median storage projection line. Typical 1:20 year droughts can however lead to a relative quick depletion of the storage in Makhaleng Dam, as the ORP requires high volumes of support during these drought periods.


7006 - High Transfer Makhaleng to Botswana
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
186 million m³/a
1:20
1:100
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

A


7006 - Low Transfer Makhaleng to Botswana
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
97 million m³/a
1:20
1:100
1:200
Volume (million m³/a)
Years
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

B



C

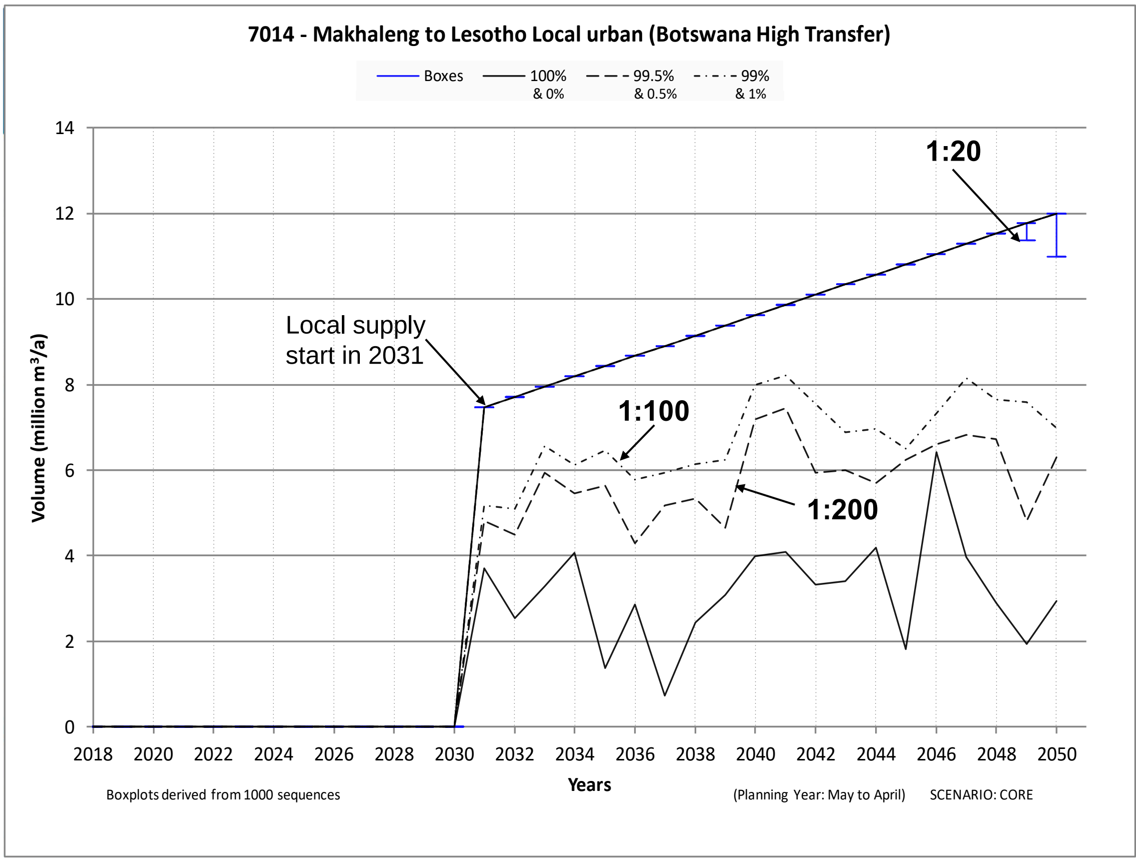
Figure 7-21: Supply of the transfer volume from Lesotho to Botswana

The option with the low Botswana transfer and high irrigation development results in the lowest storages over the projection period. This is due to the Botswana transfer that only reach its full amount by 2050, while it was accepted that the irrigation development will be fully developed about three years after the completion of the dam.

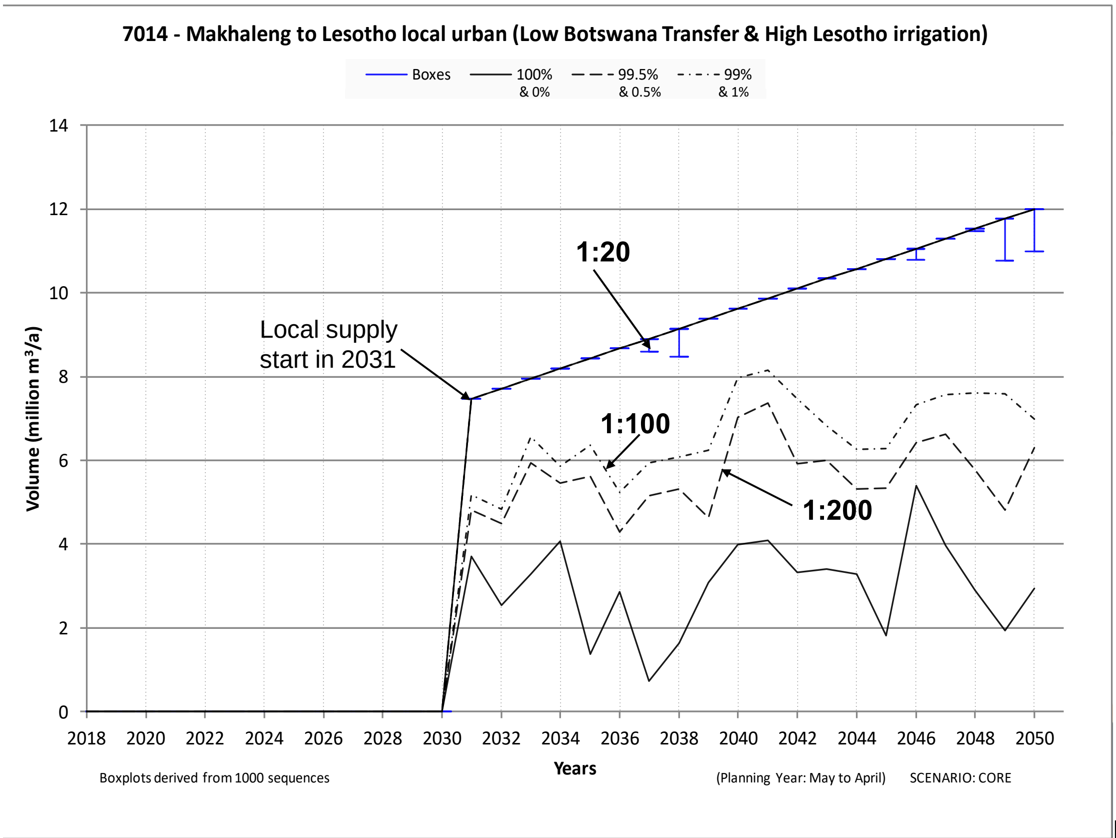
The high Botswana transfer option shows the lowest assurance of supply (**Figure 7-21**). In general, for all three the options considered, the assurance of supply is too low for supply to urban/industrial users as deficits at 95% (1: 20 year) is not acceptable for urban/industrial use.

The supply assurance to the local Lesotho domestic users (first priority users) in general appears quite acceptable (**Figure 7-22**) and deficits for the high Botswana Transfer option only start to occur close to the end of the analysis period by 2049. For the low Botswana transfer option, the supply to the Lesotho local domestic use is slightly worse, but still acceptable.

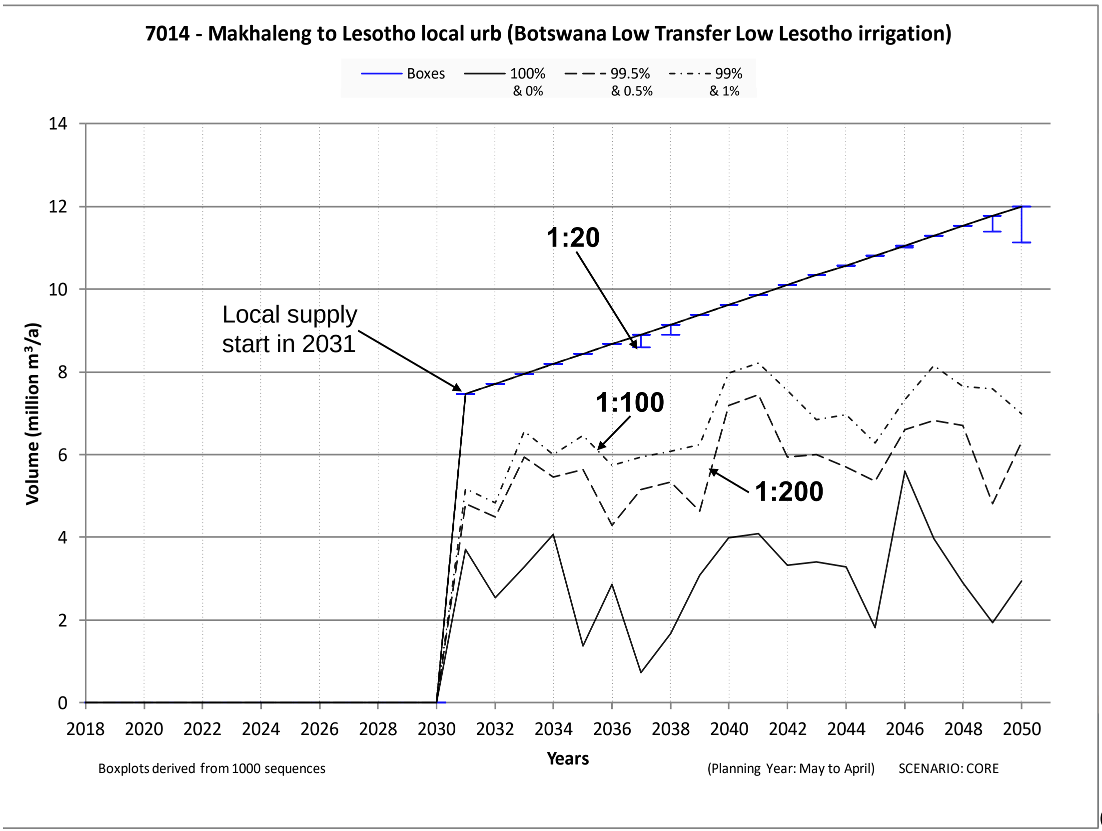
The water supply to irrigation users in Lesotho (**Figure 7-23**) is for both the high and low irrigation development options acceptable, although better for the low development option. The required assurance of supply for irrigation use depends on the type of crops irrigated as well as what is regarded as acceptable from the Lesotho Government perspective and the related users to ensure an economic viable irrigation development/scheme.


7014 - Makhaleng to Lesotho Local urban (Botswana High Transfer)
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Volume (million m³/a)
Years
Local supply start in 2031
1:20
1:100
1:200
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

A

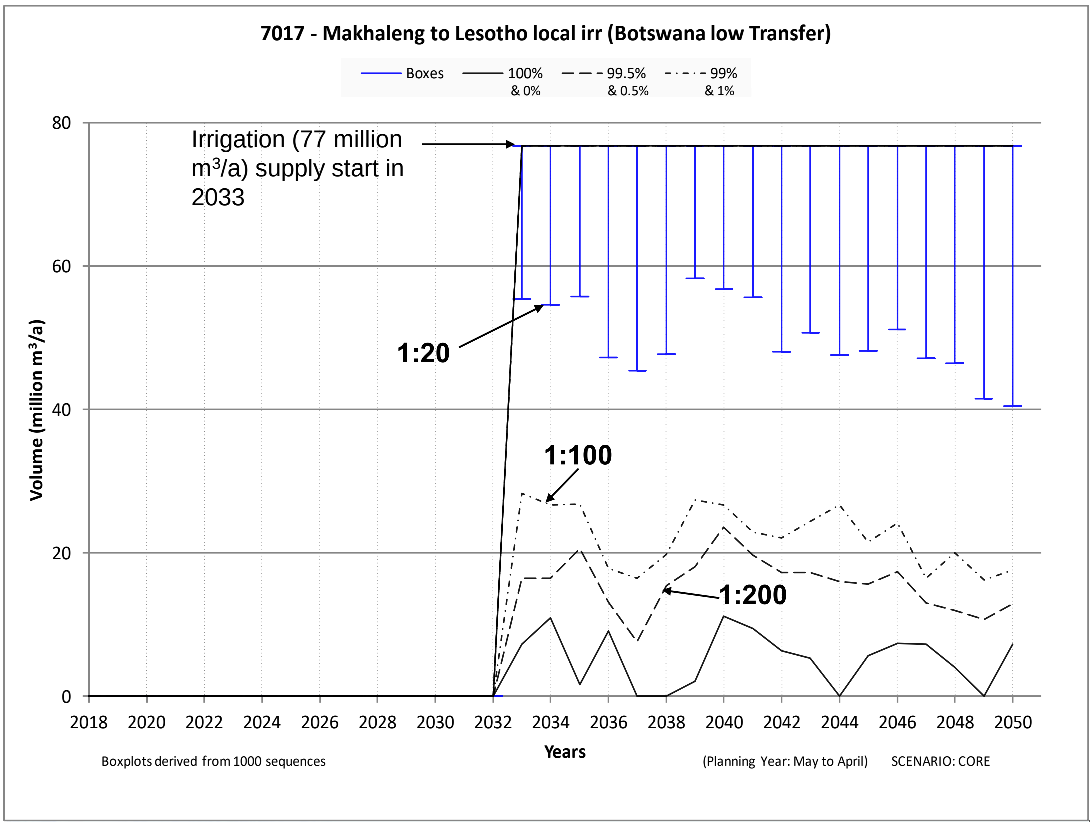

7014 - Makhaleng to Lesotho local urban (Low Botswana Transfer & High Lesotho irrigation)
Boxes
100% & 0%
99.5% & 0.5%
99% & 1%
Volume (million m³/a)
Years
Local supply start in 2031
1:20
1:100
1:200
Boxplots derived from 1000 sequences
(Planning Year: May to April)
SCENARIO: CORE

B



C

Figure 7-22: Water supply to local Lesotho domestic water use



A

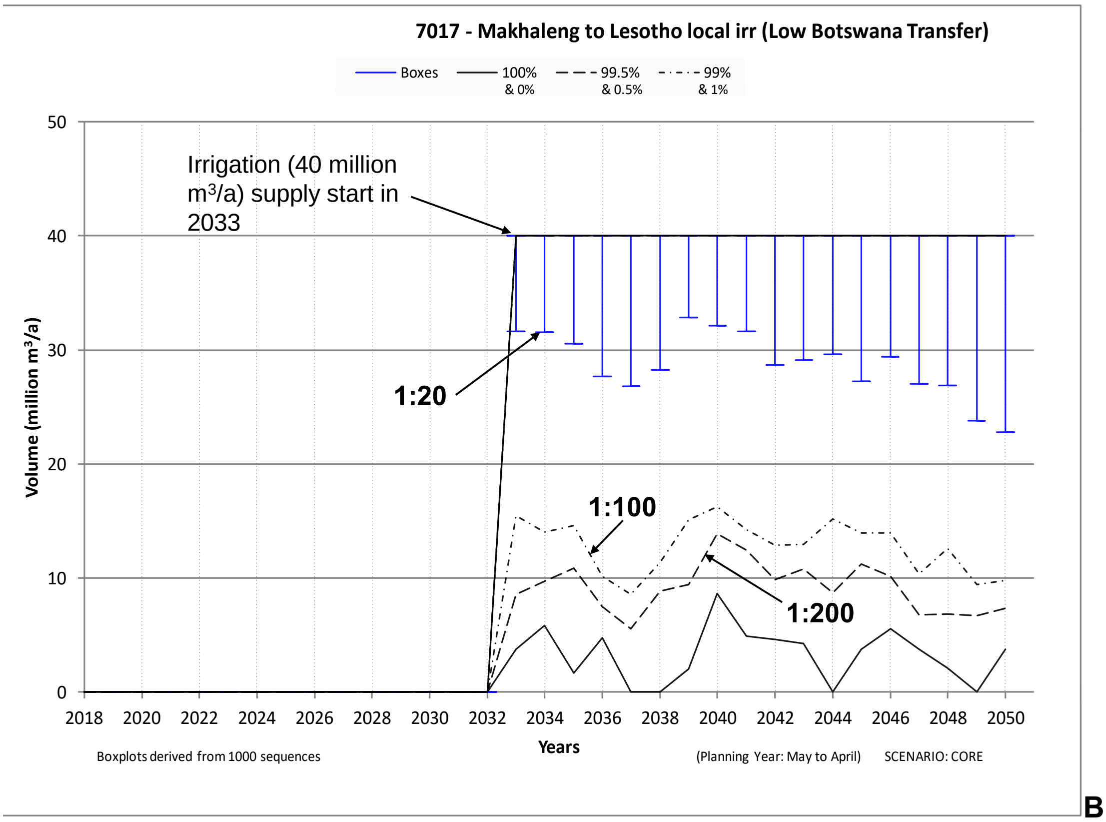


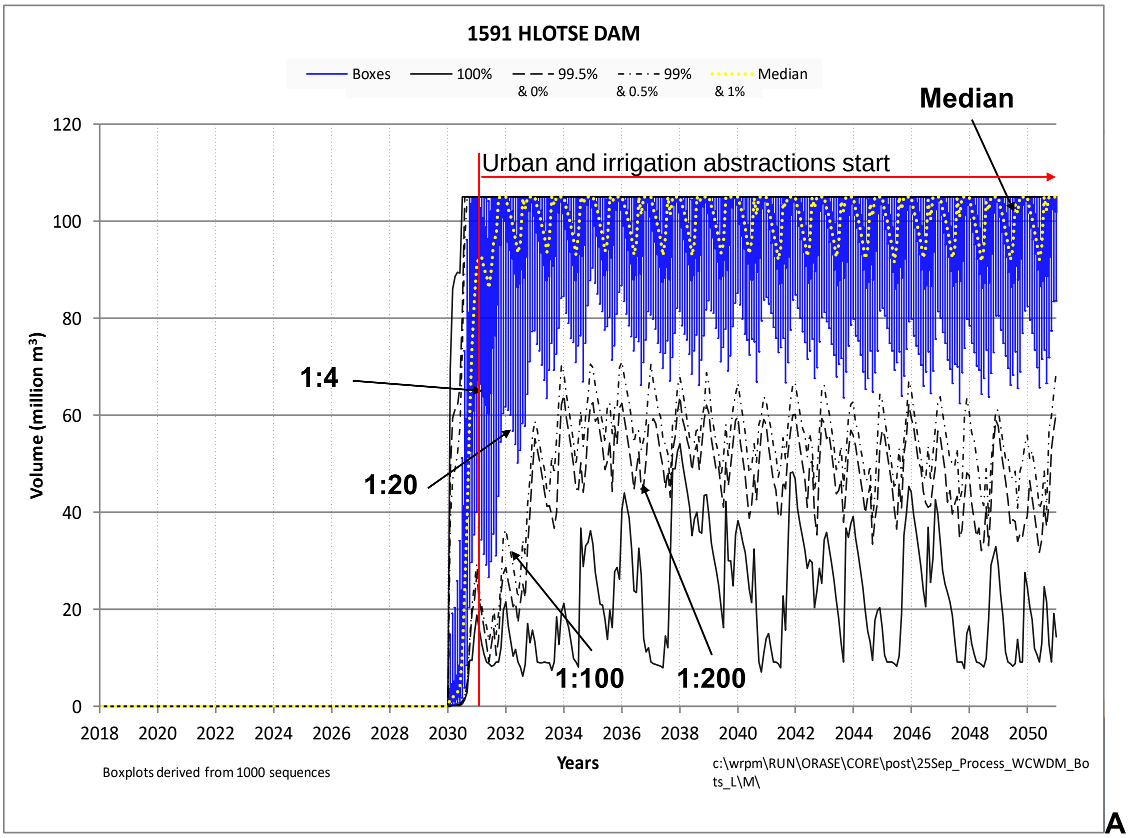
Figure 7-23: Supply to Lesotho irrigation supplied from Makhaleng Dam.

It is suggested to include some changes to the Makhaleng operating rule, to improve the assurance of supply, specifically to the users receiving water from the Lesotho Botswana transfer.

7.3.2 Hlotse Water Supply Scheme in Lesotho Lowlands

The possible future Hotse Dam is located in the Hlotse River, a tributary of the Mohokare (Caledon) River. Based on work carried out in the Feasibility Study of the of the Lesotho Lowlands Water Supply Scheme, the recommended gross storage for Hlotse Dam is given as 105 million m^3. According to current planning Hlotse Dam will be used to supply water for domestic purposes to towns and rural areas as well as for irrigation in the Hlotse River catchment upstream and downstream of the dam. Although the upstream irrigation will not get water directly from the dam, it will impact on the yield available from the dam.

The storage projection for Hlotse Dam is given in **Figure 7-24A**. The storage projection shows that the dam is utilized fairly well, but not in full, even by the end of the projection period. From the median projected storage, it’s evident that the dam will most of the time be relative full and do not empty even during a 1:200-year drought.



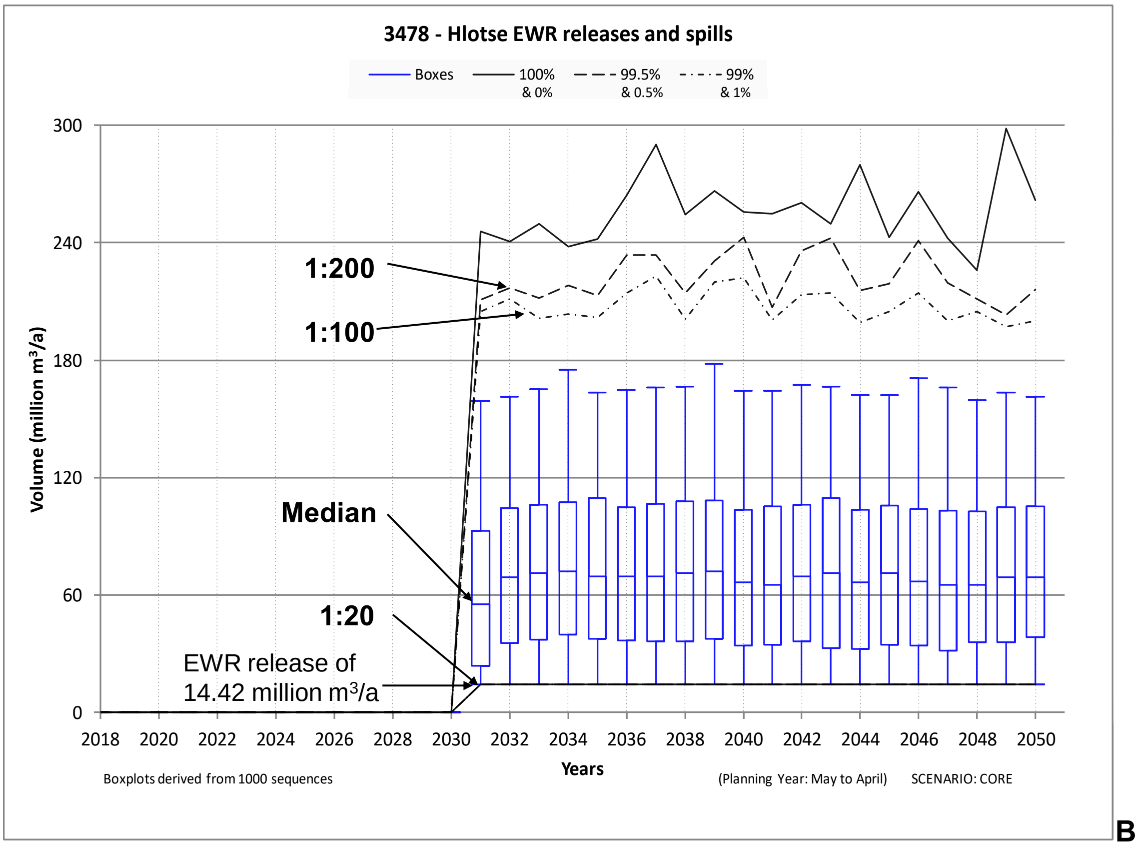
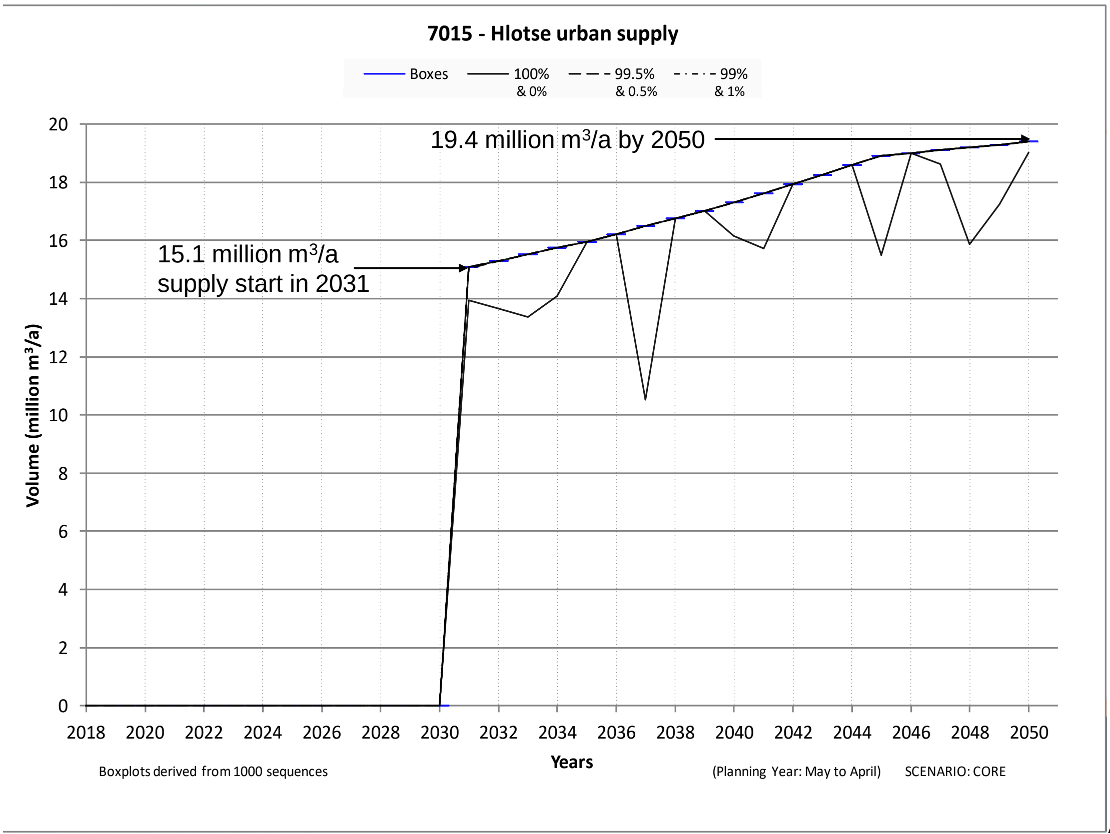


Figure 7-24: Hlotse Dam storage projection and EWR releases and spills

Based on work done in the Lesotho Lowlands Feasibility Study (SMEC 2017) the EWR imposed on Hlotse Dam was taken as 14.42 million m^3/a (See **Section 8.2** for more detail) The monthly distribution of the annual EWR target value was based on the distribution of the average monthly natural historic flow of the related flow sequence just upstream of Hlotse Dam.

The urban/rural domestic and irrigation supply from Hlotse Dam is shown in **Figure 7-25**. Both the water supply projections reveal that the supply to these users are very good, as it is supplied at much higher assurances than normally required. There is thus additional yield available from Hlotse Dam that can be used to support the current sub-systems along the Mohokare/Caledon River even as far downstream as the ORP.

Leribe is one of the main Lesotho towns that will be in future supplied from Hlotse Dam. The current supply to Leribe from river runoff is given in **Figure 7-26**. From this projection plot it is evident that Leribe can only be supplied at an acceptable assurance level until about 2021. From then onwards deficits can be expected on a regular basis at the 95% exceedance probability. Hlotse Dam is expected to be in place by 2030 at the earliest.



A

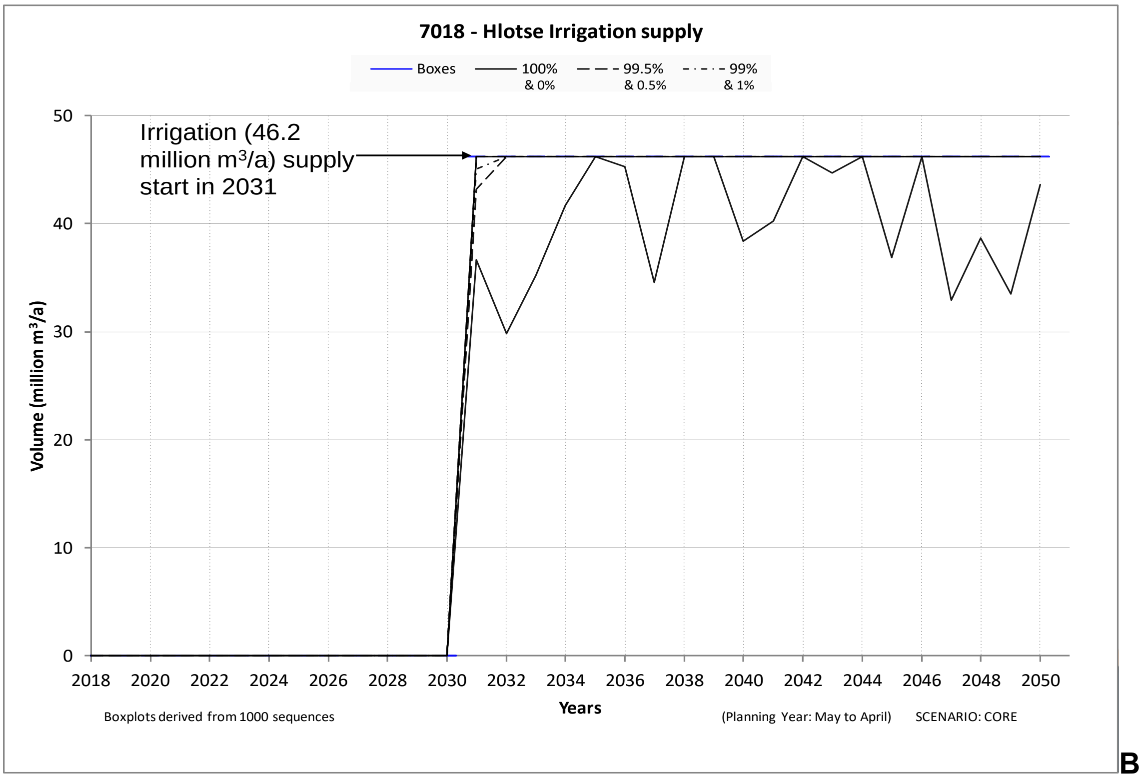


Figure 7-25: Supply to users supplied from Hlotse Dam

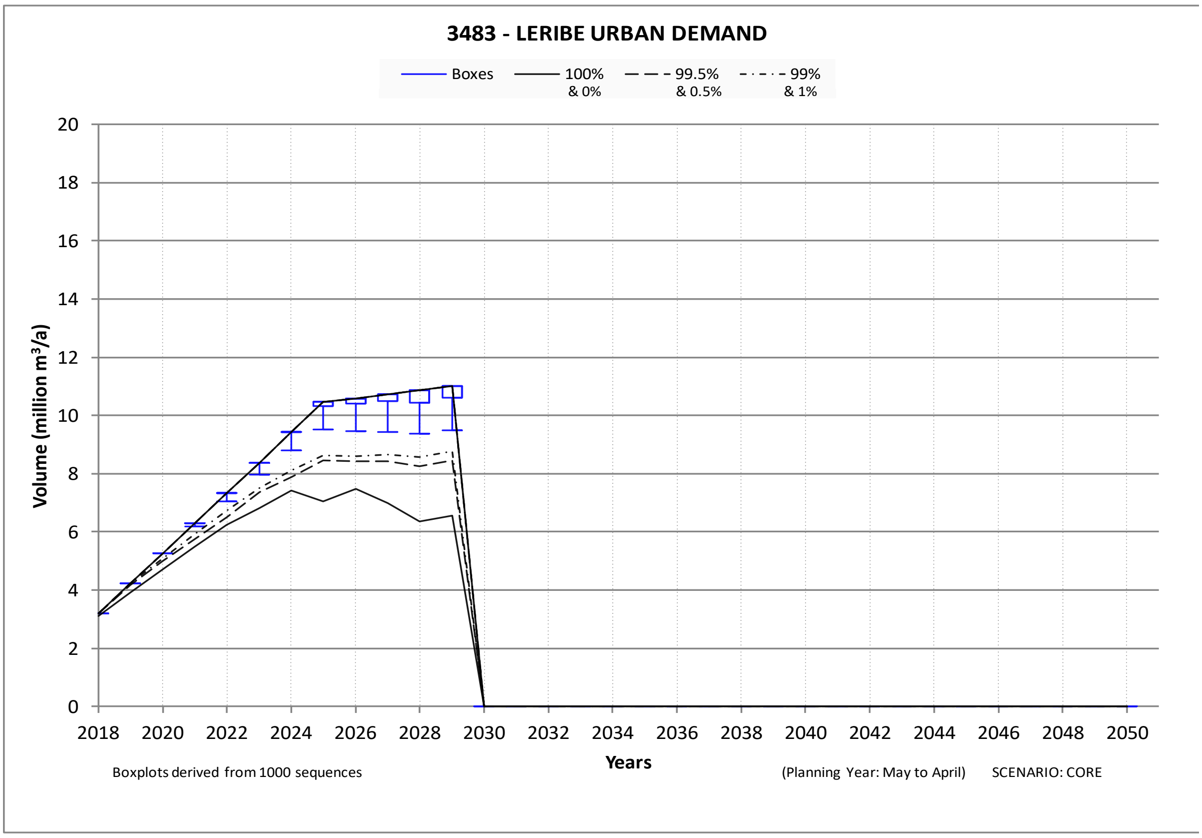


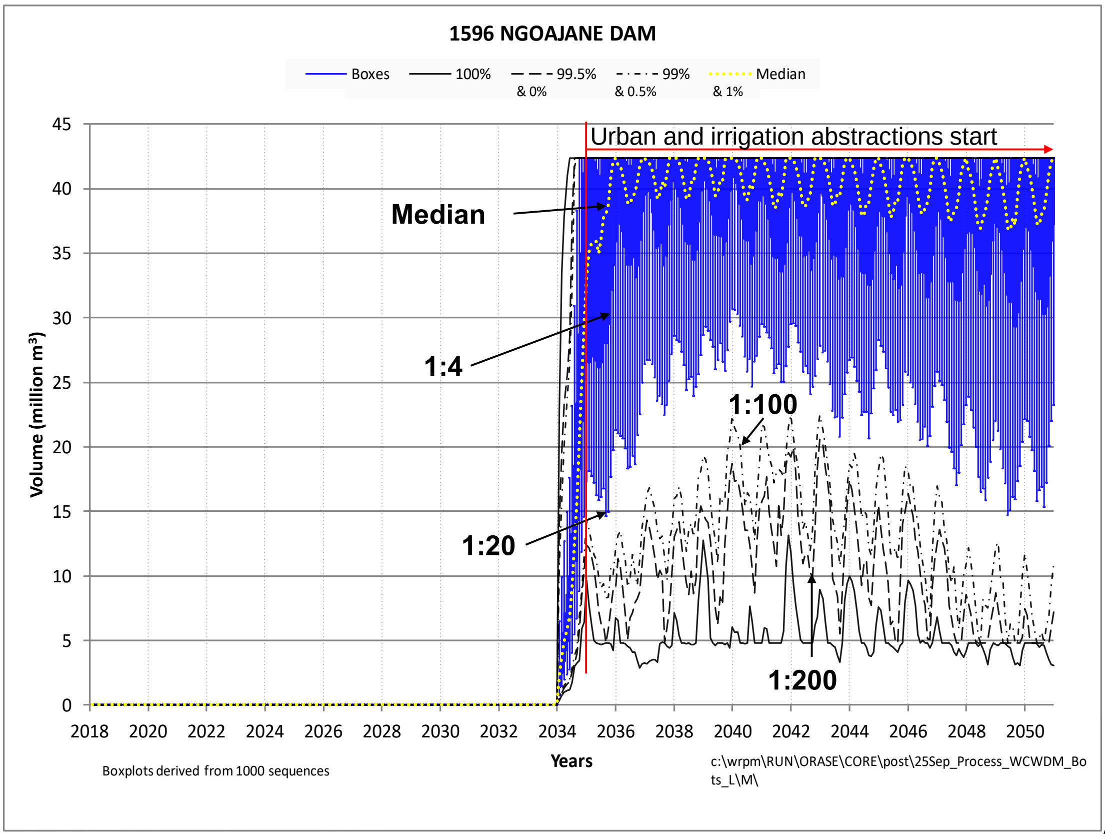
Figure 7-26: Water supply to Leribe directly from the river

7.3.3 Ngoajane Water Supply Scheme in Lesotho Lowlands

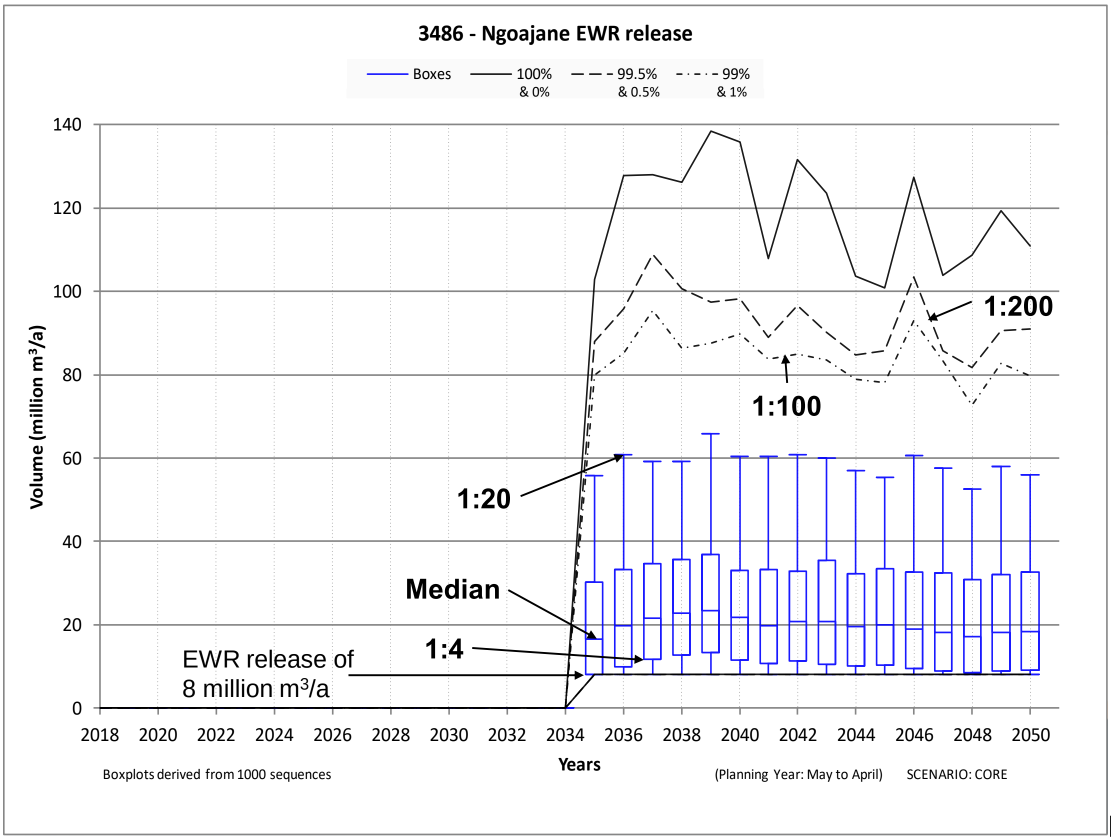
The possible future Ngoajane Dam is located just north of Hlotse Dam in the Hololo River, a tributary of the Mohokare/Caledon River. Ngoajane Dam is a much smaller dam with a net storage capacity of 36 million m^3. Similar to Hlotse Dam, Ngoajane Dam will be used to support irrigation as well as domestic water use. From the data given in the Feasibility Study of the of the Lesotho Lowlands Water Supply Scheme (SMEC 2017) the EWR to be imposed on Ngoajane Dam was taken as 8.02 million m^3/a (See **Section 8.2**) and distributed into monthly flows based on the distribution of the average monthly flows from the historic natural flow record.

The Ngoajane Dam storage projection, EWR releases and spills over the simulation period are shown in **Figure 7-27**. The storage projection plots show that the dam is well utilized over the simulation period, in particular close to the end of the simulation period. The EWR releases were fully supplied over the simulation period (**Figure 7-27B**).

The urban and rural domestic water requirements (**Figure 4-28A**) were well supplied over the projection period at assurance levels higher than that in general required for domestic supply.

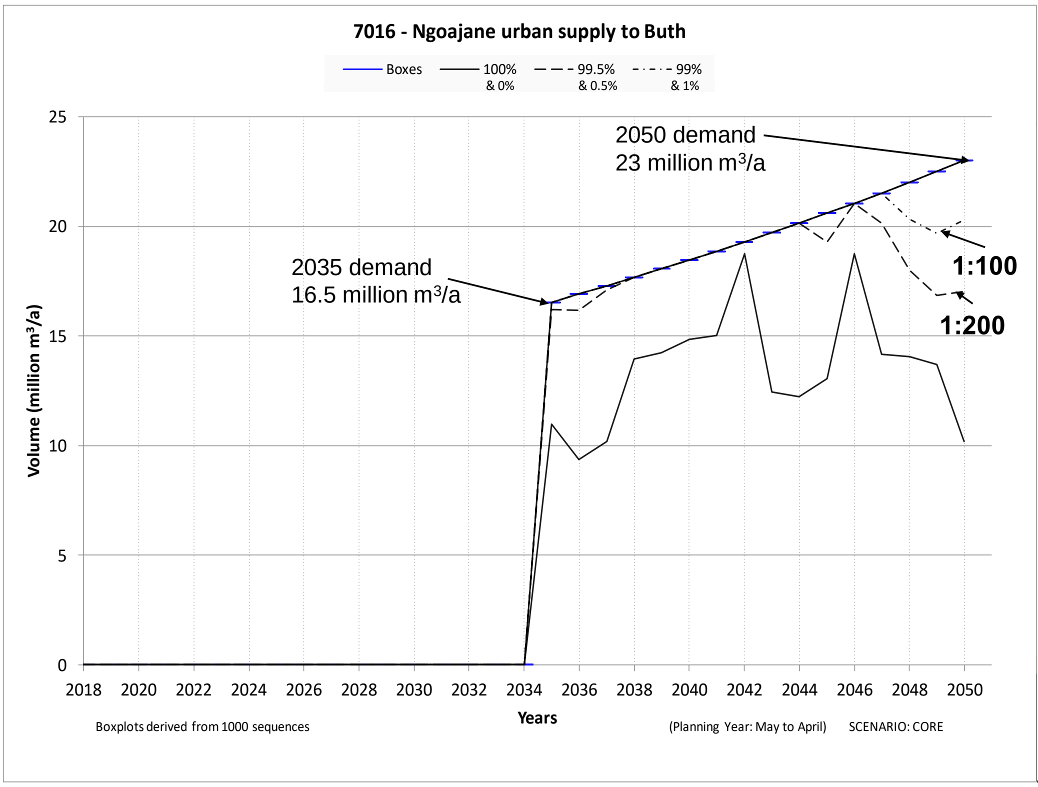


A

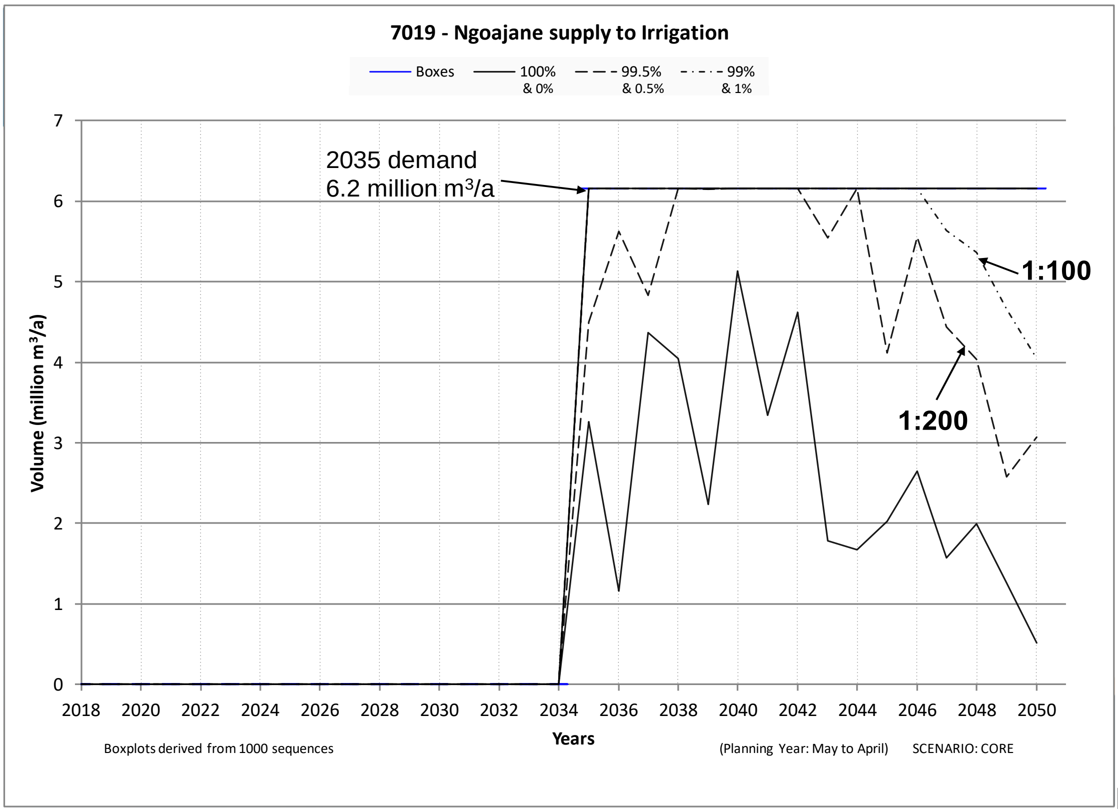


B

Figure 7-27: Ngoajane Dam storage projection and EWR releases and spills



A



B

Figure 7-28: Supply to users supplied from Ngoajane Dam

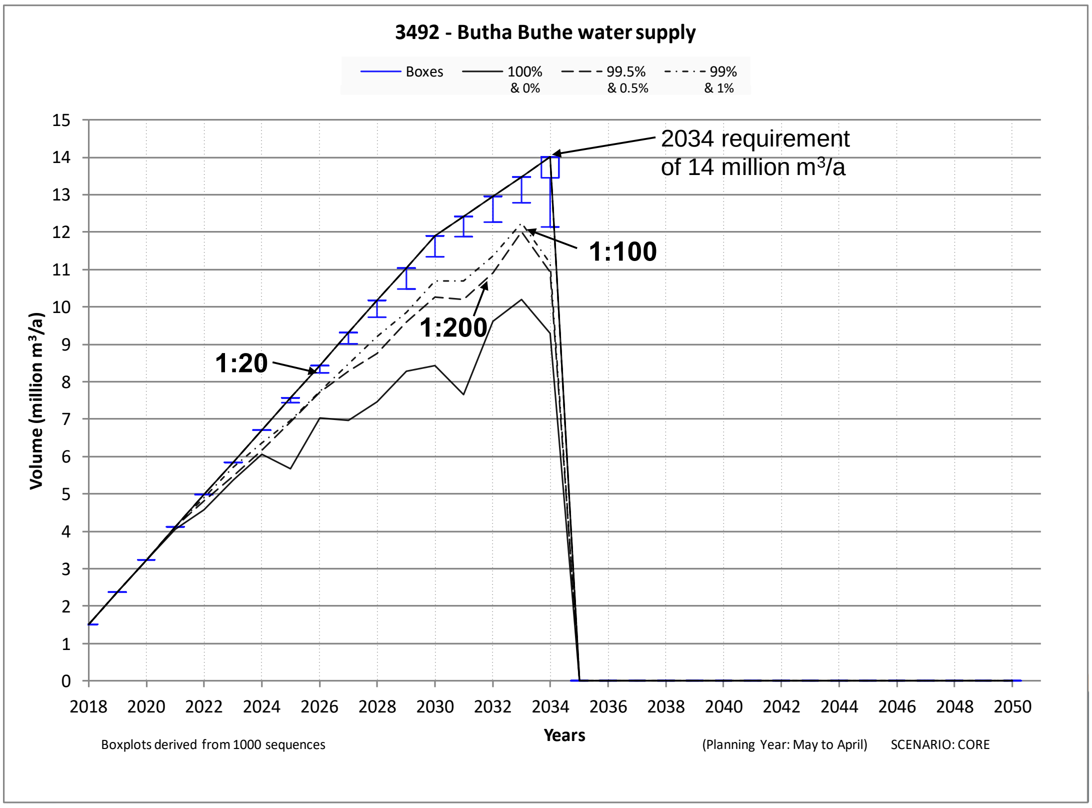


Figure 7-29: Water supply to Butha Buthe mainly from river runoff abstractions

The irrigation requirements were also supplied well above the required assurance levels (**Figure 7-28B**).

Butha Buthe is one of the larger Lesotho towns that will in future be supplied from Ngoajane Dam. Currently it is mainly supplied from runoff river abstractions. The simulated results showed that the towns can still be reasonably well supplied but deficits will start to increase over time, and a more stable resource such as Ngoajane Dam will be required in future.

7.4 Core Scenario Sensitivity analyses

Several core scenario sensitivity analyses were carried out around key components in the Orange Senqu System, specifically for those having uncertainties regarding assumptions or decisions to be made. The following sensitivity analyses were undertaken:

- Exclude water conservation and water demand management in some of the key large water supply systems. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the final reserve to be imposed on the ORP. The Preliminary Reserve already approved by DWS RSA will then be in place from 2022 to the end of the analysis period. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the option to utilize the Lower Level Storage in Vanderkloof Dam due to its impact on hydro-power generation from Vanderkloof Dam. The Core Scenario with the high Lesotho Botswana transfer was used as basis for this analysis.
- Exclude the future Hlotse and Ngoajane water supply systems from the Core Scenario with the high Lesotho Botswana transfer to determine the impact of these two systems on the water supply to the Greater Bloemfontein system.
- Include the large Noordoewer/Vioolsdrift Dam instead of the medium size Noordoewer/Vioolsdrift Dam as agreed on for the Core Scenario.
- Determine the change in behaviour for the Makhaleng Dam and transfer system for the low Botswana transfer option when the Lesotho irrigation is reduced to 40 million m^3/a.
- The results from the Core Scenario with the high Botswana transfer showed that the Lesotho-Botswana transfer was supplied at unacceptable low assurance levels. Include a lower zone in Makhaleng Dam from which water can’t be used to support the ORP, but only to support users allocated to Makhaleng Dam and transfer scheme. The purpose of this zone is to adjust the operating rule and thereby increase the assurance of supply to users from Makhaleng Dam.

Results from the sensitivity analyses are described in the sub-sections to follow.

7.4.1 Exclude WC/WDM from the large key water supply systems.

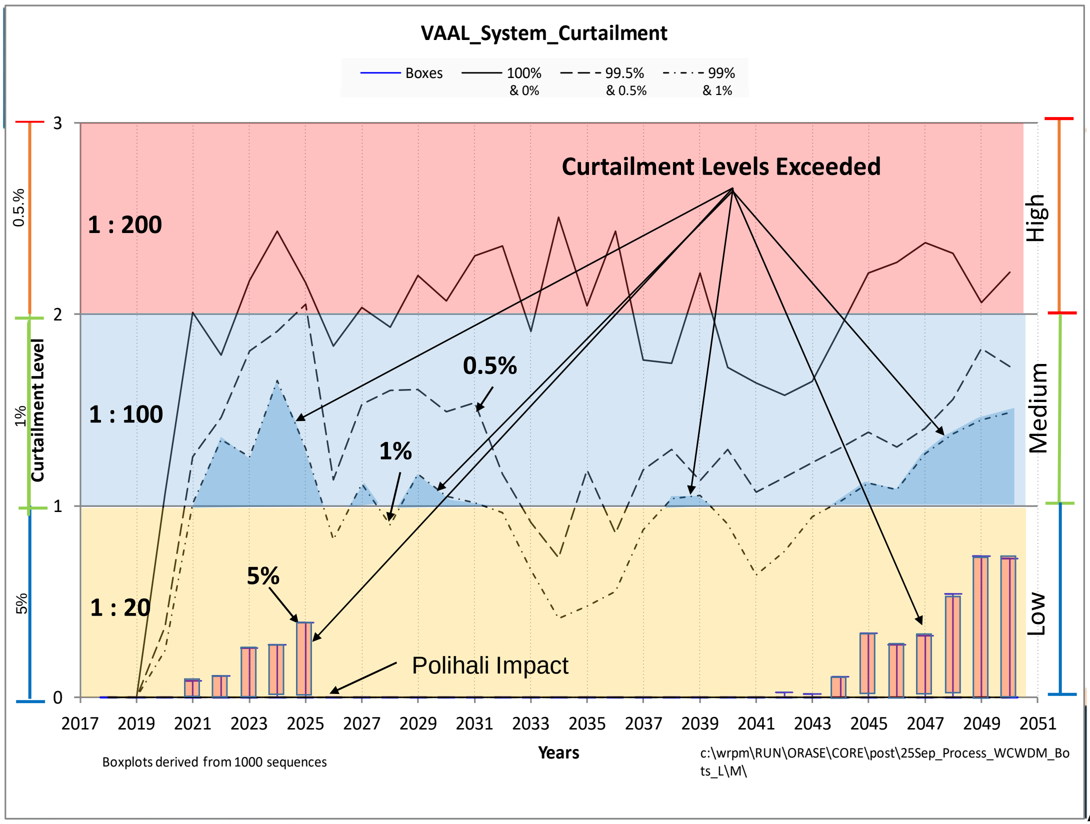
For the purpose of this sensitivity analysis the IVRS and ORP was selected as it is by far the two largest water supply systems in the Orange Senqu basin.

IVRS

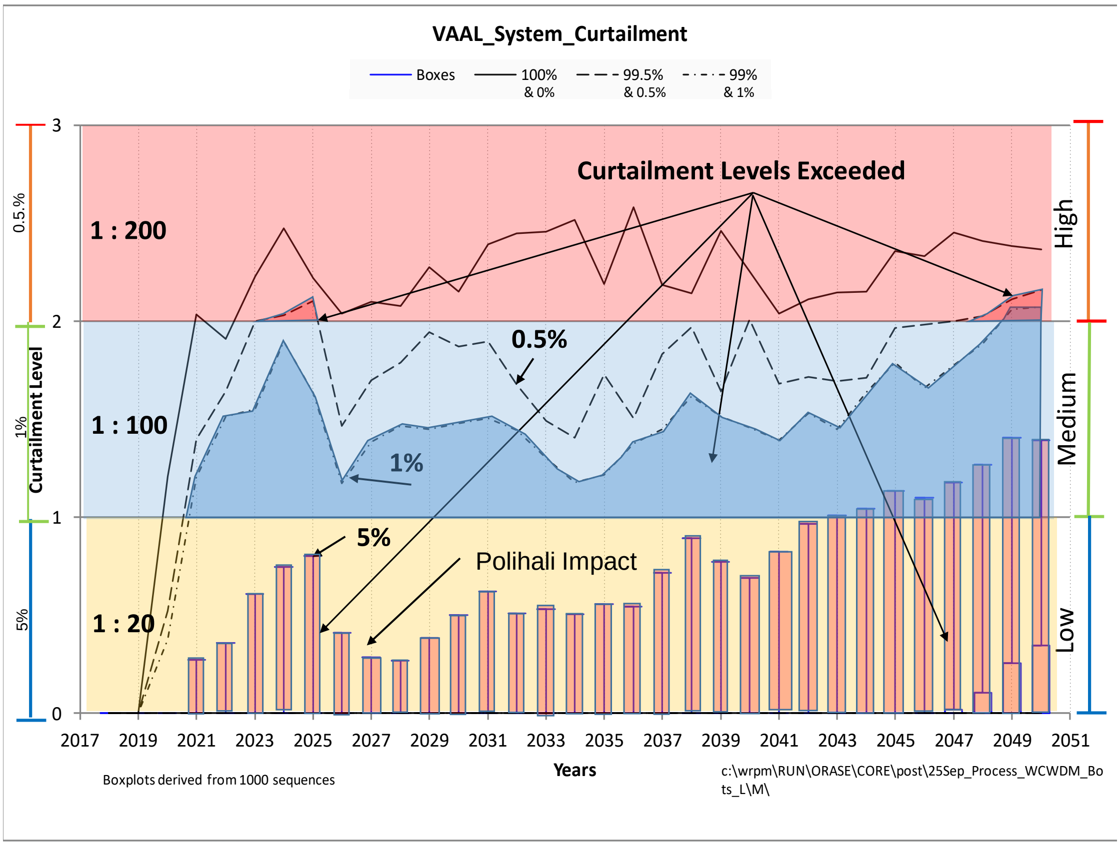
The impact of not implementing WC/WDM within the IVRS is severe and is illustrated in **Figure 7-30** by means of the system curtailment level plots. With WC/WDM implemented in the IVRS it is evident that when Polihali Dam is in place the IVRS is more or less in balance from 2026 to 2041. When no WC/WDM is practiced in the IVRS, it is clear that significant deficits are expected in the IVRS, even at the time when Polihali Dam is phased in (**Figure 7-30B**).

The storage projection plots for the Core Scenario and the Core Scenario without WC/WDM are given in **Figure 7-31**. From the two projection plots it is clear that the Vaal System storage is significantly lower when WC/WDM is not practiced in the IVRS.

It is thus crucial that WC/WDM is at all times regarded as a high priority within the IVRS and need to be in place and improved on over time.

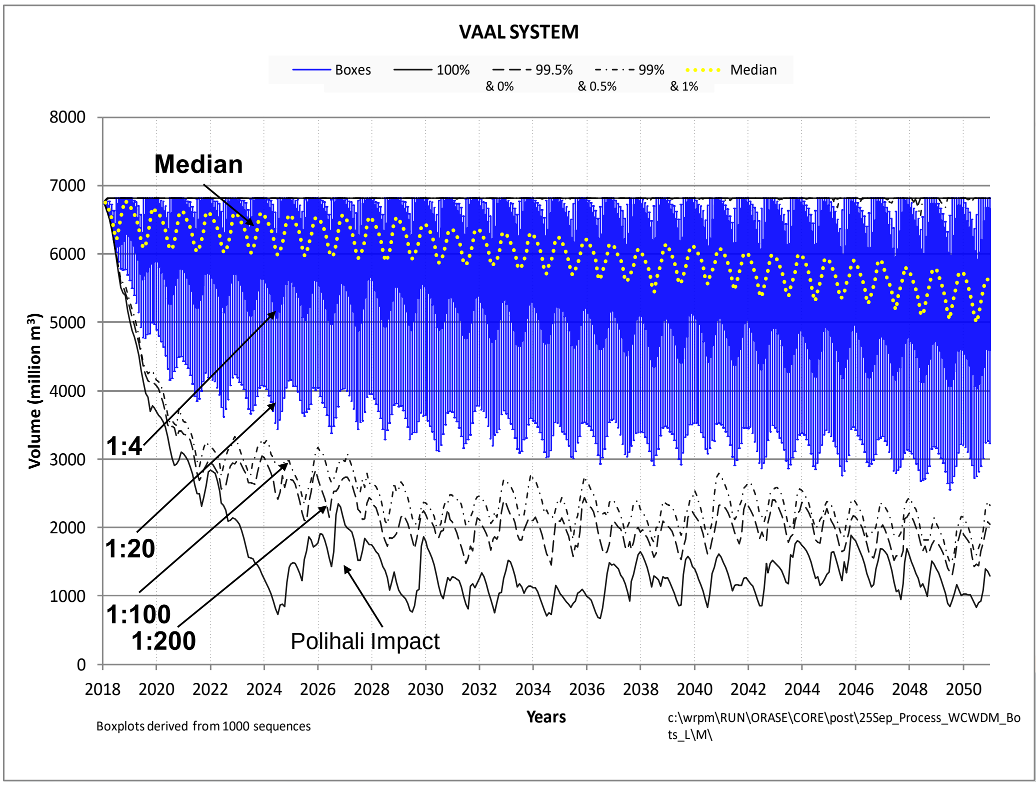


A

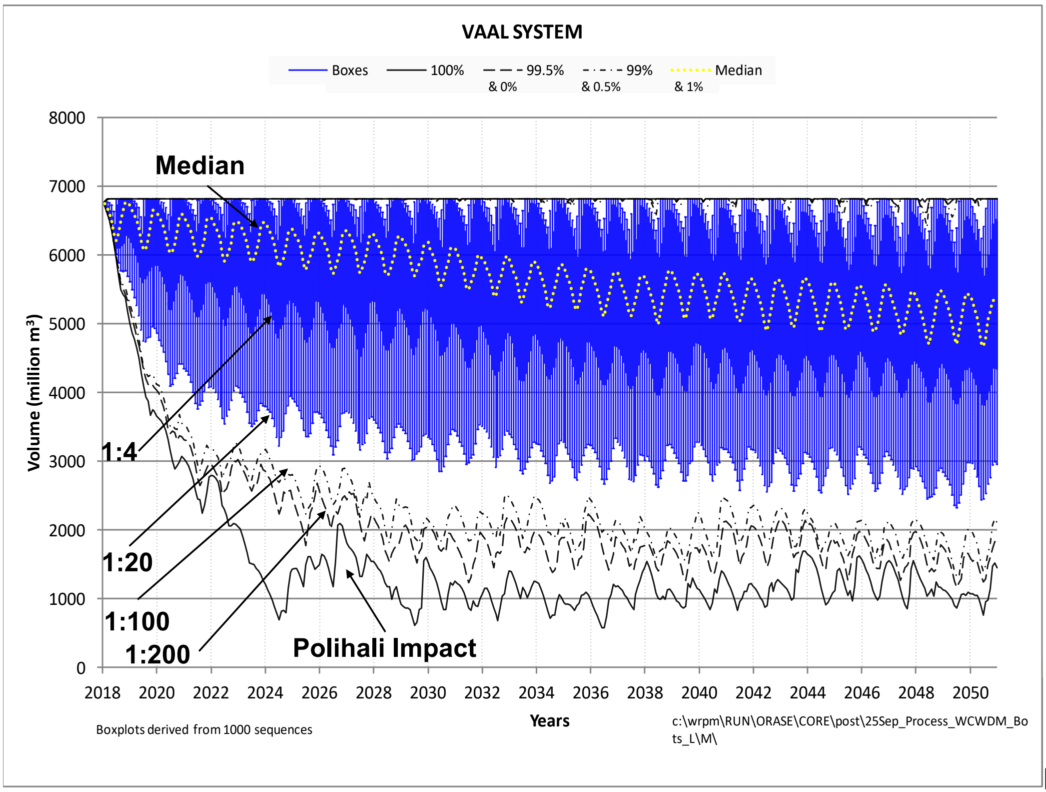


B

Figure 7-30: Vaal System Curtailment Plot for the current Core Scenario with WD/WDM in place (A) and with no WC/WDM in place (B)



A



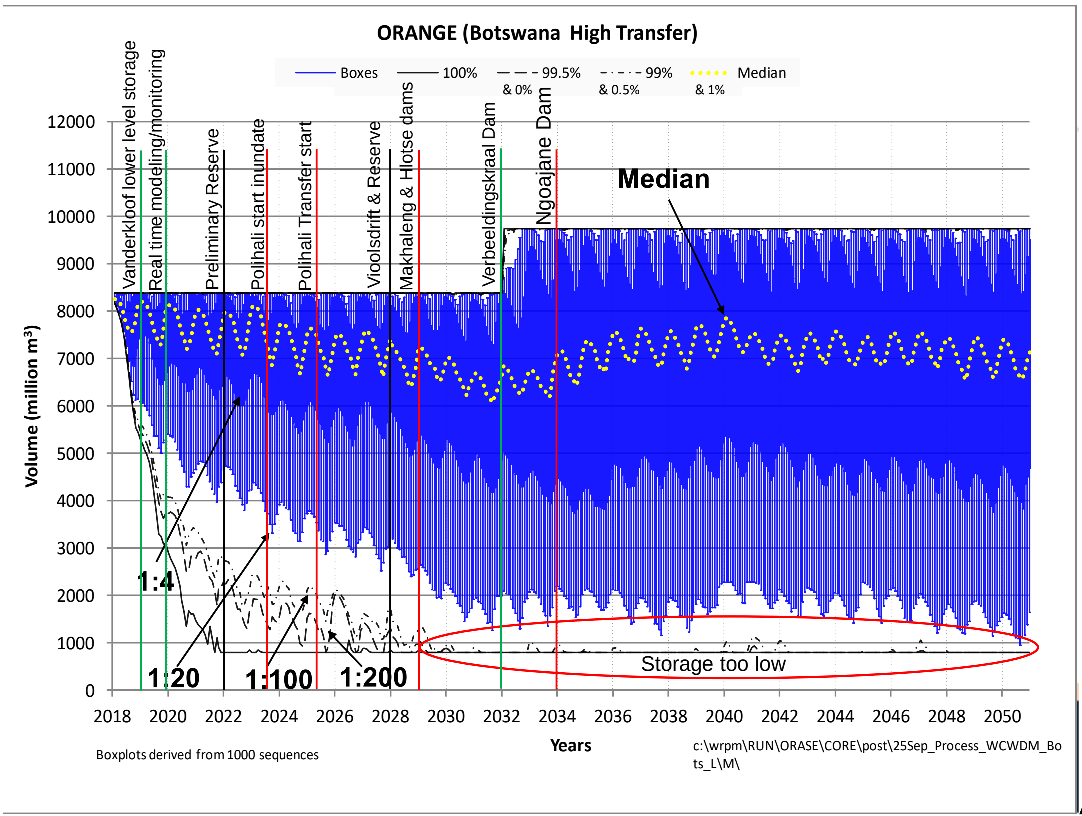
B

Figure 7-31: Vaal System Storage projection for the current Core Scenario with WC/WDM included (A) and with no WC/WDM in place (B)

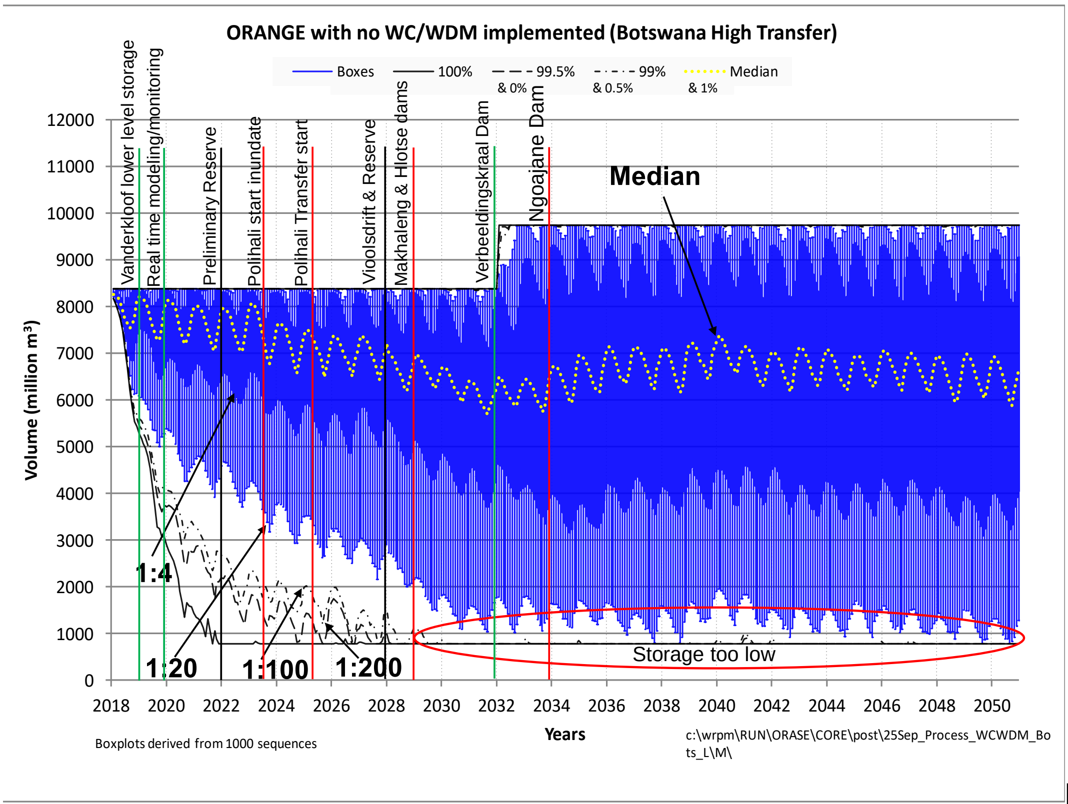
<u>ORP</u>

Irrigation is by far the largest water user from the ORP. The urban/industrial/mining component receiving water from the ORP is relatively small. The WC/WDM saving from the urban/industrial sector in the ORP is still very important to implement but will on the overall system contribute a relatively small amount of savings. When WC/WDM is implemented by the irrigation sector the saving is in most cases used by the irrigators themselves to expand on their irrigation areas. This seldom makes water available for other users or water use sectors. The Orange River System Reconciliation Strategy as prepared by DWS RSA estimated possible saving of 10% in the irrigation sector from WC/WDM. Of this 10% saving, half is expected to be used to increase irrigation areas by the irrigators themselves. The remaining half or 5% saving was regarded as water available for other users or water use sectors.

In the Current Core Scenario WC/WDM was implemented on both the Urban/Industrial sector as well as on the irrigation sector. Even with WC/WDM actions in place deficits are expected to occur in the ORP in future (see **Figure 7-32A** and **Section 7.2.3**).



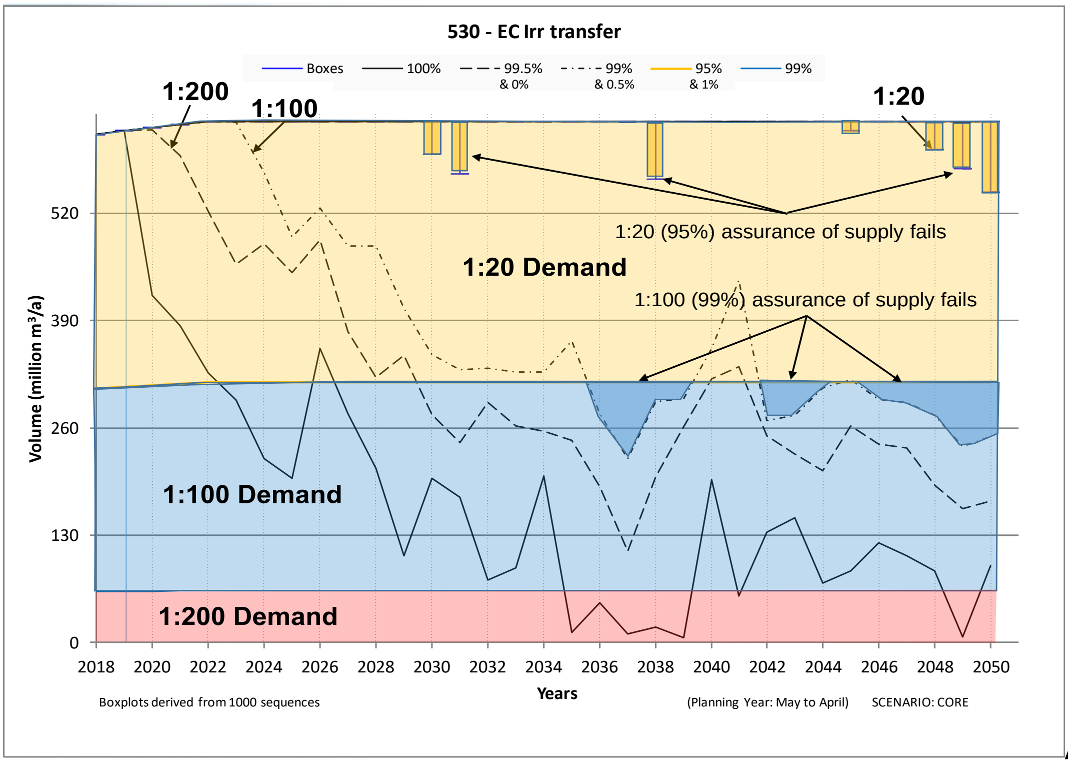
A



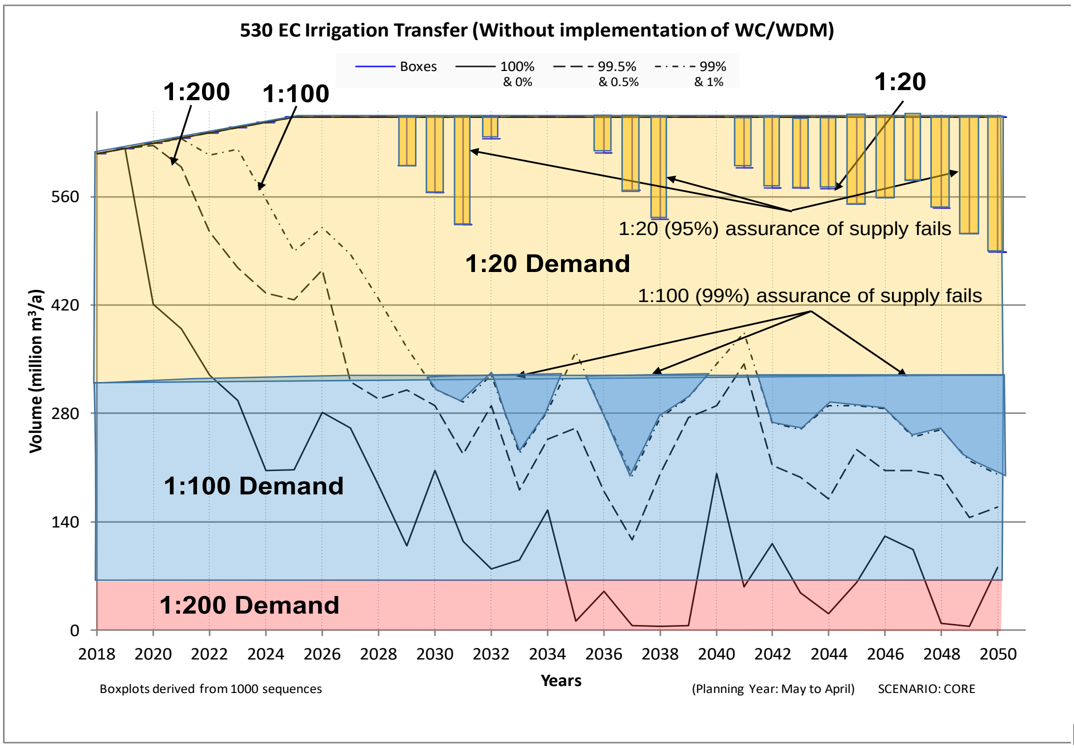
B

Figure 7-32: ORP system storage projection plots for Current Core Scenario (A) and the Current Core Scenario with no WC/WDM (B) actions implemented in the ORP

The ORP system storage projection for the ORP system without implementing WC/WDM shows significantly lower storage level projections due to the higher water requirements (See **Figure 7-32B**).



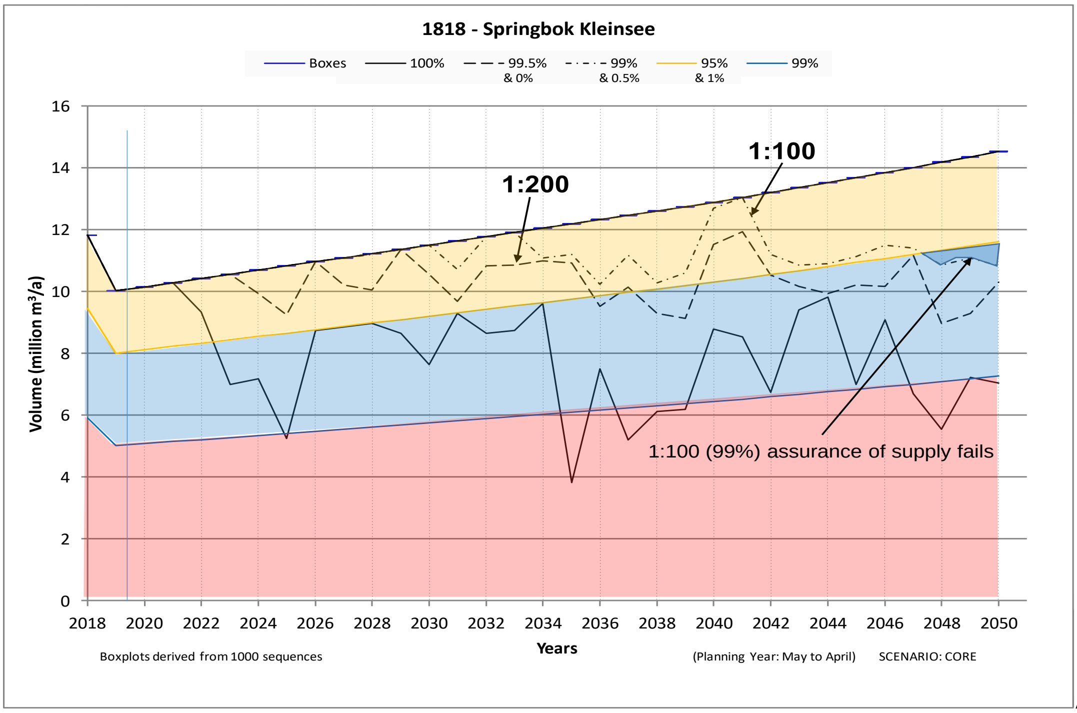
A



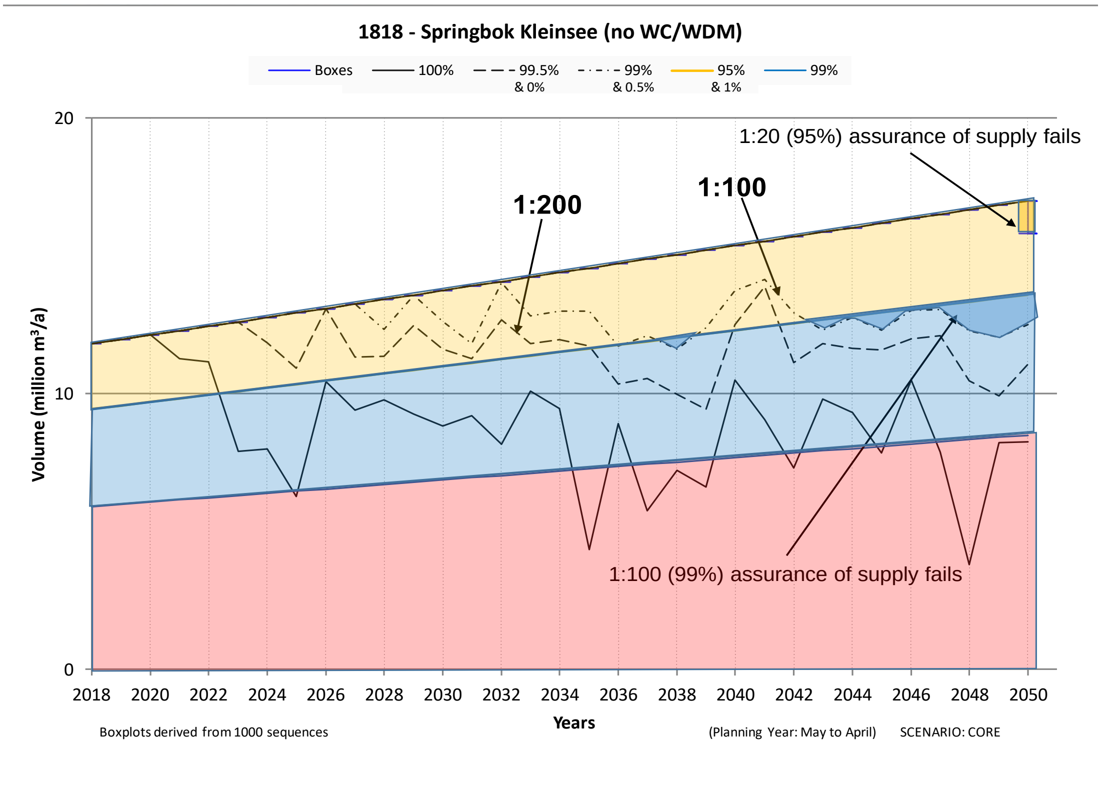
B

Figure 7-33: Water supply for irrigation in the EC for the Current Core Scenario (A) and the Current Core Scenario with no WC/WDM (B) implemented in the ORP

The required assurance of supply for the Urban/Industrial and irrigation sectors are quite different. Two comparison examples are thus shown in the report, one for the irrigation supply to the Eastern Cape and one for urban/mining water requirements of Springbok and Kleinsee.



A



B

Figure 7-34: Water supply to Springbok and Kleinsee for the Current Core Scenario (A) and for the Current Core Scenario with no WC/WDM (B) actions implemented in the ORP

The comparison for the Eastern Cape irrigation is given in **Figure 7-33**. Deficits in the irrigation supply to the Eastern Cape were already evident for the Current Core Scenario (**Figure 7-33A**) at the 95% and 99% assurance levels. These deficits increased significantly when no WC/WDM actions are implemented in the ORP (See **Figure 7-33B**).

The Springbok Kleinsee urban/mining water supply for both options are shown in **Figure 7-34**. Deficits in supply to the urban/mining sector also increased when WC/WDM were not implemented but to a lesser extent than evident from the irrigation supply comparison.

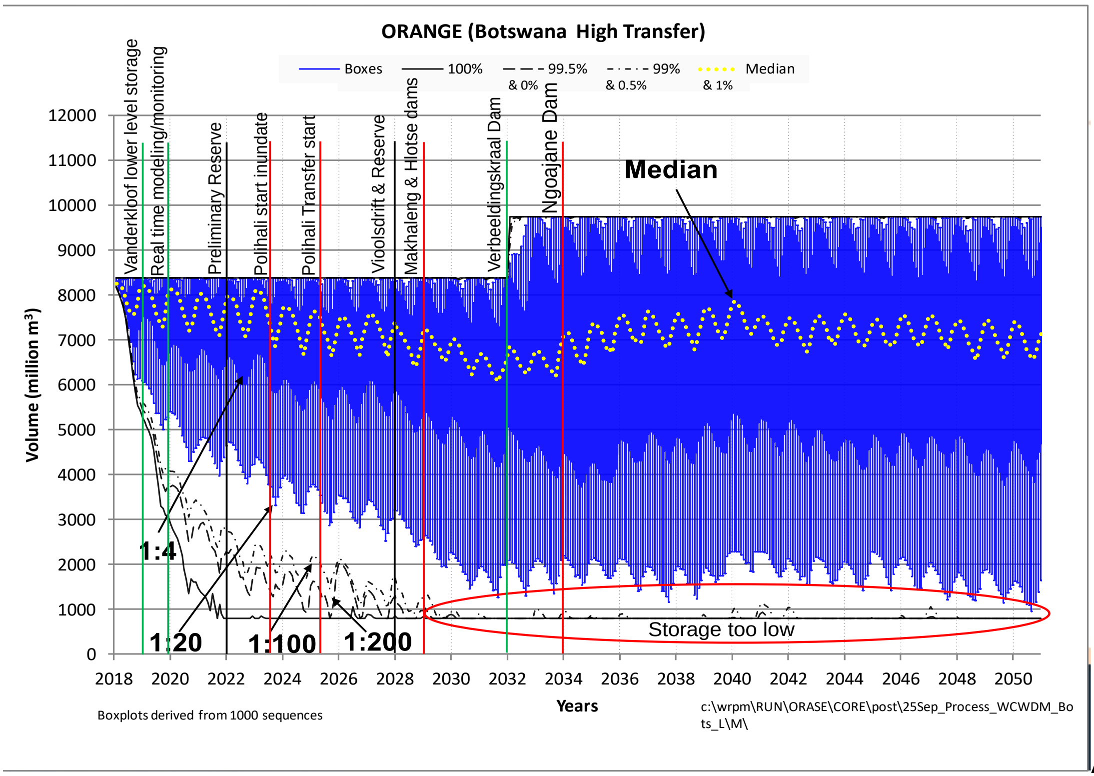
The overall increase in deficits are still quite significant and highlight the importance of WC/WDM to be implemented in the ORP system. This is in particular required as the ORP system is already almost fully utilized.

7.4.2 Exclude the final reserve to be imposed on the ORP

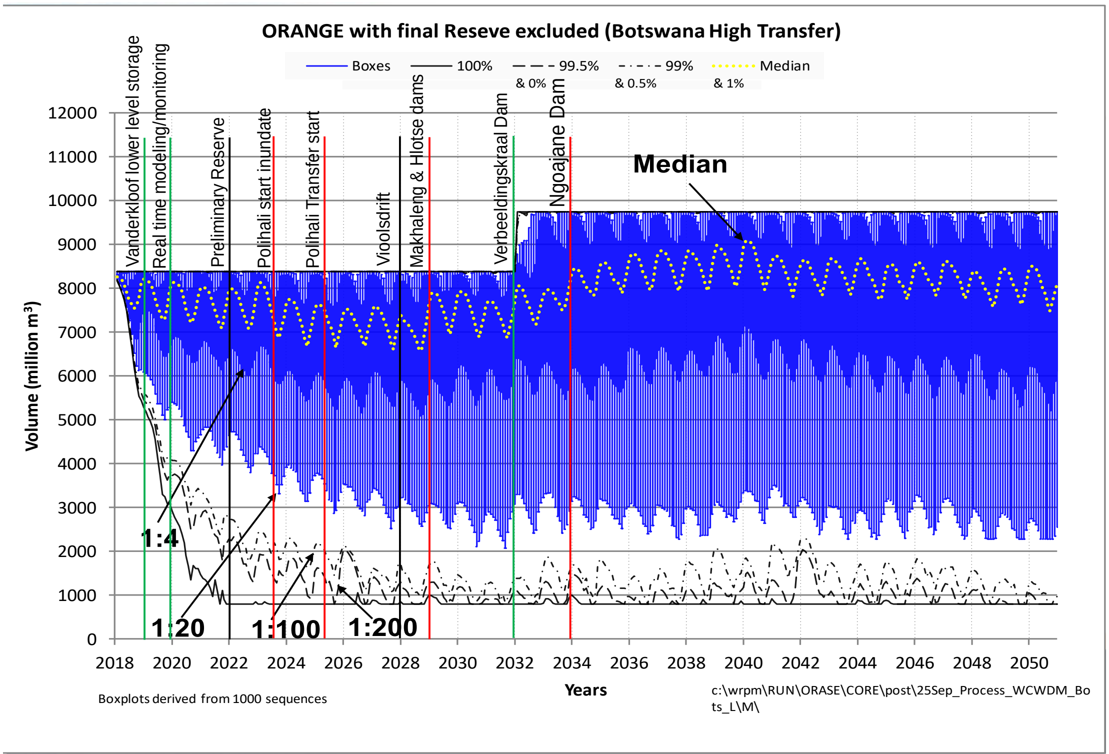
The final Reserve for the Orange River System still needs to be determined. Previous EWR studies already indicated that the preferred ecological environmental requirement would result in a significant decrease in the yield available from the ORP (**See Section 7.2.3**). The final Reserve to be determined will however be a balance between the environmental impacts and the economic and socio-economic impacts due to a reduced yield from the ORP. At this stage there is still great uncertainty of what the final Reserve impact will be. For this reason, it was regarded as important to carry out a sensitivity analysis on the impact of this Reserve on the water supply of the ORP system.

The final Reserve is planned to be implemented by 2028 at the same time when Noordoewer/Vioolsdrift Dam becomes active. The Current Core Scenario storage projection indicated that even with Noordoewer/Vioolsdrift Dam being implemented by 2028, the ORP total system storage still showed a downward trend thereafter. When evaluating the ORP system storage projection plot with the final reserve excluded, a definite recovery in the ORP system storage is evident when Noordoewer/Vioolsdrift Dam is activated. In the Current Core Scenario, the implementation of the final Reserve at the same time Noordoewer/Vioolsdrift is implemented, resulted in the canceling of the positive benefit of adding Noordoewer/Vioolsdrift Dam. Removing the final Reserve and only keeping in place the Preliminary Reserve showed the significant increase in the ORP system storage projection, which will result in a much-improved water supply to the users from the ORP.

The improvement in supply to irrigation as well as to the urban/mining sector is surprising, showing no deficits in water supply to both water supply sectors over the entire simulation period. The final Reserve to be implemented can thus result in significant impacts in the water supply to the ORP users. This need to be carefully addressed in the environmental requirement classification study and reserve determination work that still need to be carried out in future.

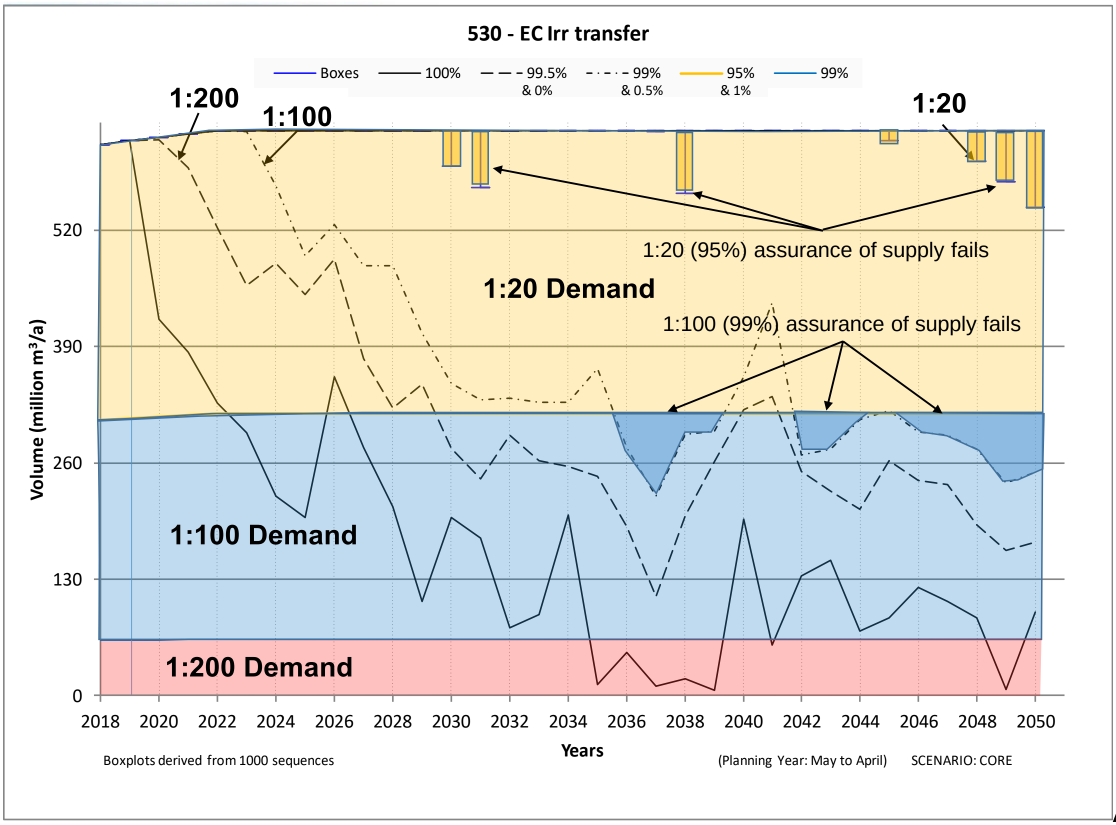


A

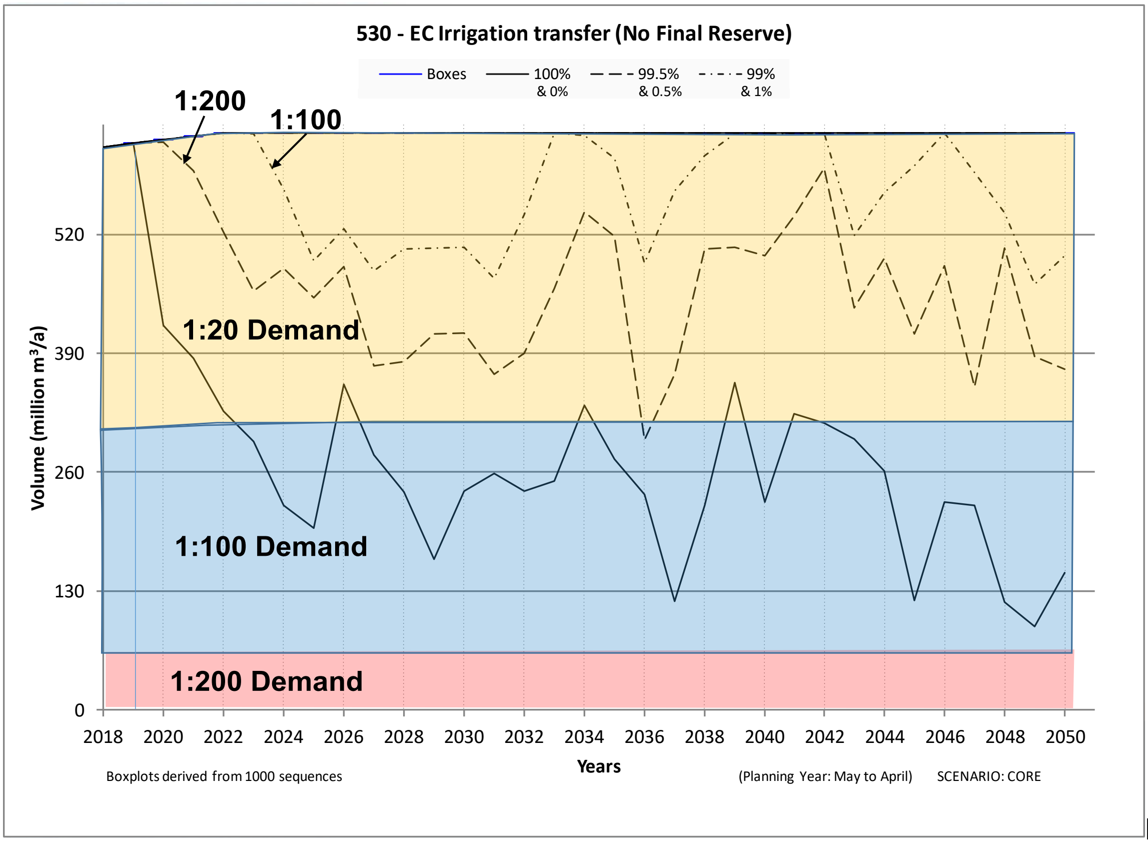


B

Figure 7-35: ORP system total storage projection for the Current Core Scenario (A) and the Current Core Scenario when the final Reserve is (B) excluded from the ORP

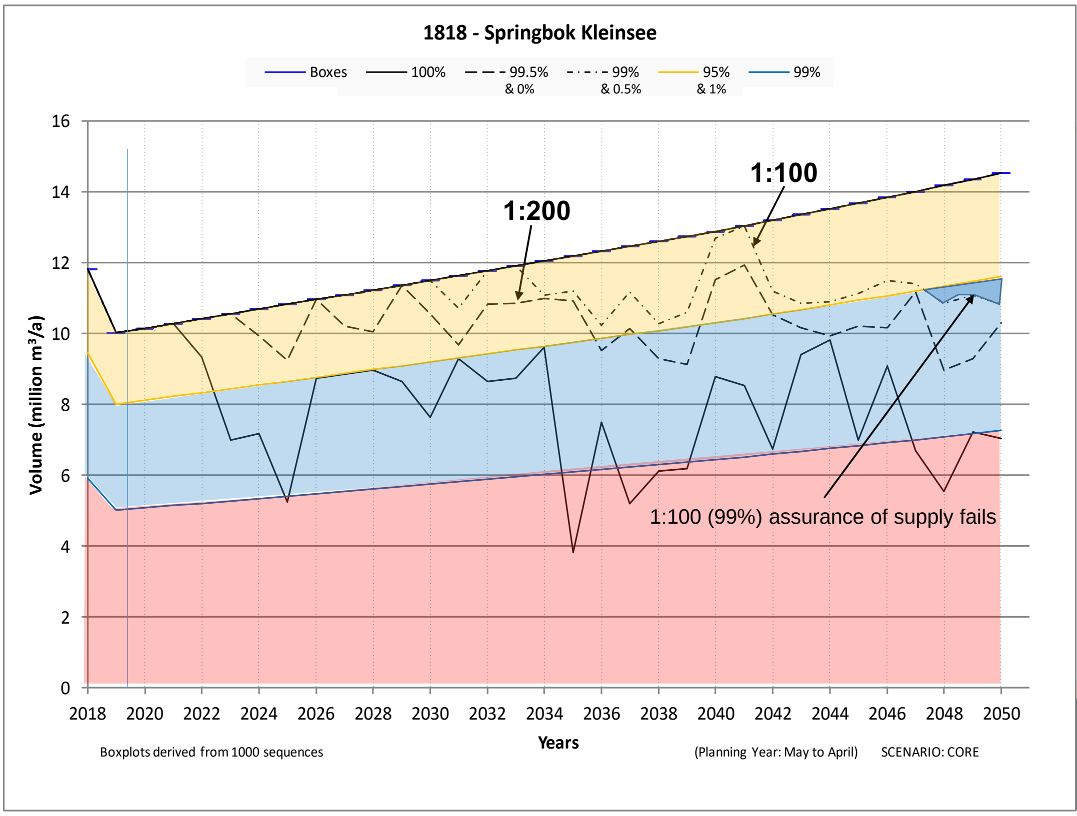


A

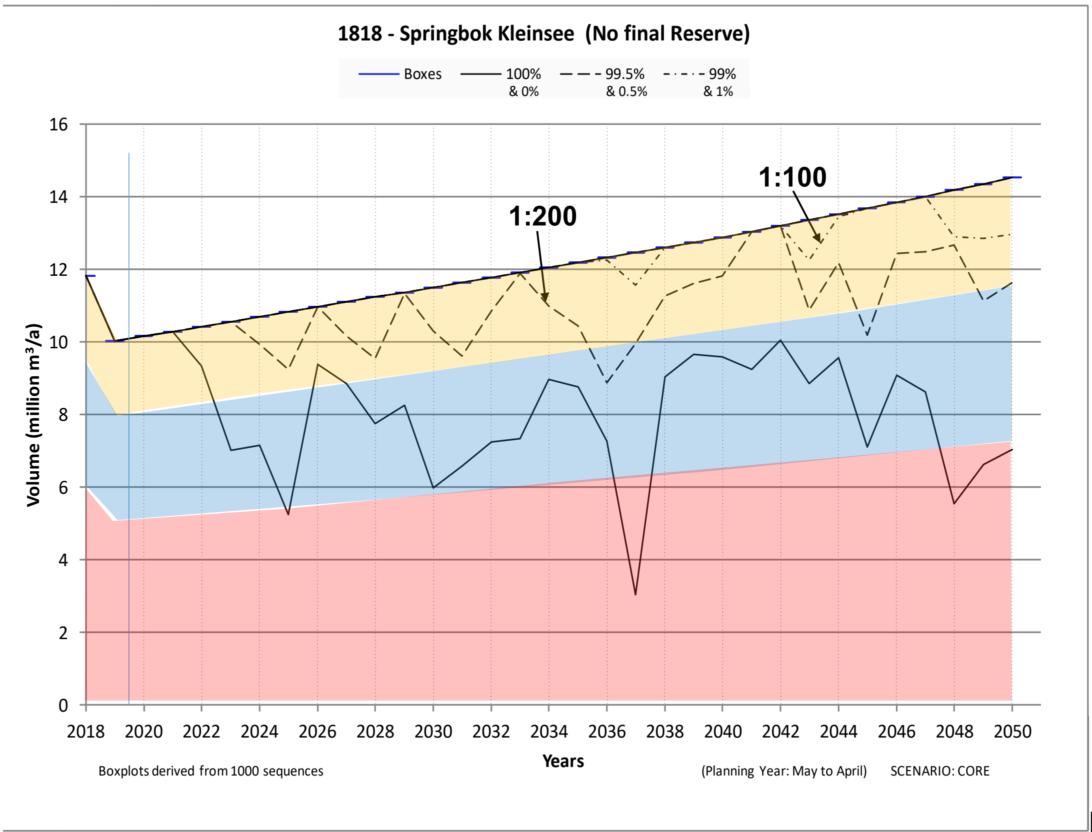


B

Figure 7-36: Supply to EC Irrigation transfer for the Current Core Scenario (A) and the Current Core Scenario when the Final Reserve is (B) excluded from the ORP



A



B

Figure 7-37: Supply to Springbok & Kleinsee for the Current Core Scenario (A) and the Current Core Scenario when the Final Reserve is (B) excluded from the ORP

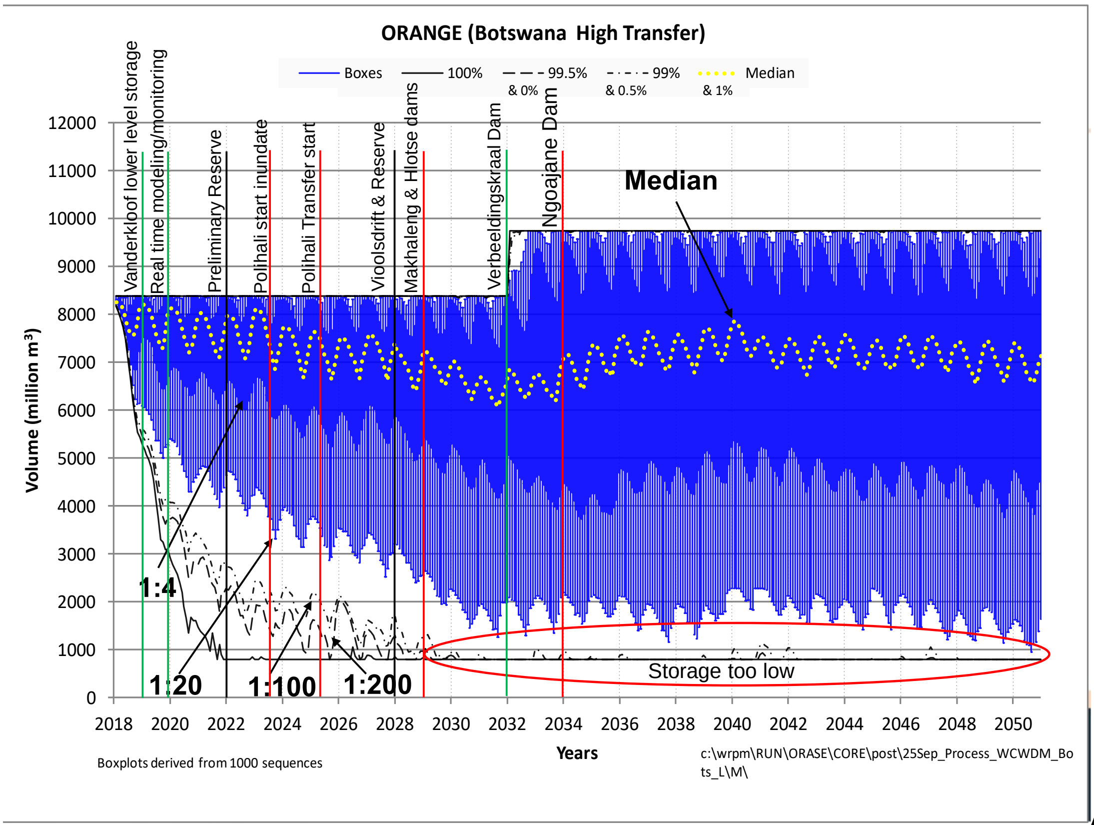
7.4.3 Not utilizing the Lower Level Storage in Vanderkloof Dam as an intervention option

Utilizing the current lower level storage (LLS) in Vanderkloof Dam is one of the most cost effective and fast to implement intervention options, to increase the ORP system yield. This option has the disadvantage that as soon as the storage in the dam drops into this LLS zone, no hydropower can be generated at Vanderkloof Dam, as the water level will then be below the hydro-power plant intake.

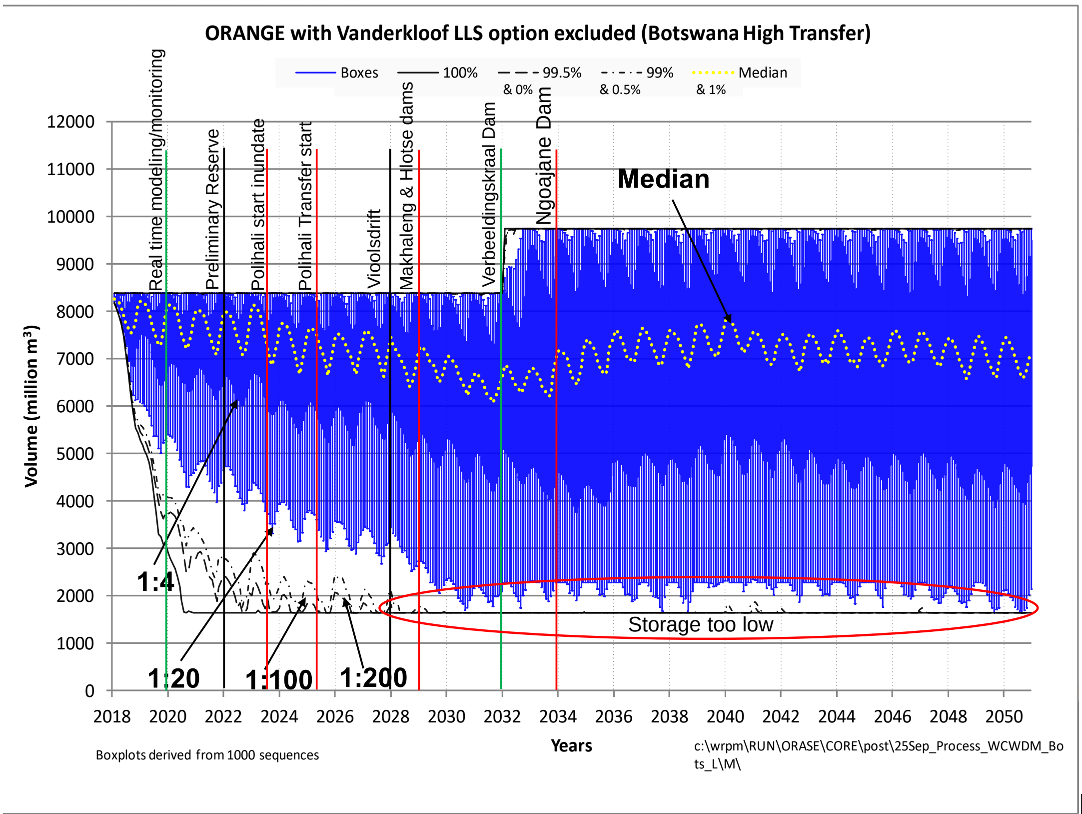
DWS RSA therefore requested that a sensitivity analysis be carried out to show how frequently the Vanderkloof Dam LLS will be and the related impacts when not using the LLS. The ORP system storage projection plots for the two options (the current Core Scenario and Core Scenario without Vanderkloof LLS) are compared in **Figure 7-38**. From the comparison it is evident that when the Vanderkloof LLS is not utilized, the ORP storage levels drop unacceptably low from 2028 onwards. The ORP system is now running empty even at the 95% exceedance probability level. This will result in significant more deficits in the ORP system.

Storage projections for Vanderkloof Dam on its own for both options are given in **Figure 7-39**. From **Figure 7-39A** it is evident that it is only the 99.5%, 99% and 95% exceedance probability levels that enters into the LLS zone in Vanderkloof Dam, which means that no hydropower generation occurs approximately 1: 20 years. By optimizing the operating rules between Gariep and Vanderkloof dams as well as Verbeeldingskraal Dam when implemented, can significantly further reduce the events when no hydropower can be generated at Vanderkloof Dam.

Figures 7-40 and **7-41** show the impact of not utilizing the Vanderkloof LLS on the water supply to irrigation and towns from the ORP respectively. From these figures it is clear that the negative impact of not using Vanderkloof LLS on irrigation supply is quite severe and to a lesser extent also on the supply to the urban/mining component. The Vanderkloof LLS is thus a very valuable source to be used, which should not be neglected. The frequency of using the LLS should be minimized by optimizing related operating rules.

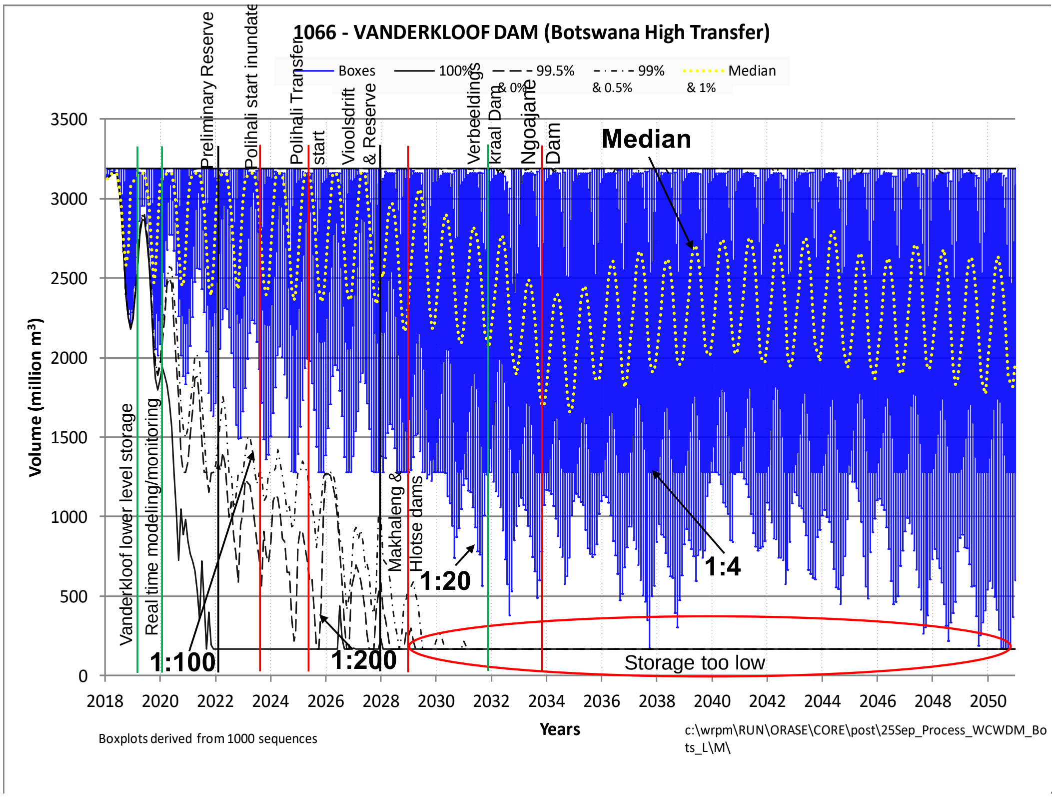


A

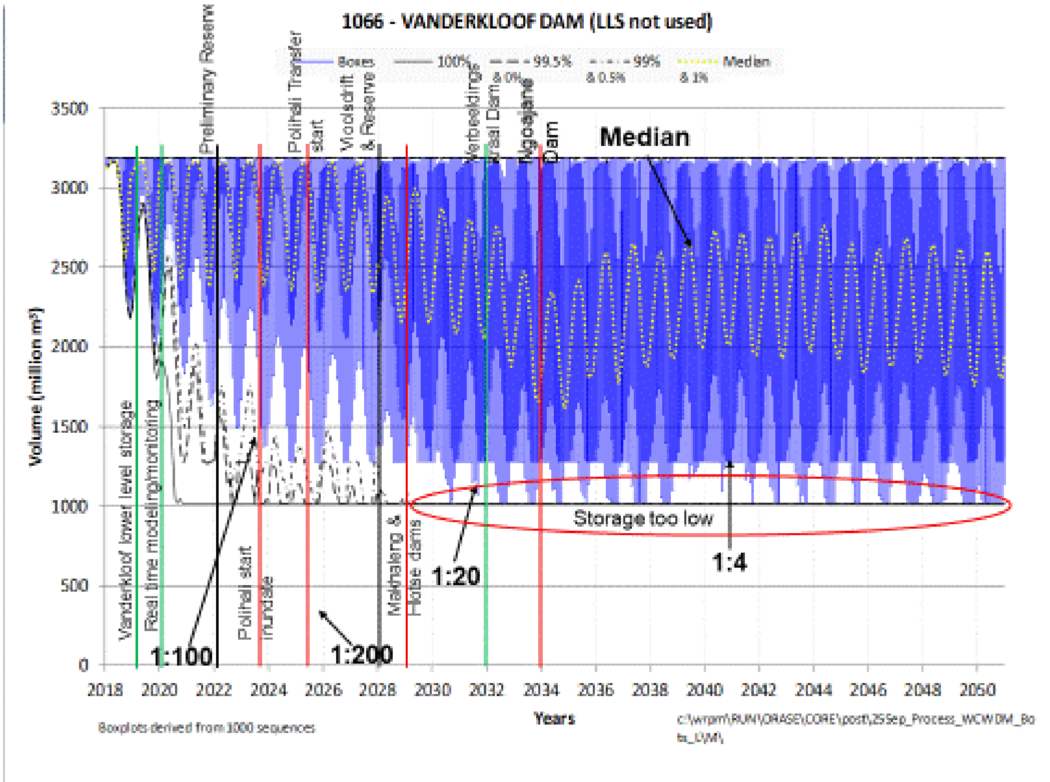


B

Figure 7-38: ORP system total storage projection for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized (B)

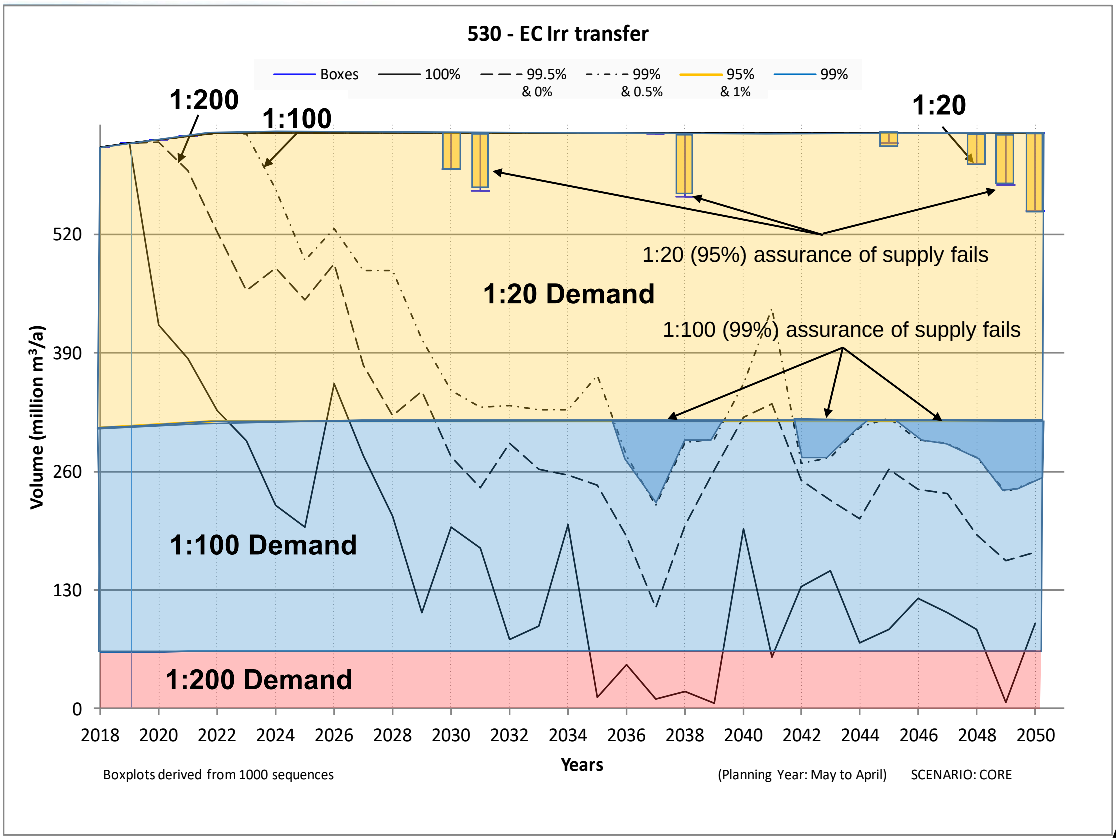


A

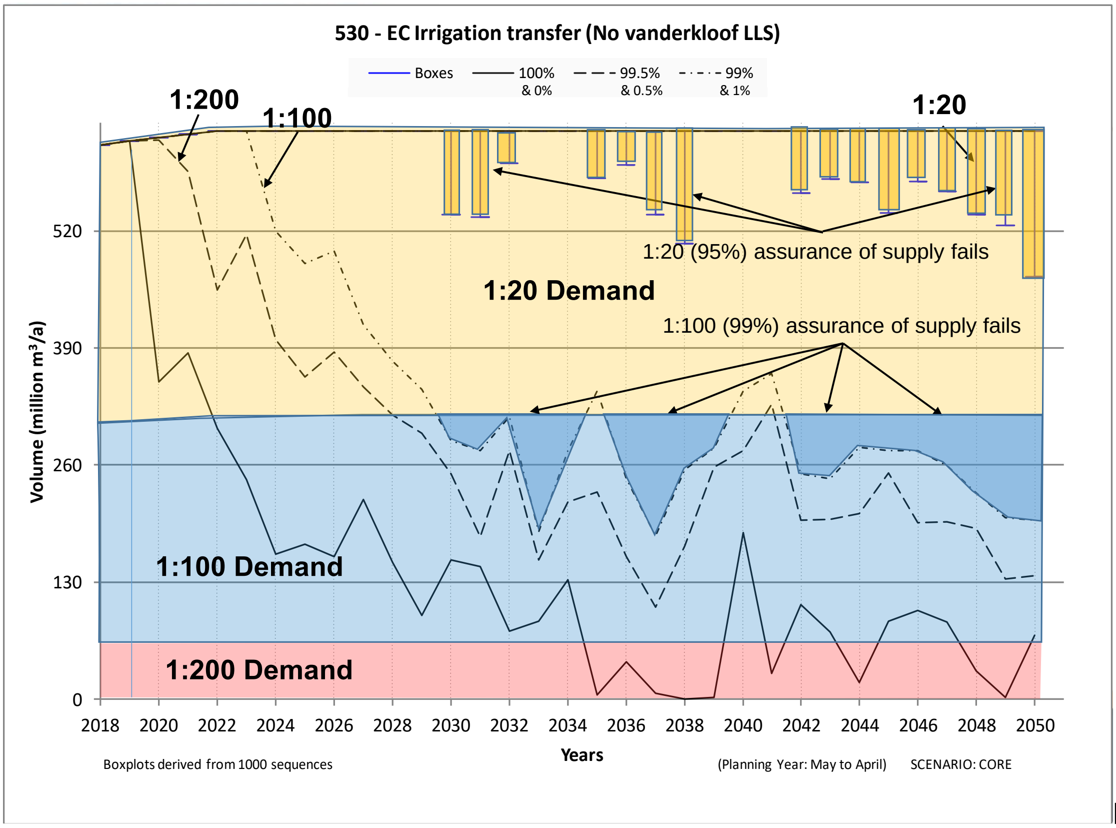


B

Figure 7-39: Vanderkloof Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)

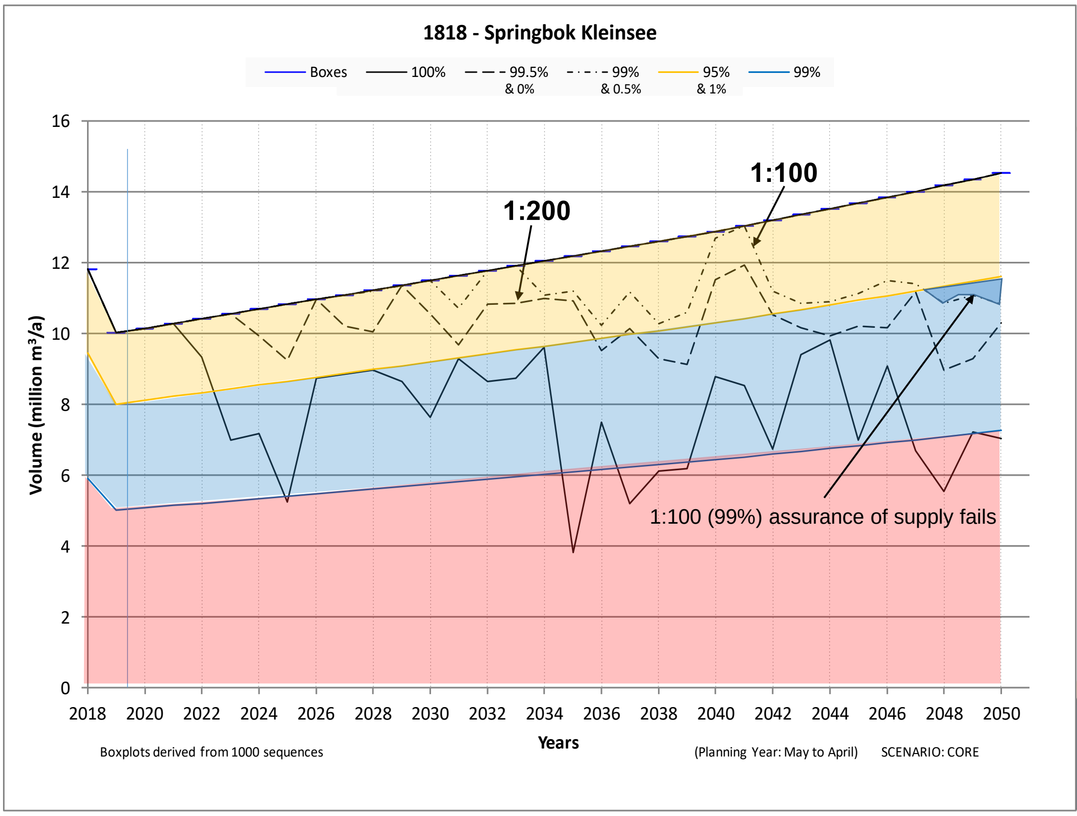


A

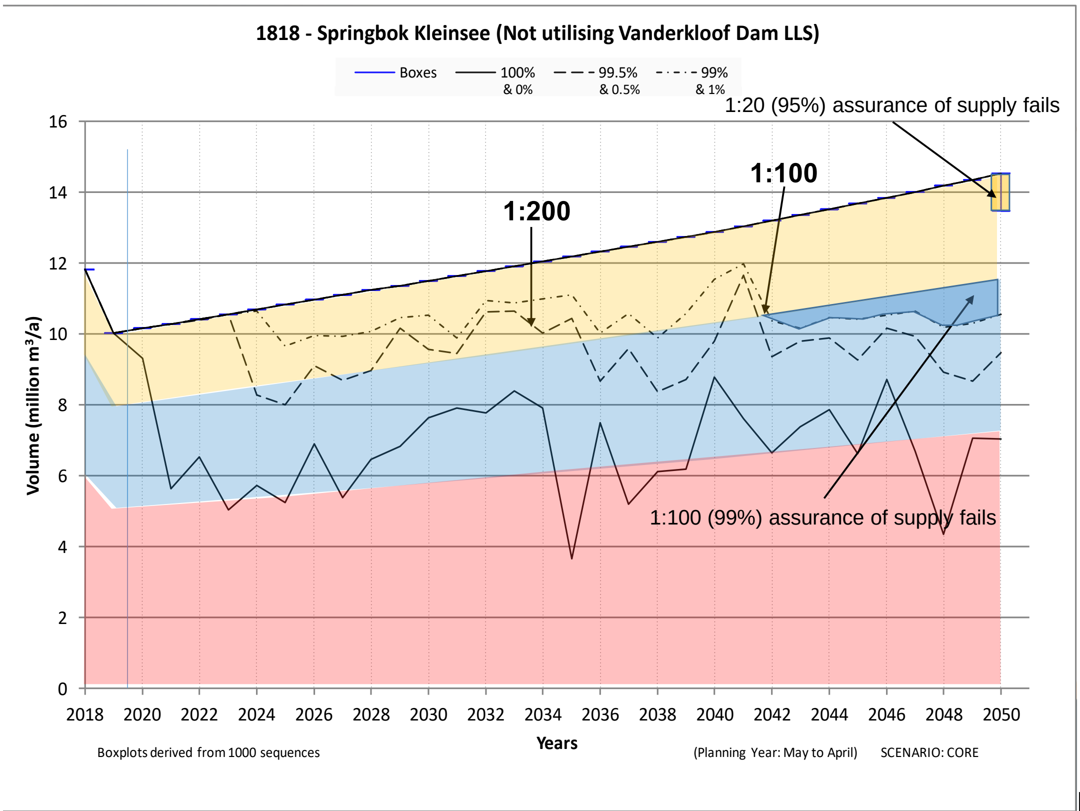


B

Figure 7-40: Supply to EC irrigation transfer for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)



A



B

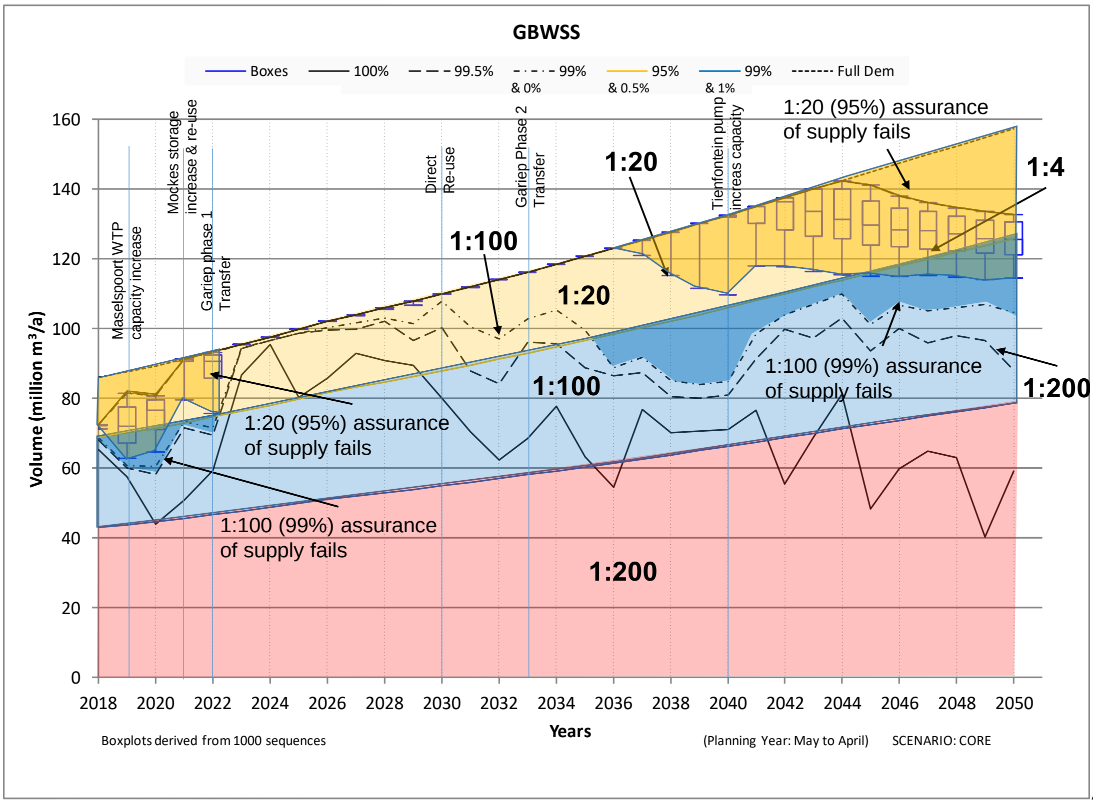
Figure 7-41: Supply to Springbok and Kleinsee for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)

7.4.4 Exclude the future Hlotse and Ngoajane water supply systems from the Core Scenario

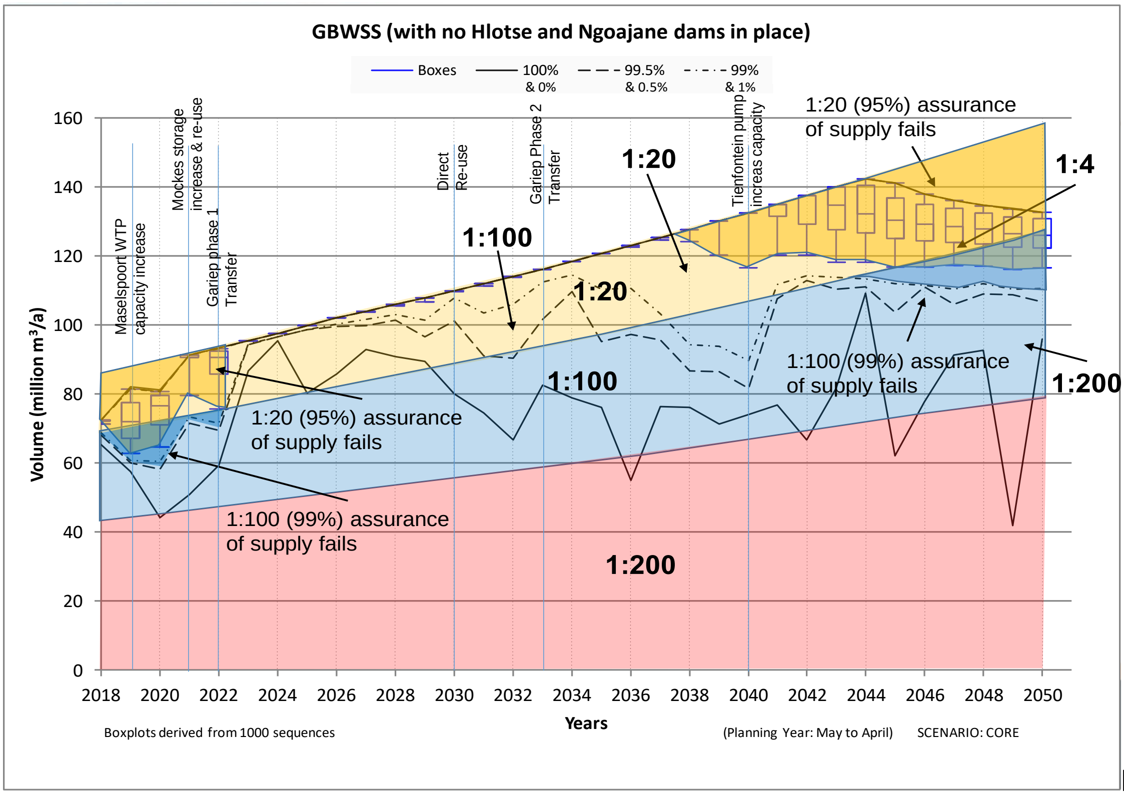
The Hlotse and Ngoajane Lesotho Lowland Schemes are expected to be activated by 2030 and 2034 respectively. Impacts on the Greater Bloemfontein Water supply system due to these two schemes can thus only occur after 2030.

The water supply to the Greater Bloemfontein for the two options are compared in **Figure 7-42** with the results from the Current Core Scenario (with the high Botswana transfer). From the comparison it is clear that the impact of these two schemes on the Greater Bloemfontein system is quite significant, and deficits in the supply to Bloemfontein will occur about 2 years earlier, when these two Lesotho Lowland schemes are implemented. It is important to note that the Greater Bloemfontein Reconciliation Strategy was developed without considering the development of Hlotse and Ngoajane dams in the Lesotho Lowlands. The same also applies for the Mangaung Metro study. The increasing of the Tienfontein pump station to 7 m^3/s is one of the Greater Bloemfontein intervention options that will most probably not achieve the set targets when the Hlotse and Ngoajane schemes are in place.

Results from the current Core Scenario showed a downward trend in the Welbedacht Dam storage between 2034 to 2046 (See **Figure 7-43A**). This is due to the combination of the Hlotse and Ngoajane schemes with the increased pumping capacity at Tienfontein pump station by 2040. This resulted in a decrease in the supply from the Welbedacht WTP to Bloemfontein. Some of these intervention options proposed for the Greater Bloemfontein need to be re-evaluated in future, also considering the impacts of the Hlotse and Ngoajane Lesotho Lowland schemes. The feasibility study to be carried out for the Hlotse and Ngoajane Lesotho Lowland schemes need to be carefully evaluated and should analyze in detail the impacts on the downstream developments to be able to satisfy the overall water balance in the greater system.

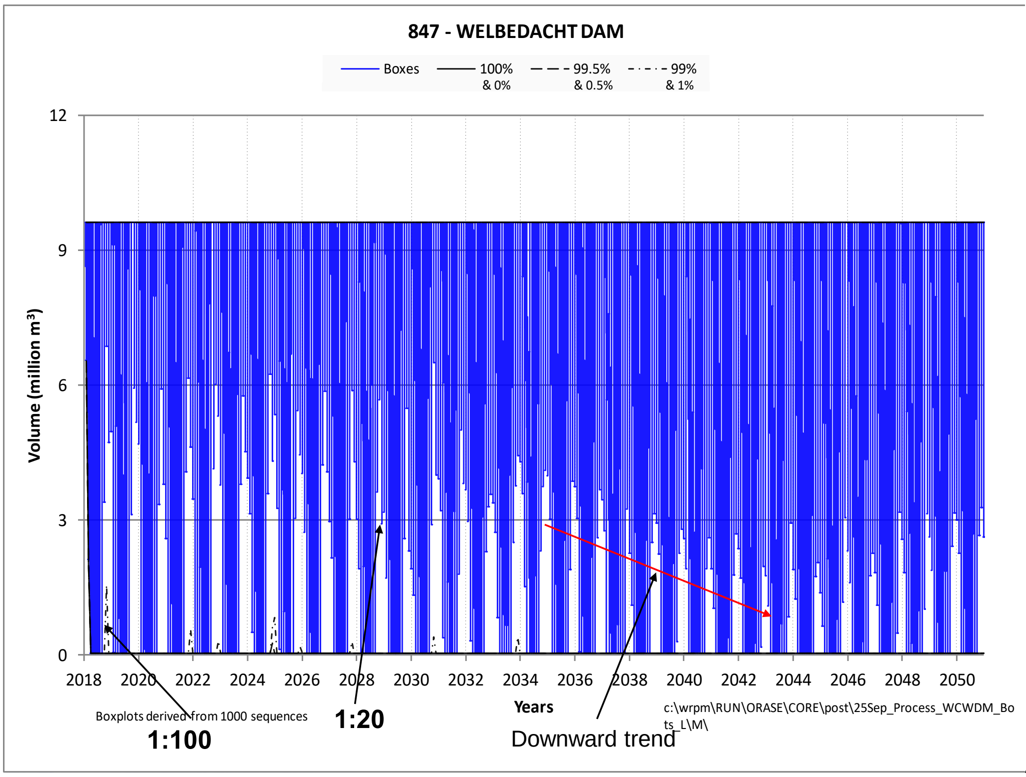


A

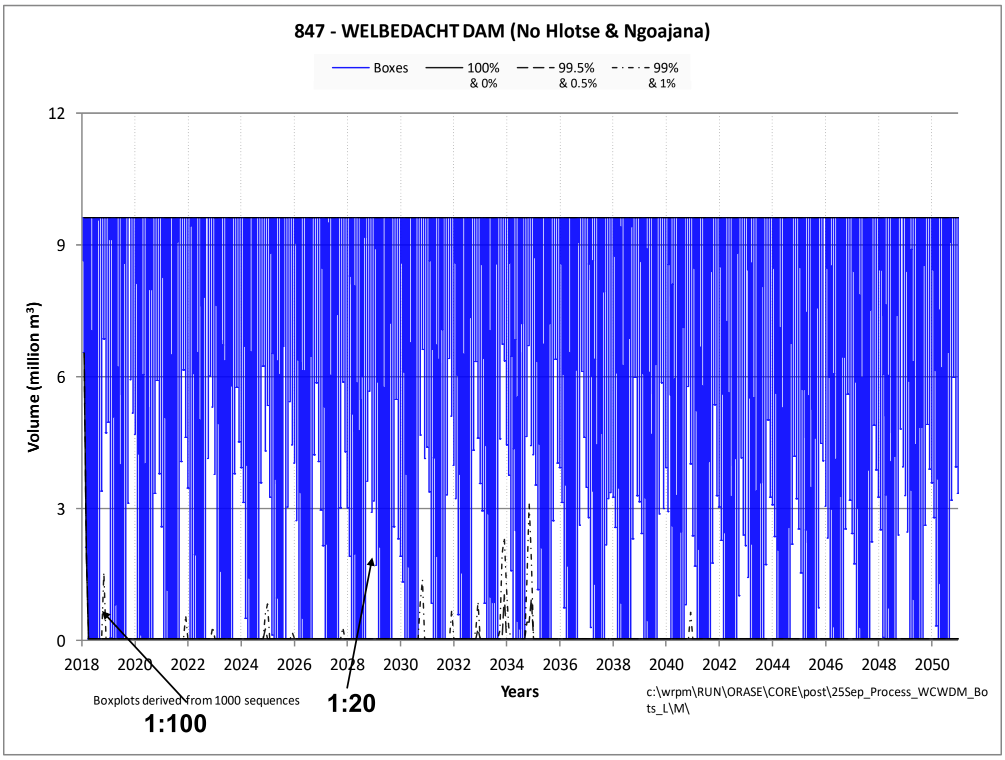


B

Figure 7-42: Water supply to the Greater Bloemfontein system for the Current Core Scenario (A) and the Current Core scenario with Hlotse and Ngoajane schemes removed(B)



A



B

Figure 7-43: Welbedacht Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario that excludes the Hlotse and Ngoajane Schemes (B)

7.4.5 Large Noordoewer/Vioolsdrift Dam

The combined study by Namibia and the RSA on the Noordoewer/Vioolsdrift Dam (Permanent Water Commission Namibia RSA, (PWC,2017)) is currently still ongoing. At this point the study still focus on two possible dam size options, a large Noordoewer/Vioolsdrift Dam and a medium size dam. The RSA prefers the medium size dam for environmental impact reasons, while Namibia prefers the larger dam to be able to significantly increase its irrigation along the Lower Orange.

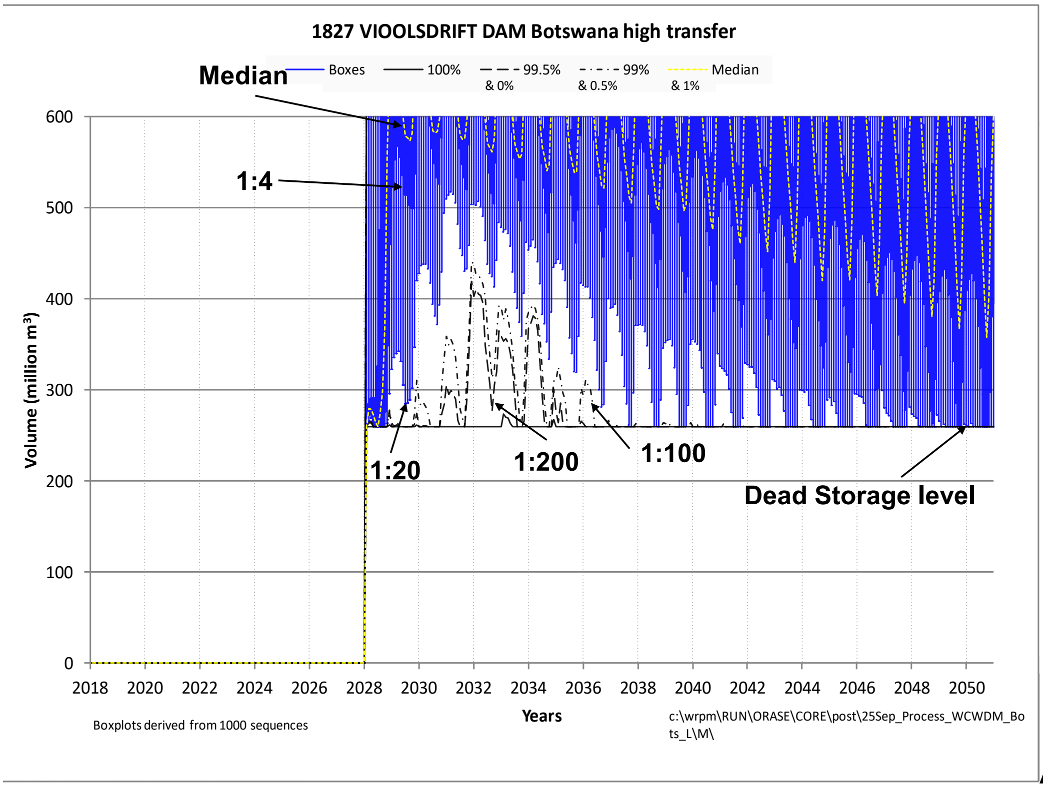
The Current Core Scenario includes the medium size Noordoewer/Vioolsdrift Dam. As part of the sensitivity analyses the large Noordoewer/Vioolsdrift Dam was thus included to evaluate the differences in water supply when the larger dam is used.

A comparison of the storage projections for the medium size and large Noordoewer/Vioolsdrift dams is shown in **Figure 7-44**. The medium size Noordoewer/Vioolsdrift Dam depletes fairly quickly due to the significant increase in water requirement, mainly due the Namibia irrigation requirements as well as the Final Reserve that is implemented by 2028. It is not necessarily a water supply problem when the Noordoewer/Vioolsdrift Dam reaches its minimum operating level, as this is part of the operating rule between Noordoewer/Vioolsdrift and Vanderkloof dams as explained in **Section 7.2.3**.

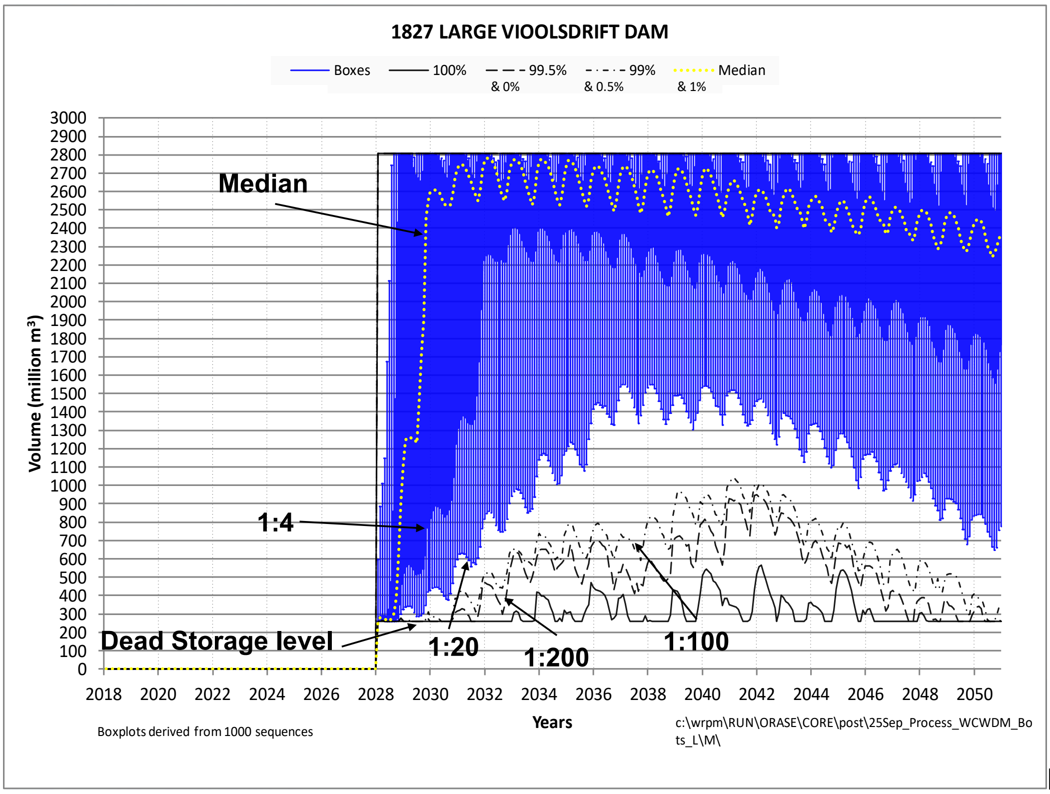
The operating rule dictates that releases from Vanderkloof Dam to supply the downstream users are firstly to support the users between Vanderkloof and Noordoewer/Vioolsdrift dams. Only when the water available in Noordoewer/Vioolsdrift Dam is not sufficient to support the downstream water requirements, will releases at Vanderkloof Dam be increased to also support the Noordoewer/Vioolsdrift Dam and related users.

The large Noordoewer/Vioolsdrift Dam is able to sustain the downstream water requirements for a much longer time (**Figure 7-44B**) and will require less support from Vanderkloof Dam but will have a negative impact on the environment downstream of the dam.

From Figure **7-45A** it is evident that the medium size Noordoewer/Vioolsdrift Dam can't fully support the planned future Namibia irrigation and deficits are expected to start occurring from 2043 onwards. With the large Noordoewer/Vioolsdrift Dam in place, the future Namibia irrigation can be supplied very well over the entire simulation at a higher assurance than normally required for irrigation purposes.

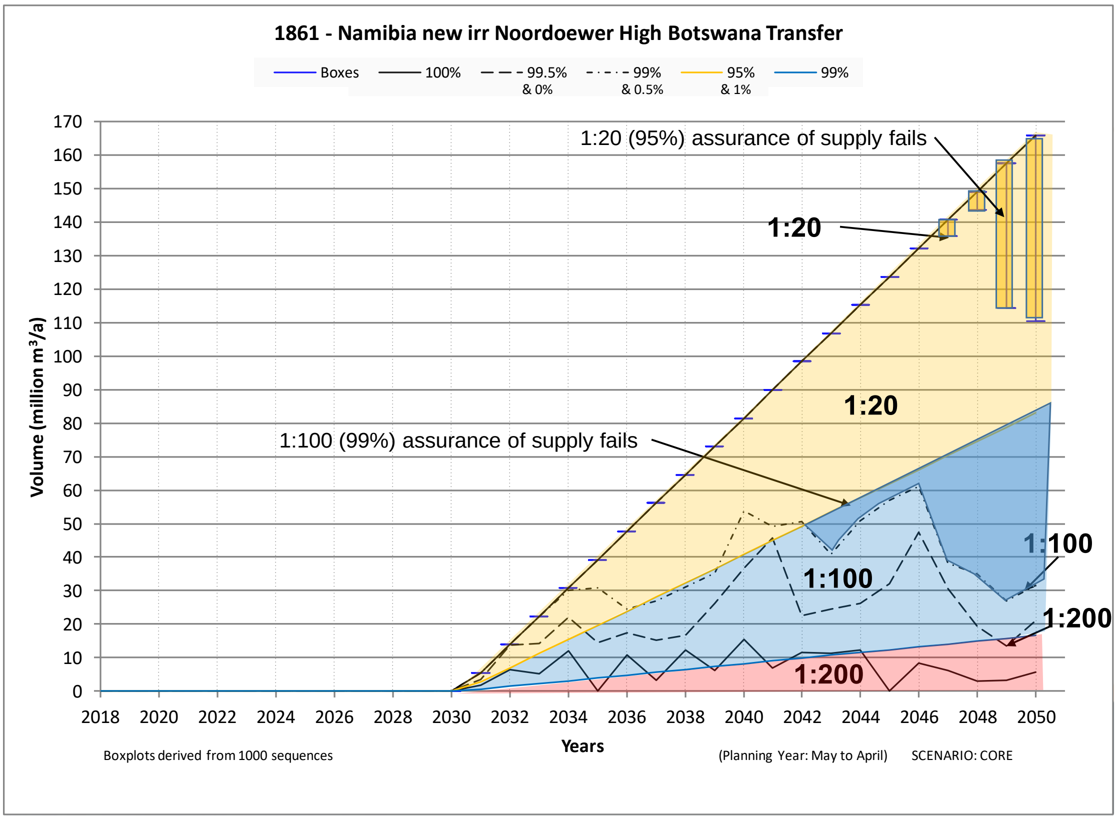


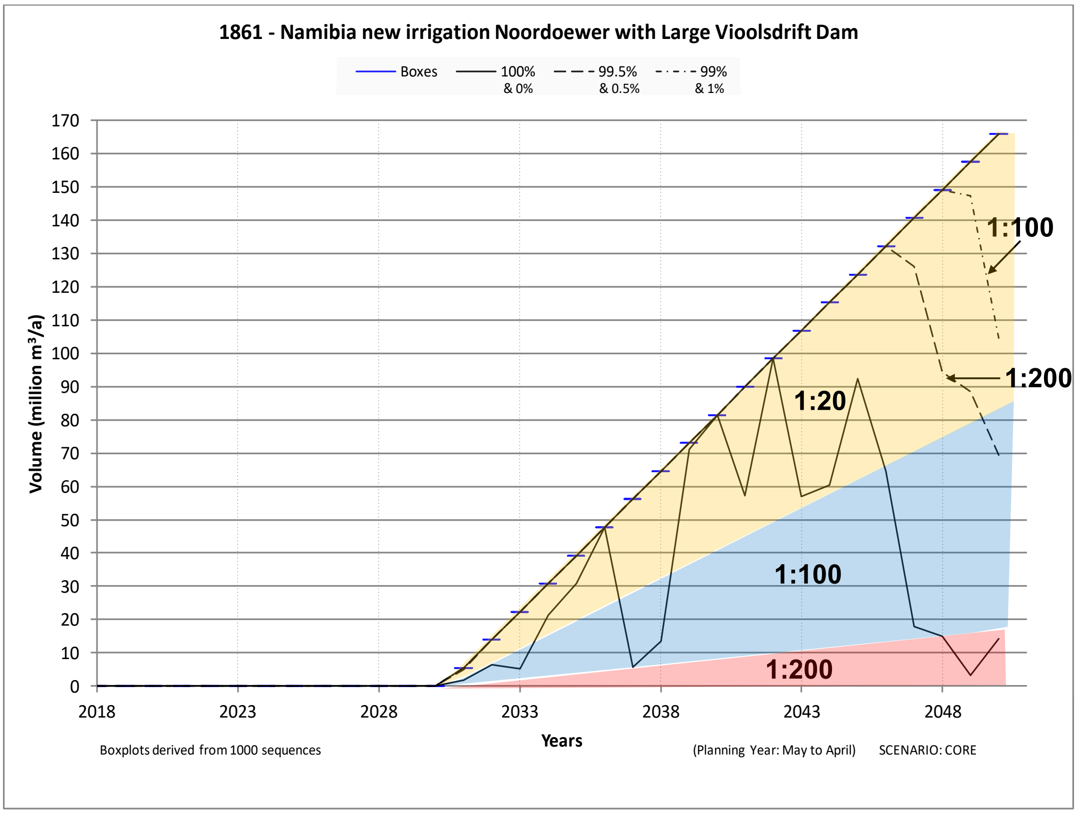
A



B

Figure 7-44:Noordoewer/Vioolsdrift Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario with the large Noordoewer/Vioolsdrift Dam (B) included





B

Figure 7-45: Supply to future Namibia irrigation as supported from the ORP system with the medium size Noordoewer/Vioolsdrift Dam (A) and when the large Vioolsdrift Dam (B) is in place

7.4.6 Makhaleng Dam and transfer system for the low Botswana transfer option and reduced irrigation

The results from this sensitivity analysis was already presented and discussed in **Section 7.3.1** of this report. The difference in the assurance of supply to the irrigation supplied from Makaleng Dam for the large and for the smaller irrigation area is clear from the water supply projection plots in **Figure 7-46**.

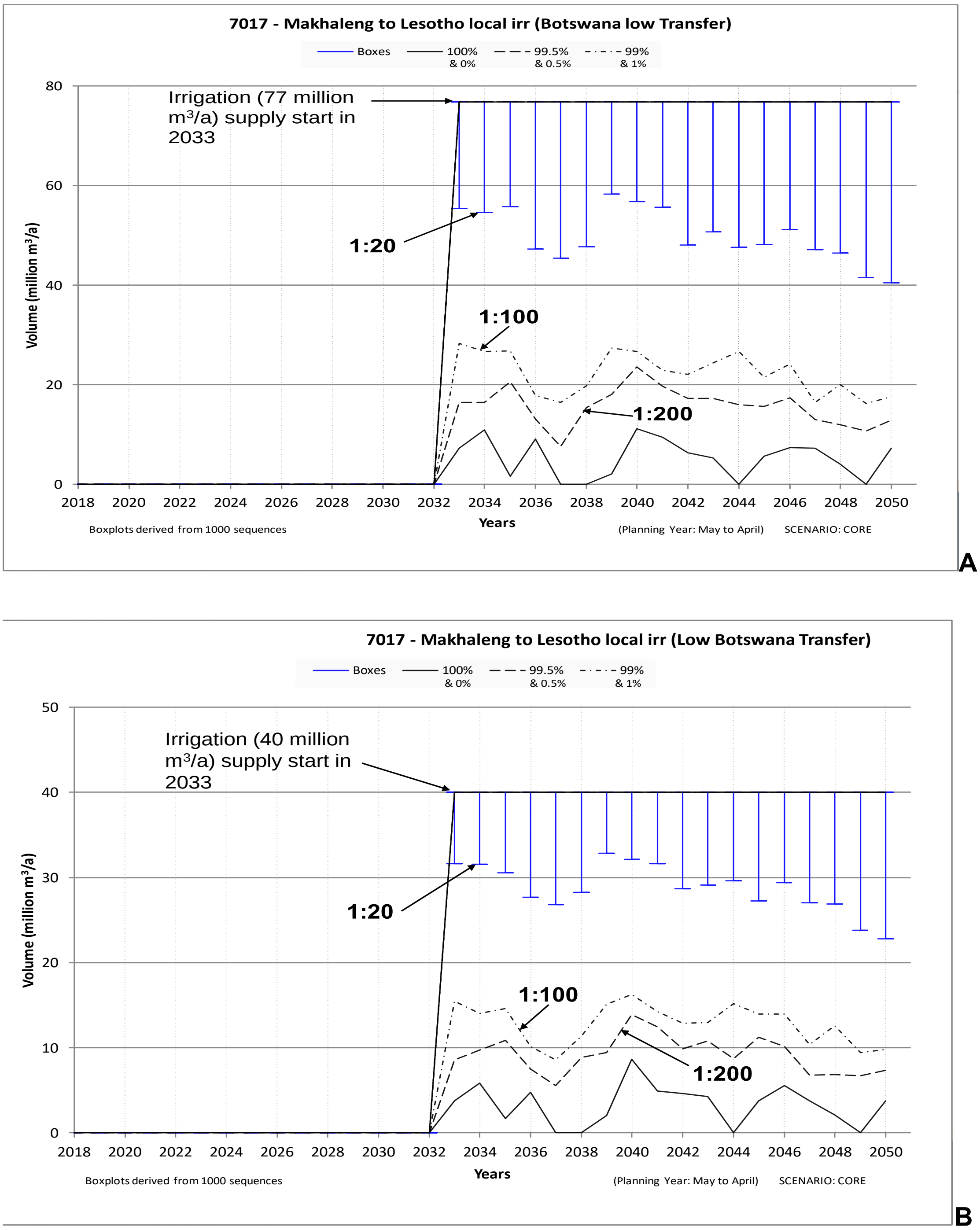


Figure 7-46: Supply to Lesotho irrigation supplied from Makhaleng Dam

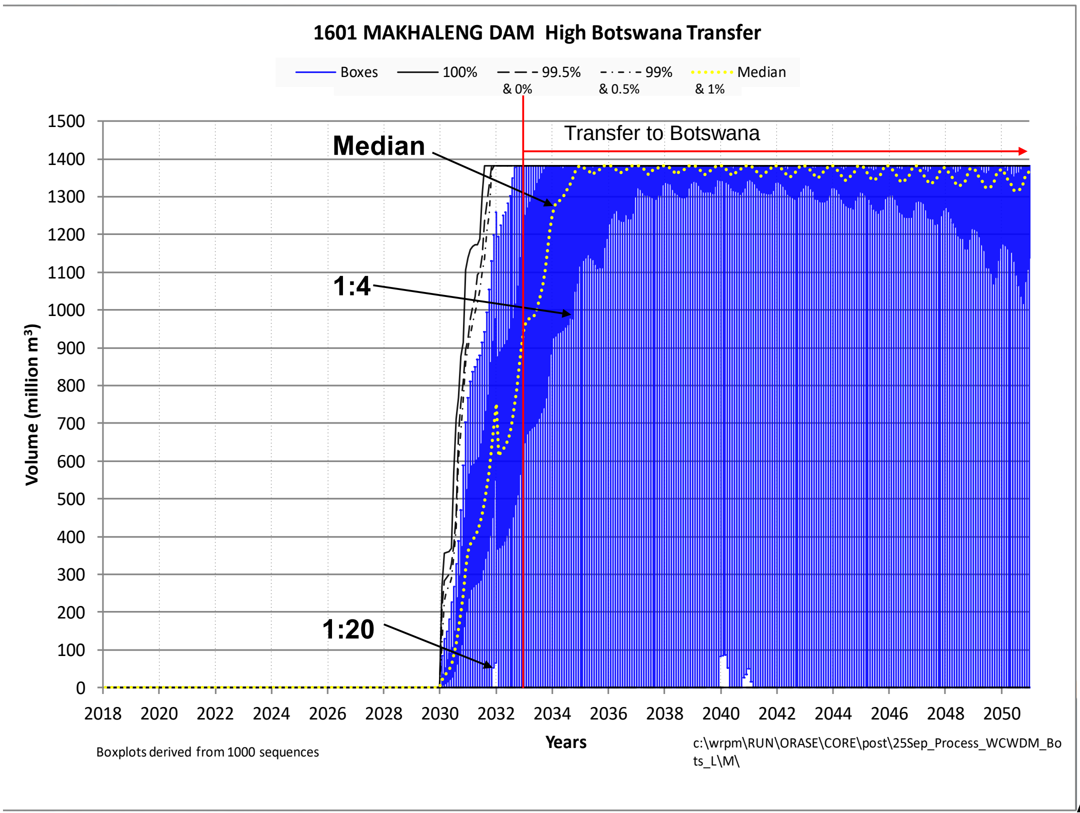
The assurance of supply to irrigation can be further improved by reducing the irrigation more or by improving the operating rule of the Makhaleng Dam and transfer system. In **Section 7.1.7** detail is given on the operating rule improvement and the related results.

7.4.7 Adjusted Makhaleng Dam operating rule to increase the assurance of supply

Results from the two Current Core Scenario's, (one with a high Lesotho Botswana transfer and one with low Lesotho Botswana transfer) showed that the assurance of supply to the Lesotho Botswana transfer for both the high and low transfer options were unacceptably low for typical urban/industrial/mining water use purposes.

To be able to increase the assurance of supply to the users from the Makhaleng water supply scheme, the operating rule of this system was first adjusted. When considering adjustments to the operating rule it is important to note that about half of the yield available from Makhaleng Dam is used to support the ORP to ensure that the ORP water balance remain positive when Makhaleng Dam is in place.

The operating rule used for the Current Core Scenario was to only support the ORP from Makhaleng Dam when the storage levels in the ORP system are very low. This rule has a major advantage in saving evaporation losses from Gariep and Vanderkloof dams. The saving in these evaporation losses then resulted in less support required from Makhaleng Dam.



A

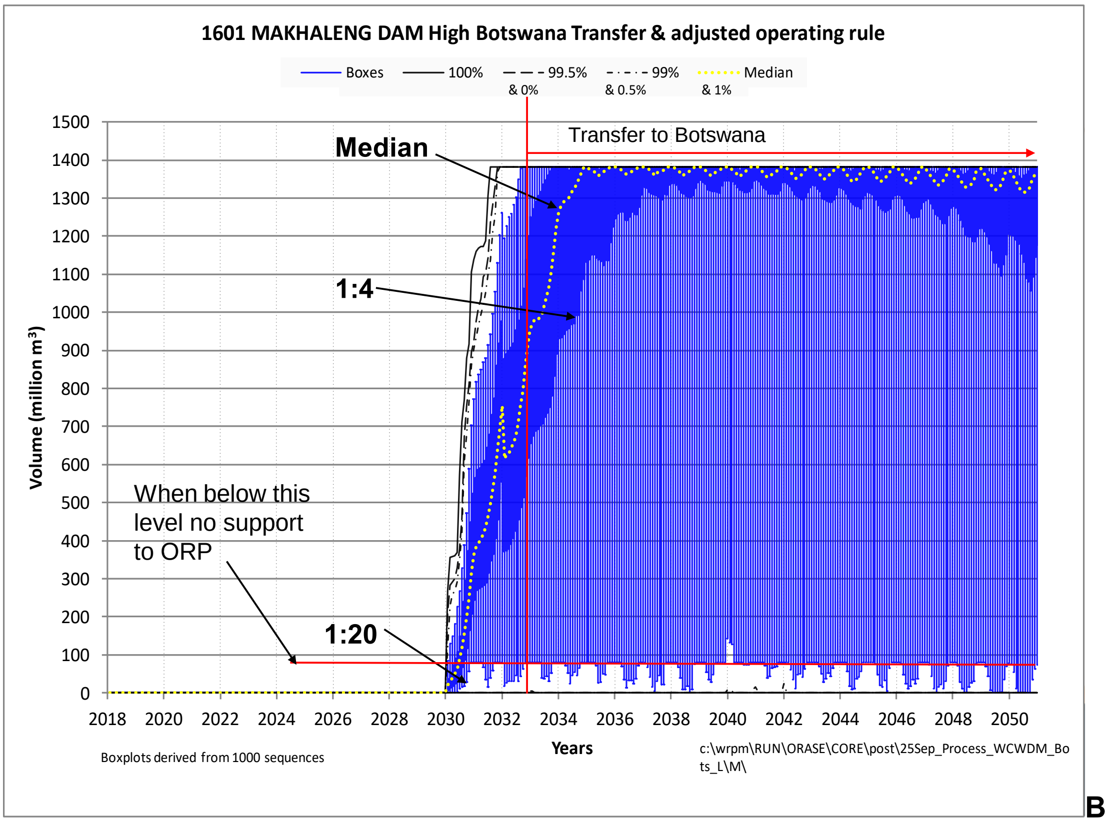


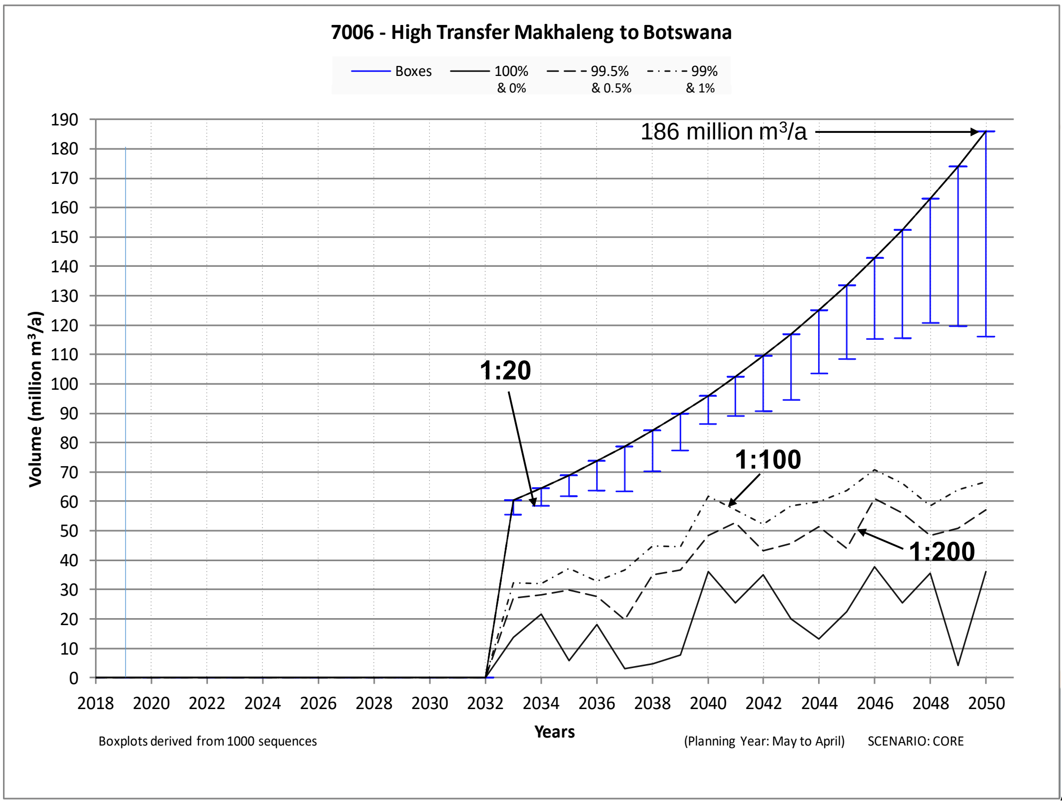
Figure 7-47:Makhaleng Dam storage projection for the Current Core Scenario with high Botswana transfer (A) and for Makhaleng Dam with the adjusted operating rule(B)

During drought periods the ORP system suddenly requires large volumes of water to prevent Gariep and Vanderkloof dams from running empty. This in turn empties, or almost empties Makhaleng Dam resulting in deficits in supply to users from Makhaleng Dam. It was therefore necessary to build in some safe storage in Makhaleng Dam, that can only be utilized by the Makhaleng Dam users but is not available to support the ORP system. For the purpose of this sensitivity analysis a save storage of just over 80 million m^3 was defined for the save zone in Makhaleng Dam. This save volume was based on the typical deficits evident from analysis already carried out thus far.

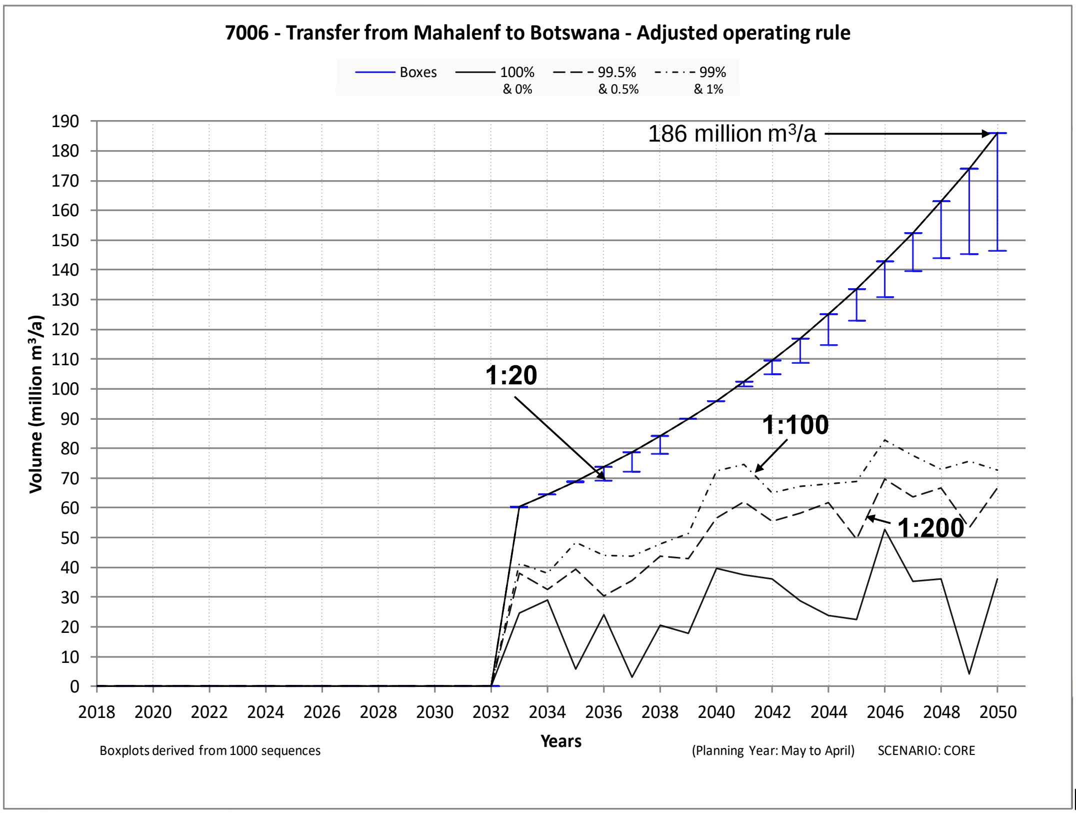
From the storage projection plots for Makhaleng Dam before and after the operating rule adjustment (**Figure 7-47**) one can see that the save storage zone is only occasionally depleted over the simulation period. One should thus consider a further slight increase in the volume of the save zone.

The water supply to the Lesotho Botswana transfer requirements for the two options, Makhaleng Dam before and after the adjustment of the operating rule is given in **Figure 7-48**.

By comparing the two water supply plots it is clear that the adjusted operating rule has significantly improved the assurance of supply to users from the Makhaleng Dam scheme.



A



B

Figure 7-48: Water supply to users from the Lesotho Botswana transfer for the Current Core Scenario with high Botswana transfer (A) and when the adjusted Makhaleng operating rule is in place (B)

A slight further improvement of the assurance of supply is still required and could be obtained by an increase in the volume of the safe storage zone.

The adjustment in the Makhaleng operating rule had no negative impact on the supply to users from the ORP system.

Further work is recommended to improve and optimize the Makhaleng system operating rule. It is however important that the adjustments to the operating rule do not negatively impact on the supply to users from the ORP system.

8 ASSESSMENT OF MUTI PUPOSE DAMS IN LESOTHO

8.1 Background

It is expected that deficits will be experienced in the greater system with the updated Core Scenario in place, as more water is removed from the Senqu basin in support of the Integrated Vaal River System, the possible transfer to Botswana as well as due to local developments within Lesotho.

To be able to overcome the deficit in the main Orange River, the Mohokare/Caledon River or in some places within Lesotho, additional multipurpose dams in Lesotho were assessed to increase the yield available from the basin. This additional yield can then be used to balance the deficits that might have been created due to the updated Core Scenario.

Possible future dams from previous studies in Lesotho including those originally identified for the LHWP were used as the basis for the selection of possible future dams to be analyzed. These possible dams are summarized in **Table 8.1** and shown in **Figure 8-1**.

Table 8-1: Possible future dams that were investigated in previous studies

Name of Dam	From Study	Purpose	River	Storage Capacity (million m^3)	Yield (million m^3/a)
Polihali	LHWP (5)	Transfer & hydropower	Senqu	2322 (gross) 1904.3 (live)	437 (gross HFY) 153 (net HFY)
Taung	LHWP (1)	Transfer	Senqu	1298.9 (live) 1518.9 (live) 1738.9 (live)	525 (gross HFY) 549 (gross HFY) 566 (gross HFY
Mashai	LHWP (1)	Transfer	Senqu	3305.5 gross 2300.8 live	662 (gross HFY) 209 (net HFY)
Tsoelike	LHWP (1)	Transfer	Senqu	2 223.5 gross 1 300.0 live	378 (gross HF) 88 (net HFY)
Lebelo	LHWP (5)	Transfer	Senqunyane	430 (live) 990 (live) 1390 (live)	185 (gross HFY) 218 9 (gross HFY) 226 (gross HFY)
Ntoahae	LHWP (1)	Transfer	Senqu	1432.0 gross 712.0 live	168 (gross HF) 36 (net HFY)
Malatsi	LHWP (1)	Transfer	Senqunyane	1030.0 gross 380.0 live	224 (gross HF) 78 (net HFY)
Ngoajane	Lesotho Lowlands	Urban/rural, Irrigation & hydropower	Hololo	36 (SMEC study) (2) 36 (Parmn) (3)	36 (1 in 50)
Hlotse	Lesotho Lowlands	Urban/rural, Irrigation & Hydropower/ Industrial	Hlotse	105 (SMEC study) (2) 60 (Parkmn) (3)	205.1 29 (1 in 50)

Name of Dam	From Study	Purpose	River	Storage Capacity (million m^3)	Yield (million m^3/a)
Makhaleng	Lesotho Lowlands and Current study	Hydropower, urban/ Industrial, Irrigation and transfers	Makhaleng	48 (SMEC study) [(2)] 1094 (this study) 28.4(Parkm) [(3)]	26.8 to 336.7 (gross) 363 (gross HFY) 149 (net HFY) 92.0(1 in 50 gross)
Oxbow	LHWP [(5)] & Monenco study Connect to Muela Dam	Hydropower	Malibamatso	Monenco [(6)] LHWP [(5)] 57 live 82.9 live 116.0 live	94.7 (HP flow) 60.4 (gross HFY) 69.0 (gross HFY) 80.9 (gross HFY)
Verbeeldings-kraal Dam	Orange [(4)] River Reconcilia tion Strategy	Increase system yield and support to ORP system	Orange/ Senqu	1363[(4)] live	200 (gross HFY)
Two possible future dams on the Senqu (Senqu B and Senqu D dams)	Lesotho Lowlands and Hydro-Power	Hydropower/Irrigation/domestic/industrial	Senqu	Final storage capacities still to be determined	Yield from these two dams still to be determined
Maletsunyane /Semonkong	Lesotho Lowlands and Hydro-Power	Hydropower/Irrigation/domestic/industrial	Maletsunyane	Storage capacity not yet determined	Yield still to be determined

Notes: (1) Orange River System Analysis Study 1993

(2) Lesotho Water Sector Improvement Project ll - Consulting Services for the Update Detail designs, and Construction supervision of the Lesotho Lowlands Water Supply Scheme (SMEC) 2017

(3) Lesotho Lowlands Water Supply Scheme – Consultancy Services for a Feasibility Study of the Scheme (Parkman) 2004 Study

(4) Development of Reconciliation Strategies for Bulk Water Supply Systems: Orange River – Final Reconciliation Strategy 2014

(5) Lesotho Highlands Water Project: Consulting Services for the Feasibility Study for Phase ll – Water Resources & System analyses: Stage 1 Supporting Report 2007

(6) Oxbow Scheme Study by Monenco Consultants 1989

Although the development of new dams mainly impacts on users downstream of the dam, some smaller impacts can also be expected on upstream systems. A simple illustration of this would be the following:

- Let’s assume there is no water use from the Orange River by the RSA and Namibia as it was many years ago.
- If Lesotho wanted to build a dam in the Senqu under such conditions, this dam would have no impact on downstream users as there were no users, except for the environment.

- Over and above the environmental release no additional releases (compensation releases) would then be required from the Lesotho Dam.
- Currently however the Orange River in the RSA and along the RSA/Namibia border is highly developed with many users as well as major dams.
- Under these conditions any dam build by Lesotho in the upstream catchment will have a significant impact on the water supply downstream and compensation releases from the Lesotho Dam will be required to be able to maintain the existing downstream water balance.

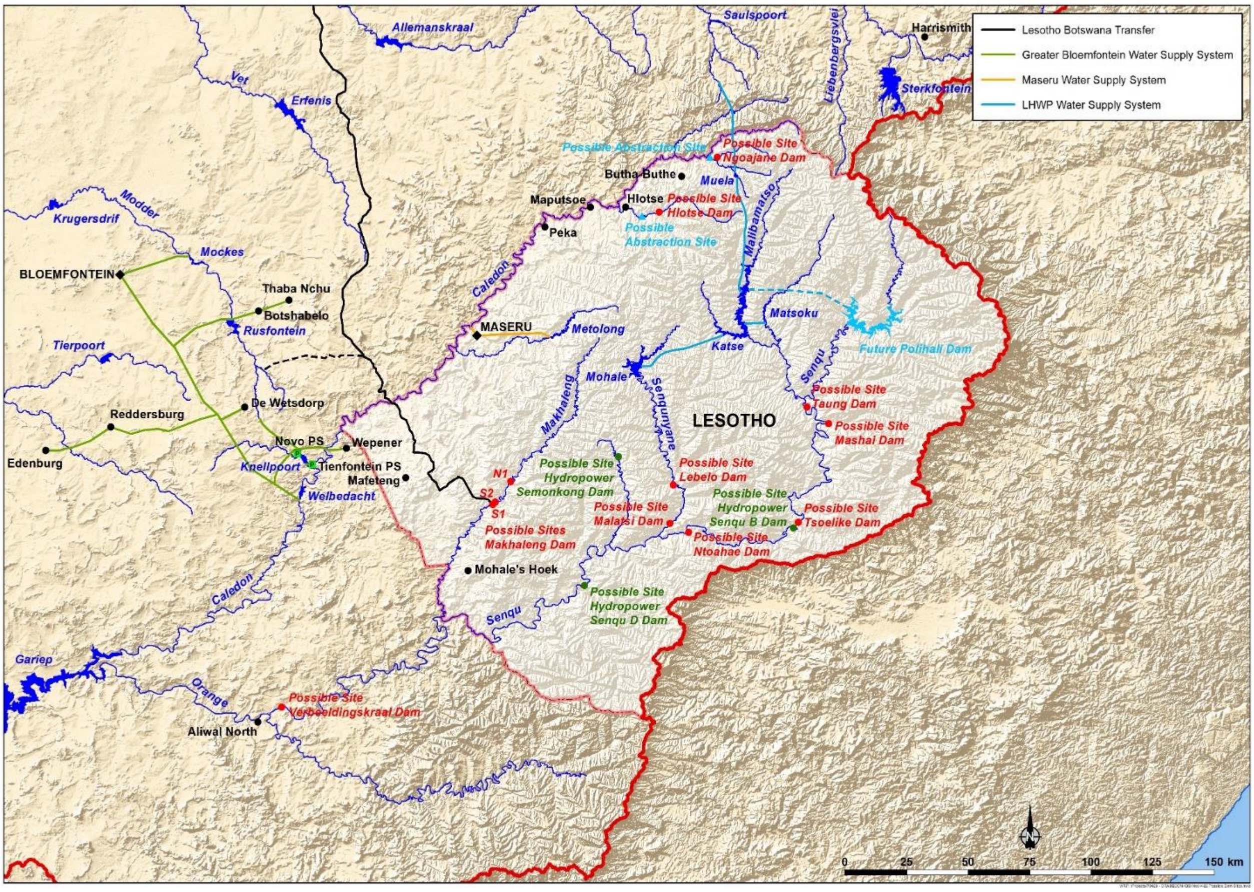


Figure 8-1: Possible dam sites and major water supply systems

A practical example of such a case can be illustrated by the impact of Polihali and Verbeeldingskraal dams on the available yield from the future Makhaleng Dam in Lesotho. This will be described in more detail in **Sections 8.2** and **8.3** to follow.

8.2 Yield analyses Scenarios

The WRYM data set previously used for Orange River analyses during the ORASECOM Integrated Water Resources Management Plan Phase 3 (2014) Study was used as basis. The historic firm yield determined for the Orange River Project (Gariep and Vanderkloof dams) with this data set was reported on as 3 252 million m^3/a. This data set included the full Phase 1 of the LHWP and related transfer to the Vaal River in the RSA as well as Metolong Dam. All the upstream RSA and Lesotho demands were set at 2013 development level at the time.

2018 Base Scenario: The 2014 data set was updated by including the 2018 water requirements to be imposed on the system and upstream users as obtained from the Water Requirement task (ORASECOM, 2019d) of the current study. This scenario is referred to as the 2018 Base Scenario.

2030 Base Scenario: The following major water supply schemes from Vanderkloof Dam and upstream should most probably be in place by approximately 2030. These schemes are expected to include:

- Lesotho Highlands Phase ll scheme (Polihali Dam and transfer tunnel)
- Verbeeldingskraal Dam in RSA, located upstream of Aliwal North (the main purpose of this dam is to restore the ORP system yield due to Polihali Dam which resulted in a significant reduction in the yield of the ORP
- Utilizing the Lower Level storage in Vanderkloof Dam to increase the ORP system yield. It will not be possible to generate hydro power when water from the lower level storage is released from Vanderkloof Dam. (The resulting increase in the ORP system yield will be used in combination with Verbeeldingskraal Dam to counteract the reduction in yield of the ORP system when Polihali Dam comes into operation)
- Makhaleng Dam and transfer system used to transfer water from Lesotho to Botswana (Gaborone) and RSA as well as to support local Lesotho water requirements urban and irrigation.

A second Base scenario was thus defined to represent the 2030 development level. The 2030 Base scenario used the 2030 development level water requirements. Major infrastructure developments included in this 2030 Base Scenario were Polihali Dam, Verbeeldingskraal Dam and the use of the Vanderkloof Lower Level Storage. The Orange River Reconciliation Strategy study done by the RSA (DWS, 2015a) included these latter two infrastructure options as part of the strategy to counteract the deficit in yield from the ORP as result of the inclusion of Polihali Dam and the related increase in transfer to the Integrated Vaal River System. A brief description of each of the scenarios analyzed is given in **Table 8-2**.

Scenario 2 is as the 2030 Base Scenario, but with Makhaleng Dam and the transfer to Botswana included. Based on current knowledge this will most probably be the next of the Lowlands Schemes to be implemented by Lesotho, together with Botswana and the RSA. It is currently uncertain when the other two Lesotho Lowland schemes, Hlotse and Ngoajane will be implemented although estimations given by Lesotho indicated 2030 and 2035 respectively.

From this study, Component III Phase 1 (ORASECOM, 2019a) results for Makhaleng Dam indicated that the S2 Makhaleng Site is one of the best sites that will be investigated further. Although different dam sizes were analyzed at this site, the 3 MAR dam size is expected to be taken forward.

The yield from this dam will be sufficient to support the estimated Botswana transfer (Lesotho and RSA demand components included) as well as to provide compensation releases to the ORP system to prevent or significantly limit the reduction in yield at the ORP, due to the upstream Makhaleng Dam and associated transfer development. The yield results for the S2 Makhaleng Dam as obtained from the analyses carried out as part of Component III Phase 1, Water Resource assessment task (ORASECOM, 2019a), is given in **Figure 8-1**. From the yield capacity curve for a live storage of approximately 270 million m^3 a historic firm yield (HFY) of just over 200 million m^3/a can be obtained.

From **Figure 8-1** it is evident that at site S2 the yield of Makhaleng Dam can still be increased significantly when the storage is increased. It will thus be possible by increasing the storage capacity of Makhaleng Dam, to use the increased yield to restore or partly restore the yield reduction in the ORP system.

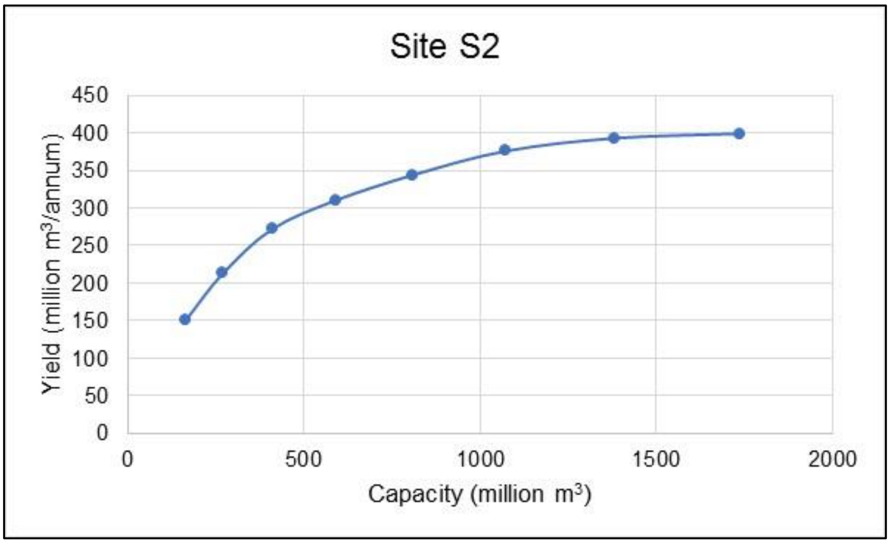


Figure 8-2: Makhaleng Dam yield at site S2

Table 8-2: Summary of proposed scenarios for historic firm yield analyses

Scenario	Description	Purpose
ORP yield 2013	ORASECOM Phase lll at 2013 development level	HFY of the then existing ORP
2018 Base Scenario	Current system with existing infrastructure and 2018 development level	Determine yield from ORP to compare with the Phase 3 ORP yield result and related yield impact due to increased upstream water requirements.
2030 Base Scenario	As 2018 Base scenario but including future infrastructure developments: Polihali Dam, Verbeeldingskraal Dam, Lower Level storage in Vanderkloof and 2030 development level water requirements.	Determine yield from ORP to confirm whether Verbeeldingskraal and Vanderkloof Lower Level storage were able to balance the ORP yield reduction due to Polihali Dam.
Scenario 2 (2030)	As the 2030 Base Scenario but including the proposed Makhaleng Dam and related transfer to Botswana	Determine yield from ORP and verify whether the proposed Makhaleng Dam is able to support the Botswana transfer and not reduce the ORP yield.
The purpose of Scenarios 2d to 2h is to determine the impact on yield from upstream dams due to the development of downstream dams		
Sub-scenario 2d (2030)	As Scenario 2 but excluding Polihali, Verbeeldingskraal and Makhaleng Dam.	To determine the HFY at Vanderkloof/Gariep when none of the three dams are in place
Sub-scenario 2e (2030)	As scenario 2d but including a 3 MAR Makhaleng Dam. Makhaleng Dam allowed to support Gariep and Vanderkloof dams to maintain the downstream water balance.	This scenario will provide the HFY available at Makhaleng when the downstream system (ORP) still produces the same HFY as for Scenario 2d
Sub-scenario 2f (2030)	As scenario 2 but excluding Makhaleng Dam. This scenario is in fact the same as the 2030 Base Scenario	This scenario provides the HFY available at Vanderkloof/Gariep when Polihali and Verbeedingskraal dams are in place.
Sub-scenario 2g (2030)	As scenario 2f but including a 3 MAR Makhaleng Dam. Makhaleng Dam allowed to support Gariep and Vanderkloof dams to maintain the downstream water balance.	This scenario will provide the HFY available at Makhaleng when the downstream system (ORP) still produces the same HFY as for Scenario 2f.
Sub-scenario 2h (2030)	As scenario 2g but not allowing Makhaleng Dam to support Gariep and Vanderkloof dams.	This scenario will provide the HFY available at Makhaleng with no support to the ORP and will show the impact of Makhaleng Dam on the yield available from the ORP
Scenario 3 (2030)	As Scenario 2 but including the proposed Hlotse Dam (105 million m^3 gross storage) in the Lesotho Lowlands.	Determine the yield from Hlotse Dam. Determine the impact of the Hlotse Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River

Scenario	Description	Purpose
Scenario 3c (2030)	As Scenario 3 but increase Hlotse Dam by 15 million m^3 to gross storage to 120 million m^3	Determine the increase in yield due to the larger Hlotse Dam. Determine the impact of the Hlotse Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River
Scenario 3d (2030)	As Scenario 3c: Supply the expected 2050 demand (urban/rural, irrigation and EWR) from the dam. Use the remaining yield to support users along the Caledon and the ORP.	Determine whether the remaining yield from Hlotse Dam will be able to restore the downstream water balances.
Scenario 4 (2030)	As Scenario 2 but including the proposed Ngoajane Dam in the Lesotho Lowlands.	Determine the yield from Ngoajane Dam. Determine the impact of the Ngoajane Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River.
Scenario 4c (2030)	As Scenario 4 but increase Ngoajane Dam by 27.3 million m^3 to a gross storage of 63.3 million m^3	Determine the increase in yield due to the larger Ngoajane Dam. Determine the impact of the Ngoajane Scheme on the yield available from the ORP, Greater Bloemfontein systems and on the Lesotho abstractions from the Mohokare River
Scenario 4d (2030)	As Scenario 4c: Supply the expected 2050 demand (urban/rural, irrigation and EWR) from the dam. Use the remaining yield to support users along the Caledon and the ORP.	Determine whether the remaining yield from Ngoajane Dam will be able to restore the downstream water balances.
Scenario 5 (2030)	Proposed Maletsunyane/Semonkong Dam	No data was available for this dam
The purpose of Scenario 6a to 6b is to determine the impact of large hydro-power dams on the Senqu River on the yield available from the ORP and Makhaleng Dam.		
Scenario 6a	Senqu B2 and D2 cascade hydropower scheme in combination with sub-scenario 2g Hydro-power releases to provide a base load	Determine the yield impact on the ORP system and the proposed Makhaleng Dam
Scenario 6b	Senqu B2 and D2 cascade hydropower scheme in combination with sub-scenario 2g Hydro-power releases to be aligned with normal monthly flow distribution pattern	Determine the yield impact on the ORP system and the proposed Makhaleng Dam
Scenario 7b	Scenario 2g with Ntoahae Dam (gross storage 2 280 million m^3) included.	Determine the net yield available from Makhaleng Dam when Ntoahae Dam is used to release compensation water in support of

Scenario	Description	Purpose
		the ORP. Reduce compensation releases from Makhaleng Dam to the minimum possible.
Scenario 8b	Scenario 2 with a raised Verbeeldingskraal Dam (14 m raising) included. Gross storage of the raised Verbeeldingskraal Dam is 2 327 million m^3. This is the maximum raising based on the available dam basin characteristics	The purpose of the raising of Verbeeldingskraal Dam is to generate additional yield from the system which can be used to release compensation water in support of Gariep and Vanderkloof dams and thereby reduces the compensation requirements from Makhaleng Dam. This will result in an increase net yield available from Makhaleng Dam.

By increasing Makaleng storage to be in line with a 3 MAR storage, like most of the other Lesotho Highland dams, will most probably be the largest dam size to consider for this study. The storage capacity of Makaleng Dam will then be in the order of 1 382 million m^3, which is about five times the storage required to produce a yield of 200 million m^3/a.

For the purpose of Scenario 2, a target transfer volume of 200 million m^3/a was imposed on Makhaleng Dam as well as the Class D EWR. When there is still water available in Makhaleng Dam, after first supplying the EWR and transfer volume, Makhaleng Dam was allowed to support the Orange River Project when the storage levels in Gariep and Vanderkloof dams are very low. The available yield for this scenario was then determined at the Orange River Project (Gariep and Vanderkloof dam combination) to evaluate the reduction or increase in the ORP yield as result of Makhaleng Dam and the associated transfer.

Scenario 2 sub-scenarios: The purpose of the Scenario 2 sub-scenarios is to determine the impact of RSA dam developments on a future Lesotho Dam development. For the purpose of this scenario the RSA dam developments of Verbeeldingskraal in combination with Polihali Dam was selected, and the impact was determined on the future Makhaleng Dam in Lesotho. This is a realistic scenario as all three these dams are included in the short to medium planning horizon of the two countries.

These sub-scenarios focus on the yield impact specifically on Makhaleng Dam, and it is thus important to keep the yield required at Vanderkloof/Gariep fixed at the historic firm yield (HFY) and then vary the yield target at Makhaleng Dam to determine the new HFY at Makhaleng Dam, that will indicate the impact on the available yield from Makhaleng Dam. Four sub-scenarios are required to be able to determine the yield impact on Makhaleng Dam:

- Sub-scenario 2d: As scenario 2, but excluding Polihali, Verbeeldingskraal and Makhaleng. This scenario will give the HFY at Vanderkloof/Gariep when none of the three dams are in place.
- Sub-scenario 2e: As scenario 2d but including a 3 MAR Makhaleng Dam with a transfer from the dam and a class D EWR imposed on Makhaleng Dam. Makhaleng Dam is allowed to release compensation water in support of the ORP system to maintain the same HFY for the ORP as determined for Scenario 2d. This scenario will provide the HFY available (maximum transfer volume) at Makhaleng Dam when the downstream system (ORP) still produces the same HFY as for Scenario 2d. This Makhaleng Dam HFY thus represents the available yield before the RSA dam developments of Polihali and Verbeeldingskraal are in place.
- Sub-scenario 2f: As scenario 2 but excluding Makhaleng Dam. This scenario is in fact the same as the 2030 Base Scenario. This scenario provides the HFY available at Vanderkloof/Gariep (ORP) when Polihali and Verbeedingskraal dams are in place.
- Sub-scenario 2g: As scenario 2f but including a 3 MAR Makhaleng Dam with a transfer from the dam and a class D EWR imposed on Makhaleng Dam. Makhaleng Dam is allowed to release compensation water in support of the ORP system to maintain the same HFY for the ORP as for Scenario 2f. This scenario will provide the HFY (maximum transfer) available at Makhaleng when the downstream system (ORP) still produces the same HFY as for Scenario 2f. The HFY for Makhaleng Dam for this scenario thus represents the Makhaleng Dam HFY when the RSA dam developments of Polihali and Verbeeldingskraal dams are in place.

The difference in the Makhaleng Dam HFY between sub-scenario 2g and 2e will represent the impact on the available yield from Makhaleng Dam due to the RSA Dam developments of Polihali and Verbeeldingskraal dams.

Sub-scenario 2h: As scenario 2g but not allowing Makhaleng Dam to release compensation water in support of Gariep and Vanderkloof dams. The gross HFY will be determined at Makhaleng Dam for this scenario. The class D EWR will still be imposed on Makhaleng Dam as part of scenario 2h. This scenario will then provide the gross HFY that can be produced from Makhaleng Dam without compensation releases from Makhaleng Dam. The reduced yield from the ORP will also be determined from this scenario. Comparing this ORP yield with the ORP yield from Scenario 2f will provide the yield impact of a 3 MAR Makhaleng Dam on the existing ORP system at 2030 development level.

Sub-scenario 2j: As scenario 2h but with a much smaller Makhaleng Dam but with a gross HFY that will be sufficient to supply the local as well as intended high transfer requirements from the dam. A live storage of 298 million m^3 for Makhaleng Dam was considered for this purpose.

Scenarios 3 and 4: The Lesotho Water Resources Assessment Report from the SMEC Study (SMEC, 2017) recommended that dams be built at Hlotse and Ngoajane with storage capacities of 105 million m^3 and 36 million m^3 respectively. The time when these dams need to be built was not given, although it is expected that it will take place after Makhaleng Dam. Hlotse and Ngoajane possible future dams will form part of Scenarios 3 and 4 respectively. The SMEC report (SMEC, 2017) provides an indication of the EWRs required downstream of Hlotse and Ngoajane dams, but no detail on how it was determined or what the monthly distribution is. For the Ngoajane Dam the lowest annual value of 8.02 million m^3/a was used for Scenario 4 as it already represents 22. % of the MAR upstream of Ngoajane Dam. For Hlotse Dam the 2030 EWR of 14.42 million m^3/a was taken which is in line with the development level of the scenario to be analyzed and represents more or less the average over the period 2015 to 2045 as given in the SMEC Report (SMEC, 2017). The monthly distribution of these two annual EWR target values was based on the distribution of the average monthly natural flow of the related flow sequence just upstream of the two dams.

Scenario 5:

Lesotho indicated that Semonkong Dam is also one of the future dams to be developed. It is expected that this dam can be in place by 2040. Information available for this dam was however insufficient to be able to model the dam in the WRYM.

Scenario 6: The Government of Lesotho is currently carrying out a study (LHDA, 2018) to investigate the increase of conventional hydro-power generation to achieve independence in the energy supply to Lesotho. Currently Lesotho is only generating approximately 47% of its own electricity needs. The rest is obtained from the RSA and Mozambique. The current hydro-power study (LHDA, 2018) is not yet completed, but preliminary results indicated that one of the better options to consider is a cascading scheme making use of two dams on the Senqu River. The upper dam (Senqu B2 site) is located just downstream of the previously identified Tsoelike (LHWP possible future dam) site. The lower dam site referred to as the Senqu D2 site is in the Senqu River on the border between the Mohale’s Hoek and Quiting districts. These dams will mainly be used for hydro-power generation purposes, resulting in non-consumptive demands being imposed on the dams. River flow downstream of these two dams will thus be largely regulated and should provide a more stable base flow entering the future Verbeeldingkraal Dam and or Gariep Dam, which in turn will increase the yield available from the ORP system.

Scenario 2 and related sub-scenarios already indicated the significant decrease in the yield of the ORP system as result of the possible future Makhaleng Dam and transfer. A large portion of the gross yield available from Makhaleng Dam is required just to balance the reduction in yield of the ORP system. As result of this, the net yield available from Makhaleng Dam reduced substantially.

There is thus a need to evaluate the possible contribution of these two hydro-power dams on the available system yield from the ORP and Makhaleng Dam systems. Scenario 2g was used as basis for Scenario 6. The two proposed hydro-power dams (cascading option) was then included based on the recommendation from the current hydro-power study.

Operating rules for the two proposed hydro-power dams are not yet available and can significantly impact on the yield benefit produced by the two dams. Two operating options were thus considered for Scenario 6, Scenario 6a and 6b.

- Scenario 6a: This scenario will focus on the production of a base load energy supply, which will result in a fairly stable release pattern that will in general not vary much from month to month. It is expected that this option will produce the higher increase in the overall system yield.
- Scenario 6b: This scenario will keep the monthly release more or less in phase with the natural flow variation over the year, as typically would be required for EWR release purposes. This option will most probably result in a lower increase in the overall system yield.

The key characteristics of the two hydro-power dams are summarized in **Table 8.3**.

For Scenario 6a the average flow of 22 m^3/s and 33.5 m^3/s were imposed on the Senqu B2 and Senqu D2 dams respectively, for each month of the year. In months when higher inflows were available, higher releases through the turbines were allowed up to the maximum turbine capacity, to prevent or reduce spills from the dam.

The average modeled flow from Scenario 6a through the turbines per annum was determined as 22.9 m^3/s for the Senqu B2 dam and 38.7m^3/s for Senqu D2 dam. For Scenario 6b these average annual flows were used and distributed based on the monthly inflow patterns at the dam sites, before the hydro-power dams were in place. This was then used as the target flow settings for Scenario 6b. Similar to Scenario 6a, higher releases up to the maximum turbine capacity were allowed to prevent or reduce spills from the dam in high flow months.

Table 8-3: Key characteristics of possible hydropower dams

Dam height (m) (at FSL)	Reservoir volume (million m^3)	M.O.L (m)	Live Storage (million m^3)	Number of turbines	Design flow per turbine (m^3/s)	Generating hours per day	Average flow (m^3/s) target releases
Senqu B2 Site							

100 (1720)	720.4	1657	547.3	4	25	5 to 6	22*
Senqu D2 Site							
60 (1520)	624.5	1499	416.6	2	30	±16	33.5*

Note: * - The average flow was determined by evaluating WRYM analyses results to obtain optimum use from the dam. This is more ore les in line with the generating hours per day given in the hydro-power report (LHDA, 2018)

Results from the Scenario 6 analysis were documented in **Section 8.3**.

Scenario 7b: The purpose of Scenario 7b was to include Ntoahae Dam (one of the previously LHWP identified dams) to increase the net yield of the system. The increased net yield will then be used to supply compensation water to the ORP system to reduce or eliminate the compensation releases required from 3 MAR Makhaleng Dam. Ntoahae Dam was selected for this purpose over and above the other possible previously identified LHWP dams as it was the most downstream dam, having the largest incremental catchment downstream of the existing as well as the near future Polihali Dam. This will result in the highest additional net yield that can be generated from these previously selected LHWP possible dams. The URV for Ntoahae Dam is also relatively low in comparison with other dams considered as part of the DWS RSA study "Development of Water Reconciliation Strategies or large Bulk Water Supply Systems: Orange River" (DWS,2015a) (See **Table 8-4**).

Table 8-4: Summary of estimated costs, yield and URVs

Option	Cost (R million)	Yield (million m^3/a)	URV		
			6%	8%	10%
Verbeeldingskraal FSL 1385	1048	200	R0.39	R0.51	R0.63
Malatsi FSL1652	1373	119	R0.87	R1.11	R1.39
Ntoahae FSL 1645	1370	232	R0.44	R0.57	R0.71

Note: Costs based on 2012 related costs

Scenario 2g was used as basis for Scenario 7b, but with a large Ntoahae Dam included. The live storage for Ntoahae was taken as 1 890 million m^3 for the purpose of this scenario.

Scenario 8b: Scenario 8b is as Scenario 2, but with a raised Verbeeldingskraal Dam (14 m raising) included. This is the maximum raising based on the available dam basin characteristics. The purpose of the raising of Verbeeldingskraal Dam is to generate additional yield from the system which can be used to release compensation water in support of Gariep and Vanderkloof dams and thereby reduces the compensation requirements from Makhaleng Dam. This will result in an increase net yield available from Makhaleng Dam. The initial main purpose of Verbeeldingskraal Dam was to partly compensate for the reduction in yield at the

ORP system due to the inclusion of Polihali Dam. The maximum storage considered by DWS RSA for this purpose was limited to not inundate Lesotho. It is however possible to consider a larger dam at this site, if it is agreed by both counties (RSA and Lesotho) that part of Lesotho can also be inundated by the larger Verbeeldingskraal Dam.

8.3 Yield analyses Results

The historic firm yield results for the given scenarios were summarized in **Table 8.4**.

Yield results are provided for each of the major sub-systems in the Orange-Senqu catchment from Vanderkloof Dam and upstream. The Orange River Project is the largest of these major sub-systems comprising of the two largest dams in the overall system, Gariep and Vanderkloof dams. All the other sub-systems, current and possible future sub-systems is located upstream of the ORP system. These sub-systems already have, or will in future impact on the ORP system, resulting in a decrease in the ORP system yield. The ORP is currently already fully utilized and any reduction in yield will result in deficits in water supply to the users supplied from the ORP.

Other important water supply systems that were also evaluated for each of the scenarios includes the Greater Bloemfontein system as well as all the Lesotho towns including Maseru that takes water from the Mohokare (Caledon) River.

The 2018 Base Scenario showed a decrease in the ORP yield of 134 million m^3/a due to increased upstream water requirements from 2013 to 2018.

The 2030 Base Scenario clearly showed that the inclusion of Verbeeldingskraal Dam and the Lower Level Storage in Vanderkloof Dam were sufficient to balance the decrease in the ORP yield due to the inclusion of Polihali Dam, the increased transfer to the Vaal System, as well as the increase in upstream water requirements.

Scenario 2: Results from the analysis showed that the large Makhaleng Dam at S2 (Scenario 2) was almost able to restore the ORP yield balance with only a 43 million m^3/a reduction in the ORP yield. Although the large Makhaleng Dam was able to generate a gross yield of 378.4 million m^3/a, the net increase for the system yield was only 158 million m^3/a. It is also evident that the large Makhaleng Dam can't support a total transfer/demand of 200 million m^3/a without having a negative impact on the yield available from the ORP.

Scenario 2 Sub-scenarios: As explained in **Section 8.2** the purpose of the Scenario 2 sub-scenarios 2d to 2g is to determine the impact of RSA dam developments on a future Lesotho dam development. The focus for these sub-scenarios is to determine the impact on the Makhaleng Dam yield in Lesotho, due to the inclusion of the RSA related dams Verbeeldingskraal and Polihali. Scenario 2h is used to show the impact of a 3 MAR Makhaleng

Dam on the ORP system yield and to determine the gross yield available from Makhaleng Dam, after supplying the Class D EWR downstream.

Sub-scenario 2d: An HFY of 3 336 million m^3/a is available at Gariep/Vanderkloof (ORP system) at 2030 development level with no Polihali, Verbeeldingskraal and Makhaleng dams in place.

Sub-scenario 2e: This scenario shows that the net yield available from a 3 MAR Makhaleng Dam is 199 million m^3/a when no Verbeeldingskraal and Polihali dams are included and the water balance for the downstream ORP remains the same as for Scenario 2d.

Table 8-5: Summary of historic firm yield results focused on 2030 development level

Scenario	System and sub-system yield (million m^3/a)						
	ORP	LHWP	Makhaleng	Hlotse	Ngoajane	Total	Net yield increase
ORASECOM IWRMP Phase III	3 252	780	0.0	0.0	0.0	4 032	n.a.
2018 Base Scenario	3 118	780	0.0	0.0	0.0	3 898	n.a.
2030 Base Scenario	3 297	1 171.2	0.0	0.0	0.0	4 468	n.a.
Scenario 2	3 254	1 171.2	200[$] (and ± 178 support to the ORP)	0.0	0.0	4 625	(2–2030base)* 158
Sub-scenario 2d	3 336	780	0	0.0	0.0	4 116	
Sub-scenario 2e	3 336	780	199	0.0	0.0	4 315	(2e–2d)* 199
Sub-scenario 2f	3 297	1 171.2	0	0.0	0.0	4 468	
Sub-scenario 2g	3 297	1 171.2	188	0.0	0.0	4 656	(2g – 2f)* 188
Sub-scenario 2h	3 045	1 171.2	378.4	0.0	0.0	4 595	(2h – 2f)* 126
Sub-scenario 2j	3 112	1 171.2	218	0.0	0.0	4 501	(2–2030base)* 33
Scenario 3	3 228	1 171.2	200[$]	84.6	0.0	4 684	(3 – 2)* 59 (54[+])
Scenario 3c	3 228	1 171.2	200[$]	93.9	0.0	4 688	(3c-2)*63 (57.7[+])
Scenario 3d	3 239	1 171.2	200[$]	66.3[#]	0.0	4 677	(3d-2)*51(48[+])
Scenario 3e	3 211	1 171.2	200[$]	112.8	0.0	4 695	(3e-2)*70 (62[+])
Scenario 4	3 209	1 171.2	200[$]	84.6	30.8	4 696	(4 – 3)*12 (10.5[+])
Scenario 4b	3 192	1 171.2	200[$]	112.8	30.8	4 707	(4b-3e)*12 (10[+])
Scenario 4c	3 204	1 171.2	200[$]	84.6	38.8	4 699	(4c-3)* 15 (12[+])
Scenario 4c2	3 187	1 171.2	200[$]	112.8	38.8	4 710	(4c2-3e)* 15 (13.4[+])
Scenario 4d	3 220	1 171.2	200[$]	66.3[#]	29.2[#]	4 687	(4d-3d)*10 (8.2[+])
Scenario 5	No results						
Scenario 6a	3 297	1 171.2	321.9	0.0	0.0	4 790	(6a – 2g)* 134
Scenario 6b	3 297	1 171.2	312.4	0.0	0.0	4 781	(6b – 2g)* 124
Scenario 7b	3 570	1 171.2	188	0.0	0.0	4 929	(7b-2030base)* 461
Scenario 8b	3 415	1 171.2	200[$]	0.0	0.0	4 786.	(8b-2030base)* 318

Note: *- Net yield increase based on the difference between indicated scenarios

[+] Net yield increase when average reduction in supply in the Caledon/Mohokare is included

2050 demand imposed on dam – not the yield

$ Target transfer imposed on dam – not yield

Sub-scenario 2f: An HFY of 3 297 million m^3/a is available at Gariep/Vanderkloof (ORP system) at 2030 development level with Polihali and Verbeeldingskraal dams in place.

Sub-scenario 2g: When Verbeeldingskraal and Polihali dams are included, it is evident that the Makhaleng net HFY reduces to 188 million m^3/a. The impact of Verbeeldingskraal and Polihali dams on the available net yield from Malhaleng Dam is thus relatively small at 11 million m^3/a (199 -188=11).

Sub-scenario 2h: When Makhaleng Dam is not used to supply compensation tot Gariep and Vanderkloof dams (ORP), the gross HFY from the 3 MAR Makhaleng Dam is 378 million m^3/a at 2030 development level. As a result of no compensation support to the ORP from Makhaleng Dam, the HFY available at the ORP reduced to 3 045 million m^3/a in comparison with the 3 297 million m^3/a with no Makhaleng Dam is in place. A reduction of 252 million m^3/a is thus evident from the ORP yield. It is further interesting to note that Scenario 2g where Makhaleng is used to release compensation water in support of the ORP, the net system yield increase is about 62 million m^3/a higher than for Scenario 2h where Makhaleng is not used to provide compensation releases in support the ORP. From a system perspective it is thus beneficial to use Makhaleng Dam to provide compensation in support of the ORP, as the overall system yield increases.

Sub-scenario 2j: With a smaller Makhaleng Dam (live storage 298 million m^3) and not used to release compensation water in support of Gariep and Vanderkloof dams, a gross HFY of 218 million m^3/a could be obtained. This is sufficient to support the estimated high transfer to Botswana and RSA as well as the local requirements in Lesotho. Although this is a relatively small dam, the impact of this dam and its related abstraction do have a significant impact on the HFY available from Gariep and Vanderkloof dams (ORP system) resulting in a reduction in the ORP HFY of 185 million m^3/a. The net system yield increase for the smaller Makhaleng Dam is thus only 33 million m^3/a.

Scenario 3: The yield for the Hlotse sub-system was determined at the abstraction point located downstream of the dam. The EWRs were released from Hlotse Dam in such a manner that it is not available for the users within the Hlotse sub-system. The yield however included the use of the incremental flow between Hlotse Dam and the abstraction point. The gross HFY was determined as 84.6 million m^3/a and is slightly higher than the expected total 2050 demand of 66.3 million m^3/a. The net system yield increase with Hlotse Dam included is only 54 million m^3/a and thus not adequate to meet the expected 2050 water requirement. This demand includes the urban/rural and irrigation expected developments to be supplied from Hlotse Dam.

The environmental requirements were already released from the dam as part of the analysis and do not form part of the HFY.

For this scenario, Hlotse Dam was not used to supply compensation releases in support of the ORP system and resulted in a relatively small reduction in yield of 26 million m^3/a in the ORP yield (Scenario 3 versus Scenario 2). The reason for the relative low reduction in yield is twofold:

- The critical period for Hlotse (1994/95) in the Caledon River catchment is totally different from those in the Senqu and main Orange River (1930/33).
- Other users such as towns along the Caledon River as well the water supply to the Greater Bloemfontein system were also reduced. A reduction in the average supply to Greater Bloemfontein of approximately 3.8 million m^3/a and about 1.1million m^3/a reduction in the supply to Maseru and other Lesotho Towns along the Mohokare River, were obtained from the WRYM results (See **Table 8.5 and 8.6**).

The gross yield of 84.6 million m^3/a from Hlotse Dam can thus not be fully utilized without having a negative impact on downstream water balances and resulted in a net yield of 54 million m^3/a. The 2050 urban/rural and irrigation requirement to be supplied from Hlotse dam is estimated at about 66 million m^3/a. It was thus decided to slightly increase the storage capacity of Hlotse Dam and to use the additional yield to support downstream sub-systems to restore the water balance, as it was before the inclusion of Hlotse Dam (see Scenarios 3c and 3d).

Sub-scenario 3c: For this scenario the storage of Hlotse Dam was increased by 15 million m^3 to gross storage to 120 million m^3. This increased the gross yield of Hlotse Dam by 9.3 million m^3/a to 93.9 million m^3/a with the net yield increasing to 57.7 million m^3/a.

Sub-scenario 3d: In Scenario 3d the additional yield from Hlotse Dam was used to release compensation water in support of downstream users. The compensation releases took place mainly during the dry months when the flow in the Mohokare (Caledon River) is low. This is important as there is almost no storage in the Caledon and most of the abstractions for the towns including Maseru depends on runoff river abstractions. The demand imposed on Hlotse Dam for this scenario was 66.3 million m^3/a and represents the expected 2050 water requirement for irrigation (46.2 million m^3/a) and urban/rural of 20.1 million m^3/a.

Results from the analysis showed that reduction in the supply to the Greater Bloemfontein, reduced to 3.1 million m^3/a with no impact on the Maseru abstraction and other smaller Lesotho towns. The reduction in yield of the ORP system was reduced from the 26 million m^3/a (Scenario 3) to only 15 million m^3/a.

Sub-scenario 3e: The results from Scenario 3d clearly indicate that the increased yield from the 120 million m^3 storage Hlotse Dam was not sufficient to cover the compensation releases as well as the demands imposed on the dam. Scenario 3e thus represent a further increase in the Hlotse Dam size to 150 million m^3 net storage.

Table 8-6: impact of scenarios on ORP yield and water supply to Greater Bloemfontein, Maseru and Lesotho small towns along the Mohokare River

Scenario	ORP yield million m^3/a	Greater Bloemfontein abtsraction (million m^3/a)	Maseru & Towns supply from Mohokare (million m^3/a)	Total supply (million m^3/a)
2030 Base Scenario	3,297	47.9	22.8	70.7
Scenario 2	3,254	47.9	22.8	70.7
Scenario 2d	3,336	47.9	22.8	70.7
Scenario 2e	3,336	47.9	22.8	70.7
Scenario 2f	3,297	47.9	22.8	70.7
Scenario 2g	3,297	47.9	22.8	70.7
Scenario 2h	3,045	47.9	22.8	70.7
Scenario 2j	3,112	47.9	22.8	70.7
Scenario 3	3,228	44.1	21.7	65.8
Scenario 3c	3,223	43.8	21.5	65.4
Scenario 3d	3,239	44.8	22.8	67.6
Scenario 3e	3,211	43.1	21.4	64.5
Scenario 4	3,209	43.1	21.3	64.4
Scenario 4b	3,192	42.2	21.0	63.2
Scenario 4c	3,204	43.0	21.2	64.2
Scenario 4c2	3,187	42.0	21.0	62.9
Scenario 4d	3,220	43.5	22.3	65.8
Scenario 6b (Senqu B2 & D2)	3,297	47.9	22.8	70.7
Scenario 7b	3,570	47.9	22.8	70.7
Scenario 8b	3,415	47.9	22.8	70.7

Results from this scenario showed a gross HFY of almost 113 million m^3/a with a net yield increase to 62 million m^3/a. This is slightly lower than the 2050 demand of 66.3 million m^3/a. The HFY represents in general a relative high assurance. The bulk of the demand (70%) imposed on Hlotse Dam is for irrigation purposes, which do not require a very high assurance of supply. This means that the net HFY of 62 million m^3/a will most probably be adequate for this sub-system.

Scenario 4: Similar to the Hlotse Dam sub-system, the yield for the Ngoajane Dam sub-system was determined at the abstraction point on the Lower Hololo River. Hlotse Dam as for Scenario 3 formed part of Scenario 4. EWRs were released from Ngoajane Dam and could not be used by users in the Ngoajane sub-system. The gross historic firm yield for this sub-system was determined as 30.8 million m^3/a and is slightly higher than the 2050 demand of 29.2 million m^3/a to be imposed on the dam. The inclusion of Ngoajane Dam resulted in a further reduction in the ORP system yield of 19 million m^3/a in comparison with Scenario 3. The water supply to the Greater Bloemfontein reduced by 1.1 million m^3/a and 0.4 million m^3/a for Maseru and smaller Lesotho towns along the river in comparison with Scenario 3. The net yield from system for Scenario 4 is just over 10 million m^3/a. The analysis thus clearly shows that it will not be possible to utilize the full yield of 30.8 million m^3/a from Ngoajane Dam without impacting negatively on downstream water supply systems.

Two additional scenarios were therefore defined. For the first scenario (Scenario 4b) the larger Hloste dam was used in combination with Ngoajane Dam. For the second scenario the storage of Ngoajane Dam was increased by 27.3 million m^3 to a gross storage of 63.3 million m^3 to increase the sub-system yield, so that it can be utilized to compensate downstream users. (See Scenarios 4c and 4d).

Sub-scenario 4b: This scenario is as Scenario 4 with the only difference the inclusion of the larger Hlotse Dam as used for Scenario 3e (150 million m^3 net storage) and the related HFY imposed as a demand on the large Hlotse Dam. After taking into account the reduction in yield and water supply in the Orange and Mohokare/Caledon river systems, the net increase in the system yield for Scenario 4b relative to Scenario 3c is only 10 million m^3/a and 20 million m^3/a when compared to Scenario 3. The net yield still needs to be increased for Scenario 4b. Scenario 4c2 will include a larger Ngoajane Dam with a gross storage of 63.3 million m^3 to increase the system yield, (see results from Scenario 4c2)

Sub-scenario 4c: Based on Scenario 4. For this scenario the storage of Ngoajane Dam was increased by 27.3 million m^3 which resulted in an increased gross yield for Ngoajane Dam by 8 million m^3/a to 38.8 million m^3/a. This indicated that a much higher increase in yield can be obtained from Hlotse Dam than for Ngoajane Dam for the same increase in volume (Hlotse increase in storage of 15 million m^3 resulted in a yield increase of 9 million m^3/a). Sub-scenario 4d will show the impact on downstream sub-systems and average supply when this additional yield is used to compensate downstream users.

Sub-scenario 4c2: Based on Scenario 4b. For this scenario the storage of Ngoajane Dam was increased by 27.3 million m^3 which resulted in an increased gross yield for Ngoajane Dam by 8 million m^3/a to 38.8 million m^3/a as for Scenario 4c. Scenario 4c2 however also included the larger Hlotse Dam (150 million m^3 net storage) in combination with the large Ngoajane Dam.

In comparison with Scenario 3e the net yield for Scenario 4c2 increased to 13.4 million m^3/a which is only 3.4 million m^3/a higher than that obtained from Scenario 4b.

Sub-scenario 4d: Based on Scenario 4c. Sub-scenario 4d used the additional yield from Ngoajane and Hlotse dams to provide compensation releases in support of the downstream users. As for Hlotse Dam, the support from Ngoajane Dam took place mainly during the dry months. The demand imposed on Ngoajane Dam for this scenario was 29.2 million m^3/a and represents the expected 2050 water requirement for irrigation (6.2 million m^3/a) and urban/rural of 23 million m^3/a).

The downstream impacts on the average water supply from this scenario reduced by 16 million m^3/a while the net yield only reduced by 3.8 million m^3/a in comparison with Scenario 4c.

Scenario 5.

Due to lack of data scenario 5 could not be analyzed.

Scenario 6a: In the definition of Scenario 6a (**Section 8.2**) it was stated that a minimum hydro-power release of 22 m^3/s was defined in the WRYM for Senqu B2 Dam, with a maximum hydro-power release of 100 m^3/s. Results from the analysis showed that during the winter months it was not always possible to supply the target of 22 m^3/s as shown in **Figure 8-3**.

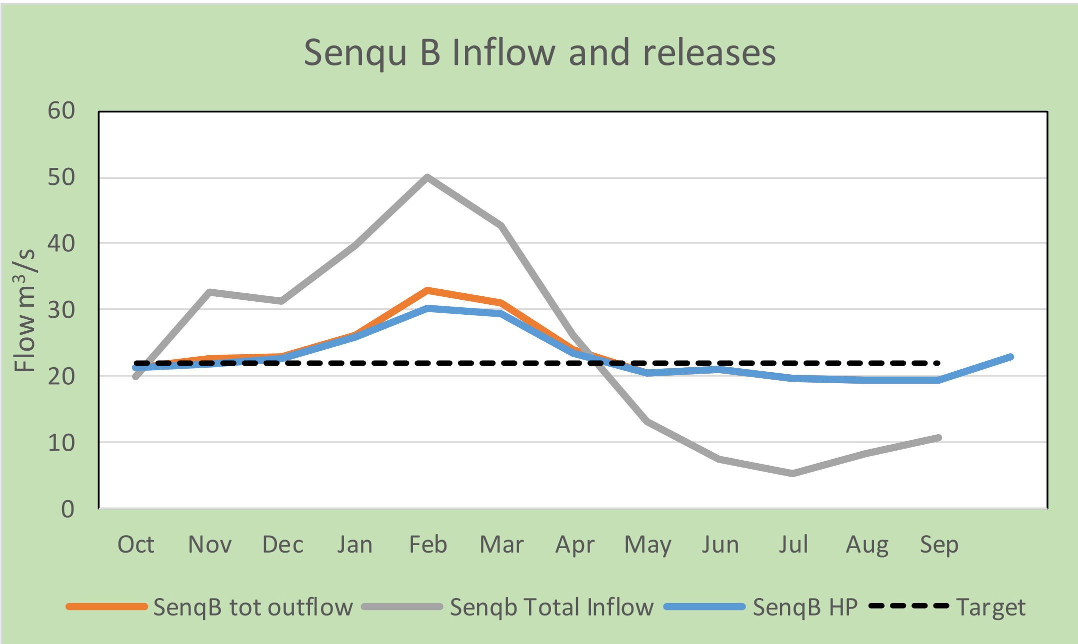


Figure 8-3: Average monthly simulated inflows and releases from Senqu B Dam

During the summer months more than the 22 m^3/s could be supplied. In some of the individual summer months the maximum release capacity of 100 m^3/s was in fact reached. The difference between the orange and blue line in **Figure 8-3** represents the spills from Senqu B2 Dam, showing that almost all the outflows were routed through the turbines. Its further evident that the winter month outflows from Senqu B2 Dam are much higher than the river flows before the dam was in place, due to the hydro-power releases.

The average releases from Senqu B2 Dam through the turbines over the 85-year period was 22.87m^3/s.

Results from the WRYM analysis for Senqu D2 Dam is shown in **Figure 8-4**. From this figure it is evident that simulated average monthly turbine flows were for most months higher than the imposed target of 33.5m^3/s.

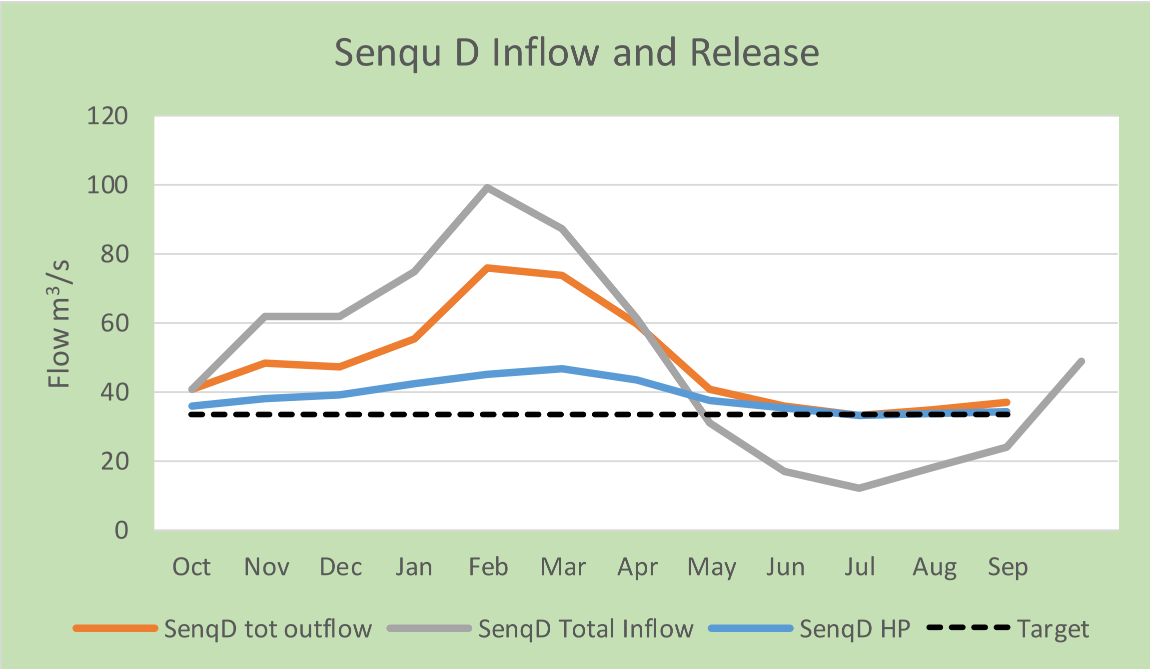


Figure 8-4: Average monthly simulated inflows and releases from Senqu D2 Dam

The difference between the total outflow (orange line) and the hydro-power releases is quite significant over all the summer months, indicating high spill volumes. This is mainly due to the much lower maximum total turbine flow capacity of 60m^3/s in comparison with the 100 m^3/s for the Senqu B2 Dam. The much higher winter base flow with Senqu D2 in place is clearly evident from **Figure 8-4**. The average annual modelled turbine releases from Senqu D2 Dam was found to be 38.68 m^3/s.

The stable outflow from the two upstream Senqu dams resulted in an increase of 134 million m^3/a in the ORP system yield. This resulted in reduced compensation releases required from Makhaleng Dam in support of the ORP, allowing the net yield from Makhaleng Dam to increase to 322 million m^3/a, in comparison with the 188 million m^3/a from Scenario 2g.

Scenario 6b: The average annual releases through the turbines for Senqu B2 and Senqu D2 dams of respectively 22.87m^3/s and 38.68 m^3/s were used as the minimum target flows to be imposed on the two Senqu dams for Scenario 6b. The monthly flow distributions were however adjusted to follow the typical distribution pattern before the dams were in place (See **Figures 8.5 and 8.6**)

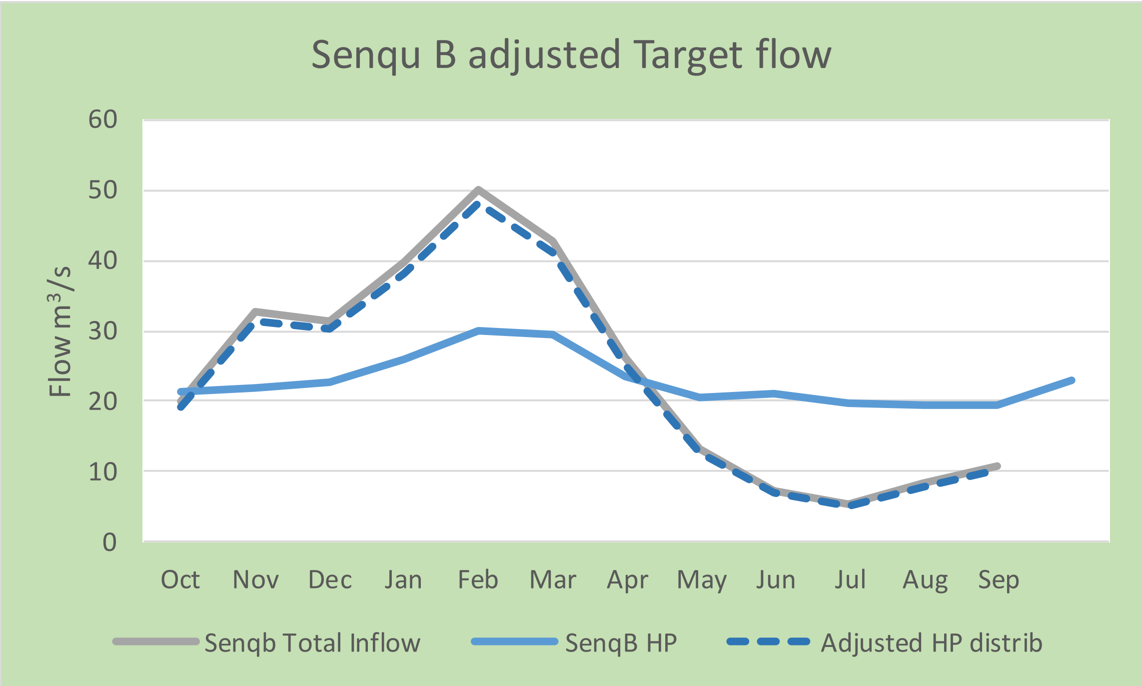


Figure 8-5: Monthly target flows adjusted for implementation in Scenario 6b Senqu B

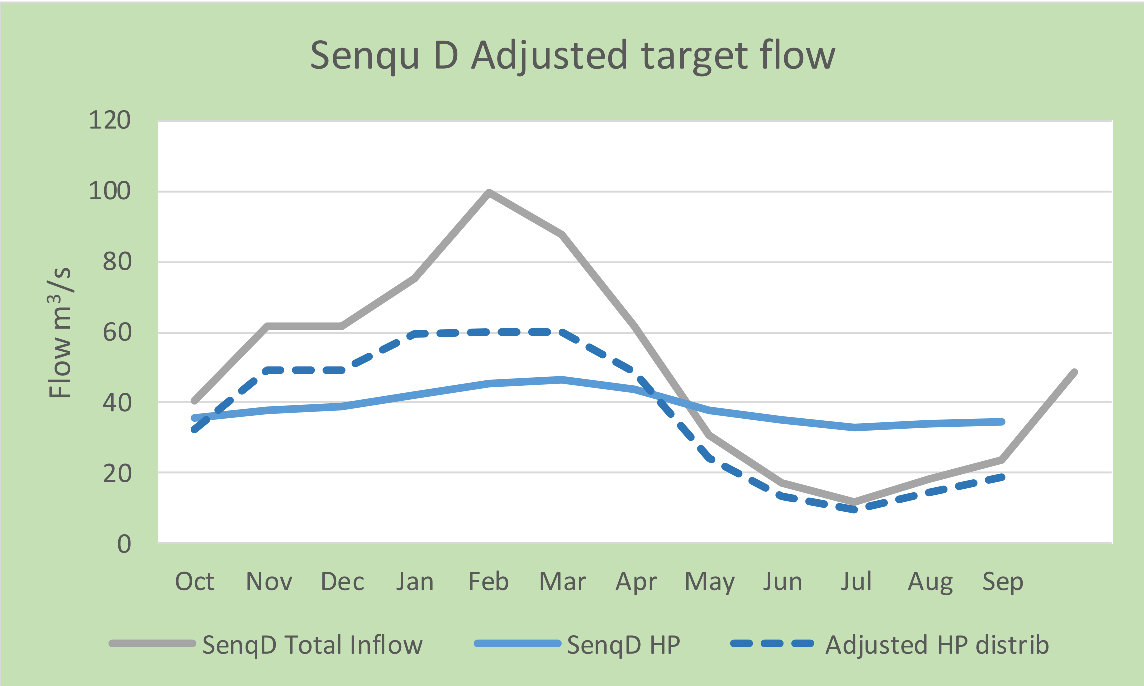


Figure 8-6: Monthly target flows adjusted for implementation in Scenario 6b Senqu D

The Scenario 6b simulated in and outflows from the WRYM analysis for Senqu B2 Dam can be seen in **Figure 8-7**. The total flow through the turbines (22.84m^3/s) in Senqu B2 Dam is for practical purposes the same as for Scenario 6a. The main difference is the outflow pattern which is more in line with the average flow pattern before the dam was in place.

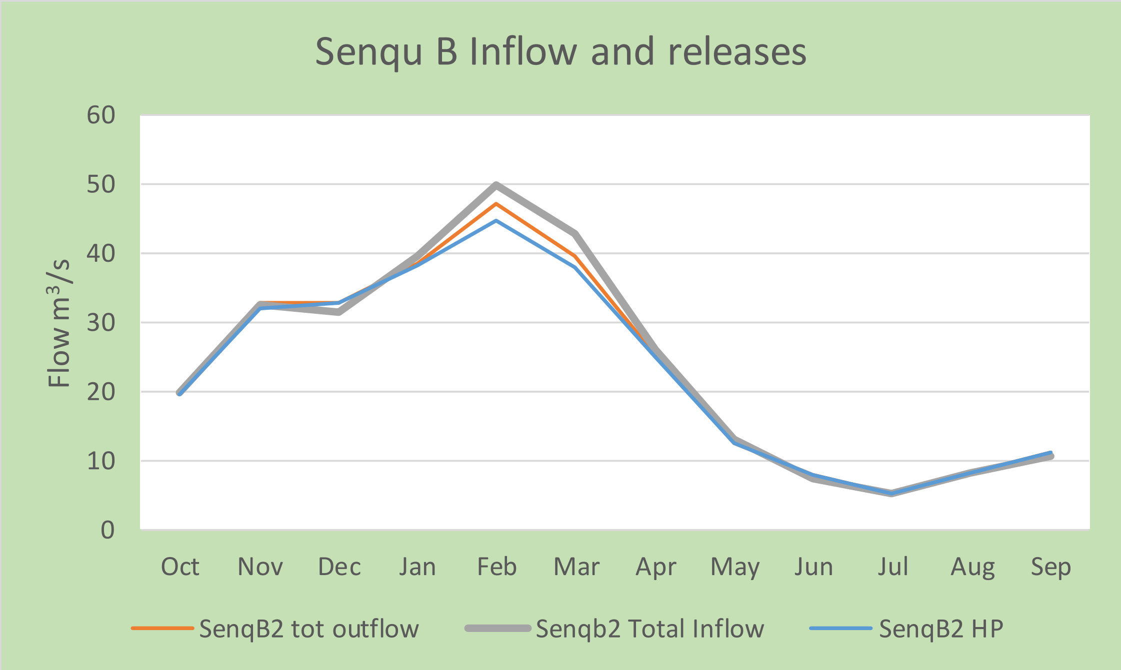


Figure 8-7: Average monthly simulated inflows and releases from Senqu B Dam Scenario 6b

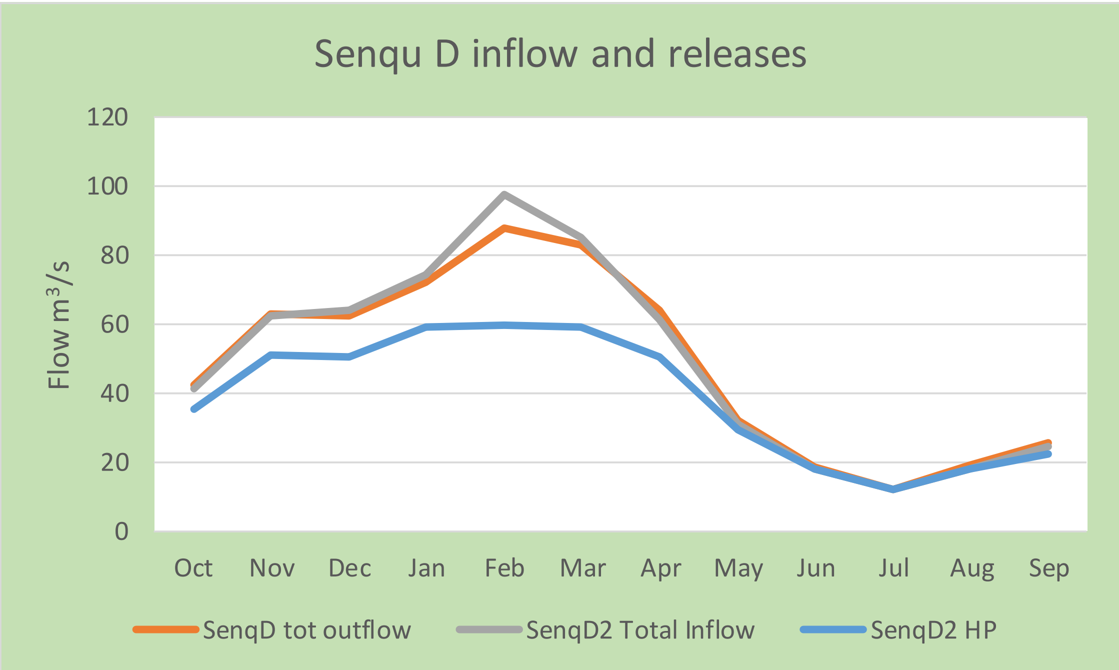


Figure 8-8: Average monthly simulated inflows and releases from Senqu D Dam Scenario 6b

Similar to Senqu B2 dam the average annual flows (38.64m^3/s) through the turbines at Senqu D2 dam is basically the same as that obtained for Scenario 6a. The main difference is the hydro-power release pattern that is following the flow patterns as before the dam was in place. The limitation of the maximum combined turbine flow of 60 m^3/s is clearly evident from the average turbine release and slightly hamper the required release pattern.

Although the same volumes are released through the turbines for both scenario 6a and 6b, the system yield improvement for Scenario 6b is 10 million m^3/a less, determined as 124 million m^3/a. This resulted in the net yield available from Makhaleng Dam to increase to 312 million m^3/a in comparison with the 188 million m^3/a for Scenario 2g.

Scenario 7b: The net yield from Scenario 7b in comparison with the 2030 Base Scenario was determined as 461 million m^3/a. This is higher than the 3 MAR Makhaleng Dam gross yield of 378.4 million m^3/a (See Scenario 2h) which means that the Makhaleng Dam gross yield can be fully abstracted from Makhaleng Dam as the net yield, as Ntoahae Dam can take over the full compensation releases from Makhaleng Dam. The only releases from Makhaleng into the river will then be for EWR purposes. This means that there is still 83 million m^3/a yield of the 461 million m^3/a available in Ntoahae Dam for other purposes, or Ntoahae Dam can be built slightly smaller.

Scenario 8b: The net increase in yield from Scenario 8b in comparison with the 2030 Base Scenario was found to be 318 million m^3/a. This is the combined net yield generated from the 3MAR Makhaleng Dam plus the 14m raising of Verbeeldingskraal Dam. The maximum gross HFY from a 3 MAR Makhaleng Dam was determined as 378.4 million m^3/a (See Scenario 2h) which is higher than the net yield from Scenario 8b. This means the total net yield of 318 million m^3/a can be made available from Makhaleng Dam when the raised Verbeeldingkraal Dam is used to release some of the compensation water to the ORP system on behalf of Makhaleng Dam.

8.4 Summary of Selected Scenario combinations to achieve positive water balances

The two largest future developments in Lesotho are Phase II of the Lesotho Highlands (Polihali Dam and transfer tunnel) as well as Makhaleng Dam and transfer system to the RSA and Botswana. The Lesotho Highlands Phase II development significantly impacts on the water supply to the downstream users from the main Orange in Namibia and the RSA (See **Figure 8-1**).

8.4.1 LHWP Phase II Development

The RSA DWS study “Development of Water Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River” (DWS,2015a) was completed in early 2015. This study specifically addressed the impact of Polihali Dam on the main Orange River and provided solutions to restore the water balance in the Orange River to what it was before the inclusion of Polihali Dam. Gariep and Vanderkloof dams also known as the Orange River Project (ORP) is used to supply all the users (RSA and Namibia) from the main Orange River downstream of the two dams, as well as users in the Eastern Cape via the Orange/Fish tunnel. The inclusion of Polihali Dam resulted in a reduction of 284 million m^3/a in the historic firm yield (HFY) from the ORP.

Several solutions or intervention options to make up for this reduction in yield was recommended from the DWS RSA Reconciliation Strategy Study (DWS,2015a), which included the following:

- Utilize the Lower Level Storage in Vanderkloof Dam
- Real time modelling and monitoring
- Verbeeldingskraal Dam or raised Gariep Dam
- Noordoewer/Vioolsdrift Dam

Not all the above-mentioned intervention options are required to balance the 284 million m^3/a reduction in the HFY, as these options were also used to cater for the increasing of water requirements and EWRs. For the purposes of the multipurpose dam analysis, only the first three intervention options were used with Verbeeldingskraal Dam selected as the third option. The yield analysis results clearly showed that these three intervention options were sufficient to maintain the available HFY from the ORP system at 3 297 million m^3/a after the inclusion of Polihali Dam, in comparison with the HFY of 3 252 million m^3/a, before Polihali Dam was included (Compare ORASECOM IWRMP Phase lll scenario with 2030 base scenario **Table 8-4**).

For the purpose of the possible future developments in Lesotho it is important to first distinguish between developments within the Senqu/Makhaleng River catchments and those located in the Mohokare/Caledon River catchment.

8.4.2 Senqu-Makhaleng: Lesotho/Botswana Transfer Scheme

The possible future Lesotho/Botswana Transfer Scheme is one of the major future schemes and is located in the Makhaleng River, a major tributary of the larger Senqu River. From the work carried out as part of the Prefeasibility Phase I (ORASECOM, 2019a) of the current study, the 3 MAR Makhaleng Dam at site S2, is one of the final recommended sites, and can provide a HFY of 378 million m^3/a, which will result in a reduction in the HFY of the ORP system of 252 million m^3/a, thus a net increase in the system yield of only 126 million m^3/a. As this is the most favorable dam site, the Makhaleng Dam option at site S2 was selected for the purpose of the Multipurpose Dam analyses.

A small and a large dam was initially considered at site S2. The target water requirement to be supported from the future Makhaleng Dam was in the order of 200 million m^3/a.

Small Makhaleng Dam-Option1: A small dam with a live storage of 298 million m^3/a at site S2 can provide a historic firm yield of 218 million m^3/a (see Scenario2j in **Table 8-4**) Taking the 218 million m^3/a from the small Makhaleng Dam will unfortunately result in a reduction in the yield of the next downstream major water supply system in the Orange River (referred to as the Orange River project or ORP) of 185 million m^3/a. This means that the net yield for the overall system only increased by 33 million m^3/a, which is by far too small for the intended Lesotho/Botswana transfer Scheme.

Large Makhaleng Dam-Option 2: The next option to evaluate was the large 3 MAR Makhaleng Dam at site S2. From **Table 8-4** Scenario 2h it is evident that the 3 MAR Makhaleng Dam can generate a historic firm yield of 378 million m^3/a. Utilizing this full yield for the Lesotho/Botswana transfer system will result in a decrease in the downstream system yield of 252 million m^3/a, providing a net system yield increase of only 126 million m^3/a. A flow diagram (**Figure 8-6**) shows the different options considered to retain the water balance in the overall system after the inclusion of the Lesotho/Botswana transfer option. Little yield can be gained by increasing Makhaleng Dam storage above the 3 MAR capacity and another way of increasing the available net yield need to be identified.

Changed operating rule for Large Makhaleng Dam-Option 3: The available yield from the Large Makhaleng Dam exceeds the target requirement of about 200 million m^3/a for the Lesotho/Botswana transfer. By introducing a different operating rule to the Large Makhaleng Dam, one can allow for compensation releases from Makhaleng Dam to downstream users, to restore the downstream water balance and at the same time also supply the users forming part of the Lesotho/Botswana transfer scheme. For this purpose, the maximum net yield that can be produced from Makhaleng Dam was determined as 188 million m^3/a (Scenario 2g in **Table 8-4**). This is higher than the 149 million m^3/a net yield obtain for the dam at the TOR site, which is due to the larger dam at the S2 site, as well as the optimizing of the net yield. When only 188 million m^3/a is taken from Makhaleng Dam to support the Lesotho/Botswana transfer, the impact on the downstream users will be zero, due to the compensation releases from Makhaleng Dam.

These compensation releases are released from Makhaleng Dam over and above the EWR releases that were imposed on the dam as part of the system analyses. The 188 million m^3/a yield is however just too small to fully supply the intended demand of approximately 200 million m^3/a for the Lesotho/Botswana transfer system, when the high projected demand is considered. The 188 million m^3/a is not sufficient to support a substantial amount of irrigation in Lesotho, however this will also depend on how the available net yield is divided amongst the users forming part of the Lesotho Botswana Transfer. When the low Botswana transfer projected water requirements are considered, the 188 million m^3/a is sufficient to support the intended users as well as 78 million m^3/a for irrigation purposes in Lesotho (see Option 3 in **Figure 8-6**).

Large Makhaleng Dam in combination with hydropower dams-option 4: If more water is required for the Lesotho/Botswana transfer scheme including the irrigation in Lesotho, it will require some support from other possible infrastructure developments. Three possible future schemes were considered for this purpose. One of the most attractive options is the hydropower scheme currently investigated by Lesotho. This scheme consists of two dams (Senqu B and Senqu D dam see **Figure 8-1**) in the Senqu River, both located upstream of the confluence of the Makhaleng and Senqu rivers. The live storages of the Senqu B and D dams are 775 and 624 million m^3 respectively. The Senqu B dam is located at about the same site as previously identified for Tsoelike Dam, one of the possible further phases of the LHWP. The system yield increase will depend on the operating rules followed between the two hydropower dams and Verbeeldingskraal Dam, as well as the monthly release pattern. Two possible release patterns were evaluated and analysed. Release pattern 1 followed equal releases every month, to provide a good base power supply. Release pattern 2 followed a monthly distribution pattern equal to that of a typical average monthly flow pattern as produced from the natural flow record, that will benefit the downstream environmental requirements. Flow pattern1 and 2 resulted in an increase in the ORP system HFY of 134 million m^3/a and 124 million m^3/a respectively (See Scenarios 6a and 6b in **Table 8-4**). This means that the compensation releases from Makhaleng Dam to the Orange River can be reduced, which in return will increase the net yield available in Makhaleng Dam to 312 million m^3/a for Scenario 6b. Although the fairly constant base flow released from the hydropower dams is purely a by-product of the hydropower scheme, it significantly increases the net yield available from Makhaleng Dam (see **Figure 8-6**). For this option the net yield available in Makhaleng Dam is sufficient to support the high Botswana Transfer option as well as the maximum irrigation development (107 million m^3/a) to be supplied from Makhaleng Dam, leaving still a 7 million m^3/a surplus available in Makhaleng Dam.

Large Makhaleng Dam in combination with a raised Verbeeldingskraal Dam-Option 5: If the hydropower dams do not realize in future, the most cost-effective option to increase the ORP yield will most probably be the raising of Verbeeldingskraal Dam, although the dam wall is physically not located in Lesotho. The maximum size of Verbeeldingskraal Dam as considered in the DWS RSA Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River, was limited to not inundate part of Lesotho. It is thus possible to consider a larger dam at this site, if it is agreed that part of Lesotho be inundated. Just increasing a planned future dam wall height by a few meters can significantly increase the yield produced by the dam. This means that Verbeeldingskraal Dam can be used to provide some or all the compensation releases that are required from Makhaleng Dam.

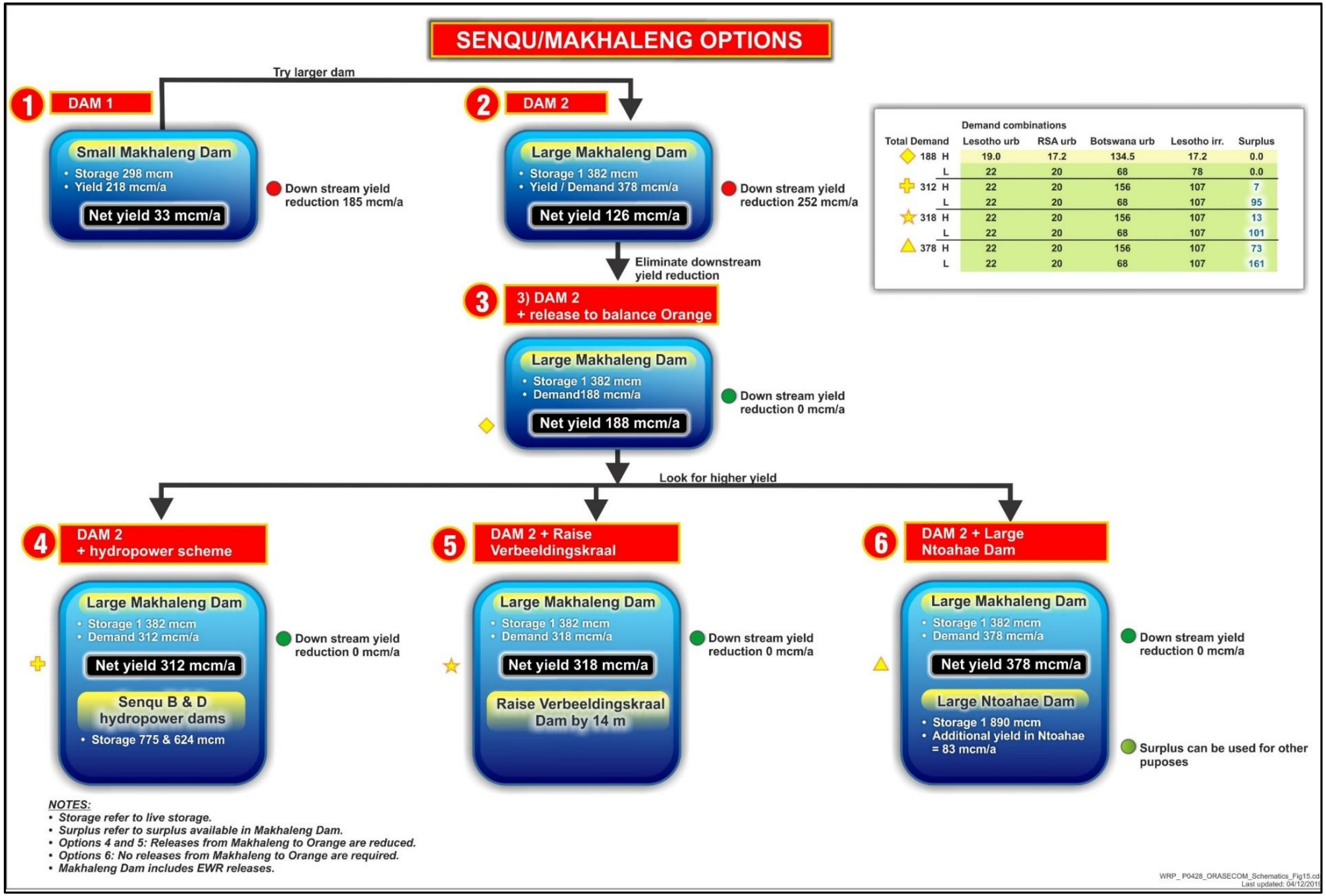


Figure 8-9: Possible Senqu/Makhaleng options

This will in turn result in a higher abstraction or net yield from Makhaleng Dam, without a negative impact on the ORP system. For the purpose of this option the Verbeeldingskraal Dam as proposed by DWS RSA was raised by 14m, which is the maximum allowed within the area, capacity, height characteristics currently available for this dam. Results from the analysis indicated (See Scenario 8b in **Table 8-4**) that the compensation releases from Makhaleng Dam can considerably be reduced to be able to increase the net yield available from Makhaleng Dam to 318 million m^3/a.

This will enable Makhaleng Dam to fully support the high Botswana transfer option as well as the maximum irrigation development in Lesotho, with a surplus yield of 13 million m^3/a still available in Makhaleng Dam (see **Figure 8-9** option 5). Depending on the characteristics of the larger Verbeeldingskraal Dam basin, Verbeeldingskraal Dam should have the capability to produce a much higher yield than Ntoahae Dam (see details in description of Scenario 7b) as result of the much larger incremental catchment and related higher runoff. This need to be investigated further as well as the suitability of the dam site to accommodate a much larger dam.

Large Makhaleng Dam in combination with Ntoahae Dam-Option 6: When selecting one of the previously defined LHWP further phases dams to increase the system yield, it is important to take into account that Polihali Dam will soon be in place. It is thus important to rather consider one of the most downstream LHWP further phases dam sites to obtain a reasonable size incremental catchment upstream of the selected dam, enabling the dam to generate sufficient additional yield. For this reason, the Ntoahae dam site was selected, which is the most downstream LHWP dam option on the Senqu River and includes the largest incremental catchment downstream of the existing LHWP dams, including Polihali Dam.

A large Ntoahae Dam with a live storage of 1 890 million m^3/a was analysed in combination with the Large Makhaleng Dam. The net yield generated from Ntoahae Dam was so much (See Scenario 7b **Table 8-4**), that no compensation releases where required from Makhaleng Dam for this option, meaning that the full historic firm yield of 378 million m^3/a was now available as the net yield from Makhaleng Dam. As for the hydropower and Verbeeldingskraal Dam options, the Ntoahae option allows for a fully supplied high Botswana Transfer option, as well as the maximum irrigation development (107 million m^3/a) to be supplied from Makhaleng Dam, leaving still a 73 million m^3/a surplus available in Makhaleng Dam. Over and above this surplus in Makhaleng Dam, there was an additional yield of 83 million m^3/a available in Ntoahae Dam after restoring the balance in the Orange River (See **Figure 8-9**). This surplus can be used for other purposes or a smaller Ntoahae Dam can be considered.

Work previously carried out as part of the RSA DWS study "Development of Water Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River" (DWS, 2015) investigated two alternative dam options for Verbeeldingskraal Dam. These were Malatsi and Ntoahae dams in Lesotho, previously identified to form part of the five phases of the LHWP. The following results (see **Table 8-4**) for the three possible dams were obtained from the Orange River Reconciliation Strategy study. Please note that the cost of Lesotho options excludes royalties, which still need to be considered in future comparisons. The comparisons in **Table 8-4** clearly show that Verbeeldingskraal and Ntoahae dams is the two best options with the Verbeeldingskraal URV being the lowest.

8.4.3 Mohokare/Caledon River catchment future developments

Other future Lesotho developments to consider as part of the multipurpose dam analyses are Hlotse and Ngoajane dams in the Mohokare/Caledon River catchment. The Lesotho Water Resources Assessment Report from the SMEC Study (SMEC, 2017) recommended that dams be built at Hlotse and Ngoajane with gross storage capacities of 105 million m^3 and 36 million m^3 respectively. The analyses related to these two dams therefore started with these recommended dam sizes. These two dams are located in separate tributaries of the Mohokare River and is not used to support each other. Both these dams will however impact on the water supply to downstream users along the Mohokare/Caledon River as well as along the Orange River including Gariep and Vanderkloof Dams.

Results from the analyses showed that for the proposed dam sizes the gross historic firm yield available (See **Table 8-4** Scenarios 3 and 4 respectively) from these two dams were sufficient to supply the intended users as well as the EWR releases from each dam (See **Figure 8-10** options 1 and 3). The impact of these dams and their related abstractions on other existing downstream water users from the Mohokare/Caledon River, as well as on the Orange River (ORP) is significant and need to be addressed as part of the multipurpose dam analysis. Hlotse Dam is expected to be constructed first, followed by Ngoajane Dam about 4 to 5 years later.

Initial proposed Hlotse Dam - Option 1: The proposed Hlotse Dam resulted in a reduction in yield of the Orange (ORP) system of 26 million m^3/a (See Scenario 3 versus Scenario 2 in **Table 8-4**). Water users along the Mohokare/Caledon River mainly make use of river runoff abstractions, as dams in the river quickly silts up. Firm yield analyses could thus not be carried out for these sub-systems, and the average water supply to these users were compared for the different scenarios that were simulated. For this purpose, the supply to the main urban/industrial water users were considered, which included the following:

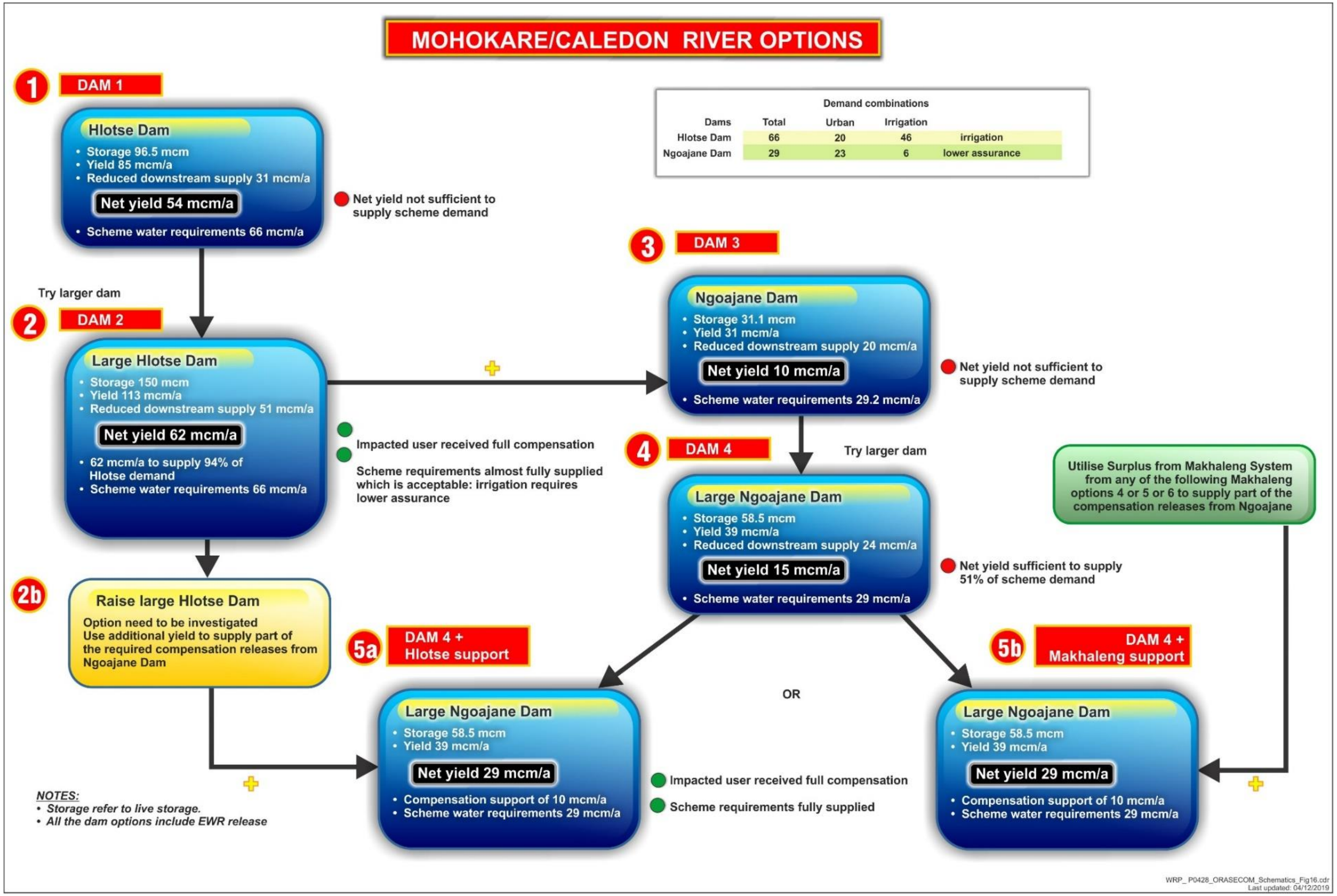


Figure 8-10: Mohokare/Caledon catchment options

- Bloemfontein
- Botshabelo
- Thaba Nchu
- Small towns supplied from the Welbedacht Dam sub-system
- Maseru river abstraction
- Maseru rural supply
- Berea
- Mafeteng

The combined supply to these users from the Mohokare/Caledon River on average reduced by 5 million m^3/a with the proposed Hlotse Dam in place. Hlotse Dam also resulted in a decrease in the ORP yield of 26 million m^3/a. The total demand to be supplied from Hlotse Dam is 66 million m^3/a, of which 20 million m^3/a is for domestic use and 46 million m^3/a for irrigation. Due to the downstream impacts the net yield from Hlotse Dam is 54 million m^3/a, (Scenario 3 **Table 8-4**) although the historic firm yield was determined as 85 million m^3/a after releasing the EWR. The net yield is thus not adequate to supply the total demand of 66 million m^3/a to be imposed on the dam (See Option 1 in **Figure 8-10**).

Large Hlotse Dam - Option 2: The second option considered to overcome these deficits was to increase the live storage of Hlotse Dam from the initial 96.5 million m^3 to 150 million m^3 (1.5 MAR dam). This resulted in an increased HFY of 113 million m^3/a (See **Table 8-4** Scenario 3e), which can be used to restore or partly restore the downstream negative impacts.

The net yield available from the large Hlotse Dam is 62 million m^3/a, almost equal to the intended demand of 66 million m^3/a to be imposed on the dam (see **Figure 8-10** option 2). The bulk of the water demand is to be used for irrigation purposes, which is supplied at lower assurances than urban requirements. The slightly lower firm net yield of should 62 million m^3/a should thus be adequate to support the proposed users

Initial proposed Ngoajane Dam - Option 3: For the purpose of the analysis it was assumed that the 1.5 MAR Hlotse Dam will already be in place at the time when Ngoajane Dam is to be constructed. Ngoajane Dam with a 36 million m^3 gross storage (31 million m^3/a net storage) was included for the initial Ngoajane system analysis. The net yield from this Ngoajane Dam was determined as 10 million m^3/a (See **Table 8-4** Scenario 4b) due to the reduction in supply to downstream users of 20 million m^3/a. Ngoajane Dam can thus not fully support the intended demands of 29 million m^3/a to be imposed on the dam (See **Figure 8-10** option 3).

Large Ngoajane Dam – Option 4: As a next possible option a larger Ngoajane Dam (59 million m^3 net storage) was thus considered and analysed, increasing the net yield to 13,4 million m^3/a (See **Table 8-4** Scenario 4c2). Although the Large Ngoajane Dam can be used to balance the negative impact of 25,6 million m^3/a on the downstream users, it will be able to only supply just under 50% of the demand intended to be supported from the dam. The Ngoajane Dam catchment is relatively small, and it is already evident from the option 4 result that increasing of the storage of this dam do not increase the system yield significantly. One should rather look at other possible options to support Ngoajane Dam.

Large Ngoajane Dam with two possible support options-Options 5a & 5b: Two main options (See **Figure 8-10** options 5a and 5b) were suggested to overcome the deficit in supply from the Large Ngoajane Dam:

- 5a: Increase the size of Hlotse Dam further and use the additional yield from Hlotse to provide water to cover some of the Ngoajane compensation requirements, so that the water balance can be restored.
- 5b: Utilize the surplus yield available in Makhaleng Dam as created by the Makhaleng Dam options 4, 5 or 6 (Scenarios 6b, 7b, and 8b in **Table 8-4**), to support part of the Ngoajane compensation releases and restore the water balance.

Results from the analyses, as well as practical experience from the past clearly indicated that the compensation releases from Hlotse and Ngoajane dams should not be released into the Mohokare/Caledon River due to extensive losses experienced in the past (in excess of 50%) with flow releases into this river. Due to the high silt load in the river, dams are not constructed in this river, and basically all abstractions to supply users along the river is from river runoff abstractions. The only dam built in the Caledon River is the Welbedacht Dam, which has almost totally silted up to the extent that it currently is mainly used as a diversion weir.

It will further be very difficult to release the correct compensation volume at the correct time to satisfy the requirements of all the downstream users due to the lack of storage in the river. There are several irrigation abstractions along the river, of which some might be unlawful, and it will most probably utilize these compensation releases that was intended for other users. It will thus be almost impossible to operate these releases and water supply to the downstream users successfully by means of river releases. It is therefore strongly recommended that the compensation support should take place via pipelines to the impacted users along the Mohokare/Caledon River. Releases to restore the water balance in the main Orange River should rather be done by releases from Makhaleng Dam and or related options in the Senqu catchment as discussed under **Section 8.4.2**.

8.5 Stochastic or risk Yield analyses and Climate change impacts

Stochastic yield analyses were carried out for two sub-systems that formed part of the assessment of multipurpose dams in Lesotho. These two sub-systems are:

- Makhaleng Dam and transfer to RSA and Botswana. This is one of the largest future developments in Lesotho and impacts significantly on existing downstream developments. Sub-scenario 2g was selected for the risk analysis.
- Orange River Project (ORP) consisting of Gariep and Vanderkloof dams. This system is impacted on the most by the upstream Lesotho related developments. This is also the largest water supply system in the Orange Senqu basin. The 2030 Base Scenario was selected for the risk analysis.

Both sub-system analyses were carried out at 2030 development levels and represents Scenario 2g that includes Polihali, Makhaleng and Verbeeldingskraal dams as well as utilizing the lower level storage in Vanderkloof Dam.

The historic firm yield for the ORP system was determined as 3 297 million m^3/a and represents a recurrence interval of 1 in 76 years (see **Figure 8-8**). Key results from the ORP system stochastic analyses is given in **Table 8-6**.

Table 8-7: Summary of the ORP system long-term stochastic yield results

Description	**1 :20 year**	**1:50 year**	**1:100 year**	**1:200 year**	**HFY**
Annual Risk of supply failure	5%	2%	1%	0.5%	
Yield (million m^3/a)	3700	3420	3200	3030	3297

The net stochastic yield results for Makhaleng Dam (Sub-scenario 2g) are summarized in **Table 8-8**. This is the yield available after compensation releases were made in support of Verbeeldingskraal, Gariep and Vanderkloof dams. The historic firm yield for this Makhaleng Dam scenario was determined as 188 million m^3/a and represents a recurrence interval of 1 in 120 years.

Table 8-8: Summary of Makhaleng Dam long-term stochastic net yield results

Description	**1 :20 year**	**1:50 year**	**1:100 year**	**1:200 year**	**HFY**
Annual Risk of supply failure	5%	2%	1%	0.5%	
Yield (million m^3/a)	398	328	216	143	188 (378)*

Note: * gross yield

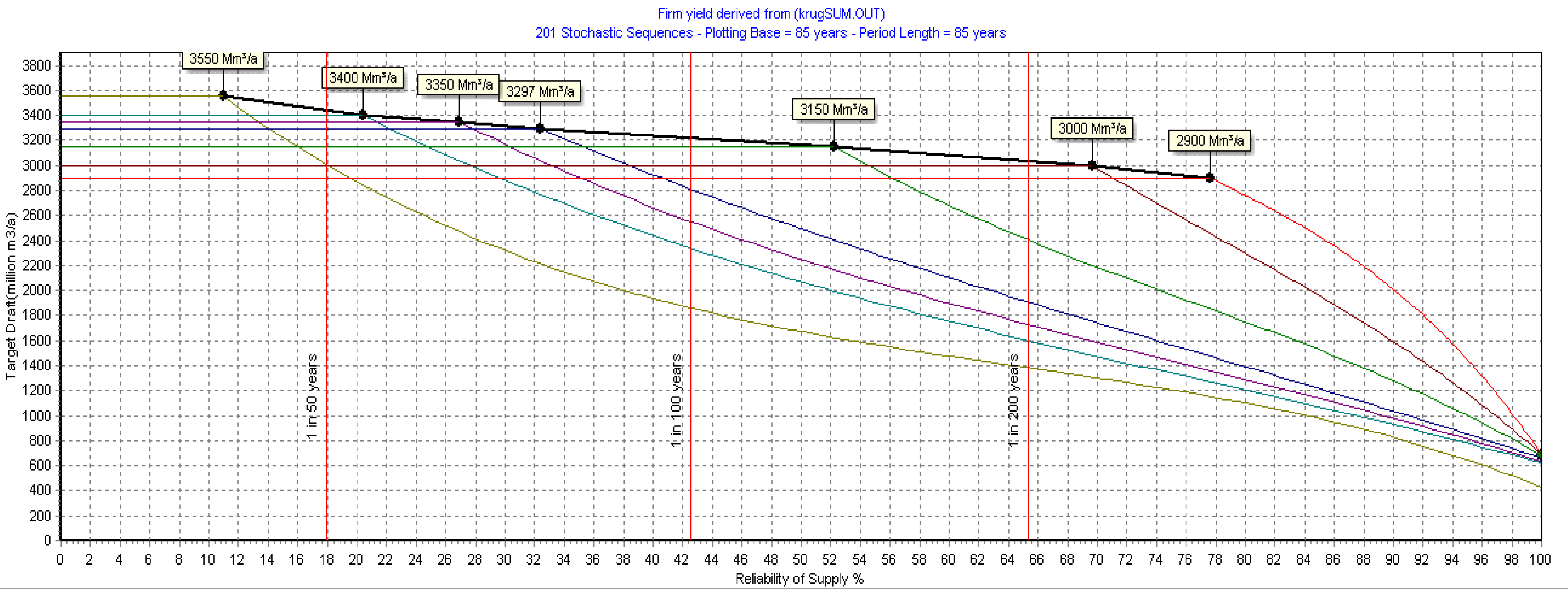


Figure 8-11: Orange River Project long-term stochastic yield curve at 2030 development level

The firm yield line for the Makhaleng Dam long-term stochastic net yield curve (**Figure 8-12**) is clearly much steeper than the firm yield line for the Orange River Project long-term stochastic gross yield as well as that for the smaller Makhaleng Dam (**Figure 8-13**) at site S2 with no compensation releases from Makhaleng Dam. The reason for this significant difference is due to the compensation releases from Makhaleng Dam in support of the large downstream dams in the Orange River and the related operating rule used to provide the compensation releases. The operating rule to a large extent dictates the steepness of the firm yield line for the Makhaleng Dam long-term stochastic net yield. Using the correct operating rule is thus of high importance. The operating rule need to maintain the historic firm yield of 3 297 million m^3/a at the ORP system and at the same time also provide an acceptable assurance of supply for the water to be supplied from Makhaleng Dam to its users.

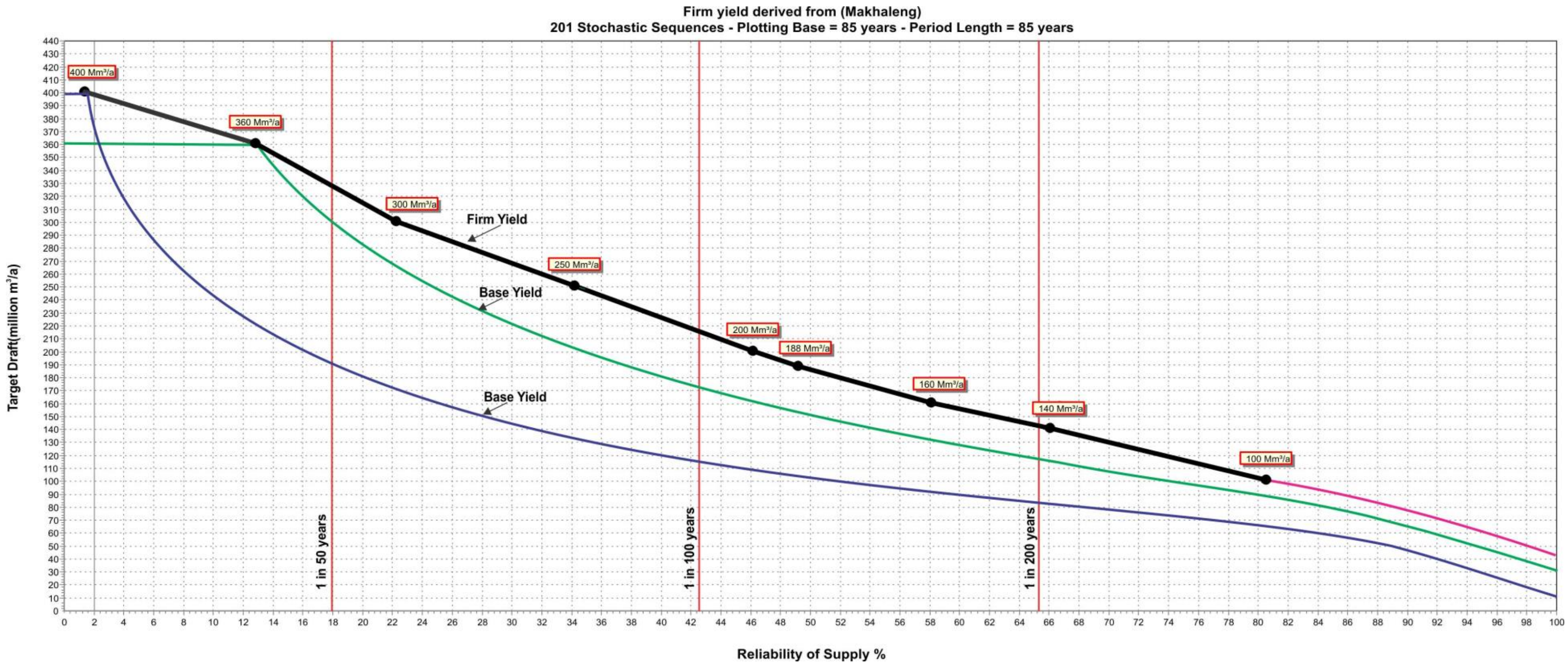


Figure 8-12: Makhaleng Dam long-term stochastic net yield curve at 2030 development level

The long-term stochastic gross yield for the smaller Makhaleng Dam at site S2 was added (**Figure 8-13**) mainly to illustrate the difference between the shape of the net yield and gross yield long-term stochastic yield curves. The smaller Makhaleng Dam was initially investigated as part of Component III of the study, Task 3d (Water Resource Assessment) (ORASECOM, 2019a). Although the gross storage of the two dams differ, 810 million m^3 versus 1 382 million m^3, the difference in the shape of the long-term stochastic gross yield curves is clearly evident. Due to the compensation releases from Makhaleng Dam, the yield from the dam significantly reduces at the high assurance levels (**Figure 8-12** versus **Figure 8-13**).

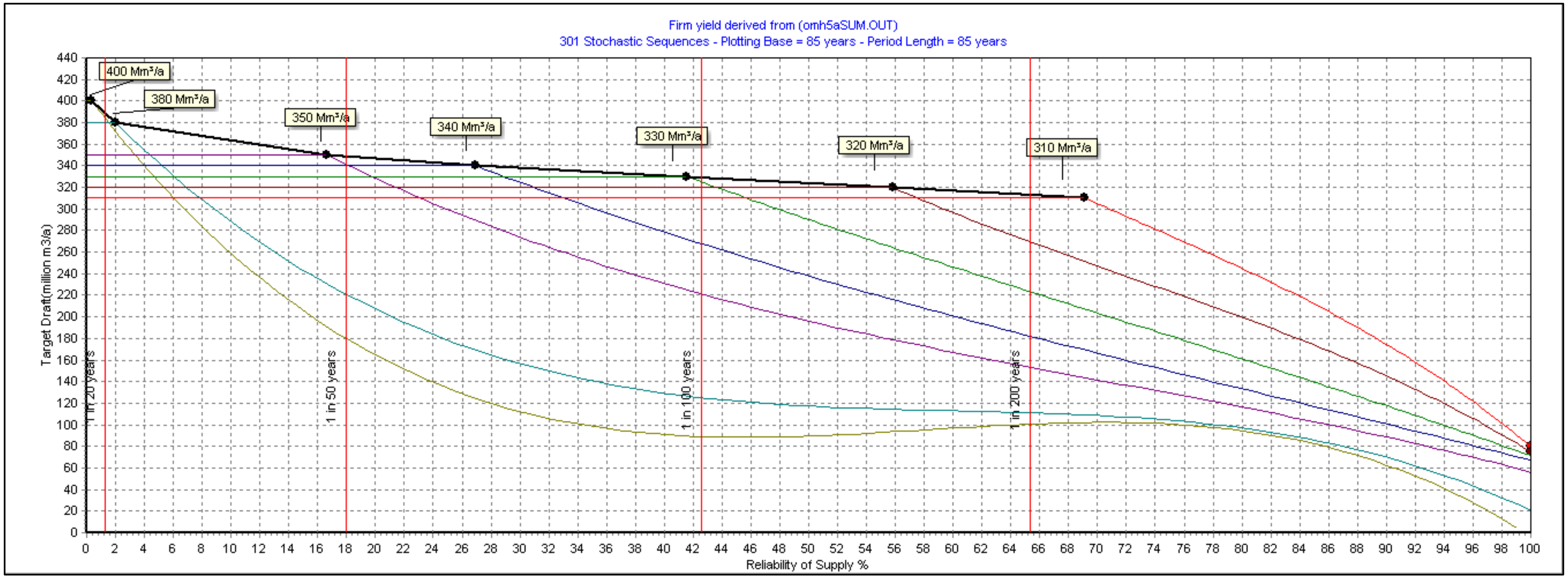


Figure 8-13: Long-term Stochastic gross yield curve: Makhaleng Dam at Site S2, Capacity 810 million m^3

As part of the Climate change task, climate change impacts were determined on the yield available from key water supply sub-systems within Orange/Senqu basin. Six climate models were selected among others on the basis that they simulate a realistic ENSO (EL-Nino-Southern Oscillation) signal (Bellenger et al. 2014). This variable exhibits a strong association between South African climate variability.

The six Global Climate Models that were selected and downscaled are:

- Australian Community Climate and Earth System Simulator (ACCESS1-0), hereafter referred to as ACC.
- Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL-CM3), hereafter referred to as GFD.
- National Centre for Meteorological Research Coupled Global Climate Model, version 5 (CNRM-CM5), hereafter referred to as CNR.
- Max Planck Institute Coupled Earth System Model (MPI-ESM-LR), hereafter referred to as MPI.
- Norwegian Earth System Model (NorESM1-M), hereafter referred to as NOR.
- Community Climate System Model (CCSM4), hereafter referred to as CCS.

The climate change models where downscaled and bias corrected to obtain acceptable regional metrological trends, correlating with historic data within the accepted Southern African hydrology. The bias corrected climate change rainfall and evaporation data were used to determine their impacts on the natural runoff on each of the sub-catchments used in the Pitman, WRYM and WRPM models. The natural runoff, rainfall and evaporation datasets that were derived based on the output from each of the six climate change models were then used as inputs tor the Water Resources Yield Model (WRYM) to determine the related yield impacts. Results for the Makhaleng and Orange River Project water supply systems are summarised in **Table 8-7**.

The ORP yield from the six different climate change models varied between 2 853 million m^3/a to as high as 3 665 million m^3/a in comparison with the historic firm yield (HFY) of 3 339 million m^3/a. The average yield from the six climate change models was 3 074 million m^3/a and is about 8% lower than the HFY based on the historic rainfall, evaporation and flow data.

For the Makhaleng sub-system the average impact from the six climate change models is very small, indicating an increase of 1% above the HFY of 378 million m^3/a. The lowest yield was obtained from the CCS climate change model at 345 million m^3/a with the highest yield of 448 million m^3/a from the GFD climate change model.

It is interesting to note that the range of yield from the six climate change models lies within the range of the stochastic yield results produced for the ORP.

For more detail the reader is referred to the climate change report (ORASECOM, 2019f).

Table 8-9: Firm yield results for Historical and future climate scenarios

Description		Firm Yield for 85year simulation period (million m^3/annum)		Percentage difference of Firm Yield results for the climate change scenarios compared to the Historical Firm Yield	
Sub-system	**CCM**	**Scenario 1 (Adjusted rainfall)**	**Scenario 2: (Adjusted rainfall and evaporation)**	**Scenario 1 vs. Historical Firm Yield**	**Scenario 2 vs. Historical Firm Yield**
Makhaleng	Gross yield based on the historic flow sequences 378 million m^3/a				0%
	ACC	398	379	5%	0%
	CCS	367	345	-3%	-9%
	CNR	394	388	4%	3%
	GFD	446	448	18%	19%
	MPI	380	358	1%	-5%
	NOR	388	375	3%	-1%
	Average	**396**	**382**	**5%**	**1%**
Orange River Project	Yield based on the historic flow sequences 3339 million m^3/a				0%
	ACC	3194	3011	-4%	-10%
	CCS	3116	2927	-7%	-12%
	CNR	3060	2974	-8%	-11%
	GFD	3702	3665	11%	10%
	MPI	3037	2853	-9%	-15%
	NOR	3175	3011	-5%	-10%
	Average	**3214**	**3074**	**-4%**	**-8%**

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Water Requirements and Return flows

The Orange-Senqu water requirements have seen a major increase for the urban component with the irrigation and industrial component remaining relatively constant. Except for new irrigation schemes built on the Fish River in Namibia, as well as an uptake in irrigation allocations along the Lower Orange Main Stem. Another noteworthy universal trend is the increase in water requirements in urban settings due to migration from rural areas.

- The overall trend for the Study Area indicates a continues growth in urban/industrial water requirements, with either a constant or decreasing rural domestic component.
- Irrigation water requirements remain constant except for resource poor farmers allocation uptake, and new irrigation schemes on the Fish River in Namibia and along the Lower Orange Main Stem as well as possible future schemes planned by Lesotho.
- Most of the water requirements for the Molopo Catchment in Botswana are satisfied by groundwater, with only limited data available.
- Measured and confirmed water requirements have not been obtained for Lesotho from WASCO or local water authorities, this should be addressed to ensure the accuracy of data to be used for reporting and modelling purposes

The water requirements for the IVRS and ORS are based on verified sources, which are continuously updated, this is however not the case for Botswana, Namibia or Lesotho. Existing water master plans were reviewed to derive acceptable water requirements, which are in line with estimated per capita water consumption values and demographic projections.

The approaches followed by the different counties relating to assurance of supply is quite different and the implementation of that in practice is not at the same level. It is important that a common understanding of assurance of supply be established and implemented in the different countries.

9.2 Groundwater

- The quantification of groundwater use remains to be a problem. Problems found are that groundwater use is recorded as either a licensed use rather than an actual use, many groundwater users are not recorded, rural water use is undocumented and needs to be estimated.
- The study found that recharge estimates for the arid regions of South Africa and for Lesotho had large errors, since they cannot be reconciled with the water balance. Revised groundwater recharge was developed for the ORASECOM Transboundary

project which is calibrated against the water balance. These were used to recalibrate the hydrology including surface-subsurface interactions and were utilized for this study.

- Recharge estimates also vary for similar geologies in South Africa and Botswana.
- Inconsistency in data collection results in ‘edge effects’ appearing at national boundaries, are difficult to reconcile.
- The volume that can be sustainably abstracted is referred to as the Utilizable Groundwater Exploitation Potential, and range from less than 300 $m^3/km^2/a$ to 25000 $m^3/km^2/a$. The data also shows that the largest volume of remaining allocable groundwater, calculated as Utilizable Groundwater Exploitation Potential minus current legal water use, is found in the Karst aquifers of the Ghaap Plateau in South Africa, where high borehole yields are still possible.
- From the bullet point above it is evident that the Mahikeng Local Municipality, which was identified as one of the RSA urban/rural centres to receive water from the possible future Lesotho-Botswana transfer, has sufficient groundwater resources to support their water requirement needs and should rather develop their groundwater resources.
- Groundwater resources are highly stressed in Lower Orange basin and the Middle to lower Vaal.
- Generally, groundwater can be used for domestic and stock watering and supply for smaller towns supplied by well fields within the Upper and Lower Orange River basin. It can be assumed that there is in general adequate groundwater resources available in the Upper and Lower Orange River basin to supply towns and communities not connected to the main surface water supply schemes.
- Data indicates that for most of the Namibian part of the basin, there is little scope for development of large-scale groundwater use schemes for potable use. In Botswana, the aquifers with the highest Utilizable Groundwater Exploitation Potential (UGEP) are Ecca North, Lebung and Lower Transvaal South.
- In Botswana, the aquifers with the highest Utilizable Groundwater Exploitation Potential (UGEP) are Ecca North, Lebung and Lower Transvaal South.
- The majority of the Botswana part of the basin with exception Ecca North, Lower Transvaal South, Upper Transvaal East and Lebung hydrogeologic units have very little scope for further development of potable groundwater resources.
- Areas in Botswana underlain by Archean Gneiss (Goodhope water supply area) and the Olifantshoek North (Tsabong water supply area) are being over abstracted i.e. high to heavily used.
- The Drakensberg Highlands in Lesotho consist of a fractured aquifer of low storage potential, although recharge is high, most is lost as interflow feeding and is not available

to boreholes tapping the regional aquifer, consequently the Exploitation potential is lower than the other groundwater regions.

- The Northeastern Lesotho Highlands have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the southeastern highlands. Locally, the Northeastern Highland region is moderately stressed by existing abstraction

9.3 Water Conservation and Water demand management

9.3.1 Urban and industrial

- Municipalities in the IVRS managed to achieve savings of 110.0 million m^3/a of a projected 212 million m^3/a by June 2018, mainly through water restrictions. The actual savings for the IVRS in 2017 and 2018 were 6.4% and 6.7% respectively.
- Crocodile (West) River water supply system includes the Northern Johannesburg, Pretoria, Rustenburg, Hammanskraal, etc. areas also receiving water from the IVRS. These municipalities have not achieved their June 2018 targets, although reasonable savings were achieved. The actual savings achieved for the 2017 and 2018 years were 8.2% and 8.9% respectively.
- Restrictions of 15% have been implemented in Mangaung Metropolitan Municipality during July 2015, which was increased to 20% in February 2016, due to resources being under stress and care should be taken to distinguish between savings achieved because of WCWDM and the restrictions implemented simultaneously. Actual saving achieved for 2017 and 2018 were 30.4% and 28.7% respectively, which is most probably partly due to the restrictions imposed on the system.
- The available data for the Orange River Water Supply System have a low confidence level. Savings of 28.1% and 28.9% were however indicated for the 2017 and 2018 years, which seems optimistic.
- Botswana WUC has set NRW targets in its Corporate Strategy 2019 – 2022 and has been forced to reduce consumption in recent years due to the ongoing droughts. Water use efficiency is within acceptable international standards, except for Gaborone management centre which include industrial and commercial water use. NRW is above 40% in all the southern management centres except Gaborone and Ghanzi. Most significant is the NRW in Lobatse which needs to be addressed to ensure sustainability of water supply services.
- The improved management of existing water sources including reducing losses, increasing water savings is a key strategic objective of Namibia's National Development Plan. Namibia plans to achieve 100% access to safe drinking water by 2020/21 in the urban areas from the current 98.6% (2016) and 95% in the rural areas

from the current 84% (2016). No water loss or NRW targets have been set. Initial results indicate low NRW and poor efficiency.

- Botswana WUC has not set NRW and water use targets, however, has been forced to reduce consumption in recent years due to the ongoing droughts. The NRW is above 40% in all the southern management centres except Gaborone and Ghanzi. Most significant is the NRW in Lobatse which needs to be addressed to ensure sustainability of water supply services.
- Lesotho WASCO has not achieved the set target of 26% NRW and no water use targets have been set. The NRW achieved by WASCO for the 2017/18 year was 36%. The WASCO should embark on a programme to eliminate intermittent supply as it corrupts consumer meter readings, damage infrastructure, increase number of bursts, demotivate staff and impacts on service delivery and willingness to pay.
- It is important to note that the beneficiaries of irrigation water savings depend on the makeup of the irrigation scheme, the location as well as prevailing management goals or policies. In general, savings from schemes sourcing water from smaller tributary rivers do not directly improve the water balance of the Vaal or Orange systems, implying the benefits of the savings are limited to the users receiving water from that source. The Large Bulk Water Reconciliation Strategy for the Orange River, is the only strategy that included large irrigation schemes, making provision for some of the irrigation water use savings to be utilized by other users, which is not necessary from the irrigation sector. Of the total estimated saving of 10% in the ORP, 5% is used by the irrigators for expansion and the remaining 5% saving can be allocated for other purposes.

9.3.2 Mining

- Data on WCWDM in the mining sector is limited due the sensitivity of such information. WCWDM should be implemented as outlined in national policy and planning documents, especially in South Africa and Botswana.

9.3.3 Re-use

- In the IVRS, the desalination of AMD will ensure a reduction in water that is needed for dilution purposes; it will reduce demand through reclamation and direct re-use and improve the salinity in the Vaal River system and Orange-Senqu basin by eventually eliminating the discharge of saline AMD.
- In Ekurhuleni/ERWAT and the City of Tshwane, substantial volumes of wastewater would be recycled, reused and reclaimed for eventual use for potable and industrial use.

- In Lesotho, there is only small-scale re-use by the Agricultural Collage. The previous report recommended that Maseru investigate the possibility to re-use its treated wastewater to irrigate its sports fields and golf course.

The eventual re-use of wastewater and the desalination of seawater could provide substantial volumes of water to all sectors, thereby securing water within the Orange-Senqu River basin. It is thus recommended that all the countries incorporate the re-use of water into formal its respective policies.

9.4 Core Scenario

9.4.1 IVRS

- The LHWP – IVRS operating rule has a significant impact on the water supply situation in the IVRS. A study recently completed by the Lesotho Highlands Water Commission on the operating rules to be implemented for Phase II of the LHWP was used as the basis of the operating rule used in the Current Core Scenario. This is only one of the recommended operating rules from the study and the two countries (Lesotho and RSA) still need to agree on the final operating rule to be implemented. It is thus important that agreement be obtained on the final operating rule, so that the consequences of the selected operating rule to all parties involved are also known. The final selected LHWP Phase II operating rule can thus impact on the results from the Current Core Scenario.
- The selected LHWP Phase II operating rule was agreed with the four basin states to be used for the purpose of the Core Scenario analysis. This rule resulted in a much-improved water supply from the IVRS. The IVRS will however experience possible deficits in supply from 2021 to 2025 before Polihali Dam is in place. Significant deficits are then only again expected by around 2044. The next intervention option which will be the further Phase from the Thukela Transfer system, need to be implemented by then.
- For the IVRS it is crucial that the WC/WDM targets be met as well as the reduction/eliminating of unlawful irrigation in the Upper Vaal. The IVRS will experience significant deficits if these targets are not achieved.
- The planned re-use of return flows in the Crocodile River from the Northern Johannesburg, Pretoria, Rustenburg areas etc. receiving water from the IVRS was assumed to be in place in future. This will reduce the demand imposed on the IVRS. It is however important that DWS RSA check that there will still be sufficient flow available in the Crocodile River System to satisfy the Reserve requirements after the implementation of re-use.

- The Current Core Scenario included the implementation of the desalination and re-use of the Acid Mine Drainage in the Middle Vaal according to the recommended planning from the Vaal Reconciliation Strategy study. DWS RSA is currently in the process to update the Vaal System Integrated Water Quality Strategy, which might result in a change of approach regarding the treatment and use of the Acid Mine Drainage water. This need to be followed up in future, to determine whether significant changes will occur that will impact on water supply from the IVRS.

9.4.2 Greater Bloemfontein Water Supply system

- The Greater Bloemfontein System is already experiencing significant deficits in water supply. This is expected to last at least until 2022 if the proposed intervention options are in place at the planned time. The implementation of these intervention options is already behind schedule and it is thus expected that the deficits will continue to beyond 2022.
- The Lesotho Lowland developments such as the Hlotse and Ngoajane schemes was not taken into account in the planning of the intervention options, and it might be required to do some refinements to some of these intervention options.
- The Makhaleng Dam and related transfer scheme should be considered to also support the Greater Bloemfontein. This might be a more beneficial option than the supply from Gariep Dam, which will involve much higher pumping costs. Taking the water from Gariep Dam or from Makhaleng Dam, will have more or less the same impact on the ORP water balance.

9.4.3 ORP

- The storage projection plot of the ORP system (Verbeedingskraal Dam included) shows very low storage levels at the 99% and 99.5% exceedance probability levels from about 2030 onwards. This is partly due to the ORP system being overloaded, thus supplying more than the available yield, but also due to the operating rule that allow support from Verbeeldingskraal and Makhaleng dams once the storage in Gariep and Vanderkloof dams is very low. From the future major upstream developments, only Makhaleng Dam was used to support the ORP, to make good the reduction in yield of the ORP, due to the Makhaleng Dam development. The reduction in ORP yield due to the development of the Hlotse Dam and Ngoajane Dam schemes were not compensated for. Only EWR releases were made from these two dams.
- The water supply plots from the ORP system show a more positive picture than the storage projection plots, as deficits in the irrigation supply for the first time occurred in 2030 and 2031, then again on a more continuous basis from 2037 onwards. Supply to

the urban/industrial/mining component showed deficits from 2044 onwards. The filling up of several future dams around the 2030's such as Noordoewer/Vioolsdrift, Makhaleng and Hlotse dams, is probably the main reason for the deficits experienced in 2030 and 2031.

- When Hlotse and Ngoajane Dams are removed from the Current Core Scenario, the supply from the ORP is acceptable. This means that some compensation needs to be made from Hlotse and Ngoajane Dams, to make up for the reduction in yield of the ORP when these two dams are included in the Core Scenario.
- The medium size Noordoewer/Vioolsdrift Dam is not sufficient to support the significant growth in the Namibia irrigation requirement over the entire projection period and deficits start to occur from 2043 onwards.
- With the large Noordoewer/Vioolsdrift Dam in place these irrigation requirements are very well supplied. The supply to the remainder of the ORP system also improved to acceptable levels, when the large Noordoewer/Vioolsdrift Dam is in place.
- The implementation of WC/WDM within the ORP for urban/Industrial/Mining and irrigation use is of high importance, as deficits in water supply will increase significantly and is expected to already start by 2029.
- Not utilizing the Lower Level Storage in Vanderkloof Dam will significantly increase the deficits in the ORP system. Deficits is expected to then already start from 2030 onwards. Its only for droughts with a recurrence interval of 1 in 20 years and more that Vanderkloof Dam storage drop too low to be able generated hydropower. This can however be improved by adjustments to the operating rules.
- At this stage there is still great uncertainty of what the final Reserve requirement will be. For this reason, it was regarded as important to carry out a sensitivity analysis on the impact of this Reserve on the water supply from the ORP system. If the current approved preliminary reserve is maintained for the total projection period and not replaced by a Reserve with a higher water requirement, the positive water supply impact on the system is significant. The ORP dams will operate at much higher storage levels and demands will be fully supplied. The impact of this can however be detrimental on the environmental condition of the river and the river mouth. It is thus very important to carry out the classification study followed by the Reserve determination to obtain a balance between the ecology and the economy of the area.

9.4.4 Metolong sub-system

- The water requirement projections for Maseru and surrounding areas significantly increased since the previous study in 2014 when the Core scenario was defined for the first time. The Previous Core Scenario thus indicated no deficits for the supply to

Maseru. The current Core Scenario shows deficits to occur already from approximately 2030 onwards. By 2050 the deficits are quite severe.

- It is recommended that the old existing system taking water directly from the Mohokare River be upgraded so that it can again provide a substantial amount of support to the Maseru water supply system. Propper operating rules also need to be developed and implemented to optimise the water supply from the existing water resources.
- Consider also to support Maseru from the Makhaleng Dam and transfer system.

9.4.5 Makhaleng Dam and transfer scheme

- The impact of Makhaleng Dam and transfer scheme on the available yield from the ORP is significant, and it is thus important to utilize Makhaleng Dam to also support the ORP. The yield from a 3 MAR Makhaleng Dam is sufficient to support the ORP as well as to supply the local Lesotho water requirements and transfer to Botswana, but within the limits of the available yield.
- When the high Botswana water requirement needs to be transferred from Makhaleng Dam, there will not be water available for irrigation in Lesotho from Makhaleng Dam.
- With the low Botswana transfer in place, Lesotho will be able to allocate between 40 to 77 million m^3/a for irrigation, depending on the assurance of supply required for irrigation purposes.
- The impact of the Low and High Botswana transfer option on the ORP is almost the same. This is due to the local Lesotho irrigation requirement that is added to the Low Scenario and not to the High Scenario.
- The assurance of supply to users from the Makhaleng to Botswana transfer was found to be unacceptably low based on the initial analyses carried out. It was found that the assurance of supply is quite sensitive to the operating rule used for Makhaleng Dam. The operating rule was then adjusted, and the assurance of supply was significantly improved without jeopardizing the water supply assurance from the ORP. Further improvement in the water supply from Makhaleng Dam is still required. It is thus recommended that this be investigated in more detail as part of the feasibility study.

9.4.6 Hlotse sub-system

- The EWR as obtained from the SMEC Report is a very low level EWR with little information available to be able to model it properly. It is thus recommended that a high level EWR be determined as part of the Feasibility Phase.
- The results from the Current Core Scenario showed that Hlotse Dam performed well with the EWR (14.4 million m^3/a), irrigation requirement of 46.2 million m^3/a as well as an urban requirement growing from 15.1 to 19.4 million m^3/a by 2050, imposed on the

dam. The demands imposed on the sub-system was supplied at a high assurance level. This indicates that there is some surplus yield available in the system that can be used to support the Greater Bloemfontein and or ORP system.

- It is recommended to investigate the possibility of increasing this dam to generate an increased yield that can be used to make good the reduction in yield at the Greater Bloemfontein and ORP systems, caused by the implementation of Hlotse Dam.

9.4.7 Ngoajane sub-system

- The EWR as obtained from the SMEC Report is a very low level EWR with little information available to be able to model it properly. It is thus recommended that a high level EWR be determined as part of the Feasibility Phase.
- As for the Hlotse sub-system, results from the Ngoajane sub-system revealed a well-supplied system with no deficits over the entire simulation period. The total water demand that was imposed on the sub-system included 8 million m^3/a for EWR purposes, 6.2 million m^3/a for irrigation and an urban requirement starting at 16.5 million m^3/a and increases to 23 million m^3/a by 2050. The demands were in general supplied at high assurance levels which indicates that there might be some surplus yield available in the sub-system.
- It is recommended to investigate the possibility of increasing this dam to generate an increased yield that can be used to make good the reduction in yield at the Greater Bloemfontein and ORP systems, caused by the implementation of Ngoajane Dam.

9.4.8 Neckartal Dam

- Results from the system analysis of the Current Core Scenario showed that Neckartal Dam take approximately 10 years to stabilize after inundation started. The dam is expected to be seldom full or spilling (approximately1:20 years).
- Neckartal Dam performed quite well supplying water for irrigation purposes of 90 million m^3/a, EWR requirements with median of approximately 6 million m^3/a and releases of 100 million m^3/a for hydropower generation. The hydropower releases are a non-consumptive demand and is utilised downstream of the dam to supply the irrigation and EWR. All the water requirements imposed on the dam were well supplied at relative high assurances.

9.4.9 Hardap and Naute dams

- Hardap urban requirements were supplied at reasonable assurance levels.
- Irrigation were supplied at acceptable assurance levels, although a bit low.
- No further allocation of water requirements should be imposed on Hardap Dam.

- The assurance of supply to the Naute urban component was a bit low.
- Irrigation supply from Naute Dam was at an acceptable level of assurance.
- The water demand on Naute should not be increased.

9.5 Assessment of Multipurpose Dams

In general, the construction of dams in the upstream parts of a basin impacts much more severely on the yield available from the downstream dams, than what the building of downstream dams will have on the yield of possible future upstream dams. This also depends on the extent of the overall development in the basin, the location of the dams, operating rules used, agreements between users/countries, etc.

9.5.1 Most important conclusions and Recommendations

The most important conclusions and recommendations relating to the assessment of multipurpose dams include the following:

- It is possible to restore the water balances after the incorporation of Makhaleng, Hlotse and Ngoajane dams and target supply areas. This will, however, have cost implications resulting in higher URVs as well as the cost of water supplied.
- The large 3 MAR Makhaleng Dam will be the most cost-effective option, but one will then have to slightly reduce the target demand imposed on the dam from about 200 million m^3/a to 188 million m^3/a.
- If the Lesotho hydropower scheme in the Senqu River goes ahead, it will significantly increase the net yield in Makhaleng Dam, allowing the intended high transfer water requirement to be fully met.
- If a higher net yield is required at Makhaleng Dam and the Lesotho hydropower scheme is not going ahead, the next economically most viable option will be the raising of Verbeeldingskraal Dam. This will depend on whether the RSA will finally use Verbeeldingskraal Dam to restore the Orange River water balance due to the impacts of Polihali Dam.
- If none of the above-mentioned options are considered, the large Ntoahe Dam option can be used.
- The large Hlotse Dam seems to be the better option to be used to restore the water balances in the Mohokare/Caledon systems than the increase in storage of Ngoajane Dam.
- Support from the Makhaleng surplus as well as the alternative dams analysed in the Senqu River, can also be used to restore the water balance due to the negative water

supply impacts on downstream users as result of Hlotse and Ngoajane dams. The alternative dams in the Senqu can to a large extent take over the function of compensation releases from Makhaleng Dam to downstream users. This will increase the available net yield in Makhaleng Dam, which can in turn be used to take over some of the compensation releases to be made from Hlotse and Ngoajane dams.

9.5.2 Other relevant conclusions and recommendations from the multipurpose dam analyses include:

- When a 3 MAR Makaleng Dam is in place and the full yield is utilized by Lesotho for their own and or transfer purposes, the impact on the downstream Orange River Project (ORP) is quite significant, reducing the ORP HFY by 252 million m^3/a. The gross HFY then available from Makaleng Dam is 378 million m^3/a with a net yield of only 126 million m^3/a.
- This impact of Makaleng Dam on the ORP can be reduced to zero if Makhaleng Dam is used to also support the ORP. Under such conditions there will still be an HFY of between 158 and 188 million m^3/a available from Makhaleng Dam to be utilized by Lesotho at 2030 development level, depending on the specific scenario and operating rule used.
- From a system perspective it is better to use Makhaleng Dam to also support the ORP. This approach will result in the system yield being higher by approximately 62 million m^3/a in comparison with the option where Makhaleng Dam is not used to support the ORP.
- The combined impact of Verbeeldingskraal and Polihali dams (RSA related dams) on the yield available from a 3 MAR Makaleng Dam (Lesotho dam) is much less, and was determined as 11 million m^3/a. For this option Makaleng Dam was used to support the ORP system to restore the negative yield impact on the ORP. The drop-in yield from Makhaleng Dam is mainly as result of the higher support required for the ORP when more RSA dams were developed in the system.
- The historic firm yield for Hlotse and Ngoajane dams were determined as 84.6 million m^3/a and 30.8 million m^3/a respectively. The net system yield increases due to Hlotse and Ngoajane dams are however only 54 million m^3/a and 10 million m^3/a respectively.
- The inclusion of Hlotse and Ngoajane multipurpose Lesotho Lowland schemes as reflected in scenarios 3 and 4 resulted in a further decrease in yield of 45 million m^3/a for the ORP system, although the large Makhaleng Dam was used to partly support the ORP system by means of compensation releases.
- The reduction in yield to the Greater Bloemfontein system, Maseru and smaller Lesotho towns along the Mohokare River (-6.4 million m^3/a) brings the total reduction (ORP

reduction of 45 million m^3/a included) in yield/water supply to 51.4 million m^3/a for Hlotse and Ngoajane dams combined.

- With some increase in storage at both Hlotse and Ngoajane dams of 15 million m^3 and 27.3 million m^3 respectively, the gross yield from the two dams can be increased by 9.3 million m^3/a and 8 million m^3/a, thus a total of 17.3 million m^3/a.
- The analyses carried out mainly focused on the yield impact of the ORP, Greater Bloemfontein and Maseru sub-systems, and did not include the smaller impacts on river abstractions directly from the Caledon, Orange and Senqu rivers in Lesotho and the RSA. These impacts should be investigated in detail before any of the future schemes are constructed.
- The possible future hydro-power dams on the Senqu River will result in an increase in yield from the ORP system if operated correctly. This can lead to reduced compensation releases in from Makhaleng Dam to the ORP, which in turn will increase the net yield available from Makhaleng Dam. The possible increase in the yield was determined for two possible flow pattern release scenarios from the hydro-power dams. An almost stable base flow over the entire year, or a flow pattern that will mimic the natural monthly flow distribution over the year. The increase in yield determined for these two flow release options was 134 million m^3/a and 124 million m^3/a, which can be used to balance the negative yield impacts and or to make more yield available from Makhaleng Dam for Lesotho's owns usage and or transfers to Botswana and the RSA.
- It is important to note that it is possible to also lower the ORP yield when the possible future hydro-power dams on the Senqu River are not operated correctly, in particular during critical drought periods.
- Increasing the storage of Hlotse and Ngoajane dams will assist to reduce the deficits along the Caledon (Mohokare) River but will not be sufficient.
- Providing water from the Makhaleng transfer system to the Greater Bloemfontein and maybe some of the larger towns along the Caledon River experiencing deficits, might solve the Caledon deficits.
- Decreasing some of the planned Lesotho irrigation schemes to slightly smaller schemes will also contribute to the reduction of deficits along the Caledon/Mohokare River.
- One would further need to confirm whether all the EWRs along the Caledon and Orange River (final Reserve in Orange) can still be met, once all the planned developments are in place.

From the assessment of multipurpose dams in Lesotho it is evident that it will be difficult to maintain a positive balance in the downstream water supply schemes with all the developments envisaged for Lesotho in place, which includes major transfers to the RSA and Botswana. It is however not impossible, in particular when the benefit of hydropower dams on the main Senqu River is utilized. This will to a large extend address the deficits on the main Orange and ORP system. Another cost-effective option for the Main Orange and ORP to consider is increasing the storage of Verbeeldingskraal Dam. The DWS RSA study only considered the maximum size at Verbeeldingskraal that will not inundate Lesotho. There is thus scope to increase the storage at this site, when it is agreed between the two counties to also inundate part of Lesotho. The possible combination of dams to be able to maintain a positive water balance with Makhaleng dam in place is given in **Figure 8-9** in **Section 8.4.2** of this report. These options further include increasing the yield available from Makhaleng Dam to support a higher transfer to Botswana as well as larger areas under irrigation within Lesotho.

Increasing the storage of Hlostse and Ngoajane dams will assist to reduce the deficits along the Caledon (Mohokare) River. Providing water from the Makhaleng transfer system to the Greater Bloemfontein and maybe some of the larger towns along the Caledon River experiencing deficits, might solve the Caledon deficits. Decreasing some of the planned Lesotho irrigation schemes to slightly smaller schemes will also contribute to the reduction of deficits along the Caledon/Mohokare River. One would further need to confirm whether all the EWRs along the Caledon and Orange River (final Reserve in Orange) can still be met, once all the planned developments are in place. Taking into account all these possibilities a combination of dams and sub-systems were derived as shown in **Figure 8-10** in **Section 8.4.3** of this report. These possible combinations as given in **Figure 8-10** will be able to maintain a positive water balance in the ORP and ensure a similar water supply to the main users from the Caledon/Mohokare River.

9.5.3 Conclusions from the Risk analysis carried out on Makhaleng Dam

- The net stochastic yield results for Makhaleng Dam based on sub-scenario 2g were determined. This represent the yield available after compensation releases were made in support of Verbeeldingskraal, Gariep and Vanderkloof dams. The historic firm yield for this Makhaleng Dam scenario was determined as 188 million m^3/a and represents a recurrence interval of 1 in 120 years. This means that the historic firm yield represents a relative high assurance which will open the possibility of making more water available for irrigation purposes in Lesotho.

- Based on the results from the 6 selected climate change models natural flow records were generated using the Pitman Model for each of the 6 climate change model results. These updated natural flow records were then included in the WRYM to determine the impact of the changed natural runoff due to climate change on the yield available from Makhaleng Dam. For the Makhaleng sub-system the average impact from the six climate change models natural flow records is relatively small, indicating an increase of 1% above the HFY (from current historic natural flow records) of 378 million m^3/a. The lowest yield was obtained from the CCS climate change model at 345 million m^3/a with the highest yield of 448 million m^3/a from the GFD climate change model.
- It is interesting to note that the range of yield from the six climate change models lies within the range of the stochastic yield results produced for the ORP.

10 REFERENCES

DWAF, 1996. the Orange River Replanning Study (ORRS) Refinement of the instream flow requirements for the Orange River by BKS and Ninham Shand for the Department of Water Affairs and Forestry RSA. September 1996. Report number PD 00/00/617.

LHDA, 2003. Draft Procedure for the Implementation of the LHWP Phase I Instream Flow Requirement Policy.

Parkman, 2004. Lesotho Lowlands Water Supply Scheme – Feasibility Study – Funded by the 8th EDF

SMEC/EHES, 2006. National Water Master Plan Review. Vol 6: Rural Water Supply. Gaborone, Botswana: Department of Water Affairs.

DWAF, 2007a. Vaal River System Large Bulk Water Supply Reconciliation Strategy: Urban Water Requirements and Return Flows. Prepared by: DMM Development Consultants, Golder Associates Africa, SRK, WRP Consulting Engineers and Zitholele Consulting. DWAF Report Number: P RSA C000/00/4406/01.

DWAF, 2007b. Vaal River System Large Bulk Water Supply Reconciliation Strategy: Irrigation Water Use and Return Flows. Prepared by: DMM Development Consultants, Golder Associates Africa, SRK, WRP Consulting Engineers and Zitholele Consulting. DWAF Report Number: P RSA C000/00/4406/04.

ORASECOM, 2007a. Orange River Integrated Water Resources Management Plan – Demographics and Economic Activity in the Four Orange Basin States.

ORASECOM, 2007b. Orange River Integrated Water Resources Management Plan: Review of Existing Infrastructure in the Orange River Catchment. By WRP Consulting Engineers, Jeffares and Green, Sechaba Consulting, WCE Pty Ltd, and Water Surveys Botswana (Pty) Ltd. ORASECOM, Gaborone, Botswana.

ORASECOM, 2007c. Orange River Integrated Water Resources Management Plan: Summary of Water Requirements from the Orange River. By WRP Consulting Engineers, Jeffares and Green, Sechaba Consulting, WCE Pty Ltd, and Water Surveys Botswana (Pty) Ltd. ORASECOM, Gaborone, Botswana.

DWAF, 2007. VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGY:URBAN WATER REQUIREMENTS AND RETURN FLOWS (February 2007) - Report No. P RSA C000/00/4406/01

DWAF, 2009. VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGIES: WATER RESOURCE ANALYSIS (March 2009). Prepared by: DMM Development Consultants, Golder Associates Africa, SRK, WRP Consulting Engineers and Zitholele Consulting. DWAF Report Number: P RSA C000/00/4406/05.

DWAF,2009b. VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGY: IRRIGATION WATER USE AND RETURN FLOWS. - P RSA C000/00/4406/04

DWAF,2009c. INTEGRATED WATER QUALITY MANAGEMENT PLAN FOR THE VAAL RIVER SYSTEM: Task 3: Salinity Balance of the Vaal River System. Report No. P RSA C000/00/2305/2. Directorate National Water Resource Planning. Department of Water Affairs and Forestry, South Africa, September 2009.

DWAF,2009d. VAAL RIVER SYSTEM: LARGE BULK WATER SUPPLY RECONCILIATION STRATEGY: SECOND STAGE RECONCILIATION STRATEGY (March 2009)

DWA,2010. Comprehensive Reserve Determination Study of the Integrated Vaal River System. Report No. RDM/C000/01/CON/0607. BY WRP, Hydrosol, DMM Joint Venture for DWA, Surface Water Reserve Requirements.

MAWF, 2010. Integrated Water Resources Management Plan for Namibia prepared for Ministry of Agriculture, Water and Forestry. Prepared by IWRM Plan Joint Venture Namibia – August 2010.

DWS, 2011. DEVELOPMENT OF A RECONCILIATION STRATEGIES FOR ALL TOWNS IN THE CENTRAL REGION. CONTRACT/PROJECT NUMBER WP9713

MAWF, 2011. Integrated Water Resources Management: Orange-Fish River Basin. Presentation to MAWF.

http://www.the-eis.com/data/literature/MAWF_IWRM%20booklet%20-%20Orange%20Fish%20River%20Basin_RV2.pdf accessed on 27 November 2018

ORASECOM, 2011a. Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan: WP 5: Assessment of Environmental Flow requirements. Prepared by WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE.

ORASECOM, 2011b. Support to Phase II of the ORASECOM Basin Wide Integrated Water Resource Management Plan: The Promotion of WCWDM in the Irrigation Sector (ORASECOM, 2011), ORASECOM, 2011c. Support to Phase II of the ORASECOM Basin Wide Integrated Water Resource Management Plan: Extension of Hydrological (ORASECOM, 2011),

DWA, 2012a. Classification of Significant Water Resources (River, Wetlands, Groundwater and Lakes) in the Upper, Middle and Lower Vaal Water Management Areas (WMA) 8,9,10. Water Resource Analysis Report. Report No. RDM/WMA8,9,10/00/CON/CLA/0411.

DWA,2012b. Water Reconciliation Strategy Study for the Large Bulk Water Supply Systems. Greater Bloemfontein Area. Reconciliation Strategy Report June 2012. Report no. P WMA 14/C520/00/0910/05

DWS, 2012-2013. Water Management Plans to Improve Water Use Efficiency in the Agricultural Sector

ORASECOM, 2012. Orange-Senqu River Commission Secretariat Governments of Botswana, Lesotho, Namibia and South Africa UNDP-GEF Orange-Senqu Strategic Action Programme Research Project on Environmental Flow Requirements of the Fish River and the Orange-Senqu River Mouth Volume 5: Hydrology and River Hydraulics Technical Report 31 Rev 1, 10 May 2012. This report has been prepared by: Rivers for Africa, e-Flows Consulting (PTY) Ltd.

DWS, 2013. National Water Resources Strategy June 2013 Second Addition. RSA

MMEWA, 2013. Botswana Integrated Water Resources Management & Water Efficiency Plan (L. Dikobe, Ed.) Gaborone, Botswana: Government of Botswana.

DWS, 2014a. DEVELOPMENT OF RECONCILLIATION STRATEGIES FOR LARGE BULK WATER SUPPLY SYSTEMS ORANGE RIVER: Current and Future Urban/Industrial Water Requirements. Prepared by: WRP Consulting Engineers, Aurecon, Golder Associates Africa, and Zitholele Consulting. Authored by van Rooyen P. and Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216.

DWS, 2014b. DEVELOPMENT OF RECONCILLIATION STRATEGIES FOR LARGE BULK WATER SUPPLY SYSTEMS: Orange River - Irrigation Demands and Water Conservation/Water Demand Management. Prepared by: WRP Consulting Engineers, Aurecon, Golder Associates Africa, and Zitholele Consulting. Authored by Authored by van Rooyen P. and Mare M DWS Report No: RDM/WMA06/00/CON/COMP/0216.

DWS, 2014c. Department of Water and Sanitation. November 2014. The Development of a Comprehensive Water Conservation and Water Demand Management

Strategy and Business Plan for the Fish to Tsitsikamma Water Management Area: Agricultural Sector Strategy and Business Plan. Report No. P WMA 15/000/00/2012/2/2

ORASECOM, 2014a. Integrated Water Resources Management Plan for the Orange-Senqu River Basin: Water Demand Projections and Synthesis of Planned Infrastructure Investments. By WRP Consulting Engineers, BRL Ingenierie, Pegasys, and Hydroc Consult. ORASECOM, Gaborone, Botswana.

ORASECOM, 2014b. Integrated Water Resources Management (IWRM) plan, for the Orange-Senqu River Basin. Main Report December 2014. Report Number 019/2014 By WRP Consulting Engineers, BRL Ingenierie, Pegasys, and Hydroc Consult.

ORASECOM, 2014c. Integrated Water Resources Management (IWRM) plan, for the Orange-Senqu River Basin. Water Resources Modelling Baseline Scenario, Yield Analysis, Stochastic Verification and Validation. Report Number ORASECOM 014/2014 By WRP Consulting Engineers, BRL Ingenierie, Pegasys, and Hydroc Consult.

DWS, 2015a. DEVELOPMENT OF RECONCILLIATION STRATEGIES FOR LARGE BULK WATER SUPPLY SYSTEMS: Orange River – Final Reconciliation Strategy. Prepared by: WRP Consulting Engineers, Aurecon, Golder Associates Africa, and Zitholele Consulting. Authored by Authored by van Rooyen P. and Mare M DWS Report No: RDM/WMA06/00/CON/COMP/0216.

DWS, 2015b. CONTINUATION OF THE CENTRAL PLANNING REGION ALL TOWNS RECONCILIATION STRATEGIES CONTRACT WP 10589.

MMEWR, 2015. Countrywide Comprehensive Assessment of Water and Wastewater Situation. 29 March 2015

MMEWR, 2015b. Lesotho Lowlands Botswana Water Transfer Desktop Study (Final Report). Prepared by Bigen Africa Association (Bigen, Stephenson, SEED, CDM Smith) on behalf of the Republic of Botswana Ministry of Minerals, Energy and Water Resources, Botswana.

WASCO, 2015. Strategic Plan 2015/2016-2019/2020

DWS, 2016a. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. River EWR report. Prepared by: Rivers for Africa e-Flows Consulting (Pty) Ltd. Authored by Louw D, Birkhead D, Koekemoer S, Mare M. DWS Report No: RDM/WMA06/00/CON/COMP/0216.

DWS,2016b. Orange River System: Annual Operating Analyses 2015/2016- Main Report. July 2016. Report Number. P RSA D 000/00/21515. By Aurecon in Association with WRP for DWS Directorate Water Resource Planning Systems.

DWS, 2016c. Vaal System 2016/2017 AOA Main Report. October 2016 Report no. P RSA 000/00/21415. By Aurecon in Association with WRP for DWS Directorate Water Resource Planning Systems.

MMEWR, 2016. Botswana Water Accounting Report 2014/2015. Water Accounting Unit Department of Water Affairs.

DWS,2017. Orange River System: Annual Operating Analyses 2016/2017- Main Report. May 2017. Report Number. P RSA D 000/00/21816. By Aurecon in Association with WRP for DWS Directorate Water Resource Planning Systems.

DWS, 2017b. The Development of a Comprehensive WC/WDM Strategy and Business Plan for the Fish to Tsitsikamma Water Management Area. Agricultural Sector Strategy and Business Plan PWMA 15/000/00/2012/2/2

LWC, 2017. Lesotho Water Sector Improvement Project II. Contract number LWSIP II/Comp III/C/17-2015 for Consulting Services for the Update Detail Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme. June 2017. By SMEC International PTY (LTD) for Lesotho Water Commission.

PWC, 2017. Permanent Water Commission Namibia RSA, 2017. Noordoewer/Vioolsdrift Dam Feasibility Study. Noordoewer/Vioolsdrift Dam Size Optimization 20170525 Final Draft (currently ongoing)

SMEC, 2017. Final Water Resources Assessment Report. Consulting Services for the Update Detail Designs, and Construction Supervision of the Lesotho Lowlands Water Supply Scheme. The Government of Lesotho, Lesotho Water Commission.

BNWMP, 2018. Botswana National Water Master Plan Update Based on Smart Water Management (February 2018)

DWS,2018. Annual Operating Analyses for the Orange River Project and Greater Bloemfontein sub-systems 2018/2019. Dec 2018. Report Number. P RSA D 000/00/22819. By WRP for DWS Directorate Water Resource Planning Systems.

DWS, 2018a. Vaal System 2017/2018 AOA Main Report. October 2016 Report no. P RSA 000/00/21415. By Aurecon in Association with WRP for DWS Directorate Water Resource Planning Systems.

DWS,2018b. Continuation of the Integrated Vaal River System Reconciliation Strategy Study – Phase ll. Vaal River Annual Operating Analysis 2018/19. WRPM Scenario Results. Compiled by WRP Consulting Engineers for DWS

DWS, 2018c. South Africa. Dept. of Water Affairs. 2018. National Water Act, 1998 (Act No. 36 of 1998). Proposed Reserve Determination of Water Resources for the Vaal Catchment. Government Gazette No. 42127:1419 21 Dec.

DWS, 2018d. Continuation of the Integrated Vaal River system Reconciliation Strategy (Phase 2), Status Report 1

LesMW, 2018. Lesotho Ministry of Water: Commissioner of Water: State of Water Resources Report 2016/2017. Submitted to Commissioner of Water 15 UN Road Sentinel Park Building Maseru Lesotho

LHDA, 2018. Professional Services for the Phase ll Hydropower facility, Further Studies. Pre-feasibility Screening Study of other viable Hydropower options in Lesotho (Outside the LHWP)

LHWC,2018. Determination of the Operating Rule for the Operation of Phase ii of the Lesotho Highlands Water Project Contract no. 15 (004), completed in January 2018. By WRP in Association with GWC and Seed Consult.

Mangaung Metro Municipality, 2018. Mangaung Gariep Water Augmentation Project. Scenario analyses Greater Bloemfontein Water Supply System. Prepared by WRP and BIGEN for Mangaung Metro

Metolong Authority, 2018. Components Webpage, http://www.metolong.org.ls/# accessed on 28 November 2018.

MMM,2018. Mangaung Gariep Water Augmentation Project. Report no. P0428-1 August 2018 By BIGEN and WRP for Mangaung Metropolitan Municipality.

WASCO, 2018. WASCO Corporate Profile Webpage, http://www.wasco.co.ls/company-establishment/ accessed on 27 November 2018.

ORASECOM, 2019a. Lesotho-Botswana water transfer multipurpose transboundary project Component lll Pre-feasibility Phase. Pre-feasibility report Phase 1 Report Component lll, report number ORASECOM 014/2019. By WRP Consulting Engineers and Knight Piésold Consulting. ORASECOM, Pretoria, South Africa.

ORASECOM, 2019c. Lesotho-Botswana water transfer multipurpose transboundary project Component lll Pre-feasibility Phase. Water Conservation, Water Demand management and Re-use Report Component I, report number

ORASECOM 005/2019. By WRP Consulting Engineers and Knight Piésold Consulting. ORASECOM, Pretoria, South Africa.

ORASECOM, 2019d. Lesotho-Botswana water transfer multipurpose transboundary project Component lll Pre-feasibility Phase. Water Requirements and Return flows Component I, report number ORASECOM 004/2019. By WRP Consulting Engineers and Knight Piésold Consulting. ORASECOM, Pretoria, South Africa.

ORASECOM, 2019e. Lesotho-Botswana water transfer multipurpose transboundary project Component lll Pre-feasibility Phase. Ground Water Report Component l, report number ORASECOM 006/2019. By WRP Consulting Engineers and Knight Piésold Consulting. ORASECOM, Pretoria, South Africa.

ORASECOM, 2019f. Preparation of climate resilient water resources investment strategy & plan Component l. Climate Change. Report no. ORASECOM 007/2019. By WRP Consulting Engineers and the CSIR. ORASECOM, Pretoria, South Africa.

APPENDIX A

Strategy Action Matrix for WC/WDM measures and related interventions in the irrigation sector (January 2018)

Ref.	Action	Responsibility	Current Status (November 2018)	Target Date	Comment
1	Compile and implement Water Management Plans for each Irrigation Scheme	Country Water Management Authorities.	Management Plans were developed for seven schemes. (**see Section 3.4** for summary information)	Fist Plans for remaining schemes: Date Updated plans indicating progress with implementation: Annually.	ORASECOM has an oversight role to engage with the Water Authorities in the respective countries.
2	ORASECOM should interact with the relevant ministries of the member states to implement legislation, with reference to the obligations of the Water User Associations, to compile Water Management Plans.	ORASECOM to provide oversight.	See above.	See above.	Progress has been made in the development of Water Management Plans (See current status of Item 1 above). Similar actions should be undertaken in the respective countries.
3	Improve irrigation water measurements.	Information on the status of each scheme to be provided in the respective Water Master Plans.	Status of water measurements are provided in each Water Master Plan.	See Item 1.	Status of water measurement in irrigation schemes in the respective countries to be provided. ORASECOM to provide oversight.
4	Initiate modern irrigation scheduling systems with appropriate professional support where required.	Status of scheduling systems should be presented in the Water Management Plans.	Examples of schemes applying best practices have been identified.	See Item 1.	Investment required by private sector. The incentives for such could either be (a) expansion of irrigation area (b) increase in assurance of supply (c) trading of the saving to other system users.
5	Promote and disseminate information (including examples) to the respective countries as to what the best practices are in the irrigation sector.	ORASECOM to prepare promotion material (using existing references and best practice pilot site examples).	Examples of schemes applying best practices has been identified.	Ongoing.	

Ref.	Action	Responsibility	Current Status (November 2018)	Target Date	Comment
6	Limit operational losses through real time monitoring of river flows in the Orange and Vaal rivers to maximize the beneficial use of the spillages from the Vaal River System.	DWS South Africa in association with ministries of the Basin States.	-	2021	Alignment required with the operationalization of the EWR described in DWS, 2017.
7	Engage with WUA and remaining Irrigation Boards/Schemes to investigate the option to lower the irrigation assurance of supply.	Ministries of all Basin States	-	2022	The benefit of a lower assurance of supply is that over the long term the volume of water supplied increases. (b) ORASECOM to ensure the same action is consistently applied in all member countries/Basin States
8	The formulation and introduction of a mechanism whereby water, saved through water use efficiency can be made available to other water users in the system.	ORASECOM to devise principles and consult with Basin States.	-	2020	This action should be performed in conjunction with Items 4 and 7.
9	Eradication of unlawful water use in the irrigation sector in South Africa.	ORASECOM to engage with DWS: South Africa to obtain information on the current status of this intervention.	A rigorous legal process was implemented by DWS:SA to curb unlawful water use since 2012. (c)	At the IVRS Strategy Steering Committee meeting held on March 2018, updated information was requested to quantify the current status regarding eradication of unlawful water use at the next SSC.	

Ref.	Action	Responsibility	Current Status (November 2018)	Target Date	Comment
10	Track progress with achieving water use saving targets – 5% in net system savings (a) was set as a target in the Orange River Reconciliation Strategy.	ORASECOM to provide oversight. Responsibility reside with the various Water User Associations (or alike) and the respective countries water regulators.	Overall system saving target and detail estimates at seven irrigation schemes has been established.	2022	A consolidated tracing spreadsheet should be compiled with the information in this chapter. An annual review process to track progress should be implemented.
11	Reduce uncertainty in water use estimates of diffuse irrigation (d)	ORASECOM to engage with respective countries' water regulators.	Validation and Verification (V&V) process was concluded in S.A.	2019	The point of departure for this activity would be to carry out a comparison between the water use data currently in the models with the final datasets of the V&V and any additional supplementary information that becomes available in future for all member countries/Basin States.

Notes:

(a) Net system savings: Overall saving of interventions, accounting for the net effect of reduction in water abstraction and reduction in return flows.

(b) There is an inverse relationship between assurance of supply and volume available from a resource.

(c) The progress is documented in a series of Status Reports and meeting minutes since 2012. (Proceedings of the Strategy Steering Committee that guides the implementation of the Vaal River System Reconciliation Strategy.)

(d) A comparison of diffuse irrigation water use from different sources presented in the Orange River Reconciliation Strategy (DWS, 2015) indicated that there are substantial discrepancies. At the time of writing that report the Validation and Verification assessments were not complete and further research was recommended to reduce the uncertainties in the water use estimates. This uncertainty was also described in (ORASECOM, 2011)

APPENDIX B

WRPM SYSTEM SCHEMATICS

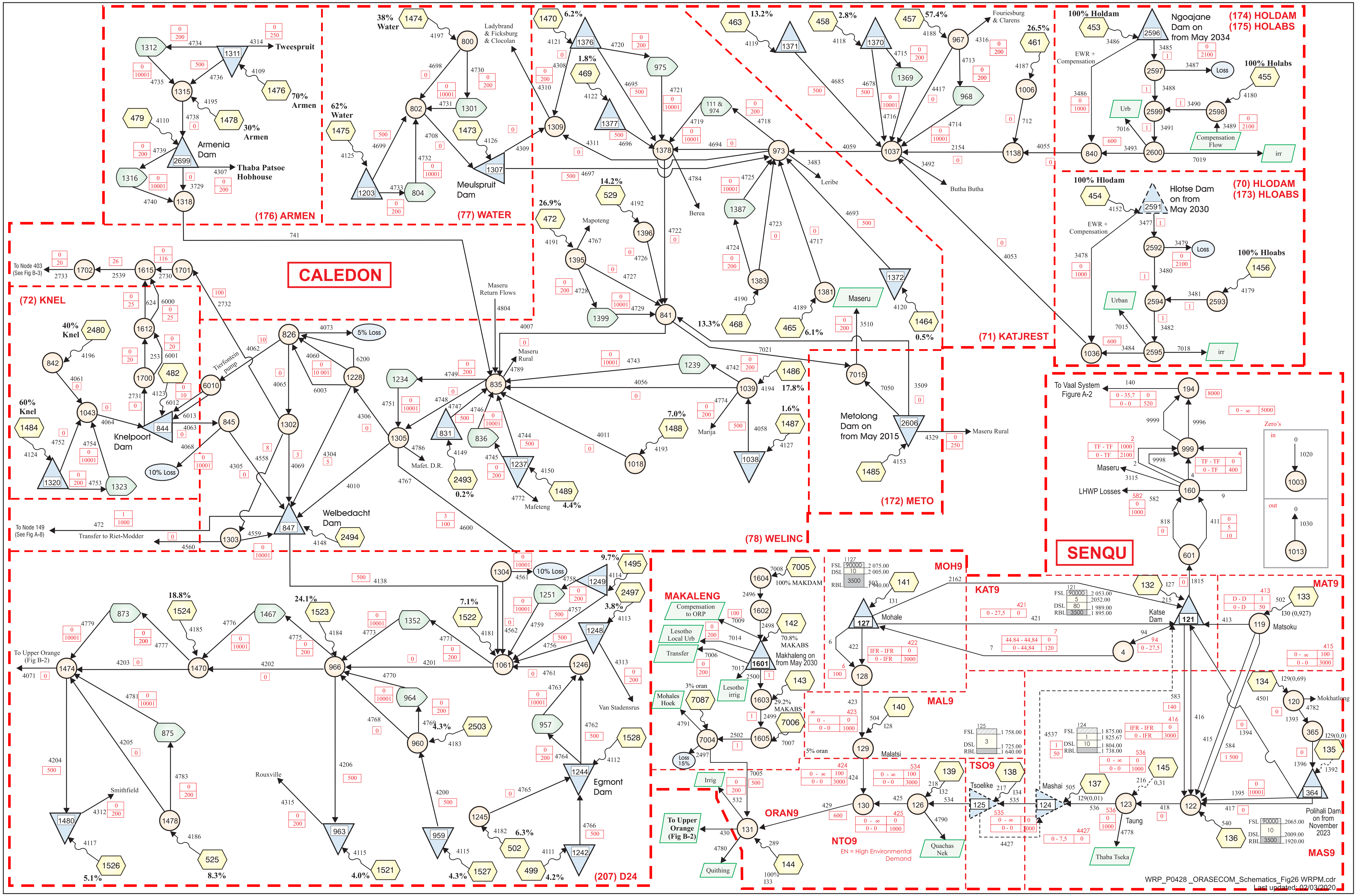
Orange Senqu sub-systems

Figure number	Description
B-1	Senqu and Caledon sub-systems (Lesotho and RSA)
B-2	Upper Orange sub-system (RSA)
B-3	Lower Vaal and Riet/Modder sub-systems (RSA)
B-4	Lower Orange sub-systems (RSA and Namibia)
B-5	Molopo (Botswana, Namibia, RSA) sub-systems
B-6	Lower Orange Tributaries and Namibia Fish River sub-systems (RSA and Namibia)
B-7	Eastern Cape upper sub-systems (RSA)
B-8	Eastern Cape Lower sub-systems (RSA)

IVRS sub-systems

B-9	Upper Vaal, Olifants and Usutu sub-systems (RSA)
B-10	Komati sub-systems (RSA)
B-11	Upper and Lower Thukela sub-systems (RSA)
B-12	Witbank Dam sub-system -Olifants River (RSA)
B-13	Middelburg Dam sub-system – Klein Olifants River (RSA)
B–14	Vaal Dam to Vaal Barrage sub-system (RSA)
B-15	Middle Vaal sub-systems (RSA)

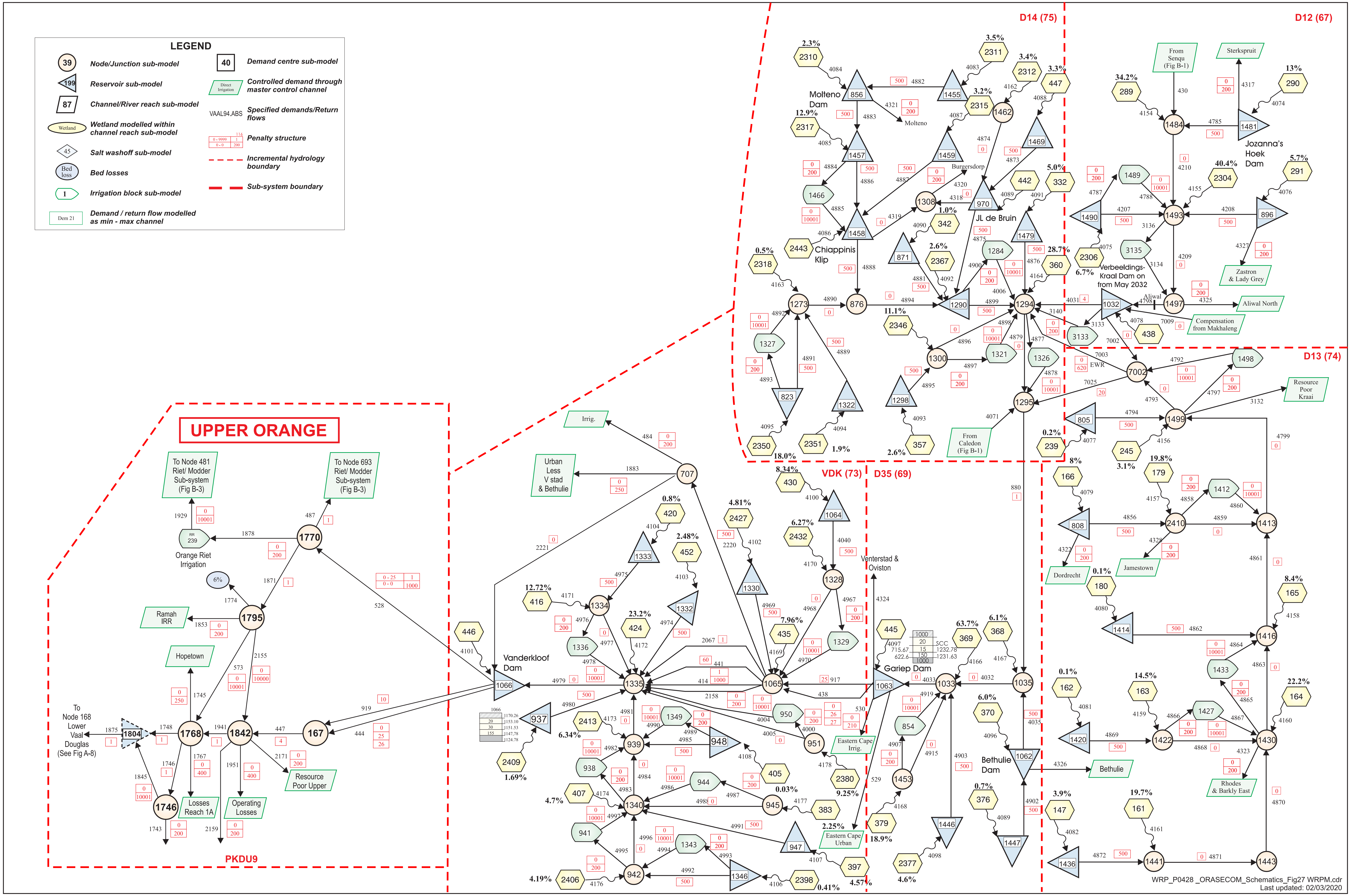
Note: Lower Vaal see Schematic B-3



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Senqu and Caledon Sub-system with Penalty Structure

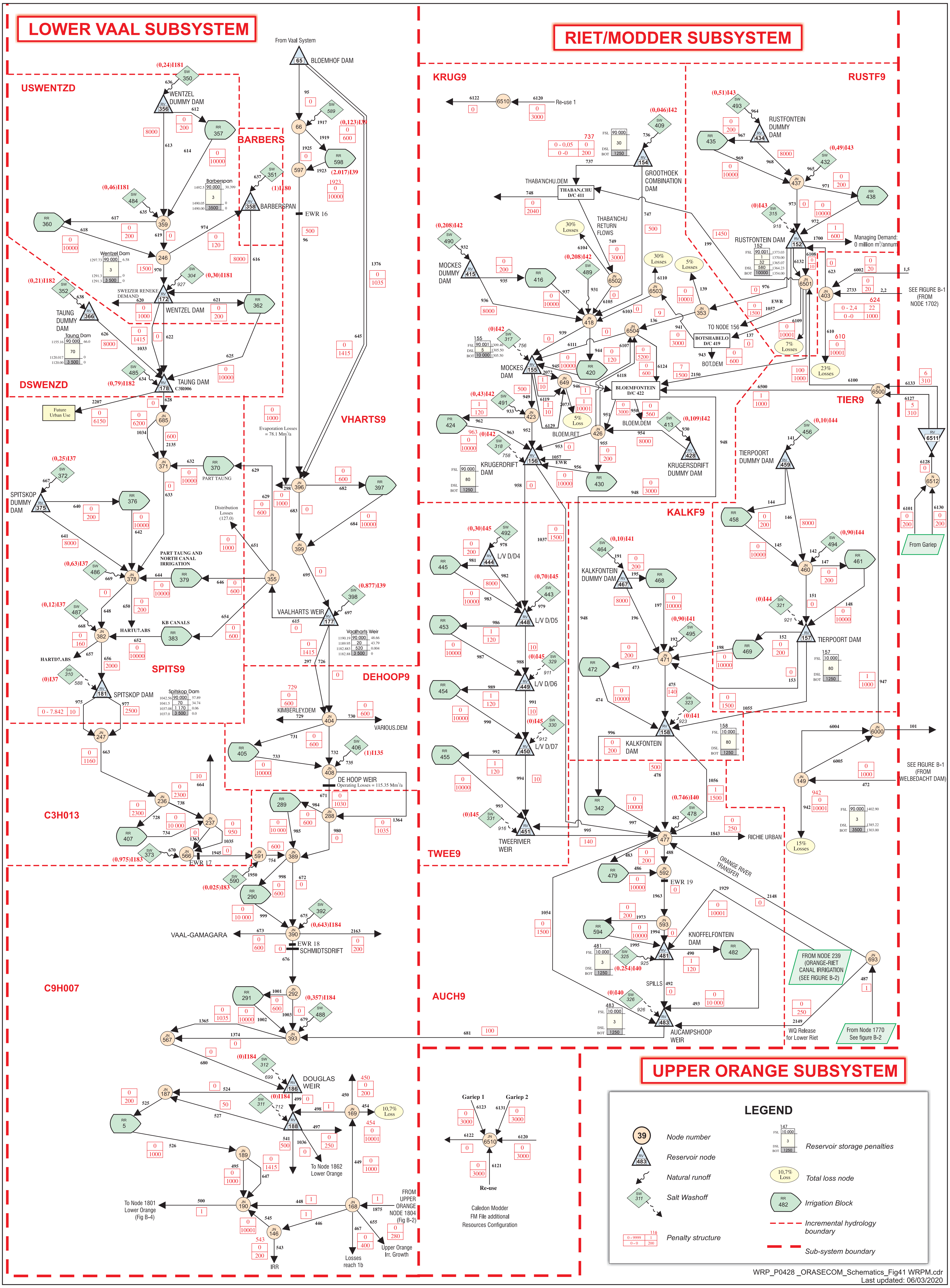
B-1



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Upper Orange Sub-system with Penalty Structure

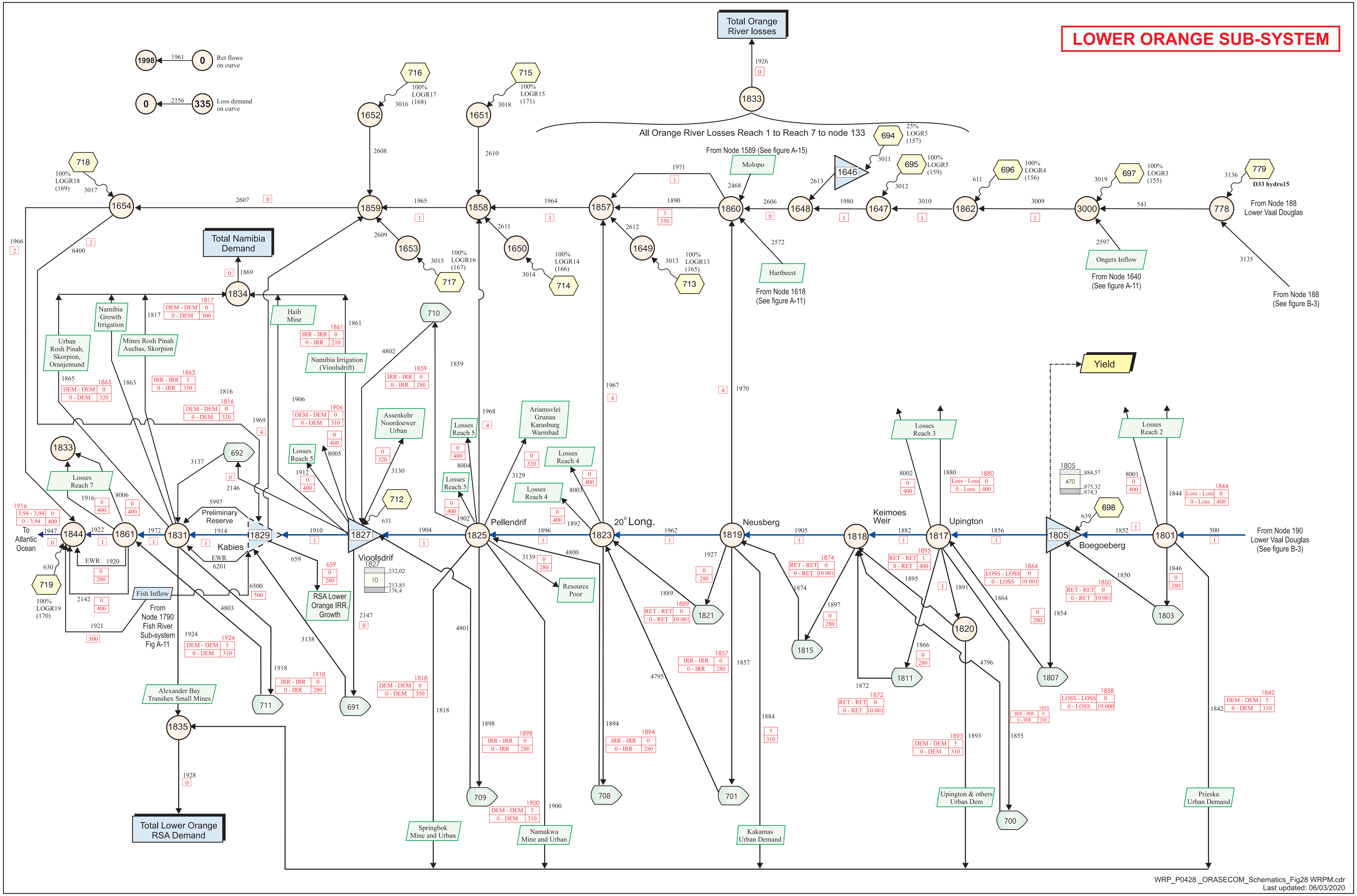
B-2



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Lower Vaal & Riet/ Modder Sub-systems with Penalty Structures

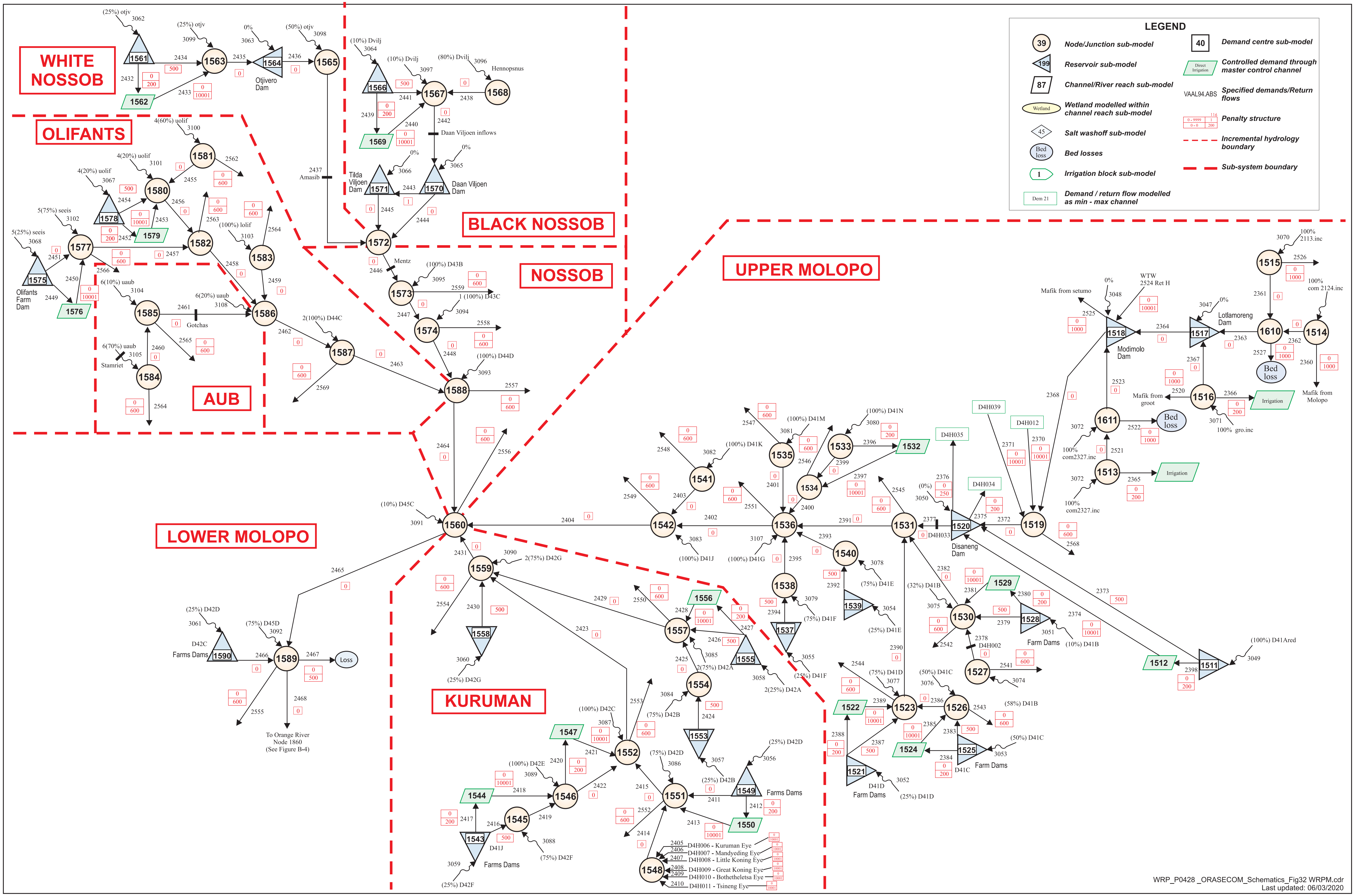
B-3



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Lower Orange Sub-system with Penalty Structures

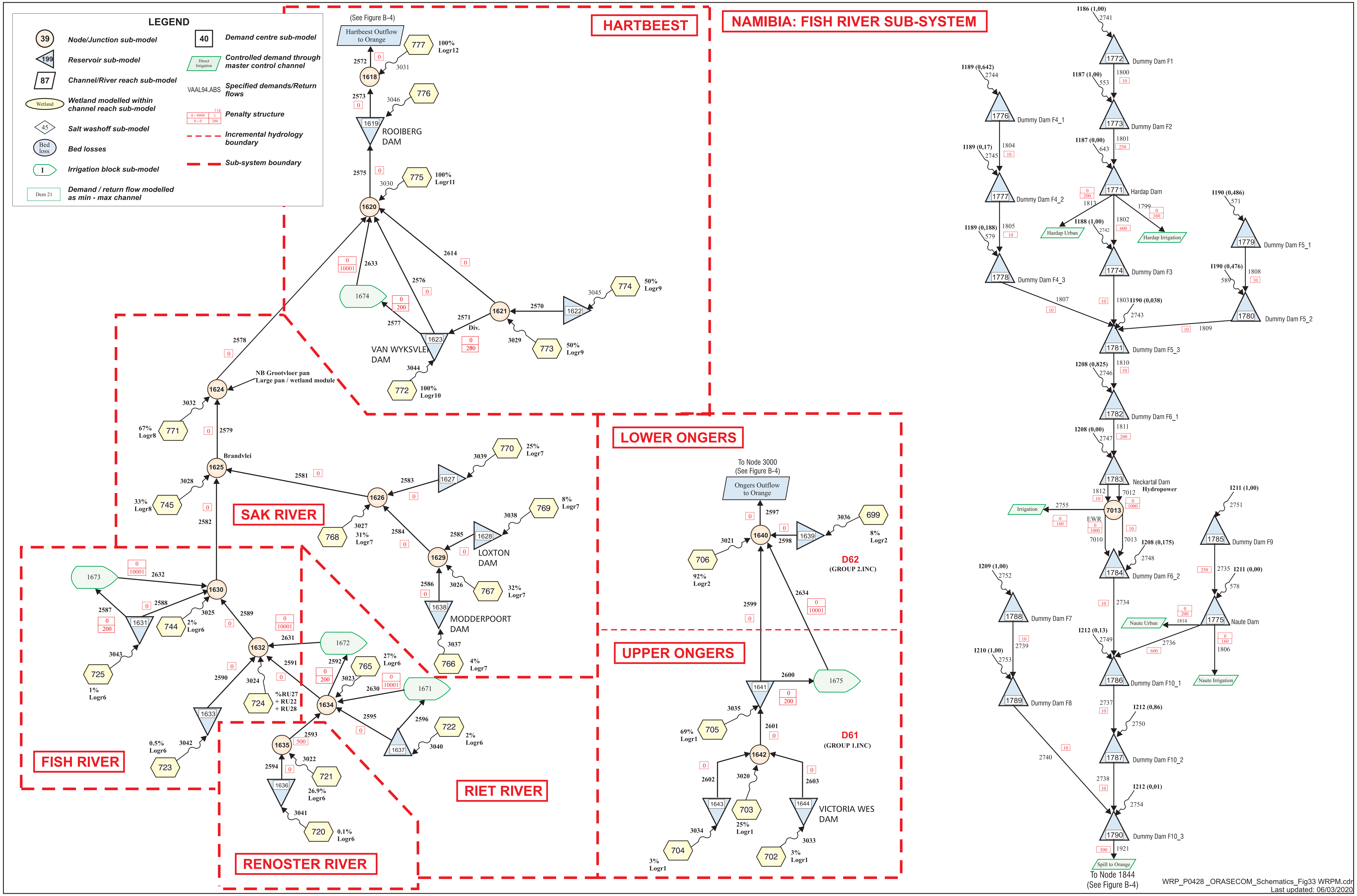
B-4



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Molopo Sub-system with Penalty Structure

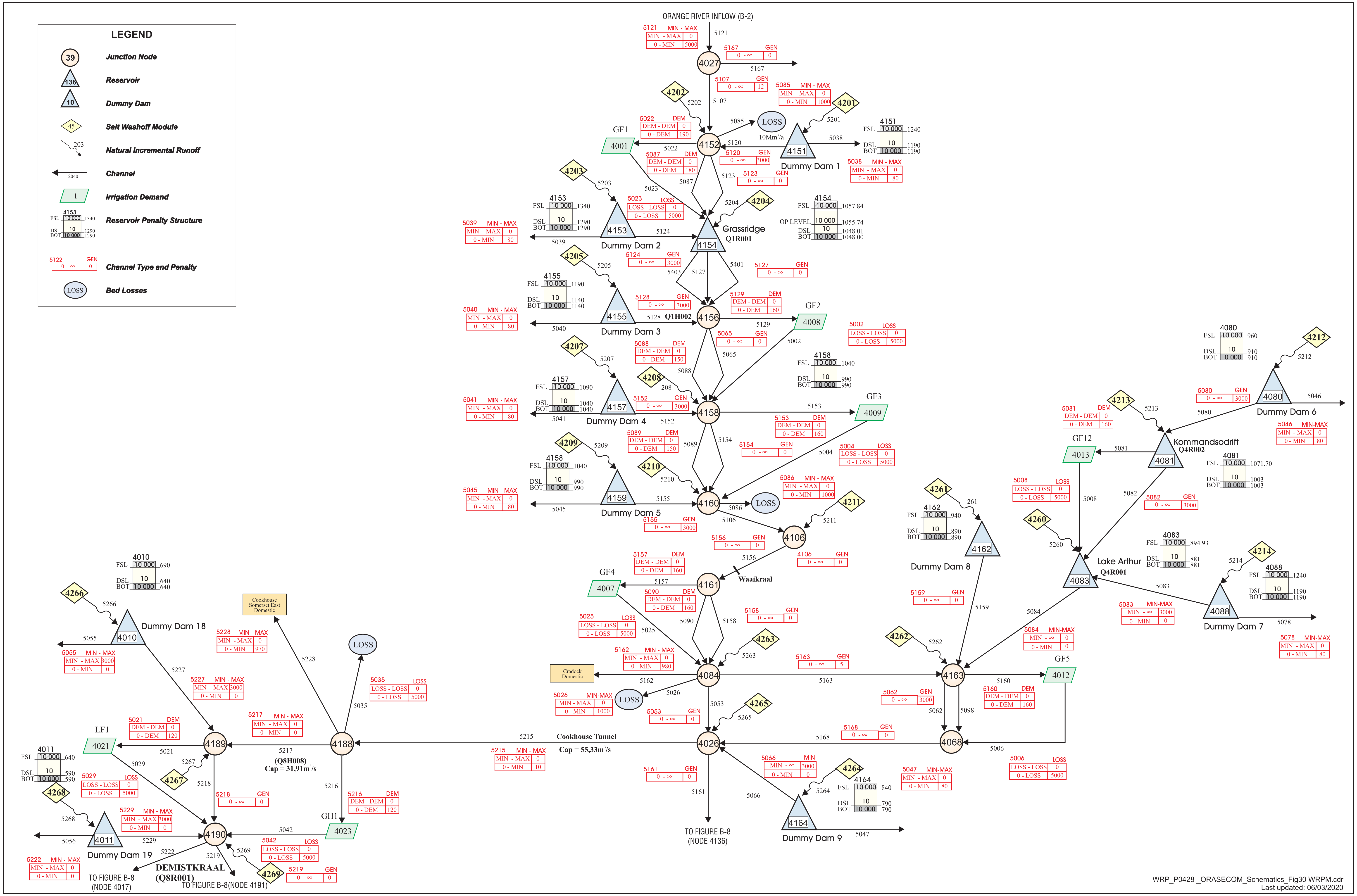
B-5



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Lower Orange tributaries & Namibia Fish Sub-system with Penalty Structure

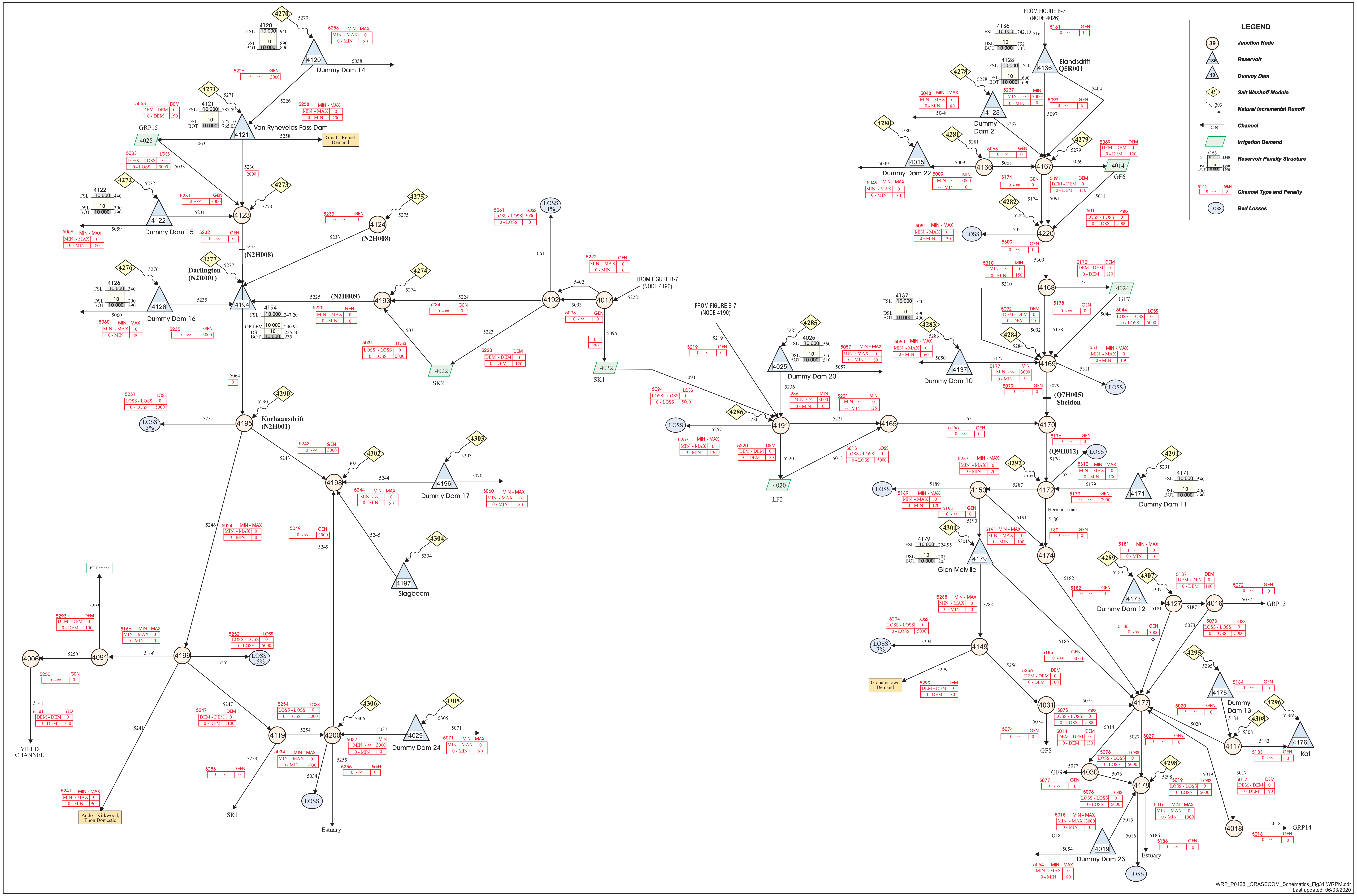
B-6



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM System Diagram:
Eastern Cape Upper Sub-systems: Core Scenario

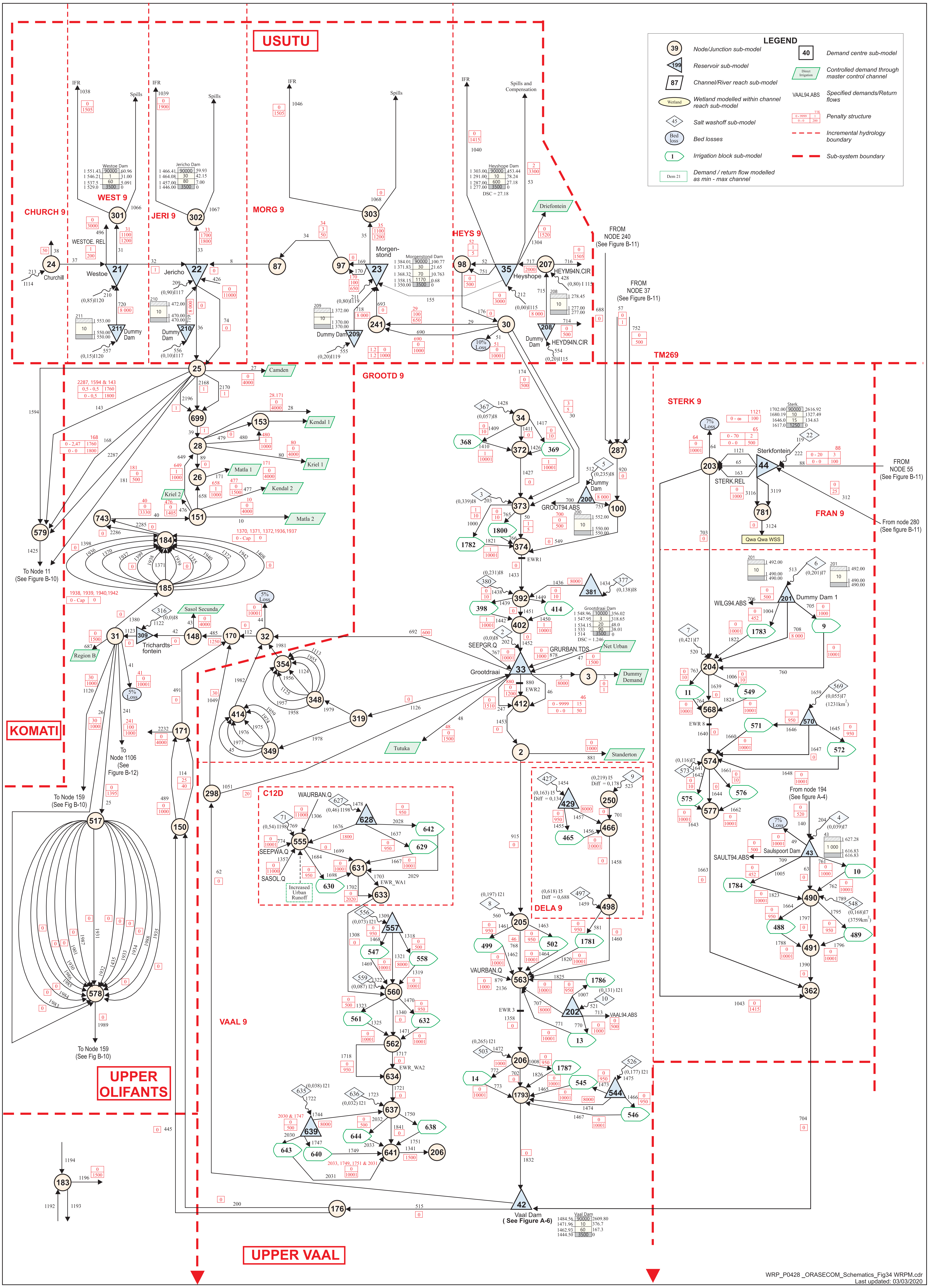
B-7



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM System Diagram:
Eastern Cape Lower Sub-systems: Core Scenario

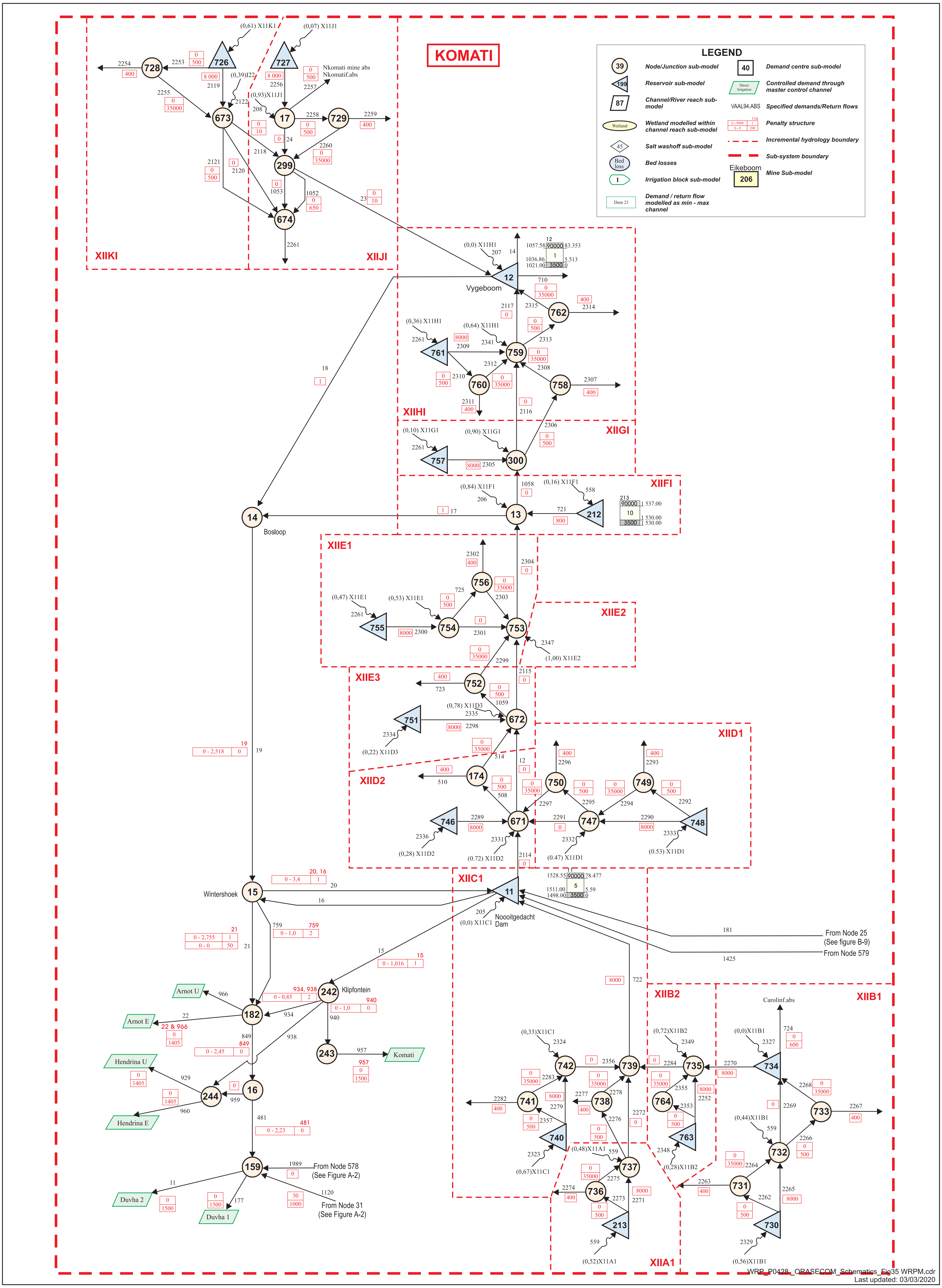
B-8



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Upper Vaal, Upper Olifants and Usutu Sub-systems

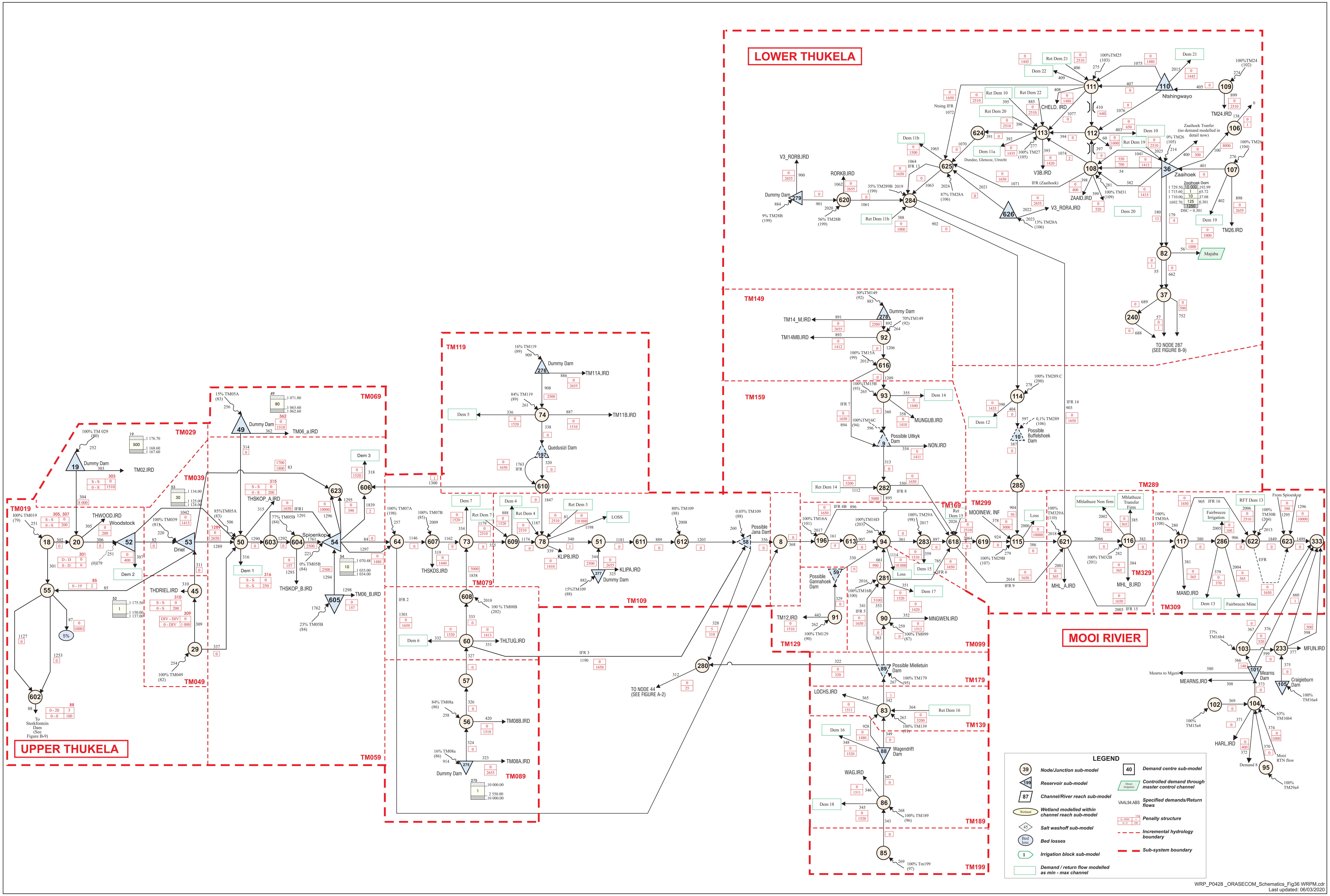
B-9



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Komati Sub-systems with Penalty Structures

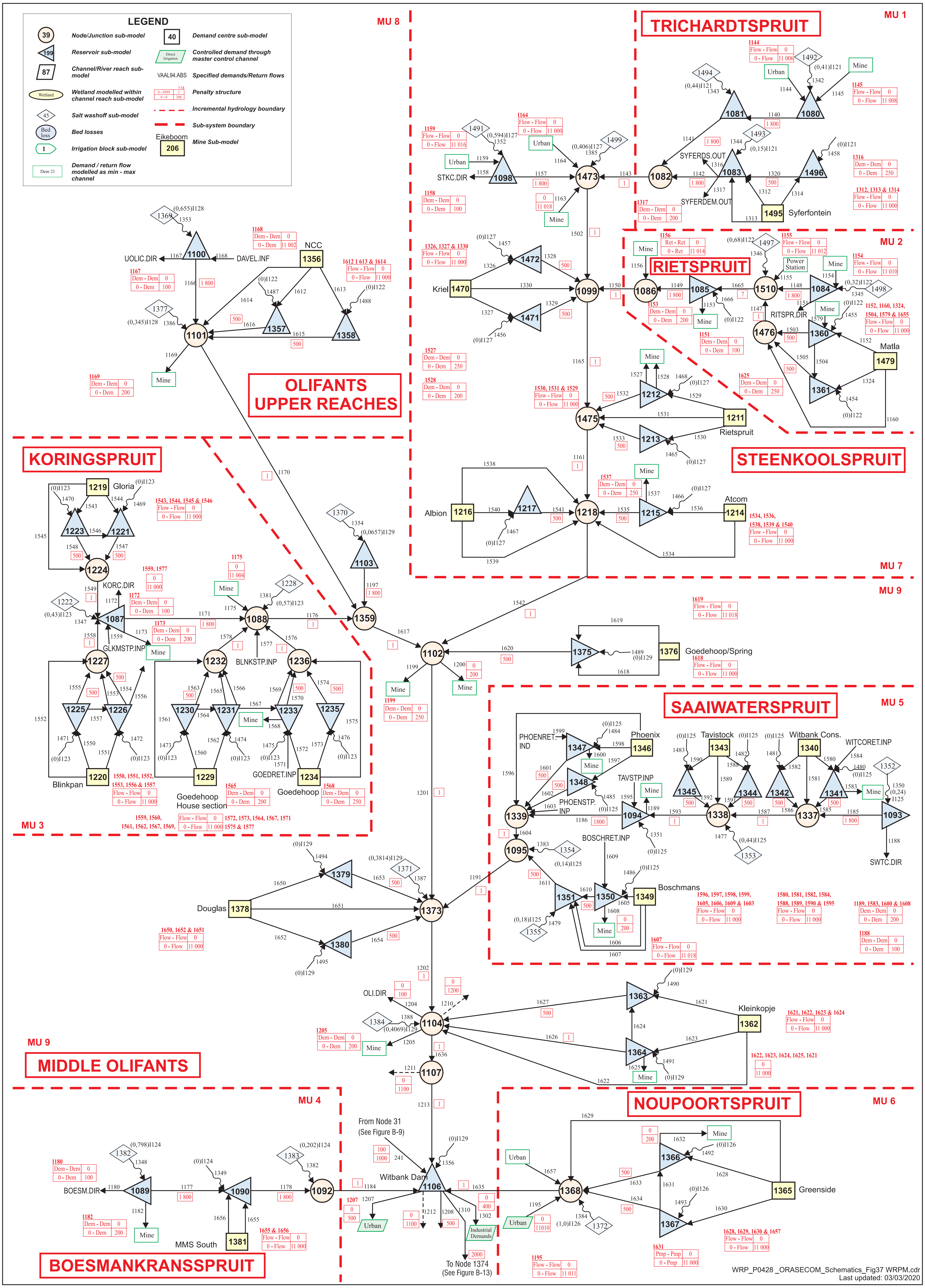
B-10



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Upper Thukela and Lower Sub-systems

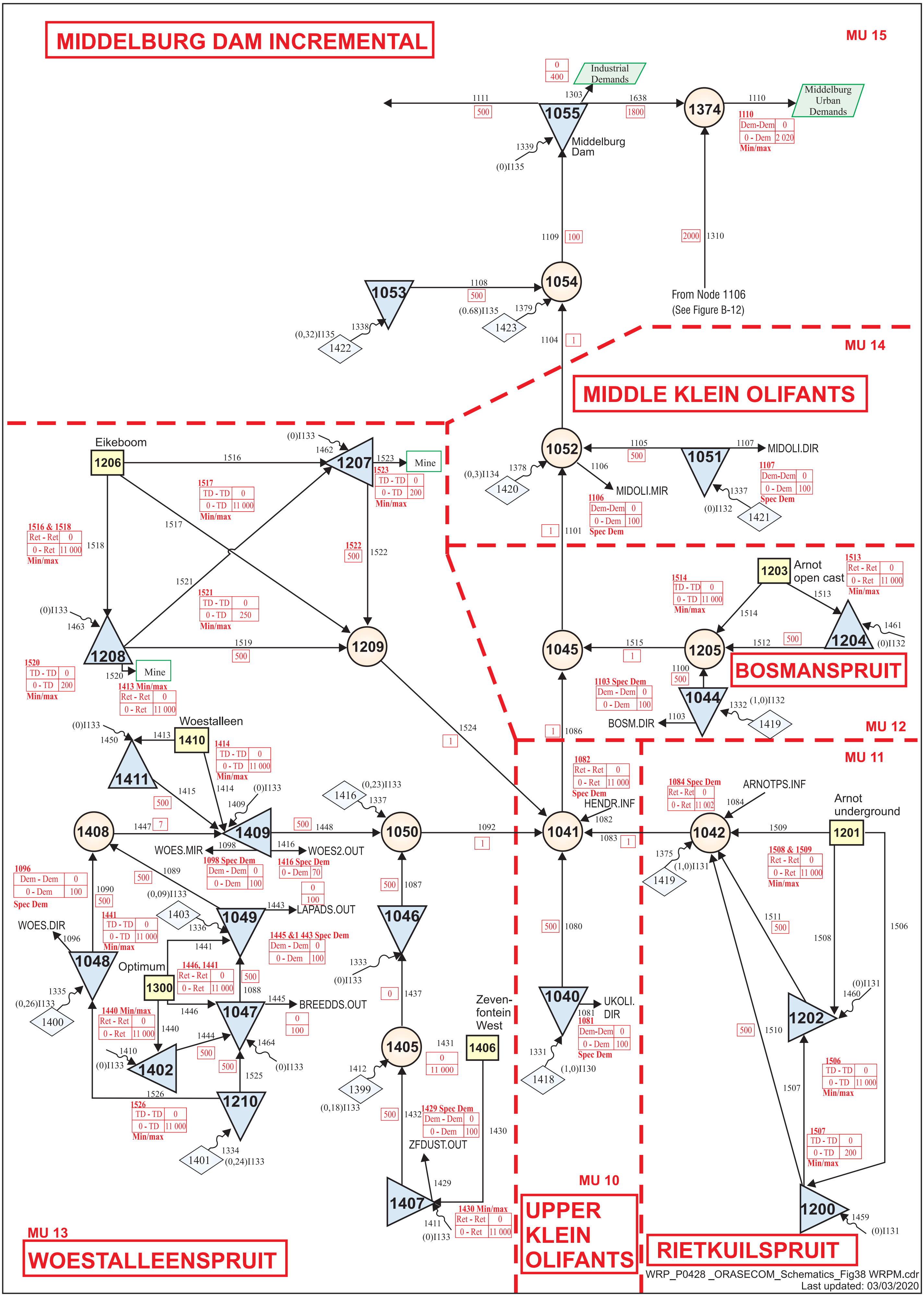
B-11



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram:Core Scenario
Witbank Dam Sub-system with Penalty Structure

B-12

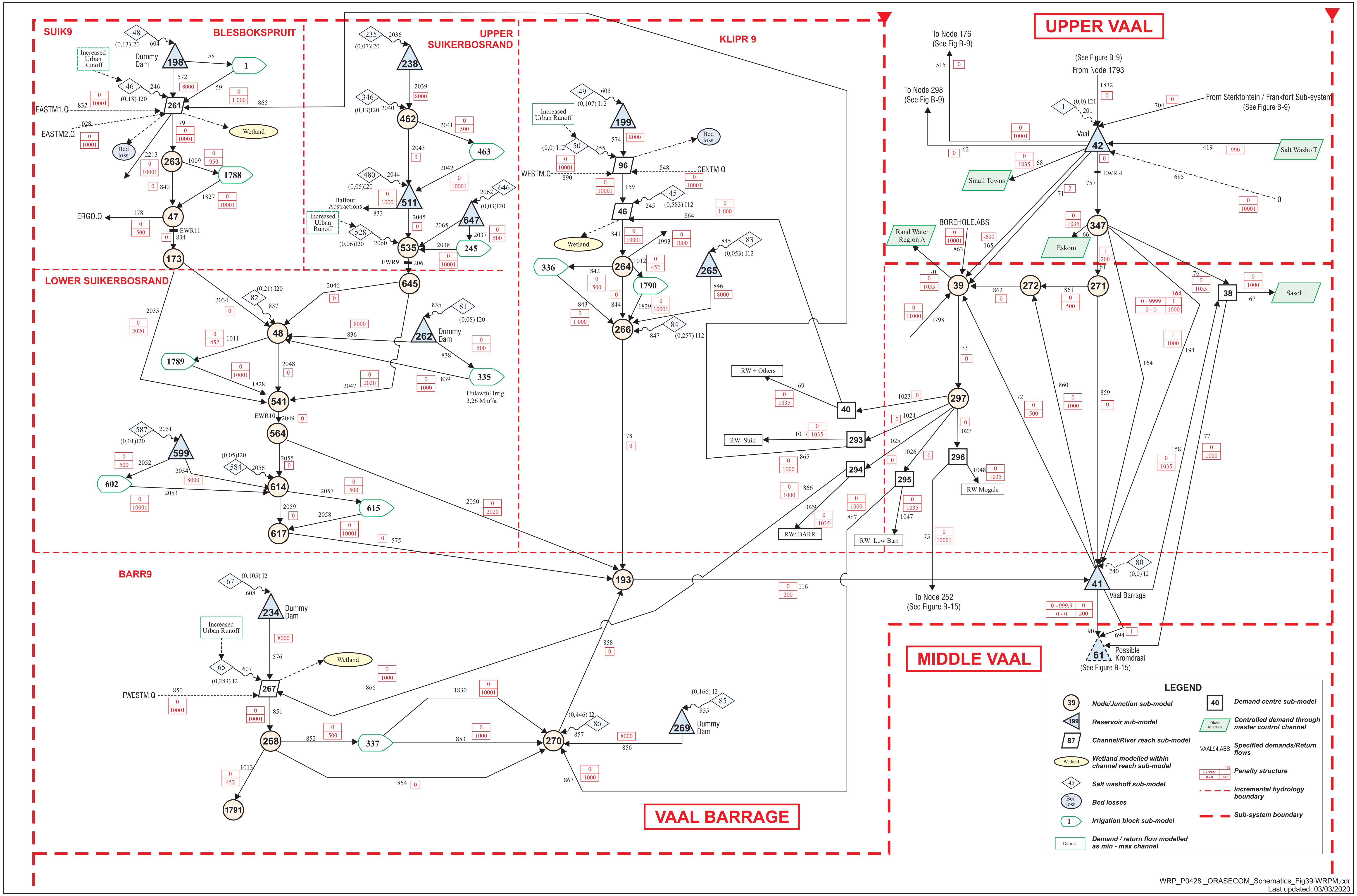


WRP_P0428 _ORASECOM_Schematics_Fig38 WRPM.cdr
Last updated: 03/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario Middelburg Dam Sub-system with penalty structures

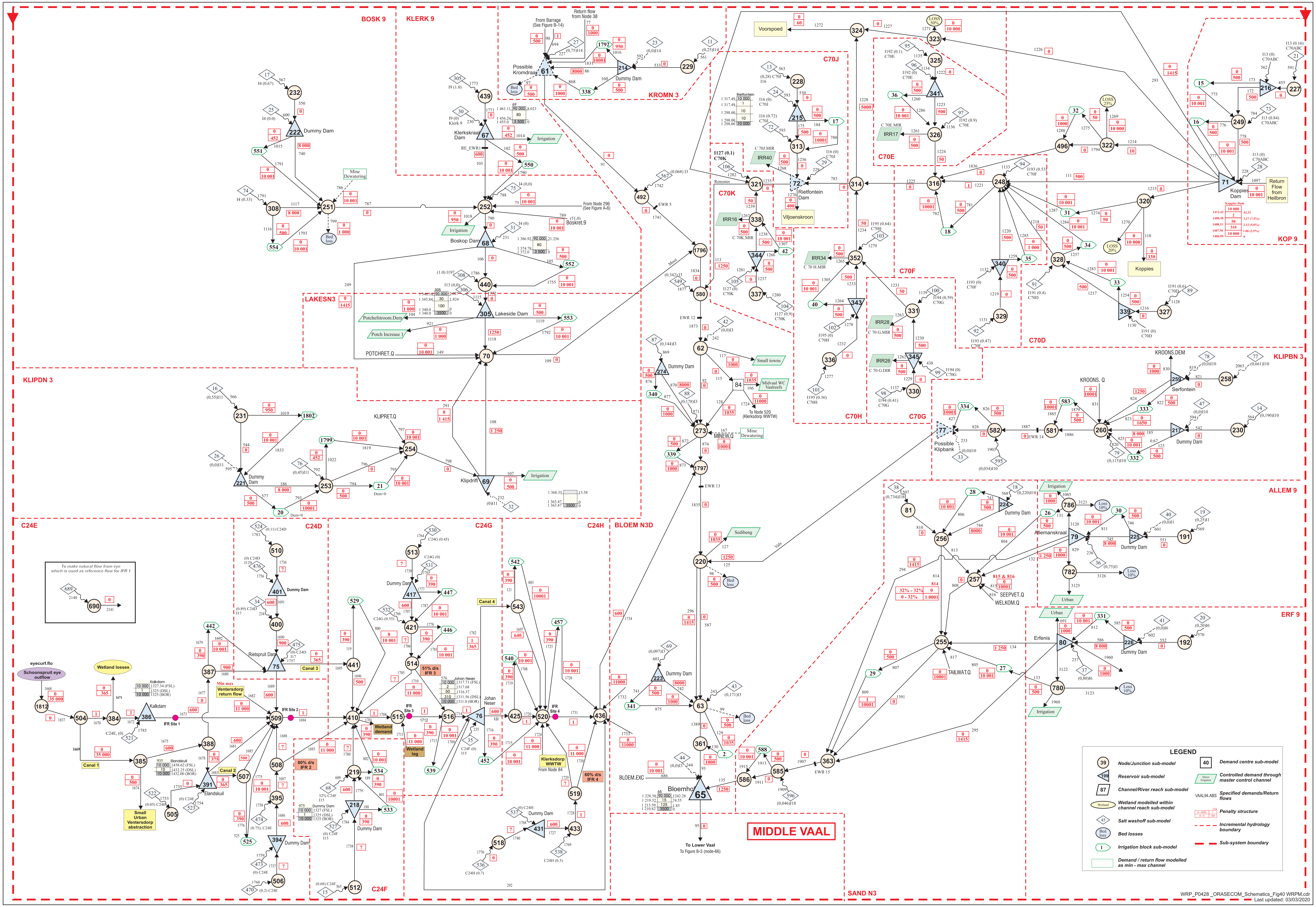
B-13



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Vaal Dam to Vaal Barrage

B-14



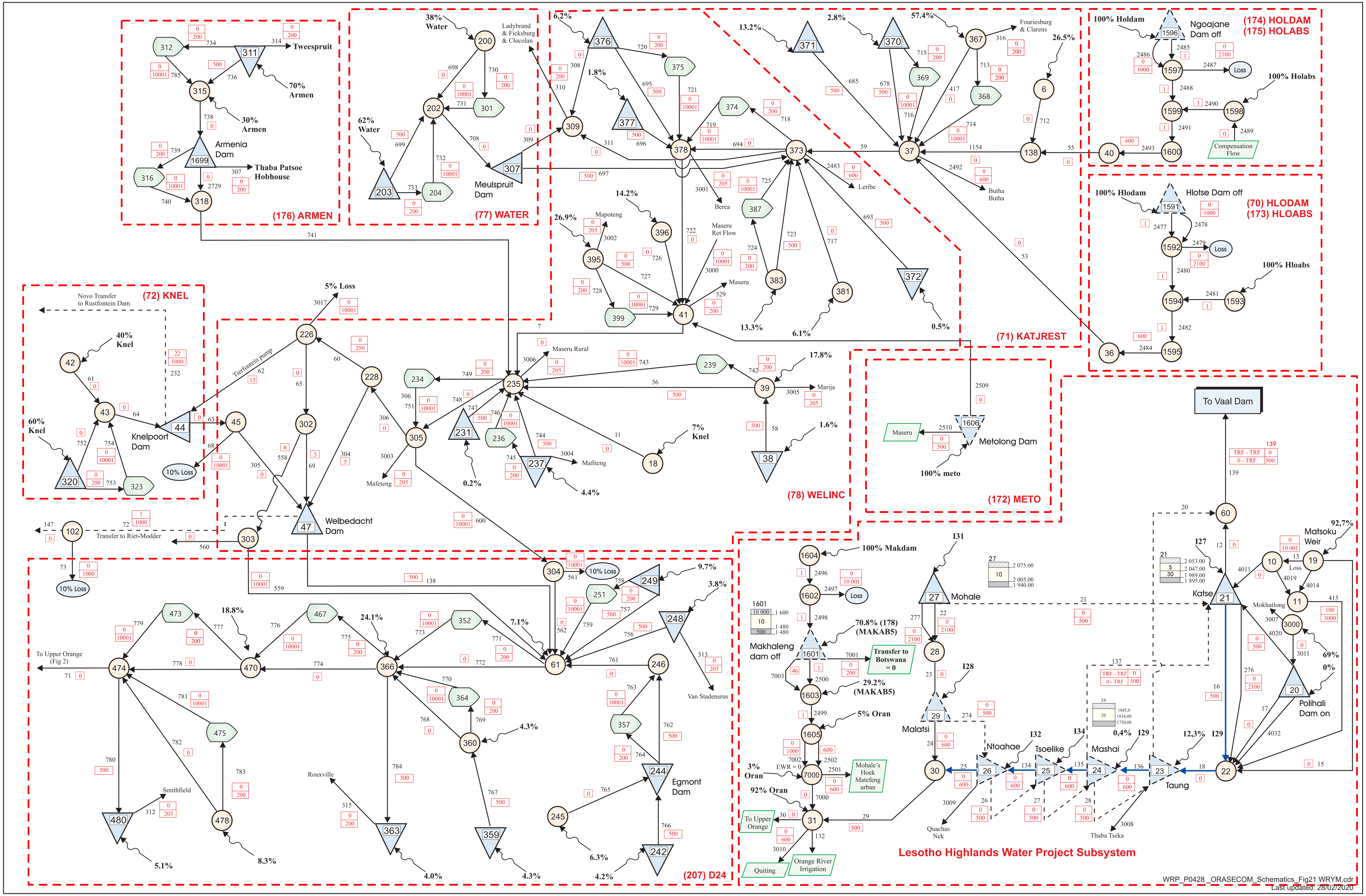
CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic diagram: Core Scenario
Middle Vaal Sub-system with Penalty Structures

B-15

APPENDIX C

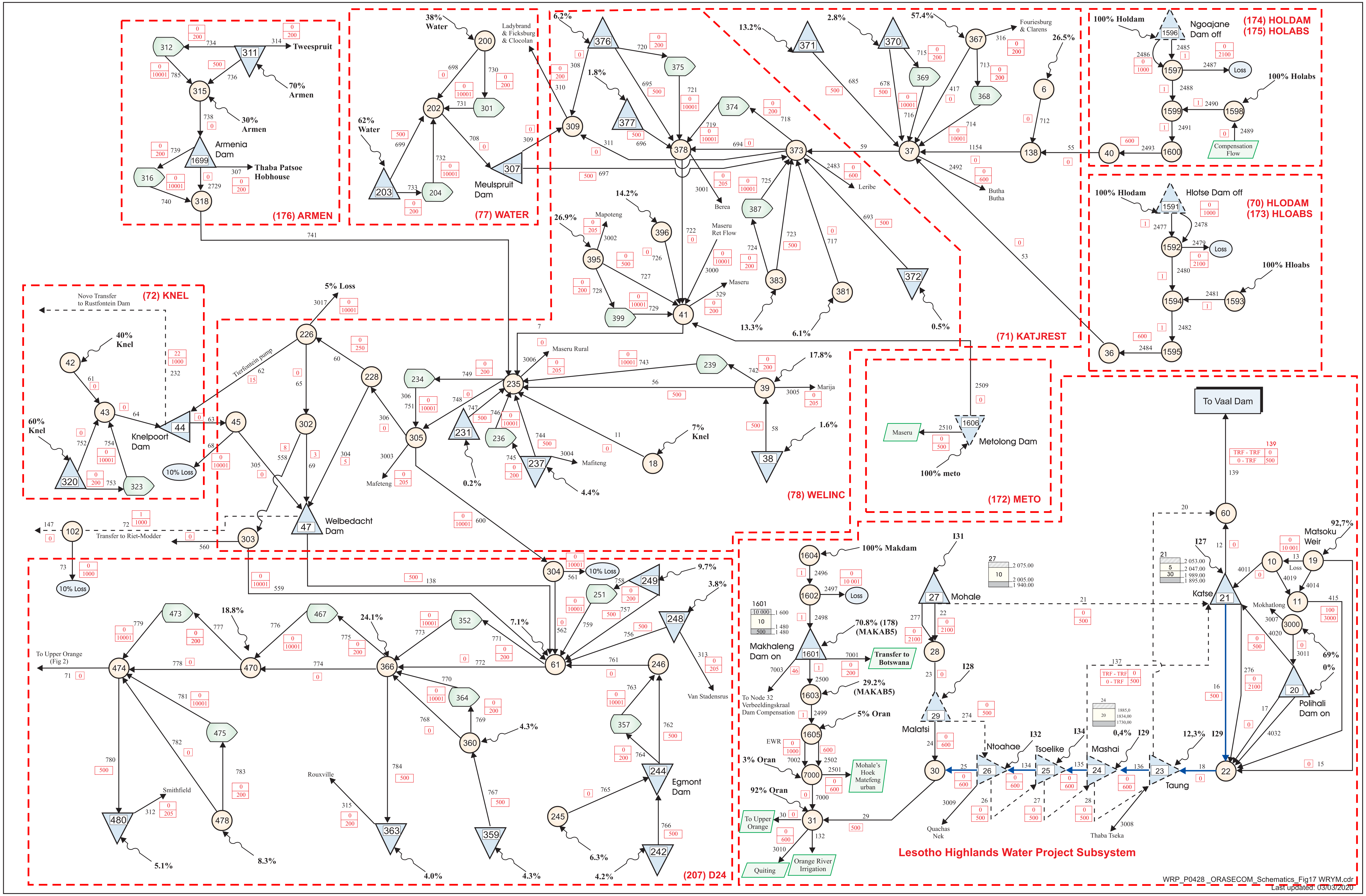
WRYM SYSTEM SCHEMATICS



CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Base scenario with penalty structures Senqu & Caledon

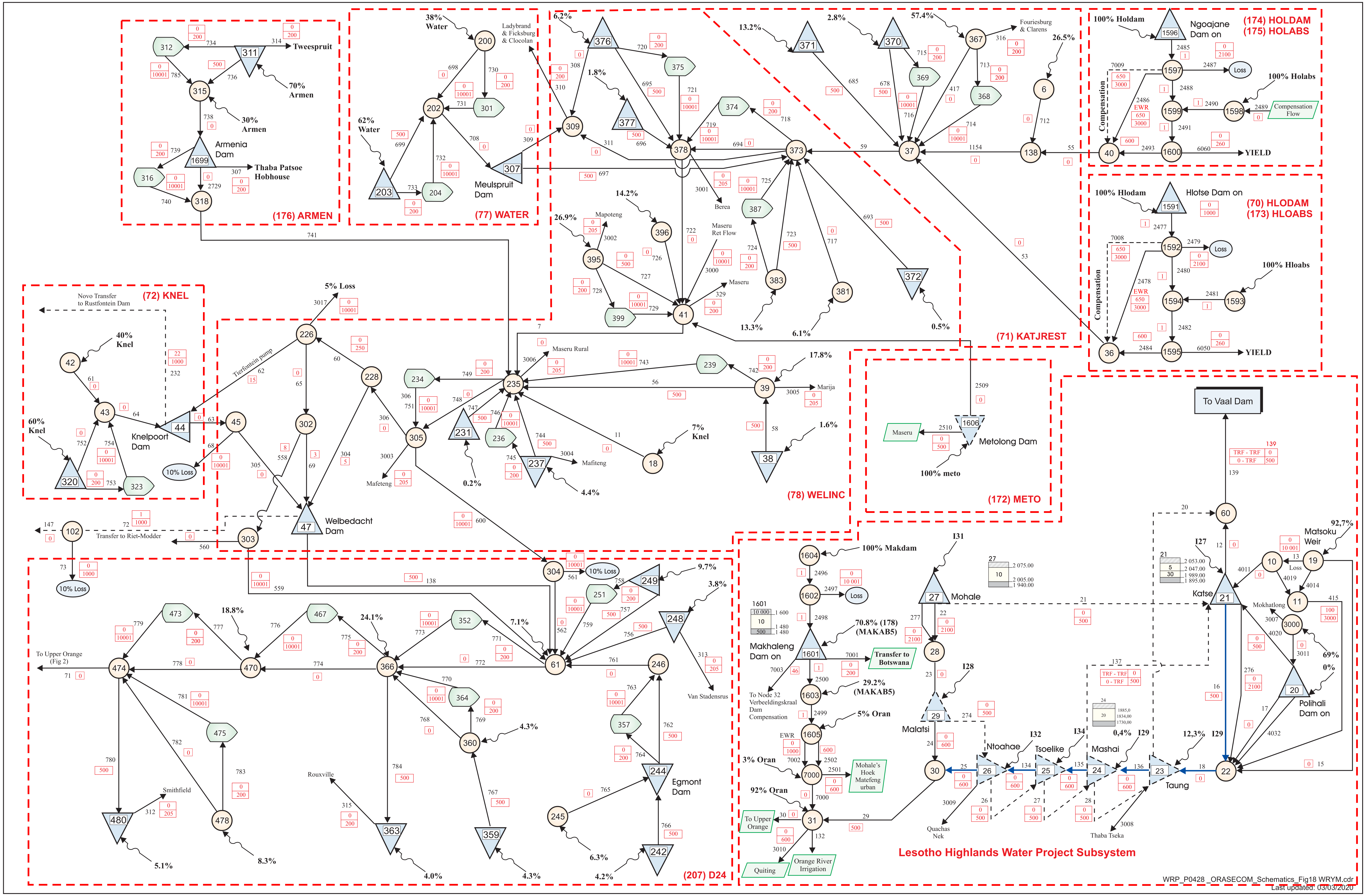
C-1



CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Base with Makhaleng and penalty structures (1 of 5) Senqu & Caledon

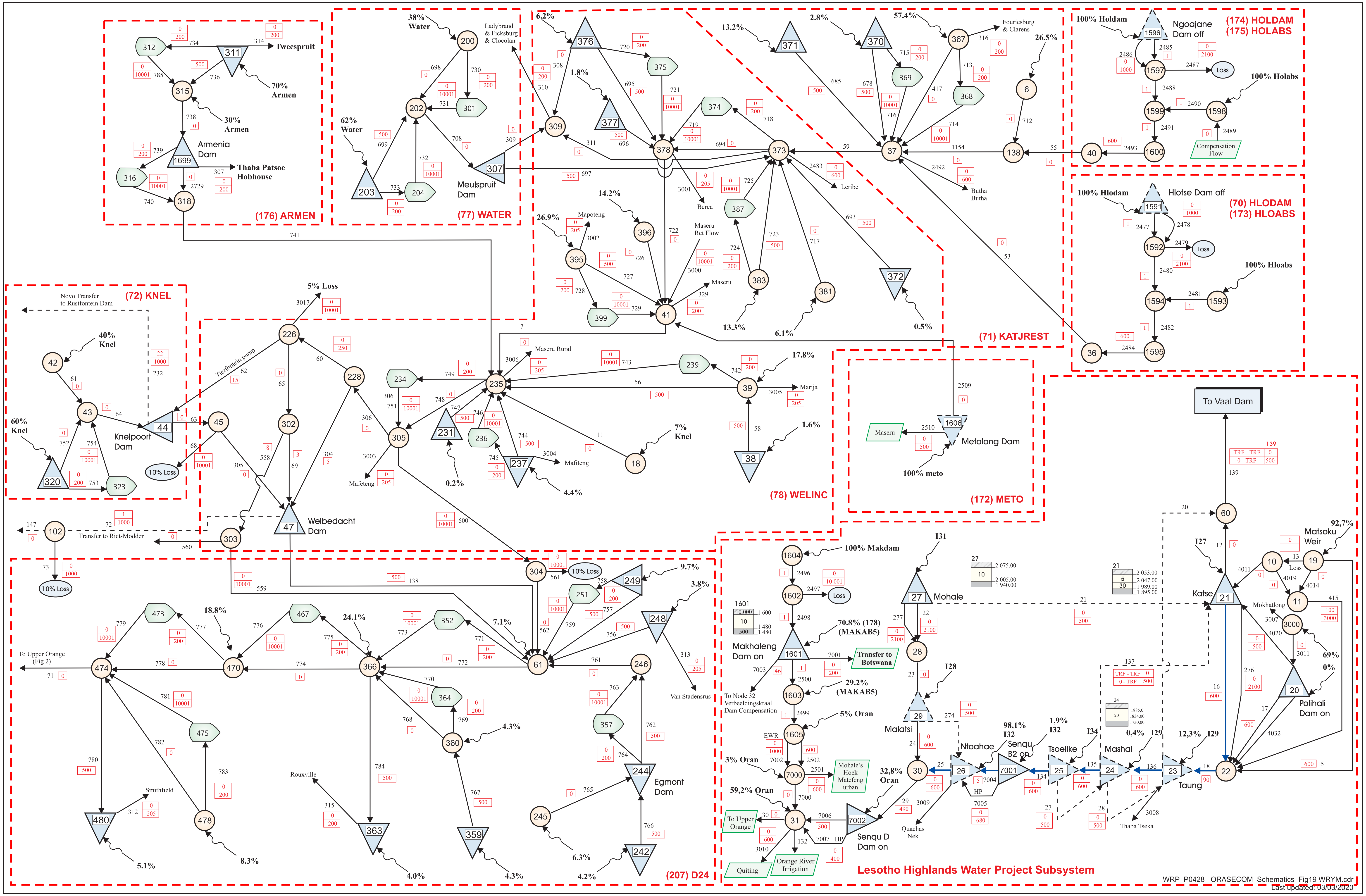
C-1b



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM with penalty structures (1 of 5) Senqu & Caledon base and Hlotse, Ngoajane and Makhaleng dams

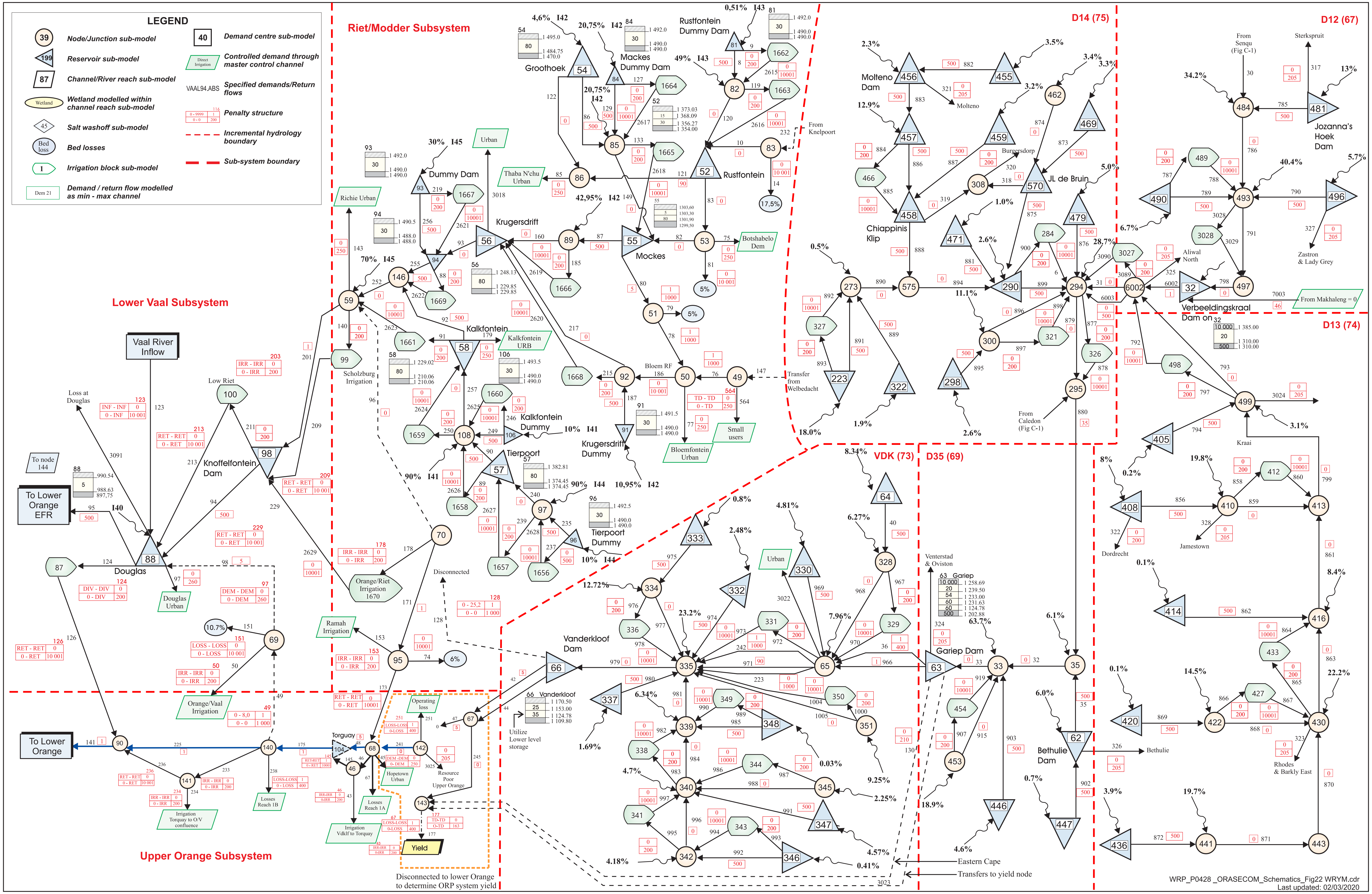
C-1c



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM with penalty structures (1 of 5) Senqu & Caledon Base plus Hydro-Power Dams and Makhaleng Dam

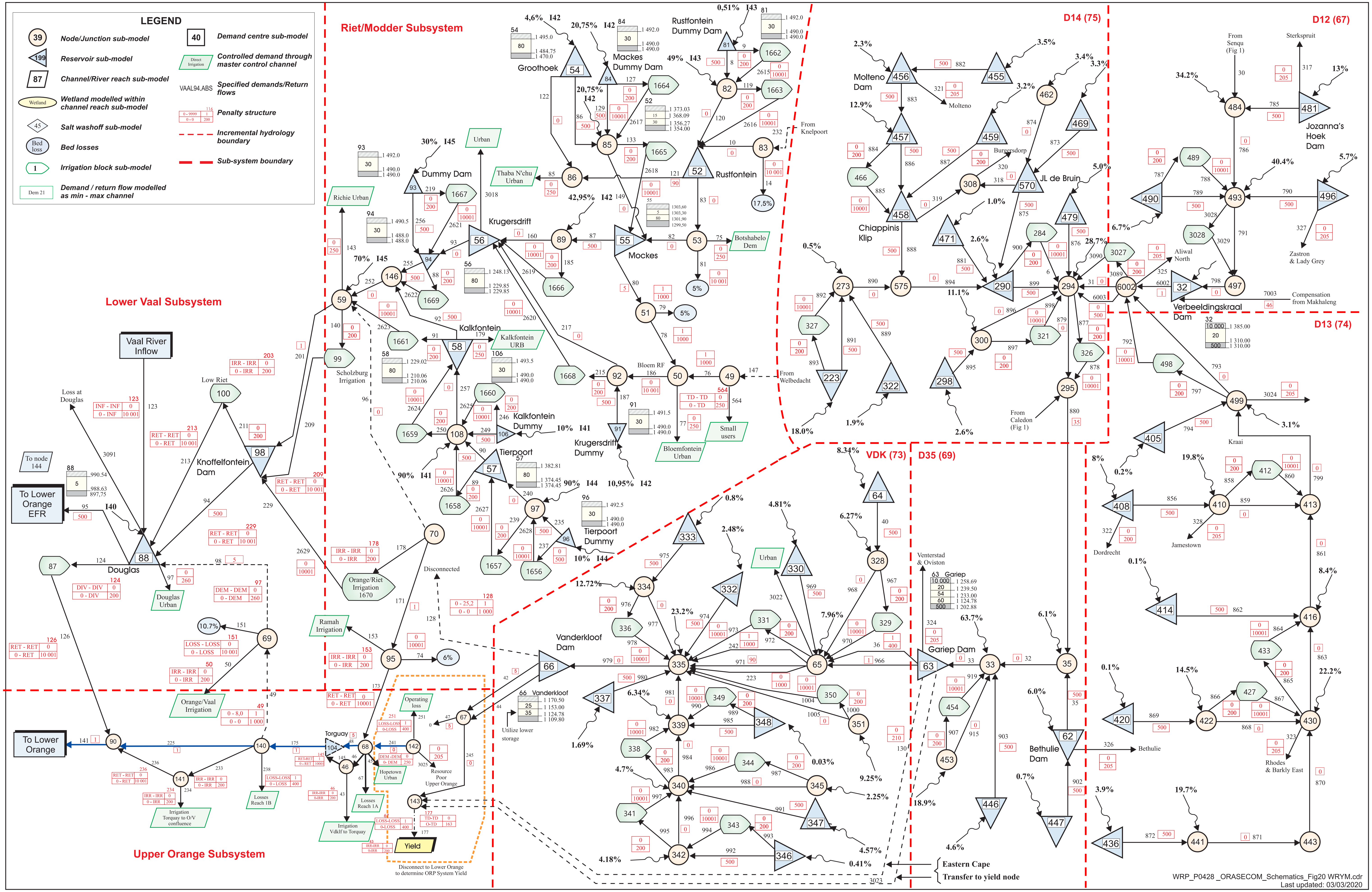
C-1d



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Base Scenario with penalty structures (2 of 5) Upper Orange and Riet Modder

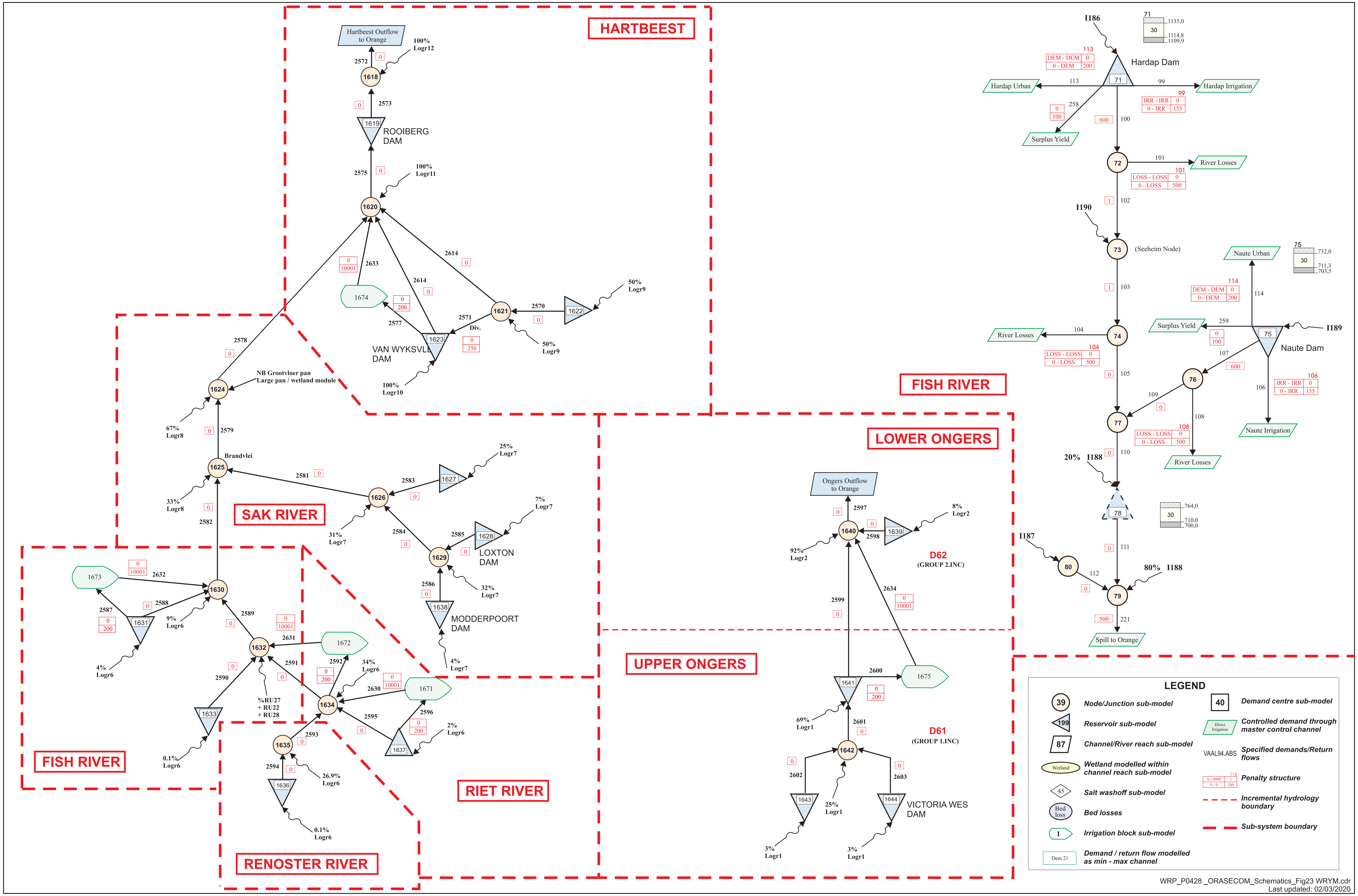
C-2



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Base with Makhaleng and penalty structures (2 of 5) Upper Orange and Riet Modder

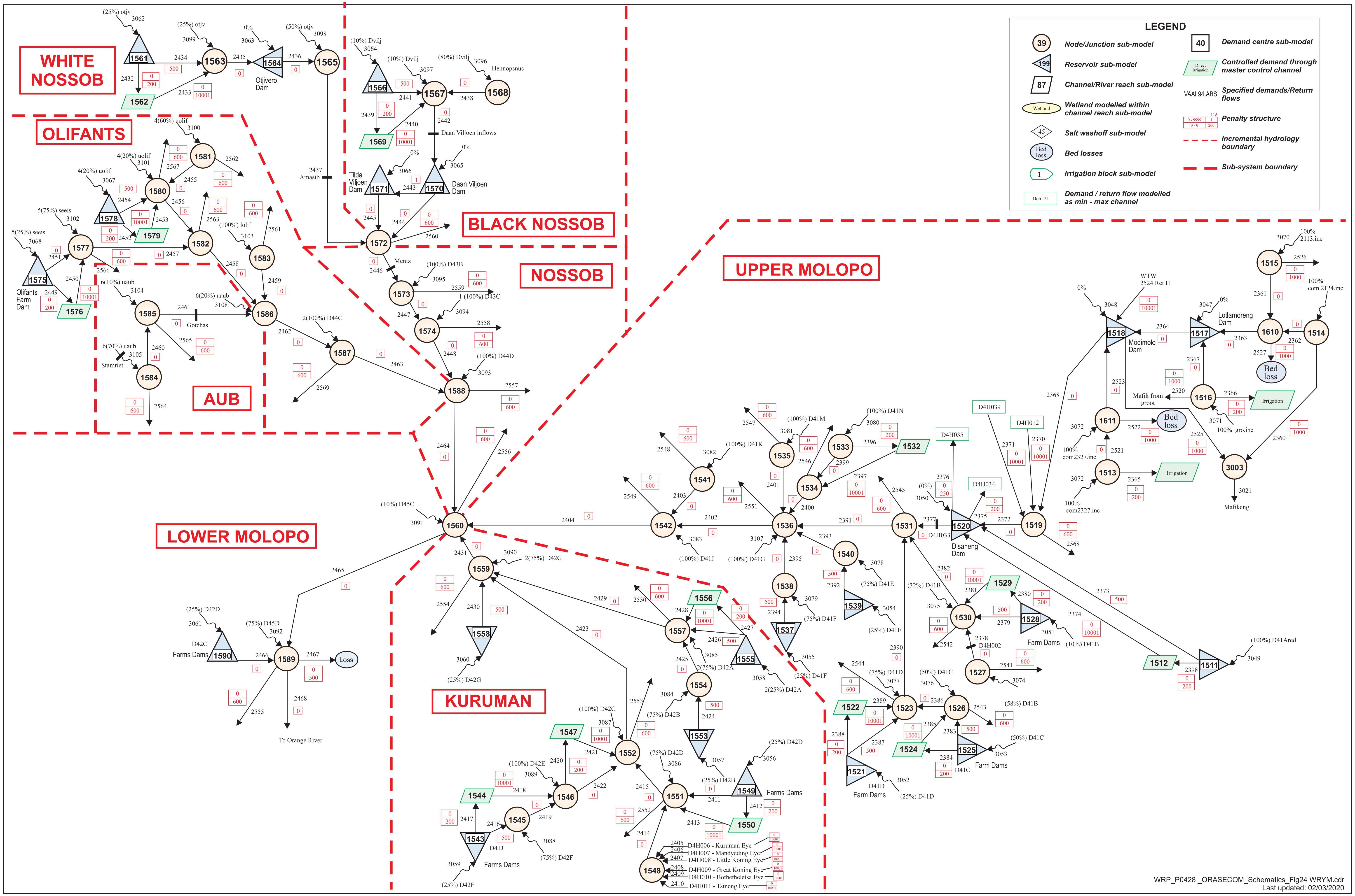
C-2b



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Applicable to all scenarios with penalty structures (3 of 5)Lower Orange tributaries & Fish

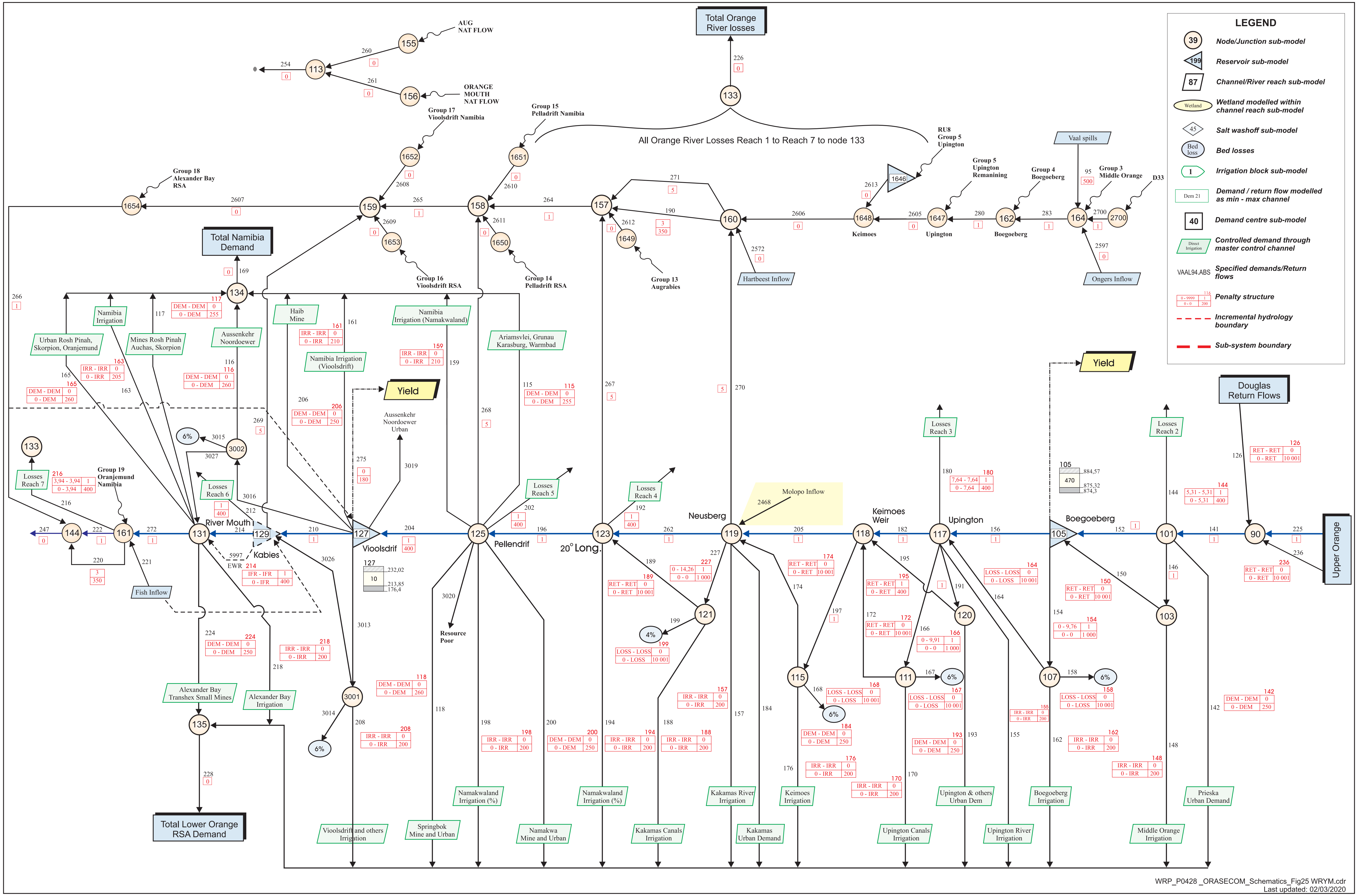
C-3



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Applicable to all scenarios with penalty structures (4 of 5) Molopo

C-4



CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

Orange River Subsystem Schematic - 2030 WRYM
Applicable to all scenarios with penalty structures (5 of 5) Lower Orange

C-5