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

SYSTEM ANALYSIS REPORT

Component I and III

FC/03067.cdr

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

COMPONENT I AND III

SYSTEM ANALYSIS REPORT

Prepared for

Orange-Senqu River Commission (ORASECOM)

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

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ORASECOM Document No.   ORASECOM 011/2019

Date of Publication: May 2023

Authors: C Seago, HG Maré

Status: Final Report

APPROVALS

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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
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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)

The purpose if this Report. This report falls under Component I: Climate Resilient Water Resources Investment Plan. The purpose of this report is to provide the details of all the water resource system analysis related work carried out as part of this study in one single report. Most of the system analysis work was carried out as part of Component I of the study and is documented in the Core Scenario updated work where the focus was on the Core Scenario. 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.

Other system analysis work was carried out as part of the Pre-feasibility Phase 1 Report that focused on the Lesotho-Botswana water transfer multipurpose transboundary project and is documented in the Pre-feasibility Phase 1 Report.

This report contains only summarized information on water requirements and detail on the 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 m³/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

L-BWT Scheme water requirements

The projected net water requirements for Botswana in the period 2018 to 2050 range from approximately 59 million m³/a to 136 million m³/a for the low scenario and high scenario respectively. These demand estimates exclude any water treatment or conveyance losses which may or may not have to be taken into account depending upon the type of conveyance (full pipeline or mixed pipeline and canal) to be selected during Phase 2 of the study.

The estimated allocation to South Africa from the pipeline as originally proposed was approximately 18 million m³/a which will cover various small demand centres up to the year 2050. An additional option of supplying water to Bloemfontein from the pipeline was also raised in discussions although this has not been agreed to or confirmed. Should the Bloemfontein demand be included, it would add an additional 43 million m³/a at 2030 development levels. It should be noted that the Bloemfontein allocation is already included as part of the demand being supported from the Orange River Project although the transfer infrastructure from Gariep Dam to Bloemfontein has yet to be developed. For the full pipeline option, the following scenarios and related gross demands were considered:

- **High Scenario.** The total gross urban, mining, and industrial water requirement, including losses, is **199 million m³/a** of which approximately 80% of the water

requirement is for Botswana with approximately 10% each for South Africa and Lesotho. These demands were taken from the Reconnaissance Phase report undertaken for Lesotho/Botswana by BIGEN and updated.

- **Low Scenario.** The total gross urban, mining, and industrial water requirement, including losses, is **111 million m³/a** of which approximately 60% of the water requirement is for Botswana with about 20% each for South Africa and Lesotho. Subsequent discussions between the basin states have indicated that the Low Demand Scenario will not be taken forward to Phase 2 of the Pre-feasibility Study.

The total potential irrigable land below Makhaleng Dam at site S2 is 9 500 hectares, which equates to a water requirement of approximately 84 million m³/a. The estimated net water requirement to be supplied to Lesotho from the pipeline is estimated to be 19 million m³/a at 2050 development levels.

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 **Error! Reference source not found.**. 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	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

Core scenario description (2014)	Adjust / update for this study
included where applicable. In most areas however, irrigation will not be growing.	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
	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

Core scenario description (2014)	Adjust / update for this study
	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.

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 mitigation 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.
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 III 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 III 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	Current transfer schemes and related operating rules from the Caledon to the Modder River catchment in

Core scenario description (2014)	Adjust / update for this study
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).	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.
	Include mitigation 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 flow 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 defined 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 4** of this report.

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

The Integrated Vaal River System (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 ll 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.

The Orange River Project (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 Dam and mitigation releases from Makhaleng Dam once the storage in Gariep and Vanderkloof dams is low. From the future major upstream developments, mitigation releases were only made from Makhaleng Dam in support of the ORP. The purposes of the mitigation 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 mitigation releases need 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 levels drop too low to be able to generate 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 possible future 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 mitigation water in support the ORP. The yield from a 3 MAR Makhaleng Dam is sufficient to balance the ORP through mitigation releases, 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 in combination with mitigation releases to the ORP..

- With the low Botswana transfer in place plus mitigation releases to the ORP, 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 which included mitigation releases to balance the ORP water balance. 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 mitigation water in support of the Greater Bloemfontein and or ORP systems.

- It is recommended to investigate the possibility of increasing the storage of 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 mitigation 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 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 the size of 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.

<u>Neckartal Dam sub-system</u>

- 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 m³/a, EWR requirements with the median demand at approximately 6 million m³/a and releases of 100 million m³/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.

<u>Hardap and Naute dams</u>

- 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 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 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 (mitigation 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 mitigation 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 of 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 are briefly described in **Table vi**.

Table vi: 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	This scenario will provide the HFY available at Makhaleng when the downstream system (ORP) still

Scenario	Description	Purpose
	Vanderkloof dams to maintain the downstream water balance.	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 m³ 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 m³ to gross storage to 120 million m³	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 m³ to a gross storage of 63.3 million m³	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	Determine the yield impact on the ORP system and the proposed Makhaleng Dam

Scenario	Description	Purpose
	with sub-scenario 2g Hydro-power releases to provide a base load	
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 mitigation water in support of the ORP. Reduce mitigation 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 mitigation water in support of Gariep and Vanderkloof dams and thereby reduces the mitigation 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 vii**.

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 mitigation 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 vii: Summary of historic firm yield results focused on 2030 development level

Scenario	System and sub-system yield (million m³/a)						
	ORP	LHWP	Makhaleng	Hlotse	Ngoajane	Total	Net yield increase
ORASECOM IWRMP Phase lll	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 m³/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 m³/a and 30.8 million m³/a respectively. The net system yield increases due to Hlotse and Ngoajane dams are however only 54 million m³/a and 10 million m³/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 m³/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 m³/a) brings the total reduction (ORP reduction of 45 million m³/a included) in yield/water supply to 51.4 million m³/a for Hlotse and Ngoajane dams combined

- With some increase in storage at both Hlotse and Ngoajane dams of 15 million m³ and 27.3 million m³ respectively, the gross yield from the two dams can be increased by 9.3 million m³/a and 8 million m³/a, thus a total of 17.3 million m³/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 m³/a and 124 million m³/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 5-9** in **Section 5.4.2** 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 5-10** in **Section 5.4.3** of this report. These possible combinations as given in **Figure 5-10** 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 mitigation 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.

The Lesotho Botswana Water Transfer Scheme water resource analyses.

The water resource assessment took into consideration a number of key issues which have a significant impact on the yield and potential viability of any new development.

Historical Firm Yield and Stochastic Yields. The analyses results presented in this report are all based on the historical flow sequences derived from previous hydrological assessments. The resulting yield estimates are therefore considered to be the Historical Firm Yields which are typically based on streamflow records of between 70 and 100 years in length. Due to the long droughts experienced in Southern Africa, it is normal practice to undertake further analyses which are based on multiple stochastic streamflow sequences which are synthetic flow sequences that have similar statistical properties to the historical streamflow sequence at each node in the system. These stochastic sequences are then analysed in exactly the same manner as the historical sequence in order to derive a more accurate estimate of the yield which is tied to a specific level of assurance of supply. In this way, the yield and reliability characteristics for any specific development option can be calculated. The stochastic analyses are very time-consuming due to the large number of streamflow sequences that are analysed to calculate the yield for a specific dam development option. For this reason, the initial dam selection process is based on the historical sequences and the resulting "Historical Firm Yield" is used to select the one or two most promising options which will then be analysed in more detail using stochastic sequences. The yield figures provided in this report may therefore change slightly in future in accordance with the results from the subsequent stochastic analyses to be undertaken in the next phase of the project.

Impact on downstream users. One of the most important issues, concerns the impact of any new upstream development on the downstream users. In a river basin system that has abundant water resources, a new dam development may not cause any noticeable impact on the downstream users and in such cases, there may be no need to investigate additional reconciliation strategies to support the downstream users since they have not experienced any reduction in their supply. This was the situation with the first phase of the Lesotho Highlands Water Project which was planned back in the 1970's and developed in the 1980's. At this time, there was still water available for new developments. Over the past 30 years, however, the situation has changed and water in the Orange/Senqu basin is over utilised and has become a scarce resource. It is therefore important to evaluate the impact of any new dam development options on the downstream users and if possible, to quantify any reduction in water availability that will be experienced by them. It should be noted that if it is considered necessary to mitigate

the reduction in water availability to the downstream users, then a separate study will be required that evaluates viable and cost-effective reconciliation strategies that address the basin-wide shortfalls. In the case of a new dam anywhere in the Orange/Senqu river basin, the initial yield assessment will determine the possible maximum yield that can be abstracted from the new dam at the location of the dam, referred to as the local yield. A second basin-wide assessment will then be undertaken to assess the net or incremental yield from the Orange/Senqu river basin as a whole which will still be a positive yield but is likely to be lower than the local maximum yield available at the dam site. It is therefore important to present both the maximum local yield as well as the net additional basin yield also referred to as the incremental yield, for any proposed new development.

Mitigation Releases. Another important issue concerns the required releases from any proposed new development. The term "mitigation releases" is often used to cover the required water to be released from a proposed new dam primarily for environmental purposes. In certain scenarios, an additional volume of water is included to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. If both the environmental requirements (usually very small) and the additional mitigation flows (often very large) are combined and shown as "mitigation releases" it can create both confusion and some concern as it may appear that much of the benefit of the proposed new dam is being released for no apparent reason. In such cases, the incremental yield from the proposed new dam may be half of the gross maximum local yield which may, in turn, make a potentially viable project appear to be unviable.

Local Yield and Net System Yield. Having highlighted the key issues of the maximum local yield as well as the possible incremental yield of a potential new dam development, it is also important to mention one more very significant consideration when assessing any new dam development. The maximum local yield given in the report for each possible new development is the actual yield that can be abstracted at the proposed dam site. This water is available high up in the catchment and as such may have significant additional value due to the fact that it can be used to supply specific areas or consumers which cannot be supplied from a development lower down in the system. Even in cases where the incremental yield may be half of the local maximum yield, the full local maximum yield can still be used or diverted to external users. In such a case, it may be necessary to investigate some further reconciliation strategies to provide additional yield somewhere in the river basin to restore the status quo to the existing downstream users. Releasing water from the new Makhaleng Dam high up in the catchment for this purpose is possible but would not always be an attractive strategy due to the fact that water higher up in a catchment has greater value and usually experiences low evaporation making it an ideal location to store water.

The various local yields and incremental system yields provided in the remainder of this section are presented in a manner in which any flow required by the downstream users is shown as a separate item and is not included in the "mitigation flows" which relate specifically to the Environmental Flow Requirements.

The water resources yield analyses were carried out in support of the Dam Engineers to provide yields at various dam sites and for a wide range of dam sizes. The gross yield of a large dam (approx. 3 times Mean Annual Runoff, i.e. 3 MAR) in the Makhaleng River is dependent on the location and size of the dam. At the upstream sites, N1a and N1, the **gross yield** is estimated to be a maximum of 335 million m^3/a. At the downstream sites, S1 and S2, the maximum gross local yield is estimated to be approximately **390 million m^3/a**. The recommended and preferred dam site will be selected not only on the yield but will include various other technical and environmental considerations

Key Yield Results

There is more than sufficient local yield (390 mil m^3/a) at Makhaleng Dam to support the **high demand scenario (approx. 200 mil m^3/a).** It will, however, result in some decrease in water availability to the downstream users in the Orange-Senqu system. It should be noted that there are a number of possible options to offset the reduction in downstream yield that must still be investigated in detail as part of a separate study.

Recommendations

It is recommended that the large Makhaleng Dam should be built to provide more flexibility in the system as well as to support additional irrigation in Lesotho. Water stored high up in the catchment will generally have significant additional value due to the fact that it can be used to supply or support more areas at lower pumping costs. Mitigation releases may be required to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. Such releases can be supplied from Makhaleng Dam or from another development in the Orange Senqu system which would be preferable. The cost of the proposed Makhaleng Dam is an order of magnitude lower than the cost of the conveyance infrastructure and it is therefore sensible to develop the largest dam possible on the selected site.

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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 ll	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.**
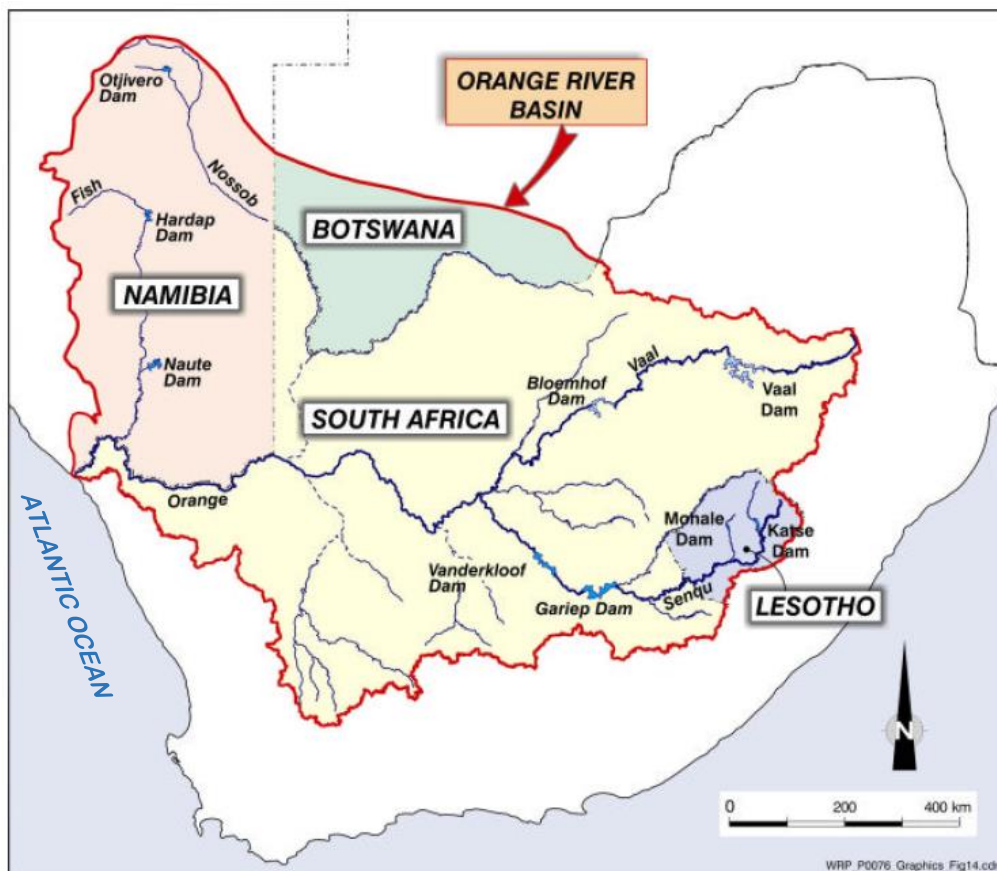
 Figure 1-1: Orange-Senqu River Basin

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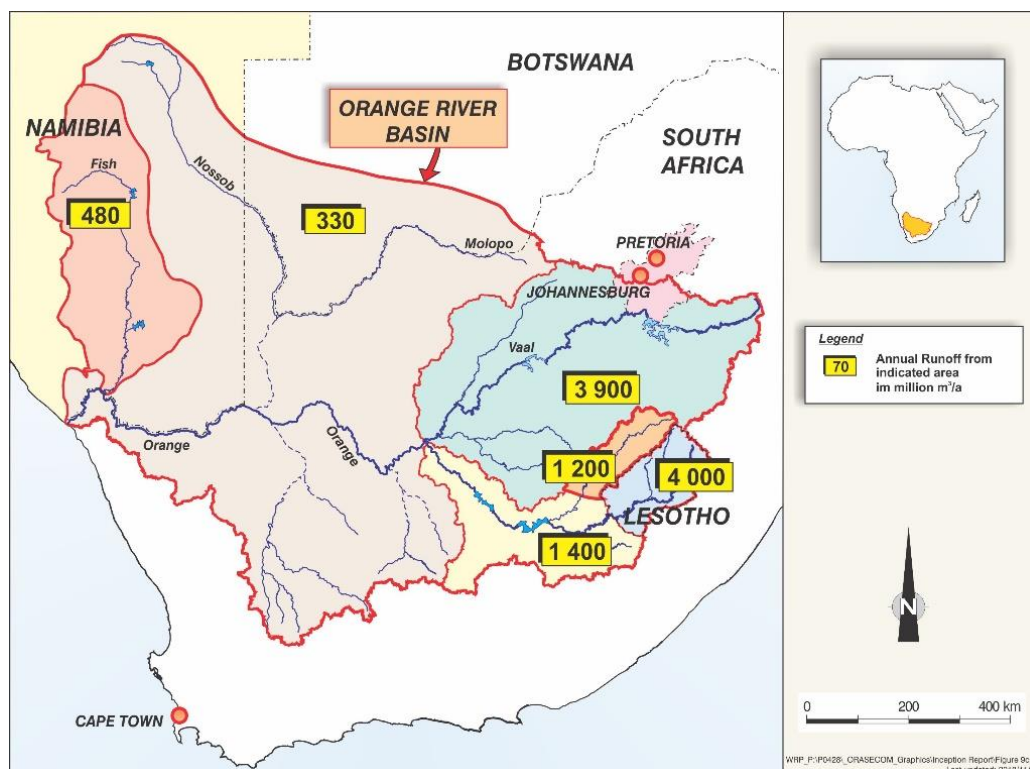
Figure 1-2: Approximate Natural Run-off in the Basin

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 m³/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.
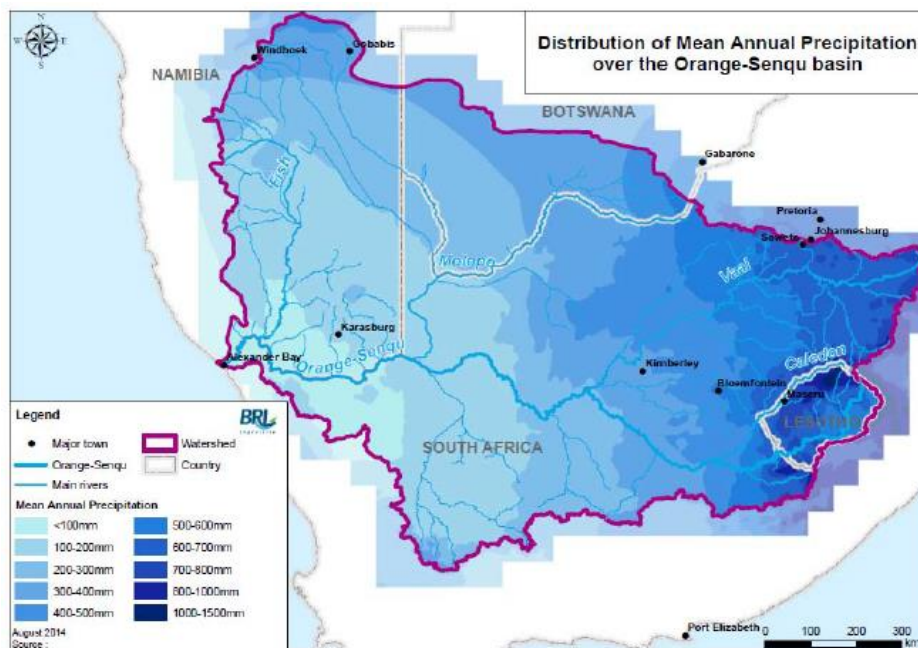
Figure 1-3: Distribution of Mean Annual Precipitation

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.
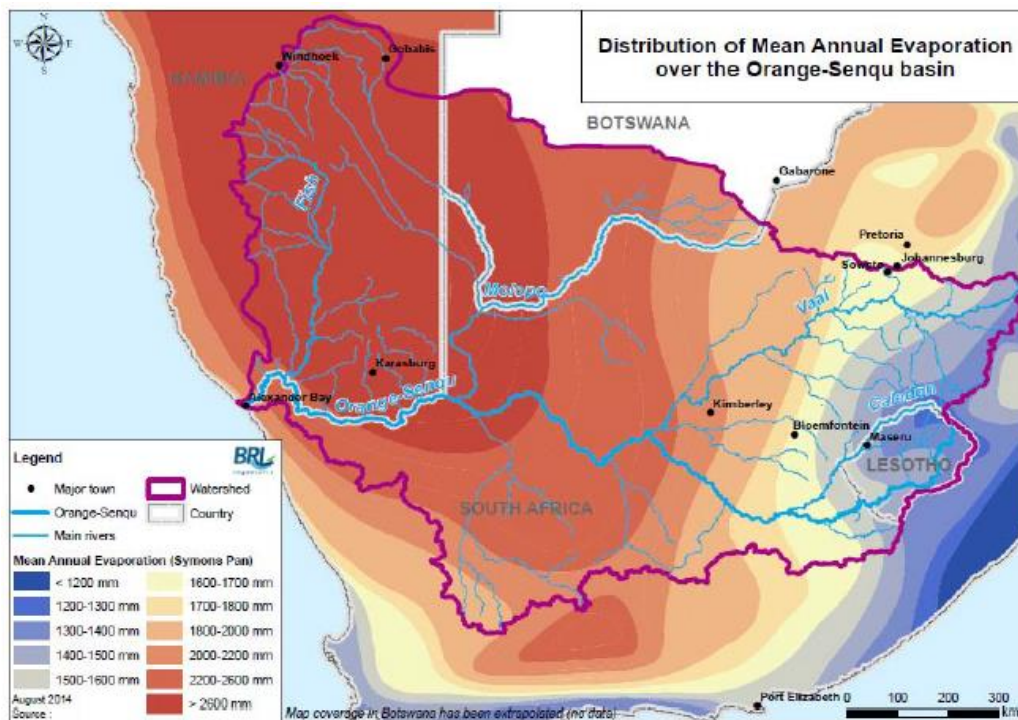
Figure 1-4: Distribution of Mean Annual Evaporation

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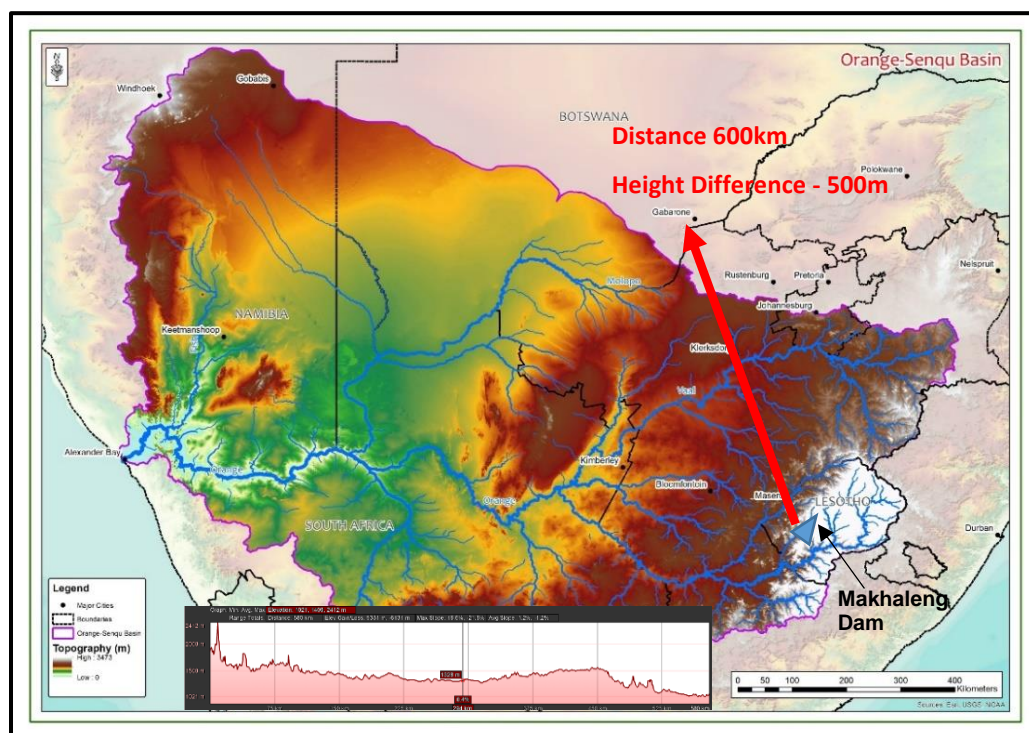
Figure 1.5: Orange Senqu basin topographical map showing the possible Lesotho Botswana Water Transfer Project

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:

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

- 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.

Component III - Phase 2 - Pre-feasibility of the Makhaleng Scheme

- 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.

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

- 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 provide the details of all the water resource system analysis related work carried out as part of this study in one single report. Most of the system analysis work was carried out as part of Component I of the study and is documented in the Core Scenario updated work where the focus was on the Core Scenario. 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. Chapter 3 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.

Other system analysis work was carried out as part of the Pre-feasibility Phase 1 Report that focused on the Lesotho-Botswana water transfer multipurpose transboundary project and is documented in the Pre-feasibility Phase 1 Report.

This report contains only summarized information on water requirements and detail on the water resource system analysis related work. Detail information can be obtained from the following reports produced as part of this Study.

- Core Scenario Update Report (ORASECOM 003/2019),
- Water Requirement and Return flows Report (ORASECOM 004/2019)
- Water Conservation, Water demand management and re-use report (ORASECOM 005/2019
- Climate change report (ORASECOM 007/2019)
- Pre-feasibility Phase 1 Report (ORASECOM 014/2019)

2   UPDATED WATER REQUIREMENTS FOR ORANGE/SENQU BASIN

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 for the Orange/Senqu Study Area are 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 were reviewed, and the information captured in the Data Base Inventory.

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

2.2.1   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).

2.2.2   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.
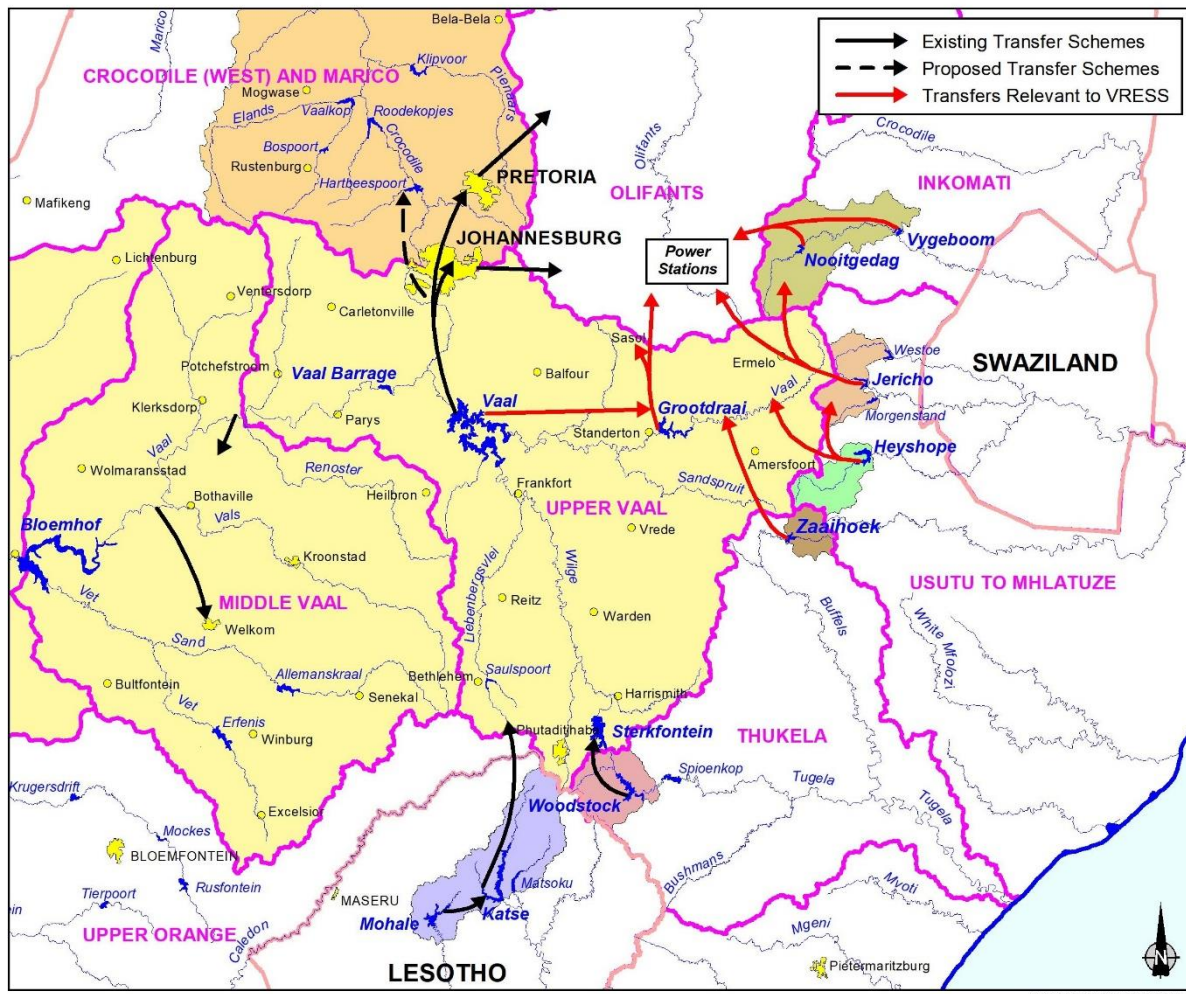
Figure 2-1: Transfers from the Komati, Usuthu Thukela and Lesotho

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 **Figure 2-2**. 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.

Figure 2-2: Vaal System Water Requirements and Return Flows Projection with WC/WDM (ORASECOM, 2019d)

Description	Water Requirements (million m³/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 m³/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.

2.2.3   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 **Figure 2-3**.

Figure 2-3: Orange-Senqu Water Requirements and Return Flows Projection with WC/WDM (ORASECOM, 2019d)

Description	Water Requirements (million m³/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 m³/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 m³/a at 2018 development level

2.2.4   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/km², compared to 42.4 people/km² 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 km² 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 **Figure 2-4**.

Figure 2-4: 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**

2.2.5 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 m³/a according to the low scenario and 136 million m³/a for the high scenario, and excludes treatment and conveyance losses (ORASECOM, 2019a).

The future water requirements for Botswana are summarised in **Figure 2-5** (ORASECOM, 2019a), containing both Urban and irrigation water requirements.

Figure 2-5: Future Botswana Water Requirements and Return Flows (ORASECOM, 2019d)

Description	Water Requirements (million m³/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**

2.2.6   Lesotho: Senqu/Caledon River

Lesotho has the highest population density of the four basin counties with 71 people/km² followed by the RSA with 42.4 people/km². 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 m³/a to the Vaal Catchment. Phase 2 of the LHWP will allow for an additional volume increase of 460 million m³/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 m³/a can be supported downstream by the planned Makhaleng Dam, 49.19 million m³/a for the Likhutlong & Ts'ehlanyane catchments, supported by the planned Hlotse Dam, 35.23 million m³/a for the Senqu Basin and 6.17 million m³/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 **Figure 2-6**.

Figure 2-6: Future Lesotho Water Requirements (ORASECOM, 2019d)

Description	Water Requirements (million m³/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 m³/a at 2018 development level.

2.3   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 for each of the water supply system forming part of the entire Orange/Senqu basin.

2.3.1   Approach followed for most of the large to medium size water supply systems.

These 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 5-11**) 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).

2.3.2   Other systems

Other water supply systems within the overall Orange/Senqu system make use of specific levels in the dams to control the supply to different users. In general first priority is given to Urban, Industrial and rural water requirements followed by agriculture and irrigation as second priority with recreation as the lowest priority. Environmental requirements are in general supplied at a relative high priority, but it differs from area to area also depending on the specific country. A high priority user are for example allowed to use all the water available in the dam or water supply system with the second priority user limited by a specific level in the dam at which water supply to that user will stop when the dam storage drop below that level. Similar another higher storage level will be used to manage water supply to a third or fourth priority user.

The very small dams such as typical farm dams do not make use of levels within the dam and the demand imposed on the dam is fully supplied until the dam is empty.

2.4   Lesotho Botswana Transfer Scheme Water Requirements

The full detail of the water requirements to be supplied from the Lesotho Botswana transfer scheme is given in the L-BWT Scheme Pre-feasibility Phase 1 study report (ORASECOM, 014/2019). This section only provides a summary of the related water requirements.

The net water requirements for Botswana in 2050 that were selected to be used for Phase 1 of the Prefeasibility Report range from 59 million m^3/a for the low scenario to 136 million m^3/a for the High Scenario. This estimate excludes water treatment losses (10%) and conveyance losses (5%). For the High Scenario, approximately 80% of the water requirement is for Botswana with about 10% each for South Africa and Lesotho.

High Scenario no irrigation - Total Water Requirement 199 million m^3/a
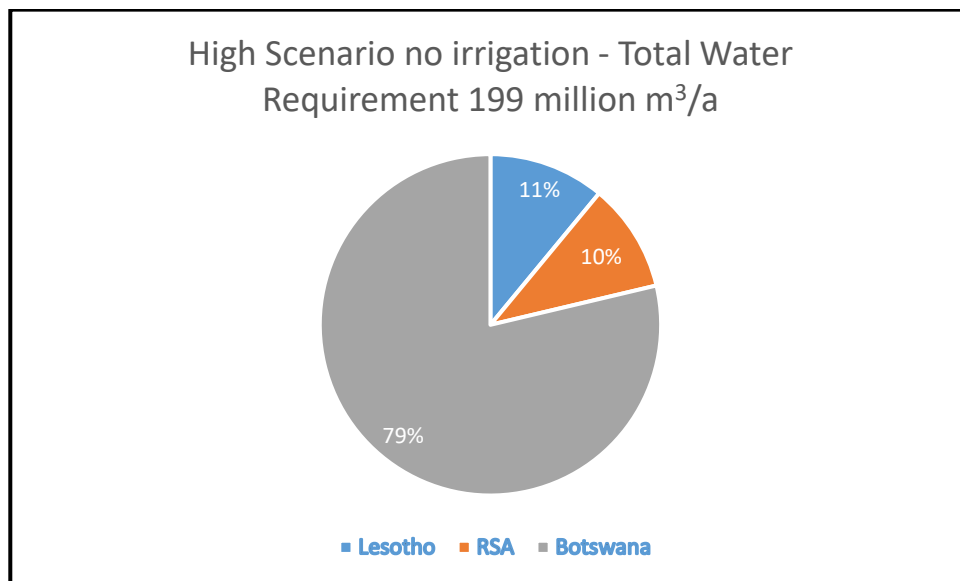
Figure 2-7: L-BWT Project Net Water Requirements 2050 for High Scenario

It is important to note that the Low Scenario were considered as an alternative to the option that requires an additional development to supply the mitigation or part of the mitigation releases to restore the water balance of the downstream users. For the Low Scenario all the required mitigation releases can be made from Mahaleng Dam. The Low Scenario also allows for the development of irrigation in Lesotho. The net yield from a possible Makhaleng Dam for the Low Scenario allows for the inclusion of about 40 million m^3/a for irrigation, which is approximately half of the possible maximum irrigation area downstream of Makhaleng Dam. For this scenario the allocations to Botswana and Lesotho are both over 40% with only 14% to the RSA.

Low Scenario with irrigation - Total Water Requirement 151 million m³/a
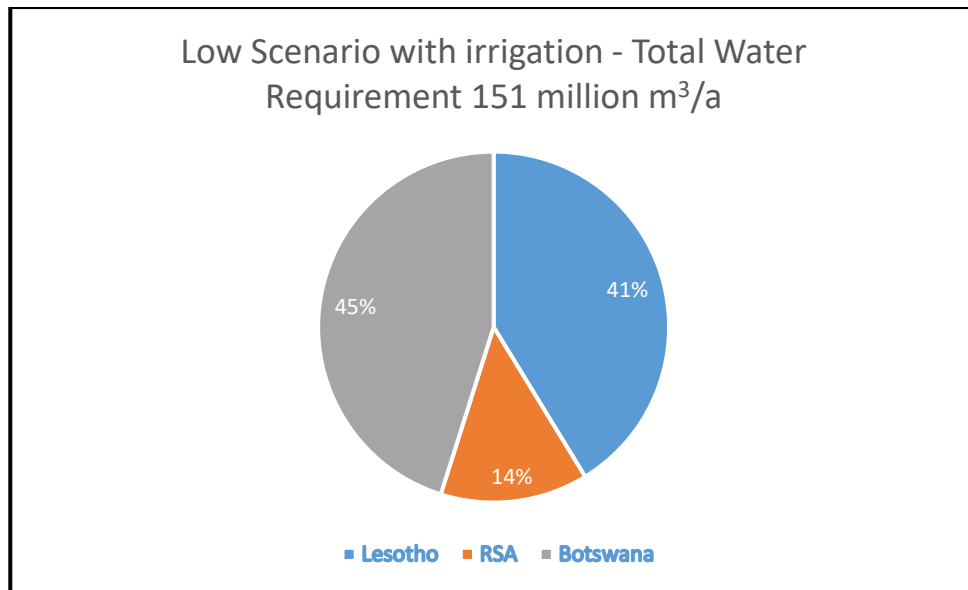
Figure 2-8:L-BWT Project Net Water Requirements 2050 for Low Scenario with Lesotho irrigation

DWS RSA requested that the option of augmenting the Greater Bloemfontein System from the L-BWT scheme pipeline also be tested as a possible additional RSA water requirement. This means that the RSA augmentation requirement from the L-BWT scheme pipeline will then have to be increased by another 43 million m³/a by 2050. The current RSA planning is to transfer the 43 million m³/a from Gariep Dam to Bloemfontein. Whether the 43 million m³/a transfer to the Greater Bloemfontein is taken from Gariep Dam or from Makhaleng Dam, the resulting impact on the ORP will be more or less the same.

Low Scenario with irrigation and support to Bloemfontein - Total Water Requirement 194 million m³/a
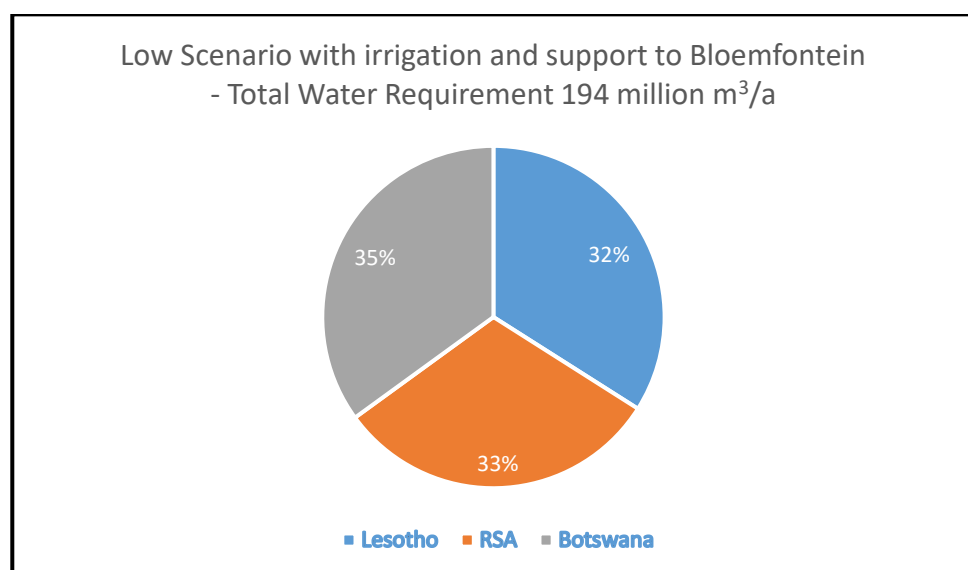
Figure 2-9: Low Scenario with support to Greater Bloemfontein – 2050 Net Water Requirements

This means that the Lesotho irrigation to be supported from Makhaleng Dam can remain the same as determined for the Low Scenario with irrigation as presented in **Figure 5-20**. When the Low Scenario is used to also augment the Greater Bloemfontein, the RSA, Botswana, and Lesotho proportions are almost similar, being just above 30% (**Figure 5-23**).

The Ecological Status was estimated to be a D, which represents the response of the biota to the lack of habitat diversity due to sedimentation from overgrazing, erosion, and removal of riparian vegetation, as well as the presence of alien vegetation in the riparian zone.

The Revised Desktop Reserve Model (RDRM, v2) was used to estimate the EWR requirements for the site. This was done for a B, C, and D Ecological statuses. If releases are made to achieve the B status, it will have a major impact on the yield of the dam, whereas a D would have a minor impact. These impacts will also depend on how Makhaleng Dam is operated. In the case where Makhaleng Dam is also used to mitigate the negative water balance in the Orange River project (ORP) as result of the transfer to Botswana and RSA, significant mitigation releases from Makhaleng Dam will be required to support the ORP. In this case the mitigation releases for support purposes will most probably be sufficient to achieve EWR flows for a B or C ecological class downstream. It is quite possible that this option will be followed, in which case the higher ecological class will not have a significant impact on the net yield available from Makhaleng Dam.

3   UPDATE OF CORE SCENARIO

3.1   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.

3.2   Core Scenario Updates'

Detail of the Core Scenario, the methodology used to update the Core Scenario as well as the updated Core Scenario are given in the Core Scenario Update Report. (ORASECOM, 003/2019)

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.

Figure 3-1: 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.

Figure 3-2: 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 database for ORASECOM Phase III 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 **Error! Reference source not found.**. 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

Core scenario description (2014)	Adjust / update for this study
	Include further Phase of Thukela transfer by 2040 when Vaal requirements growth exceeds allowable risk of supply criteria based on the analysis results

Figure 3-3: 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.

Figure 3-4: 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.

Core scenario description (2014)	Adjust / update for this study
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 mitigation releases from Makhaleng Dam to Verbeeldingskraal Dam if required based on system analyses results

Figure 3-5: 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

Core scenario description (2014)	Adjust / update for this study
	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 III 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

Core scenario description (2014)	Adjust / update for this study
	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.
	Include mitigation 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.

Figure 3-6: 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.

4 RESULTS OF CORE SCENARIO ANALYSES

4.1 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 4-1.**
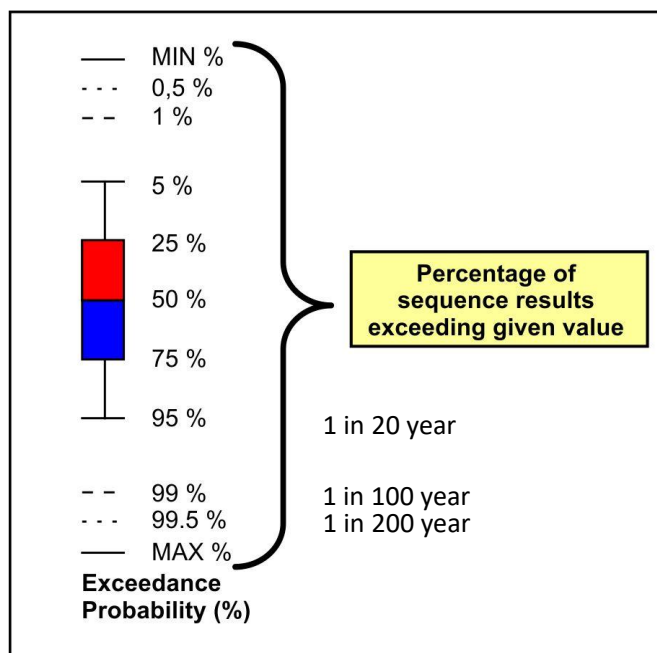
Figure 4-1:Box plot definition

4.2   Results and Comparison with Previous Core Scenario Results

4.2.1   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 4-2**.
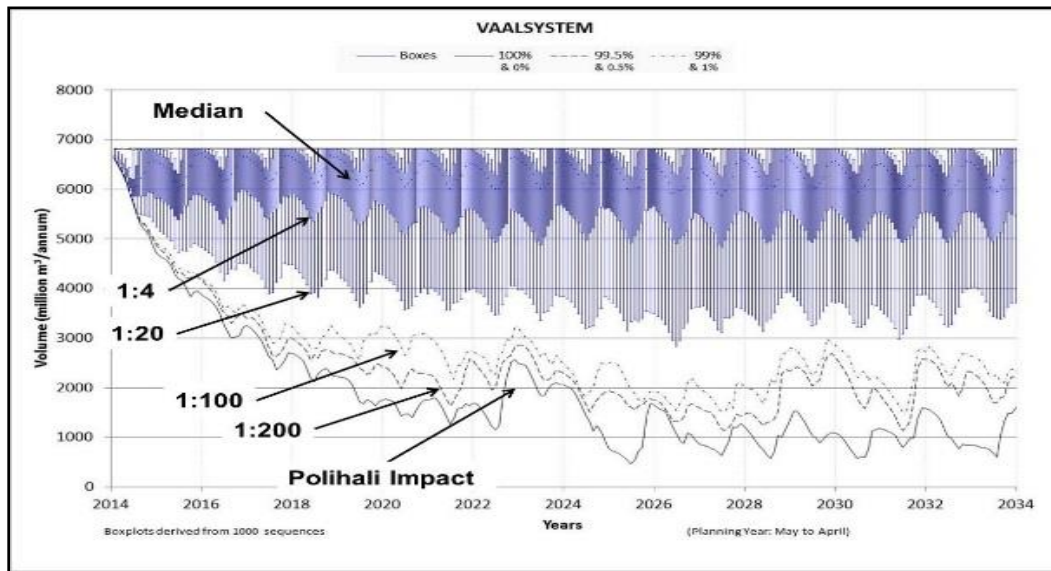
A
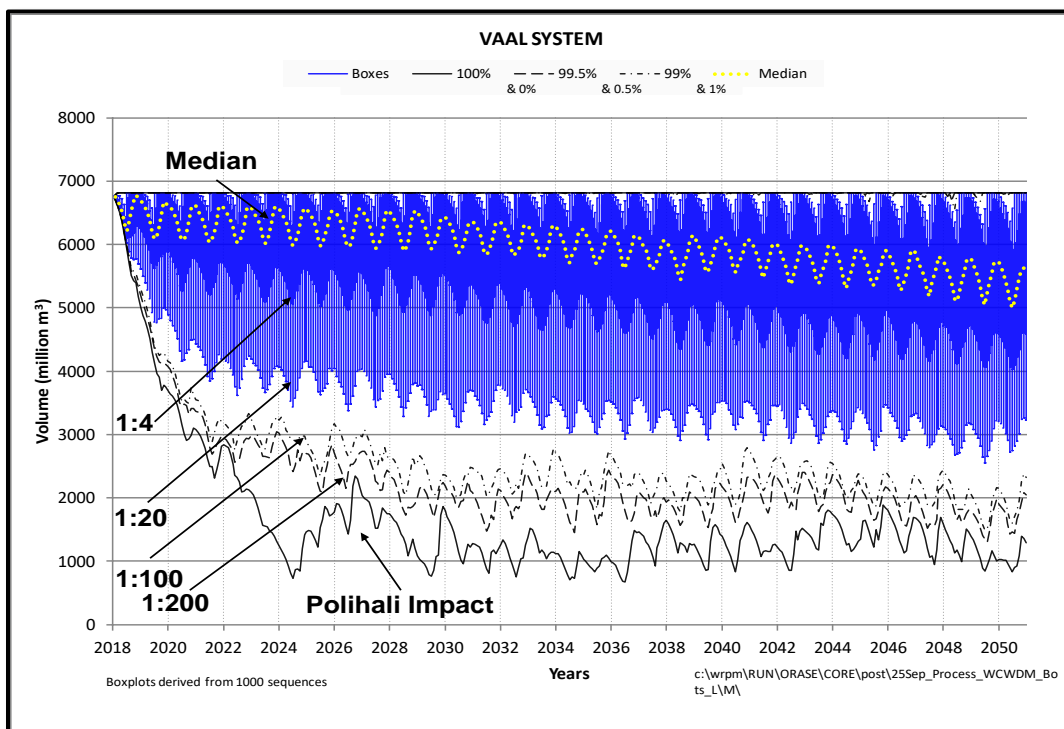
B

Figure 4-2: 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 ll operating rule, the operating rule was adjusted for the purpose of the current Core Scenario. The current Core Scenario allowed the Phase l 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 2.3.1** according to the methodology used by the RSA for large dams. 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 4-1**.

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.

Figure 4-3: 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 4-3 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 4-4 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.
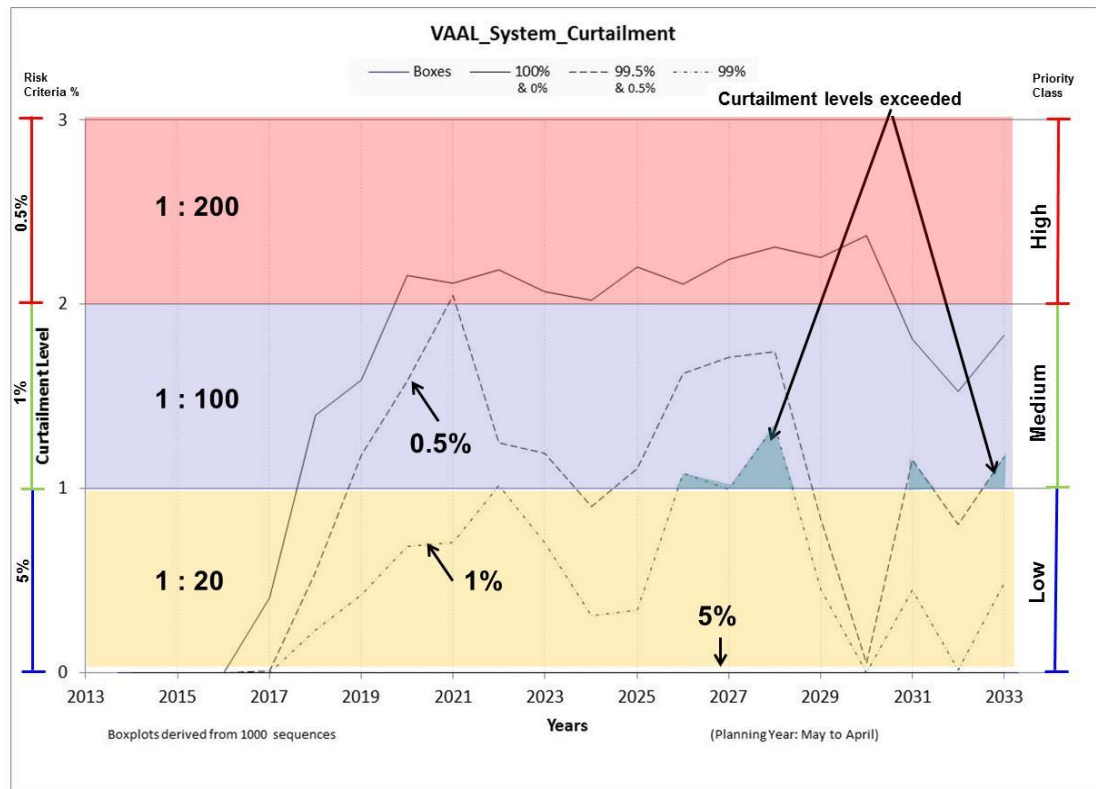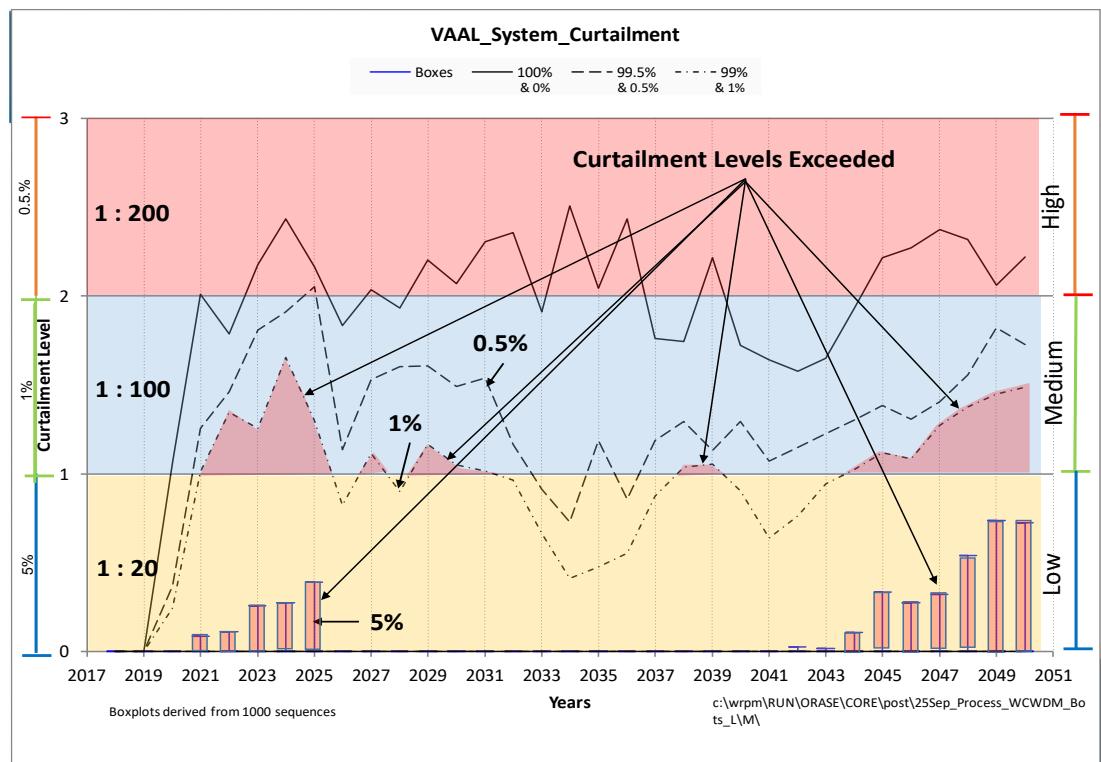
Figure 4-4: Vaal System Curtailment Plot for the previous (A) and current (B) Core Scenario
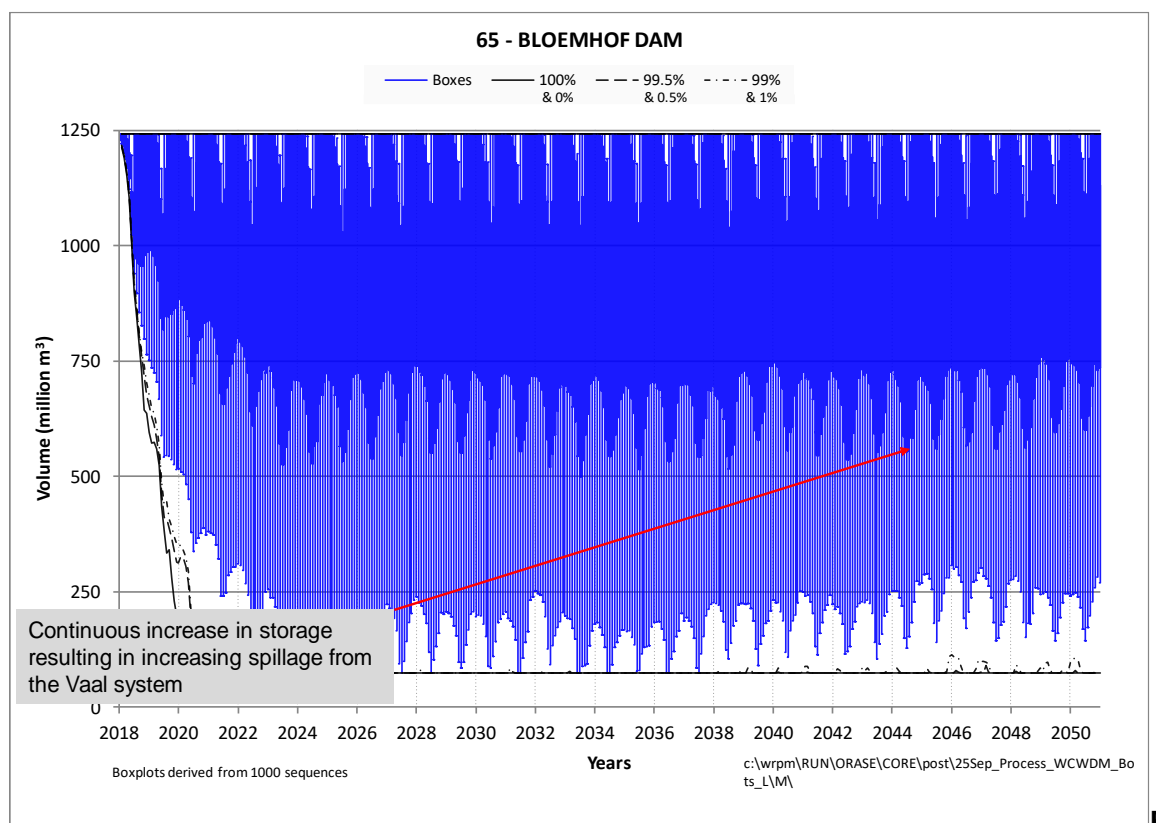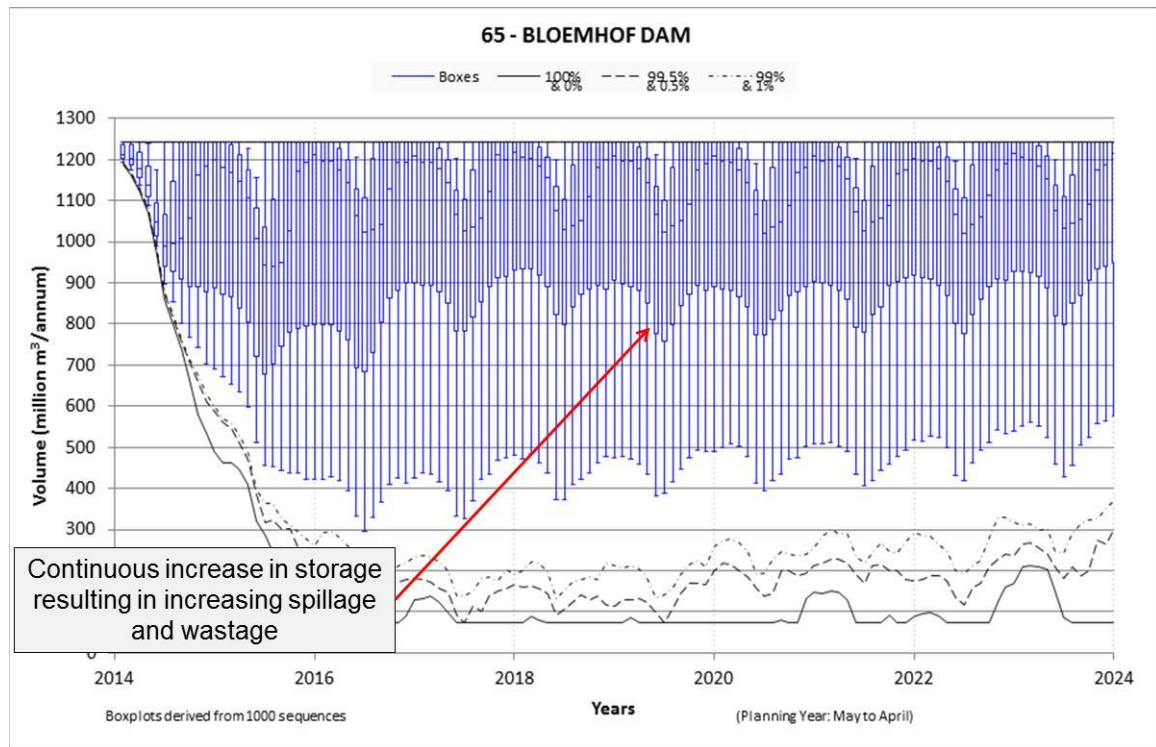
Figure 4-5: Bloemhof Dam Storage projection for the previous (A) and current (B) Core Scenario

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 4-5 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 ll 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.
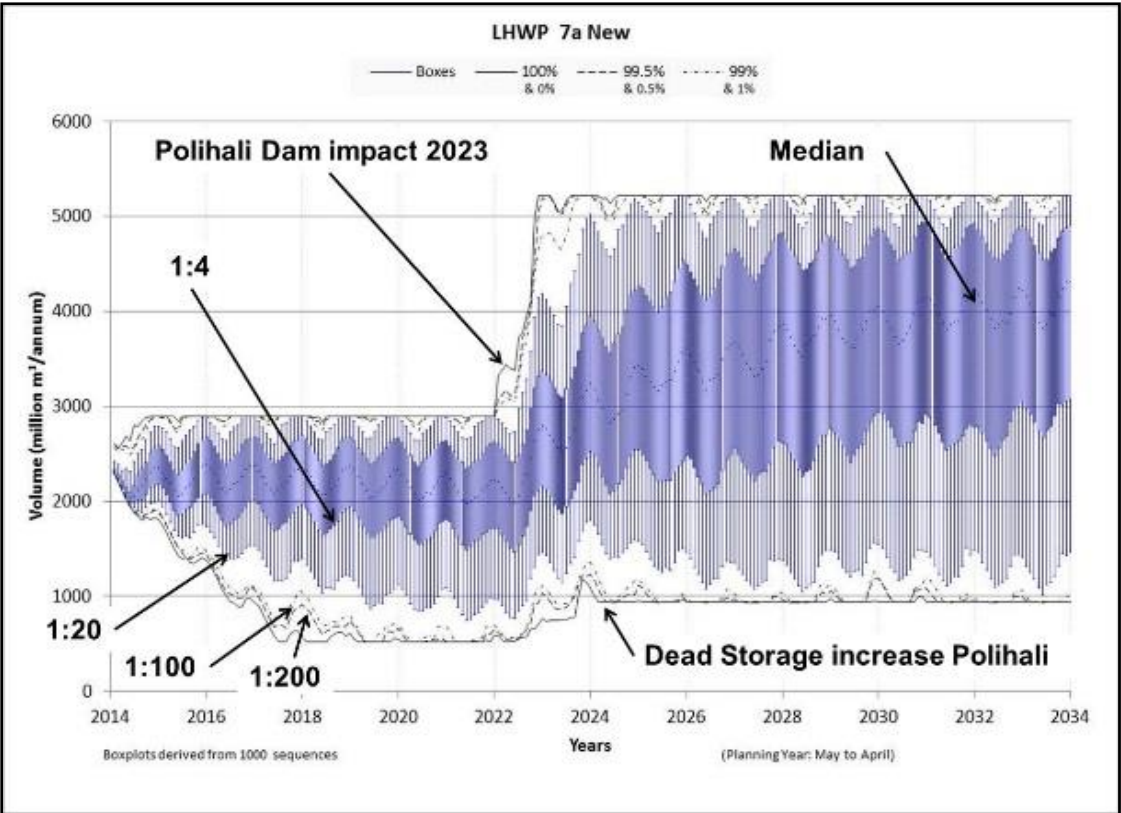
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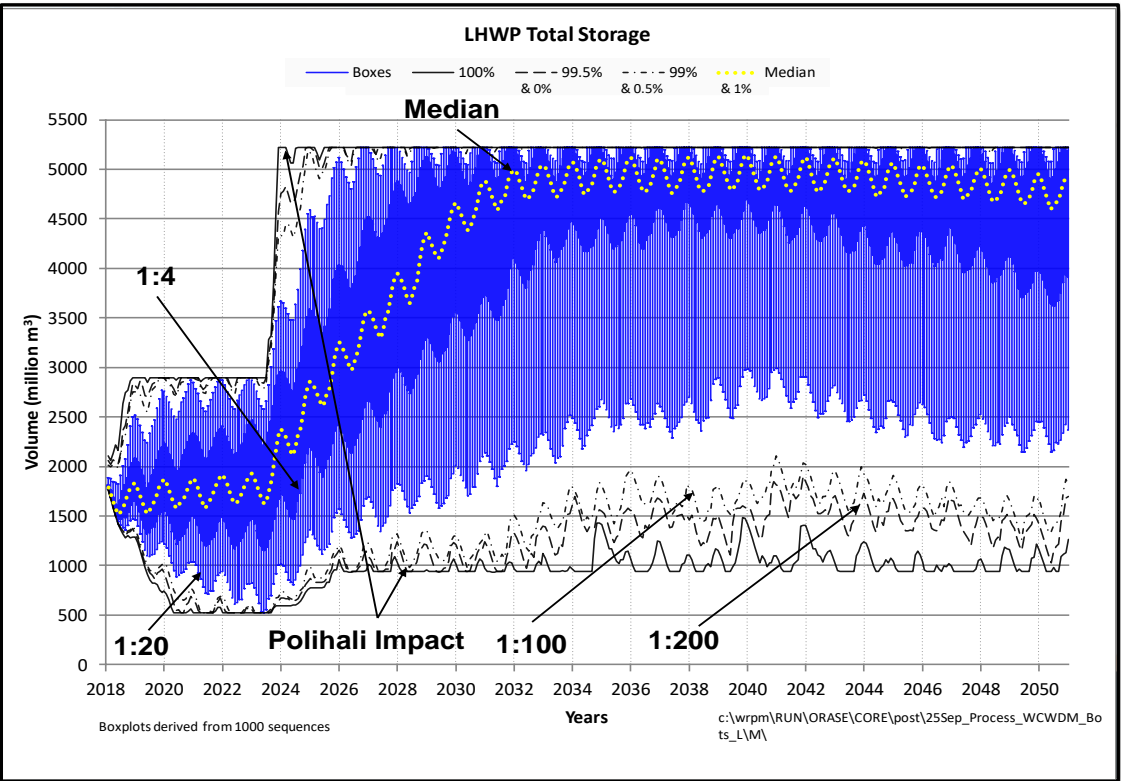
B

Figure 4-6 : LHWP System Storage projection for the previous (A) and current (B) Core Scenario

4.2.2   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 4.6**).
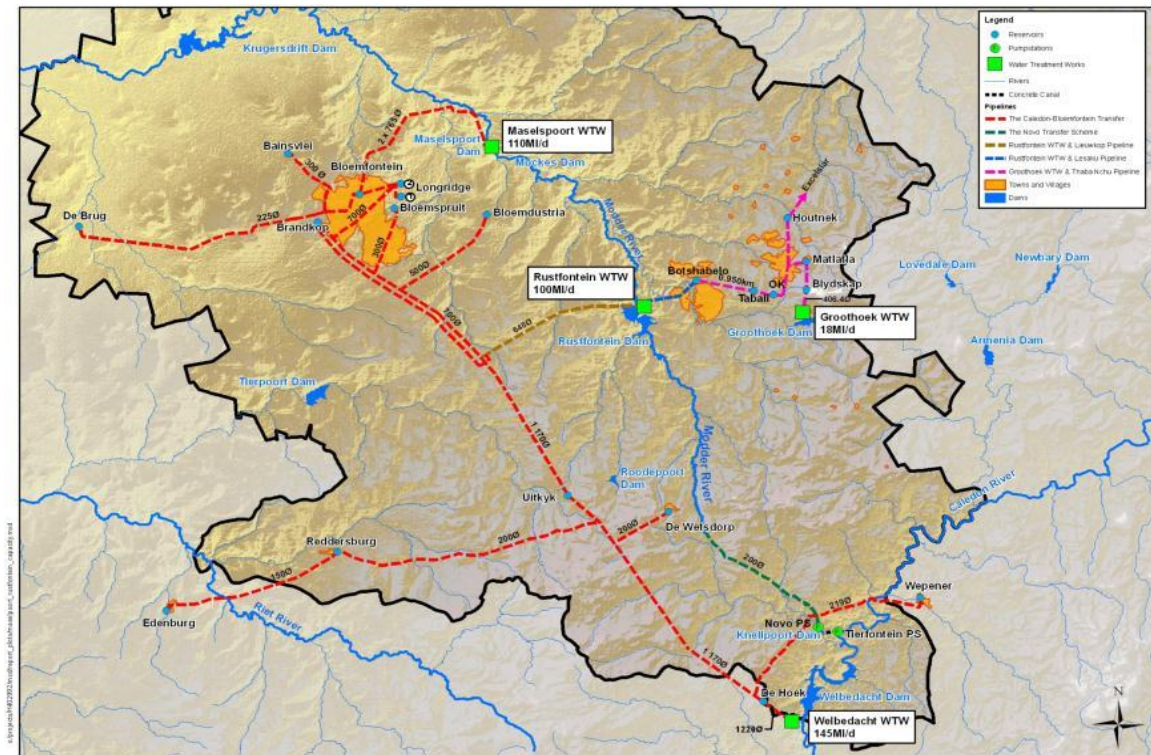
Figure 4-7: Greater Bloemfontein Water Supply System

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).
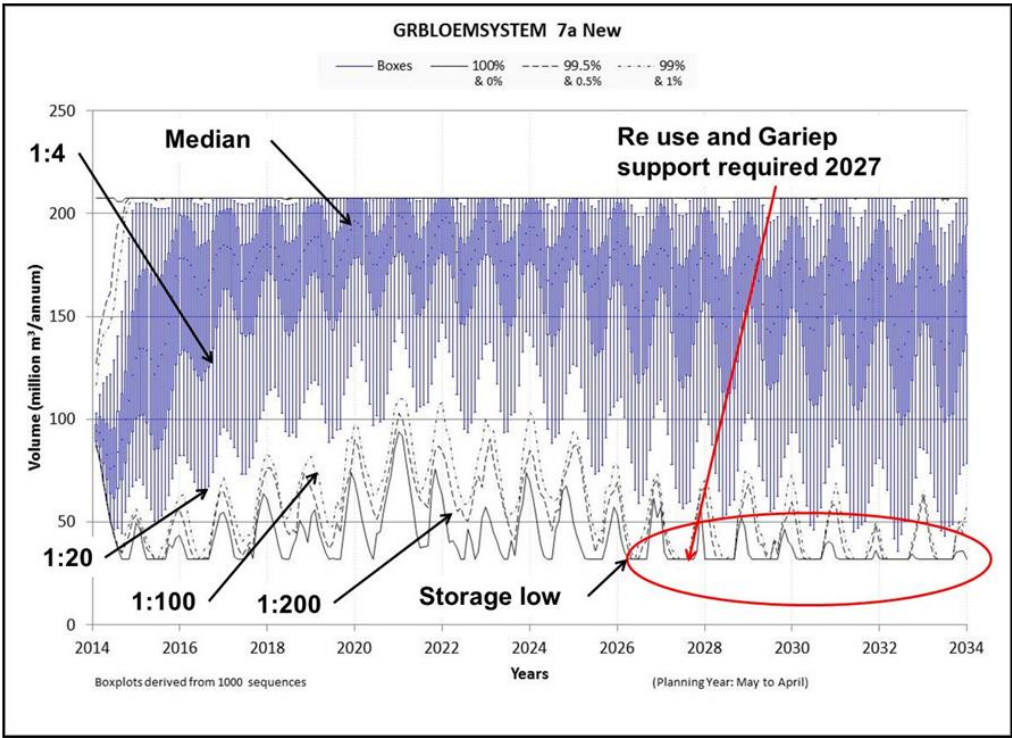
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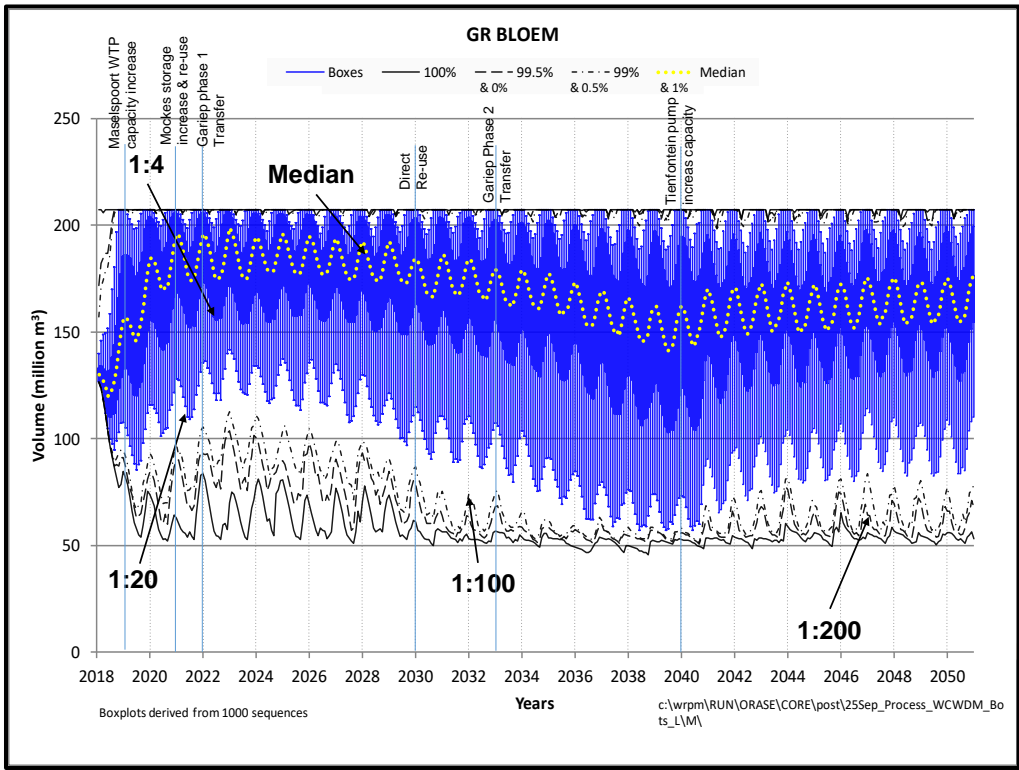
B

Figure 4-8: :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 III 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 4-8B**).
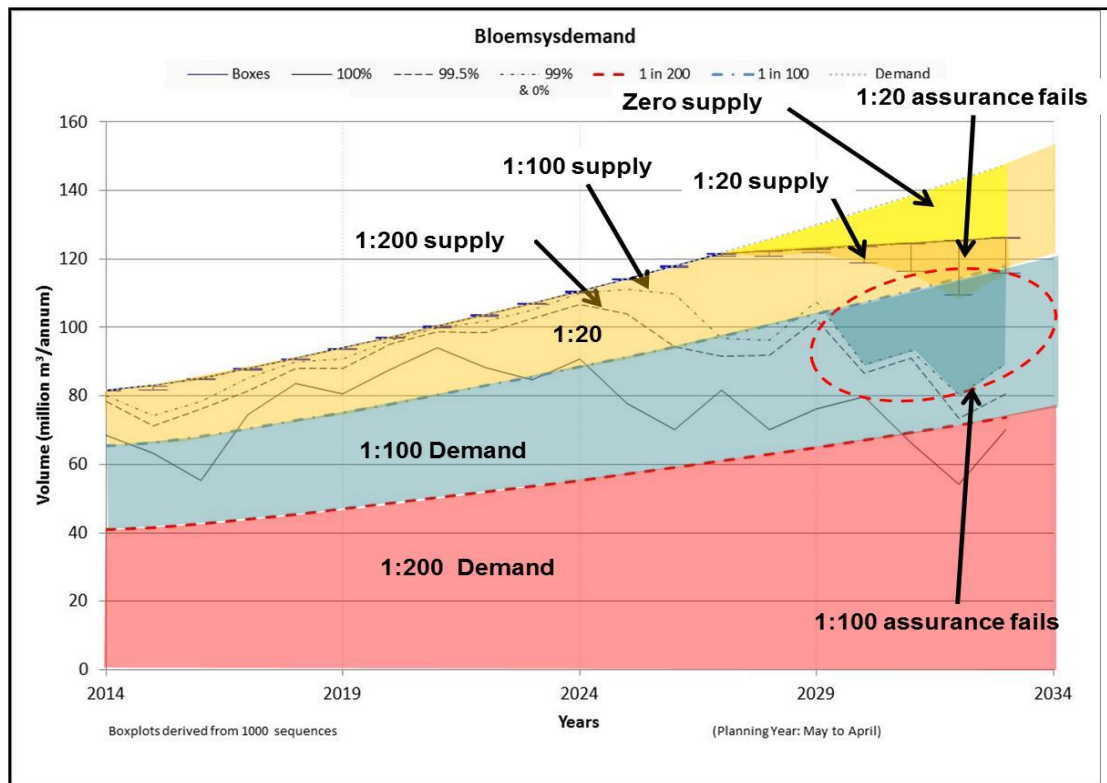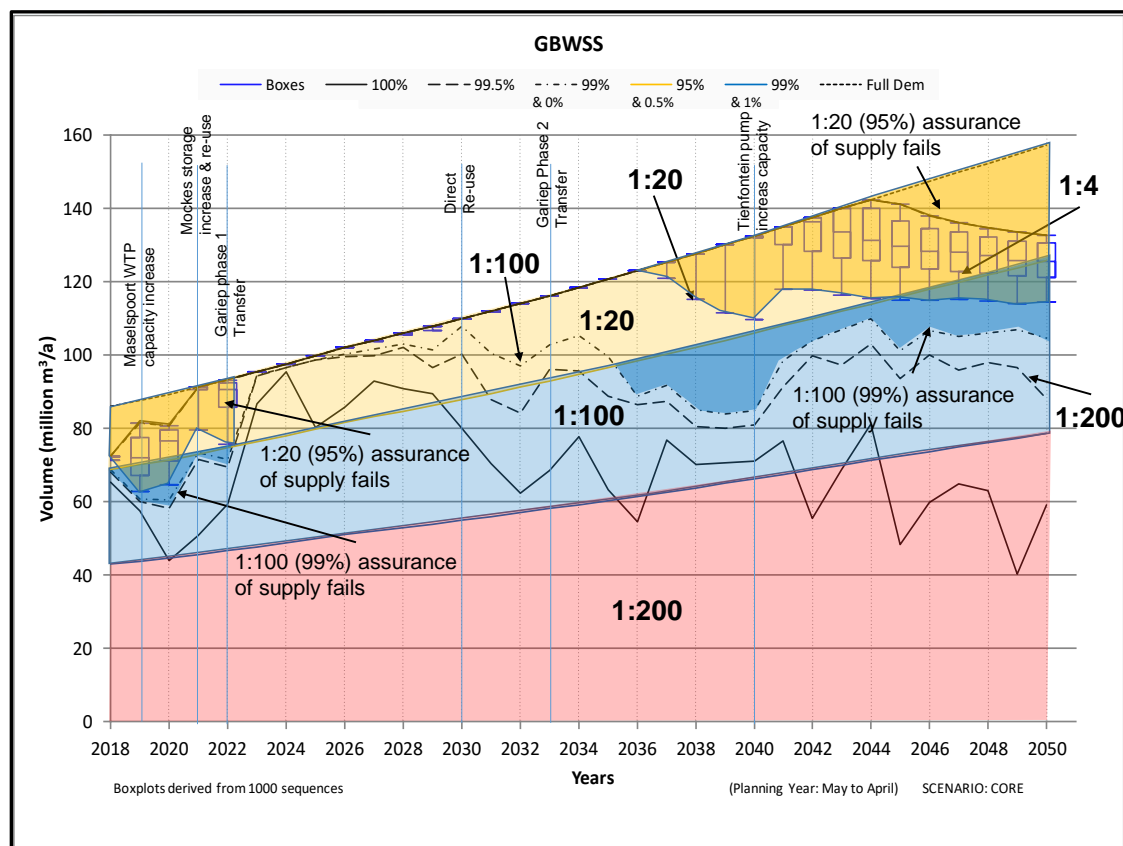
Figure 4-9: Greater Bloemfontein System demand and supply projection for the previous (A) and current (B) Core Scenario

From **Figure 4-8** 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.
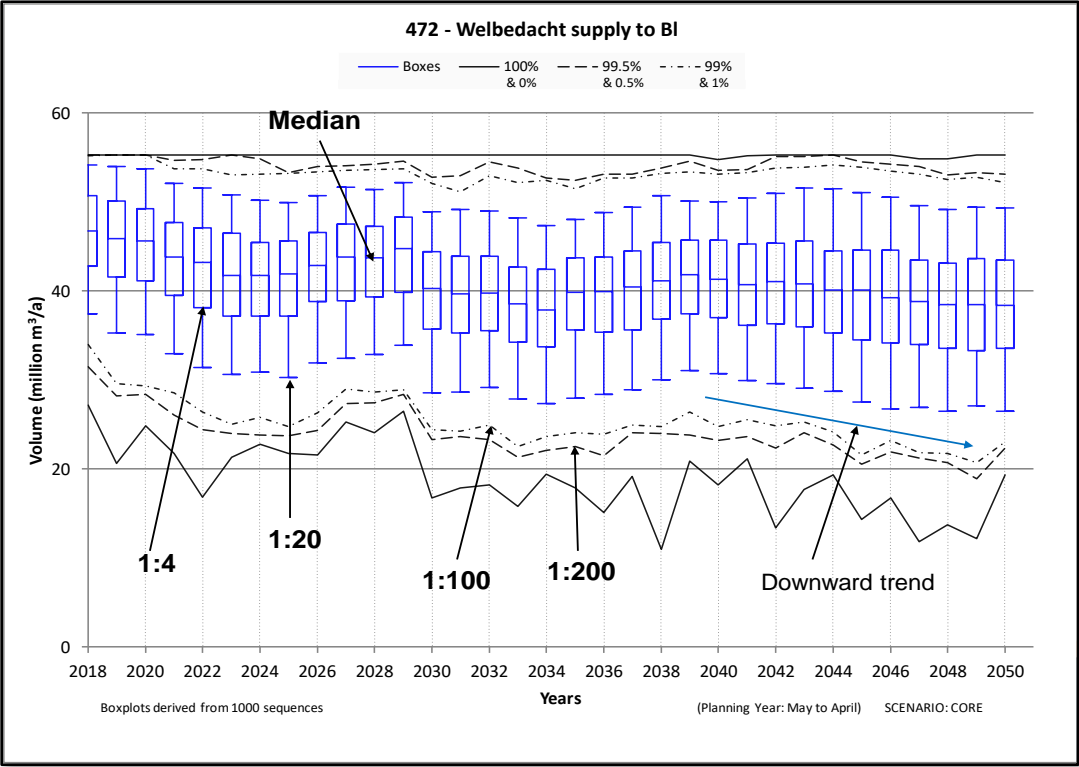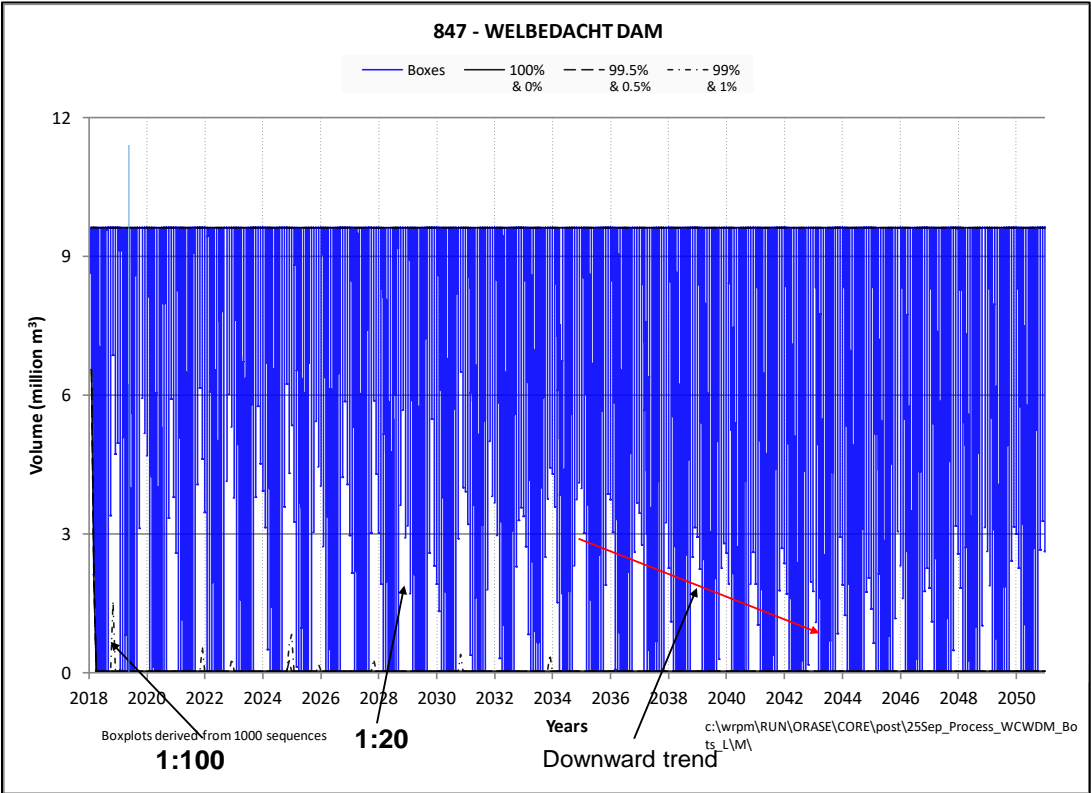
Figure 4-10: Welbedacht Dam storage projection and supply to Bloemfontein

4.2.3   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 4-10**.

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.
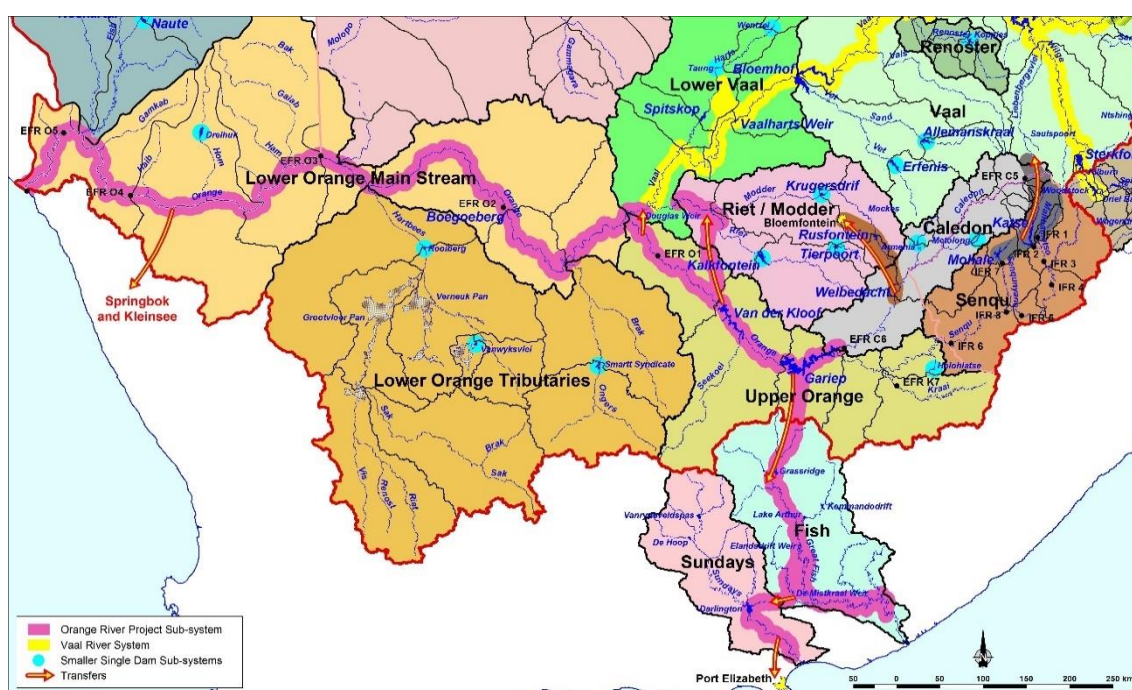
Figure 4-11: Orange River project water supply system and supply area

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 4-11B**. 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.
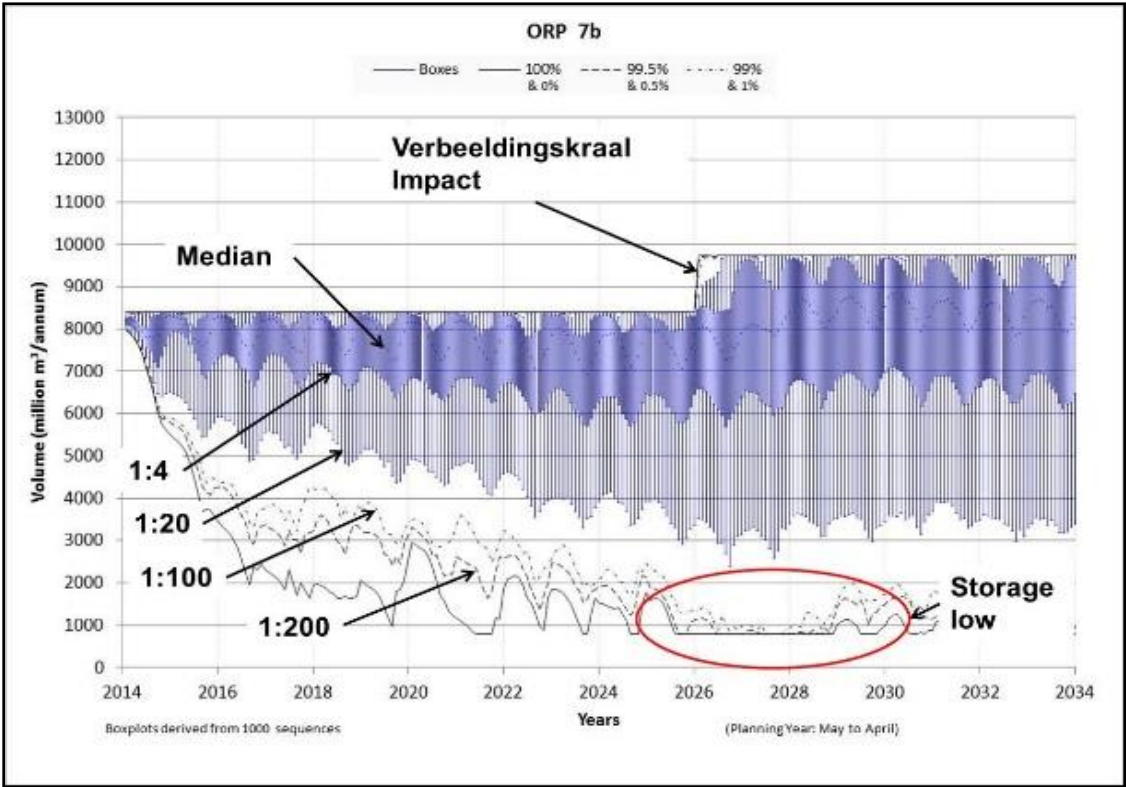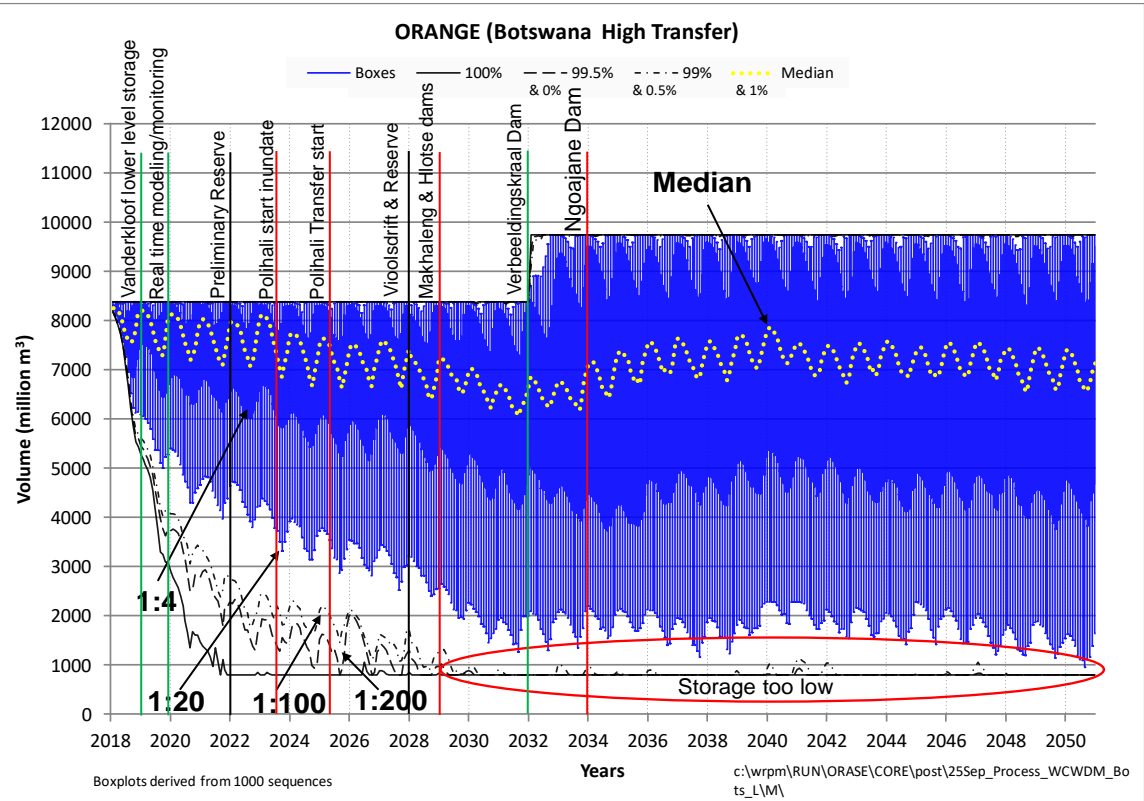
Figure 4-12: ORP System Storage projection for the previous (A) and current (B) Core Scenario

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 ll 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 lll 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 4-12, 7-13** and **7-14**).

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 4-12**.

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 4-13**. 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 4-14**. Both the Previous and Current Core scenario showed some failure in supply at the 99% assurance but was both in general well supplied. **Figure 4-14** 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 4-15**. 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 4-15B**. The steep growth in irrigation is clearly evident and failure in the assurance of supply are already seen from 2043 onwards.
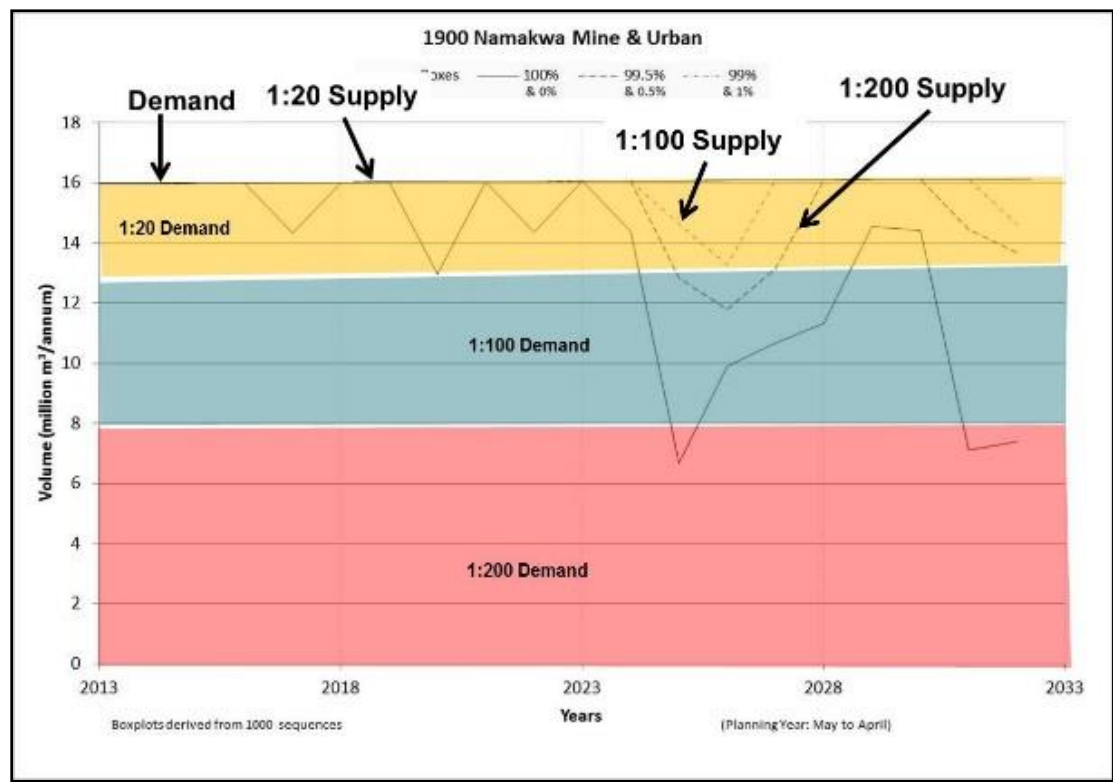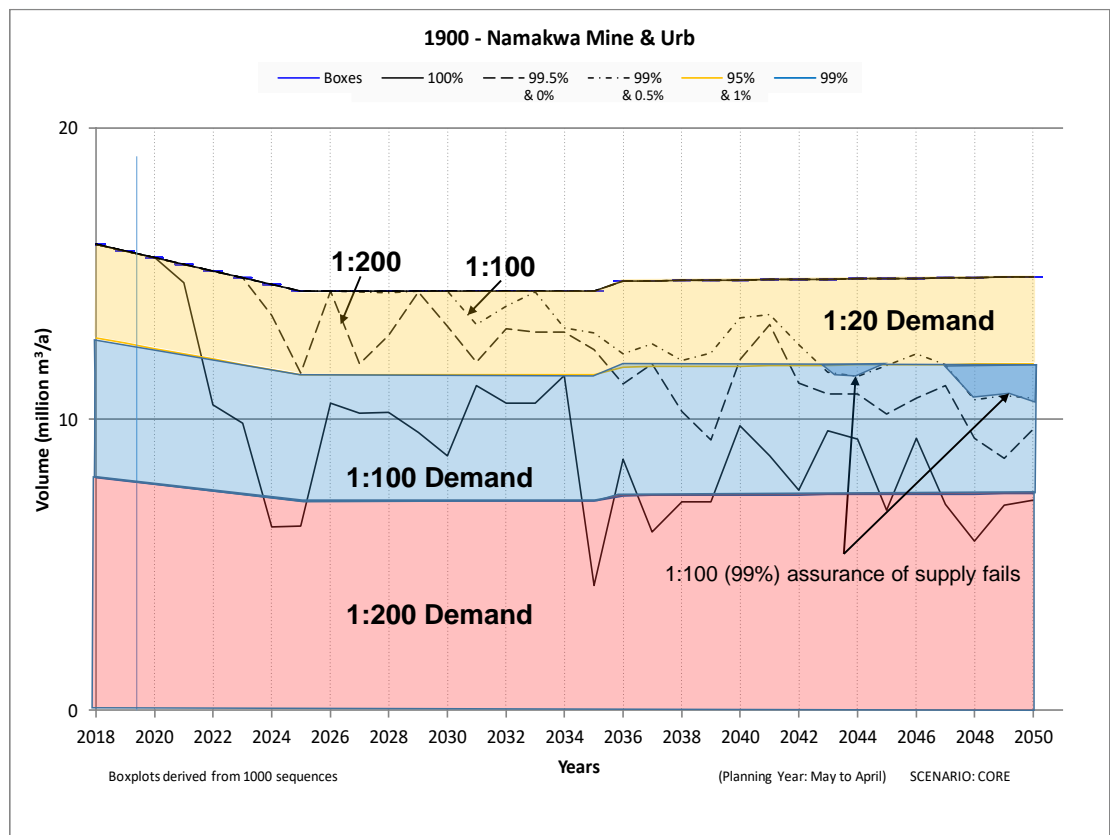
Figure 4-13: Namakwa urban and mining water supply for the previous (A) and current (B) Core Scenario
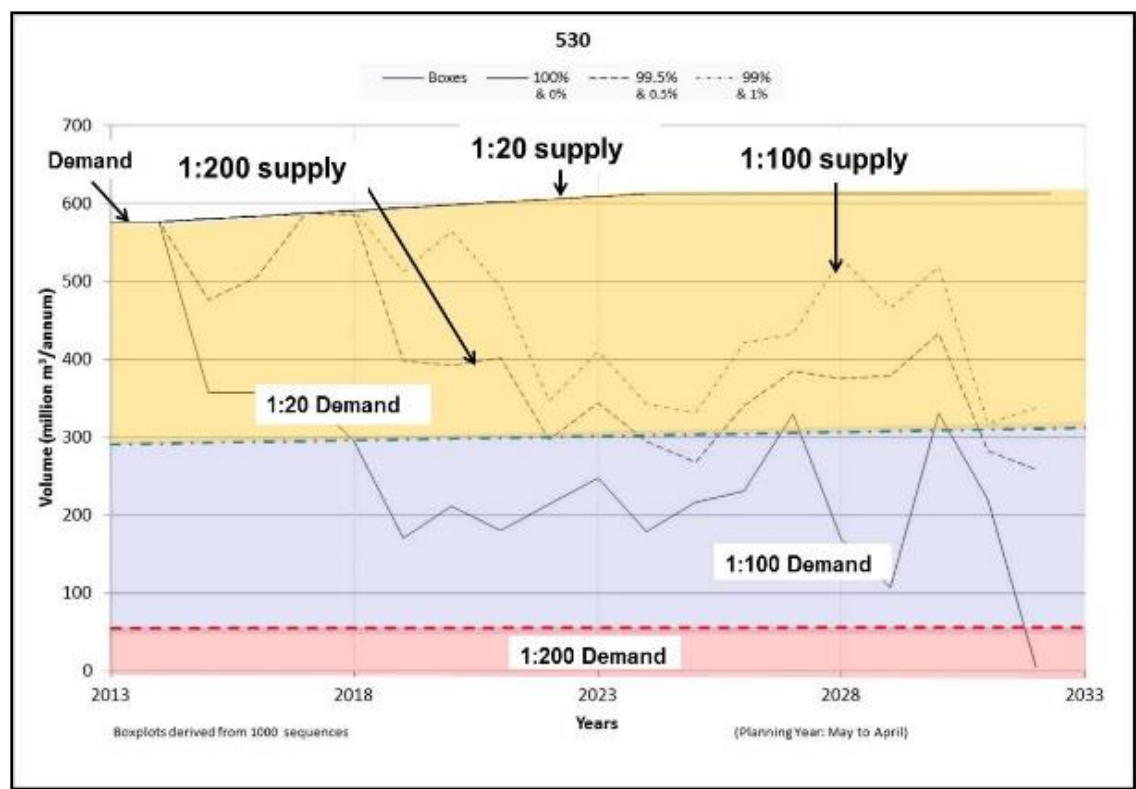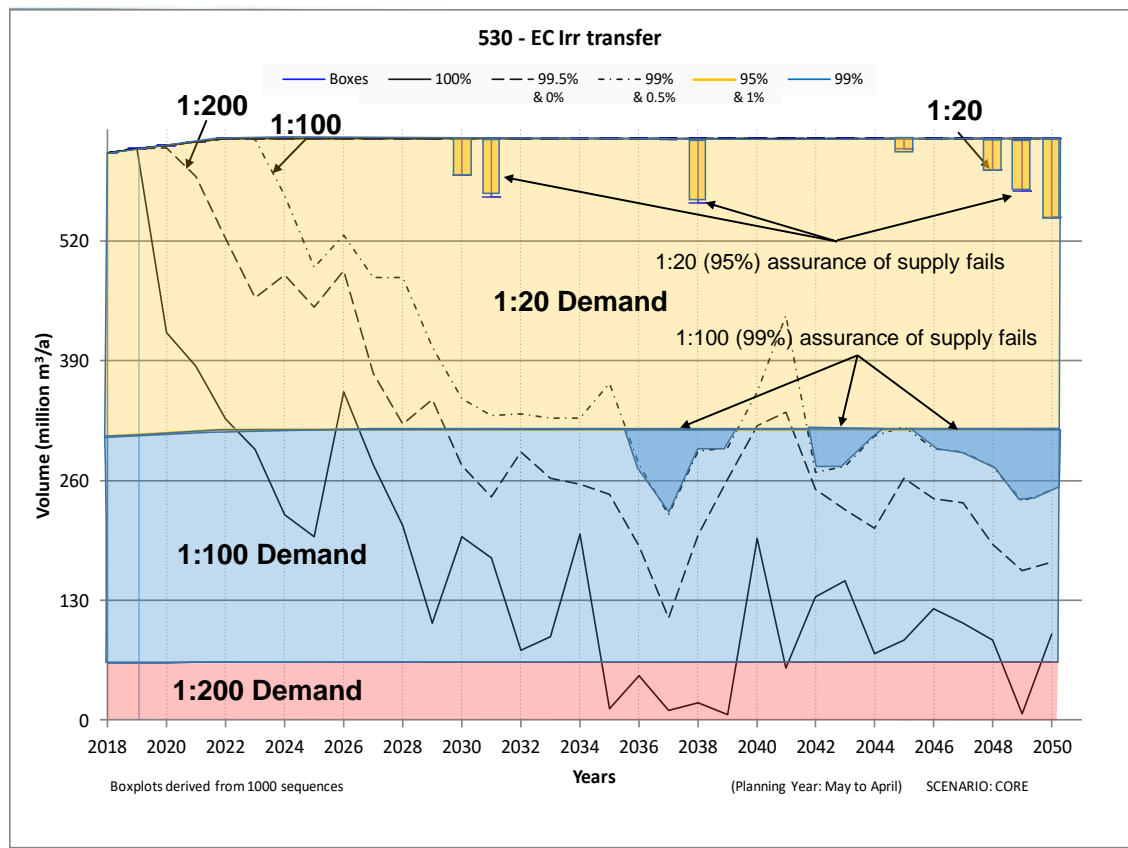
Figure 4-14: Water supply to the Eastern Cape from Gariep Dam for the previous (A) and current (B) Core Scenario

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 4-15B**).

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 4-15C** 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.
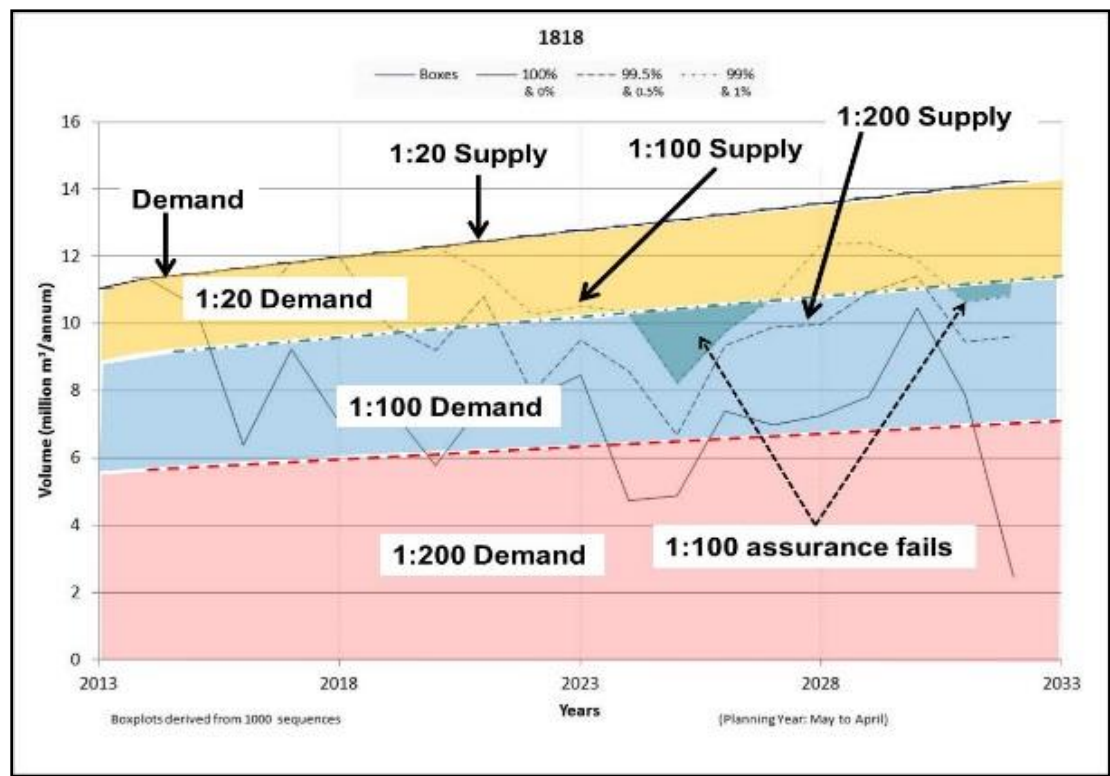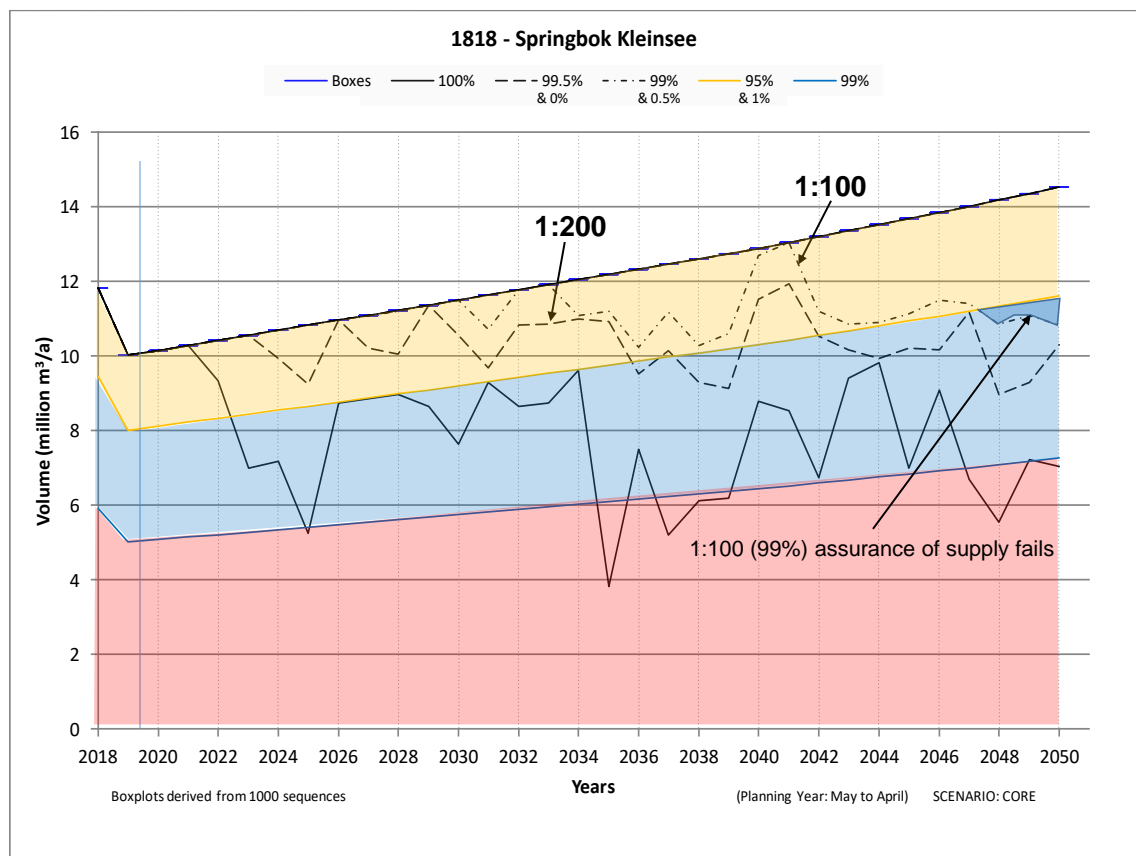
Figure 4-15: Water supply to the Springbok Kleinsee system for the previous (A) and current (B) Core Scenario

1827 VIOOLSDRIFT DAM Botswana high transfer

A

1861 - Namibia new irr Noordoewer High Botswana Transfer
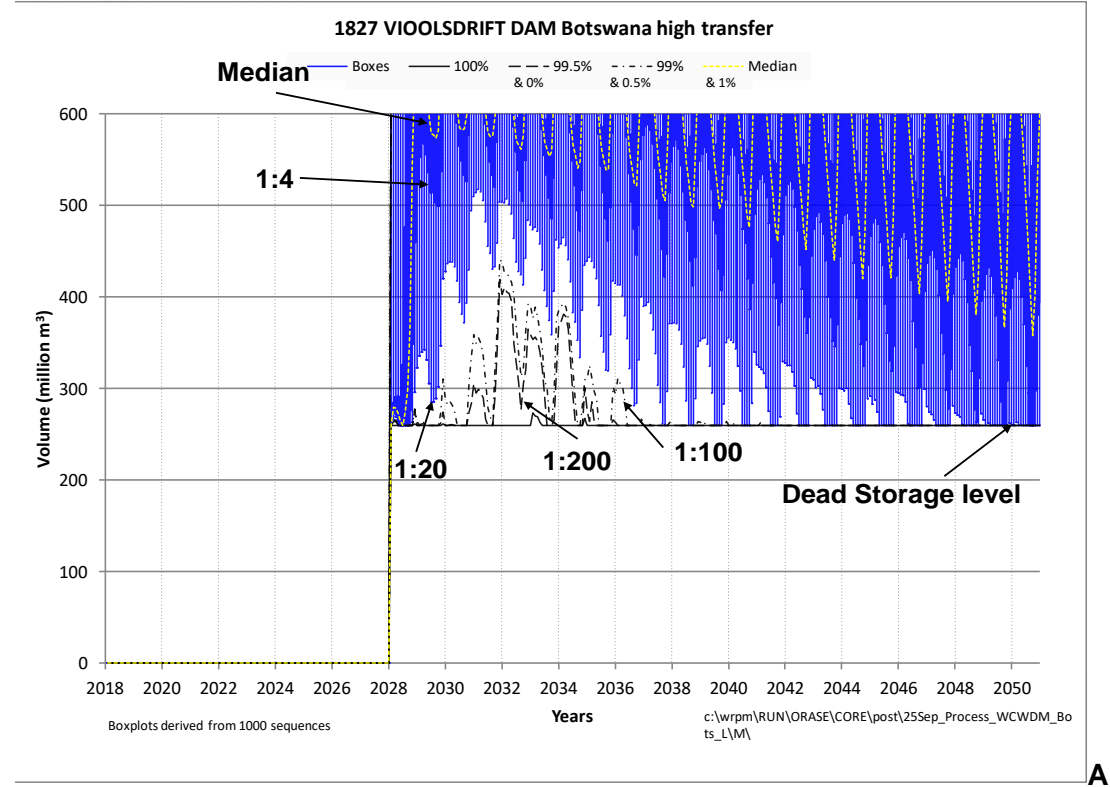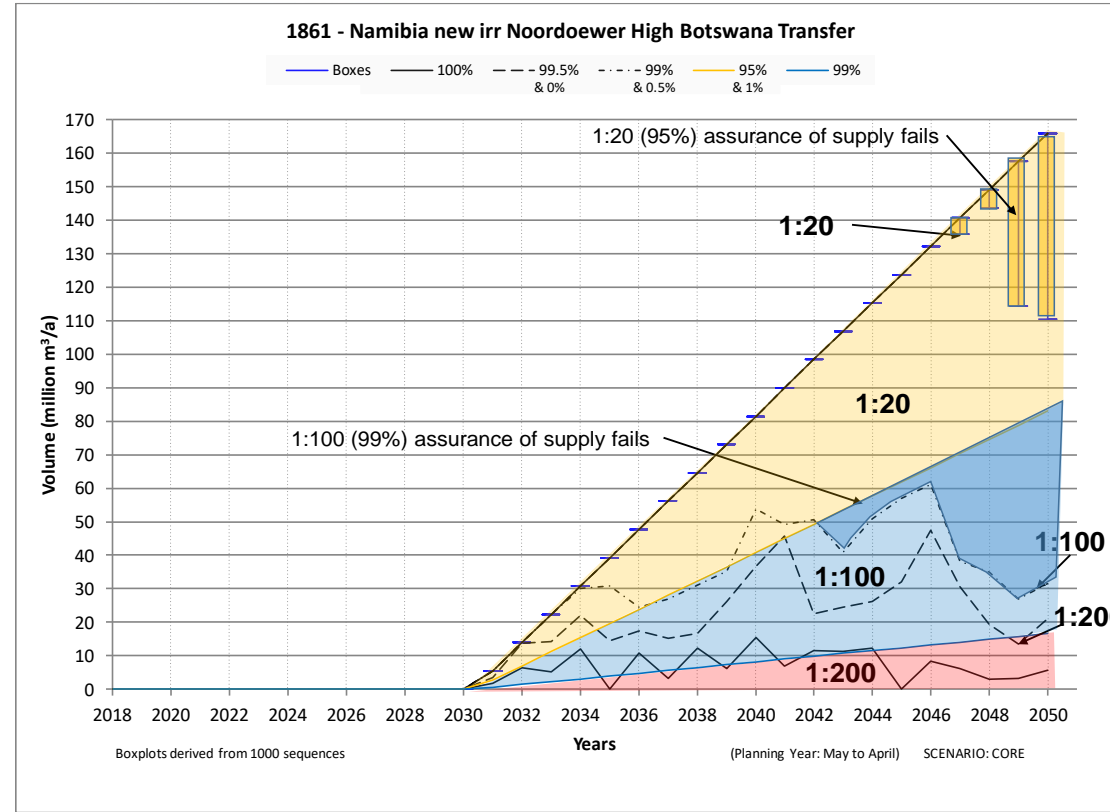
B
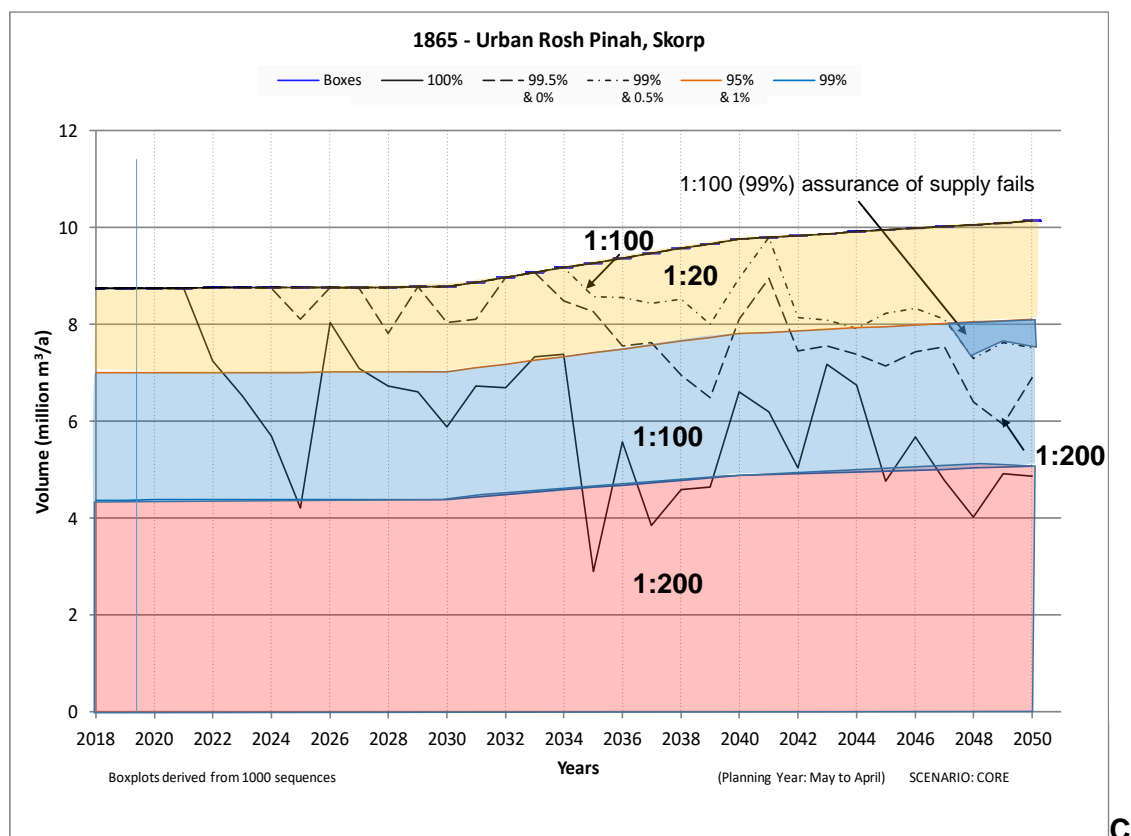
Figure 4-16: Current Core Scenario Noordoewer/Viooolsdrift Dam Storage projection and downstream water supply

4.2.4   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.
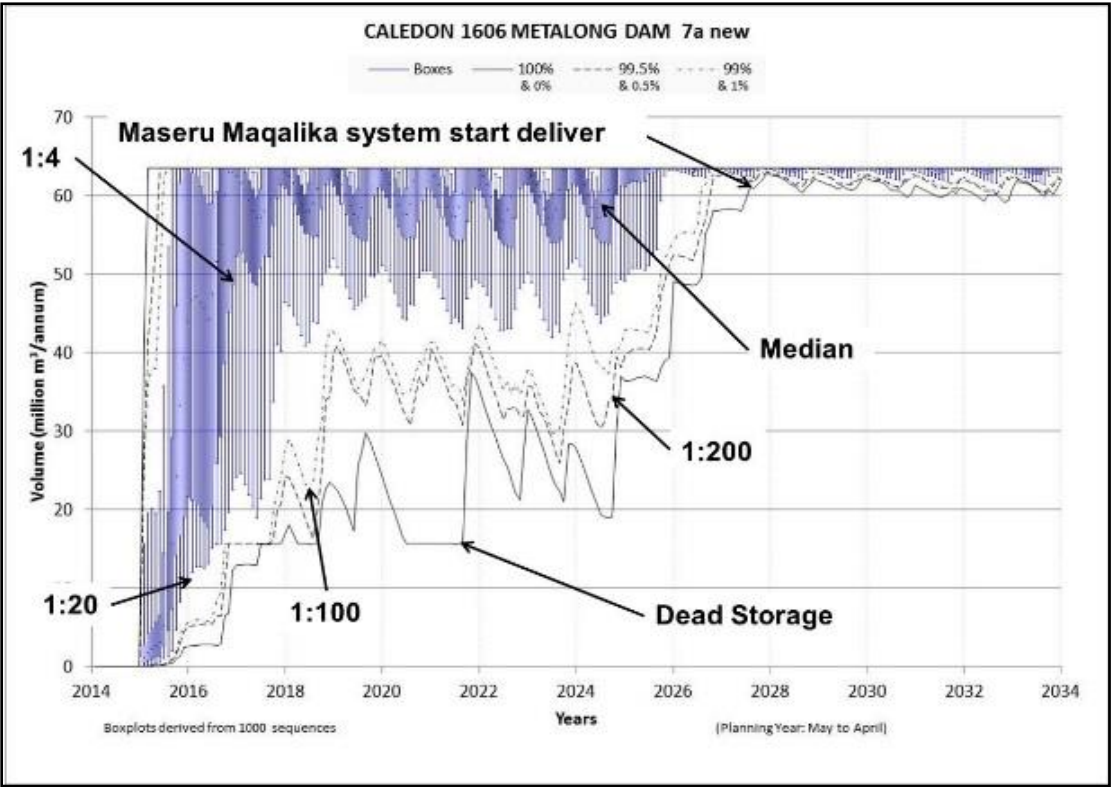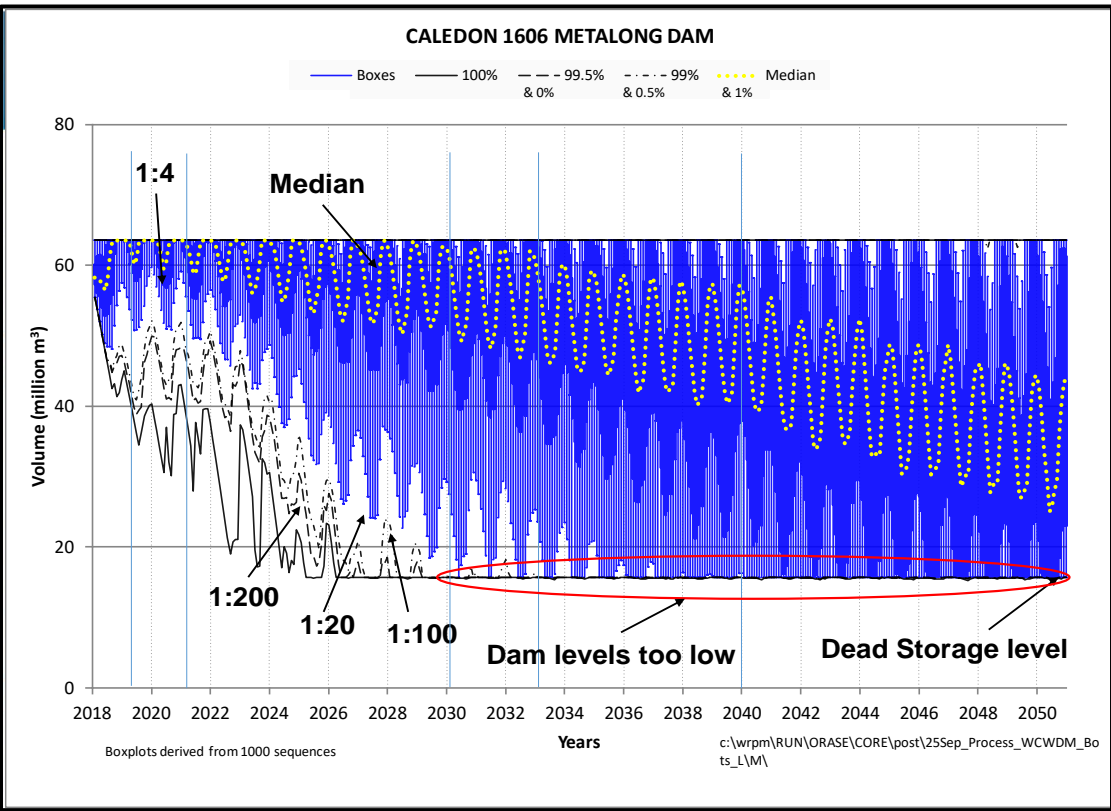
Figure 4-17: Metolong Dam storage projection for the previous (A) and current (B) Core Scenario

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 4-17A**).

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 4-17a** versus **4-17b**). From the previous Core Scenario, a maximum of about 19 million m³/a was supplied from Metolong to Maseru by 2024. The current Core Scenario analysis (**Figure 4-17b**) showed that the median supply from Metolong Dam at 2024 already reached about 24 million m³/a and increased to almost 49 million m³/a by 2050. The supply to Maseru (Current Core Scenario) already reached about 32 million m³/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 4-17A and 17B)**.

Total from Metolong

Boxplots derived from 1000 sequences

(Planning Year: May to April)   SCENARIO: CORE

B

Total Maseru

Boxplots derived from 1000 sequences

(Planning Year: May to April)   SCENARIO: CORE
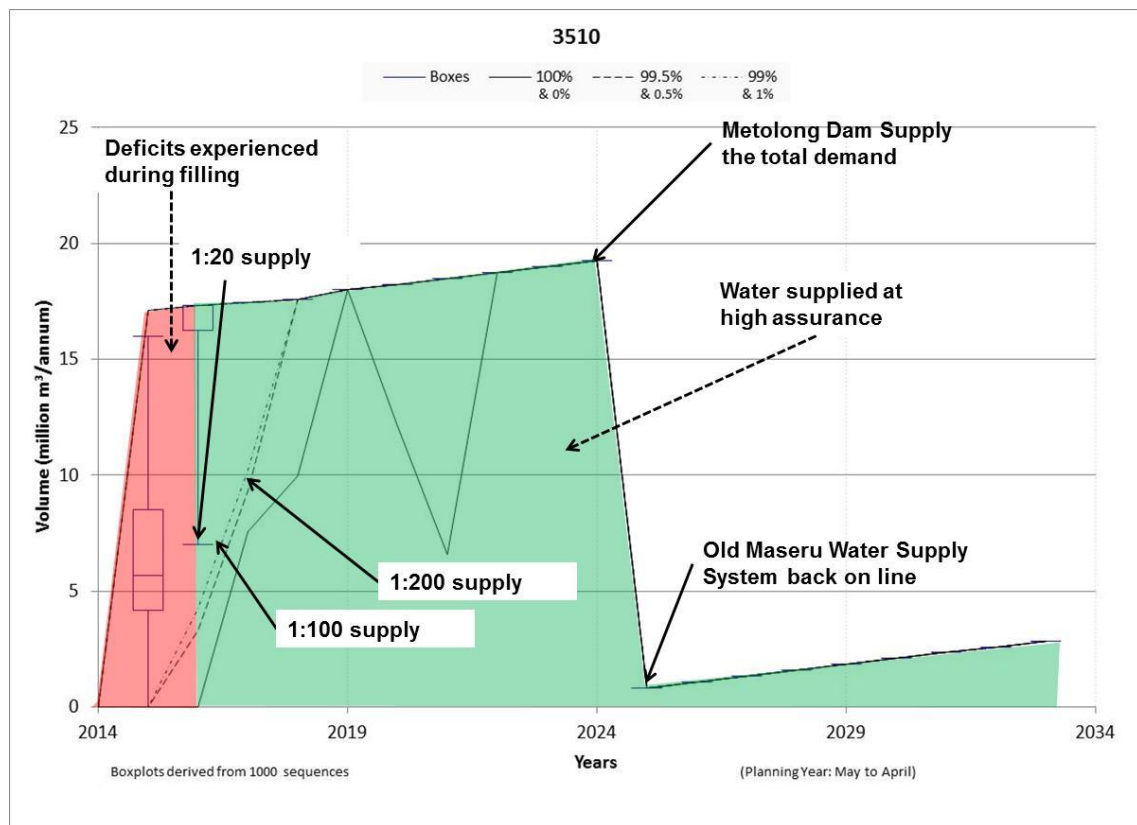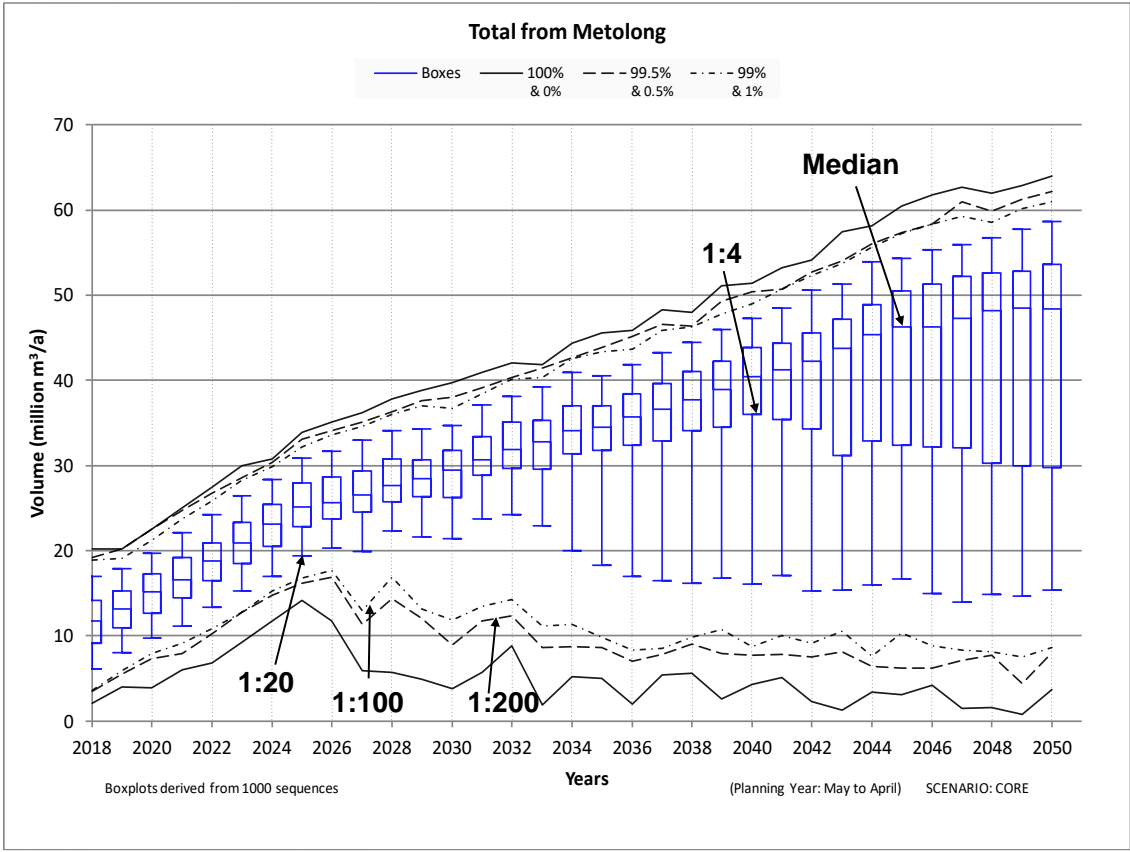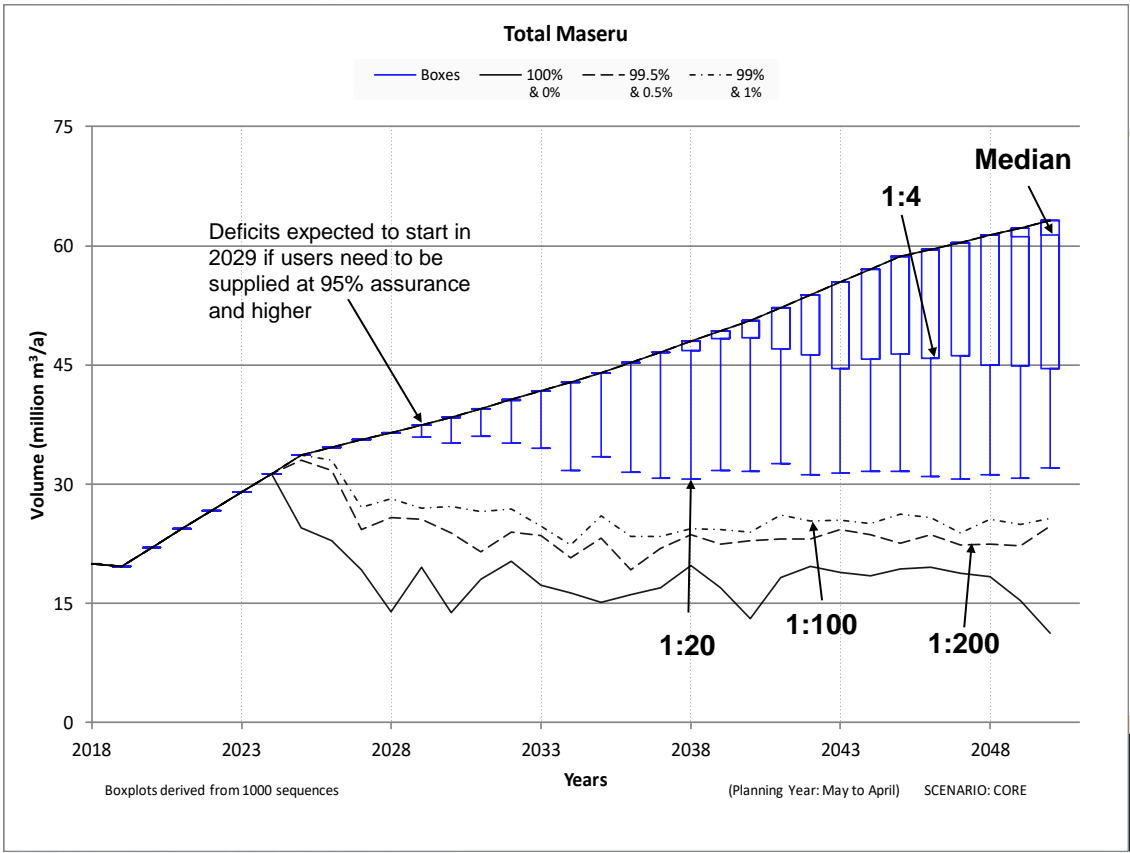
C
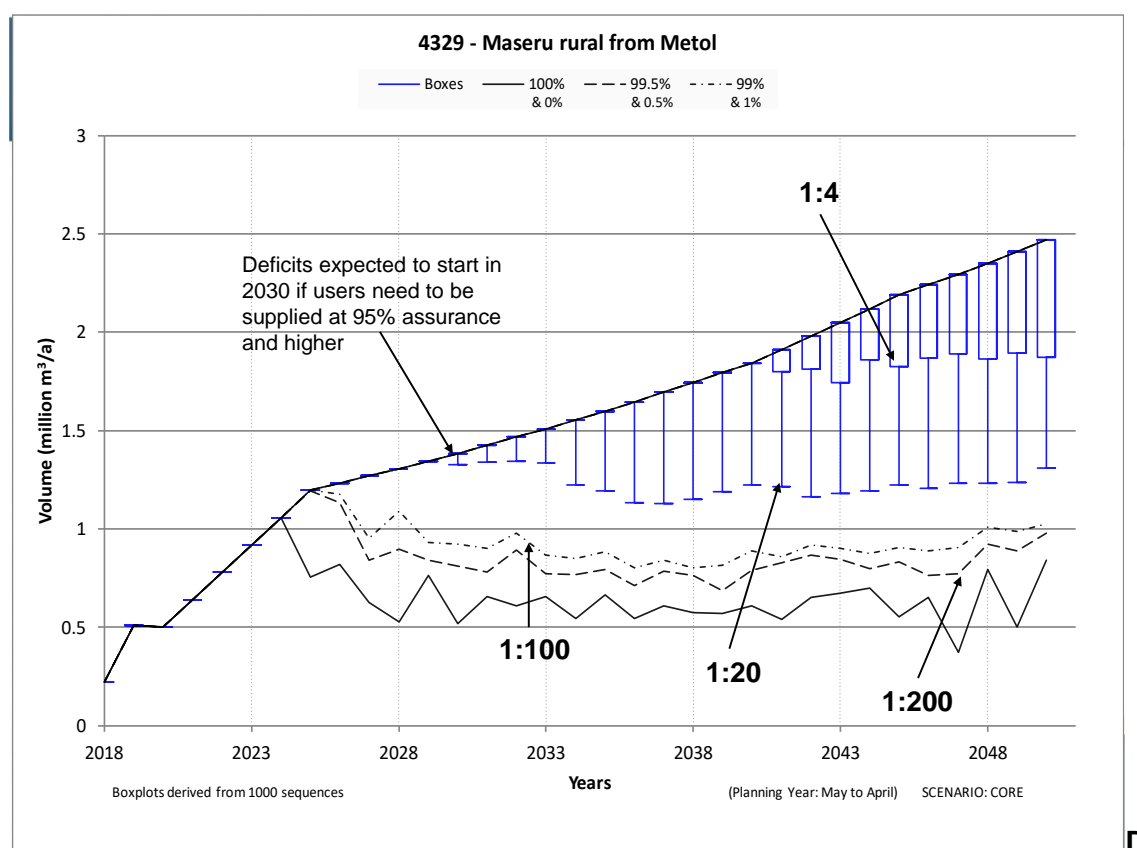
Figure 4-18: Water supply from Metolong Dam for the previous (A) and current (B, C & D) Core Scenario

The previous Core Scenario analysis indicated that there is surplus water available in the system even beyond 2034, when both resources were used (**Figures 4-17A** and **4-17B**. 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 4-17B, 4-17C & D**). This is mainly as result of the steep increase in water requirements from 2018 to 2025 as shown in **Figures 4-17C & 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 4.3**.

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 4-18**) 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 4-19** 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 4-19C**) were in general supplied at fairly high assurances of 99%, after the filling period of the dam.
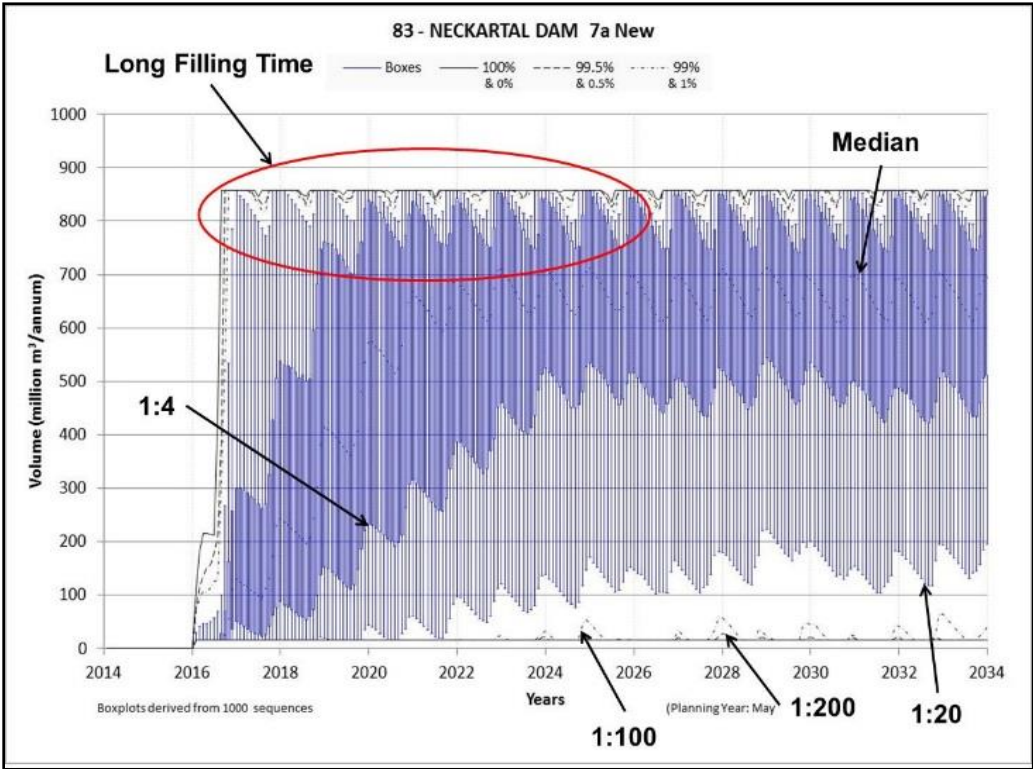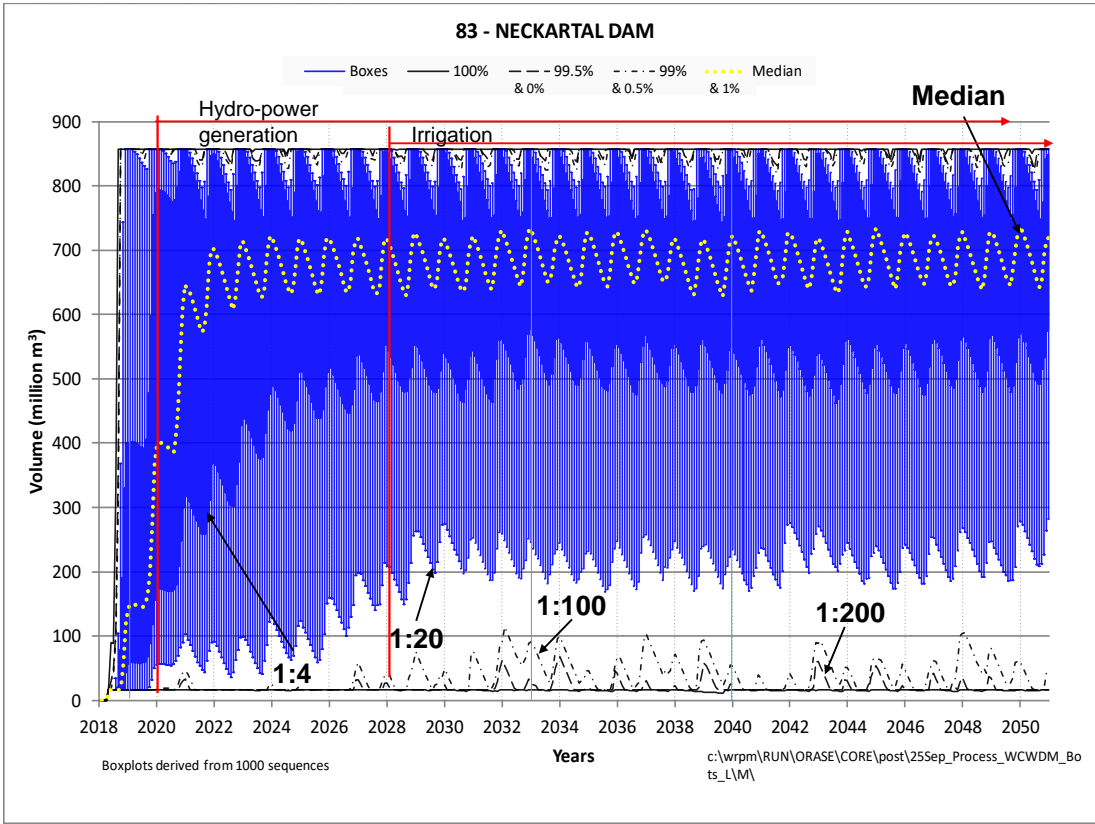
Figure 4-19: Neckartal Dam storage projection for the previous (A) and current (B) Core Scenario
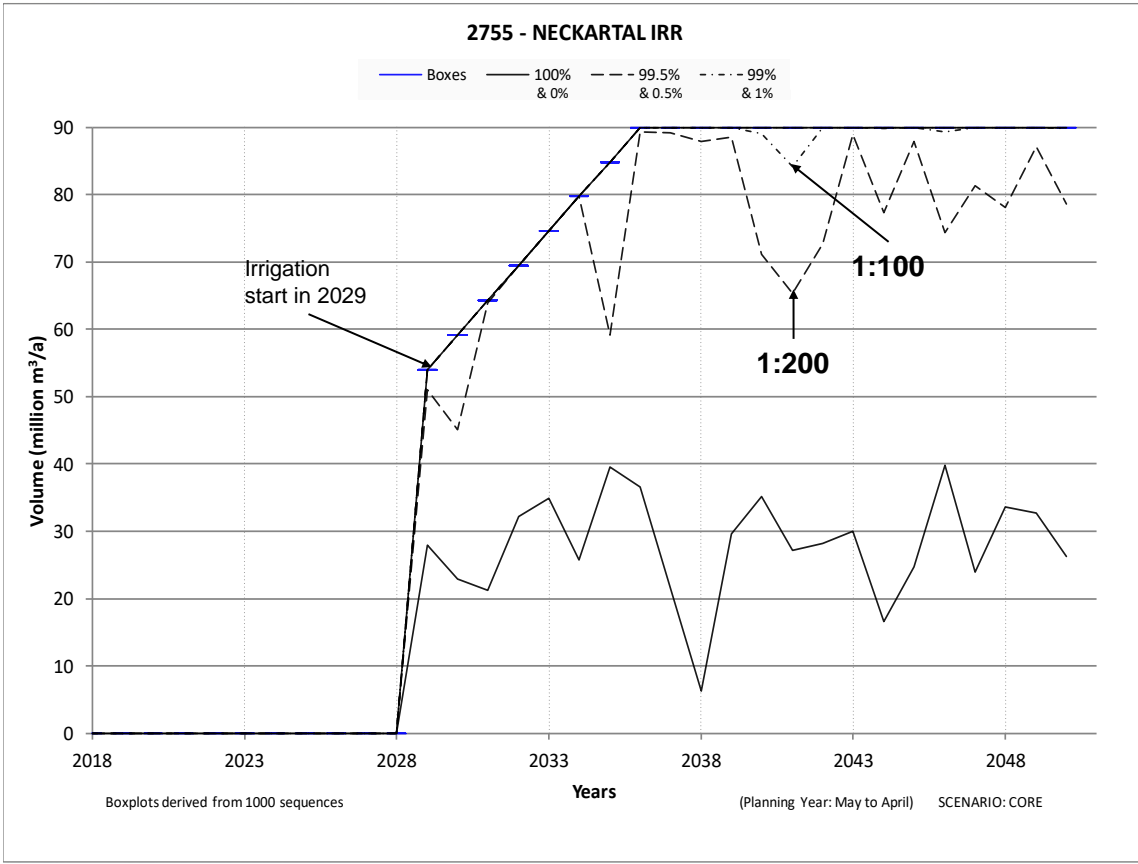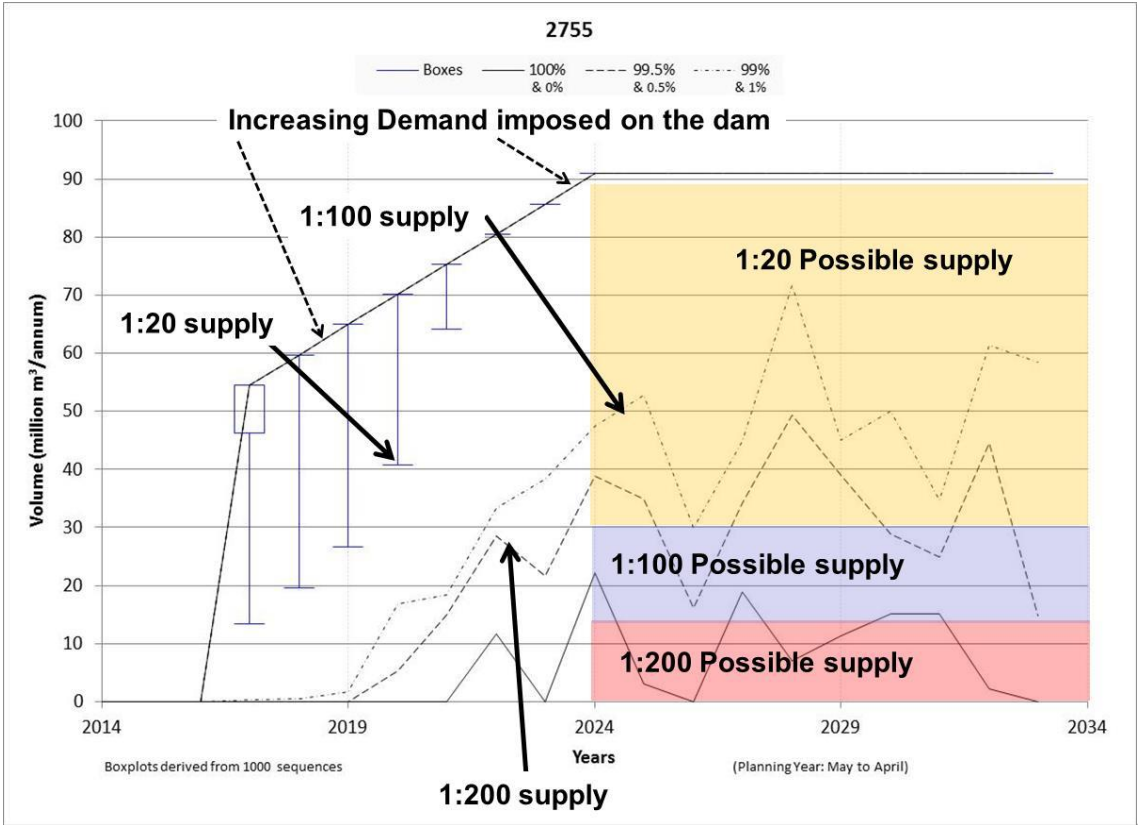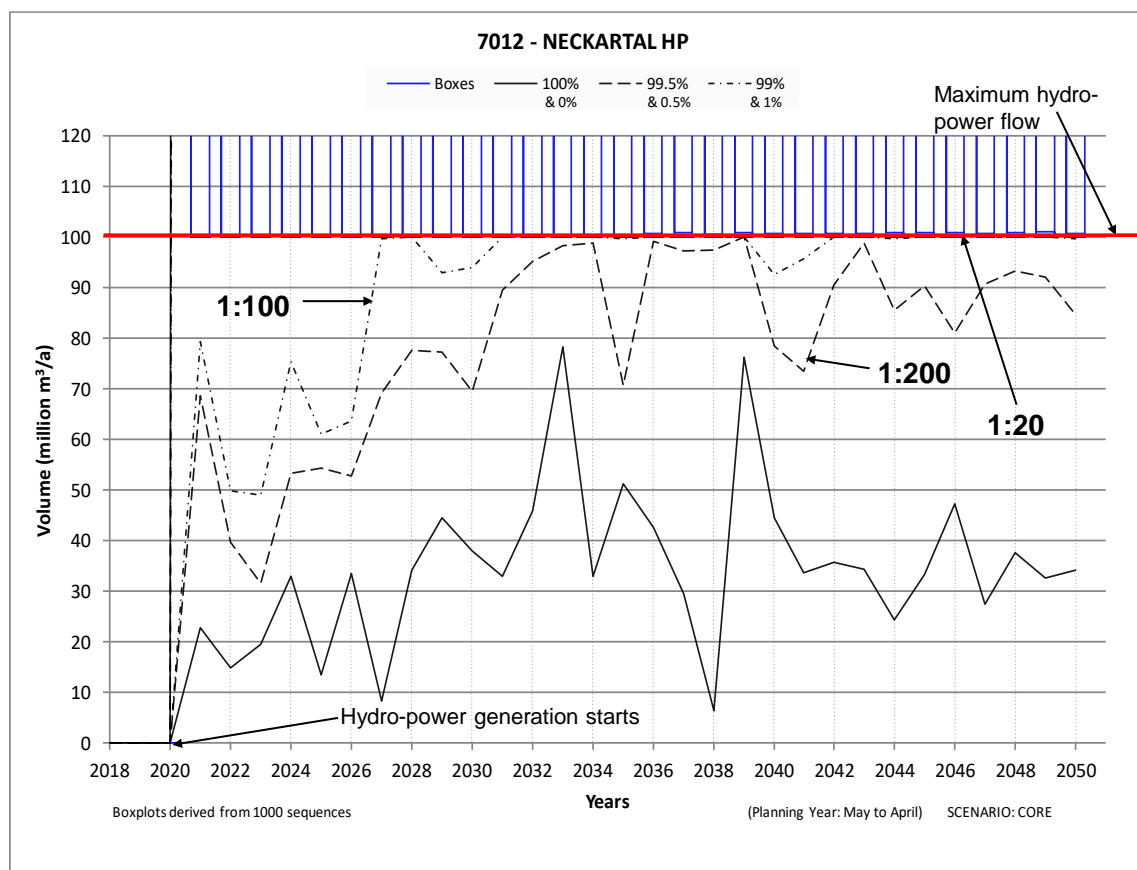
Figure 4-20: Water supply from Neckartal Dam for the previous (A) and current (B & C) Core Scenario

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

4.3.1   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 4-2**.

Figure 4-21: Makhaleng Dam water requirement components

Description and Country	2050 Gross Low Augmentation Water Requirements (million m³/a)	2050 Gross High Augmentation Water Requirements (million m³/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 4-20**. A three MAR Makhaleng Dam at site S2 with a gross storage of 1 382 million m³ 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 5.3** showed that this 3 MAR Makhaleng Dam will result in a decrease in the yield available from the ORP system of 252 million m³/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

A

1601 MAKHALENG DAM Low Botswana Transfer

B
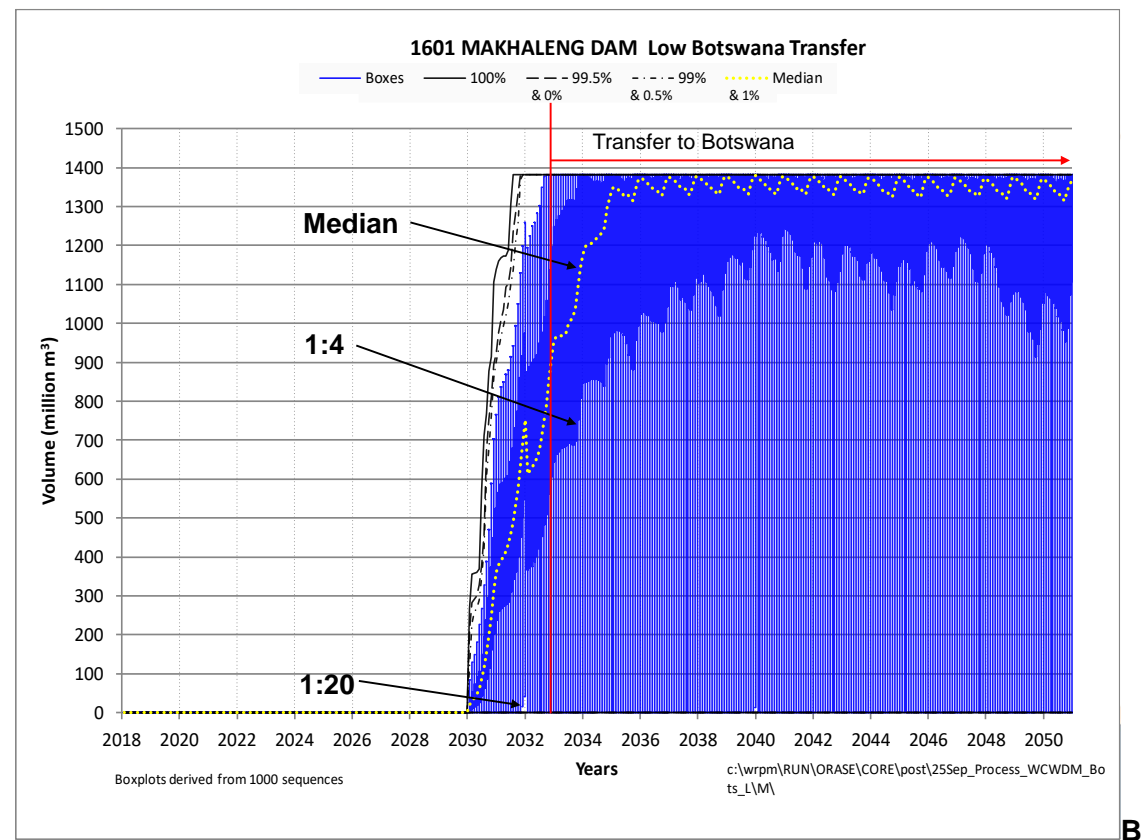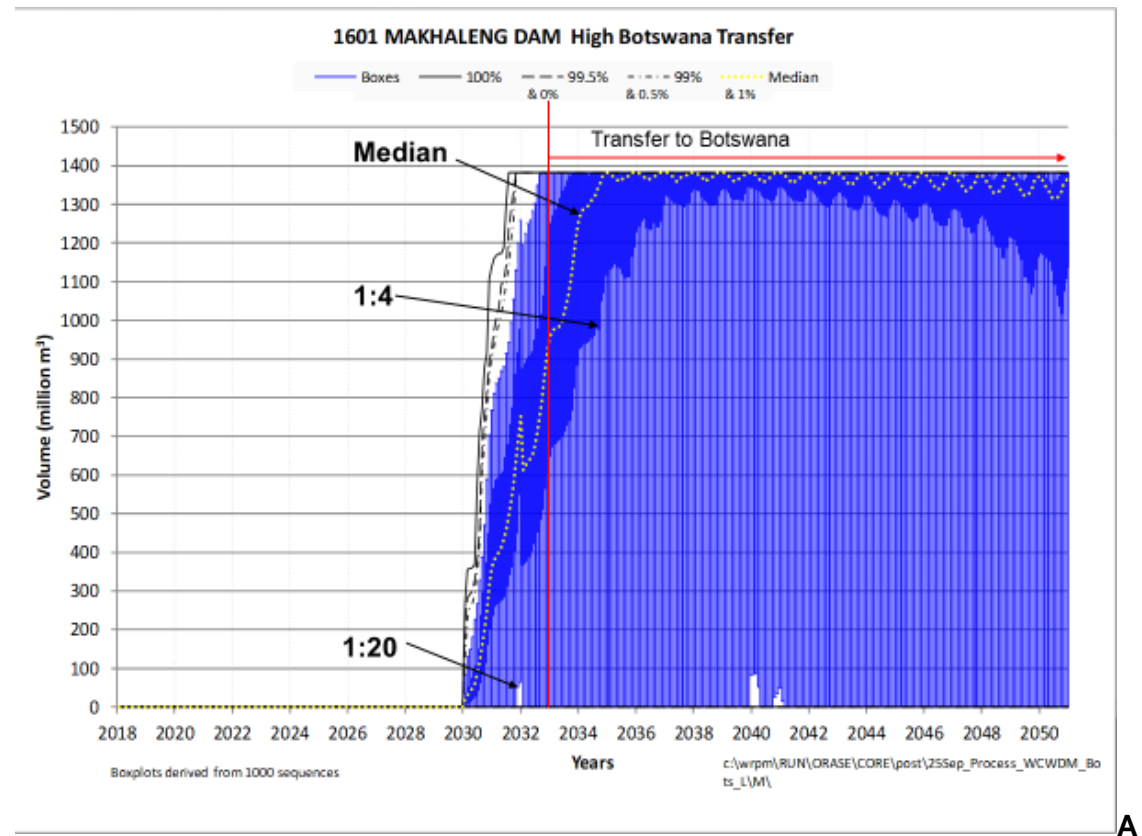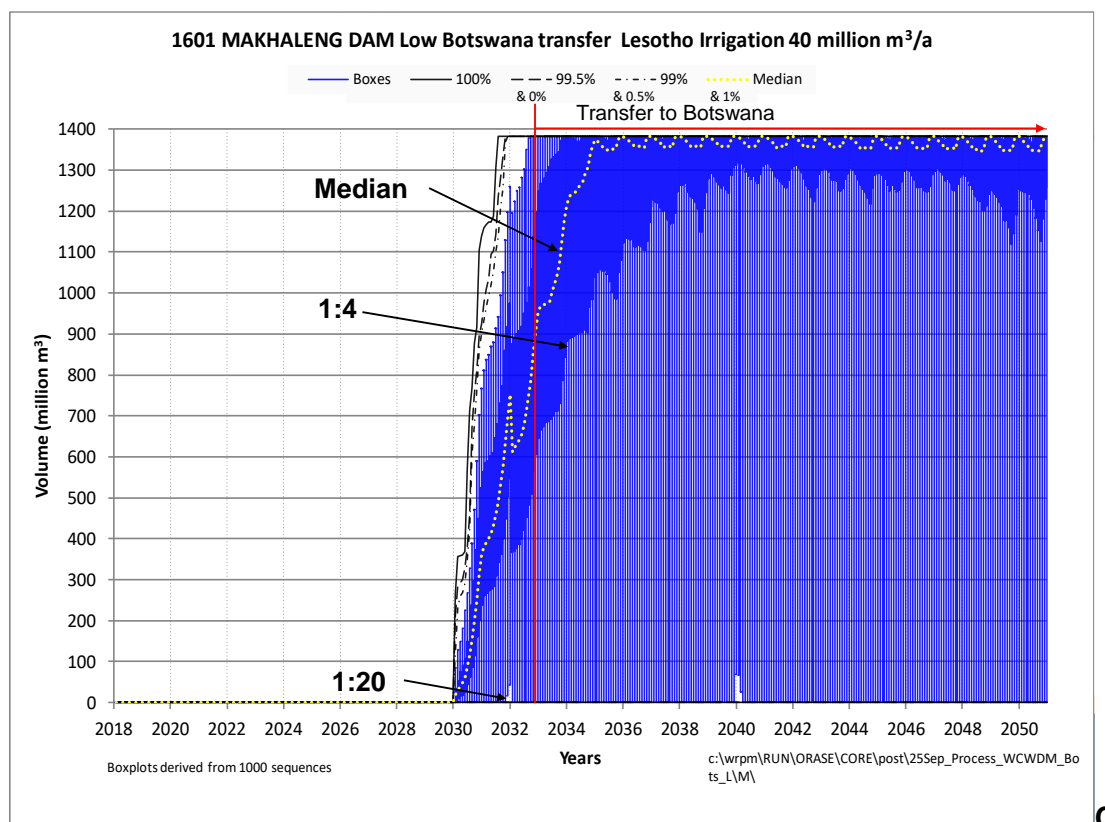
Figure 4-22: Makhaleng Dam storage projections for the high & low Botswana transfers

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 4-21A & 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

Boxplots derived from 1000 sequences

(Planning Year: May to April)   SCENARIO: CORE

A

7006 - Low Transfer Makhaleng to Botswana

Boxplots derived from 1000 sequences

(Planning Year: May to April)   SCENARIO: CORE
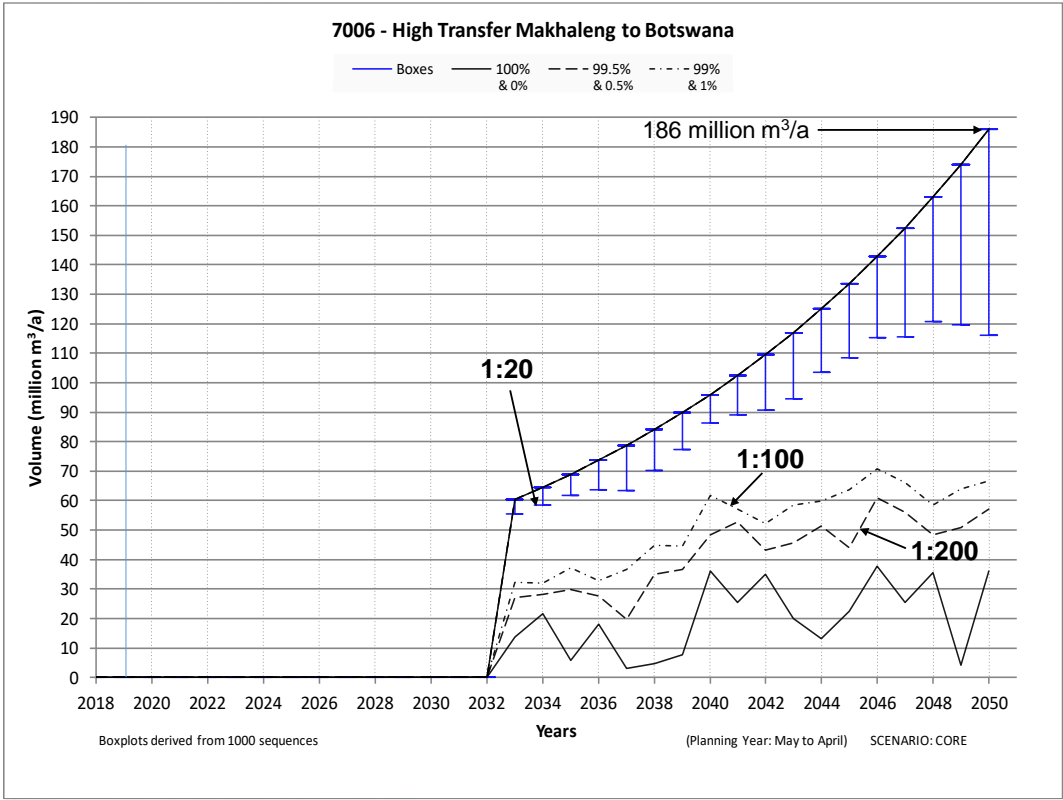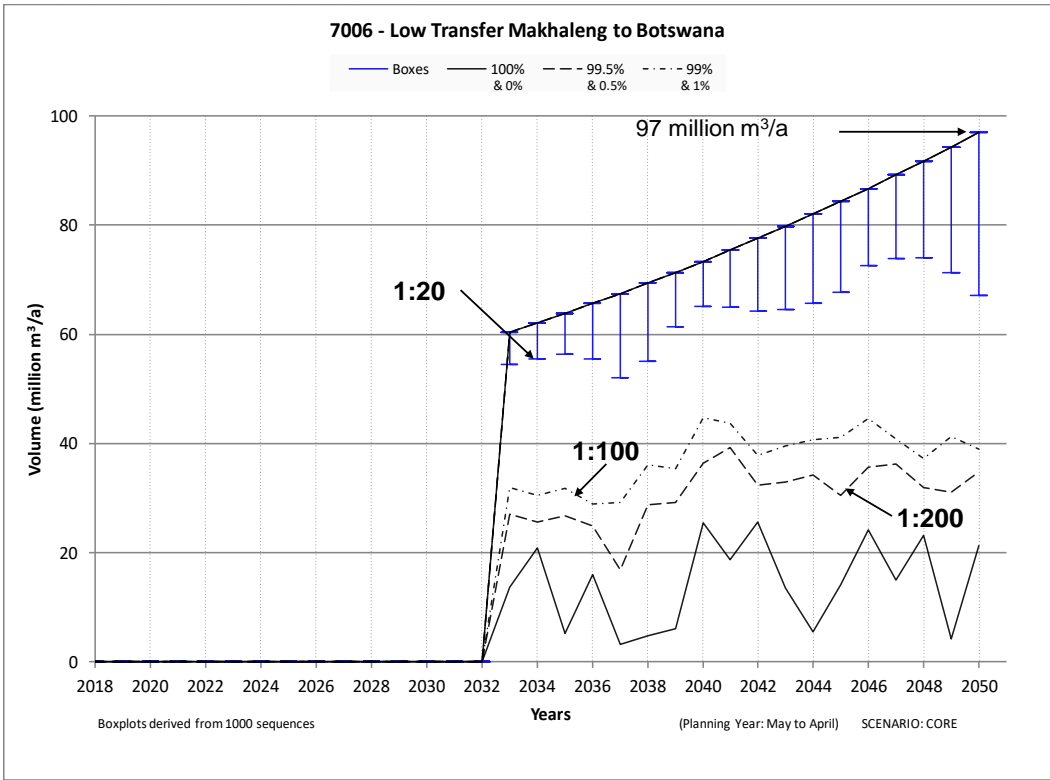
B
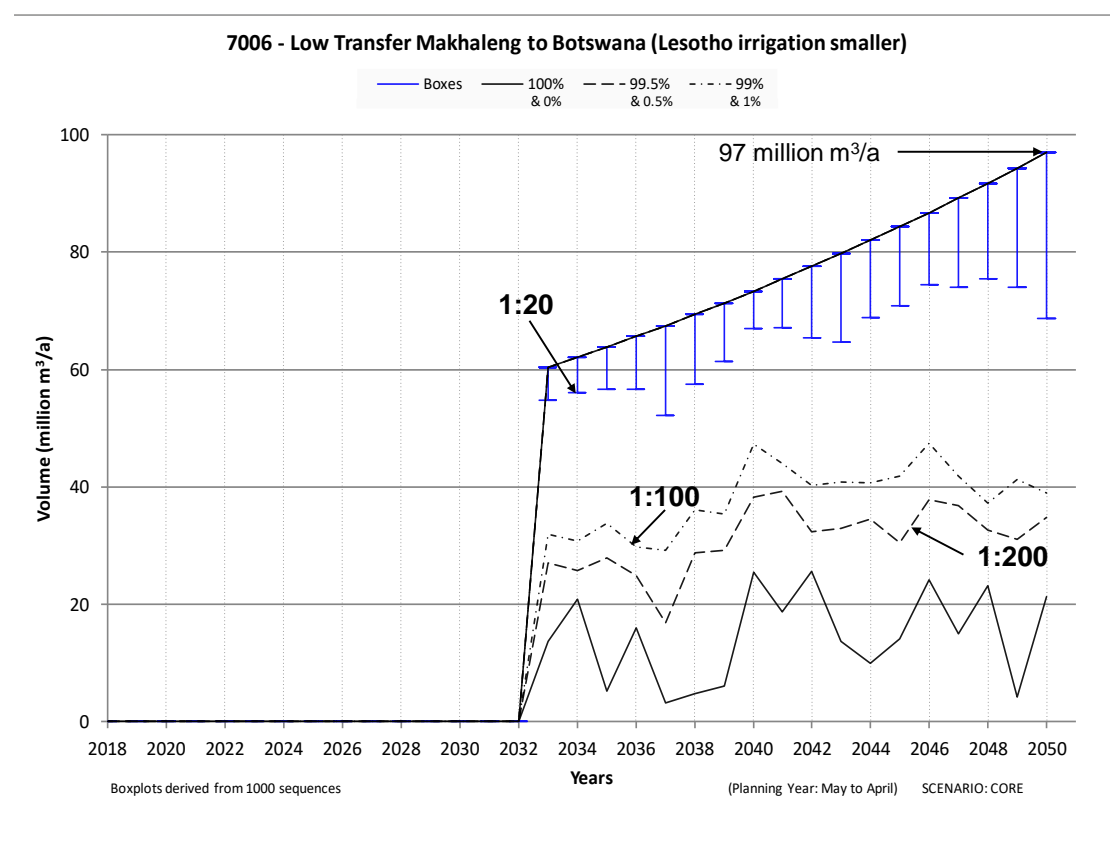
Figure 4-23: Supply of the transfer volume from Lesotho to Botswana

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 4-21**). 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 4-22**) 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 4-23**) 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)

A

7014 - Makhaleng to Lesotho local urban (Low Botswana Transfer & High Lesotho irrigation)

B

7014 - Makhaleng to Lesotho local urb (Botswana Low Transfer Low Lesotho irrigation)

Boxplots derived from 1000 sequences   *(Planning Year: May to April)   SCENARIO: CORE*

C
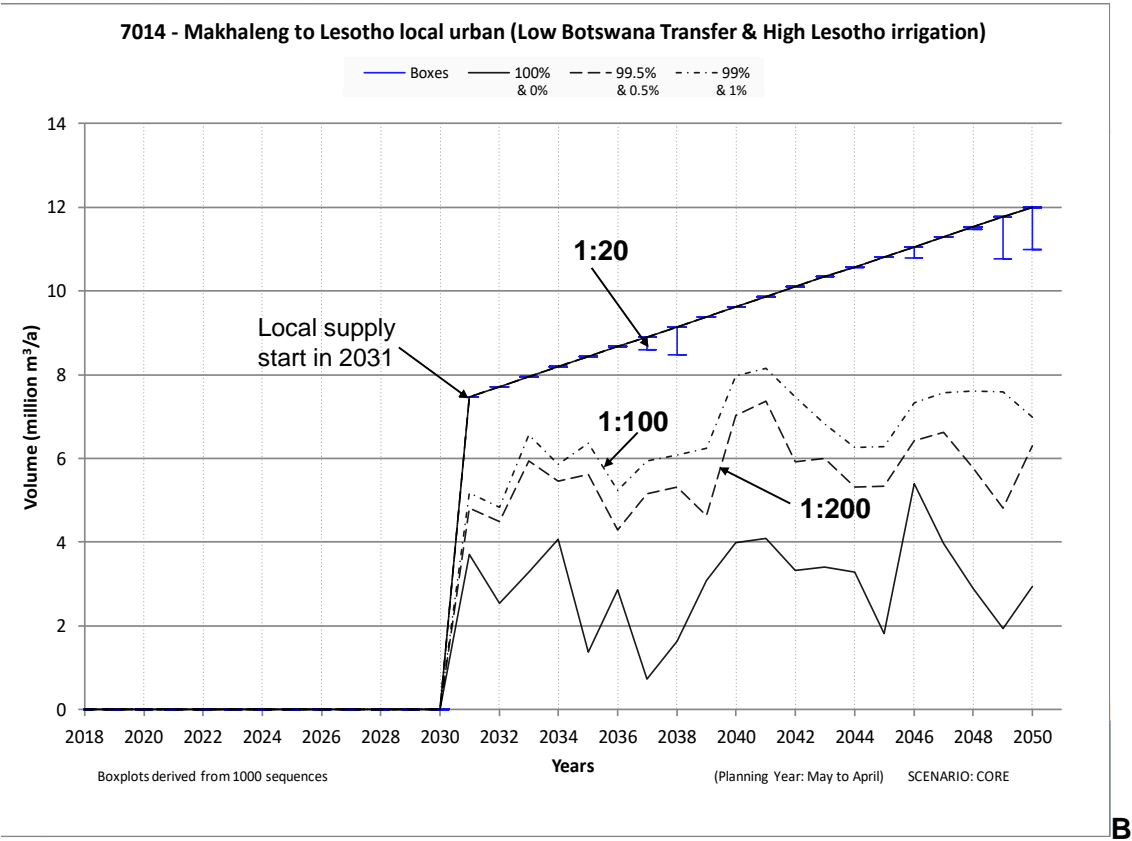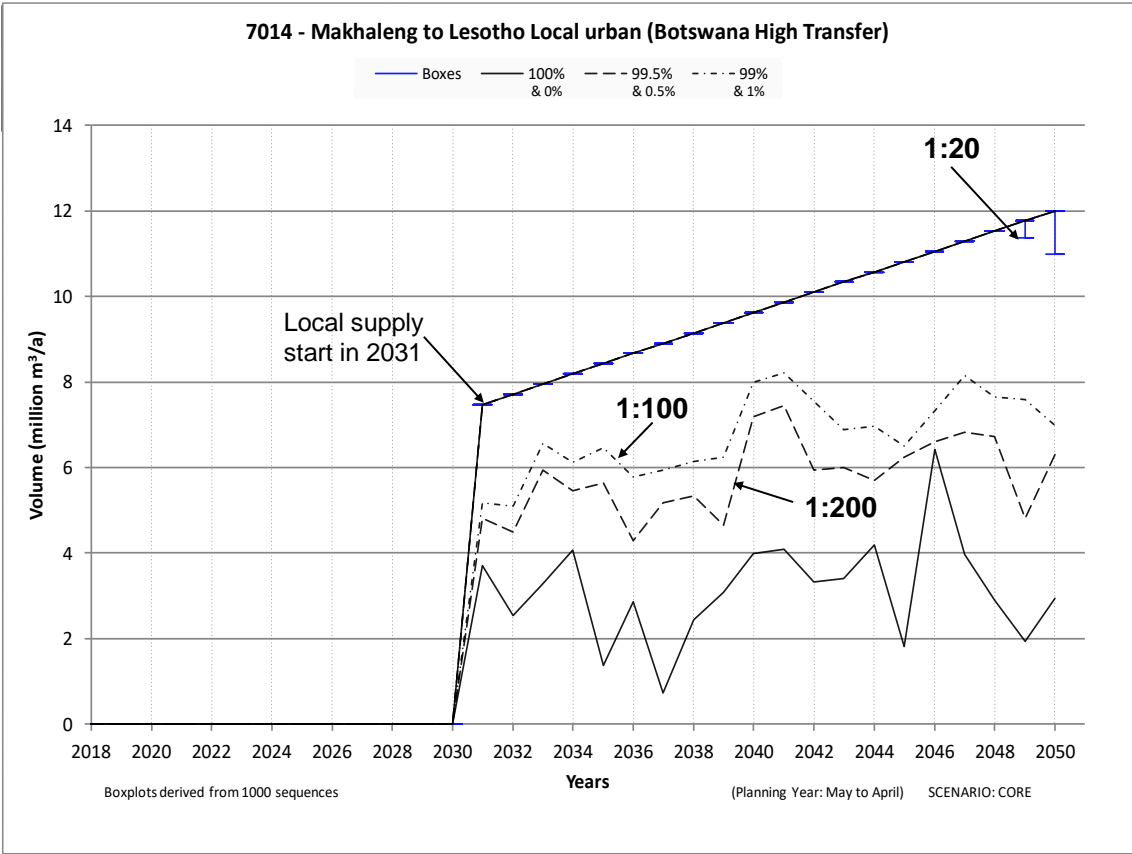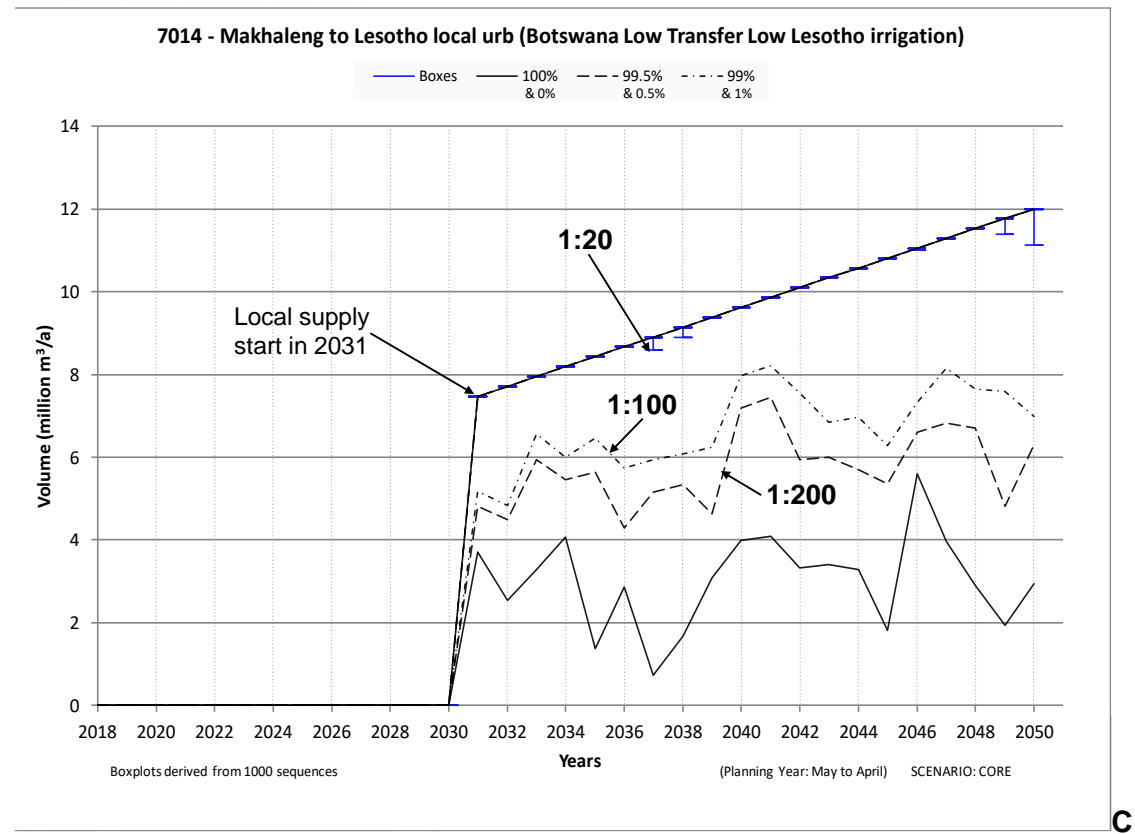
Figure 4-24: Water supply to local Lesotho domestic water use

7017 - Makhaleng to Lesotho local irr (Botswana low Transfer)

Boxplots derived from 1000 sequences   *(Planning Year: May to April)   SCENARIO: CORE*

A
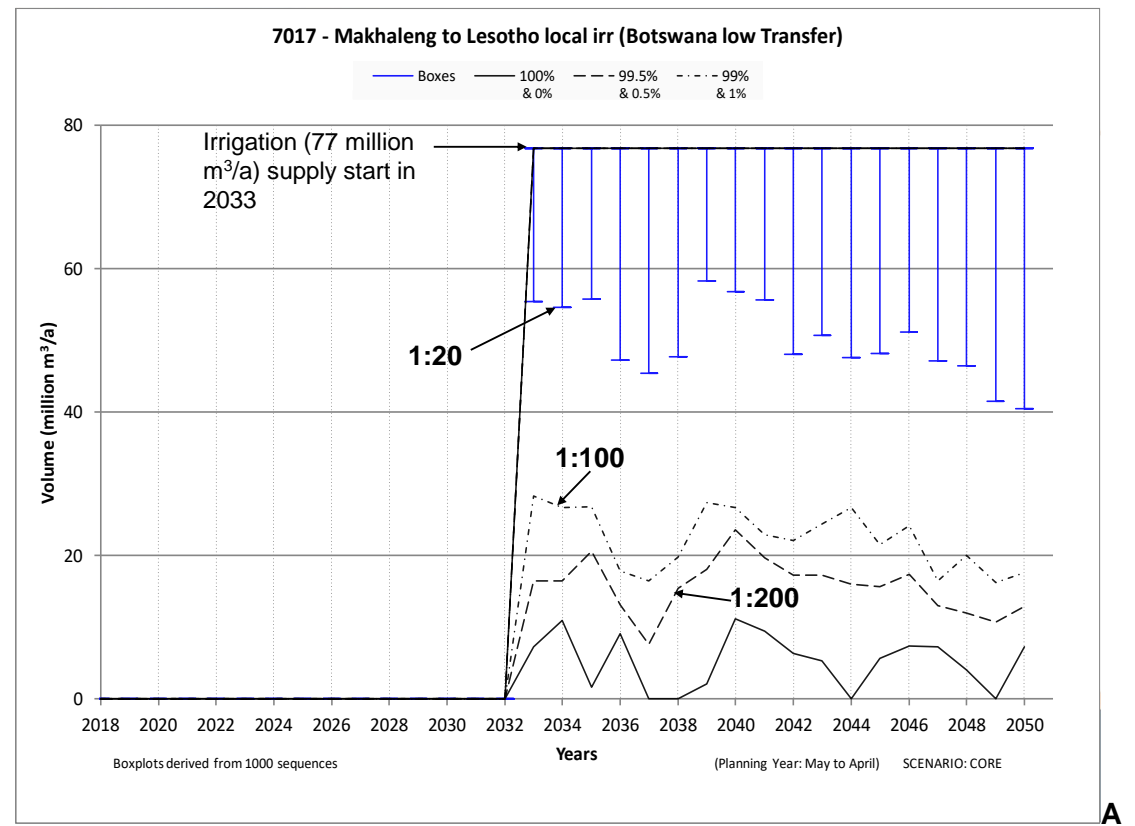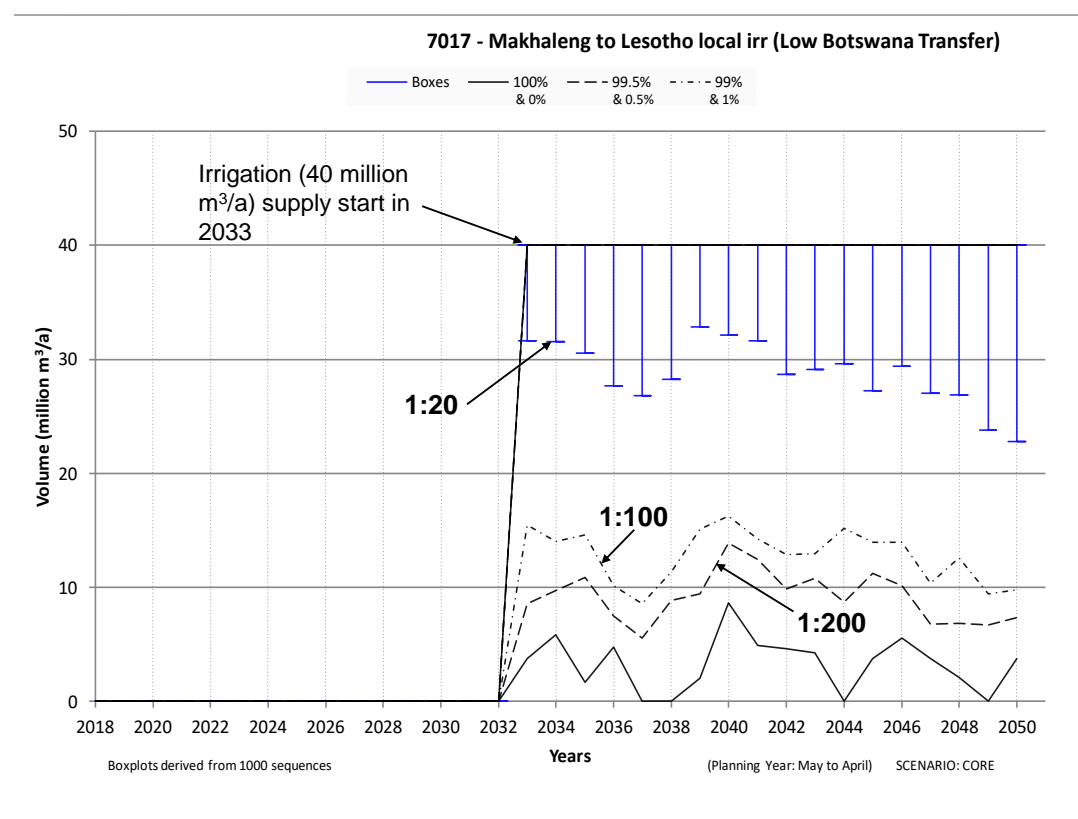
Figure 4-25: Supply to Lesotho irrigation supplied from Makhaleng Dam.

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.

4.3.2   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 4-24A**. 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.
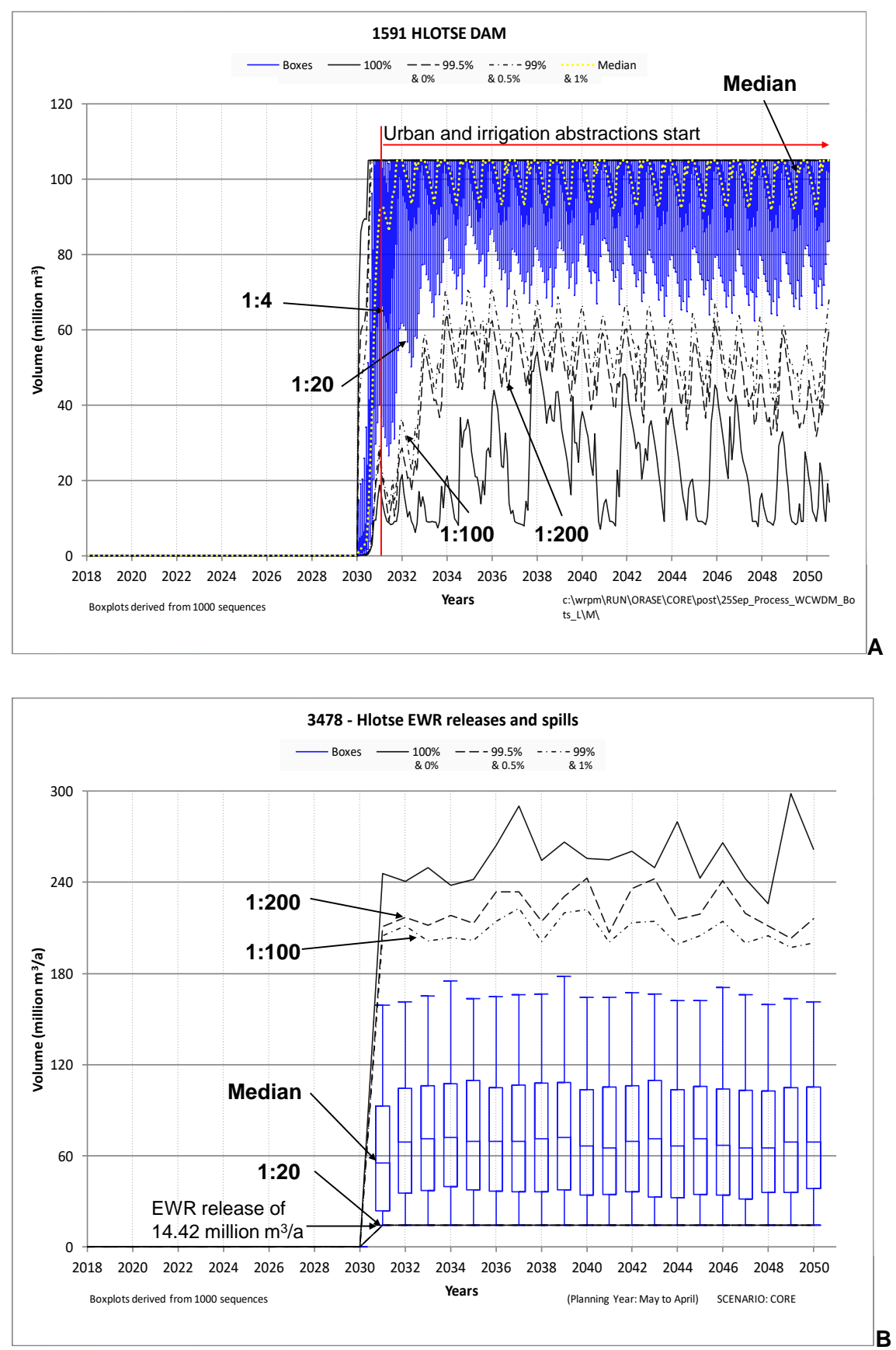
Figure 4-26: Hlotse Dam storage projection and EWR releases and spills

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 5.2** 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 4-25**. 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 mitigate 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 in future be supplied from Hlotse Dam. The current supply to Leribe from river runoff is given in **Figure 4-26**. 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.
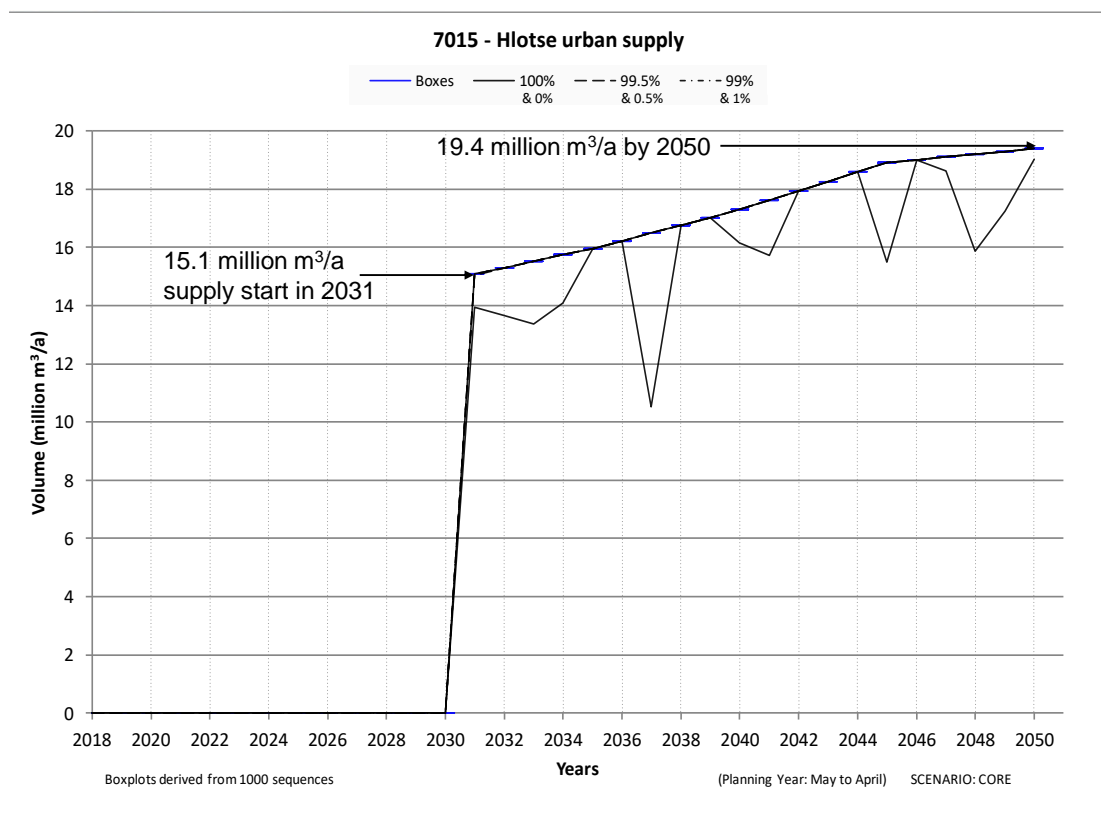
A
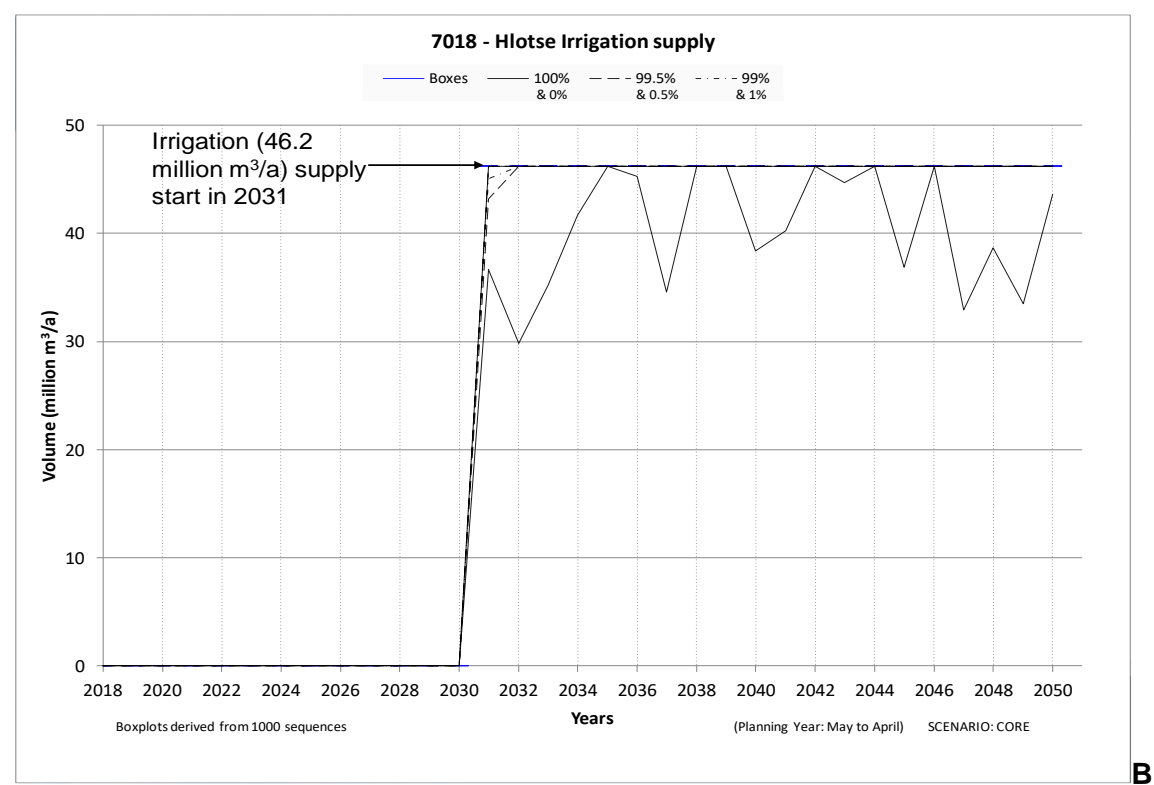
Figure 4-27: Supply to users supplied from Hlotse Dam
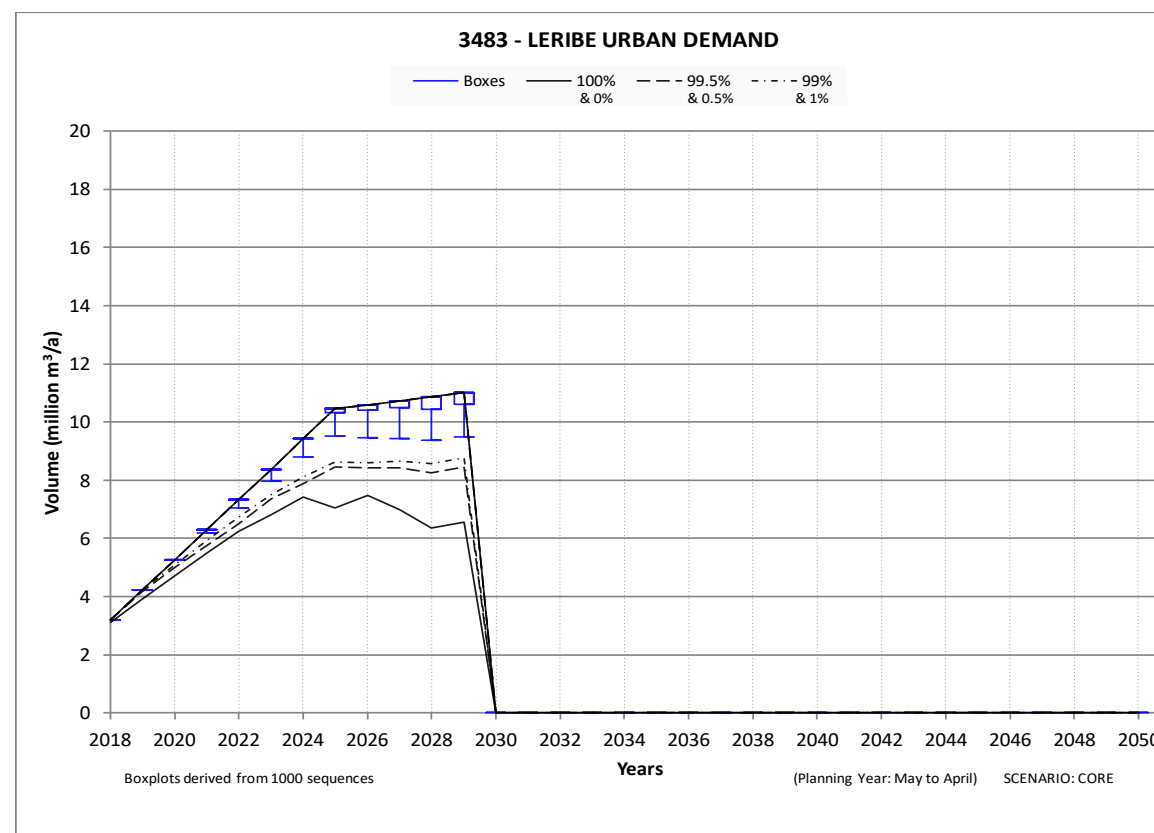
Figure 4-28: Water supply to Leribe directly from the river

4.3.3   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 5.2**) 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 4-27**. 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 4-27B**).

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.
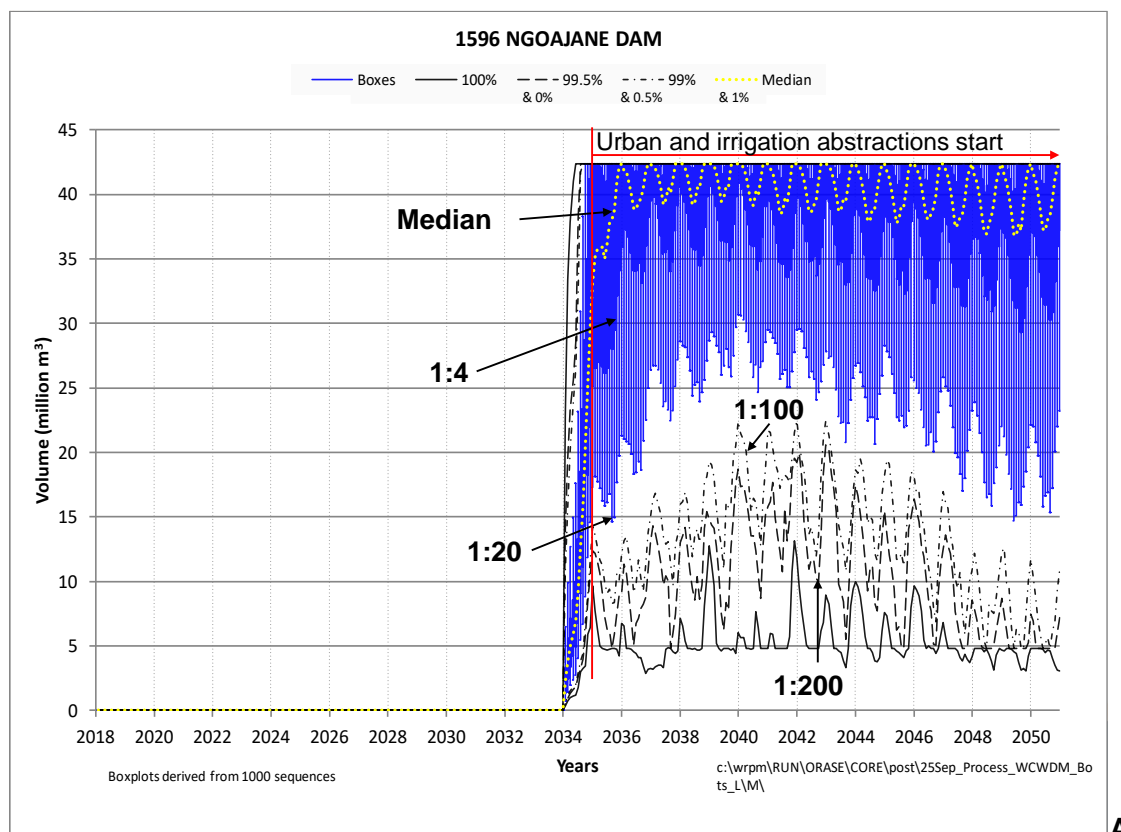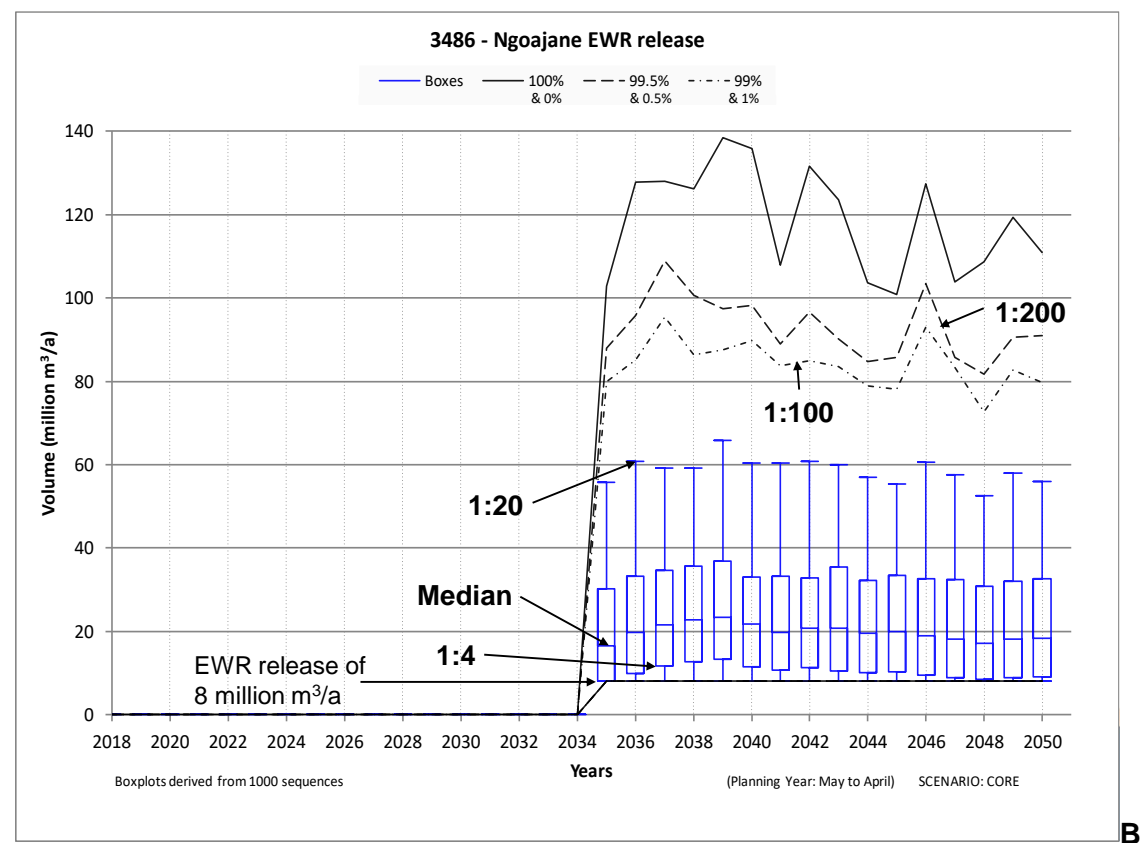
Figure 4-29: Ngoajane Dam storage projection and EWR releases and spills
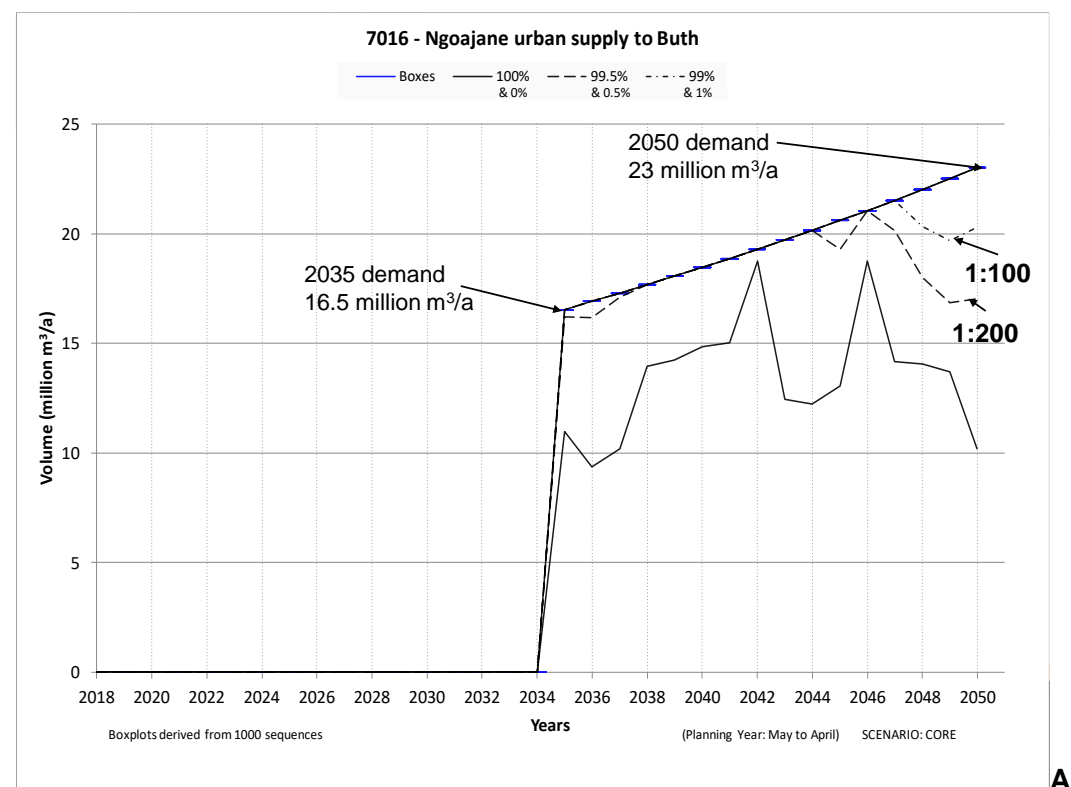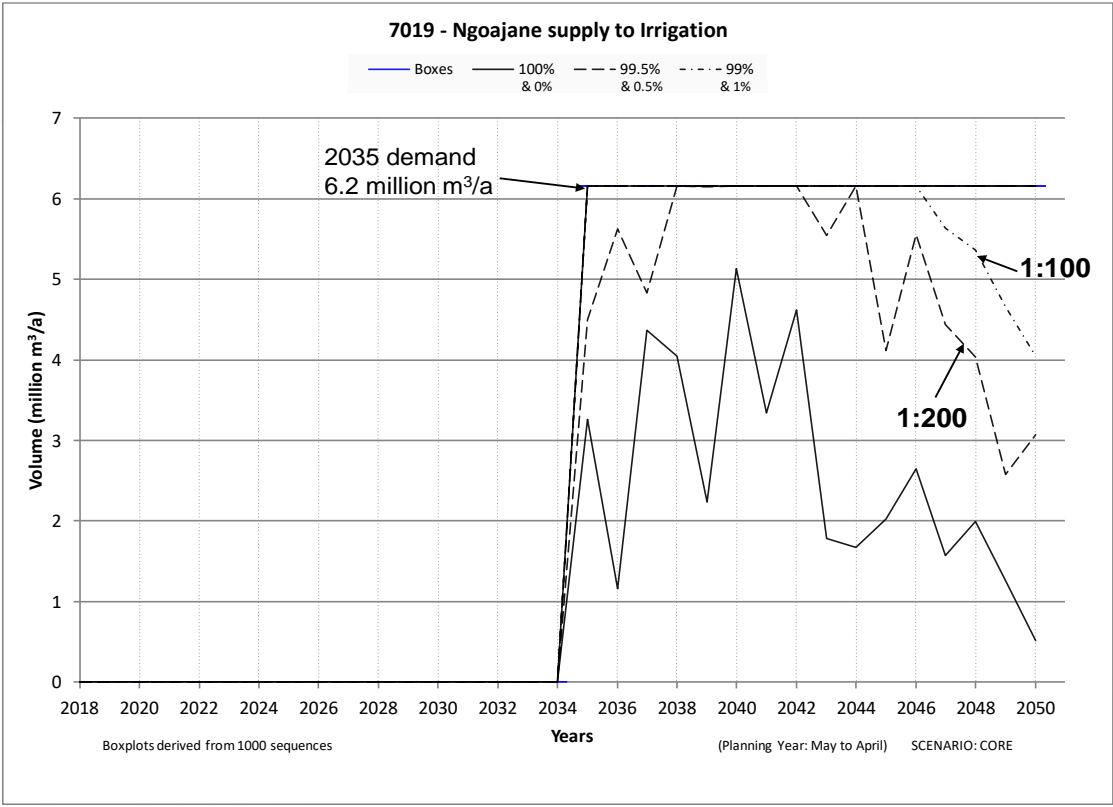
Figure 4-30: Supply to users supplied from Ngoajane Dam
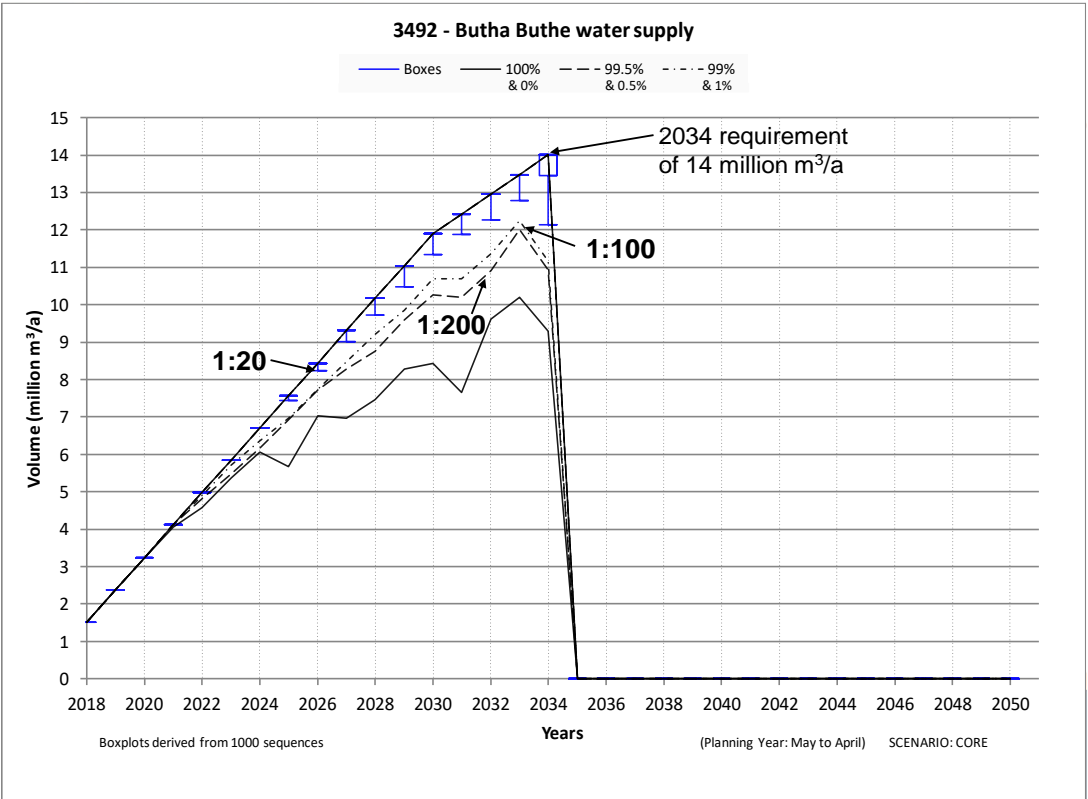
Figure 4-31: Water supply to Butha Buthe mainly from river runoff abstractions

The irrigation requirements were also supplied well above the required assurance levels (**Figure 4-28B**).

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.

4.4   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 m³/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.

4.4.1   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.

<u>**IVRS**</u>

The impact of not implementing WC/WDM within the IVRS is severe and is illustrated in **Figure 4-30** 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 4-30B**).

The storage projection plots for the Core Scenario and the Core Scenario without WC/WDM are given in **Figure 4-31**. 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.
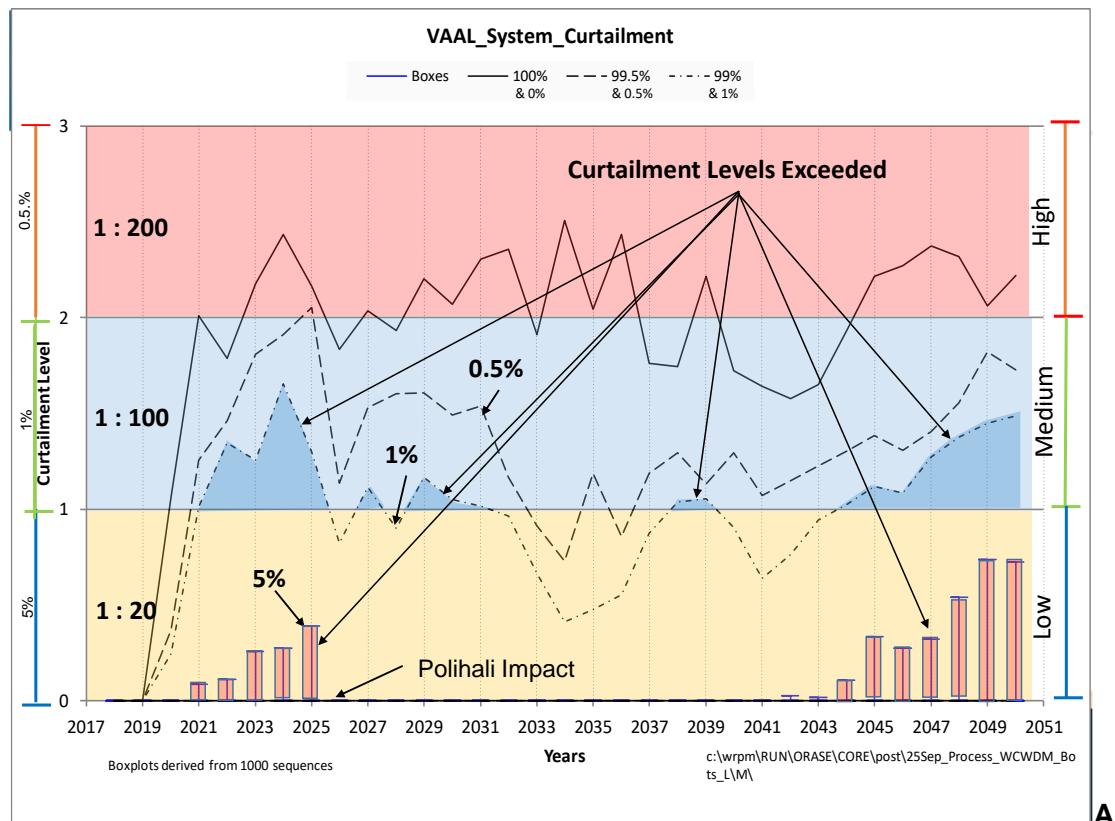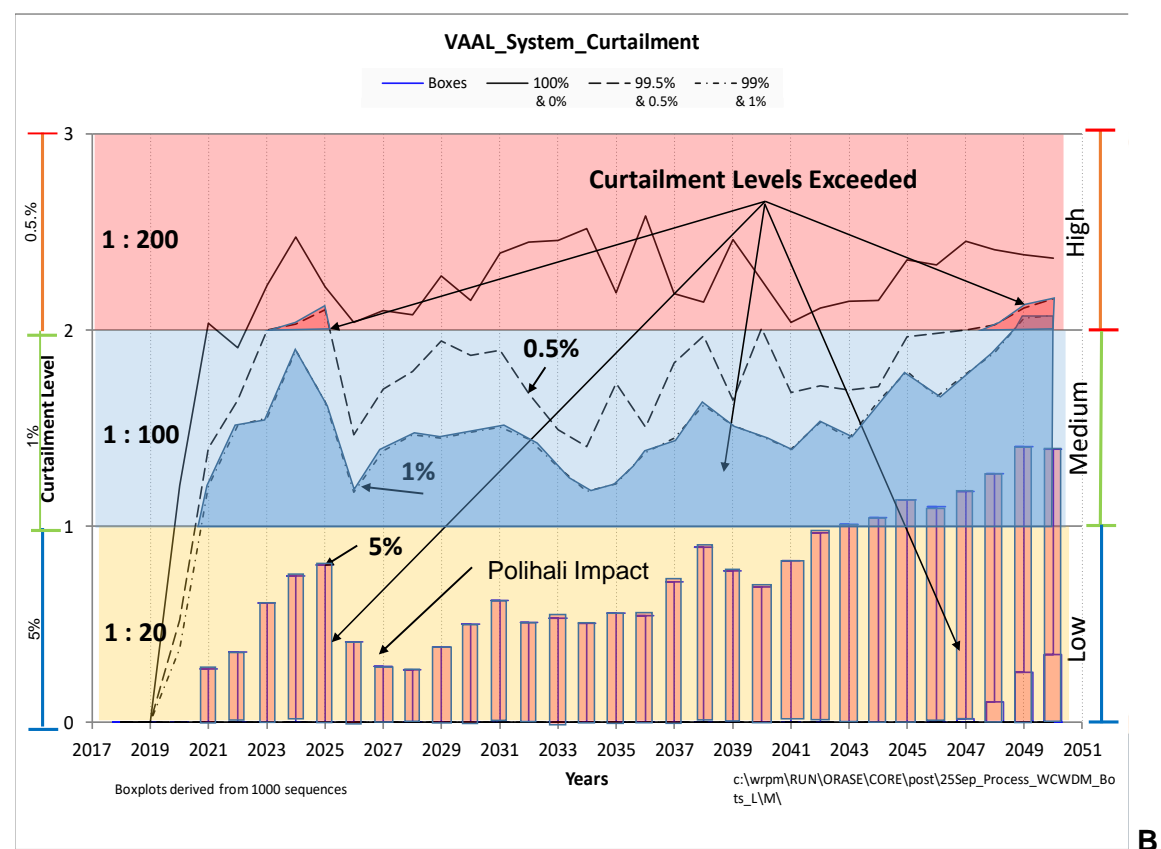
Figure 4-32: Vaal System Curtailment Plot for the current Core Scenario with WD/WDM in place (A) and with no WC/WDM in place (B)
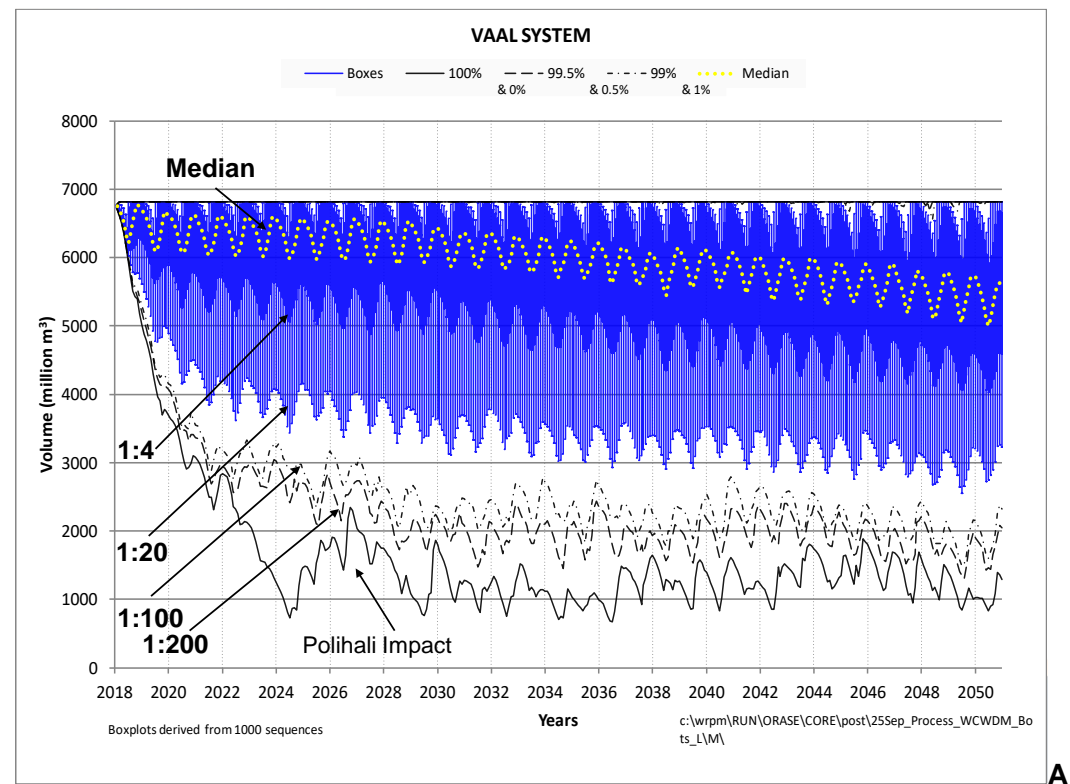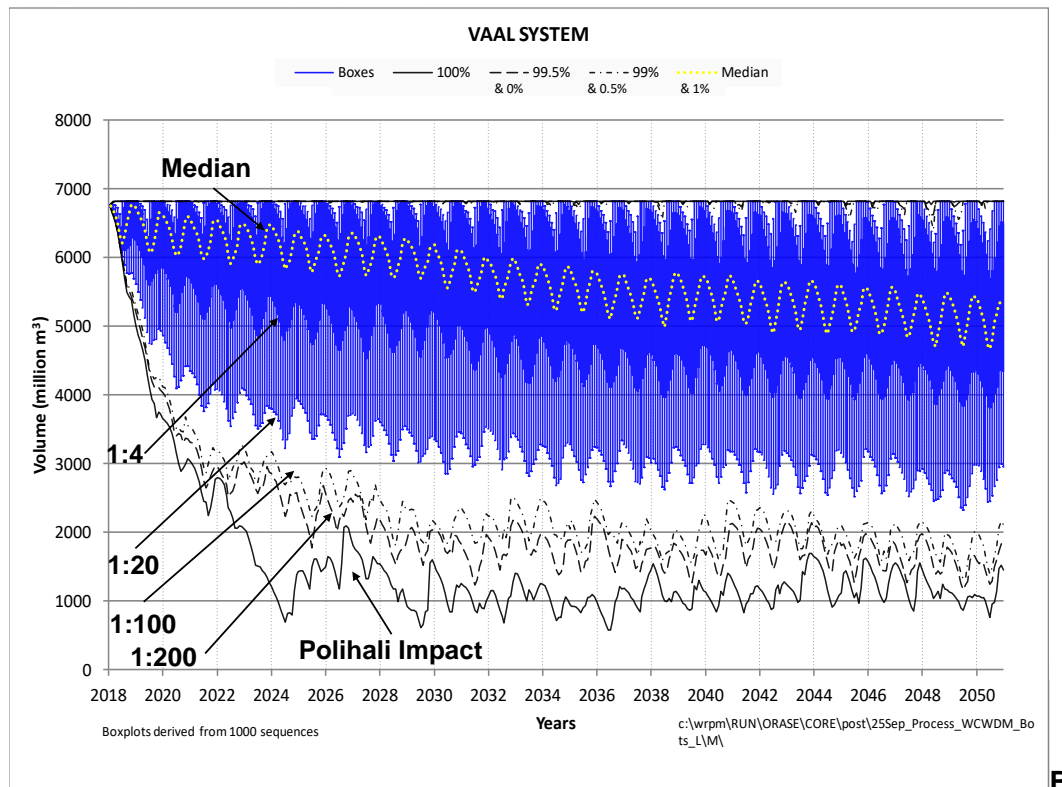
Figure 4-33: Vaal System Storage projection for the current Core Scenario with WC/WDM included (A) and with no WC/WDM in place (B)

ORP

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 4-32A** and **Section 4.2.3**).
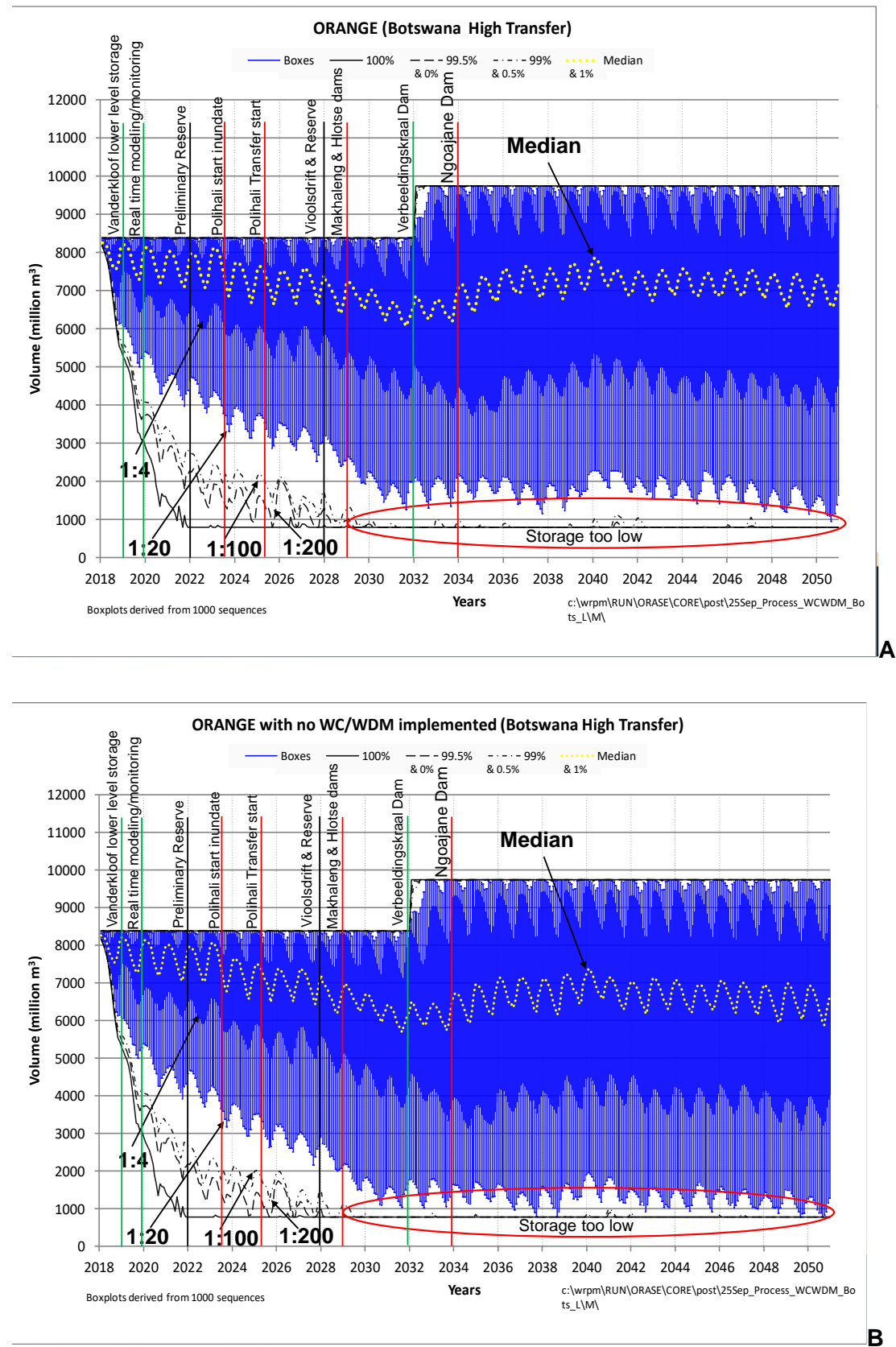
Figure 4-34: ORP system storage projection plots for Current Core Scenario (A) and the Current Core Scenario with no WC/WDM (B) actions implemented in the ORP

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 4-33B**).
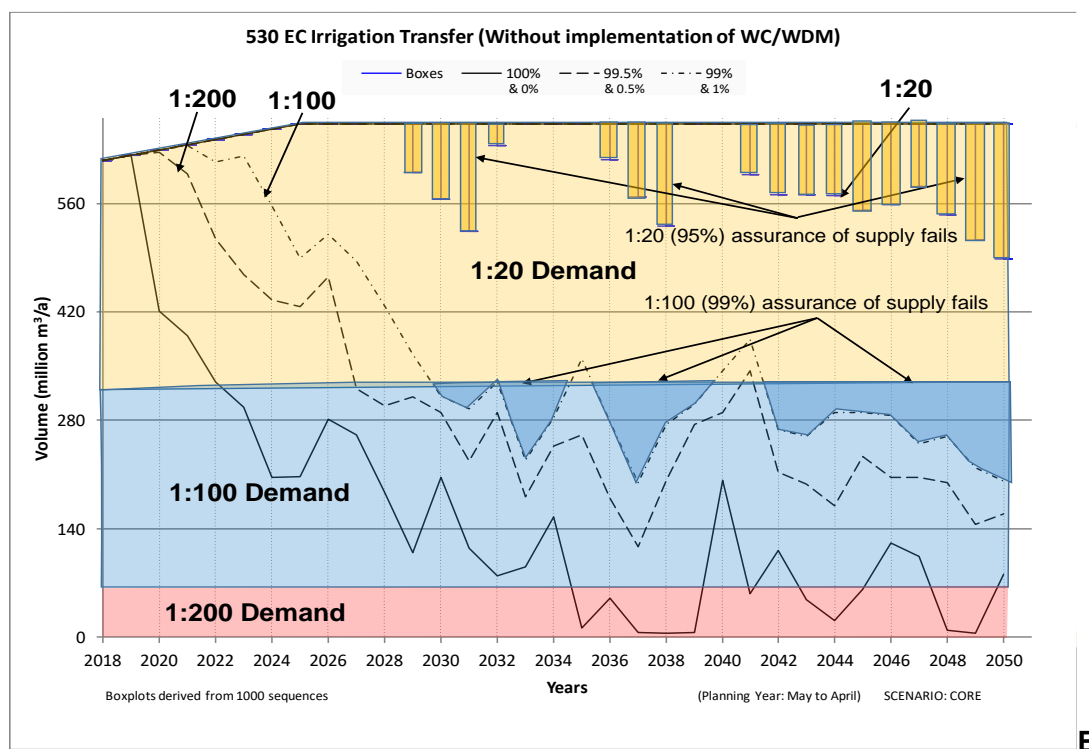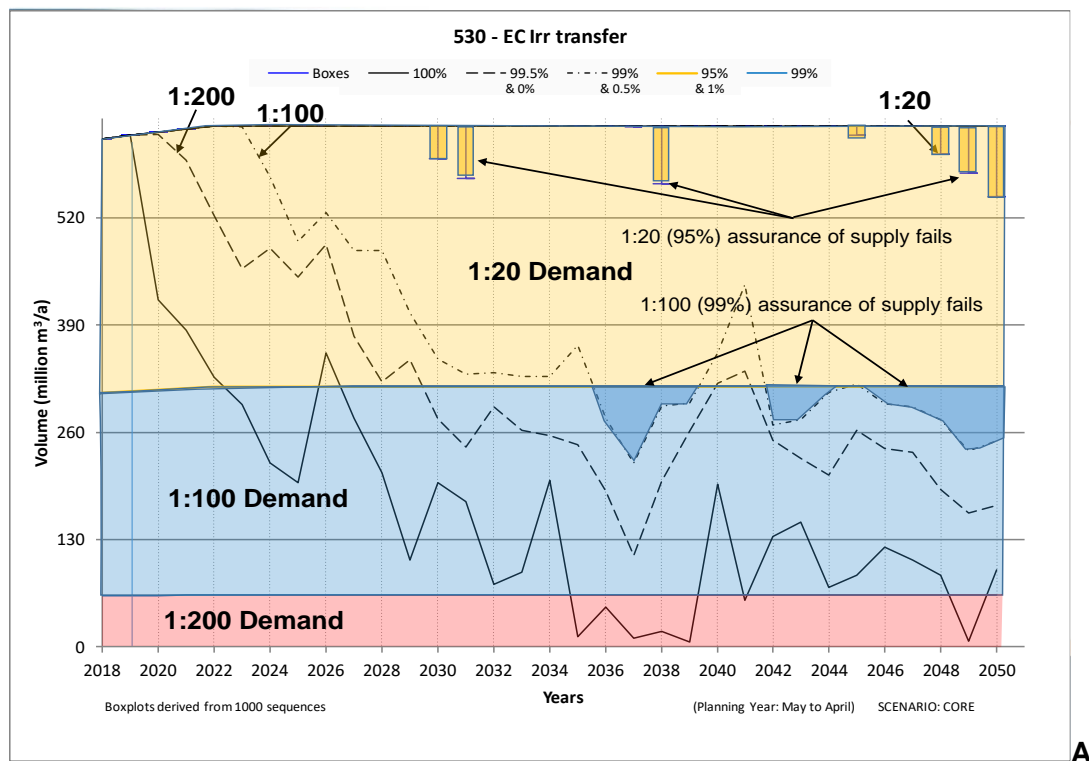
Figure 4-35: Water supply for irrigation in the EC for the Current Core Scenario (A) and the Current Core Scenario with no WC/WDM (B) implemented in the ORP

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.
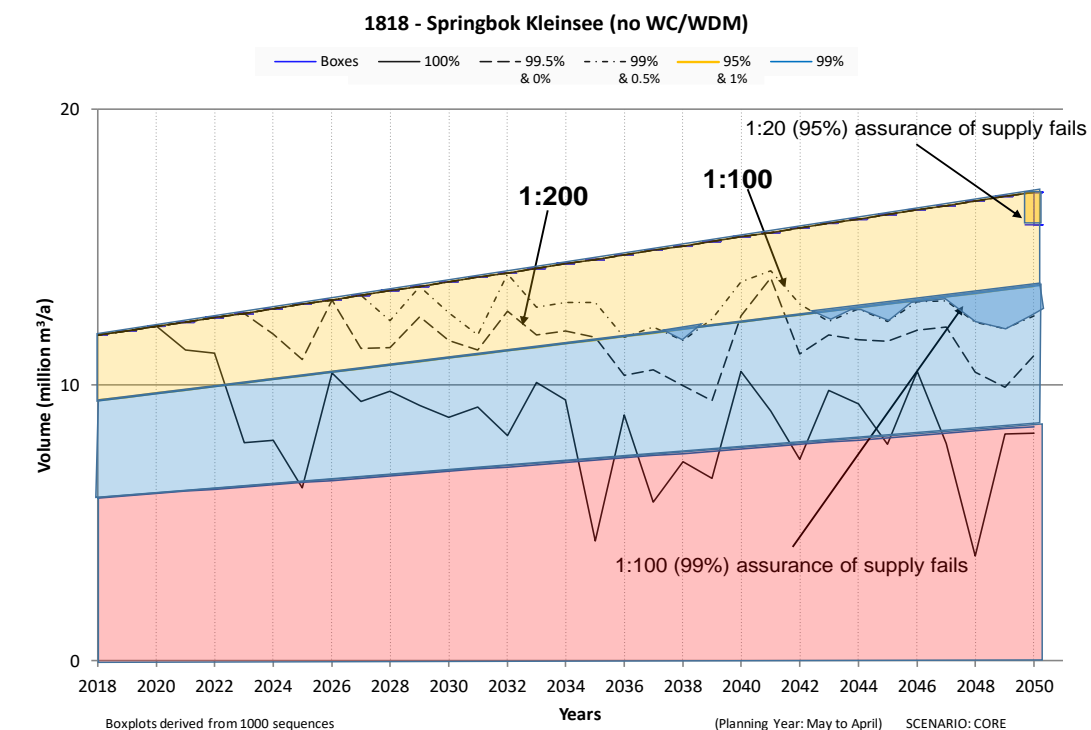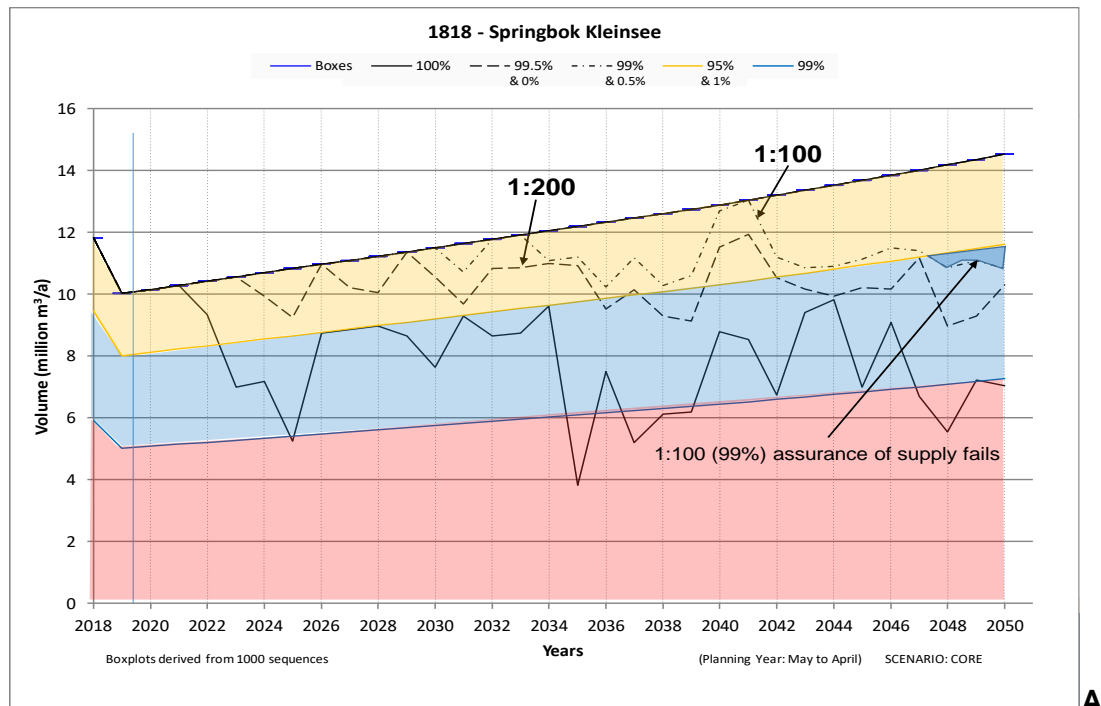
Figure 4-36: Water supply to Springbok and Kleinsee for the Current Core Scenario (A) and for the Current Core Scenario with no WC/WDM (B) actions implemented in the ORP

The comparison for the Eastern Cape irrigation is given in **Figure 4-33**. Deficits in the irrigation supply to the Eastern Cape were already evident for the Current Core Scenario (**Figure 4-33A**) at the 95% and 99% assurance levels. These deficits increased significantly when no WC/WDM actions were implemented in the ORP (See **Figure 4-33B**).

The Springbok Kleinsee urban/mining water supply for both options are shown in **Figure 4-34**. 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 is 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.

4.4.2   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 4.2.3**). 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.
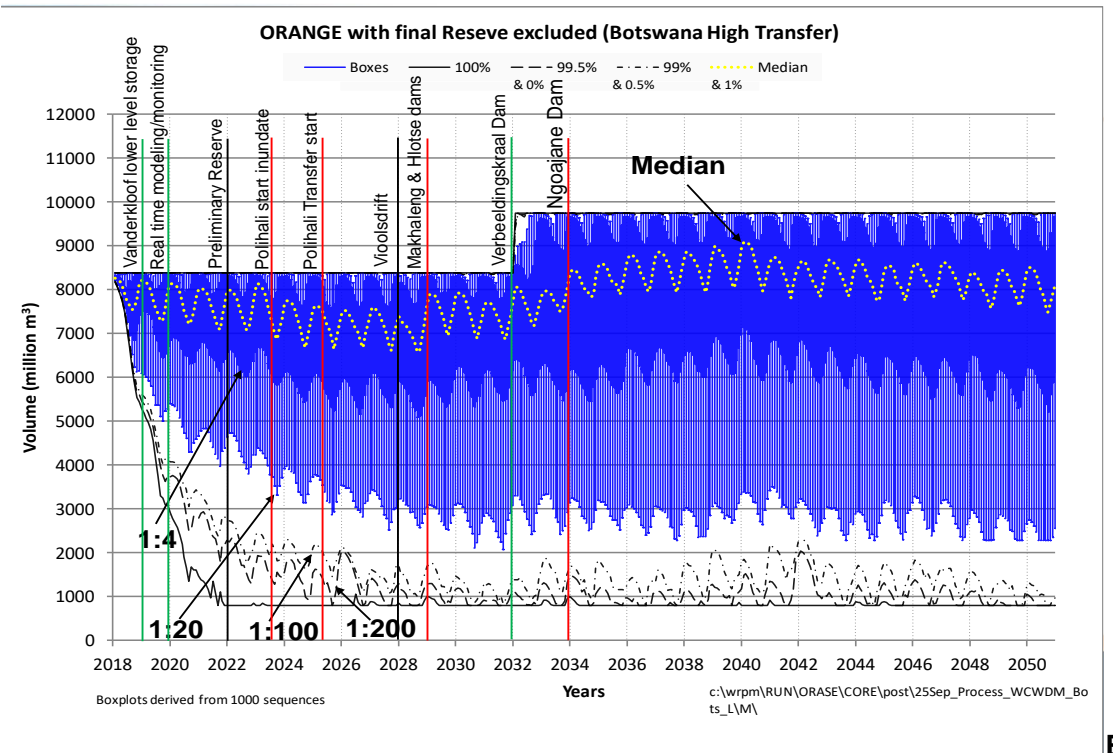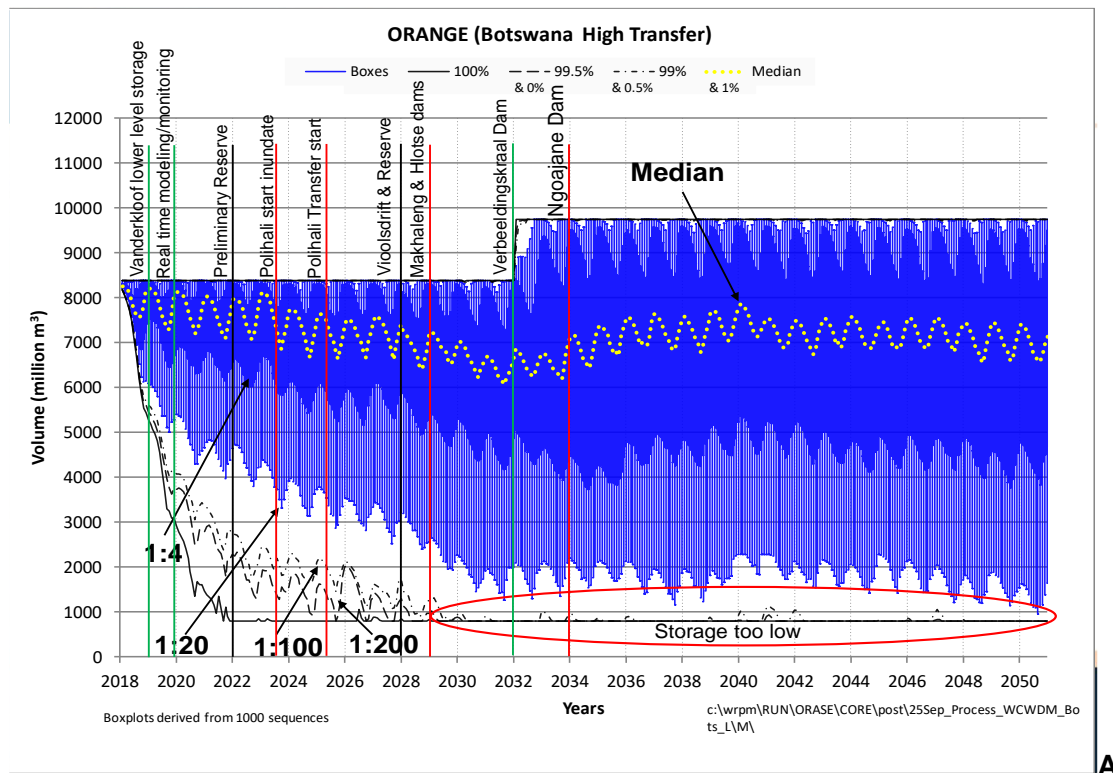
Figure 4-37: ORP system total storage projection for the Current Core Scenario (A) and the Current Core Scenario when the final Reserve is (B) excluded from the ORP
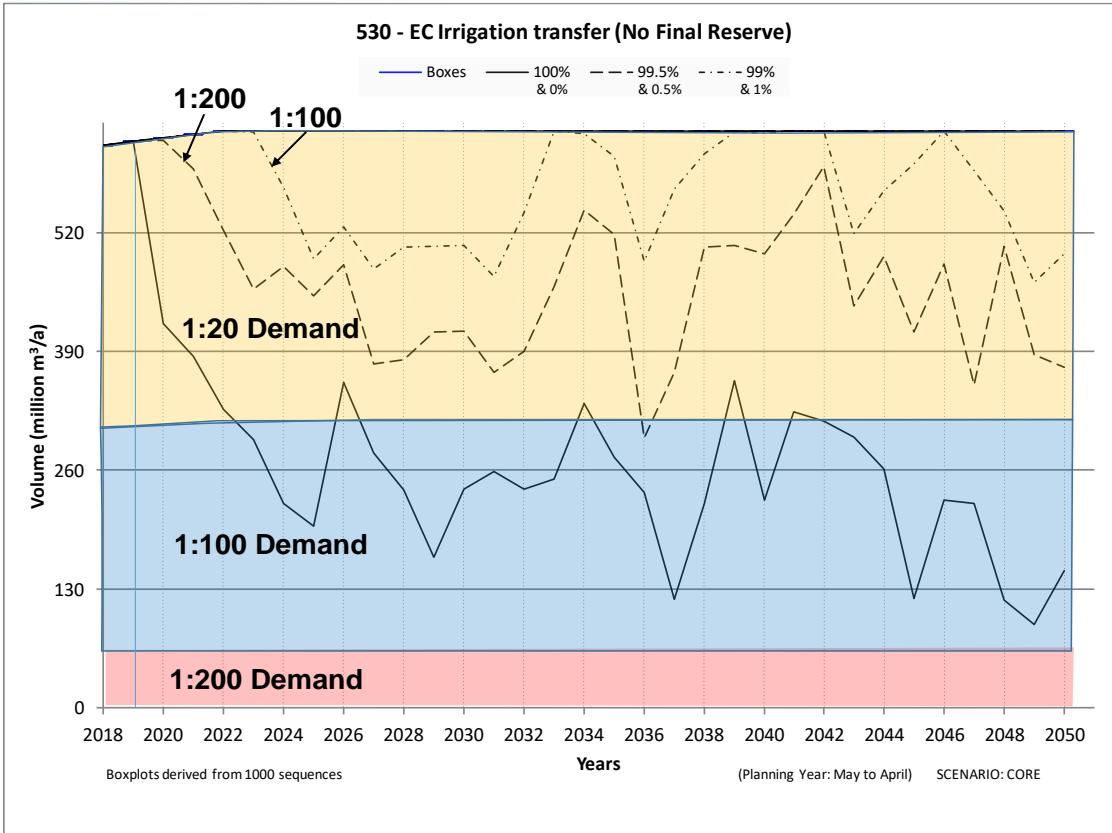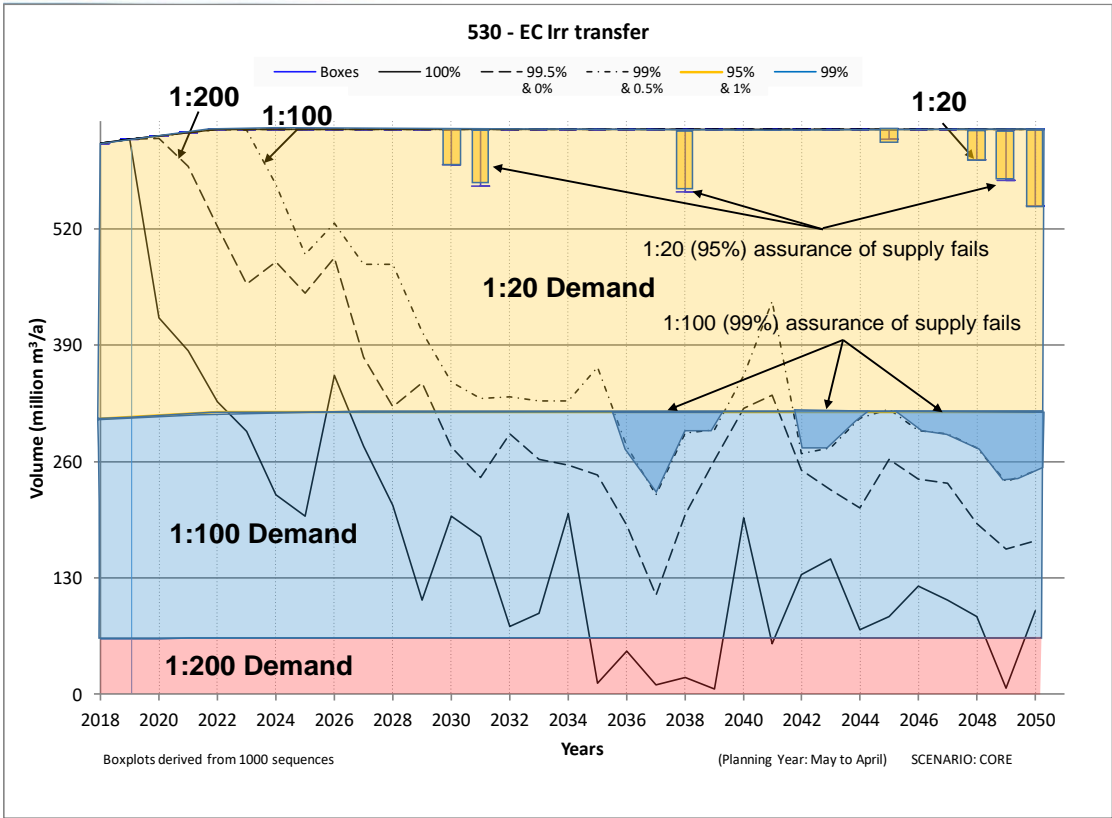
Figure 4-38: Supply to EC Irrigation transfer for the Current Core Scenario (A) and the Current Core Scenario when the Final Reserve is (B) excluded from the ORP

1818 - Springbok Kleinsee

Legend: Boxes | 100% | 99.5% & 0% | 99% & 0.5% | 95% & 1% | 99%

1:200

1:100

1:100 (99%) assurance of supply fails

Volume (million m³/a)

Years

Boxplots derived from 1000 sequences   (Planning Year: May to April)   SCENARIO: CORE

A

1818 - Springbok Kleinsee (No final Reserve)

Legend: Boxes | 100% | 99.5% & 0% | 99% & 0.5% | 99% & 1%

1:100

1:200

Volume (million m³/a)

Years

Boxplots derived from 1000 sequences   (Planning Year: May to April)   SCENARIO: CORE

B
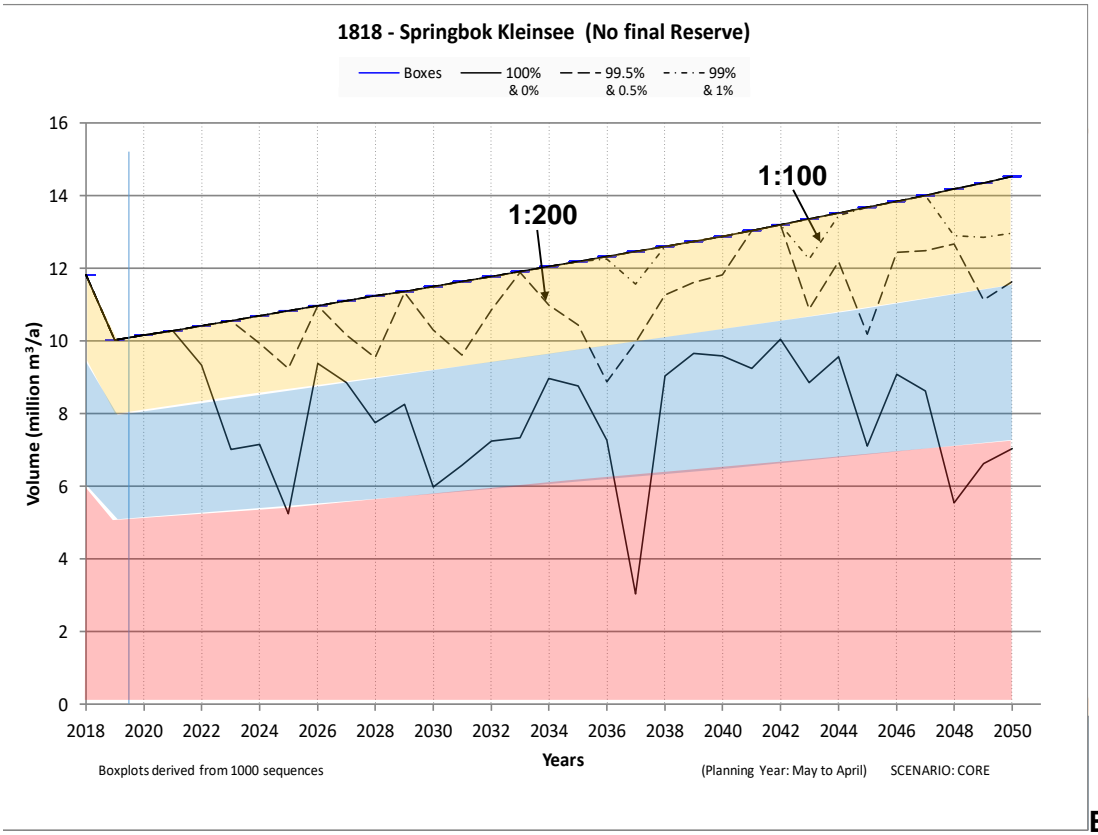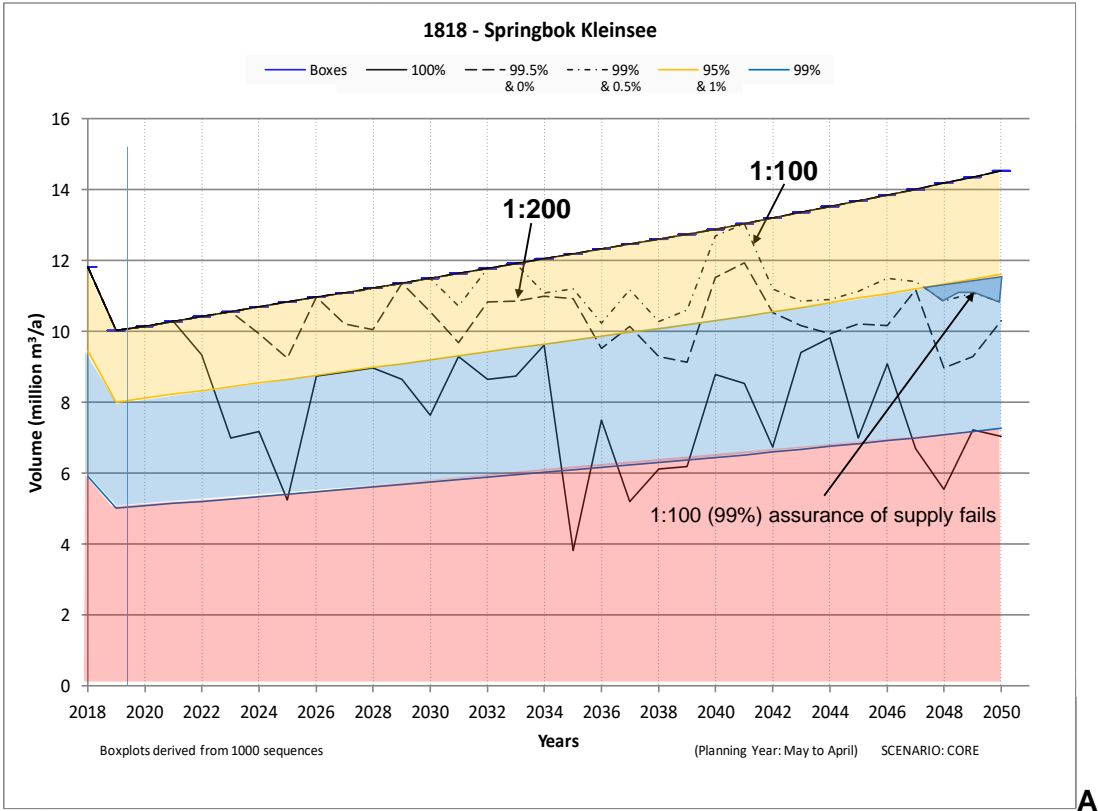
Figure 4-39: Supply to Springbok & Kleinsee for the Current Core Scenario (A) and the Current Core Scenario when the Final Reserve is (B) excluded from the ORP

4.4.3   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 4-38**. 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 4-39**. From **Figure 4-39A** 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 4-40 and **4-41** 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.
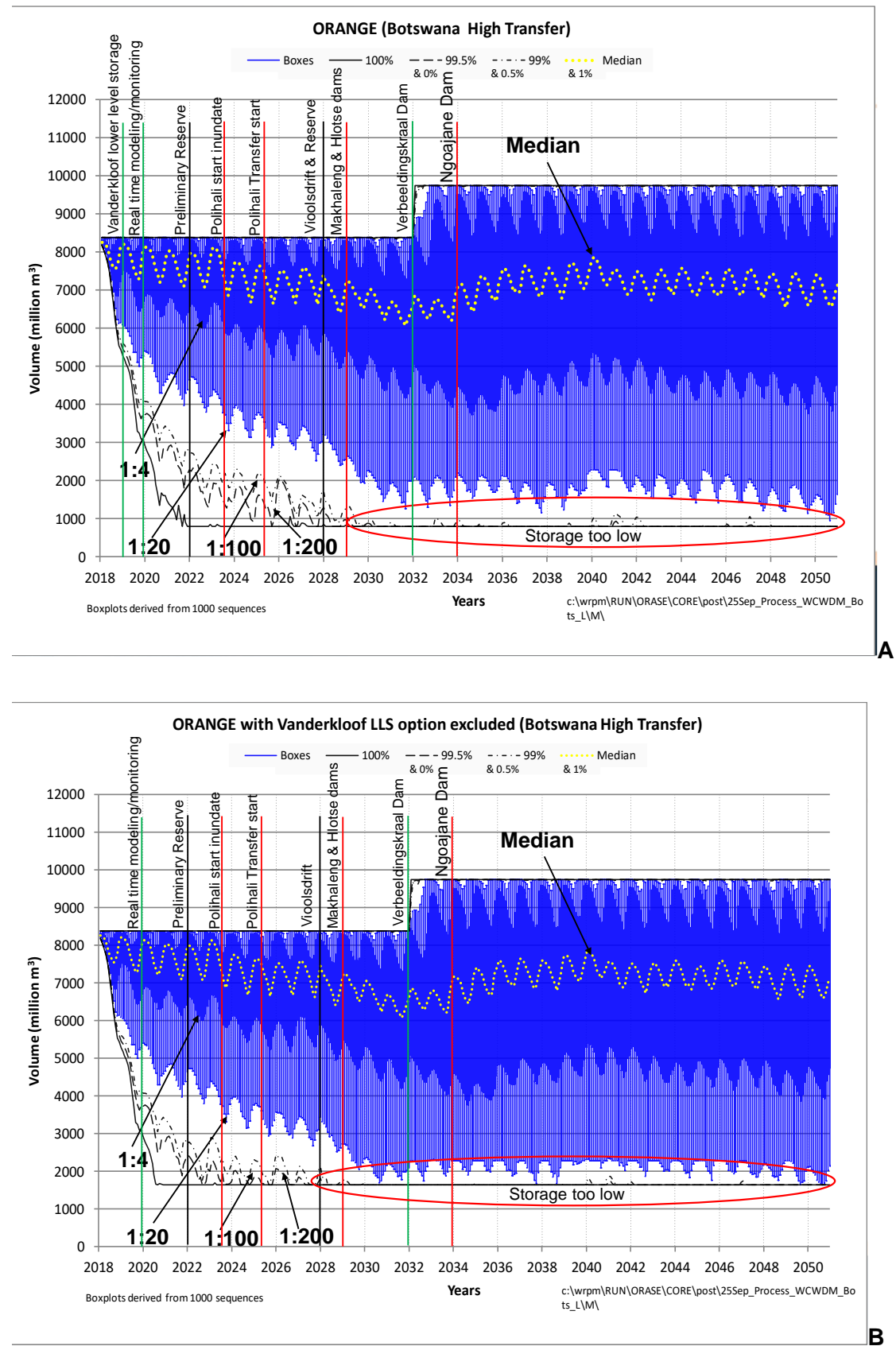
Figure 4-40: ORP system total storage projection for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized (B)
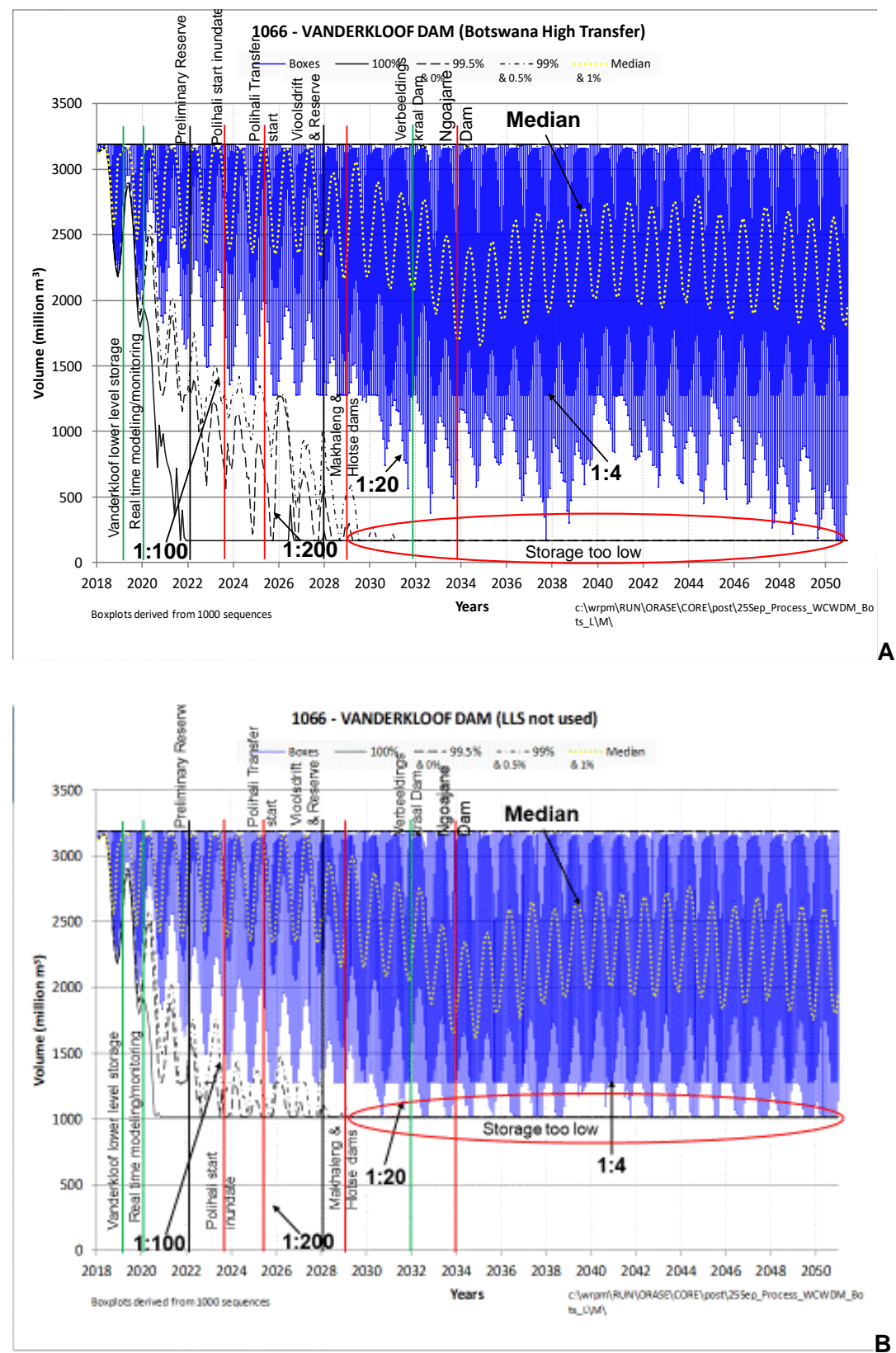
Figure 4-41: Vanderkloof Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)
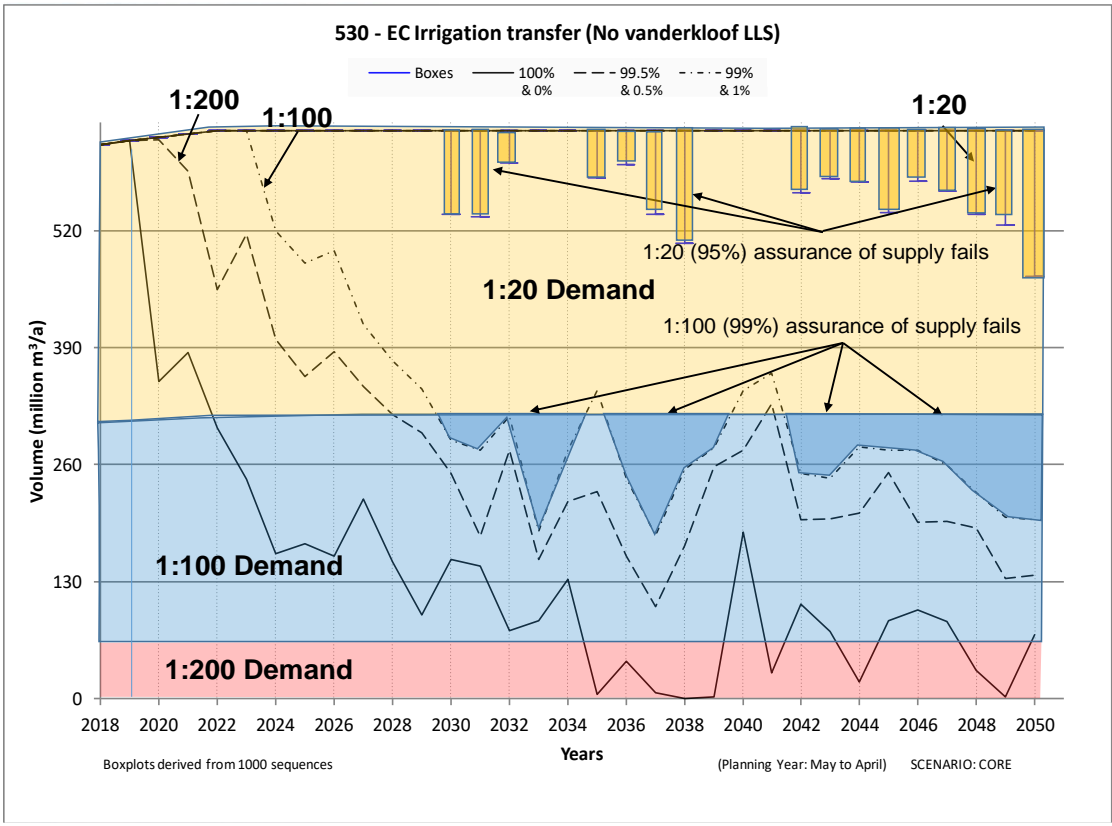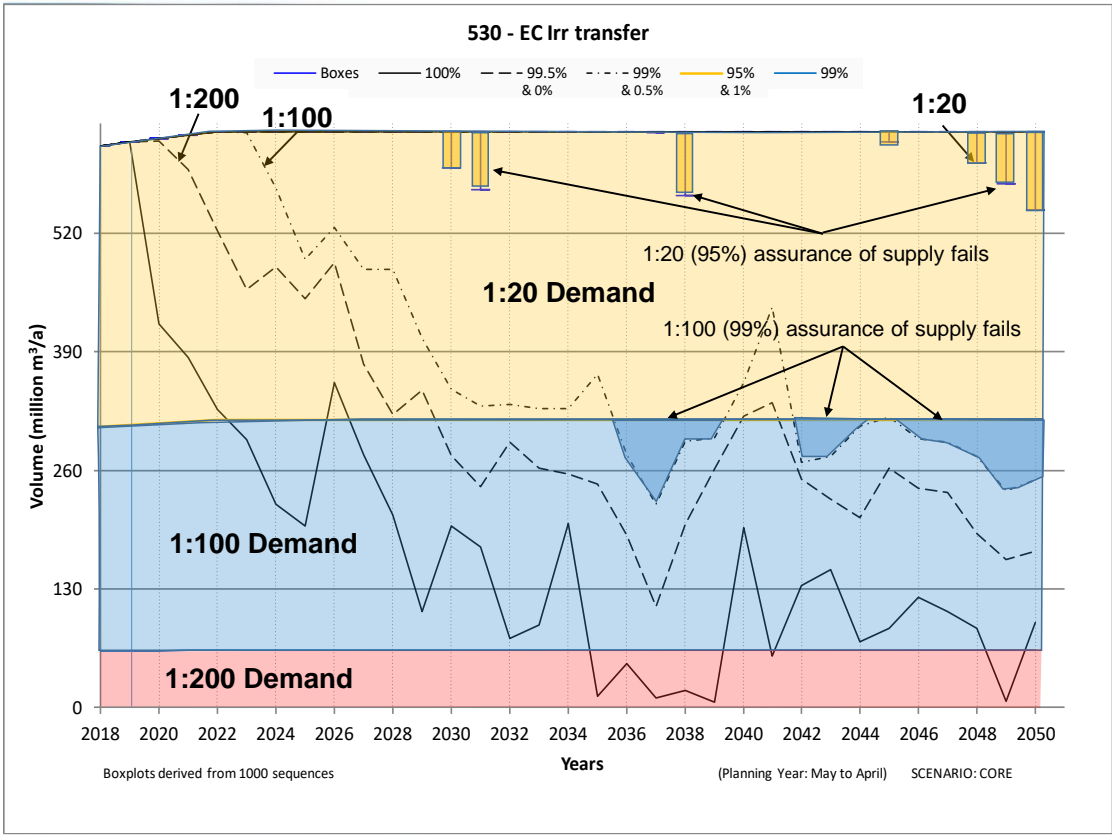
Figure 4-42: Supply to EC irrigation transfer for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)
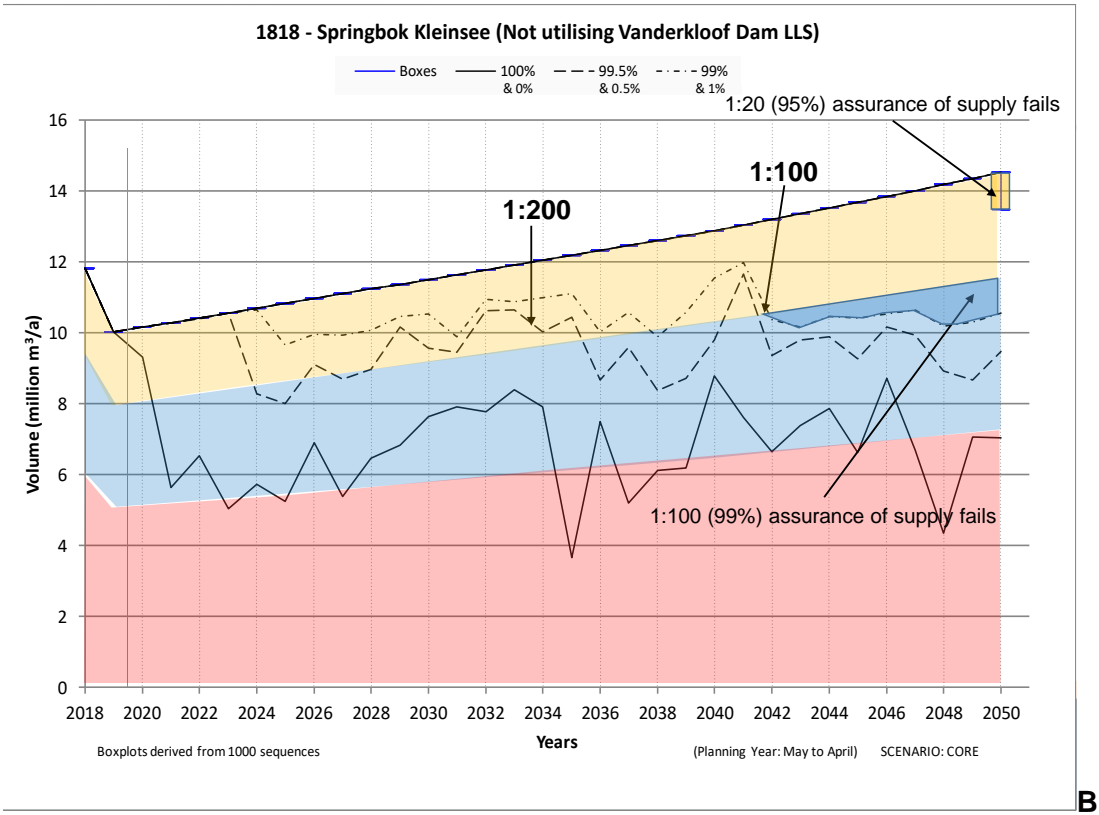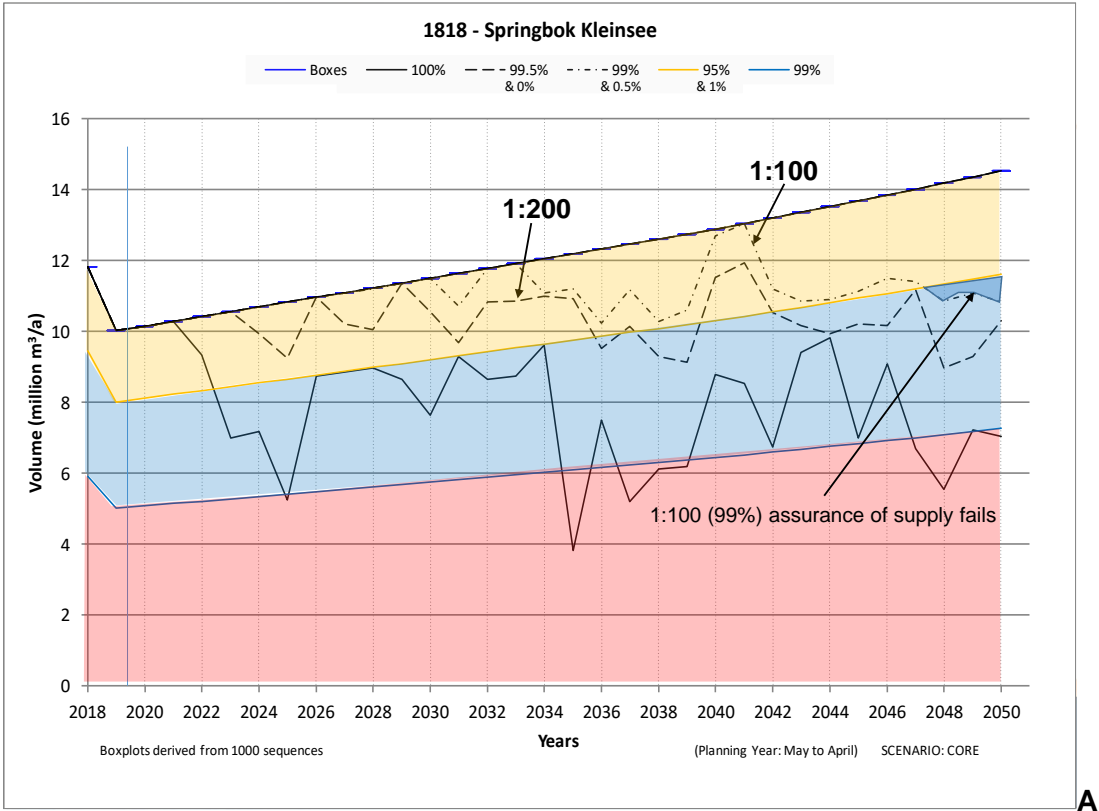
Figure 4-43: Supply to Springbok and Kleinsee for the Current Core Scenario (A) and the Current Core Scenario when Vanderkloof Dam LLS is not utilized(B)

4.4.4   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 4-42** 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 4-43A**). 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.
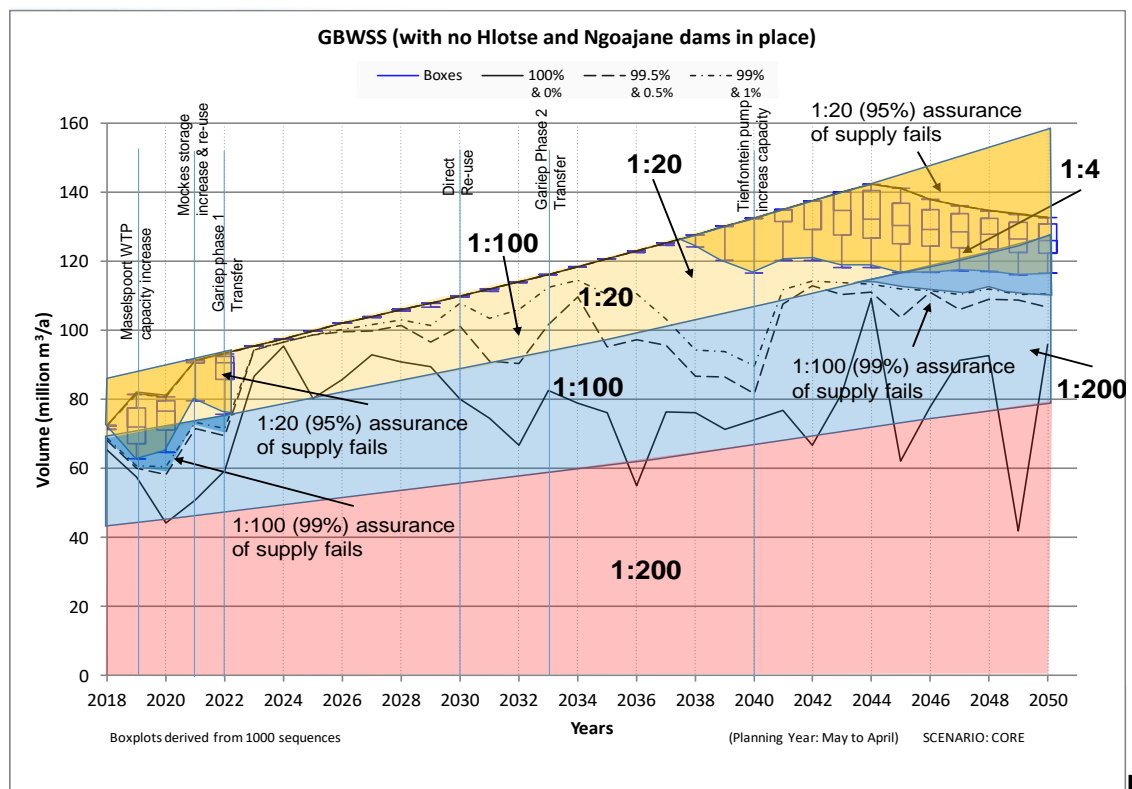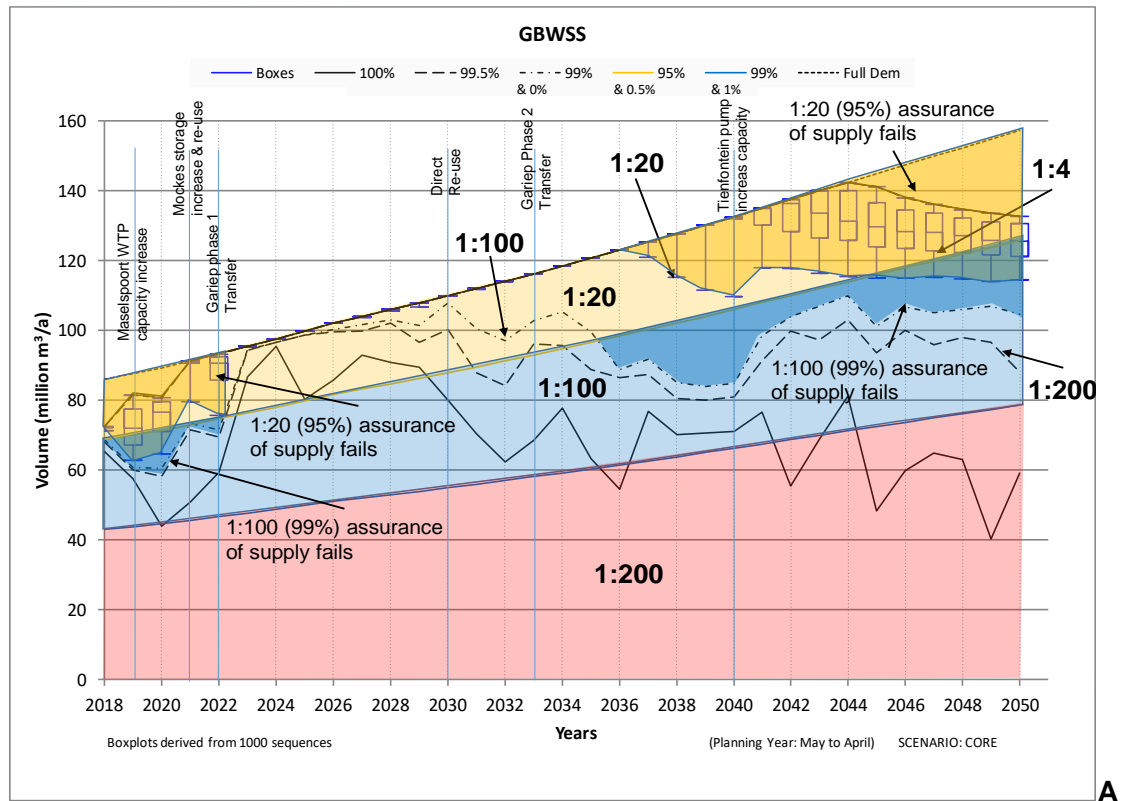
Figure 4-44: Water supply to the Greater Bloemfontein system for the Current Core Scenario (A) and the Current Core scenario with Hlotse and Ngoajane schemes removed(B)
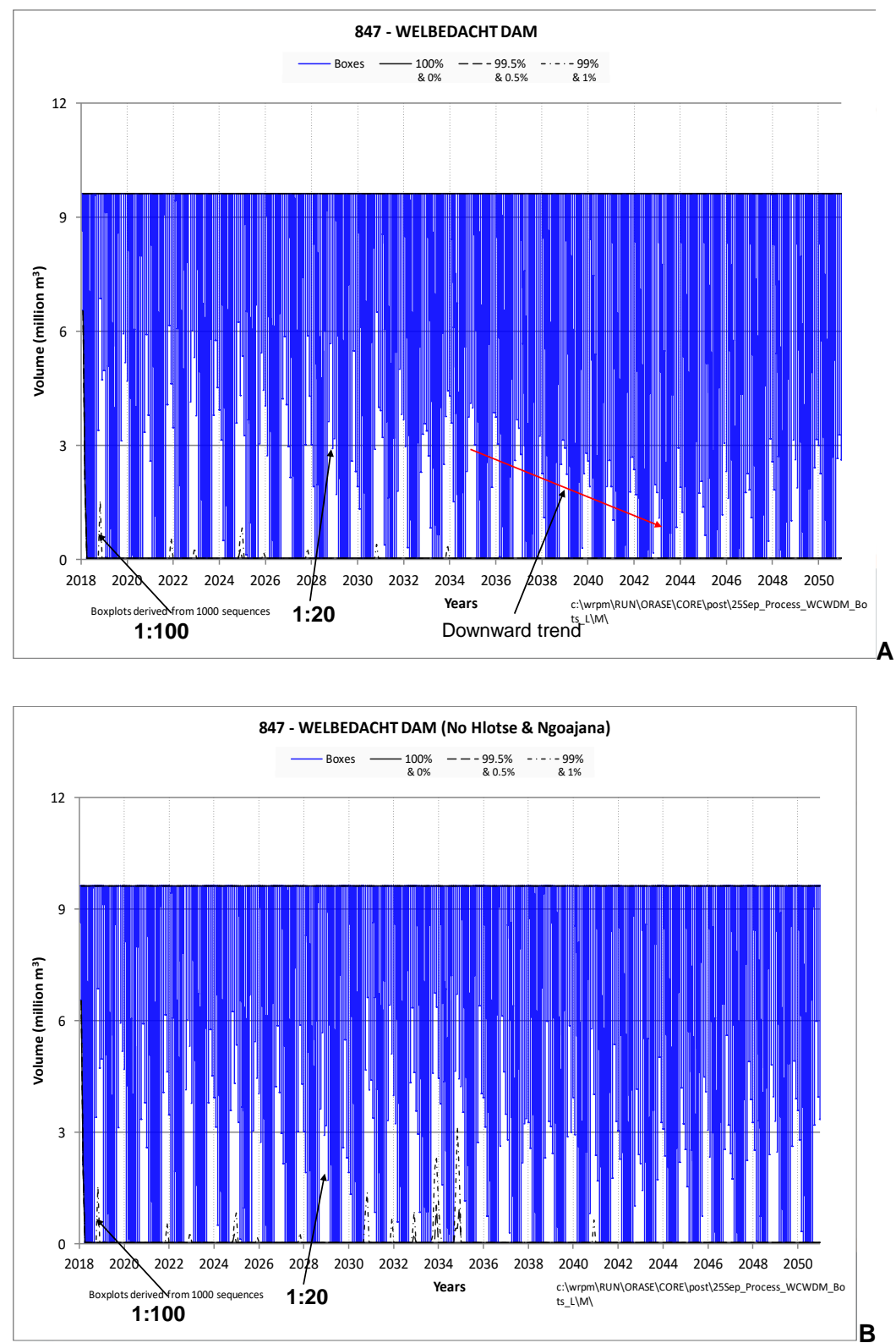
Figure 4-45: Welbedacht Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario that excludes the Hlotse and Ngoajane Schemes (B)

4.4.5 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 4-44**. 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 4.2.3**.

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 4-44B**) and will require less support from Vanderkloof Dam but will have a negative impact on the environment downstream of the dam.

From Figure **4-45A** 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.
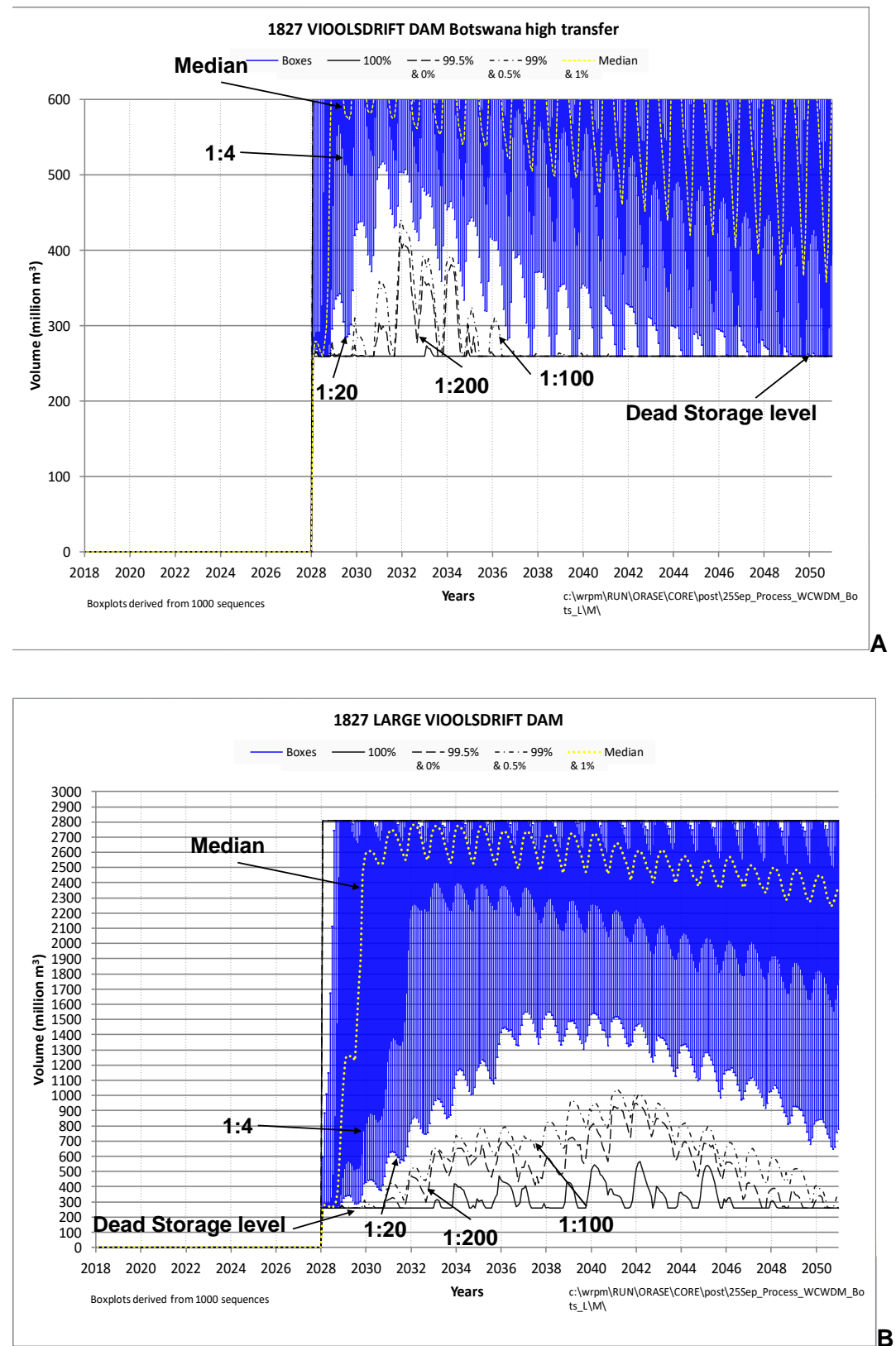
Figure 4-46:Noordoewer/Vioolsdrift Dam storage projection for the Current Core Scenario (A) and the Current Core Scenario with the large Noordoewer/Vioolsdrift Dam (B) included.
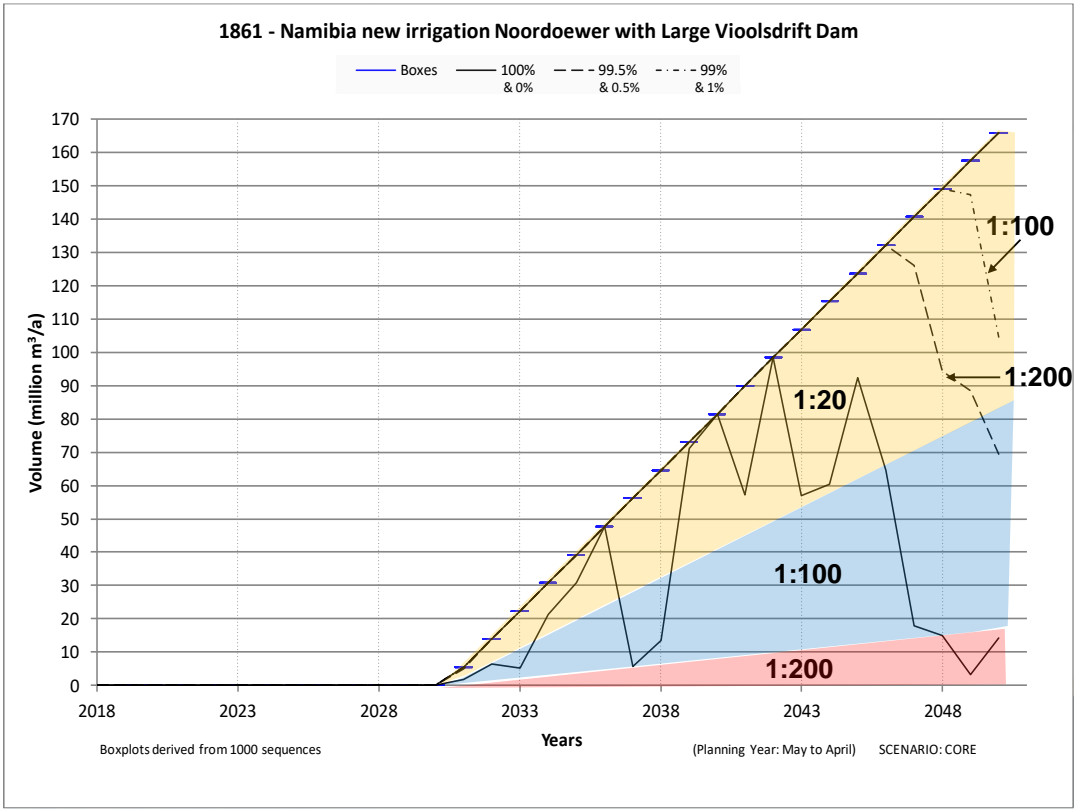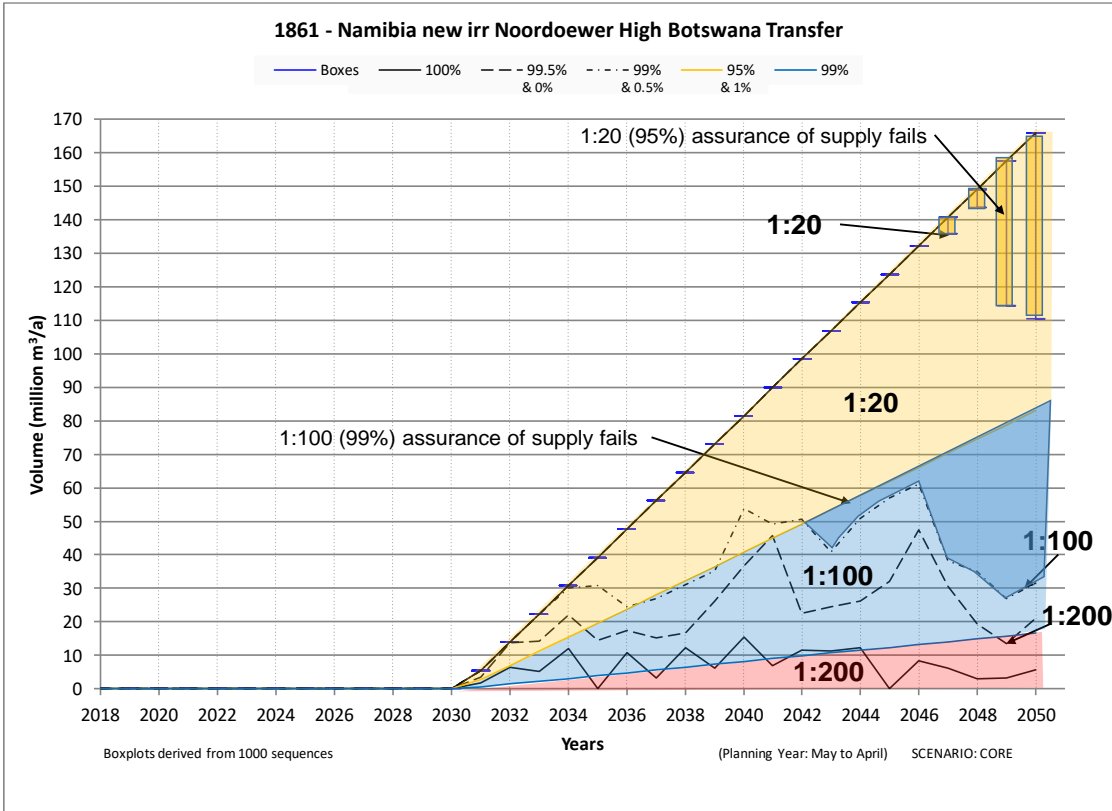
Figure 4-47: Supply to future Namibia irrigation as supported from the ORP system with the medium size Noordoewer/Vioolsdrift Dam (A) and when the large Vioolsdrift Dam (B) is in place

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

The results from this sensitivity analysis were already presented and discussed in **Section 4.3.1** 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 4-46**.
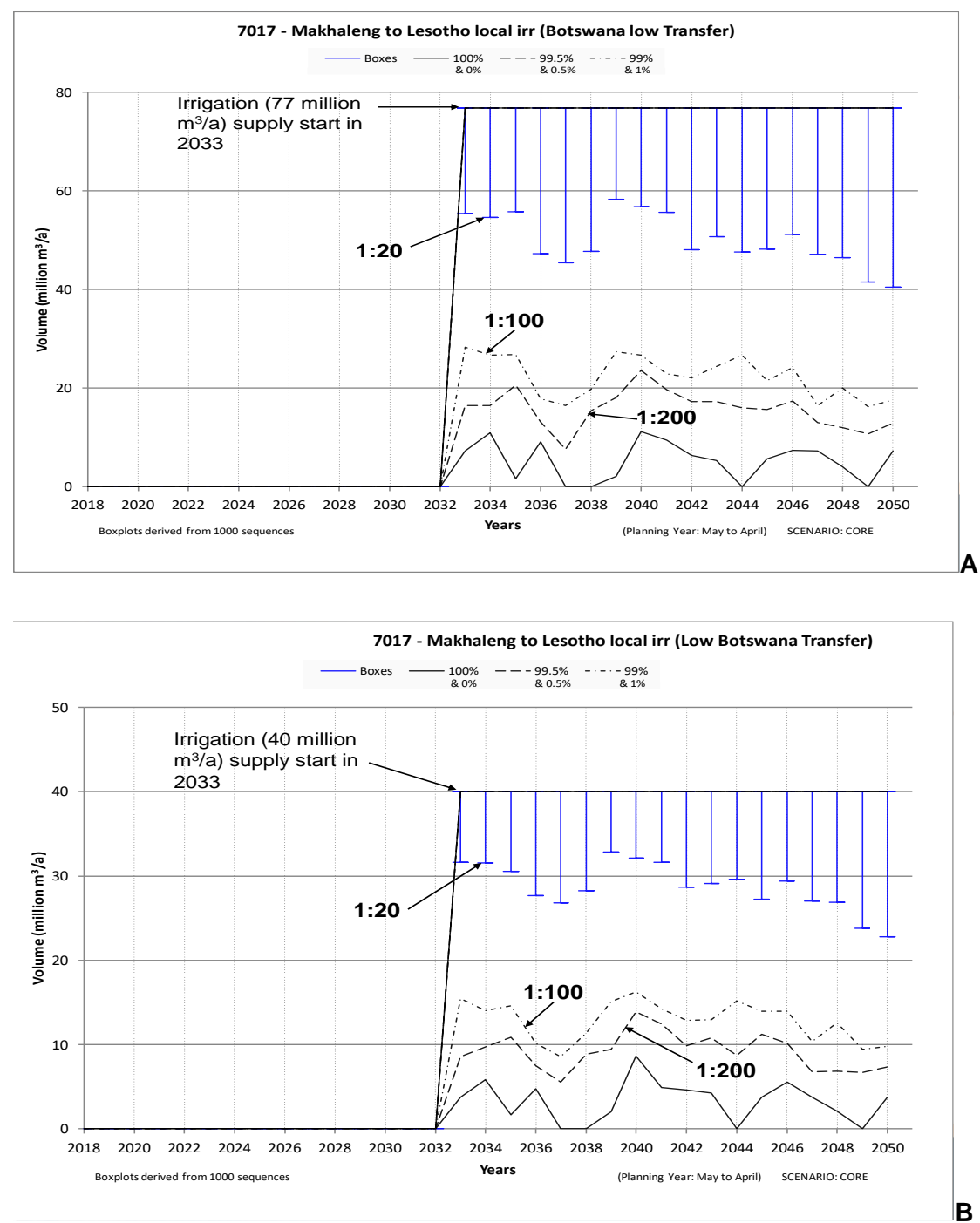
Figure 4-48: Supply to Lesotho irrigation supplied from Makhaleng Dam

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 4.1.7** detail is given on the operating rule improvement and the related results.

4.4.7   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 mitigation required from Makhaleng Dam.
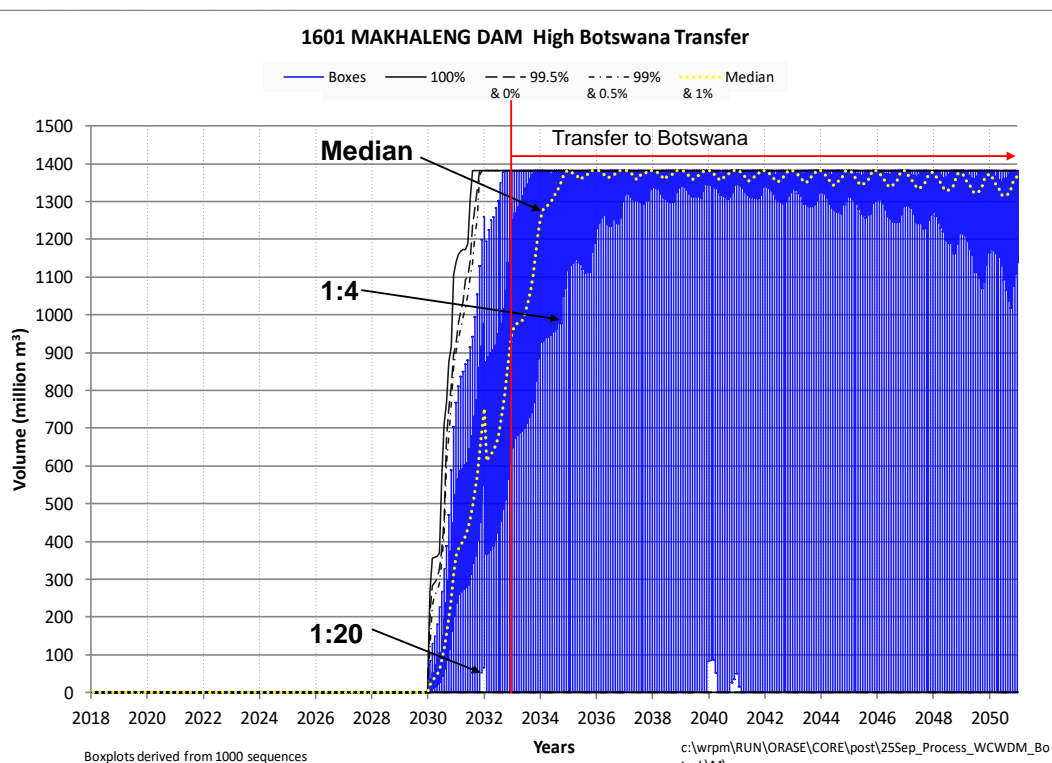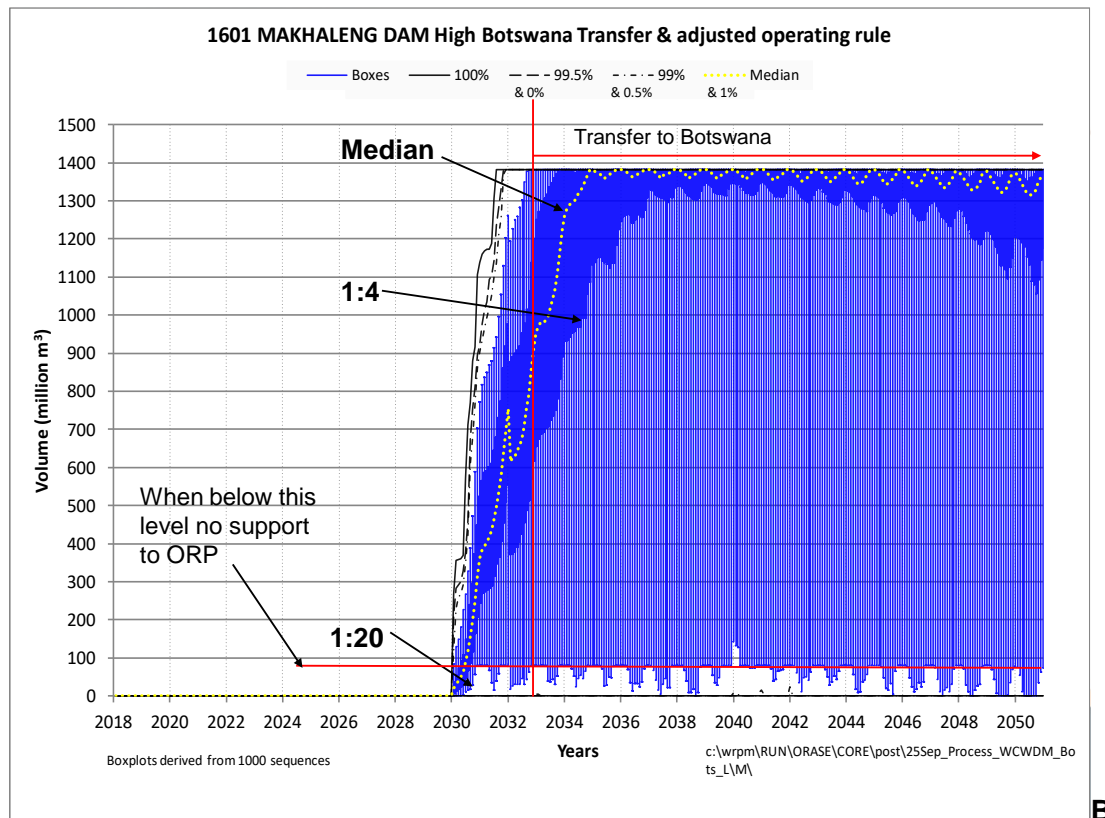
Figure 4-49:Makhaleng Dam storage projection for the Current Core Scenario with high Botswana transfer (A) and for Makhaleng Dam with the adjusted operating rule(B)

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 4-47**) 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 4-48**.

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.
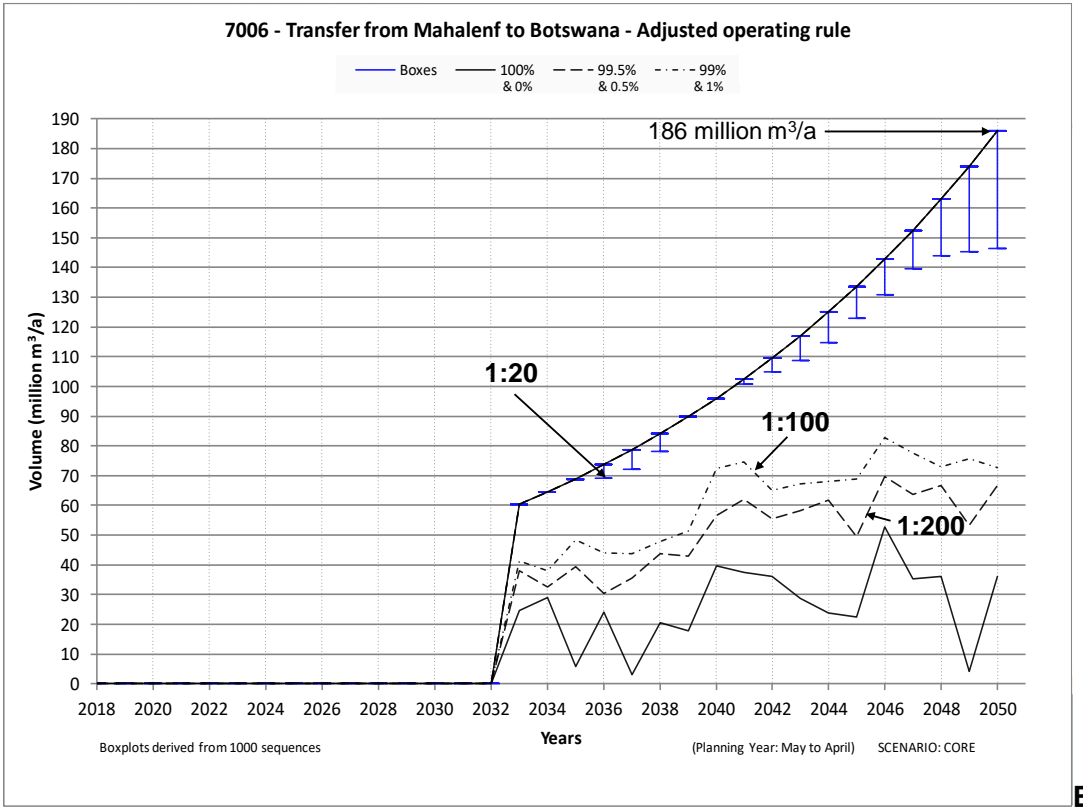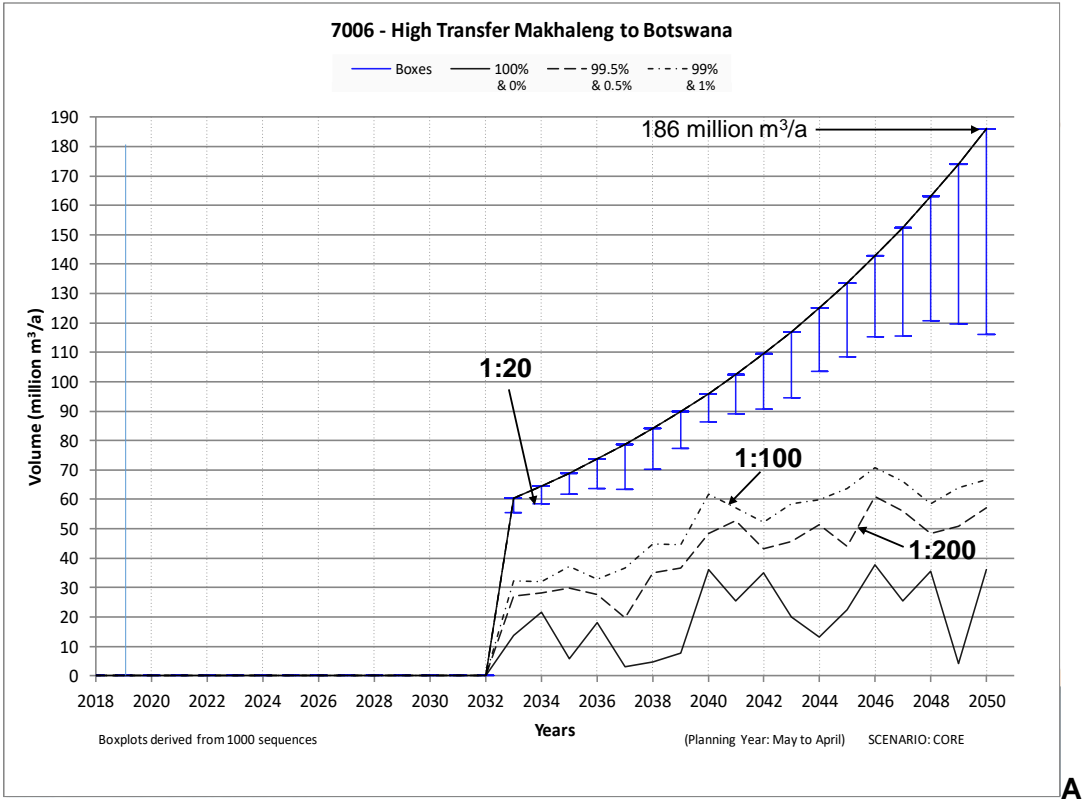
Figure 4-50: Water supply to users from the Lesotho Botswana transfer for the Current Core Scenario with high Botswana transfer (A) and when the adjusted Makhaleng operating rule is in place (B)

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.

5   ASSESSMENT OF MUTI PUPOSE DAMS IN LESOTHO

5.1   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 5.1** and the locations shown in **Figure 5-1**.

Figure 5-1: 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 Reconciliation 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 (mitigation 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 mitigation releases from the Lesotho Dam will be required to be able to maintain the existing downstream water balance.
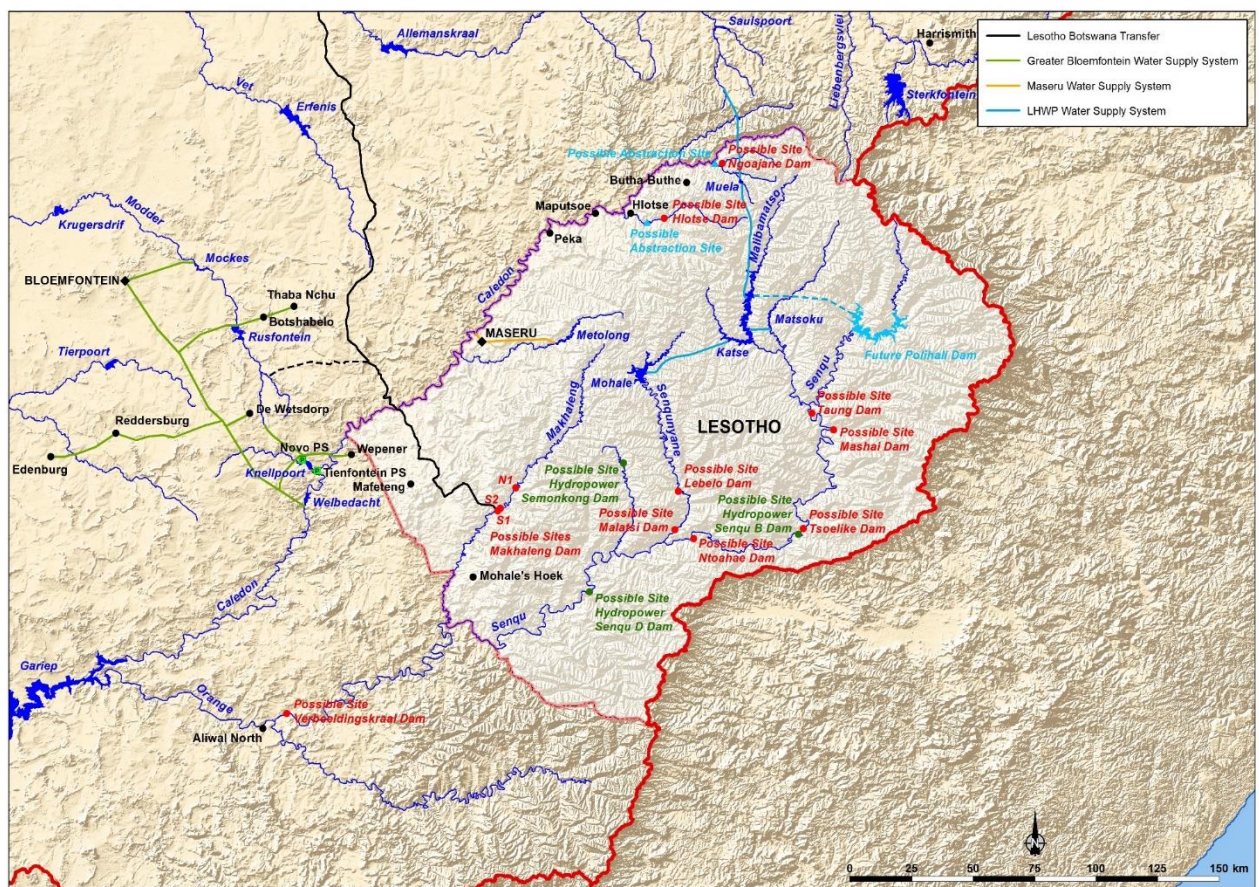
Figure 5-2: Possible dam sites and major water supply systems

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 5.2** and **5.3** to follow.

5.2   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 5-2**.

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 lll 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 mitigation 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 lll Phase 1, Water Resource assessment task (ORASECOM, 2019a), is given in **Figure 5-2**. 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 5-2** 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 as result of Makhaleng Dam.
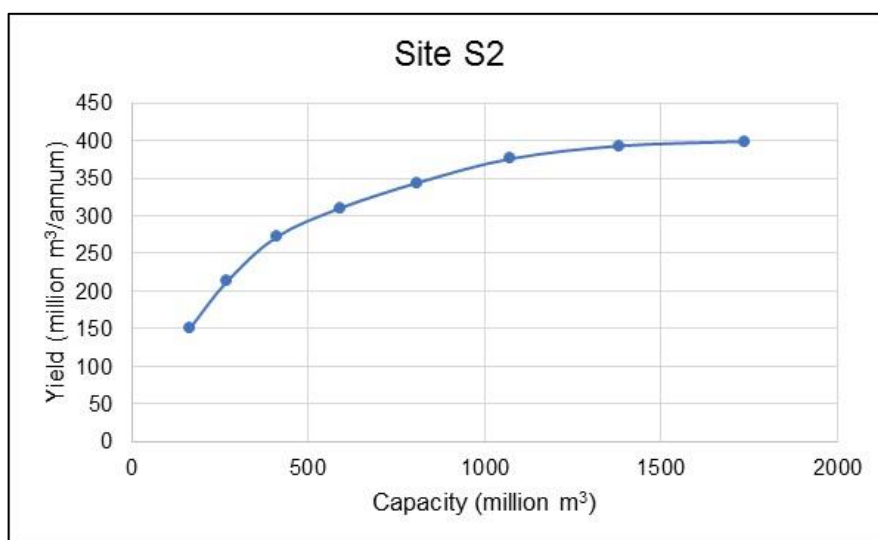
Figure 5-3: Makhaleng Dam yield at site S2

Figure 5-4: Summary of proposed scenarios for historic firm yield analyses

Scenario	Description	Purpose
ORP yield 2013	ORASECOM Phase III 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 mitigation water in support of the

Scenario	Description	Purpose
		ORP. Reduce mitigation 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 mitigation water in support of Gariep and Vanderkloof dams and thereby reduces the mitigation 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 mitigation 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 mitigation 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 mitigation 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 mitigation 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 5.3**.

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.

Figure 5-5: Key characteristics of possible hydropower dams

Dam height (m) (at FSL)	Reservoir volume (million m³)	M.O.L (m)	Live Storage (million m³)	Number of turbines	Design flow per turbine (m³/s)	Generating hours per day	Average flow (m³/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 5.3**.

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 mitigation water to the ORP system to reduce or eliminate the mitigation 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 5-4**).

Figure 5-6: Summary of estimated costs, yield and URVs

Option	Cost (R million)	Yield (million m³/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 m³ 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 mitigation water in support of Gariep and Vanderkloof dams and thereby reduces the mitigation 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.

5.3   Yield analyses Results

The historic firm yield results for the given scenarios were summarized in **Table 5.5**.

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 m³/a without having a negative impact on the yield available from the ORP.

Scenario 2 Sub-scenarios: As explained in **Section 5.2** 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 m³/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 m³/a when no Verbeeldingskraal and Polihali dams are included and the water balance for the downstream ORP remains the same as for Scenario 2d.

Figure 5-7: Summary of historic firm yield results focused on 2030 development level

Scenario	System and sub-system yield (million m³/a)						
	ORP	LHWP	Makhaleng	Hlotse	Ngoajane	Total	Net yield increase
ORASECOM IWRMP Phase lll	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 mitigation 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 mitigation 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 mitigation 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 mitigation releases in support the ORP. From a system perspective it is thus beneficial to use Makhaleng Dam to provide mitigation 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 mitigation 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 mitigation 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 mitigation water in support of downstream users. The mitigation 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 m³/a and represents the expected 2050 water requirement for irrigation (46.2 million m³/a) and urban/rural of 20.1 million m³/a.

Results from the analysis showed that reduction in the supply to the Greater Bloemfontein, reduced to 3.1 million m³/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 m³/a (Scenario 3) to only 15 million m³/a.

Sub-scenario 3e: The results from Scenario 3d clearly indicate that the increased yield from the 120 million m³ storage Hlotse Dam was not sufficient to cover the mitigation 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 m³ net storage.

Figure 5-8: 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 m³/a	Greater Bloemfontein abtsraction (million m³/a)	Maseru & Towns supply from Mohokare (million m³/a)	Total supply (million m³/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 m³/a with a net yield increase to 62 million m³/a. This is slightly lower than the 2050 demand of 66.3 million m³/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 m³/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 m³/a and is slightly higher than the 2050 demand of 29.2 million m³/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 m³/a in comparison with Scenario 3. The water supply to the Greater Bloemfontein reduced by 1.1 million m³/a and 0.4 million m³/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 m³/a. The analysis thus clearly shows that it will not be possible to utilize the full yield of 30.8 million m³/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 m³ to a gross storage of 63.3 million m³ 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 m³ 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 m³/a and 20 million m³/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 m³ 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 m³ which resulted in an increased gross yield for Ngoajane Dam by 8 million m³/a to 38.8 million m³/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.

<u>Sub-scenario 4c2</u>: 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.

<u>Sub-scenario 4d</u>: Based on Scenario 4c. Sub-scenario 4d used the additional yield from Ngoajane and Hlotse dams to provide mitigation 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 5-3**.
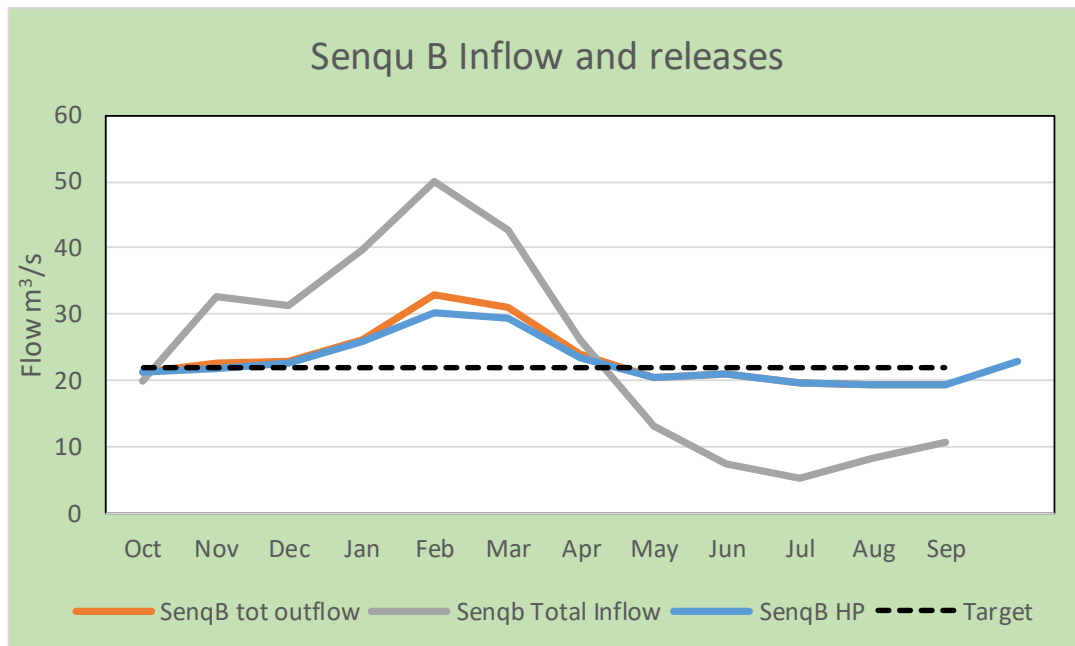
Figure 5-9: Average monthly simulated inflows and releases from Senqu B Dam

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 5-3** 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 5-4**. 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.
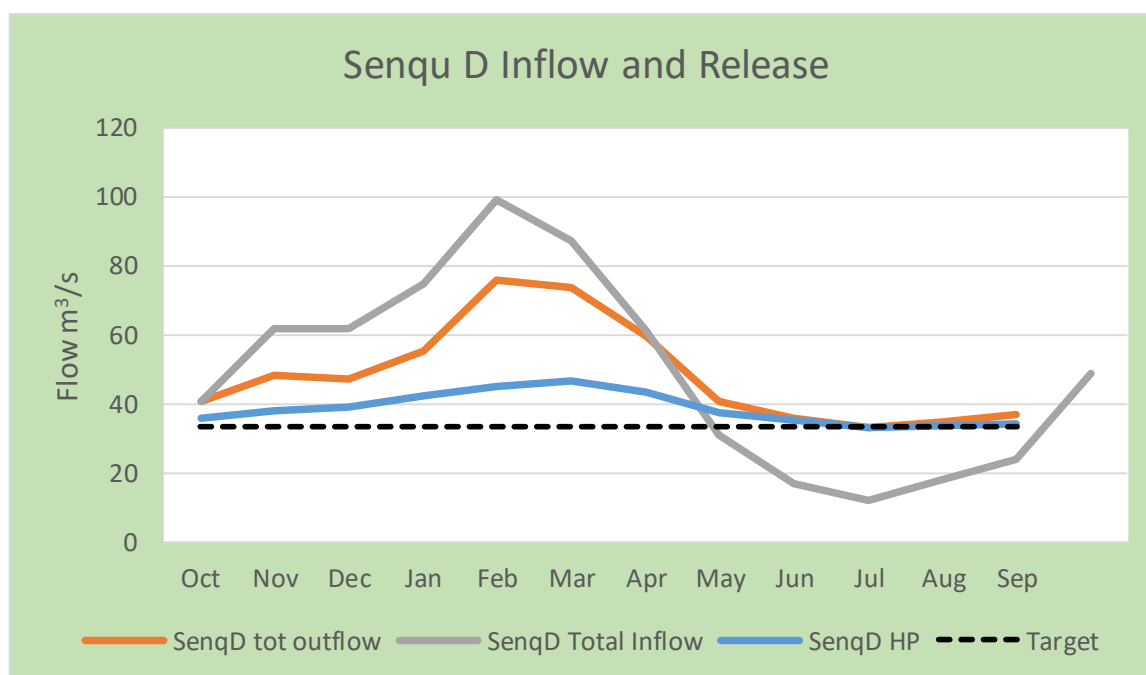
Figure 5-10: Average monthly simulated inflows and releases from Senqu D2 Dam

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 5-4**. 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 mitigation 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 5.5 and 5.6**)
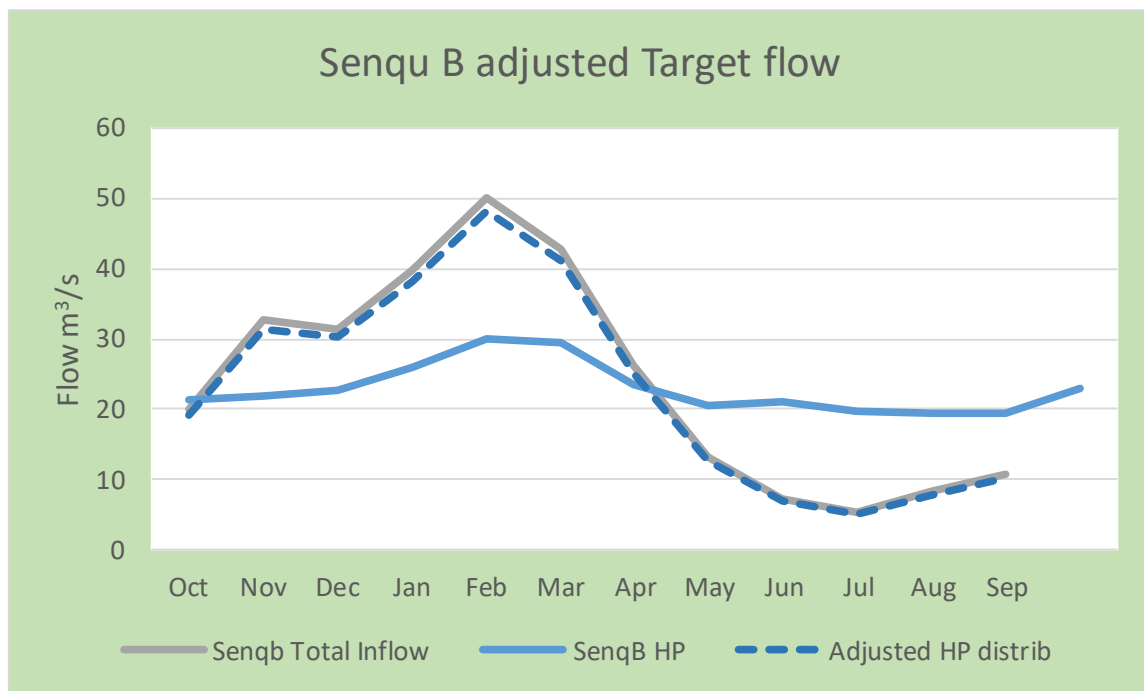
Figure 5-11: Monthly target flows adjusted for implementation in Scenario 6b Senqu B
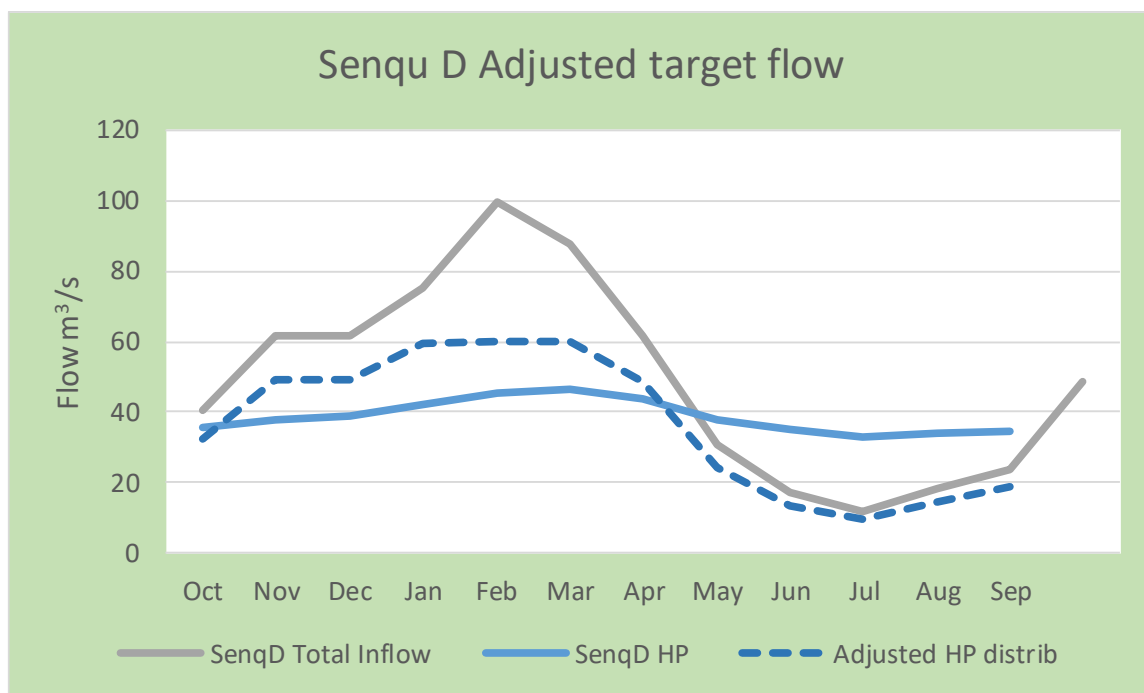
Figure 5-12: Monthly target flows adjusted for implementation in Scenario 6b Senqu D

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 (22.84m³/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.
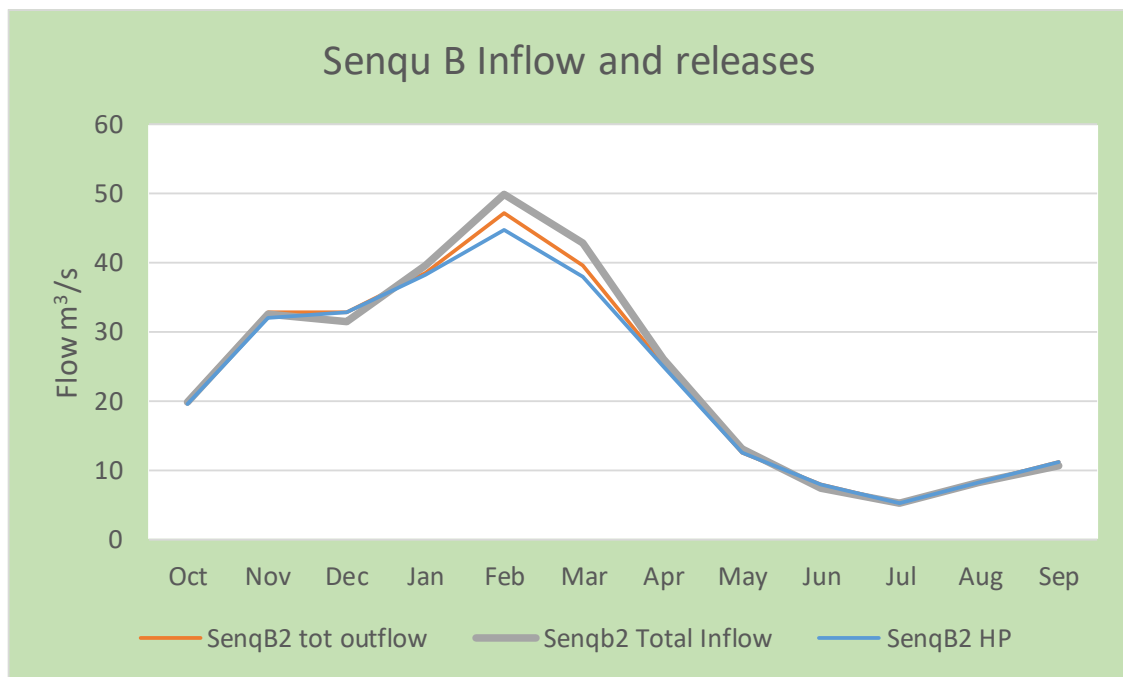
Figure 5-13: Average monthly simulated inflows and releases from Senqu B Dam Scenario 6b
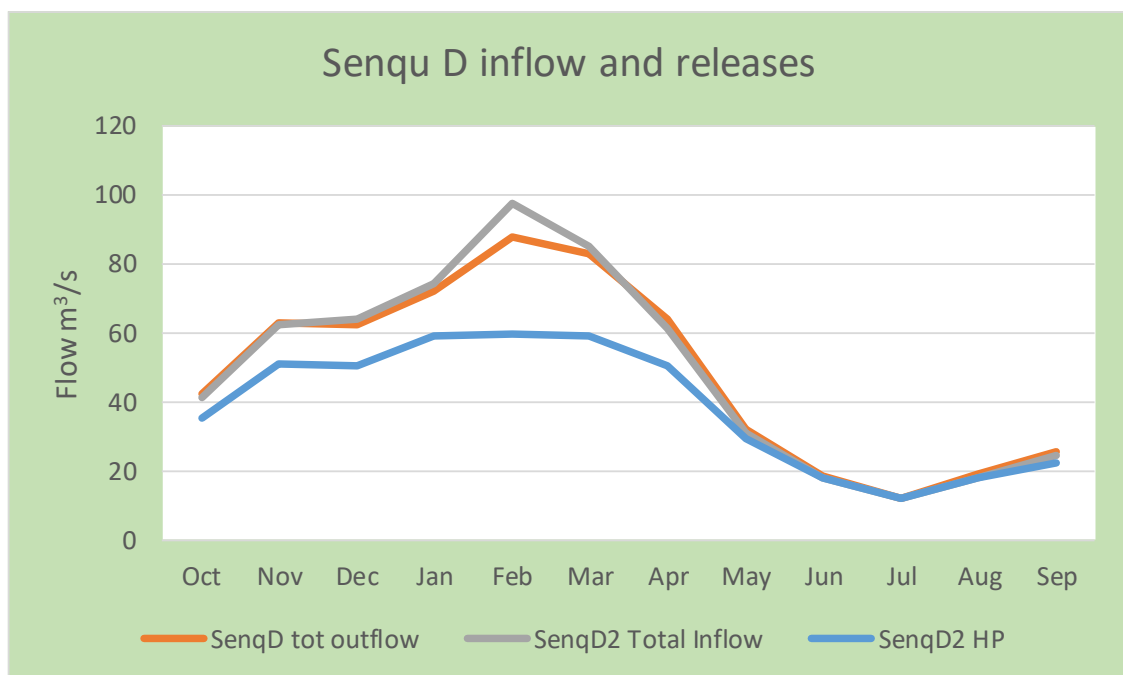
Figure 5-14: Average monthly simulated inflows and releases from Senqu D Dam Scenario 6b

Similar to Senqu B2 dam the average annual flows (38.64m³/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 m³/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 m³/a less, determined as 124 million m³/a. This resulted in the net yield available from Makhaleng Dam to increase to 312 million m³/a in comparison with the 188 million m³/a for Scenario 2g.

Scenario 7b: The net yield from Scenario 7b in comparison with the 2030 Base Scenario was determined as 461 million m³/a. This is higher than the 3 MAR Makhaleng Dam gross yield of 378.4 million m³/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 mitigation 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 m³/a yield of the 461 million m³/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 m³/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 m³/a (See Scenario 2h) which is higher than the net yield from Scenario 8b. This means the total net yield of 318 million m³/a can be made available from Makhaleng Dam when the raised Verbeeldingkraal Dam is used to release some of the mitigation water to the ORP system on behalf of Makhaleng Dam.

5.4   Summary of Selected Scenario combinations to achieve positive water balances

The two largest future developments in Lesotho are Phase ll 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 ll development significantly impacts on the water supply to the downstream users from the main Orange in Namibia and the RSA.

5.4.1   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 m³/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 5-5**).

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.

5.4.2   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 l (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 5-5**) 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 5-5** 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 5-9**) 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 needs 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 mitigation 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 5-5**). 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 mitigation releases from Makhaleng Dam.

These mitigation 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 5-9**).

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 5-1**) 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 5-5**). This means that the mitigation 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 5-9**). 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 mitigation releases that are required from Makhaleng Dam.

SENQU/MAKHALENG OPTIONS
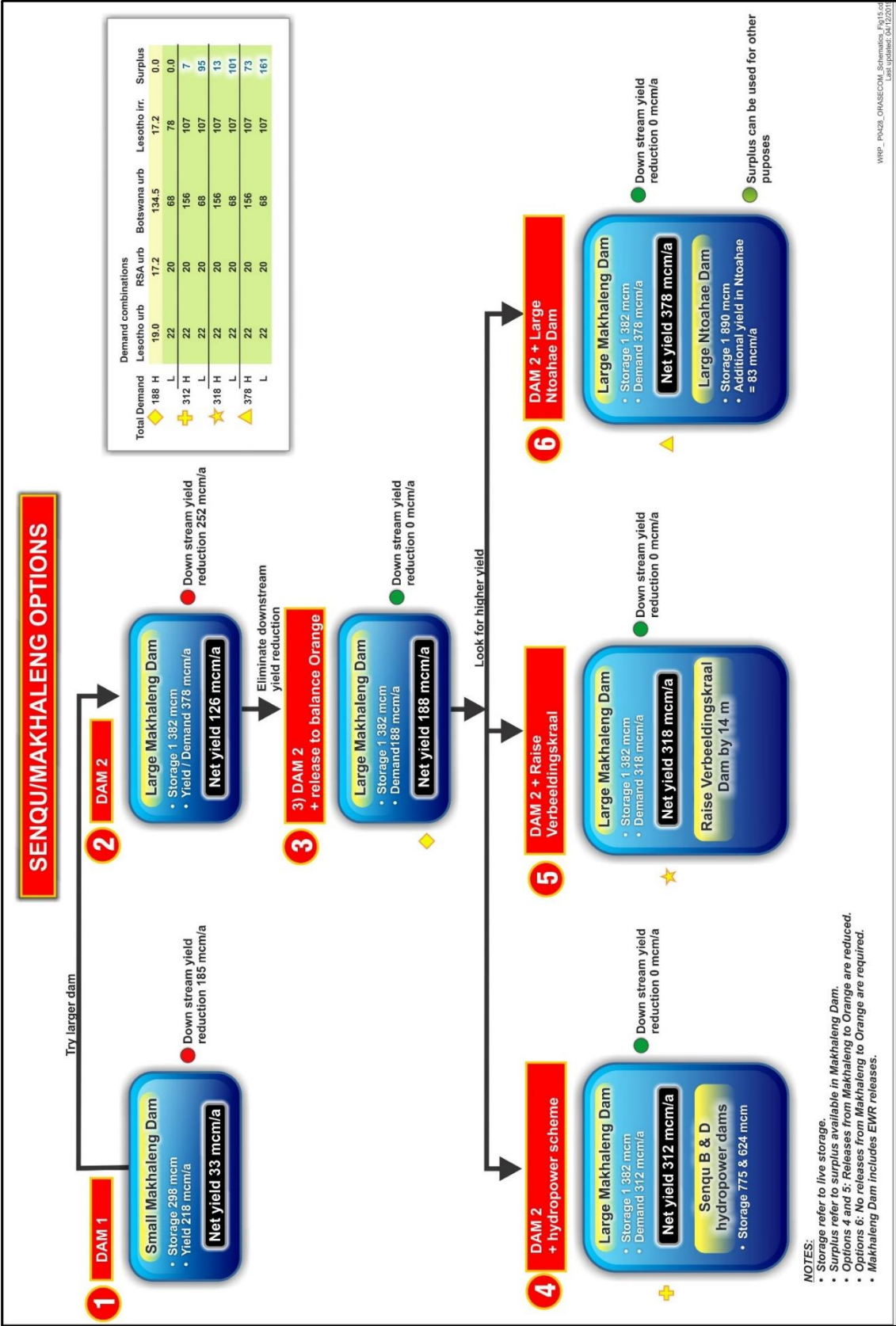
Figure 5-15: Possible Senqu/Makhaleng options

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 5-5**) that the mitigation 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 5-9** 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 5-5**), that no mitigation 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 5-9**). 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 5-5**) 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 5-4** clearly show that Verbeeldingskraal and Ntoahae dams is the two best options with the Verbeeldingskraal URV being the lowest.

5.4.3   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 5-5**). 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:
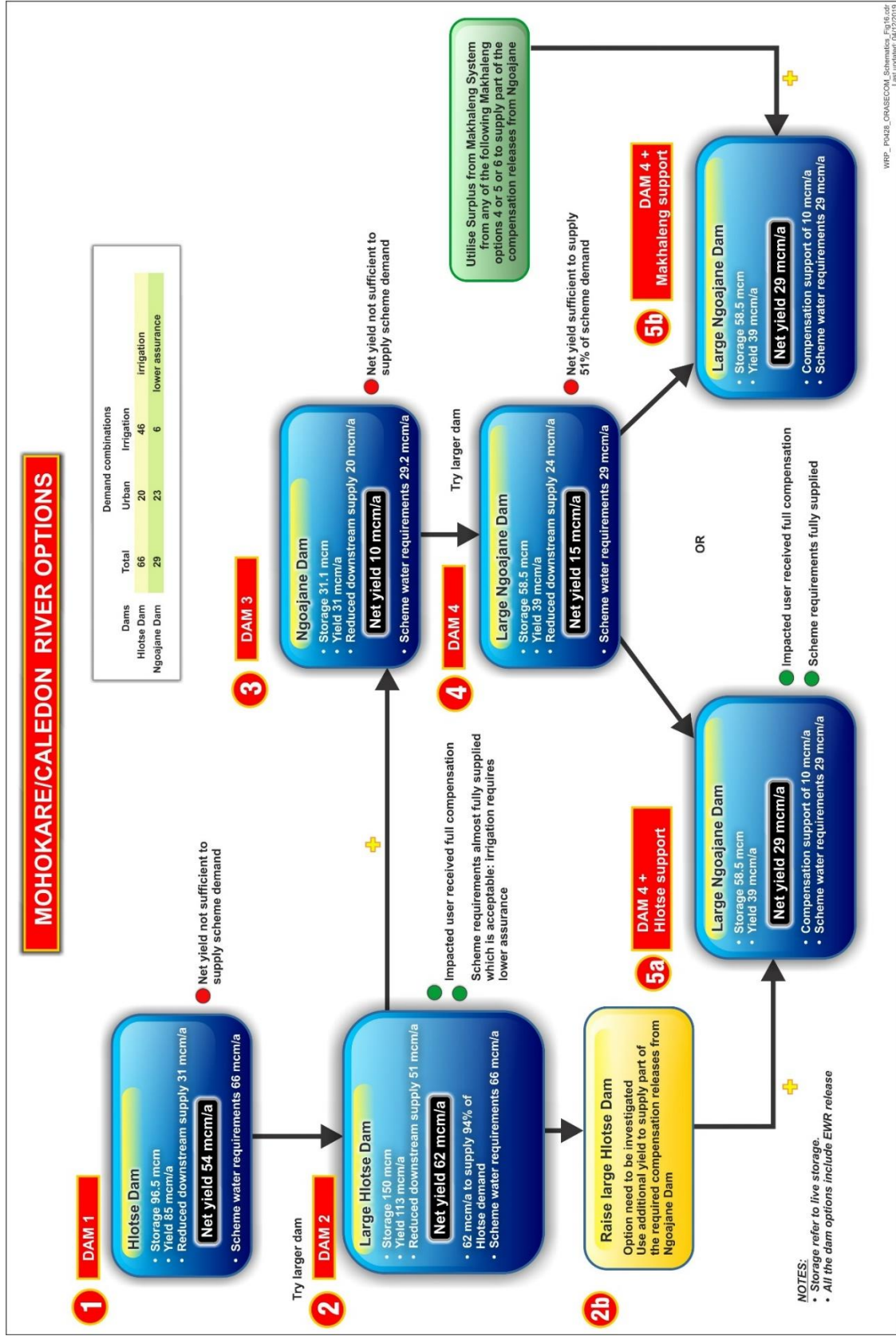
Figure 5-16: Mohokare/Caledon catchment options

- 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 m³/a with the proposed Hlotse Dam in place. Hlotse Dam also resulted in a decrease in the ORP yield of 26 million m³/a. The total demand to be supplied from Hlotse Dam is 66 million m³/a, of which 20 million m³/a is for domestic use and 46 million m³/a for irrigation. Due to the downstream impacts the net yield from Hlotse Dam is 54 million m³/a, (Scenario 3 **Table 5-5**) although the historic firm yield was determined as 85 million m³/a after releasing the EWR. The net yield is thus not adequate to supply the total demand of 66 million m³/a to be imposed on the dam (See Option 1 in **Figure 5-10**).

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 m³ to 150 million m³ (1.5 MAR dam). This resulted in an increased HFY of 113 million m³/a (See **Table 5-5** 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 m³/a, almost equal to the intended demand of 66 million m³/a to be imposed on the dam (see **Figure 5-10** 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 m³/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 m³ gross storage (31 million m³/a net storage) was included for the initial Ngoajane system analysis. The net yield from this Ngoajane Dam was determined as 10 million m³/a (See **Table 5-5** Scenario 4b) due to the reduction in supply to downstream users of 20 million m³/a. Ngoajane Dam can thus not fully support the intended demands of 29 million m³/a to be imposed on the dam (See **Figure 5-10** option 3).

Large Ngoajane Dam – Option 4: As a next possible option a larger Ngoajane Dam (59 million m³ net storage) was thus considered and analysed, increasing the net yield to 13,4 million m³/a (See **Table 5-5** Scenario 4c2). Although the Large Ngoajane Dam can be used to balance the negative impact of 25,6 million m³/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 5-10** 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 mitigation 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 5-5**), to support part of the Ngoajane mitigation releases and restore the water balance.

Results from the analyses, as well as practical experience from the past clearly indicated that the mitigation 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 mitigation 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 mitigation 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 mitigation 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 5.4.2**.

5.5   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 5-11**). Key results from the ORP system stochastic analyses is given in **Table 5-7**.

Figure 5-17: 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 5-8**. This is the yield available after mitigation 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.

Figure 5-18: 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
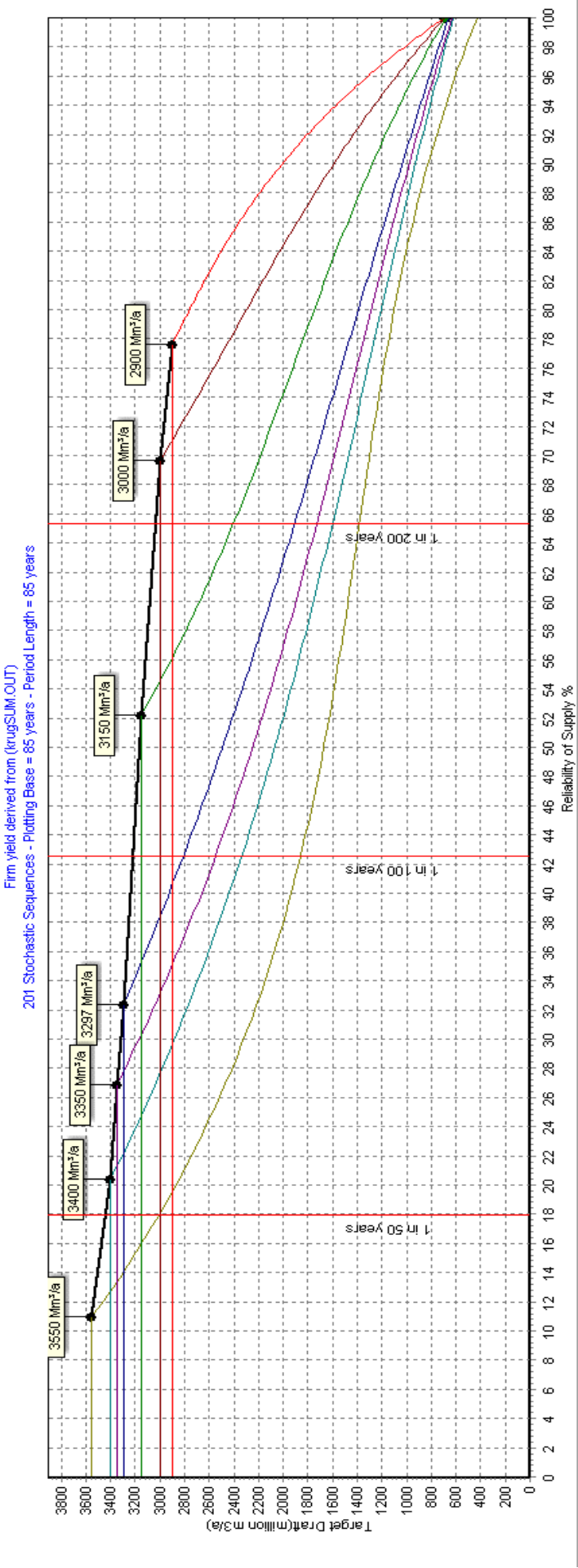
Figure 5-19: Orange River Project long-term stochastic yield curve at 2030 development level

The firm yield line for the Makhaleng Dam long-term stochastic net yield curve (**Figure 5-12**) 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 5-13**) at site S2 with no mitigation releases from Makhaleng Dam. The reason for this significant difference is due to the mitigation releases from Makhaleng Dam in support of the large downstream dams in the Orange River and the related operating rule used to provide the mitigation 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 m³/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.
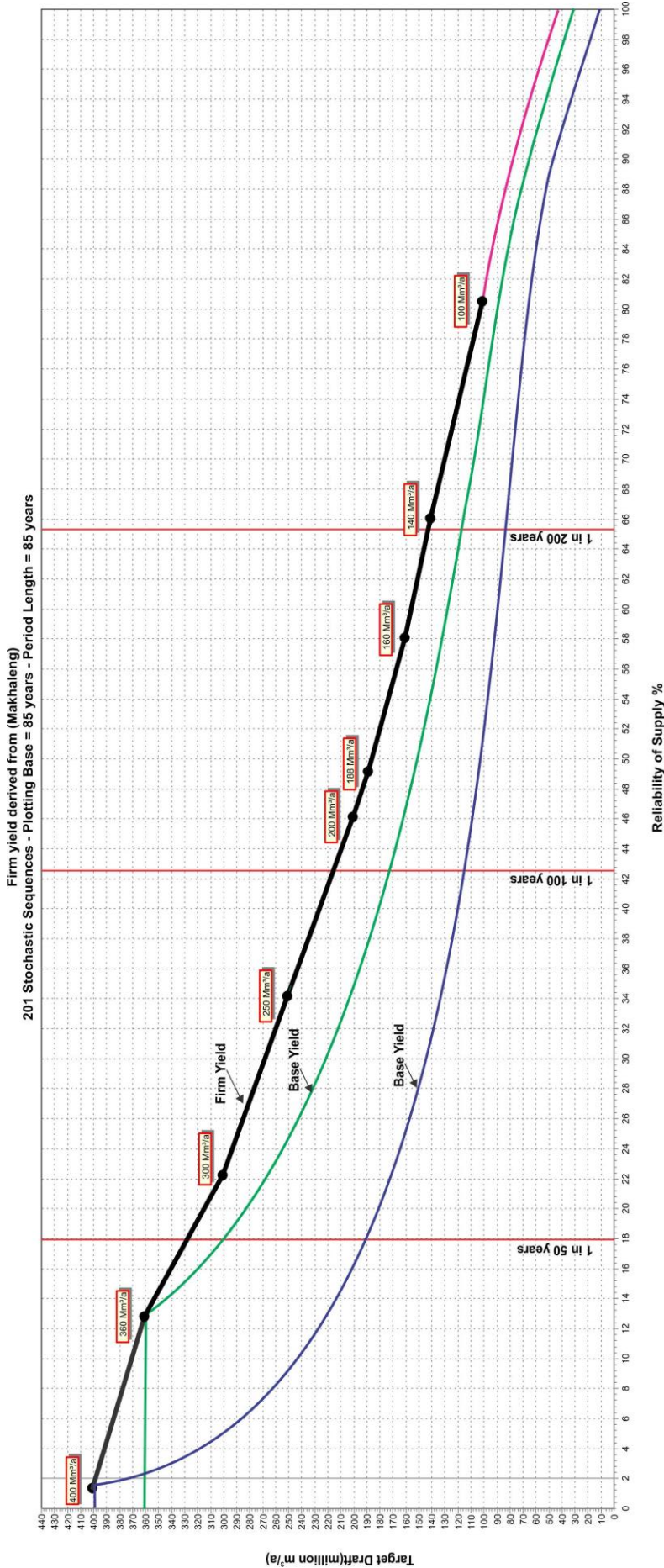
Figure 5-20: Makhaleng Dam long-term stochastic net yield curve at 2030 development level

The long-term stochastic gross yield for the smaller Makhaleng Dam at site S2 was added (**Figure 5-13**) 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 m³ versus 1 382 million m³, the difference in the shape of the long-term stochastic gross yield curves is clearly evident. Due to the mitigation releases from Makhaleng Dam, the yield from the dam significantly reduces at the high assurance levels (**Figure 5-12** versus **Figure 5-13**).
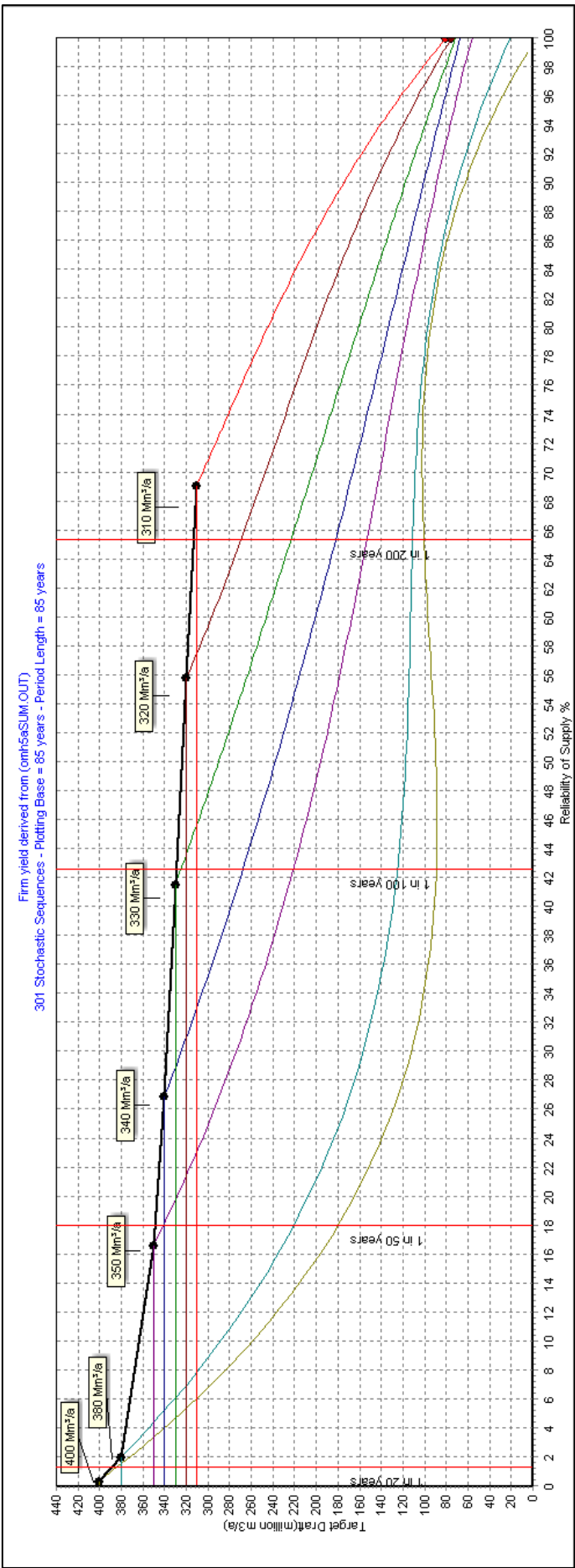
Figure 5-21: Long-term Stochastic gross yield curve: Makhaleng Dam at Site S2, Capacity 810 million m³

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 5-9**.

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 average 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).

Figure 5-22: Firm yield results for Historical and future climate scenarios

Description		Firm Yield for 85year simulation period (million m³/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 m³/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 m³/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%**

6   WATER RESOURCE ASSESSMENT OF A FUTURE DAM ON THE MAKHALENG RIVER IN LESOTHO

6.1   Review and validate hydrological data

6.1.1   Initial Hydrology Development

The hydrology representing the Makhaleng River catchment was first produced as part of the Lesotho Lowlands Study (Parkman, 2004). At that time, the simulated hydrology covered the time period 1935 to 1999. Two incremental catchment time series files were applicable and used to assess the water resources of the Makhaleng River catchment for a specified dam site and abstraction point; the two files were titled MAKDAM.INC and MAKABS.INC. Two flow gauging stations were used for calibration purposes, namely MG19 and MG23. **Figure 6-1** provides a locality map of the applicable flow gauges and incremental catchments.
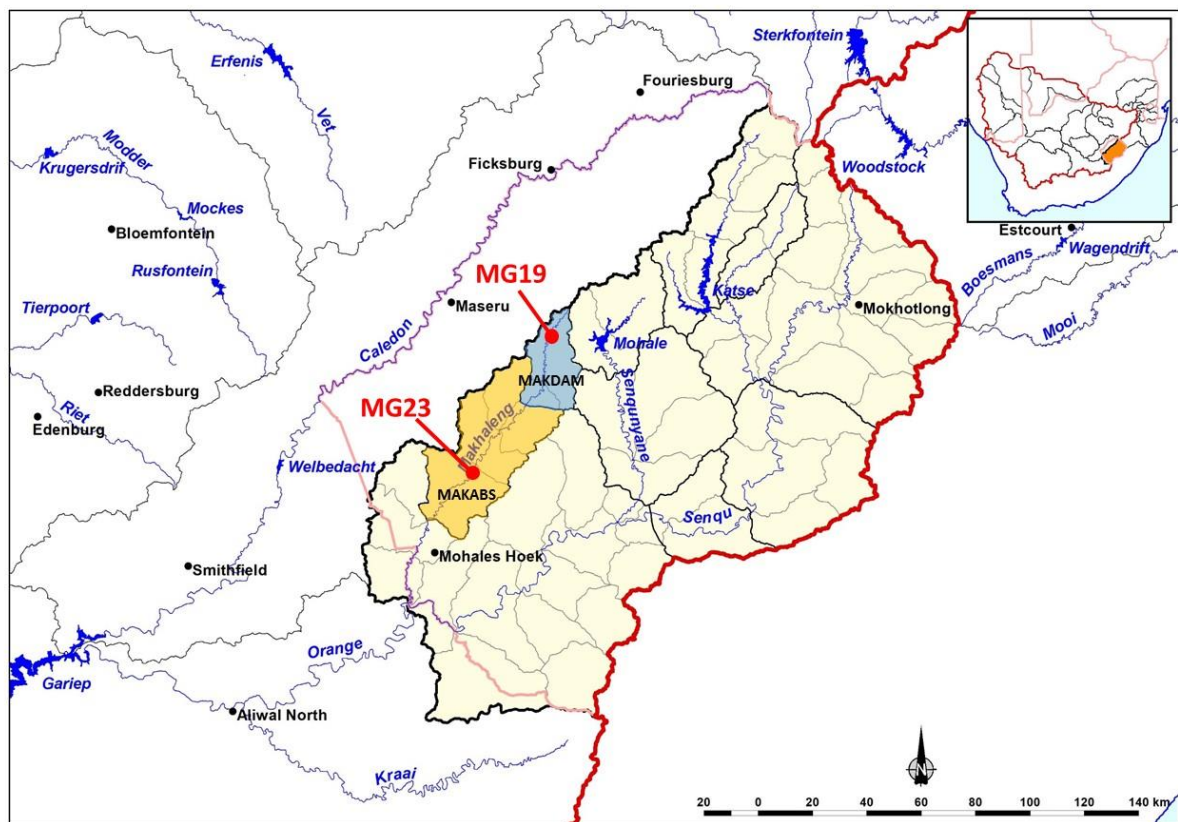
Figure 6-1 :Locality of Makhaleng Incremental Catchments and Flow Gauges

Figure 6-2 provides a Table representing a summary of the calibration statistics for the gauging stations and the incremental hydrology. This Table is extracted directly from the Lesotho Lowlands Report (Parkman, 2004).

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Table 3.13 : Statistics of the streamflow sequences in the Makhaleng catchment.

Statistic	Unit	MG19	MG23	Dam site	Abstraction site
MAR	million m³	30.32	388.27	166.85	365.51
Standard deviation of annual flows	million m³/yr	10.58	161.74	56.99	133.96
Coefficient of variability	%	34.89	41.66	34.16	36.65
Coefficient of skewness	-	0.0989	0.3881	0.3812	0.2759
Range	% MAR	207.81	302.11	341.63	389.59
Autocorrelation coefficient of annual flows	-	0.0542	0.3812	0.0102	0.0798
Mean of logs of annual flows	Million m3	1.4523	2.5504	2.195	2.5307
Standard deviation of logs of annual flows	-	0.1698	0.1951	0.1614	0.1757
Index of seasonal variability	%	23.87	23.61	23.65	22.99

Figure 6-2: Table Extracted from Lesotho Lowlands Report

Figure 6-3 and **Figure 3-4** present the calibration plots of the observed and simulated monthly flows produced using the Pitman Rainfall Runoff Model during the Lesotho Lowlands study.
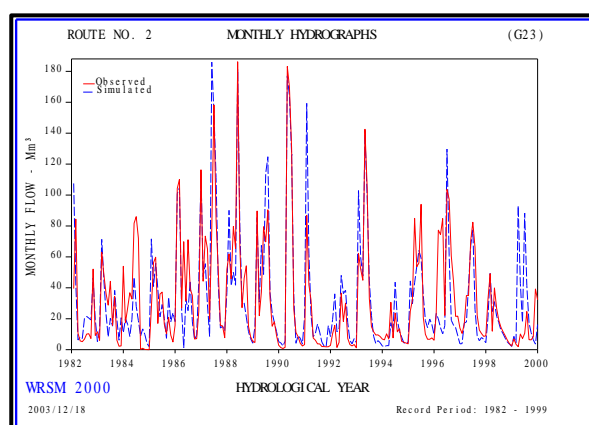
Figure 6-3: Calibration: MG23
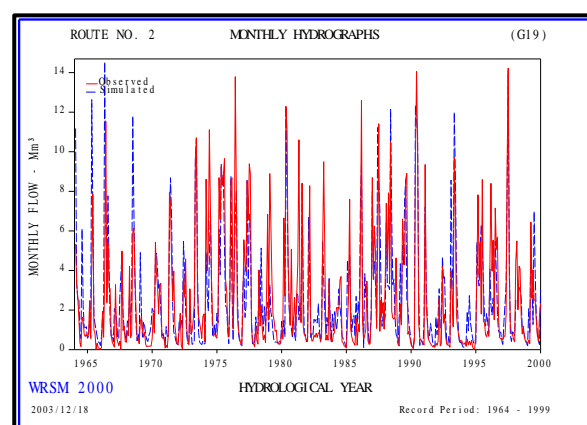
Figure 6-4: Calibration MG19

The calibrations were deemed to be satisfactory at the time based on the statistics of the observed and simulated records.

6.1.2   Hydrology Extension and Incorporation

The initial hydrology representing the Senqu River catchment consisted of eight incremental catchments as presented in **Figure 6-5**. One of the Tasks carried out as part of the ORASECOM Integrated Water Resources Management Plan (ORASECOM, 2014) was to incorporate all available hydrology from other studies and to extend all hydrology to cover the time period 1920 to 2004.
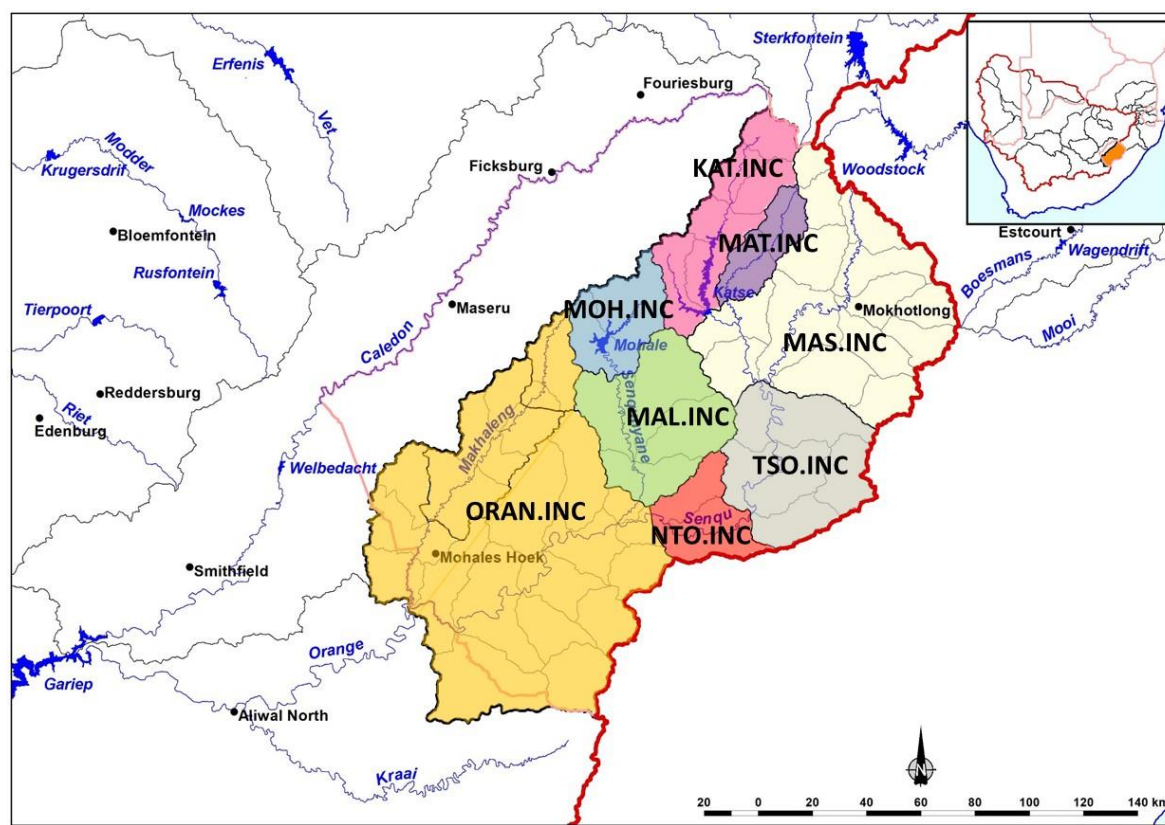
Figure 6-5:Initial Eight Incremental Catchments Representing The Senqu

The actions applicable to the Makhaleng River catchment involved the extension of MAKDAM.INC and MAKABS.INC to cover the required period, and the split in the original ORAN.INC to specifically include the Makhaleng River catchments. Some manipulation of the incremental hydrological files took place such that the overall averages of the combined MAKDAM.INC, MAKABS.INC and ORAN.INC$_{net}$ equalled the original ORAN.INC$_{gross}$. Error! Reference source not found. provides a summary of this. The table shows that the original MAR of the ORAN.INC catchment (1542.7 million m^3/a) was maintained when the catchment was adjusted to the three subdivisions.

Table 6-1: MAR of incremental catchments for varying time periods

Hydrology	Incremental Catchment Area (km^2)	Time Period (years)	MAR (million m^3/a)
MAKDAM.INC$_{orig}$	535	1935-1999	166.8
MAKABS.INC$_{orig}$	1628	1935-1999	365.5
ORAN.INC$_{orig}$	9269	1920-1995	1542.7
MAKDAM.INC$_{new}$	535	1935-1999	174.5
MAKABS.INC$_{new}$	1628	1935-1999	364.9
MAKDAM.INC$_{new}$	535	1920-1995	169.7
MAKABS.INC$_{new}$	1628	1920-1995	354.8

Hydrology	Incremental Catchment Area (km^2)	Time Period (years)	MAR (million m^3/a)
ORAN.INC$_{new}$	7106	1920-1995	1018.2
Sub-total		1920-1995	1542.7
MAKDAM.INC$_{new}$	535	1920-2004	169.7
MAKABS.INC$_{new}$	1628	1920-2004	354.8
ORAN.INC$_{new}$	7106	1920-2004	1018.2

6.1.3   Updated Observed Flow Data

The approach used to validate the hydrological data that is required for the Makhaleng Dam assessment was to obtain updated observed flow gauge records available since the original calibration took place, and to compare the observed records with model simulations. This was done to determine if the model is still simulating in line with observed records. It was found that flow gauge MG19 had closed and was therefore not used in the assessment. Updated raw flow data was obtained for gauge MG23 from DWA Lesotho Hydrology Division, covering the period 2002 to 2015. An additional flow gauge (D1H006) located approximately 20 km downstream from the MAKABS.INC catchment (Lat: -30.15972; Lon: 27.40138) was identified for potential comparisons, and data from this gauge was also sourced from the DWS RSA data base. It is unclear why this gauge was not used in the original calibrations of the Makhaleng hydrology.

Figure 6-6 to **Figure 6-9** provide pictures of the two flow gauges, and a locality map.

Figure 6-6: Flow Gauge D1H006

Figure 6-7: Flow Gauge D1H006

Figure 6-8: Flow Gauge MG23
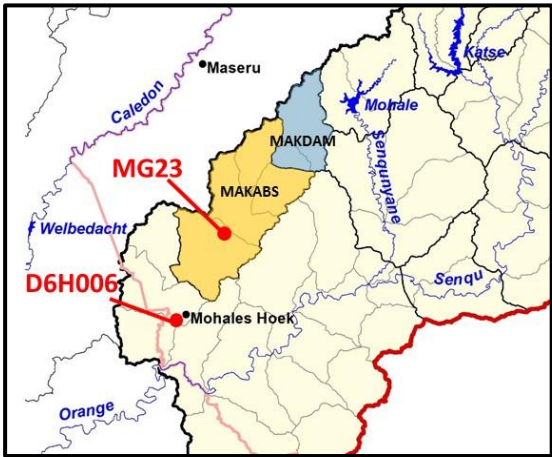
Figure 6-9: Locations D1H006 & MG23

Figure 6-10 and **Figure 6-11** provide plots of the raw flow records. The time series files are presented in **Appendix B**.
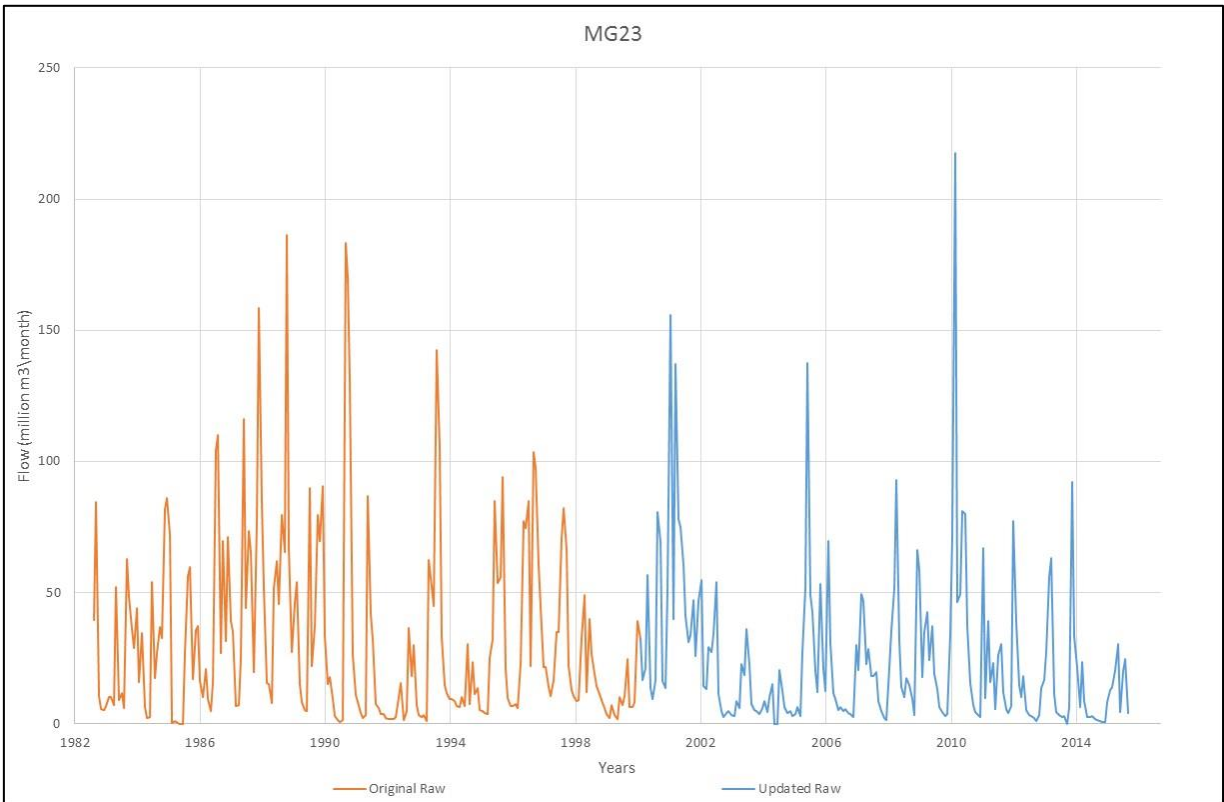
Figure 6-10: Raw Monthly Flows: MG23
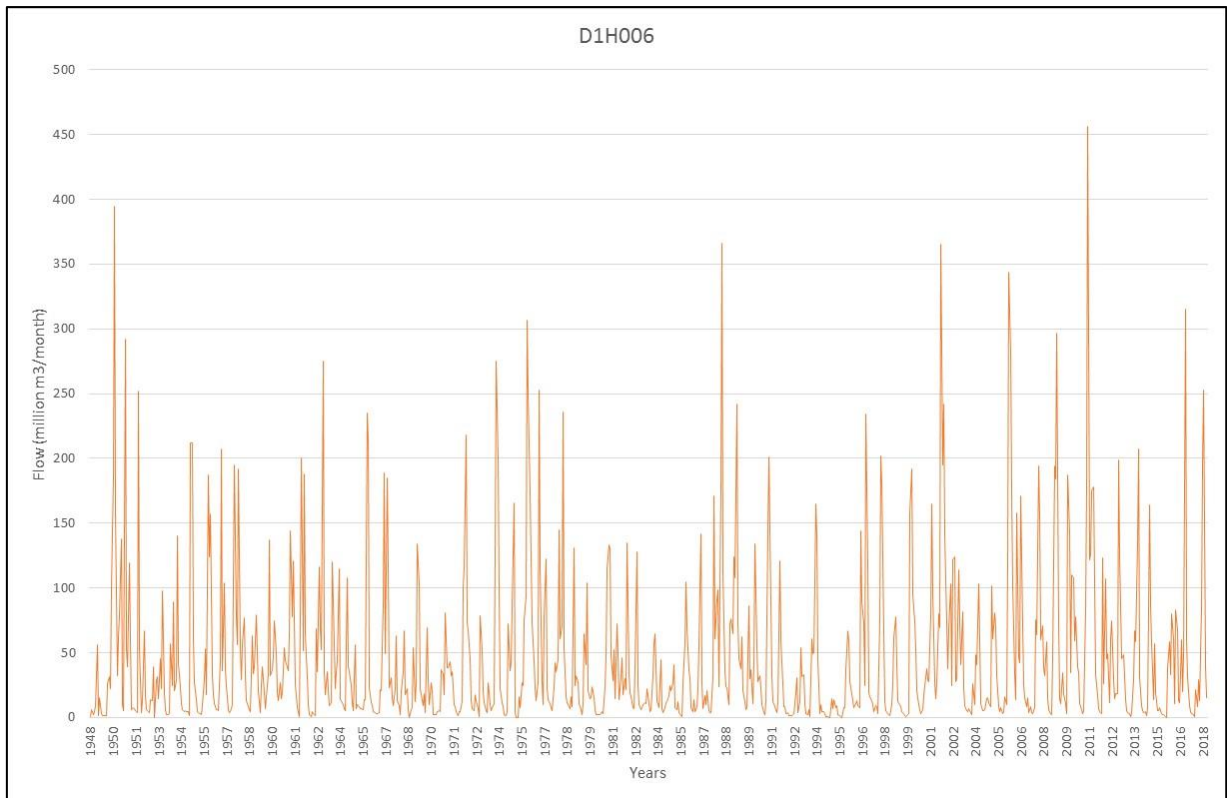
Figure 6-11: Raw Monthly Flows: D1H006

6.1.4   Simulated vs Observed Data

The Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) were configured to represent the present-day catchments and to extract simulated flows from the models at points representing the flow gauges. **Figure 6-12** provides a network diagram of the model configuration.
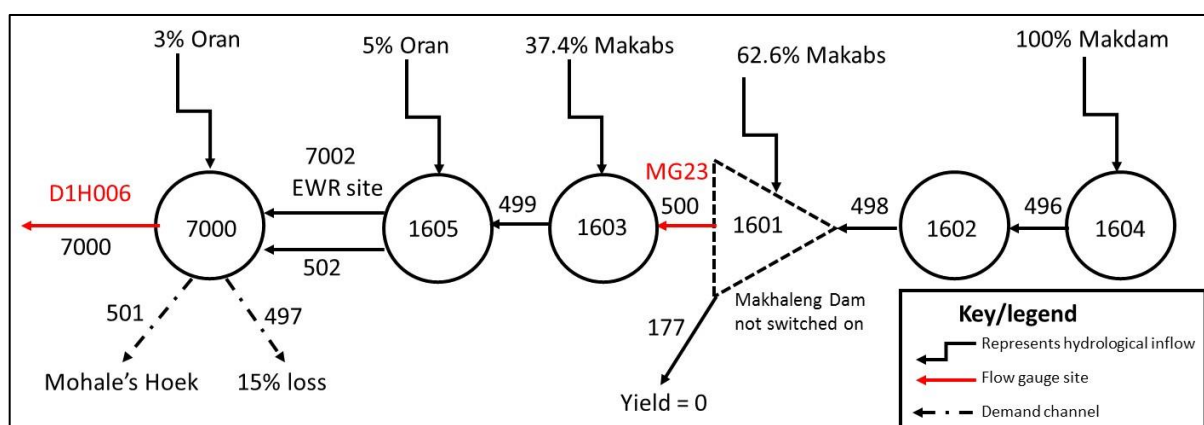
Figure 6-12: Network Diagram of Models Showing Channels Representing Flow Gauges

The WRYM was used to compare the simulated and observed historical flows up until 2004 at the flow gauge points. The WRPM (in stochastic mode) was used to compare the stochastic simulated flows with the observed flows from 2005 to 2018.

Figure 6-13 and **Figure 6-14** provide the results for flow gauges MG23 and D1H006 respectively.
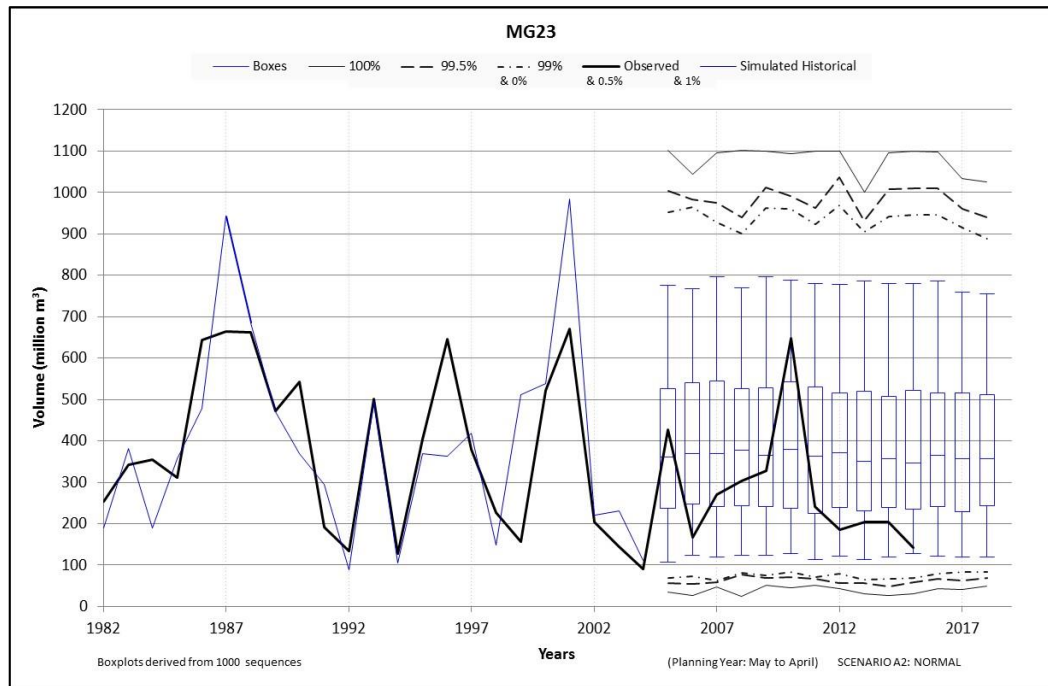
Figure 6-13: Simulated vs Observed Flows: MG23
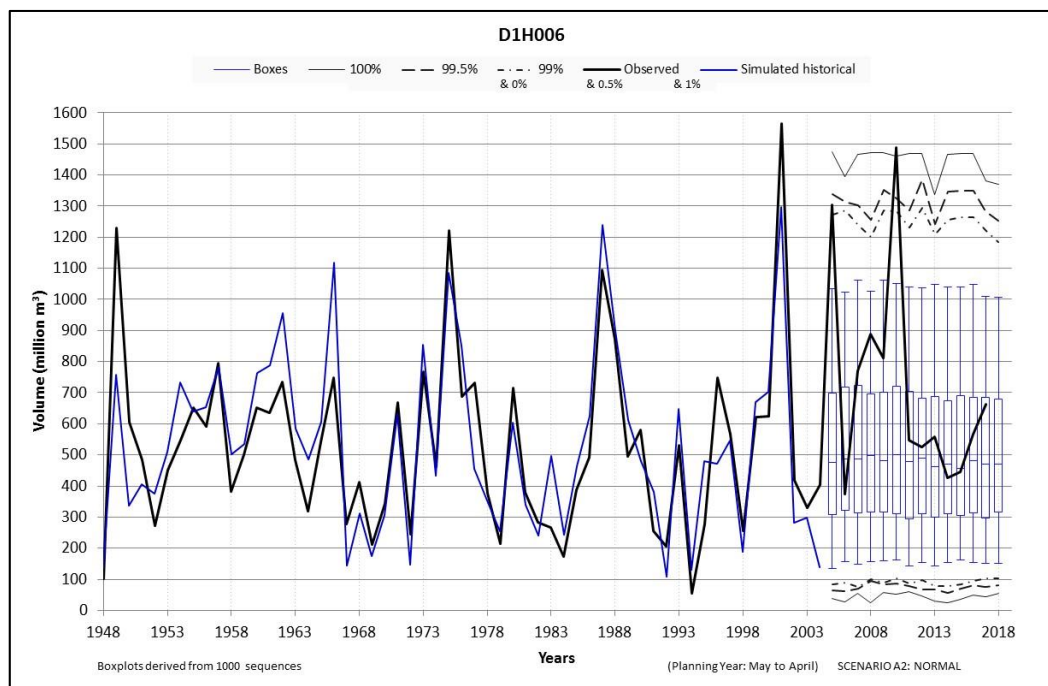
Figure 6-14: Simulated vs Observed Flows: D1H006

The Mean Annual Run-off (MAR) for flow gauge D1H006 and the WRYM simulation over the period 1948-2004 are comparable, with the gauge measuring 525.3 million m^3/a and the WYRM simulating 530.7 million m^3/a. Similarly, the MAR for gauge MG23 for the period 1982-2004 are comparable with the WRYM simulation, with 375.9 million m^3/a measured at the gauge and 388.9 million m^3/a simulated from WRYM. The only noticeable differences on gauge MG23 are the two times where the model simulated higher peaks than observed, in 1987 and 1999. The observed flow gauge records suggest that the gauge measures a maximum flow of approximately 670 million m^3/a, and it is likely that the gauge is not correctly recording the higher flows.

Comparing the simulated stochastic flows of the WRPM between the period 2005 and 2018, indicates that the observed flows fall within the band of stochastic flows. The model does produce some higher flows as well as some lower flows than the observed. The observed flow in January 2011 is greater than the highest stochastic flow generated by the model, but this was known to be a flood of extreme magnitude.

6.1.5   Recommendations Regarding Hydrology

From a yield perspective, low flows are of greater importance when assessing hydrology for dam design. For this reason, it is considered acceptable that the only observed flow that falls slightly outside the band of model generated flows is a high flow. From the observed flow gauging data, it can be seen that the flows included after the original calibration was done, i.e. from 2004 onwards, are never lower than previously measured. There has therefore not been a dryer year since the observed time period that the hydrology spans. The stochastic flows are generated in the models using the historical natural hydrology. Because flows in recent years are higher, it is unlikely that the stochastic flows produced using the extended observed flow data would differ from a low flow perspective. Again, because base flows are considered more important for yield analyses, it is therefore concluded that the original hydrology is suitable for use in the pre-feasibility assessment of the Dam site selection.

Given that flow gauge D1H006 was not included in the original calibration of the hydrology for the Makhaleng River catchment, it is recommended that this be incorporated, and the hydrology reassessed as part of the Dam Feasibility Component. Ideally one would want to consider all available flow gauge data when producing hydrology which should be at a higher confidence level for the Feasibility Phase.

6.2   CATCHMENT WATER RESOURCE MODELLING

When undertaking the water resource assessment there are a few key issues that should be considered which can have a significant impact on the yield and potential viability of any new development. One of the most important and often controversial issues concerns the impact

of any new upstream development on the downstream users. In a river basin system that has surplus water resources, a new dam development may not cause any noticeable impact on the downstream users and in such cases, there may be no need to releasew mitigation flows to support the downstream users since they have not experienced any reduction in their supply. This was the situation with the first phase of the Lesotho Highlands Water Project which was planned back in the 1970's and developed in the 1980's. At this time, there was significant surplus water available for new developments in the Orange/Senqu basin with the result that when the major dams and transfer infrastructure was developed in the Lesotho Highlands, there was no need to supply mitigation releases in support of any of the downstream users. Over the past 30 years, the situation has changed and there is no longer any significant surplus water in the Orange/Senqu basin. Water in the basin has become a scarce resource and it is therefore important to evaluate the impact of any new dam development options on the downstream users and if possible, to quantify any reduction in water availability that will be experienced by them. It should be noted that if it is considered necessary to mitigate the reduction in water availability to the downstream users, then the reconciliation strategies required, should be included in any financial or technical assessment of the proposed development.

In the case of a new dam anywhere in the upper reaches of the Orange/Senqu river basin, the initial yield assessment will determine the possible maximum yield that can be abstracted from the new dam at the location of the dam, referred to as the local yield at the dam. A second basin-wide assessment will then be undertaken to assess the net or incremental yield from the Orange/Senqu river basin as a whole which will be a positive yield but is likely to be lower than the local maximum yield available at the dam site. It is therefore important to present both the maximum local yield as well as the net additional basin yield also referred to as the incremental yield, for any proposed new development. Another important and sometimes confusing issue concerns the required releases from any proposed new development. The term "mitigation releases" is often used to cover the required water to be released from a proposed new dam for environmental purposes. In certain scenarios, an additional volume of water is included to restore the overall balance so that there is no noticeable impact to the downstream users from the proposed development. If both the environmental requirements (usually very small) and the additional mitigation flows (often very large) are combined and shown as "mitigation releases" it can create both confusion and some concern as it may appear that much of the benefit of the proposed new dam is being released for no apparent reason. In such cases, the incremental yield from the proposed new dam may be half of the gross maximum local yield which may, in turn, make a potentially viable project appear to be unviable.

Having highlighted the key issues of the maximum local yield as well as the possible incremental yield of a potential new dam development it is also important to mention one more very significant consideration when assessing any new dam development. The maximum local yield given in the report for each possible new development is the actual yield that can be abstracted at the proposed dam site. This water is available high up in the catchment and as such may have significant additional value due to the fact that it can be used to supply specific areas or consumers which cannot be supplied from any downstream dam developments. Even in cases where the incremental yield may be half of the local maximum yield, the full maximum yield can still be used or diverted to external users. In such a case, it may then be necessary to investigate another development to provide additional yield in the river basin to restore the status quo to the existing downstream users. Releasing water from the new Makhaleng Dam high up in the catchment for this purpose is possible but would not be an attractive strategy due to the fact that water higher up in a catchment has greater value and usually experiences low evaporation making it an ideal location to store water.

The various local yields and incremental system yields provided in the remainder of this section will be presented in a manner in which any mitigation flow required by the downstream users is shown as a separate item and is not included in the "mitigation flows" which relate specifically to the Environmental Flow.

The water resources yield analyses were carried out in support of the Dam Engineers to provide yields for a range of requested dam sites and sizes. Only a few sites were selected for specific model analyses, and results were extrapolated to make decisions relating to the other sites. The following sub-sections describe the scenarios analysed and the results obtained.

6.2.1   Model Configuration

A simplified WRYM data set focusing on only the Makhaleng River Catchment was configured to carry out the yield analyses of the Makhaleng Dam. Adjustments were made to the incremental hydrology upstream of the Dam, depending on the dam site being assessed. **Figure 6-15** provides the basic WRYM network, with "X" and "Y" used to identify where variations took place.
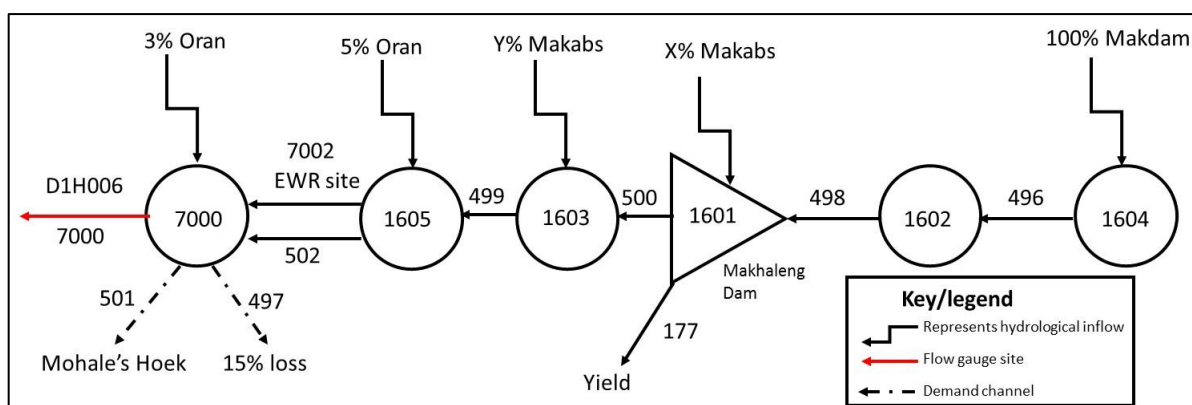
Figure 6-15: Simplified Makhaleng Dam System Network Diagram

Error! Reference source not found. provides the values for X and Y indicated in the diagram for the various dam sites.

Table 6-2: Percentage Hydrology Entering Upstream of The Various Dam Sites Assessed

Dam Site	X% Makabs	Y% Makabs
Lowlands	16.4	83.6
N1	53.5	46.5
TOR	63.7	36.3
S2	70.8	29.2
D4	91.3	8.7

The only other difference between the model configurations for the various dam sites was the height/elevation-capacity relationships for the dams. This was provided by the Dam Engineers and is presented in **Appendix E**.

Additional analyses were carried out to determine the impact of a selected dam size and abstraction on the existing Orange River Project (ORP), namely Gariep and Vanderkloof dams. For these analyses, the larger integrated WRYM configuration was used, incorporating all the catchments upstream of Gariep and Vanderkloof dams. A network layout of this is provided in **Appendix F**. The integrated WRPM was further used to determine the impacts of other systems and sub-systems such as the proposed Noordoewer/Vioolsdrift Dam on the Lower Orange.

6.2.2   Yield Results

The results of the selected yield analyses scenarios are presented in the various Tables and Figures that follow in this subsection. All the results are provided in the form of Historic Firm Yields, i.e. the Dam almost touched empty once in the historic simulation period 1920 to 2004.

Table 6-3: Yield Results of Lowlands Site

Elevation (mamsl)	Capacity (million m³)	Local Yield (million m³/a)
1 715	1 119.61	224
1 705	875.64	218
1 695	670.83	213
1 685	503.98	196
1 670	316.63	168
1 665	267.33	157
1 655	186.92	139
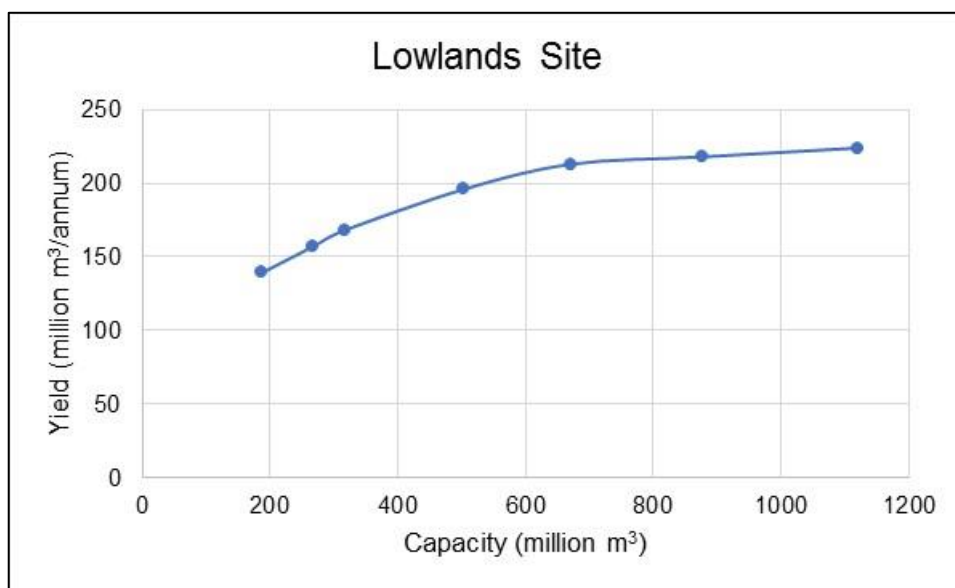
Figure 6-16: Yield Capacity Relationship: Lowlands Site

Table 6-4: Yield results of TOR Site

Elevation (mamsl)	Capacity (million m³)	Local Yield (million m³/a)
1 615	1 234.41	372
1 610	1 094.85	368
1 600	846.14	336
1 585	543.54	290
1 570	316.60	236
1 565	256.61	202
1 555	160.10	145
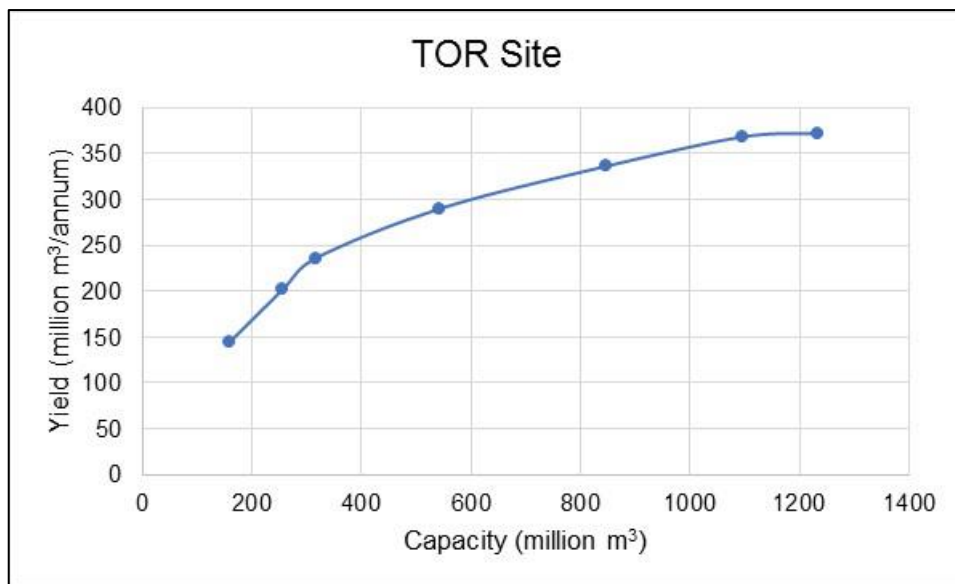
Figure 6-17: Yield Capacity Relationship: TOR site

Table 6-5: Yield Results of Site D4

Elevation (mamsl)	Capacity (million m³)	Local Yield (million m³/a)
1 575	1 696.76	466
1 570	1 488.17	461
1 555	964.03	406
1 540	578.16	340
1 525	312.11	248
1 520	245.44	209
1 515	189.22	175
1 510	143.29	150
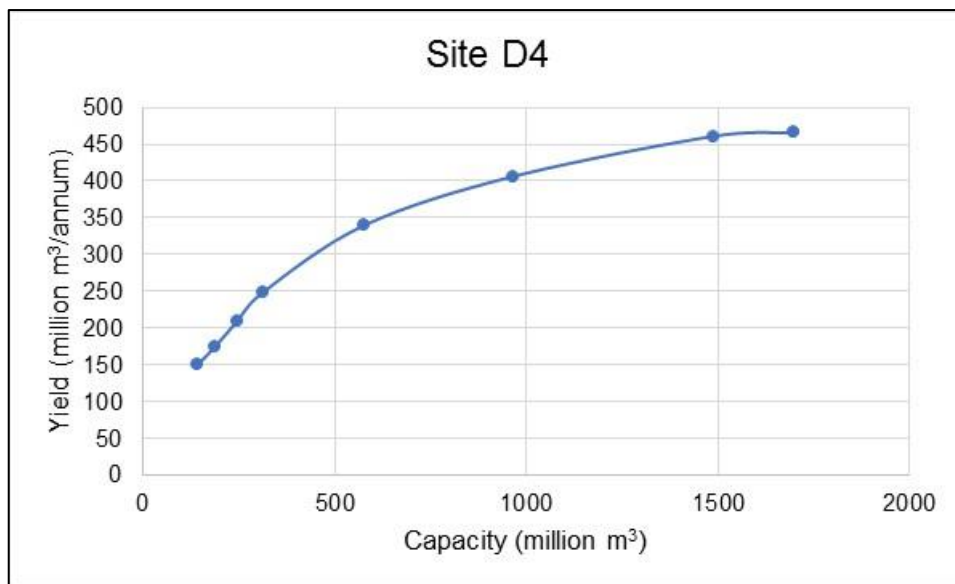
Figure 6-18: Yield Capacity Relationship: Site D4

Table 6-6: Yield Results of Site N1

Elevation (mamsl)	Capacity (million m³)	Local Yield (million m³/a)
1 645	1 467.11	347
1 630	1 028.30	335
1 615	694.74	295
1 605	517.62	268
1 595	371.36	237
1 585	252.74	195

Note: this Yield includes EWR category D
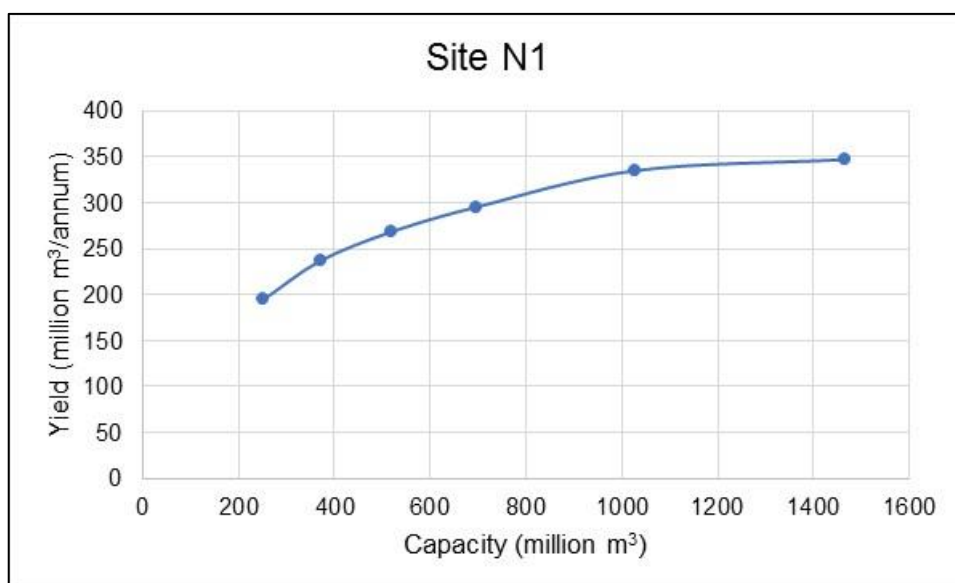
Figure 6-19: Yield Capacity Relationship: Site N1

Table 6-7: Yield Results of Site S2

Elevation (mamsl)	Capacity (million m³)	Local Yield (million m³/a)
1 610	1 738.02	399
1 600	1 381.83	393
1 590	1 073.57	376
1 580	810.02	344
1 570	589.35	310
1 560	409.97	272
1 550	270.35	213
1 540	165.42	151

Note: this Yield includes EWR category D
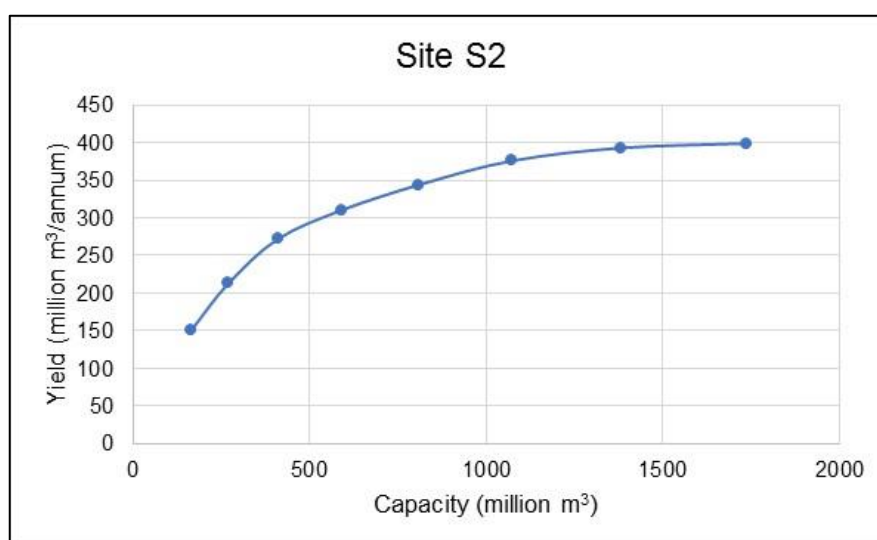
Figure 6-20: Yield Capacity Relationship: Site S2

6.2.3   Impact of Environmental Water Requirements

Additional analyses were carried out for Site 2 including the Environmental Water Requirements provided by the environmental specialists. Two Environmental Water Requirement scenarios were analysed to assess the sensitivity of the available yields on the environmental category (A to D) selected. Originally a category D was selected which is the category that will have the least impact on the resulting yields. This was found to have very little impact on the yields due to the relatively small water volume required under this low category. A second analysis was undertaken using category B to provide an indication of the potential impact of what would most likely be the most demanding category from a yield perspective. It still remains to be seen which category would actually be selected, and this would be assessed in the Feasibility phase. The Environmental Water Requirement

requirements based on the natural flows for both category D and category B are included in

Table 6-8: Yield Results of TOR Site Excluding and Including EWRs

Elevation (mamsl)	Capacity (million m³)	Local Yield excl EWR (million m³/a)	Local Yield Incl EWR D (million m³/a)	Local Yield Incl EWR B (million m³/a)
1 615	1 234.41	372	366	282
1 610	1 094.85	368	363	278
1 600	846.14	336	330	256
1 585	543.54	290	284	207
1 570	316.60	236	231	159
1 565	256.61	202	198	147
1 555	160.10	145	140	115
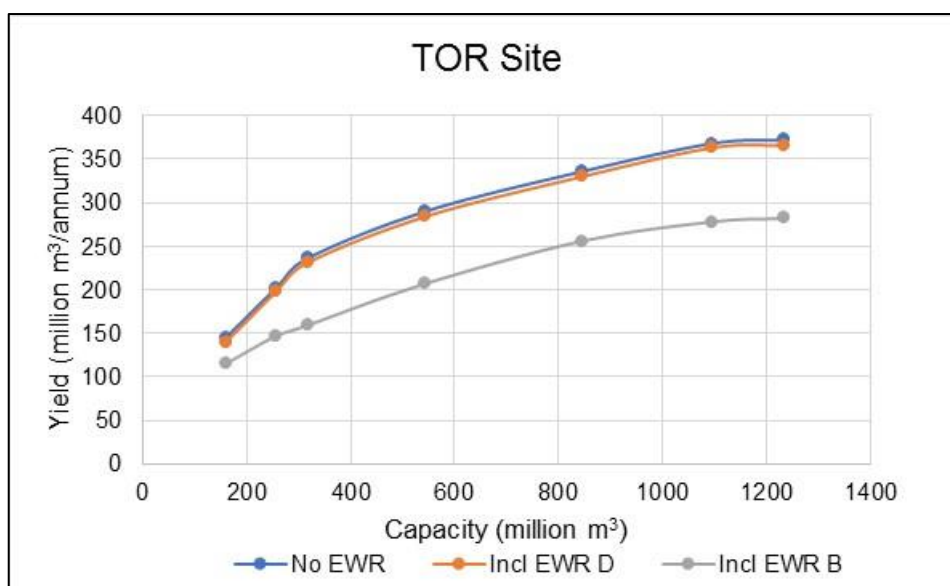
Figure 6-21: Yield Results Including Two EWR Categories

The results show that a category D Environmental Water Requirement requiring a release of
approximately 19% of the inflows to the dam has very little impact on the yield. If a category B
Environmental Water Requirement is imposed on the system, the impact on the yield is highly
significant. Substantial mitigation releases are required from Makhaleng Dam or an alternative
development to restore the impact of Makhaleng Dam on the downstream Gariep and
Vanderkloof dams. If a category B EWR is later indicated from the Phase II work or the
feasibility study, these mitigation releases can be utilised to supply the flow required for the
increased Makhaleng EWR.

The reserve for the Upper Orange in the RSA has not yet been determined and was thus not
included in the analysis. The Lower Orange Preliminary Reserve was recently determined and

signed off by DWS RSA. This Preliminary Reserve was included in the modelling of the system and is part of the water requirements to be supplied from Gariep and Vanderkloof dams.

6.2.4   Impact of Makhaleng on Downstream Water Users

Basin Wide Impacts: As part of the Core Scenario analyses as captured in the Updated Core Scenario Report (ORASECOM, 2019) the Core Scenario was analysed using the Water Resource Planning Model (WRPM). This model takes into account the growth in water requirements over time as well as new development options as developed over the planning period of 2018 to 2050. Results from this model, therefore, provide the basin-wide impacts of growing demands and developments\interventions options over time.

The Core Scenario data sets as defined for the Planning Model include the operating rules and water requirement projections as per the status in 2018. In addition, the current 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 all captured in the data sets. A detailed description of the Core Scenario is given in the Updated Core Scenario Report Section 6 (ORASECOM, 2019). The Core Scenario Planning Model data set represents mainly the surface water resources schemes and users for the entire basin as in 2018 at the start of the analysis, and then added the future developments and increasing water requirements at the date according to current planning. The main future water resource developments included are given in **Table 6-9**.

A large number of Core Scenario and related sensitivity analyses were carried out and documented in the Updated Core Scenario Report (ORASECOM, 2019). For the purpose of this "Pre-feasibility Phase 1" report, only a few selected key scenarios are discussed to illustrate the basin-wide impact of the upstream developments.

The Orange River Project (ORP) is basically the section of the Orange/Senqu river basin which is supplied from the two largest storage reservoirs in Southern Africa, namely Vanderkloof and Gariep. These two dams have a combined storage capacity of some 9 000 million m^3 representing approximately half of all storage capacity in the whole of the Orange/Senqu river basin including all of the Vaal River basin.

Table 6-9: Core Scenario future developments

	Cluster 1: Orange River Project Scheme future improvements	Implementation	Project Type
1	Utilise the lower-level storage in Vanderkloof Dam	2019	Dam
2	Real-Time flow modelling and monitoring in the Lower Vaal downstream of Bloemhof Dam and in the Orange River downstream of Vanderkloof Dam to the Orange River mouth;	2020	Dam
3	Building of the Verbeeldingskraal Dam upstream of Gariep Dam;	2032	Dam
4	Formally agreed to Environmental Water Requirements & release to Orange River Mouth	2025	Integrated Water Management
5	Noordoewer/Viooolsdrift Dam used as a resource for Namibia and RSA, and for flow re-regulation for Orange-Senqu River Mouth	2028	Dam
6	Development of 12 000ha for resource-poor farmers of which ± 30% was already developed	Ongoing	Integrated Water Management
7	Polihali Dam (Lesotho Highland Water project (LHWP) Phase ll and connecting tunnel to Katse Dam; using new operating rule	2025	Dam
	Cluster 2: L-BWT Scheme		
8	Makhaleng Dam	2030	Dam
9	L-BWT pipeline, transfer pipe to Gaborone/Lobatse and irrigation	2033	Pipeline/Pumping Scheme
	Cluster 3: Lesotho Lowlands		
10	Hlotse Dam: Urban/rural demands plus irrigation developments	2029	Dam
11	Ngoajane Dam: Urban/rural demands plus irrigation developments	2034	Dam
	Cluster 4: IVRS intervention options		
12	Thukela transfer further phase	2037	Pipeline/Pumping Scheme
13	Desalination and re-use of mine water effluent;	2025	Wastewater Treatment
14	Utilise Croc Return Flows in Tshwane to reduce the load from Rand Water via Vaal	2025	Pipeline/Pumping Scheme
	Cluster 5: Caledon to Greater Bloemfontein transfer		
15	Tienfontein pump station capacity increase to 7m^3/s;	2040	Pipeline/Pumping Scheme
16	Increase Tienfontein pumping capacity to 3.87 m^3/s Novo Transfer scheme capacity to 2.2 m^3/s; to Rusfontein Dam	2019	Pipeline/Pumping Scheme
	Cluster 6: Greater Bloemfontein internal resource improvements		
17	Raise Mockes Dam to increase storage capacity	2023	Dam
18	Increase Maselport WTW Capacity to 130 Ml/d	2021	Wastewater Treatment
19	Planned indirect reuse from the Bloem Spruit WWTW (± 16 million m^3/a); Maselspoort	2021	Wastewater Treatment
20	Planned direct reuse from the Bloem Spruit WWTW (± 11 million m^3/a); Maselspoort	2030	Wastewater Treatment
	Cluster 7: Gariep to Greater Bloemfontein Transfer		
21	Pump station and pipeline from Gariep Dam to Bloemfontein Phase 1	2023	Pipeline/Pumping Scheme
22	Pump station and pipeline from Gariep Dam to Bloemfontein Phase 2	2034	Pipeline/Pumping Scheme
	Cluster 8: Neckartal Scheme		
23	Neckartal Dam irrigation demands (large schemes)	2028	Dam
24	Neckartal Dam hydropower releases	2021	Dam
	Cluster 9: Integrated Water management options		
25	Removal of unlawful irrigation	Ongoing	IWM
26	WCDM Irrigation	2020	IWM

| 27 | WCDM Urban and Industrial | 2018 | IWM |

These two large storage reservoirs capture water from Lesotho as well as the upper parts of the Orange River basin and provide a reliable and continuous flow of water into the lower Orange River mainly for the large-scale irrigation along the Orange River in South Africa and Namibia.

In the late 1980's and early 1990's, the initial system analysis carried out as part of the Orange River System Analysis study (DWAF,1993) indicated that Phase 1 of the Lesotho Highlands Water Project could be fully implemented without lowering the yield from the Orange River Project below its planned requirements. (See **Figure A-2 in Appendix A**) This analyses highlighted that Phase 1 of the Lesotho Highlands Water Project would not impact negatively on any of the users supplied from the ORP system and no mitigation releases from any of the LHWP Phase 1 dams would be necessary. The analysis further indicated that there was still a small surplus available from the ORP.

The Orange River Reconciliation Strategy Study (DWS, 2015) completed in 2015 clearly indicated that the inclusion of Polihali Dam will impact significantly on the ORP system resulting in deficits that will be experienced in the water supply from the ORP users. DWS (RSA) at the time decided to over the long-term not make any mitigation releases from Polihali Dam to rectify the downstream impact due to the high value of the water in the Vaal River System. Additional storage would rather be created in the Orange River System to make up for the yield lost from the ORP due to Polihali Dam, of which Verbeeldingskraal Dam was one of the selected developments.

Up until approximately the year 2016, there was always surplus water resources in the Orange/Senqu river basin even after including the revised estimates for the environmental requirements. As new dams have been developed and the existing users have increased their water use due to natural population growth etc, the surplus water in the basin has now been utilised to the point that there is basically no surplus water in the basin that can be used without first developing new storage capacity. Any new developments in either Lesotho or the upper reaches of the Orange River basin in South Africa will therefore impact on water availability along the lower reaches of the Orange River. For this reason, any proposed new dam developments must be carefully analysed using the systems models to assess the impacts of the proposed developments, and if necessary, propose some form of additional storage at some point in the system to ensure that the existing water users in the basin are not adversely affected.

In order to carry out the impact assessment of Makhaleng Dam on the Orange River Project, the Water Resource Yield Model (WRYM) data set previously used for Orange River analyses was used. The last analyses undertaken for the Orange River Project date back to 2013 when the model was used in the study for Phase 3 of the ORASECOM Integrated Water Resources Management Plan. From this study, it was found that the total available yield from the Orange River Project was 3 252 million m^3/a.

The final data set used in the 2013 analyses was used as the basic starting point for a new assessment. The first step in the process was to repeat the previous analysis and ensure that the model was producing the same results as in the 2013 study. Having established the same yield results, the model was then modified to first include Polihali Dam followed by Makhaleng Dam which is expected to be in place by approximately 2030. The various water demands throughout the river basin were then updated within the model to the projected 2030 development levels and in addition, Verbeeldingskraal Dam was included together with the utilization of the Vanderkloof Dam Lower-level Storage. It should be noted that Verbeeldingskraal Dam and the Vanderkloof Dam Lower-level Storage are two development options that are required to mitigate the reduction in yield from the Orange River Project due to the construction of the Polihali Dam, which is already underway. From the results given in

Table 6-10, it shows that the reduction in the Orange River Project yield due to the inclusion of Polihali Dam is 200 million m^3/a (Base Scenario A versus Scenario 1). By utilizing these two intervention options (Base Scenario B) it was possible to restore the yield balance in the Orange River Project and provide a small surplus estimated to be in the order of 45 million m^3/a or 1.4%.

The data set was then modified to represent the current configuration of the Makhaleng River catchment as used to carry out the WRYM analyses described under **Section 6.2.2**. The Environmental Water Requirements based on the "D" category were included and the hydrological splits were adjusted. A 3 MAR Makhaleng Dam was included at the S2 dam site (Scenario 2) to determine the 2030 base yield of the Orange River Project. The 2030 Base Scenario B was simulated again with the Environmental Water Requirements and Makhaleng Dam turned off. The yield of the 2030 Base Scenario B was confirmed to be 3 297 million m^3/a which indicates an increase in yield of .45 million m^3/a when compared to the original 2013 yield for the Orange River Project of 3 252 million m^3/a, as mentioned before.

Four additional scenarios were then carried out as shown in **Table 6-10**. It should be noted that the basic data set was identical to the 2030 Base Scenario B with the specific changes itemised in the scenario description. The results presented, therefore, represent the relative changes to the local yield as well as the impacts on the overall system yield.

Table 6-10: Impact on ORP Scenarios and Results

Scenario	Historic Firm Yield (million m³/a)		Reduction in ORP Yield (million m³/a)	Overall Incremental Yield Increase (million m³/a)	Description
	ORP	Other Local Yield/demand			
Scenario1 existing system	3200				The existing infrastructure at 2020 levels but including the system demands as expected in 2030. i.e. it excludes Polihali Dam
Scenario A	3 000	Polihali Local yield 391	200	191	Same as **Scenario 1** but including Polihali Dam with full 391 local yield from the dam.
Scenario B	3 297				Same as **Scenario A** but including Verbeeldingskraal Dam and utilization of Vanderkloof Lower-Level storage
Scenario 2 Large Makhaleng Dam	3 254	Demand imposed on Makhaleng 200	40	160	Same as **Scenario B** with a 3 MAR Makhaleng at site S2. Demand on Makhaleng of 200 and 178 mitigation releases to ORP
Scenario 2g Large Makhaleng Dam	3 297	Demand imposed on Makhaleng 188	0	188	**Scenario 2** with demand from Makhaleng reduced from 200 to 188
Scenario 2h Large Makhaleng Dam	3 045	Demand imposed on Makhaleng 378	252	126	**Scenario 2** with no mitigation releases to ORP and full local yield of 378 from Makhaleng Dam.
Scenario 2j Small Makhaleng Dam	3122	Demand imposed on Makhaleng 218	175	33	**Scenario 2h** with no mitigation releases to ORP and full local yield of 218 from smaller Makhaleng Dam.

The results shown in Error! Reference source not found. should be considered as preliminary values which may be refined through further stochastic analyses as part of Phase 2 of the Pre-feasibility study. They mainly highlight the key analyses to assess the local yield from the Makaleng Dam for both a large dam (3 MAR = 1 382 million m³ live storage,) and a smaller dam (0.65 MAR dam with a 298 million m³ live storage,) that is just sufficient to meet the proposed transfer demands. The dam development will clearly have an impact on the availability of water from the downstream Orange River Project and mitigation measures

required to restore the water availability to the downstream users may therefore be required. This have been indicated where appropriate. It should be noted that the mitigation flows can be released directly either from the new Makhaleng Dam or from some other development option in the Orange/Senqu river system, such as the proposed Verbeeldingskraal Dam or the proposed Vioolsdrift Dam for example. Further analyses of the different options for supplying the mitigation flows are discussed in **Section 6.2.5** of this report.

Scenario 2 includes Base Scenario B with the addition of a 3 MAR Makhaleng Dam at the S2 site and a 200 million m^3/a transfer/demand imposed on the dam which resulted in a reduction in yield from the Orange River Project of 40 million m^3/a. **This indicates that the incremental yield increase resulting from this development option is 160 million m^3/a (i.e. 200 million m^3/a - 40 million m^3/a).** Should the full 200 million m^3/a local yield be abstracted from the dam (eg to supply to Gaborone via the pipeline) it will therefore be necessary to provide approximately 40 million m^3/a from some other development lower down in the system to mitigate the yield reduction from the Orange River Project as Makhaleng Dam was not able to supply all the required mitigation releases.

Scenario 2g also includes the 3 MAR Makhaleng Dam at the S2 site and simulates the scenario where the yield from the Orange River Project system is unaffected by the new dam. To avoid the dam having an impact on the yield from the Orange River Project, the operating rules are selected to allow the new dam to provide some support to downstream users when required and the remaining local yield is therefore reduced to some degree. The demand abstracted from Makhaleng Dam in this scenario is reduced from 200 million m^3/a to 188 million m^3/a, which is the maximum local yield that can be abstracted from the Makhaleng Dam without reducing the yield from the Orange River Project. For this scenario, the mitigation releases from Makhaleng Dam were thus sufficient to restore the downstream yield and be able to take 188 million m^3/a from Makhaleng Dam.

Scenario 2h includes the 3 MAR Makhaleng Dam at the S2 site but represents the option where the maximum local yield is abstracted from the new dam and no mitigation releases are made from the dam (the relatively small environmental releases are still being made). This scenario effectively provides an indication of the maximum local yield that can be abstracted from a 3 MAR Makhaleng Dam, but it must be noted that some form of additional development in the system will be required to restore the yield balance at the Orange River Project. **This Scenario indicates that the maximum local yield available at the dam site of the 3 MAR Makhaleng Dam is approximately 378 million m^3/a.** This scenario indicates a reduction of 252 million m^3/a from the yield from the Orange River Project and additional yield would

therefore have to be provided to restore the balance to the downstream users. This will be discussed and analysed in more detail in the subsequent Phase 2 of the project

Scenario 2j represents the option when a smaller Makhaleng Dam is considered at site S2 which is just sufficient to supply the full estimated target transfer of 218 million m^3/a. This scenario indicates a reduction of 175 million m^3/a from the yield from the Orange River Project and additional yield would therefore have to be provided somewhere in the system to restore the balance to the downstream users.

Noordoewer/Vioolsdrift Dam

When the various system analyses were undertaken, the results from the combined study by Namibia and the RSA on the Noordoewer/Vioolsdrift Dam were unavailable and the study was still in progress.   The study focused on two possible dam size options for the Noordoewer/Vioolsdrift Dam, a large, and a medium size dam. For the purpose of the Core Scenario, the medium size dam was selected although a sensitivity analysis was also undertaken to assess the impacts of a large Noordoewer/Vioolsdrift Dam. The operating rules for both scenarios were identical to ensure that releases from Vanderkloof Dam would be made to support the users between Vanderkloof and Noordoewer/Vioolsdrift dams. Additional water would be released from Vanderkloof Dam only in cases where the proposed Noordoewer/Vioolsdrift Dam could not support the water requirements between the dam and the river mouth.

It is important to note that the Core Scenario indicated in **Table 6-9** includes the Noordoewer/Vioolsdrift Dam from 2028 onwards, Makhaleng Dam from 2030 onwards and the high transfer to Botswana from 2033 onwards. Mitigation releases were made from Makhaleng Dam to restore the balance in the ORP. Hlotse Dam with its demands was included from 2029 and Ngoajane Dam and demands from 2034 onwards.

Results from the planning analyses showed that deficits in the increased Namibia irrigation demand start to occur from 2043 onwards if the medium Noordoewer/Vioolsdrift Dam is considered. With the large Noordoewer/Vioolsdrift Dam in place, no deficits occur until after 2050. In both scenarios, the same expected growth in the Namibia Irrigation requirement was used.   These results should be confirmed once the Noordoewer/Vioolsdrift Dam study is completed so that the final dam size and the updated growth in irrigation can be included in the analysis.

In the most recent report of May 2020 for the Noordoewer/Vioolsdrift Dam study, the medium sized dam has been replaced with a small dam. The large dam, however, remains the same size as the dam already analyzed and described above. The revised Namibia demand to be supplied from the large dam also remains the same as previously used and therefore the results presented for the large dam option remain valid.

Orange River Mouth Environmental impacts

The current annual Environmental Water Requirements to be released from Vanderkloof Dam for the Orange River and river mouth amount to 289 million m^3/a, which has more recently been shown to be insufficient. DWS RSA has since reassessed the requirements and approved the new figures which will be released from Vanderkloof Dam from 2022 onwards. These new Environmental Water Requirements for the Preliminary Reserve were included in the modeling of the current Core Scenario.

The final agreed and approved reserve for the Orange River System must therefore still be determined and the figures used in this report may therefore change in future. Previous Environmental Water Requirement studies already indicated that the preferred ecological environmental requirement would result in a decrease in the yield available from the Orange River Project which will obviously have a significant impact on the overall yield balance in the Orange/Senqu system. While it is accepted that the final reserve must still be determined, the preferred ecological environmental requirement was used in the Core Scenario and implemented in the Planning Model by 2028 in association with the large Noordoewer/Vioolsdrift Dam.

With all the planned upstream developments in place, the Planning Model results for the Core Scenario indicated no deficits in the assurance of supply in the Lower Orange until after 2043 on the assumption that agreed Water Conservation and Water Demand measures are implemented successfully. Should these water conservation measures not be implemented successfully, the system yield failures start to occur around the year 2038. The Core Scenario includes the Makhaleng Dam option that releases mitigation water in support of Gariep Dam to have a zero impact on the ORP yield.

As the final Reserve still need to be determined, a sensitivity analysis was carried out using the Preliminary Reserve from 2022 until the end of the simulation (2050). This led to a significant increase in the water supply in the Lower Orange, and subsequently no deficits were experienced. It is expected that the Final Reserve figures will not differ significantly from the

Preliminary Reserve figures used in the Core Scenario in which case the reserve will most probably be supplied at the required level of assurance until at least 2050.

6.2.5   Confidence bands and climate change

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 were downscaled, and bias corrected to obtain acceptable regional meteorological 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 in the Water Resources Yield Model (WRYM) to determine the related yield impacts.

For the Makhaleng sub-system the average impact from the six climate change models were found to be 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. In all the results from the climate change task it was evident that the GFD climate change model results represented an outlier in comparison with results from the other models. The yield impact results given in Error! Reference source not found. represented a large dam at the S2 site on the Makhaleng River.

Table 6-11: Firm yield results for Historical and future climate scenarios

Description	Local Historic Firm Yield for 85year simulation period (million m³/a)		Percentage difference of local Firm Yield results for the climate change scenarios compared to the local Historical Firm Yield	
CCM	Scenario 1 (Adjusted rainfall)	Scenario 2: (Adjusted rainfall and evaporation)	Scenario 1 vs. local Historical Firm Yield	Scenario 2 vs. local Historical Firm Yield
Yield based on the historic flow sequences 378 million m³/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%**

From the analyses carried out as part of the Climate Change task it was found that almost all the results from the six different climate change models were within the range of results produced from the stochastic analyses. This is also evident from the long-term stochastic yield results for the S2 Makhaleng Dam given in Error! Reference source not found., although it represents a slightly smaller Makhaleng Dam than the one selected for the climate change impact analyses.

A long-term stochastic yield analysis was also undertaken using the Site S2 option, size 810 million m³. This dam provided a historic firm yield result of 344 million m³/a, slightly lower than for the larger Makhaleng Dam used for the Climate Change impact analysis.

The long-term stochastic yield results are presented in Error! Reference source not found. and the graph provided in **Figure 6-34**. These yield results were determined for the scenario when no mitigation releases were released from Makhaleng Dam to balance the impact of Makhaleng Dam on Gariep and Vanderkloof dams.

Table 6-12: Long Term Stochastic local Yield Results

Recurrence Interval	1 in 20 year	1 in 50 year	1 in 100 year	1 in 200 year
Annual risk of supply failure	5%	2%	1%	0.5%
Yield (million m³/a)	386	349	329	314

The climate change impact on the yield available from Makhaleng Dam is small and do not require adjustments to the yield results obtained from the historical data.

The stochastic analyses are however important to provide a wider range of yield results at different assurance levels. It was found that the range of the stochastic yield results in general includes the range of yield results produced from the climate change impacts, using the six different climate change models.
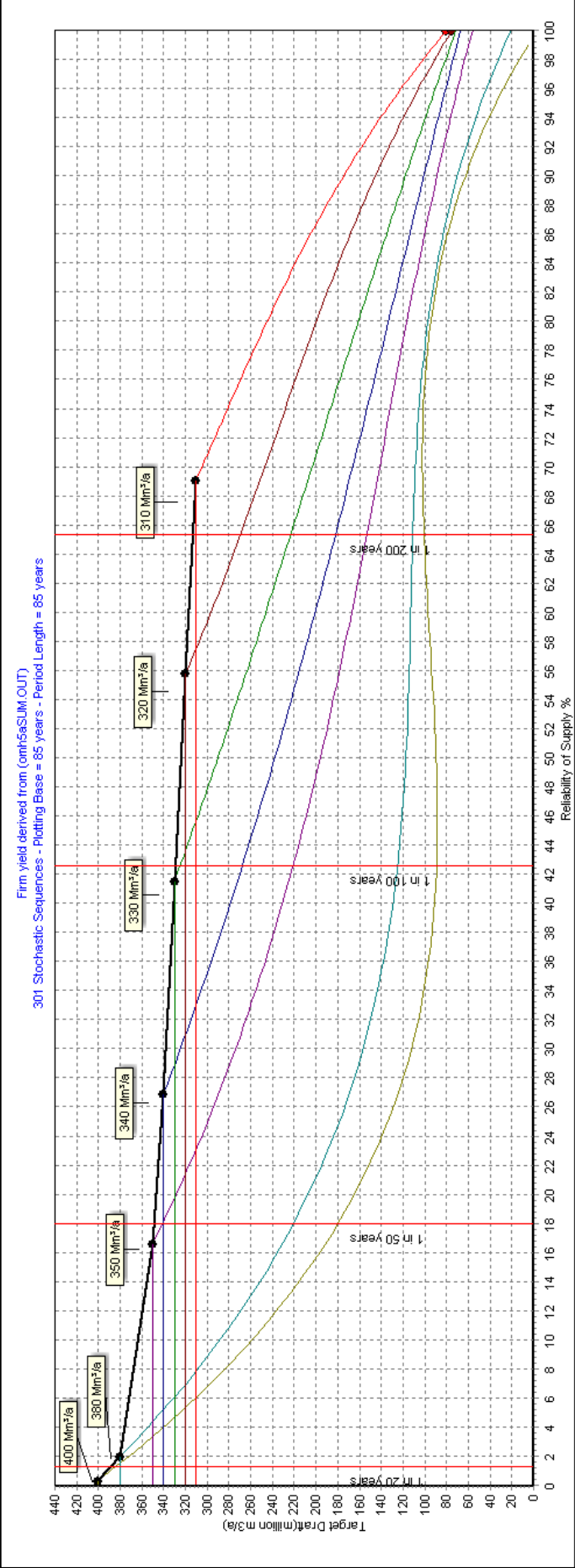
Figure 6-22: Long Term Curve: Site S2, Capacity 810 million m³

6.2.6   Summary of Water Resource findings relating to the dam on the Makhaleng River

The local yield available from the proposed Makaleng Dam (**Section 6.2.2**) at the two final selected dam sites is estimated to be in the order of 380 million m^3/annum which is more than sufficient to supply the required high transfer volume to Botswana as well as to supply the RSA and Lesotho estimated future water requirements imposed on this scheme. Abstracting this water from the proposed Makhaleng Dam, however, will result in a reduction in available yield from the Orange River Project of approximately 200 million m^3/a as highlighted in **Error! Reference source not found.**.   It is therefore important to ensure that the shortfall to the downstream users is made up from some other resource developments. It can be provided directly from the proposed Makhaleng Dam by additional river releases, however, it may be more efficient to use one of the numerous developments in the system since keeping water in an elevated low evaporation environment is usually a more effective storage strategy.

Using the option to provide all the mitigation releases from Makhaleng Dam will require a reduced transfer volume from Lesotho to Botswana and allow for very limited supply for possile irrigation developments in Lesotho. Combining this option with a relative small additional resource development option to increase the net (incremental) yield available from Makhaleng Dam should be considered.

The results provided in Error! Reference source not found. therefore indicate that sufficient local yield can be generated at the proposed Makhaleng Dam site to supply the full requirement for the high transfer scenario. Some additional development will, however, be required to mitigate the loss in yield from the downstream resources. **Table A-8** in **Appendix A** provides further details of the demands versus the resource capability for options that includes the possible supply to Greater Bloemfontein.

From **Section 6.2.5** it is clear that there are several promising options that can be used to provide some or all of the required mitigation flows required to restore the water yield to the downstream users. Some of the options that were investigated as part of this study in accordance with the guidelines specified in the Terms of Reference include the following:

- Hydropower schemes in Lesotho. The options in the Senqu River comprise two dams, the Senqu B and Senqu D. By operating these two dams in the correct manner in combination with the large Makhaleng Dam will increase the net yield of the dam from 188 to 312 million m^3/a.

- Raising of the planned Verbeeldingskraal Dam by approximately 14m in combination with the large 3 MAR Makhaleng Dam will increase the net yield of the dam from 188 to 318 million m^3/a.
- Building a large Ntoahae Dam in the Senqu River in combination with the large Makhaleng Dam will increase the net yield of the dam from 188 to 378 million m^3/a.

These options can provide in excess of 100 million m^3/a for other use such as for irrigation developments in Lesotho or support to the Greater Bloemfontein area, etc.

For the high transfer option, the large Makhaleng Dam was not able to provide sufficient mitigation releases as there was still a deficit of 40 million m^3/a yield in the downstream ORP system. For this option Makhaleng Dam was able to supply a maximum of 219 million m^3/a mitigation releases

Table 6-13: Demand versus yield balances for Makhaleng Dam (S2 site)

Description	Gross Water Requirement imposed on Makhaleng Dam (million m^3/a)	
	High transfer option	**Low transfer option**
Botswana	156	68
RSA	21	21
Lesotho	22	22
Namibia	0	0
Total	**199**	**111**
Yield Resource capability (million m^3/a)		
Local yield at dam	378	378
After transfer remaining yield	179	267
Mitigation releases if direct from the dam	219**	190
Remaining Yield	**-40**	**77**
Remaining yield when mitigation releases are supplied from another development	**179**	**267**
Incremental/net Yield	159	188*
Gross requirement	199	111
Remaining Yield	**-40**	**77**

If the Final Reserve for the Orange River is similar in magnitude to the Preliminary Reserve (currently being used), the water supply to the Lower Orange users and river mouth will be supplied at the required assurance of supply even after the large Makhaleng Dam has been commissioned with related mitigation measures in place.

7   CONCLUSIONS AND RECOMMENDATIONS

7.1   Core Scenario

7.1.1   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 ll 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 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.

7.1.2   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.

7.1.3   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 mitigation 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.

7.1.4   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.

7.1.5 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.

7.1.6 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.

7.1.7   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.

7.1.8   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.

7.1.9   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.

7.2   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.

7.2.1   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 mitigation 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 mitigation releases to be made from Hlotse and Ngoajane dams.

7.2.2	**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 m³/a. The gross HFY then available from Makaleng Dam is 378 million m³/a with a net yield of only 126 million m³/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 m³/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 m³/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 m³/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 m³/a and 30.8 million m³/a respectively. The net system yield increases due to Hlotse and Ngoajane dams are however only 54 million m³/a and 10 million m³/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 m³/a for the ORP system, although the large Makhaleng Dam was used to partly support the ORP system by means of mitigation releases.

- The reduction in yield to the Greater Bloemfontein system, Maseru and smaller Lesotho towns along the Mohokare River (-6.4 million m³/a) brings the total reduction (ORP reduction of 45 million m³/a included) in yield/water supply to 51.4 million m³/a for Hlotse and Ngoajane dams combined.

- With some increase in storage at both Hlotse and Ngoajane dams of 15 million m³ and 27.3 million m³ respectively, the gross yield from the two dams can be increased by 9.3 million m³/a and 8 million m³/a, thus a total of 17.3 million m³/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 mitigation 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.

7.2.3   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 mitigation 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 m³/a with the highest yield of 448 million m³/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.

7.3   Water Resource assessment of the proposed dam on the Makhaleng River

The latest available data was collected from the streamflow gauge MG23 and D1H006 and compared to the values generated by the WRYM model of the catchment. The latest measured runoff was found to compare reasonably well with the data in the existing catchment model.

A storage yield relationship was developed for the lowlands site, N1, TOR site, S2, and D4. The maximum yield from any of the sites was achieved at about three times the MAR. From these relationships, the height of a dam to achieve a yield of 200 million m³/a was determined as well as the height of a dam to achieve the maximum yield. In **Figure 7-1**, the upstream dams have lower MARs, and require higher dams to achieve a yield of 200 million m³/a; they also have lower maximum yields.

Figure 7-1: Dam Site – MAR, Dam Height to Achieve a 200 million m³/a Yield, Maximum Yield and Dam Height to Achieve the Maximum Yield

Site	MAR	Dam height for 200 million m³/a local yield	Maximum Local Yield	Dam height for maximum local yield
	(million m³/a)	(m)	(million m³/a)	(m)
Lowlands	241	129	209	136
N1a	378	84	334	126
N1	379	86	335	133
N2	381	78	346	123
N3	382	78	347	123
N4	418	76	380	127
TOR	419	74	381	125
S4	434	69	394	121
S3	439	74	399	127
S2	440	78	389	128
S1	443	74	402	127
S1a	460	79	407	130

D4	498	70	459	120
D3	507	71	467	121
D2	647	53	596	110

The impact on the yield of Gariep Dam was also analysed. If the Makhaleng Dam is constructed to:

- the height required to achieve the 218 million m^3/a transfer with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) decreases by 175 million m^3/a, or
- the maximum height and 378 million m^3/a are transferred with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) decreases by 252 million m^3/a, or
- the maximum height and 188 million m^3/a are transferred with the L-BWT, then the yield of the ORP system (Gariep and Vanderkloof dams) remains the same as a significant portion of the local Makhaleng Dam yield is used to supply all the required mitigation releases.

The original total high scenario demand of 199 million m^3/a cannot be met without negatively impacting the ORP requirements if all the mitigation releases are to be made from Makhaleng Dam. If the demands are tempered with the total demand reduced to 188 million m^3/a, there will be a negligible negative impact on the ORP. Lesotho has expressed interest in new irrigation development, which further reduces the available yield for transfer purposes. If 17.2 million m^3/a is allocated to Lesotho irrigation, the available yield for transfer purposes reduces to 171 million m^3/a, a reduction of 14 %.

There are several different dam development options that have been identified (see Error! Reference source not found.**)** that can be used to mitigate the impact on the ORP on behalf of Makhaleng Dam. Results from these analyses showed that sufficient local yield can be generated at the proposed Makhaleng Dam site to supply the full requirement for the high transfer scenario and more (local yield of approximately 380 million m^3/a).

By utilizing any of the above-mentioned development options in combination with the large Makhaleng Dam, it is clear that the high Botswana Lesotho transfer option can easily be supplied from Makhaleng Dam without having negative impacts on downstream users. These options can in fact provide approximately an additional 100 million m^3/a and more for other use such as for irrigation developments in Lesotho or even support to the Greater Bloemfontein, etc.

It should be noted that these options will add to the total cost of the Makhaleng Scheme although the value and benefits from the additional yield from the dam will offset some of these costs and must also be taken into account in any financial analysis.

The Botswana water requirements are largely dependent on growth in the mining sector and associated growth in the neighbouring towns and urban centres.

The Botswana mining sector is predominantly dependent on groundwater and the mining houses have expressed their intention to utilize groundwater resources as far as possible for economic reasons. A detailed geohydrological and water balance study per mine site should be considered in the Feasibility Phase to determine the sustainable groundwater exploitation potential, derive a water balance, and then determine the final augmentation requirements for the mines.

It is recommended that a large Makhaleng Dam (approx. 3 MAR) should be built to provide more flexibility in the system as well as to support additional irrigation in Lesotho. It should be noted that water supplied in a northerly direction from the Makhaleng Dam will be used predominantly for urban and industrial purposes. Such water carries a very high value which will typically be in the order of R10/m^3 but can be as high as R70/m^3 at 2022 tariffs.

It is recommended that a critical review of the rating curves and the accuracy of the flow records from gauges MG19, MG23, and D1H006 be undertaken by a river gauging expert and the level of reliability be determined.

Flow gauge D1H006 was not included in the original calibration of the hydrology for the Makhaleng River catchment, it is recommended that this be incorporated, and the hydrology reassessed and extended to 2018 as part of the Dam Feasibility Component.

The environmental requirements determined for Makhaleng Dam during the Phase 1 study were carried out at a desktop level. It is thus recommended that various other EWRs are determined focused on the final location of the Makhaleng Dam. These results should be evaluated during Phase 2 and or at the start of the Feasibility Phase as part of a scenario evaluation process to determine the impact of each scenario on the yield available from the dam as well as on the Recommended Ecological Category (REC).

Due to the significant difference in the incremental and local yield from Makhaleng Dam, other intervention options to balance the deficit in the Orange River Project should be investigated in detail through a separate and independent study.

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APPENDIX A

WATER REQUIREMENT MAP AND TABLES

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Legend

ID	Description
1.1	Vanderkloof Lower Level Storage
1.2	Real Time Flow Modeling and Monitoring
1.3	Possible Verveeldingskraal Dam
1.4	Orange EWR (Reserve)
1.5a	Vioolsdrift/Noordoewer Dam to Compensate for Polihali Dam
1.5b	Vioolsdrift/Noordoewer Dam as Resource
1.7	Future Polihali Dam and Tunnel
2.1	Possible Makhaleng Dam and Irrigation
2.2	LBWT Pipeline
3.1	Possible Hlotse Dam
3.2	Possible Ngoajane Dam

Cluster 1, Cluster 2, Cluster 3

BOTSWANA

NAMIBIA

REPUBLIC OF SOUTH AFRICA

LESOTHO

ATLANTIC OCEAN

INDIAN OCEAN

WINDHOEK, Gobabis, Rehoboth, Mariental, Helmeringhausen, Keetmanshoop, Seeheim, Rosh Pinah, Aussenkehr, Oranjemund, Alexander Bay, Vioolsdrift, Goodhouse, Karasburg, Dreihuk, Onseepkans, Riemvasmaak, Augrabies, Keimoes, Kakamas, Upington, Prieska, Hopetown, Douglas, Ritchie, KIMBERLEY, BLOEMFONTEIN, Mafeteng, Mohale's Hoek, Aliwal North, MASERU, Butha-Buthe, GABORONE, Lobatse, MAFIKENG, PRETORIA, JOHANNESBURG, VEREENIGING, Parys, Orkney, WELKOM, Standerton, Harrismith, Schweizer-Reneke, Kuruman, Vanzylsrus, Tshabong

EWR 1, EWR 2, EWR 3, EWR 4, EWR 5, Estuary EWR, EWR C5, EWR C6, EWR K7

Possible Vioolsdrift Dam
Possible Ngoajane Dam
Possible Hlotse Dam
Possible Makhaleng Dam
Possible Verbeeldingskraal Dam
Future Polihali Dam
Van der Kloof
Gariep
Existing Orange-Fish Transfer Tunnel
Mohale and Katse LHWP Phase 1
LHWP Phase 2
ORP Dams and Supply Area
Support to Nelson Mandela Bay

Cluster 1, Cluster 2, Cluster 3

0 100 200 300 400 500 km

WRP : Projects/P0428 - ORASECOM/GIS/Mxd/A-2.mxd

Table 5-15: Realistic Scenario — Lesotho L-BWT Nett Demands (million m3/a)

Lesotho Zone	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Zone 3 Peka/ Mapoteng/ TY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 4 Maseru/ Mazenod/ Roma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.891	1.946	3.001	4.056	5.111	6.166	7.222	8.277	9.332	10.387
Zone 5 Morija/ Matsieng	1.547	1.552	1.558	1.565	1.572	1.580	1.587	1.594	1.601	1.608	1.615	1.623	1.630	1.637	1.644	1.651	1.658	1.666	1.673	1.680	1.687	1.694	1.701	1.708	1.716	1.723	1.730	1.737	1.744	1.751	1.759	1.766	1.773
Zone 6 Mafeteng	3.388	3.585	3.783	3.831	3.880	3.928	3.977	4.025	4.074	4.122	4.171	4.219	4.268	4.316	4.365	4.413	4.462	4.510	4.559	4.607	4.656	4.704	4.753	4.801	4.850	4.898	4.947	4.995	5.044	5.092	5.141	5.189	5.238
Total	4.935	5.138	5.341	5.396	5.452	5.508	5.563	5.619	5.675	5.730	5.786	5.842	5.897	5.953	6.009	6.064	6.120	6.176	6.231	6.287	6.343	6.398	6.454	7.401	8.512	9.622	10.733	11.844	12.954	14.065	15.176	16.287	17.397

Table 5-16: High Scenario — Lesotho L-BWT Nett Demands (million m3/a)

Lesotho Zone	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Zone 3 Peka/ Mapoteng/ TY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 4 Maseru/ Mazenod/ Roma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.759	2.474	4.188	5.903	7.957	10.011	12.065	14.119	16.173	18.227	20.281	22.335	24.389	26.443
Zone 5 Morija/ Matsieng	1.547	1.552	1.558	1.565	1.572	1.580	1.587	1.594	1.603	1.611	1.620	1.629	1.638	1.648	1.659	1.669	1.679	1.690	1.702	1.714	1.726	1.738	1.751	1.765	1.779	1.794	1.808	1.822	1.837	1.851	1.865	1.880	1.894
Zone 6 Mafeteng	3.388	3.585	3.783	3.831	3.880	3.928	3.977	4.025	4.082	4.139	4.196	4.253	4.310	4.376	4.443	4.510	4.577	4.643	4.722	4.801	4.880	4.958	5.037	5.130	5.223	5.316	5.409	5.502	5.596	5.689	5.782	5.875	5.968
Total	4.935	5.138	5.341	5.396	5.452	5.508	5.563	5.619	5.685	5.750	5.816	5.882	5.947	6.025	6.102	6.179	6.256	6.333	6.424	7.274	9.080	10.885	12.691	14.852	17.013	19.175	21.336	23.498	25.659	27.821	29.982	32.143	34.305

Table 5-17: Lesotho L-BWT Nett Demands (million m3/a)

Water Requirements	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Zone 5 Morija/ Matsieng (SMEC, 2017)	1.65	1.65	1.66	1.66	1.67	1.68	1.68	1.69	1.70	1.70	1.71	1.72	1.73	1.74	1.75	1.75	1.77	1.78	1.79	1.80	1.81	1.82	1.83	1.84	1.86	1.87	1.88	1.90	1.91	1.92	1.94	1.95	1.97	1.98	2.00	2.01
Zone 6 Mafeteng (SMEC, 2017)	3.82	4.02	4.21	4.41	4.61	4.81	4.85	4.90	4.95	5.00	5.05	5.10	5.16	5.22	5.28	5.33	5.40	5.47	5.53	5.60	5.67	5.74	5.82	5.90	5.98	6.06	6.15	6.25	6.34	6.43	6.53	6.62	6.71	6.80	6.90	6.99
Zone 7 Mohale's Hoek (SMEC 2017)	7.67	8.06	8.45	8.84	9.23	9.61	9.65	9.68	9.71	9.75	9.78	9.82	9.86	9.89	9.93	9.97	10.02	10.06	10.11	10.15	10.20	10.25	10.30	10.36	10.41	10.47	10.53	10.59	10.65	10.72	10.78	10.84	10.91	10.97	11.03	11.10
Total Requirement	13.14	13.73	14.32	14.91	15.50	16.09	16.18	16.27	16.36	16.45	16.54	16.64	16.75	16.85	16.95	17.06	17.18	17.30	17.43	17.55	17.67	17.81	17.96	18.10	18.25	18.39	18.56	18.73	18.90	19.08	19.25	19.42	19.59	19.76	19.93	20.10
Resources																																				
Zone 5 (WTW & Boreholes/Springs)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Zone 6 Mafeteng (WTW & Boreholes/Springs)	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Zone 7	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Total Resources	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
Lesotho net requirement	11.58	12.18	12.77	13.36	13.95	14.54	14.63	14.72	14.81	14.90	14.98	15.09	15.19	15.30	15.40	15.51	15.63	15.75	15.87	16.00	16.12	16.26	16.41	16.55	16.70	16.84	17.01	17.18	17.35	17.52	17.69	17.86	18.03	18.21	18.38	18.55

Table 5-18: Realistic Scenario — South Africa Towns L-BWT Nett Demands (million m³/a)

Province	District Municipality	Local Municipality	Town	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Free State	Lejweleputswa	Masilonyana	Verkeerdevlei	0.132	0.147	0.161	0.169	0.177	0.185	0.193	0.201	0.208	0.216	0.224	0.232	0.240	0.248	0.256	0.264	0.272	0.280	0.287	0.295	0.303	0.311	0.319	0.327	0.335	0.343	0.351	0.359	0.366	0.374	0.382	0.390	0.398
	Dr Ruth Segomotsi Mompati	Mamusa	Glaudina	0.029	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.056	0.059	0.063	0.066	0.070	0.074	0.077	0.081	0.084	0.088	0.092	0.095	0.099	0.102	0.106	0.110	0.113	0.117	0.120	0.124	0.128	0.131	0.135	0.138	0.142
			Migdol	0.282	0.296	0.310	0.324	0.338	0.352	0.366	0.380	0.396	0.412	0.428	0.444	0.460	0.476	0.492	0.508	0.524	0.540	0.556	0.572	0.588	0.604	0.620	0.636	0.652	0.668	0.684	0.700	0.716	0.732	0.748	0.764	0.780
		Ditsobotla	Lichtenburg	0.000	0.000	0.000	0.054	0.107	0.161	0.214	0.268	0.309	0.351	0.392	0.434	0.475	0.516	0.558	0.599	0.641	0.682	0.723	0.765	0.806	0.848	0.889	0.930	0.972	1.013	1.055	1.096	1.137	1.179	1.220	1.262	1.303
North West	Ngaka Modiri Molema	Mahikeng	Mahikeng	6.439	6.436	6.433	6.490	6.547	6.605	6.662	6.719	6.773	6.827	6.880	6.934	6.988	7.046	7.104	7.162	7.220	7.278	7.356	7.434	7.511	7.589	7.667	7.745	7.823	7.900	7.978	8.056	8.134	8.212	8.289	8.367	8.445
			Driehoek South Cluster	1.396	1.409	1.422	1.429	1.436	1.442	1.449	1.456	1.462	1.468	1.475	1.481	1.487	1.493	1.499	1.506	1.512	1.518	1.524	1.530	1.537	1.543	1.549	1.555	1.561	1.568	1.574	1.580	1.586	1.592	1.599	1.605	1.611
			Miga North Cluster	0.157	0.167	0.176	0.182	0.189	0.195	0.202	0.208	0.213	0.218	0.224	0.229	0.234	0.239	0.244	0.250	0.255	0.260	0.265	0.270	0.276	0.281	0.286	0.291	0.296	0.302	0.307	0.312	0.317	0.322	0.328	0.333	0.338
		Ramotshere Moiloa	Motswedi Gopane	0.003	0.004	0.005	0.011	0.017	0.024	0.030	0.036	0.038	0.041	0.043	0.046	0.048	0.050	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.070	0.072	0.074	0.077	0.079	0.082	0.084	0.086	0.089	0.091	0.094	0.096
			Khunotswane	0.257	0.264	0.271	0.274	0.278	0.281	0.285	0.288	0.288	0.289	0.290	0.290	0.291	0.291	0.292	0.292	0.293	0.293	0.294	0.294	0.295	0.295	0.296	0.296	0.297	0.297	0.298	0.298					
			Dinokona	1.082	1.145	1.208	1.234	1.260	1.285	1.311	1.337	1.345	1.352	1.360	1.367	1.375	1.383	1.390	1.398	1.405	1.413	1.421	1.428	1.436	1.443	1.451	1.459	1.466	1.474	1.481	1.489	1.497	1.504	1.512	1.519	1.527
			Zeerust	0.062	0.083	0.104	0.119	0.133	0.148	0.162	0.177	0.181	0.185	0.190	0.194	0.198	0.202	0.206	0.211	0.215	0.219	0.223	0.227	0.232	0.236	0.240	0.244	0.248	0.253	0.257	0.261	0.265	0.269	0.274	0.278	0.282
		Ratlou	Maaipeng / Mareetsane	0.030	0.032	0.034	0.035	0.036	0.038	0.039	0.040	0.042	0.043	0.045	0.046	0.048	0.050	0.051	0.053	0.054	0.056	0.058	0.059	0.061	0.062	0.064	0.066	0.067	0.069	0.070	0.072	0.074	0.075	0.077	0.078	0.08
			Delareyville	0.036	0.048	0.060	0.074	0.088	0.102	0.116	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	0.210	0.220	0.230	0.240	0.250	0.260	0.270	0.280	0.290	0.300	0.310	0.320	0.330	0.340	0.350	0.360	0.370	0.38
			Atemelang	1.078	1.104	1.130	1.156	1.182	1.208	1.234	1.260	1.286	1.312	1.338	1.364	1.390	1.416	1.442	1.468	1.494	1.520	1.546	1.572	1.598	1.624	1.650	1.676	1.702	1.728	1.754	1.780	1.806	1.832	1.858	1.884	1.91
			Motsitlane	0.008	0.010	0.013	0.015	0.018	0.021	0.024	0.027	0.030	0.032	0.035	0.038	0.041	0.044	0.047	0.050	0.052	0.055	0.058	0.061	0.064	0.067	0.070	0.072	0.075	0.078	0.081	0.084	0.087	0.089	0.092	0.095	0.098
			Setlagole	0.016	0.019	0.022	0.025	0.029	0.032	0.036	0.039	0.042	0.045	0.048	0.051	0.054	0.057	0.060	0.063	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.087	0.090	0.093	0.096	0.099	0.102	0.105	0.108	0.111	0.114

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Province	District Municipality	Local Municipality	Town	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
																				High Scenario: South Africa Towns L-BWT Nett Demands (million m^3/a)																
Free State	Fezile Dabi	Moqhaka	Kroonstad	3.619	3.847	4.076	4.305	4.534	4.762	4.991	5.220	5.449	5.677	5.906	6.135	6.363	6.592	6.821	7.050	7.278	7.507	7.736	7.964	8.193	8.422	8.651	8.879	9.108	9.337	9.565	9.794	10.023	10.252	10.480	10.709	10.9378
Free State	Lejweleputswa	Masilonyana	Verkeerdevlei	0.132	0.147	0.161	0.169	0.177	0.185	0.193	0.201	0.208	0.216	0.224	0.232	0.240	0.248	0.256	0.264	0.272	0.280	0.287	0.295	0.303	0.311	0.319	0.327	0.335	0.343	0.351	0.359	0.366	0.374	0.382	0.390	0.398
North West	Dr Ruth Segomotsi Mompati	Mamusa	Glaudina	0.029	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.056	0.059	0.063	0.066	0.070	0.074	0.077	0.081	0.084	0.088	0.092	0.095	0.099	0.102	0.106	0.110	0.113	0.117	0.120	0.124	0.128	0.131	0.135	0.138	0.142
North West	Dr Ruth Segomotsi Mompati	Mamusa	Migdol	0.282	0.296	0.310	0.324	0.338	0.352	0.366	0.380	0.396	0.412	0.428	0.444	0.460	0.476	0.492	0.508	0.524	0.540	0.556	0.572	0.588	0.604	0.620	0.636	0.652	0.668	0.684	0.700	0.716	0.732	0.748	0.764	0.78
North West	Ngaka Modiri Molema	Ditsobotla	Lichtenburg	0.000	0.000	0.000	0.054	0.107	0.161	0.214	0.268	0.309	0.351	0.392	0.434	0.475	0.516	0.558	0.599	0.641	0.682	0.723	0.765	0.806	0.848	0.889	0.930	0.972	1.013	1.055	1.096	1.137	1.179	1.220	1.262	1.303
North West	Ngaka Modiri Molema	Mahikeng	Mahikeng	6.439	6.436	6.433	6.490	6.547	6.605	6.662	6.719	6.773	6.827	6.880	6.934	6.988	7.046	7.104	7.162	7.220	7.278	7.356	7.434	7.511	7.589	7.667	7.745	7.823	7.900	7.978	8.056	8.134	8.212	8.289	8.367	8.445
North West	Ngaka Modiri Molema	Mahikeng	Driehoek South Cluster	1.396	1.409	1.422	1.429	1.436	1.442	1.449	1.456	1.462	1.468	1.475	1.481	1.487	1.493	1.499	1.506	1.512	1.518	1.524	1.530	1.537	1.543	1.549	1.555	1.561	1.568	1.574	1.580	1.586	1.592	1.599	1.605	1.611
North West	Ngaka Modiri Molema	Mahikeng	Miga North Cluster	0.157	0.167	0.176	0.182	0.189	0.195	0.202	0.208	0.213	0.218	0.224	0.229	0.234	0.239	0.244	0.250	0.255	0.260	0.265	0.270	0.276	0.281	0.286	0.291	0.296	0.302	0.307	0.312	0.317	0.322	0.328	0.333	0.338
North West	Ngaka Modiri Molema	Ramotshere Moiloa	Motswedi Gopane	0.003	0.004	0.005	0.011	0.017	0.024	0.030	0.036	0.038	0.041	0.043	0.046	0.048	0.050	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.070	0.072	0.074	0.077	0.079	0.082	0.084	0.086	0.089	0.091	0.094	0.096
North West	Ngaka Modiri Molema	Ramotshere Moiloa	Khunotswane	0.257	0.264	0.271	0.274	0.277	0.281	0.285	0.288	0.288	0.289	0.289	0.290	0.290	0.290	0.291	0.291	0.292	0.292	0.292	0.293	0.293	0.294	0.294	0.294	0.295	0.295	0.296	0.296	0.296	0.297	0.297	0.298	0.298
North West	Ngaka Modiri Molema	Ramotshere Moiloa	Dinokona	1.082	1.145	1.208	1.234	1.260	1.285	1.311	1.337	1.345	1.352	1.360	1.367	1.375	1.383	1.390	1.398	1.405	1.413	1.421	1.428	1.436	1.443	1.451	1.459	1.466	1.474	1.481	1.489	1.497	1.504	1.512	1.519	1.527
North West	Ngaka Modiri Molema	Ramotshere Moiloa	Zeerust	0.062	0.083	0.104	0.119	0.133	0.148	0.162	0.177	0.181	0.185	0.190	0.194	0.198	0.202	0.206	0.211	0.215	0.219	0.223	0.227	0.232	0.236	0.240	0.244	0.248	0.253	0.257	0.261	0.265	0.269	0.274	0.278	0.282
North West	Ngaka Modiri Molema	Ratlou	Maaipeng / Mareetsane	0.030	0.032	0.034	0.035	0.036	0.038	0.039	0.040	0.042	0.043	0.045	0.046	0.048	0.050	0.051	0.053	0.054	0.056	0.058	0.059	0.061	0.062	0.064	0.066	0.067	0.069	0.070	0.072	0.074	0.075	0.077	0.078	0.08
North West	Ngaka Modiri Molema	Ratlou	Delareyville	0.036	0.048	0.060	0.074	0.088	0.102	0.116	0.130	0.140	0.150	0.160	0.170	0.180	0.190	0.200	0.210	0.220	0.230	0.240	0.250	0.260	0.270	0.280	0.290	0.300	0.310	0.320	0.330	0.340	0.350	0.360	0.370	0.38
North West	Ngaka Modiri Molema	Ratlou	Atemelang	1.078	1.104	1.130	1.156	1.182	1.208	1.234	1.260	1.286	1.312	1.338	1.364	1.390	1.416	1.442	1.468	1.494	1.520	1.546	1.572	1.598	1.624	1.650	1.676	1.702	1.728	1.754	1.780	1.806	1.832	1.858	1.884	1.91
North West	Ngaka Modiri Molema	Ratlou	Motsitlane	0.008	0.010	0.013	0.015	0.018	0.021	0.024	0.027	0.030	0.032	0.035	0.038	0.041	0.044	0.047	0.050	0.052	0.055	0.058	0.061	0.064	0.067	0.070	0.072	0.075	0.078	0.081	0.084	0.087	0.089	0.092	0.095	0.098
North West	Ngaka Modiri Molema	Ratlou	Setlagole	0.016	0.019	0.022	0.025	0.029	0.032	0.036	0.039	0.042	0.045	0.048	0.051	0.054	0.057	0.060	0.063	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.087	0.090	0.093	0.096	0.099	0.102	0.105	0.108	0.111	0.114

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Botswana Node	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
										Low Scenario: Botswana L-BWT Nett Demands (million m3/a)																							
Lobatse Node																																	
Lobatse	3.320	3.467	3.618	3.771	3.930	4.094	4.263	4.437	4.616	4.799	4.988	5.183	5.383	5.589	5.801	6.014	6.045	6.474	6.711	6.955	7.206	7.465	7.731	8.005	8.286	8.576	8.874	9.181	9.471	9.761	10.051	10.341	10.631
Pitshane	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
Good Hope	0.127	0.131	0.135	0.138	0.142	0.146	0.151	0.155	0.159	0.164	0.169	0.174	0.180	0.186	0.191	0.197	0.203	0.209	0.215	0.222	0.229	0.236	0.243	0.250	0.258	0.266	0.274	0.282	0.290	0.298	0.305	0.313	0.321
School at Good hope	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
Moshupa	1.418	1.463	1.509	1.557	1.606	1.657	1.709	1.763	1.819	1.877	1.936	1.994	2.054	2.116	2.179	2.244	2.312	2.381	2.451	2.523	2.597	2.674	2.752	2.833	2.916	3.002	3.090	3.181	3.267	3.353	3.438	3.524	3.610
NWMPR Jwaneng	0.444	0.448	0.451	0.455	0.458	0.462	0.465	0.469	0.473	0.477	0.481	0.485	0.489	0.494	0.498	0.503	0.508	0.512	0.517	0.522	0.526	0.531	0.536	0.540	0.545	0.550	0.555	0.560	0.565	0.570	0.574	0.579	0.584
Jwaneng Diamond Mine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Mmamashia/Gaborone Node																																	
Lotlhakane	0.269	0.281	0.293	0.302	0.314	0.327	0.34	0.353	0.363	0.377	0.391	0.406	0.421	0.415	0.431	0.447	0.463	0.479	0.49	0.502	0.514	0.526	0.539	0.552	0.565	0.579	0.593	0.607	0.6206	0.6342	0.6478	0.6614	0.675
Ranaka	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Otse	0.465	0.491	0.514	0.533	0.557	0.581	0.606	0.632	0.653	0.679	0.706	0.734	0.762	0.879	0.814	0.84	0.847	0.883	0.906	0.929	0.953	0.978	1.003	1.029	1.056	1.083	1.111	1.14	1.1674	1.1948	1.2222	1.2496	1.277
Ramotswa Station Taung	0.061	0.061	0.061	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Ramotswa	2.915	2.99	3.086	3.119	3.195	3.273	3.353	3.432	3.513	3.594	3.676	3.759	3.843	3.927	4.013	4.1	4.188	4.277	4.365	4.455	4.548	4.642	4.738	4.836	4.936	5.038	5.143	5.249	5.3512	5.4534	5.5556	5.6578	5.76
Thamaga	1.255	1.347	1.447	1.554	1.668	1.791	1.923	2.065	2.218	2.381	2.557	2.659	2.766	2.876	2.991	3.111	3.235	3.365	3.479	3.597	3.719	3.845	3.975	4.11	4.25	4.394	4.543	4.697	4.8414	4.9858	5.1302	5.2746	5.419
Manyana	0.096	0.097	0.099	0.1	0.101	0.102	0.104	0.105	0.107	0.108	0.11	0.111	0.113	0.115	0.117	0.118	0.12	0.122	0.124	0.126	0.128	0.13	0.132	0.134	0.136	0.138	0.14	0.142	0.144	0.146	0.148	0.15	0.152
Ntlhantlhe, Magotlhwane,	0.121	0.122	0.124	0.125	0.127	0.128	0.13	0.131	0.133	0.135	0.136	0.138	0.14	0.142	0.146	0.146	0.148	0.15	0.152	0.154	0.156	0.158	0.16	0.163	0.165	0.167	0.169	0.172	0.1744	0.1768	0.1792	0.1816	0.184
Mmamashia/Gaborone Node and North (Letsibogo, Palapye & Mahalapye Ndes and Mines)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.381	1.229	2.004	2.840	3.757	4.619	8.738	9.564	10.402	11.252	12.113	12.988	13.875	14.774	15.688	16.615	17.557	18.471	19.384	20.298	21.212	22.126
Total	**10.69**	**11.10**	**11.54**	**11.91**	**12.36**	**12.82**	**13.31**	**21.80**	**22.32**	**22.85**	**23.54**	**24.29**	**25.64**	**27.00**	**28.28**	**29.74**	**30.95**	**35.85**	**37.23**	**38.65**	**40.09**	**41.56**	**43.06**	**44.59**	**46.15**	**47.74**	**49.37**	**51.03**	**52.62**	**54.22**	**55.81**	**57.41**	**59.00**

HUV˘Y˘5 !+.˘6 c¦gk UbU˘@¦6 K H˘bYh¦k UhYf˘f Ye¦]f Ya Yb¦g.˘<][\ ˘GW¥bUf]cÁ

Botswana Node	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
																			Realistic Scenario: Botswana L-BWT Nett Demands (million m3/a)													
Lobatse Node																																
Lobatse	3.320	3.467	3.618	3.771	3.930	4.094	4.263	4.437	4.616	4.799	4.988	5.383	5.589	5.801	6.014	6.045	6.474	6.711	6.955	7.206	7.465	7.731	8.005	8.286	8.576	8.874	9.181	9.471	9.761	10.051	10.341	10.631
Pitshane	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
Good Hope	0.127	0.131	0.135	0.138	0.142	0.146	0.151	0.155	0.159	0.164	0.169	0.180	0.186	0.191	0.197	0.203	0.209	0.215	0.222	0.229	0.236	0.243	0.250	0.258	0.266	0.274	0.282	0.290	0.298	0.305	0.313	0.321
School at Good hope	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
Kanye	3.038	3.152	3.269	3.391	3.518	3.649	3.785	3.927	4.073	4.225	4.383	4.650	4.789	4.933	5.081	5.234	5.391	5.540	5.694	5.852	6.015	6.182	6.353	6.530	6.711	6.897	7.089	7.270	7.452	7.633	7.815	7.996
Moshupa	1.418	1.463	1.509	1.557	1.606	1.657	1.709	1.763	1.819	1.877	1.936	2.054	2.116	2.179	2.244	2.312	2.381	2.451	2.523	2.597	2.674	2.752	2.833	2.916	3.002	3.090	3.181	3.267	3.353	3.438	3.524	3.610
NWMPR Jwaneng	0.444	0.448	0.451	0.455	0.458	0.462	0.465	0.469	0.473	0.477	0.481	0.489	0.494	0.498	0.503	0.508	0.512	0.517	0.522	0.526	0.531	0.536	0.540	0.545	0.550	0.555	0.560	0.565	0.570	0.574	0.579	0.584
Jwaneng Diamond Mine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Mmamashia/Gaborone Node																																
Lotlhakane	0.269	0.281	0.293	0.302	0.314	0.327	0.34	0.353	0.363	0.377	0.391	0.421	0.415	0.431	0.447	0.463	0.479	0.49	0.502	0.514	0.526	0.539	0.552	0.565	0.579	0.593	0.607	0.6206	0.6342	0.6478	0.6614	0.675
Ranaka	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Otse	0.465	0.491	0.514	0.533	0.557	0.581	0.606	0.632	0.653	0.679	0.706	0.762	0.879	0.814	0.84	0.847	0.883	0.906	0.929	0.953	0.978	1.003	1.029	1.056	1.083	1.111	1.14	1.1674	1.1948	1.2222	1.2496	1.277
Ramotswa Station Taung	0.061	0.061	0.061	0.061	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Ramotswa	2.915	2.99	3.086	3.119	3.195	3.273	3.353	3.432	3.513	3.594	3.676	3.843	3.927	4.013	4.1	4.188	4.277	4.365	4.455	4.548	4.642	4.738	4.836	4.936	5.038	5.143	5.249	5.3512	5.4534	5.5556	5.6578	5.76
Thamaga	1.255	1.347	1.447	1.554	1.668	1.791	1.923	2.065	2.218	2.381	2.557	2.766	2.876	2.991	3.111	3.235	3.365	3.479	3.597	3.719	3.845	3.975	4.11	4.25	4.394	4.543	4.697	4.8414	4.9858	5.1302	5.2746	5.419
Manyana	0.096	0.097	0.099	0.1	0.101	0.102	0.104	0.105	0.107	0.108	0.11	0.113	0.115	0.117	0.118	0.12	0.122	0.124	0.126	0.128	0.13	0.132	0.134	0.136	0.138	0.14	0.142	0.144	0.146	0.148	0.15	0.152
Ntlhantlhe, Magotlhwane,	0.121	0.122	0.124	0.125	0.127	0.128	0.13	0.131	0.133	0.135	0.136	0.14	0.142	0.146	0.146	0.148	0.15	0.152	0.154	0.156	0.158	0.16	0.163	0.165	0.167	0.169	0.172	0.1744	0.1768	0.1792	0.1816	0.184
Mmamashia/Gaborone Node Remainder and Northern Nodes (Letsibogo, Palapye & Mahalapye Nodes and Mines)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.038	5.133	11.375	15.624	18.483	21.542	24.871	28.049	41.466	44.512	47.611	50.759	53.964	57.225	60.542	63.917	67.353	70.853	74.416	77.854	81.292	84.730	88.168	91.606
Total	13.728	14.249	14.805	15.305	15.877	16.471	17.090	25.730	28.426	32.210	39.169	44.686	48.272	51.917	55.933	59.613	73.970	77.723	81.551	85.448	89.425	93.477	97.608	101.821	106.118	110.503	114.977	119.277	123.576	127.876	132.176	136.476

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HUV̀Ÿ5!,˙K UhŸf˙FŸ Ye][fŸa Ÿbhˇj Yfg˙i g˙F Ygci f ŸWŸ WUdUVˇ][mˇUhˇG&ˇXa ˙g]hŸ

; fcgg̀K UhŸf˙F Yeu][fŸa ŸbhˇgWŸbŬf]cg̀hcˇVŸ a dcgŸX̀cb ˇM U˙UˇYb [ˇ8a ˇf¦i][ˇ]cb ˇa ˇ#£					
8 YgWˇ]dh]cb	F YWˇbbUˇggUbWˇ Gh i Xm	<][\	@ck	<][\ ˇ]bWˇi X]b [ˇ 6 ˇcYa ˇzˇcbhŸ]b	Low including Bloemfontein
Ó[ơ¸ àŷæ	FÍ €	FÍ Î	Î Ì	FÍ Î	68
ÜÙŒ	GÍ	GF	GF	Î Í	64
Š^•[œ@Á;¦àˌåD	GÍ	GG	GG	GG	22
Š^•[œ@ÁÃãˇ¦æ}D	€	€	ÏÎ	€	76
Þæ̧ˇãˇãˇæ	€	€	€	€	0
HcHŬ	**&$$**	**%˙-**	**%ˌ+**	**&(˙&**	**230**

F Ygci f ŸWˇ WUdUVˇ][mˇf¦i][ˇ]cb ˇa ˇ#£ ˇ-Ë¬m d]WUhˇcbg˙zˇcfˇgWŸbŬf]cg̀UˇhˇG&ˇXa ˙g]hŸ					
8 YgWˇ]dh]cb		<][\	@ck	<][\ ˇ˙]bWˇi X]b [ˇ 6 ˇcYa ˇzˇcbhŸ]b	Low including Bloemfontein
Š[&æ̦Ã̂ẑ¦à		Ḧ Ì	Ḧ Ì	Ḧ Ì	378
Tˇãˇã̆æ¦}Á^̆ˇã^{ ^ơÆ		GFJ	FJ€	FÏ Î	147
Q&¦^}æ¦^}ơæ¦D^ơÁ̂ẑ¦à		FÍ J	FÏ Ì	G€G	231
V¦^æ¦^}ơ Á̇••^•		G€	FJ	GˌÌG	23
Ô[}ç^̂`æˌ&̂Á̇••		F€̂È	J	FGˌÈ	12
F Ya Uˇ]bˇb [ˇ]yŸ̂X˙f¦Ł		**%˙&ˇ-**	**%˙$**	**%˙)**	**196**
F Ya Uˇ]bˇb [ˇ]yŸ̂X˙f¦&Ł		**'˙(,**	**'˙)$**	**'˙(%**	**343**

BYhˇK UhŸf˙F Ye Ye][fŸa ˇYbhˇf¦i][ˇ]cb ˇa ˇ#£ˇVˇYcfˇˇˇgg̀Yg˙cˇfˇVˇYcˇˇjˇYˇnŬbWŸˇÈˇf¦Uma ŸbhˇŁ					
Ó[ơ¸ àŷæ		FHH	Í Ì	FHH	58
Š^•[œ@ Á¦àˌåˌå		FÌ	FJ	FJ	19
ÜÙŒ		FJ	FÌ	Í Í	55
HcHŬ ˇˇˇˇbYh ˇˇˇXYa UbX ˇ Yˇl Wˇi X]b [ˇ]ˇff][ˇ][Uh]cb		**%˙-**	**-˙)**	**&$˙+**	**132**
BYhˇXYZˇWˇhˇ#Gi fdˇi g˙f¦Ł		**!˙($**	***˙)**	**!˙(%**	**65**
BYhˇXYZˇWˇhˇ#Gi fdˇi g˙f¦Ł		**%˙-ˇ-**	**&˙)˙)**	**%˙)**	**212**
Š^•[œ@Áˇãˇ¦æˌæ}ÁÃ̂D			Î Í	€	65
Uœ@¦Á•ˌ^¦•ŇÁ̂D		FÏ J	FJ€	FHÍ	147

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ˌˇD˙ËÜ^ˇæˌ]ˌ̇*Á̂ˌàˌ|Á̂Á̧ãˇ¦æˌæ}Á^̂¦æ^^̂ˌæˌ^ˇˇ]]ˌãˌ̂Á{ Ầ æˌ|@¦^̇*Ö̇æˌ}ˌ^̂Á
ˌˇD˙Á.Ü^ˇæˌ]ˌ̇*Á̂ˌàˌ|ˇÁ̧ãˇ¦æˌæ}Á^̂¦æ^^̂ˌæˌ^ˇˇ]]ˌãˌ̂Á{ Ầ[œ@¦ˇ̆ˇ¦^Á
ˌˇDÁ.Ö̂^̂̂−ˌ̆˙¦¦^ˌ]]ˇˌˇ•̂Á&@Á̂ç¦àˌ^̂^¦ơ̂{ Á @Á̧ãˇ¦æˌæ}Á^̂¦æ^^̂ˌæˌ^ˇˇ]]ˌãˌ̂Á{ Ầ æˌ|@¦}̇*ˇ̂}¦^Á
ˌˇDÁ.ËÜˇˇˌˇ]̂ˇˇˇ•̧Áˇ@¦^̂¦̇ˌˇˇˇˇ&ˌˇ́o̧&¦[̇ſæˌ̇æˌ̇æˌ̂Tˌaˌ̇¦æˌ}̇*Ö̇æ¦̇ˌ̧@Áˇ@Á̧ãˇ¦æˌæ}Á^̂¦æ^^̂ˌæˌ^ˇˇ]]ˌãˌ̂Áˀ̂¦^̂ˇ̂
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ˌˇDÁ.Á/@Á̂ˇˇˇ]̂ˇˇˇ•̂Á{ Ầ&Š̀[œ̂Á̂ˌ̂−ˇˇ́æ̂&ˌ}̇æˌ̂̃ˌ&æˌ}¦̂̂[¢æ{]]̂æ^̂^̂ˇˌå̂¦̂ˌãˌ̇æˌ̂Á̂Š^•[œ@¦¦¦àˇ̂^ˌ^̂
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APPENDIX B: Water Resources

Flow Gauge Data

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	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
													D1H006: Monthly flow (million m3)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
1948	0.67	5.77	2.26	4.55	8.96	56.1	1.65	15	3.31	1.7	1.36	1.14	102.47
1949	1.46	25.7	31.2	22.2	101	187	395	155	32.2	62	79.7	138	1230.46
1950	9.84	5.17	292	52.5	39	119	57.6	6.33	7.74	6.53	5.15	4.07	604.93
1951	252	52.3	3.63	13.5	67.1	15.7	6.13	4.55	3.89	14	12.6	38.9	484.3
1952	0	28.5	31.8	14.2	45	22.3	98.1	18	6.24	2.25	2.06	3.32	271.77
1953	56.7	24.8	89.1	20.7	28.2	140	41.4	23.1	11	6.02	4.6	5.52	451.14
1954	4.31	4.33	1.42	211.55	211.84	58.42	26.95	13.91	4.75	4.05	3.07	2.41	547.01
1955	9.82	29.86	53.31	17.58	187.42	124	157	32	17.3	10.9	6.09	5.73	651.01
1956	4.97	44.3	207	36.4	104	36.9	24.6	5.97	3.79	4.15	9.9	108	589.98
1957	195	76.4	56	192	52.6	29	57.2	77.2	31.8	13.1	8.52	5.72	794.54
1958	4.67	62.9	33.6	38.9	79.2	48.3	20.2	3.59	26.3	39.3	19.5	6.98	383.44
1959	15.7	33.7	137	31.9	37.1	47.6	75	49.3	18.9	12.7	26.7	14.7	500.3
1960	19	54	44.1	41.6	35.9	65.3	144	77.7	121	25.5	16.7	7.76	652.56
1961	0.49	81.4	200	51.6	188	63.7	30.6	9.86	2.31	0.8	4.6	2.99	636.35
1962	1.63	68.8	35	116	68.2	52.5	275	34.8	17.7	35.4	20.7	9.34	735.07
1963	11.2	120	87.7	22.4	35.7	43.9	115	13.8	13	10.2	6.51	5.23	484.64
1964	108	39.4	35.7	24.2	11.3	5.53	56.4	7.13	9.69	8.56	6.62	6.94	319.47
1965	5.77	13.4	13.7	235	213	23.3	11.6	9.93	4.82	4.06	3.28	2.57	540.43
1966	4	21.1	20.9	88.7	189	48.83	185.18	111.33	23.2	31	15.4	9.21	747.85
1967	22.2	63.1	12.8	9.25	2.09	20.1	35.4	67.1	17.6	22	5.88	0	277.52
1968	6.06	7.41	53.6	12.1	27.9	134	102	22.2	17.4	8.99	18.6	3.4	413.66
1969	69.1	28.1	9.98	26.5	20.9	2.26	2.01	2.18	4.28	5.56	4.13	37.2	212.2
1970	33.9	17.7	80.7	38.7	38.6	43.2	32.6	35	9.88	8.3	4.71	1.52	344.81
1971	4.21	4.49	13	101	117	218	73.3	67	44.8	13	6.81	5.52	668.13
1972	17.9	13.3	6.72	0.31	78.7	50.9	20	11.6	4.93	3.69	26.9	10.2	245.15
1973	5.18	7.47	10.4	131	275	198	94.2	22.4	11.5	7.97	2.16	1.6	766.88
1974	4.72	72.4	36.1	42	86.1	166	3.79	0	0	15.9	7.52	26.8	461.33
1975	24.6	75.8	93.9	307	247	172	122	72.4	42.9	22.6	12.7	27.6	1220.5
1976	253	115	27	10.1	77.5	122.8	22	13.7	10.7	7.78	5.3	23.9	688.78
1977	42.1	35.2	44.4	145	61	70.9	236	53.2	16	11.1	9.52	7.18	731.6
1978	15.7	8.08	131	24.7	32.3	27.3	9.97	9.03	2.56	10.5	64.8	41.1	377.04
1979	104	21	14.7	15.1	23.5	15.6	6.24	2.18	2.34	2.07	2.04	4.56	213.33
1980	3	23.8	48.3	115	133	130	47.3	28.7	52.5	14.6	72	47.7	715.9
1981	13.6	31.8	46.1	17.5	30.2	21.8	135	33.6	18.8	15.8	7.8	6.55	378.55
1982	39.3	128	24.7	10.1	5.89	7.29	9.8	11.5	10.5	21.9	10.6	4.4	283.98
1983	6.36	33.2	56.7	64.9	11.9	10.3	7.58	44.7	6.6	3.94	7.6	11.6	265.38
1984	12.3	16.6	24.6	20.6	26.7	40.7	7.25	5.87	12.5	3.46	1.37	0.6	172.55
1985	26.5	57.5	105	68.8	36.4	30.8	7.31	4.4	14.1	4.74	8.36	22.7	386.61
1986	57.1	142	25.6	6.51	16.7	9.85	20.5	5.27	3.8	3.71	31.2	171	493.24
1987	60.6	91	98.5	24	180	366	110	35.2	24.1	22.8	9.93	72	1094.13
1988	76.1	64.6	124	108	242	71.6	45.3	37.6	62.7	20.7	12.1	6.16	870.86
1989	7.58	85.9	30.2	36.9	11	42.9	134	54	27.3	32.4	22	9.99	494.17
1990	3.49	2.04	12.5	145	201	142	31.2	12.1	10.5	6.34	4.06	11.2	581.43
1991	121	58.4	42.4	8	8.52	2.65	3.92	1.52	1.64	1.68	2.33	2.62	254.68
1992	19.2	30.7	3.42	12.1	54	31.3	32.9	10.9	3.03	2.15	6.4	0.7	206.8
1993	60.5	49	49.7	165	138	43.6	2.87	9.68	4.73	4.43	2.8	0.98	531.29
1994	0.33	0.07	0.16	14.4	6.54	13.8	7.2	9.46	2.21	1.39	0.33	0	55.89
1995	7.59	7.68	36.68	67.24	58.64	27.68	18.48	12.84	7.95	10.96	12.91	9.08	277.73
1996	7.86	144	89	72.4	24.3	234	115	19.23	15.75	13.34	9.69	4.12	748.69
1997	9.26	8.13	3.08	77.06	202.07	178.65	63.53	12.45	5.05	2.96	1.94	1.77	565.95
1998	9.7	26.5	61.76	77.69	40.84	12.33	10.13	8.27	4.57	2.65	1.41	0.41	256.26
1999	2.34	2.8	157.9	192.18	94.64	74.27	51.73	20.34	9.64	5.96	3.06	6.29	621.15
2000	17.19	24.76	37.61	28.93	27.4	79.74	165.14	95.58	26.52	14.55	27	79.9	624.32
2001	69.1	365	195	242	140	72.7	38	68.8	103	24.5	122	124	1564.1
2002	27.3	29.6	114	73.2	40.4	81.6	22.6	8.83	5.22	4.76	6.7	3.89	418.1
2003	2.31	25.8	9.75	48.8	40.7	103	57.9	10.5	5.09	5.04	5.9	14.43	329.22
2004	15.16	11.52	8.5	102	60.8	80.8	69.4	32.4	8.06	4.76	7.38	2.66	403.44
2005	4.51	16.1	10.1	127	344	280	170	102	32.7	13.9	158	46.8	1305.11
2006	41.9	171	69.2	25.1	15.2	8.12	15	4	8.68	4.01	3.05	7.94	373.2
2007	75.7	63.6	194	154	60.2	71.1	38.3	31.9	58.4	14.3	6.07	3.11	770.68
2008	2.5	48.2	194	184	297	69.2	14.8	11	34.2	18.7	10.8	3.1	887.5
2009	187	142	34.8	110	108	59.4	77.6	39.3	34.6	11	5.78	2.63	812.11
2010	5.49	84.3	184	456	122	126	175	178	101	32.7	16.7	7.12	1488.31
2011	4.76	3.07	123	26.1	107	45.2	49.4	11.4	60.7	74.7	28.9	14.2	548.43
2012	18.6	18.1	199	123	45.1	46.9	48.5	14	5.28	3.97	2.7	0.932	526.082
2013	3.86	29.9	67.2	58.7	136	207	30.9	9.23	5	3.88	4.29	1.69	557.65
2014	7.96	164	85.4	57.2	13.7	56.8	18.8	4.96	5.56	7.69	3.18	1.88	427.13
2015	2.11	0.428	0	38.3	58.4	32.9	80	60.2	10.8	83.3	67.2	12.6	446.238
2016	11.6	59.9	20.3	49.3	315	59.6	30.8	9.05	4.32	3.26	1.92	0.814	565.864
2017	21.4	8.07	29.1	13.2	86.6	198	253	38.4	15.2	0	0	0	662.97

	MG23: Monthly flow (million m3)												
1982	39.50	84.41	10.68	5.67	5.18	6.82	10.05	10.33	7.24	52.09	9.22	11.59	252.78
1983	6.02	62.97	48.47	36.24	28.79	44.21	15.76	34.44	6.23	2.21	2.41	53.93	341.68
1984	17.43	26.84	36.79	32.73	81.81	86.04	72.11	0.16	0.87	0.12	0.05	0.00	354.95
1985	26.97	56.29	59.82	17.02	35.92	37.21	16.45	10.21	20.98	9.36	4.98	15.77	310.98
1986	104.22	110.06	26.91	69.80	31.51	71.07	39.29	35.04	6.91	7.11	24.98	116.31	643.21
1987	44.30	73.38	65.17	19.76	77.41	158.28	84.26	51.60	15.70	15.33	7.74	51.90	664.83
1988	61.85	45.80	79.62	65.50	186.18	66.70	27.21	46.05	54.20	15.07	8.38	5.22	661.78
1989	4.71	89.68	21.96	37.40	79.46	69.73	90.45	33.46	15.16	18.01	9.31	2.88	472.21
1990	1.33	0.72	1.52	183.16	169.97	130.49	26.33	11.13	8.42	4.11	2.35	3.33	542.86
1991	86.88	41.92	31.99	7.56	6.10	3.76	3.69	2.05	1.98	1.84	1.86	2.74	192.37
1992	10.34	15.72	1.42	4.68	36.58	18.24	30.07	7.30	3.29	2.41	3.32	1.16	134.53
1993	62.28	52.06	44.92	142.56	105.00	33.08	14.89	11.59	9.45	9.56	8.55	6.88	500.82
1994	6.33	10.24	6.89	30.57	7.65	23.64	11.53	13.53	5.40	4.83	4.28	3.77	128.66
1995	25.10	32.19	84.94	53.69	56.05	93.98	21.00	9.93	6.72	6.71	7.63	6.11	404.05
1996	23.18	77.30	74.45	84.78	22.17	103.61	97.34	60.64	44.51	21.52	21.68	13.94	645.12
1997	10.50	16.61	34.98	34.98	70.67	82.40	66.12	22.19	12.71	10.45	8.60	8.88	379.09
1998	32.62	49.10	11.98	39.92	26.74	19.11	14.54	11.52	8.96	6.05	3.78	2.34	226.66
1999	6.98	3.39	1.95	10.11	7.22	10.55	24.65	6.45	6.33	8.36	39.23	32.20	157.42
2000	16.50	21.33	56.65	13.71	9.38	16.78	80.74	69.32	16.22	13.55	51.40	155.93	521.50
2001	39.93	136.99	77.86	74.91	60.63	41.19	30.97	33.83	47.23	25.89	46.95	54.85	671.24
2002	14.42	13.19	29.33	27.40	34.37	53.92	11.45	4.70	2.73	4.19	5.03	3.41	204.15
2003	2.80	8.61	5.83	22.74	18.40	36.29	22.48	7.38	5.38	4.81	3.74	6.16	144.59
2004	8.85	4.33	10.34	15.21	0.00	0.00	20.53	12.48	6.20	4.06	4.68	3.02	89.70
2005	3.75	6.22	3.08	27.27	51.57	137.59	49.09	42.45	20.25	11.92	53.11	21.06	427.36
2006	12.33	69.65	30.91	11.63	9.38	5.07	6.51	4.91	5.60	4.19	3.59	2.65	166.44
2007	30.02	20.49	49.39	46.82	22.71	28.61	18.22	18.27	19.54	8.77	4.68	2.27	269.79
2008	1.55	21.10	35.52	51.85	93.04	31.55	13.94	10.12	17.32	14.93	9.39	3.50	303.81
2009	66.29	58.71	17.84	34.95	42.62	24.37	37.30	19.05	13.06	6.37	4.61	3.00	328.17
2010	3.64	34.06	71.49	217.62	46.57	49.44	81.21	79.87	37.27	15.48	7.27	4.29	648.22
2011	3.25	2.73	66.80	9.89	39.22	16.08	22.98	5.74	26.18	30.27	12.24	5.50	240.87
2012	4.12	6.79	77.30	38.60	14.89	10.02	18.32	5.32	3.46	2.78	2.19	1.24	185.02
2013	3.24	13.77	16.70	27.40	55.82	63.05	11.23	4.61	3.27	2.72	2.87	0.00	204.67
2014	6.22	92.09	33.61	21.29	6.23	23.47	8.80	2.49	2.69	3.12	1.69	1.36	203.06
2015	0.92	0.79	0.49	8.43	12.90	13.95	20.61	30.56	4.40	20.21	24.79	4.17	142.22

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LOWLANDS

1.1 LOCATION

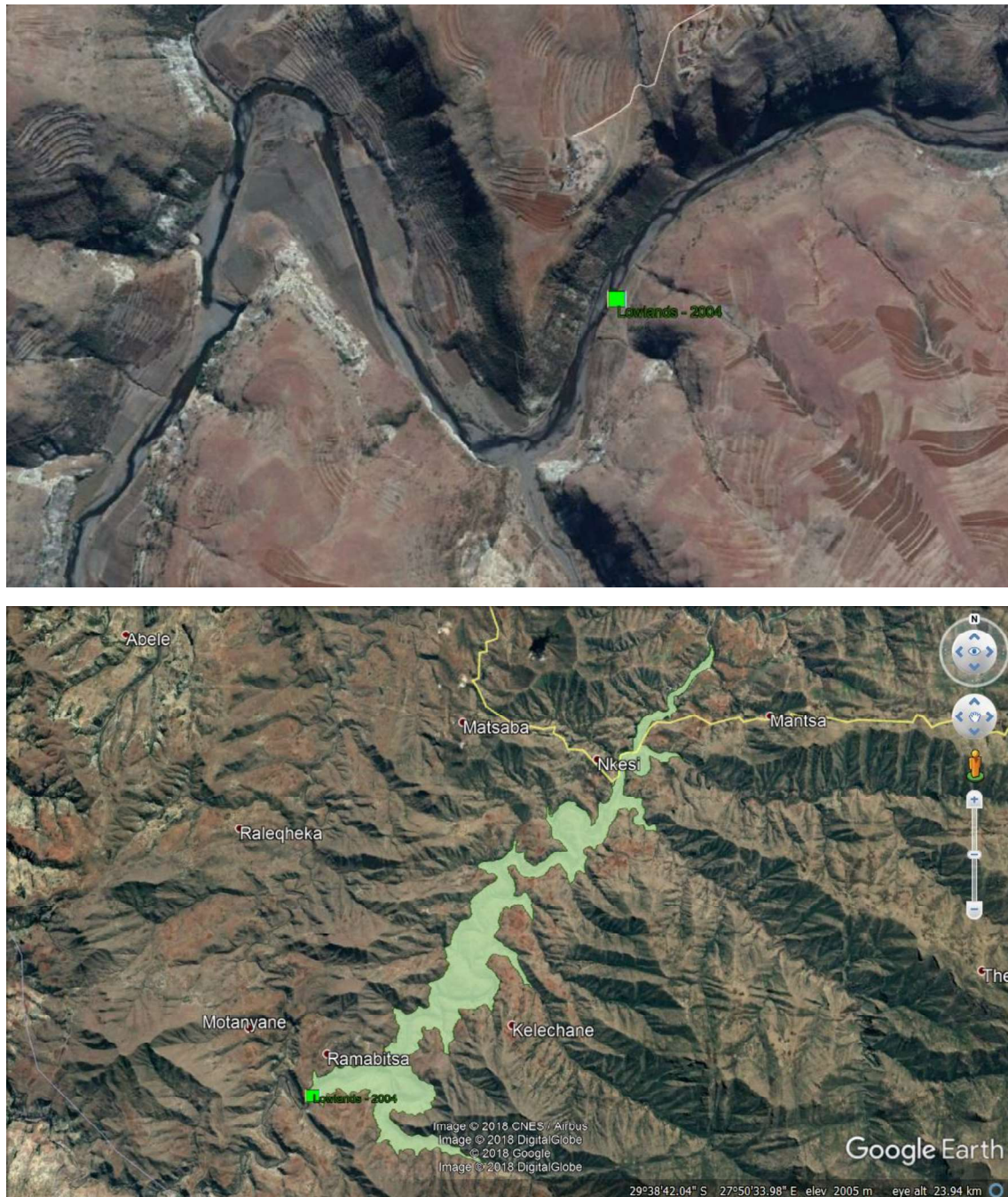The Lowlands dam site is located at 29°44'31.40"S and 27°43'10.26"E in the West of Lesotho.

Figure 1: Map of Dam Site Location

1.2 GENERAL

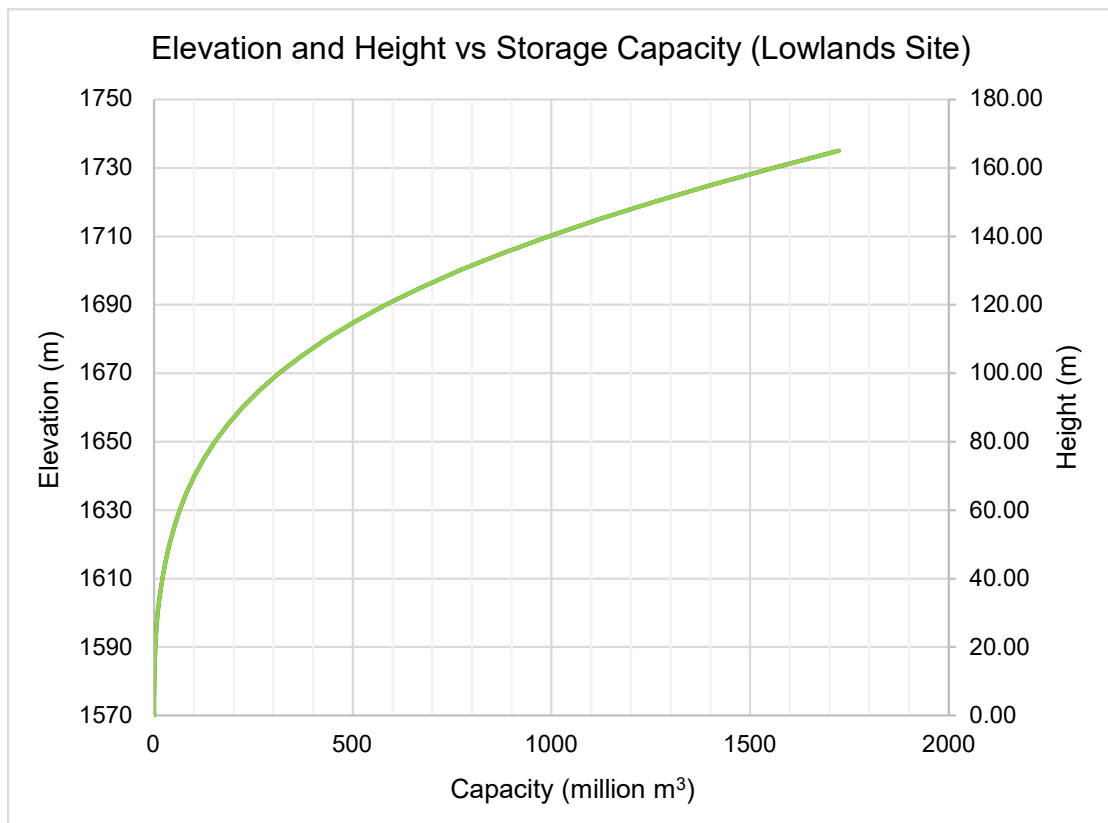|	
• Catchment Size (km²):	803
• MAR (MCM/a):	240
• Design Floods (m³/s):	
• 1:10 year (River diversion):	780
• 1:200 (Design Flood):	1 855
• RMF + Δ (Safety Evaluation):	3 580
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m³)	6.03

Figure 2: Photograph of Dam Site

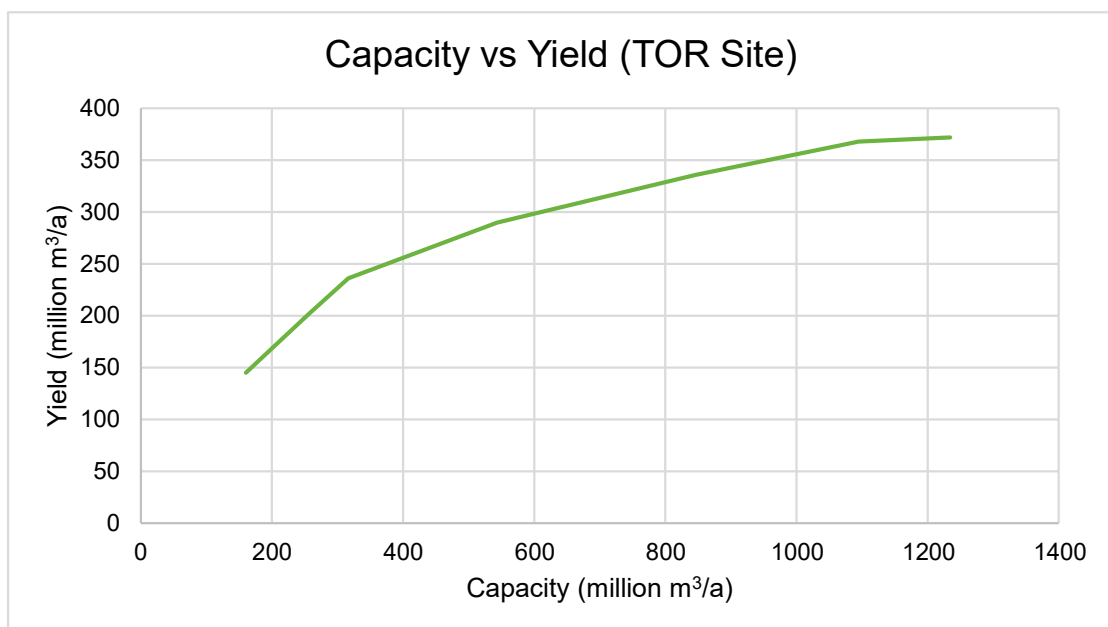**Figure 3: Elevation and Height vs Storage Capacity Graph**

Figure 4: Capacity vs Yield Graph

Site_Lowlands Valley Profile

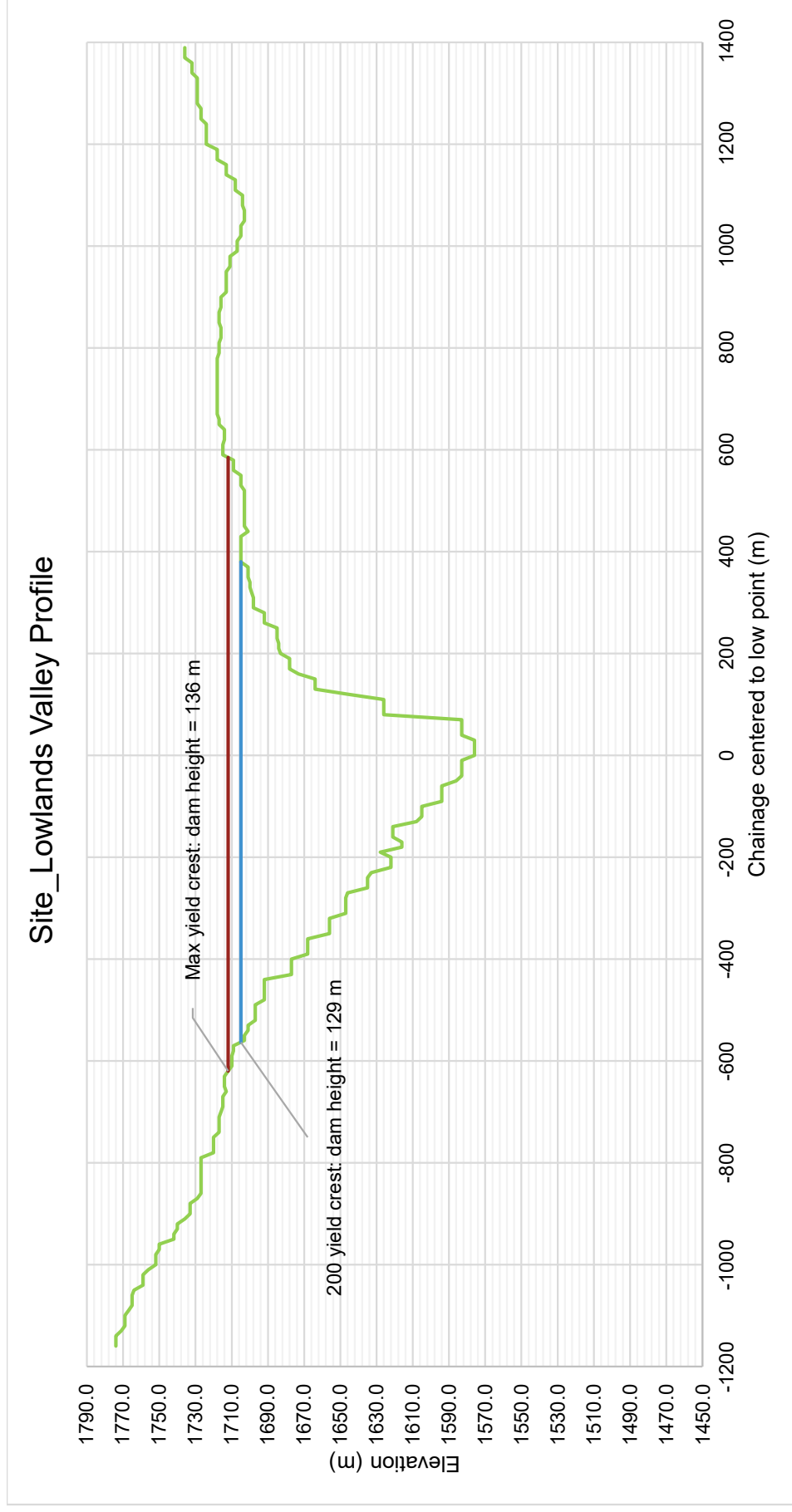Max yield crest: dam height = 136 m

200 yield crest: dam height = 129 m

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

Appendix E - Lowlands

Knight Piésold
C O N S U L T I N G

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	129	136
Capacity (MCM)	605	729
Yield (MCM/a)	200	209
Impact on the yield of Gariep Dam (MCM/a)	-165	-159
Aspect Ratio	7.3	8.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	2 020 165	2 372 370
Hydropower potential - continuous flow (MW)	7.55	8.93
Hydropower potential - peak power (MW)	50.7	60.0
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 6 060	R 7 117
URV of yield assured (i = 8%)	3.6	4.1

N1A

1.1 LOCATION

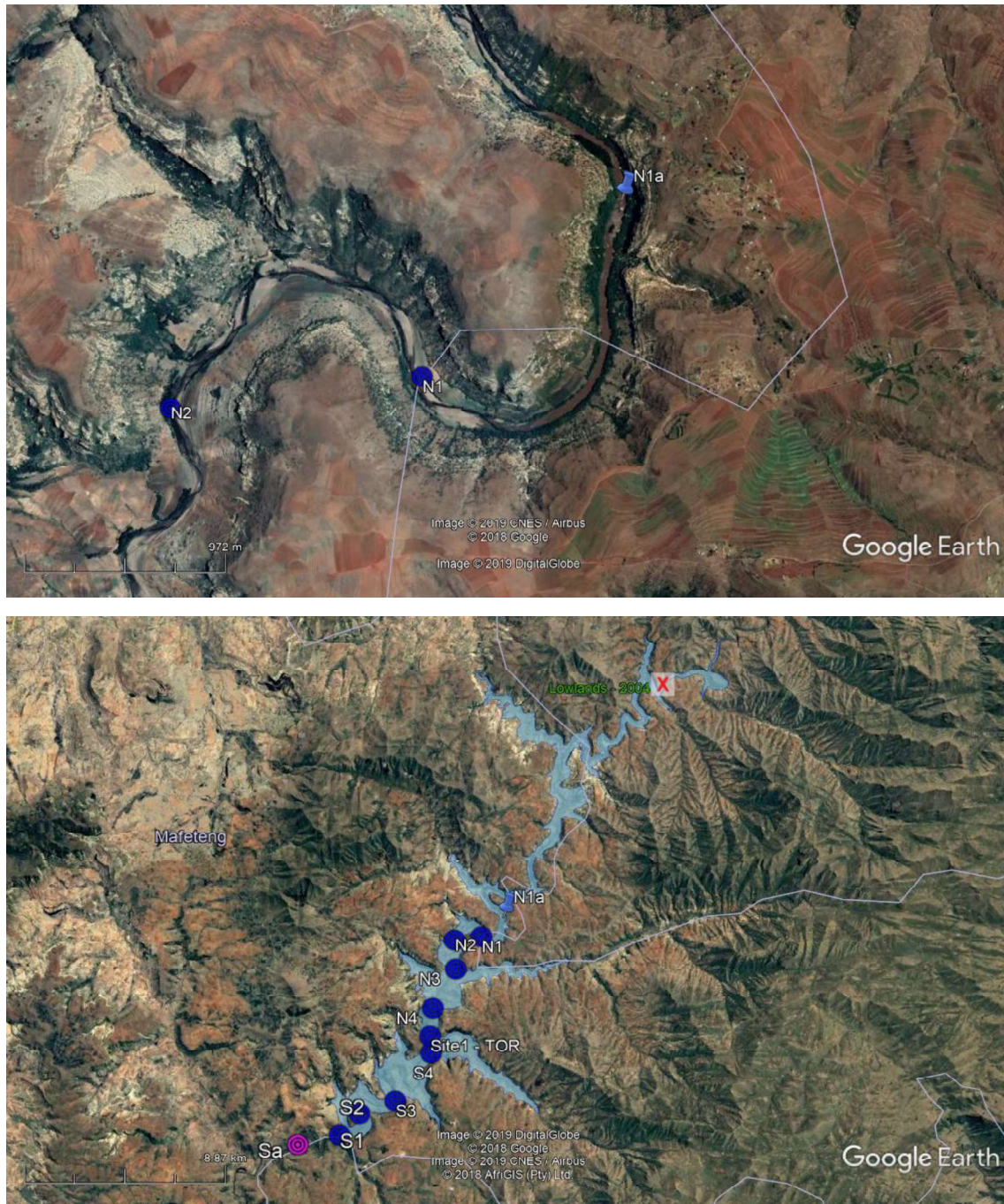The N1a dam site is located at 29°50'13.46"S and 27°38'45.31"E in the West of Lesotho.

Figure 1: Map of Dam Site Location

1.2   GENERAL

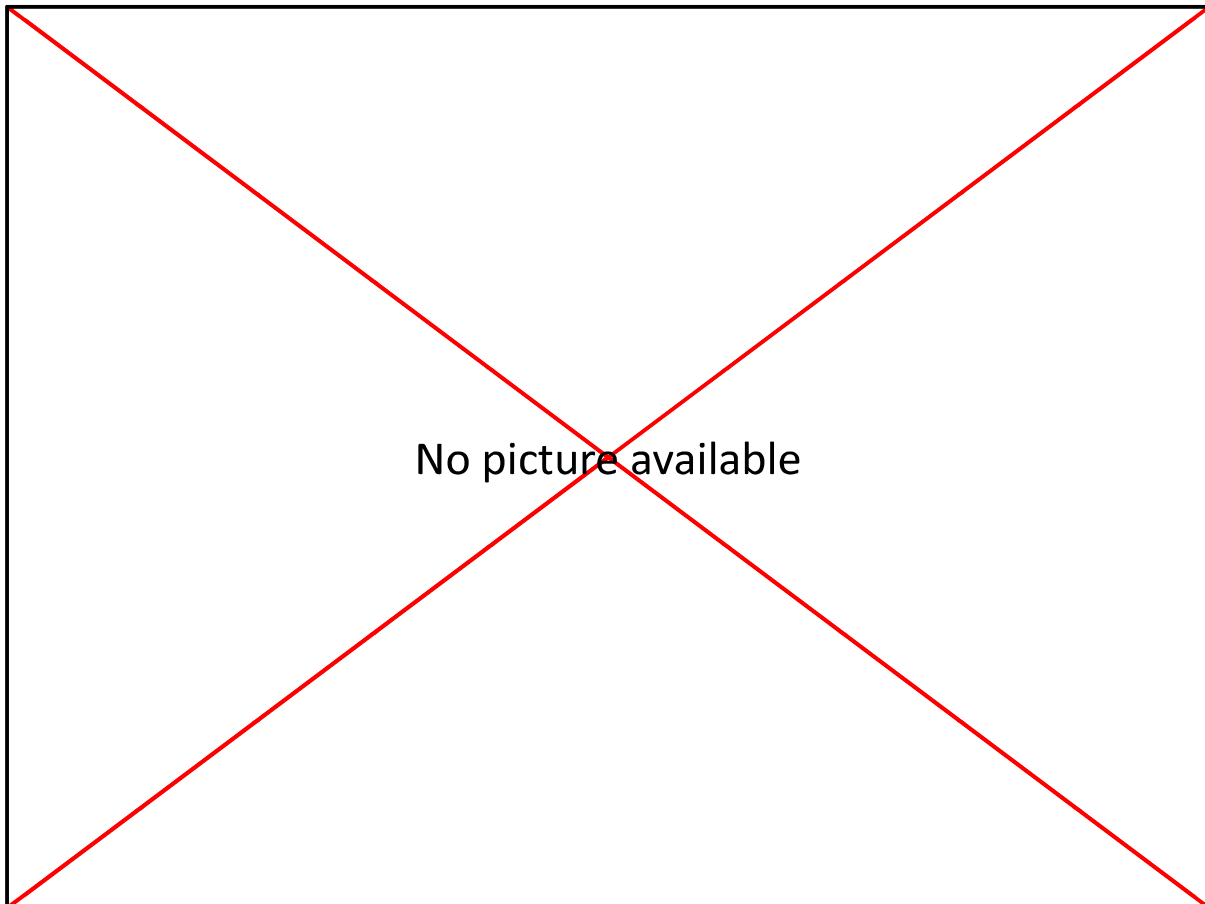|	
• Catchment Size (km^2):	1 402
• MAR (MCM/a):	378
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 030
• 1:200 (Design Flood):	2 504
• RMF + Δ (Safety Evaluation):	4 682
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.57

No picture available

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_N1a Valley Profile

Max yield crest: dam height = 126 m

200 yield crest: dam height = 84 m

Chainage centered to low point (m)

Elevation (m)

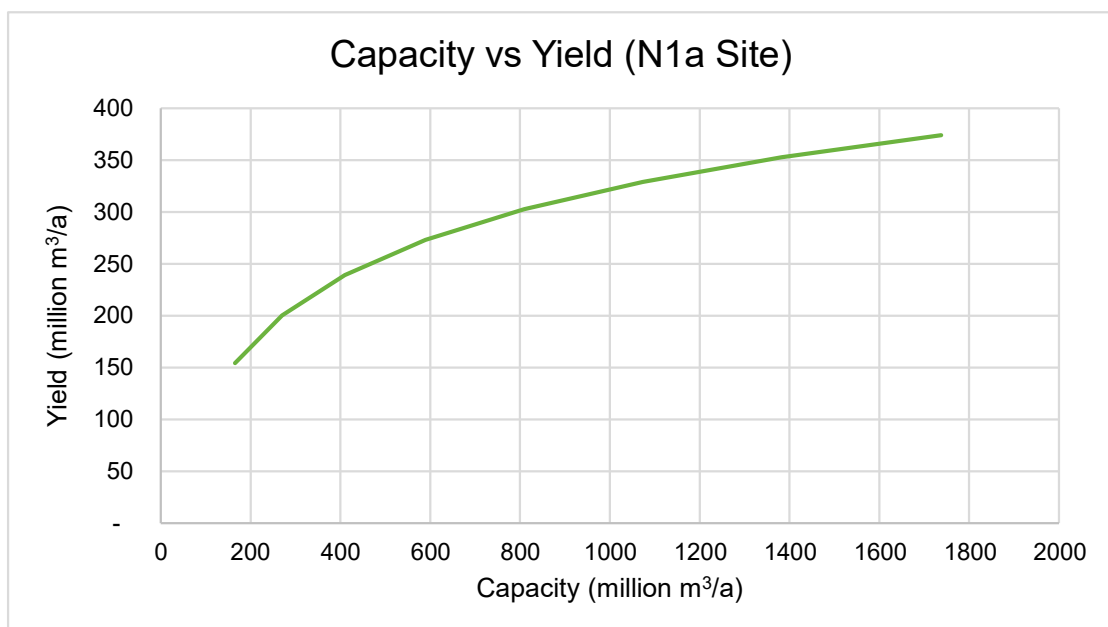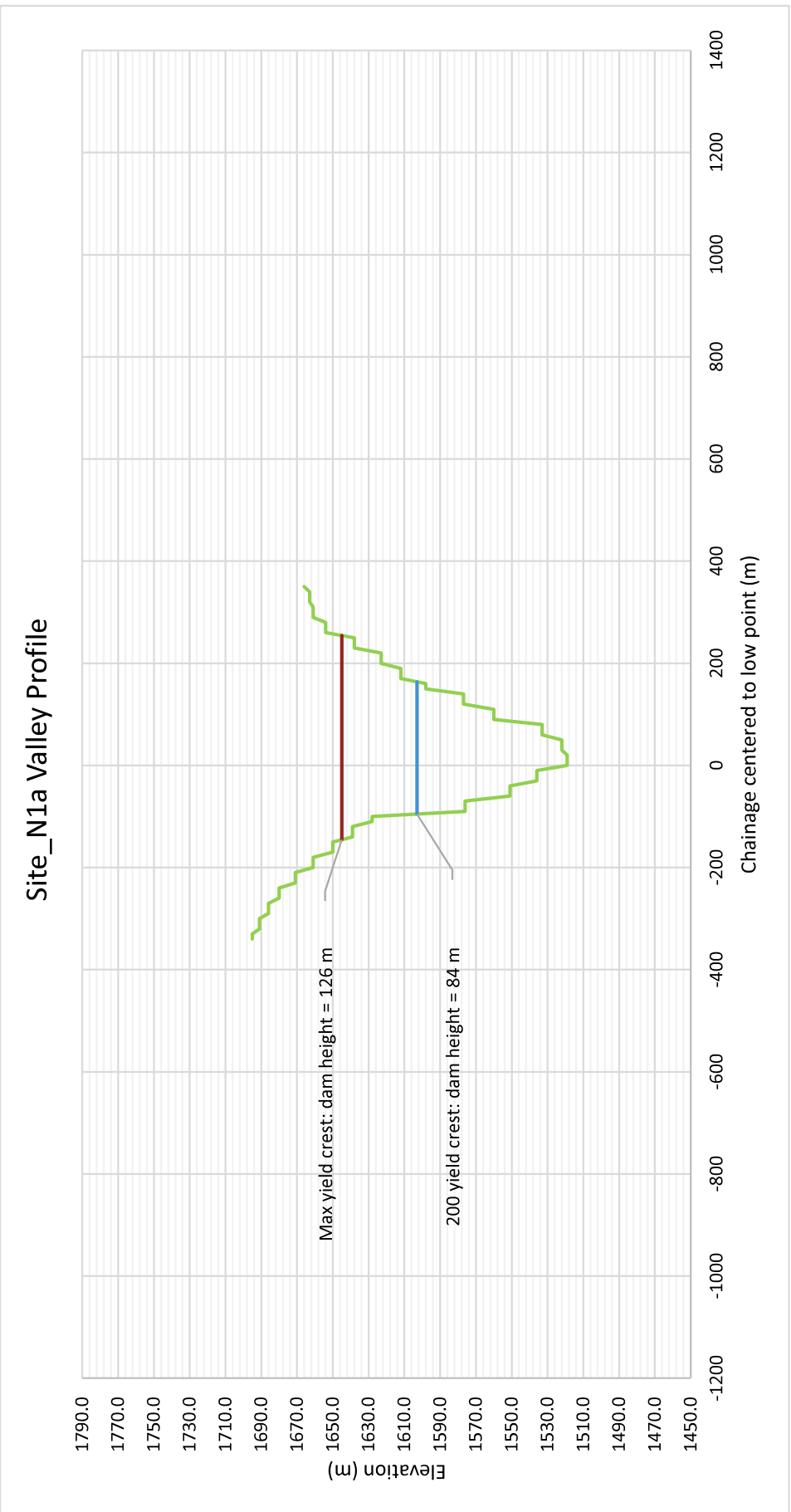**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

Knight Piésold
CONSULTING

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	84	126
Capacity (MCM)	270	1 133
Yield (MCM/a)	200	334
Impact on the yield of Gariep Dam (MCM/a)	-165	-74
Aspect Ratio	3.1	3.2
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	415 668	1 119 549
Hydropower potential - continuous flow (MW)	4.74	12.33
Hydropower potential - peak power (MW)	31.90	82.90
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 247	R 3 359
URV of yield assured (i = 8%)	0.7	1.2

N1

1.1 LOCATION

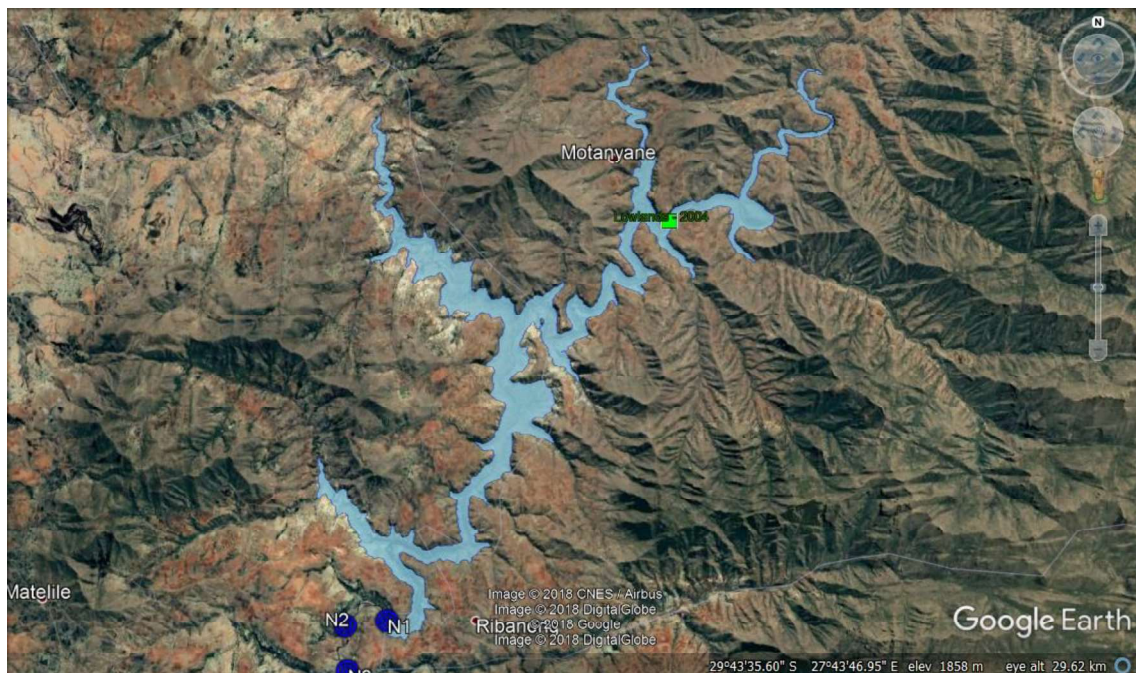The N1 dam site is located at 29°50'40.87"S and 27°38'10.13"E in the West of Lesotho.

Figure 1: Map of Dam Site Location

1.2   GENERAL

• Catchment Size (km^2):	1 406
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 030
• 1:200 (Design Flood):	2 510
• RMF + Δ (Safety Evaluation):	4 690
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.71

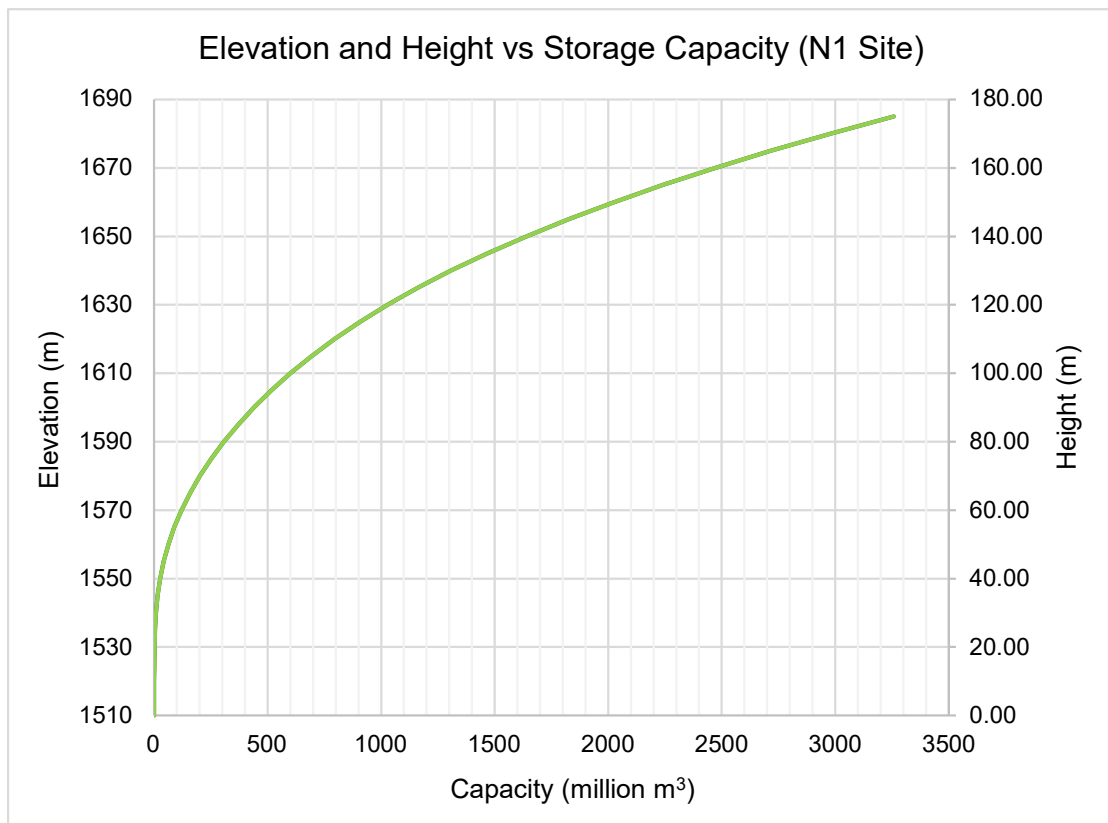
Figure 2: Photograph of Dam Site

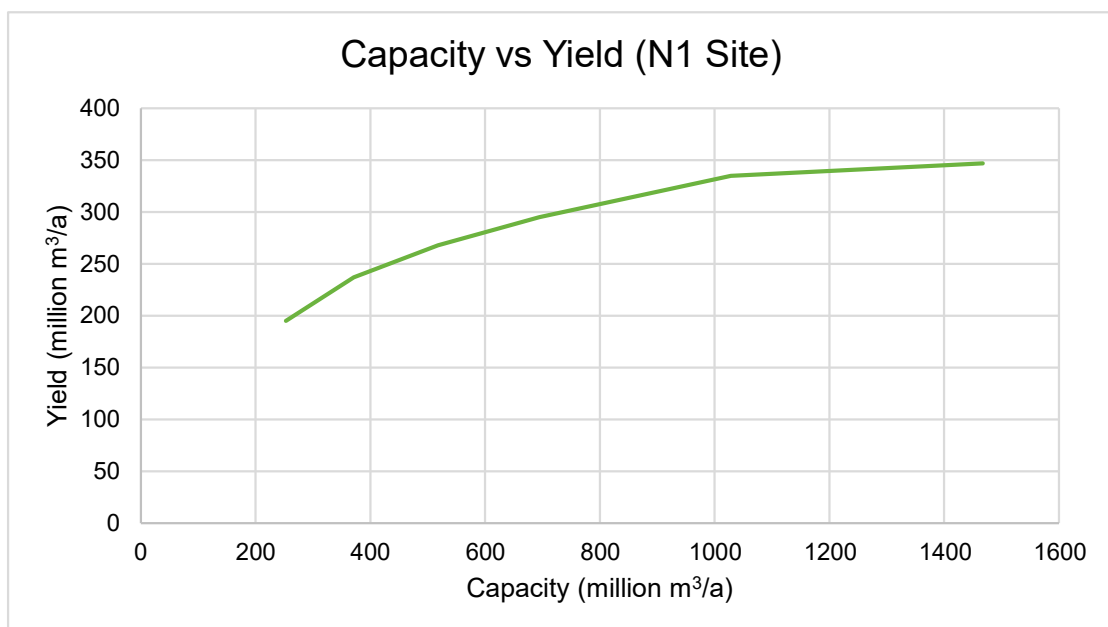**Figure 3: Elevation and Height vs Storage Capacity Graph**

Figure 4: Capacity vs Yield Graph

Site_N1 Valley Profile

Max yield crest: dam height = 133 m

200 yield crest: dam height = 86 m
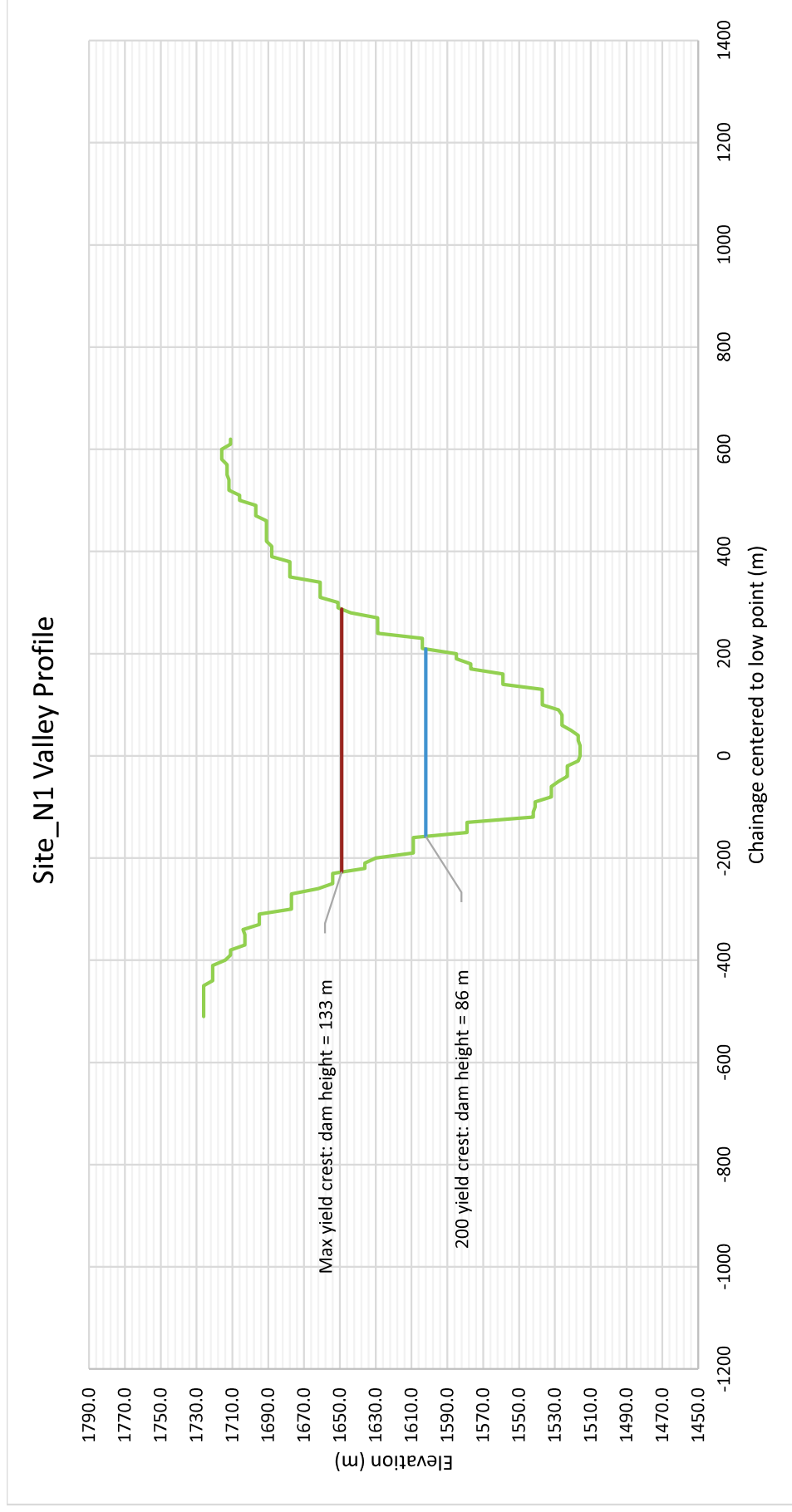
Chainage centered to low point (m)

Elevation (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	86	133
Capacity (MCM)	271	1 137
Yield (MCM/a)	200	335
Impact on the yield of Gariep Dam (MCM/a)	-165	-74
Aspect Ratio	4.3	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	714 539	1 972 415
Hydropower potential - continuous flow (MW)	4.85	13.50
Hydropower potential - peak power (MW)	32.60	90.73
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 144	R 5 917
URV of yield assured (i = 8%)	1.3	2.1

N2

1.1 LOCATION

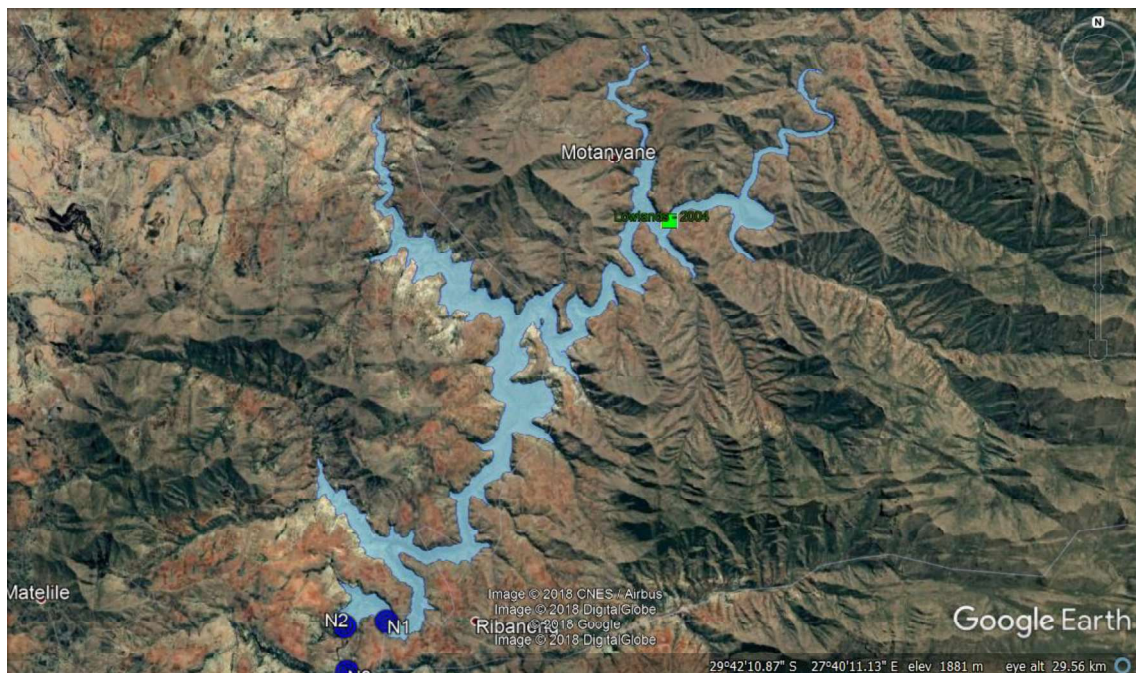The N2 dam site is located at 29°50'45.77"S and 27°37'25.50"E in the West of Lesotho.

Figure 1: Map of Dam Site Location

1.2   GENERAL

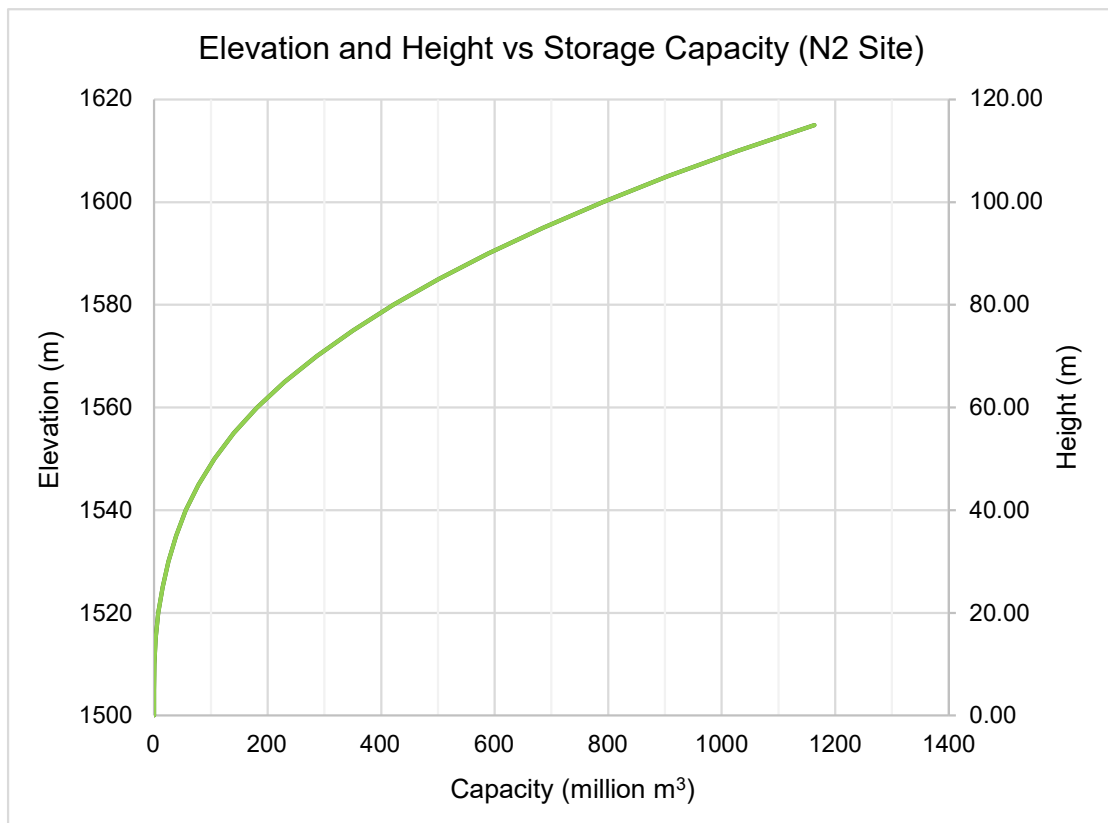|	
• Catchment Size (km^2):	1 412
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 035
• 1:200 (Design Flood):	2 515
• RMF + Δ (Safety Evaluation):	4 700
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	28.93

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_N2 Valley Profile

Max yield crest: dam height = 123 m

200 yield crest: dam height = 78 m

Chainage centered to low point (m)

Elevation (m)

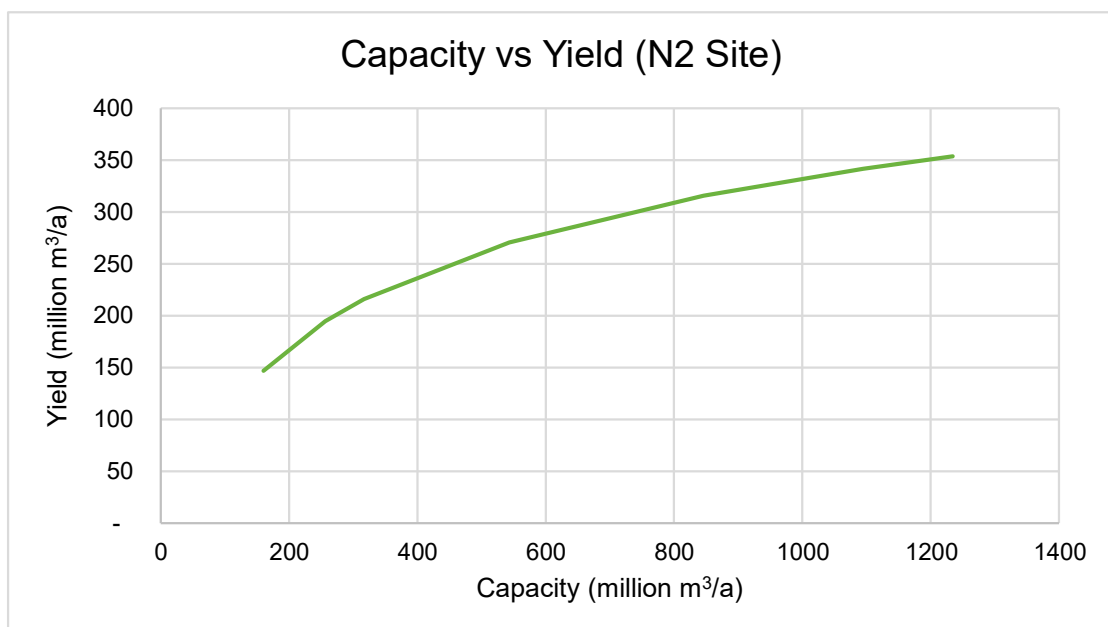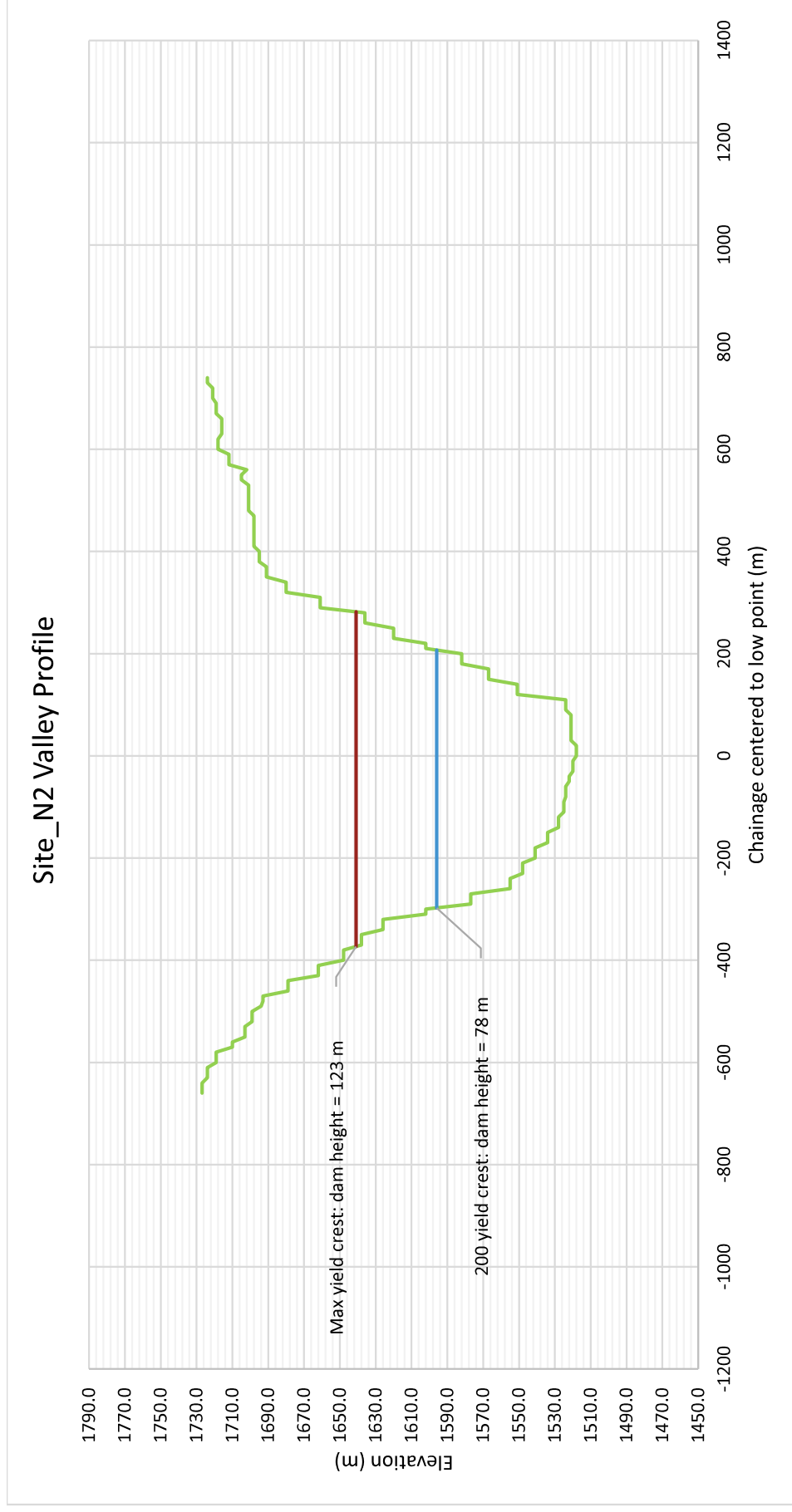**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

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1.3   DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	123
Capacity (MCM)	270	1 143
Yield (MCM/a)	200	346
Impact on the yield of Gariep Dam (MCM/a)	-165	-66
Aspect Ratio	6.5	5.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	872 493	2 397 463
Hydropower potential - continuous flow (MW)	4.33	12.63
Hydropower potential - peak power (MW)	29.10	84.87
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 617	R 7 192
URV of yield assured (i = 8%)	1.6	2.5

N3

1.1 LOCATION

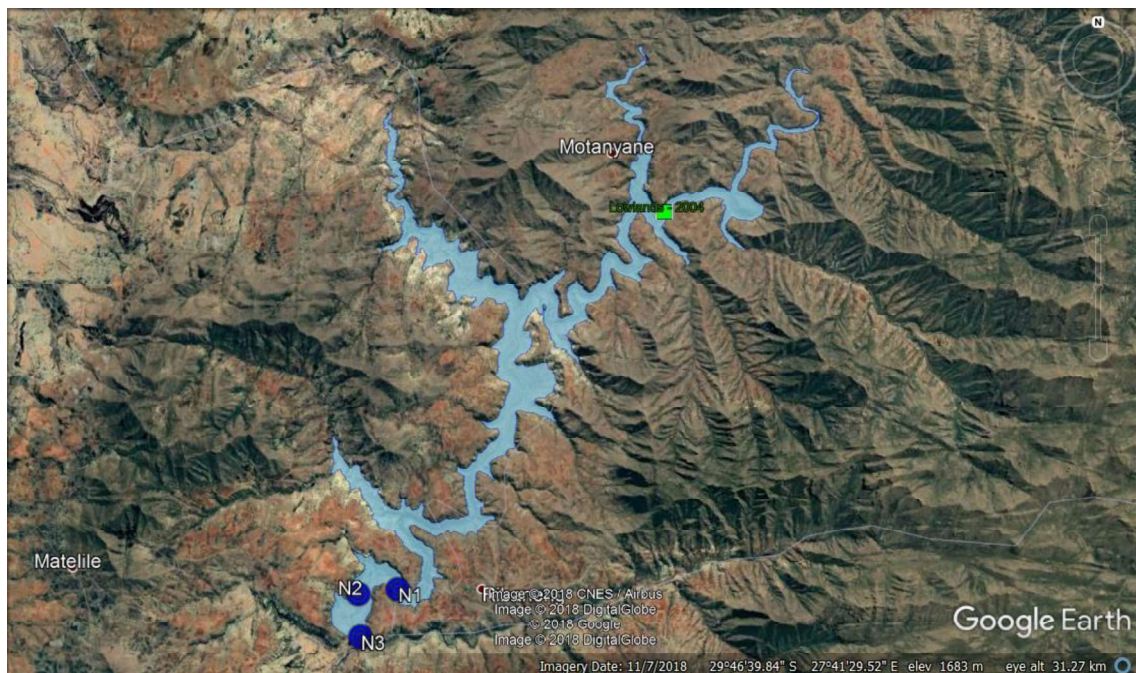The N3 dam site is located at 29°51'27.89"S and 27°37'27.70"E in the West of Lesotho.
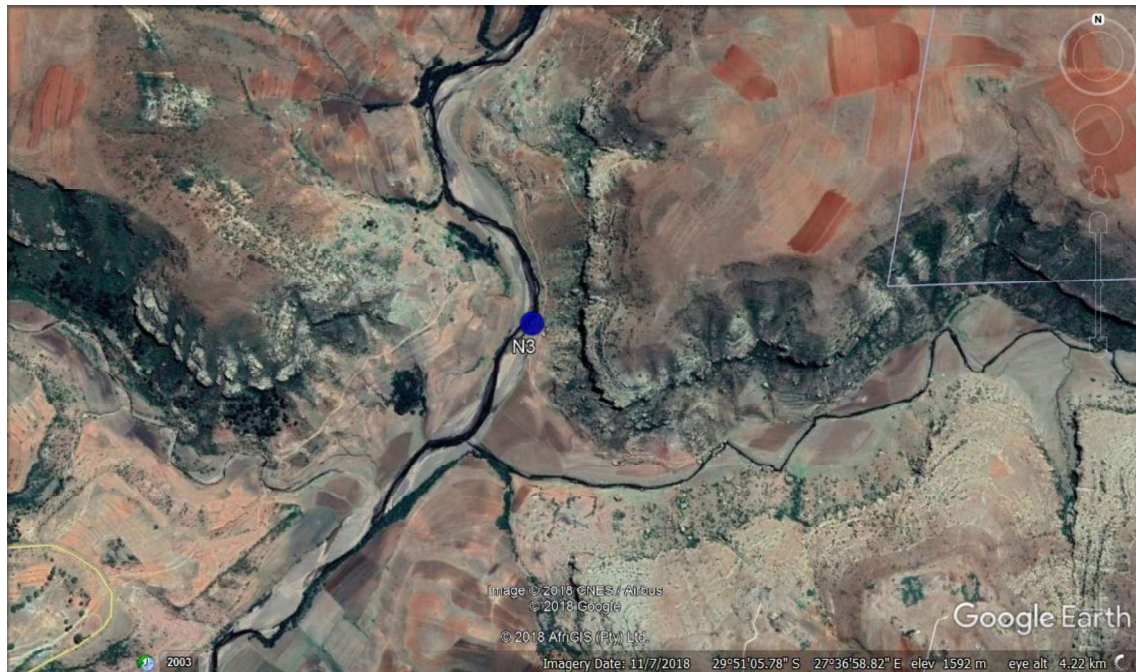
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 416
• MAR (MCM/a):	380
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 035
• 1:200 (Design Flood):	2 515
• RMF + ∆ (Safety Evaluation):	4 705
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	29.09

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_N3 Valley Profile

Max yield crest: dam height = 123 m

200 yield crest: dam height = 78 m

Chainage centered to low point (m)

Elevation (m)

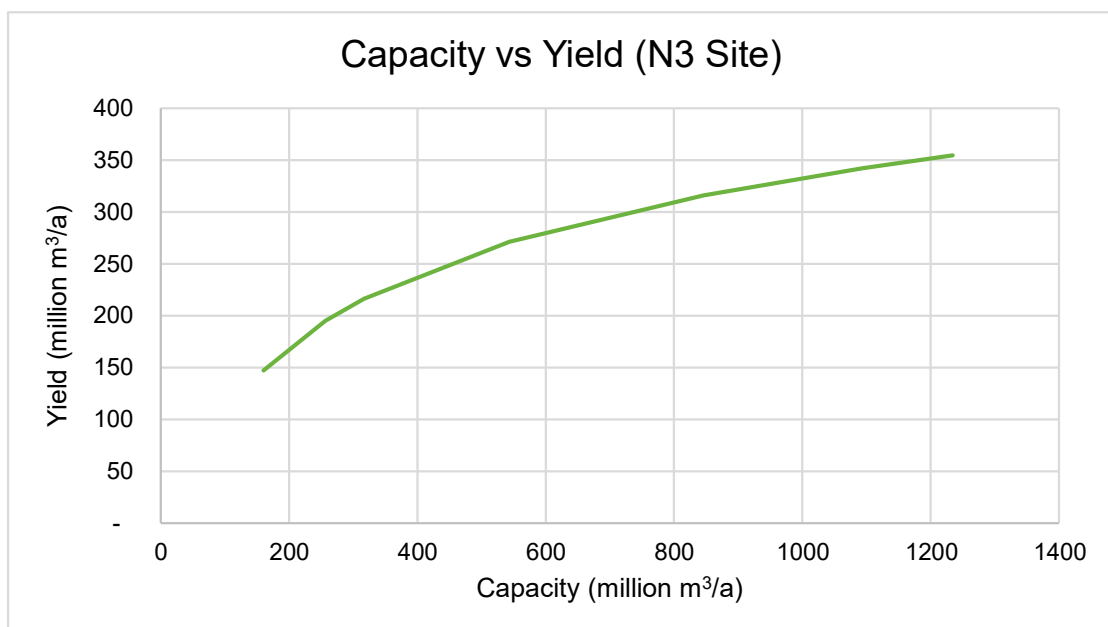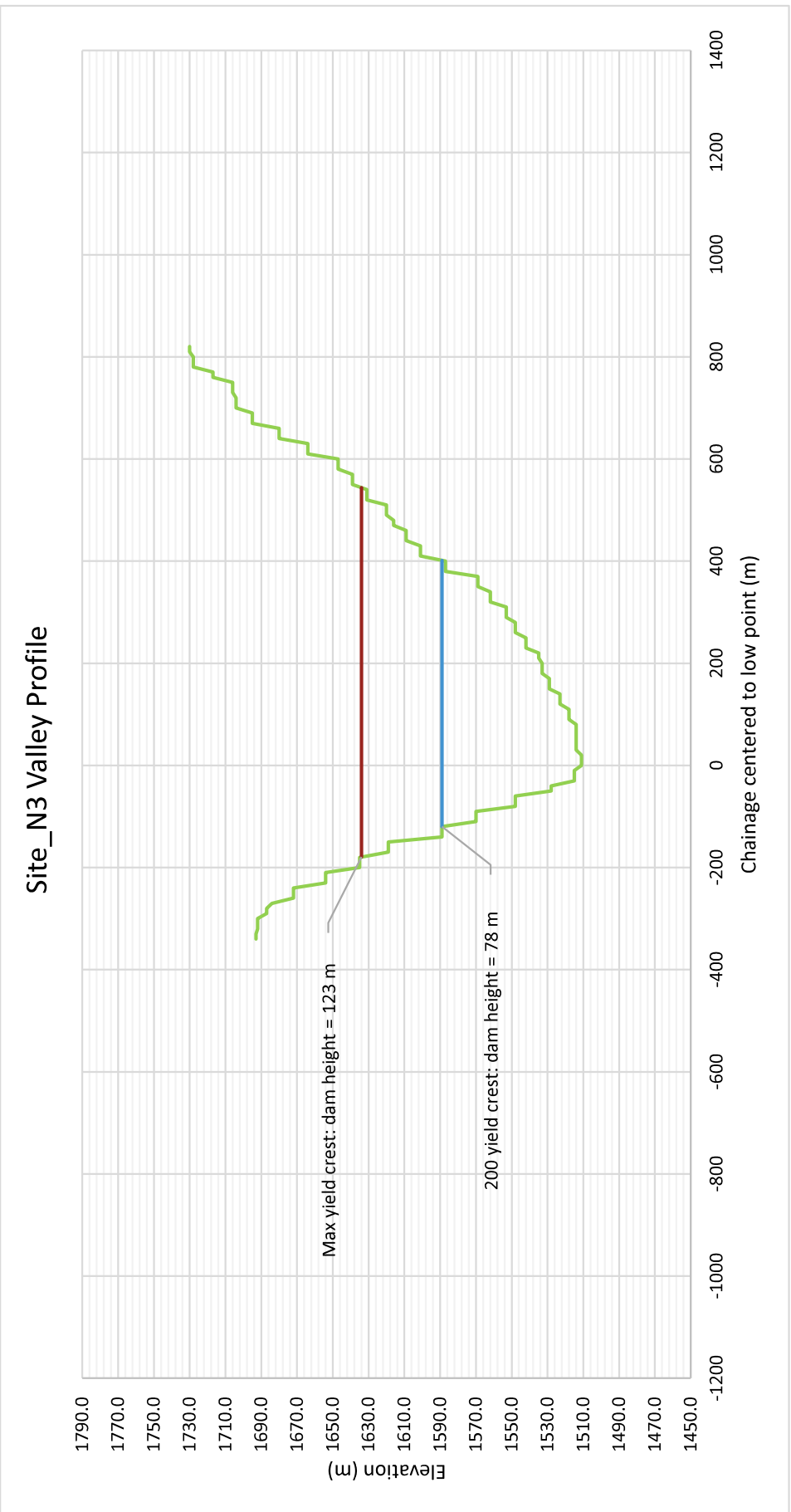**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

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1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	123
Capacity (MCM)	269	1 147
Yield (MCM/a)	200	347
Impact on the yield of Gariep Dam (MCM/a)	-165	-66
Aspect Ratio	6.7	5.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	753 928	2 242 203
Hydropower potential - continuous flow (MW)	4.33	12.67
Hydropower potential - peak power (MW)	29.08	85.13
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 262	R 6 727
URV of yield assured (i = 8%)	1.4	2.3

N4

1.1 LOCATION

The N4 dam site is located at 29°52'25.33"S and 27°36'49.60"E in the West of Lesotho.
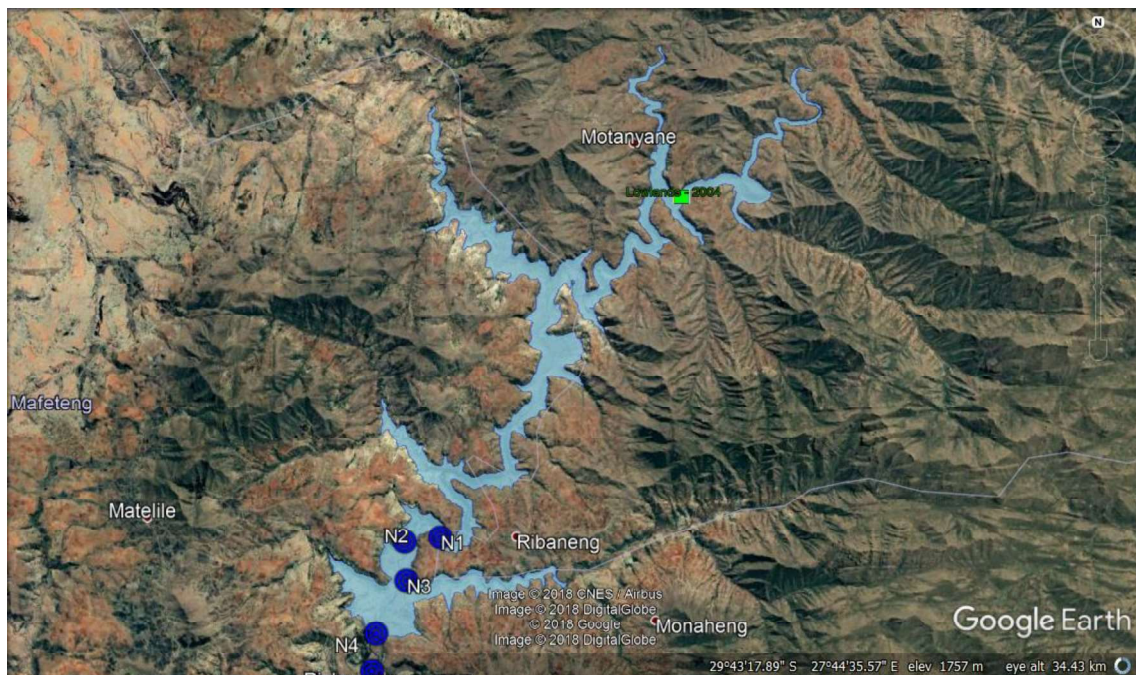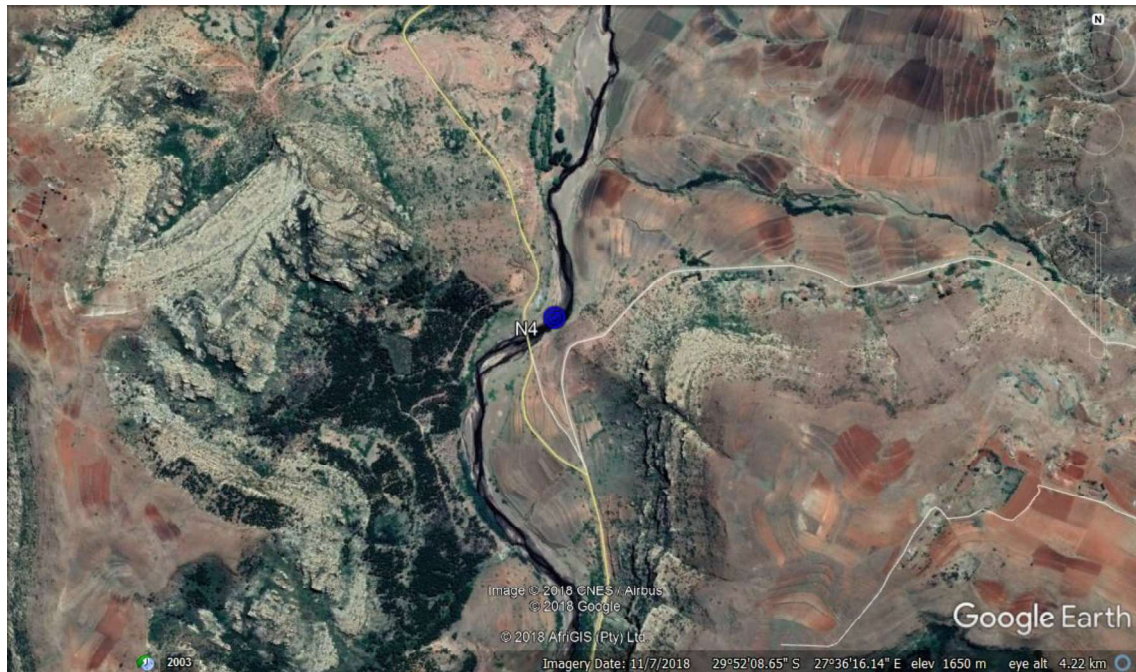
Figure 1: Map of Dam Site Location

1.2   GENERAL

• Catchment Size (km^2):	1 570
• MAR (MCM/a):	420
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 090
• 1:200 (Design Flood):	2 660
• RMF + ∆ (Safety Evaluation):	4 945
• Distance to Construction material	+ 5 km
• Expected 50-year Sediment Volumes (million m^3)	34.88

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_N4 Valley Profile

Max yield crest: dam height = 127 m

200 yield crest: dam height = 76 m

Elevation (m)

Chainage centered to low point (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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C O N S U L T I N G

1.3 DAM HEIGHT OPTIONS

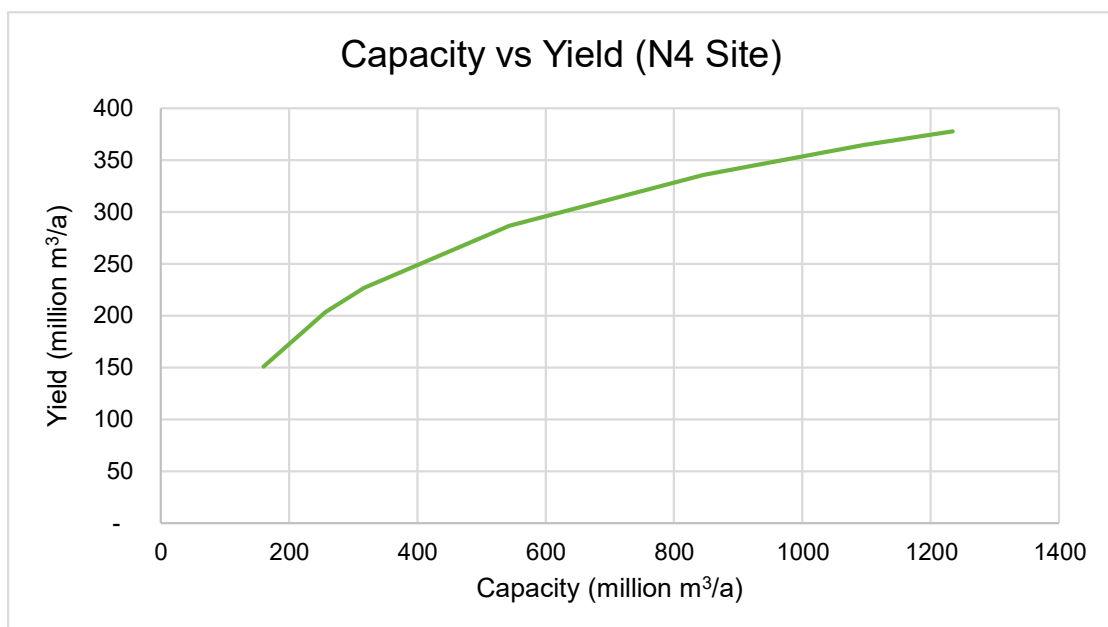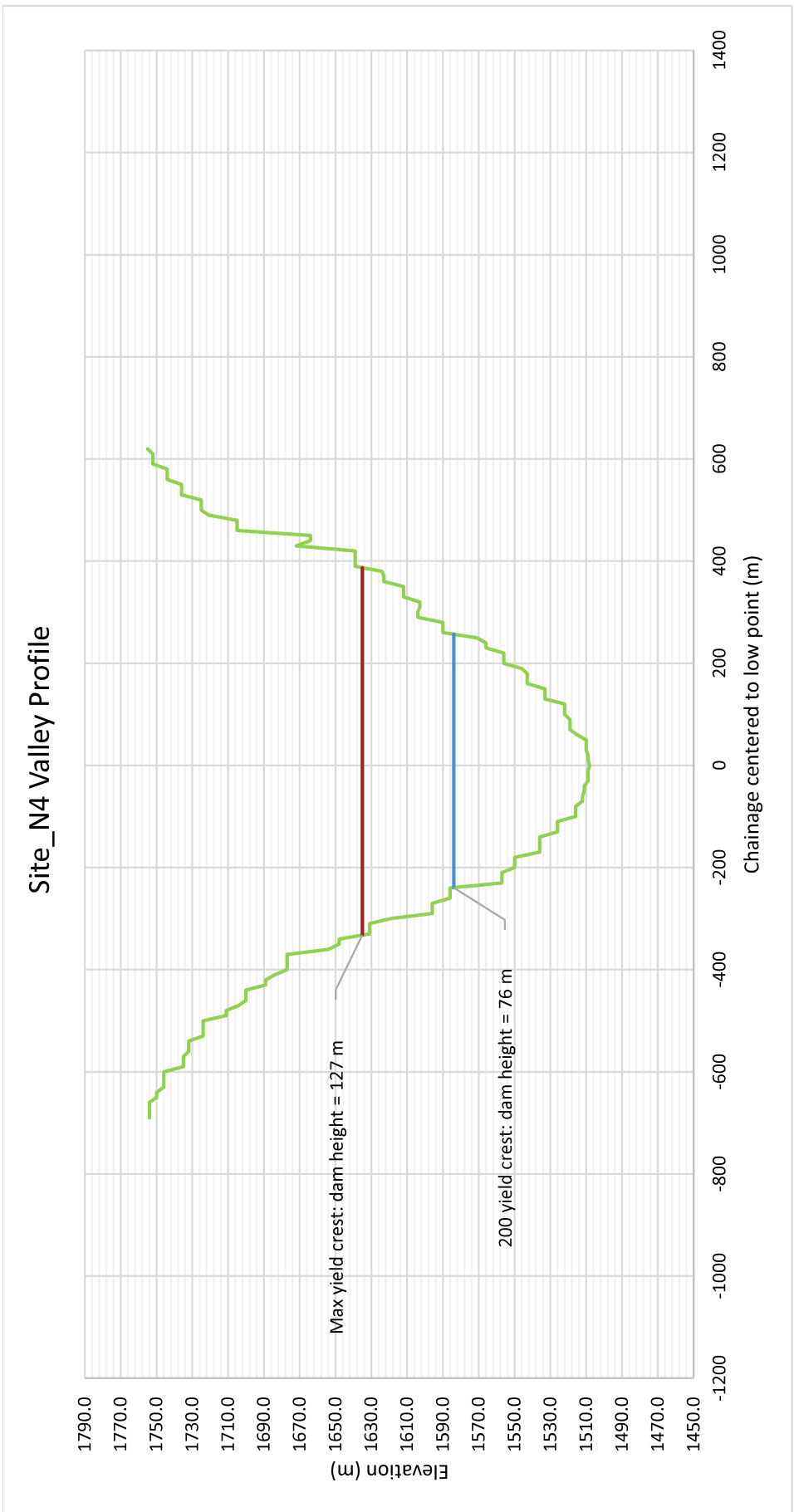| Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	76	127
Capacity (MCM)	248	1 254
Yield (MCM/a)	200	380
Impact on the yield of Gariep Dam (MCM/a)	-165	-44
Aspect Ratio	6.5	5.7
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	758 815	2 518 354
Hydropower potential - continuous flow (MW)	4.26	13.95
Hydropower potential - peak power (MW)	28.60	93.71
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 276	R 7 555
URV of yield assured (i = 8%)	1.4	2.4

TOR

1.1 LOCATION

The TOR dam site is located at 29°53'05.80"S and 27°36'44.86"E in the West of Lesotho.
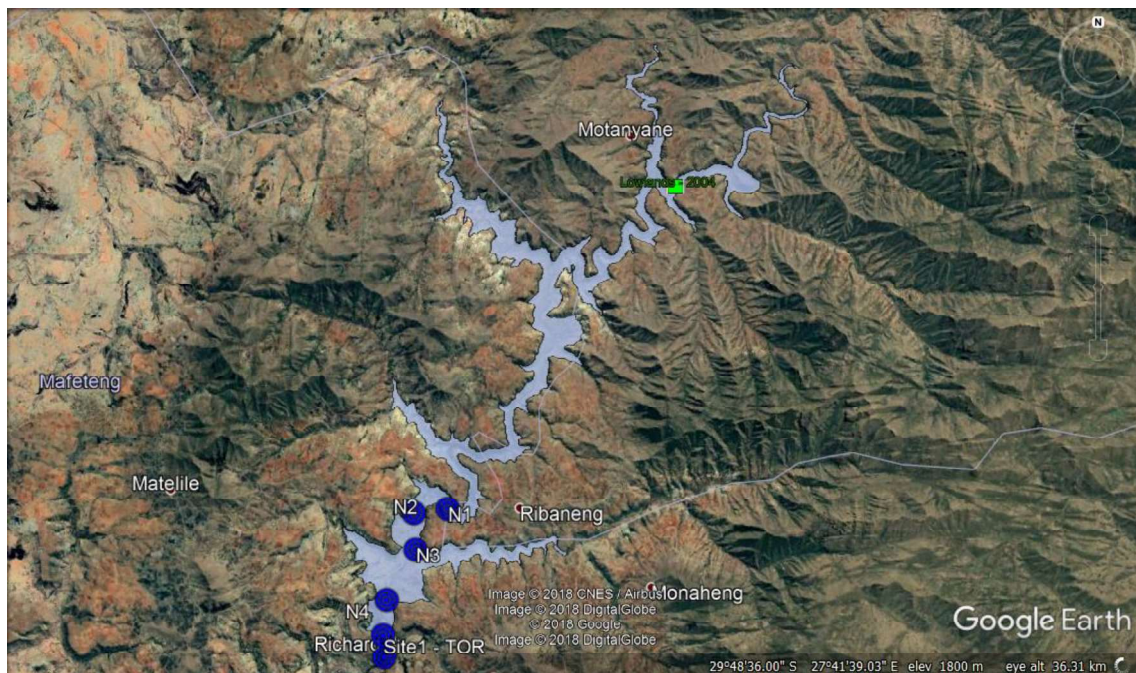
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 572
• MAR (MCM/a):	420
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 090
• 1:200 (Design Flood):	2 665
• RMF + Δ (Safety Evaluation):	4 945
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	35.06

Figure 2: Photograph of Dam Site
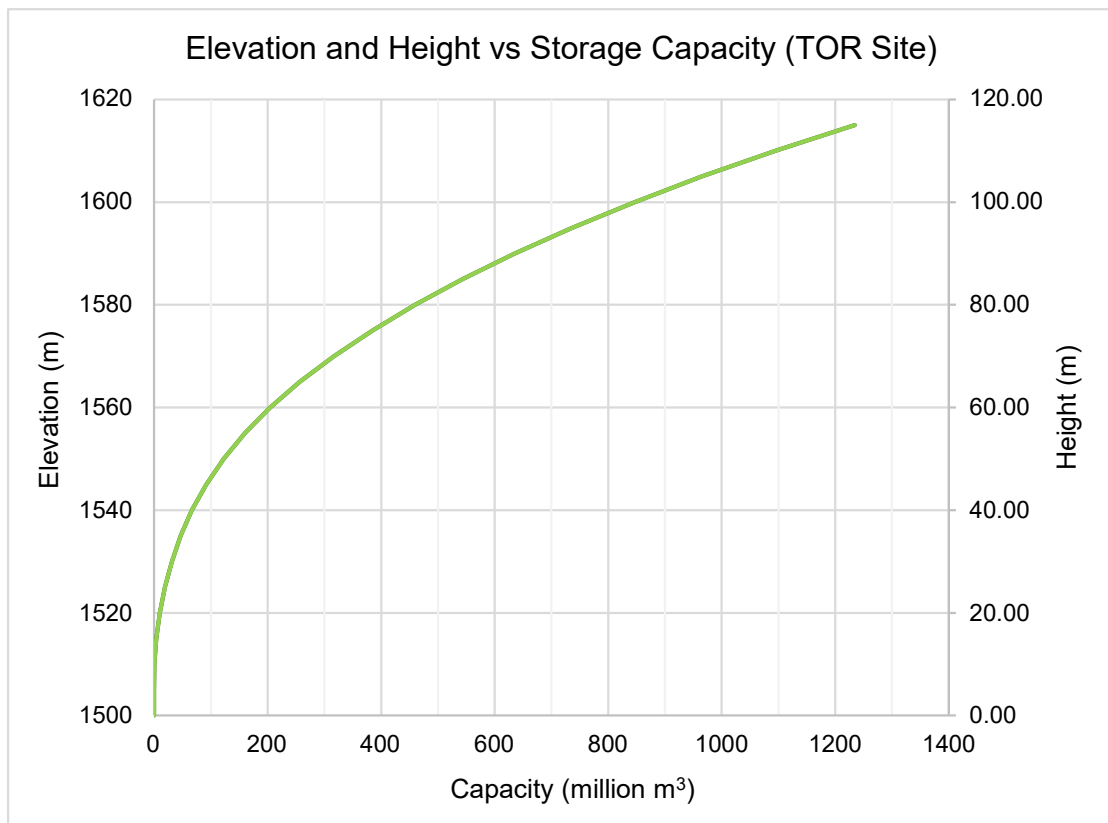
Figure 3: Elevation and Height vs Storage Capacity Graph
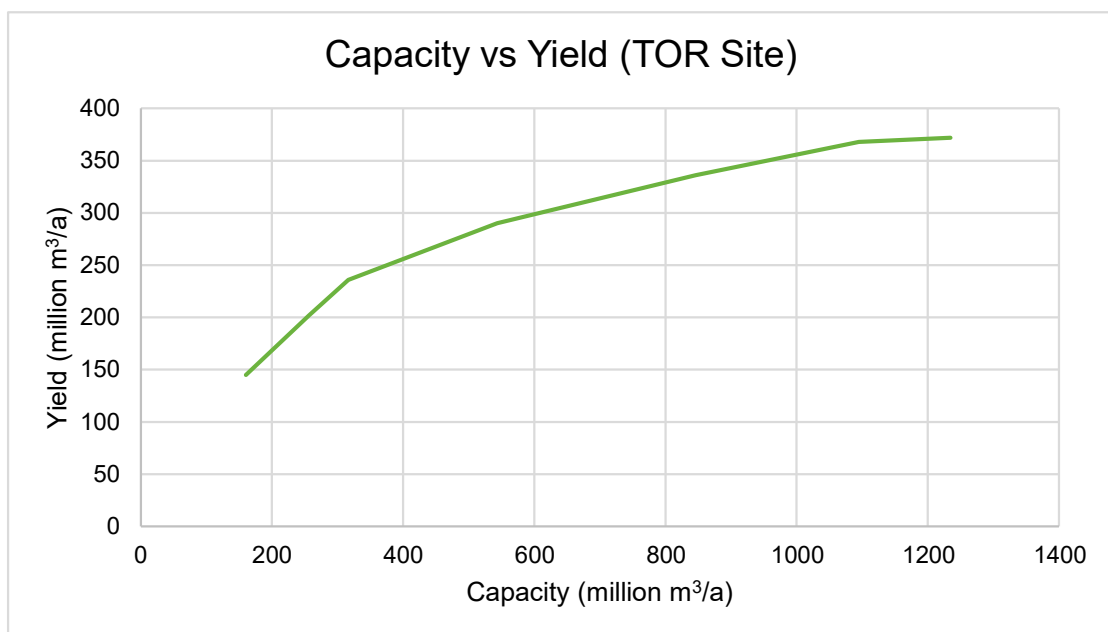
Figure 4: Capacity vs Yield Graph

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	125
Capacity (MCM)	248	1 258
Yield (MCM/a)	200	381
Impact on the yield of Gariep Dam (MCM/a)	-165	-43
Aspect Ratio	5.9	4.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	623 576	2 156 303
Hydropower potential - continuous flow (MW)	4.13	13.75
Hydropower potential - peak power (MW)	27.76	92.39
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 871	R 6 469
URV of yield assured (i = 8%)	1.1	2.0

S4

1.1 LOCATION

The S4 dam site is located at 29°53'31.17"S and 27°36'46.27"E in the West of Lesotho.
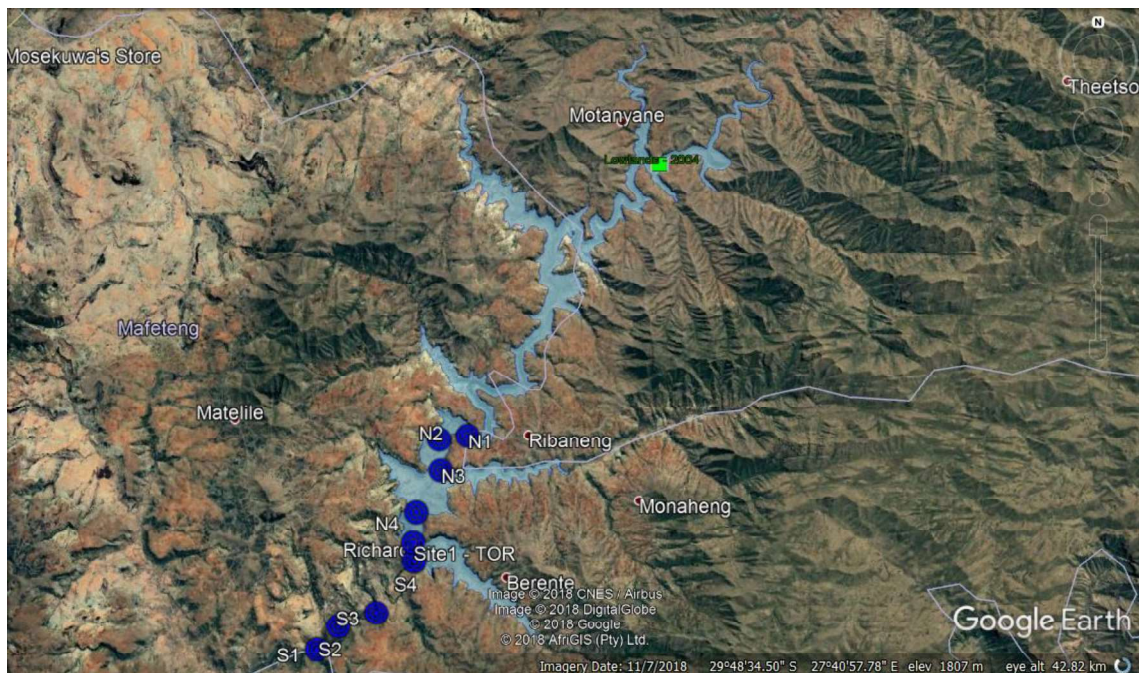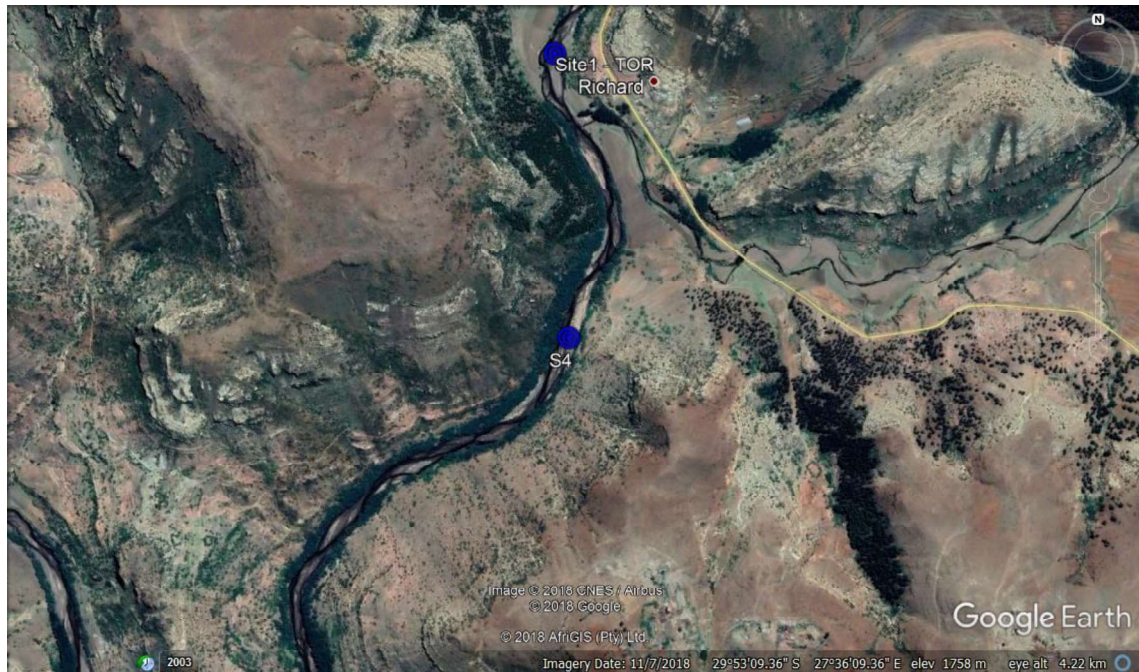
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	1 653
• MAR (MCM/a):	435
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 120
• 1:200 (Design Flood):	2 735
• RMF + Δ (Safety Evaluation):	5 065
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	41.14

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_S4 Valley Profile

Max yield crest: dam height = 121 m

200 yield crest: dam height = 69 m
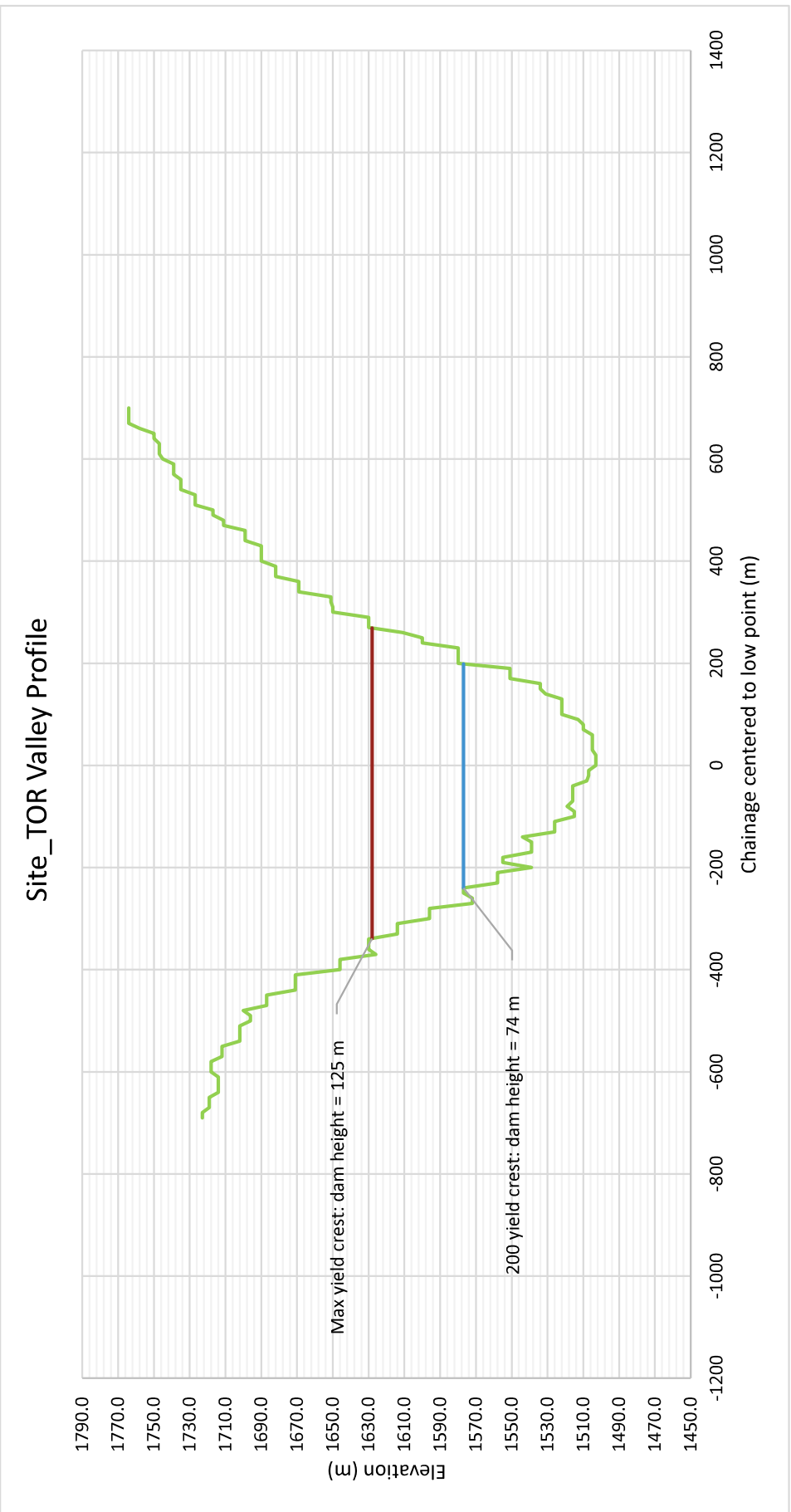
Elevation (m)

Chainage centered to low point (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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Appendix E – S4

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	69	121
Capacity (MCM)	242	1 301
Yield (MCM/a)	200	394
Impact on the yield of Gariep Dam (MCM/a)	-165	-34
Aspect Ratio	4.7	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	406 076	1 511 229
Hydropower potential - continuous flow (MW)	3.82	13.66
Hydropower potential - peak power (MW)	25.66	91.82
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 218	R 4 534
URV of yield assured (i = 8%)	0.7	1.4

S3

1.1 LOCATION

The S3 dam site is located at 29°54'41.63"S and 27°35'46.90"E in the West of Lesotho.
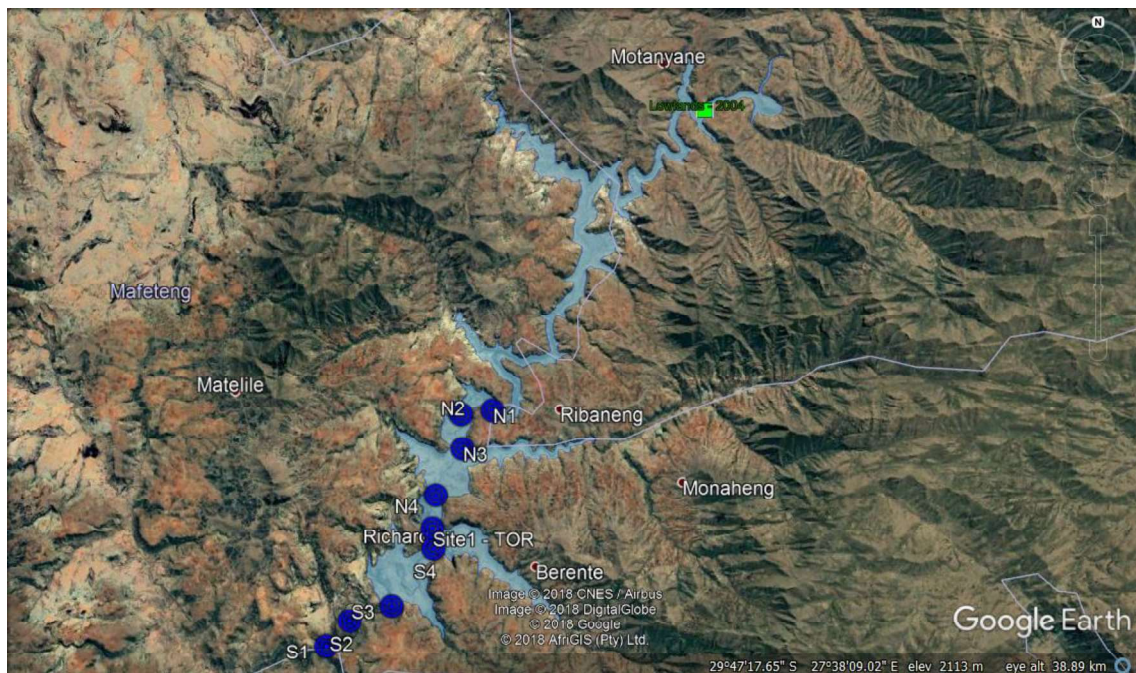
Figure 1: Map of Dam Site Location

1.2 GENERAL

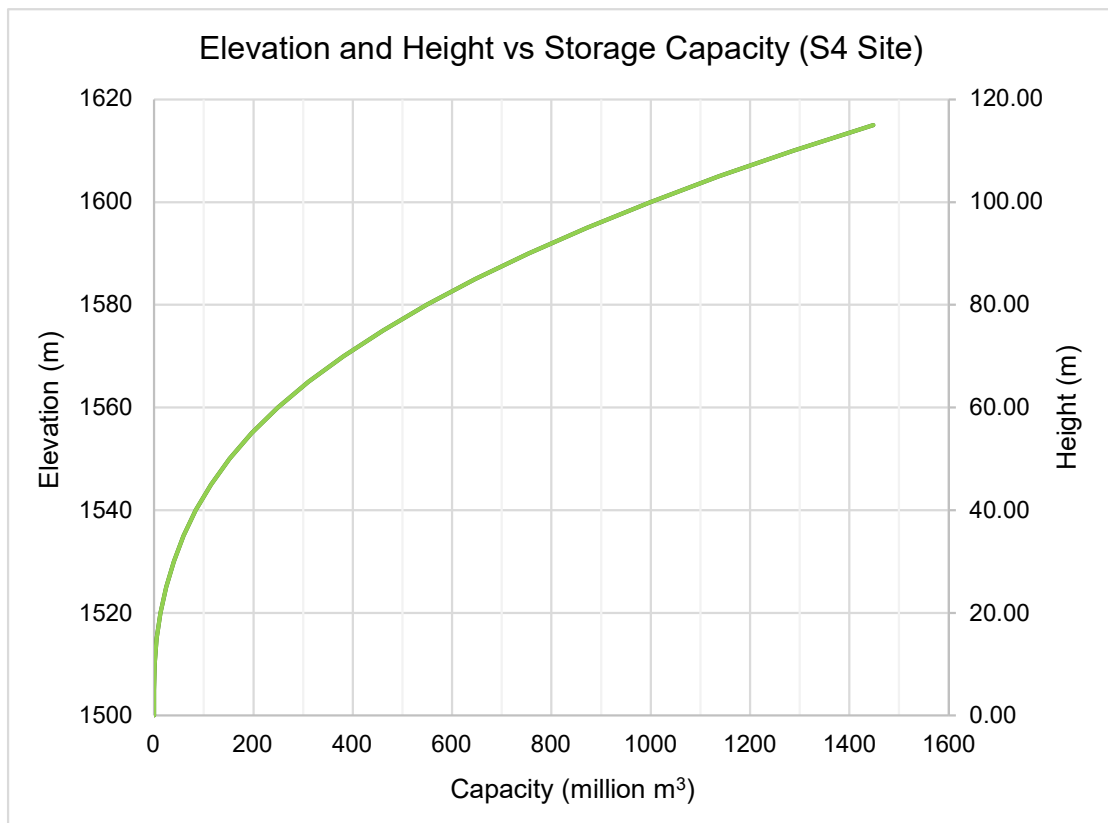|	
• Catchment Size (km^2):	1 684
• MAR (MCM/a):	440
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 130
• 1:200 (Design Flood):	2 760
• RMF + Δ (Safety Evaluation):	5 110
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	43.45

Figure 2: Photograph of Dam Site

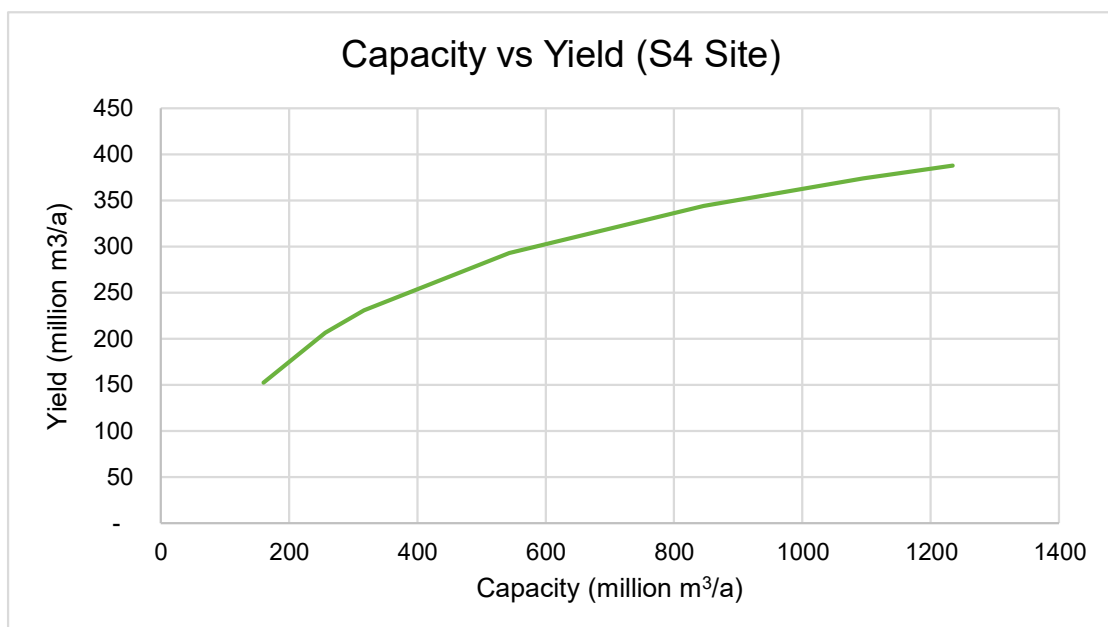**Figure 3: Elevation and Height vs Storage Capacity Graph**

Figure 4: Capacity vs Yield Graph

Site_S3 Valley Profile

Max yield crest: dam height = 127 m

200 yield crest: dam height = 74 m
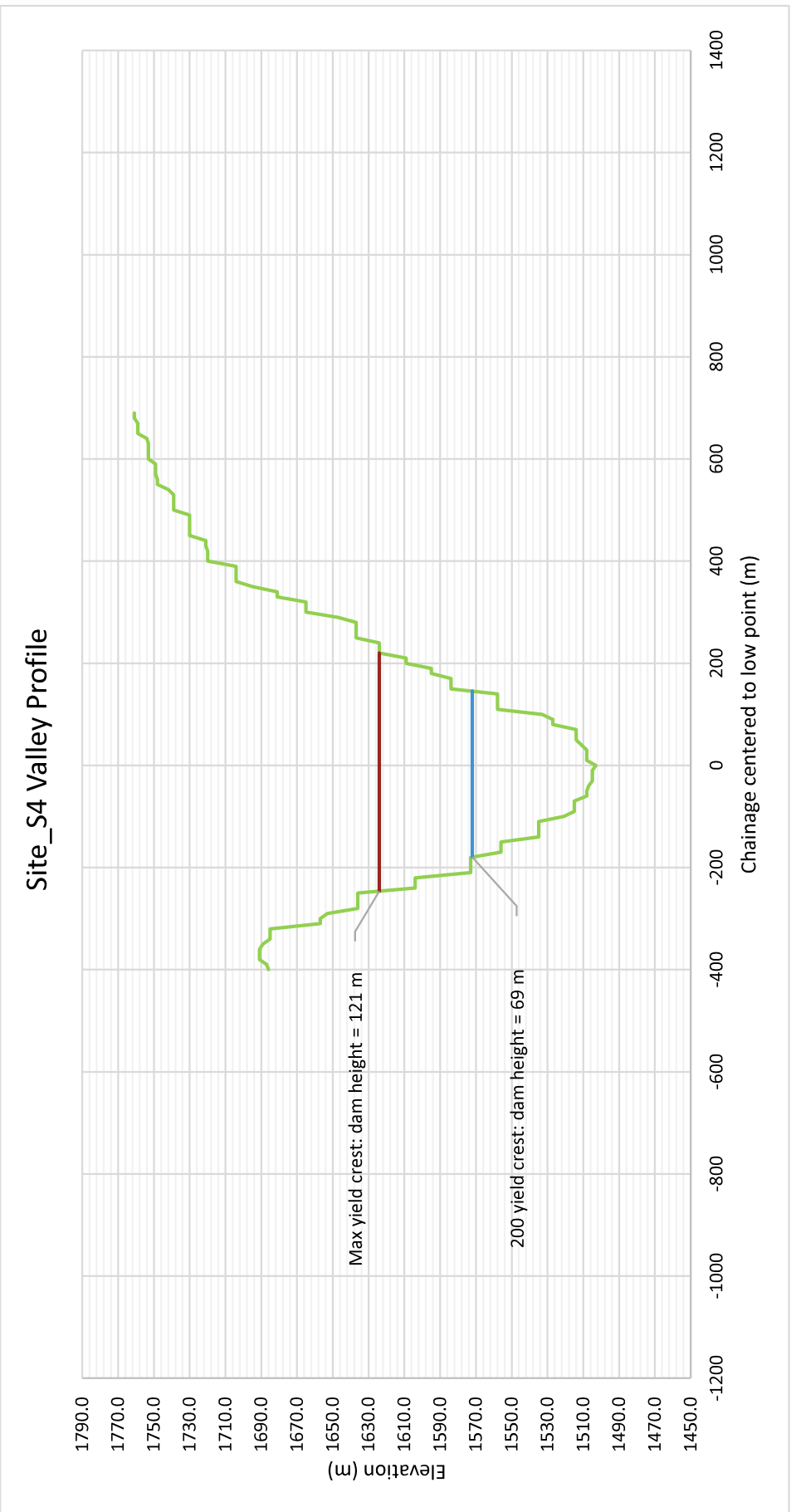
Elevation (m)

Chainage centered to low point (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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1.3   DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	127
Capacity (MCM)	239	1 318
Yield (MCM/a)	200	399
Impact on the yield of Gariep Dam (MCM/a)	-165	-31
Aspect Ratio	9.1	7.6
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	801 511	2 977 179
Hydropower potential - continuous flow (MW)	4.13	14.47
Hydropower potential - peak power (MW)	27.75	97.21
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 405	R 8 932
URV of yield assured (i = 8%)	1.4	2.7

S2

1.1 LOCATION

The S2 dam site is located at 29°54'59.79"S and 27°34'47.34"E in the West of Lesotho.
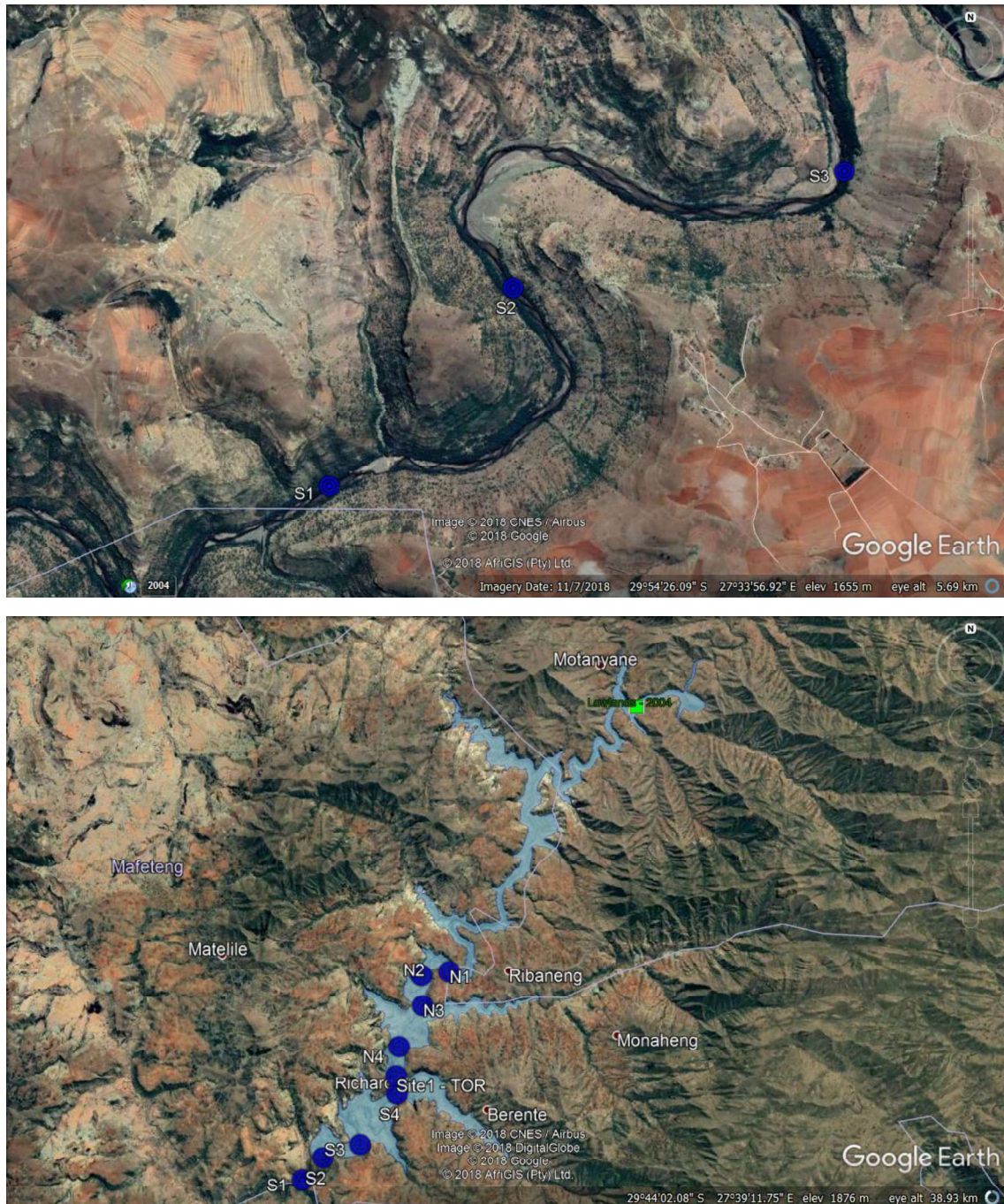
Figure 1: Map of Dam Site Location

1.2   GENERAL

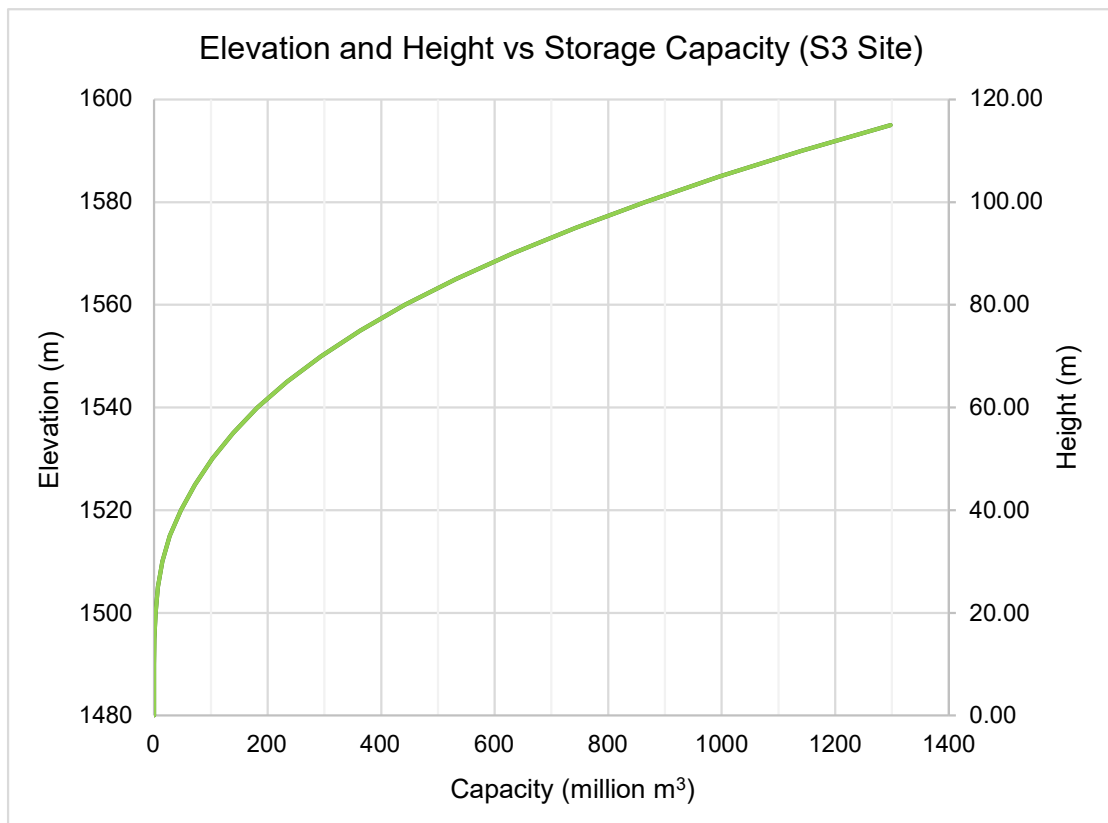|	
• Catchment Size (km^2):	1 688
• MAR (MCM/a):	440
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 130
• 1:200 (Design Flood):	2 765
• RMF + Δ (Safety Evaluation):	5 120
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	43.76

Figure 2: Photograph of Dam Site
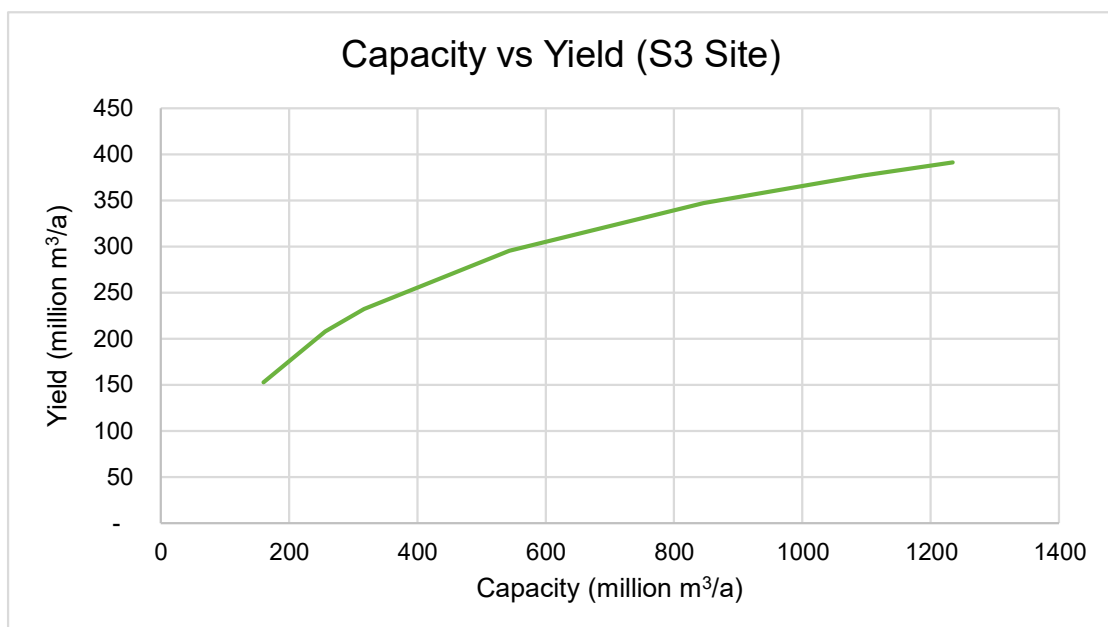
Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_S2 Valley Profile

Max yield crest: dam height = 128 m

200 yield crest: dam height = 78 m

Elevation (m)

Chainage centered to low point (m)

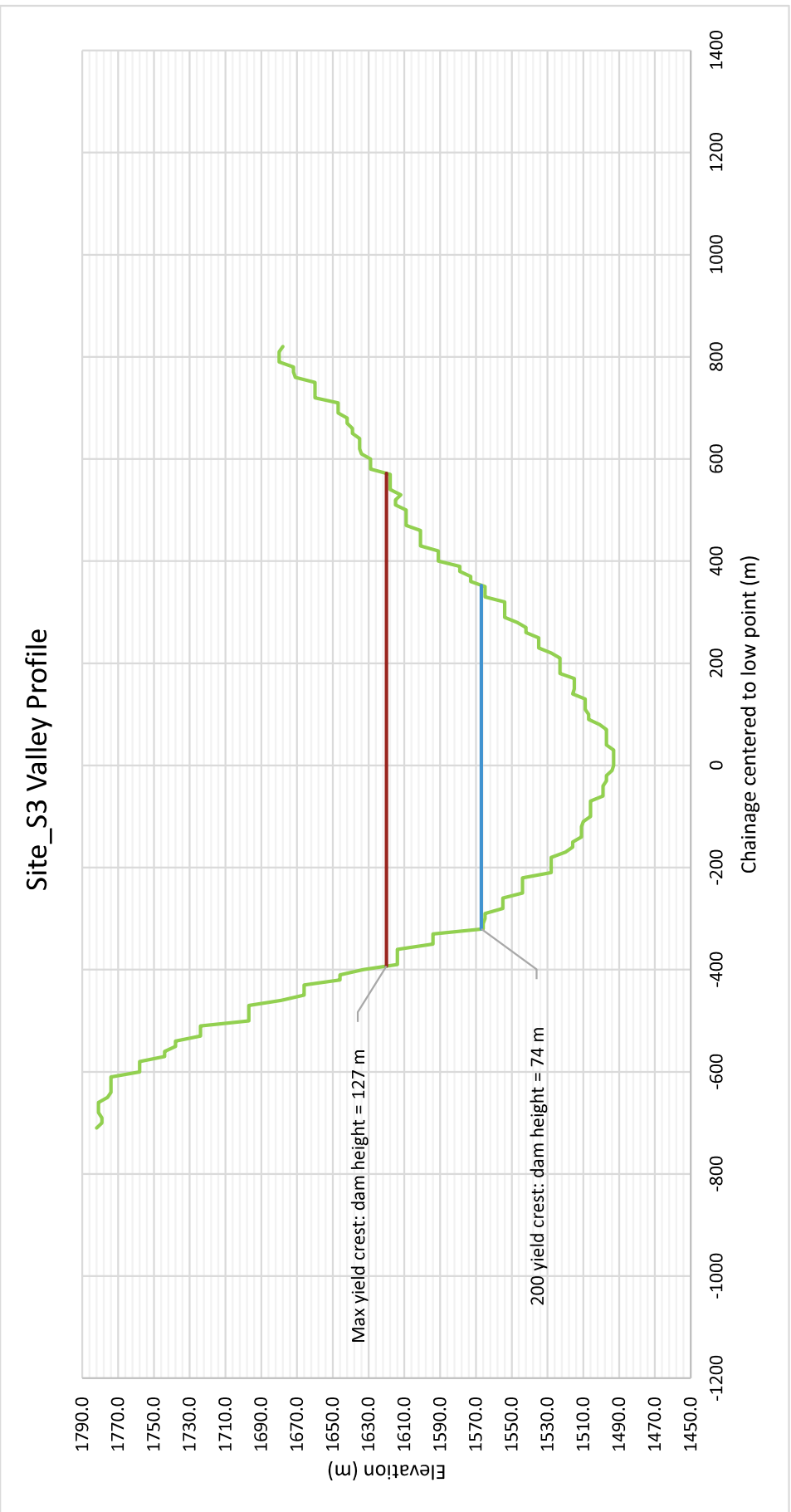**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

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Appendix E – S2

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	128
Capacity (MCM)	236	1 319
Yield (MCM/a)	200	389
Impact on the yield of Gariep Dam (MCM/a)	-165	-38
Aspect Ratio	4.4	3.6
Likely Dam Type	RCC Gravity Dam	CFRD
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Side Channel
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with free standing tower
Dam material volumes (m^3)	436 976	5 856 101
Hydropower potential - continuous flow (MW)	4.35	14.84
Hydropower potential - peak power (MW)	29.26	99.73
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 311	R 2 928
URV of yield assured (i = 8%)	0.8	0.9

S1

1.1 LOCATION

The S1 dam site is located at 29°55'30.64"S and 27°34'14.27"E in the West of Lesotho.
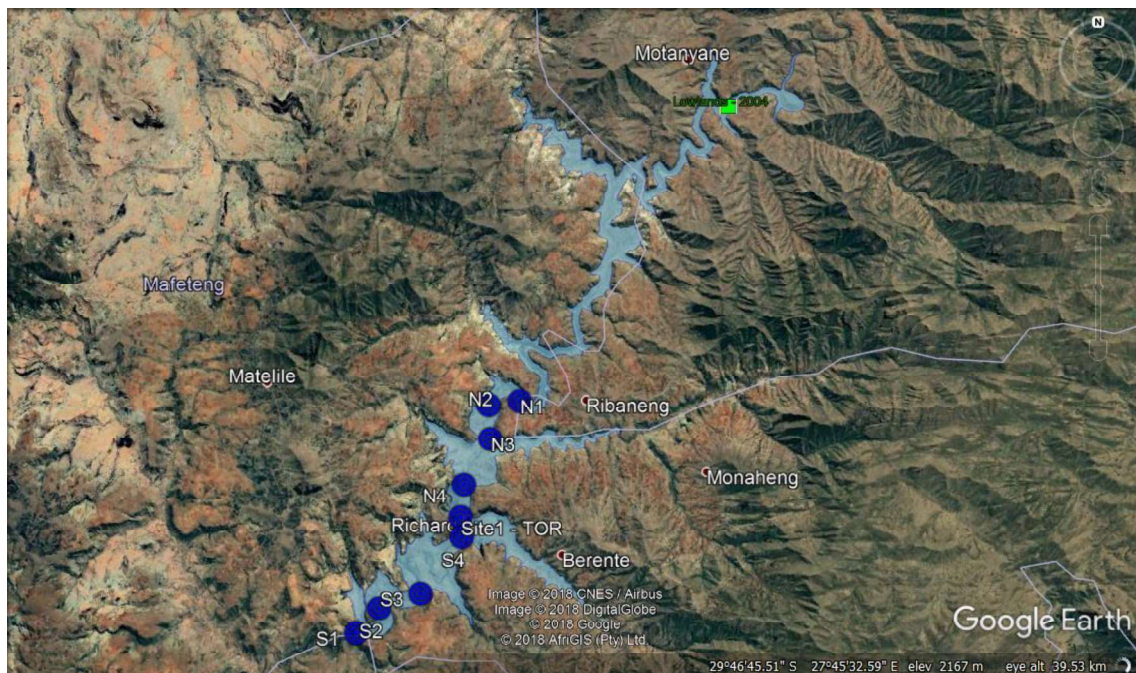
Figure 1: Map of Dam Site Location

1.2 GENERAL

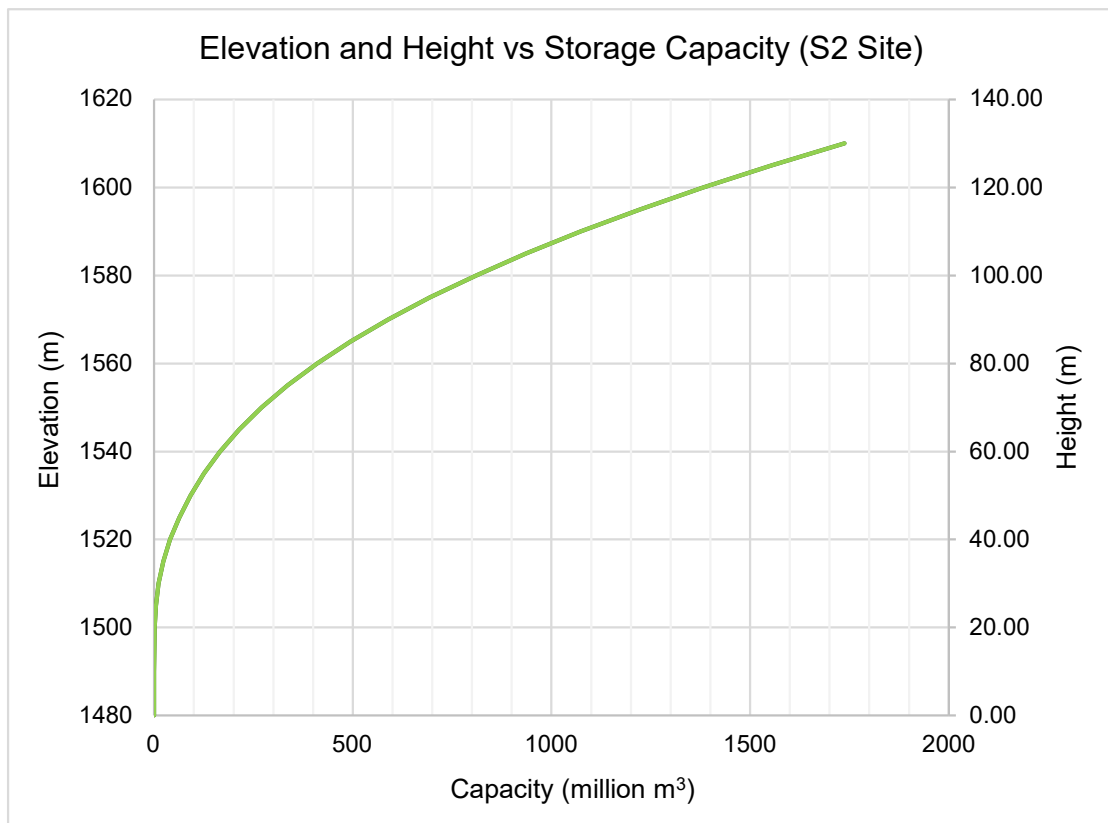|	
• Catchment Size (km^2):	1 703
• MAR (MCM/a):	445
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 135
• 1:200 (Design Flood):	2 780
• RMF + Δ (Safety Evaluation):	5 140
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	44.86

Figure 2: Photograph of Dam Site
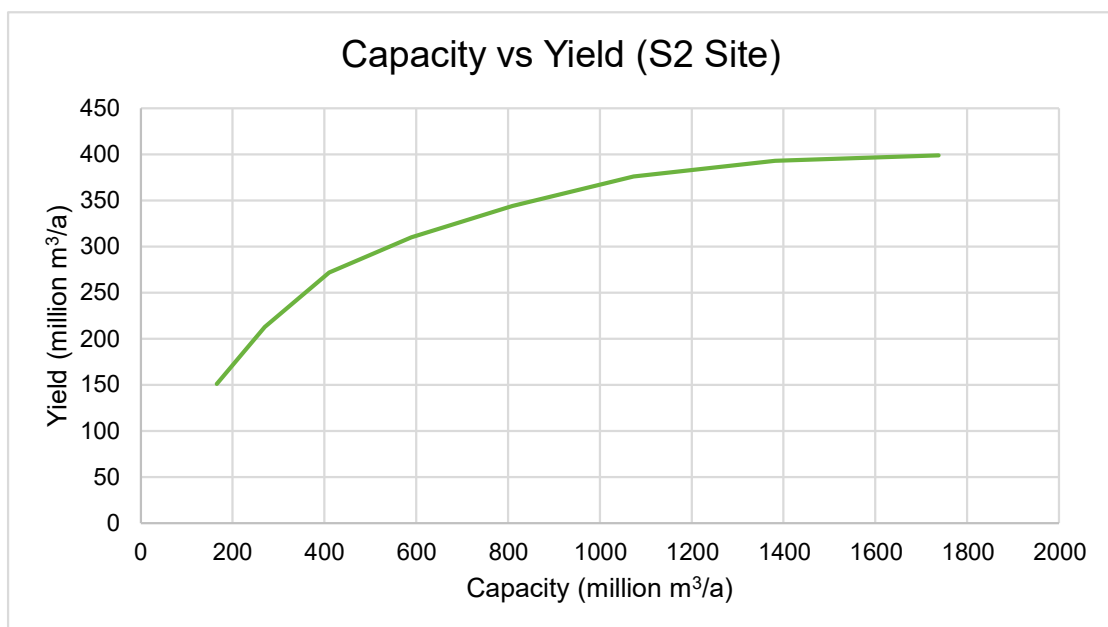
Figure 3: Elevation and Height vs Storage Capacity Graph

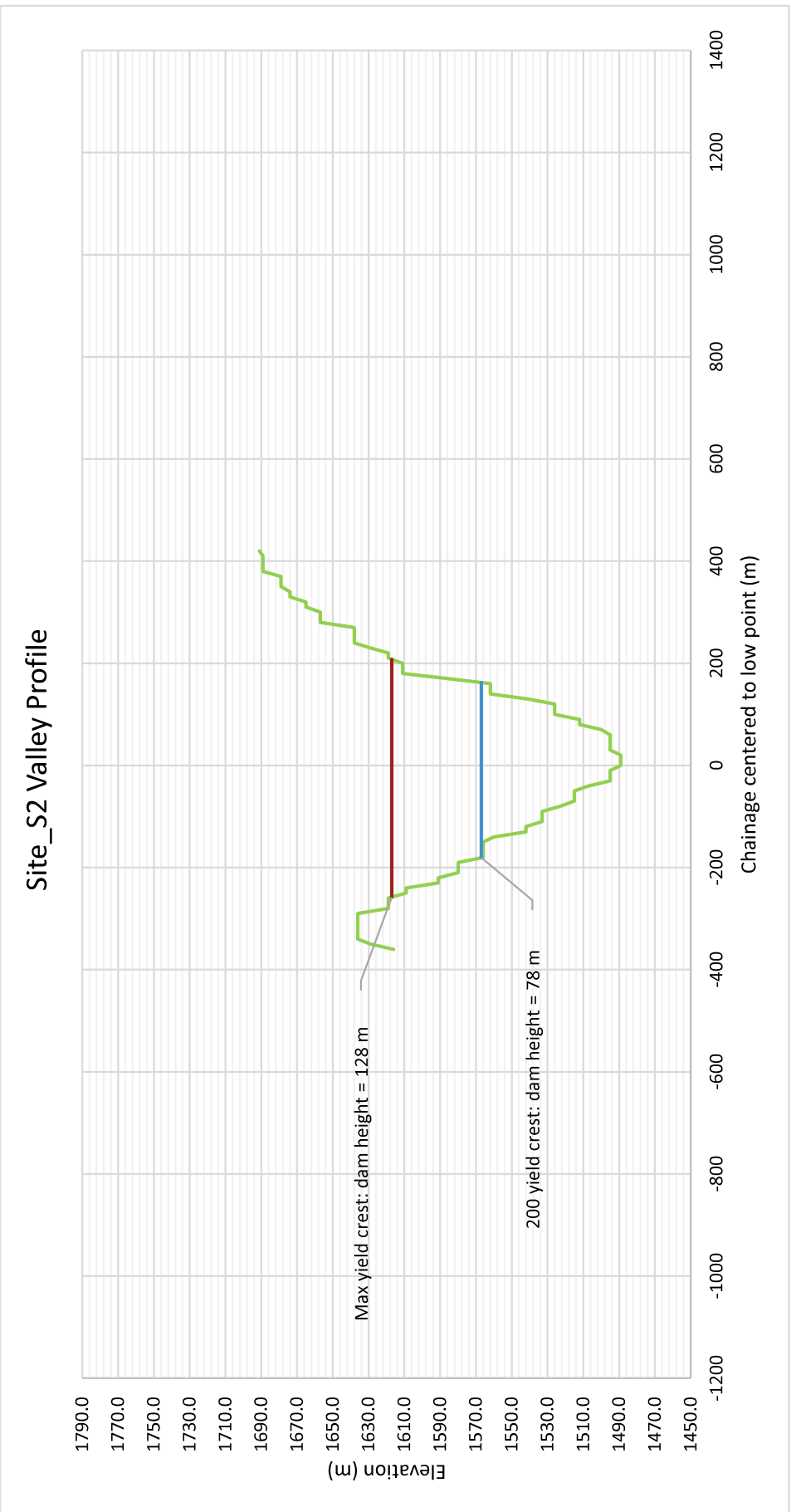
Figure 4: Capacity vs Yield Graph

Site_S1 Valley Profile

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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C O N S U L T I N G

1.3   DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	74	127
Capacity (MCM)	238	1 328
Yield (MCM/a)	200	402
Impact on the yield of Gariep Dam (MCM/a)	-165	-29
Aspect Ratio	4.2	3.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	348 110	1 403 860
Hydropower potential - continuous flow (MW)	4.13	14.59
Hydropower potential - peak power (MW)	27.76	98.02
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 044	R 4 212
URV of yield assured (i = 8%)	0.6	1.3

S1A

1.1 LOCATION

The S1a dam site is located at 29°55'44.80"S and 27°33'05.02"E in the West of Lesotho.
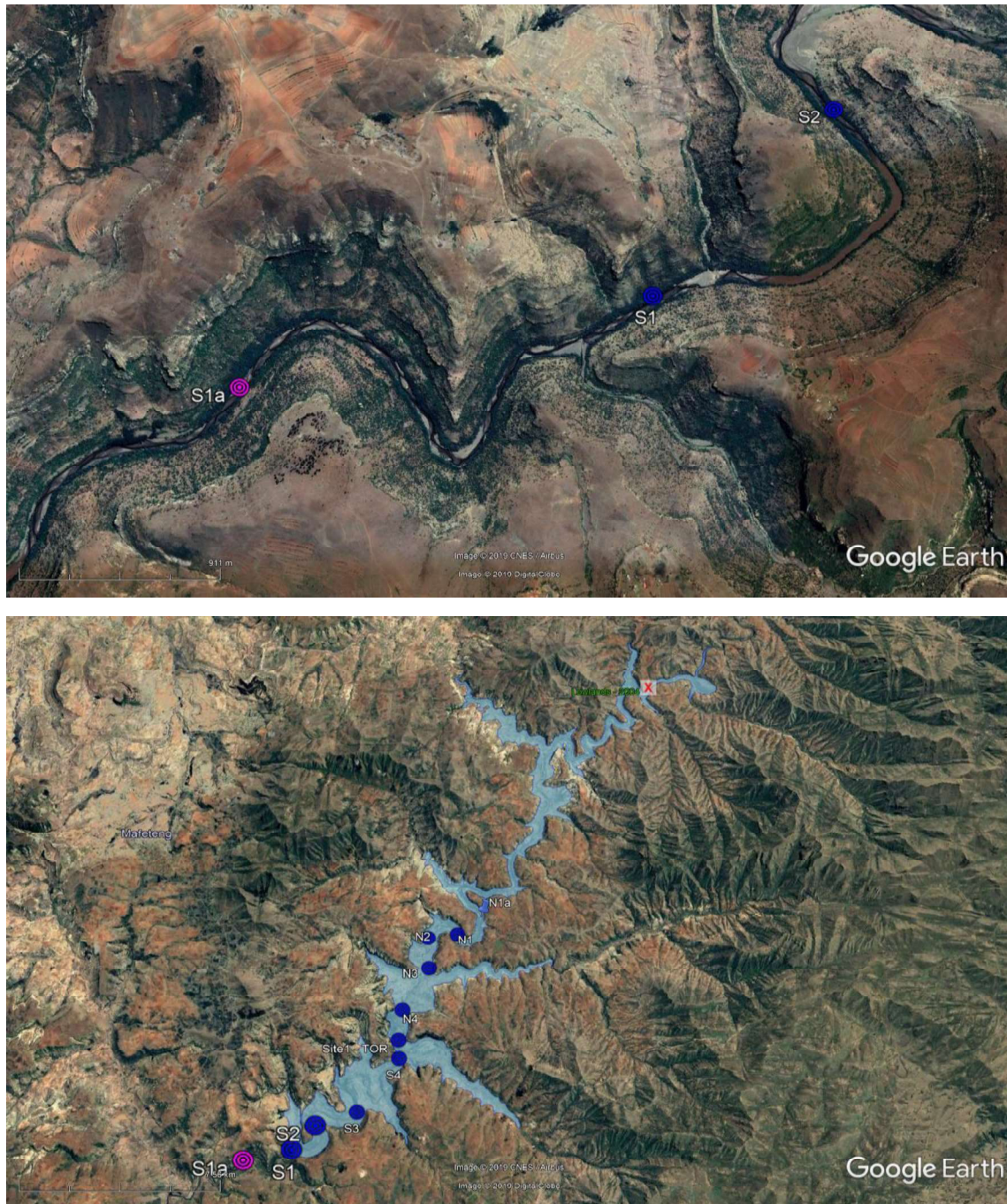
Figure 1: Map of Dam Site Location

1.2 GENERAL

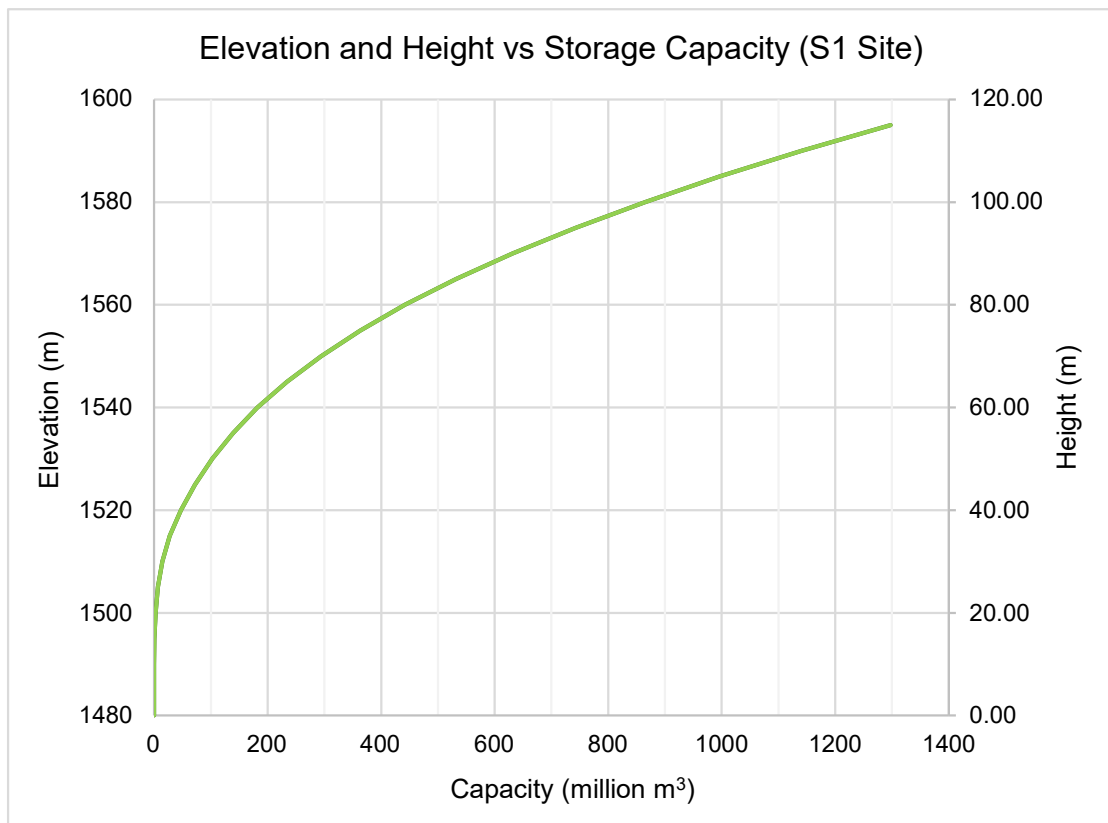|	
• Catchment Size (km^2):	1 803
• MAR (MCM/a):	460
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 168
• 1:200 (Design Flood):	2 865
• RMF + Δ (Safety Evaluation):	5 285
• Distance to Construction material	12 km E or 22 km SE
• Expected 50-year Sediment Volumes (million m^3)	52.43

Figure 2: Photograph of Dam Site

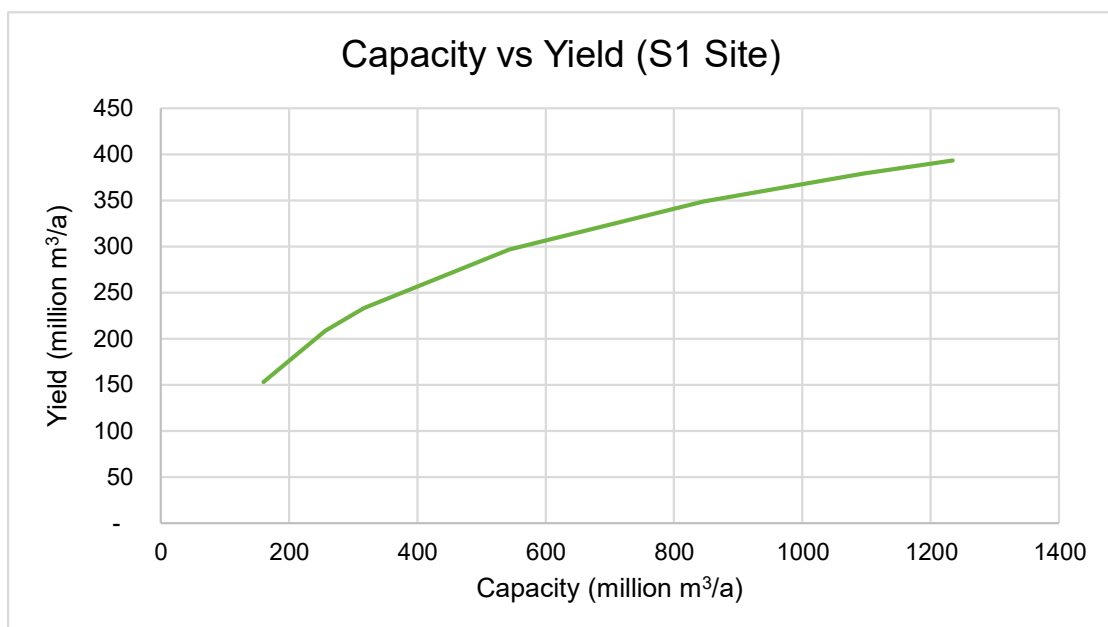**Figure 3: Elevation and Height vs Storage Capacity Graph**

Figure 4: Capacity vs Yield Graph

Site_S1a Valley Profile

Max yield crest: dam height = 130 m

200 yield crest: dam height = 79 m

Chainage centered to low point (m)

Elevation (m)

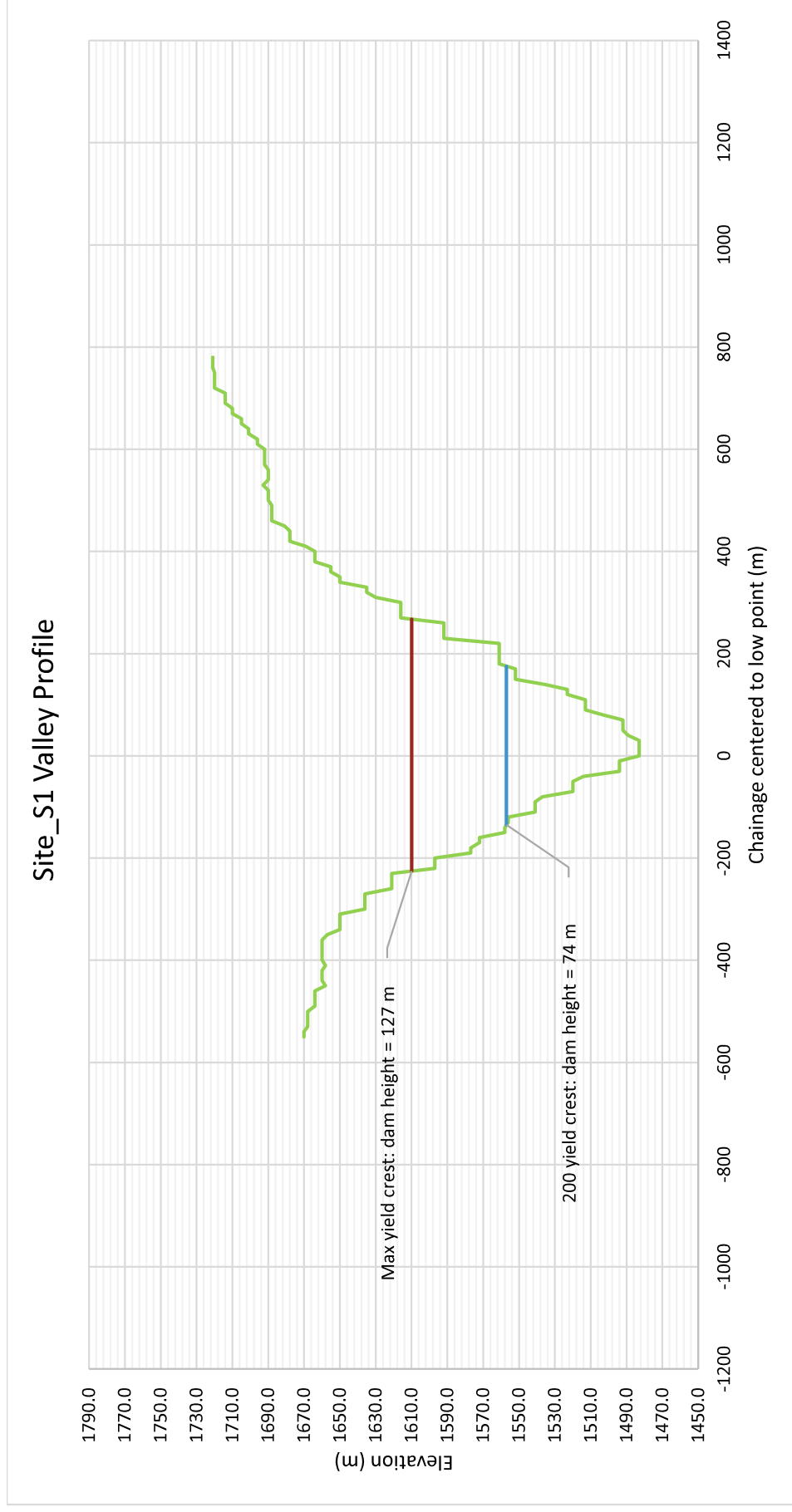**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

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Appendix E – S1a

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	78	130
Capacity (MCM)	224	1 381
Yield (MCM/a)	200	402
Impact on the yield of Gariep Dam (MCM/a)	-165	-25
Aspect Ratio	5.2	4.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	642 246	2 041 314
Hydropower potential - continuous flow (MW)	4.34	15.40
Hydropower potential - peak power (MW)	29.17	103.50
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 927	R 6 124
URV of yield assured (i = 8%)	1.2	1.9

D4

1.1 LOCATION

The D4 dam site is located at 29°59'07.10"S and 27°30'24.84"E in the West of Lesotho.
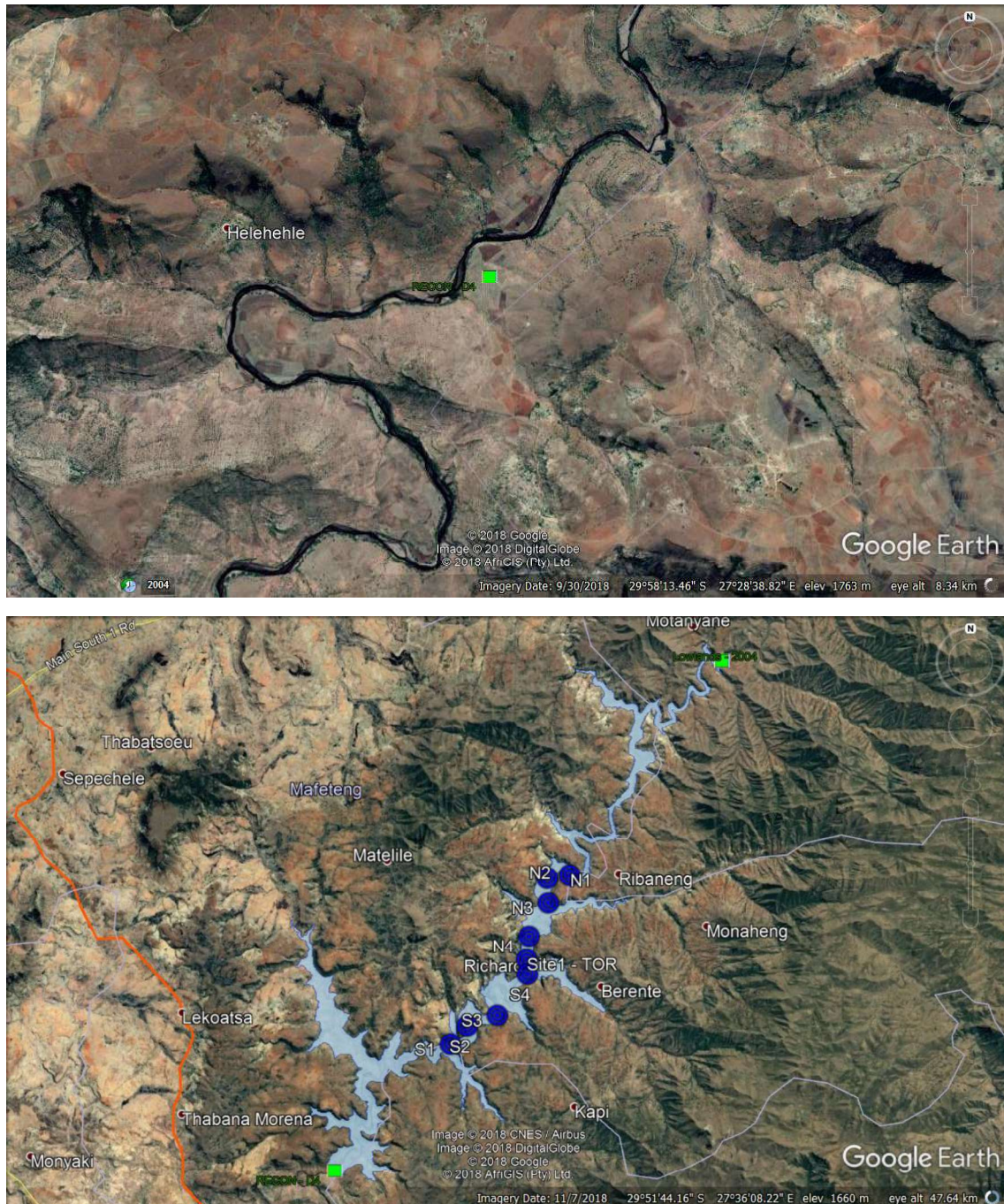
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km²):	2 021
• MAR (MCM/a):	500
• Design Floods (m³/s):	
• 1:10 year (River diversion):	1 235
• 1:200 (Design Flood):	3 045
• RMF + Δ (Safety Evaluation):	5 580
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m³)	80.80

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph
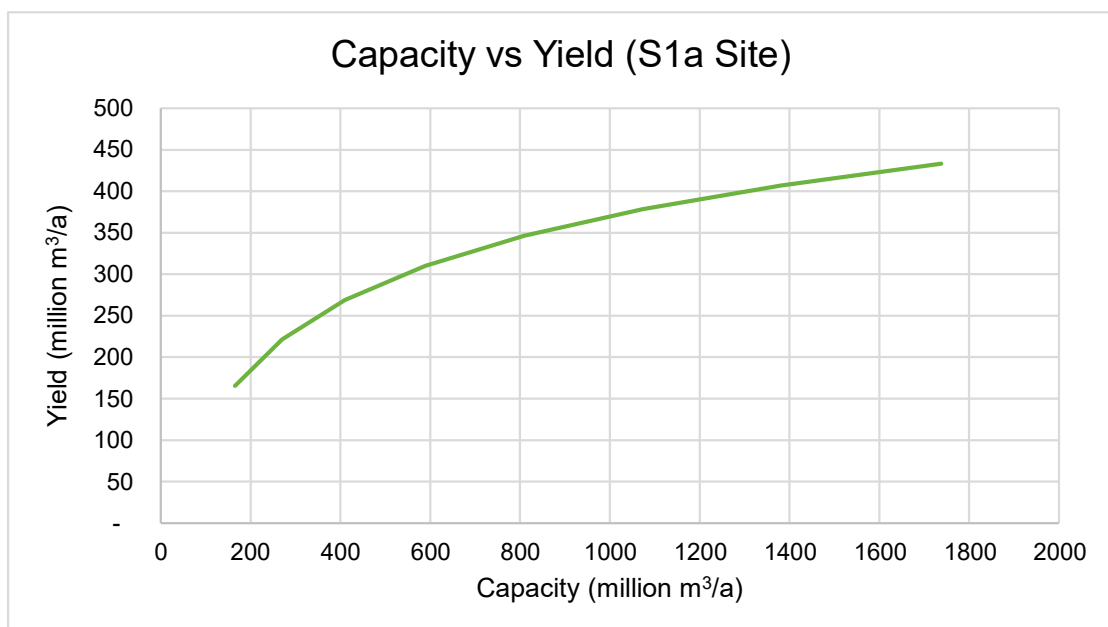

Figure 4: Capacity vs Yield Graph

Site_D4 Valley Profile

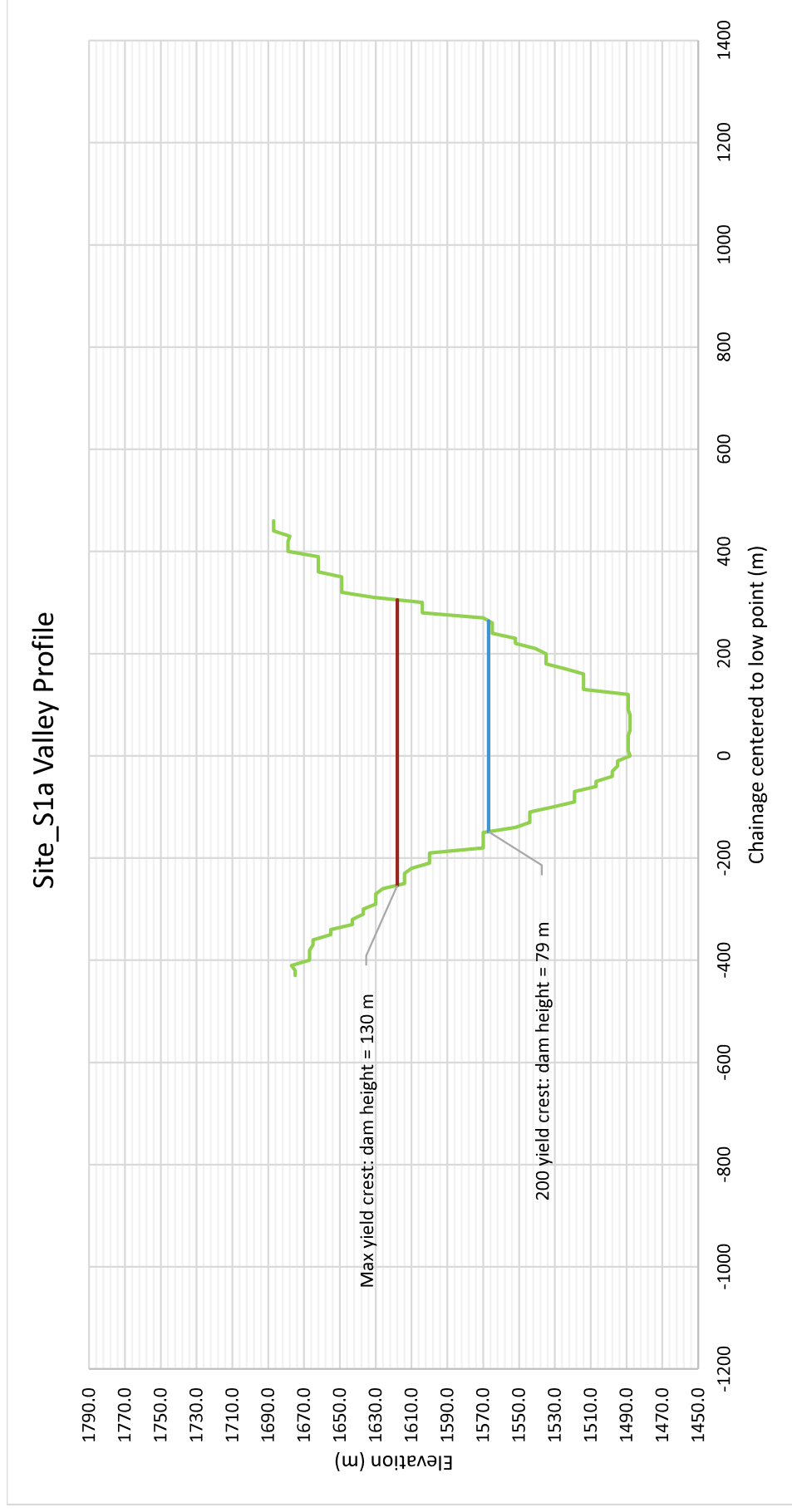**Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR**

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Appendix E – D4

1.3 DAM HEIGHT OPTIONS

Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	70	120
Capacity (MCM)	217	1 494
Yield (MCM/a)	200	1 494
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	11.3	8.3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	1 016 033	3 505 171
Hydropower potential - continuous flow (MW)	3.89	16.58
Hydropower potential - peak power (MW)	26.12	111.44
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 3 048	R 10 516
URV of yield assured (i = 8%)	1.8	2.7

D3

1.1 LOCATION

The D3 dam site is located at 30°01'07.63"S and 27°29'00.68"E in the West of Lesotho.
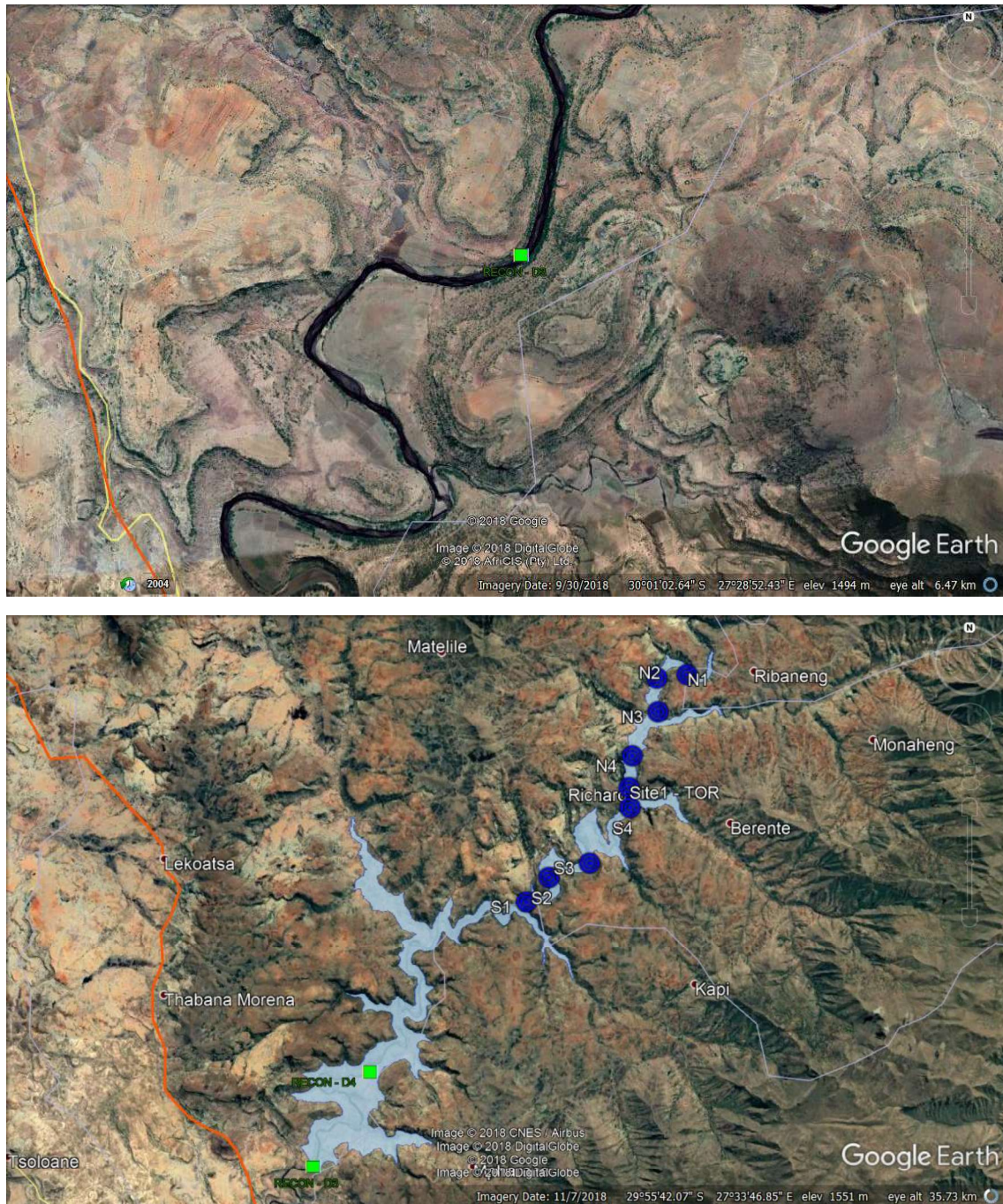
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km^2):	2 069
• MAR (MCM/a):	505
• Design Floods (m^3/s):	
• 1:10 year (River diversion):	1 250
• 1:200 (Design Flood):	3 085
• RMF + Δ (Safety Evaluation):	5 645
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m^3)	86.23

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_D3 Valley Profile

Max yield crest: dam height = 121 m

200 yield crest: dam height = 71 m

Elevation (m)

Chainage centered to low point (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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Appendix E – D3

1.3 DAM HEIGHT OPTIONS

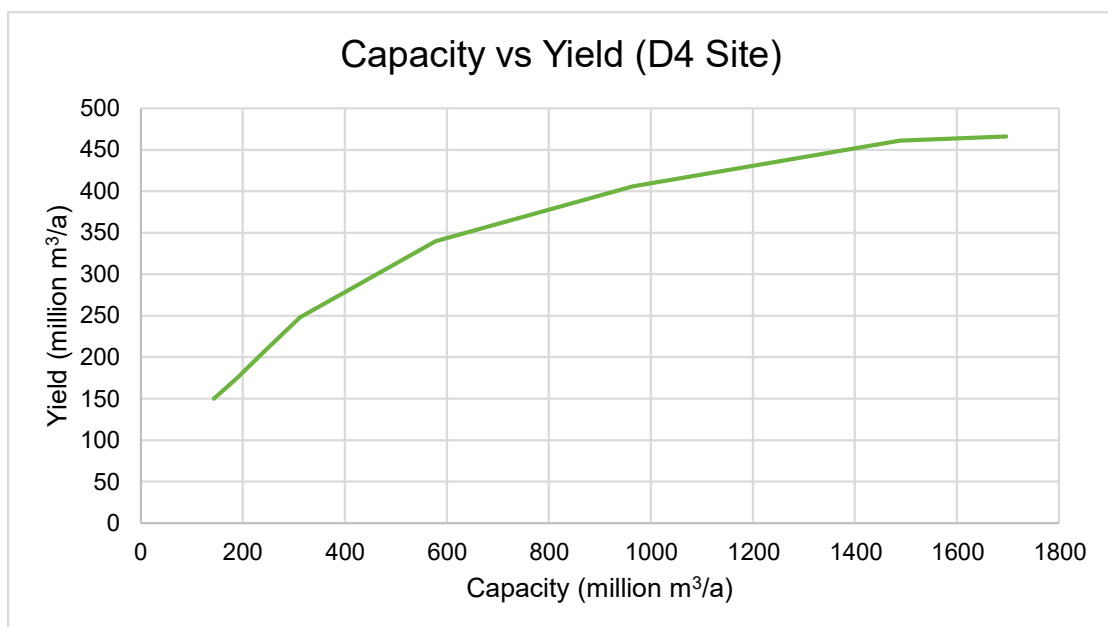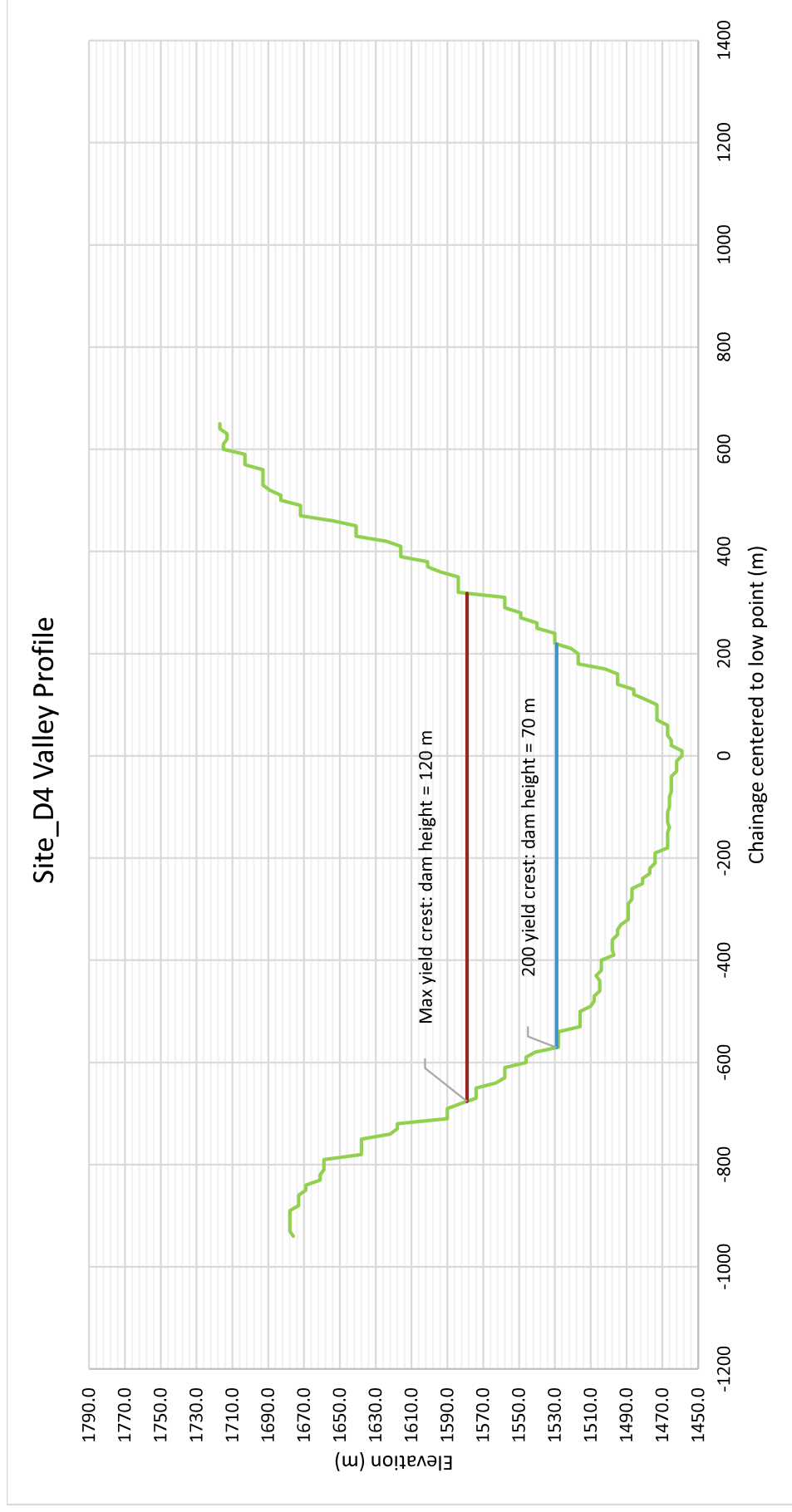| Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	71	121
Capacity (MCM)	215	1 520
Yield (MCM/a)	200	467
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	12.4	11 3
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	676 659	3 207 938
Hydropower potential - continuous flow (MW)	3.90	16.90
Hydropower potential - peak power (MW)	26.22	113.60
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 2 030	R 9 624
URV of yield assured (i = 8%)	1.2	2.5

D2

1.1 LOCATION

The D2 dam site is located at 30°03'52.37"S and 27°26'45.99"E in the West of Lesotho.
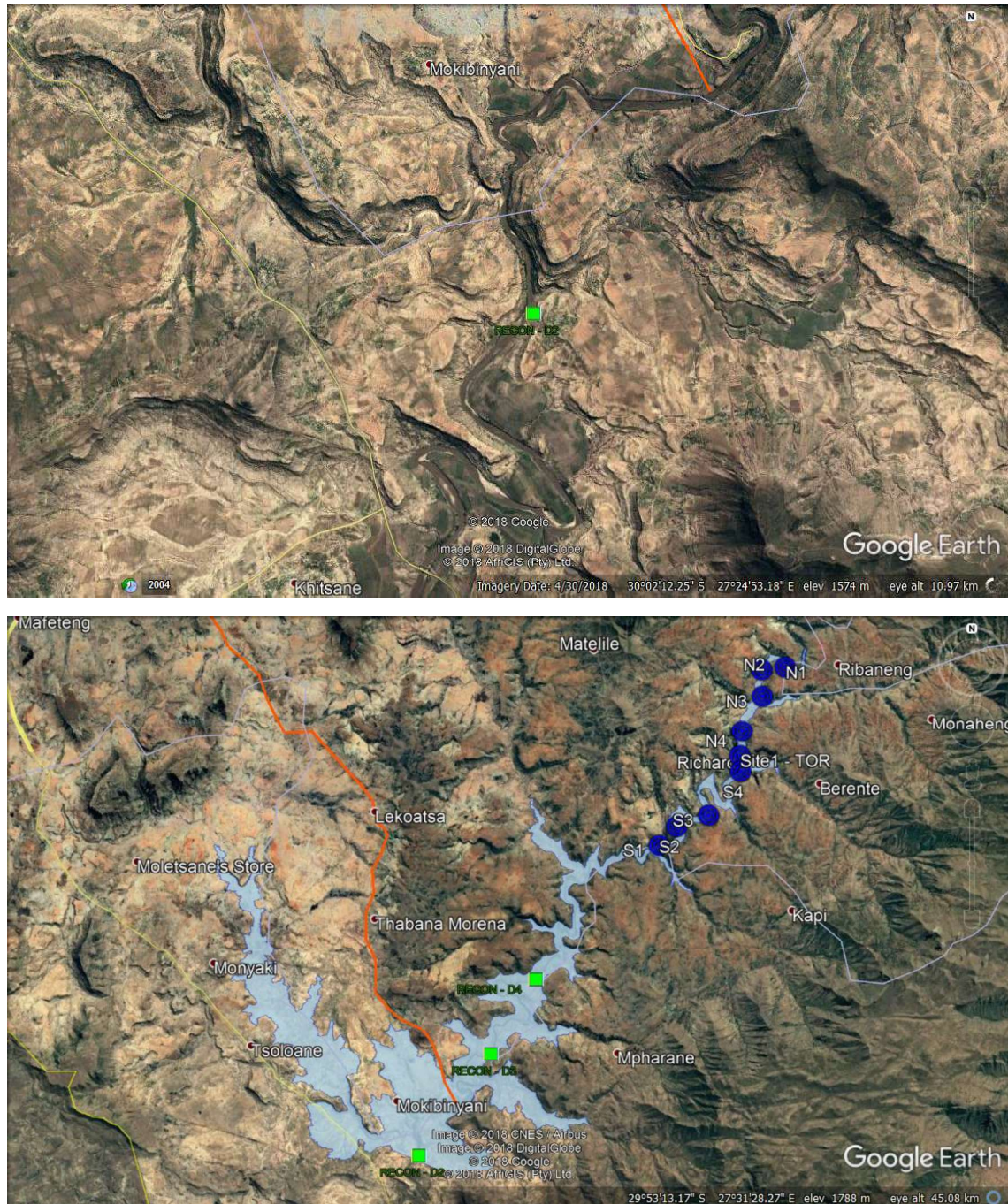
Figure 1: Map of Dam Site Location

1.2 GENERAL

• Catchment Size (km²):	2 554
• MAR (MCM/a):	645
• Design Floods (m³/s):	
• 1:10 year (River diversion):	1 390
• 1:200 (Design Flood):	3 455
• RMF + Δ (Safety Evaluation):	6 245
• Distance to Construction material	22 km SE or 13 km NW of site
• Expected 50-year Sediment Volumes (million m³)	140.85

Figure 2: Photograph of Dam Site

Figure 3: Elevation and Height vs Storage Capacity Graph

Figure 4: Capacity vs Yield Graph

Site_D2 Valley Profile

Max yield crest: dam height = 110 m

200 yield crest: dam height = 53 m

Chainage centered to low point (m)

Elevation (m)

Figure 5: Dam valley profile with dam heights for a dam with 200 MCM/a yield and for a maximum a yield that equates to a capacity of 3 MAR

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C O N S U L T I N G
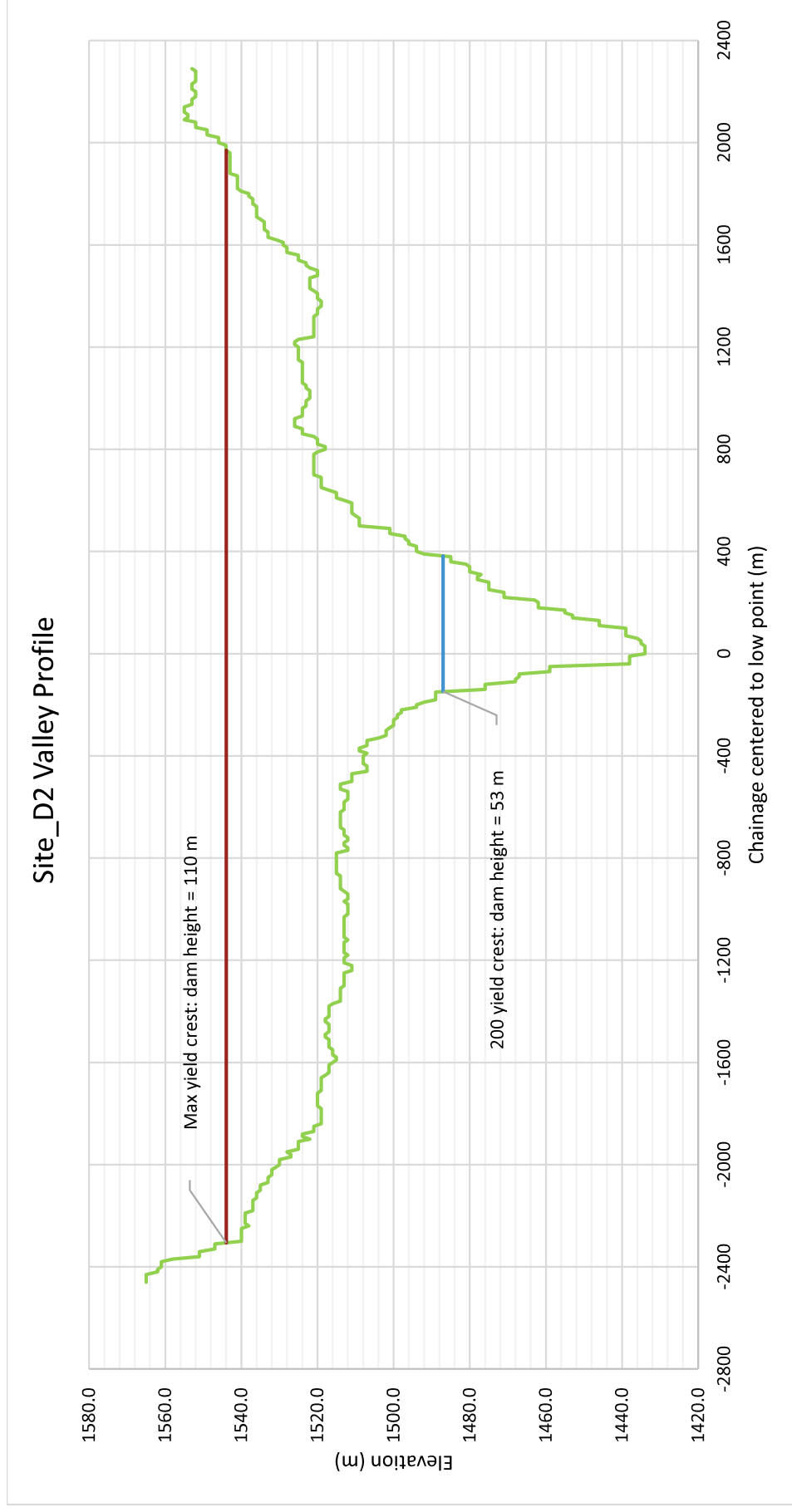
1.3 DAM HEIGHT OPTIONS

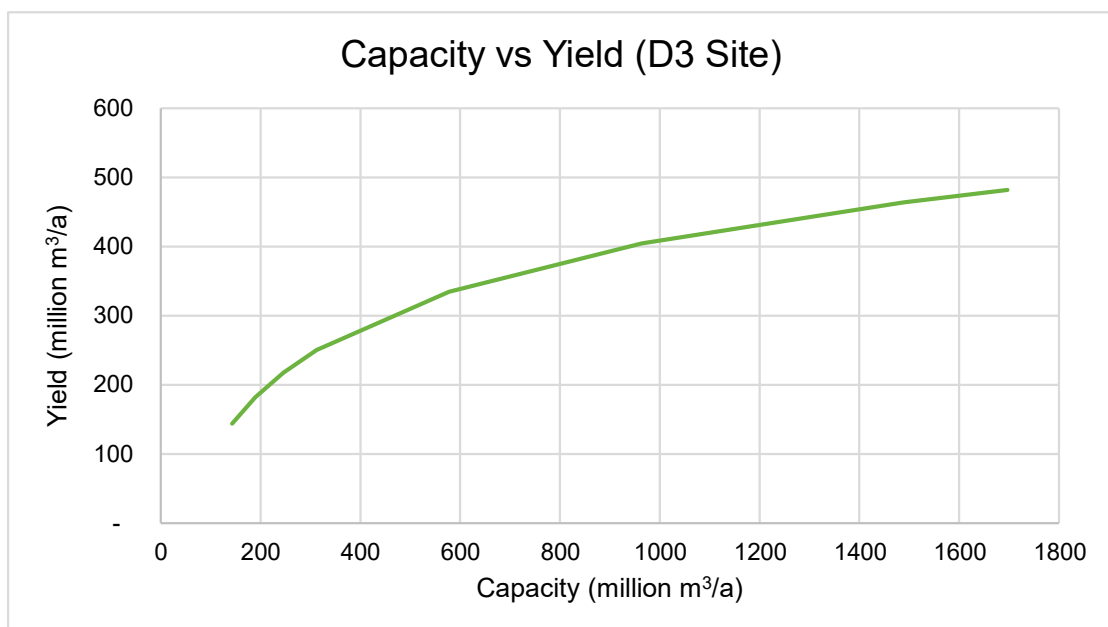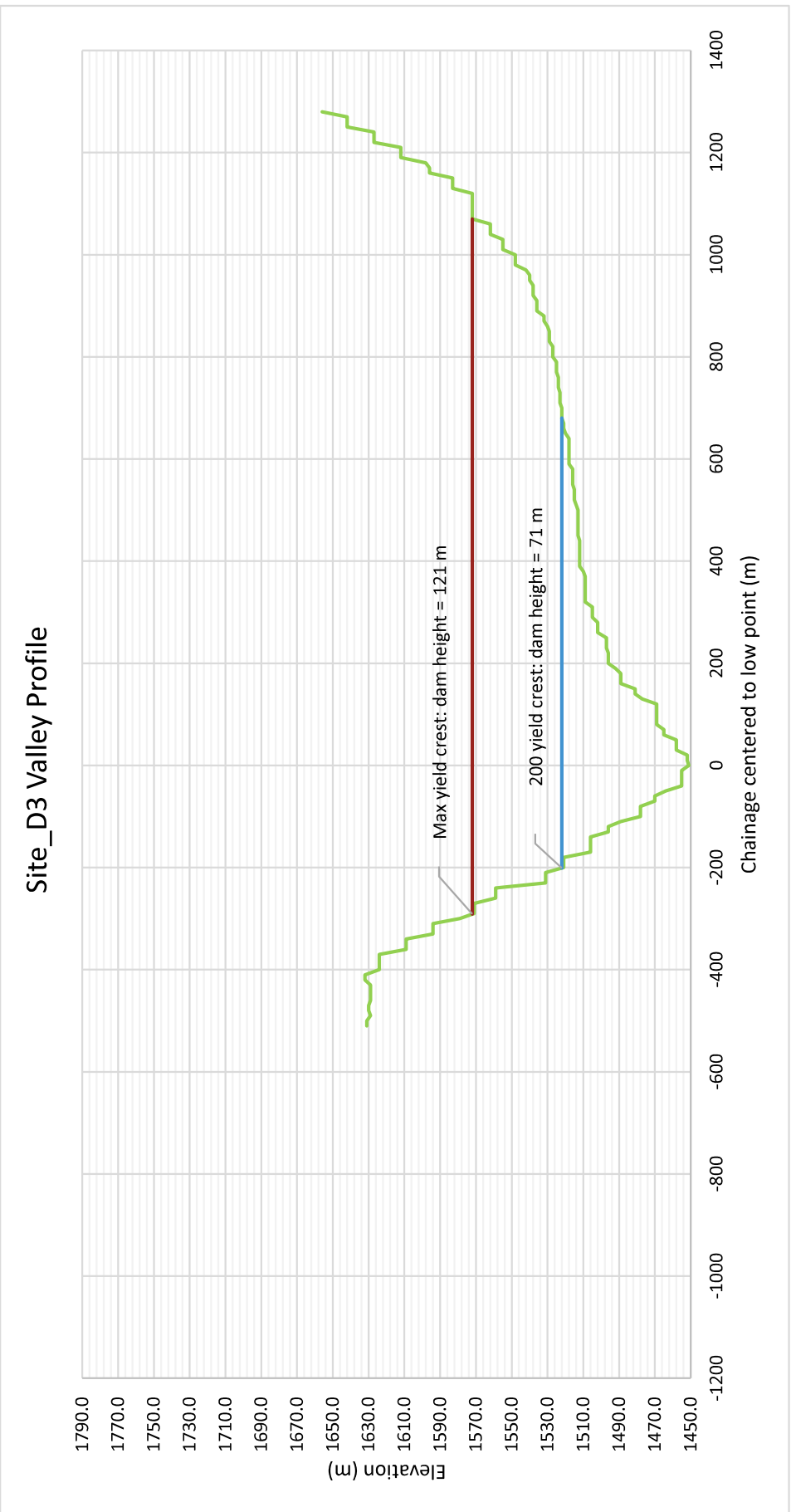| Scenarios	Dam Height to meet 200MCM/a Yield (Scenario 1)	Dam Height for 3 MAR Capacity (Scenario 2)
Height (m)	53	110
Capacity (MCM)	200	1 940
Yield (MCM/a)	200	596
Impact on the yield of Gariep Dam (MCM/a)	-165	0
Aspect Ratio	10.0	38.9
Likely Dam Type	RCC Gravity Dam	RCC Gravity Dam
River Diversion	Coffer dam, with twin diversion tunnels	Coffer dam, with twin diversion tunnels
Spillway type	Free ogee over crest	Free ogee over crest
Outlet arrangement	Multi-level outlet, with tower against upstream face	Multi-level outlet, with tower against upstream face
Dam material volumes (m^3)	393 123	4 166 319
Hydropower potential - continuous flow (MW)	2.81	18.25
Hydropower potential - peak power (MW)	18.89	122.62
Turbine type - continuous flow	Horizontal Francis	Horizontal Francis
Turbine type - peak power	Vertical Francis	Vertical Francis
Dam Capital Cost Estimate (million R)	R 1 179	R 12 499
URV of yield assured (i = 8%)	0.7	2.5

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APPENDIX D. System Diagrams

Pre-release bioustudy Phase I release

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INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE
ORANGE-SENQU RIVER CATCHMENT

Orange River Subsystem Schematic -
with penalty structures (1 of 5) Senqu & Caledon

D-1

WRP_P0325_ORASECOM Phase 3_Graphics_Fig1.cdr
Last updated: 06/08/2013

INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE
ORANGE-SENQU RIVER CATCHMENT

Orange River Subsystem Schematic -
with penalty structures (2 of 5) Upper Orange and Riet Modder

D-2

APPENDIX E

WRPM SYSTEM SCHEMATICS

Orange Senqu sub-systems

IVRS sub-systems

Note: Lower Vaal see Schematic E-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

E-1

WRP_P0428 _ORASECOM_Schematics_Fig27 WRPM.cdr
Last updated: 02/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Upper Orange Sub-system with Penalty Structure

E-2

WRPM Schematic Diagram: Core Scenario
Lower Vaal & Riet/ Modder Sub-systems with Penalty Structures

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRP_P04428_ORASECOM_Schematics_Fig41_WRPM.cdr
Last updated: 06/03/2020

E-3

LOWER ORANGE SUB-SYSTEM

WRP_P0428_ORASECOM_Schematics_Fig28 WRPM.cdr
Last updated: 06/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Lower Orange Sub-system with Penalty Structures

E-4

WHITE NOSSOB

OLIFANTS

BLACK NOSSOB

NOSSOB

UPPER MOLOPO

AUB

LOWER MOLOPO

KURUMAN

LEGEND

39 Node/Junction sub-model	40 Demand centre sub-model
199 Reservoir sub-model	Controlled demand through master control channel
87 Channel/River reach sub-model	VAAL94,ABS Specified demands/Return flows
Wetland Wetland modelled within channel reach sub-model	Penalty structure
45 Salt washoff sub-model	Incremental hydrology boundary
Bed loss Bed losses	Sub-system boundary
1 Irrigation block sub-model	
Dem 21 Demand / return flow modelled as min - max channel	

WRP_P0428 _ORASECOM_Schematics_Fig32 WRPM.cdr
Last updated: 06/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Molopo Sub-system with Penalty Structure

E-5

WRPM Schematic Diagram: Core Scenario
Lower Orange tributaries & Namibia Fish Sub-system with Penalty Structure

E-6

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM System Diagram:
Eastern Cape Upper Sub-systems: Core Scenario

E-7

WRP_P0428 _ORASECOM_Schematics_Fig31 WRPM.cdr
Last updated: 06/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM System Diagram:
Eastern Cape Lower Sub-systems: Core Scenario

E-8

WRPM Schematic Diagram: Core Scenario
Upper Vaal, Upper Olifants and Usutu Sub-systems

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

E-9

WRP_P0428_ORASECOM_Schematics_Fig34 WRPM.cdr
Last updated: 03/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Komati Sub-systems with Penalty Structures

E-10

WRP_P042B_QRASECOM_Schematics_Fig35 WRPM.cdr
Last updated: 03/03/2020

WRPM Schematic Diagram: Core Scenario
Upper Thukela and Lower Sub-systems

E-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

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRP_P0428_ORASECOM_Schematics_Fig37_WRPM.cdr
Last updated: 03/03/2020

E-12

MIDDELBURG DAM INCREMENTAL

MU 15

CLIMATE RESILIENT WATER
RESOURCES INVESTMENT STRATEGY/PLAN
AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic Diagram: Core Scenario
Middelburg Dam Sub-system with
penalty structures

E-13

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
Vaal Dam to Vaal Barrage

E-14

WRP_P0428 _ORASECOM_Schematics_Fig39 WRPM.cdr
Last updated: 03/03/2020

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

WRPM Schematic diagram: Core Scenario
Middle Vaal Sub-system with Penalty Structures

E-15

APPENDIX F

WRYM SYSTEM SCHEMATICS

Orange River Subsystem Schematic - 2030 WRYM
Base scenario with penalty structures Senqu & Caledon

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

F-1

WRP_P0428 _ORASECOM_Schematics_Fig21 WRYM.cdr
Last updated: 28/02/2020

Orange River Subsystem Schematic - 2030 WRYM
Base with Makhaleng and penalty structures (1 of 5) Senqu & Caledon

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

F-1b

WRP_P0428 _ORASECOM_Schematics_Fig17 WRYM.cdr
Last updated: 03/03/2020

Orange River Subsystem Schematic - 2030 WRYM with penalty structures (1 of 5) Senqu & Caledon base and Hlotse, Ngoajane and Makhaleng dams

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
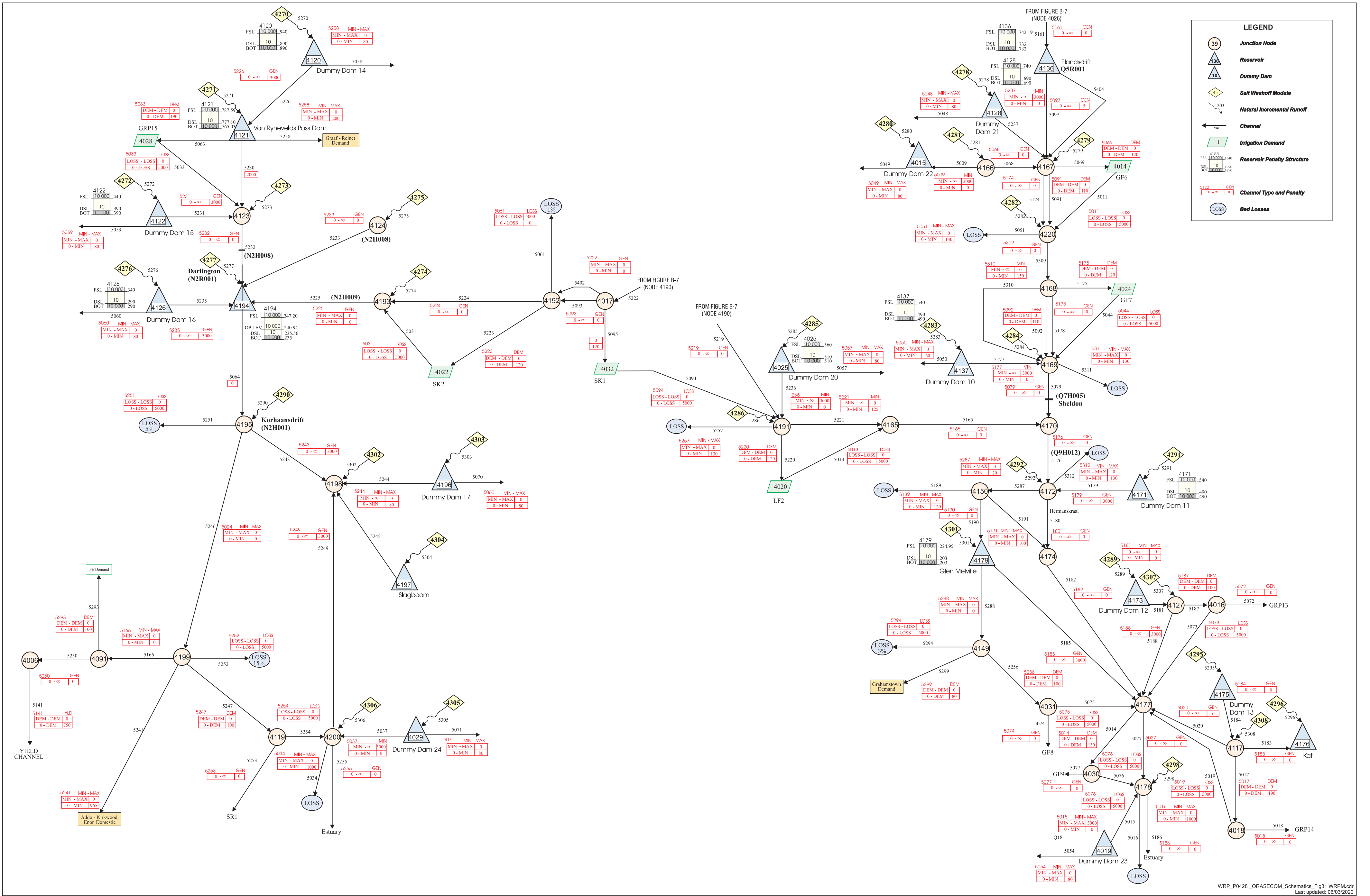STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

F-1c

WRP_P0428 _ORASECOM_Schematics_Fig18 WRYM.cdr
Last updated: 03/03/2020

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

F-1d

WRP_P0428 _ORASECOM_Schematics_Fig19 WRYM.cdr
Last updated: 03/03/2020

Orange River Subsystem Schematic - 2030 WRYM. Base Scenario with penalty structures (2 of 5) Upper Orange and Riet Modder. Figure F-2. CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER. WRP_P0428_ORASECOM_Schematics_Fig22 WRYM.cdr. Last updated: 02/03/2020.

Orange River Subsystem Schematic - 2030 WRYM
Base with Makhaleng and penalty structures (2 of 5) Upper Orange and Riet Modder

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

F-2b

WRP_P0428_ORASECOM_Schematics_Fig20 WRYM.cdr
Last updated: 03/03/2020

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

F-3

Orange River Subsystem Schematic - 2030 WRYM
Applicable to all scenarios with penalty structures (4 of 5) Molopo

CLIMATE RESILIENT WATER RESOURCES INVESTMENT
STRATEGY/PLAN AND LESOTHO-BOTSWANA WATER TRANSFER

F-4

WRP_P0428 _ORASECOM_Schematics_Fig24 WRYM.cdr
Last updated: 02/03/2020

Orange River Subsystem Schematic - 2030 WRYM — Applicable to all scenarios with penalty structures (5 of 5) Lower Orange