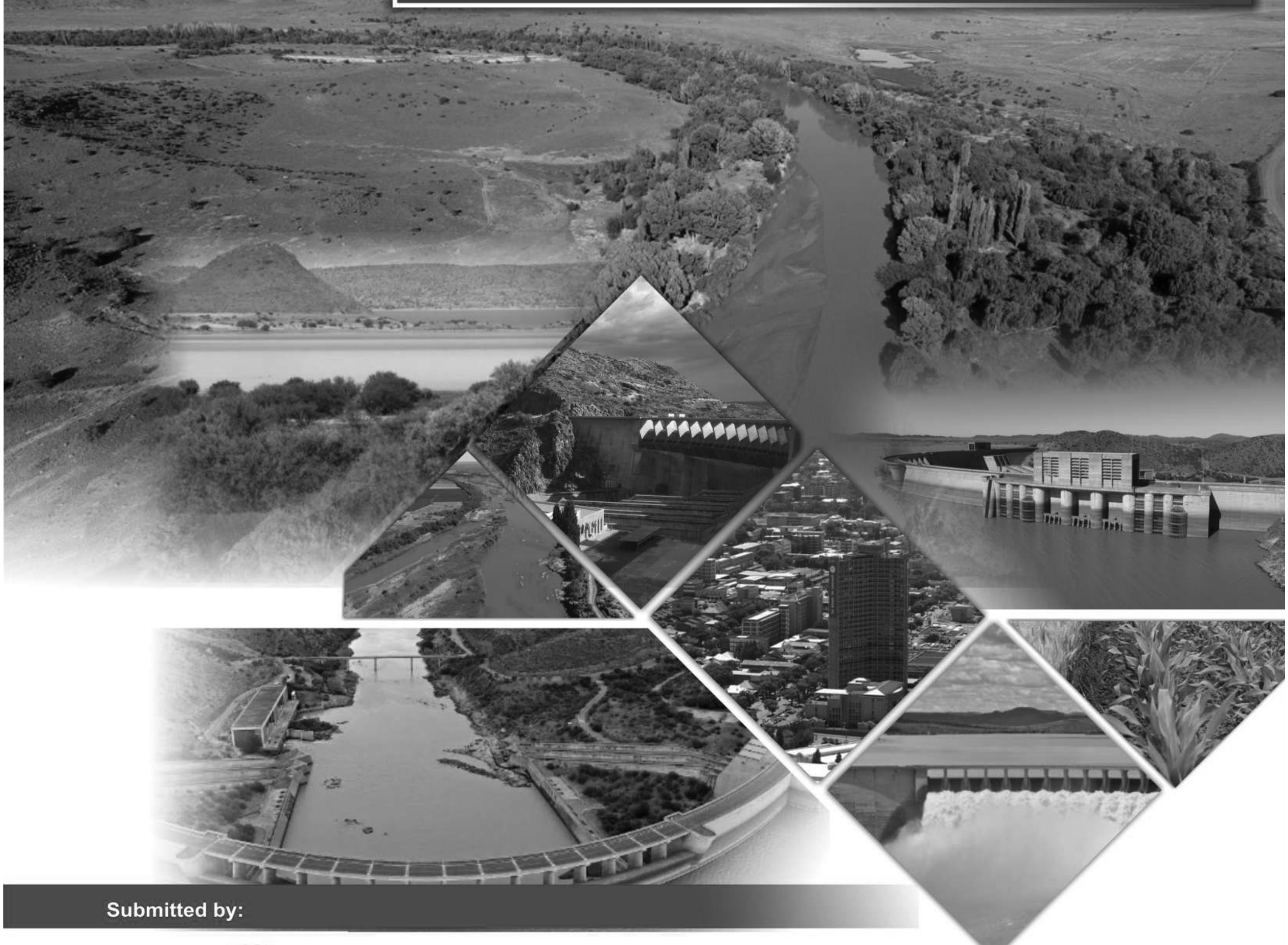
Prepared for:

MANGAUNG

Mangaung Metropolitan Municipality

MANGAUNG GARIEP WATER AUGMENTATION PROJECT

SCENARIO ANALYSES GREATER BLOEMFONTEIN



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MANGAUNG GARIEP WATER AUGMENTATION PROJECT

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1. INTRODUCTION

The Mangaung Gariep Water Augmentation Project (MGWAP) is currently in process and was initiated by Mangaung Metro Municipality (MMM) with BIGEN Africa Services (Pty)Ltd as the consulting engineers appointed by the MMM. WRP Consulting Engineers was requested by both parties to assist with the scenario analysis of the water resource system to provide support regarding the water supply capabilities and system yield for the different options that are currently investigated to supply the Greater Bloemfontein with sufficient water at the required assurance levels over the planning period.

This required the update of the existing Water Resources Planning Model (WRPM) setup to accommodate the suggested future changes and intervention options. Three different types of analyses were carried out for the purpose of this study:

- Historic firm yield analysis
- Water supply analysis
- Stochastic projection analysis or risk analysis

Each of the different types of analyses carried out is briefly described in the sub-sections to follow.

1.1. HISTORIC FIRM YIELD ANALYSES

The historic firm yield is defined as the maximum volume that can be supplied per annum, over the entire available historic monthly flow record period, without failing in any single year over that period. Thus a 100% assurance over the historic record period. The historic natural flow records within the WRPM cover the period 1920 to 2004 hydrological years, i.e. 84 years.

It was agreed that initially only two scenarios will be analysed. The purpose of these two scenarios was to determine the historic firm yield available from the combined Greater Bloemfontein water supply system. These two scenarios include:

- Base scenario representing the current system as is,
- Second scenario that includes some re-use from the Bloemfontein return flows.

These scenarios were followed by several other scenarios (see **Section 2.2.1**) of which the historic firm yield was determined. Most of these additional scenarios were defined based on the results from scenarios already completed at the time, as well as the inclusion of different possible future intervention options. The purpose of all these scenarios was to determine the historic firm yield of that specific option or scenario and to compare that with the existing and future water requirements of the system.

1.2. WATER SUPPLY HISTORIC ANALYSES

The purpose of the second set of scenarios (see **Section 2.2.2**) was to determine the water supply from selected yield scenarios, as obtained for each of the water treatment plants within the system, current and future. These results were used to support the cost and economic calculations and related evaluations of selected scenarios.

1.3. STOCHASTIC PROJECTION ANALYSES

The stochastic projection analyses use stochastic natural flow sequences generated by the WRPM, which are then used to carry out projection analyses into the future, taking into account the expected growth in water requirements, different intervention options phased in over time, as well as the assurance of supply as required by the different users and user categories. These analyses are used to determine the time when deficits in the water supply within the greater system starts to occur, so that intervention options can be phased in over time at the correct time, to ensure that the water users are supplied at their required assurance over the total planning period. These analyses are also referred to as risk analysis, as the risk of non-supply at the required assurance is determined as part of the projection analysis (see **Section 2.2.3**).

2. SCENARIO DESCRIPTION

A brief description of two possible scenarios that need to be analysed was obtained from BIGEN as summarized in **Table 2-1**.

Table 2-1: Summary of proposed Scenarios

Scenario number	**Scenario Description**	**Description**	**Modder River**		**Caledon River**	**Return flows from MMM WWTW's**	
			Mockes Dam Maselspoort	**Rustfontein**	**Welbedacht**	**Botshabelo & Thaba Nchu**	**North Eastern and Bloemspruit**
		WTW capacity (Mℓ/d)	**110**	**100**	**128.7**	**20 + 6**	**1 + 45**
		Abstraction Location					
A	Continue with status quo		Maselspoort	Rustfontein	Welbedacht		
					Novo Transfer		
B	Status quo with introduction of re-use		Maselspoort	Rustfontein	Welbedacht	Maselspoort	Maselspoort
					Novo Transfer		

Scenario A represents the current situation and will be used as the base scenario. Any changes or improvements to the system within Scenario B will be tested and evaluated against the Base Scenario (Scenario A), to determine the water supply improvements and related changes. Scenario A excludes some possible re-use of the return flows from Botshabelo and Thaba Nchu, entering the system upstream of Mockes Dam.

Scenario B include the introduction of additional re-use (maximum of 45 Mℓ/day) from the North Eastern sewage treatment plant (Bloemspruit and NE WWTW are interconnected), to be pumped into Mockes Dam, as well as part of the return flows from Botshabelo and Thaba Nchu, after provision was made for losses before entering Mockes Dam.

2.1. BASE SCENARIO ASSUMPTIONS AND RELATED DESCRIPTIONS

2.1.1. Background Information

The Greater Bloemfontein Reconciliation Strategy Study was completed by middle 2012. Some of the recommendations from the reconciliation strategy study have already been implemented and some are still in the process to be implemented. It is important to understand which of these actions or components were already included, to be able to make sensible decisions regarding those components that need to be part of the base scenario setting or not.

Figure 2-1 shows the bulk water distribution system and the main water resources used to supply the Greater Bloemfontein with water.

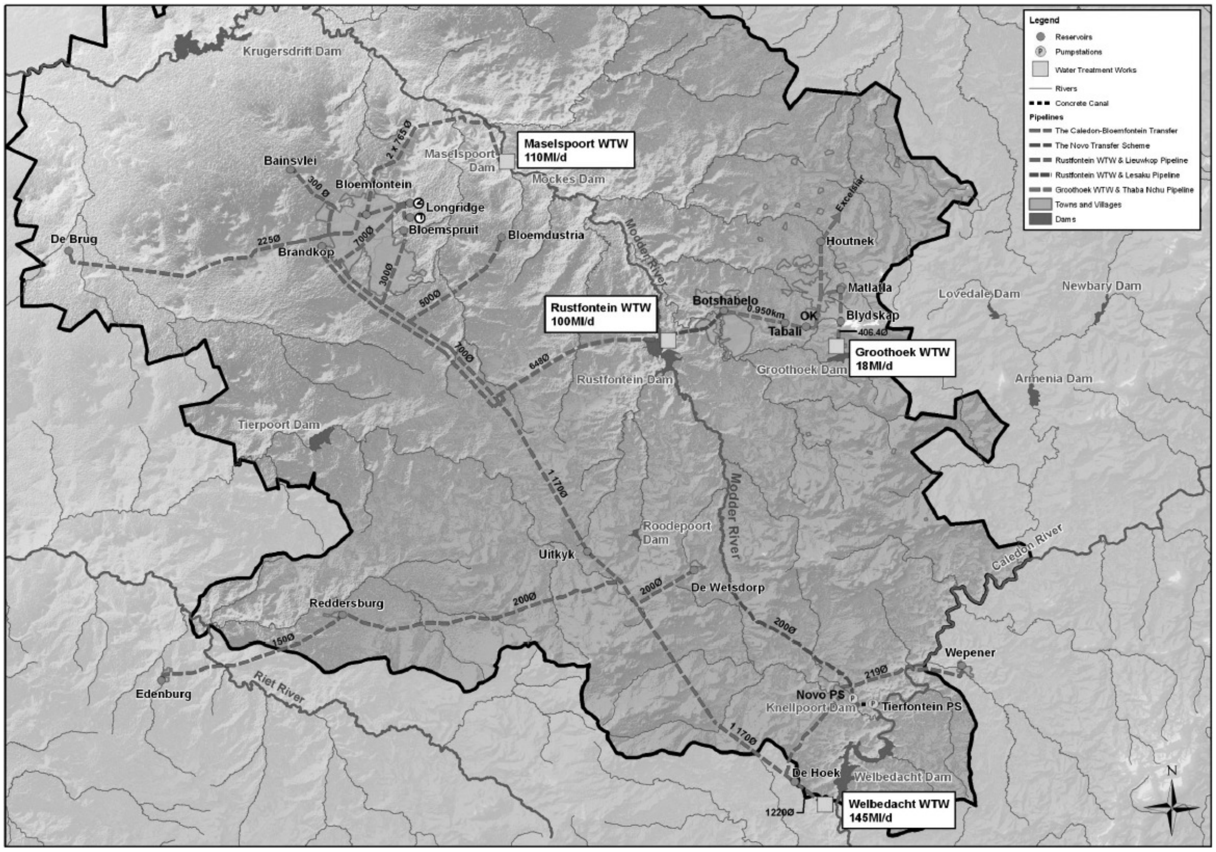


Figure 2-1: Greater Bloemfontein bulk water supply system

The water demand projection for the high growth water requirement scenario used in the reconciliation strategy study started in 2009. It was assumed that this High Growth Water Requirement Scenario will take place on account of a high population growth rate and high economic growth rates. Given the relatively low population projection growth rates obtained from the Reconciliation Strategy Study and the contrasting relatively high historic growth in water requirements (the authorized billed and unbilled water consumption figures for the last 3 years (2006 – 2009) that have grown at a rate of 3% per annum) it was decided to use the long term historical growth rate of 3% per annum as the basis for the high growth scenario for the purpose of the Greater Bloemfontein Reconciliation Strategy Study.

Scenario D as referred to in the **Greater Bloemfontein Reconciliation Strategy Study** was considered as the most probable reconciliation scenario and includes the different intervention options as shown in **Figure 2-2** with the related time schedule of implementation as indicated.

After the completion of the Greater Bloemfontein Reconciliation Strategy Study, the Greater Bloemfontein Reconciliation Study Implementation phase started, to ensure that the recommended intervention options are in fact implemented. Some success was achieved through WC/WDM as evident from **Figure 2-2**. The implementation of the higher pump capacity from Tienfontein pump station was not in place by 2013, as initially planned. The larger pumps were only installed by middle 2016 as indicated in **Figure 2-2**. The higher pump capacity at Tienfontein can currently not yet be utilized due to problems with the capacity of the Eskom power lines serving Tienfontein pump station as well as for the Novo Transfer pump station. Civil works such as the increase of the canal capacity from Tienfontein to Knellpoort Dam as well as increasing the capacity of the de-siltation works, still need to be done. The reconciliation strategy study analysis indicated an expected yield increase of 12 Mℓ/d (4,4 million m^3/a) when Tienfontein pump capacity is increased to 4 m^3/s or 346 Mℓ/d (capacity if running 24 hours/day). Along with the increased Tienfontein pump capacity, the Novo transfer capacity had to be increased to 2,2 m^3/s or 190 Mℓ/d (capacity if running 24 hours/day). The Novo pump capacity was physically increased early in 2016. It was, however, not possible to utilize the full increased pump capacity, as power supply from the Eskom power lines is insufficient.

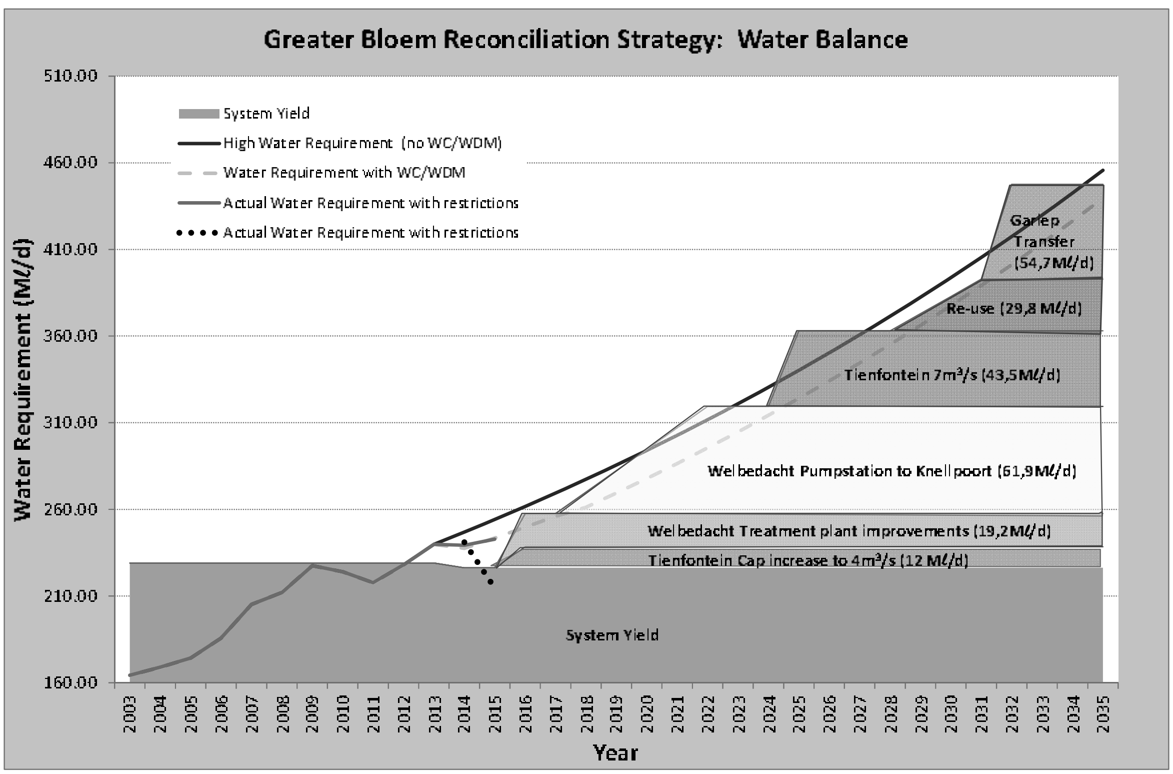


Figure 2-2: Adjusted 2016 Greater Bloemfontein most probable intervention options and related water balance based on the reconciliation strategy by DWS

Effectively it means that currently none of these intervention options are fully active, except for the portion of the WC/WDM already achieved.

2.1.2. Pumping and Transfer Capacities

For the purpose of the Base Scenario definition for this study, one need to agree on the pump capacities to be used. It was proposed and agreed that the increased pumping capacities (see **Table 2-2**) be used for the base scenario definition, although these might in practice only be available in a years' time. None of the other possible intervention options as given in **Figure 2-2** will be included in the base scenario, except for the WC/WDM.

Table 2-2: Key Pump and transfer capacities

Component Description	Current maximum capacity *		Recommended maximum capacity for base scenario *	
	(m^3/s)	(Mℓ/d)	(m^3/s)	(Mℓ/d)
Tienfontein pump station	2,58 m^3/s net	223	3,71 m^3/s net	320
			4,00 m^3/s gross	346
Novo pump station	1,5 m^3/s	130	2,2 m^3/s	190
Welbedacht to Rustfontein	0,16 m^3/s	13,8	0,16 m^3/s	13,8
Transfer from Welbedacht	1,42 m^3/s long-term average	123	1,49 m^3/s (2016/17 target)	129
	1,6 m^3/s max safe pumping capacity	138		
	1,68 m^3/s max design capacity	145		

Note: * Some of the pump and transfer capacities were changed for specific scenarios, which will be indicated in the section dealing with the scenario descriptions.

2.1.3. Hydrology and related diffuse catchment water use

Sub-catchments forming part of the Greater Bloemfontein system is located in the Riet/Modder River and Caledon River main catchments as indicated in **Figure 2-3** and **Figure 2-4,** respectively.

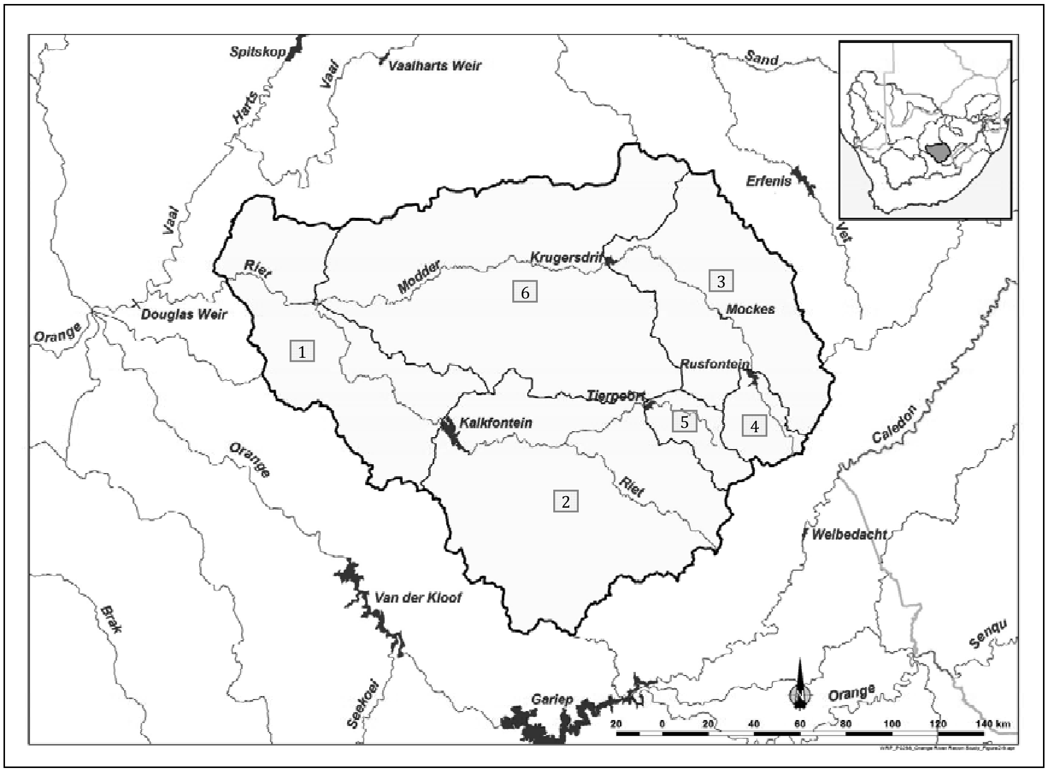


Figure 2-3: Riet/Modder catchment and related sub-catchments

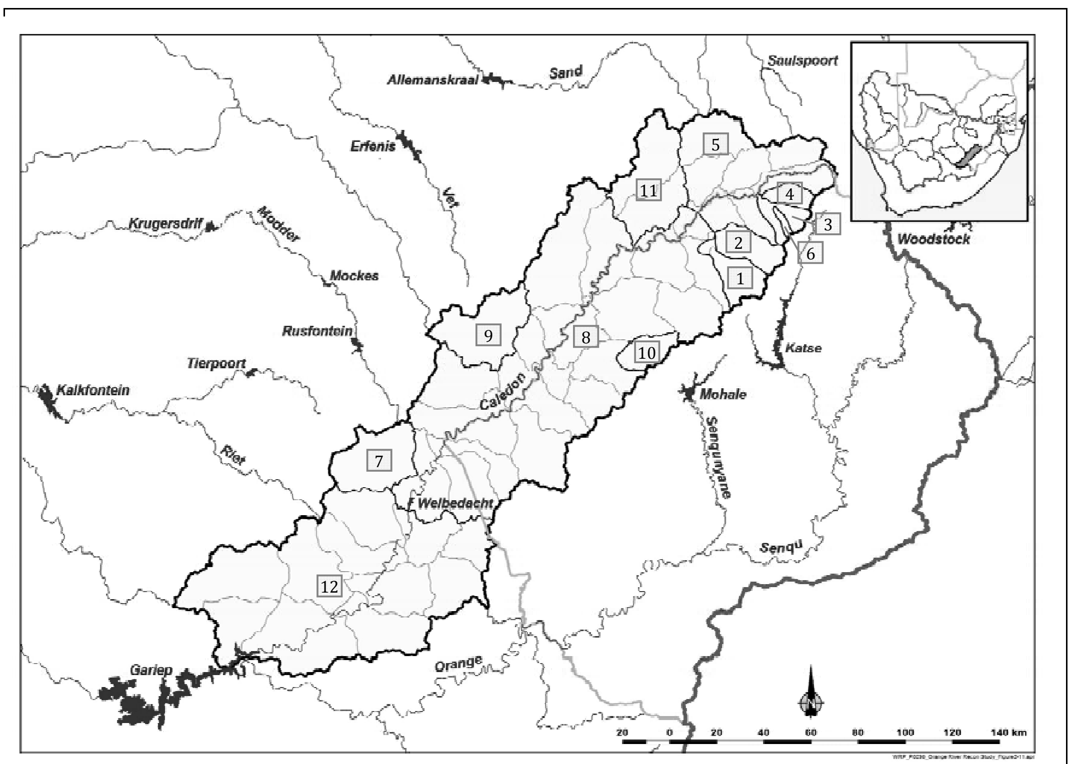


Figure 2-4: Caledon River catchment and related sub-catchments

The natural runoff generated from each of these sub-catchments is used in the WRPM and is summarized in **Table 2-3**.

Table 2-3: Summary of hydrology and diffuse water use in Riet/Modder and Caledon River's sub-catchments

Locality map reference	Hydrology reference name	MAR (million m^3/annum)	Diffuse irrigation (million m^3/annum)	Afforestation (million m^3/annum)
Riet-Modder River sub-catchments				
1	AUCH4	5.80	0.00	0.00
2	KALKF4	185.85	0.00	0.00
3	KRUG4	118.06	0.00	0.00
4	RUSTF4	30.96	0.00	0.00
5	TIER4	23.23	0.00	0.00
6	TWEE4	15.67	0.00	0.00
Caledon River sub-catchments				
1	HLOABS	103.94	0.00	0.00
2	HLODAM	99.48	0.00	0.00
3	HOLABS	43.72	0.00	0.00
4	HOLDAM	36.34	0.00	0.00
5	KATJREST	206.83	0.00	0.00
6	MUELA	5.91	0.00	0.00
7	KNELL	17.57	0.00	0.00
8	WELINC	556.42	0.00	0.00
9	ARMEN	30.08	0.00	0.00
10	METO	61.83	0.00	0.00
11	WATER	63.64	0.00	0.00
12	D24	151.65	0.00	0.00

The Krugersdrift Dam (KRUG4) incremental natural inflow record was sub-divided to represent the inflows into Groothoek Dam (4.6% of natural flow), Mockes Dam (20.8% of natural flow), Mockes Dummy dam (20.8% of inflow), Krugersdrift Dummy dam (10.9% of natural flow) and 43% into Krugersdrift Dam.

There are no diffuse irrigation and afforestation abstraction included in the hydrology related files. The irrigation abstractions taking place in these sub-catchments were modelled as point abstractions in the WRPM with details given in **Section 2.1.4**.

2.1.4. Water Requirement Projections

There are currently two water demand projections available for the Greater Bloemfontein System: one originating from the Greater Bloemfontein Reconciliation Strategy Study and one recently prepared demand projection by BIGEN for the purpose of this study which excludes the small towns. The Greater Bloemfontein demand projections (small towns excluded) and related WC/WDM impact is shown in **Figure 2-3**. The demand projection originated from the Greater Bloemfontein Reconciliation Strategy was slightly adjusted as part of the Reconciliation Strategy Implementation Phase. This slightly adjusted demand projection is currently included in the WRPM setup and was used for the Orange Annual Operating Analysis (AOA). The BIGEN water requirement projection (small towns excluded), also shown on **Figure 2-3** is slightly higher in the initial four years, but significantly lower by the end of the projection period. It is also evident from **Figure 2-3** that the BIGEN projection is showing a higher growth for Botshabelo and Thaba Nchu and lower growth for Bloemfontein, in comparison with the Greater Bloemfontein Reconciliation Strategy Study.

It was proposed and agreed that the 2018 development level demands be used for the initial constant development level option scenarios, of which the base scenario will be the first one to analyze. The BIGEN demand projection were used for the purpose of this study.

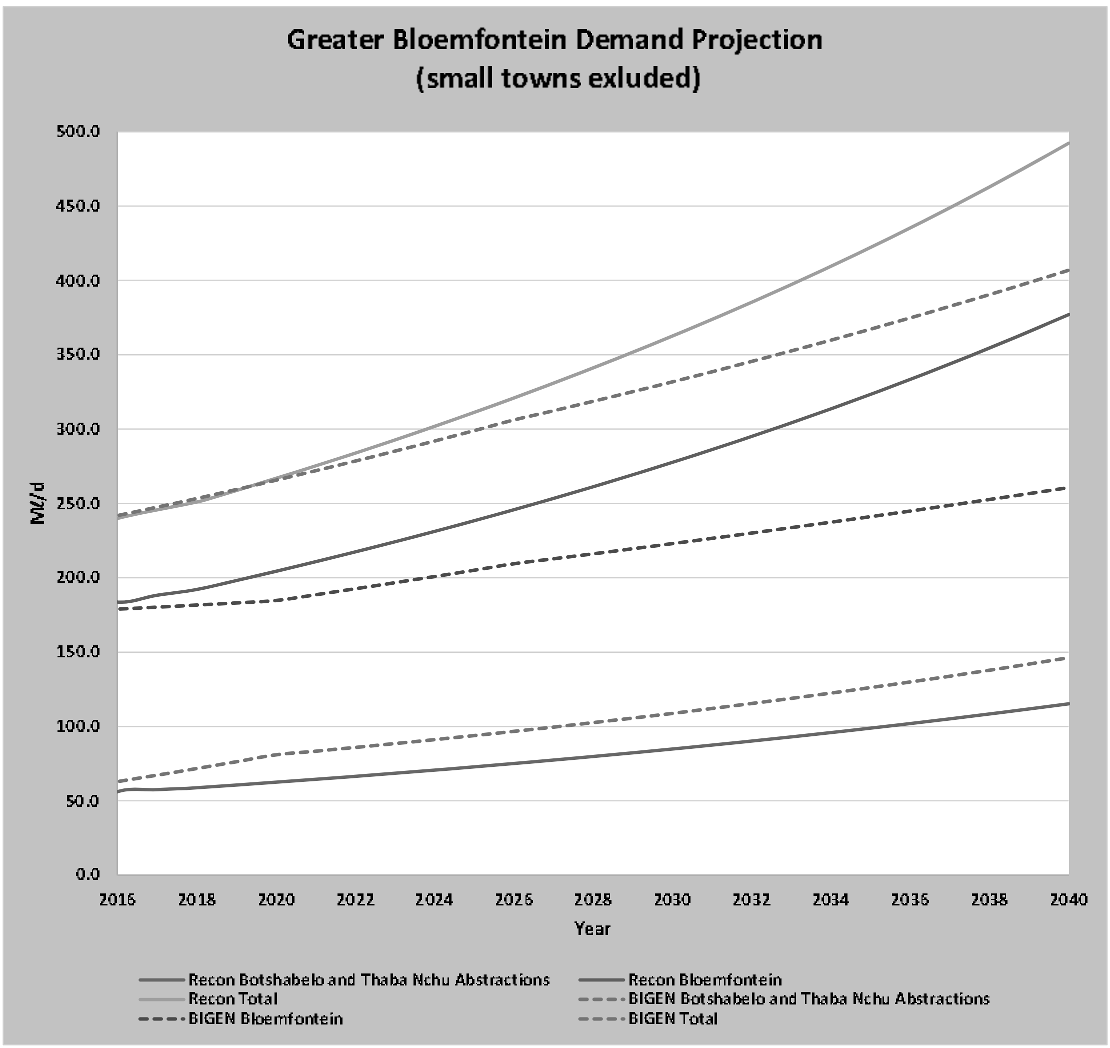


Figure 2-5: Greater Bloemfontein water requirement projections

The total demand for the Greater Bloemfontein system need to be broken down for modelling purposes into the following main demand centers and needs to include the small towns:

- Bloemfontein
- Botshabelo
- Thaba Nchu
- Small Towns (Edenburg, Reddersburg, Wepener, De Wetsdorp and Excelsior)

Most of the small towns use their own groundwater resources in combination with support from the Greater Bloemfontein system and the percentage groundwater use versus surface water use needs to be verified. Of the total surface water provided to the Greater Bloemfontein System, only approximately 4% goes to the small towns listed in the previous paragraph.

Updated water demand growth projections for the small towns were only available for Edenburg and Reddersburg as obtained from Rikus Viljoen of Phethogo Consulting in Bloemfontein. The average growth from the updated Edenburg and Reddersburg growth projections was then applied to the other small towns for the purpose of this study. The updated water demand projections are summarized in **Table 2-4**.

One of the future intervention options is the transfer from Gariep Dam to Bloemfontein. This pipeline will also be used to supply several small towns on the route of the pipeline which include:

Gariep, Bethulie, Springfontein, Philippolis, Trompsburg, Bethanië, Jagersfontein and Fauresmith.

Table 2-4: Breakdown of projected annual water requirement (Mℓ/d) for the Greater Bloemfontein System – BIGEN Projection (Potable water with WC/WDM in place)

Demand Center	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Thaba Nchu Abstractions	25.52	27.26	29.06	30.91	32.82	33.81	34.82	35.87	36.94	38.05
Botshabelo	37.41	39.97	42.60	45.32	48.12	49.56	51.05	52.58	54.15	55.78
Bloemfontein	178.95	180.28	181.69	183.17	184.73	188.65	192.66	196.74	200.90	205.15
Mang-Total	**241.87**	**247.51**	**253.36**	**259.41**	**265.67**	**272.02**	**278.52**	**285.18**	**292.00**	**298.98**
Reddersburg	2.82	2.85	2.88	2.91	2.94	2.97	3.00	3.04	3.07	3.10
Edenburg	1.76	1.79	1.82	1.86	1.89	1.93	1.96	2.00	2.03	2.07
Dewetsdorp	3.04	3.08	3.13	3.18	3.22	3.27	3.32	3.36	3.41	3.46
Excelsior	0.54	0.55	0.56	0.57	0.58	0.58	0.59	0.60	0.61	0.62
Wepener	2.72	2.76	2.81	2.85	2.89	2.93	2.97	3.02	3.06	3.10
Total small	**10.88**	**11.04**	**11.20**	**11.36**	**11.52**	**11.68**	**11.85**	**12.02**	**12.19**	**12.36**
Total system	**252.75**	**258.55**	**264.55**	**270.76**	**277.19**	**283.70**	**290.37**	**297.20**	**304.19**	**311.34**

Table 2 4 (Continue): Breakdown of projected annual water requirement (Ml/d) for the Greater Bloemfontein System – BIGEN Projection (Potable water with WC/WDM in place)

Demand Center	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Thaba Nchu Abstractions	39.19	40.37	41.58	42.83	44.11	45.43	46.80	48.20	49.65	51.14
Botshabelo	57.45	59.18	60.95	62.78	64.66	66.60	68.60	70.66	72.78	74.96
Bloemfontein	209.48	212.79	216.16	219.57	223.04	226.55	230.12	233.75	237.43	241.16
Mang-Total	**306.12**	**312.34**	**318.69**	**325.18**	**331.81**	**338.59**	**345.52**	**352.61**	**359.85**	**367.26**
Reddersburg	3.13	3.17	3.20	3.23	3.27	3.30	3.34	3.37	3.41	3.45
Edenburg	2.11	2.15	2.19	2.23	2.27	2.32	2.36	2.40	2.45	2.49
Dewetsdorp	3.51	3.57	3.62	3.67	3.72	3.78	3.83	3.89	3.95	4.00
Excelsior	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72
Wepener	3.15	3.20	3.24	3.29	3.34	3.39	3.44	3.49	3.54	3.59
Total small	**12.54**	**12.72**	**12.90**	**13.08**	**13.27**	**13.46**	**13.65**	**13.85**	**14.05**	**14.25**
Total system	**318.66**	**325.05**	**331.59**	**338.26**	**345.08**	**352.05**	**359.17**	**366.45**	**373.90**	**381.50**

The total water requirement for these towns starts at 11.4 Mℓ/day in 2017 growing to 12.8 Mℓ/day by 2040 (See **Table 2-5**).

Table 2-5: Small Town demands supplied from the Gariep pipeline

Year	Yearly Average Demand (Ml/day)	Peak Demand (Ml/day)	Yearly Average Demand million m^3/a
2017	11.4	16.2	4.16
2018	11.5	16.3	4.20
2019	11.5	16.4	4.20
2020	11.6	16.4	4.24
2021	11.6	16.5	4.24
2022	11.7	16.6	4.27
2023	11.7	16.7	4.27
2024	11.8	16.8	4.31
2025	11.9	16.9	4.35
2026	11.9	16.9	4.35
2027	12.0	17.0	4.38
2028	12.0	17.1	4.38
2029	12.1	17.2	4.42
2030	12.2	17.3	4.46
2031	12.2	17.4	4.46
2032	12.3	17.4	4.49
2033	12.4	17.5	4.53
2034	12.4	17.6	4.53
2035	12.5	17.7	4.57
2036	12.5	17.8	4.57
2037	12.6	17.9	4.60
2038	12.7	18.0	4.64
2039	12.7	18.1	4.64
2040	12.8	18.2	4.68

The Greater Bloemfontein System is not used to support irrigation activities. Within the catchments upstream and downstream of the main resources irrigation developments, however, do occur. These irrigation developments will have an impact on the available resources of the

Greater Bloemfontein System and thus need to be taken into account when modelling the system.

Irrigation abstractions from the Caledon River catchment upstream of Welbedacht Dam accumulates to 38.3 million m^3/a of which about 2 million m^3/a is located in the Knellpoort Dam catchment. Compensation releases from Welbedacht Dam mainly to support downstream irrigation is 2 m^3/s and if the inflow into Welbedacht is less than 2m^3/s the total inflow need to be released.

Table 2-6: Irrigation abstractions from key areas in the Greater Bloemfontein System

Description	Node	Channel	Irrigation supply (million m^3/a)
Caledon River sub-catchments			
River abstractions in Katjrest	967	4713	6.248
Farm dam abstractions in Katjrest	1370	4715	0.568
River abstractions in Wel	973	4718	6.406
River abstractions in Wel	1383	4724	0.0
River abstractions in Wel	1395	4728	0.568
River abstractions in Wel	1039	4742	1.578
River abstractions in Wel	835	4749	0.884
Farm dam abstractions in Wel	1376	4720	7.321
Farm dam abstractions in Wel	1237	4745	4.292
Farm dam abstractions in Amen	1311	4734	2.304
Armenia Dam abstraction in Armen	2699	4739	2.493
River abstractions in Water	800	4730	1.609
Farm dam abstractions in Water	1203	4733	2.020
Farm dam abstractions in Knel	1320	4753	1.957
Total irrigation upstream of Welbedacht Dam			**38.248**
Welbedacht compensation releases	1228	4600	63.115 (52.922)
Riet/Modder sub-catchments			
River abstractions in Rustf	437	971	0.221
Farm dam abstractions in Rustf	434	967	1.105
River abstractions in Mock (Krug4)	418	944	1.041
Farm dam abstractions in Mock (Krug4)	415	935	0.126
River abstractions in Krug4	426	955	1.357
River abstractions in Krug4	423	962	6.630
Modder total irrigation upstream of Krugersdrift Dam			**10.480**

The 2 m^3/s compensation release represents an annual release of 63.12 million m^3/a. Over the historic simulation period 1920 to 2004 the average compensation release was 52.92 million m^3/a as the inflow to Welbedacht Dam were several times less than the 2 m^3/s required releases.

The total irrigation abstractions in the Modder River catchment upstream of Krugersdrift Dam amounts to almost 10.5 million m^3/a. Of this, only 2.5 million m^3/a is abstracted upstream of Mockes Weir which will directly impact on the water available to the Greater Bloemfontein system. The remainder of almost 8 million m^3/a is abstracted between Mockes and Krugersdrift dams. A substantial part of this irrigation is most probably supported by return flows from Bloemfontein. Previous studies also indicated the yield available from Krugersdrift Dam can significantly be increased by the Bloemfontein return flows. There is, however, uncertainty on the volume of return flows that eventually reached Krugersdrift Dam.

2.1.5. Monthly Distribution of Water Requirement

Although monthly distribution patterns over the year for most towns and cities follows a relative equal distribution, it is important for the purpose of this study that it should accurately reflect the real situation as obtained from observed data. The reason for this is the importance of re-use as an additional water resource to be utilized for the Greater Bloemfontein System. The correct monthly demand distribution patterns for the three main demand centers listed below are thus essential, as well as the monthly distribution patterns of the associated return flows from these demand centers:

- Bloemfontein
- Botshabelo
- Thaba Nchu

Data for the actual water use by the MMM was provided for July 2009 to June 2016 for both the water purchased by MMM from Bloemwater and the water supplied by MMM to Bloemfontein from Maselspoort WTW (see **Table 2-7**). This water use data were available for Bloemfontein, Botshabelo and Thaba Nchu, but not for the small towns. This data were mainly used to determine the typical monthly water use pattern for the three main water use centers. The data obtained and the monthly distributions pattern for each of the main demands centers are summarized in **Tables 2-7, 2-8** and **2-9**.

Table 2-7: Actual water use July 2009 - June 2015 by Bloemfontein (million m³)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
	Bloemfontein												
2009/2010	2.39	2.91	3.57	3.57	3.18	3.14	4.11	2.50	2.67	2.83	2.40	3.82	37.10
2010/2011	2.16	3.32	3.56	3.65	2.51	2.61	3.04	2.57	3.11	3.68	2.80	4.91	37.91
2011/2012	1.93	3.14	3.39	3.32	4.24	3.01	3.74	4.08	4.13	4.92	3.63	6.17	45.70
2012/2013	2.18	3.26	4.80	3.68	4.20	3.47	4.49	4.24	4.04	4.93	3.95	4.77	48.01
2013/2014	4.71	3.65	4.13	3.33	4.50	3.78	5.61	5.41	3.51	3.03	4.23	3.80	49.69
2014/2015	4.01	4.02	3.96	3.94	3.29	3.41	5.86	4.40	4.41	4.20	3.80	3.92	49.24
Unit	Average												
million m³	**2.90**	**3.38**	**3.90**	**3.58**	**3.65**	**3.24**	**4.47**	**3.87**	**3.64**	**3.93**	**3.47**	**4.56**	**44.61**
m³/s	**1.082**	**1.263**	**1.506**	**1.337**	**1.410**	**1.208**	**1.671**	**1.585**	**1.361**	**1.517**	**1.296**	**1.760**	**1.414**
Mℓ/d	**93.5**	**109.1**	**130.1**	**115.5**	**121.8**	**104.4**	**144.3**	**136.9**	**117.6**	**131.1**	**111.9**	**152.1**	**122.1**
Distribution factor	**0.764**	**0.892**	**1.063**	**0.944**	**0.995**	**0.853**	**1.180**	**1.119**	**0.961**	**1.071**	**0.915**	**1.243**	**12.000**

Table 2-8: Actual water use July 2009 - June 2015 by Botshabelo (million m³)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
	Botshabelo												
2009/2010	0.40	0.71	0.40	0.72	0.62	0.68	0.68	0.68	0.68	0.68	0.68	0.67	7.61
2010/2011	0.69	0.68	0.68	0.88	0.94	0.89	0.86	0.80	0.84	0.84	0.81	1.16	10.06
2011/2012	0.69	0.69	0.73	0.64	0.68	0.76	0.98	0.96	0.87	0.86	0.97	1.23	10.06
2012/2013	0.36	0.86	0.89	0.99	0.95	0.93	1.04	0.99	0.94	1.02	0.89	1.25	11.10
2013/2014	0.97	0.85	0.85	1.02	0.95	0.86	1.15	0.95	0.82	0.91	0.81	0.83	10.97
2014/2015	0.90	0.82	0.92	0.93	0.95	0.97	1.05	1.04	0.79	0.99	0.92	0.93	11.22
Unit	Average												
million m³	**0.67**	**0.77**	**0.74**	**0.86**	**0.85**	**0.85**	**0.96**	**0.90**	**0.82**	**0.88**	**0.85**	**1.01**	**10.17**
m³/s	**0.250**	**0.287**	**0.287**	**0.322**	**0.328**	**0.317**	**0.358**	**0.369**	**0.308**	**0.340**	**0.316**	**0.391**	**0.322**
Mℓ/d	**21.6**	**24.8**	**24.8**	**27.8**	**28.3**	**27.4**	**30.9**	**31.9**	**26.6**	**29.4**	**27.3**	**33.8**	**27.8**
Distribution factor	**0.775**	**0.890**	**0.890**	**0.996**	**1.016**	**0.981**	**1.109**	**1.145**	**0.954**	**1.054**	**0.979**	**1.211**	**12.000**

Table 2-9: Actual water use July 2009 - June 2015 by Thaba Nchu (million m³)

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
	Thaba Nchu												
2009/2010	0.26	0.30	0.26	0.48	0.32	0.46	0.62	0.58	0.00	0.51	0.50	0.81	5.11
2010/2011	0.25	0.52	0.62	0.58	0.53	0.52	0.52	0.51	0.48	0.50	0.69	0.55	6.30
2011/2012	0.34	0.32	0.41	0.50	0.67	0.57	0.61	0.64	0.61	0.61	0.71	0.87	6.86
2012/2013	0.24	0.67	0.64	0.78	0.69	0.69	0.87	0.73	0.68	0.76	0.65	0.99	8.38
2013/2014	0.74	0.62	0.56	0.26	0.72	0.61	0.77	0.66	0.62	0.65	0.68	0.48	7.38
2014/2015	0.59	0.58	0.63	0.63	0.63	0.69	0.72	0.70	0.60	0.71	0.61	0.49	7.59
Unit	Average												
million m³	**0.40**	**0.50**	**0.52**	**0.54**	**0.59**	**0.59**	**0.69**	**0.64**	**0.50**	**0.62**	**0.64**	**0.70**	**6.94**
m³/s	**0.151**	**0.188**	**0.201**	**0.201**	**0.229**	**0.221**	**0.256**	**0.261**	**0.186**	**0.241**	**0.239**	**0.270**	**0.220**
Mℓ/d	**13.0**	**16.2**	**17.4**	**17.4**	**19.8**	**19.1**	**22.2**	**22.6**	**16.1**	**20.8**	**20.7**	**23.3**	**19.0**
Distribution factor	**0.685**	**0.852**	**0.914**	**0.912**	**1.039**	**1.003**	**1.164**	**1.186**	**0.844**	**1.092**	**1.085**	**1.224**	**12.000**

2.1.6. Water Treatment Works

The capacities of the water treatment Works are given in **Table 2-10** under the heading "Potable Water". The losses were determined from the difference between the actual raw water abstracted from the various resources and the actual potable water supplied from the given WTW's.

Table 2-10: Capacities of existing Water Treatment Works and losses

Treatment Works	Raw water intake		Potable Water		losses	
	Mℓ/d	m^3/s	Mℓ/d	m^3/s	Mℓ/d	%
Rustfontein	107	1,241	100	1,157	7,273	7
Groothoek	19	0,224	18	0,210	1,217	7
Maselspoort	120	1,384	110	1,273	9,601	9
Welbedacht (Design) (Recommended)	159	1,847	145 128,7	1,68 1,49	14,372	10 15

For Rustfontein WTW the averages of actual data from May 2014 – October 2016 was used. For Groothoek WTW the averages of actual data from May 2014 – April 2015 was used. For Maselspoort WTW the averages of actual data from May 2015 – October 2016 was used. For Welbedacht WTW the averages of actual data from May 2013 to October 2016 was used.

2.1.7. Waste Water Treatment Plants

The re-use of return flows is an important future resource that will be included in the scenario analysis. It is therefore important that the correct maximum capacity of each of the waste water treatment plants are included in the WRPM setup, as well as the associated return flow losses that are experienced or expected before it becomes available for re-use at the given abstraction or re-use point. These waste water treatment plants capacities and related losses are not yet captured in the WRPM and need to be included as part of the system setup.

The locations of the existing waste water treatment plants are shown on **Figure 2-6** and their related treatment capacities given in **Table 2-11**. Re-use is planned to take place from the Bloemfontein North Eastern sewage treatment plant from where it will be pumped into Mockes Dam. Some return flows from the existing sewerage treatment plants of Botshabelo and Thaba Nchu might already contribute to inflows into Mockes Dam. Fairly high losses are, however, expected to occur along the natural stream flows regarding these return flows, before it reaches Mockes Dam.

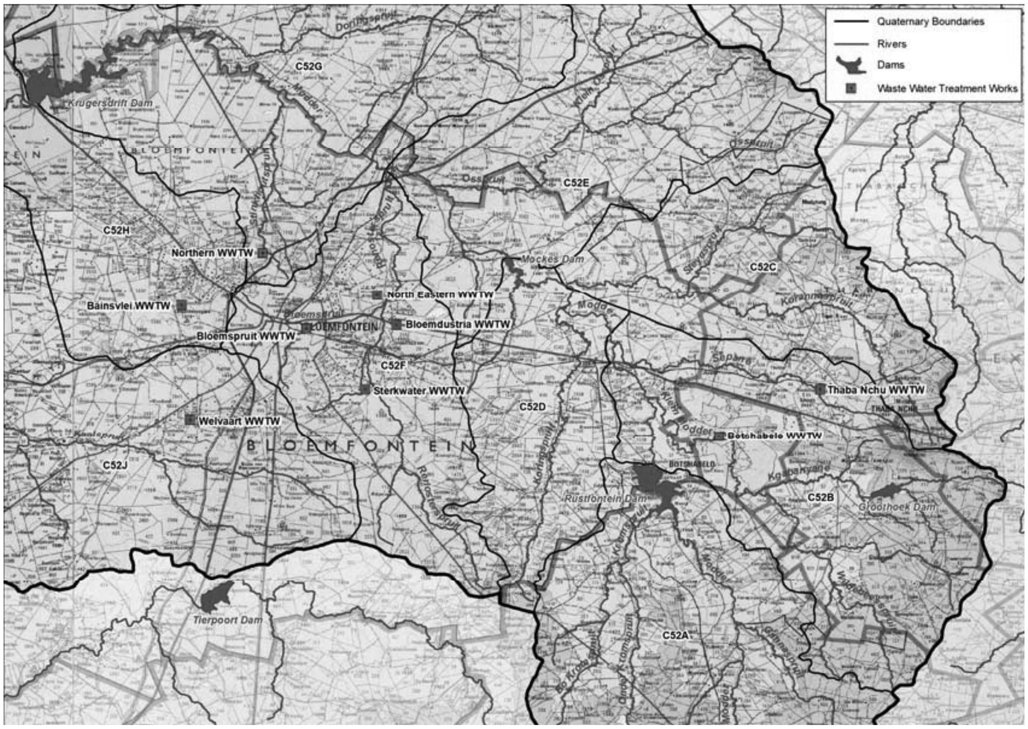


Figure 2-6: Location of waste water treatment plants within the Greater Bloemfontein System

The estimates given in **Table 2-11** were used for modeling purposes, as no observed data in this regard is available.

The average return flows expressed as a percentage of the water requirement are given in **Table 2-12** and were used for scenario modeling purposes. Very little observed data on return flows were available, which will relate in some inaccuracies in the calculation of these percentages. As only a portion of the return flows will be used for re-use purposes, these inaccuracies should not be a major problem for the scenario analyses.

Table 2-11: Waste Water Treatment plant capacities and associated losses

Waste Water Treatment Plant	Capacity		Associated loses* (%)
	Mℓ/d	m^3/s	
Bloemspruit	56	0.648	5%
Sterkwater	40	0.463	30%
Welvaart	6	0.069	50%
Bainsvlei	5	0.058	50%
Northern Plant	5	0.058	5%
Bloemdustria	1.0	0.012	100%
New North Eastern Plant	45	0.521	5%
Botshabelo	20	0.231	30%
Selosesha	6	0.069	30%

Note: * - These losses refer to the expected losses from where the return flow enters into the river or stream to the point where it can be abstracted again forming part of the greater water supply system

Table 2-12: Expected return flow percentage from main demand centers

Demand Center	Percentage return flows	Remarks
Bloemfontein	50%	Average from all WWTPs
Botshabelo	39%	Average from all WWTPs
Thaba Nchu	21%	Average from all WWTPs

2.2. ADDITIONAL SCENARIOS

2.2.1. Yield related scenarios

As referred to in **Section 1.1** several additional yield scenarios were analysed to determine the Greater Bloemfontein System yield that could be obtained for the different scenarios. These scenarios are briefly described hereafter:

<u>All the A scenarios related to the Base Scenario referred to as Scenario A</u>

Scenario A2 is based on Scenario A (Base Scenario as described in **Section 2**) with an additional channel added to the system to enable the system to fully utilize the storage in Knellpoort Dam.

Scenario A3 is based on Scenario A2 with refinements added to the current operating rule to reduce pumping as well as to reduce spills at Rustfontein Dam.

Scenario A3b is based **on Scenario A3** but with reduced pump and transfer capacities to represent a system that is not operated to its full potential. This scenario therefore represents results closer to that obtained in reality, due to several difficulties currently experienced in the system, such as lack of power supply, high electricity costs during peak hours, maintenance problems, etc.

The capacities of the Tienfontein pump station, Novo transfer, and Welbedacht Bloemfontein transfer were for the purpose of this scenario reduced as given in **Table 2-13**.

Table 2-13: Reduced capacities as used for Scenario A3b

Component Description	Scenario A3 Max capacity		Recommended max capacity for Scenario A3b *	
	(m^3/s)	(Mℓ/d)	(m^3/s)	(Mℓ/d)
Tienfontein pump station	3,71 m^3/s	320	2,06 m^3/s	178
Novo pump station	2,2 m^3/s	190	1,7 m^3/s	146
Transfer from Welbedacht	1,49 m^3/s (2016/17 target)	129	1,42 m^3/s	123

Note: * Capacities of the Tienfontein pump station, Novo transfer, and Welbedacht Bloemfontein transfer were reduced for the purpose of scenario A3b.

Scenario A4: This scenario is similar to Scenario A2, but the abstraction from Mockes Dam (Maselspoort WTW) was limited to 22 Mℓ/d which is in line with the current practice. The starting storage of the dams were set equal to the 1 May 2017 starting storages. The current 2017 water demand was imposed on the system. The analysis to start in May and not in October as the other scenarios thus far. This was done to align Scenario 4 with the annual operating analysis that was carried out earlier by a separate DWS study. A historic analysis only to be carried out.

Scenario A5: This scenario is as A4, but with the abstraction from Mockes Dam (Maselspoort WTW) limited to the current capacity of 110 Mℓ/d treated water. Results from this Scenario are to be compared with those from Scenario A4. A historic analysis only to be carried out.

The purpose of Scenarios A4 and A5 is to indicate that the current practice of only running the Maselspoort WTW at 22 Mℓ/d, is limiting the recovery of the system. To be able to end the heavy restrictions currently imposed on the system, it is important that the maximum possible water volume should be routed through this WTW, without releasing from Rustfontein.

<u>All the B Scenarios includes re-use options</u>

Scenario B2 is based on Scenario B as described in **Section 2**, but include a higher additional re-use from Bloemfontein (maximum of 77 Mℓ/day) from the Bloemfontein North Eastern WWTP, to be pumped into Mockes Dam.

Scenario B3: As alternative to Scenario C2 it was requested to analyze Scenario B3 which is similar to Scenario B2 but with Maselspoort WTW capacity increased to 130 Mℓ/d and 32 Mℓ/d of the 77 Mℓ/d re-use considered as direct re-use. Thus, only 45 Mℓ/d of the re-use will enter Mockes Dam. Mockes Dam storage is not increased for this scenario. The refined operating rule as developed for Scenario A3 was used.

All the C Scenarios includes the Mockes Dam increased storage.

Scenario C is based on Scenario A2, but includes an increased storage at Mockes Dam. For this scenario the storage in Mockes Dam is increased from the current 3,58 million m^3 storage to 12,13 million m^3 storage.

Scenario C2: Results from Scenario B2 showed that the increased re-use of treated return flows could not be utilized in full, when used in combination with the existing Mockes Dam. It was therefore requested that Scenario C2 also be analysed, which is similar to Scenario B2, but including the larger Mockes Dam storage as well as the increased Maselspoort WTW capacity of 130 Mℓ/d.

The raw- and potable water pump stations at the Maselspoort WTW currently has capacity to supply a 7-day peak capacity of 130 Ml/day. There are, however, a few bottlenecks in certain processes of the WTW itself which limits the 7-day peak capacity of the Maselspoort WTW to approximately 108 Ml/day. As part of the Maselspoort WTW upgrade to address water quality concerns, improvements to these process will also be done to increase the WTW capacity to that of the pump-station (i.e. from 108 Ml/day to 130 Ml/day).

The refined operating rule as developed for Scenario A3 was used.

Scenario C3: This scenario was only analysed as part of the water supply related scenarios (see **Section 2.2.2**).

2.2.2. Water supply related scenarios

The purpose of the water supply related scenarios was to support the cost and economic calculations and evaluations. These analyses will provide monthly flows over the entire analysis period as produced at each of the water treatment plants for selected scenarios at a given development level.

The following scenarios were requested by the MMM to be analysed for this purpose:

- **Scenario A3b** with the 2017 demand imposed on the system. This scenario represents the current system which is not operated to its full potential.
- **Scenario B3** with 2024 demand imposed on the system. This scenario includes 45Mℓ/d indirect re-use entering into Mockes Dam in combination with 32Mℓ/d direct re-use.
- **Scenario C2** with 2024 demand imposed on the system. This scenario includes the larger Mockes Dam with a 77Mℓ/d indirect re-use entering Mockes Dam, with Maselspoort WTW capacity increased to 130 Mℓ/d.
- **Scenario C3** with 2040 demand imposed on the system. This scenario is as Scenario C2 but also includes the support from Gariep Dam to the Greater Bloemfontein System. The maximum average monthly support from Gariep Dam to the Greater Bloemfontein System was taken as 120 Mℓ/d. Small towns to be supplied directly from the Gariep pipe line was not included in this analysis.

2.2.3. Stochastic Projection Analysis

This analysis will take into account the assurance of supply as required for the different user categories within the Greater Bloemfontein system, along with the estimated growth in demand over time. The stochastic projection analyses will all start on 1 May 2017, as by that time all the summer rainfall runoff has entered the storage dams. This is also in line with the start month of the annual operating analysis carried out by DWS on a regular basis. At the start of the analysis (May 2017) it is assumed that the system represents the conditions of Scenario A3b. During the analysis period 2017 to 2040 the model will impose restrictions on the system as and when required. The required assurance of supply as defined for the users will then be compared with the assurance of supply that could be provided to the users over the simulation period, as obtained from the model results. By doing this, one can identify the point in time when the assurance of supply from the resource is not sufficient to maintain the required assurance of supply as applicable to the users. This will typically be the time when a new intervention option need to be in place, such as for example the re-use of water to increase the system yield as well as the assurance of supply to the users. The stochastic projection analysis is therefore a very useful tool to determine the required timing of the identified intervention options, to be able to maintain the assurance of supply to users over the total planning period. The following sub-tasks or steps are required to be able to carry out the stochastic projection analysis.

1. Convert historic analysis system setup to the stochastic analysis mode.

2. Include the required changes in the WRPM data sets to allow the system to change over time from Scenario A3b in 2017 towards Scenario C3 by 2040. Use implementation dates that is practical and in line with indications from the water balance prepared by using the historic yield results.
3. Discuss and agree on the assurance of supply to be used in the analysis.
4. Carry out test runs using a single stochastic sequence to ensure that the system is functioning in the correct manner.
5. Carry out the first full stochastic analysis by analyzing 1000 different flow sequences.
6. Plot and evaluate the results obtained.
7. Discuss results with the MMM and agree on changes to be included.
8. Carry out the second full stochastic analysis by analyzing 1000 different flow sequences with agreed changes included.
9. Plot and evaluate the results obtained and discuss with MMM.
10. Depending on the results from the first and second stochastic projection analyses further analyses might be required, but will be discussed with the MMM at the time.

2.3. STOCHASTIC ANALYSIS BASE SCENARIO

The interventions option to be included in the analysis of the Base Scenario were the following:

- Increase Maselspoort WTW from 110 Mℓ/d to 130 Mℓ/d (May 2018).
- Increase Tienfontein and Novo transfer capacities due to improved Eskom Power supply (May 2018) from 178 Mℓ/d to 320 Mℓ/d and from 146 Mℓ/d to 190 Mℓ/d respectively.
- Improvement of the system management and operation (May 2018).
- Re-use of return flows from Bloemfontein of 45 Mℓ/d of treated return flows entering Mockes Dam (May 2018)
- Increase Mockes Dam storage from 3,58 million m^3 to 12,13 million m^3 storage (May 2020).
- Increase re-use into Mockes Dam to 77 Mℓ/d (May 2021).
- Support from Gariep Dam (±120 Mℓ/d by May 2024).

The first six intervention options need to be in place as soon as possible. This means that the time when these six intervention options can be included, will depend on the time required to physically get these interventions options in place and operational as quickly as possible. Please note that this is the Base Scenario and results will be used to determine improved and more realistic timing of intervention options.

It is important to note that the water requirement projections used in all the analyses already includes WC/WDM. This means that the first step in addressing Bloemfontein's bulk water supply problems is to implement WC/WDM. A high percentage of the water users also represent low income consumers.

The current assurance of supply as used in the WRPM is given in **Table 2.14**, referred to as the Priority Classification Table. Based on the information in **Table 2.14,** 20% of the total demand are supplied at a 95% assurance, 30% at a 99% assurance and 50% at a 99.5% assurance. These required assurances can, however, be adjusted for the purpose of the stochastic projection analysis and need to be agreed on with the MMM.

Table 2-14: Greater Bloemfontein Priority classification table

User group	Demand allocated to given assurance level (million m^3/a)			
	Total	1:20 Year (95%)	1:100 year (99%)	1:200 year (99.5%)
Urban	100%	20%	30%	50%

The current priority of supply from the different resources for supply to Bloemfontein is to first obtain water from Welbedacht Dam, then from Mockes Dam and finally from Rustfontein Dam. The current operating rule of support from Knellpoort Dam to Rustfontein Dam still apply. When the future 77 Mℓ/d re-use option is in place, the re-use was considered as part of the supply from Mockes Dam and was according to priority, still regarded as the second priority resource to supply Bloemfontein after Welbedacht Dam, as explained above.

The priority setting start to change at the time when the transfer from Gariep Dam is in place. The supply from Gariep Dam was then taken as the first priority resource to be used to supply Bloemfontein, then Welbedacht and finally from Mockes Dam and re-use. Thaba Nchu used Groothoek Dam as it first priority resource followed by Rustfontein Dam with support from Knellpoort Dam and finally also from Welbedacht Dam as the last resource. Botshabelo used Rustfontein Dam with support from Knellpoort Dam as the first priority resource followed by Rustfontein Dam as the second resource and Welbedacht as the last resource.

The results from the Base Projection Scenario will provide further information on the timing of the support from Gariep Dam to Bloemfontein as well as the size of the required transfer to Bloemfontein. The second stochastic analysis will include typical changes such as the timing of intervention options and the capacity of the support from Gariep Dam, as well as possible adjustments to the operating rules, etc. The purpose of the adjusted operating rule will not be to optimize the system yield but rather to ensure that the water available in the system are fully utilized.

Results from the Stochastic Projection analysis of the Base Scenario were discussed with MMM and BIGEN. This led to a request for two more stochastic projection scenarios to be analysed:

- Stochastic Projection analysis Scenario 1: Implementation Scenario where MMM implement the re-use projects with the current limited Urban Settlements Development Grant Funding (USDG) with DWS constructing the Gariep pipeline.
- Stochastic Projection analysis Scenario 2: Implementation Scenario where additional grant funding from National Treasury can assist the MMM to speed up the process.

Details of these two Scenarios are given in **Sections 2.4** and **2.5,** respectively.

2.4. STOCHASTIC PROJECTION ANALYSIS SCENARIO 1

For this Scenario it was assumed that MMM has limited USDG funding and DWS will be responsible for the construction of the Gariep pipeline with a resulting slower implementation of intervention options.

This scenario is as the Base Stochastic Projection Analysis Scenario with the following changes included (Changes indicated by text in bold). It is important to note that the second phase re-use is in general referred to as direct re-use, but can also be indirect re-use depending on the technology available at the time and related costs:

- Changes in the phasing of intervention options:
    - Improvement of the system management and operation (May 2018)
    - Increase Tienfontein and Novo transfer capacities due to improved Eskom Power supply (May 2018)
    - Increase Maselspoort WTP from 110 Ml/d to 130 Ml/d **(May 2019)**
    - Increase Mockes Dam storage from 3,58 million m^3 to 12,13 million m^3 storage **(May 2021)**

- Indirect Re-use 45 Mℓ/day in place by **June 2023**
- Support from Gariep in place by **June 2026**
- **Direct/indirect potable re-use of 32 Mℓ/day in place by approximately June 2026.**

* Capacity Changes:
    - **Transfer capacity of the Gariep Pipeline reduced to 90 Mℓ/day average maximum.**
    - **Average potable water capacity of the Maselspoort WTW to be taken as 88 Mℓ/day with a peak capacity of 130 Mℓ/day.**
* Operating rule changes
    - Thaba Nchu and Botshabelo rule remains the same as for the base scenario with Thaba Nchu taking water first from Groothoek Dam, then from Rustfontein Dam with support from Knellpoort Dam and finally from Welbedacht Dam, if water is available. Botshabelo taking water first from Rustfontein with support from Knellpoort and finally from Welbedacht Dam if water is available.
    - Bloemfontein and small towns: **Maselspoort Weir abstraction as first priority followed by re-use, then Welbedacht Dam, then Gariep Dam and as last resort transfers from Knellpoort Dam [thus relying also on off-channel storage]. Small towns can, however, not obtain water from Maselspoort Weir.**
* Demands imposed on the system
    - **As soon as the Gariep pipeline is in place the following towns are also supplied with water from Gariep Dam via the Gariep Bloemfontein pipeline.**
        - **Gariep, Bethulie, Springfontein, Philippolis, Trompsburg, Bethanië, Jagersfontein and Fauresmith.**
        - **The total water requirement for these towns starts at 11.4 Mℓ/day in 2017 growing to 12.8 Mℓ/day by 2040.**

Return flows and the related re-use options for future use significantly impacts on the future water balances. It was therefore decided to obtain updated information on the return flows and to refine the assumptions regarding the available return flow in the WRPM demand centers.

Initial evaluation of the 2016/17 observed return flows indicated slightly higher percentage return flows. This represents data for mainly one year in which severe restrictions was imposed on the system and need to be verified with observed data from previous years, specifically for the years where no restrictions were imposed on the system.

Table 2-15: Updated return flow percentage from main demand centers

Demand Center	Percentage return flows (initial)	Percentage return flows (updated)
Bloemfontein	50%	56%
Botshabelo	39%	47%
Thaba Nchu*	21%	24%

Note: * Thaba Nchu return flows are treated at the Selosesha WWTP

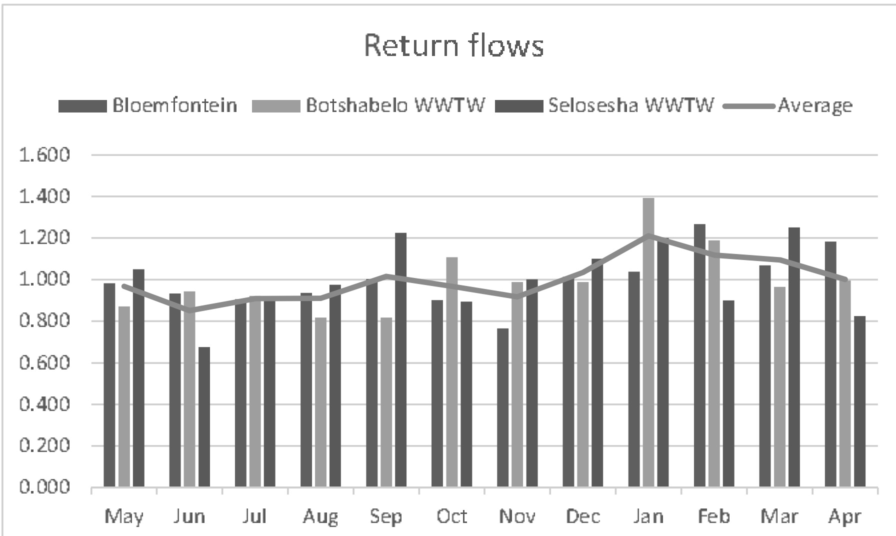


Figure 2-7: Monthly return flow distribution based on 2016/17 data

2.5. STOCHASTIC PROJECTION ANALYSIS SCENARIO 2

Stochastic Scenario 2 consider the option where additional grant funding from National Treasury is available to assist the MMM to speed up the implementation of intervention options.

This scenario is as the **Base Stochastic Projection Analysis Scenario** with the following changes included (Changes indicated by text in bold). It is important to note that the second phase re-use is in general referred to as direct re-use, but can also be indirect re-use depending on the technology available at the time and related costs:

- Changes in the phasing of intervention options:
    - Improvement of the system management and operation (May 2018)

- Increase Tienfontein and Novo transfer capacities due to improved Eskom Power supply (May 2018)
- Increase Maselspoort WTW capacity from 110 Mℓ/d to 130 Mℓ/d (May 2019).
- Increase Mockes Dam storage from 3,58 million m^3 to 12,13 million m^3 storage **(May 2021).**
- Indirect Re-use 45 Mℓ/day in place by **June 2021**
- Support from Gariep in place by **June 2022**
- **Direct/indirect potable re-use of 32 Mℓ/day in place by June 2024**

- Capacity Changes:
  - **Transfer capacity of the Gariep pipeline reduced to 90 Mℓ/day average**
  - **Average capacity of the Maselspoort WTP to be taken as 88 Mℓ/day with a peak capacity of 130 Mℓ/day.**
  - **Average capacity of the Welbedacht WTP to be taken as 100 Mℓ/day based on observed values due to problems with sediment at the site.**
- **Operating rule changes as for projection scenario 1.**
- **Demands imposed on the system is as for Scenario 1.**
- **Return flow assumptions and refinements as for projection scenario 1.**

2.6. STOCHASTIC PROJECTION ANALYSIS SCENARIO 3

Stochastic Scenario 3 consider the option where additional grant funding from National Treasury is available as for Scenario 2, to assist the MMM to speed up the implementation of intervention options.

This scenario is as the **Stochastic Projection Analysis Scenario 2** with the following changes included:

- Changes in the phasing of intervention options (Changes indicated by text in red):
  - Improvement of the system management and operation (May 2018)
  - Increase Tienfontein and Novo transfer capacities due to improved Eskom Power supply (May 2018)
  - Increase Maselspoort WTP from 110 Mℓ/d to 130 Mℓ/d (May 2019). **Reduce abstraction capacity to 88Mℓ/d when storage in Mockes drop to below 60%**

- Increase Mockes Dam storage from 3,58 million m^3 to 12,13 million m^3 storage (May 2021).
- Indirect Re-use 45 Mℓ/day in place by June 2021
- Support from Gariep in place by June 2022 90 Ml/d
- **Increase Gariep support to 120Mℓ/d after the 32Mℓ/d re-use. Date to be determined by results from analysis**
- Direct/indirect potable re-use of 32 Mℓ/day in place later than June 2024 **[Date to be finalized based on results from the analysis.]**
- **Remove capacity limitation from Rustfontein WRP**
- **Determine yield for Groothoek Dam and impose yield as abstraction on the dam, not WTW capacity as for Scenario 2.**
- **The monthly distribution of water use by Bloemfontein, Thaba Nchu and Botshabelo to be aligned with the latest data received from BIGEN**

3. PROPOSED METHODOLOGY

The WRPM as currently set up for the Orange AOA represents the 2016 development level as starting point and will be used as the basis for this analysis.

For the purpose of this assignment only historic analysis was initially carried out. Historic analysis is when the historic natural flows (based on observed flows and observed rainfall data) is used to determine the yield and water supply characteristics of a water supply system. This is usually carried out using a constant development level over the analysis period. The analysis period for this study is based on the current available rainfall runoff and rainfall data covering the period 1920 to 2004. For the purpose of this study the year 2018 was selected as the constant development level. As briefly referred to in the definition of historic analysis, one always carry out a historic analysis using a constant development level. This constant development level in most cases represent a development level close to the current state, as one want to know what the water supply system can yield know, or how well can the water demands be supplied now, with all the current developments upstream of and within the water supply system in place. The year 2018 was selected for the historic analysis of this study as we expect that the Eskom supply to Tienfontein and Novo pumping systems will be sorted out by then, and the pumping systems will then be able to operate at its full capacity.

The historic analysis does not provide much information on the assurance of supply or yield assurance and for that reason stochastic or risk analyses are carried out. Stochastic projection analyses were carried out once the best options for future developments were identified. Stochastic analyses also referred to as risk analysis, uses not only one flow sequence (monthly flow record covering the period 1920 to 2004) per sub-catchment, but up to a 1000 monthly flow sequences per sub-catchment. These flow sequences are synthetically (stochastic) generated. Very important however, is that the stochastic sequences are based on the statistical characteristics of the historic natural monthly flow records. To ensure that the stochastic flows indeed mimic the historic monthly flow records well, several validation and verification tests were carried out on the stochastic flows that are generated for analysis purposes. These stochastic flow sequences include wetter and drier monthly flow sequences than those represented by the historic monthly natural flow sequence.

By analyzing a large number of possible monthly flow sequences, one is able to determine the risk related to water supply, as well as the assurance of the yield available from a water resource. It is then possible to evaluate and determine the risk of non-supply of once in 100 years (99% assurance) or once in 200 year risk (99.5% assurance) which can't be done with a historic analysis based on a record period of only 85 years. A risk/stochastic analysis can be carried out by considering a constant development level over the analysis period, as in the case of the historic analysis, or by considering the expected future growth in water requirements as well as future infrastructure developments, of which the latter option is normally used for planning purposes.

The proposed methodology will include the following steps:

1. Update the WRPM setup to include all the changes as discussed in **Section 2**. Detail information on pipeline and pump capacities, expected demands and return flows as well as the related monthly distributions were obtained from MMM/BIGEN and were confirmed to ensure that all changes included is in line with the proposed changes required by MMM/BIGEN. The system setup was changed to carry out historic analysis. The system was checked thoroughly to ensure that all changes are functioning correctly and provided reliable results.
2. The historic firm yield of the current system (Scenario A) using the current operating rules was then determined (see definition of Historic Firm yield below).
3. For Scenario A, the monthly flows in all the critical channels within the entire system (Greater Bloemfontein) as well as reservoir levels, evaporation losses and system spills were provided. These were included and showed on the system schematic to provide the water resource planners with an improved understanding of the systems behavior, the related water supply, as well as the occurrence of deficits within the system. These results were then discussed to ensure that it were properly understood as they in most cases lead to changes in the remaining scenarios to be analysed, as well as defining of new scenarios not included in **Section 2**.
4. The historic firm yield for Scenario B was determined (adjusted as recommended after the evaluation of the results from the Base Scenario) using the current or slightly adjusted operating rules. The results were discussed to ensure that it is properly understood as they lead to some changes in the remaining scenarios to be analysed.
5. Development levels for historic analysis was taken as 2018.
6. Additional scenarios to be analysed that were identified after the evaluation and discussion of results from the Scenario A and Scenario B analyses are listed and described in **Section 2.2**.
7. Results from the historic analysis of all scenarios were used as basis to define the final scenarios for risk (stochastic) analysis purposes.

The historic firm yield is generally used to obtain a good first order indication of the yield from a dam or a set of dams (system). The historic firm yield is obtained when analyzing the system with the historic flow records entering the dams and then by increasing the target draft on the system and checking the volume that could be supplied from the dams. Initially the dams will be able to fully supply the target draft, but at a certain point (breakpoint) onwards the average supply will be less than the target demand imposed on the system, indicating that failures in supply occurred over the analysis period. The breakpoint is referred to as the Historic Firm Yield (HFY) point. This is thus the point just before failure in the supply of the target draft would occur. The HFY is thus the maximum water demand that can be supplied from the system every year without a failure in any of the years over the total analysis period.

Stochastic projection or risk analysis take into account the assurance of supply as required for the different users within the system, along with the estimated growth in demand over time. During the analysis period the model impose restrictions on the system as and when required. The required assurance of supply as defined for the users will then be compared with the assurance of supply that could be provided to the users over the simulation period, as obtained from the model results. By doing this, one can identify the point in time when the assurance of supply from the resource is not sufficient to maintain the required assurance of supply that apply to the users. This will typically be the time when a new intervention option needs to be in place, to increase the system yield as well as the assurance of supply to the users. The stochastic projection analysis is therefore a very useful tool to determine the required timing of the identified intervention options to be able to maintain the assurance of supply to users over the total planning period. The proposed methodology will include the following steps to be able to carry out the stochastic projection analysis.

1. Convert historic analysis system setup to the stochastic analysis mode.
2. Include the required changes in the WRPM data sets to allow the system to change over time.
3. Discuss and agree on assurance of supply to be used in the analysis.
4. Carry out test runs to ensure that the system is functioning in the correct manner.
5. Carry out the first full stochastic projection analysis by analyzing 1000 different flow sequences.
6. Plot and evaluate the results obtained.
7. Discuss results with the MMM.

4. SCENARIO ANALYSIS RESULTS

As part of the initial running and testing of the adjusted WRPM data set, it already became clear that the Greater Bloemfontein System total demand already exceeds the yield capability of the system. This was also indicated by previous analyses carried out as part of the Greater Bloemfontein Reconciliation Strategy Study initiated by DWS.

It is important to note that the historic firm yield as determined from the Greater Bloemfontein Reconciliation Strategy Study by using the WRYM represents the raw water yield, thus before losses through the water treatment plants were taken into account. In this study the QWRPM was used to determine the historic firm yield. Using the WRPM which already includes each of the water treatment plants and associated transfer losses, the historic firm yield therefore refers to the available potable water, thus after these losses were taken into account.

4.1. SCENARIO A – CURRENT SYSTEM

For Scenario A, no return flows from the existing WWTWs of the urban/industrial water use centers were allowed to enter the system and to be utilized as part of the resources for the Greater Bloemfontein System. The existing system operating rule was considered part of this scenario. The focus of this analysis was to determine the historic firm yield of the entire Greater Bloemfontein System, as well as to determine the flows at key points in the system as applicable to this scenario.

The HFY was determined for the record period of 85 years from 1920 to 2004. The HFY determined for Scenario A is 206 Mℓ/d (75,4 million m^3/a) and is significantly lower than the 2017 total system demand of 259 Mℓ/d (94,44 million m^3/a). This indicates that even under non-drought conditions, the system is already under stress. The analysis further indicated that the current system transfer and pump capacities is not able to utilize the resource in full, as water supply to all the users failed while there was still some water left in Knellpoort Dam (see **Figures 4.1 and 4.2**). **Figure 4.1** shows the variance in storage over time for Knellpoort Dam (red line) with its lowest water storage level occurring in the 1984/85 hydrological year, dropping to below the minimum operating level (MOL.) for transferring water to Rustfontein Dam through the Novo Transfer Scheme, but still above it’s dead storage level (DSL). For Scenario A-2 (**Figure 4.2**) it is clear that Knellpoort Dam reached it’s DSL, thus utilizing the full available storage in the dam (for more detail regarding Scenario A-2 see **Section 4.1.1**).

Based on the current operating rule, transfers through the Novo Transfer Scheme must take place when Rustfontein drops below 16,13 million m³/storage (1 365,64 masl) and when Knellpoort Dam is above 90% or 122,57 million m³/storage (1 450.63 masl). The purpose of this operating rule is to prevent the level in Rustfontein to drop below 16,13 million m³/storage (23% storage) and to reduce spills at Knellpoort Dam by keeping the dam at or below 90% storage level.

The blue line in **Figures 4.1 & 4.2** shows the transfers through the Novo Transfer System with a maximum transfer capacity of 2,2 m³/s or 190 Mℓ/d (transfers in m³/s is indicated on the y-axis on the left hand side of the graph). These transfers varies between 0 and 2,2 m³/s depending on the water levels in Knellpoort and Rustfontein Dams that is used to activate the transfers according to the operating rule, as described in the previous paragraph. For Scenario A the average Novo transfer over the analysis period was 0,721 m³/s or 62,3 Mℓ/d (22,76 million m³/a).

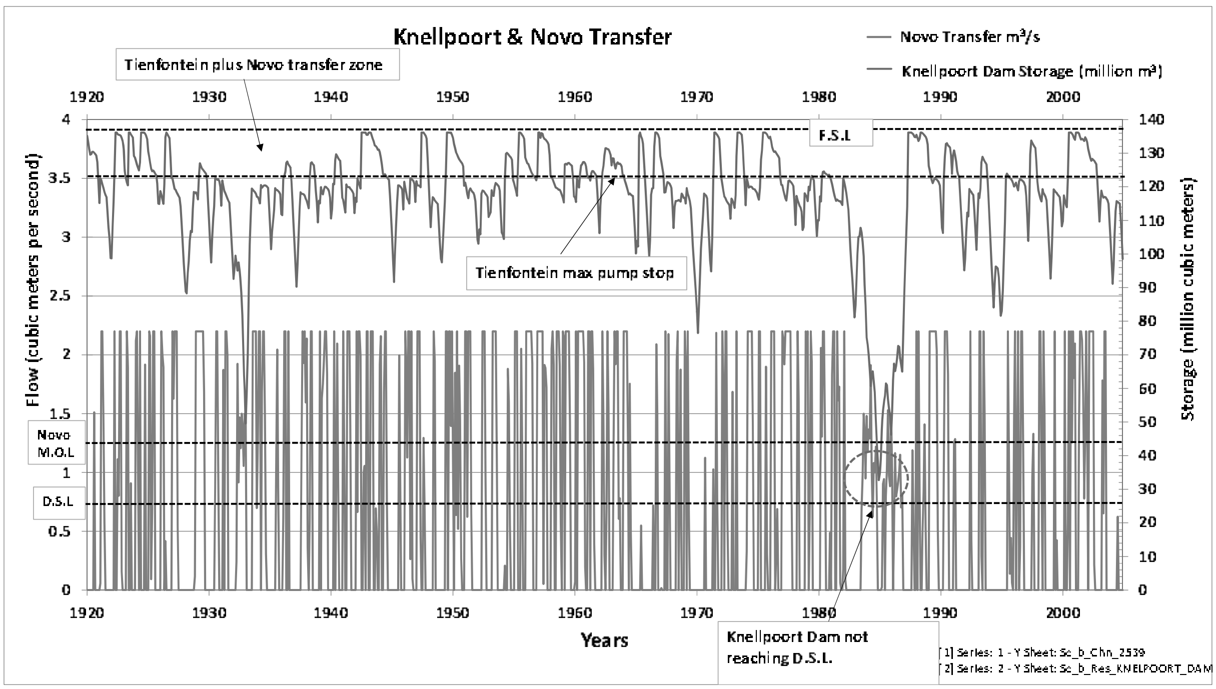


Figure 4-1: Scenario A – Knellpoort Dam storage versus Novo transfer volume

Detail of the flows in most of the channels forming part of the Greater Bloemfontein System for Scenario A is shown in **Figure 2a** of **Appendix A**, with the flows given in Mℓ/d, even if it refers to flows in the river.

These channels represent any route of water flow within the water supply system which can represent a certain section of a river such as channels 976, 136 and 6111 representing the Modder River between Rustfontein and Mockes dams. It can also represent a pipeline such as channels 472, 6005, 947 and 6102 that represents the pipeline from Welbedacht to Bloemfontein. These channels can also represent losses from the system such as channel 610, representing the losses from the Novo Transfer Scheme as well as the water requirements imposed on the system such as channels 748 (Thaba Nchu demands), 950 (Bloemfontein demand) and return flows such as channel 6112 for Bloemfontein total return flows.

These flows represent the average flow in the channel over the 85 year analysis period at constant 2018 development level, with the HFY imposed on the Greater Bloemfontein System. Most of the channel flows will have some sort of variance and in particular the flows representing rainfall runoff in the river channels, will show very high variances from month to month and also from year to year. On a system schematic it is very difficult to include all that detail. Therefore only the average annual flow from the simulated flow record over the 85 year record period are shown on the schematic diagram. By doing this an overall picture is given of the water flow in the system, showing the typical average annual flows through the different channels within the system. This was used to assist in identifying places where the bulk of the flows are available and where deficits might be occurring.

4.1.1. Scenario A2 – Current system utilizing full storage capability of the system

A second scenario (Scenario A2) was carried out based on Scenario A, but including an additional channel (Channel 6113) to be able to utilize the remaining water in Knellpoort Dam. The HFY for Scenario A2 was determined as 213 Mℓ/d (77,9 million m^3/a) and is slightly higher than that obtained for Scenario A. For Scenario A2 all the dams reached their minimum operating level (MOL) in the critical year 1984/85.

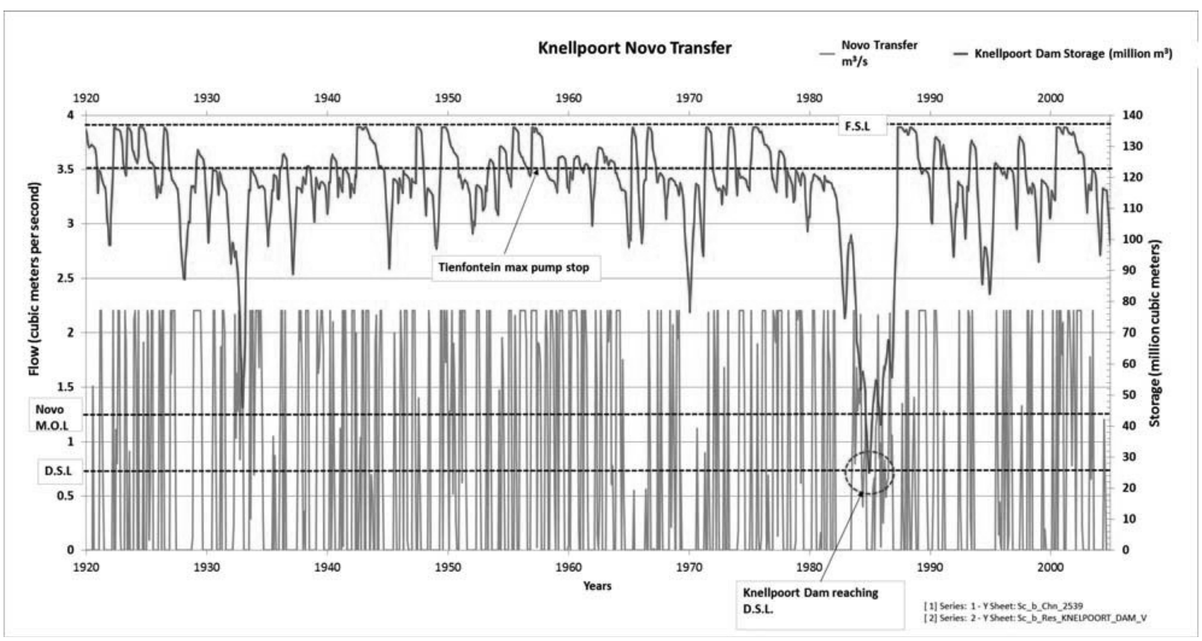


Figure 4-2: Scenario A2 – Knellpoort Dam storage versus Novo transfer volume

Demands imposed on the different dams, however, needed to be adjusted to be able to achieve simultaneous failure of all demands in the 1984/85 year.

See Knellpoort Dam reaching its DSL in the 1984/85 hydrological year (**Figure 4.2**). Support from Knellpoort Dam to Welbedacht Dam can only take place when Knellpoort Dam is at or above it's DSL.

The graphs shown in **Figures 4.2** and **4.1** are very similar with the main difference the storage level in Knellpoort Dam during the most critical drought over the analysis period dropping to the Knellpoort D.S.L in **Figure 4.2.** The average transfer through the Novo Transfer System for Scenario A2 slightly reduced to 0,712 m^3/s or 61,5 Mℓ/d in comparison with the 0,721 m^3/s or 62,3 Mℓ/d from Scenario A.

Figure 4.3 shows the variance in the Rustfontein Dam storage level over the analysis period as applicable to Scenario A2 in comparison with the simulated Novo Transfer over the same period. Only during the early 1930's and middle 1980's (periods 1 & 2 as indicated on **Figure 4.3**) Rustfontein Dam level dropped to the operating level at and below which the Novo Transfer Scheme must be running at maximum capacity according to the current operating rule. The other periods over the simulation period where Novo transfers were simulated as shown in **Figure 4.3** were due to the storage in Knellpoort Dam being at or above the 90% storage level (see **Figure 4.2**).

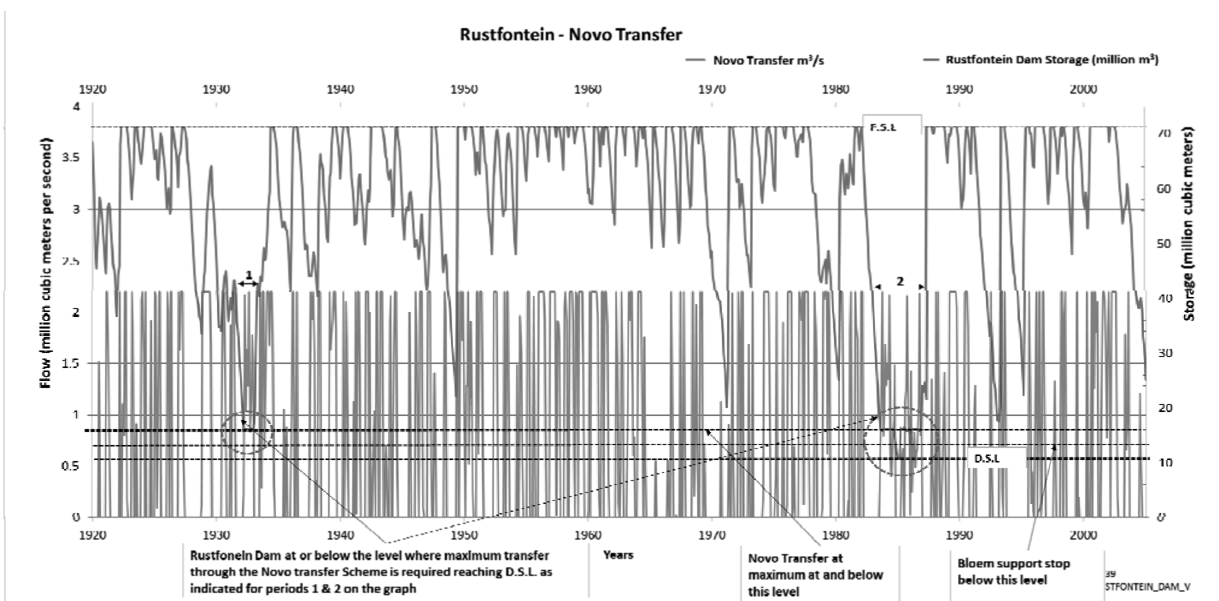


Figure 4-3: Scenario A-2 – Rustfontein Dam storage versus Novo transfer volume

During the 1984/85 year the storage in Rustfontein Dam dropped to the DSL in Rustfontein Dam. Below the DSL no water can be abstracted from Rustfontein Dam to support the water treatment plant at the dam.

In **Figure 4.4** the Knellpoort Dam storage is shown in comparison with the water pumped from the Caledon River by means of the Tienfontein Pump Station. The system operating rule distinguish between two components regarding the pumping from the Caledon River to Knellpoort Dam when using the Tienfontein Pump Station. The first component refers to maximum pumping from the Caledon River whenever sufficient water is available. This should continue until Knellpoort reaches the 90% storage level (1 450,63 masl). The second component describes the situation when Knellpoort dam is above the 90% storage level. Under this condition the pumping from the Caledon River should continue, but the Novo Transfer Scheme should then also be activated aiming to keep Knellpoort Dam at 90%. By doing this, the pumped water is then rather stored in Rustfontein Dam to minimize spillage at Knellpoort Dam. The Tienfontein pumping as simulated over the analysis period for the purpose to fill Knellpoort Dam to its 90% storage level is shown in **Figure 4.4** and represents an average of 0,388 m³/s or 33,5 Mℓ/d. The total average pumping from Tienfontein pump station over the analysis period, however, amounts to 1.059 m³/s or 91,5 Mℓ/d and includes all pumping from Tienfontein pump station, thus when Knellpoort Dam is below as well as above its 90% storage level.

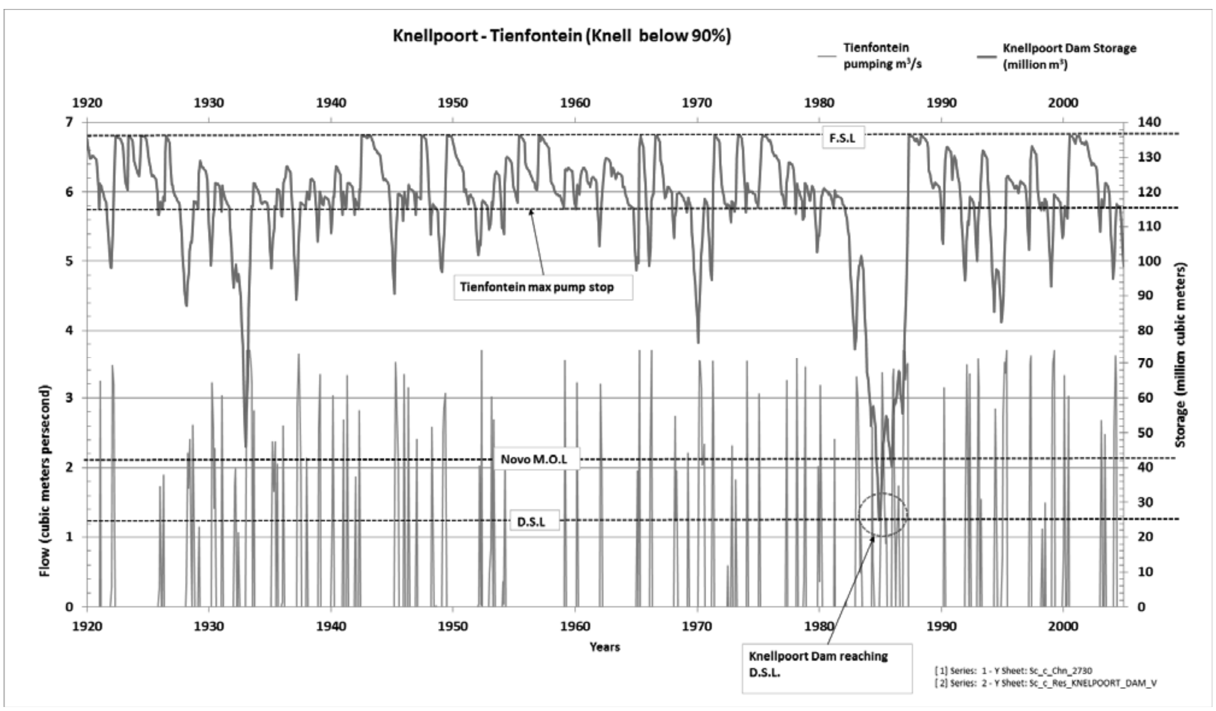


Figure 4-4: Scenario A2 – Knellpoort Dam storage versus Tienfontein pump volume

Figure 4.5 shows the monthly variation in the storage (red line) of Groothoek Dam over the simulation period in combination with the water supply to Thaba Nchu. The total water supply to Thaba Nchu is a combination of water supplied from Groothoek Dam as well as support from Rustfontein Dam. The blue line in **Figure 4.5** represents the total supply to Thaba Nchu and the green dotted line the water supplied from Groothoek Dam. On average over the simulation period 10,9 Mℓ/d was supplied from Groothoek Dam with 4.2 Mℓ/d support from Rustfontein Dam.

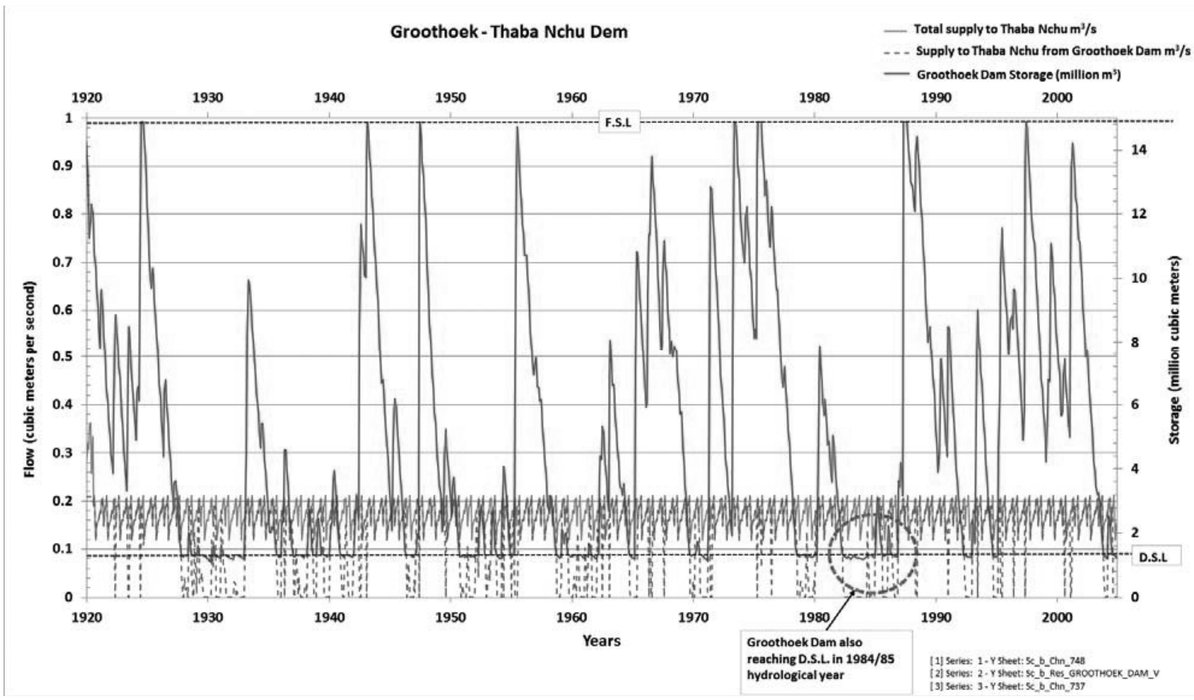


Figure 4-5: Scenario A2 – Groothoek Dam storage versus Thaba Nchu Demand

Groothoek Dam reached it's DSL many times over the simulation period in which support from Rustfontein Dam were required. Important, however, is that Groothoek Dam also emptied in the 1984/85 year simultaneously with the other dams within the larger water supply system.

The simulated monthly storage level in Mockes Dam over the simulation period is shown in **Figure 4.6**. The Mockes Dam storage is very small in comparison with the mean annual runoff generated upstream of the dam, which in combination with the maximum possible abstraction from Mockes Dam according to the operating rule, results in the large variability of the storage levels in the dam.

The Maselspoort water treatment plant can thus only operate at it's full capacity when there is sufficient water available in Mockes Dam as is clearly evident from **Figure 4.6**. Although it is possible to support Mockes Dam from Rustfontein Dam by means of releases into the Modder River, support will rather first be given from Rustfontein Dam via the Rustfontein treatment plant directly to Bloemfontein, to reduce the losses in the system as result of the river releases. This operating rule thus contributes to the high variability of the abstractions from Mockes Dam.

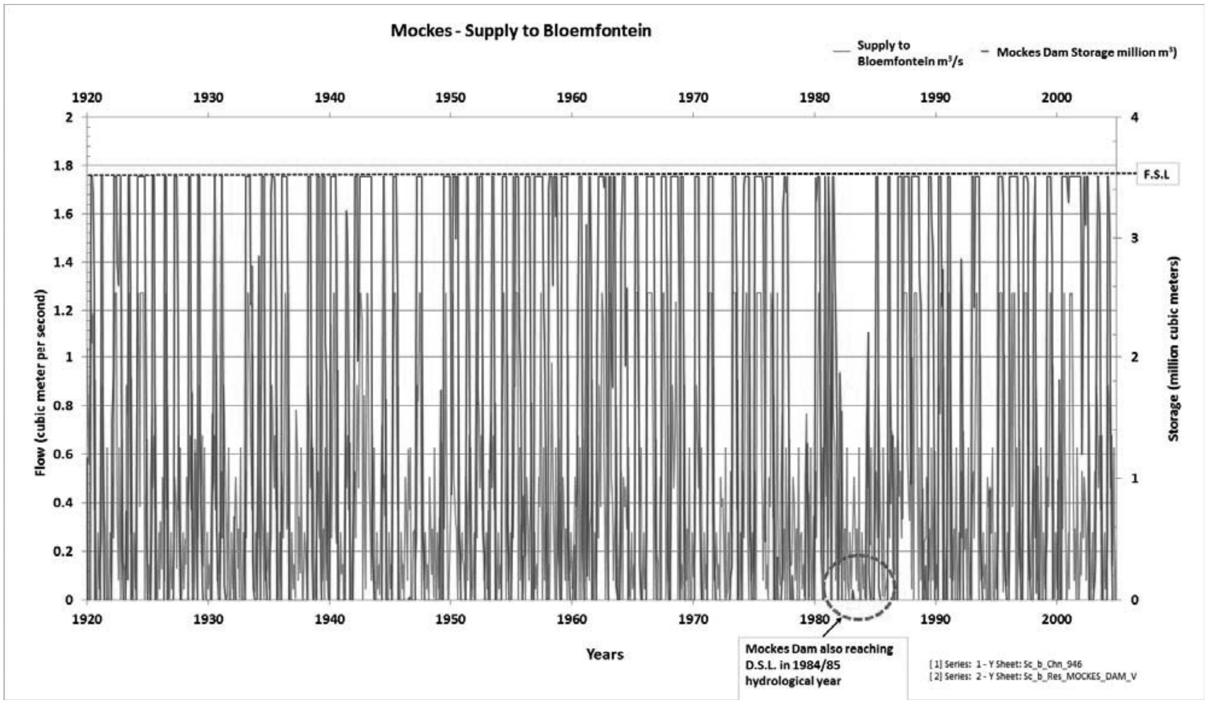


Figure 4-6: Scenario A2 – Mockes Dam storage versus its supply to Bloemfontein

Details of the channel flows in Mℓ/d for Scenario A2 is given in **Figure 1b**.

4.1.2. Scenario A3 – Current system with improved operating rule

From the results of Scenarios A and A2 it was evident that transfers via the Novo Transfer Scheme are sometimes taking place under conditions where Rustfontein Dam is at its full supply level. This should not be the case, as it will result in unnecessary pumping costs and spilling from Rustfontein Dam. The proper functioning of this operating rule and related penalty structures within the WRPM setup were therefore thoroughly examined and evaluated. The current operating rule is a fairly complex rule to be defined within the model and great care had to be taken to ensure that the model is in fact simulating the operating rule correctly. Significant changes in the manner how the operating rule was previously defined in the model were done to reduce the unnecessary pumping, and to get the model to simulate the defined operating rule as good as possible.

Currently most of the available runoff within the Greater Bloemfontein System is generated in the Caledon River catchment. To be able to obtain the maximum yield from this system, one needs to utilize the existing infrastructure in such a manner that the maximum possible runoff from the Caledon River can be captured and utilized by the Greater Bloemfontein System. The current operating rule therefore dictates the following regarding pumping and related transfers from the Caledon River:

- Transfer the maximum possible from Welbedacht Dam and related treatment plant to Bloemfontein and small towns.
- When sufficient water is available in the Caledon River, pump maximum possible from the Caledon at Tienfontein Pump Station into Knellpoort Dam.
    - This pumping must continue until Knellpoort Dam reaches its 90% storage level (1450,63 masl)
    - When Knellpoort is at or above the 90% storage level, pumping from Tienfontein into Knellpoort Dam must still continue, but the Novo Transfer Scheme should then also be activated, trying to keep Knellpoort Dam at the 90% level, to reduce possible spills from Knellpoort Dam and to store this additional water still available in the Caledon River, in Rustfontein Dam.
- Rustfontein Dam is under drought conditions allowed to drop to 23% of its live storage. When at or below the 23% storage level, the Novo Transfer Scheme must be activated trying to prevent Rustfontein Dam to drop below the 23% storage level, but at the same time allow sufficient storage capacity in Rustfontein Dam to capture runoff from the upstream catchment and to reduce spills from Rustfontein Dam. This is an important aspect or characteristic of the Rustfontein Dam sub-system, as the runoff from the Rustfontein Dam is more than double that generated from the Knellpoort Dam catchment. The storage capacity of Knellpoort Dam is approximately 9,6 times the mean annual runoff (MAR) from the upstream catchment, while Rustfontein Dam capacity is only 2,5 times the MAR of the Rustfontein catchment. The possibility of spills from Knellpoort Dam is thus significantly less, and particular caution need to be taken to minimize spills from Rustfontein Dam.

Scenario A2 was used as the basis for Scenario A3 to improve the existing operating rules. After the operating rules were refined and improved as described above, the Greater Bloemfontein System yield increased by 5 Mℓ/d or 1.7 million m^3/a with a total system yield now of 213 Mℓ/d + 5 Mℓ/d = 218 Mℓ/d. Although this increase is not much, it’s important to note that the improvements was aimed at the reduction of unnecessary pumping and spills from Rustfontein Dam and not really to improve the system yield.

The required pumping through the Novo Transfer Scheme was reduced by 22,6% from the 61,5 Mℓ/d on average over the simulation period for Scenario A2 to only 47,6 Mℓ/d on average for Scenario A3. The reduction in pumping from the Tienfontein Pumping Station was less significant at a 4,6% reduction, from 91,5 Mℓ/d to 87,3 Mℓ/d on average for Scenarios A2 and A3 respectively.

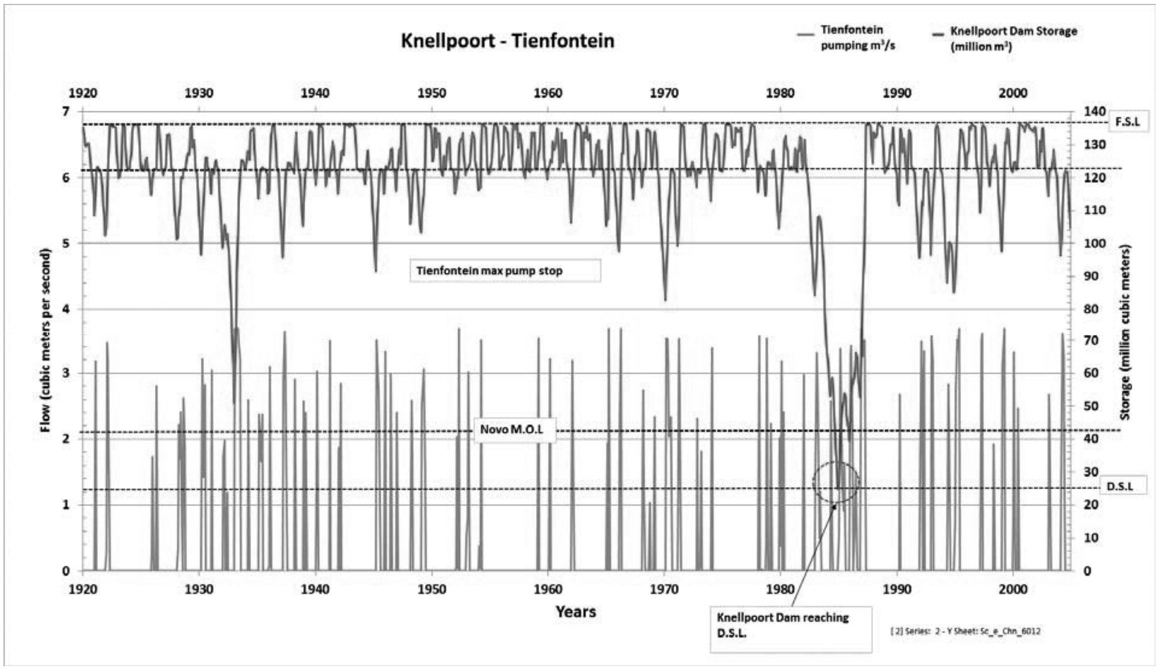


Figure 4-7: Scenario A3 – Knellpoort Dam storage versus Tienfontein pump volume

The total Tienfontein pumping (blue line) simulated over the analysis period used to fill Knellpoort Dam and transfer water to Rustfontein Dam, is shown in **Figure 4.7** and represents an average of 1,01 m^3/s or 87,3 Mℓ/d over the simulation period. The red line in **Figure 4.7** shows the monthly storage variation in Knellpoort Dam over the simulation period. The storage in the dam also reached its DSL in the 1984/85 hydrological year.

The Rustfontein Storage for Scenario A3 over the simulation period is slightly lower than that evident from **Figure 4.3** representing Scenario A2. This is as result of the reduction in the Novo Transfer Scheme transfer volume, as indicated by the blue line in **Figure 4.8** (also see **Figure 4.3**). Spills from Mockes Dam reduced from 135,4 Mℓ/d for Scenario A2 to 123,3 Mℓ/d for Scenario A3, showing the unnecessary spills from Mockes Dam as result of too much pumping from the Caledon River to Rustfontein Dam.

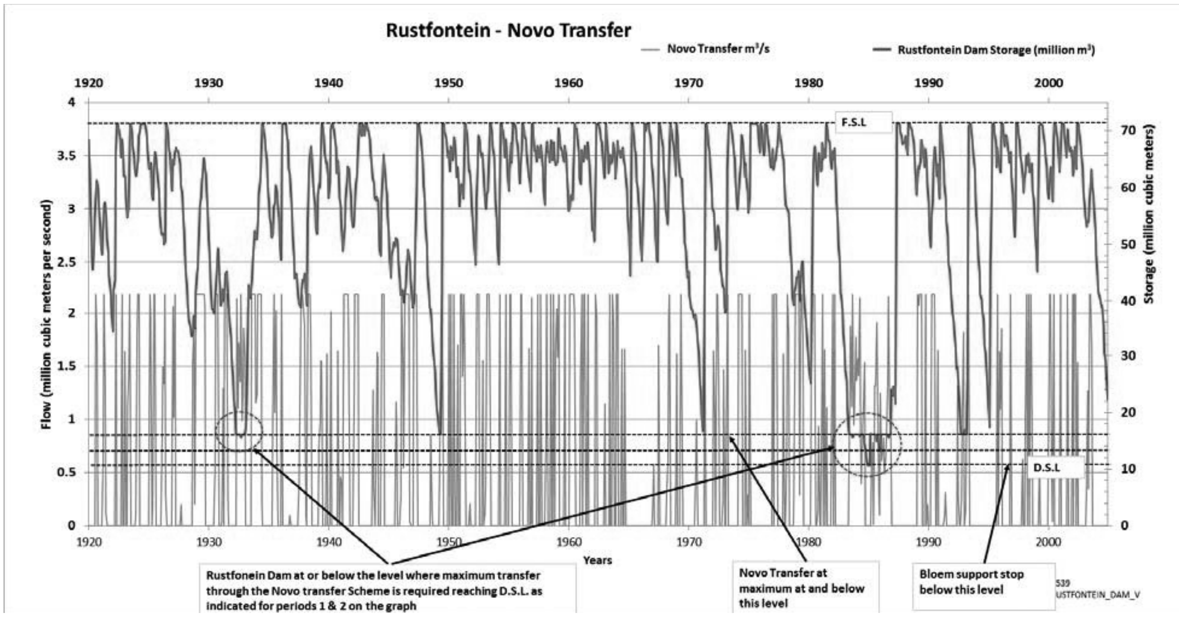


Figure 4-8: Scenario A-3 – Rustfontein Dam storage versus Novo transfer volume

4.1.3. Scenario A4 and A5 – Impact of limited abstraction from Mockes Dam

The purpose of scenarios A4 and A5, was to determine the impact of a limited abstraction of 22 Mℓ/d on the recovery time of the Greater Bloemfontein System. In practice it seemed that on average only 22 Mℓ/d is currently abstracted from Mockes Dam via the Maselspoort treatment plant. This means that Maselspoort treatment plant with its current full capacity of 110 Mℓ/d is not fully utilized and it will result in unnecessary spills from Mockes Dam, which in turn will result in a reduced yield from the greater system.

To be able to determine this impact, two scenarios were set up, one with Maselspoort limited to 22 Mℓ/d (Scenario A4) and one with the current maximum capacity of 120 Mℓ/d for Maselspoort in place (Scenario A5). For both scenarios the starting storage of the dams were set equal to the 1 March 2017 starting storage. The current 2017 water demand was imposed on the system. The analyses were for both scenarios started in March 1920 and not in October 1920 as for the other scenarios.

Results from Scenarios A4 and A5 analyses showed that based on the historic flow records starting in 1920, Rustfontein Dam could reach full supply storage levels in approximately 3 years and 1 months’ time with Knellpoort Dam in about 4 years’ time, if the system is managed according to the current operating rules (Scenario A5).

If however, the Maselspoort WTW is not fully utilized and limited to 22 Mℓ/d (Scenario A4), it will take approximately 5 years and 1 month for Rustfontein and Knellpoort Dams to fill. This clearly shows the importance to utilize the Maselspoort treatment plant at maximum capacity when sufficient water is available in Mockes Dam.

4.1.4. Scenario A3b – Reduced yield due to operational difficulties

This scenario represents results closer to that experienced in reality due to several difficulties currently impacting on the system, such as lack of power supply, high electricity costs during peak hours, maintenance problems etc. Scenario A3 was used as basis and some of the pump and transfer capacities were reduced for the purpose of Scenario A3b as described in **Section 2.2**.

Scenario A3 represents the case where the system is managed strictly according to the operating rules with proper maintenance carried out at all times. With this well managed system it was possible to obtain a historic firm yield of 218 Mℓ/d or 79,6 million m^3/a. The historic firm yield obtained from Scenario A3b reduced to 187 Mℓ/d or 68,2 million m^3/a. This represents a significant reduction of 15% in yield or 32 Mℓ/d (11.7 million m^3/a), which emphasize the importance of a well operated system and high standard of maintenance that is required for this system.

4.2. SCENARIO B – CURRENT SYSTEM WITH 45 Mℓ/D AVERAGE INDIRECT RE-USE INCLUDED

Results from Scenario B showed a significant increase in potable water yield of 49 Mℓ/d (17,8 million m^3/a) to 262 Mℓ/d (95,7 million m^3/a) in comparison with Scenario A2. This is slightly higher than the 2017 total system demand of 259 Mℓ/d (94,44 million m^3/a).

For the purpose of Scenario B additional re-use (maximum of 45 Mℓ/day) from the Bloemfontein North Eastern sewage treatment plant, was pumped into Mockes Dam. This makes more water available at the Maselspoort WTW, which is then directly available for supply to Bloemfontein. To be able to determine the historic firm yield for this scenario, the water requirements of Thaba Nchu, Botshabelo and the small towns were kept similar to that used for Scenario A2 and only the Bloemfontein water demand was increased, as the re-use was mainly available for use by this demand center. By comparing the results from Scenario B with that of Scenario A2 the following was noted:

- The HFY of the system increased significantly by 49 Mℓ/d (17,8 million m^3/a).

- The Novo transfer volume reduced slightly from 47,4 Mℓ/d to 44,5 Mℓ/d.
- Total pumping from Tienfontein to Knellpoort Dam reduced from 91,5 Mℓ/d to 88,8 Mℓ/d.
- The transfer from Welbedacht to Bloemfontein increased from 119,9 Mℓ/d to 124,9 Mℓ/d, which is quite significant.
- Support from the Welbedacht-Bloemfontein pipeline started to take place to supply water to Botshabelo and Thaba Nchu, on average only 0,17 Mℓ/d.
- Support from Mockes Dam to Bloemfontein increased significantly from 36,2 Mℓ/d to 80,2 Mℓ/d (see monthly flows in **Figures 4.6** and **4.9**).

The reduction in the Novo transfer volume and Tienfontein pumped volume resulted in more water available at Welbedacht Dam, which in turn made it possible to support more water from Welbedacht to Bloemfontein. In this scenario it was for the first time necessary to transfer some water from the Welbedacht Bloemfontein pipeline to Botshabelo and Thaba Nchu, due to the higher volumes available at Welbedacht Dam as well as from Mockes Dam, now supporting a much larger portion of the Bloemfontein water demand.

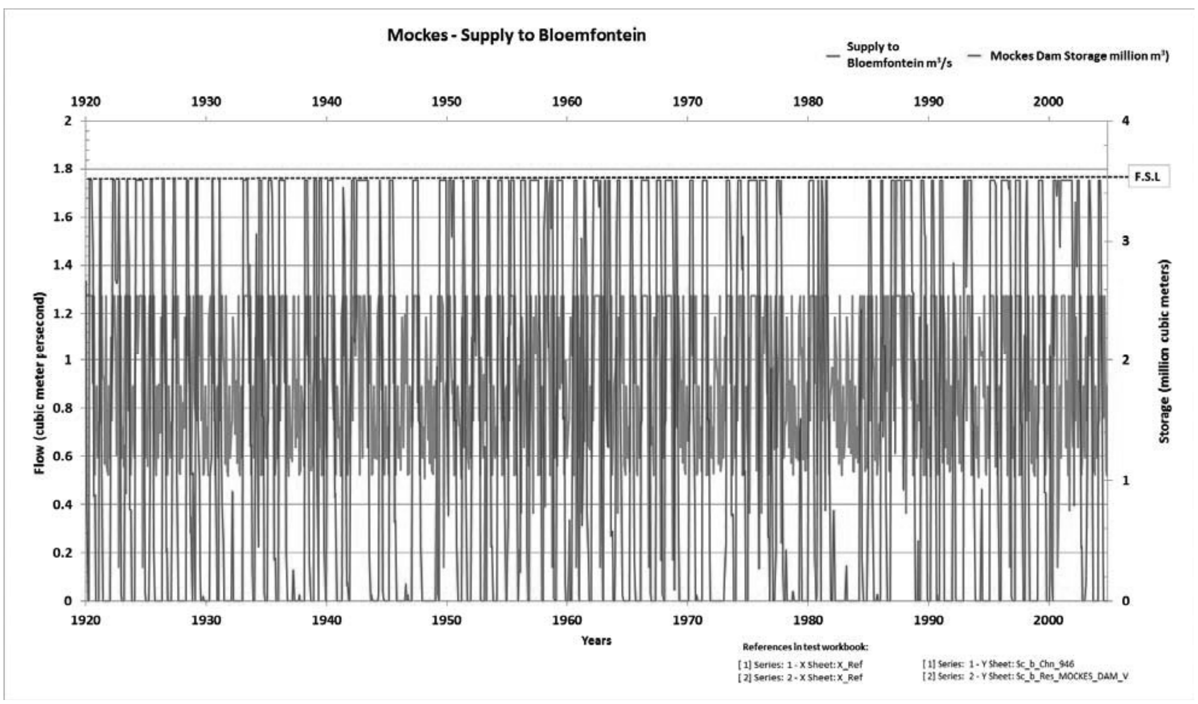


Figure 4-9: Scenario B – Mockes Dam monthly storage versus its monthly supply to Bloemfontein

The increase in supply from Mockes to Bloemfontein from 36.2 Mℓ/d average for Scenario A2 (**Figure 4.6**) to 80.2 Mℓ/d average over the simulation period for Scenario B, is quite significant and is clearly evident from **Figure 4.9**. This is as result of the re-use of return flows from Bloemfontein transferring 45 Mℓ/d of treated return flows back into Mockes Dam. This allowed for a much more constant abstraction from Mockes Dam to Bloemfontein, with less variance and an improved utilization of the Maselspoort treatment plant. Scenario B takes into account that some return flows from Thaba Nchu and Botshabelo will also contribute to the inflows into Mockes Dam. Details of the channel flows in Mℓ/d for Scenario B is given in **Figure 3a of Appendix A**.

4.2.1. Scenario B2- Current system with 77 Mℓ/d average indirect re-use included

Scenario B2 is as Scenario B but with re-use from Bloemfontein increased by 32 Mℓ/d to 77 Mℓ/d. The yield for Scenario B2 increased from 262 Mℓ/d to 290 Ml/d i.e. by only 28 Mℓ/d, indicating that the additional re-use volume could not be fully utilized. The reason for this is that Mockes Dam was in general at higher storage volumes, which then resulted in more spills at Mockes Dam, on average 8.7 Mℓ/d higher than that evident from Scenario B (See **Table 4.1**).

Similar to Scenario B the Novo Transfer for Scenario B2 reduced slightly with a slight increase in the transfer from Welbedacht Dam. To be able to utilize the full 77 Mℓ/d it will be required to add some of, or a combination of the following options.

- Increase the storage capacity of Mockes Dam
- Increase the Maselspoort water treatment plant capacity.
- Allocate a portion of the re-use to direct re-use, thus not entering Mockes Dam.

Table 4-1: Comparison of Scenario B and A2 results

Scenario	Yield Mℓ/d	Mockes Spills Mℓ/d	Mockes Bloem supply Mℓ/d	Novo transfer Mℓ/d	Welbedacht transfer Mℓ/d	Tienfontein Pumping Mℓ/d
A2	213,1	135,4	36,2	47,4	119,9	91,5
B	262,0	136,8	80,2	44,5	124,0	88,8
B2	290,2	145,5	98,0	43,7	125,5	91,1

4.2.2. Scenario B3 - Current system with 45 Mℓ/d re-use and 32 Mℓ/d direct re-use included

Results from Scenario B2 recommended that a portion of the re-use be implemented as direct re-use to decrease the possibility of spills at Mockes Dam as result of the large volume of re-use entering Mockes Dam. For this scenario 32 Mℓ/d of the 77 Mℓ/d total re-use was analysed as direct re-use, thus not entering Mockes Dam. Mockes Dam capacity is unchanged at the current capacity of 3,58 million m^3.

Scenario B3 resulted in a historic firm yield of 299 Mℓ/d (109,1 million m^3/a) which is approximately 5 Mℓ/d less than that obtained from Scenario C2 (larger Mockes Dam with 77 Mℓ/d re-use entering Mockes Dam). This is more or less in line with the yield contribution due to the increase in Mockes Dam storage capacity in combination with the 77 Mℓ/d indirect re-use.

Table 4-2: Comparison of Scenario B3 and A3 and C2 results

Scenario	Yield Mℓ/d	Mockes Spills Mℓ/d	Mockes Bloem supply Mℓ/d	Direct Re-use Mℓ/d	Novo transfer Mℓ/d	Welbedacht transfer Mℓ/d	Tienfontein Pumping Mℓ/d
A3	217,8	123,3	40,3	0,0	36,6	121,1	87,3
B3	298,8	126,9	85,5	32,0	37,5	124,1	88,9
C2	303,9	123,3	111,9	0,0	34,0	126,1	89,9

In both Scenarios B3 and C2 the total re-use of 77 Mℓ/d were fairly well utilized, although spills from Mockes increased slightly by 3,6 Mℓ/d for Scenario B3. It is, however, also important to note that the net evaporation losses from the larger Mockes Dam is approximately 6,9 Mℓ/d higher than that from the existing Mockes Dam.

4.3. SCENARIO C- INCREASED MOCKES DAM CAPACITY

Scenario C is based on Scenario A2, but includes an increased storage at Mockes Dam. The result from this scenario will therefore show the impact of an increased Mockes Dam storage on the Greater Bloemfontein System yield.

The total system yield (potable water) for Scenario C was determined as 219 Mℓ/d or 79,9 million m^3/a. This yield result need to be compared with the yield of 213 Mℓ/d (77,8 million m^3/a) for Scenario A2, showing an increase in yield of 5,5 Mℓ/d (2,1 million m^3/a) which is not that significant.

4.3.1. Scenario C2 – Increased Mockes Dam Capacity in combination with 77 Mℓ/d indirect Re-use

From the results of Scenario B2 it was recommended to use the 77 Mℓ/d indirect re-use option in combination with a larger storage at Mockes Dam. Plans are already underway to increase Maselspoort Treatment plant capacity to 130 Mℓ/d. For the purpose of this scenario the increased storage capacity (3,58 million m^3 to 12,13 million m^3 storage) as well as the increased capacity (120 to130 Mℓ/d) at Maselspoort WTW was included. This scenario also used the improved operating rule as developed from Scenario A3.

Results from Scenario C2 showed a significant increase in yield of 86 Mℓ/d or 31,4 million m^3/a, achieving a total system yield of 304 Mℓ/d (111 million m^3/a). This is the highest yield from all scenarios analysed until now and had to be compared with the results from Scenario A3 to determine the increase in yield that was obtained. Even with the high volume of re-use entering Mockes Dam, no increase in spills at Mockes Dam was evident when compared to the results from Scenario A3 (See **Table 4-2**). The increase in the Mockes Dam storage capacity in combination with the increase in the Maselspoort Treatment Plant capacity were therefore sufficient to enable the full utilization of the 77 Mℓ/d re-use entering the system.

4.3.2. Scenario C3 – Support from Gariep Dam included

No yield analysis was carried out for Scenario C3. Scenario C3 was analysed to determine the water supply to users. Results are given in **Section 4.4.4**.

Table 4-3: Summary of results from all the Scenarios analysed

Scenario	Yield Mℓ/d	Mockes Spills Mℓ/d	Mockes Bloem supply Mℓ/d	Re-use Mℓ/d	Novo transfer Mℓ/d	Rustfontein Supply Mℓ/d	Welbedacht transfer Mℓ/d	Tienfontein Pumping Mℓ/d
A	206,3	139,6	26,4	0,0	48,0	45,8	116,1	91.6
A2	213,1	135,4	36,2	0,0	47,4	42,2	119,9	91,5
A3	218.7	123,3	40,3	0,0	36,6	44,9	121,1	87,3
A3b	186,7	133,7	24,7	0,0	28.7	42,7	109,8	64,8
A4	n.a.	113.9	45,9	0,0	57,3	71,1	123,2	102,7
A5	n.a.	130,2	19,8	0,0	52,1	78,3	127,6	107,3
B	262,0	136,8	80,2	45,0	44,5	46,1	124,0	88,8
B2	290,2	145,5	98,0	77,o	43,7	49,5	125,5	91,1
B3	298,8	126,9	85,5	32,0	37,5	45,0	124,1	88,9
C	218,7	122,7	45,4	0,0	49,4	43,8	117,6	90,9
C2	303,9	123,3	111,9	0,0	34,0	46,0	126,1	89,9
C3	n.a.	136,1	102,4	77,0	57,2	80,2	111,9	94,1

4.4. WATER SUPPLY RELATED SCENARIOS

Water supply related analyses were carried for the following four scenarios as explained in **Section 2.2.2**.

- Scenario A3b with the 2017 demand imposed on the system. This scenario represents the current system, which is not operated to its full potential.

- Scenario B3 with the 2024 demand imposed on the system. This scenario includes 45 Mℓ/d indirect re-use entering into Mockes Dam in combination with 32 Mℓ/d direct re-use.
- Scenario C2 with the 2024 demand imposed on the system. This scenario includes the larger Mockes Dam with a 77 Mℓ/d indirect re-use entering Mockes Dam, and with Maselspoort WTW capacity increased to 130 Mℓ/d.
- Scenario C3 with the 2040 demand imposed on the system. This scenario is as Scenario C2 but also includes the support from Gariep Dam to the Greater Bloemfontein System.

4.4.1. Scenario A3b potable water supply

From the water supply analysis the monthly potable water supply as obtained from each of the water treatment plants for the simulation period 1920 to 2004 were captured and supplied to the client. **Table 4.4** summarizes the average annual supply, the lowest supply as well as the year with the highest supply as obtained from each of the monthly water supply records, representative of the different WTWs.

Table 4-4: Scenario A3b water supply from the WTW with 2017 Demand of 258.6Mℓ/d

Description	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
	Welbedacht WTW Capcity 123 Mℓ/d (145 Mℓ/d)												
Average	120.8	120.4	118.3	121.3	116.1	106.6	114.0	115.7	122.7	123.0	121.7	119.5	118.4
Min	123.0	123.0	123.0	80.8	69.7	41.3	61.1	33.0	123.0	123.0	123.0	123.0	95.6
Max	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0	123.0
	Rustfontein WTW Capcity 100 Mℓ/d												
Average	71.9	68.3	59.2	68.0	72.7	54.1	66.2	66.1	85.5	54.6	69.0	70.0	67.0
Min	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
Max	96.3	99.7	99.6	99.7	99.7	52.1	99.8	99.7	99.7	71.1	91.8	93.5	91.8
	Maselspoort WTW Capcity 100 Mℓ/d												
Average	29.0	48.4	35.3	88.3	81.6	65.8	73.6	42.6	77.6	2.3	16.6	41.4	49.9
Min	0.3	15.3	29.1	0.3	7.9	0.3	0.4	3.5	0.4	0.3	0.3	0.3	4.8
Max	58.2	67.4	41.8	96.5	110.0	110.0	110.0	110.0	110.0	25.7	48.8	46.7	77.6
	Thaba Nchu WTW Capcity 18 Mℓ/d												
Average	9.6	11.4	12.4	13.8	14.2	13.7	13.2	11.4	11.0	10.7	9.8	9.5	11.7
Min	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Max	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	Total												
Average	**231.3**	**248.4**	**225.2**	**291.4**	**284.6**	**240.3**	**267.0**	**235.8**	**296.8**	**190.7**	**217.1**	**240.3**	**247.0**

The 2017 demand of 259 Mℓ/d were imposed on the system and on average the system could supply about 95% of the demand with significantly less in the dry years. This is in line with the results from the Scenario A3b system yield analysis indicating a historic firm yield of 187 Mℓ/d in comparison with the 2017 demand of 259 Mℓ/d.

All the WTWs reached their maximum capacities during the summer months except for the Welbedacht WTW reaching a maximum of 123 Mℓ/d in comparison with its 145 Mℓ/d design capacity. For the purpose of this scenario the capacity of the Welbedacht WTW was reduced to 123 Mℓ/d due to the sediment and infrastructure related problems experienced at this water supply system.

4.4.2. Scenario B3 potable water supply

The HFY for scenario B3 (45 Mℓ/d indirect re-use & 32 Mℓ/d direct re-use) is 299 Mℓ/d and is almost equal to the 2024 system demand of 304 Mℓ/d. The 2024 demand was therefore imposed on the system to determine the water supply for Scenario B3.

Table 4-5: Scenario B3 water supply from the WTWs with 2024 Demand of 304 Mℓ/d

Description	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
	Welbedacht WTW Capacity 128,7 Mℓ/d (145 Mℓ/d)												
Average	114.8	118.0	114.9	123.4	115.0	96.9	111.7	108.5	127.1	107.8	102.6	113.5	112.8
Min	128.7	60.5	128.7	128.7	73.4	20.6	55.3	44.4	120.1	47.6	102.1	127.5	86.6
Max	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	116.2	128.7	127.7
	Rustfontein WTW Capacity 100 Mℓ/d												
Average	78.4	81.6	78.4	89.2	91.8	73.6	86.2	81.8	94.4	55.9	68.3	73.9	79.3
Min	87.7	93.4	90.2	99.7	93.7	74.1	48.3	5.3	7.1	0.0	0.0	0.0	49.8
Max	87.7	93.4	88.4	99.7	99.7	82.9	97.5	93.1	99.7	67.3	79.7	97.4	90.5
	Maselspoort WTW Capacity 130 Mℓ/d												
Average	54.3	61.6	36.2	93.4	88.8	71.0	80.5	53.7	102.2	25.9	56.9	77.3	66.5
Min	41.1	51.4	22.8	88.6	76.3	44.6	46.2	35.3	101.2	4.9	51.0	65.1	52.0
Max	41.1	119.7	22.8	88.6	119.7	119.7	119.7	119.7	109.8	86.1	57.3	66.2	88.8
	Direct Re-use Capacity 32 Ml/d												
Average	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Min	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Max	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
	Thaba Nchu WTW Capacity 18 Mℓ/d												
Average	9.3	11.5	12.3	13.9	14.5	14.6	13.8	12.1	11.0	10.5	9.5	8.8	11.8
Min	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Max	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	Total												
Average	**256.9**	**272.7**	**241.8**	**319.9**	**310.1**	**256.2**	**292.2**	**256.2**	**334.7**	**200.1**	**237.2**	**273.6**	**270.4**

Summarized results of the water supply simulated for Scenario B3 is given in **Table 4.5**. From these results it is evident that all the WTWs reached their maximum average capacities during the dry years except for the Maselspoort WTW reaching a maximum of

120 Mℓ/d versus the maximum capacity of 130 Mℓ/d. For the purpose of this scenario the maximum capacity for the Welbedacht WTW was selected as 129 Mℓ/d in comparison with its 145 Mℓ/d design capacity due to the sediment and infrastructure related problems experienced at this WTW.

On average over the analysis period 88.9% of the demand was supplied. This is partly due to the fact that the historic firm yield is slightly lower than the 2024 demand imposed on the system. The main reason however is that the operating rule need to be adjusted to improve the utilization of the indirect and direct water use which forms part of this scenario.

4.4.3. Scenario C2 potable water supply

Yield results for Scenario C2 and B3 is in the same order with C2 at 304 Mℓ/d and equal to the 2024 demand. The 2024 demand of 304 Mℓ/d was therefore imposed on the Greater Bloemfontein System for both scenarios (B3 and C2). Results of the water supply simulated for Scenario C2 are summarized in **Table 4.6**.

Similar to Scenario B3 the WTPs reached their maximum average capacities during the dry years. On average over the analysis period 99% of the demand was supplied, which better than that obtained from Scenario B3. This is most probably due to the larger Mockes Dam forming part of this scenario.

Table 4-6: Scenario C2 water supply from the WTWs with 2024 Demand of 304 Mℓ/d

Description	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
	Welbedacht WTW Capacity 128.7 Mℓ/d (145 Mℓ/d)												
Average	112.2	118.8	117.7	128.4	124.1	108.2	120.3	115.4	128.7	108.4	104.8	116.3	116.8
Min	128.7	128.7	103.2	128.7	117.3	85.6	107.7	76.4	128.7	46.1	71.7	106.1	127.9
Max	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	118.1	128.7	102.1
	Rustfontein WTW Capacity 100 Mℓ/d												
Average	78.3	81.6	78.4	89.7	91.7	73.6	86.6	81.9	98.4	56.0	68.4	71.4	79.6
Min	87.7	93.4	90.2	99.7	93.7	74.8	97.5	17.5	8.0	0.0	0.0	0.0	55.0
Max	87.7	93.4	88.4	99.7	99.7	82.9	97.5	93.1	99.7	67.3	79.7	99.7	90.6
	Maselspoort WTW Capacity 130 Mℓ/d												
Average	89.2	92.9	65.1	119.7	111.8	91.6	104.1	78.9	119.5	57.3	86.6	109.0	93.5
Min	73.1	83.4	54.8	119.7	108.3	76.6	96.5	67.3	119.7	36.9	73.6	97.0	83.5
Max	73.1	83.4	80.3	119.7	119.7	119.7	119.7	119.7	119.7	119.7	119.7	119.7	109.4
	Thaba Nchu WTW Capacity 18 Mℓ/d												
Average	9.3	11.5	12.5	13.9	14.5	14.6	13.8	12.1	11.0	10.5	9.5	8.8	11.8
Min	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Max	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	Total												
Average	**288.9**	**304.8**	**273.7**	**351.7**	**342.0**	**288.1**	**324.8**	**288.3**	**357.6**	**232.2**	**269.3**	**305.6**	**301.7**

4.4.4. Scenario C3 potable water supply

The system yield for Scenario C3 assuming 120 Mℓ/d support from Gariep Dam is probably in the order of 424 Mℓ/d, which is slightly higher than the 2040 system demand of 422 Mℓ/d. For the purpose of this scenario the 2040 projected demand was imposed on the Greater Bloemfontein System and not the 2024 demand of 304 Ml/d as used for Scenarios C2 and B3.

Results of the water supply simulated for Scenario C3 are summarized in **Table 4.7**.

Similar to Scenario B3 and C2, the WTWs reached their maximum average capacities during the dry years. On average over the analysis period 96% of the 422 Mℓ/d demand was supplied. The slight deficit is mainly due to operating rules that need some adjustment.

Table 4-7: Scenario C3 water supply from the WTWs with 2040 Demand of 422 Mℓ/d

Description	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVE
	Welbedacht WTW Capacity 128.7 Mℓ/d (145 Mℓ/d)												
Average	103.6	116.5	119.7	127.0	126.2	124.1	125.7	118.5	128.7	75.3	77.4	101.8	111.9
Min	52.8	69.9	44.3	112.5	112.6	128.7	128.7	128.1	128.7	58.6	51.2	79.2	91.0
Max	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	128.7	118.1	128.7	128.7
	Rustfontein WTW Capacity 100 Mℓ/d												
Average	79.6	72.7	55.2	86.9	86.1	52.2	76.0	69.1	93.3	67.1	87.4	90.2	76.2
Min	20.6	7.3	26.4	79.9	95.8	40.7	76.9	73.7	93.8	7.7	27.6	31.3	48.0
Max	98.1	97.3	97.7	96.2	95.6	97.8	95.6	96.2	93.8	99.0	97.6	97.3	96.9
	Maselspoort WTW Capacity 130 Mℓ/d												
Average	96.0	104.0	99.1	116.7	116.2	104.7	111.2	99.7	119.4	77.6	94.3	93.7	102.5
Min	77.5	74.7	61.5	103.4	99.6	109.1	99.8	89.3	119.7	65.3	91.5	87.4	89.8
Max	119.7	119.7	91.3	119.7	119.7	101.3	119.7	119.7	119.7	116.1	119.7	119.7	115.3
	Thaba Nchu WTW Capacity 18 Mℓ/d												
Average	9.3	11.5	12.4	13.9	14.5	14.8	13.8	12.1	11.0	10.5	9.5	8.8	11.8
Min	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Max	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	Gariep WTW Capacity 120 Mℓ/d												
Average	111.2	115.3	94.2	138.5	123.7	95.4	110.0	101.7	147.4	91.5	106.4	127.8	113.4
Min	113.4	119.6	89.5	7.5	17.5	0.0	0.0	36.1	149.5	91.9	107.2	127.8	71.8
Max	113.4	119.6	102.6	141.9	134.5	115.5	128.8	110.1	149.5	91.9	107.2	127.8	120.0
	Total												
Average	**390.4**	**408.4**	**368.1**	**469.1**	**452.2**	**376.3**	**423.0**	**388.9**	**488.9**	**311.5**	**365.6**	**413.4**	**404.0**

4.5. SUMMARY OF HISTORIC YIELD RESULTS

The historic firm yields (potable water) for the six scenarios are summarized in **Table 4.8** in comparison with the 2017 total system demand. The yield representative of the raw water is summarized in **Table 4.9** and is in general approximately 10% higher than the potable water yield.

Scenario A results indicated that the current system was not able to fully utilize the storage available in the system, as some water was still available in Knellpoort Dam during the critical period. Scenario A2 was therefore defined which enabled the full utilization of the available system storage and resulted in a slight increase in the system yield as shown in **Tables 4.8** and **4.9**.

Table 4-8: Greater Bloemfontein System potable water yield

Scenario	Historic Firm Yield (Potable water)		System Demand (2017) (Potable water)	
	(Mℓ/day)	(million m^3/a)	(Mℓ/day)	(million m^3/a)
Scenario A*	206	75,4	259	94,4
Scenario A2*	213	77,9	259	94,4
Scenario A3**	218	79.6	259	94,4
Scenario A3b**	187	68.2	259	94,4
Scenario B*	262	95,7	259	94,4
Scenario B2*	290	106,0	259	94,4
Scenario B3**	299	109,1	259	94,4
Scenario C*	219	79,9	259	94,4
Scenario C2**	304	111.0	259	94,4

Note * - Scenarios using the current operating rule
** - Scenarios using the improved current operating rule

Scenario B was based on Scenario A2 but included re-use of 45 Mℓ/d which resulted in a significant increase in the system yield by 49 Mℓ/d (17,8 million m^3/a).

For Scenario B2 the re-use was increased to 77 Mℓ/d (32 Mℓ/d increase in re-use) which resulted in an increase in yield of only 28 Mℓ/d. The increase in re-use entering Mockes Dam resulted in more spills from Mockes Dam and the system could therefore not fully utilize the increased re-use volume.

Table 4-9: Greater Bloemfontein System raw water yield

Scenario	Historic Firm Yield (Raw water)		System Demand (2017) (Potable water)	
	(Mℓ/day)	(million m³/a)	(Mℓ/day)	(million m³/a)
Scenario A*	233	85,0	259	94,4
Scenario A2*	241	87,9	259	94,4
Scenario A3**	246	89,7	259	94,4
Scenario B*	290	106,0	259	94,4
Scenario B2*	325	118,6	259	94,4
Scenario B3**	331	121,1	259	94,4
Scenario C*	246	90,0	259	94,4
Scenario C2**	339	123.9	259	94,4

Note * - Scenarios using the current operating rule
** - Scenarios using the improved current operating rule

Scenario C was based on Scenario A2 but included the increased Mockes Dam capacity with no re-use and must thus be compared with the results from Scenario A2. By only increasing the storage capacity of Mockes Dam from 3,58 million m^3 to 12,13 million m^3 storage, the HFY yield of the system increased by 5,5 mℓ/d (2,02 million m^3/a). Scenario C resulted in a significant reduction in spills at Mockes Dam from 135,4 mℓ/d to 122,7 mℓ/d, showing the improved usage of the local runoff.

Scenario A3 was only analysed later in the study, as the results from the other scenarios indicated that transfers via the Novo transfer scheme are sometimes taking place under conditions where Rustfontein Dam is at its full supply level, which should not happen, as expensive pumped raw water will be lost through spilling at Rustfontein Dam. This will result in unnecessary pumping costs and spilling from Rustfontein Dam. The current operating rule as modeled in the WRPM was then refined to overcome this short coming and this resulted in very positive results. Not only was the Novo transfers decreased by almost 23%, but the system yield also increased by 5 Mℓ/d or 1,7 million m^3/a. Tienfontein pumping was also reduced by almost 5%.

Scenario A3b was later requested with the purpose to simulate the impact on the system yield as result of several difficulties currently experienced in the system, such as lack of power supply, high electricity costs during peak hours, maintenance problems etc. This resulted in a significant reduction in yield of 15% in yield or reduction of 32 Mℓ/d (11.7 million m^3/a).

Scenarios A3, B3 & C2 will be the best scenarios to obtain an indication of the contribution from the different water resources (dams) to the overall system yield. Due to unnecessary Novo transfers and spills from Rustfontein Dam, the results from the other scenarios based on Scenarios A2 and B as basis will provide a skewed picture of resource contributions. The results from Scenarios A3, B3 & C2 were therefore summarized in **Table 4.10** and **Figure 4.10**, showing that almost 70% of the system yield is achieved by water received from the Caledon River and only 30% from the water obtained from the Modder River system for the current system. When 77 Mℓ/d re-use is introduced (Scenarios B3 & C2) the contribution from the Caledon River reduces to approximately 51% with around 25% from re-use and the remaining 24% from the Modder River catchment.

It is important to note that the contributions from the different resources do not represent the HFY of that particular resource, but merely represents the average contribution from that resource or dam for the given scenario. Some of these contributions is highly variable over time, such as those from Groothoek and Mockes dams. These variable contributions are made firm by means of the support received from Rustfontein and Welbedacht dams, with both also receiving support from Knellpoort Dam.

Table 4-10: Average contribution to the system yield from the individual resources

Description	System Yield (Mℓ/d)	Average contribution from the indicated resource (Mℓ/d)					
		Mockes*	Rustfontein	Groothoek*	Knellpoort	Welbedacht	Bloemfontein Re-use
Scenario A3	217,8	30,1	27,5	10,9	63,0	86,3	0,0
Percentage	100%	14%	13%	5%	29%	40%	0%
Scenario B3	298,8	28,5	28,9	11,1	63,3	89,8	77,0
Percentage	100%	10%	10%	4%	21%	30%	26%
Scenario C2	303,9	32,4	27,2	11,4	59,9	96,0	77,0
Percentage	100%	11%	9%	4%	20%	32%	25%

Note * - High variance in the contribution

Additional Scenarios B3 and C2 was requested after the development of the improved operating rule. Both these two scenarios utilized the improved operating rule and results from Scenarios B3 and C2 should therefore be compared with that from Scenario A3, which uses the same improved operating rule.

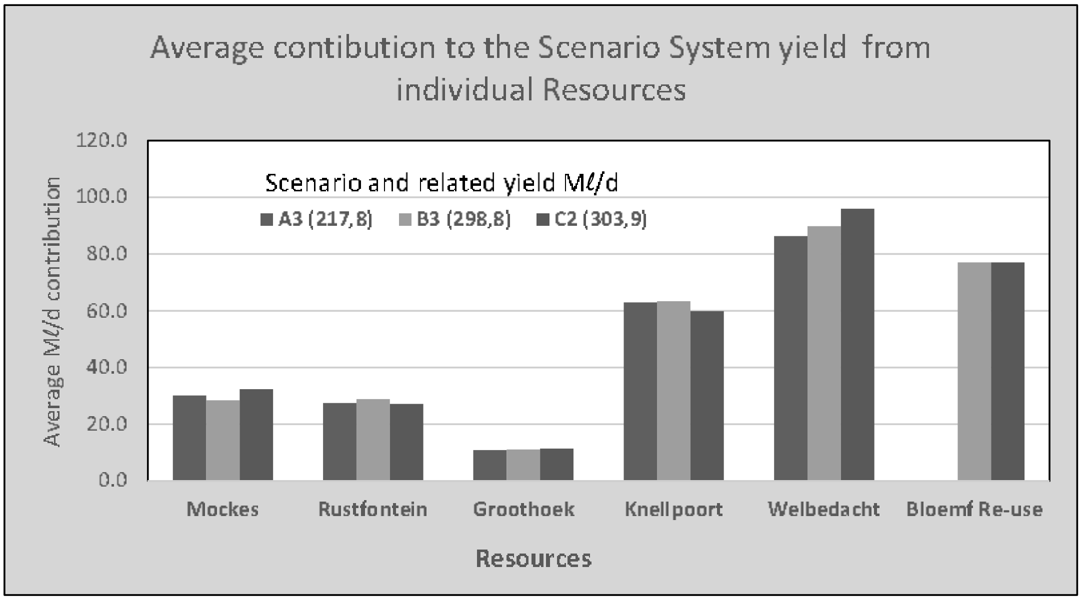


Figure 4-10: Average contribution to system yield from different resources as related to the given Scenario

Scenarios B3 and C2 are the two scenarios providing the highest system yield of all scenarios analysed. Both these scenarios include 77 Mℓ/d re-use of which 32 Mℓ/d was direct re-use in the case of Scenario B3. The slightly higher yield obtained from Scenario C2 is due to the increased capacity of Mockes Dam which increase the yield by approximately 5 Mℓ/d.

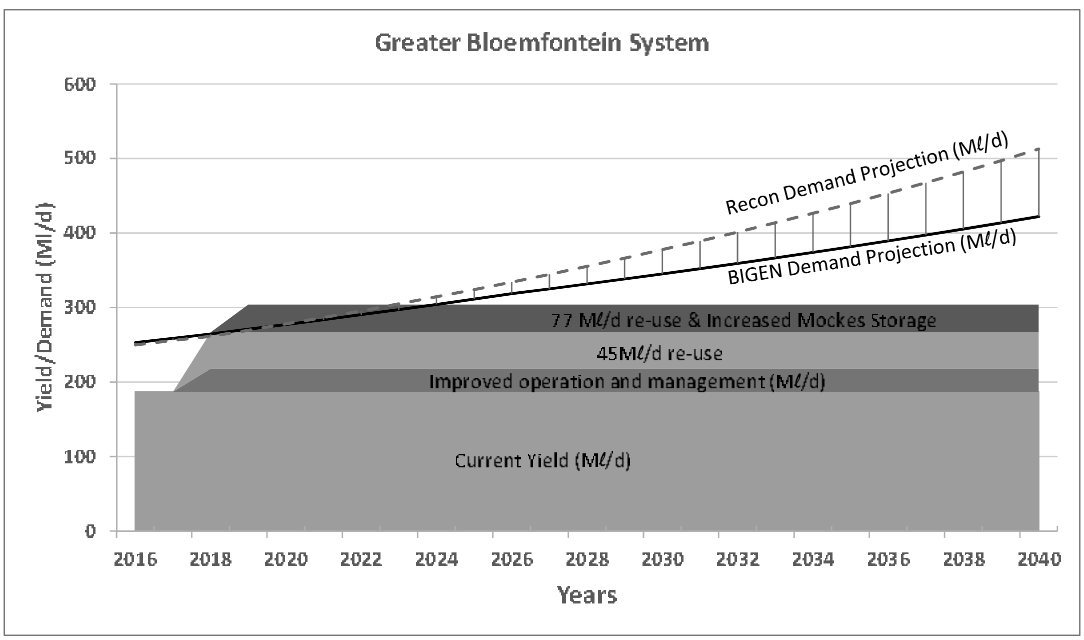


Figure 4-11: Greater Bloemfontein System Water balance

Figure 4.11 shows a preliminary water balance for the Greater Bloemfontein System indicating that with the implementation of the improved operating of the system, re-use and increased Mockes Dam storage options it is possible to supply the increasing water requirement of this system until 2024. Deficits will still remain in the initial few years until the intervention options were activated. This water balance is also used to provide a first order indication of the support required from Gariep Dam. Support of approximately 120 Mℓ/d from Gariep Dam will then be required, to keep the system in balance until 2040, based on the latest demand projection. Based on the Greater Bloemfontein Reconciliation Strategy Study a much larger support of 209 Mℓ/d from Gariep Dam will be required to maintain a positive water balance until 2040.

4.6. STOCHASTIC PROJECTION ANALYSIS RESULTS

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 is 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 4.12**.

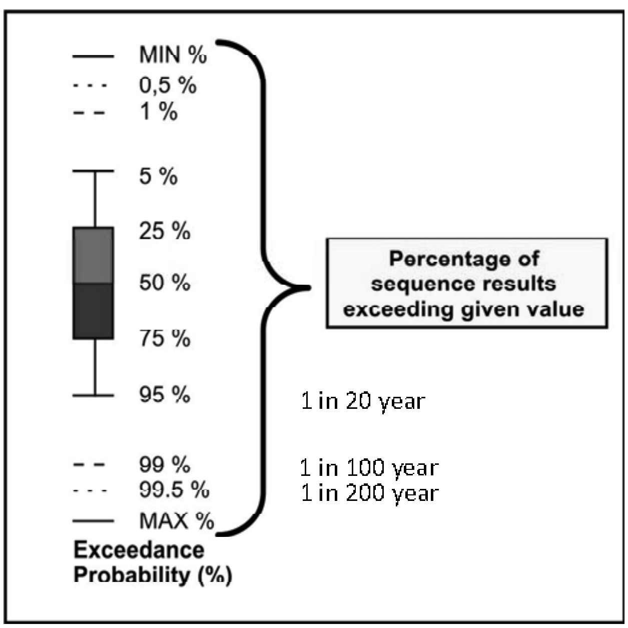


Figure 4-12: Box plot definition

From the priority classification table (**Table 2-5**) in **Section 2.2.3** it is evident that water is supplied to the Greater Bloemfontein System at a high, medium and low assurance for different purposes. The high assurance is supplied at a 99.5% assurance or risk of failure of on average 1 in 200 years, which will typically apply to drinking water. A medium assurance of 99% (risk of failure of 1 in 100 years) and the low assurance of 95% (risk of failure of 1 in 20 years). The low assurance is typical applicable to garden watering and car washing purposes etc. When interpreting the risk analysis results, the general focus will be on these three exceedance probabilities as shown by the box plot in **Figure 4-13**. These assurance levels are currently used in the annual operating analysis carried out for Greater Bloemfontein System. The assurance levels should however be reconsidered and discussed with the users, as some adjustments might be required. A different combination of assurance levels might also lead to an improved water supply situation for this system.

The median value or 50% exceedance probability is also often used when evaluating the results from the risk analysis, in particular when evaluating storage projection plots of key storage dams within the system.

4.6.1. Stochastic analysis Base Scenario results

The combined monthly storage projection plot of all the dams in the Greater Bloemfontein System over the analysis period 2017 to 2040 is shown in **Figure 4-13**. For the first year of the analysis the system is as the current system, not well managed as represented by Scenario A3b. By 2018 several intervention options were activated as indicated in **Figure 4-13** with the 45 Mℓ/d re-use being the largest component. This is then followed by increasing the storage of Mockes Dam in 2020 as evident from the overall slight increase in the system storage. The re-use was increased to 77 Mℓ/d by 2021 followed by the support from Gariep Dam from 2024 onwards. The impact of the different intervention options is clearly evident from the increasing storage levels of the total system.

Between 2025 and 2034 it is evident that the system is not fully utilizing its available storage. This clearly shows that the system operating rules need to be adjusted to either reduce the transfers from Gariep Dam or to reduce the pumping from the Caledon System to the Modder River catchment.

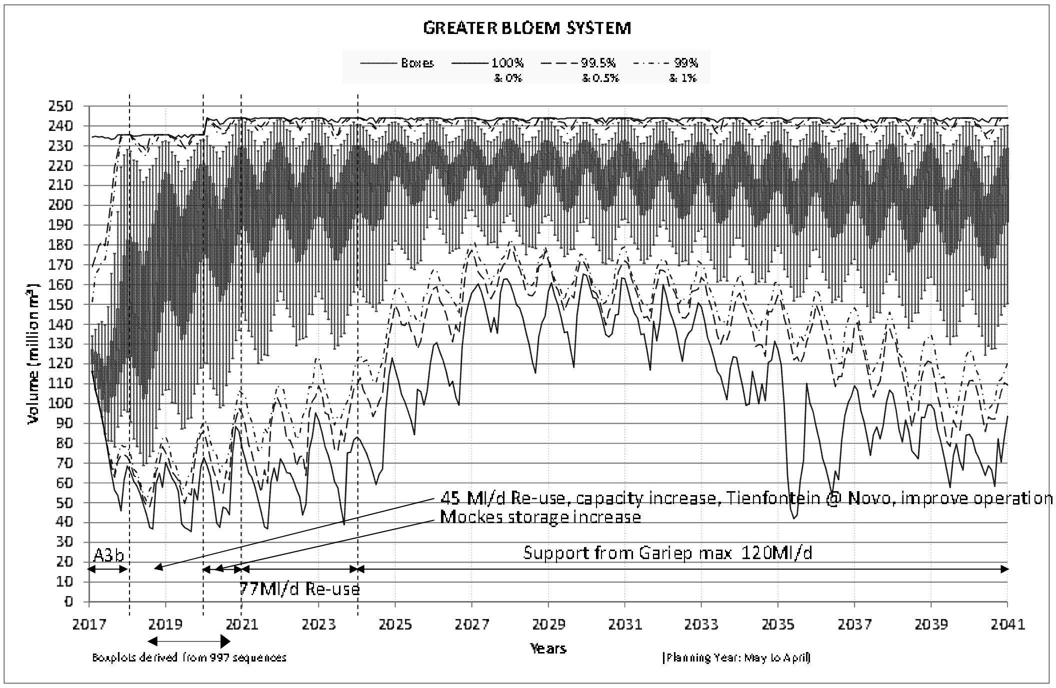


Figure 4-13: Greater Bloemfontein System Storage Projection Base Scenario

Knellpoort Dam represents the largest storage dam in the system. The storage projection plot for Knellpoort Dam (**Figure 4-14**) shows the same trend as observed for the combined system storage projection plot (**Figure 4-13**). It is clear from this plot that the storage in Knellpoort Dam is not fully utilized between 2024 to 2034 as even the worst sequence which represent a recurrence interval of well above 1 in 200 years, is not reaching the dead storage level (DSL) in Knellpoort Dam.

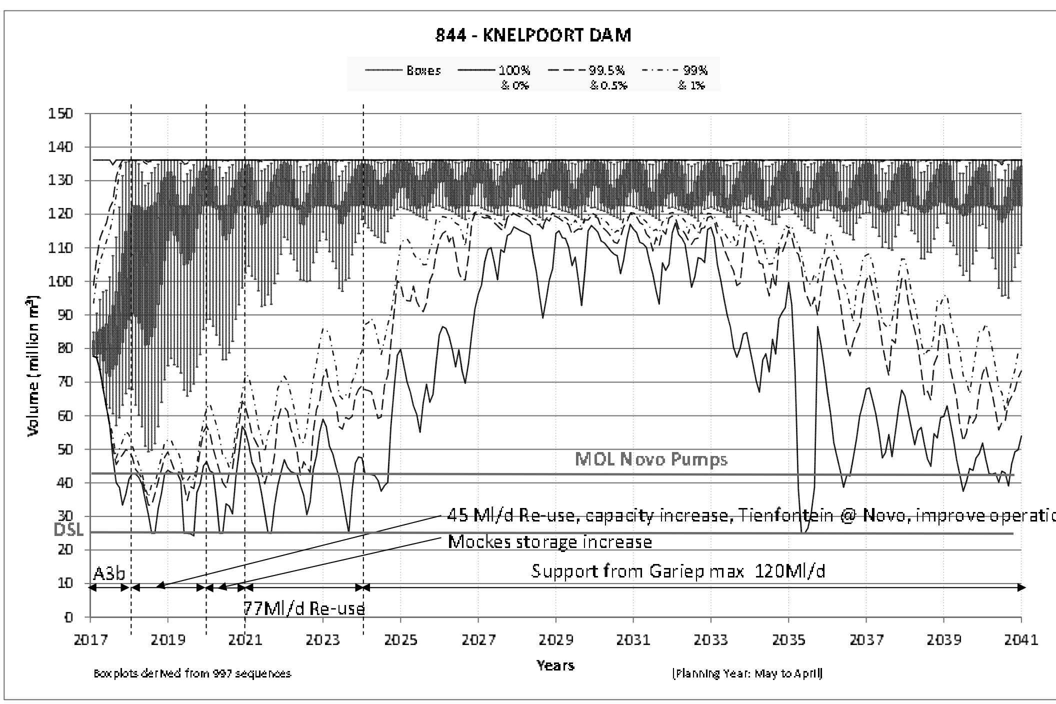


Figure 4-14: Knellpoort Dam storage projection Base Scenario

This calls for the adjustment of the operating rule used for the base scenario to either reduce the pumping from Tienfontein pump station into Knellpoort Dam or to reduce the support from Gariep Dam over this period. Due to the continuous growth in the water requirements, the storage level in Knellpoort Dam start to lower again from 2035 onwards. During the latter period the pumping from Tienfontein and/or the support from Gariep Dam should be increased again over time.

From 2017 until 2021 it can be seen from **Figure 4-14** that during severe drought conditions with recurrence intervals of between 1 in 200 and 1 in 100 years, that the water levels in Knellpoort Dam will drop below the minimum operating level (MOL) associated with the Novo transfer pump abstractions from Knellpoort Dam. This means that during those months no support from Knellpoort Dam to Rustfontein Dam can take place.

A similar storage projection plot for Rustfontein Dam (second largest storage dam) is shown in **Figure 4-15**. The trend of the storage over time is close to that observed for Knellpoort Dam and the total system storage projection, but is less severe. This is as result of the operating rule that allows water to be first stored in Knellpoort Dam and only when required to be transferred to Rustfontein Dam. The reason for this rule is to reduce pumping costs and to allow more storage capacity in Rustfontein Dam, to capture the runoff generated from the much larger catchment upstream of Rustfontein Dam and at the same time to reduce spills from Rustfontein Dam.

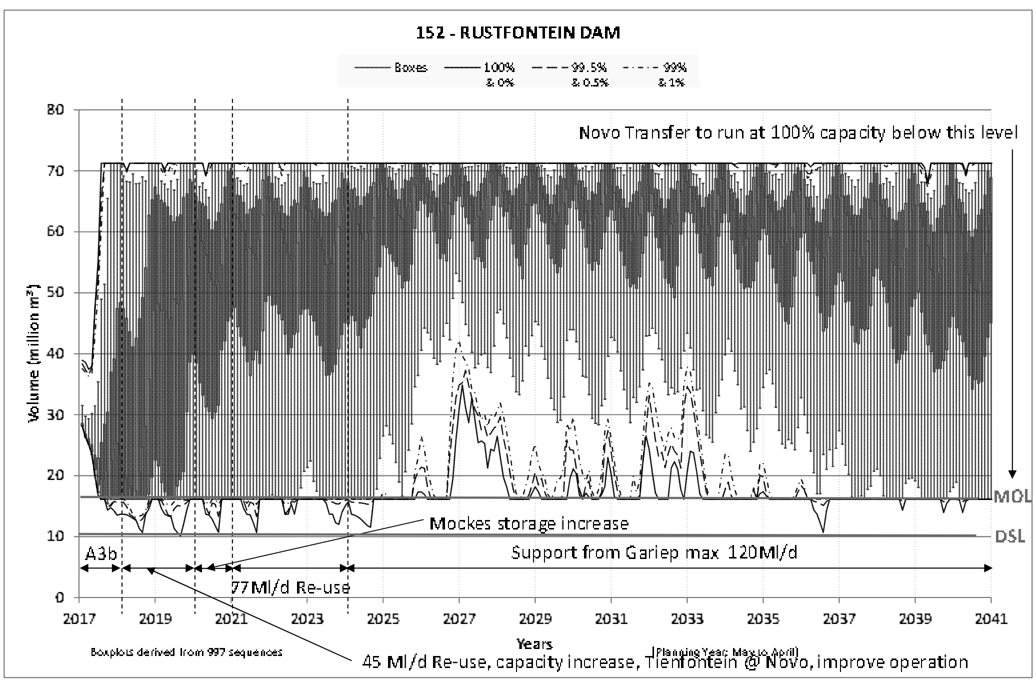


Figure 4-15: Rustfontein Dam storage projection Base Scenario

Knellpoort Dam is an off-channel storage dam with a much smaller catchment and a relative low possibility of spilling due to the lesser local runoff generated upstream of the dam.

When the storage in Rustfontein Dam reaches the MOL as indicated in **Figure 4-15**, it means that the Novo transfer needs to be operated at it's maximum capacity, to prevent the Rustfontein Dam storage to drop below this level. During severe drought events of between 1 in 100 and 1 in 200 years the storage in Rustfontein Dam drops below this MOL, mainly between 2017 and 2022, which is to a large extent as result of levels in Knellpoort Dam dropping to below the MOL of Knellpoort Dam, not allowing for pumping by the Novo transfer scheme pumps.

Figure 4-16 is referred to as the curtailment plot and shows the severity of the curtailments or restrictions in the water supply system over the analysis period. As explained in previous sections of the report, the water supplied to the Greater Bloemfontein System is supplied at three different assurance levels, low (95% assurance), medium (99% assurance) and high assurance (99.5% assurance). When applying restrictions or curtailments to the system, the principle is to first curtail the supply to the lower assurance component, to be able to protect the supply to the higher assurance components. In **Figure 4-16** the three curtailment or restriction level zones are clearly indicated by the three different colored horizontal bars.

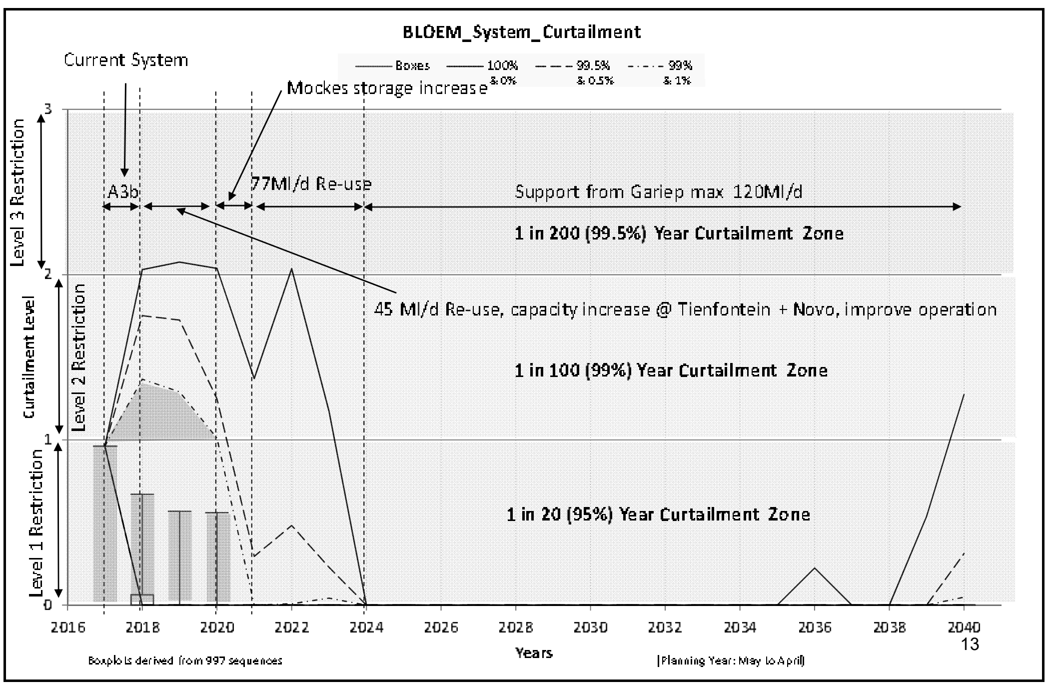


Figure 4-16: Greater Bloemfontein System Curtailment Plot – Base Scenario

When the 5% exceedance probability level starts to enter curtailment zone 1 as highlighted in red, it means that the curtailment criteria for the level 1 restrictions has been violated (restricted more often than it should be). From **Figure 4-16** it is then evident that the curtailment criteria for curtailment zone 1 (Low assurance) is violated from 2017 to 2020, with curtailment level 2 violated in 2018 and 2019 (see red area). No violations occurred in the level 3 curtailment zone. From 2021 onwards no violations occurred, indicating that the yield available from the resources is sufficient to supply the users at their required assurance levels from 2021 to 2040. Once the 77 Mℓ/d intervention option was activated the system was for the first time in balance again, with the system yield equal or higher than the demand imposed on the system at the required assurance levels.

The water supply at the required assurance levels to all three main demand centers, Bloemfontein, Botshabelo and Thaba Nchu over the analysis period, are shown in **Figures 4-17, 4-18** and **4-19,** respectively.

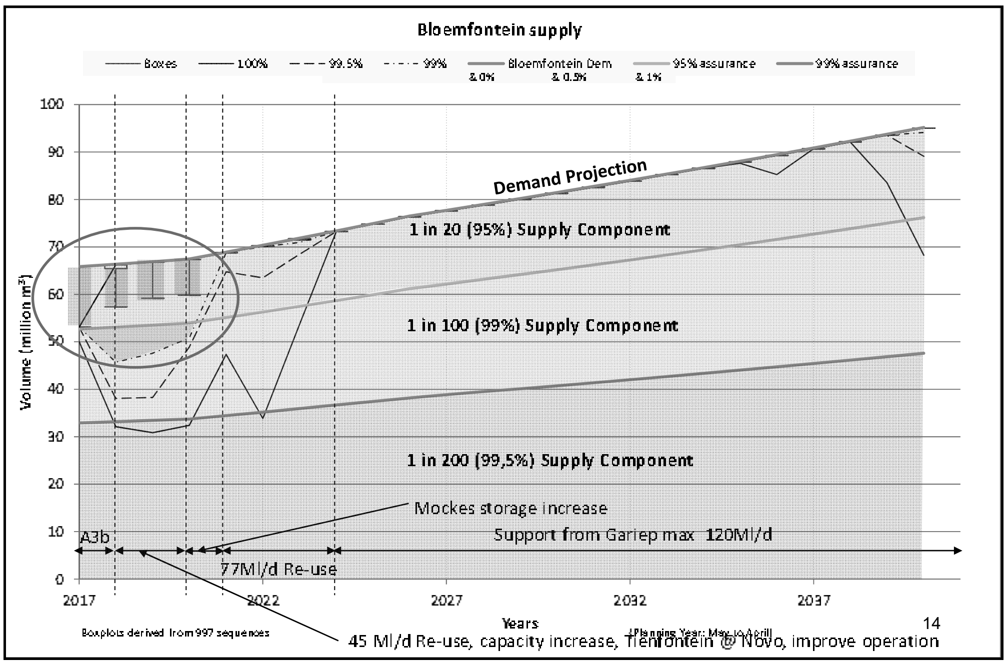


Figure 4-17: Supply to Bloemfontein Base Scenario

From the priority classification table (**Table 2-11**) in **Section 2.3** it can be seen that 50% of the total Bloemfontein demand requires a high assurance of 99.5%, 30% of the demand a medium assurance of 99% and 20% a low assurance of 95%. This is clearly indicated in **Figure 4-17** by means of the horizontal zones with different colors, also allowing for the expected growth in water requirements over time. Similar to the curtailment plot, it is also evident from **Figure 4-17** that the system is not able to supply the full low assurance component of the demand from 2017 to 2020 (see 95% exceedance probability highlighted in red). The same applies to the medium assurance demand component that was not fully supplied in the 2018 and 2019 year (see the red area just above the 99% exceedance probability level line). From 2021 onwards the Bloemfontein demand was fully supplied at the required assurance levels.

The water supply to Botshabelo as given in **Figure 4-18** is telling the same story as explained for Bloemfontein, by being fully supplied at the required assurance levels from 2021 onwards.

The Thaba Nchu water supply plot (**Figure 4-19**) shows the same trend as seen for Bloemfontein and Botshabelo until 2037. For the years 2038 to 2040 small deficits in the supply of the low assurance component are however evident in the Thaba Nchu supply graph. By evaluating key channel flow plots, such as the support channel from the Rustfontein WTP to Thaba Nchu and the support from Rustfontein Dam to the Rustfontein WTP, it was clear that these deficits were as result of the Rustfontein WTP reaching its maximum capacity, and not as result of a too low system yield (see **Figures 4-20** and **4-21**).

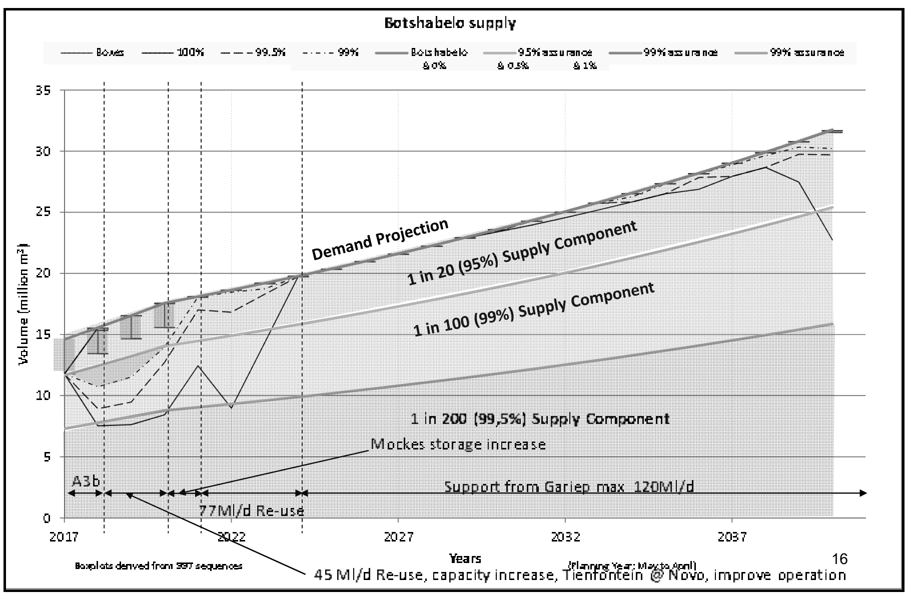


Figure 4-18: Supply to Botshabelo Base Scenario

From **Figure 4-20** it can be seen that for the last three years of the simulation period the support from the Rustfontein WTP to Thaba Nchu starts to show a slight decline. This is also evident from **Figure 4-21**, showing that the intake to Rustfontein WTP from Rustfontein Dam flattens of over the last three years, indicating that the maximum capacity of the treatment plant has been reached.

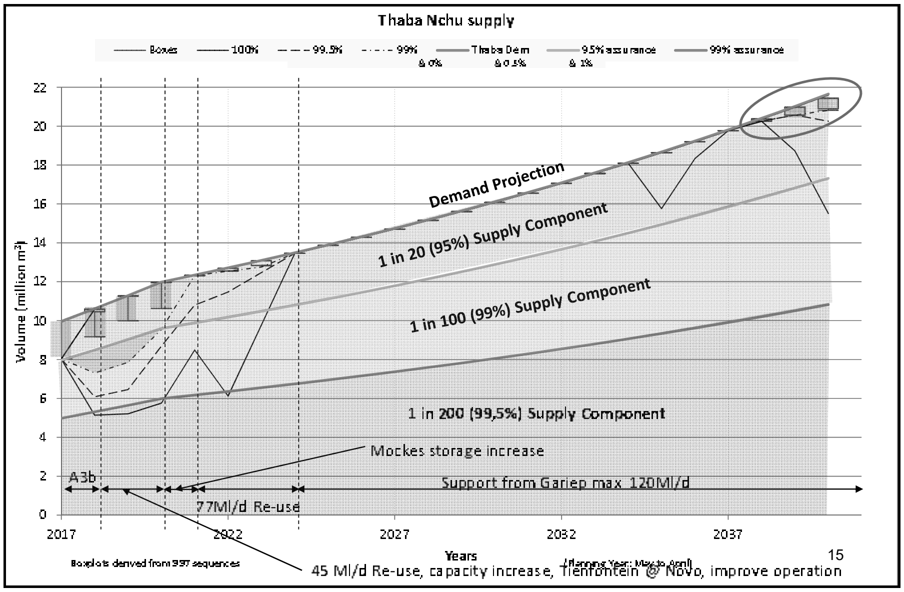


Figure 4-19: Supply to Thaba Nchu Base Scenario

The maximum average potable water capacity of the Rustfontein WTP is 100 Mℓ/d, with a resulting raw water intake of approximately 107 Mℓ/d due to losses at the WTP. Based on the water supply priorities given in the WRPM, a slightly lower priority of supply from the Rustfontein WTP was given for the supply towards Thaba Nchu than for Botshabelo, which is the reason why these small deficits were only evident in the Thaba Nchu supply plot and not in the Botshabelo supply plot.

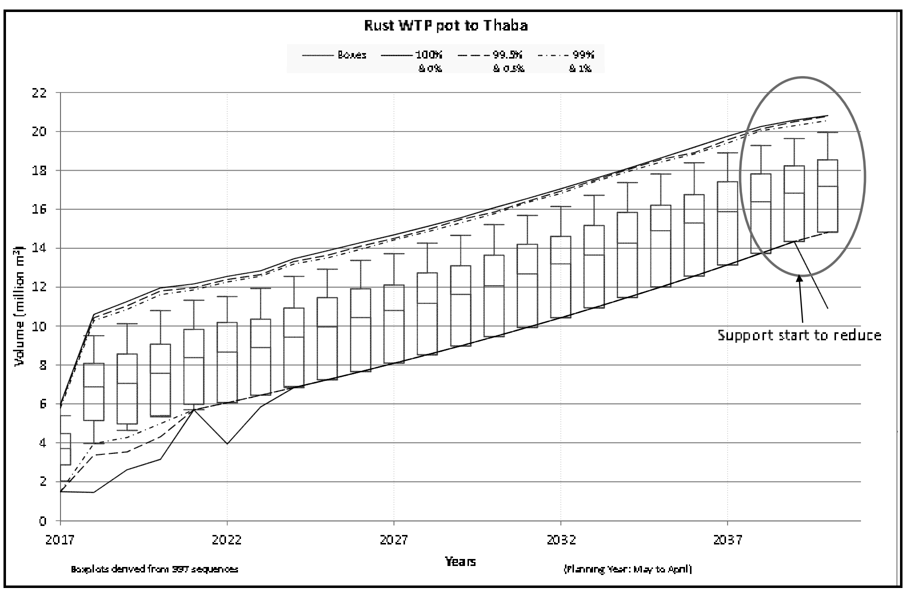


Figure 4-20: Annual support from Rustfontein WTP to Thaba Nchu

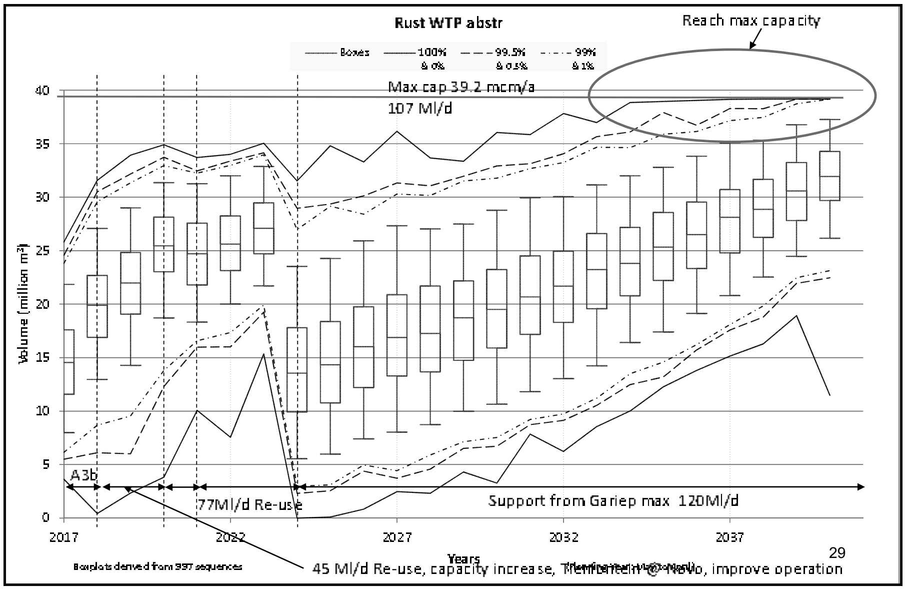


Figure 4-21: Annual inflow from Rustfontein Dam to Rustfontein WTP

With the phasing in of the different intervention options over time, the reduction in supply from the Rustfontein WTP is quite clear, in particular when the support from Gariep Dam is activated. This relates to the priority settings in the WRPM, allowing Bloemfontein to first utilize the water available from the new intervention options, as and when they are phased in over time, to reduce the support from the Rustfontein WTP to Bloemfontein. By following this approach the Rustfontein Dam yield is over time becoming more and more available as resource to Botshabelo and Thaba Nchu and less to Bloemfontein.

The above is clearly illustrated by the annual flows representing the support from the Rustfontein WTP to Bloemfontein as shown in **Figure 4-22**.

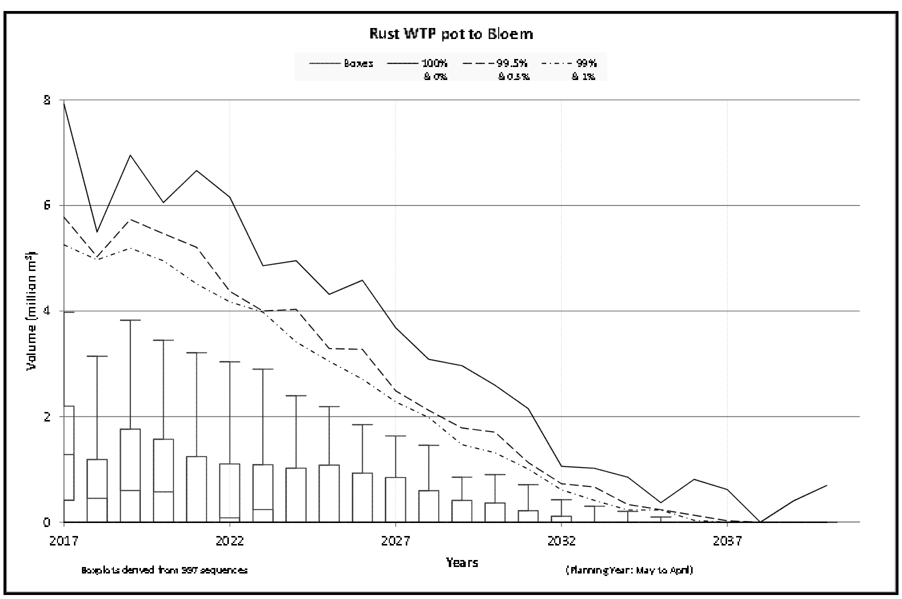


Figure 4-22: Annual support from Rustfontein WTP to Bloemfontein Base Scenario

Box plots of flows through several key channels were prepared to evaluate the performance of the different intervention options forming part of the Base Scenario. The first plots were focused on the increased Tienfontein pump capacity as well as the increased Novo transfer capacity, which were both activated in May 2018.

The pumped annual volumes from Tienfontein pump station as given **Figure 4-23** shows a slow reduction in annual volumes until 2029, where after the annual pumped volumes started to slowly increase again until 2040. This is due to the combination of the current operating rules and the initial increasing of the system storage followed by a slow decrease in system storage as evident from the storage projections of both Knellpoort and Rustfontein dams (see **Figures 4-14** and **4-15,** respectively).

The monthly pumped volumes at Tienfontein pump station are given in **Figure 4-24** and clearly show the increase in capacity by the end of 2017 and beginning 2018. The high variance in the monthly pumped volumes is as result of the variance in the river flow, being low in the winter months and high in the summer months.

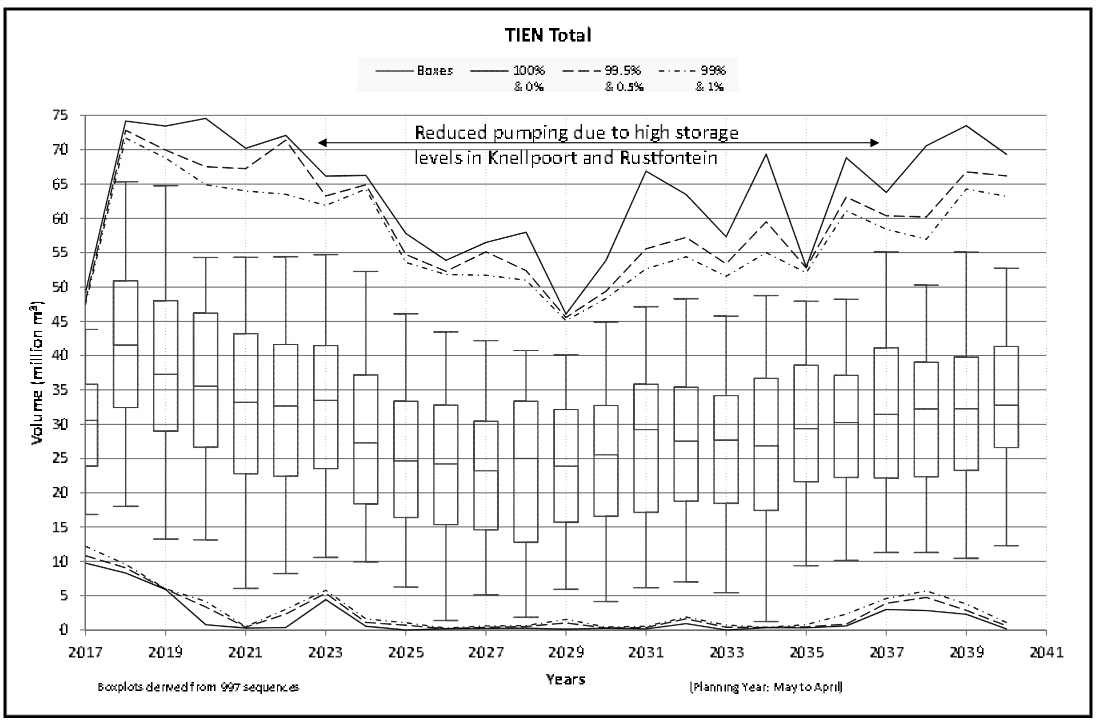


Figure 4-23: Tienfontein annual pumped volumes Base Scenario

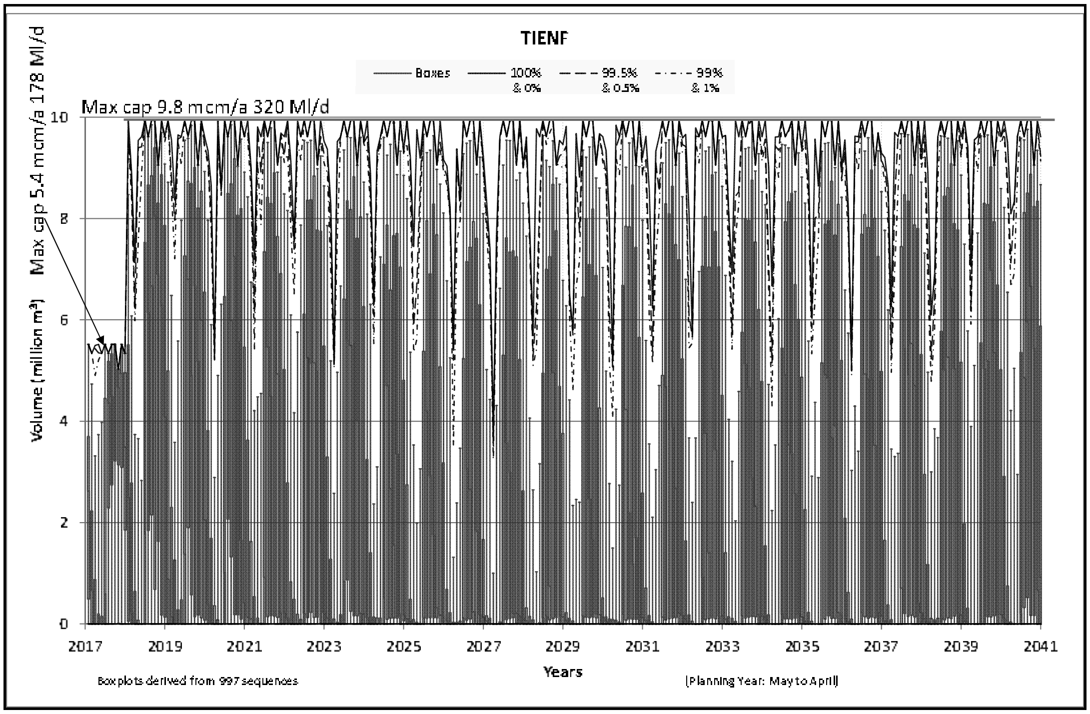


Figure 4-24: Tienfontein monthly pumped volumes Base Scenario

The annual and monthly Novo transfer volumes are given in **Figures 4-25** and **4-26,** respectively. The annual Novo transfer volumes shows a similar trend as observed from the annual Tienfontein pumped volumes, and is also mainly as result of the initial increasing of the system storage followed by a slow decrease again on the storage projections of Rustfontein Dam, in combination with the current operating rules used.

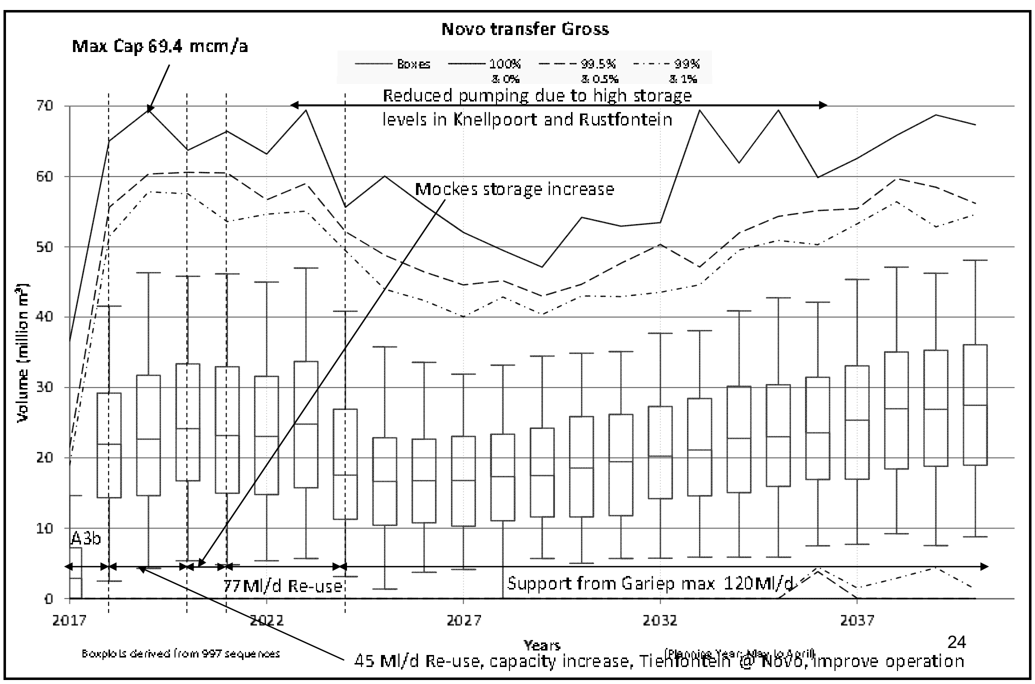


Figure 4-25: Annual Novo Transfer volumes Base Scenario

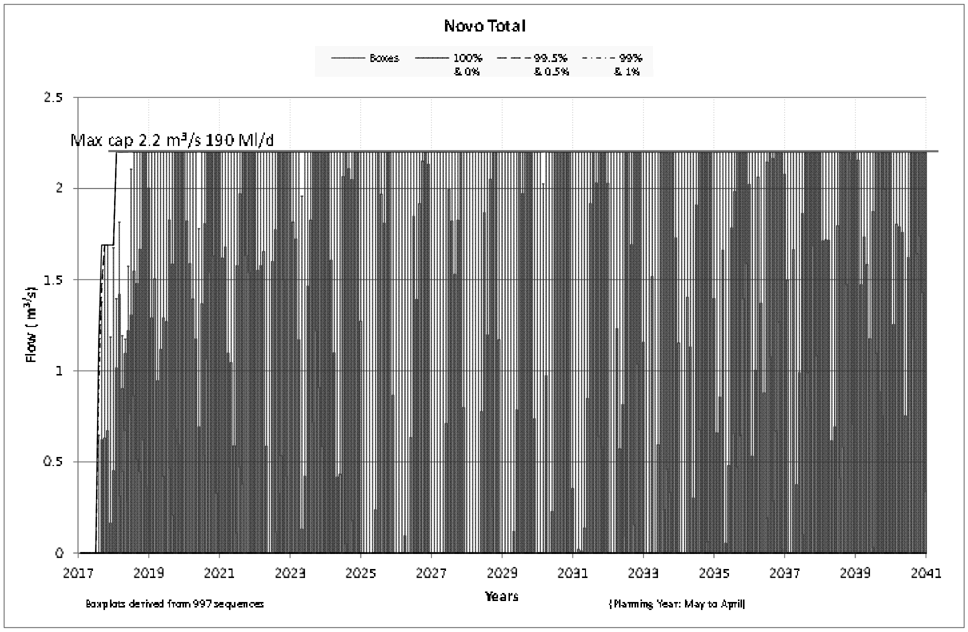


Figure 4-26: Monthly Novo Transfer volumes Base Scenario

The monthly Novo transfer volumes shows a lower variance in monthly flow than that evident from the monthly Tienfontein pumped volumes, as the Novo transfer scheme pump water from the Knellpoort Dam with a fairly large storage, providing thus a much more stable resource than river runoff. The increase in the transfer capacity at the start of 2018 is clearly evident from the boxplot in **Figure 4-26**.

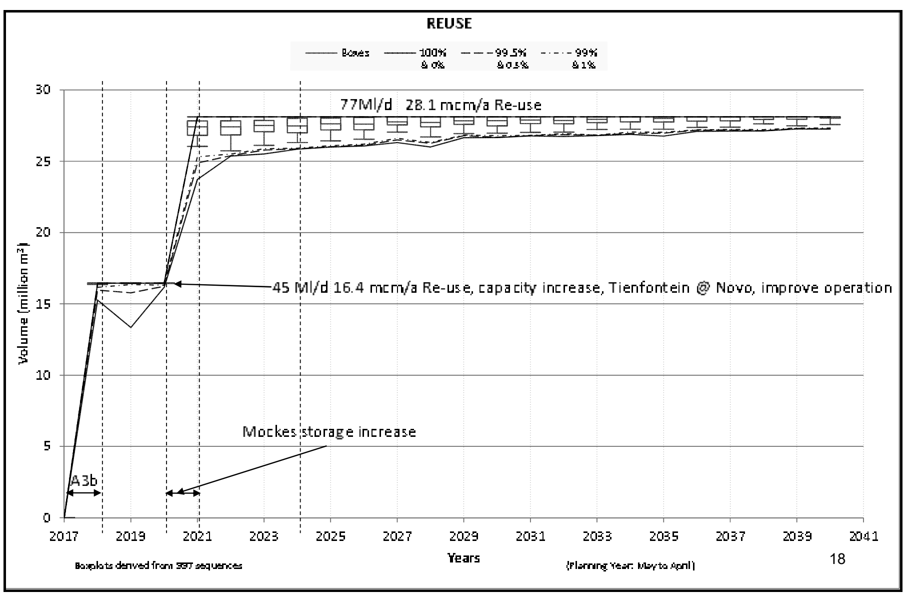
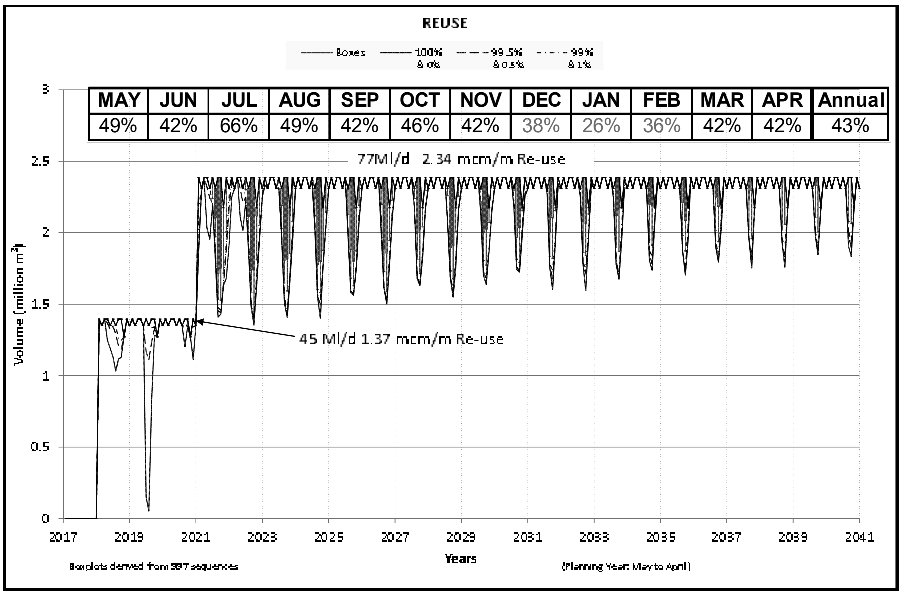


Figure 4-27: Annual Bloemfontein re-use volumes Base Scenario

The re-use of Bloemfontein return flows is activated on 1 May 2018 starting with 45 Mℓ/d indirect re-use. The reuse is increased by 2021 to a total of 77 Mℓ/d indirect re-use. The simulated annual indirect re-use is shown in **Figure 4-27** with the monthly re-use volumes in **Figure 4-28**.

From **Figure 4-26** it is evident that the first phase re-use of 45 Mℓ/d is almost fully utilized from 2018 to 2020, with the full development of 77 Mℓ/d re-use not always fully utilized, although it does improve over time due to the increase in the Bloemfontein demand. This inefficiency in return flow re-use was investigated by evaluating the monthly return flow volumes in more detail.



MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	Annual
49%	42%	66%	49%	42%	46%	42%	38%	26%	36%	42%	42%	43%

Figure 4-28: Monthly Bloemfontein re-use volumes Base Scenario

From **Figure 4-28** it was found that the summer month return flow volumes was in general lower than the winter month return flows as indicated by the table included in **Figure 4-28**. For re-use purposes it was assumed that a constant monthly volume will be available over the year. Due to the monthly return flow pattern as generated by the demand centers used in the WRPM, the lower return flows generated for the summer months, were most of the time not sufficient to support the required monthly return flow requirement for re-use purposes. These demand centers in the WRPM were calibrated as part of a previous water quality study and might require some adjustments. It was therefore at the time suggested to obtain the latest observed return flow data and re-evaluate and update the return flow characteristics within the demand centers, as this should increase the re-use efficiency.

The treated return flows for re-use purposes is released into Mockes Dam from where its again released to be abstracted by the Maselspoort WTP further downstream at Maselspoort Weir. The simulated monthly and annual water supply from the Maselspoort WTP is given in **Figures 4-29** and **4-30,** respectively.

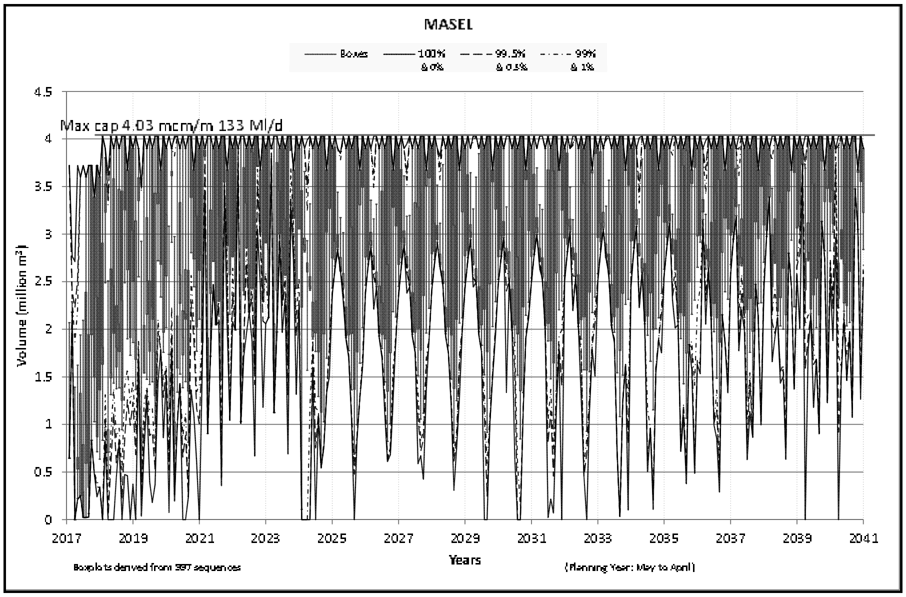


Figure 4-29: Monthly supply from Maselspoort to Bloemfontein

Based on the monthly water supply given in **Figure 4-29** the WTP is fairly often running at its full capacity, but not all the time. Storage in Mockes Dam is relatively small and can thus empty and fill quite fast, which is the main reason for the variance in monthly supply as given in **Figure 4-29**.

From the annual Maselspoort water supply plot it can be seen that the initial intervention options such as the phase 1 and phase 2 re-use options, as well as the storage capacity increase of Mockes Dam, significantly increased the annual volume supplied from Maselspoort to Bloemfontein. This volume, however, reduced again as soon as the support from Gariep Dam was activated. This is mainly as result of the operating rule used, that placed a higher priority on the use of water from Gariep Dam. This was adjusted in the next risk analysis scenario to allow a higher priority on the use of water from the re-use entering into Mockes Dam.

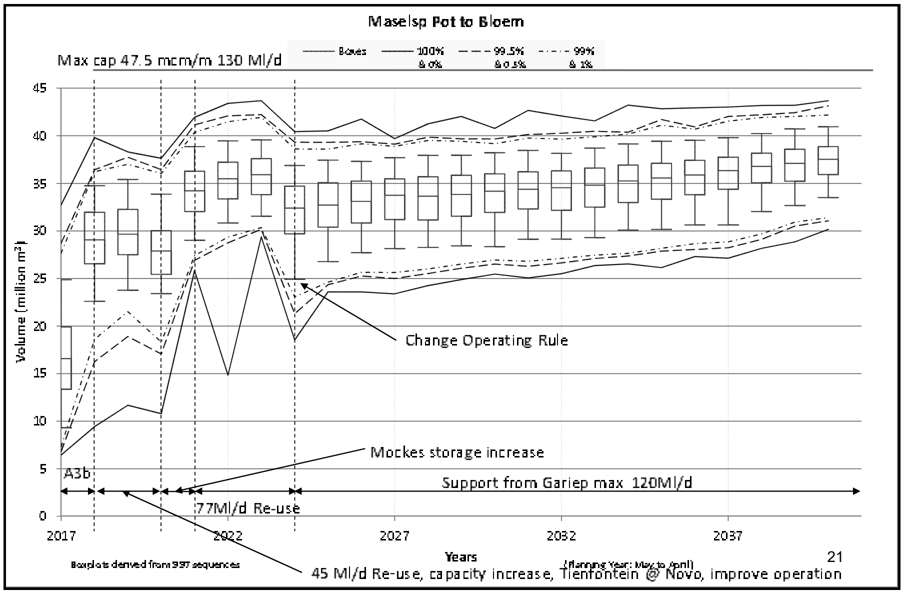


Figure 4-30: Annual supply from Maselspoort to Bloemfontein

For the purpose of the Base Scenario the transfer from Gariep Dam to Bloemfontein was activated on 1 May 2024 as shown in **Figure 4-31**. An average capacity of maximum 120 Mℓ/d (43.8 million m³/a) was considered for the Base Scenario. The results from the analysis show that although the maximum capacity was reached by the more extreme flow sequences, the median supply is much lower at approximately 30 million m³/a (82 Mℓ/d) at the start of the transfer. The median volume almost reaches the maximum average capacity of the WTP by the end of the simulation period (2040).

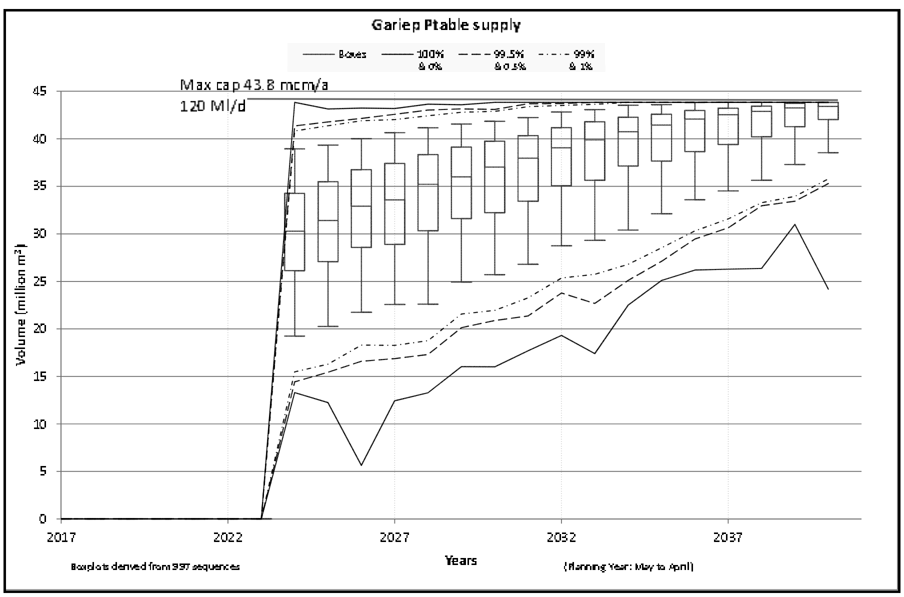


Figure 4-31: Water supply to Bloemfontein from Gariep WTP Base Scenario

The pipeline from the Rustfontein WTW currently used to support Bloemfontein with water, can also be used in the opposite direction to supply Botshabelo and Thaba Nchu with water from Welbedacht Dam. This link was also included in the WRPM with a maximum capacity of 100 Mℓ/d allowed for this link. The results from the risk analysis showed some limited initial support over the first seven years. As soon as the Gariep Dam pipeline was activated, this support increases significantly, showing the possible need for support to Thaba Nchu and Botshabelo from Welbedacht Dam and/or the Gariep Dam pipeline.

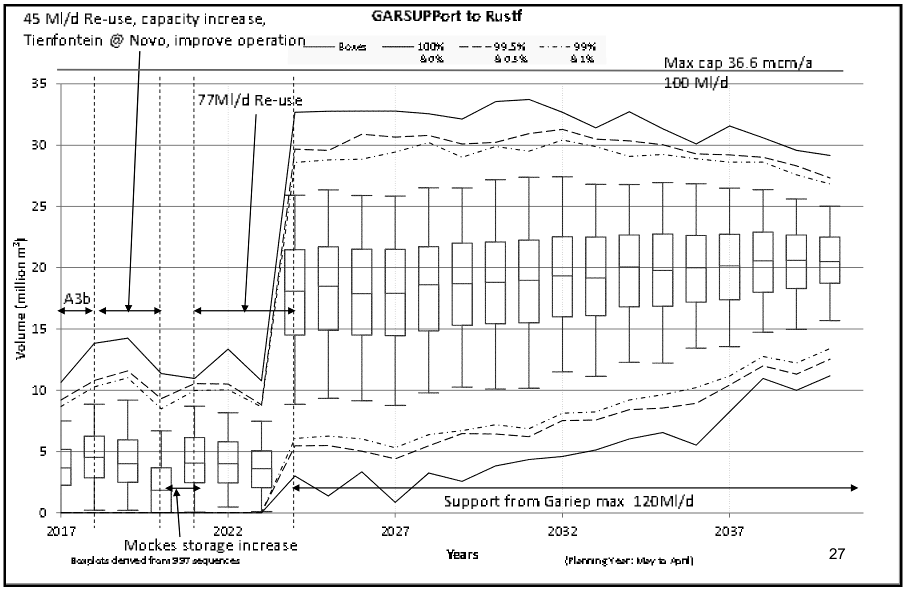


Figure 4-32: Support from Welbedacht/Gariep to Rustfontein WTP

The required volume of this support is to a large extent also regulated by means of the operating rule used, and therefore need to be evaluated in more detail in follow up risk analyses.

<u>Key conclusions and recommendations from the Base Scenario Risk analysis results</u>

- The results indicated that deficits in water supply within the Greater Bloemfontein System is expected to occur at least until 2020 and will to a large extend depend on the timing and effective operation and management of the suggested intervention options.
- Once the second phase of the re-use option is in place and active, the Greater Bloemfontein System will for the first time again reach a positive water balance. Based on the Base Scenario definition, this is expected to occur by 2021.
- From 2021 onwards, with the Gariep Dam transfer in place, it is expected that the system will maintain a positive water balance until 2040.
- Initially the Gariep transfer option will result in a surplus yield available within the Greater Bloemfontein System, which allows for the adjustment of operating rules to reduce pumping costs.

- As the intervention options mainly focus on the Bloemfontein demand center, the support required from Rustfontein Dam to Bloemfontein reduces significantly over time to almost zero by 2037. This allows Rustfontein Dam to be fully available and utilized only by Botshabelo and Thaba Nchu, to cater for the growing water requirements from these two demand centers.
- Operating rules should be adjusted to prioritize the water available from re-use by Bloemfontein.
- The monthly return flow distribution as well as the percentage return flows expected, need to be revised with updated observed data. The effectivity of the re-use option is quite sensitive to these assumptions, and therefore needs to be confirmed by actual observed data.
- Groothoek Dam is totally over utilized, resulting in the dam being empty on a frequent basis.

4.6.2. Stochastic analysis Scenario 1

As explained in **Section 2.4** the purpose of this scenario is to reflect the situation where MMM has limited USDG funding with DWS constructing the Gariep Dam pipeline with a resulting slower implementation of the intervention options. This resulted in the last intervention option to only be in place by June 2026 in comparison with May 2024 as in the Base Scenario. Indirect re-use of 45 Mℓ/d in place by May 2023 and support from Gariep Dam plus direct/indirect re-use of 32 Mℓ/d coming into operation in June 2026. Another important difference is that for the Base Scenario, the Gariep Dam to Bloemfontein transfer system capacity was taken as 120 Mℓ/d and for Scenario 1 as 90 Mℓ/d.

Important operating rule changes that need to be taken note of is that for Scenario 1 the rule regarding the supply to Bloemfontein was changed as follows:

- Maselspoort is the priority 1 resource, water is first abstracted from here to support Bloemfontein, while the Base Scenario considered abstraction from Welbedacht Dam as first priority.
- Second priority for Scenario 1 is to utilize the water available from re-use. (for Base Scenario Maselspoort and re-use was both considered as second priority)
- Abstraction from Welbedacht Dam as third priority. (Base Scenario used support from Rustfontein as third priority with support from Knellpoort Dam based on the operating rule).
- The fourth priority to supply water to Bloemfontein for Scenario 1 was taken as Gariep Dam. (Base Scenario considered Gariep Dam as the first priority to be used in support of Bloemfontein, as soon as it was activated)

- The last priority of supply to Bloemfontein for Scenario 1 was the supply from Rustfontein Dam with support from Knellpoort Dam based on the Knellpoort/Rustfontein operating rule.

When comparing the total combined system storage of the Greater Bloemfontein System obtained from Scenario 1 (**Figure 4-33**) with that of the Base Scenario (**Figure 4-13**), it is clear that the system storage was better utilized, which would have resulted in a reduction in pumping costs.

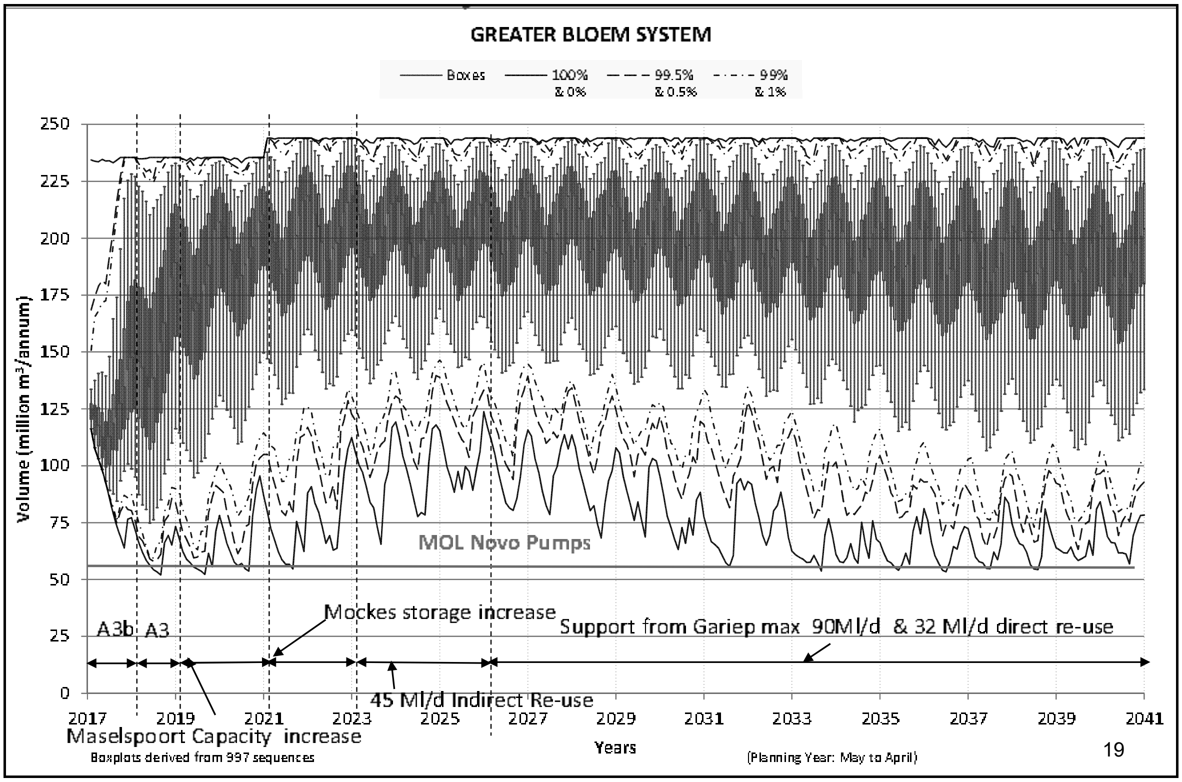


Figure 4-33: Greater Bloemfontein System Storage Projection Scenario 1

The oversupply of water to the system as evident from the Base Scenario between 2022 and 2036 is thus not evident from Scenario 1, where the period of oversupply was limited to 2026 to 2036. This is evident when comparing results from **Figure 4-16** and **Figure 4-34**. Scenario 1 resulted in system water supply deficits to be experienced until 2024 with the Base Scenario experiencing deficits only until 2020. The maximum supply of 90 Mℓ/d from Gariep is clearly not sufficient and deficits in the water supply to the Greater Bloemfontein system is already experienced from 2037 onwards.

The storage projection for Knellpoort Dam (largest storage dam) is given in **Figure 4-35**.

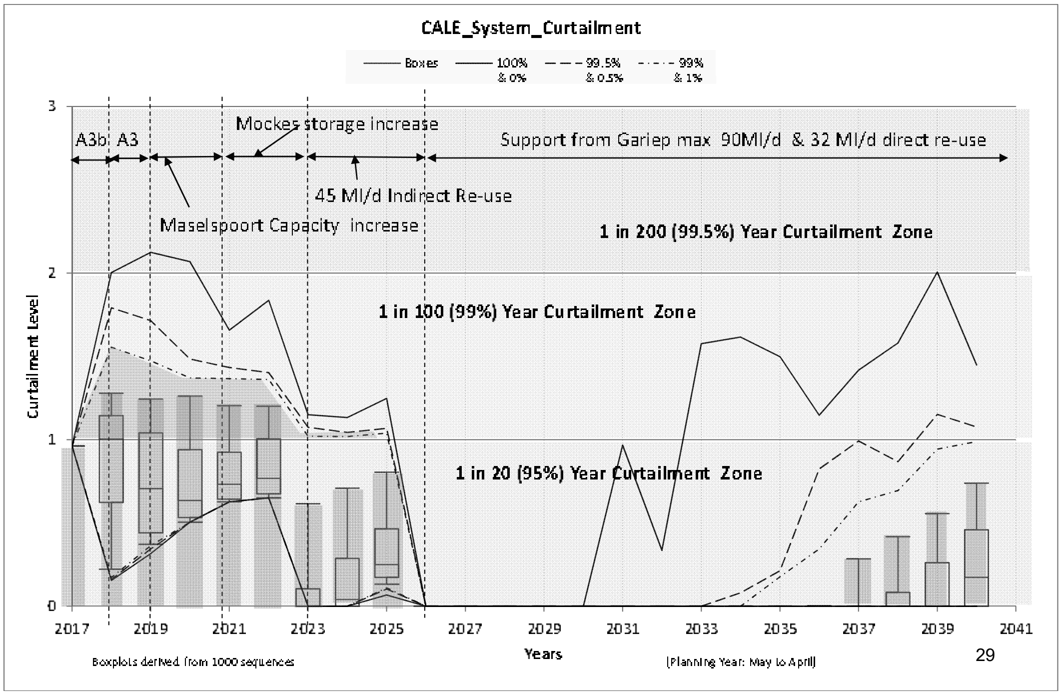


Figure 4-34: Greater Bloemfontein System Curtailment Plot – Scenario 1

Due to the current system yield which is lower than the water demand imposed on the system, the operating rule for Knellpoort Dam dictates that maximum possible should be pumped from Tienfontein pump station in the Caledon River to keep Knellpoort Dam as full as possible, without creating unwanted spills from the dam.

From the **Figure 4-35** it is, however, evident that this rule need to be adjusted for the

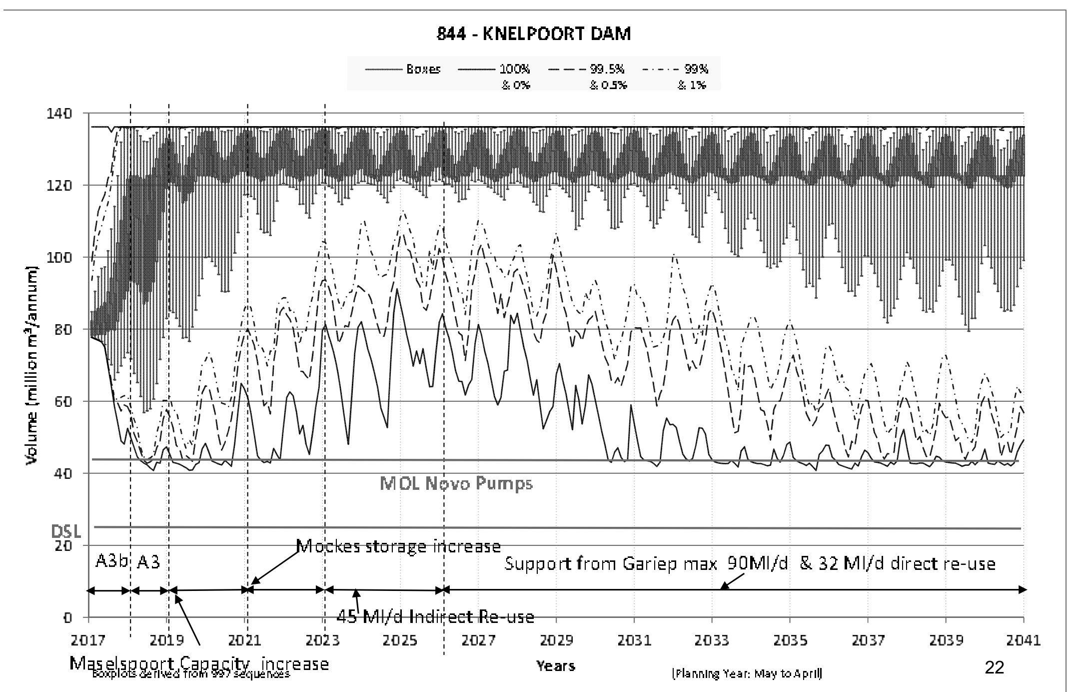


Figure 4-35: Knellpoort Dam storage projection Scenario 1

period between 2023 to 2031 to reduce pumping costs and allow Knellpoort Dam to be operated at lower levels. Towards the end of the analysis period the current operating rule seems to work well and Knellpoort Dam is again fully utilized.

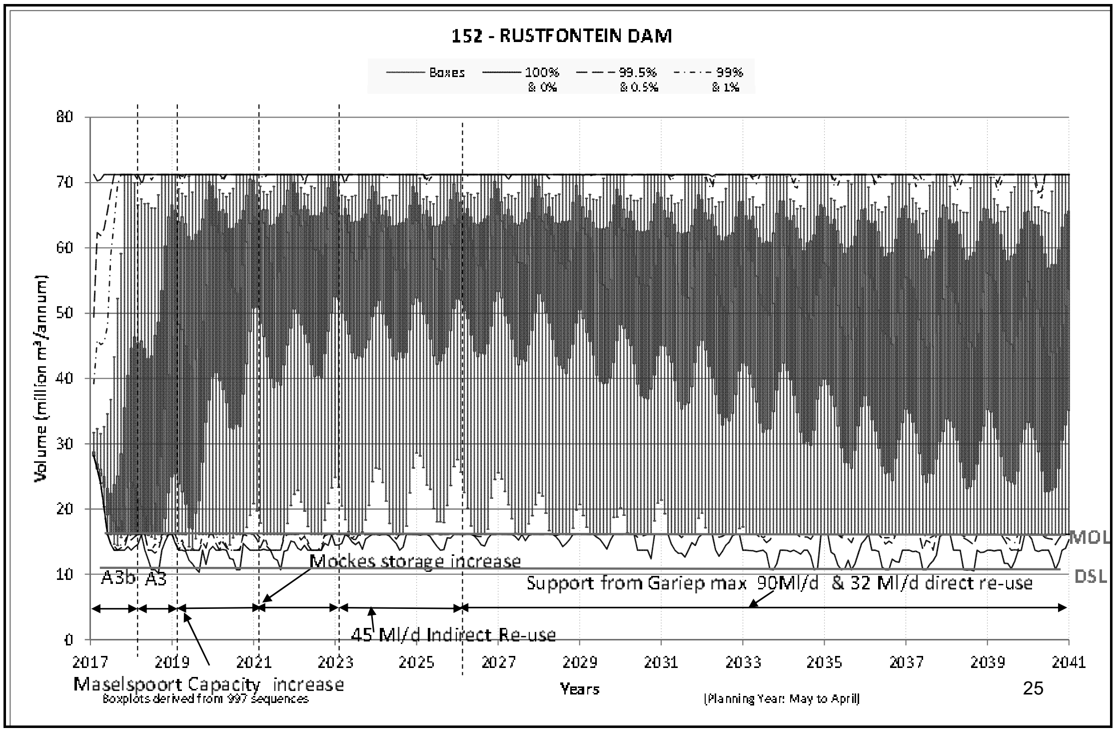


Figure 4-36: Rustfontein Dam storage projection Scenario 1

From **Figure 4-36** it can be seen that Rustfontein Dam is utilized quite well when considering Scenario 1 and that the current operating rule was able to protect the dam from total failure when considering the 1 in 200 and 1 in 100 year drought levels in the dam.

The water supply to the three main demand centers within the Greater Bloemfontein System (Bloemfontein, Thaba Nchu and Botshabelo) at the required assurance levels are given respectively in **Figures 4-37, 4-38** and **4-39**. From **Figure 4-37** it is evident that the water supply to Bloemfontein is insufficient from 2017 to 2025, with deficits experienced at the 95% (1 in 20 year) and 99% (1 in 100year) assurance levels. Deficits in supply is again starting to show up from 2035 onwards, but is only affecting the 95% assurance supply component.

Both Thaba Nchu and Botshabelo, similar to Bloemfontein, also experience deficits in supply from 2017 to 2025 at both the 95% and 99% assurance levels. It is interesting to note that deficits in supply at Thaba Nchu already starts in 2031 and for Botshabelo in 2030. In the last 2 to 3 years of the analysis deficits for both Thaba Nchu and Botshabelo started to enter into the 99% assurance levels, thus more severe than that experienced for Bloemfontein.

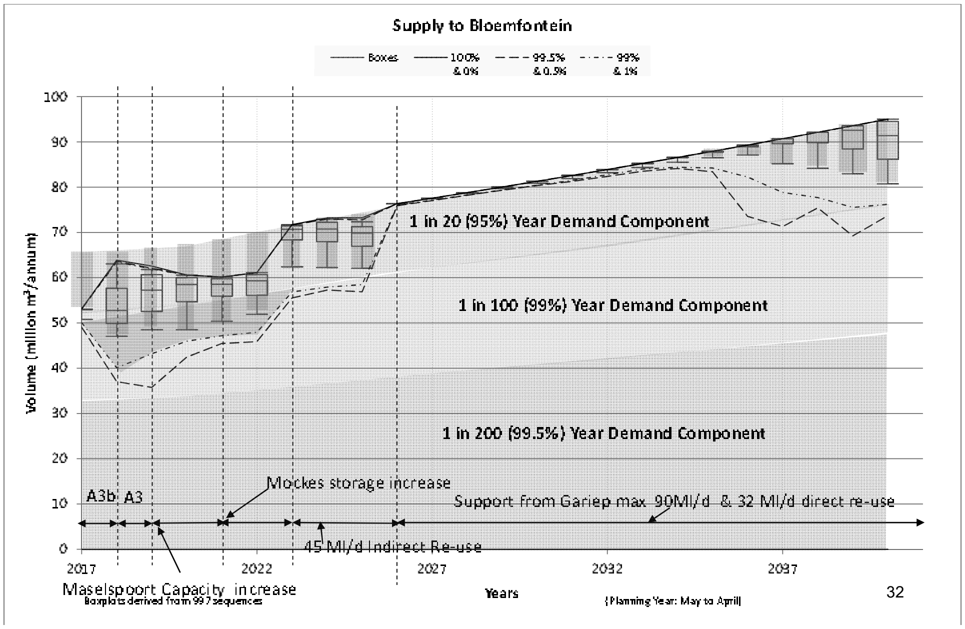


Figure 4-37: Supply to Bloemfontein Scenario 1

The Greater Bloemfontein curtailment plot (**Figure 4-37**) showed that the curtailment criteria are only exceeded from 2037 onwards, it means that something else is limiting the supply of water to the main water demand centers such as Thaba Nchu and Botshabelo. One of the main reasons for the more severe deficits experienced at both Thaba Nchu and Botshabelo is the capacity limitation of the Rustfontein WTW.

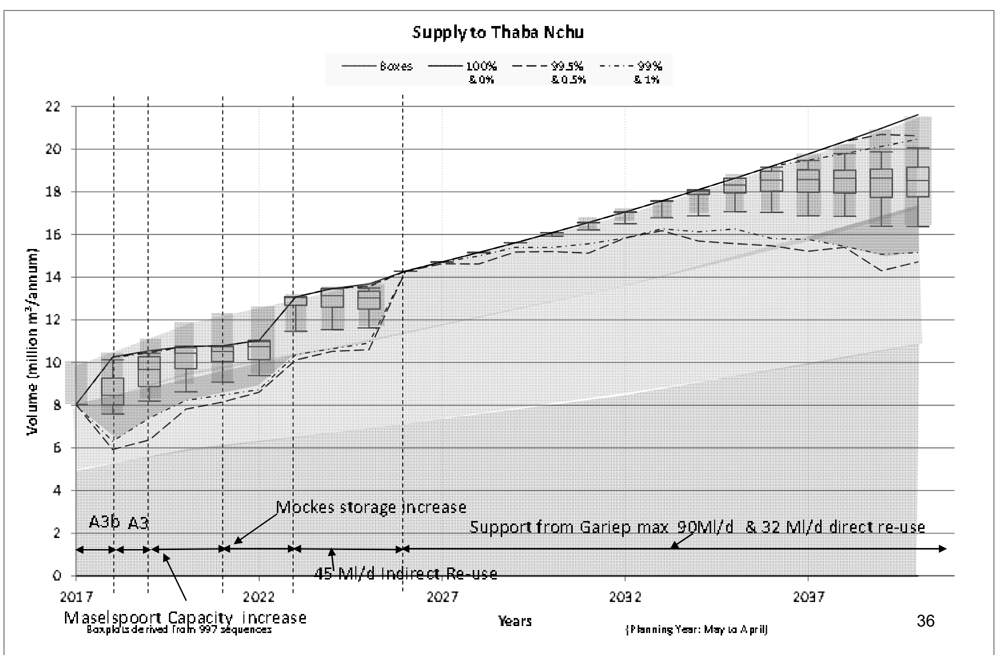


Figure 4-38: Supply to Thaba Nchu Scenario 1

This can be seen from the boxplots shown in **Figure 4-40** where the maximum capacity of the Rustfontein WTP were reached on a frequent basis from approximately 2031 onwards. Improvement of operating rules will also assist in improving the water supply between the different demand centers.

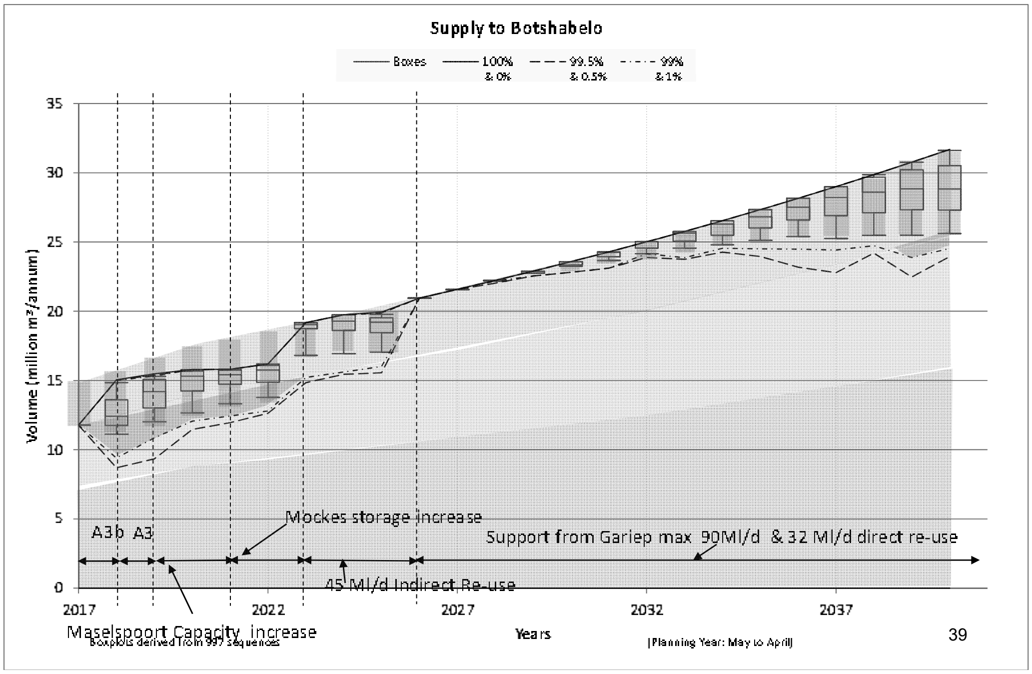


Figure 4-39: Supply to Botshabelo Scenario 1

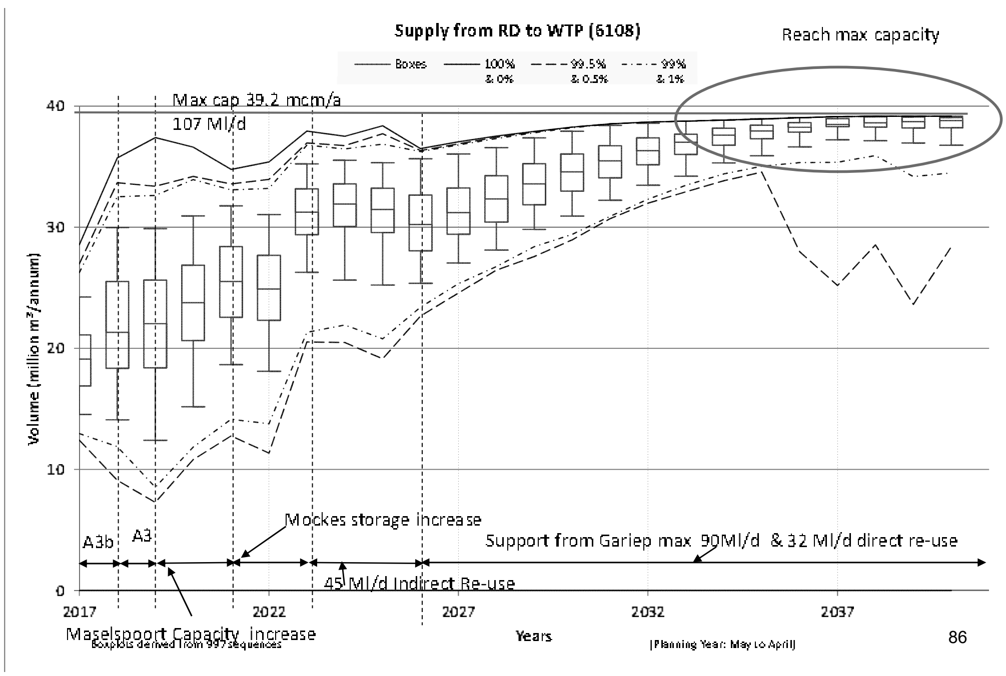


Figure 4-40: Annual supply from Rustfontein Dam to Rustfontein WTP

When evaluation the supply from the Rustfontein WTP to Thaba Nchu, it is also clear that from approximately 2033 onwards there was a reduction in the supply to Thaba Nchu which did not follow the increasing growth in demand over time.

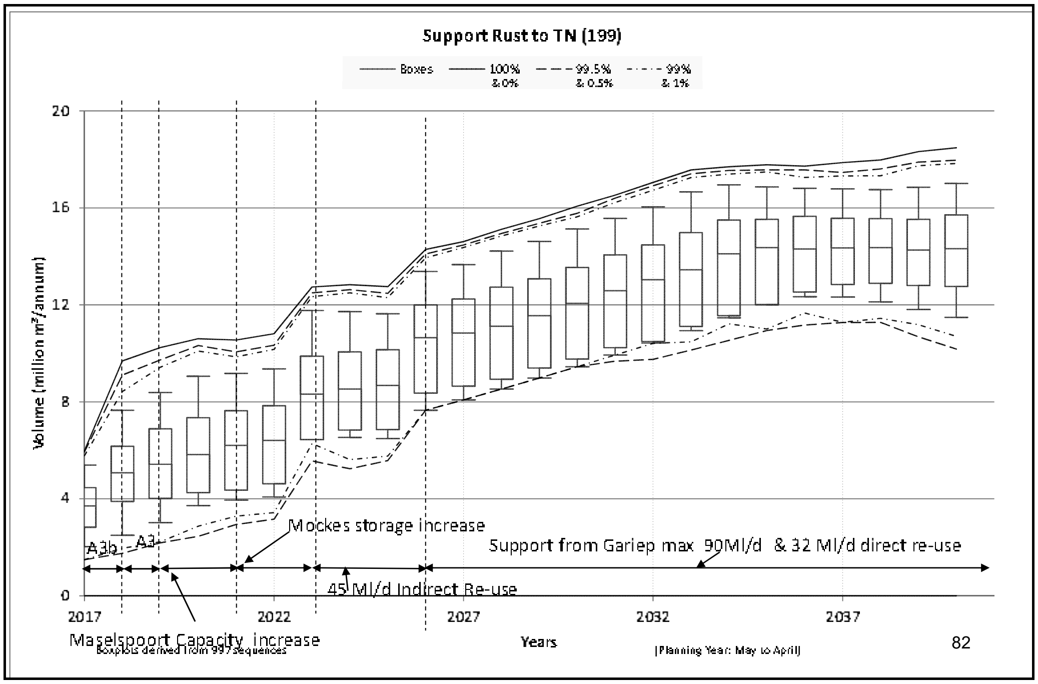


Figure 4-41: Annual support from Rustfontein WTP to Thaba Nchu

The support from Rustfontein WTW to Bloemfontein (**Figure 4-42**) reduced to zero by 2026 as the support from Gariep Dam was available from 2026 onwards, thus reducing the load on Rustfontein Dam according to the Scenario 1 operating rule. This allows for Rustfontein Dam to be primarily used to support Thaba Nchu and Botshabelo.

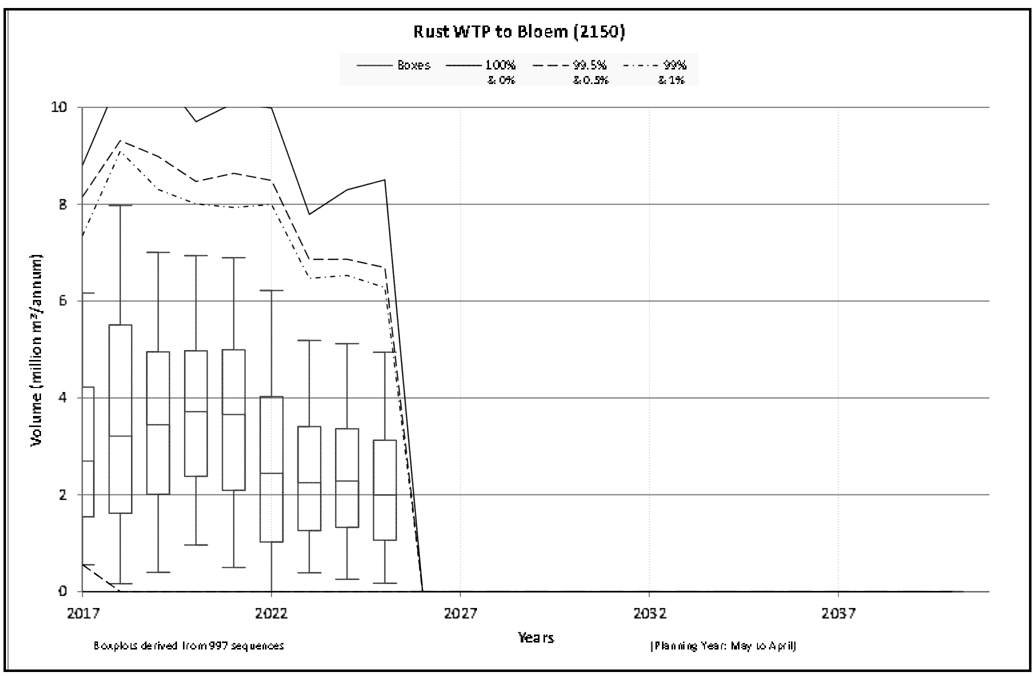


Figure 4-42: Annual support from Rustfontein WTP to Bloemfontein Scenario 1

The pumping from Tienfontein to Knellpoort Dam is initially high due to the low start storage levels in both Knellpoort and Rustfontein dams. It thereafter reduces as the dams were filled and then gradually increases again over time as the system demand increases. (see **Figure 4.43**)

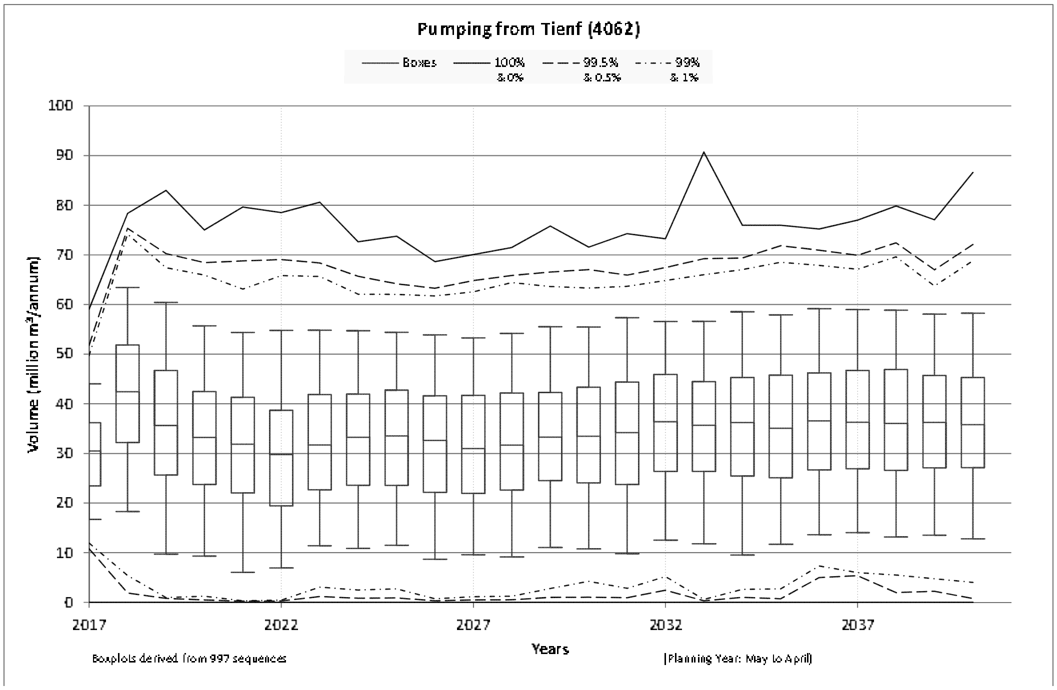


Figure 4-43: Tienfontein annual pumped volumes Scenario 1

Although the maximum Tienfontein pump capacity was not reached on an annual basis, the monthly plot showed that the maximum capacity is reached on a frequent basis during the summer months when the flow in the Caledon River is generally high.

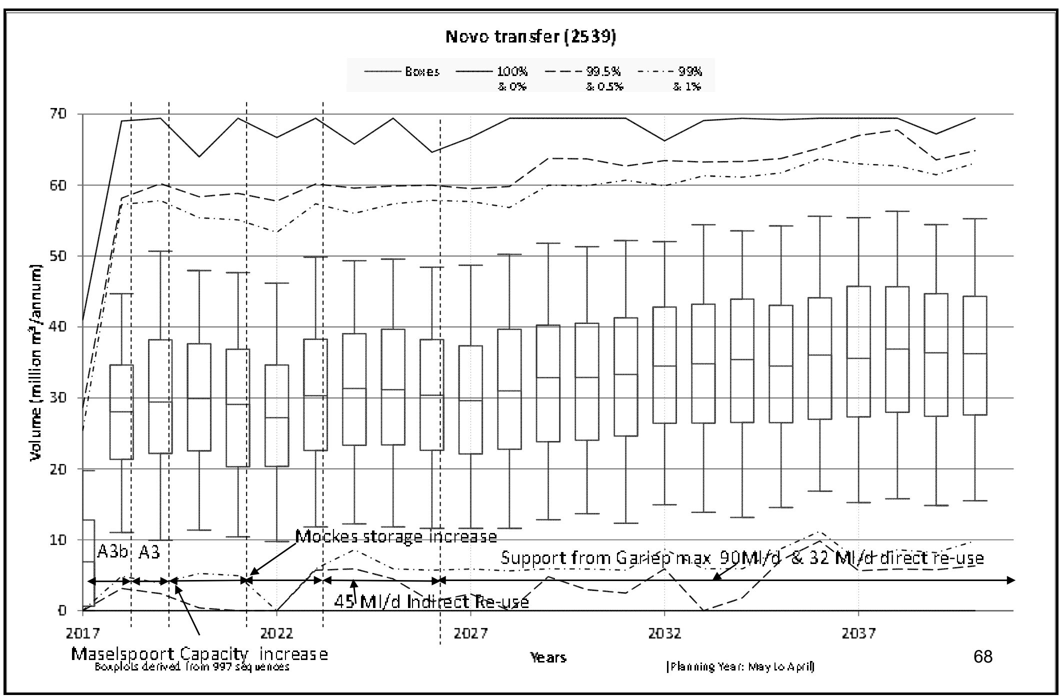


Figure 4-44: Annual Novo transfer volumes Scenario 1

Novo annual flow volumes increased over time (see **Figure 4-44**) and are higher than those obtained from the Base Scenario due to the improved utilization of Rustfontein Dam and lower support from Gariep Dam.

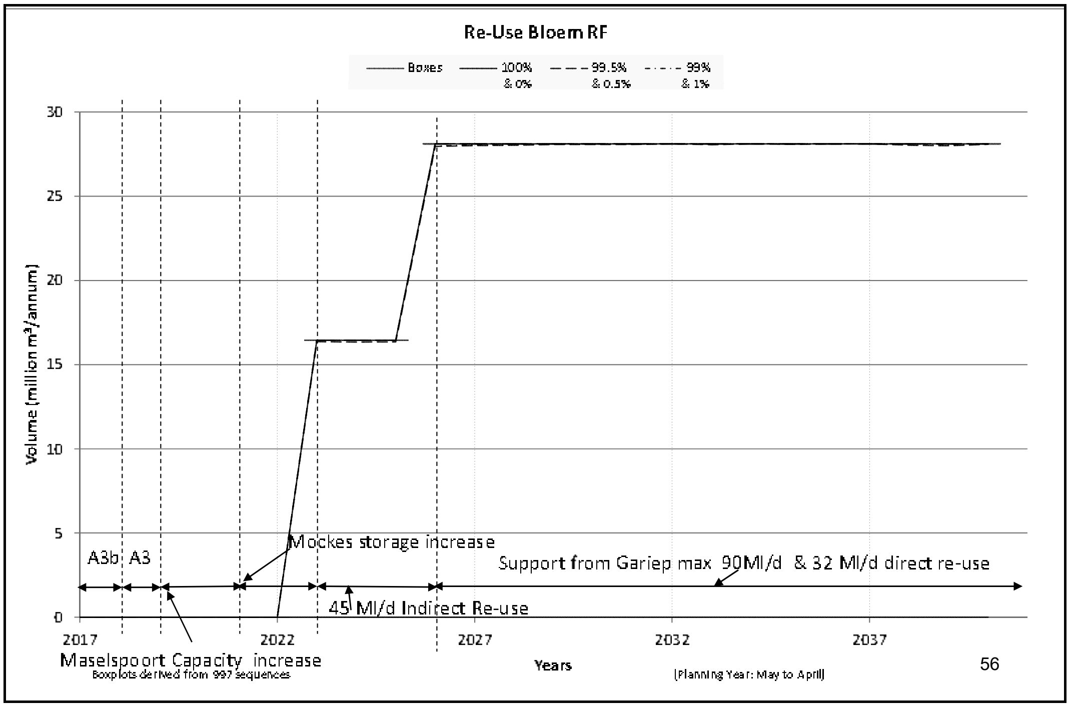


Figure 4-45: Annual Bloemfontein re-use volumes Scenario 1

The utilization of the Bloemfontein re-use (see **Figure 4-45**) has improved significantly from the Base Scenario results due to the improved data on the return flow monthly distribution patterns included in Scenario 1.

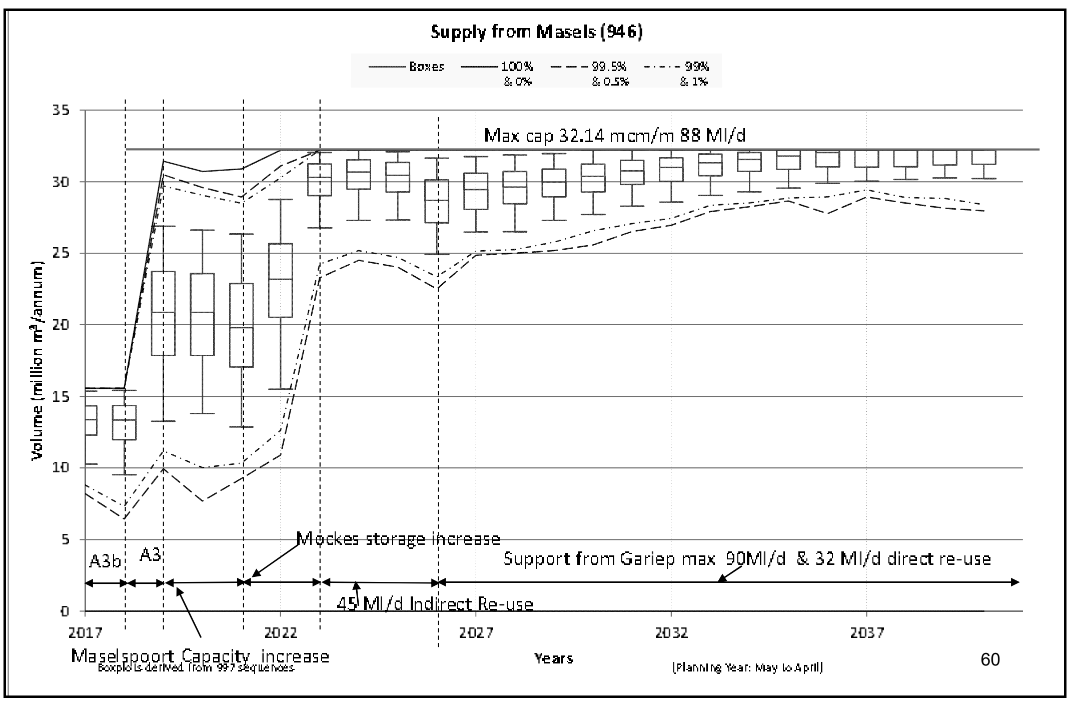


Figure 4-46: Annual supply from Maselspoort to Bloemfontein Scenario 1

Similar to the Base Scenario the intervention options such as the increase in the treatment plant capacity, re-use options and increasing of Mockes Dam storage capacity all contributed to an increased water supply from Mockes Dam. For Scenario 1 the maximum abstraction capacity from Maselspoort was, however, limited to 88 Mℓ/d, which is resulting in the underutilizing of Maselspoort from 2023 onwards. The maximum capacity of 88 Mℓ/d is already reached by 2023 (see **Figure 4-46**) with the median reaching it by 2036. For the base scenario the median reached up to 38 million m^3/a (104 Mℓ/d) with maximum annual supply of 43 million m^3/a (118 Mℓ/d). The capacity limitation of 88 Mℓ/d will result in unnecessary spills at Mockes Dam and it is recommended to increase the maximum capacity to the actual installed capacity of 130 Mℓ/d.

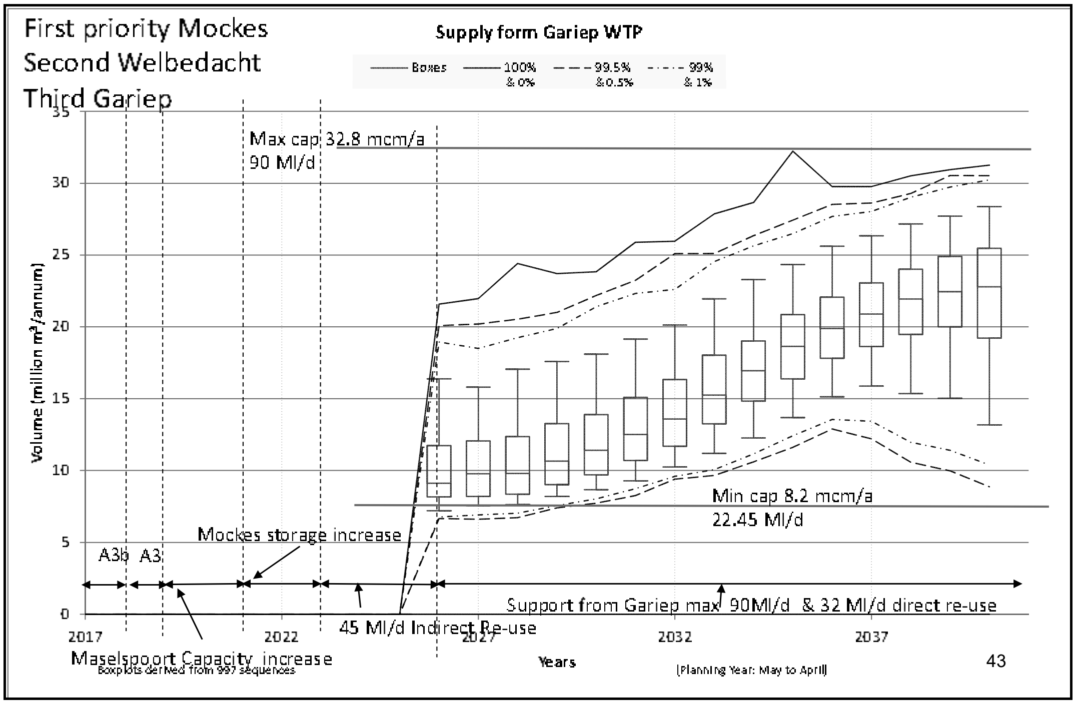


Figure 4-47: Water supply from Bloemfontein to Gariep Scenario 1

For the Base Scenario water supply from Gariep Dam was used as the first priority of supply to Bloemfontein with a maximum capacity of 120 Mℓ/d (43.8 million m^3/a). Scenario 1 considered the supply from Gariep Dam (see **Figure 4-47**) as the third priority source with Maselspoort as the first priority and Welbedacht as second priority. Scenario 1 considered the maximum capacity for the supply from Gariep Dam as 90 Mℓ/d. Although the supply from Gariep Dam on an annual basis only get close to the maximum capacity by the end of the projection period, it reaches the maximum capacity frequently on a monthly basis, already from the first month of the transfer.

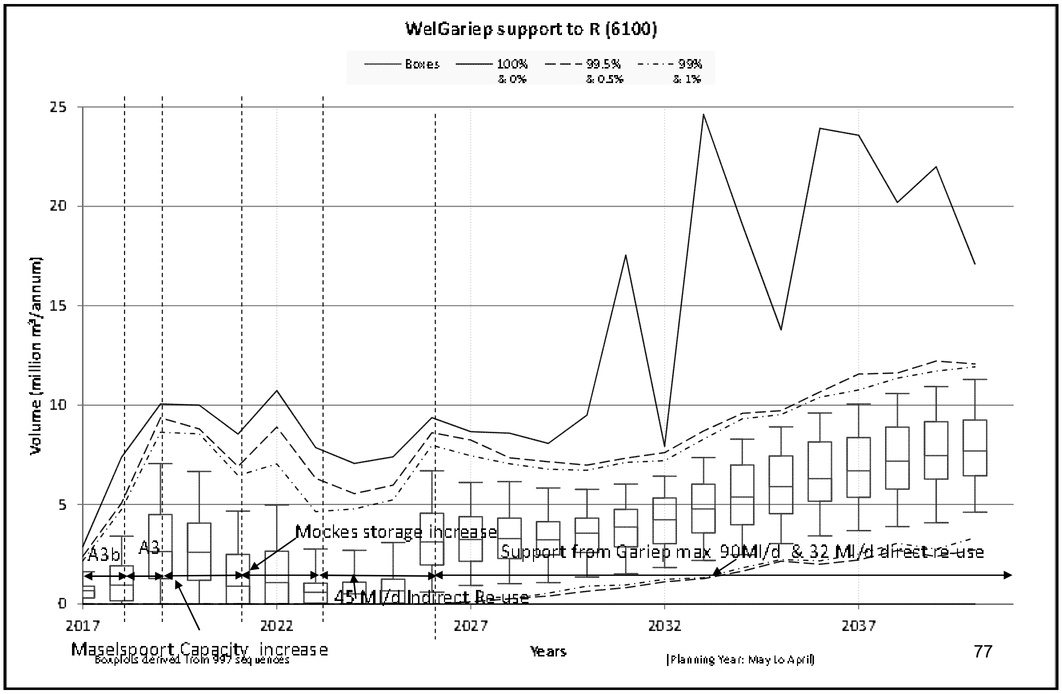


Figure 4-48: Support from Welbedacht / Gariep to Rustfontein WTP Scenario 1

The support from Welbedacht/Gariep dams via Rustfontein to Botshabelo and Thaba Nchu starts to increase from 2026 onwards (see **Figure 4-48**) as Gariep Dam start to support Bloemfontein, allowing water from Welbedacht to be used to also support the Rustfontein supply area. The support to Rustfontein supply area for Scenario 1 is, however, less than that evident for the Base Scenario, due to the reduced capacity of the Gariep Dam transfer as well as the change in the operating rules between the two scenarios.

Key conclusions and recommendations from Scenario 1 Risk analysis results

- Results indicated that the deficits in water supply for Scenario 1 are expected to continue until at least 2025 and that deficits is expected to start occurring again by 2037. Scenario 1 therefore represent a much worse water supply scenario than evident from the Base Scenario.
- Due to internal capacity constraints such as the Rustfontein WTW, deficits in the supply to Botshabelo and Thaba Nchu already start to occur by 2031, although the resource at that time still has sufficient water in storage.
- Once the indirect re-use option and support from Gariep Dam is in place, the Greater Bloemfontein water balance is for the first time positive, showing some surplus at the time.
- The Gariep Dam transfer thus need to be increased again to approximately 120 Mℓ/d to be able to maintain a positive water balance until 2040.

- The positive water balance between 2026 and 2036 will result in surplus yield available in the system over that period. Operating rules over this period should be adjusted to reduce the pumping volumes that can result in significant savings, without impacting on the assurance of supply.
- As the different intervention options are introduced over time, less and less support from Rustfontein to Bloemfontein is required. Zero support is reached by 2026 when the Gariep Dam transfer starts to deliver water to Bloemfontein, with direct re-use implemented at the same time.
- The adjustment to the monthly return flow distribution to be aligned with the latest observed data, significantly improved the efficiency of the re-use options for Scenario 1, versus the Base Scenario results.
- Groothoek Dam is totally over utilized, resulting in the dam being empty on a frequent basis.

4.6.3. Stochastic analysis Scenario 2

Scenario 2 represents the option where the implementation of interventions were included earlier due to additional grant funding from National Treasury. Indirect re-use at Mockes Dam is implemented two years earlier than for Scenario 1, support from Gariep Dam four years earlier and the direct/indirect re-use option two years earlier. The dates that were provided (for all initial water supply infrastructure including the upgrading of the Maselspoort WTW, Indirect Potable Reuse from Maselspoort WTW, raising of Mockes Dam and the first phase of Gariep WTW) took into consideration the estimated construction periods for the various components to be implemented.

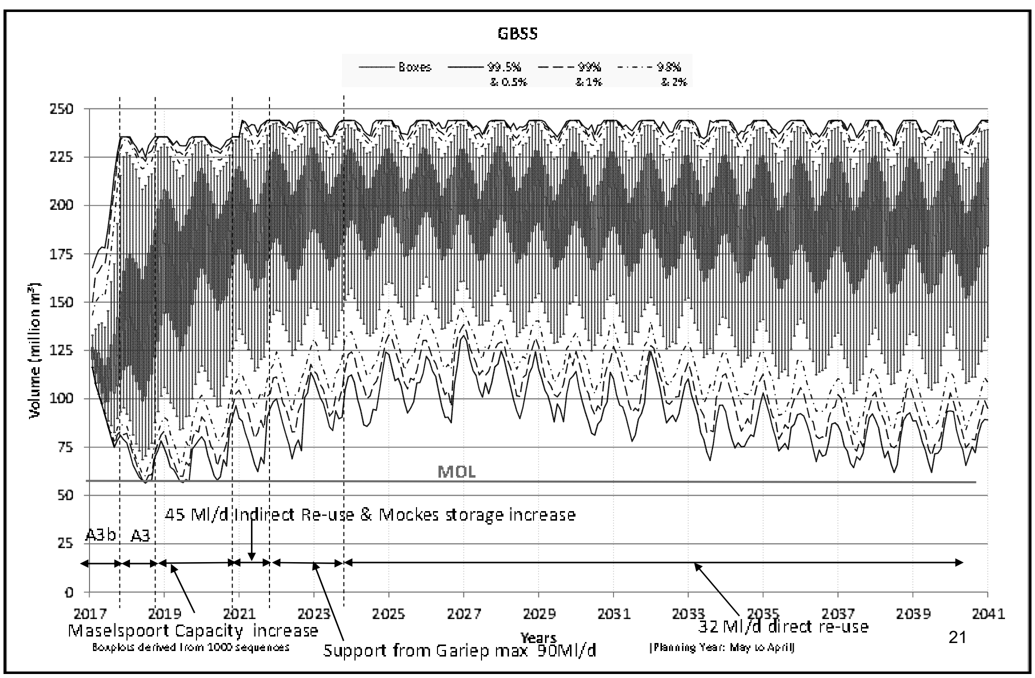


Figure 4-49: Greater Bloemfontein System Storage Projection Scenario 2

This is also evident from the total system storage projection shown in **Figure 4.49** versus **Figure 4.34**, showing an earlier recovery of the system storage from the initial low levels at the start of the analysis and an increased surplus yield available in the system from 2022 to 2034.

The operating rules for Scenario 2, however, remained as defined for Scenario 1.

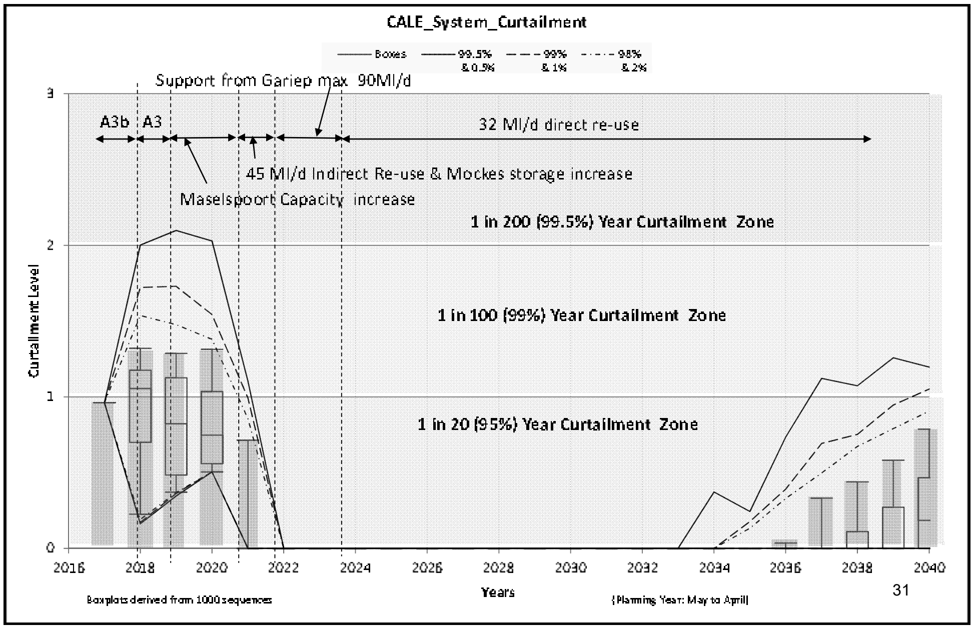


Figure 4-50: Greater Bloemfontein System Curtailment Plot – Scenario 2

The curtailment plot as given in **Figure 4-50** shows that deficits in supply is expected only until 2021 in comparison with 2026 for Scenario 1. Deficits in water supply for Scenario 2 starts again in 2037, although a very small deficit is just starting to show up in 2036. For Scenario 1 deficits also started by 2036.

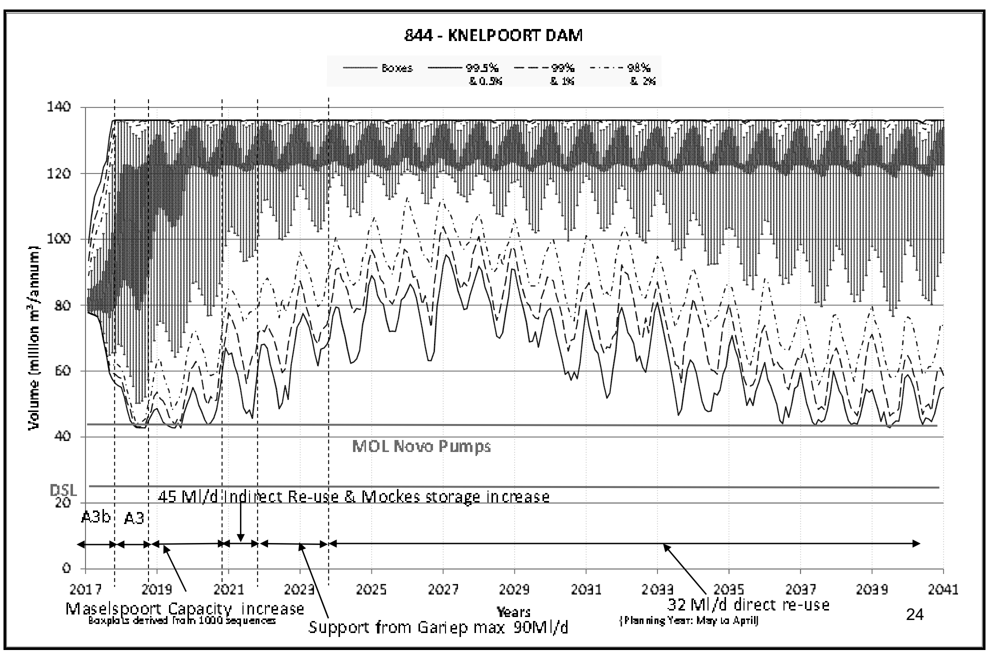


Figure 4-51: Knellpoort Dam storage projection Scenario 2

This indicates that an increased support from Gariep Dam is required from at least 2037 onwards.

The Knellpoort Dam storage projection (**Figure 4.51**) shows a much earlier recovery than that evident from Scenario 1 and allows for the adjustment of the operating rule over the period 2022 to 2035 to achieve a reduction in pumping costs from Tienfontein pumping station.

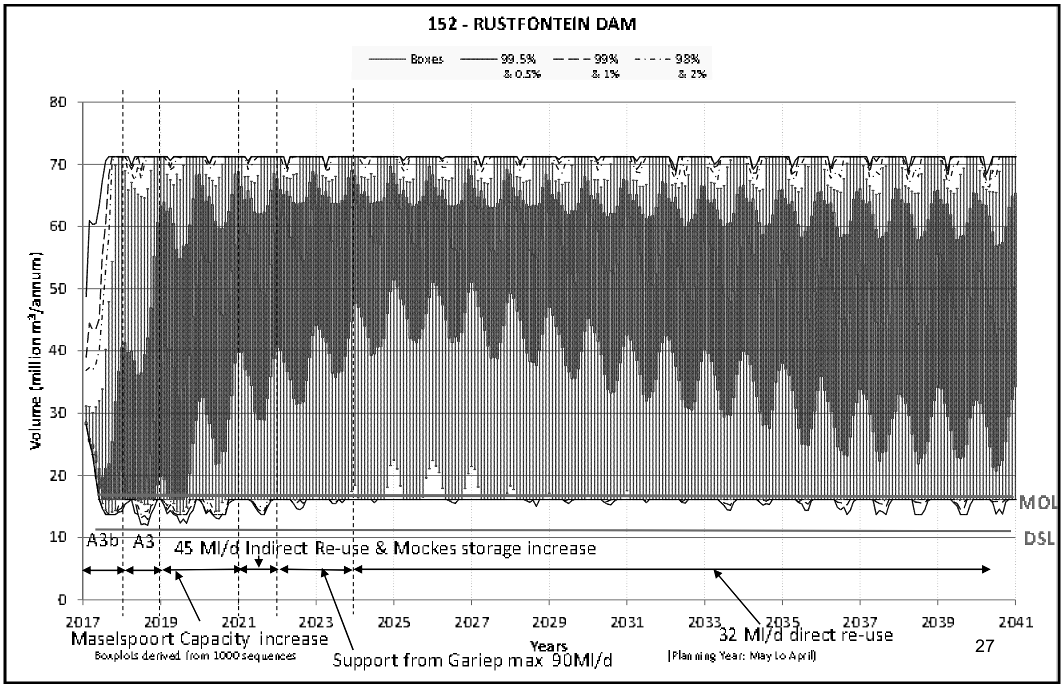


Figure 4-52: Rustfontein Dam storage projection Scenario 2

For Scenario 2 the recovery of Rustfontein Dam (**Figure 4-52**) is a bit slower than for Scenario 1, although Rustfontein Dam is better utilized in Scenario 2. The current operating rule was able to protect the dam from total failure when considering the 1 in 200 and 1 in 100 year drought levels in the dam, as it never reached the dead storage level in the dam.

The water supply to the three main demand centers within the Greater Bloemfontein System (Bloemfontein, Thaba Nchu and Botshabelo) at the required assurance levels are given respectively in **Figures 4-53, 4-54** and **4-55**. The supply to Bloemfontein is better than those obtained for Thaba Nchu and Botshabelo, and is due the maximum capacity of the Rustfontein WTP. The supply to Bloemfontein is fairly in line with the curtailments imposed on the system, with the supply to Thaba Nchu and Botshabelo worse than the curtailments, purely due to the fact that the flow of water to these two towns are restricted by the Rustfontein WTP maximum capacity. Lack in supply to Botshabelo and Thaba

Nchu both started again in 2031, while the curtailment levels were only again exceeded from 2036 onwards.

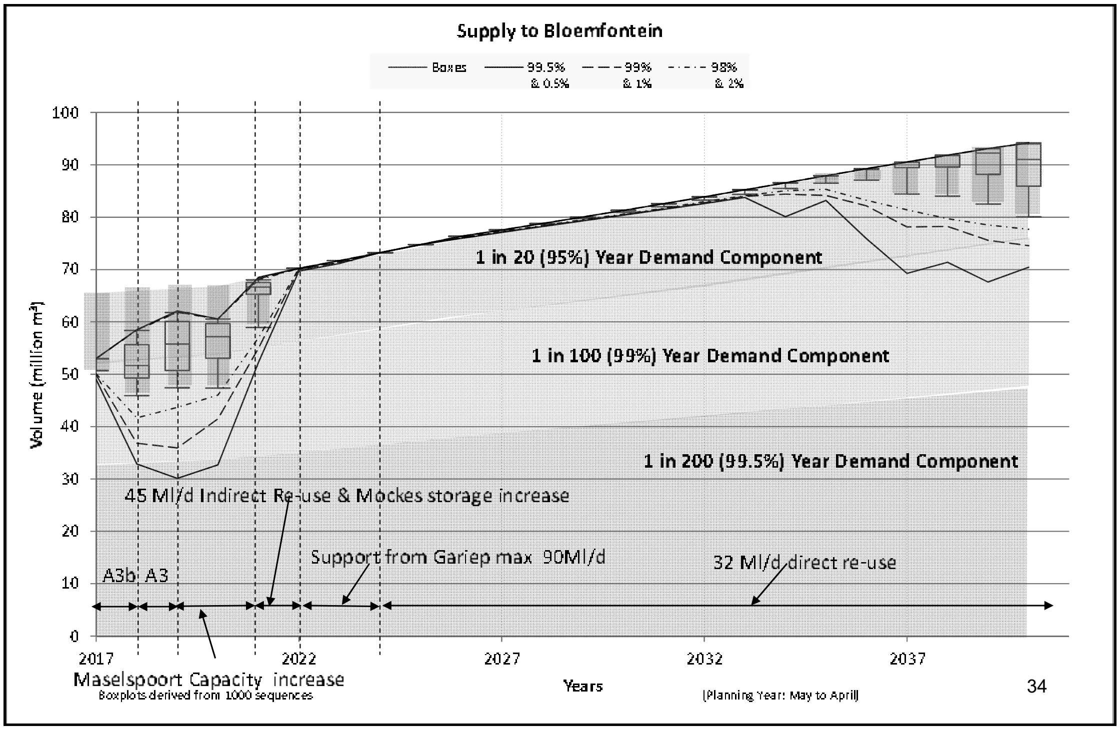


Figure 4-53: Supply to Bloemfontein Scenario 2

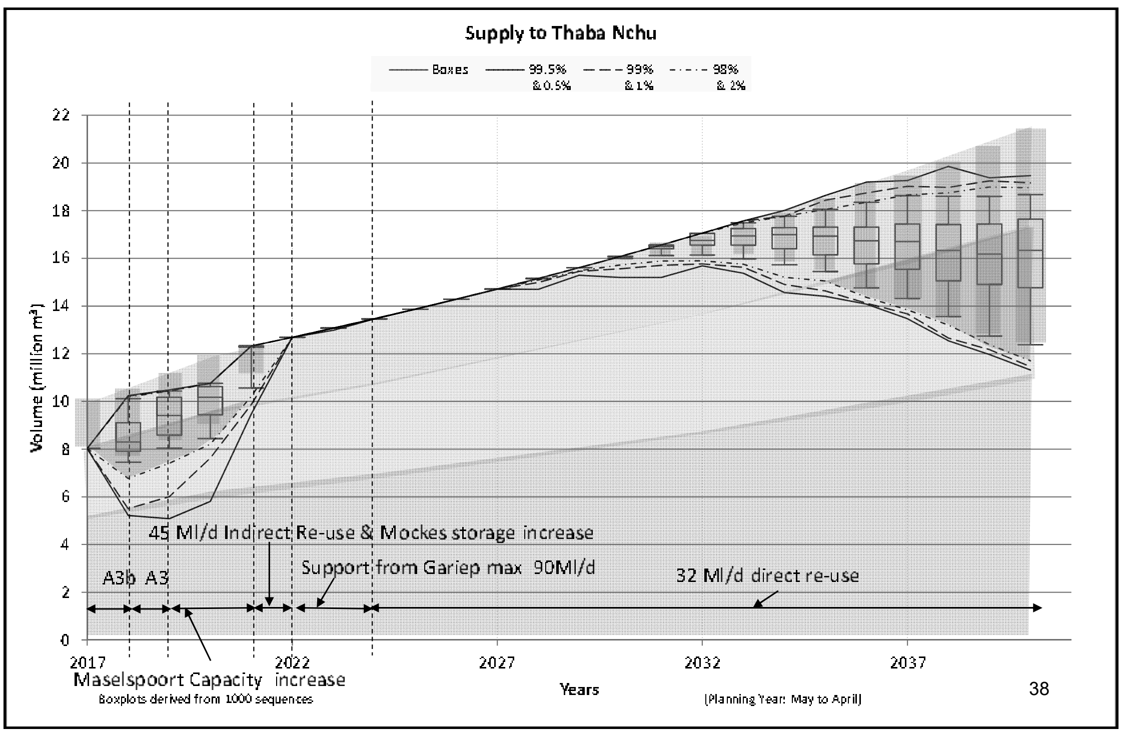


Figure 4-54: Supply to Thaba Nchu Scenario 2

From **Figure 4-56** it is evident that from approximately 2032 onwards the Rustfontein WTP were operating at its full capacity for most of the time. The supply from Rustfontein WTP to Thaba Nchu as depicted in **Figure 4-57** shows a significant reduction in support by 2036 which is as result of the increasing curtailments imposed on the system that exceeded the curtailment criteria by 2036 onwards.

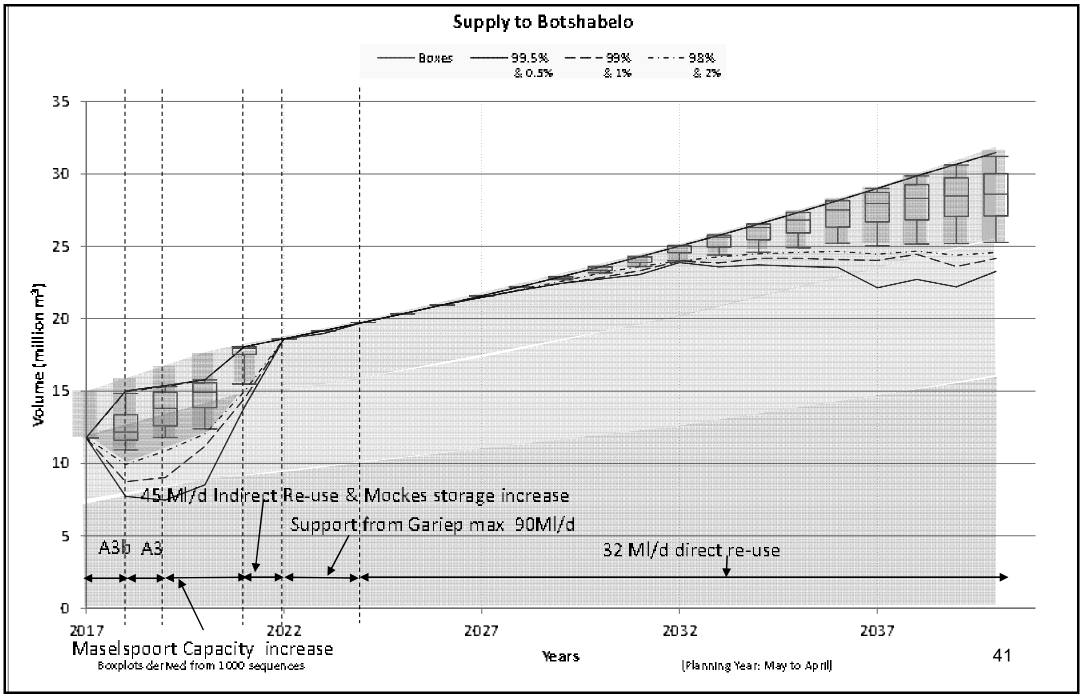


Figure 4-55: Supply to Botshabelo Scenario 2

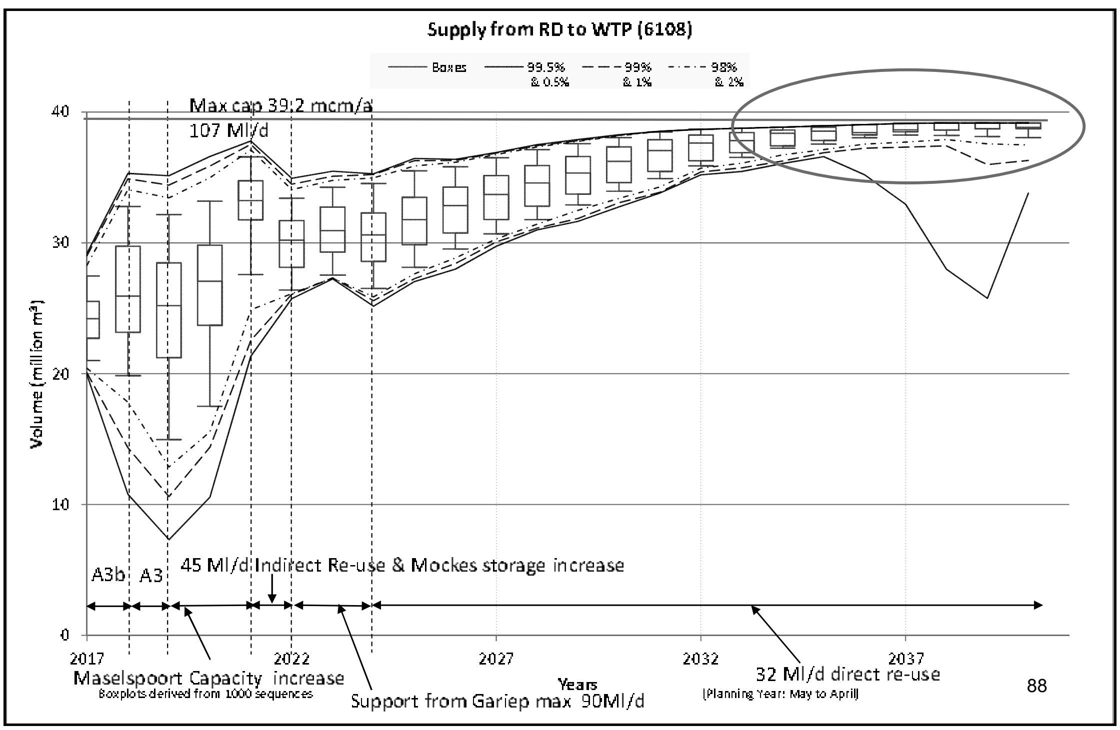


Figure 4-56: Annual supply from Rustfontein Dam to Rustfontein WTP

The annual support from Rustfontein Dam to Bloemfontein for Scenario 2 (see **Figure 4-58**) is for the first five years higher than that evident for Scenario 1 due to the reduced transfer capacity from Welbedacht Dam for Scenario 2 of 100 Mℓ/d versus 128.7 Mℓ/d for

Scenario 1. The exceedance of the curtailment requirements ended by 2022, which resulted in a significant reduction in support from Rustfontein WTP to Bloemfontein.

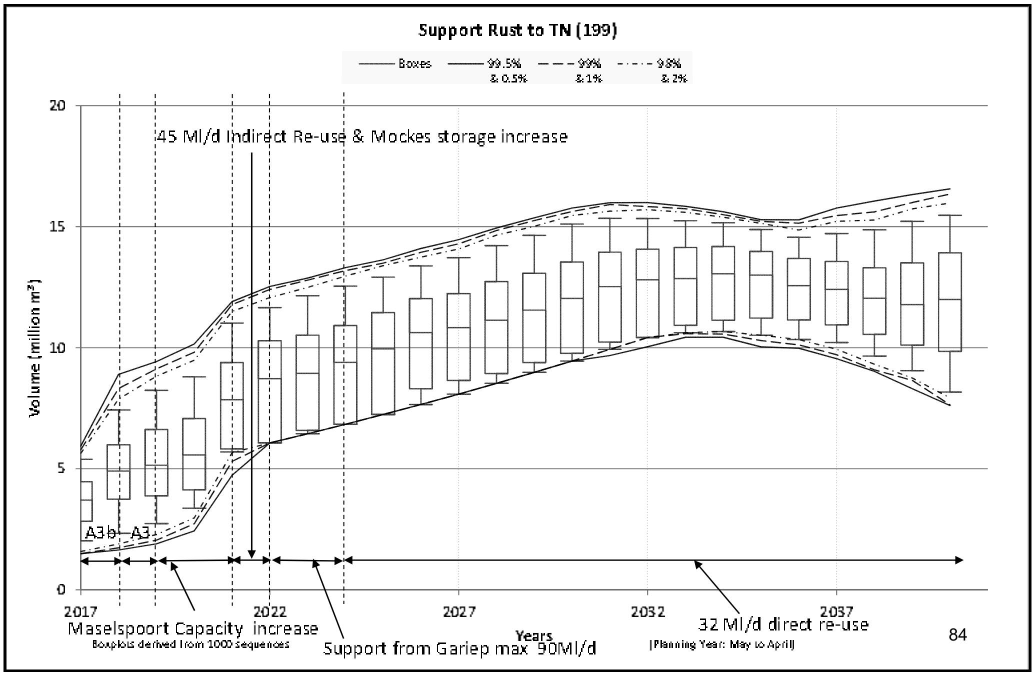


Figure 4-57: Annual support from Rustfontein WTP to Thaba Nchu

For the purpose of this Scenario the support from Rustfontein to Bloemfontein can in fact be discontinued from 2022 onwards, as sufficient support will be available from Gariep Dam by then. One should rather utilize the Bloemfontein support from Rustfontein Dam from 2022 onwards as shown in **Figure 4-58** to support Thaba Nchu and Botshabelo in future.

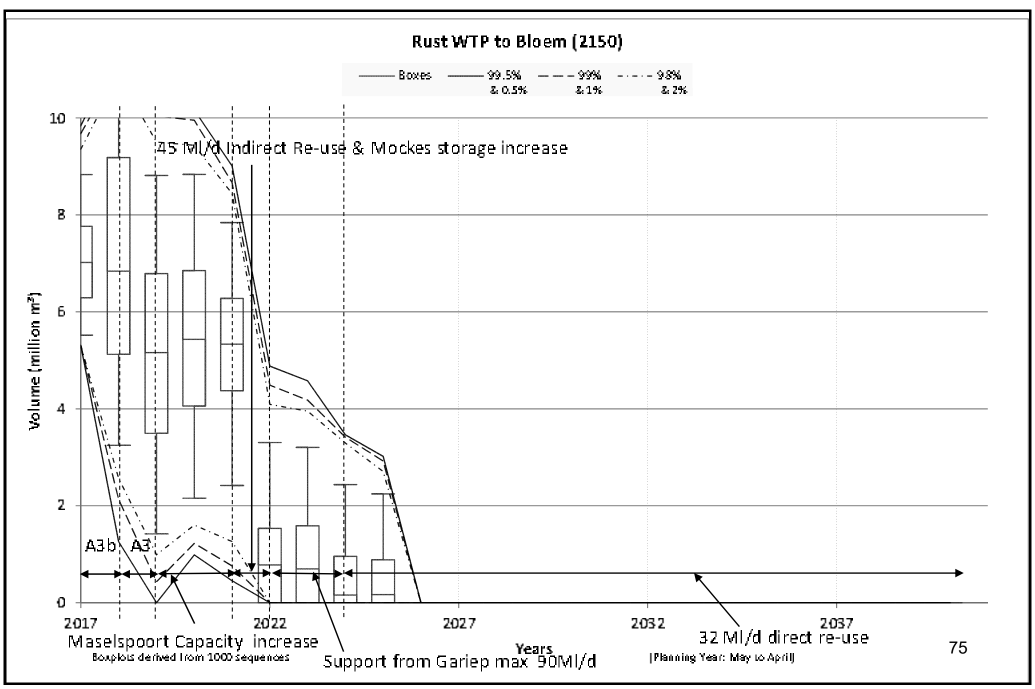


Figure 4-58: Annual support from Rustfontein WTP to Bloemfontein Scenario 2

The pumping from Tienfontein pump station to Knellpoort Dam is in the initial approximately seven years for Scenario 2 (see **Figure 4-59**) slightly higher than that evident from Scenario 1 (**Figure 4-43**). This is as result of the reduced transfer capacity from Welbedacht Dam as implemented for Scenario 2. In general, however, the pumping seems fairly similar.

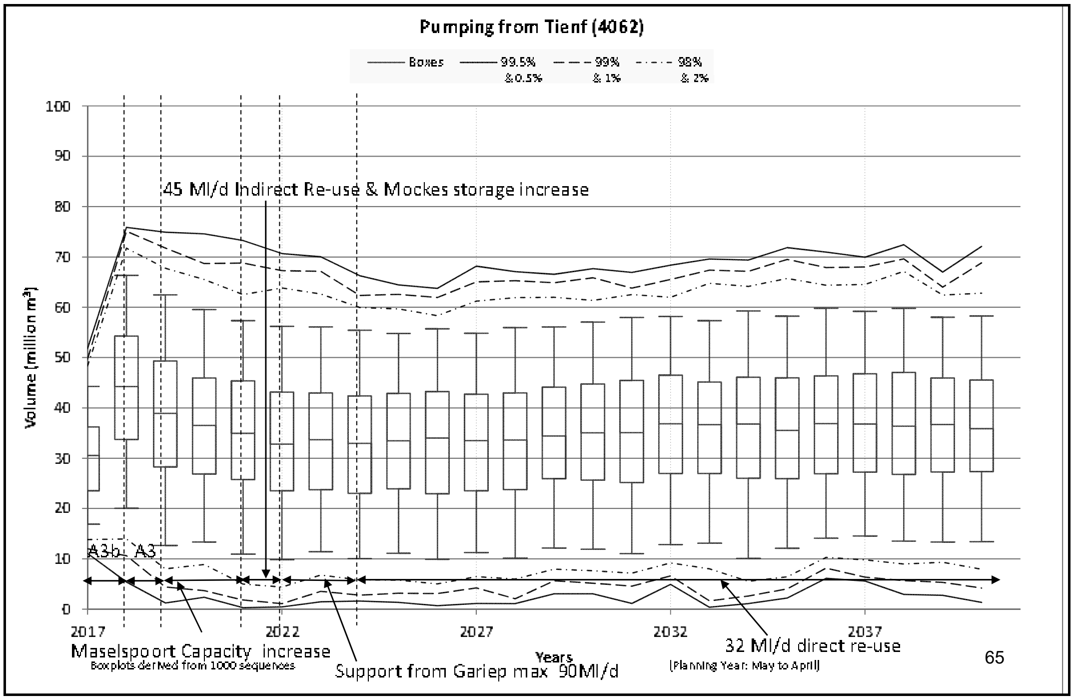


Figure 4-59: Tienfontein annual pumped volumes Scenario 2

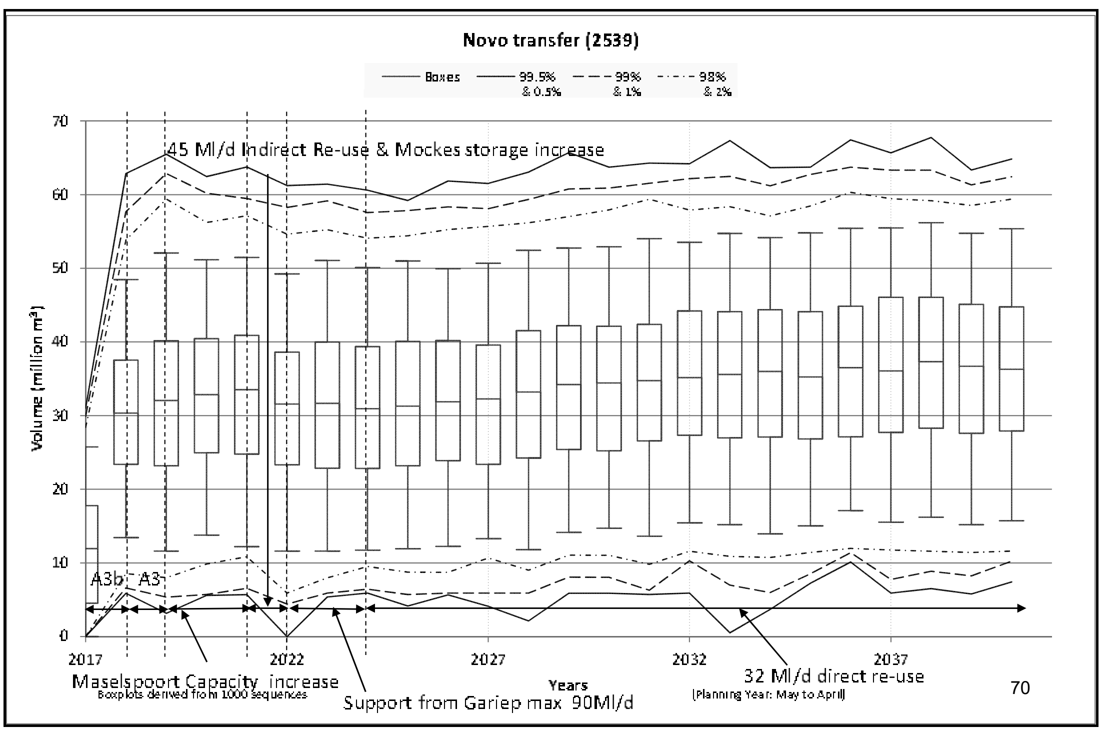


Figure 4-60: Annual Novo transfer volumes Scenario 2

The Novo transfer volumes for Scenario 2 (see **Figure 4-60**) shows a similar impact as observed from the Tienfontein pumping, being somewhat higher than the Novo transferred volumes simulated for Scenario 1 (**Figure 4-44**) as result of the lower transfer capacity from Welbedacht Dam.

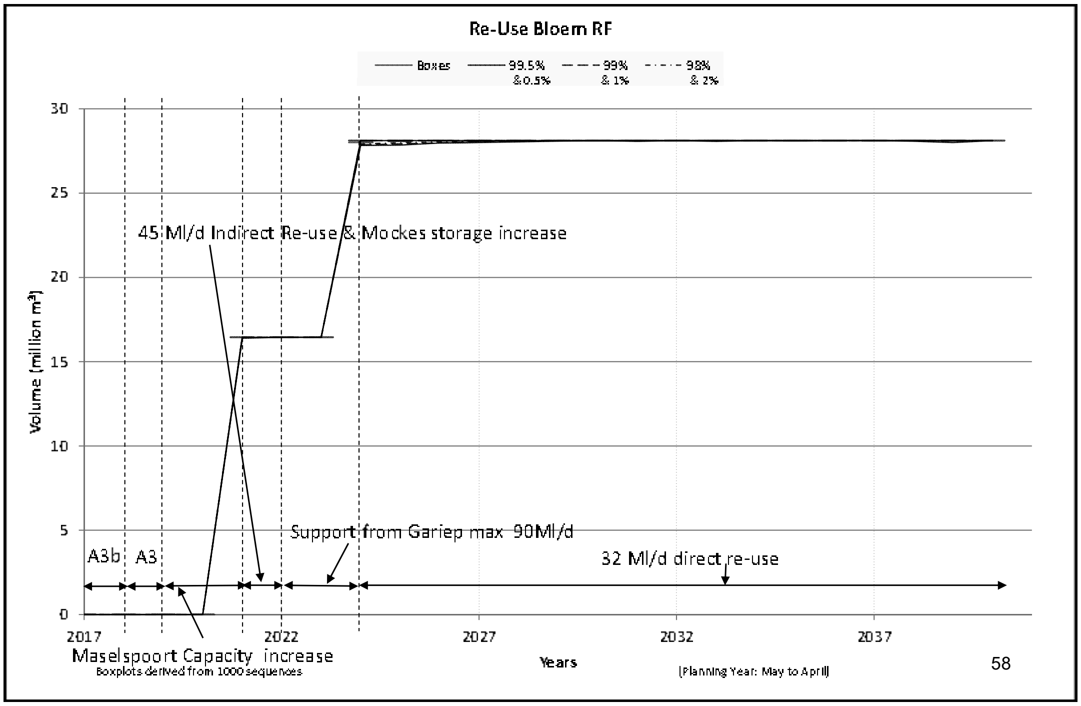


Figure 4-61: Annual Bloemfontein re-use volumes Scenario 2

The indirect and direct water re-use for Scenario 2 (**Figure 4-61**) are starting earlier than for Scenario 1 (**Figure 4-45**) but are still fully utilized over the analysis period.

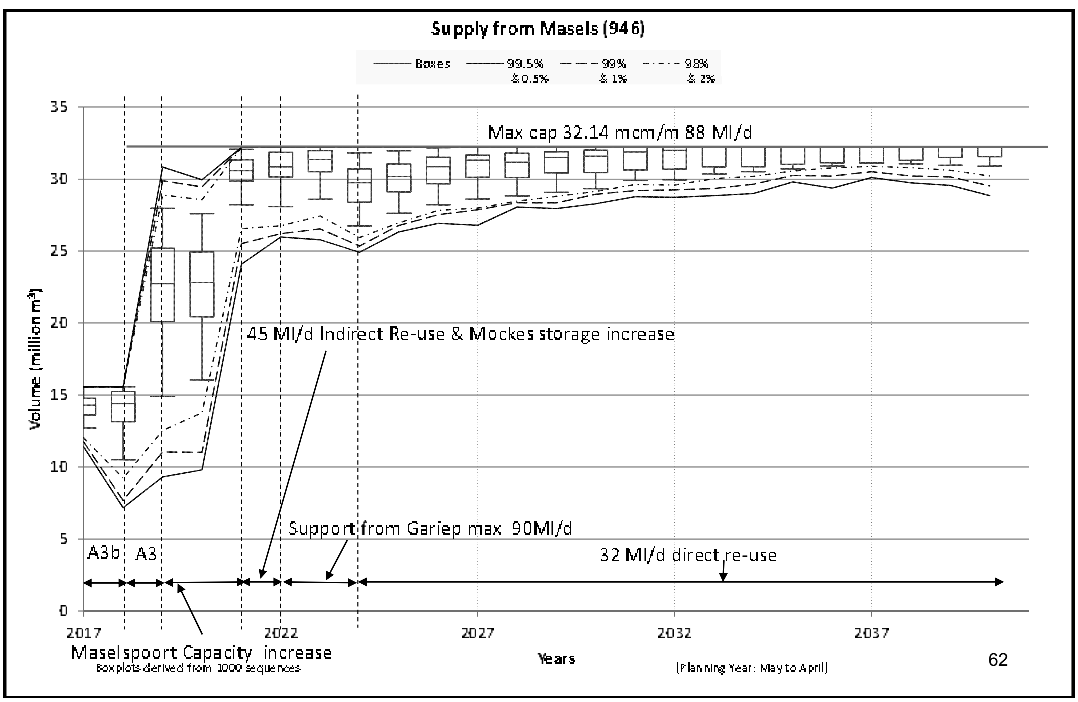


Figure 4-62 : Annual supply from Maselspoort to Bloemfontein Scenario 2

The utilization of water use from Maselspoort (**Figure 4-62**) has improved for Scenario 2 versus Scenario 1 (**Figure 4-46**) but is still limited by the maximum of 88 Mℓ/d allowed for Scenario 2. A higher abstraction capacity should be allowed for, to improve the water use from Maselspoort and to reduce spills from the system.

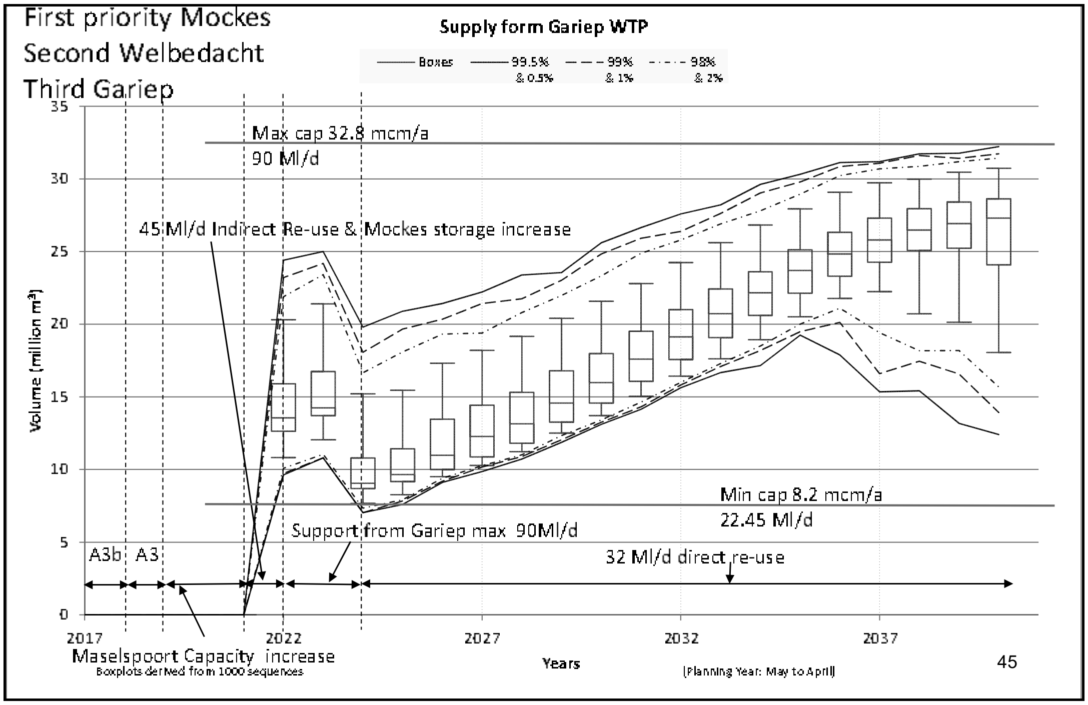


Figure 4-63 : Water supply from Gariep to Bloemfontein Scenario 2

Similar to Scenario 1, Scenario 2 also considered the supply from Gariep Dam as the third priority source with Maselspoort as the first priority and Welbedacht as second priority. The maximum transfer capacity from Gariep Dam to Bloemfontein was taken as 90 Mℓ/d for both Scenarios 1 and 2. By 2040 the total annual support for some sequences (**Figure 4-63**) reached the maximum transfer capacity, which is slightly better than that obtained from Scenario 1. The median transfer for the last two years of the projection reached approximately 27 million m^3/a, which is an improvement to the 22 million m^3/a evident from Scenario 1. Although the supply from Gariep on an annual basis only get close to the maximum capacity by the end of the projection period, it reaches the maximum capacity frequently on a monthly basis, already from the first month of the transfer.

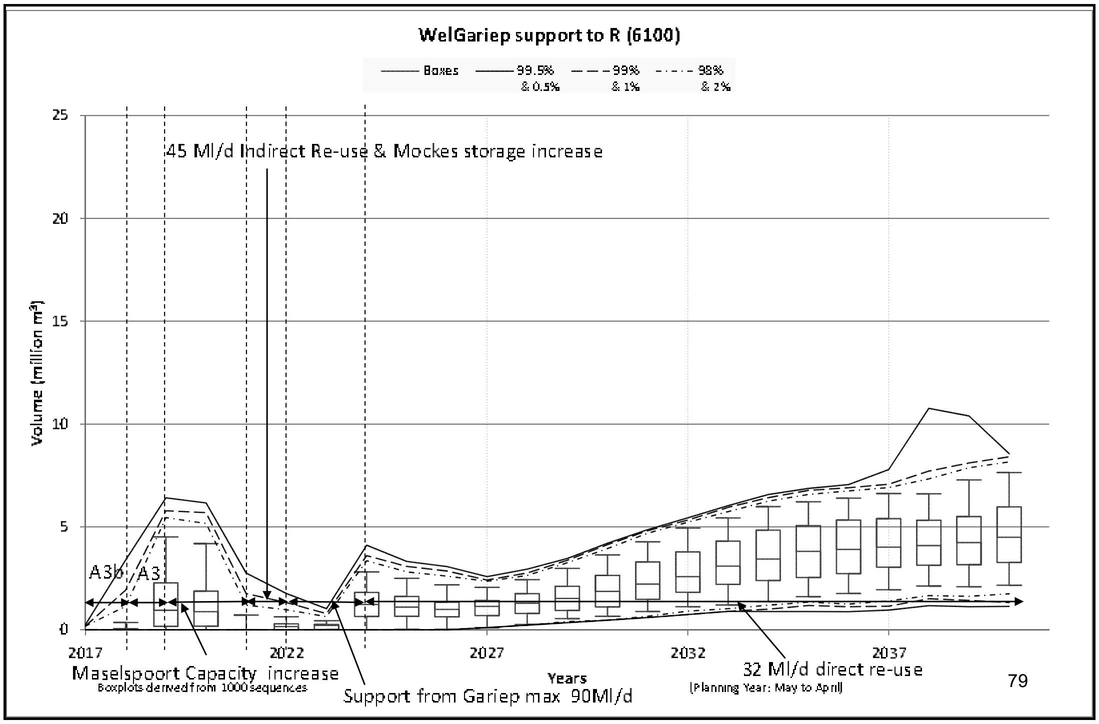


Figure 4-64: Support from Welbedacht / Gariep to Rustfontein WTP Scenario 2

The support from Welbedacht to the Rustfontein supply area reduced significantly for Scenario 2 (**Figure 4-64**), when compared with results from Scenario 1. This is mainly as result of the reduction in maximum capacity of the supply from Welbedacht to 100 Mℓ/d used for Scenario 2 in comparison with 117.7 Mℓ/d for Scenario 1.

Key conclusions and recommendations from Scenario 2 risk analysis results

- Results indicated that deficits in water supply for Scenario 2 are expected to continue until at least 2021 and that deficits is expected to start occurring again by 2037. Scenario 2 therefore represent an improved water supply scenario as deficits will only remain until 2021 in comparison with 2025 for Scenario 1.
- Due to internal capacity constraints such as the Rustfontein WTP, deficits in the water supply to Botshabelo and Thaba Nchu already start to occur by 2031, although the resource at that time still has sufficient water.
- Once the indirect re-use option and support from Gariep Dam is in place, the Greater Bloemfontein water balance is for the first time positive, showing some surplus at the time.
- The Gariep Dam transfer need to be increased again to approximately 120 Mℓ/d to be able to maintain a positive water balance until 2040.
- The positive water balance between 2022 and 2035 will result in a surplus yield available in the system over that period. Operating rules over this period should

be adjusted to reduce the pumping volumes that can result in significant savings without impacting on the assurance of supply.

- As the different intervention options are introduced over time, less and less support from Rustfontein Dam to Bloemfontein is required. Zero support is reached by 2026 for Scenario 2 when the 32 Mℓ/d direct/indirect re-use starts to deliver water to Bloemfontein. Indications from the results are that this cutoff date can occur even earlier by about 2022, without jeopardizing the supply to Bloemfontein.
- The 88 Mℓ/d abstraction limitation on Maselspoort should be increased, as it is resulting in the underutilizing of this resource.
- Groothoek Dam is totally over utilized, resulting in the dam being empty on a frequent basis.

4.6.4. Stochastic analysis Scenario 3

Important differences between Scenario 2 and Scenario 3 include the following:

- Rustfontein WTP capacity limitation was increased to improve the water utilization from Rustfontein Dam.
- Gariep Dam transfer Phase 2 was added increasing the transfer capacity from 90 Mℓ/d to 120 Mℓ/d.
- Maximum abstraction rate from Groothoek Dam was reduced to be in line with the historic firm yield of Groothoek Dam.
- Maximum abstraction rate from Mockes Dam was increased from 88 Mℓ/d to 130 Mℓ/d when Mockes Dam was above 1308.7 masl
- Times of intervention options were adjusted when required.

Several versions of Scenario 3 were analysed trying to obtain the most suitable implementation dates of the different intervention options, as well as trying to supply the users according to their required assurance levels until 2040. Version 3h did obtain the best results of all the different Scenario 3 options that were analysed. Further refinement is still possible, but due to time limitations no further adjustments to Scenario 3 were carried out. Most of the boxplots will thus refer to Scenario 3h.

The Groothoek Dam historic firm yield is just below 1.9 million m^3/a, or 5.2Mℓ/d. This is much lower than the Thaba Nchu WTP capacity of 18 Mℓ/d.

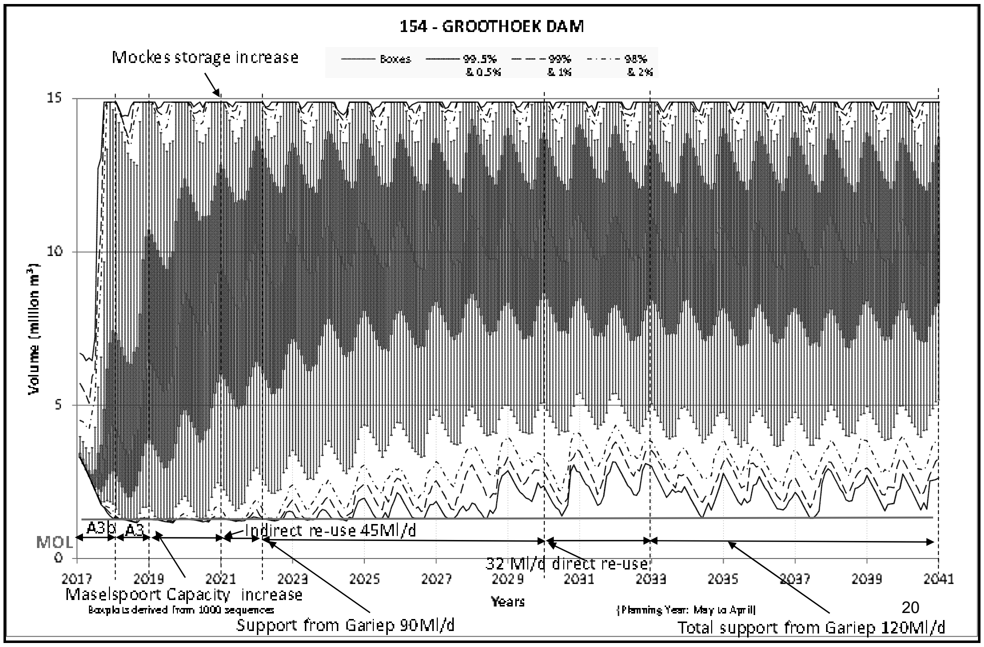


Figure 4-65: Groothoek Dam storage projection Scenario 3h

For Scenario 1 and 2 the treatment capacity was used as the demand imposed on Groothoek Dam, which resulted in frequent failures in the required supply to the Thaba Nchu WTP. For the purpose of Scenario 3, the target draft imposed on Groothoek Dam was taken as 1.9 million m^3/a, or 5.2 Mℓ/d, which is more aligned towards the historic firm yield. This resulted in a much improved storage projection for Groothoek Dam as given in **Figure 4-65**.

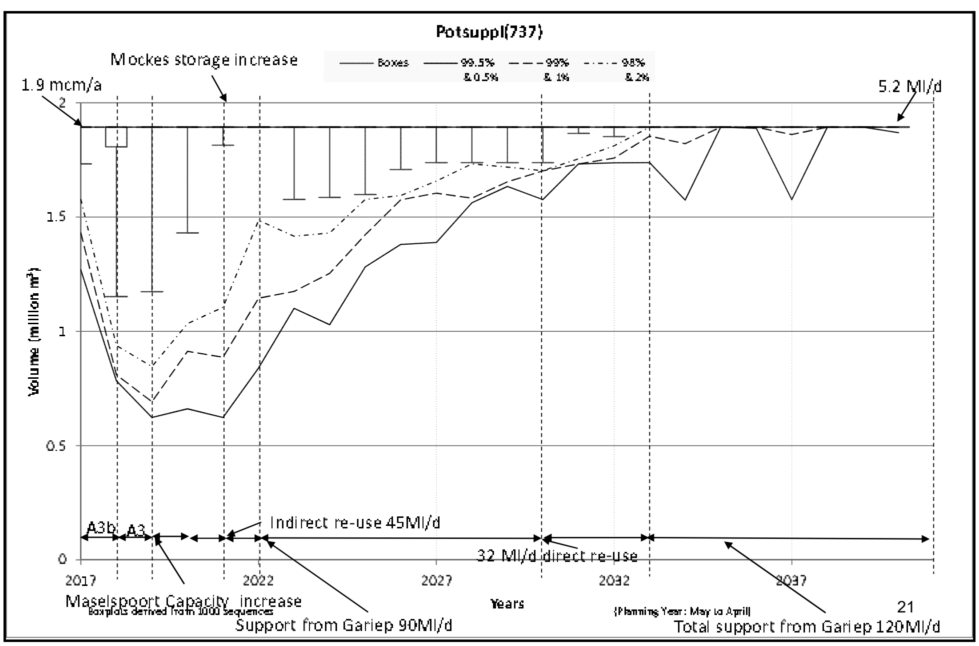


Figure 4-66: Supply from Groothoek Dam to Thaba Nchu WTP

Over time Groothoek Dam was able to recover and started to stabilize by around 2029 onwards, not showing failures at 99.5% exceedance probability levels. The supply from Groothoek Dam to Thaba Nchu is shown in **Figure 4-66**. As the dam is almost empty at the start of the analysis, significant deficits do occur initially, but reduces over time showing the resource to be in balance with the given target demand from about 2031 onwards.

The smaller failures from 2021 onwards is not significant, and only occurs on average once in 20 years, which is acceptable, as the bulk of the water used by Thaba Nchu is supplied from Rustfontein Dam.

Scenario 3 is based on Scenario 2 with refinements included, mainly based on the findings and related recommendations from Scenario 2 (**Section 2.6**). The storage projection of the total Greater Bloemfontein System storage for Scenario 3 is given in **Figure 4-67** and is similar to that obtained from Scenario 2, but do show an improved utilization of the resource. Some surplus yield seems to be available in the system between 2022 and 2030.

The operating rules for Scenario 3, however, remained as defined for Scenario 2 and briefly includes the following:

Bloemfontein.

1. Water is supplied to Bloemfontein, first from the Maselspoort/Mockes Dam sub-system. As soon as re-use is implemented, both re-use and water from Maselspoort will be regarded as first priority. Mockes Dam is not supported by means of releases from Rustfontein Dam.
2. Second priority will be the supply from Welbedacht Dam. Welbedacht Dam is not supported by releases from Knellpoort Dam.
3. Third priority is the supply from Rustfontein, but only until 2021.
4. The Phase 1 transfer from Gariep (90 Mℓ/d) will be in place by 2022 and will then be used as the third priority resource for supply to Bloemfontein, instead of Rustfontein Dam. As it is not practical to stop and start the Gariep Dam transfer system all the time, a minimum flow is always supplied from the Gariep WTP, which is increased at times when required to meet deficits within the system. For the purpose of Scenario 3, the minimum flow for Phase 1 of the Gariep transfer system was set at 0.2 m^3/s or 17.3 Mℓ/d. This was increased to 0.4 m^3/s (34.6 Mℓ/d) at the implementation of Phase 2 when the Gariep Dam transfer capacity is increased to 120 Mℓ/d.

Botshabelo and Thaba Nchu

1. Groothoek Dam is used as priority 1 supply to Thaba Nchu with maximum support limited to 5.2 Mℓ/d.
2. Rustfontein Dam is used as the priority 1 supply to Botshabelo and priority 2 supply to Thaba Nchu. Support from Knellpoort Dam and Tienfontein pump station to Rustfontein Dam is based on the current operating rule.
3. Water from Welbedacht Dam is used as the third and second priority resource to supply Thaba Nchu and Botshabelo, respectively. Supply to Bloemfontein from Welbedacht Dam has priority over the support from Welbedacht to Botshabelo and Thaba Nchu.

From the curtailment plot given in **Figure 4-68** it is evident that the system will be in balance again at the earliest by 2022 when the support from Gariep Dam is implemented. This represents Phase 1 of the Gariep Dam Bloemfontein transfer system and will have a maximum transfer capacity of 90 Mℓ/d.

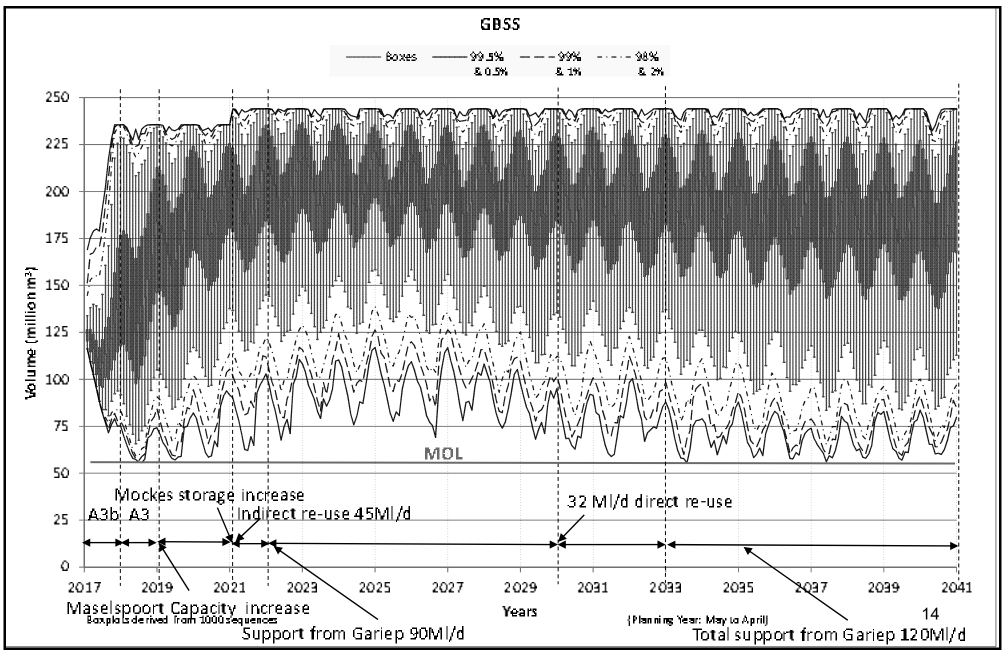


Figure 4-67: Greater Bloemfontein System Storage Projection Scenario 3h

Results from the WRPM analyses showed that the direct/indirect re-use of 32 Mℓ/d is only required by 2030. This need to be followed by Phase 2 of the Gariep Dam to Bloemfontein transfer option by 2033, with a maximum transfer capacity of 120 Mℓ/d (Phase 1 & Phase 2 combined).

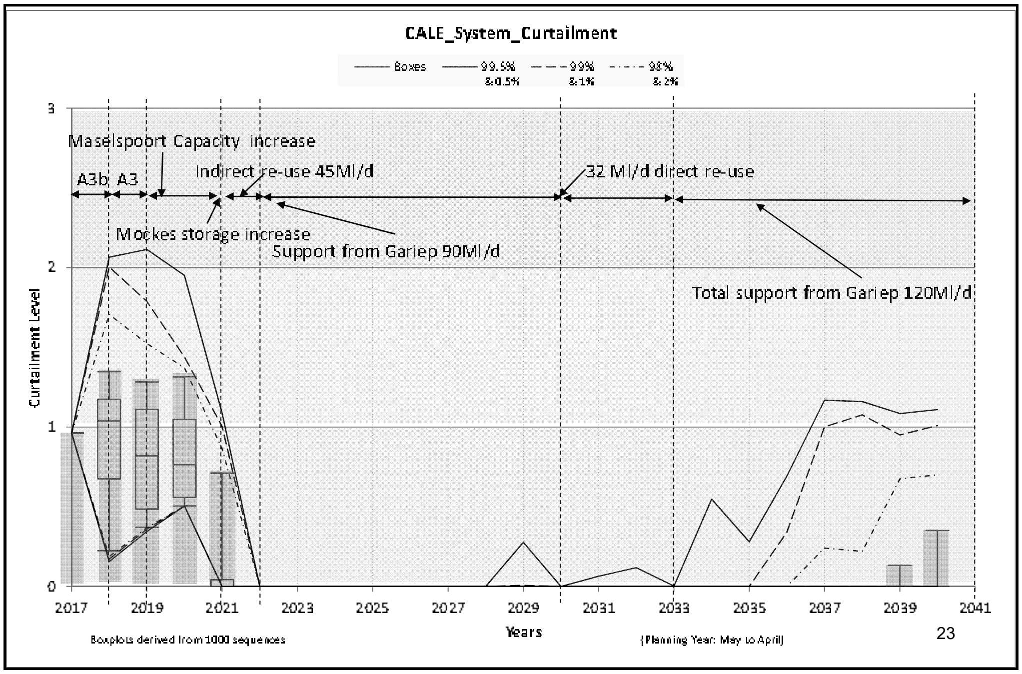


Figure 4-68: Greater Bloemfontein System Curtailment Plot – Scenario 3h

Based on the curtailment plot (**Figure 4-68**) the assurance of supply to the users will be violated again by 2039. It is quite possible that with further refinement of the operating rules, the proposed future development options will be able to provide the required assurance of supply until 2040.

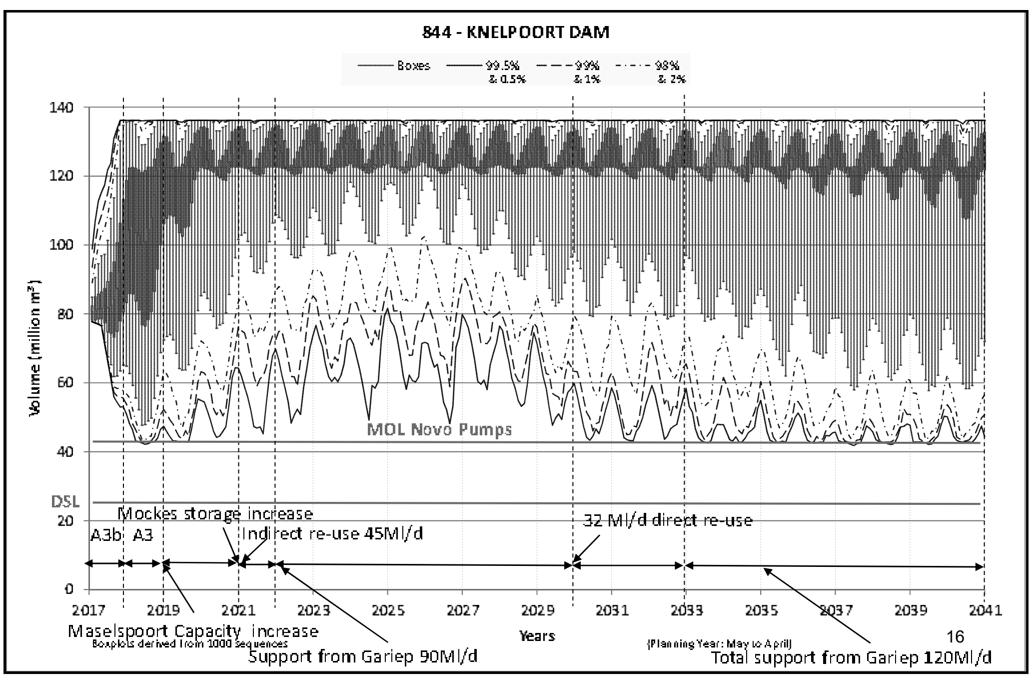


Figure 4-69: Knellpoort Dam storage projection Scenario 3h

Knellpoort Dam storage (**Figure 4-69**) is better utilized by Scenario 3 than that evident from Scenario 2. Some pumping cost savings would be possible between 2022 and 2029

by refinement of operating rules. Towards the end of the simulation period the storage levels in the dam during very severe droughts start dropping to the minimum pumping level of the Novo transfer pumps. At worst, however, the 1 in 200 year (99.5% exceedance) drought storage level just touches the given minimum operating level.
Scenario 3f carried out as a test scenario just before Scenario 3h, excluded a capacity constraint on the water supply from the Rustfontein WTP. This was done as the Scenario 2 analysis showed that there is still some water left in Rustfontein Dam that can be utilized if the capacity constraint of the Rustfontein WTP was increased. Results from Scenario 3f clearly showed that some upper limit for the Rustfontein WTP capacity limit need to be set to not over utilize Rustfontein Dam as evident from **Figure 4-70**.

Figure 4-70 shows that the 99% and 99.5% exceedance probability storage levels in Rustfontein Dam drop below the minimum operating level 2 and reaches the dead storage level from 2035 onwards. Based on this result, Scenario 3f was repeated by again including a capacity limit with the final run now referred to as Scenario 3h. For Scenario 3h, a slightly higher capacity limit of 116 Mℓ/d (raw water) for the Rustfontein WTP was used, than the current capacity limit of 107 Mℓ/d (raw water) or 100 Mℓ/d potable water.

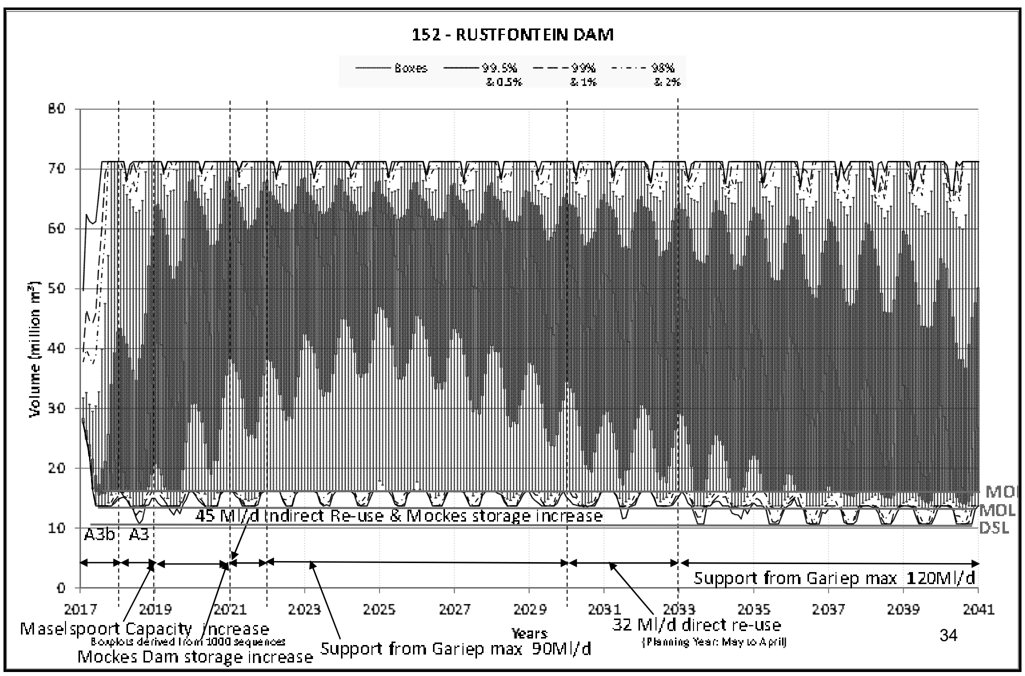


Figure 4-70: Rustfontein Dam storage projection Scenario 3f

This resulted in a much improved storage projection (Scenario 3h) as evident from **Figure 4-71**. The results from Scenario 3h showed that the 99.5% (1 in 200 year) and 99% (1 in 100 year) exceedance probability never touched the dead storage level, although they did drop slightly below the minimum operating level 2 at times. Rustfontein Dam storage is utilized fairly well over the simulation period (Scenario 3h), and slightly better than that obtained for Scenario 2b.

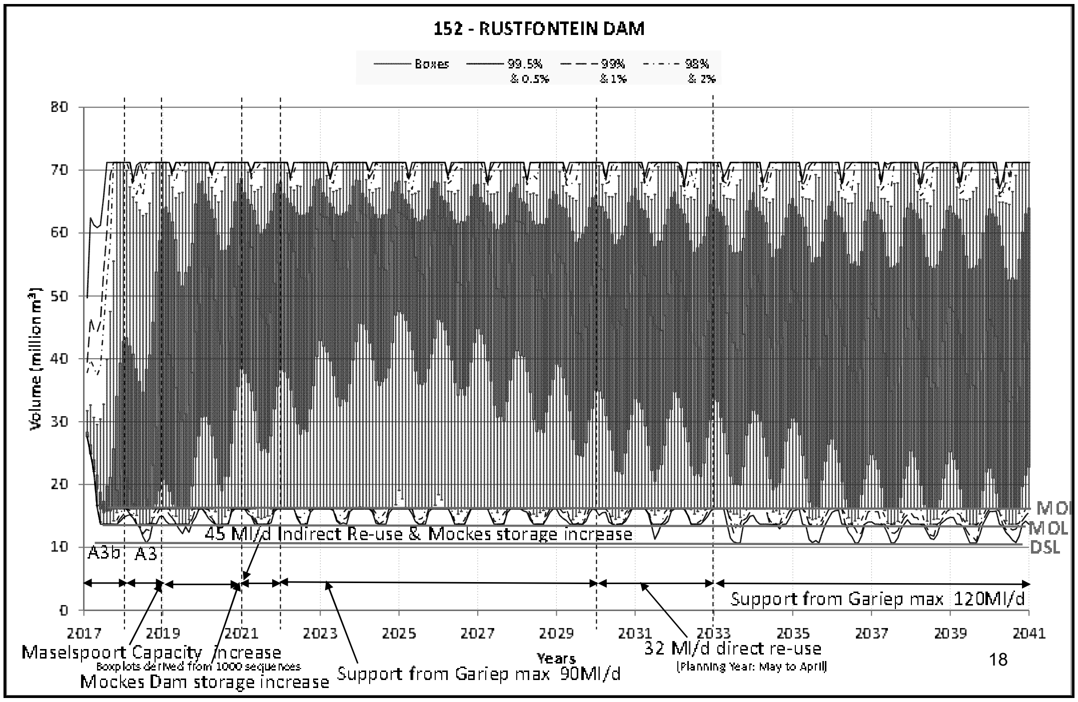


Figure 4-71: Rustfontein Dam storage projection Scenario 3h

Comparing the supply to Bloemfontein (**Figure 4-72**) with the Greater Bloemfontein System curtailment plot (**Figure 4-68**), it is evident that the water supply plot is fully aligned with the curtailment plot. There is thus no internal capacity limitations restricting the water supply to Bloemfontein.

The water supply to Thaba Nchu and Botshabelo as obtained from Scenario 3h shows a significant improvement in the water supply to that obtained from Scenario 2b.

In comparison with the Scenario 3h curtailment graph (**Figure 4-68)** it can be seen that deficits in water supply to Thaba Nchu and Botshabelo started about two years earlier than that indicated by the curtailment graph. This is most probably due to internal capacity constraints or operating rule settings that should be improved or eliminated.

Scenario 3f that excludes the capacity limitation on Rustfontein WTP shows a much higher water usage from Rustfontein Dam of up to 55 million m^3/a by 2040 (**Figure 4-75**) in comparison with only 42.3 million m^3/a for Scenario 3h (**Figure 4-76**). This is clearly one of the capacity limitations preventing sufficient water supply to Thaba Nchu and Botshabelo (**Figure 4-73** and **4-75**).

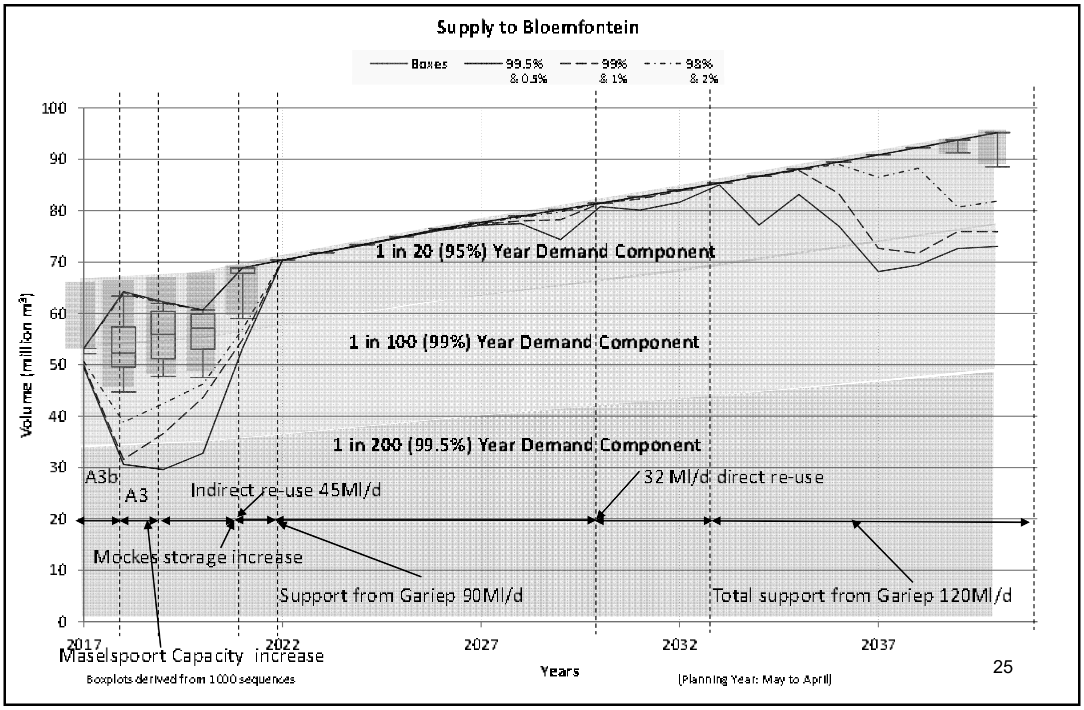


Figure 4-72: Supply to Bloemfontein Scenario 3h

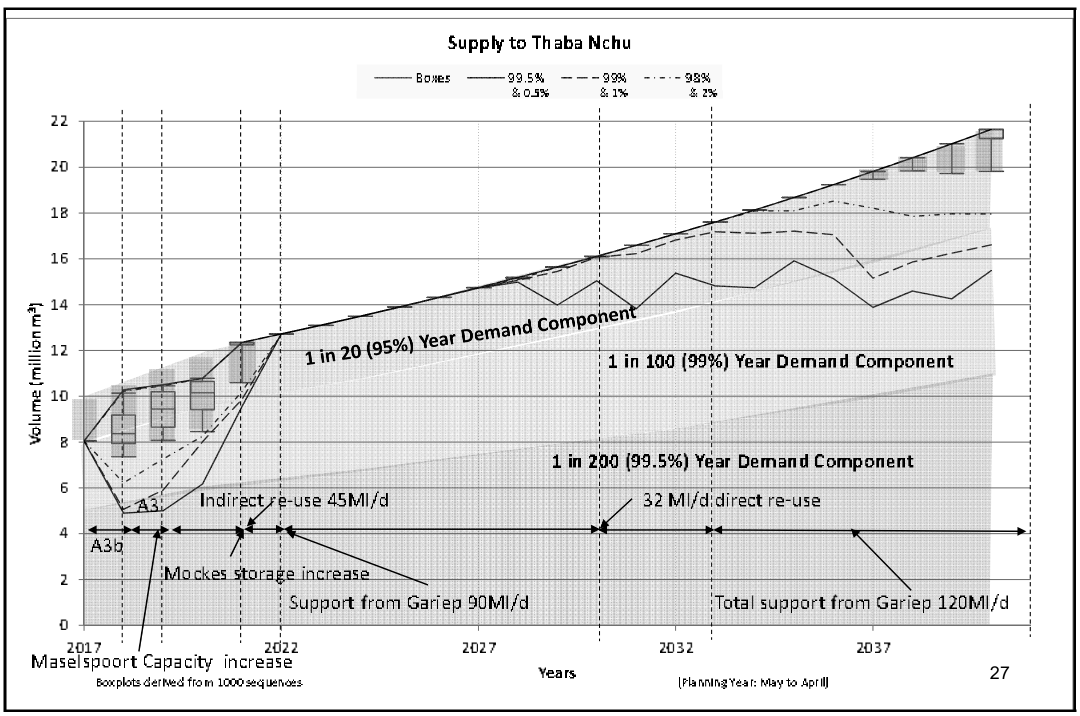


Figure 4-73: Supply to Thaba Nchu Scenario 3h

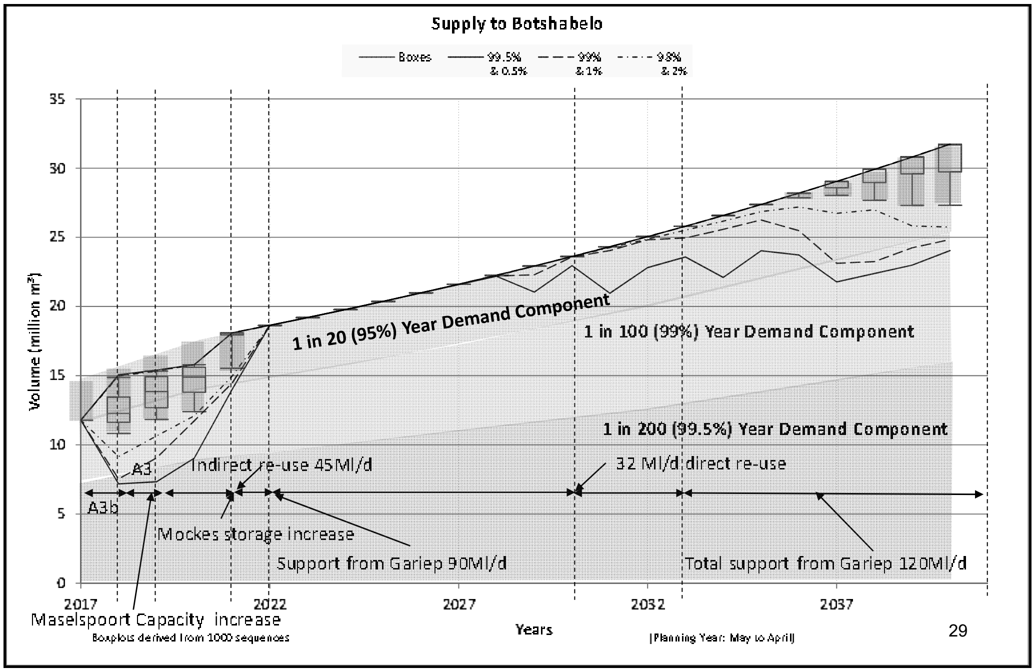


Figure 4-74: Supply to Botshabelo Scenario 3h

Other possible supply constraints could be the support from Welbedacht Dam to the Rustfontein supply area, and or the Gariep Dam support to Bloemfontein that need to be increased to reduce the load on Welbedacht Dam. This will then free up water from Welbedacht Dam to be used in support of Botshabelo and Thaba Nchu.

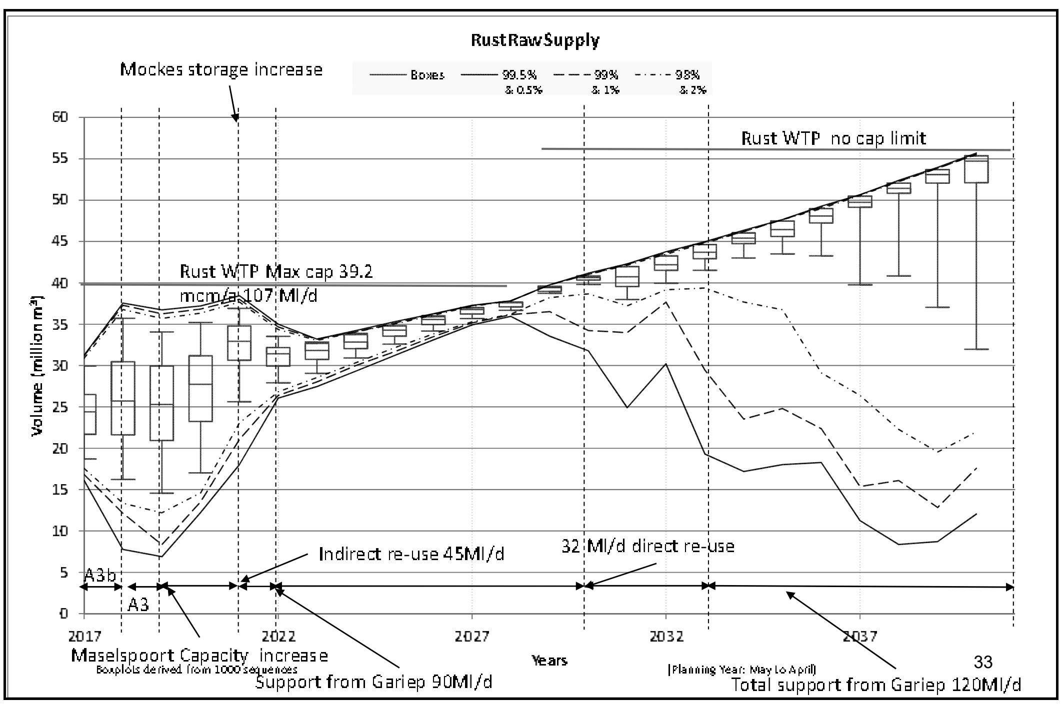


Figure 4-75: Annual supply from Rustfontein Dam to Rustfontein WTP Scenario 3f

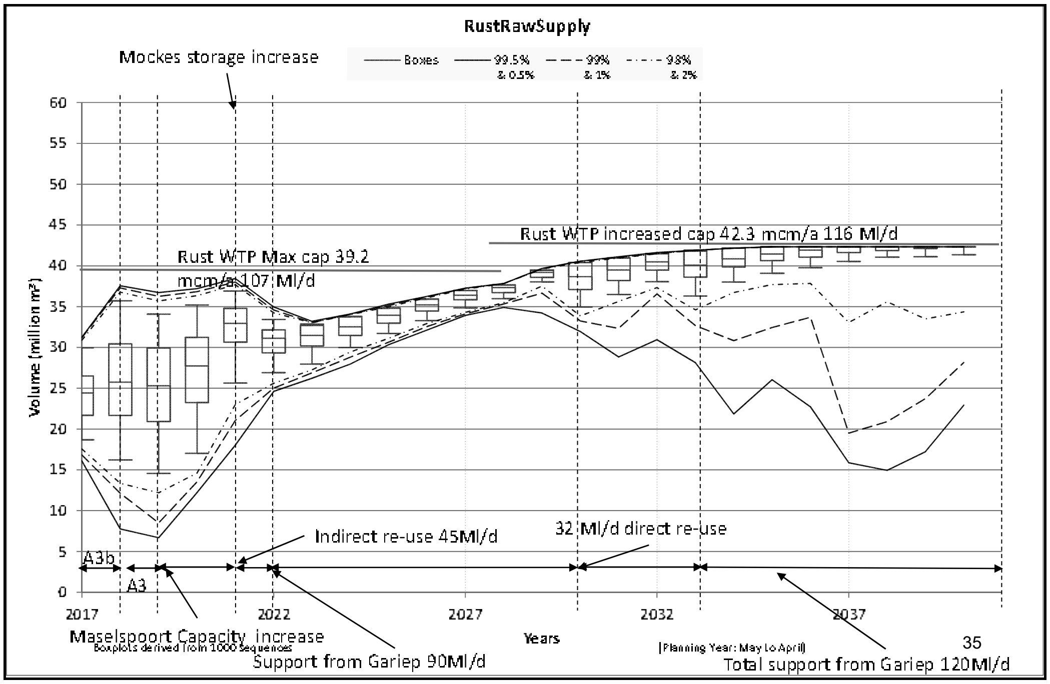


Figure 4-76: Annual supply from Rustfontein Dam to Rustfontein WTP Scenario 3h

Support from Rustfontein to Bloemfontein (**Figure 4-77**) was only required until end of 2022, from when it was taken over by the transfers from Gariep Dam with no negative impact on the supply to Bloemfontein. From 2023 onwards Rustfontein and Knellpoort dams in combination with Tienfontein pump station and Novo transfer scheme, was only used to support Thaba Nchu, Botshabelo and some small towns.

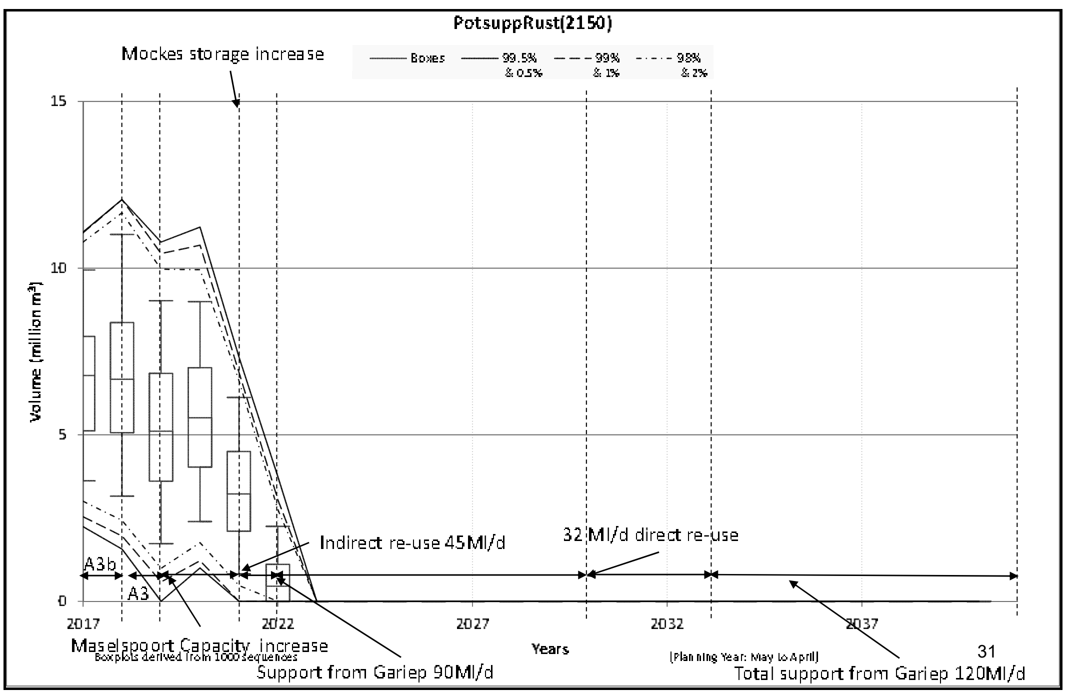


Figure 4-77: Annual support from Rustfontein WTP to Bloemfontein Scenario 3h

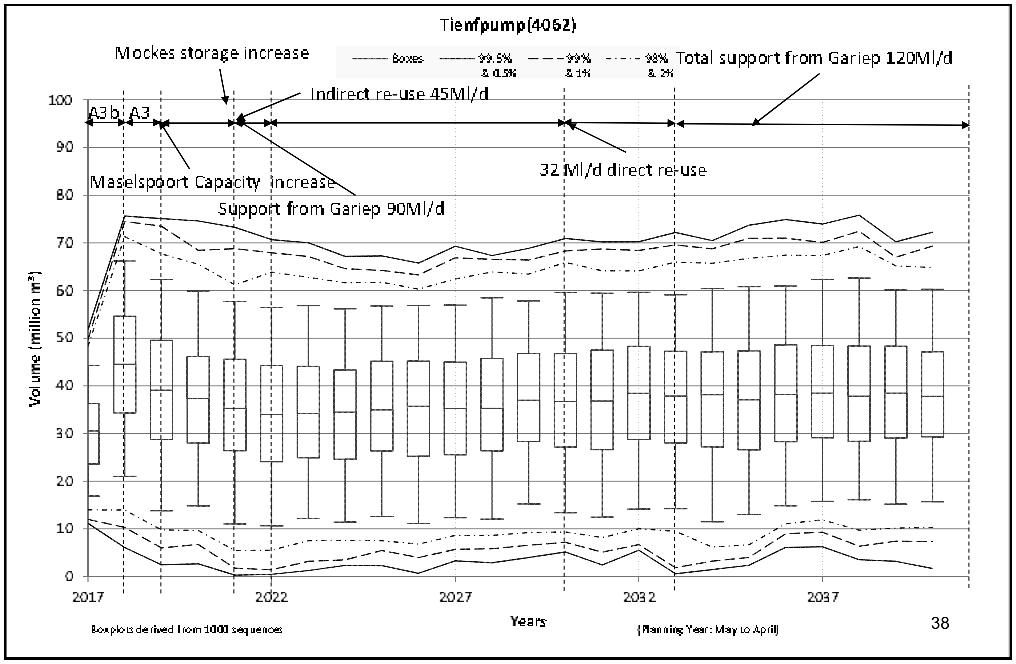


Figure 4-78: Tienfontein annual pumped volumes Scenario 3h

Tienfontein annual projected pump volumes for Scenario 3h (**Figure 4-78**) are similar to those obtained from Scenario 2b, although slightly higher. When viewing the monthly Tienfontein pump volumes as given in **Figure 4-79** it is clear that the maximum pump capacity is reached every year during the summer months when sufficient flow is available in the Caledon River.

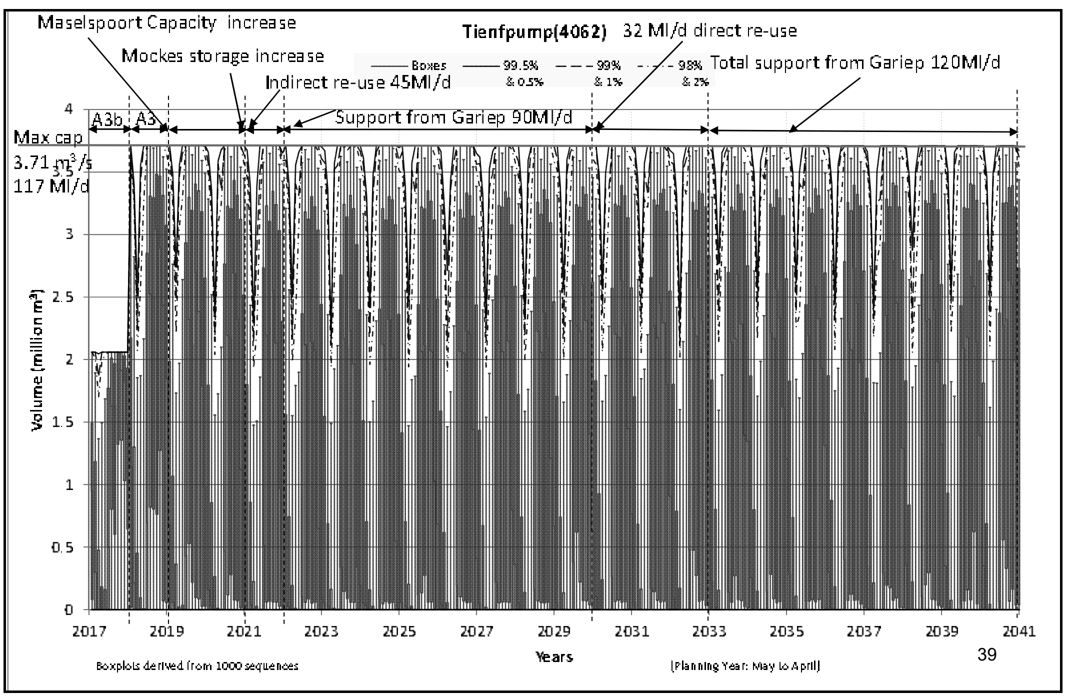


Figure 4-79: Tienfontein monthly pumped volumes Scenario 3h

Due to the much lower Caledon River flows experienced in the winter months it is, however, not possible to reach the maximum pump volume on an annual basis.

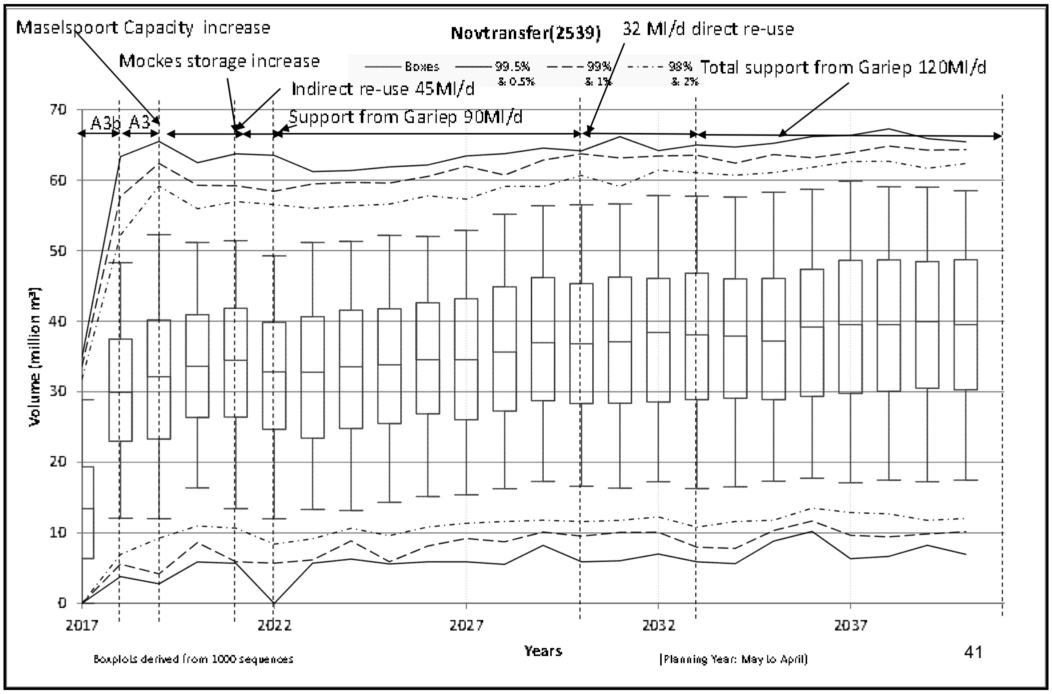


Figure 4-80: Annual Novo transfer volumes Scenario 3h

The Novo transfers for Scenario 3h (**Figure 4-80**) increased over time due to the increase in demands from Thaba Nchu and Botshabelo and is reaching higher annual transfer volumes than those obtained from Scenario 2b. This is due to the improved utilization of Rustfontein Dam, which also resulted in improved water supply to Thaba Nchu and Botshabelo in comparison with Scenario 2b.

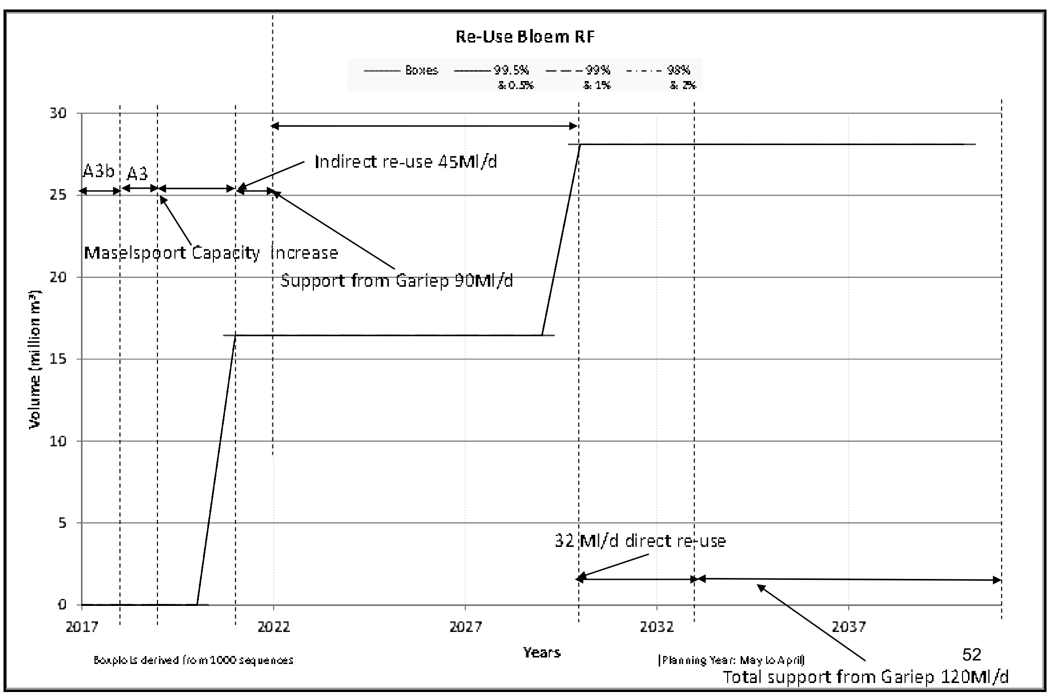


Figure 4-81: Annual Bloemfontein re-use volumes Scenario 3h

Based on recommendation from the Scenario 2 analysis, the direct re-use was for Scenario 3h postponed from 2024 to 2030. This had no negative impacts on the supply to the water users in the system. From **Figure 4-81** it can be seen that both the indirect and direct re-use volumes could be well supplied over the analysis period.

The indirect re-use directly impacts on the water availability from Mockes Dam. Mockes Dam storage capacity was thus also increased at the time the indirect re-use started. Scenario 2b indicated that the maximum abstraction of 88 Mℓ/d was too low to fully utilize the available water from Mockes Dam. For the purpose of Scenario 3h the maximum abstraction was increased to 130 Mℓ/d when Mockes Dam was above the 1308.7 m.a.s.l. and when below that, the maximum abstraction capacity was reduced to 88 Mℓ/d. The annual volume of potable water supplied to Bloemfontein from Mockes Dam via the Maselspoort abstraction point, for Scenario 3h is given in **Figure 4-82**.and shows significantly higher volumes supplied to Bloemfontein than that obtained from Scenario 2b (**Figure 4-62**).

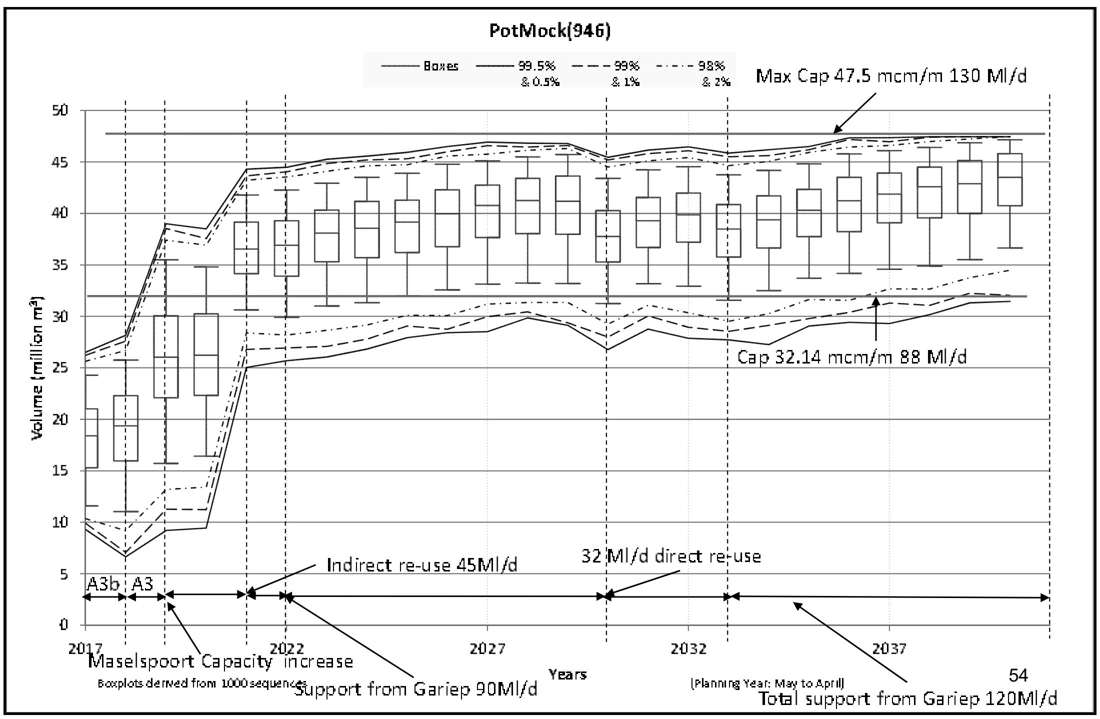


Figure 4-82: Annual supply from Maselspoort to Bloemfontein Scenario 3h

Over the analysis period for most of the years, significantly higher volumes than the 88 Mℓ/d could be supplied to Bloemfontein from Mockes Dam, confirming the need for the higher abstraction capacity.

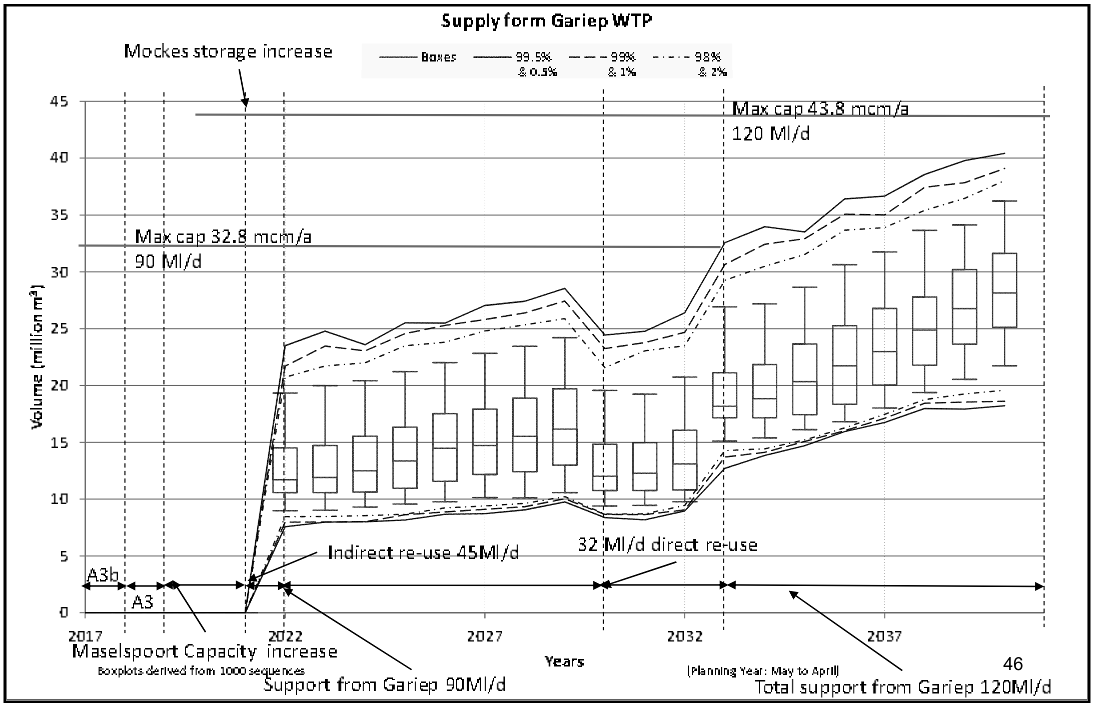


Figure 4-83:Water supply from Gariep to Bloemfontein and small towns Scenario 3h

The annual transfer volume for Scenario 3h required to be supplied from Gariep Dam to Bloemfontein and small towns on the transfer route over the analysis period, is given in **Figure 4-83**. According to the priorities set for Scenario 3, Gariep Dam is the last resource to be used for water supply to Bloemfontein. Water from the other resources will thus be utilized first and only when deficits in the water supply still exist, will water be transferred from Gariep Dam. The small towns on the transfer route however always need to be supplied, as Gariep Dam is their only resource. For practical purposes a minimum supply to Bloemfontein from Gariep Dam was included to avoid zero support from Gariep to Bloemfontein. During phase 1 of the Gariep Dam transfer, the minimum transfer rate was set at 17.3 Mℓ/d (6.3 million m^3/a, or 0.2 m^3/s) and increased to 34.6 Mℓ/d (12.6 million m^3/a, or 0.4 m^3/s) for phase 2 of the Gariep Dam to Bloemfontein transfer scheme. The monthly supply to Bloemfontein (excluding small towns) is given in **Figure 4-84**. The impact of the minimum supply as included for Scenario 3h is clearly evident from the boxplot.

The maximum supply to Bloemfontein is slightly lower than the maximum transfer capacity, as the small towns are supplied first with only the remainder of the transfers used to support Bloemfontein.

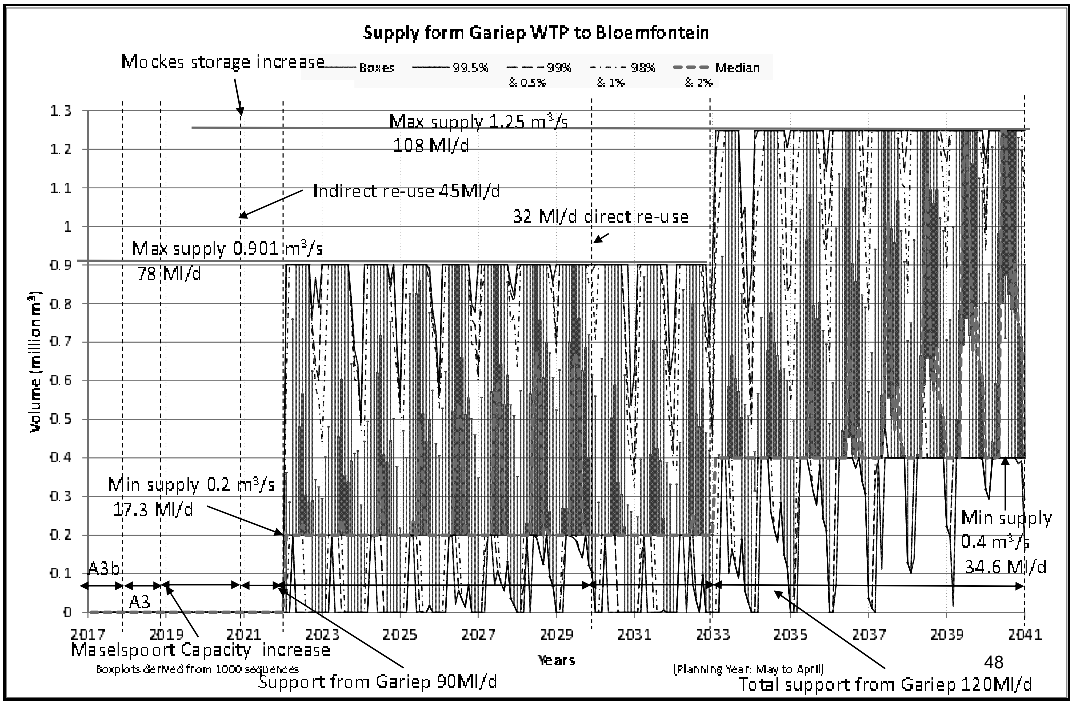


Figure 4-84: Monthly water supply from Gariep to Bloemfontein Scenario 3h

Although it seems that on an annual basis the full capacity of the transfer system is not reached, it is evident from the monthly transfers (**Figure 4-84**) that the maximum capacity is reached in all of the months. The median (red dashed line) of the monthly transfer volumes do increase over time reaching the maximum transfer capacity by 2039.

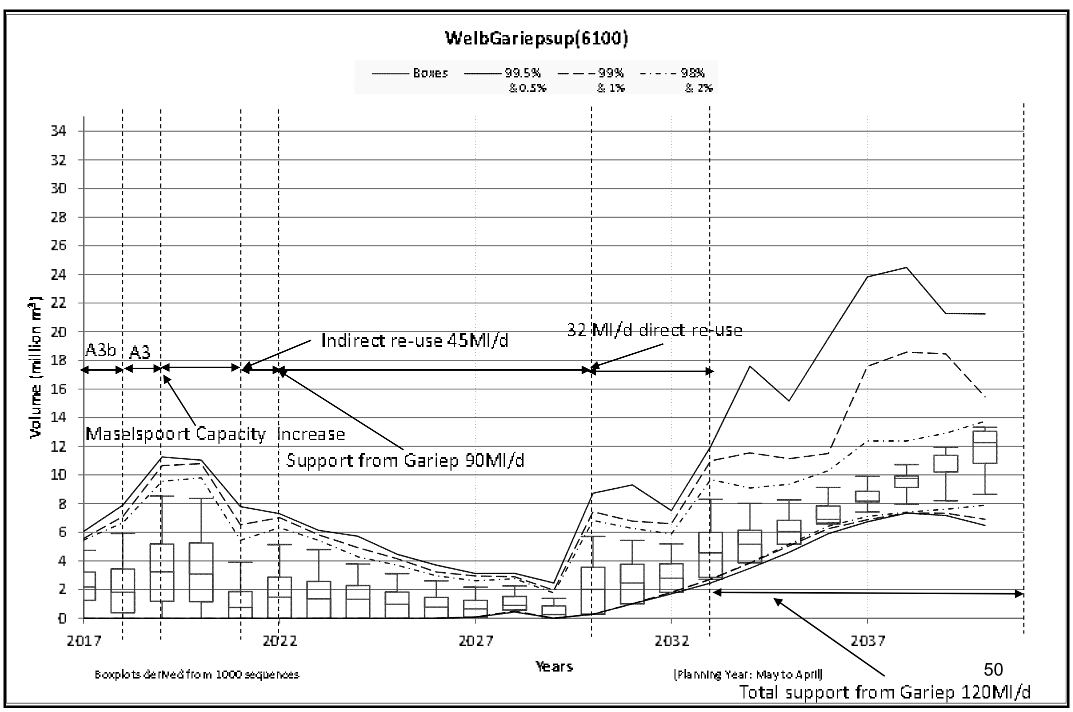


Figure 4-85: Support from Welbedacht / Gariep to Rustfontein WTP Scenario 3h

The support from Welbedacht Dam to the Rustfontein supply area (Botshabelo and Thaba Nchu) increase over the initial 3 to 4 years (**Figure 4-85**) as the system is in a severe deficit with not sufficient water in Rustfontein Dam to supply Botshabelo and Thaba Nchu. With the inclusion of the indirect re-use by 2021, more water is available for supply to Bloemfontein, reducing the load on Rustfontein Dam. More water from Rustfontein Dam is now available to supply Botshabelo and Thaba Nchu, thus requiring less support from Welbedacht Dam to Rustfontein supply area. By 2022 when Gariep Dam Phase 1 transfer is in place, no support from Rustfontein Dam to Bloemfontein is required anymore. The full yield from the Rustfontein/Knellpoort sub-system is now available for Thaba Nchu and Botshabelo, resulting in reduced support from Welbedacht Dam to the Rustfontein supply area. At the time (2030) when the direct re-use is implemented, it is evident that less transfers from Gariep is required as the resources available to Bloemfontein have increased, also making water available from the Welbedacht Dam sub-system to be utilized for support to the Rustfontein supply area, as it is starting to exceed the yield capability of the Rustfontein/Knellpoort sub-system. The support from Welbedacht Dam to the Rustfontein supply area keep on increasing over time in particular when phase 2 of the Gariep Dam Bloemfontein transfer scheme is activated. The yield available from the Rustfontein/Knellpoort sub-system is clearly not sufficient to supply the increasing demands from Botshabelo and Thaba Nchu until 2040 and need more support from the Welbedacht Dam sub-system. The Welbedacht Dam sub-system can however only be used to support the Rustfontein supply area once the transfer from Gariep Dam used to support Bloemfontein is in place, to reduce the load from Bloemfontein on the Welbedacht Dam sub-system.

The support from Welbedacht Dam to the Rustfontein supply area for Scenario 3h is significantly higher than that obtained from Scenario 2b, as evident from **Figure 4-85** and **Figure 4-48**.

The total supply from Welbedacht Dam shows some variability over time as Knellpoort Dam is not used to support Welbedacht Dam. The supply from Welbedacht Dam has slightly reduced in comparison with Scenario 2b, which is most probably due to the improved utilization of Rustfontein Dam as well as the increased support from Gariep Dam.

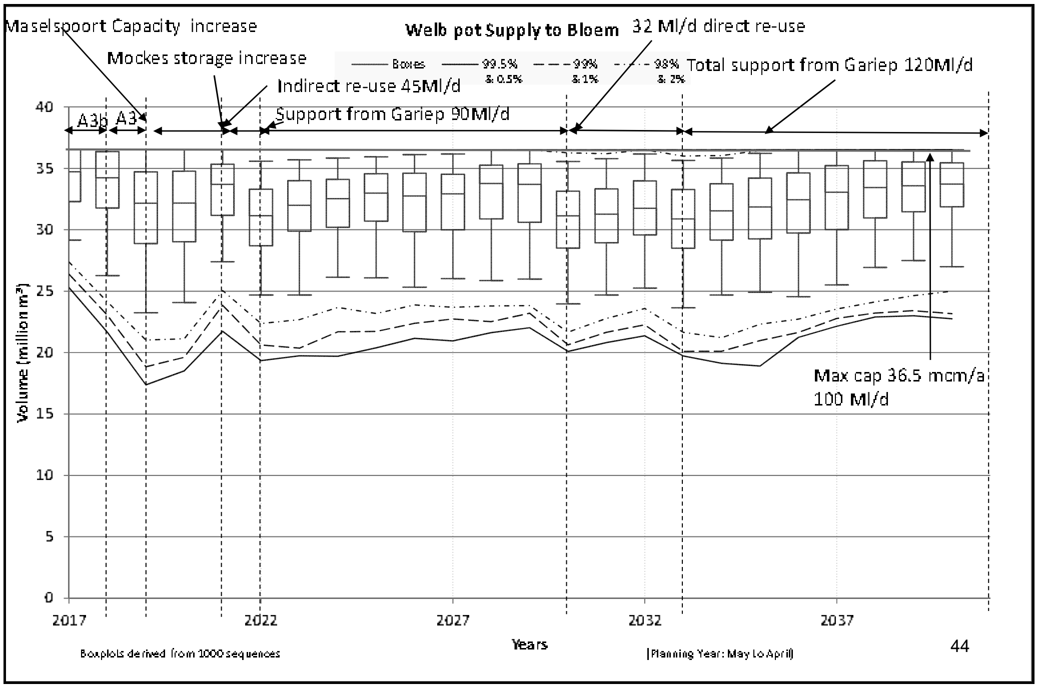


Figure 4-86: Support from Welbedacht to Bloemfontein and Rustfontein supply area – Scenario 3h

Key conclusions and recommendations from Scenario 3 risk analysis results

- Results indicated that deficits in water supply for Scenario 3 are expected to continue until at least 2021 and that deficits is expected to start occurring again by 2039. Scenario 3 in general represents a much improved water supply scenario and it is expected that with some further operating rule refinements, no deficits will be experienced until 2040.
- Results showed that the direct/indirect re-use option need to be phased in only by 2030.
- The time when Phase 2 of the Gariep Bloemfontein transfer need to be activated, is according to the results from Scenario 3 in the order of 2033 to 2035. Further refinement of the operating rule is however required to determine the exact year.
- Groothoek Dam is well in balance with the new target draft of 1.9 million m^3/a, or 5.2 Mℓ/d imposed on the dam.
- When the capacity limitation of the Rustfontein WTP is removed, the supply to Thaba Nchu and Botshabelo improved, but resulted in an overload on Rustfontein Dam.
- Increasing the Rustfontein WTP capacity to 116 Mℓ/d (raw water intake) the performance of Rustfontein Dam improved. Further improvement is required which might eventually be obtained by using the current Rustfontein WTP capacity

as the limitation in combination with more support from the Welbedacht Dam sub-system.

- The increase in water supply from the Mockes Dam sub-system to a maximum of 130 Ml/d when Mockes Dam is above the 1308.7 m.a.s.l., significantly improved the utilization of the available water from Mockes Dam.
- Support from Rustfontein Dam to Bloemfontein can be ended by 2022 without jeopardizing the assurance of supply to Bloemfontein, as the Gariep Dam to Bloemfontein transfer scheme phase 1 will then be in place.
- Deficits in the water supply to Botshabelo and Thaba Nchu occur 1 to 2 years before the violation of the system's curtailment criteria. This shows that more support is required from Welbedacht Dam to the Rustfontein supply area.
- It is recommended that the operating rule be further refined to improve the support from both Welbedacht and Gariep dams. By doing this, one should try to remove the deficits in supply still showing up in the 2039 and 2040 years for Scenario 3h.

5. OVERALL SUMMARY OF RESULTS AND RELATED RECOMMENDATIONS

5.1. YIELD ANALYSES

Key yield results and related recommendations from the yield analyses carried out as part of this study is summarized below:

- The yield (potable water) of the current system with improved operating rule was determined as 218 Mℓ/d (79,6 million m^3/a) when managed properly. This is less than the 2017 water demand of 259 Mℓ/d (94,4 million m^3/a). On top of this the system is experiencing the impacts of a drought which further increases the severity of the deficits currently experienced in the system.
- The yield analyses results showed that the current operating rule used between Knellpoort Dam and Rustfontein Dam could be improved resulting in a higher overall system yield, less pumping by the Novo transfer scheme and less spills from Rustfontein Dam. This rule was then used in the final yield and operating scenarios carried out.
- From the yield analyses results it was clearly evident that proper maintenance of the system and managing the system strictly according to the given operating rules is of utmost importance to fully utilize the available yield from the Greater Bloemfontein system. The manner in which the system was managed in 2016/17 already reduced the system yield by 15%.
- By only increasing Mockes Dam storage from the current 3,58 million m^3 to 12,13 million m^3 storage increased the yield by only 2,1 million m^3/a (5,5 Mℓ/d) before the inclusion of any indirect re-use options. When indirect re-use is added to the system, releasing additional water into Mockes Dam, the smaller Mockes Dam will easily spill, resulting in a reduction in yield that could be obtained by means of the indirect re-use. It is thus more important to raise Mockes Dam when indirect re-use options are considered. This will also assist with the managing and operating of the dam to minimize losses through un-necessary spills from this sub-system.
- The highest system yield of 304 Mℓ/d (111 million m^3/a) potable water was obtained by Scenario C2 which included the improved operating rule, well-managed system and improved Eskom power supply, raised Mockes Dam, increased Maselspoort WTP capacity of 130 Mℓ/d and 77 Mℓ/d indirect re-use.
- The second highest system yield of 299 Mℓ/d (109 million m^3/a) potable was derived from Scenario B3 which included the improved operating rule, well-managed system and improved Eskom power supply, current Mockes Dam, increased

Maselspoort WTP capacity of 130 Mℓ/d, 45 Ml/d indirect re-use and 32 Mℓ/d direct/indirect re-use.

- Yield results clearly showed that the bulk of the water (70%) is supplied from the Caledon River and only 30% from the Modder River. This is due to the much higher availability of water from the Caledon River. Although water from the Caledon River is more expensive due to the pumping costs, it is of high importance to use as much as possible from the resources from the Caledon to be able to obtain the maximum current system yield.
- When considering Scenarios B3 and C2 when the 77 Ml/d re-use is implemented, the contribution from the Caledon reduced to 51%, with approximately 25% from re-use and 24% from the Modder River. Even with the re-use options included, the Caledon River still provides the highest portion of the water requirements.
- Based on the yield results it was estimated that a further 120 Mℓ/d need to be supplied from Gariep Dam to be able to supply the estimated 2040 water requirement of the Greater Bloemfontein System.

From the yield analyses results it was recommended to utilize the following intervention options in the stochastic projection analyses to be carried out:

- Start with the current system that is not maintained properly and not managed strictly according to the given operating rules as well as taking into account the lack in power supply currently experienced.
- Intervention option 1 is to assume that the system is well-maintained and well-managed with the Eskom power supply fully restored.
- Utilizing the increased pumping capacities at Tienfontein and for the Novo transfer scheme.
- Increasing the Mockes Dam storage from 3.58 million m^3 to 12.13 million m^3.
- 45 Mℓ/d indirect re-use releasing water into Mockes Dam.
- Increasing the Maselspoort WTP capacity to 130 Mℓ/d.
- Additional 32 Mℓ/d direct/direct re-use.
- 120 Mℓ/d transfer from Gariep Dam to Bloemfontein with a possibility of two phases. Phase 1 supplying 90 Mℓ/d and Phase 2 increasing the transfer capacity to 120 Mℓ/d.

5.2. STOCHASTIC (RISK) PROJECTION ANALYSES

Although several risk analyses (stochastic projection analyses) were carried out they were focused on only four main projection scenarios:

- **Base projection Scenario**: This was the first test scenario to evaluate the impact of the different intervention options. As the Greater Bloemfontein System is already in deficit, intervention options where phased in as quickly as possible in this scenario. By **May 2018** Novo and Tienfontein pumping capacities increased due to improved Eskom power supply, improvement of the system management and operation, increase of Maselspoort WTP capacity to 130 Mℓ/d, as well as indirect re-use of 45 Mℓ/d. By **May 2020** increase Mockes Dam storage capacity. By **May 2021** increase indirect re-use to 77 Mℓ/d. By **May 2024** activate 120 Mℓ/d support from Gariep.
- **Projection Scenario 1**: This scenario represented the situation when MMM has limited USDG funding and assuming that DWS will be responsible for the implementation of the Gariep to Bloemfontein pipeline with a resulting slower implementation of the intervention options. The implementation dates for the different intervention options was given as:

  By **May 2018** Novo and Tienfontein pumping capacities increased and improvement of the system management and operation. By **May 2019** increase of Maselspoort WTP capacity from 120 Mℓ/d to 130 Mℓ/d. By **May 2021** increase Mockes Dam storage capacity from 3,58 million m^3 to 12.13 million m^3. By **June 2023** 45 Mℓ/d indirect re-use. By **June 2026** 90 Mℓ/d support from Gariep Dam in place as well as the additional 32 Mℓ/d direct/indirect re-use.

  Other important changes relative to the Base Scenario are:
    - Average abstraction from Maselspoort taken as 88 Mℓ/d with peaks of 130 Mℓ/d.
    - Bloemfontein water supply operating rule changed. Now considering Maselspoort abstraction and re-use as the priority one resource, followed by Welbedacht, then Gariep and finally Knellpoort if required.
    - When Gariep Dam pipeline is in place the following small towns also need to receive support from Gariep Dam. (Gariep, Bethulie, Springbokfontein, Philipolis, Trompsburg, Bethanie, Jagersfontein and Fauresmith).

- **Projection Scenario 2**: This scenario represented the situation when MMM received additional funding from National Treasury to assist the Metro to speed up the implementation of intervention options.

  The implementation dates for the different intervention options was given as:

By **May 2018** Novo and Tienfontein pumping capacities increased and improvement of the system management and operation. By **May 2019** increase of Maselspoort WTP capacity from 120 Mℓ/d to 130 Mℓ/d. By **May 2021** increase Mockes Dam storage capacity and indirect re-use by **June 2021**. By **June 2022** 90 Mℓ/d support from Gariep Dam. By **June 2024** direct/indirect re-use of 32 Mℓ/d.

Other important changes relative to Scenario 1 are:

- Support capacity from Welbedacht Dam reduced to 100 Mℓ/d

- **Projection Scenario 3**: Projection Scenario 3 is as Projection Scenario 2 but with some changes made based on the results from the previous projection scenarios. These changes included the following:
  - Average abstraction at Maselspoort 88 Mℓ/d when Mockes Dam is below ± 60%, and when above that increase abstraction to 130 Mℓ/d.
  - Direct/indirect potable re-use by May 2030 as determined from analysis
  - Remove capacity limitation from Rustfontein WTP.
  - Use Groothoek Dam yield as abstraction rate from the dam.
  - Align monthly distribution of water use for Bloemfontein, Botshabelo and Thaba Nchu with latest available information.

Key results and related recommendations from the stochastic (risk) projection analyses carried out as part of this study is summarized below:

- Deficits in water supply to the Greater Bloemfontein System is expected to occur at least until 2020/21 or longer, as it is not possible to activate the intervention options in time to be able to have a balanced system (water requirements versus system yield) before then.
- For all the projection scenarios analysed it is evident that a surplus yield will be available in the system, in particular after the inclusion of the Gariep Dam to Bloemfontein transfer intervention option. Operating rules need to be changed during that period to save pumping costs by avoiding un-necessary pumping from the different available resources.
- Due to the significant growth in water requirements for Botshabelo and Thaba Nchu the support from Rustfontein Dam to Bloemfontein is only available for a limited time into the future. Botshabelo and Thaba Nchu eventually require the full yield available from the Rustfontein/Knellpoort system and towards the end of the projection period also requires significant support from Welbedacht Dam. Projection Scenario 3 indicated that support from Rustfontein Dam to Bloemfontein

can be eliminated by 2022 if at least Phase 1 of the Gariep Dam Bloemfontein transfer is in place by then.

- Results from the Base Projection Scenario showed that a higher priority should be placed on the utilization of the re-use options. This recommendation was built into all the other projection scenarios.
- Base Scenario results highlighted that the monthly distribution pattern of the return flows is quite critical and can impact significantly on the efficiency of the re-use options. These aspects were followed up and actual observed return flow patterns were evaluated. The monthly return flow distribution patterns were adjusted accordingly and provided very positive results. These distribution patterns were then used in all the other projection scenarios, also achieving very good results.
- The Base Scenario projection analysis indicated that the proposed set of intervention options including a 120 Ml/d transfer from Gariep to Bloemfontein will be able to provide the expected growth in water requirements from the Greater Bloemfontein system until the end of 2040.
- Projection Scenario 1 showed that deficits in water supply can be expected until 2024 with a balanced system only achieved by 2025. This can be achieved earlier by Projection Scenario 2, reaching a balance by 2022. Thus 3 years earlier if the MMM receives additional funding from National Treasury to assist the Metro to speed up the implementation of intervention options.
- Both Projection Scenarios 1 and 2 indicated that Thaba Nchu and Botshabelo started to experience deficits in supply earlier than Bloemfontein, as well as earlier than that showed by the curtailment plots. This was due to internal capacity constraints of which the maximum capacity of the Rustfontein WTP seemed to be the most prominent.
- It was clear from both Projection Scenarios 1 and 2 that the 90 Mℓ/d Gariep Dam to Bloemfontein transfer capacity was not sufficient to obtain a positive water balance until the end of 2040 and deficits already started to show up as early as 2032.
- Projection Scenario 1 and 2 results showed that the 88 Mℓ/d limitation on the abstractions from Maselspoort, resulted in the underutilization of Mockes Dam as resource flowed by increased spills from Mockes Dam. It was therefore recommended to change this operating rule when analyzing Projection Scenario 3.
- The Base Projection Scenario as well as Scenarios 1 and 2 all showed that Groothoek Dam is totally over utilized when the Groothoek WTP capacity was imposed as a demand on the dam. It was recommended to determine the firm yield of Groothoek Dam and to impose that on Groothoek Dam as a demand for Projection Scenario 3.

- Projection Scenario 3 provided good results showing that the Greater Bloemfontein System is in balance from 2022 to 2038 with small deficits starting to occur again by 2039.
- When the capacity limitation of the Rustfontein WTP was removed, Projection Scenario 3 showed that the supply to Botshabelo and Thaba Nchu was similar to that achieved by Bloemfontein. It, however, indicated that the maximum volume to be supplied from Rustfontein by 2040 increased to 56 million m^3/a in comparison with the current WTP capacity of 39.2 million m^3/a (107 Mℓ/d) raw water intake. This resulted in an overutilization of Rustfontein Dam. It was thus recommended to include some capacity limit for the Rustfontein WTP to obtain a more realistic result. A capacity limit of 42.3 million m^3/a (116 Mℓ/d) was finally used, which provided satisfactory results.
- With the capacity limit of 42.3 million m^3/a (116 Mℓ/d) imposed on the Rustfontein WTP, slight deficits in supply were experienced at Botshabelo and Thaba Nchu about two years earlier than for Bloemfontein. Further refinement of operating rues will be required to obtain a good balance in the supply to these three main demand centers.
- The improved operating rule for Mockes Dam, allowing a limited abstraction of 88 Mℓ/d when Mockes is below 1308,7 masl and increasing to 130 Mℓ/d when above the given level, significantly increased the utilization of the water resources from Mockes Dam.

From the projection risk analyses results it is recommended to:

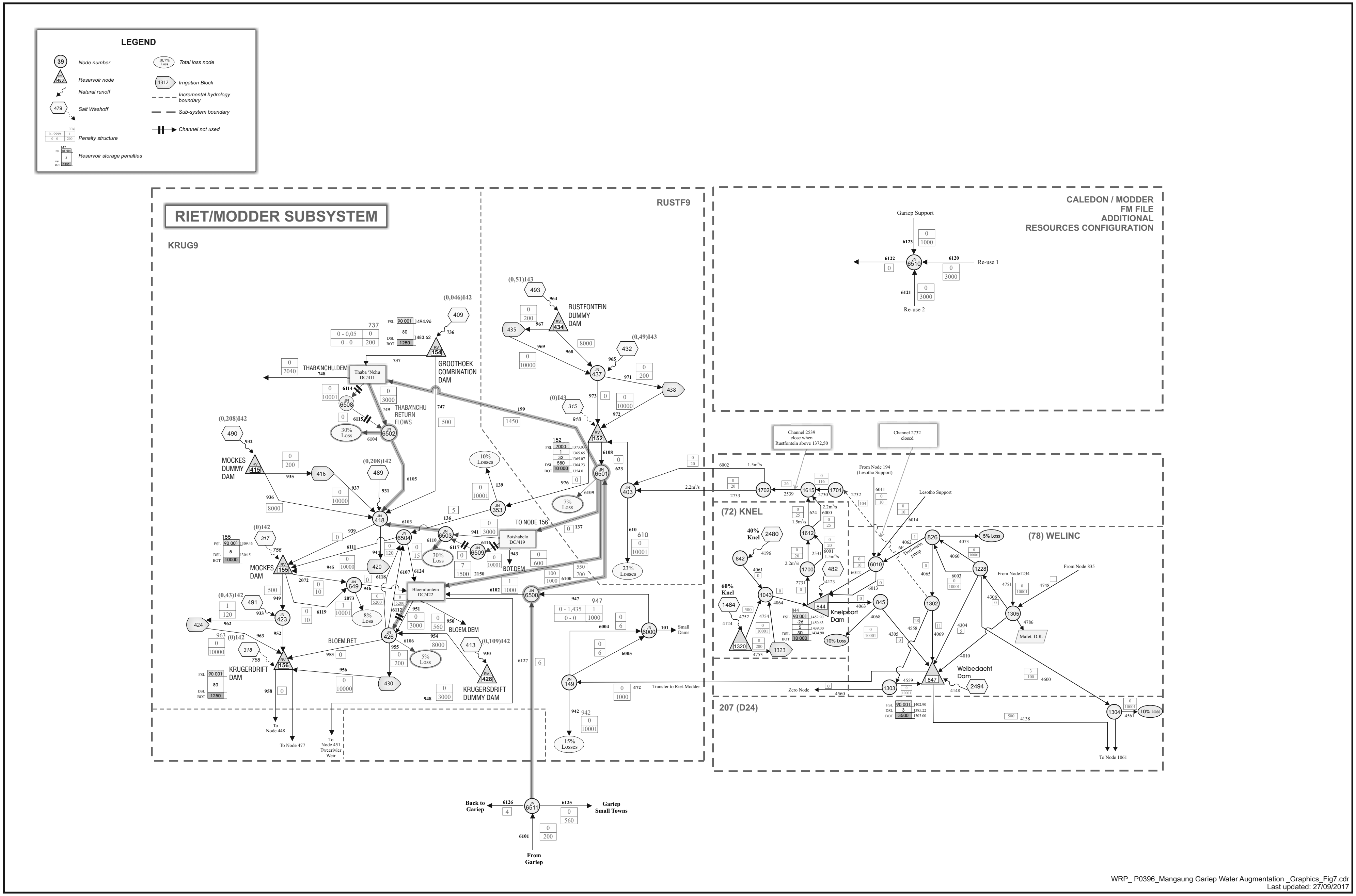
- By **May 2018** the current installed Novo and Tienfontein pumping capacities be fully utilized, thus Eskom power supply limitation removed.
- From **May 2018** the Greater Bloemfontein System be properly maintained and managed strictly according the given operating rules.
- By **May 2019** increase the Maselspoort WTP capacity from 120 Mℓ/d to 130 Mℓ/d. The Maselspoort Mockes Dam sub-system be operated to abstract only 88 Ml/d for Bloemfontein when Mockes is below 1308,7 masl and increase the abstraction rate to 130 Mℓ/d when the dam storage is above the given level.
- By **May 2021** Mockes Dam storage capacity must have been increased to 12.13 million m^3.
- Indirect re-use of 45 Mℓ/d to be activated by **June 2021.**
- Gariep Dam Phase 1 transfer of 90 Mℓ/d in place by **May 2022.** Minimum supply from Gariep to be set to 0,2 m^3/s or 17,3 Mℓ/d.

- By **May 2030** direct/indirect re-use of 32 Ml/d in place.
- Increase maximum transfer capacity from Gariep Dam to Bloemfontein to 120 Mℓ/d by **May 2033**. This date to be refined after further operating rule changes. Minimum supply from Gariep Dam to be set to 0,4 m^3/s or 34,6 Mℓ/d. This minimum volume can still be refined.
- The Thaba Nchu operating rule is to first take water from Groothoek Dam then from Rustfontein Dam, with Botshabelo taking water first from Rustfontein Dam. In both cases Rustfontein Dam receives support from Knellpoort and Tienfontein pump station, based on the current operating rule. As last priority for both these two towns, obtain water from Welbedacht Dam.
- Consider to increase the priority of supply from Welbedacht Dam to the Rustfontein Dam supply once the Rustfontein/Knellpoort sub-system is fully utilized.
- Consider increasing the capacity limitation on the Welbedacht Bloemfontein pipeline at or slightly before the Welbedacht resource is given a higher priority of supply to the Rustfontein supply area.
- Bloemfontein water supply operating rule using Maselspoort abstraction and re-use as the priority one resource, followed by Welbedacht, then Gariep and finally Knellpoort if required.
- Use return flow assumptions and refinements as for Scenario 3.
- Use monthly demand distributions as for Scenario 3.
- Reconsider the required assurance of supply based on the current priority classification table. A different combination of assurance levels can result in an improved water supply within the Greater Bloemfontein System. Based on the 50 l/c/d that could be obtained in Cape Town during the 2017/18 severe droughts in the Western Cape, one can reduce the 50% of the demand allocated to the high assurance (99,5%) significantly. Reducing the 50% to a lower percentage to be allocated to the high assurance demand component will improve the water supply to the system. It is recommended to do further work in this regard to obtain a more realistic priority classification table.

Appendix A

System Schematic Water Balances

Figure 1: WRPM Schematic diagram for Yield analyses with penalty structures
Figure 2a: WRPM Schematic diagram Scenario A water balance
Figure 2b: WRPM Schematic diagram Scenario A2 water balance
Figure 2c: WRPM Schematic diagram Scenario A3 water balance
Figure 3a: WRPM Schematic diagram Scenario B water balance
Figure 3b: WRPM Schematic diagram Scenario B3 water balance
Figure 4: WRPM Schematic diagram Projection analyses with penalty structures



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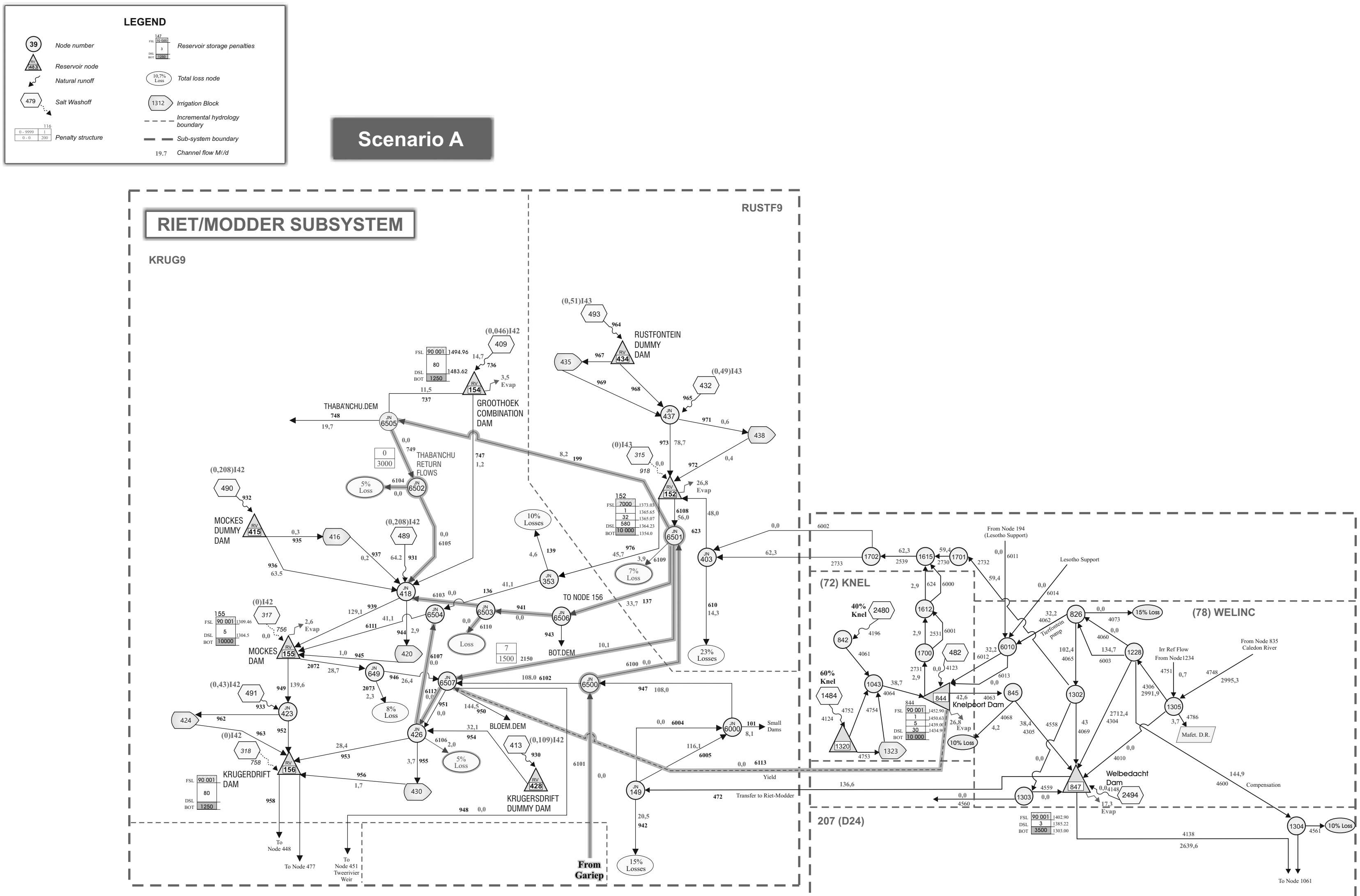
MANGAUNG GARIEP WATER AUGMENTATION PROJECT
SCENARIO ANALYSIS

WRPM Schematic Diagram:
Riet/Modder and Caledon Sub-system with Penalty Structure

Fig 1



Current system not utilizing return flows

HFY = 75,4 million m³/a
= 206 Mℓ/d

Demand 2017 = 94.44 million m³/a
= 259 Mℓ/d

WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig2.cdr
Last updated: 22/03/2018

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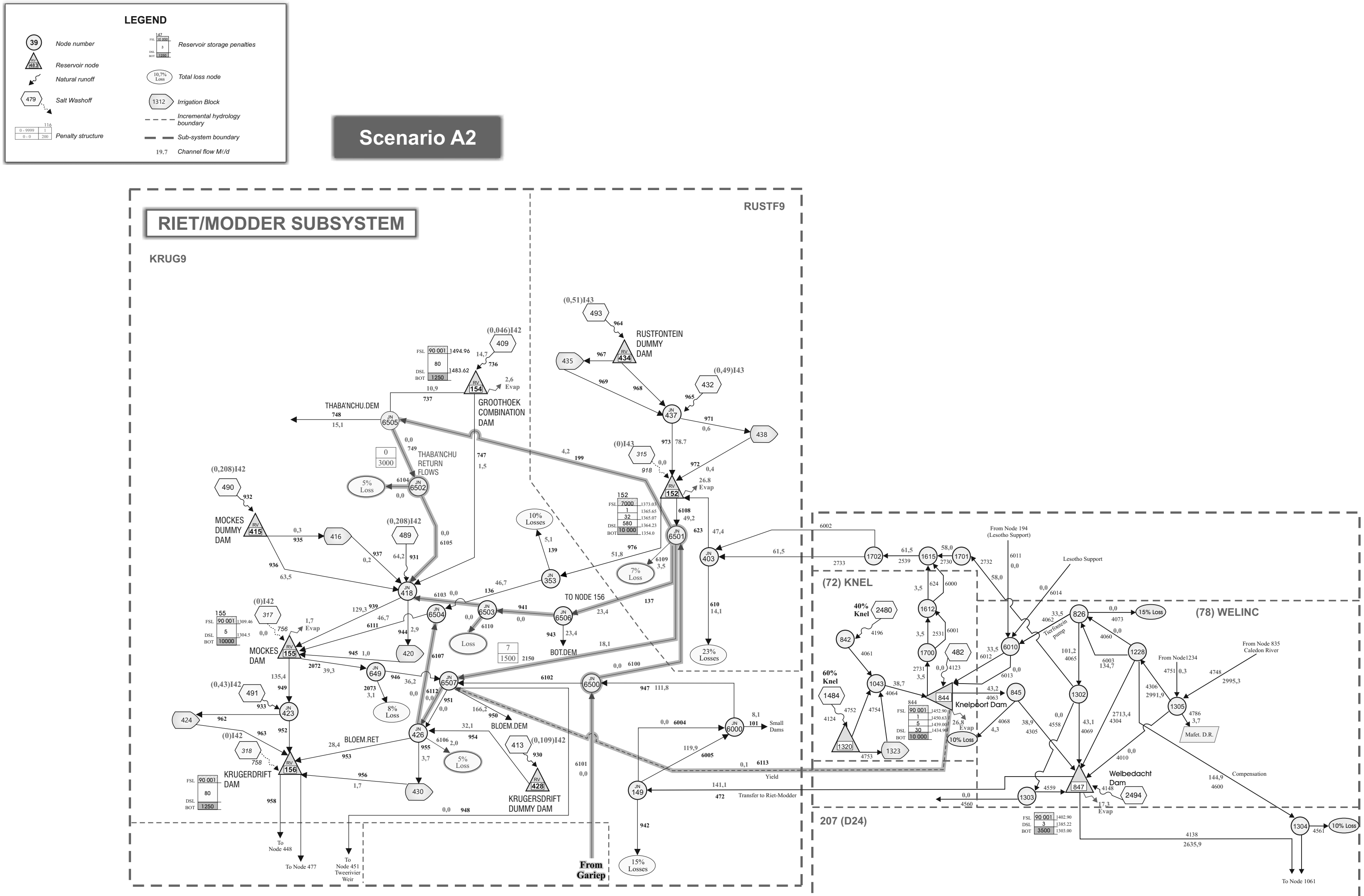
WRPM Schematic Diagram: Scenario A
Riet/Modder and Caledon Sub-system with Channel Flows

Fig 2a



Current system not utilizing return flows

HFY = 77,9 million m³/a
= 213 Mℓ/d

Demand 2017 = 94.44 million m³/a
= 259 Mℓ/d

WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig1.cdr
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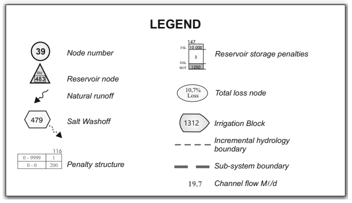
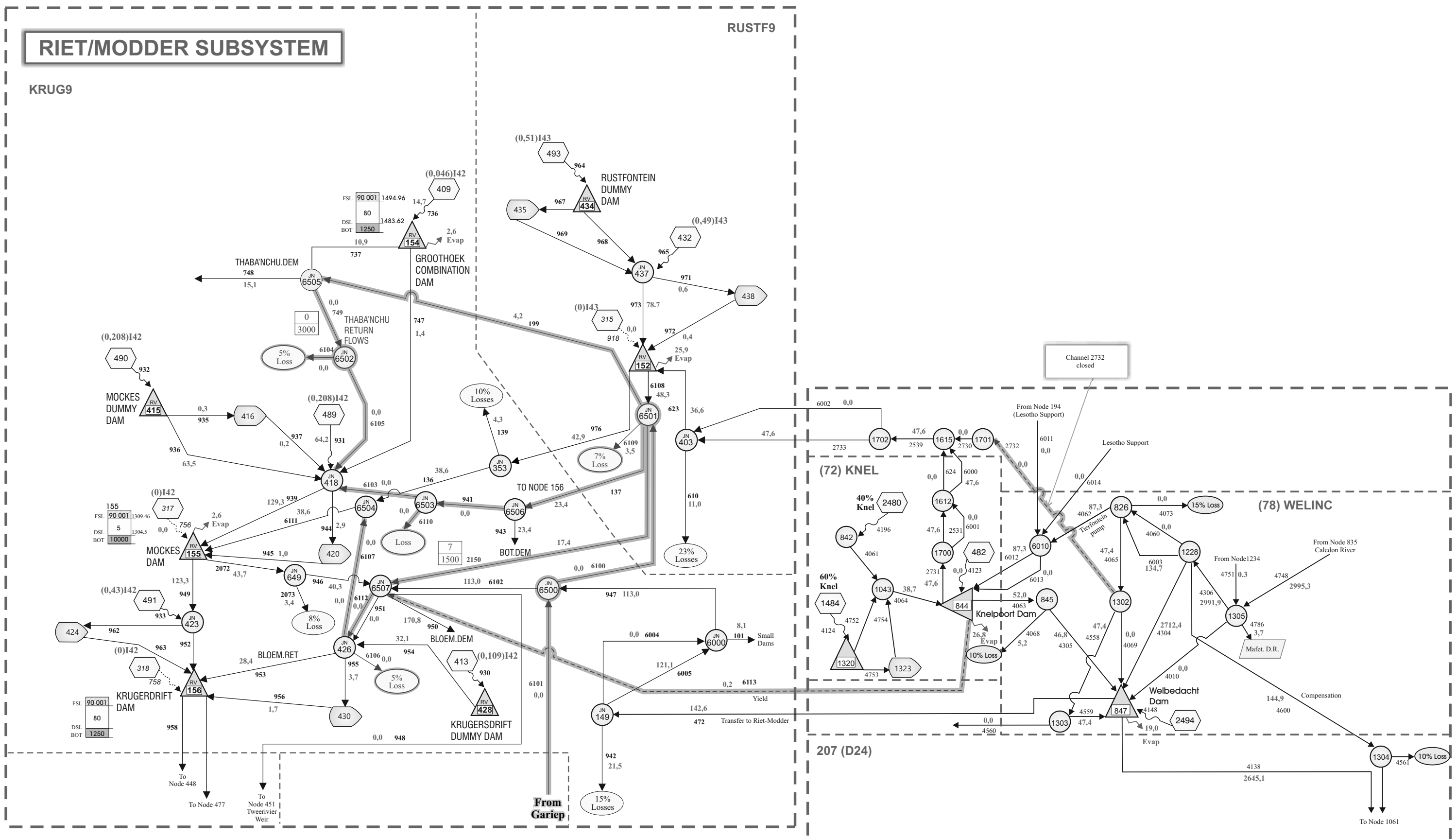
WRPM Schematic Diagram: Scenario A2
Riet/Modder and Caledon Sub-system with Channel Flows

Fig 2b



Scenario A3



Current system not utilizing return flows

HFY = 79,6 million m³/a
= 218 Mℓ/d

Demand 2017 = 94.44 million m³/a
= 259 Mℓ/d

WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig5.cdr
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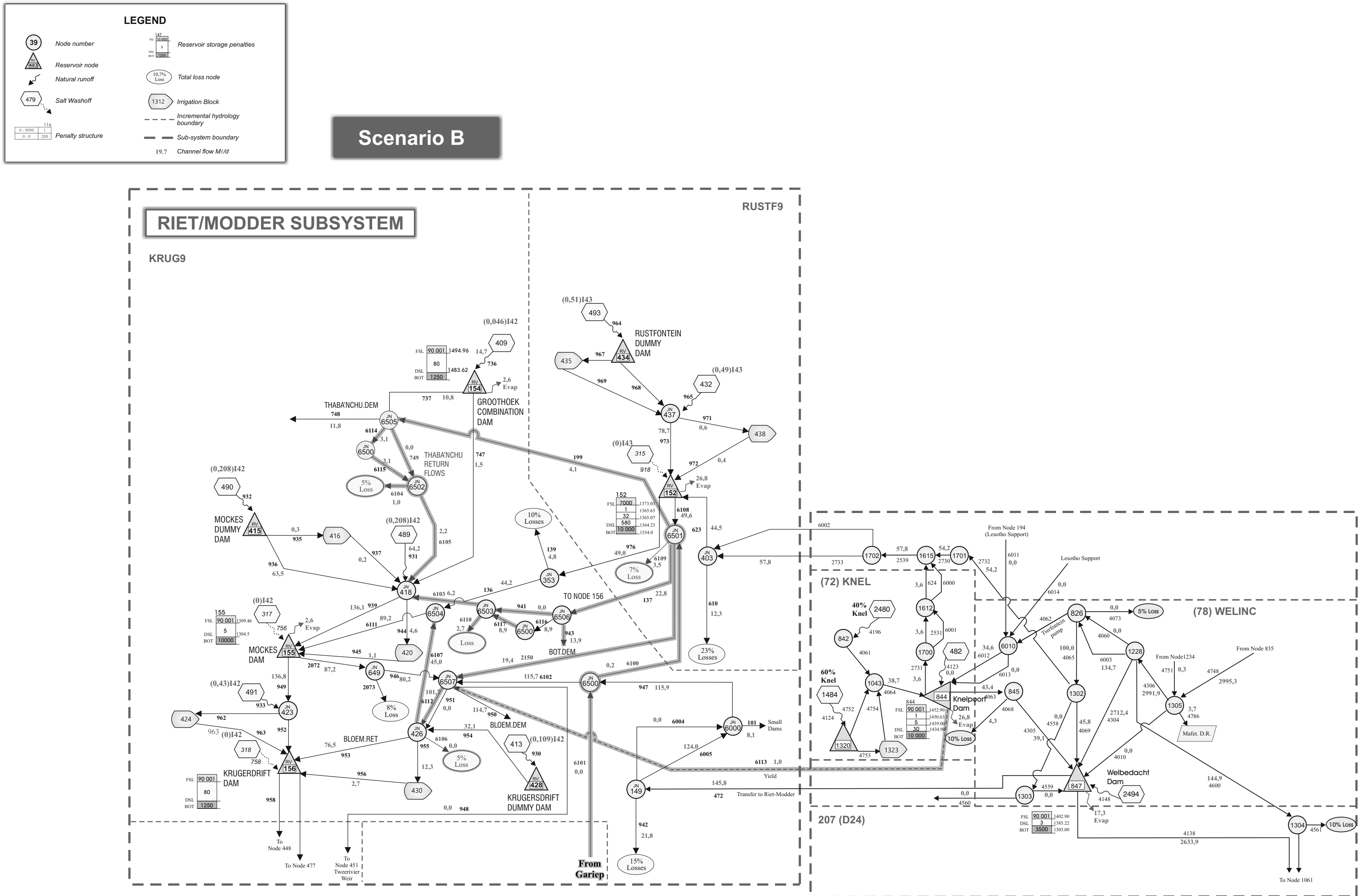
SCENARIO ANALYSIS

WRPM Schematic Diagram: Scenario A3
Riet/Modder and Caledon Sub-system with Channel Flows

Fig 2c

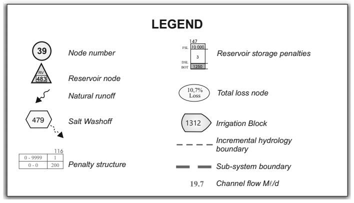


Current system not utilizing return flows

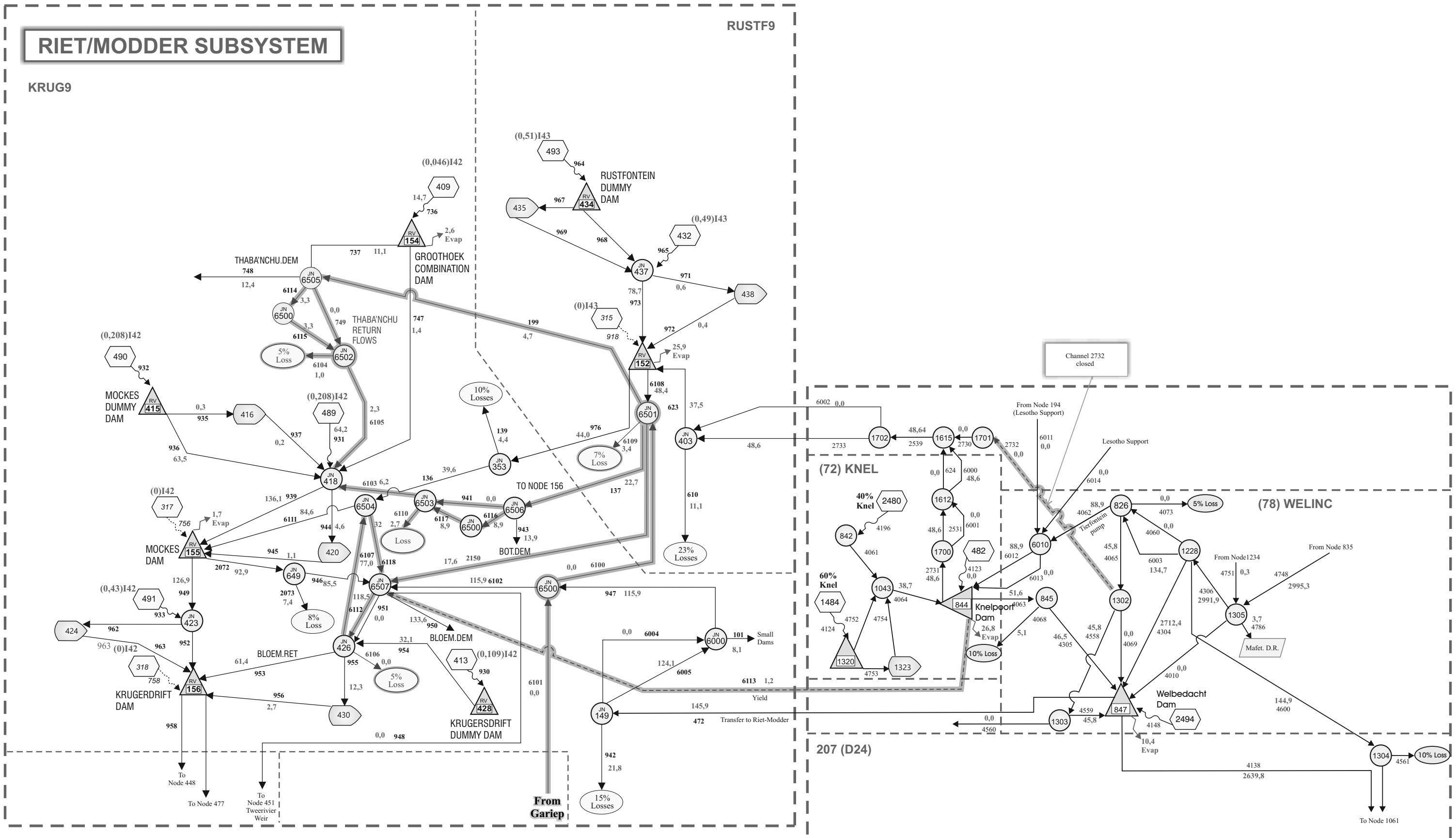
HFY = 95,7 million m^3/a
= 262 Mℓ/d

Demand 2017 = 94.44 million m^3/a
= 259 Mℓ/d

WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig4.cdr
Last updated: 22/03/2018



Scenario B3



Current system not utilizing return flows

HFY = 109,1 million m³/a
= 299 Mℓ/d

Demand 2017 = 94.44 million m³/a
= 259 Mℓ/d

WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig6.cdr
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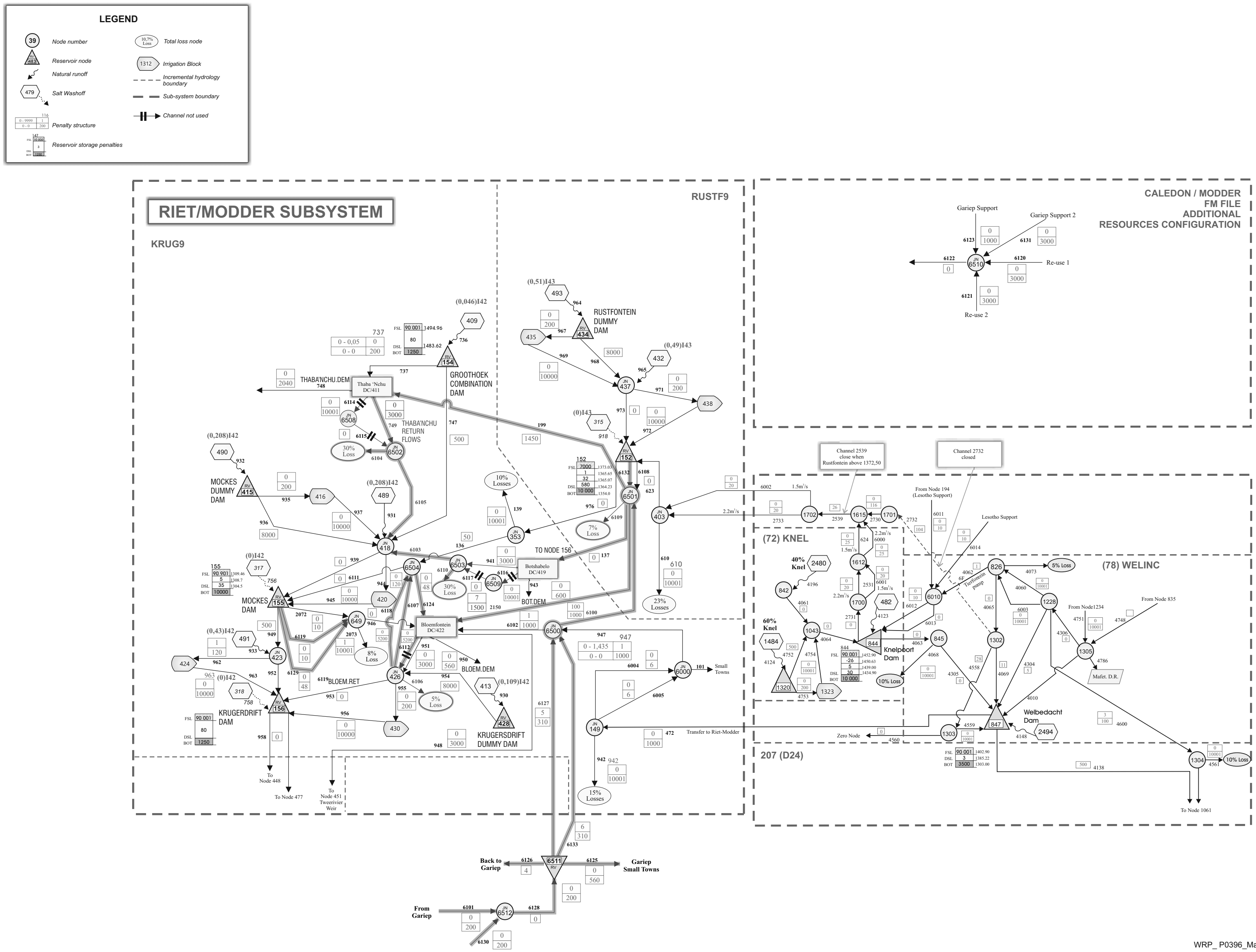
MANGAUNG GARIEP WATER AUGMENTATION PROJECT
SCENARIO ANALYSIS

WRPM Schematic Diagram: Scenario B3
Riet/Modder and Caledon Sub-system with Channel Flows

Fig 3b



WRP_ P0396_Mangaung Gariep Water Augmentation _Graphics_Fig8.cdr
Last updated: 22/03/2018

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MANGAUNG GARIEP WATER AUGMENTATION PROJECT
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WRPM Schematic Diagram: Projection analyses
Riet/Modder and Caledon Sub-system with Penalty Structure

Fig 4