REPUBLIC OF NAMIBIA

MINISTRY OF AGRICULTURE, WATER AND FORESTRY

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A PRE-FEASIBILITY STUDY INTO:

THE AUGMENTATION OF WATER SUPPLY TO THE CENTRAL AREA OF NAMIBIA AND THE CUVELAI





PART I: CENTRAL AREA OF NAMIBIA

INTERIM REPORT No. 2:
HYDROLOGICAL AND SUPPLY / DEMAND MODELLING FOR THE CENTRAL AREA OF NAMIBIA

16 FEBRUARY 2015

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ABBREVIATIONS

Refer to the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia.

REFERENCES

Refer to the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia.

1. INTRODUCTION

The document serves as a Progress Memorandum regarding the hydrological and water supply / demand modelling of the Central Area of Namibia (**CAN**), which is one of the major components of the Phase 2 of this Project. This document is submitted as an interim milestone corresponding with this important component of the Project and it is envisaged that this document will be incorporated into the Phase 2 Interim Report as a separate chapter.

The Progress Memorandum should be read in conjunction with the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia which provides details of the water resources available to the CAN (Chapter 4) and the water demands expected at the various demand centres (Chapters 5 to 12).

2. WATER SUPPLY IN THE CENTRAL AREA OF NAMIBIA

2.1 INTRODUCTION: BASIC LAYOUT OF WATER SUPPLY INFRASTRUCTURE IN THE CENTRAL AREA OF NAMIBIA

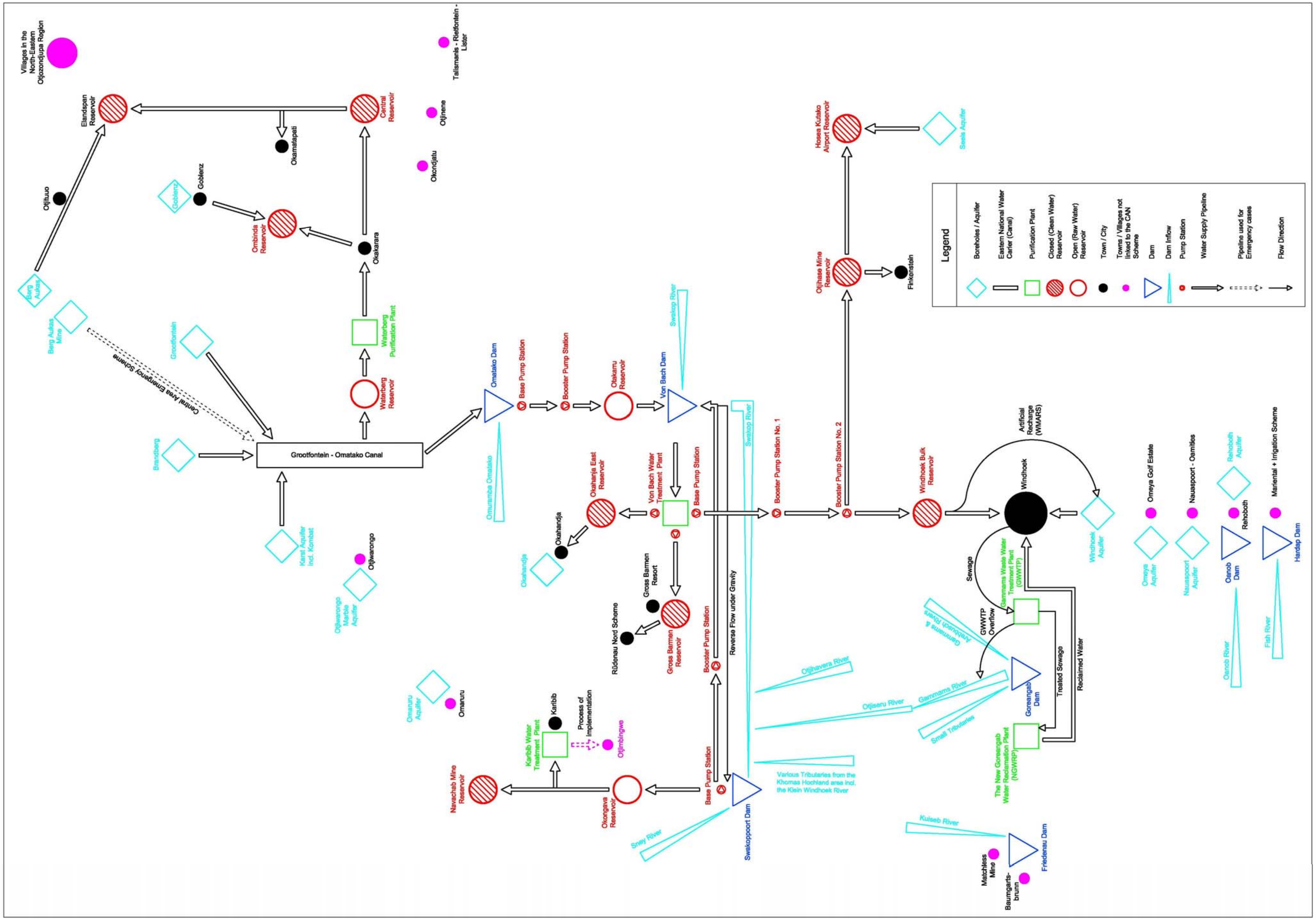
The current extent of the Central Area of Namibia is that area which is served by the Eastern National Water Carrier (**ENWC**) canal and the central 3-dam system of the Von Bach, Swakoppoort and Omatako Dams. A simplified schematic layout of the CAN infrastructure is provided in **Figure 2.1** of this document.

Groundwater from the Karst areas near Grootfontein, abstracted from boreholes and the Berg Aukas mine, is pumped into the ENWC canal, which conveys this water to the Omatako Dam under gravity.

The WWSA is supplied with water from the ENWC, two boreholes near the Berg Aukas Mine and 5 boreholes in the vicinity of Goblenz. Water is drawn off the canal near Waterberg, purified at the Waterberg Purification Plant located to the north of Okakarara, from where it gravitates to Okakarara and thence north eastwards to Ombinda as well as eastwards and then northwards to Elandspan via Central Reservoir. Water from the Berg Aukas boreholes is pumped to Otjituuo and thence to Elandspan. Water from the Goblenz boreholes is used to supply this settlement and is pumped towards Ombinda.

Surface runoff which enters the Omatako Dam is pumped to the Von Bach Dam via a pipeline with a base and one booster pump station. Surface water in Von Bach Dam is purified at the Von Bach Water Treatment Plant (**VBWTP**), located approximately 2.3 km downstream of the dam wall, which supplies treated water to the main centres of Okahandja, Gross Barmen, Windhoek, Otjihase Mine and the Hosea Kutako International Airport, plus a large number of small consumers along the pipeline routes. Okahandja is also supplied with water from two boreholes in the bed of the Okahandja River which are owned and operated by the Municipality of Okahandja.

Figure 2.1: Schematic Layout of the Bulk Water Supply Infrastructure in the CAN



Water is pumped from the VBWTP to Windhoek via three pump stations, to the Windhoek Terminal Reservoir where the City of Windhoek / NamWater handover takes place at the bulk sales meter at the outlet end of the reservoir.

Surface water in Swakoppoort Dam is abstracted and pumped either into the Okongava Reservoir to the west of the dam or upstream and to the east to the Von Bach Dam. Raw water from the Okongava Reservoir is transferred to the Karibib Treatment Plant and to the Navachab Mine. Prior to the construction of the Swakoppoort Dam scheme in 1992, six boreholes which abstract groundwater from an alluvial aquifer in the bed of the Khan River some 15 km north of Karibib were used to supply water to the town. Since the town's water requirements were met by the construction of the Swakoppoort-Okongava-Karibib bulk water supply scheme in 1992, the borehole scheme became largely redundant and was last used in November 2003.

2.2 WATER SUPPLY IN WINDHOEK

Water is supplied to Windhoek from multiple sources. The main source of supply is surface water from the 3-dam system, which has been treated at the VBWTP, which can be augmented by groundwater from the Karst area in emergency periods. Groundwater is also supplied to the City from the Windhoek Aquifer which is located beneath the southern part of the Capital, via boreholes owned and operated by the CoW. Up to 35% of the City's water can be supplied from treated sewage (direct reclamation) via the Gammams Waste Water Treatment Plant (**GWWTP**) and the New Goreangab Water Reclamation Plant (**NGWRP**). Up to approximately 7% of the water used is semi-purified water supplied via a dual pipe system for the restricted irrigation of sports fields, parks and cemeteries in the City.

2.3 WATER RESOURCES

The water resources currently used in the CAN be classified as follows:

1. Surface Water, being that abstracted from:
    a. The Omakato Dam,
    b. The Swakoppoort Dam,
    c. The Von Bach Dam,
2. Groundwater, which is abstracted from the following areas:
    a. The Karst Area,
    b. The Otjiwarongo Marble Aquifer,
    c. The Goblenz Area,
    d. The Windhoek Aquifer,
3. Unconventional water resources which include:
    a. Direct reclamation in Windhoek,
    b. Reclamation for semi-purified water which is used for restricted irrigation,
    c. Managed Aquifer Recharge of the Windhoek Aquifer.

With the surface water sources (because they are ephemeral rivers) and the groundwater sources used, to some extent the capacity of the source is linked to, and may be limited by the capacity of the abstraction infrastructure. These two components (source and abstraction capacity) are dealt with in the same sub-sections of Chapter 4 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia, whilst the bulk water transfer infrastructure and the capacity thereof are detailed in a separate sub-section of Chapter 4.

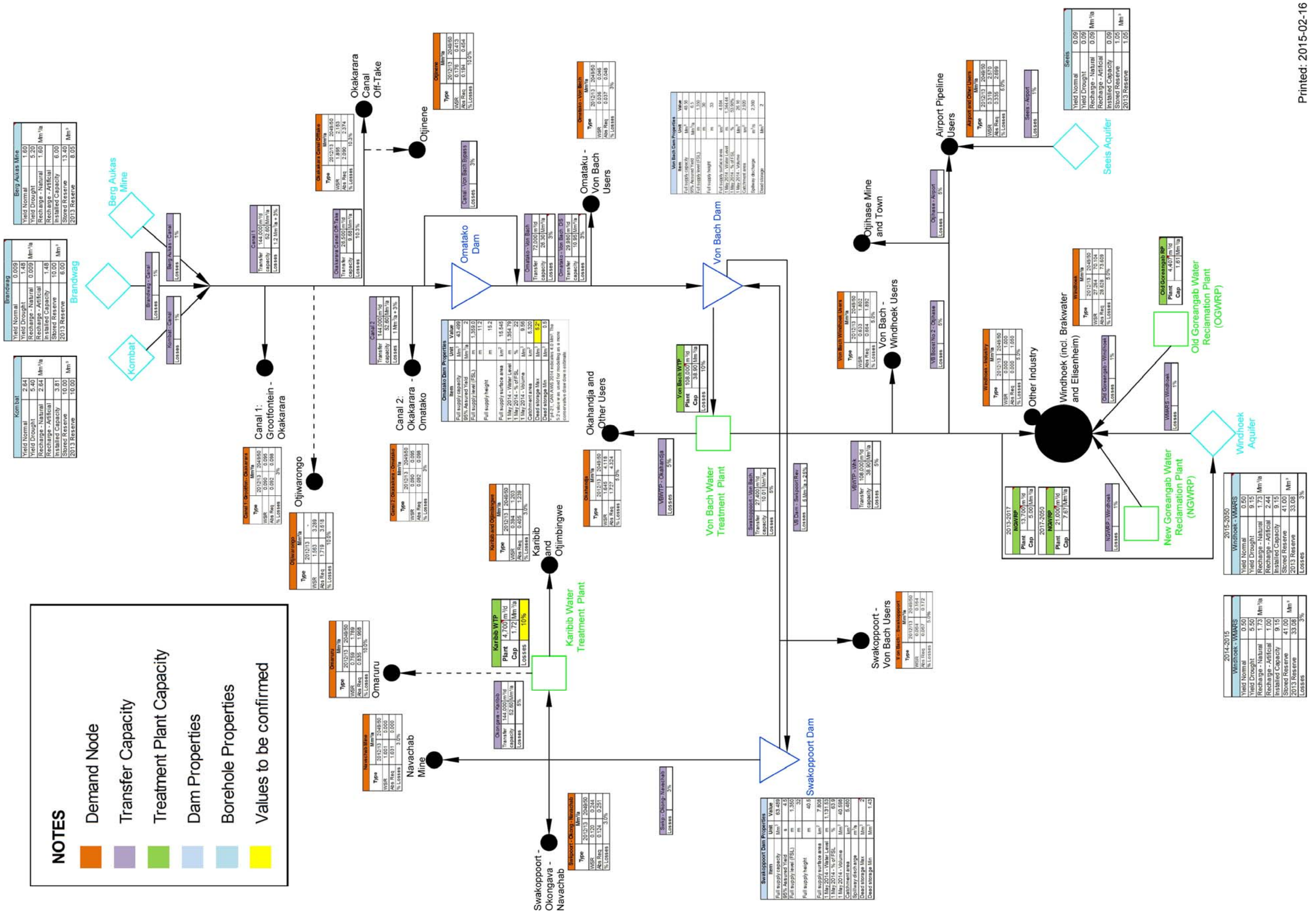
Further details of the CAN infrastructure and resources are contained in Chapter 4 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia as follows:

1. Section 4.2 – Surface Water Resources,
2. Section 4.3 – Groundwater Resources,
3. Section 4.4 – Unconventional Resources,
4. Section 4.5 – Bulk Water Transfer Schemes and Infrastructure.

2.4 WATER DEMANDS IN THE CENTRAL AREA OF NAMIBIA

A simplified schematic layout of the CAN infrastructure, as approached for the modelling, is provided in **Figure 2.2**. This schematic layout also shows the water demand nodes and the associated water demands to be used as input for the modelling simulations, together with the capacity values of the water sources and transfer infrastructure, as well as loss values associated with these (if applicable).

Figure 2.2: Schematic Layout of the Water Supply Infrastructure in the CAN as used for the Modelling, with Capacity Values and Water Demands



3. HYDROLOGICAL AND WATER SUPPLY AND DEMAND MODELLING IN THE CENTRAL AREA OF NAMIBIA

3.1 NUMERICAL MODELLING

Since a Water Resources Yield Model (**WRYM**) was set up under the 1993 Central Area Water Master Plan (CAWMP; refer to **Section 3.3.1.1** of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia), numeric computer models have been used to analyse the water demand / supply situation in the CAN. These computer models have evolved over time, the latest being the CA-Model, written in Visual Basic 6, which was developed for NamWater in 1995-98 and which has also been revised over time; the most recent version being V5.3. Version 5.3 was created in November 2014 under this Project, primarily to extend the simulation (analysis) period beyond that possible under the earlier versions, to allow modelling up to 2050, which is the planning horizon of this Project.

A numerical or mathematical model is a description of (in this instance) a natural system using mathematical concepts and language, composed of relationships and variables. A computer model refers to the algorithms and equations used to capture the behaviour of the system being modelled, whilst "*simulation*" refers to the actual running of the program which contains these algorithms or equations to generate a result.

Numerical computer models (water balance models) are used to analyse the water demand / supply situation in the CAN in lieu of other methods for a number of reasons:

1. The combination of water resources used, the complexity of the transfer systems and the highly variable rainfall events with low annual yields and very high annual evaporation rates creates a complex supply situation,
2. Operating rules can be defined for the use of the different water sources and types of sources, allowing for the most efficient use of water (for example by prioritising the use of surface water sources when available, and reserving groundwater resources for subsequent use, evaporation losses from the dams can be reduced, resulting in significant savings),
3. Given the very variable runoff events in Namibia, the firm yield of the dams has been found to vary with the length of the available record (JVC, 1993b). With a short period of historical runoff data for the 3 CAN dams (Von Bach was constructed in 1970), longer record periods are required for greater accuracy and reliability. Flow sequences are therefore stochastically (randomly) generated in order to provide a longer data series for analyses, which is only possible using computerised methods,
4. Repeated water balances need to be conducted in order to be able to quantify the security of water supply in terms of statistical probabilities, which is only possible using computerised methods,
5. Different scenarios can be analysed in terms of water sources, water demands and operating procedures, to produce range of possible outcomes which can be further evaluated in terms of costs and other criteria.

3.2 THE CENTRAL AREA MODEL (CA-MODEL)

The Central Area Model (**CA-Model**) is a computer model which simulates the hydrological water balance of the Central Area of Namibia using a monthly time scale. Since the regional hydrology of the CAN is dictated by highly variable rainfall events with low annual yields and very high annual evaporation rates, the CA-Model performs a repeated water balance using a randomised pattern of historic statistical analyses to quantify the security of water supply in terms of statistical probabilities. The CA-Model can also be used to predict the earliest run-dry date given current water storages and no future inflows (worst case scenario). Over the past 16 years, the CA-Model has become an invaluable tool in NamWater’s annual water management planning, as well as for long-term planning of regional capital infrastructure investment (after DC, 2005).

3.3 OPERATING RULES AND ANALYSING THE SUPPLY SUFFICIENCY IN THE CENTRAL AREA OF NAMIBIA

The three-dam system (Von Bach-, Swakoppoort- and Omatako Dams) is operated on an integrated basis by transferring water from dams with less favourable evaporation characteristics (Omatako Dam and Swakoppoort Dam) to Von Bach Dam with better basin characteristics in order to reduce overall evaporation. During years with good inflow when dam levels are high, evaporation rates in the existing 3-dam surface storage network can range between 22 and 49 Mm^3/a, which is of the same order or higher than the annual water demand for the Windhoek area (after CAJVC, 2004e). The efficiency of the 3 dam system over the past 10 years ending April 2013 was less than 50%.

Conjunctive use of water is practised based on the premise that surface water is used during periods of ample supply, while groundwater is used as a backup system during periods of drought. Loss of surface water through evaporation is reduced through the accelerated use of this source during periods of sufficient surface water supply. Non-surface water sources, including water reclamation facilities and several developed groundwater resources, are regularly employed to supplement or “stretch” surface waters through drought periods. Both the Windhoek Aquifer and partially the Berg Aukas mine supply more water during periods of drought, to augment supplies to the CAN. These groundwater sources are hence mined during a period of water shortages and should be given time to recover afterwards by using surface water sources when these are again available (after CAJVC, 2004e).

With the partial implementation of the Windhoek Managed Aquifer Recharge or water banking System (**WMARS**), it will be possible to fill certain parts of the “water bank” within 3 years after completion of the Von Bach to Windhoek pump station upgrade in 2014.

3.4 MODELLING ACTIVITIES UNDER PHASE 2 OF THIS PROJECT

3.4.1 Proposed Modelling Activities

With regard to the hydrological and water supply / demand modelling of the CAN, Phase 2 of this Project was envisaged to include the following steps:

1. Setting up a Water Evaluation and Planning (**WEAP**) model along similar lines to that of the current CA-Model, representing the current CAN water supply system as well as the proposed future Okavango Link,
2. Running both the CA-Model and the newly set up WEAP model to compare the results obtained,
3. Analysing further scenarios with WEAP to determine possible shortfalls,
4. Further refinement of the WEAP model.

Meeting No. 3 of the Modelling Sub-Committee was held on 02 September 2014, for the purposes of planning the CAN modelling activities under Phase 2 of the Augmentation of Water Supply to the Central Area of Namibia and the Cuvelai Project.

Following this meeting, the Consultant prepared and distributed to all interested parties (refer below) an Information Document on the Hydrological and Supply / Demand Modelling for the Central Area of Namibia, dated 14 October 2014, which contained the following information:

1. Updated water resource capacities, as determined under Phase 1 of this Project,
2. Updated water demands, as determined under Phase 1 of this Project,
3. Different scenarios to be modelled regarding supply and demand in the CAN,
4. A schematic layout of the CAN infrastructure to be modelled,
5. The required and proposed modelling input, assumptions and system operating rules.

On the basis of the (earlier) proposal put forward by the Modelling Sub-Committee, a one-week collaborative workshop involving the DWAF, NamWater, the Consultant and a WEAP expert from the SEI was held in the week of 20 – 24 October 2014. During this week, the following activities were carried out:

1. The CA-Model (V5.1) was run using the updated water demands and supply capacities from Phase 1 of this Project,
2. The basis of the WEAP model was set up for the CAN, including the Von Bach, Swakoppoort and Omatako Dams, the Windhoek Aquifer, the New Goreangab Reclamation Plant and the ground water resources in the Karst Area.

Although the results obtained from the basic WEAP model compared favourably with those obtained from the CA-Model, it became clear that setting up the WEAP model to replicate the CA-Model would take longer than envisaged.

In order to expedite this component of Phase 2 of the Project, it was agreed that the CA-Model would be used to conduct the modelling of the CAN water supply and demand situation and provide results which would allow the Environmental and Social Consultancy Team to begin their work on Phase 2, whilst the WEAP model would be refined at a later stage.

3.4.2 Revision of the CA-Model

The initial simulations conducted with the CA-Model during 20 – 24 October 2014 showed that the model could only conduct simulations for 30 years into the future. Since the planning horizon of this project extends to 2050, an analysis period of 36 years (from 2014) into the future was required. The CA-Model was consequently revised, to V5.3, by its creator, Mr. Thomas Winter, during November 2014 under this Project.

Thereafter, a number of the scenarios simulated during 20 – 24 October 2014 were repeated in November / December 2014, in order to check the results obtained from the new version of the CA-Model.

3.4.3 Final Modelling with the CA-Model

Analyses of the modelling simulations conducted with the CA-Model during 20 – 24 October 2014 and November / December 2014 provided the following indications:

1. Increasing the size of the water bank (WMARS) from 89 Mm^3 to 114 Mm^3 (the initial Scenario 5 according to the Information Document dated 14 October 2014) did not significantly improve the security of supply relative to the expected costs of this measure,
2. Climate change effects should be analysed as a “what-if” sub-scenario of the water supply alternatives or options most likely to provide the greatest security of supply to the CAN, rather than a separate, stand-alone scenario (Scenario 6 according to the Information Document dated 14 October 2014). In so doing, climate change effects could be examined to estimate worst-case impacts on the main alternatives, which could perhaps be used to climate-proof these alternatives to the extent possible,
3. NamWater requested the inclusion of supply from Abenab Mine as a supply alternative which was not previously included as one of the scenarios to be investigated,
4. The water supply situation in the CAN is very precarious. Although badly needed, it will most likely take eight to ten years (best case scenario) to implement the next supply augmentation scheme (for example supply of desalinated sea water from the coast). A dual strategy was therefore proposed with regard to the scenarios to be investigated:
    a. The expected shortfalls in the next 8 – 10 years, to 2023/24 will be analysed very carefully, and all realistic options which “are on the table” and which can be implemented within 2 to 5 years will be analysed with regard to minimising supply shortfalls in the next 8 – 10 years,
    b. Looking beyond the first 8 – 10 years, alternatives which will minimise supply shortfalls up to the end of the planning horizon in 2050 will be analysed and the timing of the implementation of these alternatives optimised as far as possible.

On the basis of the above, the water supply situation in the CAN was re-analysed during January and February 2015, using V5.3 of the CA-Model and incorporating the insights gained during the preceding two simulation "runs". The configuration of the scenarios to be analysed, as originally outlined in the Information Document dated 14 October 2014 were revised accordingly.

4. MODELLING OF THE WATER SUPPLY SITUATION IN THE CENTRAL AREA OF NAMIBIA

4.1 BASIC INPUTS FOR THE CA-MODEL

4.1.1 Simulation Period

The simulation period used for the analyses was 01 May 2014 to 30 April 2050, thus a total of 36 years. The years reflected in the following figures and modelling output are *modelling years*; for example 2017/18 represents 01 May 2017 to April 2018. This is consistent with the modelling methodology used by NamWater and that used by previous studies and is based on April being the end of the recognised rainy season in the CAN, even though the hydrological year ends in September. **Table 4.1** indicates the CA-Model input for the simulation period.

Table 4.1: Simulation Period Input of the CA Model for the Baseline Scenario

Item	Value
Analysis Period	36
Number of Runs	500
Start Year for Output	2015
Start Month of Simulation	May
Number of Months to Start a New Year	12

The *number of runs* value indicates the number of hydrological stochastic input sequences that are generated by the CA-Model (refer to **Section 4.1.2** below). A total of 500 stochastic sequences were selected for the modelling. The *number of months to start a new year* value indicates in which month operational rules of the model will change. For this modelling exercise, both operational rules and simulation start months were the same, therefore the value is 12.

4.1.2 Stochastic Simulations

The CA-Model was run using 500 sets of randomly generated (stochastic) hydrological data for the inflows into the three dams, rainfall and evaporation in the CAN. The same stochastic data was used for each of the scenarios modelled in order to provide consistency in the results obtained.

4.1.3 Dam Parameters and Input Data

The following dam parameters and initial conditions were used in the CA-Model for the three CAN dams, namely the Von Bach, Swakoppoort and Omatako Dams:

1. Full supply capacity (Mm^3),
2. Current storage as a proportion (between 0 and 1) of full supply capacity. The current storage volume of each dam at 01 May 2014 (as provided by NamWater) was used as input,
3. Area/Volume relationship, modelled as a power equation: $Area = A \times Volume^B$, where A and B are constants specific to each dam,
4. Dead storage volumes, including an initial and absolute minimum dead storage value. This is relevant to the Omatako Dam, where additional water can be abstracted from the dam at a certain dam capacity at a lower abstraction rate, and to the Swakoppoort Dam, where reverse flow transfer conditions are activated from Von Bach Dam when the absolute minimum dead storage volume is reached,
5. Sediment load as a percentage of inflow, to account for incoming sediment into the dams from river inflow, to reduce the effective volume of the dams over time.

Table 4.2 indicates the CA-Model input for the dam parameters.

Table 4.2: Input for Dam Parameters of the CA-Model for the Baseline Scenario

Dam	Current Storage	Full Supply Capacity	Area / Capacity Power Equation Constants		Sediment	Dead Storage	
	[0-1]	Mm^3	A	B	% of inflow	Maximum Mm^3	Minimum Mm^3
Omatako	0.220	43.499	91.200	0.670	0.5	5.2	0.5
Von Bach	0.539	48.560	32.450	0.699	1.5	15.07	2.073
Swakoppoort	0.639	63.489	35.000	0.742	2.5	2	1.431

4.1.4 System Losses

System losses represent the losses on the bulk supply pipeline systems, the Eastern National Water Carrier (**ENWC**), at the Von Bach and Karibib water treatment plants and spilling from the Von Bach Dam into the Swakoppoort Dam. Most of these values are estimates and/or recommendations. **Table 4.3** indicates the CA-Model input for the system losses.

Table 4.3: System Losses of the CA Model for the Baseline Scenario

Area	Loss (%)
Off-take	
Grootfontein – Waterberg Off-take	3% + 1.2 Mm^3/a
Waterberg Off-take - Omatako	3% + 1.0 Mm^3/a
Waterberg Off-take	10.3
Omatako – Von Bach Dam	3
Von Bach WTP – Windhoek	5
Otjihase Off-take	5
Otjihase – Windhoek Airport	5
Reclamation Plant – Windhoek	1
Von Bach WTP – Okahandja	5
Von Bach Dam – Swakoppoort	5
Von Bach Dam Spill	25% + 5 Mm^3
Swakoppoort – Karibib WTP Off-take	3
Swakoppoort – Navachab	3
Water Treatment Plant	
Von Bach WTP	10
Karibib WTP	10
Primary Boreholes	
Kombat – ENWC	1
Brandwag – ENWC	1
Berg Aukas Mine – ENWC	1
Windhoek Aquifer – Windhoek	1
Windhoek – Windhoek Aquifer Recharge	1
Secondary Boreholes	
Goblenz – Waterberg	1
Berg Aukas – Waterberg	1
Seeis – Windhoek Aquifer	1

4.1.5 Water Demands

Water demands for the CAN area exclude bulk system losses and treatment plant losses and include local network distribution losses where applicable. Water demand input for the different demand nodes in the CAN was determined under Phase 1 of this Project, as detailed in Chapters 5 to 11 and summarised in Chapter 12 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia. The “likely” demand scenario values were used for modelling purposes.

Table 4.4 indicates the demand areas used in the CA-Model, with additional descriptions of the areas.

Table 4.4: Demand Area Overview of the CA Model for the Baseline Scenario

Location of Area as per Supply Area	Demand Area	Description / Comments
Von Bach Dam Downstream Users	Windhoek	All water demands in Windhoek that may receive reclaimed water.
	Windhoek Industry	Includes industrial users in Windhoek as well as Brakwater and Elisenheim. These users will not receive reclaimed water.
	Okahandja	
	Airport Pipeline Users	Hosea Kutako Airport users.
	Otjihase	Includes Finkenstein, Otjihase Mine and Town users.
	Von Bach – Windhoek	All users along the Von Bach – Windhoek pipeline, excluding the above.
	Swakoppoort – Von Bach	Raw water users, typically farmers.
Swakkoppoort Downstream Users	Swakoppoort – Okongava	All users along the Swakoppoort - Okongava - Navachab pipeline. Navachab and downstream users from Karibib WTP excluded.
	Navachab	Water demand of the Navachab mine.
	Karibib	All users that are supplied by the Karibib Water Treatment Plant, including Otjimbingwe (current project).
Northern Users (Upstream from Von Bach Dam)	ENWC Canal 1	All users from the northern starting point of the ENWC to the Waterberg / Okakarara off-take.
	ENWC Canal 2	All users from the Waterberg / Okakarara off-take to the Omatako Dam.
	Omatako - Von Bach	Raw water users along the Omatako - Von Bach pipeline.
	Waterberg Water Supply Area	Includes all users in the Waterberg Water Supply Area (WWSA).
	Rundu	Available options in CA model, not used for this round of modelling.
	NYSS	

It should be noted that the users downstream from the Von Bach Dam make up between 89% and 95% of the total CAN water demand and are therefore the major demand centre in the CAN. Within the aforementioned area, Windhoek and Windhoek industry (including Elisenheim and Brakwater demands), make up between 88% and 89% of the area's demands.

4.1.6 Reclamation Plant Supply and Operation

The current reclamation capacity for the New Goreangab Water Reclamation Plant (**NGWRP**) was assumed to be 5 Mm^3/a. It is expected that the delivery capacity will be increased to 7.66 Mm^3/a following the upgrading of the Gammams Waste Water Treatment plant (construction of the works is on tender in February 2015), after which reclaimable water will be available throughout the year.

The blending ratio value indicates what proportion of total supplied water to Windhoek may contain reclaimed water, expressed as percentage reclaimed water of total supplied water. It was assumed that only 35% of the total supplied water in Windhoek may consist of reclaimed water and that 93% of all supplied water may contain reclaimed water (approximately 7% of the water supplied, that to the Namibia Breweries Ltd. and Namibia Beverages (Coca-Cola) may not contain reclaimed water).

Table 4.5 indicates the CA-Model input for the reclamation plant.

Table 4.5: Reclamation Plant Capacity of the CA-Model for the Baseline Scenario

Scenario	Start Year		End Year		Reclamation Volume
	Absolute	Relative	Absolute	Relative	Mm^3/a
Baseline	2014/15	1	2016/17	3	5.00
	2017/18	4	2049/50	36	7.66

Note that the *Relative Year* value in **Table 4.5** represents the relative year of the simulation period; 1 representing the year 2014/15 (the first year for which simulations are conducted) and 36 the year 2049/50.

4.1.7 Initial Transfer Rates

Transfer rates between the three CAN dams and the various transfer rules for both inter-dam transfer and bypassing of the Omatako Dam from the ENWC are indicated in **Table 4.6** as per the CA-Model input for the Baseline Scenario.

Table 4.6: Transfer Rates between Dams of the CA-Model for the Baseline Scenario

Transfer Area	Transfer Value (Mm^3/a)	
	Normal	Below Max Dead Storage
Omatako Dam – Von Bach Dam	30	10.95
Omatako Dam – Von Bach Dam (Emergency)		10.95
Swakoppoort – Von Bach Dam	9.5	0
Reverse Flow Active from Von Bach Dam	Yes	

4.1.8 Transfer Rules

The transfer rules according to which transfers between the three dams are to take place are provided below. These rules have been developed over a period of time, based on modelling simulations conducted under previous projects, NamWater's modelling and simulation of historic and future flows and practical experience gained over time, with the aim of maximising the yield from the combined 3-dam system.

4.1.8.1 Omatako Dam to Von Bach Dam Transfer Rules and Rates

The transfer rules are as follows:

1. Pumping between Omatako Dam and Von Bach Dam may only occur if Von Bach Dam is lower than a certain volume, expressed as a percentage of Von Bach Dam full supply capacity (to avoid spillage of Von Bach Dam),
    a. Transfer is at a certain rate above the Dead Storage Level 1 (DS 1) of Omatako Dam (bigger pumps used),
    b. Transfer is at a lower rate below DS 1 down to DS 2 of Omatako Dam (smaller pumps used),
2. There is also the option to limit Omatako Dam to Von Bach Dam transfers between December and March to allow sediment settling in Omatako Dam and to check whether inflow into Von Bach Dam occurs.

Transfer rates are expressed in Mm^3/a.

4.1.8.2 Eastern National Water Carrier Canal Transfer Rules

This rule determines whether water from the ENWC Canal must be stored in Omatako Dam or whether Omatako Dam must be bypassed for direct transfer towards Von Bach Dam. Canal water should bypass Omatako Dam if:

1. Von Bach Dam level is below a certain volume, expressed as a percentage of Von Bach Dam full supply capacity,
2. Or if Omatako dam is below a certain capacity, expressed as Mm^3.

4.1.8.3 Swakoppoort Dam to Von Bach Dam Transfer Rules and Rates

The transfer rules are as follows:

1. Pumping between Swakoppoort Dam and Von Bach Dam may only occur if Von Bach Dam is lower than a certain volume, expressed as a percentage of Von Bach Dam full supply capacity (to avoid spillage of Von Bach Dam),
   a. Transfer is at a certain rate above the Dead Storage Level 1 (DS 1) of Swakoppoort Dam (down to DS 1), with a single transfer rate, expressed in Mm^3/a,
   b. Below the lower DS 2 level in Swakoppoort Dam, reverse flow from Von Bach Dam must take place to ensure supply to Navachab, Karibib and other users supplied from Swakoppoort Dam.

Transfer between Swakoppoort Dam and Von Bach Dam may also be limited due to water quality concerns (Scenario 2):

1. Limitations may occur either between certain months of the year,
2. Or no transfer may occur at all.

The implementation of the abovementioned transfer rules into the CA Model for the Baseline Scenario are summarised in **Table 4.7** and **Table 4.8**.

Table 4.7: Dam Transfer Rules of the CA-Model for the Baseline Scenario

Transfer of Water into Von Bach Dam	
Stop pumping from Omatako Dam to Von Bach Dam (including ENWC water) if Von Bach Dam exceeds:	**% of Von Bach FSC[1]**
	90
No Pumping from Omatako Dam to Von Bach between December to March	Off
Stop pumping from Swakoppoort Dam to Von Bach WTP if Von Bach Dam exceeds:	**% of Von Bach FSC[1]**
	90

Note:
1. FSC = Full Supply Capacity

Table 4.8: Dam Transfer Rules of the CA/Model for the Baseline Scenario

Transfer water from ENWC into:	Yes / No	Comment
Von Bach Dam	Yes	Bypass Omatako Dam
Omatako Dam	No	ENWC water stored in Omatako
Conditions	**Value**	**Unit**
< Von Bach Dam Capacity	90	% of Von Bach FSC[1]
< Omatako Dam Capacity	45	Mm^3

Note:
1. FSC = Full Supply Capacity

4.1.8.4 Transfer Capacities of Infrastructure

The primary purpose of the CAN modelling is that of carrying out a water balance to determine supply shortfalls (if any), i.e. to what extent available and planned water sources can satisfy the demands, and not to assess infrastructure limitations such as transfer capacities of the pipelines and pump stations. The transfer rates as well as the capacity of the Von Bach Water Treatment Plant were consequently adjusted upwards to prevent system bottlenecks from interfering with the water balance.

Table 4.9 indicates the transfer capacities used in the CA-Model, both in monthly transfer rates as used in the input of the model, and the corresponding annual transfer rates.

Table 4.9: Transfer Rates of the CA-Model for the Baseline Scenario

Area	Transfer Rate	
	Mm^3/m	Mm^3/a
Grootfontein – Waterberg / Okakarara Off-take	7.88	94.56
Waterberg / Okakarara Off-take – Omatako	6.31	75.72
Waterberg / Okakarara Off-take	2.00	24.00
Omatako Dam – Von Bach Dam	5.26	63.12
Von Bach WTP[1]	3.24	38.88
Von Bach WTP[1] – Windhoek	8.00	96.00
Von Bach Dam – Swakoppoort	0.92	11.04

Note: WTP = Water Treatment Plant

4.1.9 Groundwater Abstraction

Groundwater sources in the CA-Model are simulated as “buckets” with independent water balances, for which a volume, recharge rate as inflow and abstraction rates and losses as outflow are defined for each source. The various groundwater sources used in the modelling procedures and respective volumes, initial fill volume, abstraction losses, natural and artificial recharge rates and regular and emergency (maximum) abstraction rates for the first year of the modelling are summarised in **Table 4.10**.

The input data for all the groundwater sources, with the exception of the Windhoek Aquifer, remains constant over the modelling period. For the Windhoek Aquifer, in the second modelling year (2015/16), the artificial recharge rate into the Auas Mountain Quartzites increases from 1.0 Mm^3/a to 2.44 Mm^3/a and the emergency (maximum) abstraction rate increases from 5.5 Mm^3/a to 9.9 Mm^3/a, according to the current estimates of the ongoing implementation of the WMARS project.

4.1.9.1 Emergency Pumping

The CA-Model has an option to activate a forecast routine that estimates whether a shortfall in the CAN will be reached within a specified future period of time that is user defined and then retroactively activates emergency pumping from groundwater sources to avoid a shortfall (a shortfall is reached when dam volumes are at or below dead storage level). As soon as the dams receive inflow, the use of emergency sources stops.

The following factors / parameters determine the emergency pumping routine:

1. Forecast period: the period of time within which a shortfall will be forecast, which event activates the emergency pumping of groundwater sources, expressed as number of months (between 6 to 18 months),
2. An emergency supply factor to adjust the emergency transfer rate, ranging between 0.5 and 2.0.

For the purpose of the modelling exercise, 12 months was selected for the forecast period and an emergency supply factor of 1.0 was used.

Table 4.10: Groundwater Input Information for CA Model for the Baseline Scenario

Aquifer	Year		Volume	Fill	Loss	Recharge		Abstraction	
						Natural	Artificial	Normal	Emergency
	Absolute	Relative	Mm^3	%	%	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a
Windhoek Aquifer	2014/15	1	41	80.7	3	1.73	1.00	0.5	5.5
	2015/16 – 2050/49	2 - 36	41	-	-	1.73	2.44	0.5	9.15
Kombat	whole period		15.06	66	0	2.64	-	2.64	5.4
Brandwag (Karst 1)	whole period		10	60	0	0.009	-	0.009	1.48
Berg Aukas Mine	whole period		13.4	60	0	1.6	-	1.6	5.2
Seeis	whole period		1.05	100	0	0.09	-	0.09	-
Goblenz	whole period		3.76	100	0	0.648	-	0.648	-
Berg Aukas Boreholes	whole period		5	80	10	1.37	-	1.37	-

4.1.9.2 Recharge of the Windhoek Aquifer

This rule allows for the transfer of water from the Von Bach Dam to Windhoek for the purposes of artificial recharge of the Windhoek Aquifer, only if the level in Von Bach dam is above the specified value, which is expressed as a percentage of Von Bach Dam full supply capacity. For this round of modelling, a value of 40% of the Von Bach Dam full supply capacity was used.

4.1.10 Leakage of Omatako Dam

Omatako Dam is the only dam with a specified leakage rate. The CA-Model allows for leakage at Omatako Dam as a leakage rate in litres per second for various volumes as per percentage of the full supply capacity, as below:

Leakage rate (l/s) = f(% of full supply capacity of the Omatako Dam)

Table 4.11 indicates the CA-Model input for the leakage rates of Omatako Dam.

Table 4.11: Omatako Leakage Rate for CA-Model for the Baseline Scenario

Percentage of Omatako Full Supply Capacity	Leakage Rate litres/second
0	0
10	4
100	15

4.2 SCENARIO OVERVIEW

Various scenarios were explored in the modelling of the CAN water supply situation. The scenarios can be divided up into two sub-sections, namely scenarios using currently implemented sources (excluding additional augmentation) and scenarios incorporating additional sources (including additional augmentation). The scenarios excluding additional augmentation are typically short term, focussing on the first ten years of the modelling period, whilst the scenarios including augmentation focus on the long term, especially the remaining modelling period up to 2050.

These scenarios, described below, were re-arranged and adjusted during January / February 2015, based on the results obtained from the preliminary modelling done during 20 – 24 October 2014 and that done in November / December 2014 following the revision of the CA-Model. They therefore differ from those detailed in the Information Document of 14 October 2014 which was distributed prior to the one-week collaborative modelling workshop (refer above). The three modelling exercises have therefore followed an iterative process with the aims of reducing the shortfalls both within the first 10 years and throughout the planning horizon and optimising the introduction of additional water sources.

Each scenario will be briefly discussed below. An overall summary of the scenarios is given in **Table 4.12**.

Table 4.12: Summary of the Scenarios Analysed

Scenario		Sub -Scenario		Base Scenario	Affected Scheme	Sub-Area	Proposed Change	Implementation Date
Number	Details / Description	Number	Details / Description					
1	Baseline		See Baseline description page					
2	Swakoppoort Water Quality Concerns	a	No transfer from Swakoppoort to Von Bach Dam	1	Von Bach WTP / Swakoppoort Dam	Swakoppoort Dam - Von Bach Dam Pipeline	N/A	
		b	Transfer from Swakoppoort to Von Bach Dam for 8 months per year				N/A	
3	Reduction in Von Bach WTP Transfer losses			1	Von Bach WTP	Von Bach WTP	Reduce VBWTP losses from 10% to 1%	**May 201**
4	WMARS improved capacity and recharge			3	Von Bach WTP	Windhoek - WMARS	Increase artificial recharge capacity to 8 Mm^3/a Increase abstraction capacity to 19 Mm^3/a Increase storage capacity of water bank to 61 Mm^3 (May 2018) Increase storage capacity of water bank to 89 Mm^3 (May 2020) and increase abstraction to 21 Mm^3/a	**May 2018** **May 2020**
5	Add Abenab mine groundwater source as emergency source.			3	Von Bach WTP	Windhoek - WMARS	Add groundwater source of capacity 36 Mm^3 and an emergency abstraction rate of 12 Mm^3/a over 15 year cycle. Analysis only relevant for first 10 years.	**May 2018:**
6	Increased volume of reclaimed water in Windhoek				Von Bach WTP	Windhoek - NGWRP	Windhoek reclamation increase by 4.2 Mm^3.	**May 2019**
7	Bulk supply from the Okavango River		Okavango River augmentation. Windhoek reclamation increase and WMARS water bank of 89 Mm^3	4	CAN overall		Okavango River augmentation as infinite source with incrementally increasing abstraction rate with losses along ENWC canal.	**May 2022**
8	Desalination augmentation from the West Coast.		Desalination augmentation. Windhoek reclamation increase and WMARS water bank of 89 Mm^3	6	CAN overall		Desalination augmentation as infinite source with incrementally increasing abstraction rate, new pipeline from Swakopmund to Von Bach Dam.	**May 2022**
9	Incorporation of other demand areas not connected to CAN. Increased mining and industrial development modelled as increase in demands at Windhoek.	a	Incorporate Omaruru, Otjinene, and Otjiwarongo demands into the CAN supply scheme.	6	WWSA Karibib WTP	Otjinene and Otjiwarongo: WWSA. Omaruru: Karibib WTP	Add Otjinene and Otjiwarongo demands and Omaruru on the Karibib WTP scheme.	**May 2020** Omaruru **May 2039** Otjiwarongo **May 2043** Otjinene
		b	Windhoek demand increase by an 10%	9a	WWSA Karibib WTP VBWTP	Windhoek	Increase Windhoek demand by 10%.	**May 2022**
		c	Windhoek demand increase by an additional 10%	9b	WWSA Karibib WTP VBWTP	Windhoek	Windhoek demand by an additional 10% (21% in total)	**May 2022**

Note: Scenarios 9d, 9e and 9f are briefly discussed in **Section 4.2.2.3** and **Sections 4.4.12-13** but are excluded from this table due to inconsistencies obtained with the results of these scenarios. It is anticipated that these inconsistencies will be clarified with the author of the CA-Model during March 2015, following which this Draft Interim Modelling Report will be updated.

4.2.1 Scenarios Excluding Additional Large Scale Supply Augmentation Options

4.2.1.1 Scenario 1: Baseline

This scenario could be considered the "*business as usual*" scenario. The input of this scenario is discussed in **Section 4.1** above and is summarised below:

1. Inclusion of the latest updated water demand figures for the CAN, as per Chapter 12 of Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia,
2. The Berg Aukas boreholes are to provide water to the local Waterberg area only,
3. The Goblenz boreholes provide water to the local Waterberg area only,
4. Normal supply from the Kombat Boreholes is 2.64 Mm³/a (limited by the natural recharge capacity[1], which is less than the permit approved abstraction rate of 3.81 Mm³/a),
5. Emergency supply from the Kombat Boreholes is 5.4 Mm³/a which is a short-term emergency abstraction rate to increase the capacity to above the current installed capacity of 3.81 Mm³/a under drought relief measures,
6. Normal supply from Berg Aukas mine is 1.6 Mm³/a (limited by the natural recharge capacity, which is less than the permit approved abstraction rate of 3.7 Mm³/a),
7. Emergency supply from Berg Aukas mine is 5.2 Mm³/a which is equal to the maximum permit approved abstraction for short term supply,
8. Restricted supply from NGWRP at 5 Mm³/a until May 2017 and 7.66 Mm³/a as from 01 May 2017[2] when the Gammams Waste Water Treatment plant will be able to provide reclaimable water throughout the year,
9. The Windhoek boreholes provide a base supply of 0.5 Mm³/a[3] and a limited-use emergency supply rate 5.5 Mm³/a until 30 September 2015 and 9.15 Mm³/a as from 01 October 2015 (implemented on 1 May 2015 for modelling),
10. Transfer from Omatako Dam to Von Bach Dam is based on one Sulzer pump (30 Mm³/a) and the use of small pumps (10.95 Mm³/a) when Omatako Dam is less than 10% full (below dead storage),
11. Normal transfer between Swakoppoort Dam and Von Bach Dam (10 Mm³/a),
12. 10% treatment losses at the Von Bach Water Treatment Plant,
13. The maximum storage capacity of the Windhoek Aquifer is 41 Mm³, with storage of 29.3 Mm³ on 01 May 2014 (start conditions).
14. Phase 1 and part of Phase 2 of the artificial recharge to the Windhoek Aquifer is already implemented with an operational installed recharge capacity of 1 Mm³/a until 30 September 2015 (implemented on 01 May 2015 for modelling) and 2.44 Mm³/a into the Auas Mountain Quartzites for the remainder of the simulation period.

1 In order to model the long-term sustainable water supply to the CAN, normal period abstraction from ground water resources is generally set equal to the natural recharge rate which is the volume which can be abstracted sustainably over time.
2 It is not possible to introduce the source as from 01 June 2017 due to limitations in the CA-Model.
3 In contrast with the methodology followed with other groundwater sources where the normal period supply is equal to the recharge rate of the aquifer, the normal period supply of 0.5 Mm³/a is less than the estimated recharge of the aquifer (1.73 Mm³/a) in order to allow the build-up of reserves in the water bank for use during emergency periods.

4.2.1.2 Scenario 2: Swakoppoort Water Quality Concerns

Scenario 2 investigates the impact on shortfalls in supply resulting from no or limited transfer of water from Swakoppoort Dam to Von Bach Dam due to water quality concerns (refer to Chapter 4 of Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia).

1. **Scenario 2a:**
   a. No transfer from Swakoppoort Dam to Von Bach Dam due to water quality concerns (mostly applicable during recharge periods and mainly as a result of high DOC values),
   b. Determine shortfall in supply,
2. **Scenario 2b:**
   a. Transfer from Swakoppoort Dam to Von Bach Dam only for 8 months of the year, due to water quality concerns (no transfer in August, September October and November as result of extremely high algal counts). This was modelled in the CA-Model by reducing the monthly transfer rate by 66.7% of the normal transfer rate to 6.33 Mm^3/a,
   b. Determine shortfall in supply.

4.2.1.3 Scenario 3: Reduction of Von Bach Water Treatment Plant Losses

Scenario 3 investigates the impact on shortfalls in supply resulting from a reduction in the losses at the VBWTP.

1. Scenario 1 (Baseline Scenario) as above, plus,
2. Reduction of VBWTP losses to 1% through the recycling of supernatant to the Von Bach Dam as from May 2016.

Unfortunately, the CA Model cannot incorporate losses that vary over time and therefore the loss reduction was incorporated over the entire 36 year modelling period.

4.2.1.4 Scenario 4: Completion of the WMARS

Scenario 4 investigates the impact on shortfalls in supply resulting from a reduction in the losses at the VBWTP and increasing the capacity of the water bank, abstraction and recharge capacities under the WMARS.

1. Scenario 3 as above, plus
2. Increased recharge to 8 Mm^3/a as from May 2018,
3. Emergency abstraction of 19 Mm^3/a from May 2018,
4. Storage capacity of the existing water bank: 61 Mm^3 after completion of boreholes and infrastructure,
5. Increased size of the water bank, from 61 Mm^3 to 89 Mm^3 and an increased emergency abstraction rate of 21 Mm^3/a from 01 May 2020 onwards.

The option to increase the water bank size to 114 Mm^3 is not feasible as a short term option and is therefore excluded because there are only a few boreholes in the area under consideration. The drilling of exploration boreholes and test pumping of these over at least 5 years will be required to determine the detailed parameters for that part of the aquifer.

4.2.1.5 Scenario 5: Water Supply from Abenab Mine

As an alternative to the completion of the WMARS, the development of the boreholes in the vicinity of the Abenab Mine which may include some abstraction from the Mine is considered. According to modelling done covering the Karst IV Area, a maximum of 12 Mm^3/a may be abstracted over 3 years during a cycle of 15 years (therefore a total of 36 Mm^3) after which 12 years must be provided for recovery (NamWater, 2014). Scenario 5 was implemented in the following way:

1. Scenario 3 as above, plus
2. An additional groundwater source with a capacity of 36 Mm^3 and an emergency abstraction rate of 12 Mm^3/a implemented in May 2018.

4.2.1.6 Scenario 6: Expansion of the Water Bank of the Windhoek Aquifer with Advanced Reclamation

Scenario 6 investigates the impact on shortfalls in supply resulting from a reduction in the losses at the VBWTP and increasing the capacity of the water bank under the WMARS, together with advanced reclamation supply to Windhoek.

1. Scenario 4 as above, plus
2. Increased reclamation in Windhoek based on available effluent for reclamation and the use of advanced membrane technology to produce ultra-pure water quality with almost no salinity, as from May 2019 at rates of 4.2 Mm^3/a.

4.2.2 Scenarios Including Large Scale Additional Augmentation

4.2.2.1 Scenario 7: Abstraction from the Okavango River

Scenario 7 investigates the impact on shortfalls in supply resulting from a reduction in the losses at the VBWTP, increasing the capacity of the water bank under the WMARS, increasing the volumes of reclaimed water in Windhoek and augmenting supply from the Okavango River.

The Okavango River will initially be analysed as an "infinite source", following which the required volumes of abstraction will be analysed in the context of flows in the Okavango River.

Scenario 7 was implemented in the following way:

1. Scenario 6 as above, plus
2. Add supply augmentation from the Okavango River, including losses along the ENWC Canal, initially analysed as an "infinite source"[4].

4.2.2.2 Scenario 8: Desalination Augmentation from the Coast

Scenario 8 investigates the impact on shortfalls in supply resulting from a reduction in the losses at the VBWTP, increasing the capacity of the water bank under the WMARS, increasing the volumes of reclaimed water in Windhoek and augmenting supply using desalinated sea water from the coast. Scenario 8 was implemented in the following way:

1. Scenario 6 as above, plus
2. Add supply augmentation from the coast assuming desalinated sea water is supplied to Von Bach, initially analysed as an "infinite source"[3]:

The difference between Scenarios 7 and 8 (apart from the sources), which both investigate the augmentation sources as "infinite", is the higher losses along the ENWC Canal under Scenario 7.

4.2.2.3 Scenario 9: Increased Water Demands, Climate Change Effects and Other

Scenario 9 investigates the impact of increased water demand from other areas and developments in the CAN. The following sub-scenarios were investigated:

- **Scenario 9a:** Either Scenario 7 and / or 8 plus the incorporation of the Omaruru, Otjinene and Otjiwarongo augmentation requirements:
    - Add Omaruru augmentation requirements to the Karibib WTP demands as of 01 May 2021,
    - Add Otjiwarongo augmentation requirements to the Waterberg Water Supply Area (Waterberg / Okakarara canal off-take as per the CA-Model) as of 01 May 2039,
    - Add Otjinene augmentation requirements to the WWSA as of 01 May 2043,
- **Scenario 9b:** Same as Scenario 9a as above, but increase the Windhoek demands by 10% to accommodate future developments such as augmenting existing mines or supplying to new mines or any other water-intensive industrial development,
- **Scenario 9c:** Same as 9b, but increase the Windhoek demands by another 10% (21% in total) to accommodate future developments such as existing mines or supplying to new mines like the Jindal or Lodestone iron ore mines, or any other water-intensive industrial development,

[4] This means that the capacity of the source is not limited for the purposes of the modelling, which is primarily for conducting a water balance. The output generated by the CA-Model is then later analysed to determine the volumes to be abstracted from the source.

- **Scenario 9d:** Same as Scenario 9a, with the addition of water supply to the currently undeveloped areas in the North-Eastern Otjozondjupa And Northern Omaheke Regions[5], with these demands added to the Waterberg / Okakarara canal off-take as per the CA-Model in 2021/22,
- **Scenario 9e:** Same as 9a, but reduce runoff into the Von Bach-, Swakoppoort- and Omatako Dams by 15% and increase the evaporation rate by 15% in order to accommodate a drier climate for possible climate change impacts,
- **Scenario 9f:** Same as 9a, but increase the Windhoek water bank size from 89 Mm^3 to 114 Mm^3.

Modelling Scenarios 9e to 9f in the CA-Model produced either inconsistent results or results of no significance and are not discussed in-depth in the results section (**Section 4.4**) as these inconsistencies could not be successfully resolved by the time of the writing. It is anticipated that these inconsistencies will be clarified with the author of the CA-Model during March 2015, following which this Draft Interim Modelling Report will be updated.

4.3 MODELLING GOAL

With the erratic rainfall and inflow into the three dam system it is important to control the magnitude of the maximum shortfall in supply. The proposed design or supply goal is based on a 99% likelihood that annual shortfall magnitudes will be no greater than 15% of the annual demand for each year of the 36-year planning horizon. This design goal for the CAN was developed under the 2004 Water Augmentation Study (after CAJVC, 2004e) and has been used since.

An acceptable shortfall in supply of 15% is based on the Failure of Supply estimate as determined under the 2001 CASU study (refer to **Section 3.3.1.4.2** of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia), where it was found that a reduction in demand of between 12% and 15% would constitute an acceptable level of savings for Windhoek where no economic losses would occur during periods of shortfall (after WTC, 2001).

This design goal implies that we are willing to accept a 1% annual or 1 in 100 year-to-year risk that shortfall magnitudes might exceed the 15% threshold, but we are not willing to accept a risk higher than that. This approach to system design provides an easy and direct method of interpreting modelling results and assessing during which year new infrastructure development is required in order to reduce future shortfall magnitudes to acceptable levels (after CAJVC, 2004e). The 15% shortfall threshold is shown as a red dotted line in the graphs provided in **Section 4.4** which details the results of the modelling.

[5] Refer to Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia. Water demands do not include any unserved areas along possible pipeline routes.

4.4 RESULTS OF THE MODELLING

4.4.1 Analysis and Interpretation of the Results

The analysis of the results obtained from the CA-Model generally focusses on the shortfalls downstream of Von Bach Dam. Since the water demands exceed the supply capacity of the water resources, the goal of the modelling is to, with acceptable probability, reduce the shortfalls to acceptable limits. Supply downstream of Von Bach Dam is the main focus of the analyses for several reasons:

1. Water demand downstream of Von Bach Dam is by far the largest in the CAN; estimated to be 89% of the total water demand in the CAN for 2013 and 95% for 2050,
2. Water demands supplied by Swakoppoort Dam are expected to decrease in future and do not generate shortfalls of the order of magnitude of those downstream of Von Bach Dam, if any,
3. Water demands upstream of Von Bach Dam constitute a small portion of those of the CAN overall (in the order of 4 to 5%) and can generally be supplied by groundwater sources in the Karst Area,
4. The demand node downstream of Von Bach dam is the furthest downstream node or link in the CAN system, meaning that with the analysis of supply augmentation to the CAN, the additional water will likely satisfy upstream demands before reaching the VBWTP to supply users further downstream.

4.4.2 Scenario 1: Baseline

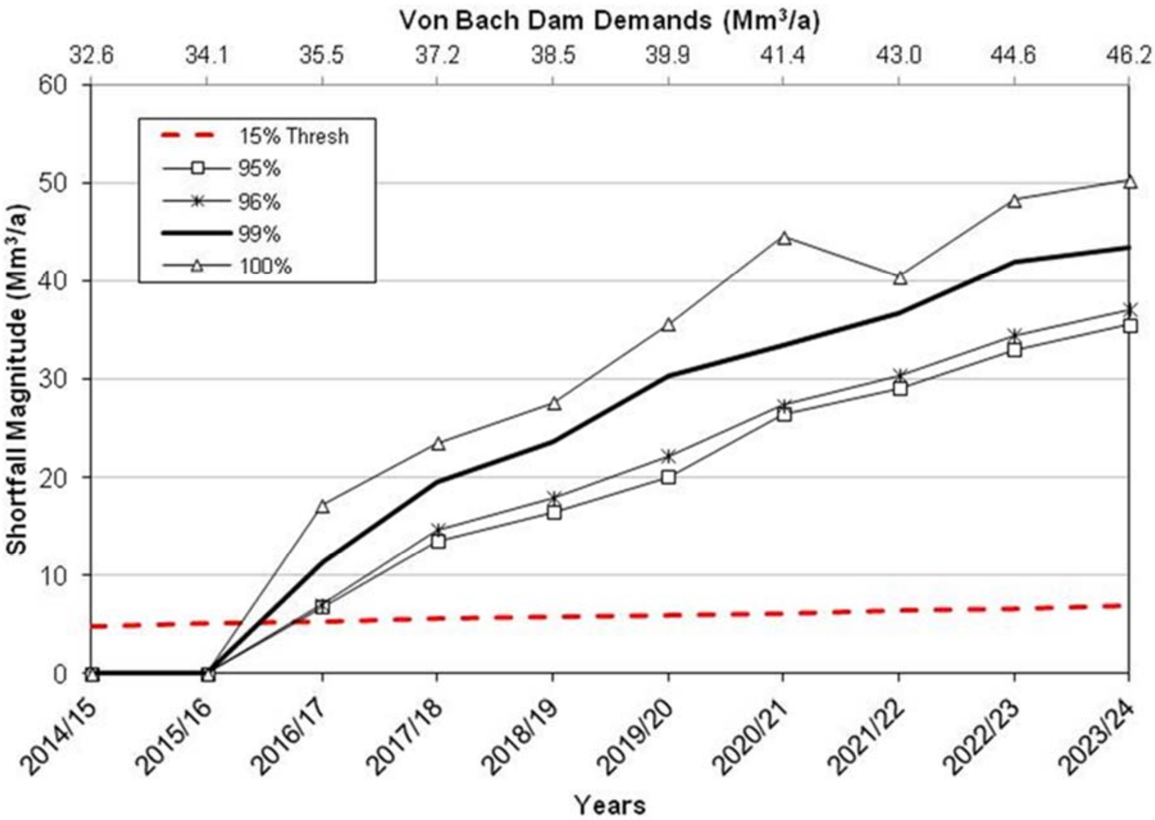
It must be emphasized that the CAN water supply system is precarious and very close to being insufficient. Only the overall above average inflow to the main supply dams over the past 4 to 6 years has prevented a total system collapse. The main reason for these shortfalls is related to the slow rate of implementation of the WMARS which was identified as the next supply option in the 2004 augmentation study (CAJVC, 2004e) – **Table 4.13** compares the proposed and actual implementation of the WMARS.

Table 4.13: Planned and Actual Implementation of the Windhoek Managed Aquifer Recharge Scheme

Year	Abstraction (Mm^3/a)	Required Storage (Mm^3)	Required AR Capacity (Mm^3/a)	Remarks
2004	5.5	35	0.97	Comply with installed infrastructure. Total injection capacity 4.1 Mm^3/a with only 1.94 Mm^3/a in the Auas Quartzites.
2008	11	47	4	Sufficient boreholes (8) were drilled by December 2008.
2011	16.5	66	4	Programme not implemented
2018	19	66	8	Future programme not implemented

The shortfall magnitudes for the Baseline Scenario (Scenario 1) are depicted in **Figure 4.1**, which shows that shortfalls in excess of 11 Mm^3/a may occur as from April 2016 onwards, with a maximum shortfall of 43 .5 Mm^3/a by April 2024, based on the design goal (99% security of supply). With the shortage of water, the production of the Windhoek boreholes reduces to the annual recharge whilst almost no water is available for reclamation, which causes a water supply system collapse.

Figure 4.1: Baseline Shortfall Magnitudes

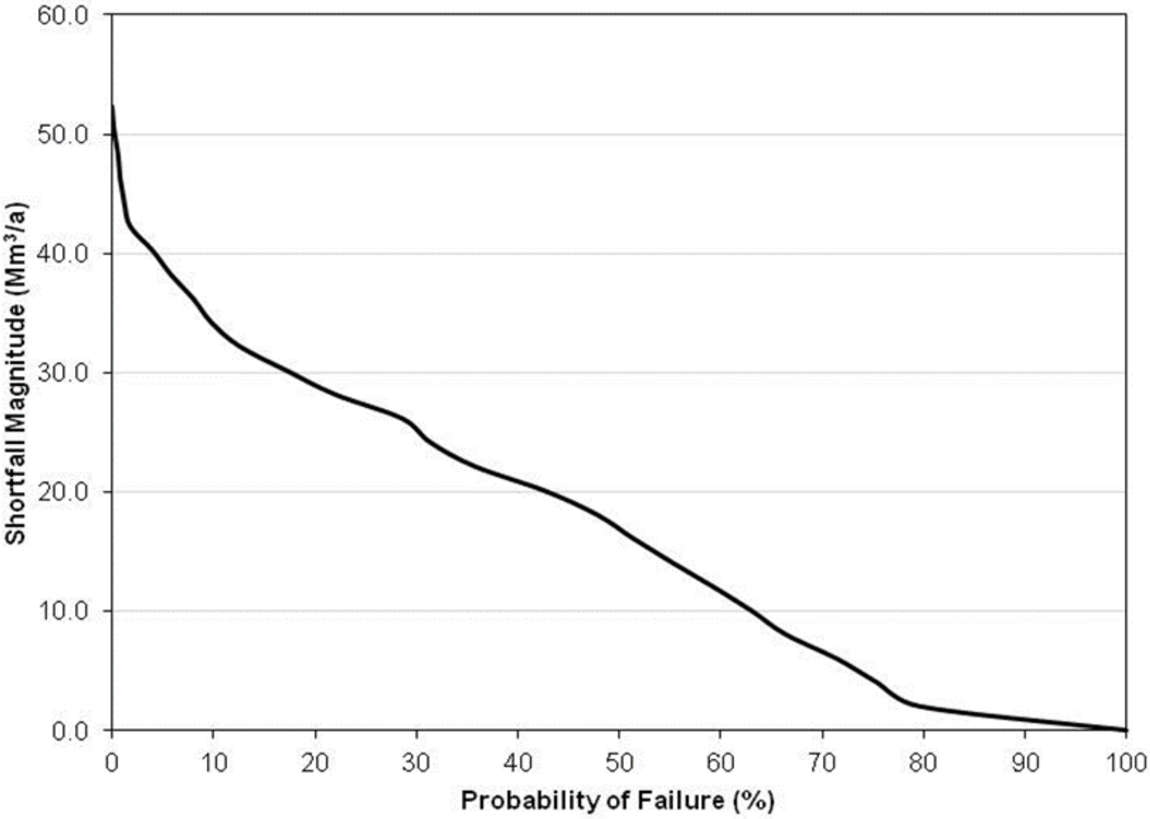


No shortfalls are expected up to 2015/16, due to the water available in the 3 CAN dams and the various aquifers (based on the initial conditions). Once these resources have been drawn down, shortfalls are expected from 2015/16 onwards.

Analysing the results of the modelling shows that CAN has a very high probability of shortfalls in water supply to all users supplied from the Von Bach Dam for the period from April 2016 onwards, based on a 99% security of supply over the 10 year period. The probabilities of failure (shortfalls greater than 15%) based on the current status of bulk water supply is (refer to **Figure 4.2**):

1. 50% probability that shortfalls up to 16 Mm^3/a may occur in any year,
2. 35% probability that shortfalls up to 22 Mm^3/a may occur in any year,
3. 10% probability that shortfalls up to 34 Mm^3/a may occur in any year, and
4. 5% probability that shortfalls up to 39 Mm^3/a may occur in any year.

Figure 4.2: Baseline Shortfall Magnitudes and Probabilities of Failure until 2023/24



Note: "Failure" denotes shortfalls greater than 15% (7.34 Mm^3/a maximum on the water demand for 2023/24).

4.4.3 Scenario 2: Effect of Swakoppoort Water Quality Concerns

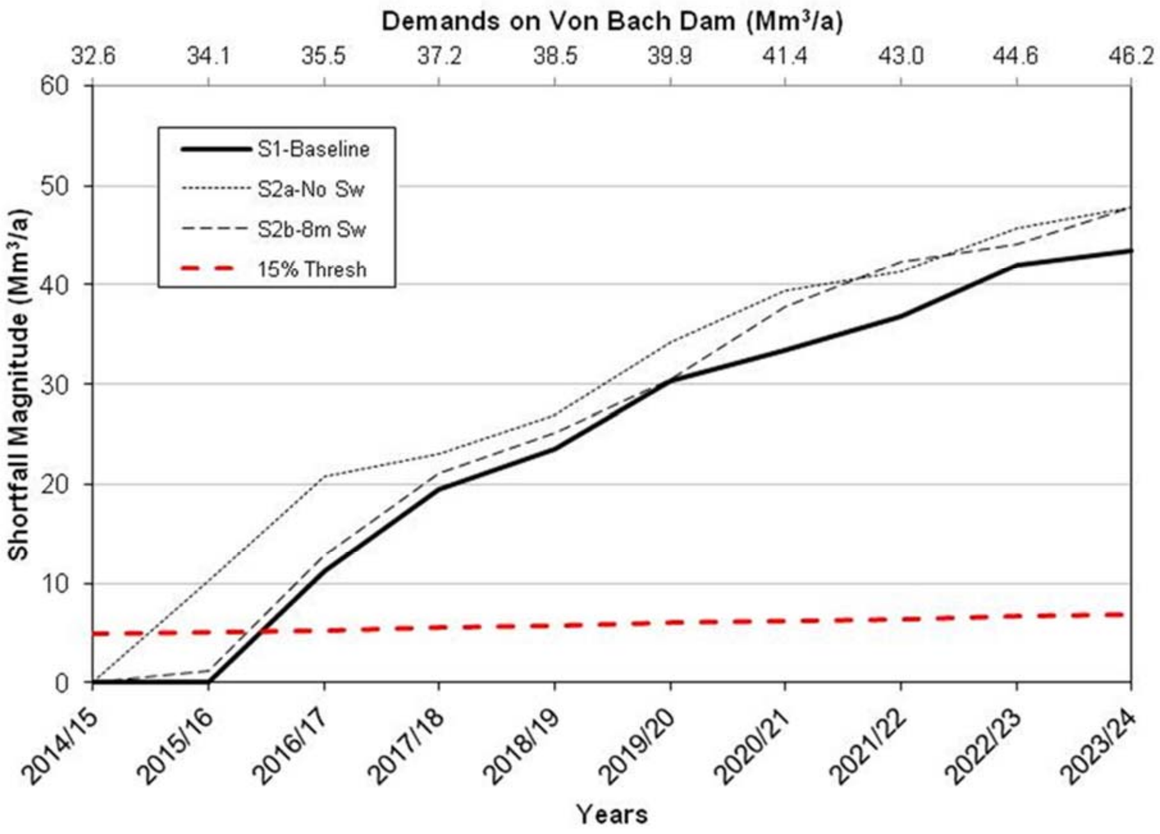
In Scenario 2 the effect of water quality problems experienced at the VBWTP is simulated based on:

1. Scenario 2a: No transfer from Swakoppoort Dam to Von Bach Dam, or
2. Scenario 2b: The transfer of water over a period 8 month per year when algal counts in Swakoppoort Dam are not so high.

The results of Scenario 2 relative to the Baseline Scenario are depicted in **Figure 4.3**, which illustrates that restricting the pumping from Swakoppoort Dam to Von Bach Dam is not an option, as the shortfalls are significantly higher than for the Baseline Scenario (Scenario 1). The shortfalls under Scenario 2a (no transfer at all from Swakoppoort Dam) also commence immediately, as opposed to the one-year delay under the Baseline Scenario.

It is therefore imperative that a scheme to solve the water quality concerns caused by high algae growth at Swakoppoort Dam through advanced treatment or treatment in the dam be implemented.

Figure 4.3: Comparative Shortfalls on Von Bach Dam for Scenario 2a and 2b (99% Percentile)



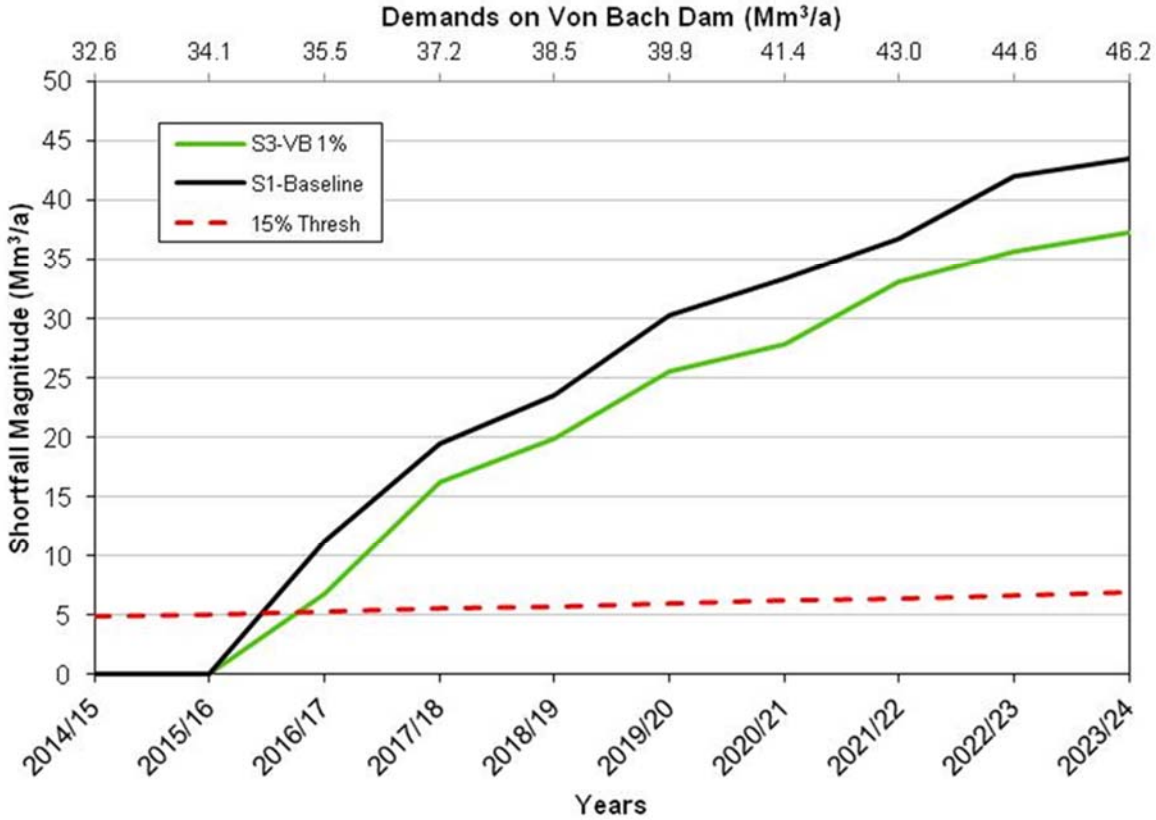
4.4.4 Results of Scenarios 3 to 6

In developing Scenarios 3 to 6 the goal was to try and establish a period of 10 years of relatively safe supply to provide some time to investigate and implement other major supply augmentation schemes such as the link to the Okavango River or the desalination of sea water. Many of the proposals will be difficult and expensive to implement, with a major effect on the unit cost of water downstream of the VBWTP, if costs are to be recovered from water tariffs. Most of the options, such as increasing the size of the Windhoek water bank or increased reclamation in Windhoek, can be phased in as required, depending on the levels of the dams. Additional deep boreholes can be drilled and tested while infrastructure can be phased in, if and when required. Similarly, advanced reclamation (membrane systems) is modular and can be implemented in stages of 100 m^3/h say.

4.4.5 Scenario 3: Reduction of Von Bach Water Treatment Plant Losses

The effect of the reduction in the currently high losses at the VBWTP is illustrated in **Figure 4.4** (reduction in losses from 15% currently to 1%). This Scenario is one of the cheapest options and needs to be implemented as soon as possible. The effect of the reduction of losses at the plant is clearly visible from **Figure 4.4** with the reduction of shortfalls in supply. If losses are reduced to 1% through recycling, the water saved is sufficient to supply all other users downstream of the VBWTP (excluding Windhoek) up to the year 2023.

Figure 4.4: Comparative Shortfalls on Von Bach Dam for Scenario 3 (99% Percentile)



Since 2012, the water from the sludge ponds at the VBWTP has been recycled directly to the inlet of the VBWTP to extend the safe supply period to mitigate against the below average inflow in the dams. This has a detrimental effect on the water quality and causes significant operational problems at the plant. Except for the long term savings, the implementation of the recycling from the sludge ponds at the VBWTP gains approximately one year before shortfalls may occur based on the design criteria.

4.4.6 Scenarios 4 and 5: Completion of the WMARS or Groundwater Abstraction from the Abenab Area

The cumulative effect on the shortfall magnitude through fast tracking the implementation of the existing WMARS (Scenario 4) in comparison with the possible development of groundwater in the Abenab Area (Scenario 5) is illustrated in **Figure 4.5**, based on 99 percentile values.

Even with fast tracking of the WMARS it is impossible to reach the design goal of shortfalls of less than 15% (dotted red line) with 99% security. Similarly, the alternative development of the Abenab groundwater sources will not solve the expected shortages based on the 99% values.

Figure 4.5: Comparative Shortfalls on Von Bach Dam for Scenarios 4 and 5 (99% Percentile)

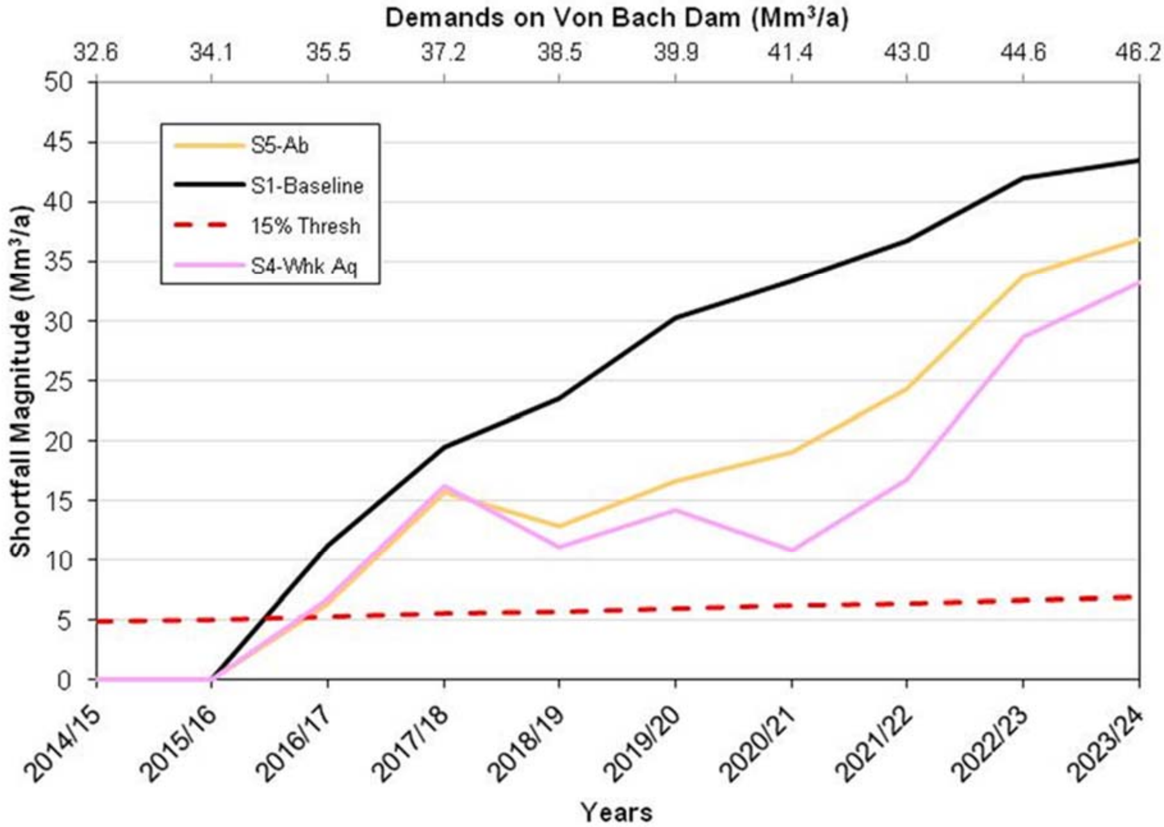


Figure 4.6: Comparative Shortfalls on Von Bach Dam for Scenarios 3, 4 and 5 (95% Percentile)

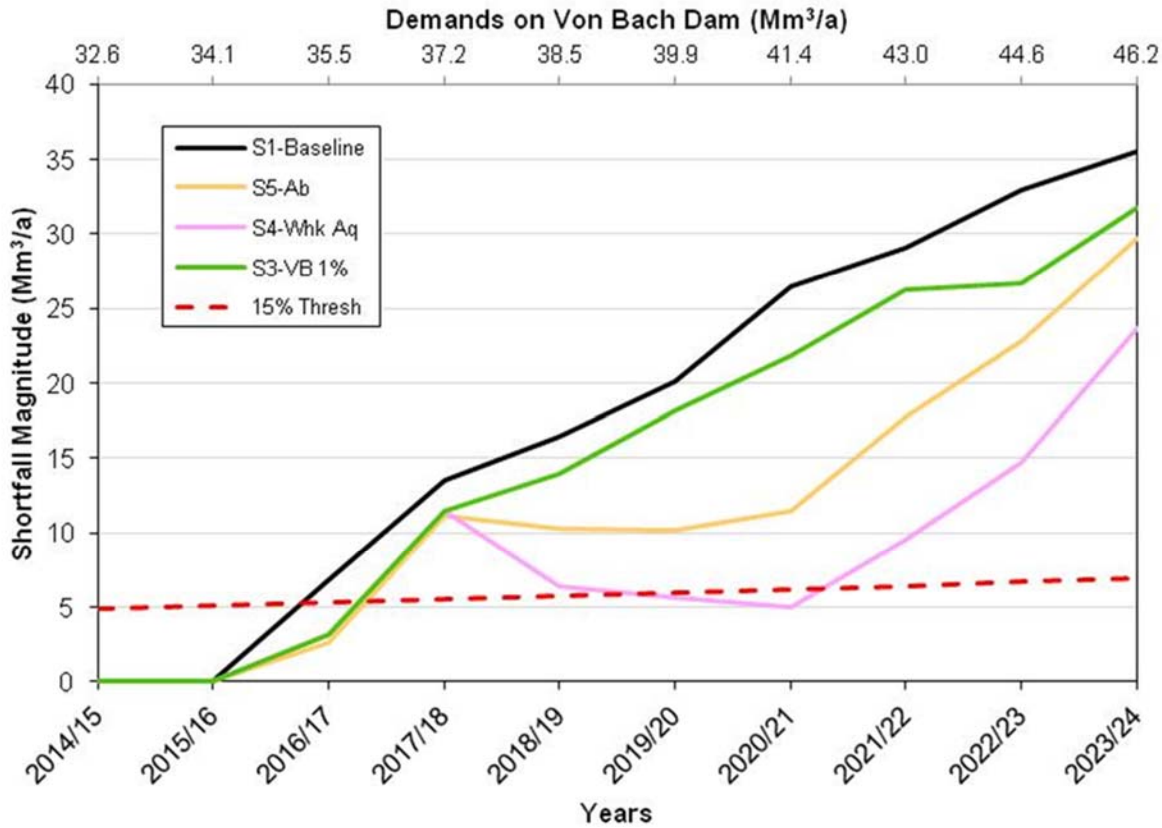


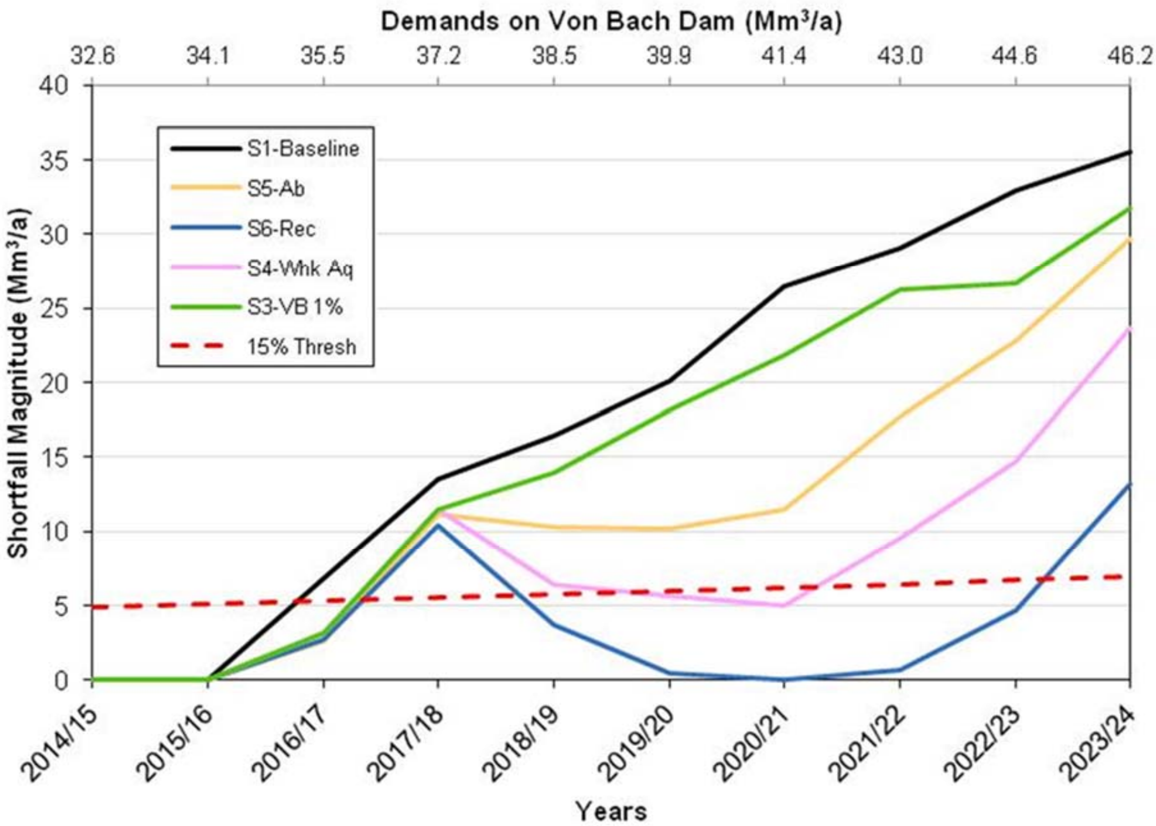
Figure 4.6 demonstrates that the completion of the WMARS, with the main exception of 2017/18, almost complies with the 95% security of supply until 2021/22 (shortfalls of less than 15% with a 95% security; i.e. there is a 5% or 1-in-20-years probability of not meeting this criterion). This is not the case with Scenario 5, which demonstrates that the completion of the WMARS is much safer as a source for augmentation than the groundwater sources in the Abenab area. The 95% values are provided in **Figure 4.6** for comparative purposed, as the 99% security of supply goal cannot be met – refer to **Figure 4.5**)

The completion of the implementation of the Windhoek Managed Aquifer Recharge Scheme, as contemplated for implementation in 2004, needs to be implemented in steps to keep the shortfall below the 15% acceptable limit.

4.4.7 Scenario 6: Increasing the Size of the Windhoek Water Bank and Advanced Reclamation

The cumulative effect of over abstraction from the Windhoek Aquifer and the bulk supply failure in the CAN increases the risks of shortfalls from 2021 onwards, based on the 95% security of supply. The expansion of the WMARS by increasing the size of the water bank, additional abstraction plus advanced reclamation improves the situation significantly as illustrated in **Figure 4.13**.

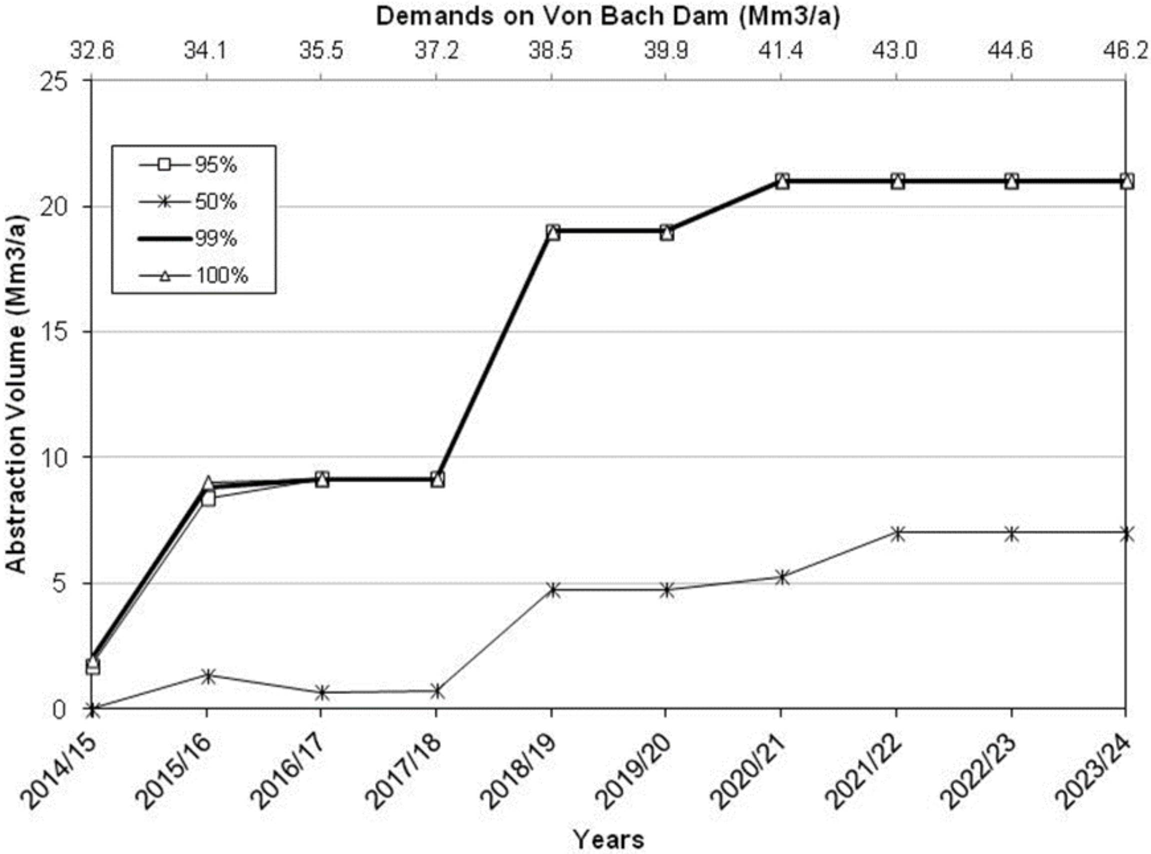
Figure 4.7: Comparative Shortfalls on Von Bach Dam for Scenarios 1, 3, 4, 5 and 6 (95% Percentile)



Scenario 6, with the exception of 2017/18, complies with the 95% security of supply criteria until 2023/24 (shortfalls of less than 15% with a 95% security[6]; i.e. there is a 5% or 1-in-20-years probability of not meeting this criterion). To address the shortfall in 2023/24, it suggested that bulk supply augmentation from the Okavango River or desalinated sea water from the coast be implemented one year earlier.

The effect of the abstraction of water from and injection of water into the Windhoek Aquifer is illustrated in **Figure 4.8** and **Figure 4.9**.

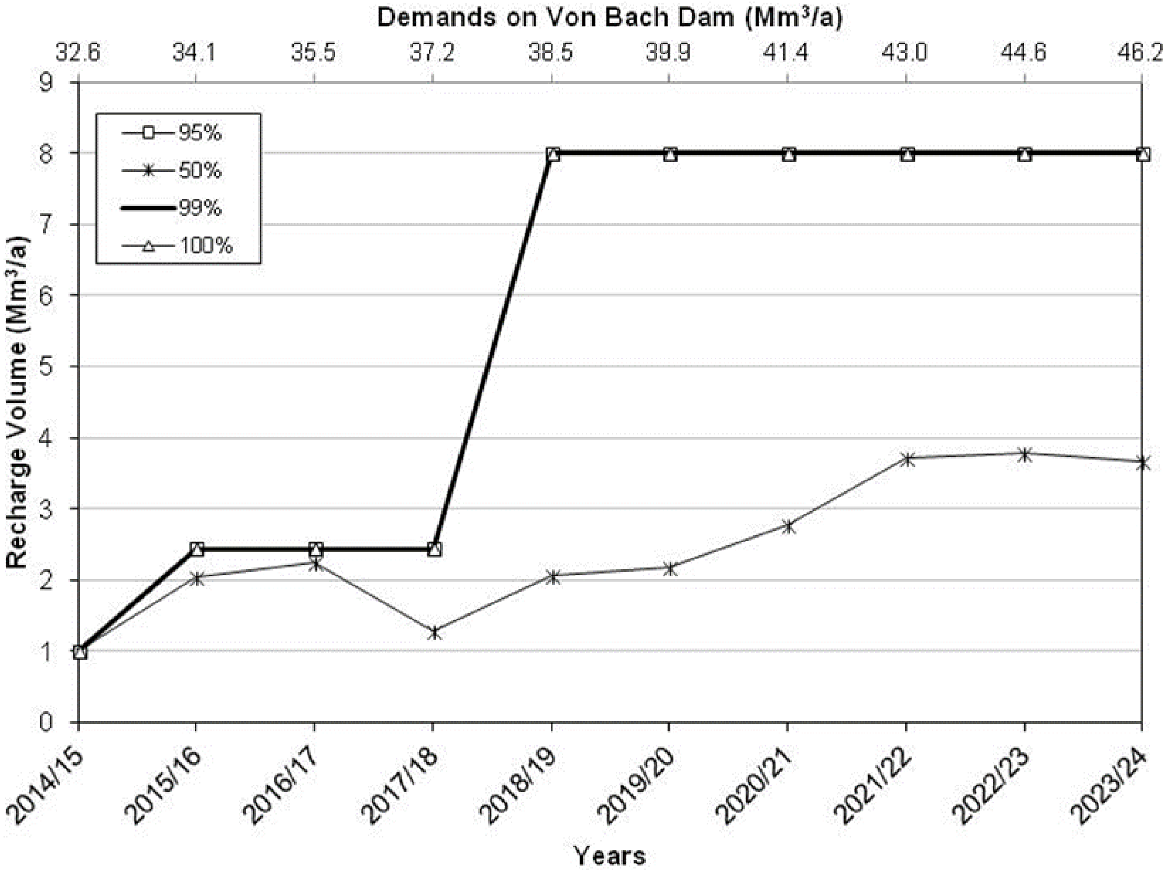
Figure 4.8: Abstraction Rates from the Windhoek Aquifer as per Scenario 6 (100%, 99%, 95% and 50% Percentiles)



Based on the modelling results the median (50 percentile) abstraction rate will be approximately 6 Mm^3/a until 2022/23.

[6] The 95% security of supply values are provided / used as a “next best”, as the 99% security of supply goal cannot be met.

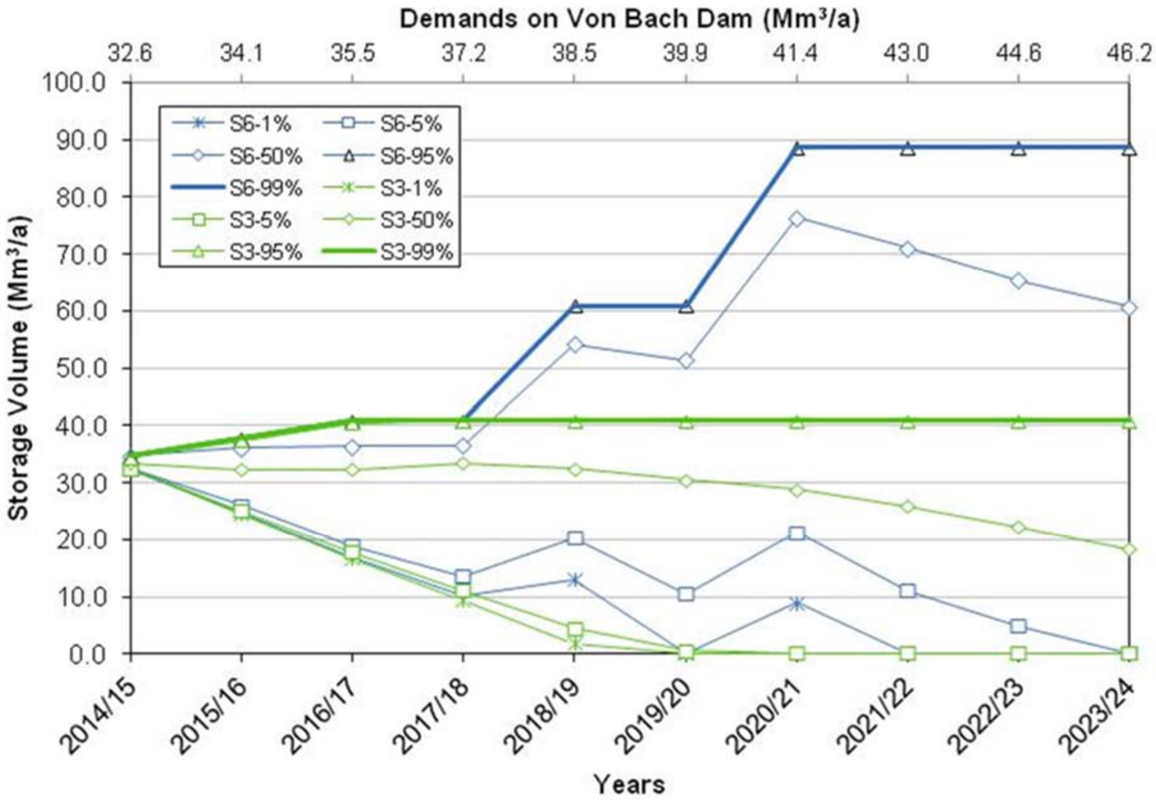
Figure 4.9: Recharge / Injection Rates into the Windhoek Aquifer as per Scenario 6 (100%, 99%, 95% and 50% Percentiles)



The 99% percentile maximum rate of recharge is 8 Mm^3/a while the expected median rate of recharge in the Windhoek aquifer is high until 2016/17 in order to fill the water bank. Once the water bank is full, the average recharge rate will be only 3.48 Mm^3/a from 2021/22 onwards. The effect on the volumes of water stored in the water bank is illustrated in **Figure 4.10** for both for the smaller water bank (Scenario 3, 61 Mm^3) and the larger water bank (Scenario 6, 8 Mm^3) aquifer storage areas.

Figure 4.10 illustrates the percentile values for each planning year of the five hundred simulation runs. The one percentile storage value gives an indication that with high rates of abstraction and very little recharge during periods of drought, the aquifer may be empty by 2019/20, even with a water bank storage volume of 89 Mm^3. This represents the 1% risk of insufficient supply based on the 99% security of supply.

Figure 4.10: Comparative Storage Volumes of the Windhoek Aquifer for Scenario 3 (VB 1%) and Scenario 6 (WMARS and Advanced Reclamation) for the Period 2014/15-2023/24



4.4.8 Risk of Failure and Shortfall Probabilities for Scenarios 1, 2, 3, 4 and 6

The risk of failure over the first 10-year planning period up to 2023/24, based on the accepted criteria ("failure" denotes shortfalls greater than 15%), is indicated in **Figure 4.11**.

Shortfalls are not expected prior to 2015/16 (assuming inflow into the 3 dams and recharge of the aquifers from rainfall), due to the water available in the 3 CAN dams and the various aquifers (based on the initial conditions). Once these resources have been drawn down, shortfalls are expected from 2015/16 onwards. Thereafter, the risk of failure to supply water to the CAN is unacceptably high for the planning period, even with the implementation of both artificial recharge (Scenario 4) and increased reclamation (Scenario 6). **Figure 4.11** shows that the risk of failure by 2023/24 is lower than for the Baseline for Scenarios 3, 4 and 6, indicating the value of implementing these scenarios in time. Scenario 6 is the only scenario to provide a probability of failure of less than 40% by 2023/24.

Figure 4.12 illustrates the shortfall magnitudes and probabilities of failure for all the short-term scenarios; Scenarios 1, 3, 4 and 6, up to 2023/24. If Scenarios 1, 3, 4 and 6 are implemented, there is still a 10% risk that shortfalls of up to 13 Mm^3/a may occur in any year until 2023/24.

Figure 4.11: Risk of Failure for Selected Scenarios 3, 4 and 6

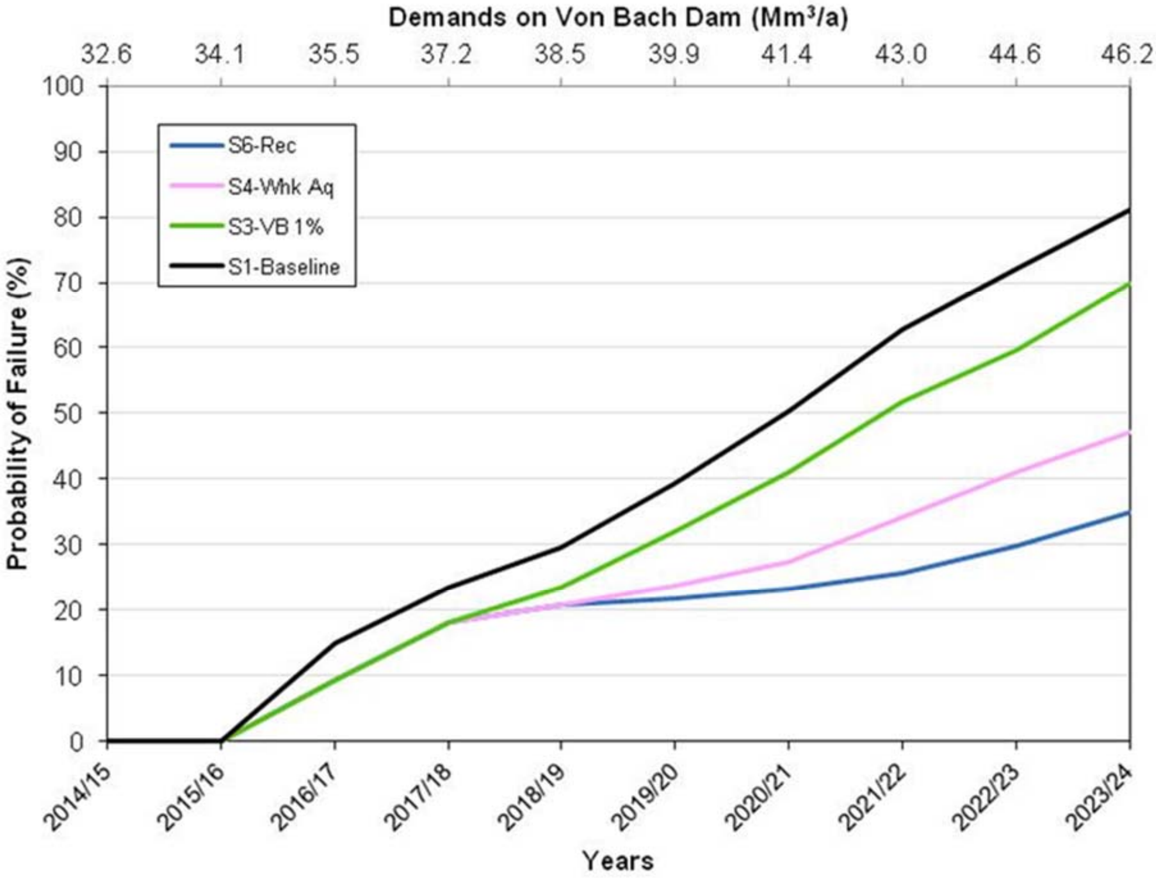
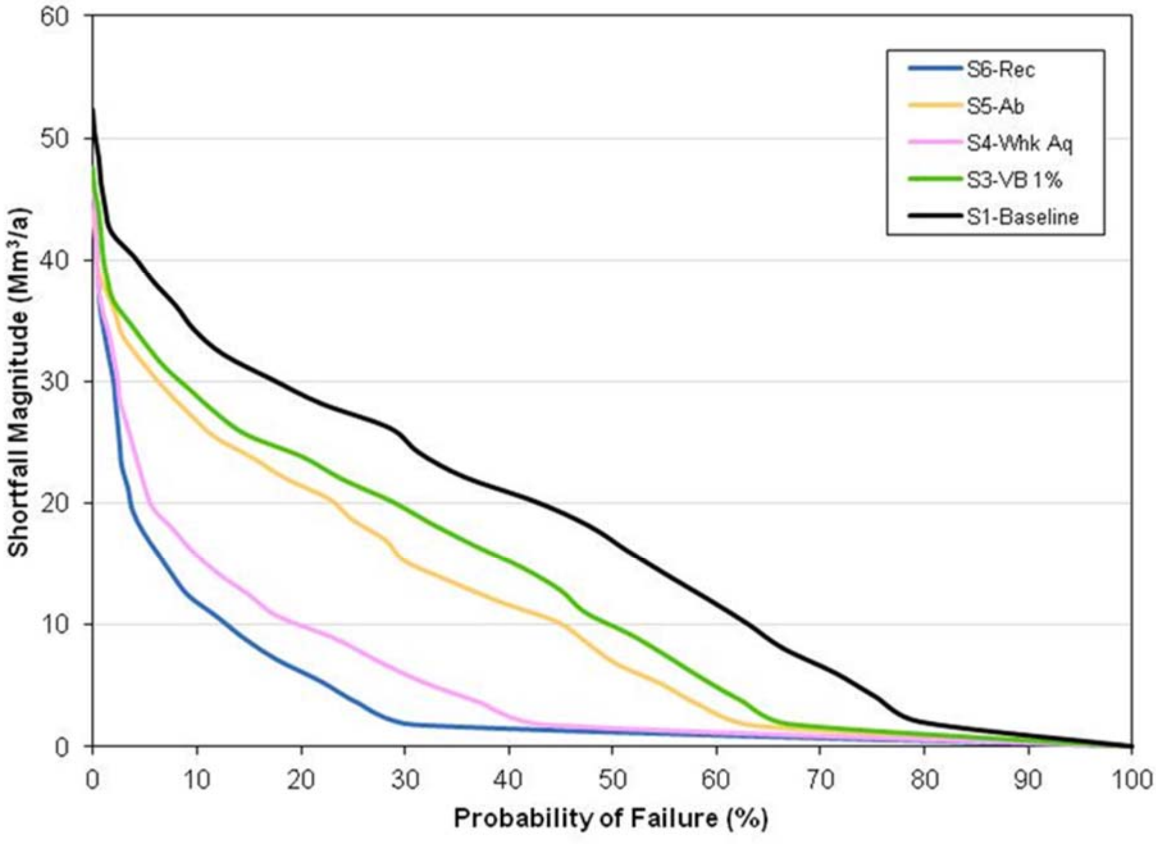


Figure 4.12: Shortfall Magnitudes and Probabilities of Failure for Scenarios 1, 3, 4 and 6



There is a very significant difference in the probability of failure for shortfalls below 20 Mm^3/a between the different scenarios, and compared with the Baseline Scenario. Implementing Scenario 6 for example can be seen to decrease the probability of failure for a shortfall of 10 Mm^3/a from approximately 63% to13%.

4.4.9 Scenario 7: Abstraction from the Okavango River

To prevent system capacity constraints influencing the results, all system transfer bottlenecks were adjusted upwards (refer to earlier footnotes). Transfer capacities of the various infrastructure components will be assessed separately, taking normal and peak transfers into account, for example with pipelines such as the Von Bach – Windhoek Pipeline.

The supply augmentation from the Okavango River was modelled as an emergency resource with no permanent transfers. This transfer is only activated if a shortfall may occur within the next 12 months. The modelling further assumed that the NGWRP would operate at full capacity while higher production from the Windhoek Aquifer is activated when a potential shortfall may occur in the next 12 months. The volume of supply from the Okavango River was increased over time in steps as summarised in **Table 4.2**. These steps are introduced to ensure full utilisation of all local resources in the modelling exercise before additional water is to be abstracted from the Okavango River.

Table 4.14: Modelled Abstraction Rates from the Okavango River

Year		Emergency Abstraction
Absolute	Relative	Mm^3/a
2022/23	9	25
2028/29	15	32
2032/33	19	45
2039/40	26	60
2044/45	31	65

Figure 4.13 illustrates that after implementation in 2022/23, the Okavango Scheme as summarised above, meets the design criteria, namely a 99% probability that shortfalls will be 15% or less. Shortfalls however exceed the 15% threshold prior to 2022/23 and the implementation of this augmentation option.

It is further important to note that the modelling of Scenario 7 was conducted in an iterative manner, both increasing abstraction from the Okavango River in a step-wise manner and bringing forward the date of implementation in order to meet the design or modelling goal / criteria. This implies that water abstracted from the Okavango River is to reach the CAN in 2022/23, which is 9 years after the start of modelling, and not 10 as initially envisaged.

This is because by 2023/24 the shortfalls in the CAN are of such magnitude that the importation of water from the Okavango River can no longer meet the design criteria.

Figure 4.13: Comparative Shortfalls on Von Bach Dam for Scenario 7 (99 Percentile)

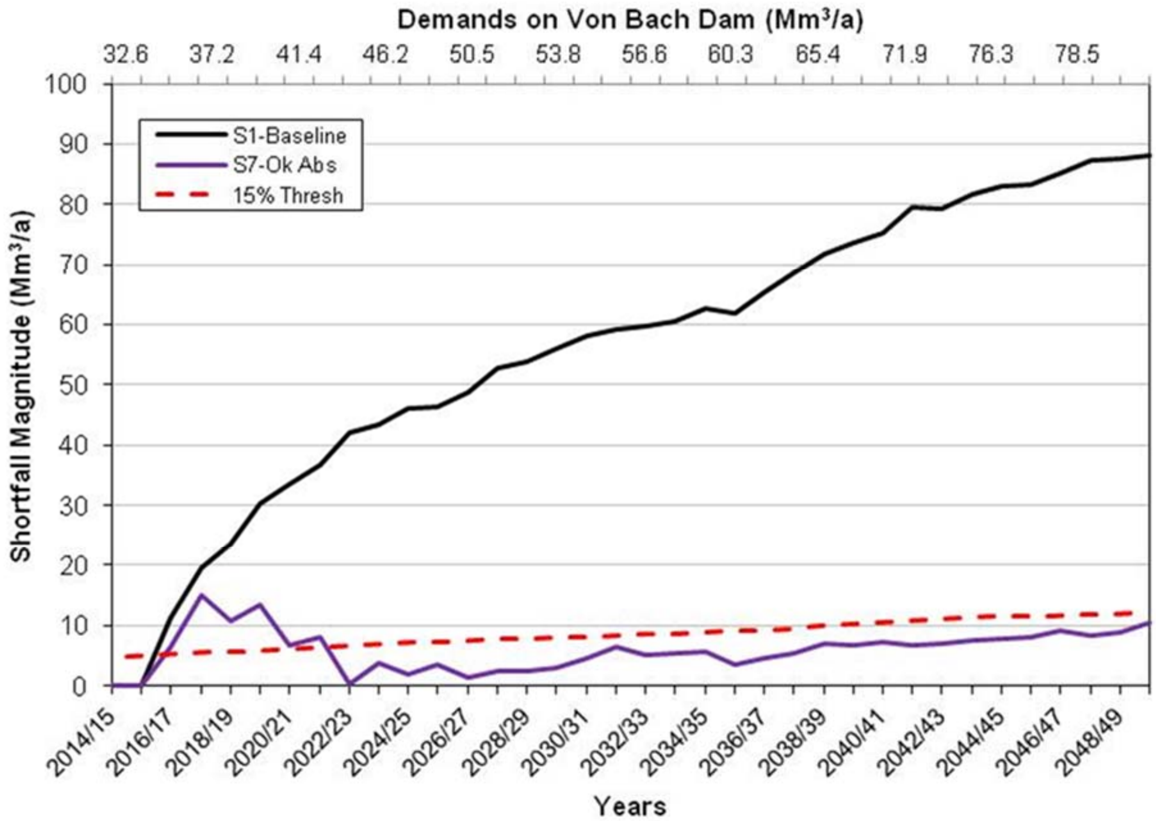


Figure 4.14: Shortfall Magnitudes and Probabilities of Failure for Scenarios 1 and 7

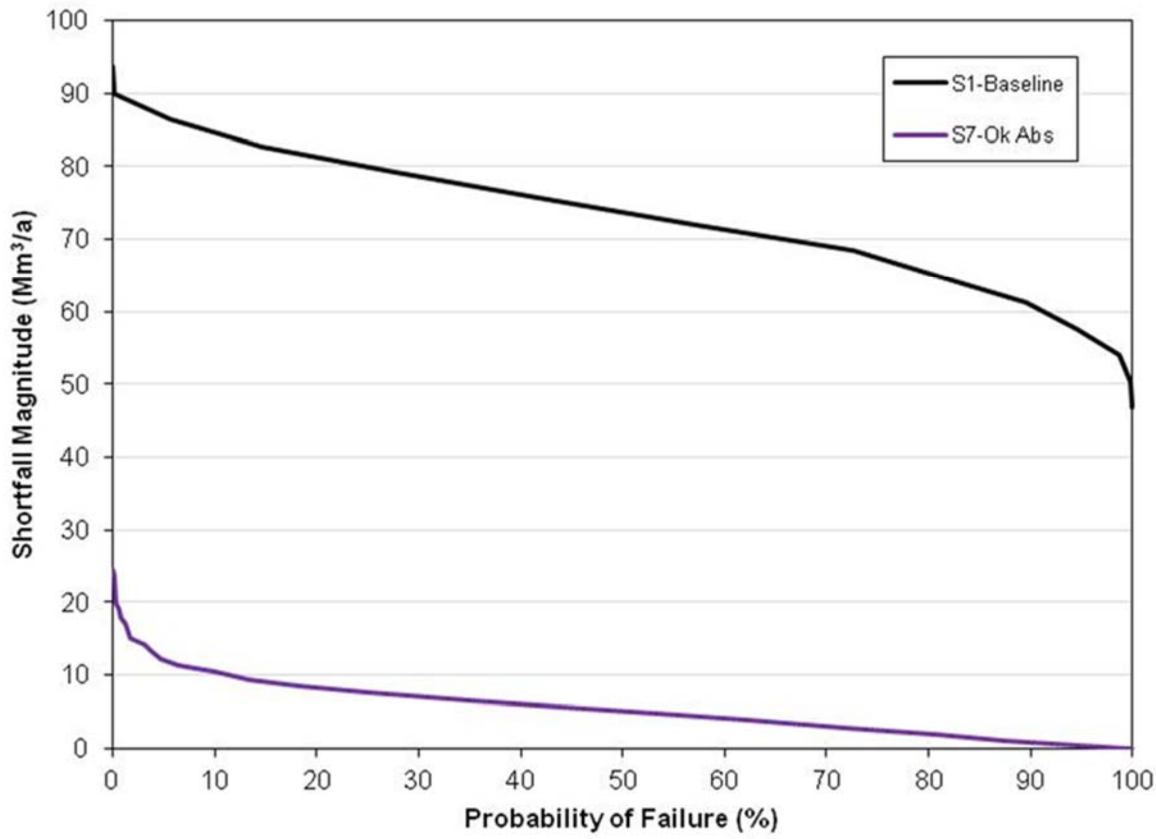
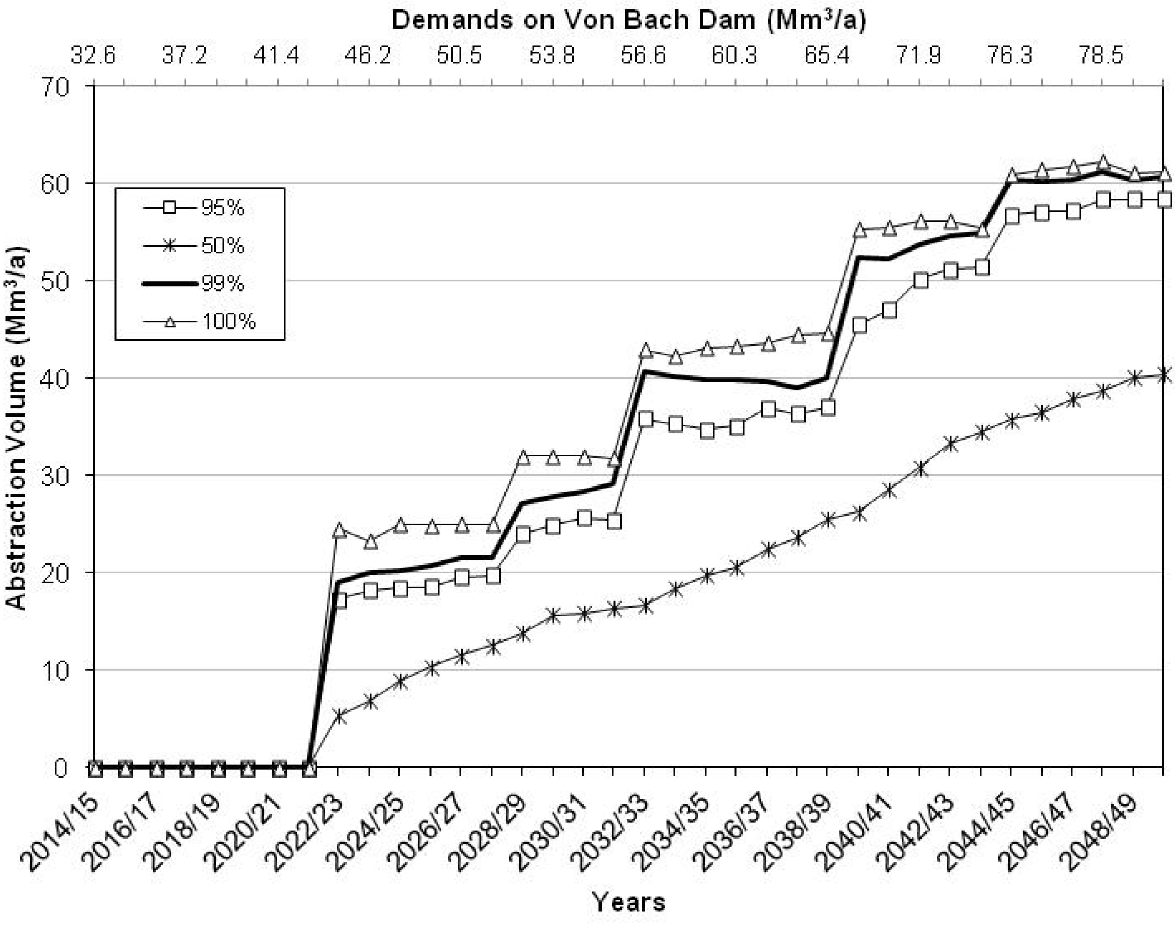


Figure 4.14 illustrates probability of failure (x-axis) and the expected shortfall magnitude (y-axis) which may occur in a specific year based on a 99% security of supply for the Baseline Scenario and Scenario 7 (the Okavango River augmentation scheme). The very large difference in security of supply for Scenario 7 compared with the Baseline Scenario is evident; for a 10% risk of failure, the Baseline shortfall is some 85 Mm^3/a compared with 10 Mm^3/a for the Okavango River augmentation scenario. Whilst Scenario 7 complies with the design parameters with an acceptable risk of failure, it is worth noting that it does not guarantee that no shortfalls will occur in the CAN: There is a 10% probability that a shortfall of 10 Mm^3/a will occur, a 5% probability that a shortfall of 12 Mm^3/a will occur and an 1 % probability that a shortfall of 17.4 Mm^3/a may occur in any year of the planning period.

The abstraction volumes from the Okavango River are illustrated in **Figure 4.15**, which also shows the commencement of the scheme in 2022/23. As expected, the abstraction from the Okavango River increases with time at almost at the same rate as the increase in the water demand. This is because the safe yields from the local resources in the CAN become relatively small in comparison with the expected water demand on the system. The median abstraction in 2049/50 is 40.5 Mm^3/a whilst the 95% abstraction is 60.6 Mm^3/a and the maximum abstraction is 61.1 Mm^3/a. These rates are equivalent to continuous abstraction rates (20 hours a day) of 1.28, 2.30 and 2.32 m^3/s respectively. There is a statistical anomaly produced by the model for the last two years. It is suggested that the figure for 99% abstraction be adjusted from 60.64 Mm^3/a to 64 Mm^3/a.

Figure 4.15: Abstraction Volumes from the Okavango River



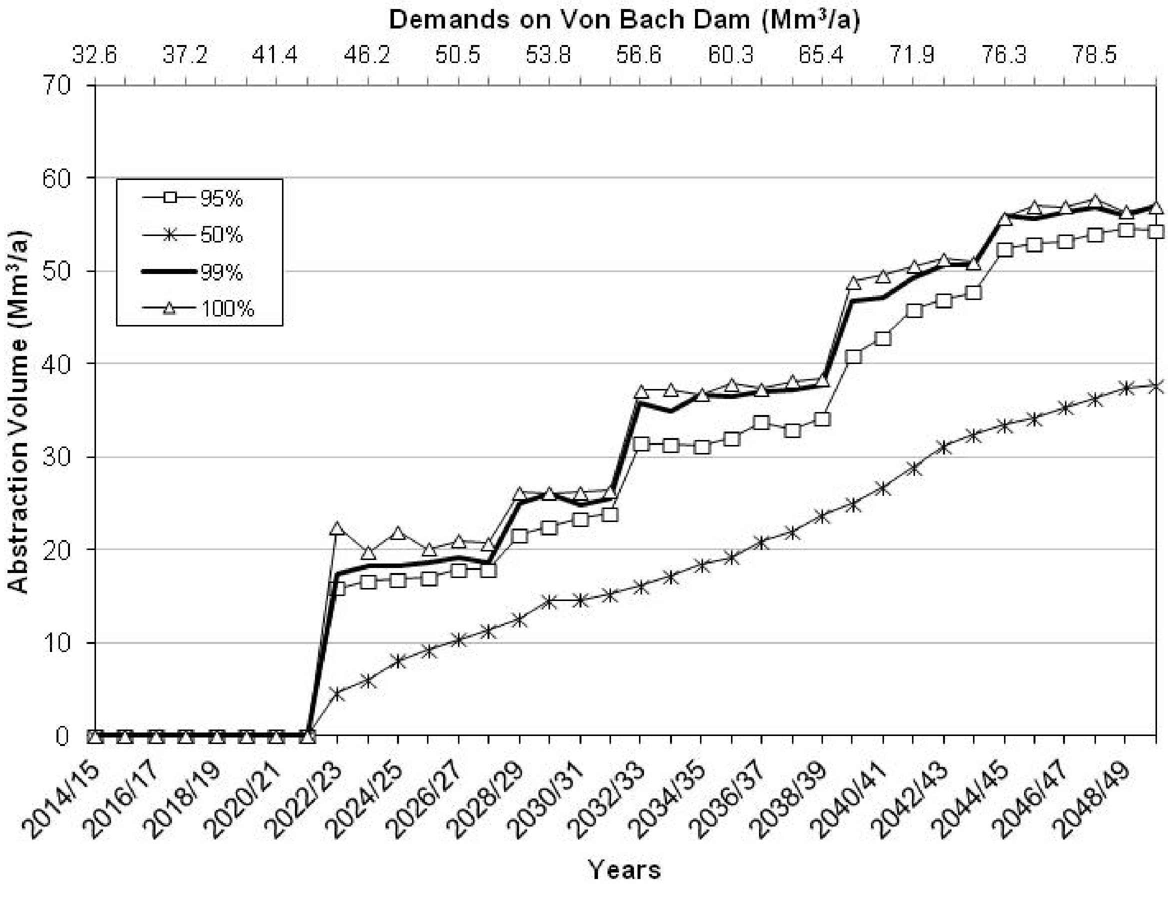
4.4.10 Scenario 8: Desalinated Sea Water from the Coast

The option is exactly the same as Scenario 7 which examines the importation of water from the Okavango River. The only difference is the lower losses through the pipeline system with Supply under Scenario 8 directly to Von Bach or Windhoek in comparison with the losses in the ENWC Canal and some evaporation losses under Scenario 7. The volumes of desalinated sea water from the coast required under Scenario 8 were calculated based on those required from the Okavango River under Scenario 7, adjusting for the lower system losses, because the CA-Model does not have the capability to adequately analyse this as a separate supply source. The expected supply required from desalinated sea water is summarised below in **Table 4.14** and the percentile values are indicated in **Figure 4.16**.

Table 4.15: Modelled Abstraction Rates from Desalinated Sea Water

Year		Emergency Abstraction
Absolute	Relative	Mm^3/a
2022/23	9	17
2028/29	15	25
2032/33	19	36
2039/40	26	47
2044/45	31	56

Figure 4.16: Supply of Desalinated Sea Water from the Coast



4.4.11 Scenarios 9a, 9b and 9c: Okavango Scheme Including Additional Demands

Scenario 9a reflects the additional demand to supply the shortfall in demand when local water resources are inadequate in Otjiwarongo, Otjinene and Omaruru (i.e. the difference between the water demands and the capacity of the local sources). Compliance with the design criteria is depicted in **Figure 4.17**. The additional demand to these centres increases the abstraction from the Okavango River with approximately 2 Mm³/a, as illustrated in **Figure 4.18**.

Scenarios 9b increases the water demand in Windhoek by 10% and Scenario 9c increases it by a further 10% (therefore 21% in total compared with the Baseline Scenario), both based on Scenario 9a. The additional abstraction rates from the Okavango River are illustrated in **Figure 4.19** and **Figure 2.20** respectively.

Figure 4.17: Comparative Shortfalls on Von Bach Dam for Scenarios 9a, 9b and 9c (99 Percentile)

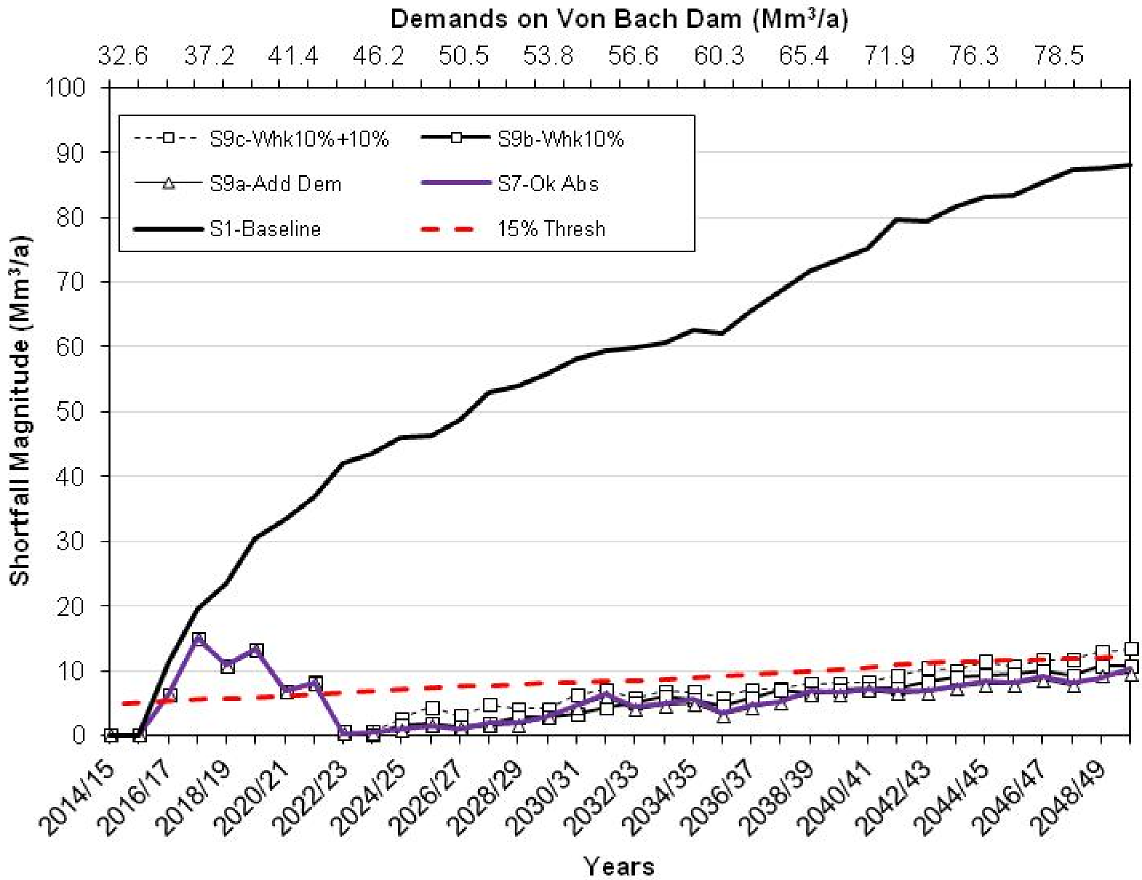


Figure 4.18: Scenario 9a (Increased Demand) Abstraction from the Okavango River

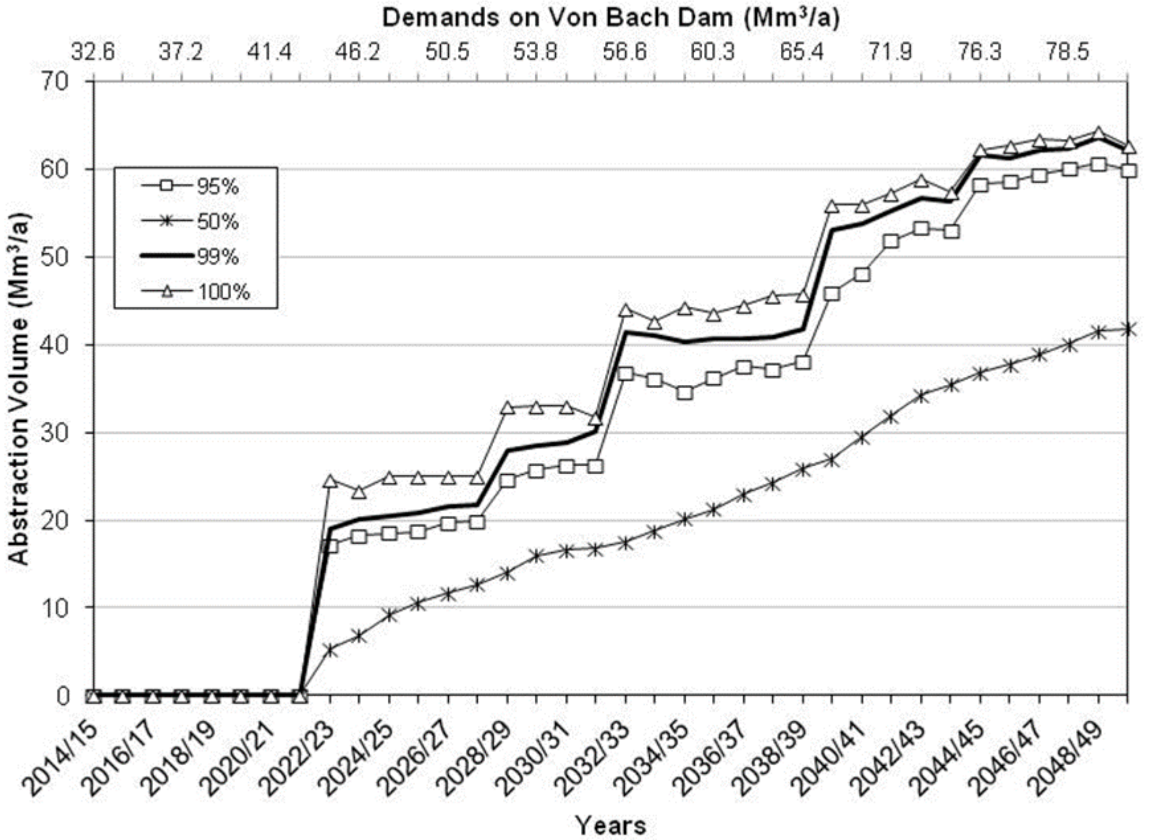


Figure 4.19: Scenario 9b (10% Increased Demand) Abstraction from the Okavango River

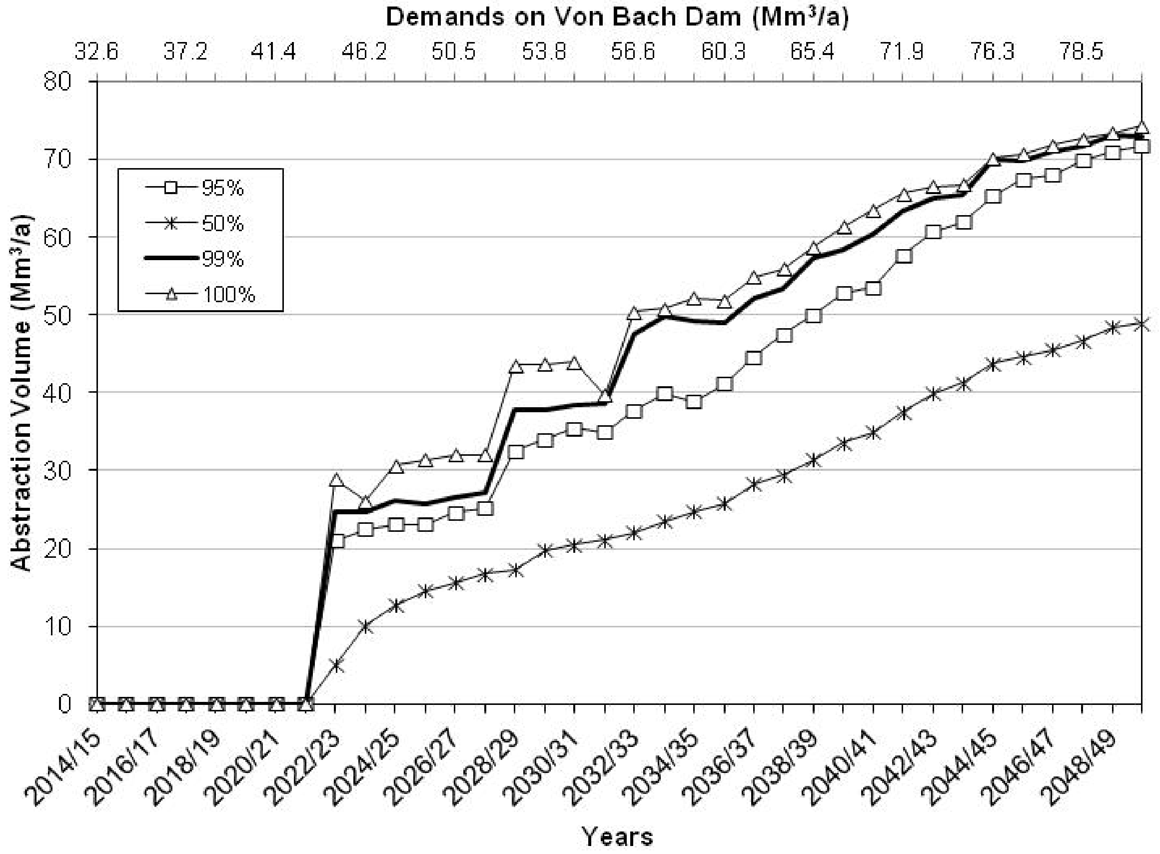
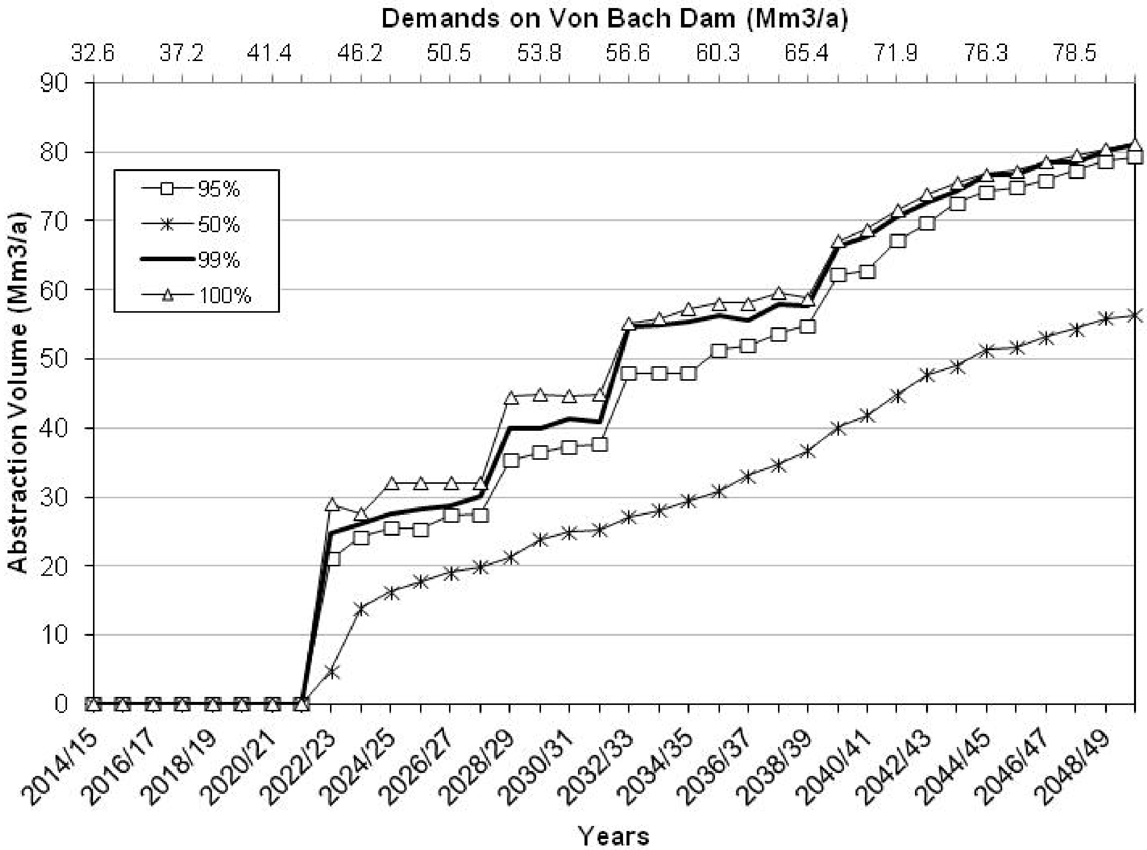


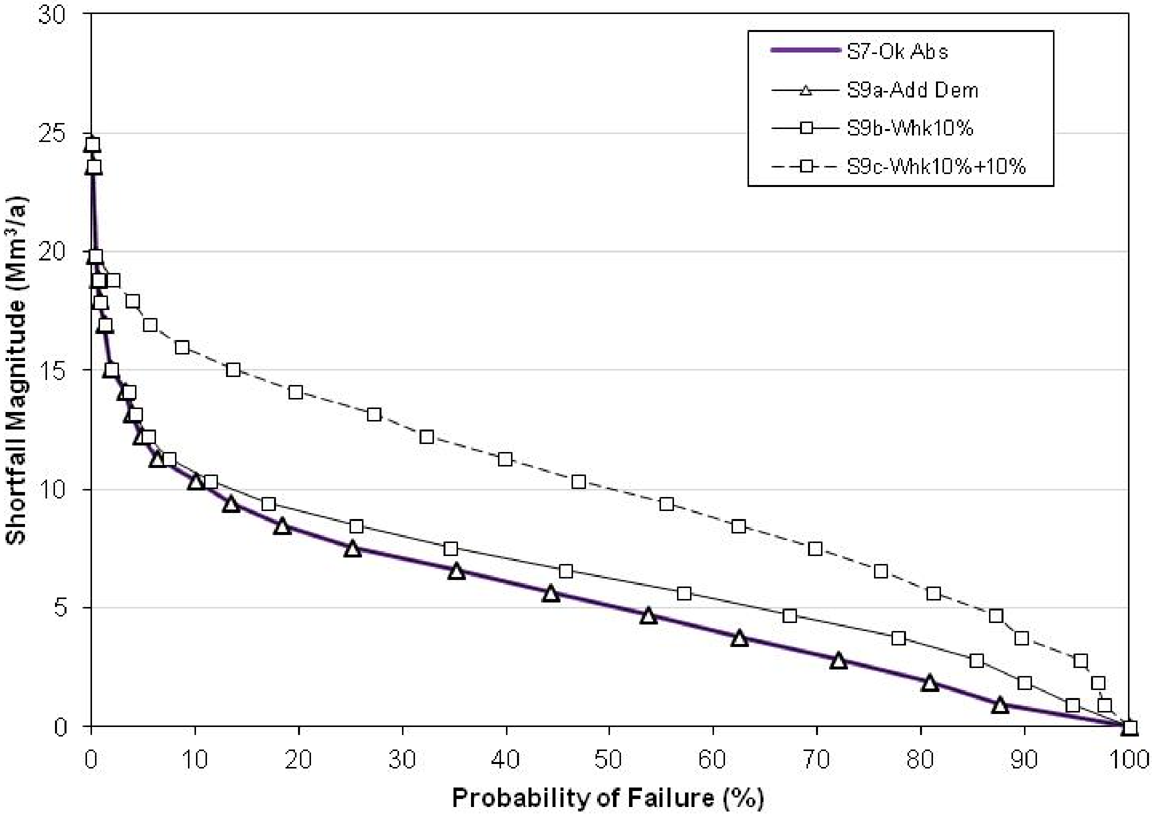
Figure 4.20: Scenario 9c (21% Increased Demand) Abstraction from the Okavango River



The lines for Scenarios 9b and 9c (**Figures 4.19** and **4.20**) are more consistent than those of Scenario 9a (**Figure 4.18**). It is suggest that with the selection of pipelines, the effect of the increased demand be assessed and quantified in greater detail. A final decision can then be taken based on risk and actual cost implications.

Figure 4.21 illustrates the probabilities of failure and the expected shortfall magnitudes which may occur in a specific year based on a 99% security of supply for Scenarios 7, 9a, 9b and 9c. Note that because the results of Scenario 7 and Scenario 9a are very similar, they overlap in **Figure 4.21**. The increased supply from the Okavango River for Scenarios 9a, 9b and 9c complies with the design goal with an acceptable risk of failure.

Figure 4.21: Shortfall Magnitudes and Probabilities of Failure for Scenarios 1, 9a, 9b and 9c



4.4.12 Scenario 9d: Additional Demand of the Currently Undeveloped Areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions

The water demands of the currently undeveloped areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions was determined in Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia. These water demands, which do not include any unserved areas along possible pipeline routes (as these are yet to be determined), were added to the Waterberg / Okakarara canal off-take for modelling. These water demands, as of 2024/25, are summarised in **Table 4.16** in 5-year intervals.

Table 4.16: Water Demands of the Currently Undeveloped Areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions

Year	Water Demand (Mm^3/a)[1]	Abstraction from the Okavango River (Mm^3/a)	
		Additional[3]	Total[4]
2024/25	1.2	2.52	22.77
2029/30	4.2	5.81	33.62
2034/35	8.6	10.6	50.40
2039/40	13.2	15.64	68.02
2044/45	16.4	19.07	79.42
2049/50	18.4[2]	21.28	81.92

Notes:

1. Refer to Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia for the determination of these water demands and the assumed implementation of a supply scheme.
2. As per **Table 10.3** of Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia.
3. Additional abstraction required from the Okavango River to supply the water demands of the currently undeveloped areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions, excluding areas along possible pipeline routes. The volumes to be abstracted from the Okavango River are greater than the water demands due to transfer losses along a possible pipeline route and along the ENWC canal.
4. Total abstraction required from the Okavango River – Scenario 9d.

4.4.13 Scenario 9e: Climate Change Effects

To model the potential impacts of a potentially drier future climate, evaporation was increased by 15% and inflow decreased by 15% for all of three CAN Dams. The results obtained the CA-Model for this scenario however appear inconsistent. This needs to be taken up with the programmer of the CA-Model when he is next in Namibia in mid-March 2015.

5. CONCLUSIONS

The modelling of the water supply to the CAN covers two periods; the first 8 years to 2023/24 and then until the end of the planning horizon in 2049/50. This reflects the dual strategy proposed for securing the water supply to the CAN; namely

1. That all the water supply options which are known about and which can implemented within 2 to 5 years be analysed with regard to minimising supply shortfalls in the next 8 – 10 years (Scenarios 2 to 6), and then
2. That alternatives which will minimise supply shortfalls up to the end of the planning horizon in 2050 be analysed and the timing of the implementation of these alternatives be optimised as far as possible (Scenarios 7 to 9). The chosen alternative(s) will need to be implemented within the 8 – 10-year period initially analysed.

5.1.1 Summary of the Scenarios Modelled

The modelled scenarios are summarised in **Table 5.1**.

Table 5.1: Summary of Modelled Scenarios

Scenario	Base Scenario	Description	Description and Target Date
1 Baseline	---	Baseline	Existing sources including WMARS currently under construction.
2a & 2b	1	Swakoppoort Water Quality Concerns	2a: No transfer from Swakoppoort to Von Bach Dam 2b: Transfer from Swakoppoort to Von Bach Dam for 8 months per year
4	3	WMARS increase injection capacity, Storage and abstraction	Increase artificial recharge to 8 Mm^3/a by May 2018 Increase abstraction to 19 Mm^3/a by May 2018 Increase storage capacity of water bank to 61 Mm^3 by May 2018 Increase storage capacity of water bank to 89 Mm and abstraction by May 2020
5	4	Abenab area groundwater source as alternative to WMARS	Add groundwater source of capacity 36 Mm^3 and an emergency abstraction rate of 12 Mm^3/a over a 15-year cycle by May 2018
6	3	Increased volume of reclaimed water in Windhoek	Windhoek reclamation increase by 4.2 Mm^3 by May 2019
7	6	Bulk supply from the Okavango River	Okavango River augmentation as infinite source with incrementally increasing abstraction rate, new pipeline to Grootfontein by May 2022
8	6	Desalination augmentation from the West Coast.	Desalination augmentation as infinite source with incrementally increasing abstraction rate, new pipeline from Swakopmund to Von Bach Dam by May 2022
9a	7	Additional demands Omaruru, Otjinene, and Otjiwarongo.	Add augmentation schemes to Otjinene (May 2043), Otjiwarongo (May 2039) and Omaruru (2020)
9b	9a	Windhoek demand increases by 10%	Increase Windhoek demand by 10% from May 2022
9c	9a	Windhoek demand increases by an additional 10%	Increase Windhoek demand by an additional 10% (21% in total) from May 2022

5.1.2 Results for the First 8-Year Period up to 2023/24

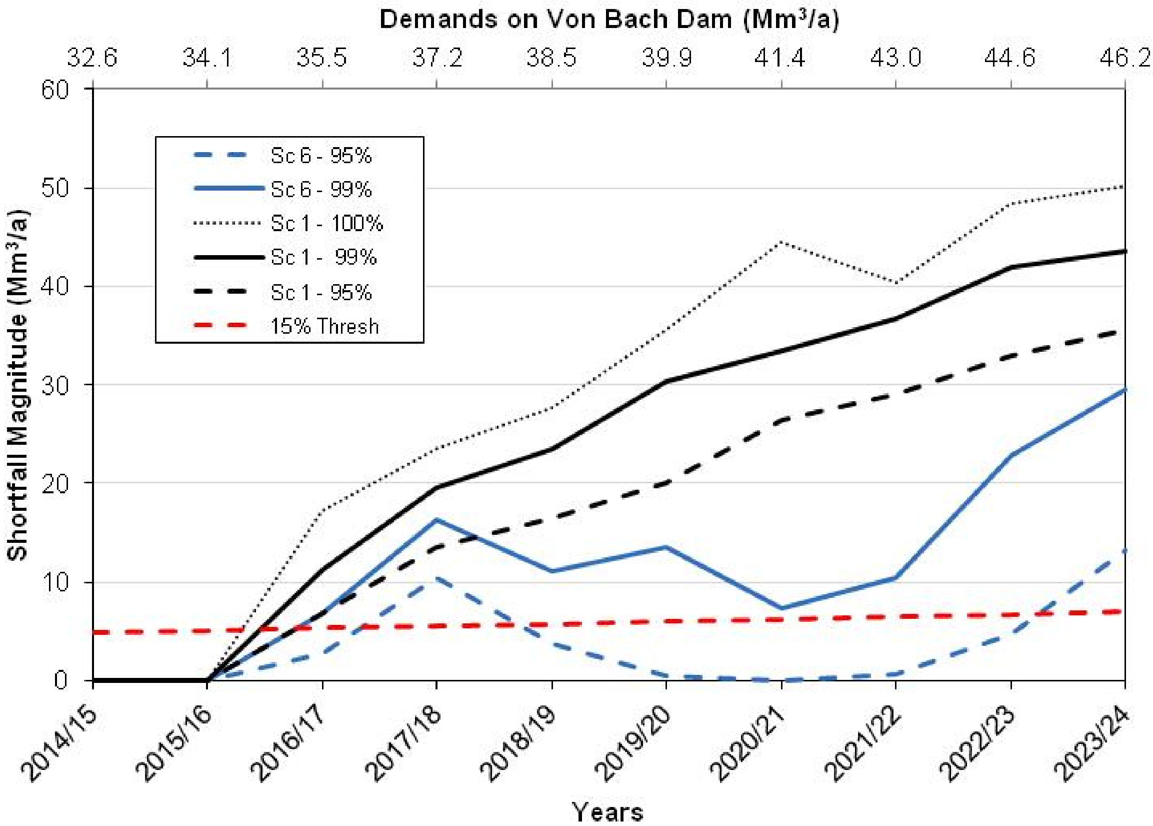
The Baseline Scenario (the "do nothing scenario") shows very high probabilities of shortfalls based on the 99% security of supply in the first 8 years. The probabilities of failure (shortfalls greater than 15%) based on the current status of bulk water supply are:

- 50% probability that shortfalls up to 16 Mm^3/a may occur in any year
- 35% probability that shortfalls up to 22 Mm^3/a may occur in any year;
- 10% probability that shortfalls up to 34 Mm^3/a may occur in any year; and
- 5% probability that shortfalls up to 39 Mm^3/a may occur in any year.

The results of Scenario 2 show higher and more immediate shortfalls. It is therefore imperative that the poor water quality in Swakoppoort Dam be addressed as a matter of urgency.

Although the supply goal of a 99% secure supply cannot be achieved, with the implementation of Scenarios 3, 4, 5 and 6, reasonable security of supply can achieved based on the 95% security of supply, or a 1 in 20 year shortfall (a 5% chance of a shortfall of 15% or more in each year). The last major shortfall in supply in the CAN was in 1996/97 (18 years ago) and therefore the probability of shortfall exceeding the acceptable 15% saving with a 95% percent security of supply may be as high as 1 in 3 years. The shortfall magnitude for the Baseline Scenario and Scenario 6 for the 95% and 99% security of supply is depicted in **Figure 5.1**.

Figure 5.1: Shortfall Magnitudes from 2014/15 until 2023/24



Scenarios:

Scenario 1: Baseline or "business as usual".

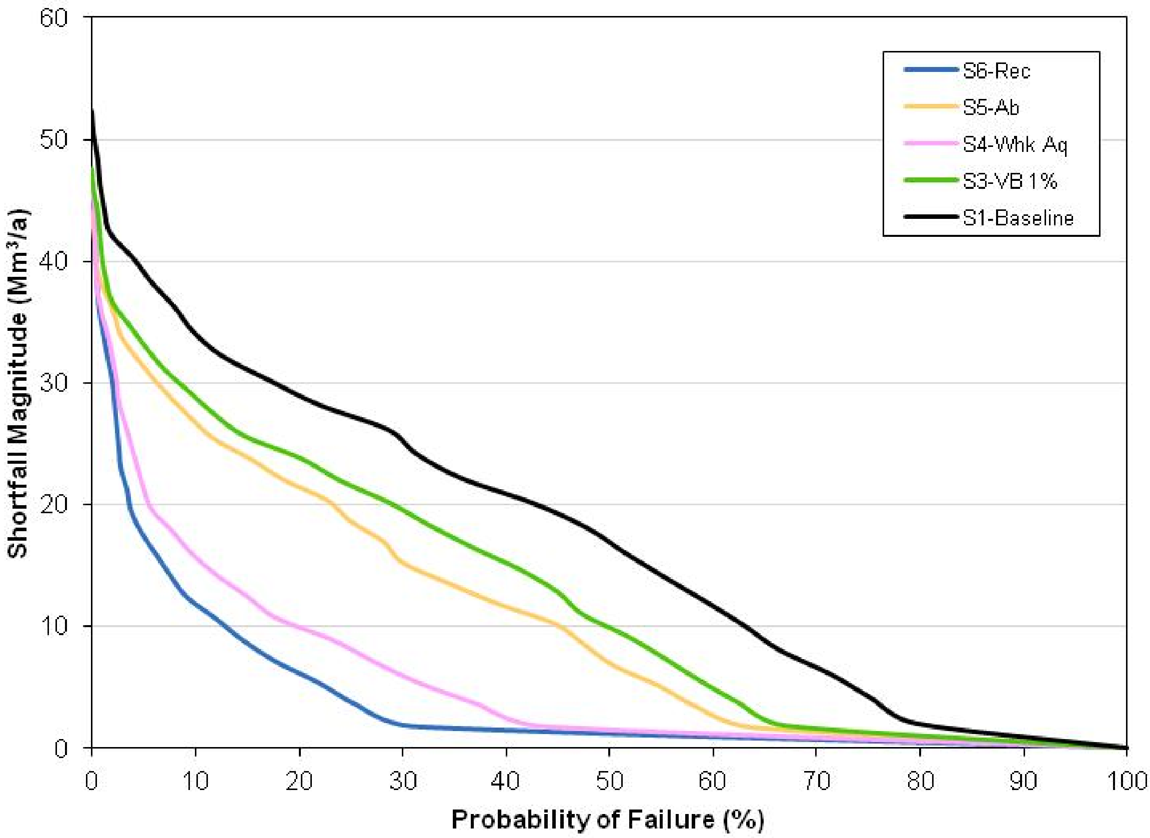
Scenario 6: Completion of the WMARS project and advanced reclamation in Windhoek.

Following the draw-down of the dams and aquifers from their initial levels in 2013/14, shortfalls are to be expected in the CAN after 2015/16, assuming inflow into the dams and recharge of the groundwater sources from rainfall.

To address the modelled shortfall in year 4 (2018/19), the abstraction capacity of the WMARS needs to be increased to at least 11 Mm^3/a as from 2017/18 (95% security of supply). Based on the 99% security of supply, the a major augmentation scheme to the CAN, such as supply from either the Okavango Scheme River or of desalinated sea water from the coast should ideally be in place by 2021/22 to comply with the design criteria.

Figure 5.2 illustrates the shortfall magnitudes and probabilities of failure until 2023/24 for the scenarios analysed over the first 8 – 10-year period; Scenarios 1, 3, 4 and 6.

Figure 5.2: Shortfall Magnitudes and Probabilities of Failure: 2014/15 to 2023/24



Scenarios:

Scenario 1: Baseline or “business as usual”.
Scenario 3: Reduction in losses at the VBWTP from 10% currently to 1%.
Scenario 4: Increased storage, abstraction and recharged capacities of the Windhoek Aquifer.
Scenario 5: Emergency supply of 36 Mm^3 from the Abenab area over three years out of a 15-year cycle.
Scenario 6: Completion of the WMARS project and advanced reclamation in Windhoek.

Even with the implementation of emergency measures, the risks of major shortfalls are very high based on the 99% security of supply. If Scenario 6 is implemented, there is still a 10% risk that shortfalls of up to 13 Mm^3/a may occur in any year until 2023/24.

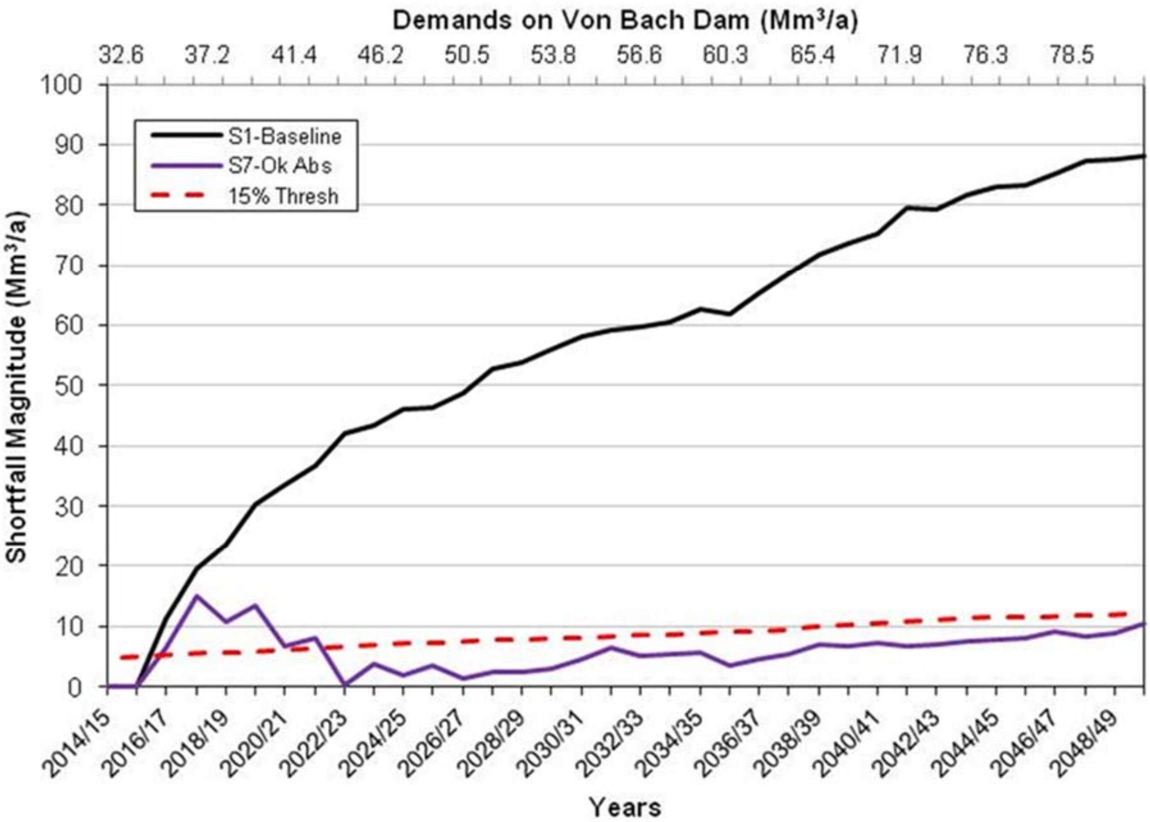
5.1.3 Results for the Long-Term Water Supply Security to the Central Area of Namibia

Due to the magnitude of the expected future shortfalls of supply in the CAN, only two sources could be identified which could secure the long-term water supply to the CAN. These were analysed as the following scenarios:

- Scenario 7: Water from the Okavango River is supplied to the start of the ENWC canal at Grootfontein,
- Scenario 8: Desalinated sea water is supplied from the coast to Von Bach Dam.

The volumes of water to be abstracted from the Okavango River were increased step-wise over time to ensure that the local sources are utilised fully before additional water is abstracted from the Okavango River. **Figure 5.3** illustrates that after implementation in 2022/23, the Okavango Scheme meets the design criteria, namely a 99% probability that shortfalls will be 15% or less. Shortfalls however exceed the 15% threshold prior to 2022/23 and the implementation of this augmentation option.

Figure 5.3: Comparative Shortfalls on Von Bach Dam for Scenario 7 (Okavango River Abstraction)



The volumes of desalinated sea water from the coast required under Scenario 8 were calculated based on those required from the Okavango River under Scenario 7, adjusting for the lower system losses, because the CA-Model does not have the capability to adequately analyse this supply source. The expected supply required from both the Okavango River and from desalinated sea water is summarised below in **Table 5.2**.

Table 5.2: Required Abstraction from the Okavango River (Scenario 7) and Desalination (Scenario 8)

Date	Scenario 7: Okavango Supply			Scenario 8: Desalination		
	50%[1] (Mm^3/a)	99% (Mm^3/a)	100% (Mm^3/a)	50% (Mm^3/a)	99% (Mm^3/a)	100% (Mm^3/a)
2022/23	5.36	18.95	24.56	4.56	17.32	22.50
2024/25	8.89	20.25	25.00	8.05	18.27	21.99
2029/30	15.68	27.81	32.00	14.52	26.08	26.11
2034/35	19.77	39.80	43.10	18.43	36.59	36.75
2039/40	26.27	52.37	55.33	24.96	46.83	48.85
2044/45	35.72	60.34	60.95	33.46	55.98	55.72
2049/50	40.35	64.05[2]	67.14[2]	37.66	57.07[2]	59.95[2]

Note:
1. % denotes percentile values.
2. Figures for 2049/50 adjusted slightly to compensate for a statistical anomaly.

As a result of the lower transfer losses to Von Bach Dam, lower volumes of water are required for Scenario 8 (desalination) than for Scenario 7 (Okavango River supply).

5.1.4 Inclusion of Additional Demand in the Central Area of Namibia

5.1.4.1 Areas which are Currently Served and Which Require Supply Augmentation as well as the Inclusion of Additional Demand to Areas Currently within the CAN

Consideration has been given to supplying the shortfall in demand of Otjiwarongo, Otjinene and Omaruru which are not currently within the CAN, once their water demands outstrip the capacity of their local sources. Given the shortfalls expected for the current extent of the CAN, this would only be possible if water was imported into the area under Scenario 7 or Scenario 8.

Scenario 9a reflects the additional demand to supply the shortfall in demand when local water resources are inadequate in Otjiwarongo, Otjinene and Omaruru. Scenarios 9b and 9c increase the water demand in Windhoek with 10% and 21% respectively under the premise of providing sufficient water to allow increased development, given that development in the CAN is currently water-limited. The compliance with the design criteria as well as the additional abstraction from the Okavango River are illustrated in **Figure 5.4** and in **Tables 5.3** and **5.4** respectively.

Figure 5.4: Shortfall Magnitude for Scenarios 9a, 9b and 9c

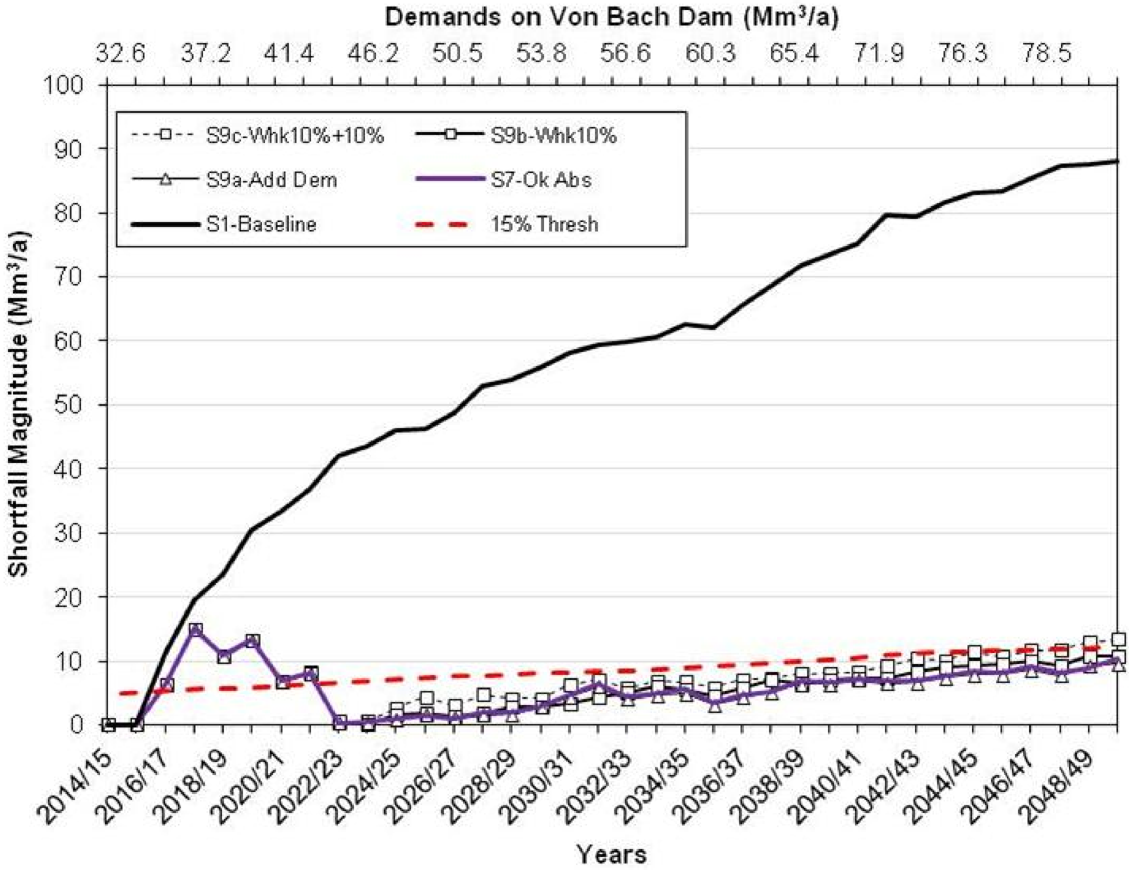


Table 5.3: Increased Abstraction from the Okavango River under Scenario 9a

Date	Scenario 9a: Including Augmentation to Omaruru, Otjiwarongo and Otjinene		
	50%[1] (Mm³/a)	99% (Mm³/a)	100% (Mm³/a)
2024/25	5.37	18.98	24.59
2029/30	9.25	20.38	25.00
2034/35	15.98	28.52	33.00
2039/40	20.16	40.26	44.30
2044/45	27.02	52.98	55.95
2049/50	41.81	65.00[2]	68.68[2]

Note:
1. % denotes percentile values.
2. Figures for 2049/50 adjusted slightly to compensate for a statistical anomaly.

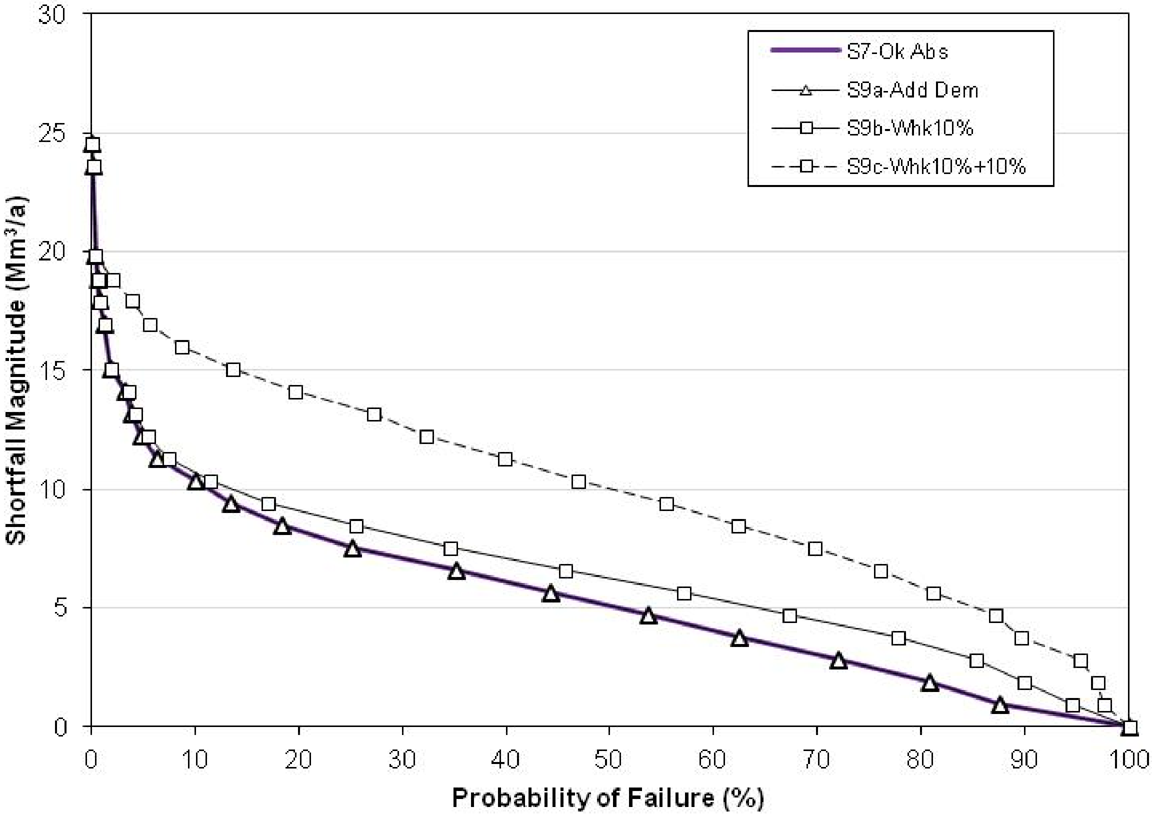
Table 5.4: Summary of Abstraction from the Okavango River for Scenarios 9b and 9c

Date	Scenario 9b: Windhoek Demand +10%			Scenario 9b: Windhoek Demand +21%		
	50%[1] (Mm^3/a)	99% (Mm^3/a)	100% (Mm^3/a)	50% (Mm^3/a)	99% (Mm^3/a)	100% (Mm^3/a)
2024/25	12.74	26.05	30.70	16.25	27.58	32.00
2029/30	19.75	37.77	43.68	23.80	40.06	44.87
2034/35	24.75	49.13	52.19	29.49	55.41	57.33
2039/40	33.55	58.45	61.27	40.16	66.39	67.13
2044/45	43.74	69.92	70.20	51.29	76.69	76.85
2049/50	48.98	72.98[2]	74.30[2]	56.36	81.18[2]	81.30[2]

Note:
1. % denotes percentile values.
2. Figures for 2049/50 adjusted slightly to compensate for a statistical anomaly.

Figure 5.5 illustrates the probabilities of failure and the expected shortfall magnitudes which may occur in a specific year based on a 99% security of supply for Scenarios 9a, 9b and 9c. The increased water demands required for augmentation to Otjiwarongo, Otjinene and Omaruru do not adversely affect the security of supply to the CAN due to the relatively small additional volumes. However, the additional water demands for Windhoek analysed under Scenarios 9b and 9c can be seen to impact negatively (particularly the latter) on the water supply security in the CAN.

Figure 5.5: Scenario 9c: Abstraction from the Okavango +10% Increased Demand



5.1.4.2 Supply to Currently Unserved Areas

Water supply to the currently unserved and undeveloped areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions was also investigated under Scenario 9d. Given the shortfalls expected for the current extent of the CAN, this would also only be possible if water was imported into the area under Scenario 7 or Scenario 8. The additional volumes to be abstracted from the Okavango River for supply to these areas are summarised in **Table 5.5**.

Table 5.5: Water Demands of the Currently Undeveloped Areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions

Year	Water Demand (Mm^3/a)[1]	Abstraction from the Okavango River (Mm^3/a)	
		Additional[3]	Total[4]
2024/25	1.2	2.52	22.77
2029/30	4.2	5.81	33.62
2034/35	8.6	10.6	50.40
2039/40	13.2	15.64	68.02
2044/45	16.4	19.07	79.42
2049/50	18.4[2]	21.28	81.92

Notes:

1. Refer to Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia for the determination of these water demands and the assumed implementation of a supply scheme.
2. As per **Table 10.3** of Chapter 10 of the Interim Report No. 01: *Water Demands and Water Resources* of 25 July 2014 for Part I: The Central Area of Namibia.
3. Additional abstraction required from the Okavango River to supply the water demands of the currently undeveloped areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions, excluding areas along possible pipeline routes. The volumes to be abstracted from the Okavango River are greater than the water demands due to transfer losses along a possible pipeline route and along the ENWC canal.
4. Total abstraction required from the Okavango River – Scenario 9d.

It was not possible to obtain meaningful results for the modelling of climate change impacts. This will to be taken up with the programmer of the CA-Model when he is next in Namibia in mid-March 2015.

6. RECOMMENDATIONS AND REMAINING WORK ON PHASE 2

The inability to use Swakoppoort Dam water (Scenario 2) impacts very severely on the water supply security of the CAN, with higher and more immediate shortfalls to be expected. It is therefore imperative that the poor water quality in Swakoppoort Dam be addressed as a matter of urgency.

It is recommended that the following Scenarios be accepted for an analysis of the possible environmental impacts and following that more detailed cost estimation under the remaining components of Phase 2 of this Project:

1. Scenario 3: VBWTP supernatant recycling to reduce the losses at the plant,
2. Scenario 4: 8 Mm^3/a recharge and 21 Mm^3/a abstraction capacity and 89 Mm^3 water bank for the Windhoek Aquifer under the WMARS project,
3. Scenario 6 Advanced reclamation be accepted as interim supply source for the first 8 years until 2020/21,
4. Scenario 7 (Okavango River supply) and Scenario 8 (Desalination) be investigated up to preliminary design and costing, including the water supply to the currently unserved and undeveloped areas in the North-Eastern Otjozondjupa and Northern Omaheke Regions (Scenario 9d).

It is hoped that the environmental assessments will indicate a preferred abstraction point from the Okavango River, if this option is found to be acceptable, as this is required for design and costing purposes.

Pending the outcome of the environmental assessments, the following is recommended:

1. That the cost sensitivity be tested for both Scenarios 9a (water augmentation to Otjiwarongo, Otjinene and Omaruru) and 9b (Scenario 9a plus an additional 10% water demand in Windhoek),
2. That capacity constraints related to the bulk supply options be identified on the existing bulk water supply infrastructure.

7. APPROVAL OF REPORT AND RECOMMENDATIONS

This report has been read and approved for submission to the Director: Infrastructure Development of the Department of Water Affairs and Forestry for concurrence. I support the recommendations set out in the report and submit it to the Deputy Permanent Secretary of the Department of Water Affairs and Forestry for endorsement.

______________________________ 04/03/2016

DEPUTY DIRECTOR: INFRASTRUCTURE DEVELOPMENT **DATE**

I endorse the recommendations set out in the report and submit it to the Permanent Secretary of the Ministry of Agriculture, Water and Forestry for approval.

______________________________ 07/03/2016

DEPUTY PERMANENT SECRETARY: DWAF **DATE**

The recommendations in this report have been decided upon as follows:

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PERMANENT SECRETARY
04-03-2016
Republic of Namibia
Ministry of Agriculture, Water & Forestry

______________________________ 07/03/2016

PERMANENT SECRETARY **DATE**