High Confidence Groundwater Reserve Determination Study in the Berg Catchment

WP11398
Operational Scenarios & Socio-Economic and Ecological Consequences Report

Report Number: RDM/WMA19/02/CON/COMP/0223

June 2023

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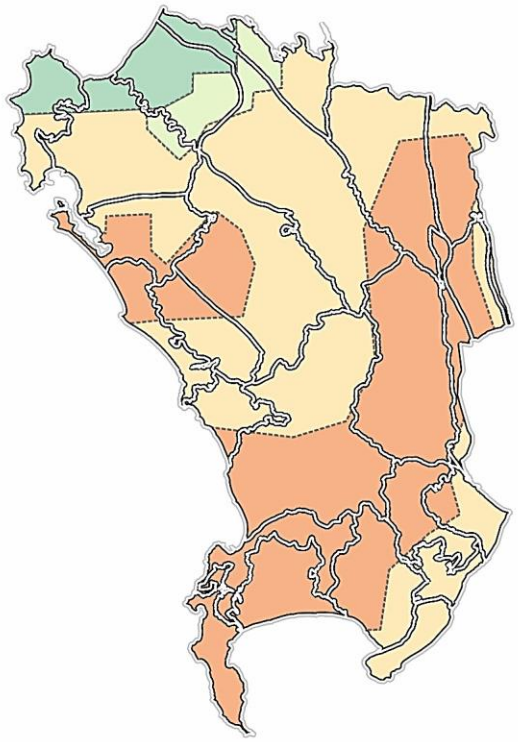

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Chief Directorate: Water Ecosystems Management

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3.7	RDM/WMA19/02/CON/COMP/0124	Groundwater Reserve Determination Report
3.8	RDM/WMA19/02/CON/COMP/0224	Database of All Information and Data (including spatial)
3.9	RDM/WMA19/02/CON/COMP/0324	Gazette Template

Executive Summary

In response to the increasing number of Water Use Licence Applications (WULAs) and their potential impact on the groundwater Reserve in the Berg catchment, the Department of Water and Sanitation's (DWS) Chief Directorate: Water Ecosystems Management (CD: WEM) initiated the High Confidence Groundwater Reserve Determination Study. The aim of this study was to provide valuable insights to facilitate well-informed management decisions regarding water resources that were under stress or experiencing excessive utilization.

To ensure the sustainable protection of significant water resources, the CD: WEM implemented the Resource Directed Measures (RDM) process outlined in Regulation 2(4) of the National Water Act (NWA, No. 36 of 1998). Through this process, the department strives to establish a sustainable level of protection for the groundwater Reserve in alignment with the Water Resource Classes (WRCs) and their corresponding Resource Quality Objectives (RQOs). The groundwater Reserve determination study plays a vital role in facilitating the completion of the RDM procedure and supporting the fulfilment of these objectives.

This report followed the eight-step groundwater Reserve determination procedure (WRC, 2013) and aimed to develop operational scenarios to assess their socio-economic and ecological impacts (i.e., Step 5 of Groundwater Reserve Determination Manual or GRDM) for the aquifer-specific Groundwater Resource Units (GRUs) identified in Step 2 of the GRDM. After conducting an extensive literature review to gain insights into the current and future trends of groundwater resources in the Berg catchment, this report presented a series of predictive scenarios (**Table A**).

The scenarios were developed in collaboration with stakeholders and primarily focused on climate change, population growth, water supply scheme development, sectoral growth and the impact of invasive alien plants (IAPs). The impacts on the groundwater Reserve, recharge and water use resulting from these scenarios were evaluated and will be reevaluated with further stakeholder input in Step 6 of the GRDM.

Table A Description of the scenarios considered in modelling the impacts on the groundwater Reserve and the associated allocable groundwater volume in the Berg catchment.

Scenario No.	Scenario Name	Scenario Description
Sc 1	**Population Growth**	Assess the impact of population growth on the groundwater component of the BHN Reserve and estimate volumes by projecting the qualifying population.
Sc 2	**Sectoral Water Demand**	Explore historical trends in groundwater demand per sector, focusing on agriculture, industry, and other sectors, to understand future water use.
Sc 3	**Groundwater Developments**	Evaluate scheduled groundwater developments and strategies for the Berg catchment, calculating their impact on the Reserve and allocable volumes.
Sc 4	**Climate Change**	Investigate the impact of climate change, particularly under warmer conditions, on groundwater recharge rates and its effects on the Reserve.
Sc 5	**Invasive Alien Plants**	Examine the impacts of Invasive Alien Plants (IAPs) on groundwater recharge and evaluate their effects on the Reserve and allocable volumes.
Sc 6a	**Combination Scenario**	Integrate population growth, sectoral growth, groundwater developments, climate change, and absence of clearing alien vegetation for impact assessment.
Sc 6b	**Combination Scenario**	Integrate population growth, groundwater developments, climate change, and clearing alien vegetation for impact assessment.

Each scenario offers a distinct perspective on the challenges and opportunities associated with the sustainable management of groundwater in the region. By integrating hydrogeological data, climate projections, and socio-economic trends, these scenarios offer a comprehensive understanding of the potential outcomes and challenges that may arise in maintaining the groundwater Reserve and estimating the allocable groundwater volumes.

To assess the potential impact on GRUs, an Allocation Stress Index was developed. This index represents the ratio of the groundwater 'still allocable' (after considering the Reserve and water use) to the total recharge for the GRU. The stress index is divided into six allocation categories, labelled 'A' through 'F,' reflecting a spectrum from unstressed to potentially critically stressed conditions (**Table B**). As this ratio approaches zero, the level of stress increases, indicating minimal remaining "still allocable" volumes and a potential threat to the groundwater Reserve.

Table B Definition of Allocation Stress Index, based on the still allocable volume after groundwater development.

Allocation Category	Description	Allocation Stress Index (Still Allocable Volume / Recharge Volume)
A	Unstressed or slightly stressed	>0.95
B		0.75 - 0.95
C	Moderately stressed	0.5 - 0.75
D		0.35 - 0.50
E	Potentially highly stressed	0.15 - 0.35
F	Potentially critically stressed	<0.15

Through the integration of findings from scenarios Sc 1 to Sc 5, two combination scenarios were formulated: Sc 6a (Worst Case) and Sc 6b (Most-Likely Case). These scenarios took into account projected population growth (Sc 1), sectoral growth (Sc 2), ongoing groundwater development initiatives (Sc 3), the impact of climate change (Sc 4), and the presence or absence of alien vegetation (Sc 5a and Sc 5b).

The most likely scenario (Sc 6b) primarily focused on the increase in Recharge resulting from climate change and the removal of all IAPs, the rise in the BHN Reserve based on population growth rate, and the increased groundwater usage due to sectoral growth and the implementation of groundwater development schemes. These changes had direct implications on the parameters used to estimate the Groundwater Reserve, consequently affecting the Total Allocable Volume and Still Allocable Volumes of individual GRUs. By comparing projected volumes in 2050 with the baseline values from the Present Status (PS) and preliminary groundwater Reserve, the analysis provided valuable insights into the cumulative effects of the identified factors. **Table C** provides a summary of the results of the preliminary "most-likely" scenario for the Berg catchment.

Table C **Table comparing preliminary groundwater Reserve and necessary parameters for calculating allocable volume per GRU, based on the results calculated in Scenario 6b: Combination Scenario – Most-Likely Case (2050).**

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Most-Likely Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	20.83	6.00	0.01	6.01	14.81	3.69	11.13	0.53
Atlantis	22.74[1]	0.08	0.03	0.11	22.63	3.84[2]	18.79	0.83	21.63	0.08	0.05	0.13	21.50	3.31	18.19	0.84
Cape Flats	41.25[3]	0.51	0.70	1.21	40.04	12.00[4]	28.04	0.68	38.70	0.51	1.29	1.80	36.90	23.02	13.88	0.36
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	9.19	5.43	0.16	5.59	3.60	0.15	3.45	0.38
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	16.26	0.87	0.36	1.23	15.03	8.71	6.32	0.39
Darling	9.95	0.03	0.02	0.05	9.91	0.76[5]	9.15	0.92	8.02	0.03	0.03	0.06	7.97	1.40	6.56	0.82
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	26.86	2.88	0.01	2.89	23.97	1.21	22.77	0.85
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	17.31	6.95	0.16	7.11	10.21	6.57	3.64	0.21
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	13.17	6.39	0.01	6.40	6.77	2.70	4.07	0.31
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	20.11	0.77	0.03	0.80	19.31	3.27	16.04	0.80
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	20.18	5.52	0.03	5.55	14.63	11.09	3.55	0.18
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	44.42	1.18	0.64	1.82	42.61	25.12	17.49	0.39
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	36.88	11.15	0.16	11.31	25.57	5.09	20.48	0.56
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	26.11	0.20	0.09	0.29	25.82	2.92	22.90	0.88

[1] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).*
[2] *Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).*
[3] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).*
[4] *Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).*
[5] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Most-Likely Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	24.60	3.01	0.21	3.22	21.38	15.50	5.88	0.24
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	19.02	2.07	0.06	2.13	16.89	9.80	7.09	0.37
Steenbras- Nuweberg	58.76[6]	1.16	0.02	1.18	57.58	8.00[7]	49.58	0.84	57.97	1.16	0.02	1.18	56.79	24.52	32.26	0.56
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	38.49	2.34	0.46	2.80	35.69	11.30	24.39	0.63
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	9.34	1.28	0.05	1.33	8.01	6.66	1.35	0.14
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	12.87	1.62	0.01	1.63	11.24	0.31	10.93	0.85
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	6.63	0.00	0.02	0.02	6.61	1.97	4.64	0.70
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	33.07	6.75	0.39	7.14	25.92	8.79	17.13	0.52
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	25.60	3.59	0.00	3.59	22.01	1.56	20.45	0.80
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.60	0.18	0.00	0.18	2.42	0.16	2.26	0.87
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	7.60	0.02	0.02	0.04	7.56	2.26	5.30	0.70
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**557.47**	**69.98**	**4.27**	**74.25**	**483.23**	**181.06**	**302.16**	

[6] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[7] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

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List of abbreviations, acronyms, symbols and units of measurement

~	Approximately
<	Less than
a	annum
AWRMS	Atlantis Aquifer Management Scheme
BHN	Basic Human Needs
CD: WEM	Chief Directorate: Water Ecosystems Management
CFA	Cape Flats Aquifer
CFAMS	Cape Flats Aquifer Management Scheme
CoCT	City of Cape Town
CS	Community Survey
DWA	Department of Water
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
e.g.	For example
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
ESBC	Ecologically Sustainable Base Configuration
Et al.	and others
etc.	etcetera
EWR	Ecological Water Requirements
GCM	General Circulation Model
GIS	Geographic Information System
GRAII	Groundwater Resource Assessment (Phase II)
GRDM	Groundwater Resource Directed Measure
GRU	Groundwater Resource Unit
GW	Groundwater
GWBF	Total groundwater contribution to baseflow
i.e.	That is.
IAP	Invasive Alien Plants
IUA	Integrated Unit of Analysis
km	Kilometres
ℓ/p/d	Litres per person per day
l/s	Litres per second
LDM	Local District Municipality
LM	Local District Municipality
LRA	Langebaan Road Aquifer
LRAS	Langebaan Road Aquifer Scheme
Ltd.	Limited Liability
m	Metres
M m3	Million Cubic Metres
m3	Cubic Metres
MAP	Mean Annual Precipitation
MAR	Managed Aquifer Recharge
mm	Millimetres
mm/a	Millimetres per annum
N	North
NWA	National Water Ac
NWP	New Water Programme
PES	Present Ecological State
pg.	Page

PHA	Philippi Horticultural Area
PMC	Project Management Committee
PS	Present Status
PSP	Professional Service Provider
Pty.	Proprietary
QC	Quaternary Catchment
QGIS	Quantum Geographic Information System
QUAT	Quaternary
RDM	Resource Directed Measure
RDP	Reconstruction and Development Programme
REC	Recommended Ecological Quaternary
Ref	Reference
RQO	Resource Quality Objective
RU	Resource Unit
SA	South Africa
SAWS	South African Weather Service
Sc	Scenario
SI	Stress Index
StatsSA	Statistics South Africa
TEC	Target Ecological Category
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TMGAMS	Table Mountain Aquifer Management Scheme
TOR	Terms of Reference
UNDP	United Nations Development Programme
WA	Water Availability
WAAS	Water Availability Assessment Study
WARMS	Water Use Allocation and Registration Management System
WC	Western Cape
WCDM	West Coast District Municipality
WCWSS	Western Cape Water Supply System
WFW	Working for Water
WMA	Water Management Area
WQ	Water Quality
WR	Water Resource
WR2012	Water Resources of South Africa 2012
WRC	Water Research Commission
WRCS	Water Resource Classification System
WRCs	Water Resource Classes
WSPD	Water Services Development Plan
WULA	Water Use Licence Application
WWTW	Wastewater Treatment Works

1. INTRODUCTION

1.1. Background

The Department of Water and Sanitation (DWS) Chief Directorate: Water Ecosystems Management (CD: WEM) initiated a "High Confidence Groundwater Reserve Determination Study for the Berg Catchment". This project supports the gazetted Water Resource Classes (WRCs) and Resource Quality Objectives (RQOs) for the Berg catchment (Gazette No.42451:121 of 10 May 2019; hereafter referred to as DWS, 2019b: 121).

The increasing number of water use licence applications (WULAs), the associated impacts that the proposed developments might have on the availability or quality of water, the conservation status of various resources, and the complexity of the study site's geological and hydrogeological characteristics make it increasingly impossible to assess WULAs using a low confidence desktop groundwater Reserve.

Integrated Units of Analysis (IUAs), WRCs and associated RQOs, delineated for the Berg catchment (DWS, 2019b: 121), have been gazetted as an outcome of the "Determination of Water Resource Classifications and Resource Quality Objectives in the Berg Catchment" study completed by Aurecon (Pty) Ltd from 15 April 2016 to 15 October 2018 (hereafter referred to as DWS, 2016; or the Berg catchment WRCs and RQOs study). The Gazette includes both WRCs (in terms of Section 13(4)(a)(i)(aa) of the National Water Act (NWA), 1998) and RQOs for prioritized Resource Units (RUs) (in terms of Section 13(4)(a)(i)(bb) of the NWA, 1998) according to the overall Class per IUA within the Berg catchment. Below is a summary of the information outlined in the Gazette:

IUAs comprised of allocation and biophysical nodes (representing inlets to estuaries and monitoring locations along rivers; hereafter referred to as "river nodes" or "estuary nodes") and provide the Target Ecological Category (TEC) to be achieved or maintained for each RU within each IUA (**Figure 1-1**).

Water Resource Classes were defined for all RUs in the catchment and are defined as:

- Class I (high environmental protection and minimal utilization)
- Class II (moderate protection and moderate utilization)
- Class III (sustainable minimal protection and high utilization)

RQOs were defined for surface water RUs within each IUA in terms of water quantity, habitat and biota, and water quality (**Figure 1-1**) for:

- Rivers
- Estuaries
- Dams
- Wetlands

RQOs were also defined for groundwater RUs (**Figure 1-1**) within each IUA in terms of groundwater quantity (abstraction, low flow in river, discharge and groundwater level) and groundwater quality (nutrients, salts, pathogens and various system variables).

This study's objectives are to determine high confidence results of the required groundwater contribution in terms of both quantity and quality to satisfy the Basic Human Needs (BHN) Reserve and Ecological Water Requirements (EWR) for the Berg catchment.

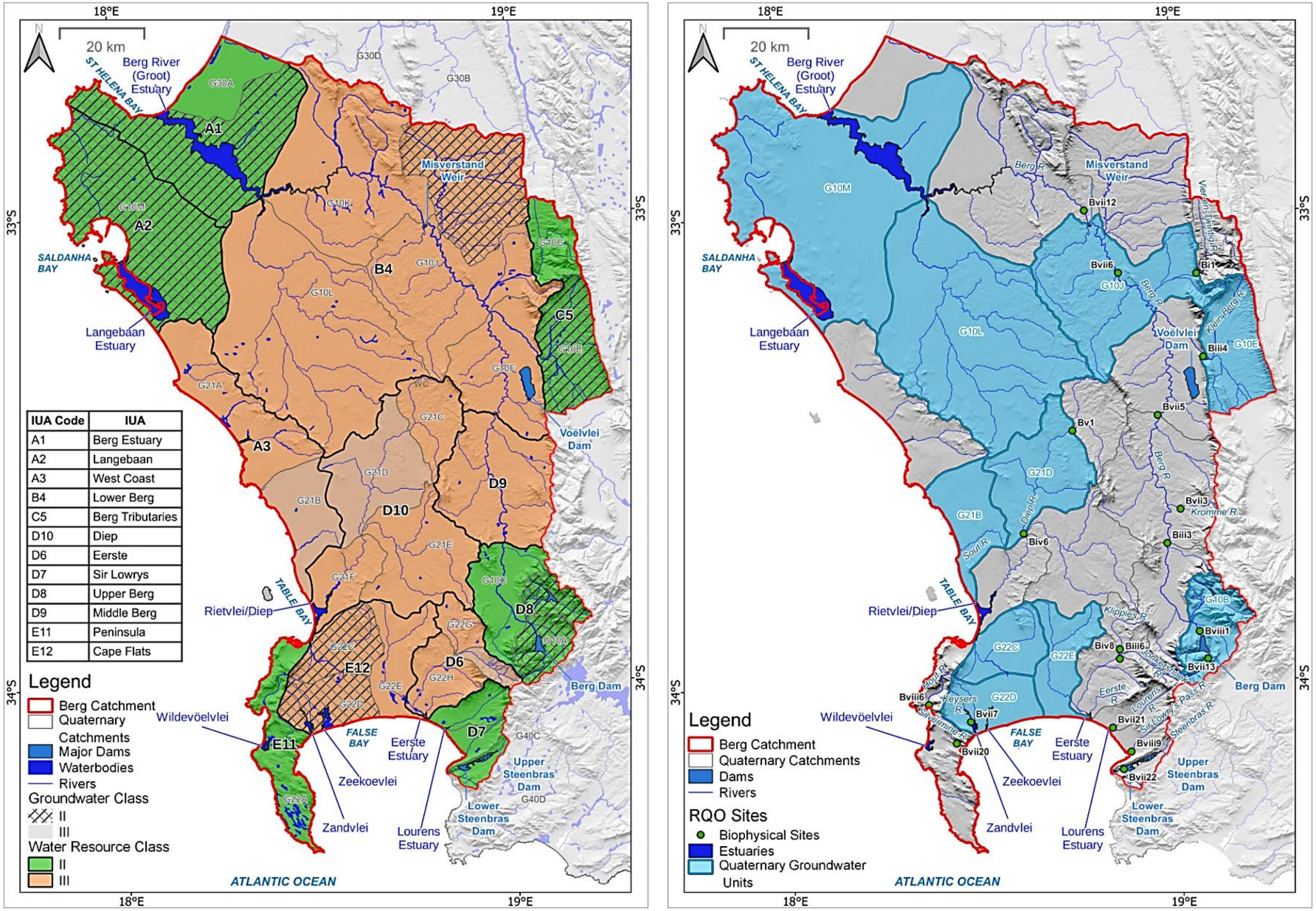

Figure 1-1 Left: Integrated Units of Analysis (IUAs), Water Resource Classes (WRCs) and Groundwater Classes for the Berg catchment; Right: Priority quaternary catchments, river and estuary nodes, and dams with gazetted Resource Quality Objectives (RQOs) (after DWS, 2019b: 121).

1.2. Terms of Reference

The Terms of Reference (TOR) for the study, as provided by the DWS CD: WEM, stipulates the aims and objectives as follows:

"The primary objective of this study is to determine a high confidence groundwater Reserve requirements (quantity and quality) to satisfy the basic human needs and to protect aquatic ecosystems in different priority water resources within the Berg catchment"

"Detailed determinations aim to produce high-confidence results, are based on site-specific data collected by specialists and are used for all compulsory licensing exercises, as well as for the individual licence applications that could have a large impact on any catchment, or a relatively small impact on ecologically important and sensitive catchments"

The groundwater Reserve determination aims to support the gazetted WRCs and associated RQOs (DWS, 2019b: 121) in completing the Resource Directed Measures (RDM) process as defined by Regulation 2(4) of the NWA (No. 36 of 1998; referred to as Regulation 2(4) hereafter). The Reserve will assist the DWS in making sound management decisions regarding stressed or over-utilized catchments and ensuring that water resources are afforded a level of protection that will assure a sustainable level of utilization in the future.

1.3. Aim of this Report

According to Regulation 2(4), the Reserve determination process must follow the eight-step procedure outlined in the RDM manuals. To distinguish between RDM in general and RDM related to groundwater, the term Groundwater Resource Directed Measures (GRDM) is used. The GRDM manuals consulted for this report include WRC (2007), WRC (2013), as well as the preliminary findings from an ongoing review of GRDM manuals by the Water Research Commission (WRC).

The aim of this report was to develop operational scenarios and determine their socio-economic and ecological impacts (i.e., Step 5 of the eight-step GRDM: Reserve determination procedure) for the aquifer-specific Groundwater Resource Units (GRUs) delineated as part of Step 2 (DWS, 2022d). A detailed overview of the study approach and scope of work was outlined in the project's Inception Report (DWS, 2022a) and summarized in **Table 1-1**.

As part of the Classification process completed during the Berg catchment WRCs and RQOs study (DWS, 2016), future catchment scenarios were developed and evaluated to determine the Ecologically Sustainable Base Configuration (ESBC) for the Berg River catchment (G1 Secondary Drainage Region) and the Coastal and Peninsula IUAs (G2 Secondary Drainage Region). These scenarios, in conjunction with the Present Status (PS) and preliminary groundwater Reserve determinations (i.e., the results of Step 3 and Step 4 of this Reserve determination process) were used to develop operational scenarios and evaluate their impacts on the aquifer systems, the groundwater component of the Reserve and the associated allocable volumes.

The scenarios were developed with stakeholder input and primarily focused on climate change, population growth, sectoral growth and water supply scheme development. These scenarios were then evaluated based on the impacts on recharge and water use and will be reevaluated with stakeholders in Step 6 of the GRDM Reserve determination procedure. The Operational Scenarios & Socio-Economic and Ecological Consequences Report is **Deliverable 3.4** of Phase 3 of this study.

Table 1-1 Summary of project phases, tasks, and associated deliverables for the High Confidence Groundwater Reserve Determination Study in the Berg Catchment. Reserve determination steps according to WRC (2013).

Phase 1	**Project Inception**		
Task 1	Inception		Deliverable 1: Inception Report
Phase 2	**Review of Water Resource Information and Data**		
Task 2.1	Data collection and collation		Deliverable 2.1: Gap Analysis Report Deliverable 2.2: Inventory of Water Resource Models
Phase 3	**Reserve Determination**		
Task 3.1	Step 1	Initiate Groundwater Reserve Study	Recorded in Deliverable 2.1 and Deliverable 2.2
Task 3.2	Step 2	Water RU Delineation	Deliverable 3.1: Delineation of Water RUs Report
Task 3.3	Step 3	Ecological Reference Conditions of RUs	Deliverable 3.2: Ecological Reference Conditions Report
Task 3.4	Step 4	Determine BHN and EWR	Deliverable 3.3: BHN and EWR Requirement Report
Task 3.5	**Step 5**	**Operational Scenarios & Socio-economic**	**Deliverable 3.4: Operational Scenarios & Socio-Economic and Ecological Consequences Report**
Task 3.6	Step 6	Evaluate Operational Scenarios with Stakeholders	Deliverable 3.5: Stakeholder Engagement of Operational Scenarios Report
Task 3.7	Step 7	Monitoring Programme	Deliverables 3.6: Monitoring Programme Report
Task 3.8	Step 8	Gazette & implement Reserve	Deliverable 3.7: Groundwater Reserve Determination Report Deliverable 3.8: Database Deliverable 3.9: Gazette Template

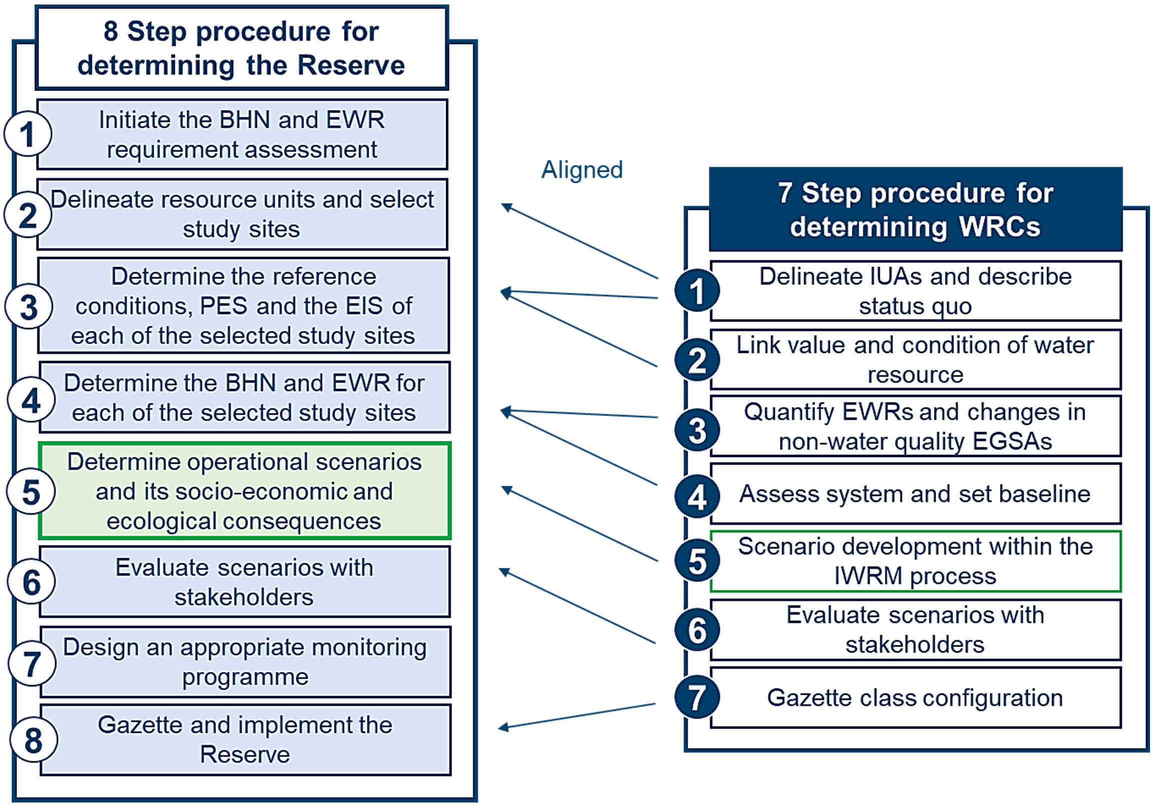

Figure 1-2 The 8-step procedure for determining the groundwater Reserve and its alignment with the 7-step Water Resource Classification (WRCs) procedure as defined by Regulation 2(4) of the National Water Act (NWA; No. 36 of 1998) and outlined in WRC (2013).

1.4. Project Overview

The National Water Act (NWA, No. 36 of 1998) provides a legal framework for managing water resources in South Africa (SA). The RDM is an important tool within this framework for achieving a balance between the protection, use, conservation, management, and control of water resources, and includes the Classification, Reserve, and RQOs. The Reserve is the only right to water in the NWA and takes priority over other uses, as it is water set aside for BHNs and to sustain priority ecosystems. The RQOs for priority sites in the Berg catchment cover the requirements of the Reserve and other water demands. Although groundwater is considered a water resource under the NWA, it sometimes requires a different management approach due to its unique characteristics. Therefore, determining the groundwater Reserve requires consideration of the volume of groundwater that can be abstracted sustainably without affecting surface water flow.

To meet the TORs for this study, the previous GRUs delineated for the Berg catchment had to be re-evaluated and updated to ensure all groundwater resources were encompassed. The revised GRU extents were described in the Delineation of Groundwater Resource Units Report (DWS, 2022d). The PS of groundwater, in terms of both quantity and quality, was also re-assessed per GRU and associated aquifers to correlate groundwater-related results to existing WRCs and RQOs outlined in the Gazette (DWS, 2019b: 121). The approach and outcomes were outlined in the Ecological Reference Conditions Report (DWS, 2022e). Once the PS was determined per GRU, the groundwater component of the BHN and EWR Reserves could be calculated, and a preliminary Groundwater Reserve was determined. The approach and outcomes were outlined in the BHN and EWR Requirements Report (DWS, 2022f).

As outlined in **Section 1.3**, the aim of this report was to develop operational scenarios and evaluate their impacts on the aquifer systems and the groundwater component of the Reserve (described below and summarised in (**Table 1-2**). This constitutes Step 5 of the Reserve determination procedure and aligns, where appropriate, with Step 5 of the seven-step WRCs procedure (**Figure 1-2**) as set out in Regulation 2(4) and outlined in WRC (2013).

Table 1-2 Summary of the scenarios considered in modelling the impacts on the groundwater Reserve and the associated allocable groundwater volume in the Berg catchment.

Scenario No.	Scenario Name	Scenario Description
Sc 1	**Population Growth**	Assess the impact of population growth on the groundwater component of the BHN Reserve and estimate volumes by projecting the qualifying population.
Sc 2	**Sectoral Water Demand**	Explore historical trends in groundwater demand per sector, focusing on agriculture, industry, and other sectors, to understand future water use.
Sc 3	**Groundwater Developments**	Evaluate scheduled groundwater developments and strategies for the Berg catchment, calculating their impact on the Reserve and allocable volumes.
Sc 4	**Climate Change**	Investigate the impact of climate change, particularly under warmer conditions, on groundwater recharge rates and its effects on the Reserve.
Sc 5	**Alien and Invasive Species**	Examine the impacts of Invasive Alien Plants (IAPs) on groundwater recharge and evaluate their effects on the Reserve and allocable volumes.
Sc 6a	**Combination Scenario**	Integrate population growth, sectoral growth, groundwater developments, climate change, and absence of clearing alien vegetation for impact assessment.
Sc 6b	**Combination Scenario**	Integrate population growth, groundwater developments, climate change, and clearing alien vegetation for impact assessment.

Sc 1 - Population Growth:

This scenario assessed the impact of population growth on the groundwater component of the BHN Reserve. The main objective was to estimate the volumes of the BHN Reserve by projecting the "qualifying population" for the year 2050, considering a daily water consumption rate of 25 liters per person per day (ℓ/p/d). The scenario assessed the consequences for the groundwater Reserve and determined the remaining groundwater volume available for allocation once the Reserve's needs and water usage were taken into account.

Sc 2 - Sectoral Water Demand:

This scenario explored historical trends in groundwater demand per sector, with a particular focus on agriculture (irrigation, livestock watering, and aquaculture) and industry (urban and non-urban) sectors. It also considered other smaller sectors, including mining, power generation, recreation, water supply service, and Schedule 1 users. The objective was to gain insights into the future water use of these sectors (extrapolated to 2050) and their impact on the volume that is available for allocation after the groundwater Reserve has been accounted for.

Sc 3 - Groundwater Developments:

This scenario evaluated groundwater developments and water strategies scheduled for implementation within the Berg catchment by 2050. It included groundwater abstraction and managed aquifer recharge (MAR) plans by the City of Cape Town (CoCT), implementation plans by the Department of Water and Sanitation (DWS) for the Western Cape Water Supply Scheme (WCWSS), groundwater strategies by local municipalities, and initiatives by agricultural organizations and irrigation boards. The aim was to calculate the groundwater volumes (inflows and outflows) associated with the proposed developments and evaluate their potential impact on volume that is available for allocation after the groundwater Reserve has been accounted for.

Sc 4 - Climate Change:

This scenario investigated the impact of climate change, particularly under warmer conditions, on groundwater recharge rates. The objective was to forecast and quantify the decline in groundwater recharge rates per GRU by the year 2050. The purpose was to evaluate the potential impact on the allocable volumes after the groundwater Reserve was satisfied.

Sc 5 - Alien and Invasive Species:

This scenario examined the impacts of Invasive Alien Plants (IAPs) on groundwater recharge. Estimations of current and future recharge reductions per vegetation biome were used to evaluate the effects of IAPs on groundwater. In this scenario, it was assumed that clearing all IAPs would restore groundwater recharge rates to their pre-invasion levels (Sc 5a). Conversely, if left unchecked, IAPs would lead to a reduction in future recharge (Sc 5b). The results were assessed based on their impact on the volume that could be allocated after the groundwater Reserve was satisfied.

Sc 6a - Combination Scenario:

This scenario integrated the outcomes of the preceding scenarios to construct a plausible 'worst-case' scenario. It considered projected population growth, sectoral growth, ongoing groundwater development initiatives, the influence of climate change, and the absence of clearing alien vegetation. The goal was to assess the potential combined impacts of these elements on groundwater resources to guide sustainable water management strategies for future development.

Sc 6b - Combination Scenario:

This scenario integrated the outcomes of the preceding scenarios to construct a plausible 'most-likely case' scenario. It considered projected population growth, ongoing groundwater development initiatives, the influence of climate change, and the clearing of alien vegetation. The goal was to assess the potential combined impacts of these factors on groundwater resources to guide sustainable water management strategies for future development.

2. PRELIMINARY GROUNDWATER RESERVE

The Present Status (PS) and preliminary groundwater Reserve, which served as the reference point for the predictive scenarios, provided an overview of the current status of groundwater resources in the Berg catchment (**Table 2-3**). The PS was re-evaluated as part of Step 3 and 4 of the eight-step GRDM: Reserve determination procedure (WRC, 2013) in terms of groundwater utilization and water quality. The study identified five (5) key hydrogeological components that were important for developing an effective water resource management strategy. These included Recharge, Groundwater Use, Discharge, Groundwater Quality, and Aquifer Stress (see the Ecological Reference Conditions Report for detail). Following this, the groundwater component of the BHN and EWR Reserves (i.e., the Preliminary Groundwater Reserve) was calculated and added to the list of components.

A combination of a comprehensive literature review, an evaluation of available data sources, and various GIS-based estimation techniques were used to assess the status quo of groundwater recharge (including artificial and lateral recharge from adjacent aquifer units), groundwater discharge, and groundwater use per GRU. These parameters were used to quantify Aquifer Stress by means of a Stress Index (SI), which considered both groundwater availability and use (**Table 2-1**). Groundwater discharge, which represents the outflow of groundwater from aquifers to the surface or surface water systems, was estimated to provide an aquifer-specific estimation of groundwater's contribution to baseflow (**Table 2-3**). In terms of groundwater quality, data from various sources were collated to provide a hydrochemical summary per GRU, assess baseline water quality for select parameters, and identify potential sources of contamination. The Groundwater Quality Present Status categories were assigned per GRU, based on compliance with RQOs (**Table 2-2**).

Table 2-1 Guide for determining groundwater availability Present Status (PS) Category.

Groundwater Availability Present Status Category	Description	Stress Index (Use / Recharge)
A	Unstressed or slightly stressed	<0.05
B		0.05 – 0.20
C	Moderatly stressed	0.20 – 0.40
D		0.40 – 0.65
E	Highly stressed	0.65 – 0.95
F	Critically stressed	>0.95

Table 2-2 Guide for determining groundwater quality Present Status (PS) Category.

Water Quality (Present Status) Category	Description	Percentage exceedance
A	Unmodified, pristine conditions	<16.7 %
B	Localised, low levels of contamination, but no negative impacts apparent	16.7 – 33.4 %
C	Moderate levels of localised contamination, but little or no negative impacts apparent	33.4 – 50.1 %
D	Moderate levels of widespread contamination, which limit the use of potential use of the aquifer	50.1 – 66.8 %
E	High levels of local contamination which render parts of the aquifer unusable	66.8 – 83.5 %
F	High levels of widespread contamination which render the aquifer unusable	>83.5 %

Table 2-3 A summary of the Present Status (PS) and the Preliminary Groundwater Reserve in the Berg catchment, including Water Availability (WA), Water Quality (WQ), Groundwater (GW) Class, Water Resource (WR) Class, Integrated Unit of Analysis (IUA), Quaternary Catchments (QC), and the hydrogeological components described in Section 2.

GRU	Present Status						Preliminary Groundwater Reserve			
	PS WA	PS WQ	GW Class	WR Class	IUA	QC	Recharge (Mm³/a)	Water Use (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)
Adamboerskraal	B	B	II, III	II	A1, B4	G10K, G10L, G10M, G30A	21.61	2.13	6.01	15.60
Atlantis	B	C	III	III	A3, D10	G21A, G21B, G21D	22.74[8]	3.84[9]	0.11	22.63
Cape Flats	C	D	III	II	D6, E12	G22C, G22D, G22E, G22H	41.25[10]	12[11]	1.21	40.04
Cape Peninsula	B	B	II, III	II	E11, E12	G22A, G22B, G22C, G22D	10.99	0.07	5.52	5.48
Cape Town Rim	C	C	II, III	II	D10, D6, E11, E12	G21F, G22A, G22B, G22C, G22D, G22E	18.6	6.21	1.07	17.54
Darling	B	C	III		A3, B4	G10L, G21A	9.95	0.767[12]	0.05	9.91
Drakensteinberge	A		II, III	II, III	D6, D7, D8	G10A, G10C, G22F, G22J, H60A, H60B	27.6	0.05	2.88	24.72
Eendekuil Basin	C	C	III	II	B4	G10F, G10H, G10J, G10K, G30B	21.88	4.85	7.04	14.84
Elandsfontein	B	B	II, III	II	A2, A3, B4	G10L, G10M, G21A	15.47	1.09	6.40	9.08
Groot Winterhoek	B		II, III	II	B4, C5	E10A, E10B, E10C, E10D, E21G, G10E, G10G, G10H, G10J, G30B	22.5	1.39	0.79	21.71
Langebaan Road	C	B	II, III	II	A1, A2, B4	G10L, G10M	23.28	8.59	5.54	17.74
Malmesbury	C	B	II, III	II, III	A3, B4, D10, D6, D8, D9, E12	G10D, G10F, G10J, G21A, G21B, G21C, G21D, G21E, G21F, G22C	52.65	14.75	1.52	51.13
Middle-Lower Berg	B	C	II, III	II	A1, B4, D10	G10F, G10J, G10K, G10L, G10M, G30A	42.49	2.23	11.24	31.26
Northern Swartland	B	C	III	III	A3, B4, D10	G10J, G10K, G10L, G21A, G21D	31.85	1.79	0.25	31.60

[8] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).
[9] Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).
[10] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).
[11] Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).
[12] The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.

GRU	Present Status						Preliminary Groundwater Reserve			
	PS WA	PS WQ	GW Class	WR Class	IUA	QC	Recharge (Mm³/a)	Water Use (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)
Paarl-Franschhoek	C		II, III	II, III	A3, D10, D6, D8, D9	G10A, G10B, G10C, G10D, G21E, G22F, H10J, H60B	26.61	9.82	3.14	23.47
Piketberg	C		II, III	II	A1, B4	G10H, G10K, G10M, G30A, G30B, G30D	20.33	5.58	2.11	18.22
Steenbras-Nuweberg	B	B	II		D7	G22J, G22K, G40A, G40B, G40C, G40D, H60A	58.76[13]	8[14]	1.18	57.58
Stellenbosch-Helderberg	C	C	II, III	III	D10, D6, D7, D8, E12	G10C, G22E, G22F, G22G, G22H, G22J, G22K, H60A	41.52	8.81	2.58	38.94
Tulbagh	C		II, III	II	B4, C5	G10E, G10G, G10J, H10F	10.87	3.78	1.30	9.57
Voëlvlei-Slanghoek	A		II, III	II	A3, B4, C5, D9	G10D, G10E, G10F, G10J, H10E, H10F, H10J	14.1	0.13	1.63	12.47
Vredenburg	B		II	II	A1, A2	G10M	7.43	1.16	0.01	7.42
Wellington	B	B	III		A3, B4, D10, D9	G10D, G10F, G10J, G21C, H10E, H10J	39.49	4.48	6.99	32.51
Wemmershoek	A	A	II	II	D8	G10A, G10B, G10C, H10J, H10K, H60B	26.83	0.81	3.59	23.24
Witzenberg	A		II	II	C5	E10A, G10E, G10G, H10C, H10D	2.78	0.08	0.18	2.60
Yzerfontein	A	A	II, III	II	A2, A3, B4	G10L, G10M, G21A	9.2	0.26	0.03	9.17
TOTAL							**620.78**	**102.66**	**72.33**	**548.45**

[13] Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).
[14] Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).

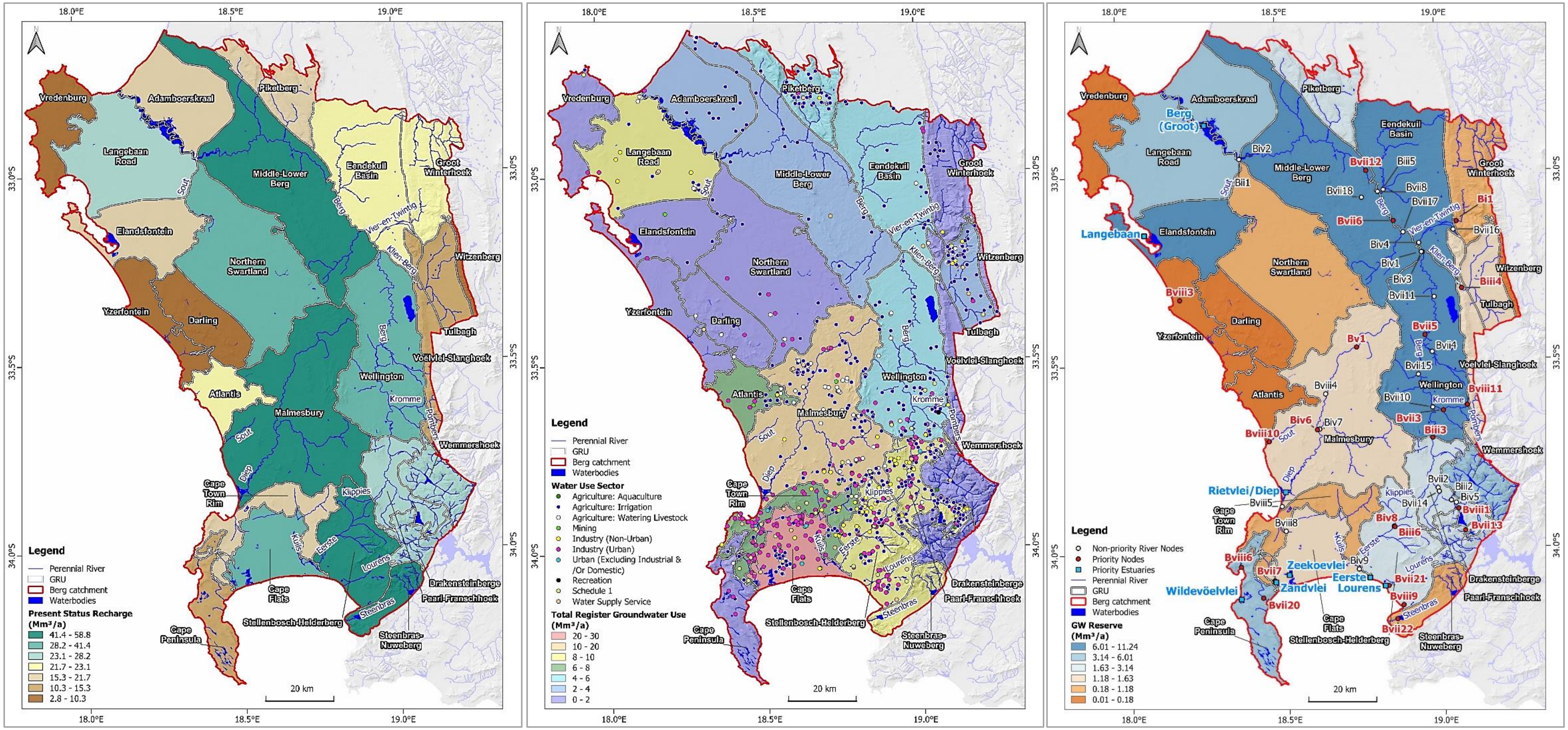

Figure 2-1 Left: Present Status (PS) recharge distribution per Groundwater Resource Unit (GRU). Centre: Total registered groundwater use per GRU, as registered in WARMS, indicating boreholes and associated water use sectors per GRU. Right: Map of the groundwater contribution to the Reserve per GRU.

3. SCENARIO LITERATURE REVIEW

Groundwater is a vital resource that plays a significant role in sustaining human, agricultural, and environmental needs. In the Berg catchment, the availability and quality of groundwater have a direct impact on the region's socio-economic development and ecological health. As such, it is crucial to understand the current state of priority groundwater resources in the region and evaluate their sustainability in the face of future challenges such as climate change, population growth, and the continual development of groundwater abstraction and managed aquifer recharge (MAR) schemes.

This scenario literature review aims to provide insights into the current state and future trends of the groundwater resources in the Berg catchment. The analysis will use a combination of hydrogeological datasets, climate projections, future groundwater development schemes, and socio-economic trends to develop plausible future scenarios for not only sustaining the groundwater Reserve but estimating the associated allocable groundwater volumes.

3.1. Water Demand

3.1.1. Total Population Growth

Population growth can have significant impacts on groundwater availability, particularly in areas where groundwater is a primary source of drinking water. As the population increases, so does the demand for water, which can lead to the over-abstraction of groundwater resources. The population growth rates of the CoCT and the Western Cape at large differ depending on the data source.

According to the Socio-Economic Profile Report (CoCT, 2021), the CoCT is expected to grow by 1.6% per annum, while the greater Western Cape region is anticipated to grow by 1.4% per annum up until 2025. This observation concurs with the 2016 Community Survey (CS, 2016), which reported a 1.6% growth rate for the Western Cape in the period from 2011 to 2016. The WCWSS had witnessed a higher growth rate of 2.7% between 2001 and 2011, though this growth rate declined to 1.7% between 2011 and 2016.

Table 3-1 Summary of the population growth rates and associated sources.

Population Growth Rate (%) per Annum	Date	Area	Source
1.6%	Up to 2025	CoCT	Socio-economic profile (2021)
1.4%	Up to 2025	Western Cape Region	Socio-economic profile (2021)
2.7%	2001 – 2011	Cape Town, Overberg, West Coast and Cape Winelands District Municipalities	WCWSS (2018)
1.7%	2011 – 2016		WCWSS (2018)
1.59%	2016 – 2040	CoCT	WCWSS (2018)
1.4%	2016 onwards	West Coast District	Community Survey (2016)
1.6%	2011 – 2016	Western Cape	Community Survey (2016)
1.46%	Average from 2002 – 2022	Western Cape	Census (2011) and Census (2022)
2.10%	Average from 2002 – 2021	Within the Berg Study area	Census (2011) and preliminary Census (2022)
2.07%	Average from 2011 – 2021	Within the Berg Study area	Census (2011) and preliminary Census (2022)

The CoCT has projected a population increase from 4.0 million in 2016 to 5.84 million by 2040 (CS, 2016), at an average annual growth rate of 1.59% (DWS, 2018). Similarly, the West Coast District Municipality is expected to experience a population growth rate of 1.4% per annum from 2016 (DWS, 2018). Overall, the total population of the WCWSS is expected to grow from 5.023 million in 2016 to 7,475 million by 2042, with 79.7% of the population situated in the CoCT. However, these estimates were made prior to the Covid-19 pandemic, which has substantially impacted population growth patterns, with an influx of individuals moving to the city. A summary of these population growth rates is presented in **Table 3-1** above.

Therefore, both Census (2011) and the preliminary Census (2022) data from Statistics South Africa (StatsSA) were used as a more reliable data source to predict current population growth trends in relation to the Berg catchment.

3.1.2. Sectoral Water Demand

South Africa (SA) witnessed significant advancements in groundwater research, development, and implementation over the past two decades (Braune et al., 2014). The registration of groundwater resources under the NWA (1998) marked a major milestone, providing valuable information through the Water Use Allocation and Registration Management System (WARMS). However, challenges remained, particularly in verifying agricultural irrigation data, as many farmers were reluctant to register their water use. This issue stemmed from the previous classification of groundwater under the previous Act (Colvin, et al., 2007 and Braune et al., 2014).

The importance of groundwater in the community water supply was underscored by Cobbing (2013) and the Reconstruction and Development Programme (RDP). SA made significant strides in improving access to an improved drinking water source, with 95.2% of the population benefiting from such sources (DWA, 2013). However, groundwater information, particularly information about borehole locations, abstraction volumes, and the duration of groundwater abstraction remained incomplete, posing challenges to the understanding and planning of sustainable groundwater use (Braune et al., 2014).

In urban areas, the importance of groundwater as a water supply source has been increasingly recognized. A notable proportion of towns in SA, comprising 22%, relied solely on groundwater, while an additional 34% rely on conjunctive use schemes (Braune et al., 2014). The “20 years of groundwater research, development and Implementation in SA, 1994-2014” report emphasized the significance of groundwater in urban development, particularly after implementing water conservation and demand management measures. These findings aligned with the guidance provided in the DWA's (2012) All Town Reconciliation Strategies for both the Southern and Northern Planning Region, and the National Water Resource Strategy (DWA, 2013).

Agriculture represents a major sector for groundwater use in SA, primarily for irrigation purposes. **Figure 3-1** displays the status of groundwater use per economic sector and the water supply improvements since 1996. However, the development of groundwater for irrigation predominantly occurred through private initiatives, leading to the exploitation of high-yielding aquifers and subsequent overuse (Braune et al., 2014). The mining sector also heavily relied on groundwater, accounting for approximately 13% of total groundwater use in the country.

While the national level recognized the growing importance of groundwater, greater integration of groundwater information and considerations into local water plans and policies was necessary. In some cases, expensive alternatives like desalination were implemented as short-term solutions without giving due consideration to groundwater's potential (Braune et al., 2014). Successful protection and sustainable groundwater management could be achieved through cooperative governance and adherence to the GRDM of the NWA (1998), which include the Classification, the Reserve, and RQOs (Colvin et al., 2007). **Table 3-2** provides a summary of groundwater use sectors, trends and associated literature references.

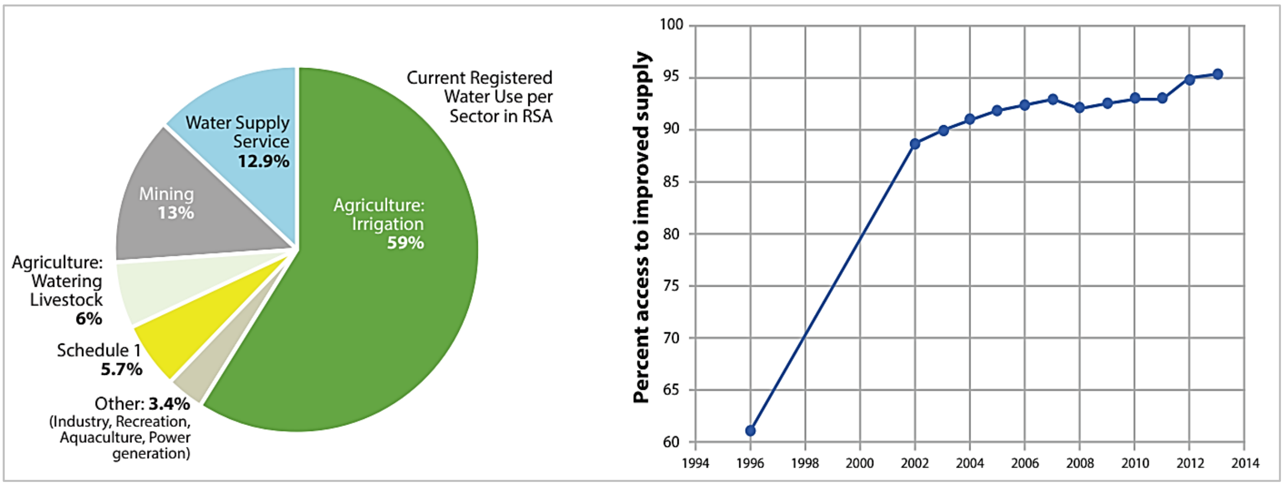

Figure 3-1 **Status of groundwater use per economic sector in South Africa and the water supply improvements since 1996 (Source: United Nations Development Programme UNDP (2010) and DWA (2012 and 2013) (after Cobbing, 2013).**

Table 3-2 **Summary of groundwater use sectors, trends, and associated literature references.**

Sector	Trends	Reference Sources
Agriculture	Exploitation of high-yielding aquifers leading to overuse and depletion in certain areas	Braune et al. (2014); DWA (2009)
Mining	Heavy reliance on groundwater, accounting for 13% of use	Braune et al. (2014)
Urban	Increasing importance as a water supply source 22% of towns solely rely on groundwater 34% of towns combine groundwater with surface water	Braune et al. (2014); DWA (2012); DWA (2013)
Community	Significant progress in improving access to improved water sources, benefiting 95.2% of the national population	Cobbing (2013); DWA (2013)
Ecosystems	Groundwater flows and discharge influencing ecological patterns and processes	Colvin et al. (2007)

3.2. Groundwater Development

Groundwater development has gained substantial attention in recent years as a crucial component of the water security strategy for the Western Cape. The increased reliance on groundwater resources stems from the need to mitigate the impacts of prolonged droughts and climate change while supporting the growing water demands of the urban, agricultural, and industrial sectors as described in **Section 3.1.2**.

Various water strategies have been adopted, including plans by the CoCT, the augmentation schemes for the WCWSS by the DWS, the ongoing groundwater development projects by local and district municipalities, as well as the strategic plans and initiatives put forward by the agricultural sector (water users associations, irrigation boards, etc.) aimed at enhancing groundwater development in the region.

This section provides an overview of the current groundwater development strategies that affect priority groundwater resources in the Berg catchment and include details such as the location of the development plans and the estimated groundwater volumes that are anticipated to be produced.

3.2.1. City of Cape Town - New Water Programme

The CoCT is actively implementing a comprehensive water management plan, referred to as the New Water Programme (NWP), to accommodate the increasing demand for water resources. The NWP incorporates a range of water management strategies, including desalination, water reuse, and notably, the development of groundwater resources. A significant component of the groundwater management efforts is the groundwater development and expansion schemes of three aquifer systems including the Table Mountain Group Aquifer (TMGA), the Cape Flats Aquifer Management Scheme (CFAMS), and the Atlantis Water Resource Management Scheme (AWRMS).

3.2.1.1. Table Mountain Group Aquifer

The Table Mountain Group (TMG) aquifers within the Steenbras-Nuweberg GRU are planned to be developed by the CoCT in a staged manner at two wellfields, namely Steenbras Wellfield and Eikenhof-Nuweberg Wellfield. Current abstraction at Steenbras Wellfield is 8 Mm^3/a, whereas subsequent staged expansion at the wellfield will likely occur between 2035-2040 (additional 3.75 Mm^3/a) and 2045-2050 (additional 4.75 Mm^3/a), resulting in a total abstraction from Steenbras Wellfield by 2050 of 16.5 Mm^3/a. Development of Eikenhof-Nuweberg Wellfield is only planned to begin from 2030-2035 with an initial abstraction volume of 5.5 Mm^3/a, followed by staged wellfield expansion between 2040-2045 (4.5 Mm^3/a) and 2045-2050 (6 Mm^3/a), resulting in a total abstraction from Eikenhof-Nuweberg Wellfield by 2050 of 16 Mm^3/a. The total proposed TMG aquifer groundwater abstraction volumes from the Steenbras-Nuweberg GRU by 2050 would therefore be 32.5 Mm^3/a (**Table 3-3** and **Table 3-4**). The timing of these staged TMG wellfield developments/expansions will be dependent on whether any future severe droughts occur, which may result in fast-tracking of TMG wellfield development/expansion by the CoCT (provided municipal budget is available, and access to wellfield sites is granted).

3.2.1.2. Cape Flats Aquifer

The Cape Flats Aquifer Management Scheme (CFAMS) is being executed in two stages. The first stage, currently ongoing, entails the exploration and drilling of production and injection (MAR) boreholes. The second stage aims to expand the CFAMS. In accordance with the PS evaluation detailed in the Ecological Reference Conditions Report (DWS, 2022e), the abstraction volume for 2022 stands at 20 Mm^3/a and the injection volume, facilitated by MAR, is 14.6 Mm^3/a (**Table 3-3**). Upon the envisaged completion of the CFAMS by 2050, the expected abstraction and injection volumes are projected to be 28 Mm^3/a and 23.5 Mm^3/a respectively (CoCT, 2022a) (**Table 3-4**).

3.2.1.3. Atlantis Aquifer

The Atlantis Water Resource Management Scheme (AWRMS) consists of two stages. The first stage involved the refurbishment and optimization of the existing wellfields, which has been completed. This phase restored a total of 9.0 Mm^3/a for abstraction and 6.92 Mm^3/a for infiltration through MAR to the current groundwater scheme. Of this, an abstraction volume of 5 Mm^3/a and infiltration volumes of 2.92 Mm^3/a are already accounted for in the PS calculation detailed in the Ecological Reference Conditions Report (DWS, 2022e). This phase was implemented to recover the water production capacity that had been lost due to the biofouling of boreholes and aging process equipment. The second phase is aimed at increasing the capacity to 12.25 Mm^3/a for abstraction and 9.84 Mm^3/a for infiltration (Umvoto, 2021) (**Table 3-4**). It is noteworthy that these are the officially licensed volumes for the scheme, although, the projected infiltration volumes would likely be lower.

A summary of the scheduled groundwater interventions and their expected abstraction and injection volumes (Mm^3/a) per stage is presented in **Table 3-3**. The 2022 PS denotes a total abstraction volume of 33 Mm^3/a and an MAR volume of 17.52 Mm^3/a, yielding a net volume of 15.48 Mm^3/a. The projected interventions by 2050 offer a total abstraction volume of 72.75 Mm^3/a and MAR volume of 33.34 Mm^3/a, resulting in a net volume of 39.41 Mm^3/a. A summary of the cumulative effective yield, calculated as the difference between MAR injections and abstractions, is presented in **Table 3-4** below.

Table 3-3 Summary of estimated yields pertaining to various water use licence application (WULA) phases of the proposed groundwater developments for the New Water Programme (NWP).

Interventions	Present Status Report (Mm^3/a)		WULA Stage 1 (Mm^3/a)		WULA Stage 2 (Mm^3/a)		WULA Stage 3 (Mm^3/a)	
	Abstraction	MAR	Abstraction	MAR	Abstraction	MAR	Abstraction	MAR
TMGA	8.00	0.00	13.5	0.00	21.75	0.00	32.50	0.00
CFAMS	20.00	14.6	20.5	14.60	28.00	23.50		
AWRMS	5.00	2.92	9.00	6.92	12.25	9.84		
TOTAL	**33.0**	**17.52**	**43.00**	**21.52**	**62**	**33.34**	**32.5**	**0**

Table 3-4 Estimated net yields pertaining to aquifer schemes for the New Water Programme (NWP).

GRU	2022 Volumes (Mm^3/a)			2050 Volumes (Mm^3/a)		
	Abstraction	Injection	Net Yield	Abstraction	Injection	Net Yield
TMGA	8.00	0.00	8.00	32.50	0.00	32.50
CFAMS	20.00	14.60	5.40	28.00	23.50	4.50
AWRMS	5.00	2.92	2.08	12.25	9.84	2.41
Total	**33.00**	**17.52**	**15.48**	**72.75**	**33.34**	**39.41**

3.2.2. Department of Water and Sanitation - WCWSS

The WCWSS consists of infrastructure components owned and operated by both the CoCT and the DWS. In 2018, the DWS undertook the Western Cape Water Supply System Reconciliation Strategy Study (DWS,2018) which investigated a range of bulk water supply schemes, such as desalination, water re-use, groundwater development, water demand management (**Figure 3-2**). However, for the context of this report, the focus will be primarily on the groundwater development schemes.

3.2.2.1. Langebaan Road Aquifer

The Langebaan Road Aquifer (LRA) wellfield commenced operations in December 1999 when the West Coast District Municipality (WCDM) was authorized to abstract groundwater to the volume of 1.46 Mm^3/a. Subsequent investigations have evaluated the practicality of implementing MAR, which have proved to be feasible (Israel et. al., 2021). The DWS issued a water license to the Saldanha Bay Municipality, permitting an abstraction of 5.52 Mm^3/a from the Langebaan Road wellfield. The license includes provisions for drilling alternative water supply boreholes, should the pumping rates from the existing production boreholes decrease (Israel et. al., 2021). As per the 2021 WARMS database, the LRA (including Hopefield wellfields) obtained three licenses between 2017 and 2019, facilitating a total abstraction of 6.87 Mm^3/a. In forthcoming years, the WCWSS anticipates supplying 14 Mm^3/a from the LRA. This operation is expected to be conjunctive with MAR schemes and involve the development of a wellfield in the untapped Elandsfontyn Aquifer System (DWAF, 2008).

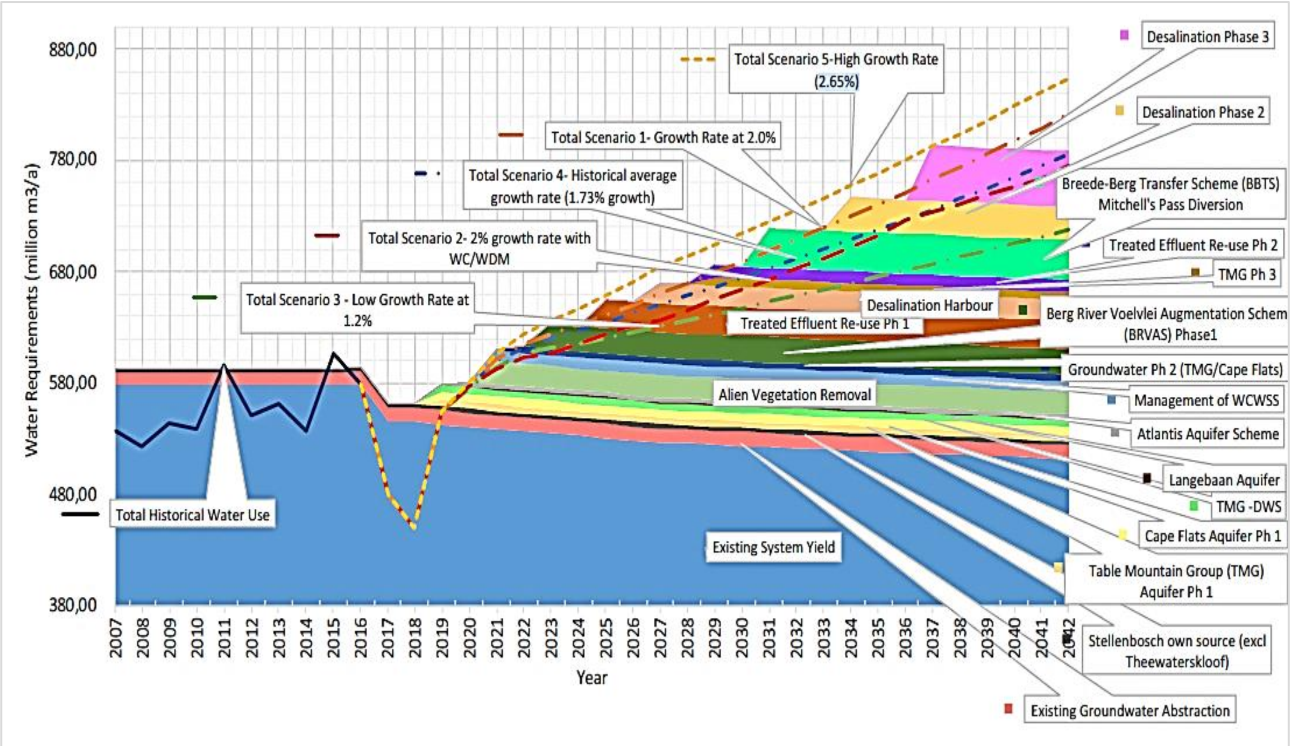

Figure 3-2 Reconciliation of water supply and requirement (DWS, 2018)

3.2.3. Municipalities

The Berg study region encompasses six local district municipalities, which include the CoCT, Drakenstein, Saldanha Bay, Stellenbosch, Swartland and the WCDM. Groundwater developments within the CoCT and Saldanha Bay were previously discussed in Sections **3.2.1** and **3.2.2**, respectively. The remaining municipalities, specifically Drakenstein, Stellenbosch, Swartland, and the WCDM have been included in the groundwater development considerations up until 2022. These developments were included in the PS calculation detailed in the Ecological Reference Conditions Report (DWS, 2022e). Groundwater development efforts are ongoing, with several municipalities already expanding their efforts.

3.2.3.1. Drakenstein Municipality

The Drakenstein Municipality had drilled two boreholes in Wellington, four boreholes at wastewater treatment works (WWTW) in Paarl, and four boreholes at Parys Sport in Paarl as of March 2023. The total yield from these expanded wellfields is expected to reach 0.63 Mm³/a by 2030 (iX Engineers, pers. com 2023; see **Table 3-5**).

3.2.3.2. Swartland Municipality

The Swartland Municipality has been exploring the potential of the Grootwater Aquifer as a supplementary or alternative water source to the conventional supply for Yzerfontein and Darling, based on current and future water requirements outlined in the Water Services Development Plan (WSDP, 2022). The Grootwater Aquifer spans ~65 km^2 and has a long-term yield of 3.36 Mm³/a. According to the Desktop Feasibility Study into Water Supply to Yzerfontein from the Grootwater Aquifer (Bigen Africa Services, 2019), approximately 2.58 Mm³/a is theoretically available for allocation.

The future infrastructure plan for the water supply scheme to Yzerfontein includes approximately 16 boreholes, set 150 meters apart in a linear configuration parallel to the coastline, to meet Yzerfontein's summer daily demand in 2029, based on a sustainable long-term yield of 5 l/s per borehole, equating to 2.52 Mm³/a (**Table 3-5**).

3.2.3.3. Berg River Municipality

The volumes related to groundwater developments within the Berg River Municipality are still under assessment. As of March 2023, wellfield development activities in the towns of Eendekuil, Redelinghuys and Aurora have been initiated (iX Engineers, pers. com 2023; see **Table 3-5**).

3.2.3.4. Stellenbosch Municipality

Prospective groundwater development initiatives within the Stellenbosch Municipality are currently under review and are yet to be confirmed (**Table 3-5**).

Table 3-5 Summary of estimated yields of proposed groundwater developments in various municipalities.

Municipality	Volume (Mm³/a)	Status	Projected Date
Drakenstein Municipality	0.63	As of March 2023	2030
Swartland Municipality	2.52	-	2029
Berg River Municipality	Under assessment	As of March 2023	-
Stellenbosch Municipality	To be confirmed	-	-

3.2.4. Agriculture

The Western Cape is highly dependent on agricultural production which is facilitated by the WCWSS. Of the total 186 Mm³/a allocated for agricultural purposes, large portions are distributed to Riviersonderend, the Berg Irrigation Board and the Wynland Water Use Authority (Patridge et. Al., 2020). Whilst ~97% of surface water is already allocated (Patridge et. Al., 2020), the agricultural sector in the Western Cape is actively investing in the development of groundwater wellfields to support irrigation practices.

Current groundwater development initiatives related to agriculture are yet to be confirmed. However, according to the 918 groundwater registrations recorded on the WARMS database (as of 2022), the estimated groundwater usage stands at 48.9 Mm³/a. A summary of the various municipalities agricultural status is described below.

3.2.4.1. City of Cape Town

The Philippi Horticultural Area (PHA), located within the city's limits, constitutes a significant agricultural sector within the region, contributing notably to the groundwater usage within the Cape Flats Aquifer (CFA). Licensed groundwater use within the CFA conceptual model domain according to the WARMS database is 7.56 Mm³/a, almost entirely for irrigation purposes (<1% for livestock watering). Farmers have estimated the water consumption by the big commercial farmers alone to be in the order of 80 Ml/day (14.6 Mm³/a, if used for 6 months as indicated by some farmers) (McGibbon et al., 2017). Other farmers stated that they irrigated all year round from groundwater.

3.2.4.2. West Coast District Municipality

This region faces challenges in municipal water supply due to limited surface water availability and significant groundwater abstraction. The primary agricultural activities consist of dryland wheat, supplemented by the cultivation of grapes, teas, vegetables, and citrus fruits.

3.2.4.3. Cape Winelands District Municipality

The municipal water supply is sourced from both groundwater and surface water resources. However, water abstraction is exceeding supply in certain areas. The region is renowned for its wine production, with an increasing trend towards the cultivation of table grapes, wheat, and fruits.

3.2.4.4. Overberg District Municipality

The water supply in the Overberg district is generally manageable, with a deficit only expected in over ten years' time. However, areas of high demand have been observed, particularly during the tourist season.

3.3. Climate Change

Numerous scientific publications have addressed the expected climatic changes that will occur in South Africa (Gintamo et. al., 2021; Adelana et. al., 2010; Conrad et. Al., 2004). Generally, the country anticipates a rise in temperatures with higher average temperatures in sub-humid regions, while the Western Cape region is likely to experience a decrease in rainfall. These changes are expected to result in an increase in extreme weather events such as floods and droughts, which will be driven by projected increases in rainfall intensity and variability (Adelana et. al.,2010). Due to the effects of global climate change, there is a possibility that future rainfall patterns will become less predictable. To address this concern, the CoCT has conducted research to explore the potential impact of multi-year droughts. According to the results of the study, which considered three climate change scenarios, there is a moderate likelihood that water availability from the six large dams will decrease by 23% by 2050 (Water Outlook, 2020).

In a study conducted by Dennis et al. (2012) entitled 'Climate Change Vulnerability index for South African aquifer', it was identified that recharge is influenced by two main factors - precipitation and slope. Slope gradient impacts recharge by dictating the amount of runoff, with steeper slopes leading to increased runoff and reduced recharge. On the other hand, precipitation was scrutinized by Cavé et al. (2003) who developed a rainfall-recharge correlation model that was applied spatially utilizing Groundwater Resources Assessment Phase 2 (GRAII) data.

Two distinct scenarios were analysed: the present and future recharge rates. The present scenario reflects the rainfall patterns from 1960 to 2000, while the future scenario, projecting from 2046 to 2065, is derived from a selected General Circulation Model (GCM) scenario. These scenarios were used to generate a map (**Figure 3-3)**, representing the changes in recharge. The outcome of this study suggests that the Western Cape region could potentially witness the most significant change in recharge, with a decrease ranging from 6 to 4.2 mm/a within the Berg study area.

These findings were consistent with previous studies, which indicate that the Western Cape region is anticipated to experience the most significant reductions in recharge in South Africa. As the region is already water-stressed, further declines in groundwater recharge may exacerbate water scarcity in the area.

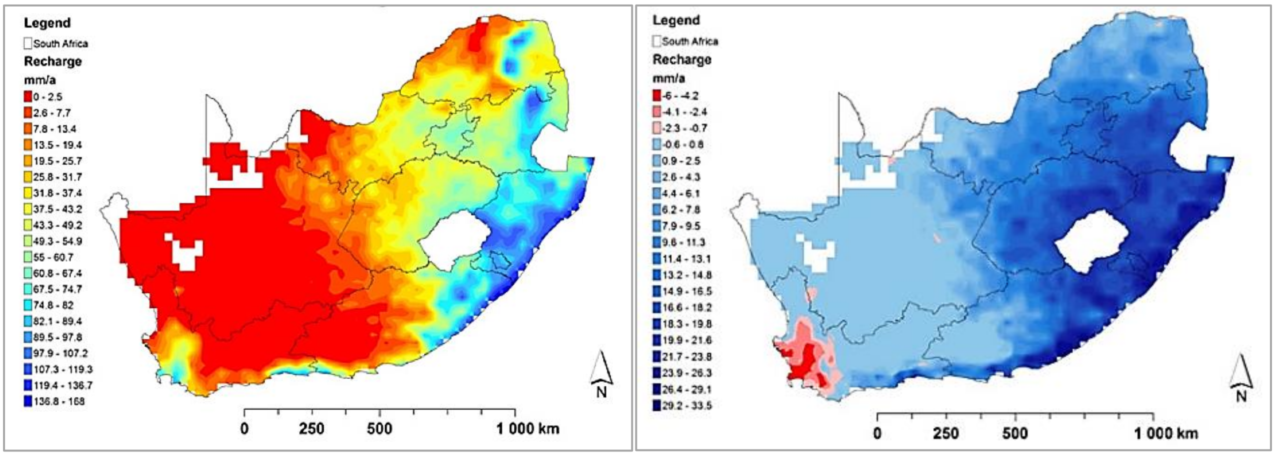

Figure 3-3 **Recharge distribution maps of South Africa displaying current recharge conditions (left) and the change in annual recharge between the current and future (right) by Dennis et.al (2012).**

3.4. Invasive Alien Plants

Invasive Alien Plants (IAPs) pose a significant threat to groundwater recharge, especially in water-scarce regions like the Western Cape. These plants consume substantial amounts of water, leading to reduced groundwater recharge and availability. In addition to depleting both surface and groundwater resources, IAPs can alter soil properties, reduce biodiversity, and increase the risk of wildfires (Chamier et al., 2012; Van Wilgen et al., 2008). Moreover, the invasion of alien plants can result in the loss of indigenous species, increased biomass and fire intensity, enhanced erosion, reduced river flows, reduced groundwater recharge, and negative effects on water quality.

To address this issue, various “clearing” programs have been implemented in the Western Cape, including the Working for Water (WFW) programme (DWAF, 1995), Land User Incentive Scheme, Working for Wetlands program, River Rehabilitation program, and Cape Floristic Region Protected Areas program. These initiatives aim to eradicate IAPs from natural areas. The positive outcomes of these programs include reducing water consumption by IAPs and increasing groundwater infiltration and recharge rates (Chamier, 2012; Le Maitre et al., 2018).

The effectiveness of these clearing programs depends on several factors. The type and density of IAPs play a crucial role, as different species may require specific clearance techniques. Additionally, prevailing climatic conditions, such as rainfall patterns and evapotranspiration rates, can impact the growth, spread, and restoration of invasive vegetation and cleared areas (Van Wilgen et al., 2008). The aim of the WFW programme is to reduce the density of IAPs through labour intensive, mechanical and chemical control, by 22% per annum (DWAF, 1995).

A study conducted by Van Wilgen et al. (2008) presents a comprehensive assessment of the impacts of IAPs in five major biomes in South Africa described by Low and Rebelo, (1996): fynbos (mediterranean shrublands), grassland, savanna (including the thicket biome), Nama karoo (arid shrublands), and succulent karoo (**Figure 3-4**). The study specifically examined the effects of these IAPs on four key ecosystem services including 1) surface water runoff, 2) groundwater recharge, 3) livestock production, and 4) biodiversity. The data was analyzed based on the distribution of 56 IAPs across the five biomes to estimate their impacts.

	Biome				
	Fynbos shrublands	Grassland	Succulent karoo	Nama karoo	Savanna and thicket
Total area (km²)	71,340	349,190	83,100	360,110	402,870
Area transformed (km²)	22,700	102,110	4110	4550	59,590
Remaining natural area (km²)	48,640	247,080	78,990	355,560	343,270
Area under conservation (km²)	14,840	7430	4450	44,520	44,520
Mean annual precipitation (mm)	503	667	170	225	544
Mean annual runoff (mm)	95	77	4	8	36
Area of groundwater-dependant vegetation (km²)	3750	2965	974	11,769	9993

Figure 3-4 **Summary of the analysis of five key biomes in South Africa, examining their degree of transformation and conservation, rainfall and runoff characteristics, and the extent of groundwater-dependent vegetation within these biomes (Van Wilgen et al., 2008).**

In terms of groundwater recharge, the study found that the projected impacts of IAPs were less severe compared to the substantial reduction of approximately 43,000 Mm^3 (around 7% of the national total) in surface water runoff. The estimated potential reductions in groundwater recharge were approximately 1.5% of the maximum reductions observed in surface water runoff. The impacts focused on specific vegetation types that were selected based on their high likelihood of dependence on groundwater. These included riparian vegetation, alluvial and aeolian deposits where woody plant species could potentially access groundwater within their root depth, dolomitic and limestone areas, and dune vegetation.

Invasive alien trees and shrubs with deep roots would reduce the recharge of groundwater aquifers in these vegetation types, assuming they had access to water that would normally infiltrate into groundwater instead of contributing to surface water runoff. To estimate the reduction in groundwater recharge, Van Wilgen et al. (2008) assumed that IAPs categorized as tall trees, medium trees, and tall shrubs decreased groundwater recharge by 20% of the mean annual runoff in the respective areas. By focusing on these specific vegetation types and considering, the study provided insight into the potential reduction of groundwater replenishment and its implications for water availability in affected areas (**Figure 3-5**).

Groundwater-dependent vegetation were most prevalent in the fynbos biome, covering approximately 45% of the total biome area. In comparison, the Nama karoo and savanna biomes had about 3% and 2.5% of their respective areas designated as groundwater dependent. The succulent karoo and grassland biomes had a smaller proportion, around 1%. Among these, the fynbos biome exhibited the highest estimated potential reduction in groundwater recharge (36 Mm³/a) (**Figure 3-5**).

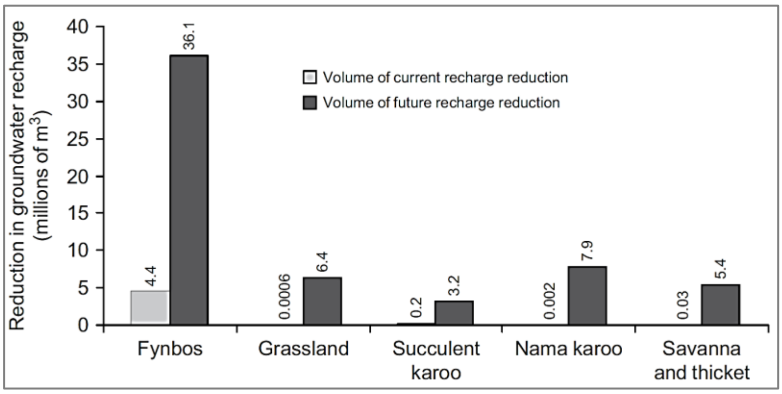

Figure 3-5 **Estimates of the current and potential impacts of invasive alien plants (IAPs) on groundwater recharge in five biomes in South Africa (Van Wilgen et al., 2008).**

However, when comparing the actual volumes, the reductions in groundwater recharge were relatively small compared to the estimates for surface water runoff. In fact, they only amounted to 1.5% of the potential reductions in surface water runoff caused by IAPs. The grassland biome demonstrated relatively minor potential reductions in groundwater recharge compared to surface water runoff. Conversely, while the reductions in groundwater recharge in the two karoo biomes were small in volume, they may be considered more significant due to their context (**Figure 3-5**).

4. PREDICTIVE SCENARIOS

The following section presents a series of predictive scenarios that aimed to provide insights into the future dynamics of groundwater resources in the Berg catchment. These scenarios considered various factors such as climate change, population growth, ongoing groundwater development schemes, and the impacts of invasive alien species. Each scenario offered a unique perspective on the challenges and opportunities that lay ahead for the sustainable management of groundwater in the region. By utilizing a combination of hydrogeological data, climate projections, and socio-economic trends, these scenarios provided an integrated look at the potential outcomes and challenges that could arise in sustaining the groundwater Reserve and estimating the associated allocable groundwater volumes. The equations used for this calculation are described below.

To assess the potential impact on the Reserve, an Allocation Stress Index was created, which represented the ratio of the groundwater 'still allocable' (after considering the Reserve and additional water use) to the total recharge for the GRU. This stress index was divided into six allocation categories, labelled 'A' through 'F', representing a spectrum from unstressed to potentially critically stressed conditions (refer to **Table 4-1**). As this ratio approached zero, the level of stress increased, indicating minimal remaining still allocable volumes and a potential threat to the groundwater Reserve.

$$\textbf{Groundwater Reserve} = \textbf{EWR Reserve} + \textbf{BHN Reserve}$$

$$\textbf{Total Allocable Volume} = \textbf{Recharge} - \textbf{Groundwater Reserve}$$

$$\textbf{Still Allocable Volume} = \textbf{Total Allocable Volume} - \textbf{Groundwater Use}$$

$$\textbf{Allocation Stress Index} = \frac{\textbf{Still Allocable Volume}}{\textbf{Recharge}}$$

All parameters, apart from the Allocation Stress Index, should be expressed as Mm³/a.

Table 4-1 Guide for determining groundwater allocation category.

Allocation Category	Description	Allocation Stress Index (Still Allocable / Recharge)
A	Unstressed or slightly stressed	>0.95
B		0.75 - 0.95
C	Moderately stressed	0.5 - 0.75
D		0.35 - 0.50
E	Potentially highly stressed	0.15 - 0.35
F	Potentially critically stressed	<0.15

4.1. Scenario 1 – Population Growth

As outlined in **Section 1.4**, the goal of this scenario was to examine the potential impact of population growth on both the BHN Reserve and consequently on the availability of allocable groundwater per GRU in the Berg catchment. The objective was to quantify the groundwater component of the BHN Reserve, by predicting the 2050 'qualifying population' and factoring in a daily water consumption rate of 25 ℓ/p/d.

The approach to estimating population growth rates employed both Census (2011) and the preliminary data from Census (2022). These databases provided population metrics for all Local District Municipalities (LDM) within the study area from 2002 through to 2022, albeit with an exception for the CoCT, for which data was available only up to 2021. The population for each LM within the Berg study area was examined - namely, WC012, WC013, WC014, WC015, WC022, WC023, WC024, WC031 and WC032 and the CoCT. **Table 4-2** summarises the growth rates for each LM, while a detailed presentation of annual population totals can be found in **Appendix A**. The growth rates varied, ranging from 2.53 to 1.34% per annum, aligning with the literature review as discussed in **Section 3.1.1**. The CoCT was projected to sustain a relatively high annual growth rate of 2.19%, while Theewaterskloof was projected to experience a lower growth rate of 1.34%.

Table 4-2 Summary of population growth rates (%) per Local District Municipality (LDM) from 2022 to 2050.

LDM Name	LDM Code	2022 Population	2050 Population	Average Relative Growth Rate per annum
City of Cape Town	CPT	4,756,255	8,716,349	2.19%
Cederberg	WC012	60,917	101,811	1.85%
Bergrivier	WC013	75,635	130,057	1.95%
Saldanha Bay	WC014	125,921	240,911	2.34%
Swartland	WC015	140,976	272,166	2.38%
Witzenberg	WC022	153,808	309,561	2.53%
Drakenstein	WC023	298,529	478,522	1.70%
Stellenbosch	WC024	199,704	386,358	2.38%
Breede Valley	WC025	196,590	288,131	1.37%
Theewaterskloof	WC031	124,341	180,337	1.34%

These population growth rates were then applied to the 2022 'qualifying population' per GRU to project the qualifying population for 2050. As stated in the PS calculation detailed in the Ecological Reference Conditions Report (DWS, 2022e), the 2022 qualifying population was 257 331, which is projected to increase to 467 667 individuals in 2050.

The predicted 2050 qualifying populations were then multiplied by a daily water consumption rate of 25 ℓ/p/d, resulting in a BHN Reserve of 4.27 Mm³/a for 2050, compared to 2.35 Mm³/a for 2022 (**Table 4-3**). This represents an increase of 81% in the BHN Reserve over the 28-year period. While this seems significant, this percentage increase corresponds to a relatively small volume when compared against the total Groundwater Reserve (comprising EWR and BHN) of 72.33 Mm³/a in 2022 and 74.25 Mm³/a in 2050 (see **Table 4-4**). Changes in the BHN Groundwater Reserve for individual GRUs are presented in **Table 4-3**, indicating that the Cape Flats, Malmesbury, Stellenbosch-Helderberg, Wellington, and Cape Town Rim GRUs had the highest BHN reserve volumes of 1.29, 0.64, 0.46, 0.39, and 0.36 Mm³/a, respectively for 2050. The Cape Flats GRU, due to its high qualifying population density, had the largest BHN Reserve allocation volumes and, therefore, the most significant impact on the BHN overall.

Table 4-3 provides a comparative summary of groundwater inflows and outflows, including groundwater Reserve, recharge, water use, and available allocation volumes for various GRUs, based on the 2022 PS volumes and the projected volumes for 2050. Notably, the forecasted BHN Reserve had a minimal effect on the total allocable volumes, resulting in a minor overall reduction of only 1.92 Mm³/a. Given that the changes in BHN Reserve volumes are relatively insignificant, the Allocation Stress Indices (refer to **Table 4-1**) largely remained consistent between the two periods.

Table 4-3 Summary of the qualifying populations per Groundwater Resource Unit (GRU) and corresponding groundwater Basic Human Needs (BHN) Reserve (Mm³/a) for 2022 and 2050.

GRU	2022		2050	
	Qualifying population	BHN Reserve (Mm³/a)	Qualifying population	BHN Reserve (Mm³/a)
Adamboerskraal	889	0.008	1,528	0.014
Atlantis	2,801	0.026	5,137	0.047
Cape Flats	76,862	0.701	140,858	1.285
Cape Peninsula	9,346	0.085	17,127	0.156
Cape Town Rim	21,348	0.195	39,423	0.360
Darling	1,640	0.015	3,155	0.029
Drakensteinberge	372	0.003	719	0.007
Eendekuil Basin	9,968	0.091	17,071	0.156
Elandsfontein	545	0.005	1,047	0.010
Groot Winterhoek	1,861	0.017	3,498	0.032
Langebaan Road	1,891	0.017	3,612	0.033
Malmesbury	37,580	0.343	69,593	0.635
Middle-Lower Berg	9,355	0.085	17,561	0.160
Northern Swartland	5,149	0.047	9,934	0.091
Paarl- Franschhoek	13,875	0.127	23,208	0.212
Piketberg	3,965	0.036	6,817	0.062
Steenbras- Nuweberg	1,709	0.016	2,559	0.023
Stellenbosch-Helderberg	26,508	0.242	50,113	0.457
Tulbagh	2,568	0.023	5,168	0.047
Voëlvlei-Slanghoek	739	0.007	1,347	0.012
Vredenburg	1,227	0.011	2,348	0.021
Wellington	25,733	0.235	43,151	0.394
Wemmershoek	187	0.002	340	0.003
Witzenberg	243	0.002	490	0.004
Yzerfontein	970	0.009	1,872	0.017
TOTAL	**257,331**	**2.348**	**467,677**	**4.268**

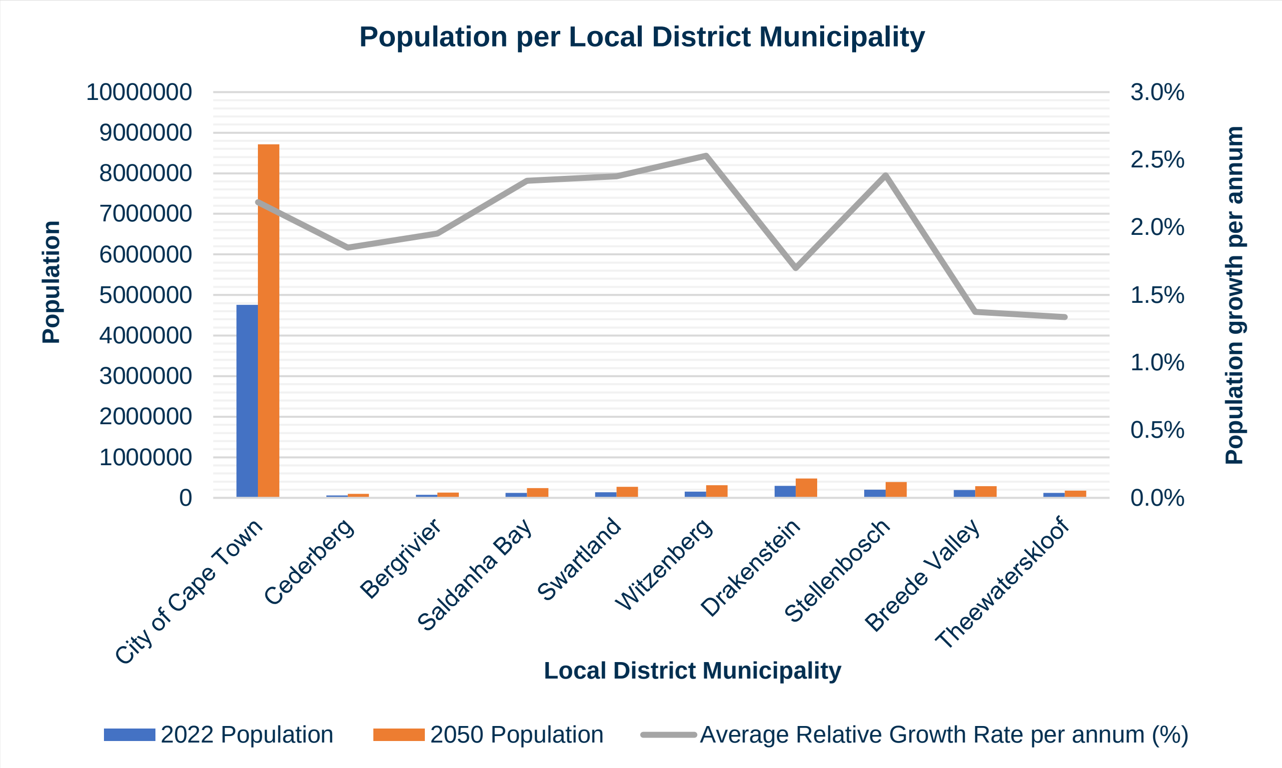

Figure 4-1 **Total population and corresponding growth rates per annum (%) per Local District Municipality (LDM) for 2022 and 2050.**

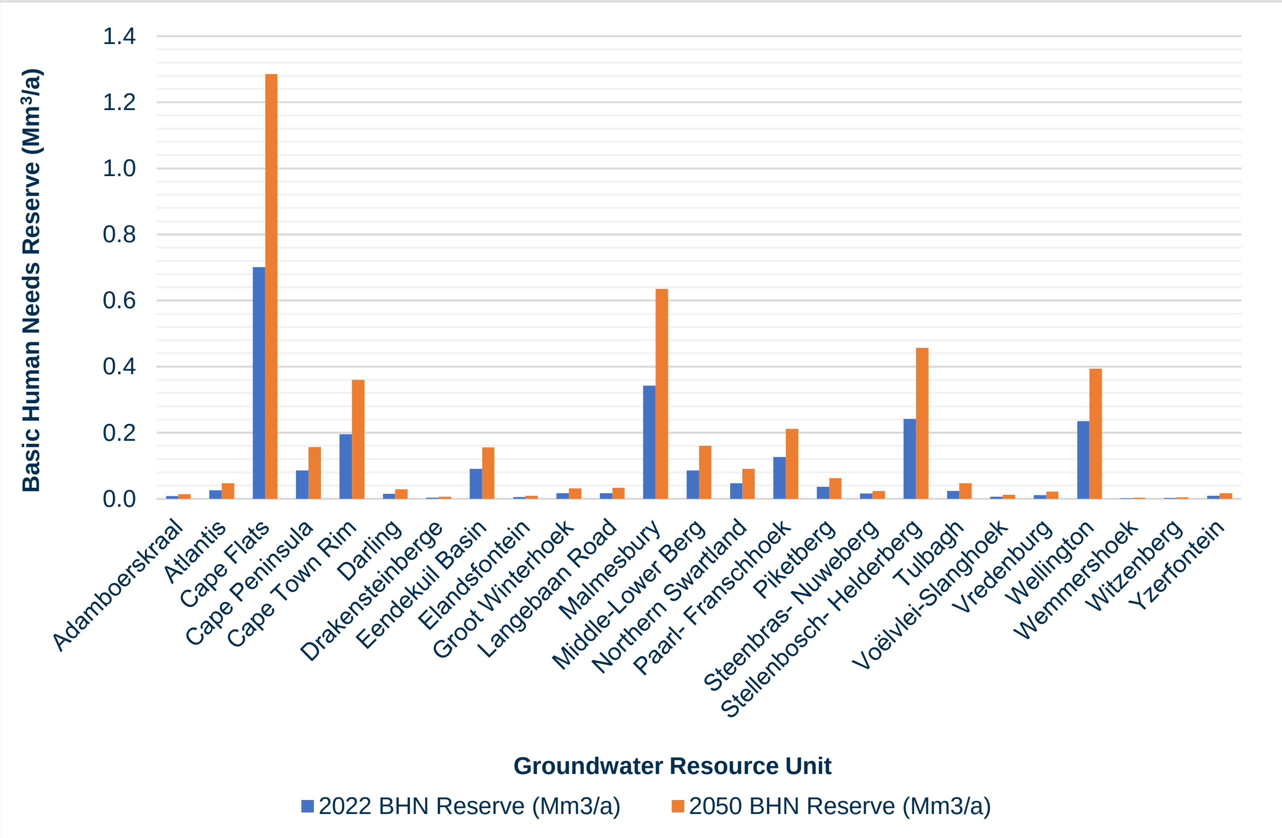

Figure 4-2 **Summary of the groundwater Basic Human Needs (BHN) Reserve (Mm³/a) per Groundwater Resource Unit (GRU) for 2022 and 2050.**

Table 4-4 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 1: Population Growth.

GRU	Preliminary Groundwater Reserve (2022)								Sc 1 – Population Growth (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62
Atlantis	22.74[15]	0.08	0.03	0.11	22.63	3.84[16]	18.79	0.83	22.74	0.08	0.05	0.13	22.61	3.84	18.77	0.83
Cape Flats	41.25[17]	0.51	0.70	1.21	40.04	12.00[18]	28.04	0.68	41.25	0.51	1.29	1.80	39.45	12.00	27.45	0.67
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	10.99	5.43	0.16	5.59	5.40	0.07	5.33	0.49
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	18.60	0.87	0.36	1.23	17.37	6.21	11.16	0.60
Darling	9.95	0.03	0.02	0.05	9.91	0.76[19]	9.15	0.92	9.95	0.03	0.03	0.06	9.89	0.76	9.13	0.92
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	27.60	2.88	0.01	2.89	24.71	0.05	24.66	0.89
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	21.88	6.95	0.16	7.11	14.77	4.85	9.92	0.45
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	15.47	6.39	0.01	6.40	9.07	1.09	7.98	0.52
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	22.50	0.77	0.03	0.80	21.70	1.39	20.31	0.90
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	23.28	5.52	0.03	5.55	17.73	8.59	9.14	0.39
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	52.65	1.18	0.64	1.82	50.83	14.75	36.08	0.69
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	42.49	11.15	0.16	11.31	31.18	2.23	28.95	0.68
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	31.85	0.20	0.09	0.29	31.56	1.79	29.77	0.93
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	26.61	3.01	0.21	3.22	23.39	9.82	13.57	0.51

[15] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).*
[16] *Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).*
[17] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).*
[18] *Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).*
[19] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

GRU	Preliminary Groundwater Reserve (2022)								Sc 1 – Population Growth (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	20.33	2.07	0.06	2.13	18.20	5.58	12.62	0.62
Steenbras- Nuweberg	58.76[20]	1.16	0.02	1.18	57.58	8.00[21]	49.58	0.84	58.76	1.16	0.02	1.18	57.58	9.13	49.58	0.84
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	41.52	2.34	0.46	2.80	38.72	8.81	29.91	0.72
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	10.87	1.28	0.05	1.33	9.54	3.78	5.76	0.53
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	14.10	1.62	0.01	1.63	12.47	0.13	12.34	0.88
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	7.43	0.00	0.02	0.02	7.41	1.16	6.25	0.84
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	39.49	6.75	0.39	7.14	32.35	4.48	27.87	0.71
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.90
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	9.20	0.02	0.02	0.04	9.16	0.26	8.90	0.97
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**620.78**	**69.98**	**4.27**	**74.25**	**546.53**	**102.66**	**443.87**	

[20] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[21] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

4.2. Scenario 2 – Sectoral Water Demand

As outlined in **Section 1.4**, the goal of this scenario was to analyse the historical trends of groundwater demand per sector, primarily focusing on the agriculture (irrigation, watering livestock, and aquaculture) and industry (urban and non-urban) sectors, as well as other smaller sectors including the water supply, mining, power generation, recreation, and schedule 1 users. The objective was to predict the future water demands by extrapolating historical WARMS data up to 2050 and assessing their potential impact on the volume of groundwater that could potentially still be allocated per GRU in the Berg catchment. **Table 4-5** provides summary of the current statistics for the water use sectors. Please note that for GRUs where future groundwater development was already known, the water supply sector was excluded from the scenario analysis. This exclusion occurred prior to applying the sectoral growth rate, as the water supply sector was addressed separately in **Section 3.2**. The purpose of separating the water supply sector was to ensure that there was no double counting in terms of future water use.

The two highest water use sectors, based on total registered volume of groundwater use, were the agriculture (irrigation) sector with 48.616 Mm^3/a (56.9% of all use) and the industry (urban) sector with 14.775 Mm^3/a (17.3% of all use) (**Figure 4-3**). Together these two sectors account for 74.2% of the total groundwater use in the study area (**Figure 4-4**).

The average volume per registration was calculated as the total registered volume divided by the number of registrations and provided insight into the typical amount of water use per registration, regardless of the frequency of use or how long the registration had been active. The total number of registrations per sector was also an important factor to consider (**Table 4-5**), with the agriculture (irrigation) and agriculture (livestock) sectors having 803 and 96 registrations respectively, and the industry (urban) sector having 257 water use registrations.

Table 4-5 also summarizes the average volume per year per water use sector, which was calculated as the total registered volume divided by the number of years between the first and last registration. This provided insight into the average amount of groundwater use per year over the associated registration period, which was useful in identifying the trend of groundwater use for a particular sector and how it changed over time. If the average volume per year was increasing, it indicated that the sector was becoming more water intensive. Conversely, if the average volume per year was decreasing, it indicated that the sector was becoming more water efficient.

Figure 4-3 and **Figure 4-5** demonstrates a sharp increase in registrations in 1998 and from 2002 onwards due to legislative changes and requirements. The NWA (1998) required individuals and organizations to register their water use, where the DWS assisted parties in completing the registration process between 1999 and 2002. The information collected was entered into the WARMS database, which was being established at that time. Since then, groundwater usage has consistently risen. However, the graph (**Figure 4-5)** showed a steeper gradient around 2015/2016, reflecting the severe drought experienced by the Western Cape (WC). To alleviate the crisis, the WC government implemented a robust water-saving campaign, including public awareness campaigns, infrastructure upgrades, and increased investment in alternative water sources, such as significant upgrades to groundwater abstraction schemes (see **Section 3.2**).

It is important to note that individuals who received water from a bulk water supplier, such as a local authority, a water board, or an irrigation board, were not required to register their water use according to the NWA (Act 36 of 1998). Instead, the DWS would register their water use (if necessary) and provide them with a certificate or semi-completed water use application. The Act also allowed individuals to take water directly from any water resource they had lawful access to for reasonable domestic use or for small-scale gardening and watering of animals on land they owned or occupied, provided that the use was not excessive in relation to the water resource's capacity and the needs of other users. As a result, most users of groundwater in cities and towns, as well as those with windmills on their own properties, did not need to register their use with WARMS.

Table 4-5 Water use sectors in the Berg catchment and their average groundwater use per registration, providing insight into the typical amount of water use per sector and the trends in groundwater use over time.

Water Use Sector	Total Registered Volume (Mm³/a)	Volume per Registration (Mm³/a)	Max Volume (Mm³/a)	Min Volume (Mm³/a)	No. of Registrations	Percentage of Total Registered Volume (%)	Registration Date From	Registration Date To	Number of Registration years	Average Volume per Year (Mm³/a)
Agriculture: Aquaculture	0.691	0.086	0.295	0.000	8	0.8%	1985	2018	33	0.021
Agriculture: Irrigation	48.616	0.061	0.756	0.000	803	56.9%	1955	2021	66	0.010
Agriculture: Watering Livestock	3.884	0.040	0.848	0.000	96	4.5%	1971	2021	50	0.014
Industry (Non-Urban)	1.901	0.031	1.040	0.000	62	2.2%	1981	2021	40	0.017
Industry (Urban)	14.775	0.057	5.000	0.000	257	17.3%	1956	2021	65	0.011
Mining	1.461	0.365	0.700	0.003	4	1.7%	2016	2019	3	0.230
Recreation	0.019	0.009	0.016	0.003	2	0.0%	2002	2021	19	0.036
Schedule 1	0.130	0.004	0.040	0.000	35	0.2%	1940	2020	80	0.009
Urban (Excluding Industrial and/or Domestic)	0.833	0.069	0.252	0.006	12	1.0%	2019	2021	2	0.346
Water Supply Service	13.166	0.263	3.500	0.000	50	15.4%	1972	2022	50	0.014
TOTAL	**85.474**	**0.064**	**5.000**	**0.000**	**1329**	**100.0%**	**1940**	**2022**	**408**	

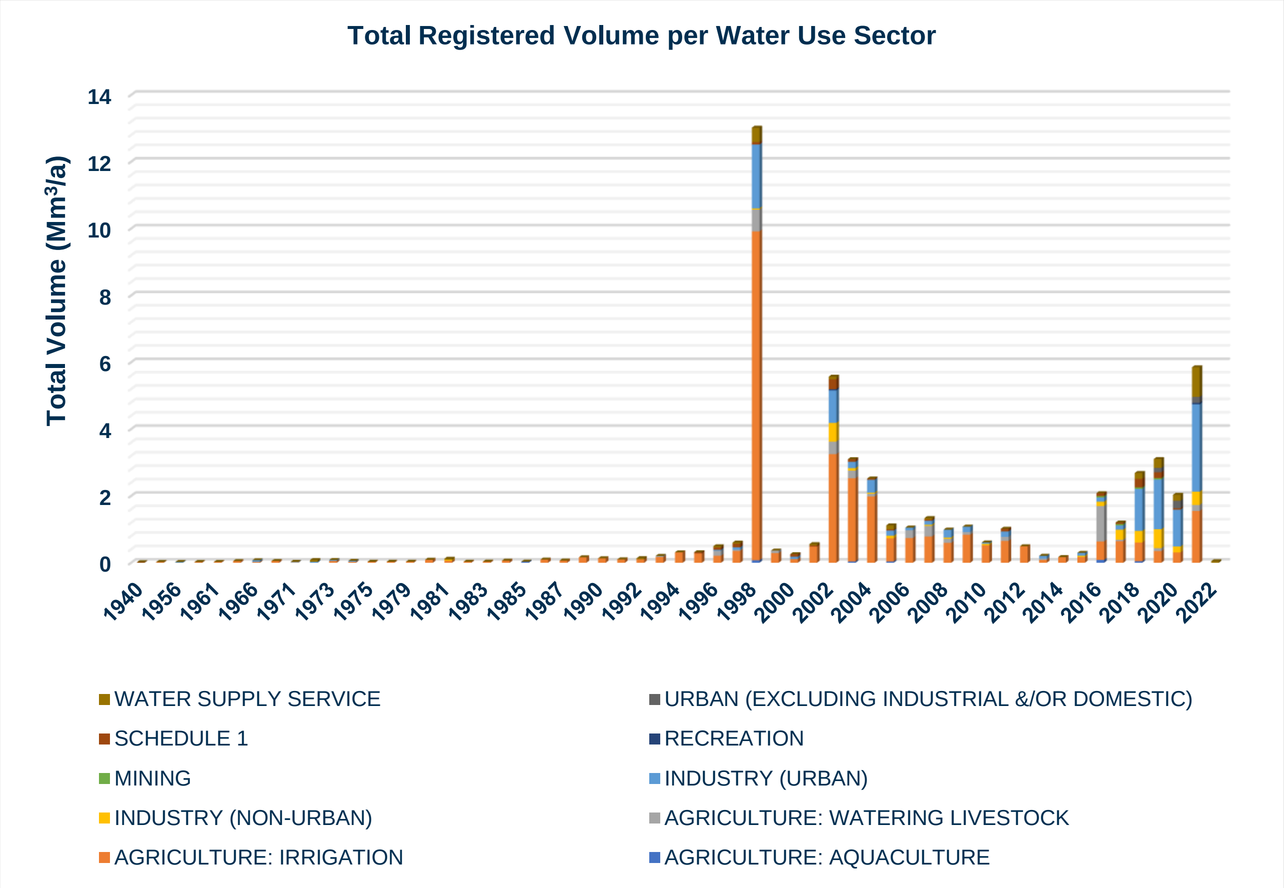

Figure 4-3 The total registered volume (Mm³/a) per water use sector in the Berg catchment.

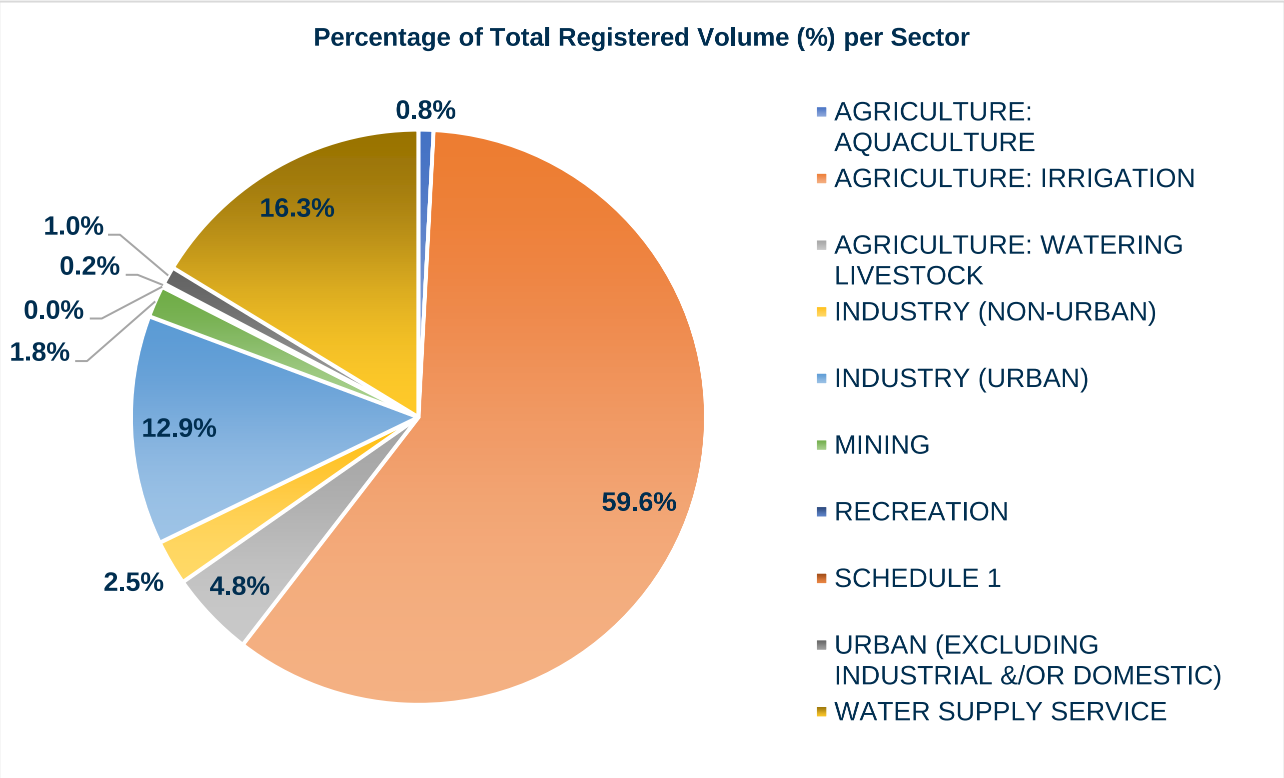

Figure 4-4 The percentage of total registered volume per water use sector in the Berg catchment.

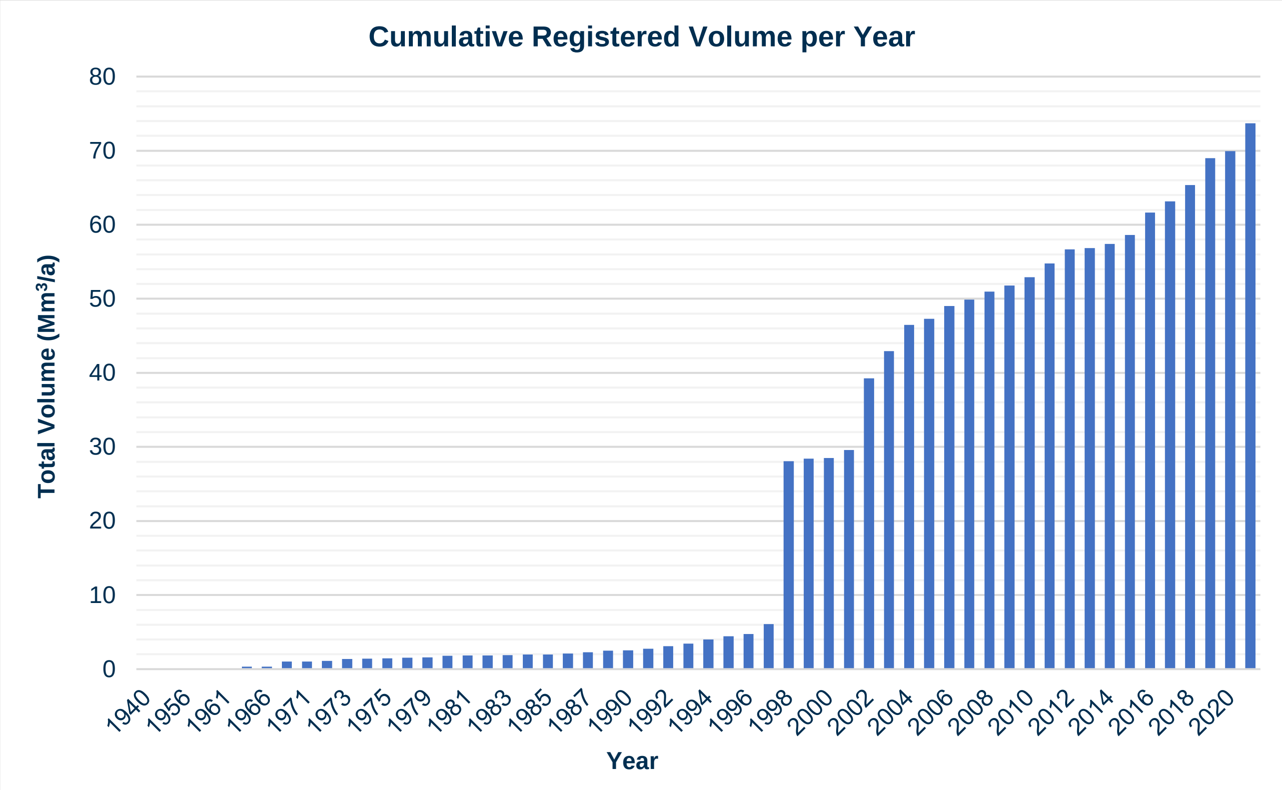

Figure 4-5 The cumulative registered volume (Mm³/a) per year in the Berg catchment.

To determine sectoral growth, the proportion of total groundwater use per sector was used to project volumes for 2050. A "least squares method" trend analysis was applied to calculate a trend line equation for each sector, which was then used to predict the total volume of groundwater use in 2050 per GRU (**Appendix B**). The relative growth trend (i.e., the gradient that represented the average rate of change over time) was calculated from 2004 – 2021 as the registrations showed sharp increases in 1998 and 2002 due to legislative changes. The equation was applied to the current total volumes of groundwater use per each sector to obtain the projected 2050 volumes. The results are presented in **Table 4-6**. These findings shed light on the potential trends in groundwater availability and allocation within the Berg Catchment.

The total allocable volume, which was calculated as recharge minus the groundwater Reserve, offered an overall measure of the total available groundwater. The still-allocable volume, on the other hand, represented the portion of the total allocable volume that remained unallocated after considering groundwater use (total allocable volume minus groundwater use). Both the current (2022) and projected (2050) values of total allocable volumes and still-allocable volumes had been calculated to assess the changes and trends in groundwater availability (**Table 4-6**).

Although the groundwater use volumes are estimated to increase by 29.85 Mm³/a from 2022 to 2050, the Allocation Stress Indices (refer to **Table 4-1**) remains largely consistent between the two periods. The most significant changes in the still allocable volumes were observed in the Malmesbury, Paarl-Franschhoek, Piketberg, and Wellington GRUs, with a decrease of 10.37 Mm³/a, 5.68 Mm³/a, 4.22 Mm³/a, 3.68 Mm³/a respectively. Certain GRUs, namely the Cape Flats, Atlantis, Langebaan, and Steenbras-Nuweberg GRUs experienced a lesser 2050 volume compared to the PS volume. This is due to the exclusion of groundwater developments in the scenario analysis which had a notable impact on groundwater use, and is extensively discussed in **Section 3.2** and **4.3**.

Table 4-6 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 2: Sectoral Water Demand.

GRU	Preliminary Groundwater Reserve (2022)								Sc 2 – Sectoral Water Demand (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	21.61	6.00	0.01	6.01	15.60	3.69	11.92	0.55
Atlantis	22.74[22]	0.08	0.03	0.11	22.63	3.84[23]	18.79	0.83	22.74	0.08	0.03	0.11	22.63	2.98	19.66	0.86
Cape Flats	41.25[24]	0.51	0.70	1.21	40.04	12.00[25]	28.04	0.68	41.25	0.51	0.70	1.21	40.04	9.32	30.72	0.74
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	10.99	5.43	0.09	5.52	5.48	0.15	5.33	0.48
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	18.60	0.87	0.20	1.07	17.54	8.71	8.82	0.47
Darling	9.95	0.03	0.02	0.05	9.91	0.76[26]	9.15	0.92	9.95	0.03	0.02	0.05	9.91	1.40	8.50	0.85
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	27.60	2.88	0.00	2.88	24.72	1.21	23.51	0.85
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	21.88	6.95	0.09	7.04	14.84	6.57	8.27	0.38
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	15.47	6.39	0.01	6.40	9.08	2.70	6.37	0.41
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	22.50	0.77	0.02	0.79	21.71	3.27	18.44	0.82
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	23.28	5.52	0.02	5.54	17.74	3.96	13.79	0.59
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	52.65	1.18	0.34	1.52	51.13	25.12	26.01	0.49
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	42.49	11.15	0.09	11.24	31.26	5.09	26.17	0.62
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	31.85	0.20	0.05	0.25	31.60	2.92	28.69	0.90
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	26.61	3.01	0.13	3.14	23.47	15.50	7.97	0.30

[22] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).*
[23] *Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).*
[24] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020)*
[25] *Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).*
[26] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

GRU	Preliminary Groundwater Reserve (2022)								Sc 2 – Sectoral Water Demand (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	20.33	2.07	0.04	2.11	18.22	9.80	8.42	0.41
Steenbras-Nuweberg	58.76[27]	1.16	0.02	1.18	57.58	8.00[28]	49.85	0.84	58.76	1.16	0.02	1.18	57.58	0.02	57.56	0.98
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	41.52	2.34	0.24	2.58	38.94	11.30	27.64	0.67
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	10.87	1.28	0.02	1.30	9.57	6.66	2.91	0.27
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	14.10	1.62	0.01	1.63	12.47	0.31	12.16	0.86
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	7.43	0.00	0.01	0.01	7.42	1.97	5.45	0.73
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	39.49	6.75	0.24	6.99	32.51	8.16	24.34	0.62
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	26.83	3.59	0.00	3.59	23.24	1.56	21.68	0.81
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.78	0.18	0.00	0.18	2.60	0.16	2.44	0.88
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	9.20	0.02	0.01	0.03	9.17	0.00	9.17	1.00
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**132.51**	**415.94**	

[27] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[28] *Includes city municipal abstraction of 8 Mm3/a in development (phase 1) as per NWA Section 21(a)*

4.3. Scenario 3 – Groundwater Developments

As described in **Section 3.2** this scenario evaluated groundwater developments and water strategies scheduled for implementation within the Berg catchment by 2050. It included groundwater abstraction and MAR plans by the CoCT, implementation plans by the DWS for the WCWSS, groundwater strategies by local municipalities, and initiatives by agricultural organizations and irrigation boards. The aim was to calculate the groundwater volumes including inflows and outflows associated with the proposed developments and evaluate their potential impact on the allocable volumes after the groundwater Reserve was accounted for.

A summary of the volume discrepancies (differences between abstraction and injection rates) for proposed groundwater developments per GRU for 2022 and 2050 are presented in **Table 4-7**, **Figure 4-6** and **APPENDIX C**.

As of 2022, included in the PS calculation detailed in the Ecological Reference Conditions Report (DWS, 2022e), the Cape Flats Aquifer Management Scheme exhibits the highest abstraction and recharge capacity, with abstraction volumes of 20 Mm³/a and recharge volumes of 14.60 Mm³/a, resulting in a net yield of 5.40 Mm³/a. Furthermore, the Steenbras-Nuweberg wellfield notably abstracts a substantial yield of 8.00 Mm³/a. Additionally, the Langebaan Road and Atlantis Aquifers contributes significant yields of 6.87 Mm³/a and 2.08 Mm³/a, respectively.

By 2050, projections indicate that the Steenbras-Nuweberg wellfield will have the highest yield, with abstraction volumes reaching 32.50 Mm³/a. The Cape Flats Aquifer Management Scheme's capacity is anticipated to increase, abstracting 28 Mm³/a and injecting 23.50 Mm³/a, leading to a net yield of 4.50 Mm³/a. The Langebaan Road aquifer is expected to increase its abstraction to 14 Mm³/a. Simultaneously, the Atlantis Water Resource Management Scheme will display an increased abstraction volume of 12.25 Mm³/a and an infiltration yield of 9.84 Mm³/a, resulting in a net yield of 2.41 Mm³/a.

The sum of all proposed groundwater developments for 2050 equates to a volume of 56.56 Mm³/a, which is approximately double that of the 2022 at 22.61 Mm³/a (**Table 4-7**). It is noteworthy that abstraction and injection volumes of the proposed groundwater developments are up for revision following the 5th Public Management Committee meeting (PMC-05).

Table 4-7 Summary of cumulative volumes (Mm³/a) per groundwater intervention within a GRU for years 2022 and 2050

GRU	2022 Volumes (Mm³/a)				2050 Volumes (Mm³/a)			
	Abstraction	Injection	Net Yield	Comment	Abstraction	Net Yield	Discrepancy	Comment
Atlantis	5.00	2.92	2.08	PS[29]	12.25	9.84	2.41	AWRMS expansion
Cape Flats	20.00	14.60	5.40	CFA Phase 1 (PS)	28.00	23.50	4.50	CFA Phase 2
Langebaan Road	6.87	0.00	6.87	PS	14.00	0.00	14.00	LRAS
Steenbras-Nuweberg	8.00	0.00	8.00	TMG Phase 1 (PS)	32.50	0.00	32.50	TMG Phase 3
Wellington	0.00	0.00	0.00	PS	0.63	0.00	0.63	Paarl & Wellington wellfields
Yzerfontein	0.26	0.00	0.26	PS & re-furbishment	2.52	0.00	2.52	Grootwater Aquifer
Total	**40.13**	**17.52**	**22.61**		**89.90**	**33.34**	**56.56**	

29 *PS stands for Present Status and is an indication current groundwater use included in the PS calculation detailed in the Ecological Reference Conditions Report (DWS, 2022e).*

The proposed groundwater development abstraction volumes were incorporated as a 'water use' for 2050, facilitating a comparative assessment with the water use volumes for 2022 (**Table 4-8**). The projected water use for 2050 equates to 151.21 Mm³/a, resulting in an increase of approximately 47% compared to the 2022 value of 102.66 Mm³/a.

Based on the Allocation Stress Index, the Langebaan Road GRU is categorized as potentially critically stressed. This classification arises from a low proportion of recharge to volumes that are still allocable, mainly due to the substantial proposed groundwater abstraction volume of 14 Mm³/a (DWAF, 2008). Once the Groundwater Reserve of ~6 Mm³/a is factored in, a mere ~2 Mm³/a remains still allocable. This indicates a considerable decline in still allocable volumes compared to the 2022 figure, which stood at ~9 Mm³/a.

The Cape Flats GRU is categorized as potentially highly stressed, given that the proposed development abstraction volumes reach 4.5 Mm³/a and PHA abstractions are estimated to be 14.6 Mm³/a, which total a significant abstraction volume of 19.10 Mm³/a. This reduces the volume available for allocation by approximately 50%, decreasing from around 28 Mm³/a to approximately 14 Mm³/a.

Furthermore, the Steenbras-Nuweberg GRU experiences a drop in classification from 'slightly stressed' to 'moderately stressed', attributable to high abstraction volumes from the TMGA. The remaining GRUs, however, maintain their present status stress categorization.

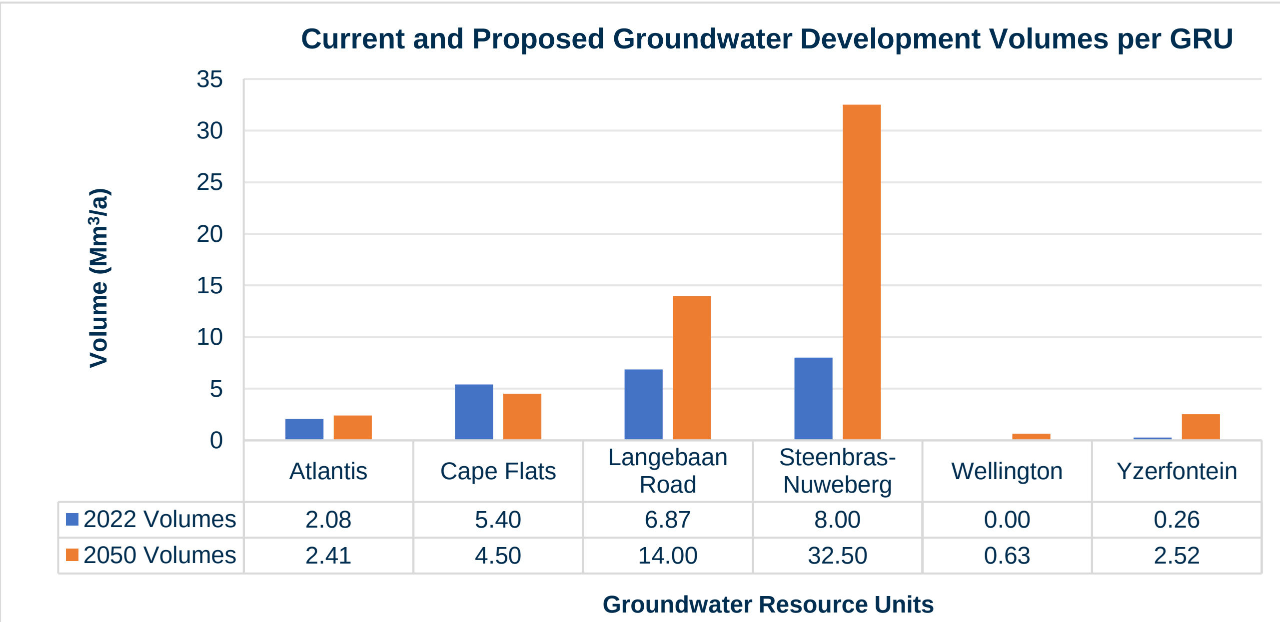

Figure 4-6 Proposed groundwater development abstraction volumes per GRU for 2050.

Table 4-8 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 3: Groundwater Developments.

GRU	Preliminary Groundwater Reserve (2022)								Sc 3 – Groundwater Developments (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62
Atlantis	22.74[30]	0.08	0.03	0.11	22.63	3.84[31]	18.79	0.83	22.74	0.08	0.03	0.11	22.63	4.17[32]	18.46	0.81
Cape Flats	41.25[33]	0.51	0.70	1.21	40.04	12.00[34]	28.04	0.68	41.25	0.51	0.70	1.21	40.04	25.70[35]	14.34	0.35
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	18.60	0.87	0.20	1.07	17.54	6.21	11.33	0.61
Darling	9.95	0.03	0.02	0.05	9.91	0.76[36]	9.15	0.92	9.95	0.03	0.02	0.05	9.91	0.76	9.15	0.92
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	27.60	2.88	0.00	2.88	24.72	0.05	24.67	0.89
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	22.50	0.77	0.02	0.79	21.71	1.39	20.32	0.90
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	23.28	5.52	0.02	5.54	17.74	15.72	2.02	0.09
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94

[30] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).*

[31] *Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).*

[32] *Includes city municipal abstraction of 12.25 Mm³/a and a total injection of 9.84 Mm³/a (as a negative water use).*

[33] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020)*

[34] *Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).*

[35] *Includes perceived PHA groundwater usage of 14.6 Mm³/a as well as municipal net abstraction of 4.5 Mm³/a.*

[36] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

GRU	Preliminary Groundwater Reserve (2022)								Sc 3 – Groundwater Developments (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62
Steenbras- Nuweberg	58.76[37]	1.16	0.02	1.18	57.58	8.00[38]	49.58	0.84	58.76	1.16	0.02	1.18	57.58	32.50	25.08	0.43
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	14.10	1.62	0.01	1.63	12.47	0.13	12.34	0.88
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	39.49	6.75	0.24	6.99	32.51	5.11	27.40	0.69
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	9.20	0.02	0.01	0.03	9.17	2.52	6.65	0.72
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**151.21**	**397.24**	

[37] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[38] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

4.4. Scenario 4 - Climate Change

As outlined in **Section 1.4**, the goal of this scenario is to examine the impact that climate change has on groundwater recharge rate. The objective is to quantify the projected reduction in groundwater recharge per GRU for 2050.

To achieve this, results from a study conducted by Dennis et.al (2012) were used and spatially adapted to the study area. In particular, the Change in Annual Recharge map (**Figure 3-3**) from Dennis et.al (2012) was utilized, which displays the change in annual recharge between the current and future scenarios. The change in recharge is based on a recharge function that incorporates both the recharge-rainfall relationship, as delineated by Cavé et al. (2003), and an assumption of slope dependency for recharge. The formula for the recharge function is expressed as follows:

$$\boldsymbol{Recharge}\ (\boldsymbol{mm}) = (\mathbf{148} \times \boldsymbol{ln}(\boldsymbol{Precipitation}) - \mathbf{880}) \times (\mathbf{1} - \mathbf{0.0025}\boldsymbol{e}\hat{}(\mathbf{0.2} * \boldsymbol{Slope}))$$

where Precipitation is the annual precipitation in mm, and Slope is the slope percentage of the area.

The change in annual recharge between current and future scenarios, both used this same formula with different values of precipitation based on climate projections for each. Thus, resulting in **Figure 3-3** which demonstrates the projected annual changes in groundwater recharge rates across South Africa.

Subsequently, this map was georeferenced to the Berg study area, facilitating a quantitative estimation of spatial reduction in recharge. This resulted in a map illustrating recharge rate reductions within the study area, as displayed in **Figure 4-7** below. Recharge reduction rates across the Berg study area range from 6 mm/a to 0.6 mm/a. Most of the Berg study area, from the Cape Peninsula GRU in the south-west to Groot Winterhoek GRU in the north-east, are subject to a recharge reduction of approximately 6 mm/a. The middle and lower sections of the study area show a recharge reduction of ~4 mm/a, whereas the upper northern portion of the Berg study area exhibits relatively low decline in recharge of 0.6 to 2.3 mm/a.

The derived reduced recharge rate values were subtracted from the PS recharge calculation as defined in the Ecological Reference Conditions Report (DWS, 2022e) to forecast 2050 recharge rates under the impact of climate change, specifically under increasingly warmer climatic conditions.

Table 4-9, **Figure 4-8** and **APPENDIX D** present recharge rates per GRU and corresponding recharge reductions. Recharge in 2022 totalled ~620 Mm^3/a, which is projected to reduce by ~64 Mm^3/a, to a total of ~556 Mm^3/a in 2050. The Malmesbury, Wellington, Northern Swartland, Middle-Lower Berg, Eendekuil, Langebaan Road, and Stellenbosch-Helderberg GRUs obtained the greatest reductions in recharge, decreasing from approximately ~8 Mm^3/a to ~3 Mm^3/a. Recharge reduction rates don't offer substantial implications if GRUs have high recharge rates; hence, the Stress Allocation index provides a better indication of potential impacts on the groundwater Reserve and allocations (see **Table 4-10**).

Table 4-10 provides a comparative summary of inflows and outflow per GRU based on the 2022 PS volumes and the projected volumes for 2050 to form the Allocation Stress Index, which highlights potential trends in groundwater availability and allocation within the Berg Catchment. Notably, the forecasted recharge rates introduce additional stress on specific GRUs between 2022 and 2050. While none are classified as 'potentially critically stressed', the Langebaan Road and Eendekuil Basin are classified as potentially 'highly stressed', a downgrade from their previous 'moderately stressed' status. Moreover, the Paarl-Franshoek and Tulbagh GRUs declined from 'slightly stressed' to 'moderately stressed', while the Cape Peninsula GRU maintained its 'moderately stressed' state throughout these two periods. The remaining GRUs are classified as 'unstressed or slightly stressed', with the Yzerfontein GRU being the least stressed. The findings of this comparative assessment between 2022 and 2050 spotlight the GRUs most likely to be affected by climate change - due to the reduction of groundwater recharge.

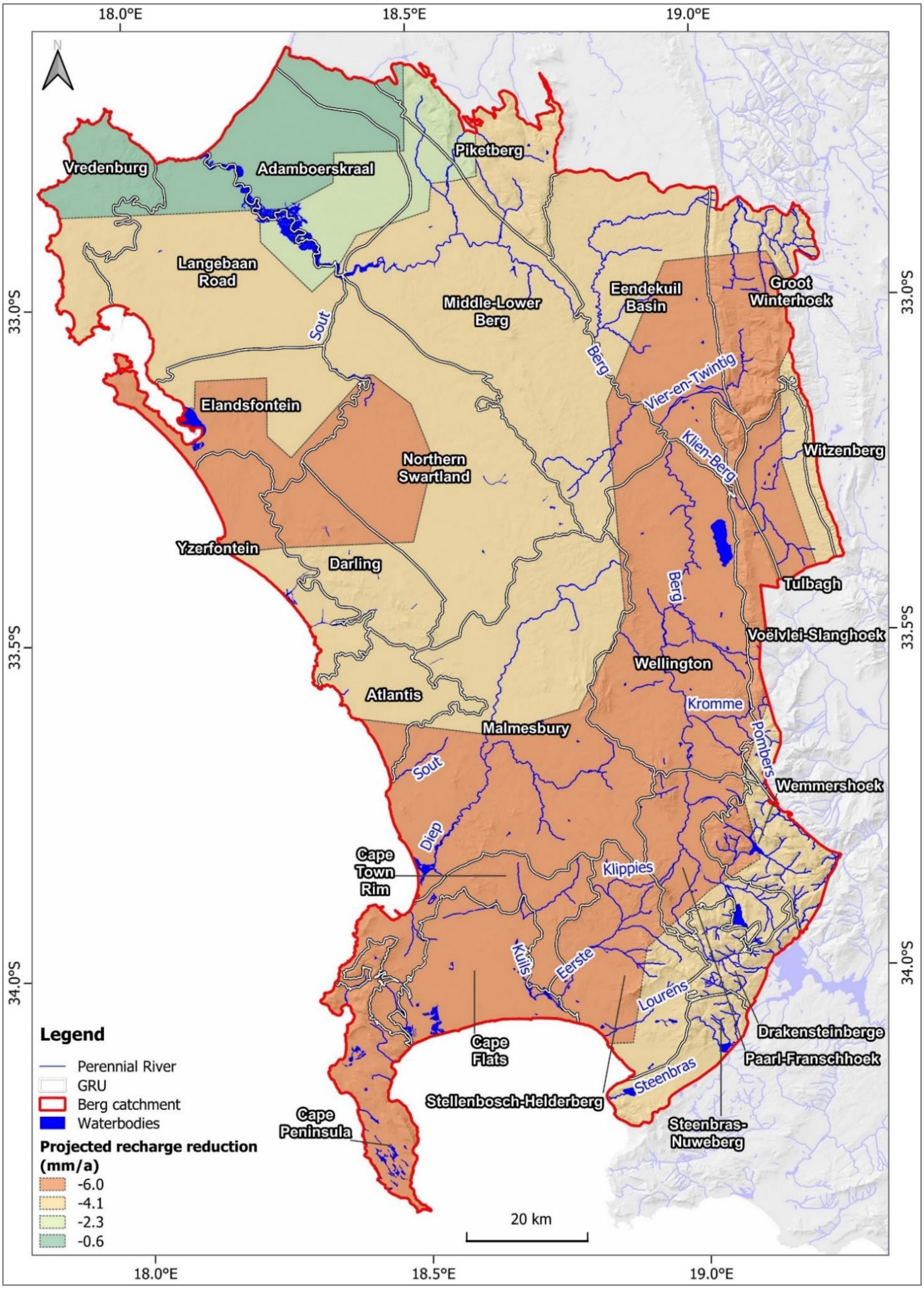

Figure 4-7 A map showing the reduction in recharge rates spatially within the Berg study area.

Table 4-9 Summary of recharge volumes and the projected recharge reduction per Groundwater Resource Unit (GRU).

GRU	2022 PS Recharge Volume (Mm^3/a)	Recharge Reduction Volume (Mm^3/a)	2050 Projected Recharge Volume (Mm^3/a)
Adamboerskraal	21.61	-0.81	20.80
Atlantis	22.74	-1.12	21.62
Cape Flats	41.25	-2.57	38.68
Cape Peninsula	10.99	-1.82	9.17
Cape Town Rim	18.60	-2.36	16.24
Darling	9.95	-1.95	8.00
Drakensteinberge	27.60	-0.75	26.85
Eendekuil Basin	21.88	-4.62	17.26
Elandsfontein	15.47	-2.32	13.15
Groot Winterhoek	22.50	-2.42	20.08
Langebaan Road	23.28	-3.11	20.17
Malmesbury	52.65	-8.32	44.33
Middle-Lower Berg	42.49	-5.70	36.79
Northern Swartland	31.85	-5.82	26.03
Paarl-Franschhoek	26.61	-2.03	24.58
Piketberg	20.33	-1.33	19.00
Steenbras-Nuweberg	58.76	-0.80	57.96
Stellenbosch-Helderberg	41.52	-3.07	38.45
Tulbagh	10.87	-1.55	9.32
Voelvlei-Slanghoek	14.10	-1.24	12.86
Vredenburg	7.43	-0.80	6.63
Wellington	39.49	-6.49	33.00
Wemmershoek	26.83	-1.24	25.59
Witzenberg	2.78	-0.18	2.60
Yzerfontein	9.20	-1.61	7.59
TOTAL	**620.78**	**-64.04**	**556.74**

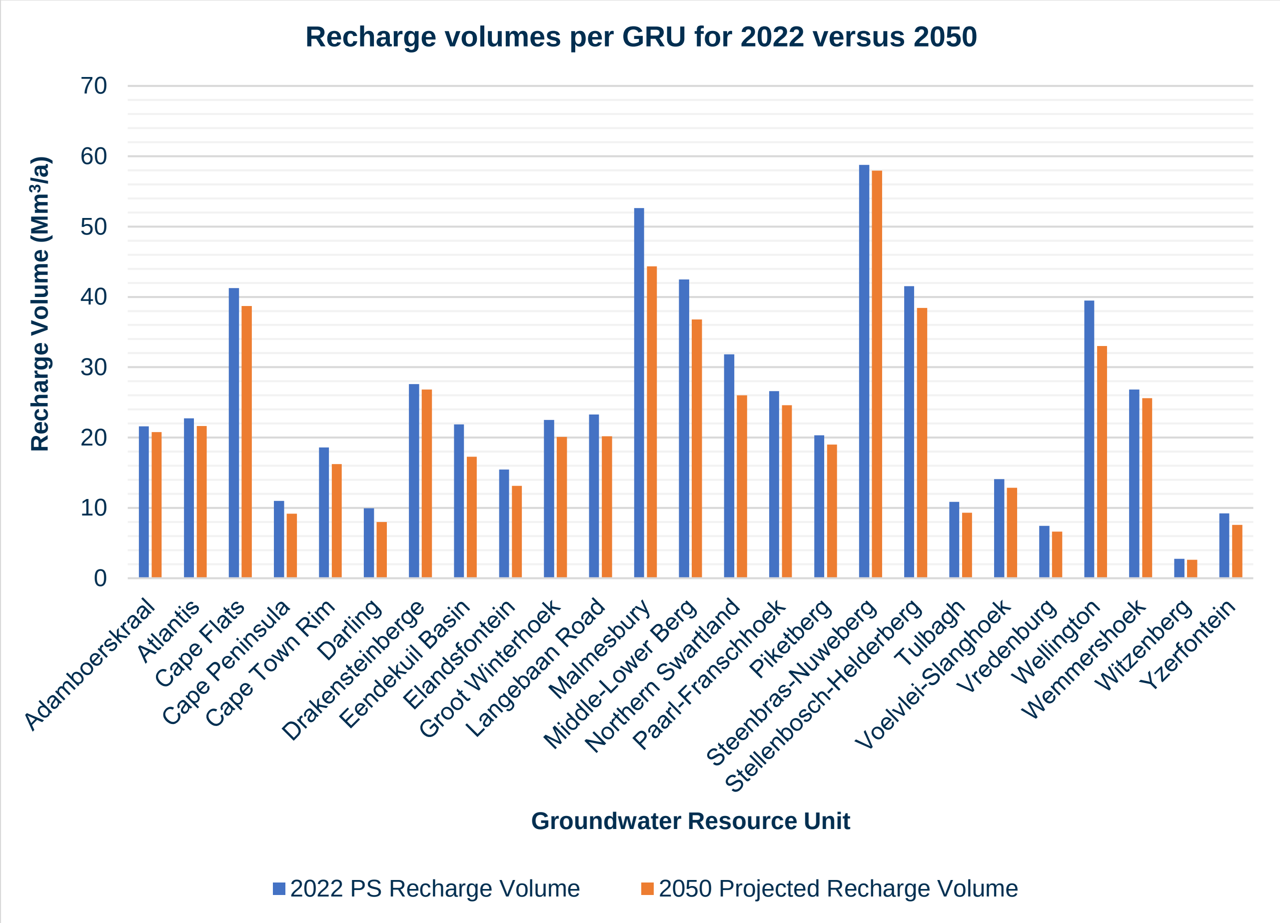

Figure 4-8 **Summary of Recharge volumes per Groundwater Resource Unit (GRU) for 2022 and 2050.**

Table 4-10 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 4: Climate Change.

GRU	Preliminary Groundwater Reserve (2022)								Sc 4 – Climate Change (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	20.80	6.00	0.01	6.01	14.79	2.13	12.66	0.61
Atlantis	22.74[39]	0.08	0.03	0.11	22.63	3.84[40]	18.79	0.83	21.62	0.08	0.03	0.11	21.51	3.84	17.67	0.82
Cape Flats	41.25[41]	0.51	0.70	1.21	40.04	12.00[42]	28.04	0.68	38.68	0.51	0.70	1.21	37.47	12.00	25.47	0.66
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	9.17	5.43	0.09	5.52	3.65	0.07	3.58	0.39
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	16.24	0.87	0.20	1.07	15.18	6.21	8.97	0.55
Darling	9.95	0.03	0.02	0.05	9.91	0.76[43]	9.15	0.92	8.00	0.03	0.02	0.05	7.95	0.76	7.19	0.90
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	26.85	2.88	0.00	2.88	23.97	0.05	23.92	0.89
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	17.26	6.95	0.09	7.04	10.21	4.85	5.36	0.31
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	13.15	6.39	0.01	6.40	6.76	1.09	5.67	0.43
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	20.08	0.77	0.02	0.79	19.30	1.39	17.91	0.89
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	20.17	5.52	0.02	5.54	14.63	8.59	6.04	0.30
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	44.33	1.18	0.34	1.52	42.80	14.75	28.05	0.63
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	36.79	11.15	0.09	11.24	25.55	2.23	23.32	0.63
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	26.03	0.20	0.05	0.25	25.78	1.79	23.99	0.92

[39] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).
[40] Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).
[41] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020)
[42] Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).
[43] The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.

GRU	Preliminary Groundwater Reserve (2022)								Sc 4 – Climate Change (2050)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	24.58	3.01	0.13	3.14	21.44	9.82	11.62	0.47
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	19.00	2.07	0.04	2.11	16.89	5.58	11.31	0.60
Steenbras- Nuweberg	58.76[44]	1.16	0.02	1.18	57.58	8.00[45]	49.58	0.84	57.96	1.16	0.02	1.18	56.78	8.00	48.78	0.84
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	38.45	2.34	0.24	2.58	35.87	8.81	27.06	0.70
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	9.32	1.28	0.02	1.30	8.02	3.78	4.24	0.45
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	12.86	1.62	0.01	1.63	11.23	0.13	11.10	0.86
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	6.63	0.00	0.01	0.01	6.62	1.16	5.46	0.82
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	33.00	6.75	0.24	6.99	26.01	4.48	21.53	0.65
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	25.59	3.59	0.00	3.59	21.99	0.81	21.18	0.83
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.60	0.18	0.00	0.18	2.42	0.08	2.34	0.90
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	7.59	0.02	0.01	0.03	7.56	0.26	7.30	0.96
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**556.74**	**69.98**	**2.35**	**72.33**	**484.41**	**102.66**	**381.75**	

[44] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[45] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

4.5. Scenario 5 - Invasive Alien Plants

As described in **Section 1.4**, the scenario examined the impacts of Invasive Alien Plants (IAPs) on groundwater recharge and allocable volumes in the Berg catchment. Estimations of current and future recharge reductions per vegetation biome were utilized to evaluate the effects of IAPs on groundwater recharge per GRU. In this scenario, it was assumed that clearing all IAPs would restore groundwater recharge rates to their pre-invasion levels (Sc 5a). Conversely, if left unchecked, IAPs would lead to a reduction in future recharge (Sc 5b), which was subtracted from the current recharge volume.

Table 4-11 presents a comparison of the current and future reduction volumes (modified after Van Wilgen, 2008) in groundwater recharge per unit area (km^2) for various biomes, as described by Low and Rebelo (1996), in the Berg catchment. The biomes included in the analysis are Fynbos, Grassland, Succulent Karoo, Nama Karoo, and Thicket (**Figure 4-9**). Among the biomes, Fynbos exhibits the highest current reduction volume (4.40 Mm^3/a) and future reduction volume (36.10 Mm^3/a) in groundwater recharge. It also has the highest current reduction rate per unit area (61.68 Mm^3/km^2/a) and future reduction rate per unit area (506.03 Mm^3/km^2/a). In contrast, the Grassland biome has the lowest reduction volumes and rates per unit area.

Table 4-11 Comparison of current and future reduction volumes in groundwater recharge per unit area for different biomes in the study area, after Van Wilgen (2008).

Biomes	Total area (km^2)	Current reduction volume in groundwater recharge (Mm^3/a)	Future reduction volume in groundwater recharge (Mm^3/a)	Current reduction rate per unit area (Mm^3/km^2/a)	Future reduction rate per unit area (Mm^3/km^2/a)
Fynbos	71340	4.40	36.10	61.68	506.03
Grassland	349190	0.00	6.40	0.00	18.33
Succulent Karoo	83100	0.20	3.20	2.41	38.51
Nama Karoo	360110	0.00	7.90	0.01	21.94
Thicket	402870	0.03	5.40	0.07	13.40

The methodology used to determine the natural (Sc 5a) and fully invaded (Sc 5b) recharge volumes per GRU involved two main steps. Firstly, the GRUs were allocated based on the distribution of biomes within each unit (**Appendix C**). This step facilitated the identification of the specific biomes present in each GRU. In the second step, the recharge reduction rates (after Van Wilgen, 2008) were applied to the corresponding biomes within each GRU. By matching the biomes present in each GRU with their respective recharge reduction rates, the current and future (2050) recharge reduction volumes were calculated for each GRU. These results are summarized in **Table 4-12**.

The results were used for the analysis of variations in the total allocable and still-allocable volumes of groundwater per GRU. These findings provided insights into the potential patterns in groundwater availability and allocation within the Berg Catchment. The total allocable volume, calculated as the difference between recharge and the groundwater Reserve, served as an encompassing measure of the available groundwater. On the other hand, the still-allocable volume represented the remaining portion of the total allocable volume that remained unallocated after accounting for groundwater use. To assess changes and trends in groundwater availability, for both the natural (Sc 5a; **Table 4-13**) and projected, fully invaded (Sc 5b; **Table 4-14**) values, the total allocable volumes and still-allocable volumes were calculated.

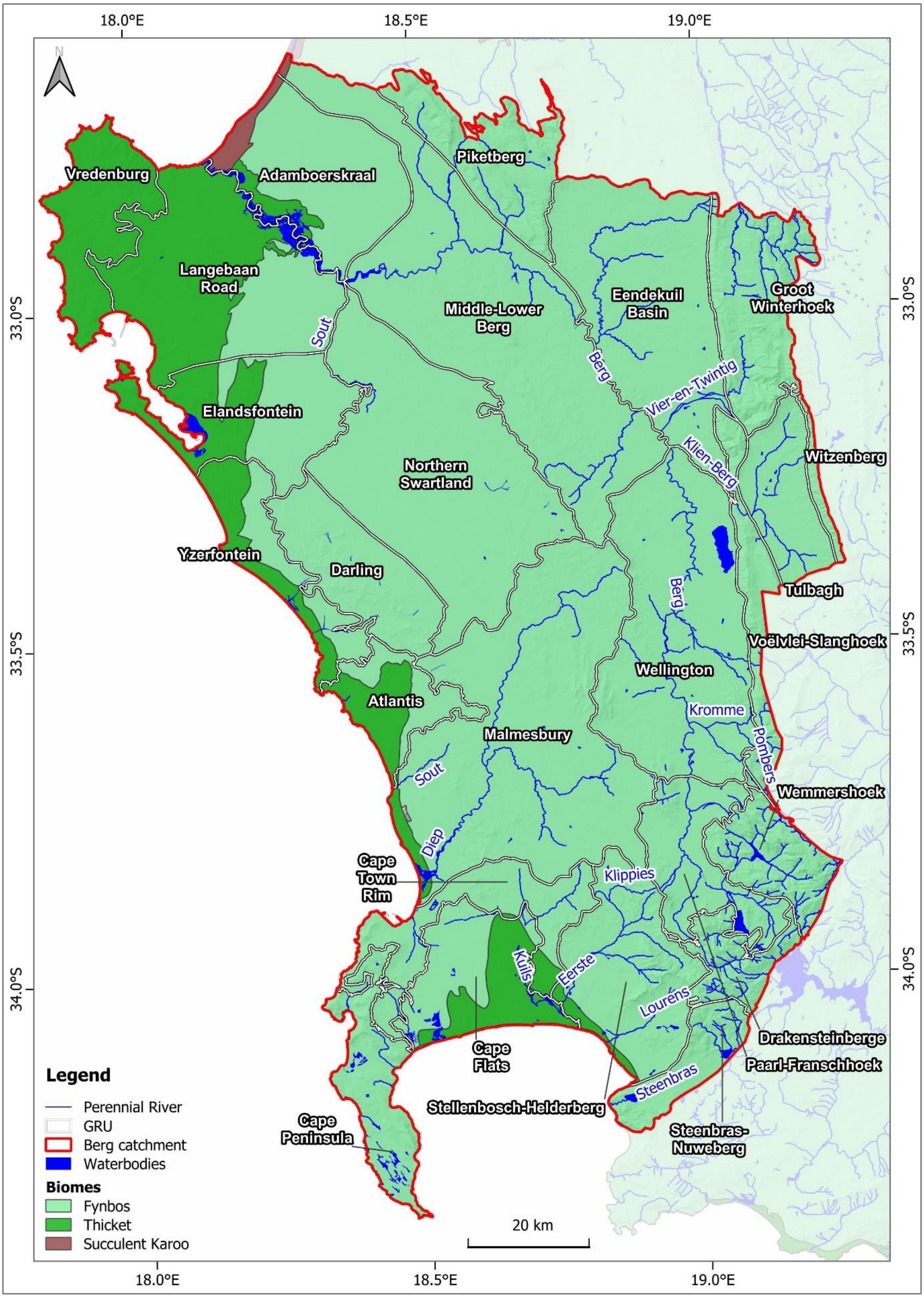

Figure 4-9 **Map of the distribution of biomes within each Groundwater Resource Unit in the Berg catchment.**

Table 4-12 Comparison of current and future reduction volumes in groundwater recharge per unit area for different biomes in the study area, after Van Wilgen (2008).

GRUs	Total Area (km^2)	Current Recharge (Mm^3/a)	IAP Cleared: Increased Recharge (Mm^3/a)	IAP Fully Invaded: Reduced Recharge (Mm^3/a)
Adamboerskraal	612.30	21.61	21.64	21.35
Atlantis	255.63	22.74	22.75	22.68
Cape Flats	422.91	41.25	41.26	41.13
Cape Peninsula	299.88	10.99	11.01	10.84
Cape Town Rim	392.57	18.60	18.62	18.42
Darling	408.82	9.95	9.98	9.74
Drakensteinberge	182.68	27.60	27.61	27.51
Eendekuil Basin	939.79	21.88	21.94	21.40
Elandsfontein	527.97	15.47	15.49	15.31
Groot Winterhoek	455.24	22.50	22.53	22.27
Langebaan Road	902.20	23.28	23.30	23.13
Malmesbury	1,601.25	52.65	52.75	51.86
Middle-Lower Berg	1,485.93	42.49	42.58	41.74
Northern Swartland	1,257.65	31.85	31.93	31.21
Paarl-Franschhoek	370.27	26.61	26.63	26.42
Piketberg	387.89	20.33	20.35	20.13
Steenbras- Nuweberg	194.82	58.76	58.77	58.66
Stellenbosch-Helderberg	569.34	41.52	41.55	41.25
Tulbagh	291.38	10.87	10.89	10.72
Voëlvlei-Slanghoek	220.55	14.10	14.11	13.99
Vredenburg	375.06	7.43	7.43	7.42
Wellington	1,086.98	39.49	39.56	38.94
Wemmershoek	268.12	26.83	26.85	26.69
Witzenberg	43.66	2.78	2.78	2.76
Yzerfontein	317.83	9.20	9.21	9.12
TOTAL	**13,870.70**	**620.78**	**621.52**	**614.71**

Table 4-12 highlights the potential impact on groundwater recharge based on two scenarios. In Sc 5a, if IAPs are cleared, groundwater recharge would increase by 0.74 Mm^3/a. This suggests that taking necessary measures to clear obstacles and improve conditions can enhance the replenishment of groundwater resources, potentially benefiting water availability in the Berg catchment. However, in Sc 5b, if the situation is left unchecked and IAPs are allowed to reach their full potential, there would be a significant decrease in groundwater recharge. The results indicate a reduction of 6.06 Mm^3/a, which signifies a substantial decline in the amount of water replenishing the groundwater resources annually. This scenario underscores the importance of implementing sustainable practices and conservation efforts to protect and preserve groundwater resources.

Considering that the changes in recharge volumes only increased by 0.74 Mm^3/a from 2022 to 2050, assuming that clearing all IAPs would restore groundwater recharge rates to their pre-invasion levels (Sc 5a), the Allocation Stress Indices (refer to **Table 4-1**) remained relatively consistent between the two periods (**Table 4-13**). This consistency is attributed to the clearing of IAPs and the resulting increase in recharge being fairly uniform across all GRUs. However, in scenario Sc 5b, the growth of IAPs, if left unchecked, would lead to a reduction in future recharge of 6.07 Mm^3/a from 2022 to 2050 (**Table 4-14**).

Table 4-13 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 5a: Invasive Alien Plants (Cleared).

GRU	Preliminary Groundwater Reserve (2022)								Sc 5a – Invasive Alien Plants (Cleared)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	21.64	6.00	0.01	6.01	15.63	2.13	13.50	0.62
Atlantis	22.74[46]	0.08	0.03	0.11	22.63	3.84[47]	18.79	0.83	22.75	0.08	0.03	0.11	22.64	3.84	18.80	0.83
Cape Flats	41.25[48]	0.51	0.70	1.21	40.04	12.00[49]	28.04	0.68	41.26	0.51	0.70	1.21	40.05	12.00	28.05	0.68
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	11.01	5.43	0.09	5.52	5.49	0.07	5.42	0.49
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	18.62	0.87	0.20	1.07	17.56	6.21	11.35	0.61
Darling	9.95	0.03	0.02	0.05	9.91	0.76[50]	9.15	0.92	9.98	0.03	0.02	0.05	9.93	0.76	9.17	0.92
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	27.61	2.88	0.00	2.88	24.73	0.05	24.68	0.89
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	21.94	6.95	0.09	7.04	14.90	4.85	10.05	0.46
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	15.49	6.39	0.01	6.40	9.09	1.09	8.00	0.52
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	22.53	0.77	0.02	0.79	21.74	1.39	20.35	0.90
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	23.30	5.52	0.02	5.54	17.76	8.59	9.17	0.39
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	52.75	1.18	0.34	1.52	51.22	14.75	36.47	0.69
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	42.58	11.15	0.09	11.24	31.35	2.23	29.12	0.68
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	31.93	0.20	0.05	0.25	31.68	1.79	29.89	0.94
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	26.63	3.01	0.13	3.14	23.50	9.82	13.68	0.51

46 Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).
47 Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).
48 Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020)
49 Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).
50 The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.

GRU	Preliminary Groundwater Reserve (2022)								Sc 5a – Invasive Alien Plants (Cleared)							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	20.35	2.07	0.04	2.11	18.25	5.58	12.67	0.62
Steenbras- Nuweberg	58.76[51]	1.16	0.02	1.18	57.58	8.00[52]	49.58	0.84	58.77	1.16	0.02	1.18	57.60	8.00	49.60	0.84
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	41.55	2.34	0.24	2.58	38.97	8.81	30.16	0.73
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	10.89	1.28	0.02	1.30	9.58	3.78	5.80	0.53
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	14.11	1.62	0.01	1.63	12.49	0.13	12.36	0.88
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	39.56	6.75	0.24	6.99	32.57	4.48	28.09	0.71
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	26.85	3.59	0.00	3.59	23.25	0.81	22.44	0.84
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	9.21	0.02	0.01	0.03	9.18	0.26	8.92	0.97
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**621.52**	**69.98**	**2.35**	**72.33**	**549.19**	**102.66**	**446.53**	

[51] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[52] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

Table 4-14 Table comparing preliminary groundwater Reserve and necessary parameters for calculating allocable volume per GRU with those calculated in Scenario 5b: Invasive Alien Plants (2050).

GRU	Preliminary Groundwater Reserve (2022)								Scenario 5b - Invasive Alien Plants (2050).							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	21.35	6.00	0.01	6.01	15.35	2.13	13.22	0.62
Atlantis	22.74[53]	0.08	0.03	0.11	22.63	3.84[54]	18.79	0.83	22.68	0.08	0.03	0.11	22.57	3.48	18.73	0.83
Cape Flats	41.25[55]	0.51	0.70	1.21	40.04	12.00[56]	28.04	0.68	41.13	0.51	0.70	1.21	39.92	12.00	27.92	0.68
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	10.84	5.43	0.09	5.52	5.32	0.07	5.25	0.48
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	18.42	0.87	0.20	1.07	17.35	6.21	11.14	0.60
Darling	9.95	0.03	0.02	0.05	9.91	0.76[57]	9.15	0.92	9.74	0.03	0.02	0.05	9.70	0.76	8.94	0.92
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	27.51	2.88	0.00	2.88	24.62	0.05	24.57	0.89
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	21.40	6.95	0.09	7.04	14.36	4.85	9.51	0.44
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	15.31	6.39	0.01	6.40	8.92	1.09	7.83	0.51
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	22.27	0.77	0.02	0.79	21.48	1.39	20.09	0.90
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	23.13	5.52	0.02	5.54	17.59	8.59	9.00	0.39
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	51.86	1.18	0.34	1.52	50.34	14.75	35.59	0.69
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	41.74	11.15	0.09	11.24	30.51	2.23	28.28	0.68
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	31.21	0.20	0.05	0.25	30.97	1.79	29.18	0.93
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	26.42	3.01	0.13	3.14	23.29	9.82	13.47	0.51

[53] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).
[54] Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).
[55] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).
[56] Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).
[57] The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.

GRU	Preliminary Groundwater Reserve (2022)								Scenario 5b - Invasive Alien Plants (2050).							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	20.13	2.07	0.04	2.11	18.03	5.58	12.45	0.62
Steenbras- Nuweberg	58.76[58]	1.16	0.02	1.18	57.58	8.00[59]	49.58	0.84	58.66	1.16	0.02	1.18	57.49	8.00	49.49	0.84
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	41.25	2.34	0.24	2.58	38.67	8.81	29.86	0.72
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	10.72	1.28	0.02	1.30	9.42	3.78	5.64	0.53
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	13.99	1.62	0.01	1.63	12.36	0.13	12.23	0.87
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	7.42	0.00	0.01	0.01	7.41	1.16	6.25	0.84
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	38.94	6.75	0.24	6.99	31.95	4.48	27.47	0.71
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	26.69	3.59	0.00	3.59	23.10	0.81	22.29	0.84
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.76	0.18	0.00	0.18	2.58	0.08	2.50	0.91
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	9.12	0.02	0.01	0.03	9.09	0.26	8.83	0.97
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**101.60**	**446.85**		**614.71**	**69.98**	**2.35**	**72.33**	**542.38**	**102.66**	**439.72**	

[58] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[59] *Includes city municipal abstraction of 8 Mm3/a in development (phase 1) as per NWA Section 21(a).*

4.6. Scenario 6a - Combination Scenarios - Worst Case

As described in **Section 1.4**, the combination scenario aimed to comprehensively assess the interplay of multiple factors and their impact on the groundwater Reserve, as well as the remaining volume available for allocation after satisfying the Reserve requirements and accounting for groundwater use (refer to equations in **Section 4**). By integrating the findings from preceding scenarios that explored projected population growth (Sc 1), sectoral growth (Sc 2), ongoing groundwater development initiatives (Sc 3), the influence of climate change (Sc 4), and the absence of clearing alien vegetation (Sc 5b), this scenario provided a worst-case analysis of the challenges and implications for sustainable groundwater management in the Berg catchment.

To enhance our understanding of future groundwater dynamics in the Berg catchment, this combination scenario analyzed various parameters affected by the predictive scenarios. The analysis focused on Recharge, the BHN Reserve, the Groundwater Reserve, and Groundwater Use, which directly influenced the Total Allocable Volume and Still Allocable Volumes of individual GRUs. By comparing projected volumes in 2050 with the PS baseline values, this analysis offered valuable insights into the cumulative effects of identified factors, with volume differences added to the PS volumes to update each parameter.

The scenario revealed significant findings regarding recharge, the BHN Reserve, and water use. Recharge experienced a notable decrease of 70.11 Mm³/a, primarily due to climate change under increasingly hotter climatic conditions (**Section 4.4**), and the absence of clearing IAPs (**Section 4.5**), which assumed their unchecked growth would lead to reduced future groundwater recharge. This decline in recharge had substantial implications for the Total Allocable Volumes.

The groundwater component of the BHN Reserve increased by 1.92 Mm³/a based on projected population growth rates (**Section 4.1**), resulting in a corresponding increases to the Groundwater Reserve (refer to equations in **Section 4**).

Groundwater use demonstrated a significant increase of 78.40 Mm³/a driven by sectoral growth (**Section 4.2**) and anticipated implementation of groundwater development initiatives (**Section 4.3**). Consequently, the Still Allocable Volume, representing the remaining volume available for allocation after meeting Reserve requirements and accounting for groundwater use, decreased by 150.43 Mm³/a. This reduction was influenced by both the decline in Total Allocable Volume (72.03 Mm³/a) and increase of future groundwater use.

Regarding the Allocation Category, several GRUs experienced categorization changes compared to the categories based on their PS (**Table 4-15, Table 4-16** and **Figure 4-10**). The Cape Flats, Eendekuil Basin, Cape Town Rim, Eendekuil, Langebaan Road, Malmesbury, Piketberg, Steenbras-Nuweberg, Vredenberg, and Yzerfontien GRUs dropped one category lower. Among them, the Cape Flats, Malmesbury, and Steenbras-Nuweberg, GRUs exhibited the most substantial differences in their Still Allocable Volumes compared to the PS volumes, with respective decreases of 14.29 Mm³/a, 19.77 Mm³/a and 17.43 Mm³/a.

Additionally, the Elandsfontein and Paarl-Franschhoek GRUs dropped two categories lower, from a moderately stressed "C" to a potentially highly stressed "E" category. The Yzerfontein GRU also dropped two categories lower, from an unstressed "A" to a moderately stressed "C" category (see **Figure 4-11**).

Notably, the Tulbagh GRU transitioned from a moderately stressed "C" to a potentially critically stressed "F" category, experiencing a decrease in Still Allocable Volume of 4.60 Mm³/a, which accounted for approximately ~16% of the PS Still Allocable Volume (see **Figure 4-11**).

Table 4-15 Summary of the PS and 2050 (after Sc 6a) Still Allocable Volumes (including volume differences) and associated Allocation Stress Index per GRU. GRUs with Groundwater Dependent Ecosystems (GEDs) are indicated with red text.

GRU	PS (2022) Still Allocable Volume (Mm³/a)	PS (2022) Allocation Stress Index	Sc 6a (2050) Still Allocable Volume (Mm³/a)	Sc 6a (2050) Allocation Stress Index	Sc 6a vs PS 2022 Still Allocable Volume Difference (Mm³/a)
Adamboerskraal	13.47	0.62	10.84	0.53	-2.63
Atlantis	18.79	0.83	18.12	0.84	-0.67
Cape Flats	28.04	0.68	13.75	0.36	-14.29
Cape Peninsula	5.41	0.49	3.28	0.36	-2.12
Cape Town Rim	11.33	0.61	6.12	0.38	-5.21
Darling	9.15	0.92	6.33	0.81	-2.81
Drakensteinberge	24.67	0.89	22.67	0.85	-2.00
Eendekuil Basin	9.99	0.46	3.11	0.19	-6.88
Elandsfontein	7.99	0.52	3.89	0.30	-4.09
Groot Winterhoek	20.32	0.90	15.78	0.79	-4.55
Langebaan Road	9.15	0.39	3.38	0.17	-5.77
Malmesbury	36.38	0.69	16.61	0.38	-19.77
Middle-Lower Berg	29.03	0.68	19.64	0.54	-9.39
Northern Swartland	29.81	0.94	22.19	0.87	-7.63
Paarl-Franschhoek	13.65	0.51	5.67	0.23	-7.98
Piketberg	12.64	0.62	6.87	0.37	-5.78
Steenbras- Nuweberg	49.58	0.84	32.15	0.56	-17.43
Stellenbosch-Helderberg	30.13	0.73	24.09	0.63	-6.04
Tulbagh	5.79	0.53	1.19	0.13	-4.60
Voëlvlei-Slanghoek	12.34	0.88	10.80	0.85	-1.54
Vredenburg	6.26	0.84	4.64	0.70	-1.62
Wellington	28.03	0.71	16.52	0.51	-11.51
Wemmershoek	22.43	0.84	20.30	0.80	-2.13
Witzenberg	2.52	0.91	2.23	0.87	-0.28
Yzerfontein	8.91	0.97	5.21	0.69	-3.70
TOTAL	**445.79**		**307.93**		**-137.87**

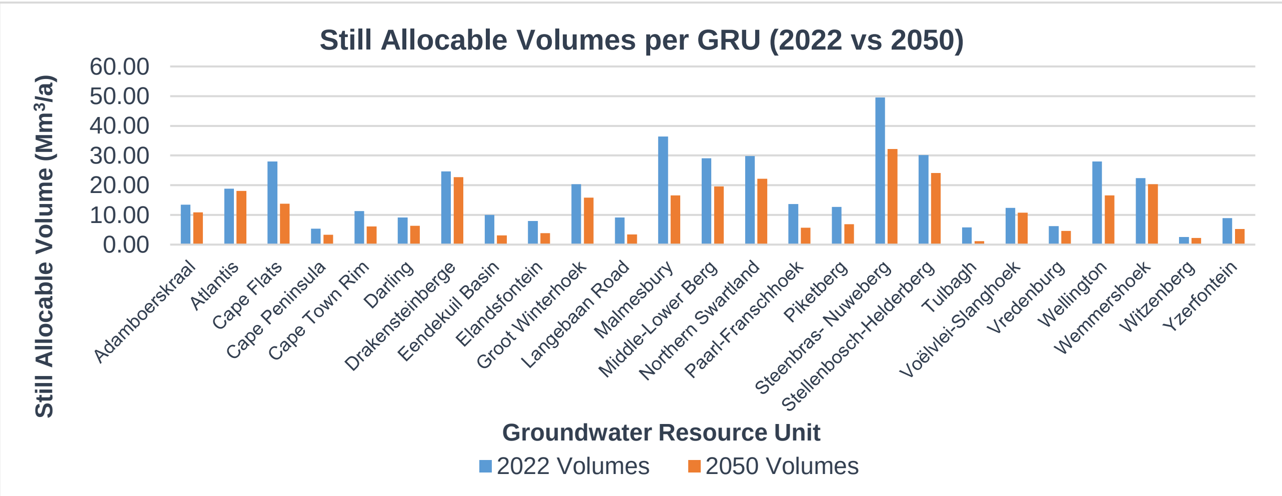

Figure 4-10 Summary graph of the PS and 2050 Still Allocable Volumes (after Sc 6a Combination Scenario – Worst Case) per GRU.

Table 4-16 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 6a: Combination Scenario – Worst Case. GRUs with Groundwater Dependent Ecosystems (GEDs) are indicated with red text.

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Worst Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	20.54	6.00	0.01	6.01	14.53	3.69	10.84	0.53
Atlantis	22.74[60]	0.08	0.03	0.11	22.63	3.84[61]	18.79	0.83	21.56	0.08	0.05	0.13	21.43	3.31	18.12	0.84
Cape Flats	41.25[62]	0.51	0.70	1.21	40.04	12.00[63]	28.04	0.68	38.57	0.51	1.29	1.80	36.77	23.02	13.75	0.36
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	9.02	5.43	0.16	5.59	3.43	0.15	3.28	0.36
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	16.06	0.87	0.36	1.23	14.83	8.71	6.12	0.38
Darling	9.95	0.03	0.02	0.05	9.91	0.76[64]	9.15	0.92	7.79	0.03	0.03	0.06	7.73	1.40	6.33	0.81
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	26.76	2.88	0.01	2.89	23.87	1.21	22.67	0.85
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	16.78	6.95	0.16	7.11	9.67	6.57	3.11	0.19
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	13.00	6.39	0.01	6.40	6.60	2.70	3.89	0.30
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	19.85	0.77	0.03	0.80	19.05	3.27	15.78	0.79
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	20.02	5.52	0.03	5.55	14.47	11.09	3.38	0.17
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	43.54	1.18	0.64	1.82	41.72	25.12	16.61	0.38
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	36.04	11.15	0.16	11.31	24.73	5.09	19.64	0.54

[60] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).
[61] Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).
[62] Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).
[63] Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).
[64] The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Worst Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	25.39	0.20	0.09	0.29	25.10	2.92	22.19	0.87
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	24.39	3.01	0.21	3.22	21.17	15.50	5.67	0.23
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	18.80	2.07	0.06	2.13	16.67	9.80	6.87	0.37
Steenbras- Nuweberg	58.76[65]	1.16	0.02	1.18	57.58	8.00[66]	49.58	0.84	57.86	1.16	0.02	1.18	56.68	24.52	32.15	0.56
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	38.18	2.34	0.46	2.80	35.38	11.30	24.09	0.63
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	9.17	1.28	0.05	1.33	7.85	6.66	1.19	0.13
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	12.74	1.62	0.01	1.63	11.11	0.31	10.80	0.85
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	6.63	0.00	0.02	0.02	6.60	1.97	4.64	0.70
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	32.45	6.75	0.39	7.14	25.31	8.79	16.52	0.51
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	25.45	3.59	0.00	3.59	21.86	1.56	20.30	0.80
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.58	0.18	0.00	0.18	2.39	0.16	2.23	0.87
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	7.50	0.02	0.02	0.04	7.47	2.26	5.21	0.69
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**550.67**	**69.98**	**4.27**	**74.25**	**476.42**	**181.06**	**295.36**	

[65] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[66] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

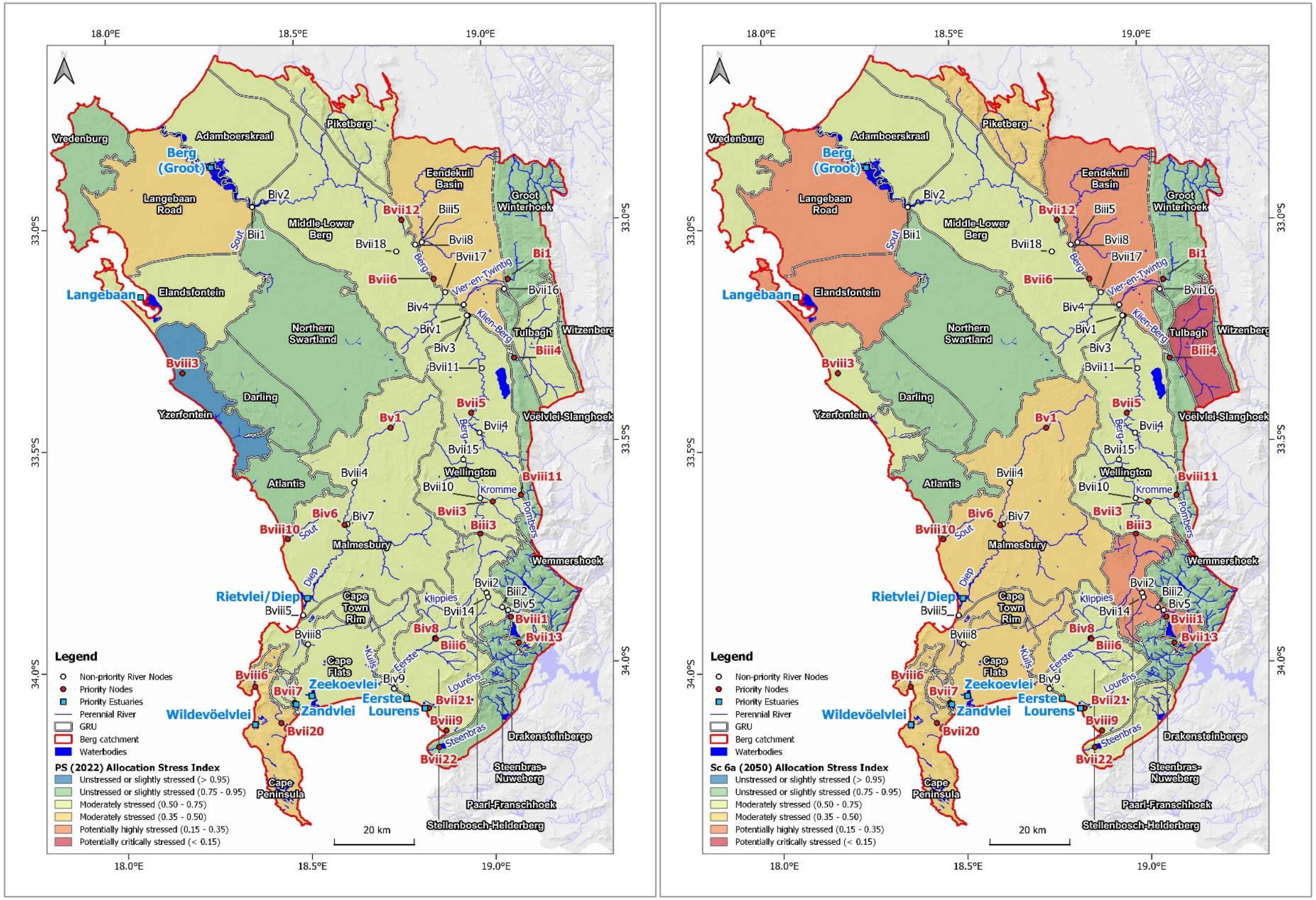

Figure 4-11 **Comparative overview maps of Present Status (2022) Allocation Stress Index and Sc6a (Worst Case) projected volumes (2050) Allocation Stress Index per GRU.**

4.7. Scenario 6b – Combination Scenarios – Most-likely

The objective of this combination scenario, as outlined in **Section 1.4**, was to evaluate the interaction between various factors and their impact on the groundwater Reserve, as well as the available volume for allocation after meeting Reserve requirements and considering groundwater use (refer to equations in **Section 4**). By integrating the findings from previous scenarios (similar to that of **Section 4.6**: Combination Scenario 6a – Worst Case) that examined projected population growth (Sc 1), sectoral growth (Sc 2), ongoing groundwater development initiatives (Sc 3), the effects of climate change (Sc 4). This scenario, however, included the clearing of alien vegetation (Sc 5a) which was assumed to restore groundwater recharge rates to their pre-invasion levels (Sc 5a), and offered an analysis of a potential most likely-case scenario in the Berg catchment.

The primary focus of the analysis was on the increase in Recharge resulting from the removal of all IAP, as discussed in **Section 4.5**. This increase had direct implications for the Groundwater Reserve, which in turn influenced the Total Allocable Volume and Still Allocable Volumes of individual GRUs (refer to equations in **Section 4**). By comparing projected volumes in 2050 with the baseline values from the PS, the analysis provided valuable insights into the cumulative effects of the identified factors. Additionally, volume differences were incorporated into the PS volumes to update each parameter accordingly.

The scenario showed significant findings regarding recharge, the BHN Reserve, and water use. Recharge experienced a notable decrease of 63.31 Mm³/a, primarily attributed to climate change under increasingly hotter climatic conditions (accounting for a decrease of 64.04 Mm³/a; see **Section 4.4**), as well as the clearing of IAPs (resulting in a recharge increase of 0.74 Mm³/a; see **Section 4.5**).

The groundwater component of the BHN Reserve also showed an increase of 1.92 Mm³/a, aligning with projected population growth rates (**Section 4.1**). This increase consequently led to a corresponding expansion of the Groundwater Reserve (refer to equations in **Section 4**).

Groundwater use revealed a significant rise of 78.40 Mm³/a, primarily driven by sectoral growth (**Section 4.2**) and the anticipated implementation of groundwater development initiatives (**Section 4.3**). As a result, the Still Allocable Volume, representing the remaining volume available for allocation after fulfilling Reserve requirements and accounting for groundwater use, experienced a decrease of 143.63 Mm³/a. This reduction was influenced by both the decline in the Total Allocable Volume (65.23 Mm³/a) and the anticipated future groundwater use.

Regarding the Allocation Category, several GRUs underwent changes in categorization compared to the PS categories (refer to **Table 4-17, Table 4-18** and **Figure 4-12**). The Cape Flats, Cape Town Rim, Eendekuil Basin, Langebaan Road, Malmesbury, Piketberg, Steenbras-Nuweberg, Vredenberg and Yzerfontien GRUs all dropped one category lower, exhibiting the most significant deviations in their Still Allocable Volumes when compared to the PS volumes (see Figure **4-13**).

Furthermore, the Elandsfontein, Paarl-Franschhoek and Piketberg GRUs experienced a downward shift of two categories, moving from a moderately stressed "C" to a highly stressed "E" category. The Yzerfontien GRU also dropped two categories, transitioning from an unstressed "A" to a moderately stressed "C" category. Notably, the Tulbagh GRU transitioned from a moderately stressed "C" to a potentially critically stressed "F" category, resulting in a decrease in Still Allocable Volume of 4.43 Mm³/a, which accounted for approximately ~17% of the PS Still Allocable Volume (see Figure **4-13**).

Table 4-17 Summary of the PS and 2050 (after Sc 6b) Still Allocable Volumes (including volume differences) and associated Allocation Stress Index per GRU. GRUs with Groundwater Dependent Ecosystems (GEDs) are indicated with red text.

GRU	PS (2022) Still Allocable Volume (Mm³/a)	PS (2022) Allocation Stress Index	Sc 6b (2050) Still Allocable Volume (Mm³/a)	Sc 6b (2050) Allocation Stress Index	Sc 6b vs PS 2022 Still Allocable Volume Difference (Mm³/a)
Adamboerskraal	13.47	0.62	11.13	0.53	-2.34
Atlantis	18.79	0.83	18.19	0.84	-0.60
Cape Flats	28.04	0.68	13.88	0.36	-14.16
Cape Peninsula	5.41	0.49	3.45	0.38	-1.95
Cape Town Rim	11.33	0.61	6.32	0.39	-5.00
Darling	9.15	0.92	6.56	0.82	-2.58
Drakensteinberge	24.67	0.89	22.77	0.85	-1.90
Eendekuil Basin	9.99	0.46	3.64	0.21	-6.35
Elandsfontein	7.99	0.52	4.07	0.31	-3.92
Groot Winterhoek	20.32	0.90	16.04	0.80	-4.29
Langebaan Road	9.15	0.39	3.55	0.18	-5.61
Malmesbury	36.38	0.69	17.49	0.39	-18.88
Middle-Lower Berg	29.03	0.68	20.48	0.56	-8.54
Northern Swartland	29.81	0.94	22.90	0.88	-6.91
Paarl-Franschhoek	13.65	0.51	5.88	0.24	-7.77
Piketberg	12.64	0.62	7.09	0.37	-5.56
Steenbras- Nuweberg	49.58	0.84	32.26	0.56	-17.32
Stellenbosch-Helderberg	30.13	0.73	24.39	0.63	-5.73
Tulbagh	5.79	0.53	1.35	0.14	-4.43
Voëlvlei-Slanghoek	12.34	0.88	10.93	0.85	-1.42
Vredenburg	6.26	0.84	4.64	0.70	-1.62
Wellington	28.03	0.71	17.13	0.52	-10.89
Wemmershoek	22.43	0.84	20.45	0.80	-1.98
Witzenberg	2.52	0.91	2.26	0.87	-0.26
Yzerfontein	8.91	0.97	5.30	0.70	-3.61
TOTAL	**445.79**		**11.13**		**-2.34**

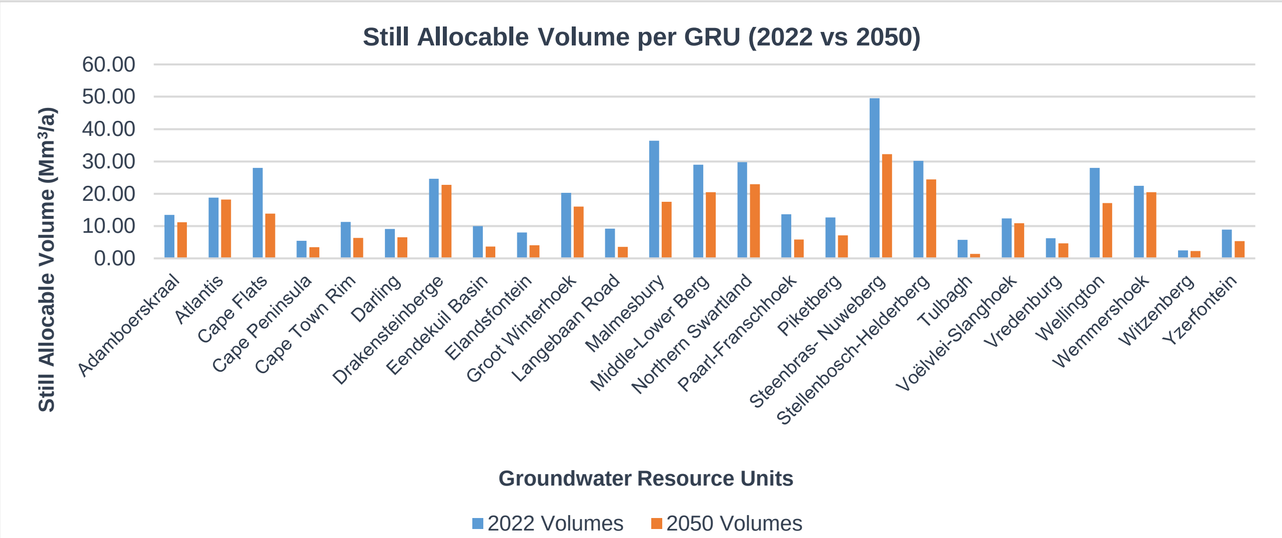

Figure 4-12 Summary graph of the PS and 2050 Still Allocable Volumes (after Sc 6b Combination Scenario – Most Likely Case) per GRU.

Table 4-18 Comparative overview of present status (2022) and projected volumes (2050) pertaining to groundwater Reserve, recharge, groundwater use, and allocable volumes to generate an Allocation Stress Index for Scenario 6b: Combination Scenario – Most-Likely Case. GRUs with Groundwater Dependent Ecosystems (GEDs) are indicated with red text.

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Most-Likely Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Adamboerskraal	21.61	6.00	0.01	6.01	15.60	2.13	13.47	0.62	20.83	6.00	0.01	6.01	14.81	3.69	11.13	0.53
Atlantis	22.74[67]	0.08	0.03	0.11	22.63	3.84[68]	18.79	0.83	21.63	0.08	0.05	0.13	21.50	3.31	18.19	0.84
Cape Flats	41.25[69]	0.51	0.70	1.21	40.04	12.00[70]	28.04	0.68	38.70	0.51	1.29	1.80	36.90	23.02	13.88	0.36
Cape Peninsula	10.99	5.43	0.09	5.52	5.48	0.07	5.41	0.49	9.19	5.43	0.16	5.59	3.60	0.15	3.45	0.38
Cape Town Rim	18.6	0.87	0.20	1.07	17.54	6.21	11.33	0.61	16.26	0.87	0.36	1.23	15.03	8.71	6.32	0.39
Darling	9.95	0.03	0.02	0.05	9.91	0.76[71]	9.15	0.92	8.02	0.03	0.03	0.06	7.97	1.40	6.56	0.82
Drakensteinberge	27.6	2.88	0.00	2.88	24.72	0.05	24.67	0.89	26.86	2.88	0.01	2.89	23.97	1.21	22.77	0.85
Eendekuil Basin	21.88	6.95	0.09	7.04	14.84	4.85	9.99	0.46	17.31	6.95	0.16	7.11	10.21	6.57	3.64	0.21
Elandsfontein	15.47	6.39	0.01	6.40	9.08	1.09	7.99	0.52	13.17	6.39	0.01	6.40	6.77	2.70	4.07	0.31
Groot Winterhoek	22.5	0.77	0.02	0.79	21.71	1.39	20.32	0.90	20.11	0.77	0.03	0.80	19.31	3.27	16.04	0.80
Langebaan Road	23.28	5.52	0.02	5.54	17.74	8.59	9.15	0.39	20.18	5.52	0.03	5.55	14.63	11.09	3.55	0.18
Malmesbury	52.65	1.18	0.34	1.52	51.13	14.75	36.38	0.69	44.42	1.18	0.64	1.82	42.61	25.12	17.49	0.39
Middle-Lower Berg	42.49	11.15	0.09	11.24	31.26	2.23	29.03	0.68	36.88	11.15	0.16	11.31	25.57	5.09	20.48	0.56
Northern Swartland	31.85	0.20	0.05	0.25	31.60	1.79	29.81	0.94	26.11	0.20	0.09	0.29	25.82	2.92	22.90	0.88

[67] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2018).*
[68] *Includes city municipal abstraction of 5 Mm³/a as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 2.92 Mm³/a (as a negative water use).*
[69] *Rainfall recharge value is from a model-based calibrated recharge estimation (after CoCT, 2020).*
[70] *Includes city municipal abstraction of 20 Mm³/a in development as per NWA Section 21(a). The total volume includes Managed Aquifer Recharge (as per NWA Section 21(e) water use licence) of up to 14.6 Mm³/a (as a negative water use).*
[71] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 Mm³/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

GRU	Preliminary Groundwater Reserve (2022)								Combination Scenario – Most-Likely Case							
	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index	Recharge (Mm³/a)	EWR Reserve (Mm³/a)	BHN Reserve (Mm³/a)	GW Reserve (Mm³/a)	Total Allocable Volume (Mm³/a)	Water Use (Mm³/a)	Still Allocable (Mm³/a)	Allocable Stress Index
Paarl-Franschhoek	26.61	3.01	0.13	3.14	23.47	9.82	13.65	0.51	24.60	3.01	0.21	3.22	21.38	15.50	5.88	0.24
Piketberg	20.33	2.07	0.04	2.11	18.22	5.58	12.64	0.62	19.02	2.07	0.06	2.13	16.89	9.80	7.09	0.37
Steenbras- Nuweberg	58.76[72]	1.16	0.02	1.18	57.58	8.00[73]	49.58	0.84	57.97	1.16	0.02	1.18	56.79	24.52	32.26	0.56
Stellenbosch-Helderberg	41.52	2.34	0.24	2.58	38.94	8.81	30.13	0.73	38.49	2.34	0.46	2.80	35.69	11.30	24.39	0.63
Tulbagh	10.87	1.28	0.02	1.30	9.57	3.78	5.79	0.53	9.34	1.28	0.05	1.33	8.01	6.66	1.35	0.14
Voëlvlei-Slanghoek	14.1	1.62	0.01	1.63	12.47	0.13	12.34	0.88	12.87	1.62	0.01	1.63	11.24	0.31	10.93	0.85
Vredenburg	7.43	0.00	0.01	0.01	7.42	1.16	6.26	0.84	6.63	0.00	0.02	0.02	6.61	1.97	4.64	0.70
Wellington	39.49	6.75	0.24	6.99	32.51	4.48	28.03	0.71	33.07	6.75	0.39	7.14	25.92	8.79	17.13	0.52
Wemmershoek	26.83	3.59	0.00	3.59	23.24	0.81	22.43	0.84	25.60	3.59	0.00	3.59	22.01	1.56	20.45	0.80
Witzenberg	2.78	0.18	0.00	0.18	2.60	0.08	2.52	0.91	2.60	0.18	0.00	0.18	2.42	0.16	2.26	0.87
Yzerfontein	9.2	0.02	0.01	0.03	9.17	0.26	8.91	0.97	7.60	0.02	0.02	0.04	7.56	2.26	5.30	0.70
TOTAL	**620.78**	**69.98**	**2.35**	**72.33**	**548.45**	**102.66**	**445.79**		**557.47**	**69.98**	**4.27**	**74.25**	**483.23**	**181.06**	**302.16**	

[72] *Rainfall recharge value is from the first order GRAII Spatial Distribution (modified after CoCT, 2022).*
[73] *Includes city municipal abstraction of 8 Mm³/a in development (phase 1) as per NWA Section 21(a).*

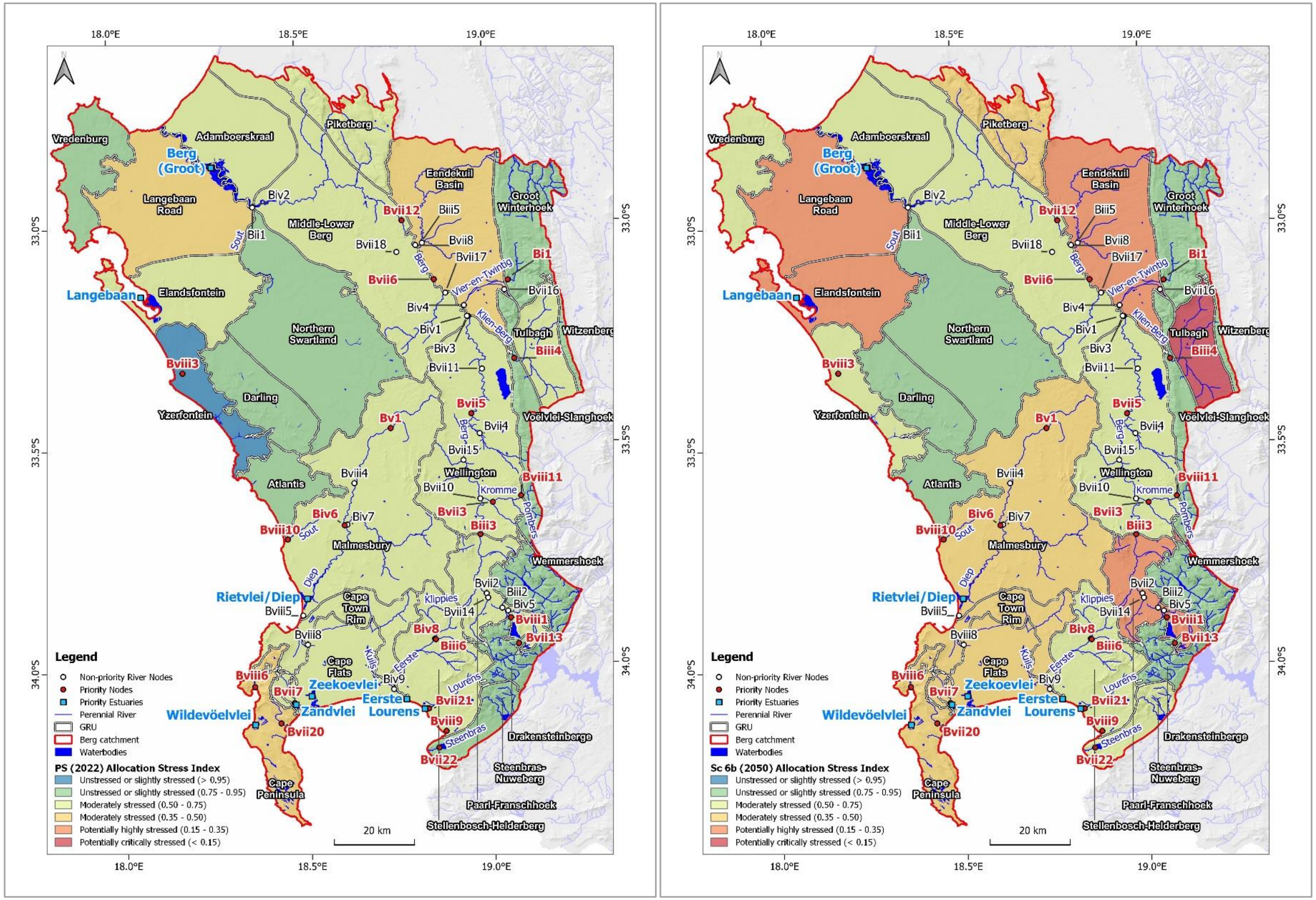

Figure 4-13 Comparative overview maps of Present Status (2022) Allocation Stress Index and Sc6b (Most Likly Case) projected volumes (2050) Allocation Stress Index per GRU.

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APPENDIX A: POPULATION GROWTH

APPENDIX A-1: Qualifying Projected Population Totals and Growth Rates per Local District Municipality (LDM)

Table A-1-1 Summary of the Projected Qualifying Populations from 2022 to 2035 for all Local District Municipalities (LDMs).

GRU	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Adamboerskraal	889	906	924	942	960	979	998	1,018	1,038	1,058	1,079	1,100	1,121	1,143
Atlantis	2,801	2,862	2,925	2,989	3,055	3,121	3,190	3,260	3,331	3,404	3,478	3,555	3,632	3,712
Cape Flats	76,862	78,543	80,261	82,016	83,810	85,642	87,515	89,429	91,385	93,383	95,426	97,513	99,645	101,824
Cape Peninsula	9,346	9,550	9,759	9,972	10,190	10,413	10,641	10,874	11,111	11,354	11,603	11,856	12,116	12,381
Cape Town Rim	21,348	21,821	22,304	22,798	23,303	23,819	24,346	24,885	25,436	26,000	26,575	27,164	27,766	28,381
Darling	1,640	1,678	1,718	1,759	1,800	1,843	1,886	1,931	1,977	2,023	2,071	2,120	2,170	2,222
Drakensteinberge	372	381	390	399	409	419	428	439	449	460	471	482	494	505
Eendekuil Basin	9,968	10,161	10,358	10,559	10,764	10,973	11,186	11,403	11,624	11,849	12,079	12,313	12,552	12,796
Elandsfontein	545	557	571	584	598	612	626	641	656	672	688	704	721	738
Groot Winterhoek	1,861	1,903	1,946	1,990	2,036	2,082	2,129	2,177	2,227	2,278	2,330	2,383	2,437	2,492
Langebaan Road	1,891	1,935	1,981	2,027	2,074	2,123	2,173	2,223	2,275	2,328	2,383	2,439	2,496	2,554
Malmesbury	37,580	38,414	39,267	40,139	41,030	41,941	42,873	43,826	44,800	45,796	46,814	47,855	48,919	50,007
Middle-Lower Berg	9,355	9,568	9,785	10,007	10,235	10,467	10,705	10,948	11,197	11,451	11,712	11,978	12,250	12,529
Northern Swartland	5,149	5,271	5,396	5,524	5,656	5,790	5,927	6,068	6,212	6,360	6,511	6,665	6,824	6,986
Paarl- Franschhoek	13,875	14,131	14,392	14,657	14,928	15,203	15,484	15,770	16,062	16,359	16,662	16,970	17,285	17,605
Piketberg	3,965	4,042	4,121	4,202	4,284	4,367	4,453	4,540	4,629	4,719	4,811	4,905	5,001	5,099
Steenbras-Nuweberg	1,709	1,734	1,759	1,784	1,810	1,836	1,863	1,890	1,917	1,945	1,973	2,002	2,031	2,060
Stellenbosch-Helderberg	26,508	27,117	27,741	28,379	29,031	29,699	30,382	31,081	31,795	32,527	33,275	34,040	34,823	35,624
Tulbagh	2,568	2,633	2,700	2,768	2,838	2,910	2,983	3,059	3,136	3,215	3,297	3,380	3,466	3,553
Voëlvlei-Slanghoek	739	755	771	787	804	822	839	857	876	895	914	934	954	975
Vredenburg	1,227	1,256	1,286	1,316	1,347	1,378	1,411	1,444	1,477	1,512	1,548	1,584	1,621	1,659
Wellington	25,733	26,209	26,695	27,190	27,694	28,208	28,732	29,265	29,809	30,363	30,928	31,503	32,090	32,687
Wemmershoek	187	191	195	200	204	208	213	217	222	227	232	237	242	247
Witsenberg	243	250	256	262	269	276	283	290	297	305	313	320	329	337
Yzerfontein	970	993	1,017	1,041	1,066	1,091	1,117	1,143	1,170	1,198	1,227	1,256	1,286	1,316
TOTAL	**257,331**	**262,864**	**268,516**	**274,292**	**280,193**	**286,223**	**292,383**	**298,678**	**305,110**	**311,682**	**318,397**	**325,258**	**332,268**	**339,431**

Table A-1-2 Summary of the Projected Qualifying Populations from 2035 to 2050 for all Local District Municipalities (LDMs).

GRU	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Adamboerskraal	1,166	1,188	1,212	1,235	1,259	1,284	1,309	1,335	1,361	1,387	1,414	1,442	1,470	1,499	1,528
Atlantis	3,793	3,876	3,961	4,048	4,136	4,227	4,320	4,414	4,511	4,610	4,710	4,814	4,919	5,027	5,137
Cape Flats	104,051	106,327	108,652	111,028	113,456	115,937	118,473	121,064	123,711	126,417	129,181	132,007	134,893	137,843	140,858
Cape Peninsula	12,651	12,928	13,211	13,500	13,795	14,097	14,405	14,720	15,042	15,371	15,707	16,051	16,402	16,760	17,127
Cape Town Rim	29,009	29,652	30,308	30,980	31,666	32,367	33,084	33,817	34,566	35,332	36,114	36,914	37,732	38,568	39,423
Darling	2,274	2,328	2,383	2,439	2,497	2,556	2,616	2,678	2,742	2,807	2,873	2,941	3,010	3,082	3,155
Drakensteinberge	517	530	542	555	568	582	596	610	624	639	655	670	686	702	719
Eendekuil Basin	13,044	13,297	13,555	13,818	14,086	14,359	14,638	14,922	15,211	15,507	15,807	16,114	16,427	16,746	17,071
Elandsfontein	755	773	791	810	829	849	869	889	910	932	954	976	999	1,023	1,047
Groot Winterhoek	2,549	2,607	2,667	2,728	2,790	2,854	2,919	2,985	3,054	3,124	3,195	3,268	3,343	3,419	3,498
Langebaan Road	2,614	2,675	2,737	2,801	2,867	2,934	3,002	3,073	3,144	3,218	3,293	3,370	3,449	3,530	3,612
Malmesbury	51,120	52,257	53,421	54,610	55,826	57,069	58,340	59,640	60,969	62,327	63,717	65,137	66,590	68,075	69,593
Middle-Lower Berg	12,814	13,105	13,403	13,708	14,020	14,339	14,666	15,000	15,341	15,691	16,048	16,414	16,787	17,170	17,561
Northern Swartland	7,152	7,322	7,495	7,674	7,856	8,042	8,233	8,429	8,629	8,834	9,044	9,259	9,478	9,704	9,934
Paarl- Franschhoek	17,931	18,264	18,602	18,948	19,300	19,658	20,023	20,396	20,775	21,162	21,556	21,957	22,366	22,783	23,208
Piketberg	5,199	5,300	5,404	5,510	5,617	5,727	5,839	5,953	6,070	6,188	6,309	6,432	6,558	6,686	6,817
Steenbras- Nuweberg	2,090	2,120	2,151	2,182	2,214	2,246	2,279	2,312	2,346	2,380	2,415	2,450	2,486	2,523	2,559
Stellenbosch-Helderberg	36,444	37,282	38,140	39,017	39,915	40,834	41,773	42,734	43,718	44,724	45,753	46,806	47,883	48,986	50,113
Tulbagh	3,643	3,735	3,830	3,927	4,026	4,128	4,232	4,339	4,449	4,562	4,677	4,795	4,917	5,041	5,168
Voëlvlei-Slanghoek	996	1,017	1,040	1,062	1,085	1,109	1,133	1,158	1,183	1,209	1,235	1,262	1,290	1,318	1,347
Vredenburg	1,698	1,738	1,778	1,820	1,863	1,906	1,951	1,997	2,044	2,091	2,140	2,191	2,242	2,295	2,348
Wellington	33,296	33,917	34,549	35,193	35,850	36,519	37,202	37,897	38,605	39,327	40,063	40,813	41,578	42,357	43,151
Wemmershoek	252	258	263	269	275	281	287	293	299	306	312	319	326	333	340
Witsenberg	345	354	363	372	382	391	401	411	422	432	443	455	466	478	490
Yzerfontein	1,348	1,380	1,412	1,446	1,480	1,515	1,551	1,588	1,626	1,665	1,704	1,745	1,786	1,828	1,872
TOTAL	**346,751**	**354,230**	**361,871**	**369,680**	**377,658**	**385,811**	**394,142**	**402,654**	**411,352**	**420,240**	**429,322**	**438,602**	**448,085**	**457,775**	**467,677**

APPENDIX B: SECTORAL WATER DEMAND

APPENDIX B-1: Proportion of Water Use Sector per GRU and associated volume change.

Table B-1-1 A summary of Groundwater Resource Units (GRUs), Water Use Sectors, Proportion of Total Groundwater Use per Sector per GRU, and the Current and Projected (2050) Total Groundwater Use Volumes (2050) for the Berg catchment. The Water Supply Sector has been omitted from this scenario (i.e., Scenario 2: Sectoral Water Demand) as this sector was analysed in Section 3.2 (i.e., Scenario 3: Groundwater Demand). GRUs with Groundwater Dependent Ecosystems (GEDs) are indicated with red text.

GRU	Water Use Sector	Proportion of Total Usage	Total Current Volume(m^3/a)	Total Current Volume: (Mm^3/a)	Total 2050 Volume: (m^3/a)	Total 2050 Volume (Mm^3/a)
Adamboerskraal	Agriculture: Irrigation	63%	1,341,000	1.34	2,305,116	2.31
	Industry (Urban)	37%	792,000	0.79	1,361,411	1.36
Atlantis	Agriculture: Irrigation	2%	157,257	0.16	64,934	0.07
	Agriculture: Watering Livestock	5%	325,276	0.33	134,312	0.13
	Industry (Non-Urban)	1%	43,713	0.04	18,050	0.02
	Industry (Urban)	87%	870,663	0.87	2,424,099	2.42
	Mining	5%	368,000	0.37	151,954	0.15
Cape Flats	Agriculture: Irrigation	62%	4,083,857	4.08	4,964,461	4.96
	Agriculture: Watering Livestock	1%	48,101	0.05	58,473	0.06
	Industry (Non-Urban)	16%	1,049,387	1.05	1,275,667	1.28
	Industry (Urban)	15%	974,710	0.98	1,184,887	1.19
	Mining	6%	390,063	0.39	474,172	0.47
	Schedule 1	0%	1,000	0.00	1,216	0.00
	Urban (Excluding Industrial &/Or Domestic)	0%	20,514	0.02	24,937	0.03
Cape Peninsula	Agriculture: Irrigation	71%	51,205	0.05	107,419	0.11
	Agriculture: Watering Livestock	14%	10,000	0.01	20,978	0.02
	Industry (Urban)	15%	10,677	0.01	22,398	0.02
Cape Town Rim	Agriculture: Aquaculture	0%	3,968	0.00	4,664	0.01

GRU	Water Use Sector	Proportion of Total Usage	Total Current Volume(m^3/a)	Total Current Volume: (Mm^3/a)	Total 2050 Volume: (m^3/a)	Total 2050 Volume (Mm^3/a)
	Agriculture: Irrigation	44%	2,384,498	2.38	2,802,998	2.80
	Agriculture: Watering Livestock	2%	88,800	0.09	104,385	0.10
	Industry (Non-Urban)	4%	220,690	0.22	259,423	0.26
	Industry (Urban)	49%	2,660,236	2.66	3,127,130	3.13
	Schedule 1	0%	25,447	0.03	29,914	0.03
	Urban (Excluding Industrial &/Or Domestic)	1%	30,745	0.03	36,141	0.04
Darling	Agriculture: Irrigation	93%	711,190	0.71	1,366,285	1.37
	Agriculture: Watering Livestock	6%	47,160	0.05	90,600	0.09
	Industry (Urban)	1%	6,290	0.01	12,084	0.01
Drakensteinberge	Agriculture: Irrigation	100%	49,800	0.05	1,206,000	1.21
Eendekuil Basin	Agriculture: Irrigation	96%	1,779,464	1.78	2,886,573	2.89
	Agriculture: Watering Livestock	3%	62,187	0.06	100,877	0.10
	Industry (Urban)	0%	5,380	0.01	8,727	0.01
Elandsfontein	Agriculture: Irrigation	35%	385,063	0.39	932,818	0.93
	Industry (Urban)	1%	6,750	0.01	16,352	0.02
	Mining	64%	700,000	0.70	1,695,756	1.70
Groot Winterhoek	Agriculture: Irrigation	100%	1,386,700	1.39	3,471,916	3.47
	Industry (Non-Urban)	0%	5,400	0.01	13,520	0.01
Langebaan Road	Agriculture: Irrigation	92%	1,582,570	1.58	3,588,572	3.59
	Agriculture: Watering Livestock	6%	94,840	0.10	215,055	0.22
	Industry (Non-Urban)	1%	10,358	0.01	23,486	0.02
	Industry (Urban)	2%	36,500	0.04	82,766	0.08
Malmesbury	Agriculture: Aquaculture	0%	11,500	0.01	18,903	0.02
	Agriculture: Irrigation	69%	9,954,305	9.95	16,361,860	16.36
	Agriculture: Watering Livestock	17%	2,510,249	2.51	4,126,088	4.13
	Industry (Non-Urban)	1%	133,133	0.13	218,830	0.22

GRU	Water Use Sector	Proportion of Total Usage	Total Current Volume(m^3/a)	Total Current Volume: (Mm^3/a)	Total 2050 Volume: (m^3/a)	Total 2050 Volume (Mm^3/a)
	Industry (Urban)	13%	1,832,935	1.83	3,012,789	3.01
	Mining	0%	2,520	0.00	4,142	0.00
	Schedule 1	0%	8,935	0.01	14,686	0.02
	Urban (Excluding Industrial &/Or Domestic)	0%	15,720	0.02	25,839	0.03
Middle-Lower Berg	Agriculture: Irrigation	100%	2,175,014	2.18	5,220,191	5.22
	Industry (Urban)	0%	300	-	720	0.00
Northern Swartland	Agriculture: Irrigation	72%	1,297,559	1.30	1,760,133	1.76
	Agriculture: Watering Livestock	9%	155,780	0.16	211,315	0.21
	Industry (Urban)	19%	341,620	0.34	463,406	0.46
Paarl-Franschhoek	Agriculture: Aquaculture	3%	220,000	0.22	342,363	0.34
	Agriculture: Irrigation	72%	6,006,325	6.01	9,347,018	9.35
	Agriculture: Watering Livestock	2%	177,450	0.18	276,147	0.28
	Industry (Non-Urban)	5%	427,858	0.43	665,831	0.67
	Industry (Urban)	18%	1,479,130	1.48	2,301,816	2.30
	Schedule 1	1%	63,598	0.06	98,971	0.10
	Urban (Excluding Industrial &/Or Domestic)	0%	8,900	0.01	13,850	0.01
Piketberg	Agriculture: Irrigation	99%	5,455,283	5.46	11,552,162	11.55
	Industry (Non-Urban)	0%	2,000	0.00	4,235	0.00
	Industry (Urban)	1%	54,240	0.05	114,859	0.12
Steenbras-Nuweberg	Industry (Urban)	100%	24,422	0.02	24,422	0.02
Stellenbosch-Helderberg	Agriculture: Aquaculture	0%	948	0.00	1,110	0.00
	Agriculture: Irrigation	62%	1,932,506	1.93	2,262,201	2.26
	Agriculture: Watering Livestock	0%	6,000	0.01	7,024	0.01
	Industry (Non-Urban)	5%	165,690	0.17	193,958	0.19
	Industry (Urban)	31%	984,996	0.99	1,153,041	1.15
	Recreation	1%	15,768	0.02	18,458	0.02

GRU	Water Use Sector	Proportion of Total Usage	Total Current Volume(m^3/a)	Total Current Volume: (Mm^3/a)	Total 2050 Volume: (m^3/a)	Total 2050 Volume (Mm^3/a)
	Schedule 1	1%	36,224	0.04	42,404	0.04
Tulbagh	Agriculture: Irrigation	98%	3,686,211	3.69	6,725,146	6.73
	Agriculture: Watering Livestock	0%	14,300	0.01	26,089	0.03
	Industry (Non-Urban)	0%	14,160	0.01	25,834	0.03
	Industry (Urban)	1%	39,300	0.04	71,699	0.07
	Schedule 1	0%	2,000	0.00	3,649	0.00
Voëlvlei-Slanghoek	Agriculture: Irrigation	27%	35,000	0.04	84,135	0.08
	Agriculture: Watering Livestock	73%	95,000	0.10	228,365	0.23
Vredenburg	Agriculture: Irrigation	22%	252,288	0.25	335,372	0.34
	Industry (Urban)	13%	148,000	0.15	196,740	0.20
	Schedule 1	0%	210	-	279	-
	Urban (Excluding Industrial &/Or Domestic)	65%	756,864	0.76	1,006,116	1.01
Wellington	Agriculture: Aquaculture	4%	160,000	0.16	307,493	0.31
	Agriculture: Irrigation	84%	3,710,632	3.71	7,131,203	7.13
	Agriculture: Watering Livestock	7%	318,395	0.32	611,901	0.61
	Industry (Non-Urban)	0%	3,490	0.00	6,707	0.01
	Industry (Urban)	5%	233,280	0.23	448,324	0.45
	Recreation	0%	2,846	0.00	5,470	0.01
	Schedule 1	0%	13,080	0.01	25,138	0.03
Wemmershoek	Agriculture: Aquaculture	36%	295,000	0.30	576,554	0.58
	Agriculture: Irrigation	54%	436,849	0.44	853,787	0.85
	Industry (Urban)	10%	80,000	0.08	156,354	0.16
Witzenberg	Agriculture: Irrigation	100%	83,720	0.08	160,863	0.16
TOTAL			**68,702,990**	**68.70**	**115,516,516**	**115.52**

APPENDIX C: GROUNDWATER DEVELOPMENTS

APPENDIX C-1: Summary Water Supply Service groundwater registrations in the WARMS database

Table C-1-1 Summary Water Supply Service groundwater registrations in the WARMS database for the Berg study area.

District Municipality	GRU Name	Registration No.	Registered Volume (Mm^3/a)
Boland District Municipality	Steenbras-Nuweberg	22139990	25.00
	Stellenbosch-Helderberg	22140005	3.50
		22006188	0.00
	Tulbagh	22043511	0.00
		22050030	0.01
		22016499	0.01
	Wellington	22022053	0.03
		22010592	0.00
		22034246	0.01
	Paarl-Franschhoek	22136207	0.44
		22136207	0.47
		22021116	0.00
		22147286	0.00
		22143958	2.00
		22028501	0.00
		22028618	0.00
		22105696	0.01
		22119976	0.04
		22136207	0.44
		22145313	0.03
	Stellenbosch-Helderberg	22124309	0.01
		22029546	0.09
		22144145	0.01
		22142780	2.04
City of Cape Town	Cape Town Rim	22047223	0.03
		22047223	0.03
		22141488	0.00
	Cape Flats	22145796	0.01
		22145867	0.06
		22143967	30.00
		22146036	0.02
		22148560	0.01

District Municipality	GRU Name	Registration No.	Registered Volume (Mm^3/a)
	Cape Town Rim	22145304	0.03
		22146018	0.05
		22146027	0.02
		22146045	0.03
		22146054	0.14
		22146063	0.05
		22147981	0.03
		22147981	0.03
		22148588	0.01
		22143654	0.05
		22144127	0.02
		22144190	0.01
		22144298	0.05
		22148533	0.09
		22031445	0.00
		22145894	0.03
		22145117	0.04
West Coast District Municipality	Darling	22036119	0.26
	Eendekuil Basin	22140023	3
	Langebaan Road	22062688	1.35
		22143404	0.79
		22143413	4.73
	Malmesbury	22148524	0.01
		22095563	0
		22021090	0
		22063516	0.16
		22144706	0
		22144706	0.02
		22045911	0
		22063491	0.09
	Middle-Lower Berg	22061055	0.06
	Piketberg	22095894	0
		22095894	0
		22066238	0.06

APPENDIX D: CLIMATE CHANGE

APPENDIX D-1: Climate Change recharge reductions (mm/a) per Groundwater Resource Unit (GRU)

Table D-1-1 Summary of recharge reduction rates (mm/a) caused by projected climate change per GRU.

GRU	Recharge Reduction (mm/a)	Area (ha)	Volume (Mm³/a)
Adamboerskraal	-4.1	1,349.37	-0.06
	-2.3	23,396.50	-0.54
	-0.6	36,484.15	-0.22
Atlantis	-6	3,741.99	-0.22
	-4.1	21,825.52	-0.89
Cape Flats	-6	42,758.46	-2.57
Cape Peninsula	-6	30,345.91	-1.82
Cape Town Rim	-6	39,302.01	-2.36
Darling	-6	14,453.59	-0.87
	-4.1	26,428.07	-1.08
Drakensteinberge	-6	45.48	0.00
	-4.1	18,222.14	-0.75
Eendekuil Basin	-6	40,598.07	-2.44
	-4.1	53,380.82	-2.19
Elandsfontein	-6	20,723.17	-1.24
	-4.1	26,229.93	-1.08
Groot Winterhoek	-6	28,973.61	-1.74
	-4.1	16,550.55	-0.68
Langebaan Road	-4.1	69,862.71	-2.86
	-2.3	7,417.53	-0.17
	-0.6	13,090.44	-0.08
Malmesbury	-6	92,503.78	-5.55
	-4.1	67,625.54	-2.77
Middle-Lower Berg	-6	9,902.95	-0.59
	-4.1	118,189.42	-4.85
	-2.3	8,343.72	-0.19
	-0.6	12,156.53	-0.07
Northern Swartland	-6	34,925.40	-2.10
	-4.1	90,839.81	-3.72
Paarl-Franschhoek	-6	26,872.01	-1.61
	-4.1	10,154.56	-0.42

GRU	Recharge Reduction (mm/a)	Area (ha)	Volume (Mm^3/a)
Piketberg	-4.1	25,921.88	-1.06
	-2.3	11,225.08	-0.26
	-0.6	1,642.11	-0.01
Steenbras- Nuweberg	-4.1	19,516.40	-0.80
Stellenbosch-Helderberg	-6	38,179.62	-2.29
	-4.1	18,904.22	-0.78
Tulbagh	-6	18,677.16	-1.12
	-4.1	10,460.69	-0.43
Voëlvlei-Slanghoek	-6	17,915.45	-1.07
	-4.1	4,139.11	-0.17
Vredenburg	-4.1	16,374.45	-0.67
	-0.6	21,243.20	-0.13
Wellington	-6	107,037.81	-6.42
	-4.1	1,659.76	-0.07
Wemmershoek	-6	7,655.30	-0.46
	-4.1	19,154.99	-0.79
Witzenberg	-4.1	4,366.10	-0.18
Yzerfontein	-6	15,795.35	-0.95
	-4.1	16,208.01	-0.66

APPENDIX E: INVASIVE ALIEN PLANTS

APPENDIX E-1: Proportion of biomes and associated recharge change per GRU

Table E-1-1 A summary of Groundwater Resource Units (GRUs), associated biome area, and related increase or decrease in recharge based on clearing or non-clearing of Invasive Alien Plants (IAPs).

GRU	Biome	Area (km²)	Area (%)	Recharge (Mm³/a)	Increase recharge (IAP Cleared) (Mm³/a)	Reduce Recharge (IAP full potential) (Mm³/a)
Adamboerskraal	Fynbos	500.81	82%	17.68	17.71	17.42
	Succulent Karoo	48.30	8%	1.70	1.70	1.70
	Thicket	63.19	10%	2.23	2.23	2.23
Atlantis	Fynbos	122.34	48%	10.88	10.89	10.82
	Thicket	133.29	52%	11.86	11.86	11.86
Cape Flats	Fynbos	227.61	54%	22.20	22.21	22.09
	Thicket	195.30	46%	19.05	19.05	19.05
Cape Peninsula	Fynbos	299.88	100%	10.99	11.01	10.84
Cape Town Rim	Fynbos	360.72	92%	17.09	17.11	16.91
	Thicket	31.84	8%	1.51	1.51	1.51
Darling	Fynbos	408.75	100%	9.95	9.97	9.74
	Thicket	0.07	0%	0.00	0.00	0.00
Drakensteinberge	Fynbos	182.68	100%	27.60	27.61	27.51
Eendekuil Basin	Fynbos	939.79	100%	21.88	21.94	21.40
Elandsfontein	Fynbos	300.29	57%	8.80	8.82	8.65
	Thicket	227.68	43%	6.67	6.67	6.67
Groot Winterhoek	Fynbos	455.24	100%	22.50	22.53	22.27
Langebaan Road	Fynbos	276.62	31%	7.14	7.15	7.00
	Succulent Karoo	0.63	0%	0.02	0.02	0.02
	Thicket	624.96	69%	16.13	16.13	16.12
Malmesbury	Fynbos	1,560.83	97%	51.32	51.42	50.53
	Nama Karoo	1.67	0%	0.05	0.05	0.05
	Thicket	38.76	2%	1.27	1.27	1.27
Middle-Lower Berg	Fynbos	1,480.93	100%	42.35	42.44	41.60
	Succulent Karoo	4.99	0%	0.14	0.14	0.14
Northern Swartland	Fynbos	1,257.65	100%	31.85	31.93	31.21
Paarl-Franschhoek	Fynbos	370.27	100%	26.61	26.63	26.42

GRU	Biome	Area (km^2)	Area (%)	Recharge (Mm^3/a)	Increase recharge (IAP Cleared) (Mm^3/a)	Reduce Recharge (IAP full potential) (Mm^3/a)
Piketberg	Fynbos	387.89	100%	20.33	20.35	20.13
Steenbras- Nuweberg	Fynbos	194.82	100%	58.76	58.77	58.66
Stellenbosch-Helderberg	Fynbos	538.43	95%	39.27	39.30	38.99
	Thicket	30.91	5%	2.25	2.25	2.25
Tulbagh	Fynbos	291.38	100%	10.87	10.89	10.72
Voëlvlei-Slanghoek	Fynbos	220.55	100%	14.10	14.11	13.99
Vredenburg	Thicket	375.06	100%	7.43	7.43	7.42
Wellington	Fynbos	1,086.98	100%	39.49	39.56	38.94
Wemmershoek	Fynbos	268.12	100%	26.83	26.85	26.69
Witzenberg	Fynbos	43.66	100%	2.78	2.78	2.76
Yzerfontein	Fynbos	160.96	51%	4.66	4.67	4.58
	Thicket	156.87	49%	4.54	4.54	4.54
TOTAL				**620.78**	**621.52**	**614.71**