High Confidence Groundwater Reserve Determination Study in the Berg Catchment

WP1139
Inventory of Water Resource Models

Report Number: RDM/WMA19/02/CON/COMP/0322

June 2022

water & sanitation

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Water and Sanitation
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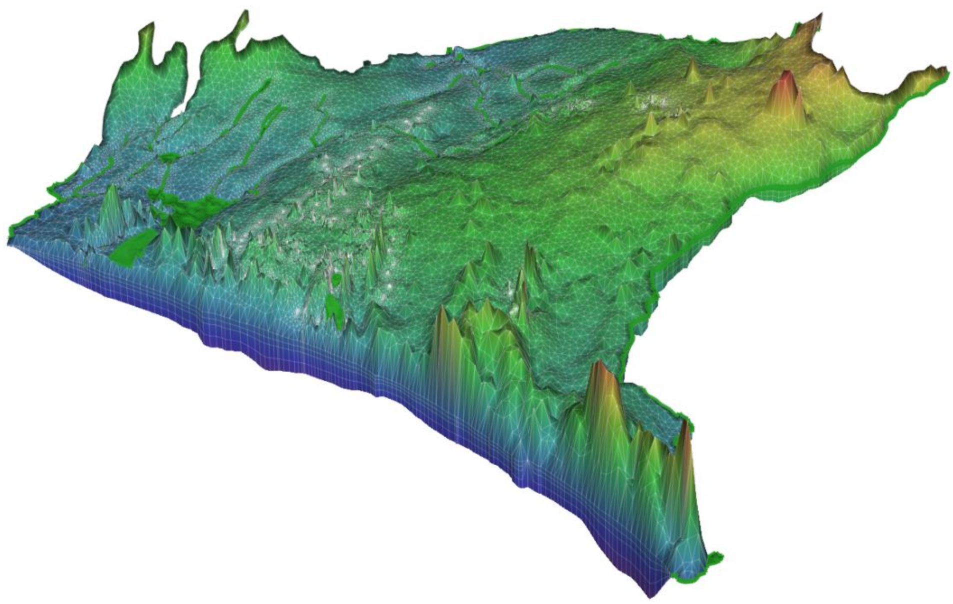

Report Number: RDM/WMA19/02/CON/COMP/0322

Version 1 – Final Draft

Prepared for:

Department of Water and Sanitation

Chief Directorate: Water Ecosystems Management

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Report Index

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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

The Department of Water and Sanitation (DWS) Chief Directorate: Water Ecosystems Management has initiated a “High Confidence Groundwater Reserve Determination Study for the Berg Catchment” in support of the gazetted Water Resource Classes and Resource Quality Objectives (RQO) for the Berg catchment. Due to the increasing number of groundwater 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 within the Berg catchment, and the complexity of geological and hydrogeological characteristics make it increasingly impossible to assess applications using a low confidence desktop groundwater Reserve. The Reserve will assist the DWS in making sound management decisions regarding stressed or over-utilised catchments, and also ensuring that water resources are afforded a level of protection that will assure a sustainable level of utilisation in the future.

The aims of this report are to collect, collate and review all available water resource models pertaining to the project area and to identify any gaps that would need to be addressed in later phases of the project.

The Inventory of Water Resource Models Report describes the available water resource models and evaluates their applicability to the study. It further reviews and analyses existing information in the context of its application and use for this study’s scope. An extensive literature review collated an inventory of existing water resource models in the study area. Various model types were assessed for their suitability, with model types ranging from desktop feasibility, conceptual, water balance, yield/storage, and numerical models consisting of hydrological (JAMS/J2000), integrated surface-water/groundwater (MIKE-SHE) and groundwater (MODFLOW and FEFLOW) types. Each of the model types were assessed for their applicability to the study and what pertinent information they could provide.

Several aquifer-scale groundwater numerical models have been developed for some of the major aquifers identified in the study area. These include the Cape Flats Aquifer, the West Coast Aquifers (including Atlantis Aquifer, Elandsfontein Aquifer System, Langebaan Road Aquifer system, Grootfontein Aquifer, and Adamboerskraal Aquifer System), and the Table Mountain Group Aquifer (TMGA).

Each of these models are potentially useful to the project, as even the reports provide information which could be incorporated into later model developments. The available numerical models are theoretically capable of quantifying groundwater availability through defining the relationships between abstraction and impacts on the flow regime. These models have each been developed under a particular project, with a particular objective or question in mind, and would need to be updated as a resource management tool supporting allocation decisions for that aquifer. Furthermore, most models were proprietary to the respective client and were unavailable for evaluation.

Of the water resource models reviewed, a selection of applicable and available models which can be adapted to quantify the impacts (availability or quality of water) of abstraction scenarios on the various resource units was made. These include the models constructed by DWAF as part of the Berg WAAS and the City of Cape Town’s New Water Programme.

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List of Abbreviations

AWSS	-	Atlantis Water Supply Scheme
BHN	-	Basic human needs
BRBS	-	Breede River Basin Study
CFA	-	Cape Flats Aquifer
CD:WEM	-	Chief Directorate: Water Ecosystems Management
CoCT	-	City of Cape Town
DWAF	-	Department of Water Affairs and Forestry
DWS	-	Department of Water and Sanitation
et al.	-	and others
etc.	-	etcetera
EWR	-	Ecological water requirements
GIS	-	Geographic Information System
GRA		Groundwater Resources Assessment
GRDM	-	Groundwater Resource Directed Measure
GRU	-	Groundwater Resource Unit
i.e.	-	That is
ISP	-	Internal Strategic Perspective
IUA	-	Integrated unit of analysis
m	-	metre
MAP	-	Mean Annual Precipitation
MAR	-	Managed Aquifer Recharge
MARS	-	Managed Aquifer Recharge and Storage
NWA	-	National Water Act
PSP	-	Professional Service Provider
RDM	-	Resource Directed Measure
RU	-	Resource unit
RQO	-	Resource Quality Objective
SVF	-	Saturated Volume Fluctuations
TMG	-	Table Mountain Group
TMGA	-	Table Mountain Group Aquifer
WAAS	-	Berg Water Availability Assessment Study
WRC	-	Water Research Commission
WRYM	-	Water Resources Yield Model
WSAM	-	Water Situation Assessment Model
WULA	-	Water Use License Application

1. INTRODUCTION

1.1. Background to the study

The Department of Water and Sanitation (DWS) Chief Directorate: Water Ecosystems Management (CD: WEM) has initiated a "High Confidence Groundwater Reserve Determination Study for the Berg Catchment". The project will support the gazetted Water Resource Classes and Resource Quality Objectives (RQO) for the Berg catchment (Gazette No.42451:121 of 10 May 2019; hereafter referred to as DWS, 2019: 121). Due to the increasing number of groundwater 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 within the Berg catchment, and the complexity of geological and hydrogeological characteristics make it increasingly impossible to assess applications using a low confidence desktop groundwater Reserve.

Figure 1-1 outlines the Integrated Unit of Analysis (IUAs) and associated Water Resource Classes that have been delineated for the Berg catchment (DWS, 2019: 121) as outcomes from 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. The Gazette (DWS, 2019: 121) included both recommendations for Water Classes for IUAs (in terms of Section 13(4)(a)(i)(aa) of the NWA, 1998) and RQOs for RUs (in terms of Section 13(4)(a)(i)(bb) of the NWA, 1998) for water resources within the catchment. This study/gazette outlined:

- IUAs classified into water resource classes and catchment configurations. Water resource classes are classified into Class I (high environmental protection and minimal utilisation), Class II (moderate protection and moderate utilisation), or Class III (sustainable minimal protection and high utilisation).
- RQOs are defined for prioritised surface water RUs for each IUA in terms of water quantity, habitat and biota, and water quality. RQOs were established for (biophysical nodes are observed in **Figure 1-1**):
    - EWR sites
    - Rivers
    - Estuaries
    - Dams
    - Wetlands
- In addition to this, the study also delineated priority GRUs (see **Figure 1-1**) and defined RQOs for these.

This study will need to determine the required groundwater contribution, in terms of quantity and quality, to satisfy the basic human needs (BHN) Reserve and ecological water requirements (EWR) for the Berg catchment.

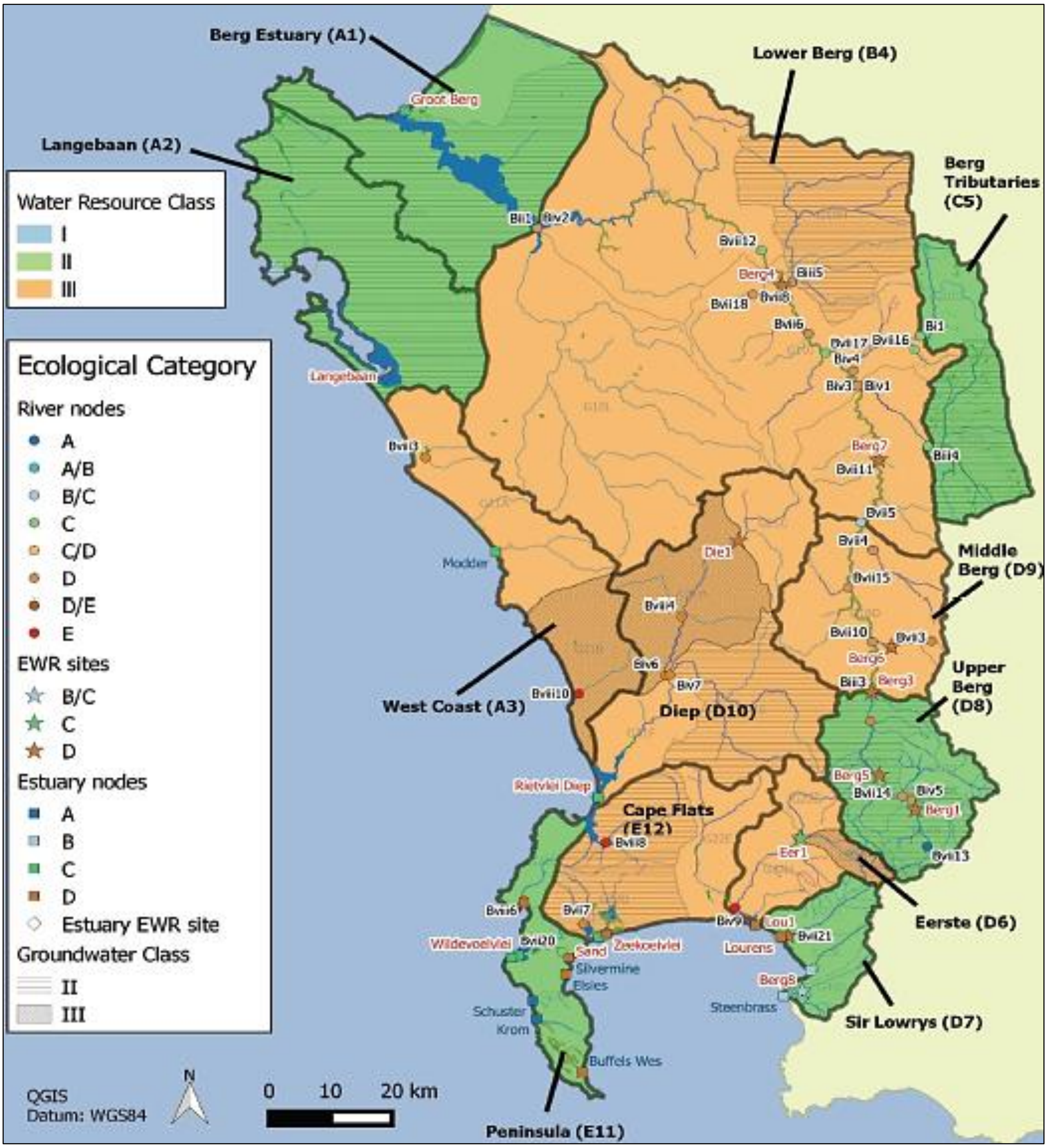

Figure 1-1 **Proposed Water Resource Classes including 12 Integrated Units of Analysis (IUAs), ecological category of each biophysical and allocation node, and groundwater class for each GRU identified (after DWS, 2019: 121).**

1.2. Terms of Reference

The Terms of Reference for the study, as provided by the DWS CD:WEM, stipulates the aim 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 Water Resource Classes and associated RQOs (DWS, 2019: 121) in completing the Groundwater Resource Directed Measures (GRDM) 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-utilised catchments, and also ensuring that water resources are afforded a level of protection that will assure a sustainable level of utilisation in the future.

The Terms of Reference indicate that the Reserve Determination process must follow the eight-step process outlined in the RDM manuals, namely the "Groundwater Resource Directed Measures" outlined by the Water Resource Commission (WRC, 2013). Additional GRDM manuals will also be consulted, such as the WRC (2007) "Groundwater Resource Directed Measures Manual" and the preliminary recommendations from an ongoing review of GRDMs by the WRC (if preliminary findings can be provided for this study) to ensure that groundwater Resource Units (GRUs) are adequately considered.

1.3. Aims of this report

The aim of this report is to collect, collate and review all available water resource models pertaining to the project area and to identify any gaps that would need to be addressed in later phases of the project. The Inventory of Water Resource Models is defined by **Deliverable 2.2** of Phase 2 of this study: Review of Water Resource Information and Data (**Table 1-1**). A detailed overview of the study approach and the scope of work is outlined in the Inception report (DWS, 2022a).

Table 1-1 Summary of project phases, tasks and associated deliverables. 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
Task 3.3	Step 3	Ecological Status and Reference Conditions per RU	Deliverable 3.2: Ecological Reference Conditions
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
Task 3.6	Step 6	Evaluate scenarios with Stakeholders	Deliverable 3.5: Stakeholder engagement of operation scenarios
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

To accurately assess the integrity, reliability and representativity of the data/information and all the available water resource models for a high confidence determination, all datasets were collated and standardised for a data quality assessment. Both the Gap Analysis Report and the Inventory of Water Resource Models Report include recommendations on how to overcome any data gaps or missing information required for Phase 3 of this study: Reserve Determination. Both reports contribute to Step 1 of the eight-step GRDM procedure for determining the groundwater Reserve as outlined by WRC (2013).

All relevant physiographical, geological and hydrogeological information, including relevant water resource models, will be collated and saved in a GIS dataset for future client use (input to **Deliverable 3.8 – Database**). The data will be evaluated for correctness and suitability, and data from different reporting institutions and companies will be collated for completeness and ease of use.

1.4. Report outline and structure

The Inventory of Water Resource Models Report describes the available water resources models and evaluates their applicability to the study. It further reviews and analyses existing information in terms of information and data gaps in context of their applications and use for this study's scope, a **high confidence groundwater reserve determination**.

2. REVIEW OF AVAILABLE WATER RESOURCE MODELS

2.1. Inventory of available Water Resource Models

Following an extensive literature review, a collated inventory of existing water resource models in the study area was produced (see **Figure 2-1** and **Table 2-1**). Various model types were assessed for their suitability, with models ranging from desktop feasibility, conceptual, water balance, storage/yield, and numerical models consisting of hydrological (JAMS/J2000), integrated surface-water/groundwater (MIKE-SHE) and groundwater (MODFLOW and FEFLOW) types. Most of the models provide valuable inputs to Steps 2 to 4 of the GRDM procedure for determining the groundwater Reserve as outlined by WRC (2013) including, but not limited to geological information, aquifer characterisation, surface and groundwater quality, groundwater levels, recharge, discharge and groundwater use. This inventory may be updated as new information comes to light through the progress of the study.

2.1.1. Berg WAAS

The Berg Water Availability Assessment Study (WAAS) conducted by the then Department of Water and Forestry (DWAF), included an extensive range of groundwater resource assessment studies which included comprehensive conceptual models and a GIS and excel-based water balance model for the whole study area (Berg catchment). The Regional Conceptual Model (DWAF, 2007) provides a conceptual understanding of the system and provides information on the geological structures (faults/folds), hydrostratigraphy, aquifer classification/boundaries, geothermal activity, surface water-groundwater interactions, hydrochemistry/water quality, identifies recharge and discharge areas and the regional flow systems including hydrotects.

The Regional Water Balance model (DWAF, 2008a) and finer scale water balance models for the TMG in the Piketberg (DWAF, 2008b) and Witzenberg-Nuy (DWAF, 2008c) areas were developed to estimate the groundwater potential from different aquifers within the study area as well as to produce reasonable values for input parameters to the groundwater modules of the Water Resources Yield Model (WRYM) and Water Situation Assessment Model (WSAM). The reports provide estimates of aquifer-specific recharge (calculated with a variety of methods including fixed percentage of Mean Annual Precipitation (MAP), Breede River Basin Study (BRBS), Internal Strategic Perspective (ISP), Groundwater Resources Assessment (GRA) II, Map-centric and Saturated Volume Fluctuations (SVF)), runoff, evapotranspiration, storage capacity in the Peninsula and Skurweberg aquifers, aquifer-specific natural discharge, aquifer-specific groundwater use (based on the WARMS database), storage yield for the confined portions of the Peninsula and Skurweberg aquifers, and groundwater potential. Due to the methodology applied in determining groundwater potential estimates, in which availability is directly equated to the sum of recharge minus use, these static water balance models are unable to satisfy the objectives of this project, quantifying the relationship between abstractions and impacts on baseflow in ecologically important and sensitive catchments. The applicability of the Berg WAAS estimates are therefore limited to desktop estimates, but provide a valuable starting point for the study (DWS, 2016).

In addition to this broader catchment-wide study, several aquifer-scale groundwater numerical models have been developed for some of the major aquifers in the study area (**Figure 2-1** and **Table 2-1**). These include the Cape Flats Aquifer, Breede River Alluvium Aquifer, the West Coast Aquifers (including Atlantis Aquifer, Elandsfontein Aquifer System, Langebaan Road Aquifer system, Grootfontein Aquifer, and Adamboerskraal Aquifer System), and on the TMGA. Aquifer specific models for the Cape Flats Aquifer (DWAF, 2008d), Langebaan Road Aquifer System (DWAF, 2008e), and Breede River Alluvium Aquifer (DWAF, 2008f) provided information on aquifer specific flow regime, water quality, a conceptual understanding of the groundwater flow system, hydraulic/storage properties, recharge, abstraction, and surface water-groundwater interactions. Predicative scenarios assessed the individual aquifers' sensitivity to rainfall, its ability to augment municipal bulk water supply based on wellfield designs, current demand, future demand, flood management, and aquifer storage and recovery.

2.1.2. City of Cape Town

The numerical models constructed as part of the City of Cape Town's New Water Programme represent the most up to date models for the respective areas. The models for the Atlantis Aquifer (CoCT, 2020a) and Cape Flats Aquifer (CoCT, 2020b) incorporate the latest drilling information, allowing for updated 3D model construction, aquifer properties and water level measurements as well as the latest information regarding recharge (including MAR) and planned abstraction, and therefore supersedes the previous iterations by Jovanovic et al. (2017) and DWAF (2008d) respectively. Model scenarios for the Cape Flats Aquifer assess the expected wellfield yields and MAR under proposed operating conditions, while model scenarios for the Atlantis Aquifer assess the aquifers' ability to accommodate additional MAR and the subsequent increases in yield and impact on stream discharge rates. This will assist with the scenario modelling in Step 5 (Determine operational scenarios and its socio-economic and ecological consequences) of the Reserve determination (WRC, 2013). The numerical model of the Steenbras-Nuweberg Nardouw Aquifer (CoCT, 2021) system builds on the previously defined conceptual understanding of the area which is based on the latest data gathered during groundwater exploration and wellfield development. The model represents current knowledge in terms of three-dimensional aquifer geometry, location and abstraction rates of groundwater users, spatial distribution of recharge, groundwater discharge and groundwater-dependent ecosystems, and aquifer boundary conditions.

2.1.3. Atlantis

The Atlantis Aquifer model (Jovanovic et al., 2017) considered a single layer system for groundwater flow and contaminant transport modelling in support of the management of the Atlantis Water Supply Scheme (AWSS). Despite not having access to the model files, the report is able to provide information on the hydraulic and storage properties of the aquifer, groundwater level observations, abstraction, as well as estimated natural recharge, MAR (artificial recharge to the recharge basins), and evapotranspiration. Predictive scenarios estimated drawdown levels associated with differing recharge and abstraction rates.

2.1.4. West Coast

The Conceptual Hydrogeological Model of the Lower Berg (including the Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerskraal Aquifer) (WRC, 2018) investigates the extent of the recharge area(s) from which replenishment of the confined portion(s) of the aquifer system occurs and leakage from the bedrock into the confined aquifer, aquifer yield and groundwater residence times. The conceptual model provides data on site specific conditions such as geological structural features (informed by lithological logs, existing maps, geophysics and field data), groundwater level data, groundwater-surface water interactions, recharge, chemical and isotopic compositions, and aquifer properties. Building on from the conceptual model (WRC, 2018), numerical modelling, as per modelling report (WRC, 2020) was conducted with the primary purpose of simulating natural seepage conditions and identifying suitable sites for the implementation of managed aquifer recharge and storage (MARS) in the Langebaan Road Aquifer and Elandsfontein Aquifer. The modelling report provides information on boundary conditions, water balance and storage capacity of the aquifers.

The desktop assessment undertaken by Bigen Africa Services (2019), focusses on water supply from the Grootwater Aquifer to the towns of Yzerfontein and Darling. The report provides the historic water consumption records from January 2000 to December 2018 as well as future consumption projections (2023, 2028, 2033 and 2038) for the main water demand centres (including Yzerfontein and Darling) as well as abstraction volumes based long-term yield analyses.

2.1.5. Others

The JAMS/J2000 rainfall–runoff model can provide an understanding of surface-water processes within the study catchments, while the SPRING and integrated MIKE-SHE models can provide valuable insight into the surface/groundwater interactions within the respective aquifer systems. The report by Watson et al. (2021) assessed hydrological process variability by analysing the observed precipitation and the resulting streamflow of each catchment, as well as the simulated streamflow, hydrological flow components (surface runoff, interflow and baseflow) and the simulated water balance. Inputs to the model included physical inputs such as climate, topography, soil, hydrogeology and land use as well as hydrogeological parameters such as storage capacity and storage coefficients. The report by Rebelo et al. (2022) investigates the impacts of restoration (clearing of alien trees) on streamflow in the upper reaches of the Berg catchment using the fully-distributed MIKE-SHE modelling tool. The report therefore provides insight into streamflow and runoff volumes in the upper Berg catchment. Mauck (2017) developed a fully-integrated MIKE SHE model of the CFA to simulate the hydrological and hydrogeological processes and is therefore able to identify the hydrological processes that influence groundwater recharge, aquifer storage and groundwater-surface water interactions. The objectives were to evaluate the feasibility of summer abstraction as a flood mitigation strategy and to assess the storage potential and feasibility of MAR. In addition, the migration of solute pollutants from the injected or infiltrated stormwater was simulated and climate change simulations were also undertaken to account for potential fluctuations in rainfall and temperature.

Each of these are potentially useful to the project, as even the reports provide information which could be incorporated into numerical models developed or updated for the project. The available numerical models are theoretically capable of quantifying groundwater availability through defining the relationships between abstraction and impacts on the flow regime. These models have each been developed under a particular project (research projects for DWS or for municipalities), with a particular purpose or question in mind, and would need to be updated as a resource management tool supporting allocation decisions for that specific aquifer.

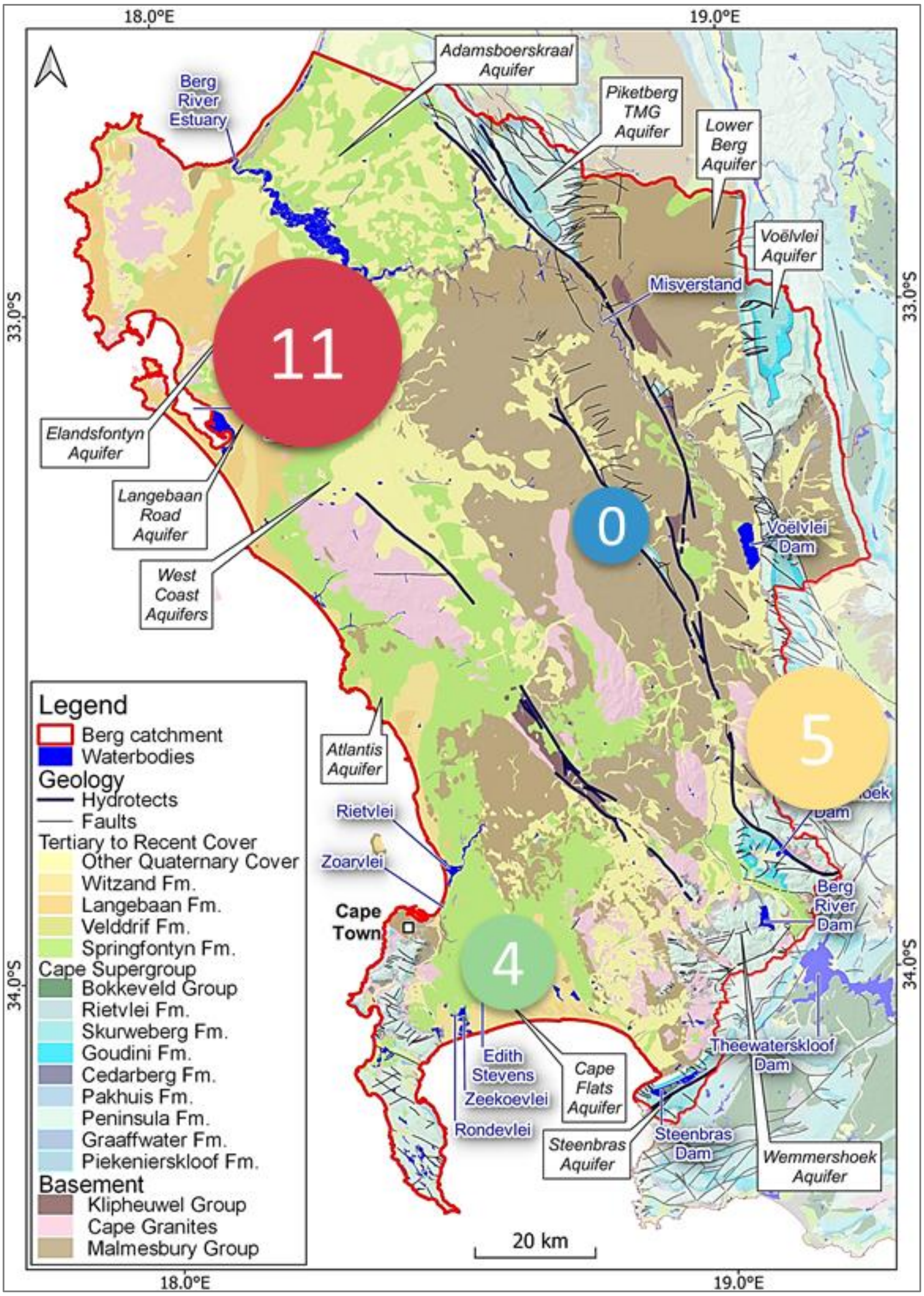

Figure 2-1 **Existing water resource models (excluding regional conceptual and water balance models) in the study area per larger GRU areas. West Coast Aquifers (including Atlantis Aquifer) in red, Cape Flats Aquifer in green, Table Mountain Group Aquifer in orange and Basement Aquifer in blue.**

Table 2-1 Inventory of current groundwater models relevant to the Berg catchment area (adapted after DWS, 2016).

<table>
<tr><th>Spatial Extent</th><th>Model Type</th><th>Reference</th><th>Relevance to study</th><th>Model/Data Available</th></tr>
<tr><td>Berg (previous) WMA, upper Breede catchment and southern Olifants/Doorn WMA (Vol 3)</td><td>Regional Conceptual Model</td><td>Berg WAAS
DWAF. 2007.</td><td>A comprehensive analysis of hydrogeological aspects (aquifer properties, recharge, flow direction, discharge), to inform conceptual development of groundwater resource units (therein termed IWRM domains).
Calculates aquifer-specific mass balance and or catchment mass balance by identifying recharge areas based on physically measurable aquifer outcrop areas underlying rainfall isohyets.</td><td>Yes</td></tr>
<tr><td>Berg (previous) WMA, upper Breede catchment and southern Olifants/Doorn WMA (Vol 4)</td><td>Regional Water Balance Model: GIS and excel based, output results available in report</td><td>Berg WAAS
DWAF. 2008a.</td><td>Spreadsheet based groundwater balance model which determined groundwater potential as recharge minus baseflow minus existing groundwater use. Calculated per aquifer type per quaternary catchment. Where necessary quaternary scale data was spatially disaggregated based on outcrop area. Output available as tables in report and excel.</td><td>Yes</td></tr>
<tr><td>TMG Aquifer, Piketberg (Vol 7)</td><td>Water Balance and Yield Model</td><td>Berg WAAS
DWAF. 2008b.</td><td>The water balance and yield model, developed for the regional scale, was applied at finer scale for the TMG Aquifer in the Piketberg area. Aquifer geometry determined through GIS assessment, as input to calculation of stored water volume. “Groundwater potential” calculated based on recharge minus baseflow minus existing groundwater use. Output available as tables in report and excel.</td><td>Yes</td></tr>
<tr><td>TMG Aquifer, Witzenberg-Nuy (Vol 8)</td><td>Water Balance and Yield Model</td><td>Berg WAAS
DWAF. 2008c.</td><td>The water balance and yield model, developed for the regional scale, was applied at finer scale for the TMG Aquifer in the Witzenberg - Nuy area. Aquifer geometry determined through GIS assessment, as input to calculation of stored water volume. “Groundwater potential” calculated based on recharge minus baseflow minus existing groundwater use. Output available as tables in report.</td><td>Yes</td></tr>
<tr><td>Cape Flats Aquifer (Vol 5a and b)</td><td>Numerical model (FEFLOW)</td><td>Berg WAAS
DWAF. 2008d.</td><td rowspan="5">Each existing numerical model provides a model theoretically capable of quantifying the impact of abstraction scenarios on baseflow / estuaries.</td><td>Yes</td></tr>
<tr><td>Langebaan Road Aquifer System, Elandsfontein Aquifer System (Vol 6)</td><td>Numerical model (FEFLOW)</td><td>Berg WAAS
DWAF. 2008e.</td><td>Yes</td></tr>
<tr><td>Breede River Alluvium Aquifer (Vol 9)</td><td>Numerical Model (MODFLOW)</td><td>Berg WAAS
DWAF. 2008f.</td><td>Yes</td></tr>
<tr><td>Langebaan Road Aquifer System, Elandsfontein Aquifer System</td><td>Various Numerical Models</td><td>Water Research Commission, 2016b.</td><td>No</td></tr>
<tr><td>Cape Flats Aquifer</td><td>Numerical Model (SPRING)</td><td>Water Research Commission, 2016a.</td><td>No</td></tr>
</table>

Spatial Extent	Model Type	Reference	Relevance to study	Model/Data Available
West Coast Aquifers	Numerical Model (SPRING)	Water Research Commission, 2016b.		No
Atlantis Aquifer	Numerical Model (MODFLOW)	Jovanovic et al. 2017.		Report only
Steenbras TMG Aquifer system (Nardouw Aquifer)	Numerical Model (FEFLOW)	City of Cape Town (2021).	Ongoing development, recent work undertaken at the Steenbras wellfield should provide the most representative predictions capable of quantifying the impact of abstraction scenarios on baseflow / estuaries.	Yes
Atlantis Aquifer	Numerical Model (FEFLOW)	City of Cape Town (2020a).	Most up to date steady state and predictive model of the Atlantis Aquifer capable of quantifying the impact of abstraction scenarios on baseflow / estuaries.	Yes
Cape Flats Aquifer	Numerical Model (FEFLOW)	City of Cape Town (2020b).	Most up to date steady state and predictive model of the CFA capable of quantifying the impact of abstraction scenarios on baseflow / estuaries..	Yes
Elandsfontein Aquifer	Dewatering Models	SRK (2016)	Local dewatering scenarios/models related to the Elandsfontein Phosphate Mine. *Results Confidential	No
		GEOSS		No
		Jaco Nel, 2019.		No
Headwaters in TMG, Upper Berg catchment	Fully Distributed MIKE-SHE	Rebelo et al., 2022.	Model the impacts of alien tree clearing on streamflow in four strategic water providing catchments.	Report only
Cape Flats Aquifer	Fully Integrated MIKE-SHE	Mauck, 2017.	Implementing Managed Aquifer Recharge (MAR) to the Cape Flats Aquifer (CFA) as a strategy for flood prevention and supplementing urban water supply.	Report only
Grootwater Aquifer	Desktop Feasibility Study	Bigen Africa Services, 2019.	Desktop feasibility study into water supply from the Grootwater Aquifer to the towns of Yzerfontein and Darling.	Report only
Lower Berg (Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerkraal Aquifer)	Conceptual Hydrogeological Model	WRC, 2018.	Conceptual hydrogeological model investigating the extent of leakage from the bedrock into the confined aquifer, aquifer yield and groundwater residence times.	Report only
Lower Berg (Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerkraal Aquifer)	Numerical Model (MODFLOW)	WRC, 2020.	Model to determine the viability of implementing MARS as an adaptive management strategy for augmenting the water supply to the WCDM.	Report only
Verlorenvlei, Berg, Eerste, Bot and Breede catchments	JAMS/J2000 rainfall–runoff model	Watson et al. (2021)	Rainfall–runoff model to simulate hydrological process and flow component dynamics such surface runoff, interflow and baseflow.	Report only

2.2. Evaluation of available Water Resource Models

Following an assessment of available models, the models were further scrutinised based on their applicability to meet the project objectives of a high confidence study. Model types excluded as part of the initial phase of elimination, are related to desktop assessments, conceptual models, water balance models, and storage/yield models and hydrological models. These are important types of models but are static and generally catchment scale and therefore can't be used to answer questions related to localized groundwater flow dynamics suitable for a high confidence study.

Furthermore, most models are proprietary to the respective client and were unavailable for evaluation beyond the report, while those related to the Elandsfontein Aquifer contain sensitive information related to the Phosphate mine with the results being considered confidential.

Table 2-2 lists applicable and available models which can be adapted to quantify the impacts (availability or quality of water) of abstraction scenarios on the various groundwater resource units. These include the models constructed by DWAF as part of the Berg WAAS and the City of Cape Town's New Water Programme, accounting for the Cape Flats, West Coast and Steenbras TMGA GRUs.

Table 2-2 Final list of available models relevant to the study.

Model	Reference
Cape Flats Aquifer (Vol 5a and b)	DWAF (2008d)
Langebaan Road Aquifer System, Elandsfontein Aquifer System (Vol 6)	DWAF (2008e)
Breede River Alluvium Aquifer (Vol 9)	DWAF (2008f)
Steenbras TMG Aquifer system (Nardouw Aquifer)	City of Cape Town (2021)
Atlantis Aquifer	City of Cape Town (2020a)
Cape Flats Aquifer	City of Cape Town (2020b)
*Lower Berg model (including the Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerkraal Aquifer)	WRC (2020)

*Should the Lower Berg model (including the Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerkraal Aquifer) by WRC (2020) be available, it would provide an updated regional model of the area, superseding the Langebaan Road Aquifer System, Elandsfontein Aquifer System (DWAF, 2008e) and negate the need for the confidential Elandsfontein models.

3. INFORMATION GAPS AND RECOMMENDATIONS

Based on the subsequent available models presented in **Table 2-2**, an assessment of information gaps for the models was undertaken. The information gap analysis undertaken identified notable information gaps as the level of detail that studies have gone into for individual systems. In addition to the information gaps discussed in the Gap Analyses Report (DWS, 2022b), the model gaps predominantly relate to uncertainties associated with model input parameters such as recharge, discharge, abstraction, and aquifer hydraulic/storage parameters. These limitations could be minimised through predicative uncertainty analyses using the null space Monte Carlo approach as implemented in PEST. The applicability of current boundary conditions applied to the models will be assessed and updated once the models' objectives are updated as a resource management tool supporting allocation decisions for that specific aquifer. As noted in **Section 2.2** above, should the Lower Berg model (including the Langebaan Road Aquifer system, Elandsfontein Aquifer and Adamboerkraal Aquifer) by WRC (2020) be available, it would provide an updated regional model of the area, superseding the Langebaan Road Aquifer System, Elandsfontein Aquifer System (DWAF, 2008e).

Given the importance of the CFA, Atlantis and West Coast Aquifers for water supply and assessing the BHNs, it is proposed to utilise numerical models for the groundwater Reserve determination in these aquifers. Similarly, numerical models should be used for the TMG Aquifers, as these are important for water supply and sustain sensitive, groundwater dependent ecosystems. In areas where data is limited and groundwater plays a limited role in sustaining EWR at defined nodes, a comprehensive numerical model would not be required, and the groundwater reserve requirements could be assessed using a simpler analytical or water balance model.

The models are to be updated iteratively as additional data is acquired and/or if predictions are significantly inaccurate. High quality model input data will prove invaluable to reducing uncertainty.

4. CONCLUSION

All the models listed in **Table 2-2** above simulate the effects of abstraction on surface water discharge either as rivers, streams, or potential groundwater discharge points. These models therefore provide valuable inputs to Steps 2 to 4 of the GRDM procedure for determining the groundwater Reserve as outlined by WRC (2013), with insight to Step 5 provided by the scenario modelling of the CFA and Atlantis Aquifers. Each of these models are therefore useful to the project, given their capability of quantifying groundwater availability through defining the relationships between abstraction and impacts on the flow regime. Going forward, these numerical models would need to be updated with the latest monitoring results and recalibrated prior to being used as management tools.

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