High Confidence Groundwater Reserve Determination Study in the Berg Catchment

WP11398

Delineation of Groundwater Resource Units Report

Report Number: RDM/WMA19/02/CON/COMP/0422

August 2022

water & sanitation

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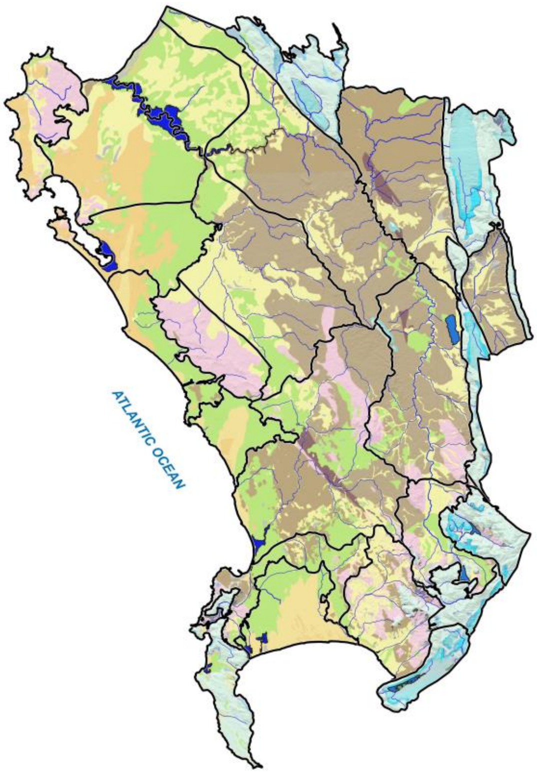

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Version 1 – Final Draft

Prepared for:

Department of Water and Sanitation

Chief Directorate: Water Ecosystems Management

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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

Due to the increasing number of Water Use Licence Applications (WULAs), and the associated effects the proposed developments may have on the groundwater Reserve in the Berg catchment, the Department of Water and Sanitation (DWS) Chief Directorate: Water Ecosystems Management (CD: WEM) has initiated a High Confidence Groundwater Reserve Determination Study in order to assist the DWS in making sound management decisions regarding stressed or over-utilised water resources. Through the implementation of the Resource Directed Measures (RDM), a process outlined in Regulation 2(4) of the National Water Act (No. 36 of 1998), and its obligation to ensure that all significant water resources are afforded a sustainable level of protection, the Reserve determination aims to support the gazetted Water Resource Classes and associated Resource Quality Objectives (RQOs) in completing the RDM.

GROUNDWATER RESERVE DETERMINATION APPROACH

The aim of this report is to delineate aquifer-specific Groundwater Resource Units (GRUs) and identify sites that may require further investigation (i.e., Step 2 of the eight-step groundwater Reserve determination procedure described as part of the Water Resource Classification Systems (WRCS) guideline. This report provides an overview of previously defined GRUs in the Berg catchment, outlines the approach for delineating aquifer-specific GRUs, and provides detail around the criteria considered for selecting GRU boundaries.

GROUNDWATER RESOURCE UNIT SELECTION CRITERIA

The GRU delineation approach follows Step 2 of the eight-step groundwater Reserve determination procedure outlined in the Groundwater Reserve Determination Measures (GRDM) manual (WRC, 2013) and considers three overarching criteria, namely:

1. **Physical Criteria**

Physical aquifer geometry, existing aquifer boundaries and associated boundary conditions, recharge (within a single aquifer system and between aquifer systems), topography, structural geology (major faults, folds and hydrotects), and potential discharge areas (including preferential groundwater flow directions).

2. **Management Criteria**

Existing Integrated Units of Analysis (IUAs), Water Resource Classes, RQOs, Strategic Water Source Areas for groundwater (SWSAgw), Subterranean Government Water Control Areas (SGWCAs), groundwater use, and both current and future aquifer reliance and associated aquifer stress.

3. **Functional Criteria**

Groundwater-surface water interactions (i.e., groundwater contribution to baseflow, and its role in maintaining hydrological integrity, discharge integrity and established ecological water requirements).

UPDATED GROUNDWATER RESOURCE UNITS

The revised aquifer-specific GRUs extents can be seen in **Figure 1** and the associated quaternary catchments they incorporate (or overlap) included in **Table 1**. It is important to note that in defining new GRU extents, the study boundary extends outside of the Berg catchment to fully encompass the hydrogeological nature of all identified GRUs.

Table 1 Summary of revised GRUs for the Berg catchment.

GRU NAME	ASSOCIATED QUATERNARY CATCHMENT
Primary Aquifers	
Cape Flats	G22C, G22D and G22E
Atlantis	G21A, G21B and G21D
Yzerfontein	G21A
Elandsfontein	G10M and G10L
Langebaan Road	G10M and G10L
Adamboerskraal	G10M, G10K and G30A
Fractured Aquifers – Table Mountain Group (TMG)	
Cape Peninsula	G22A, G22B, G22C and G22D
Steenbras-Nuweberg	G40B, G40A, G40D, G22J, G22K, H60A and G40C
Drakensteinberge	G10A, G10C, G22F, G22J, H60A and H60B
Wemmershoek	G10B, G10A, G10C, H10J, H60B and H10K
Voëlvlei-Slanghoek	G10E, G10J, G10D, G10F, H10E, H10F and H10J
Witsenberg	G10E
Groot Winterhoek	G10J, G10E, G10H, E10C and G10G
Piketberg	G10M, G30D, G10K, G30A and G10H
Fractured & Intergranular Aquifers - Basement	
Cape Town Rim	G22C, G22E, G22B and G22D
Stellenbosch-Helderberg	G22G, G22H, G22F, G22J and G22K
Paarl-Franschoek	G10C, G10A and G10B
Malmesbury	G201E, G21C, G21D, G21F and G21B
Wellington	G10D and G10F
Tulbagh	G10E and G10G
Eendekuil Basin	G10H, G10J, G10F and G10K
Middle-Lower Berg	G10J, G30A, G10K and G10M
Northern Swartland	G10L
Darling	G10L and G21A
Vredenburg	G10M

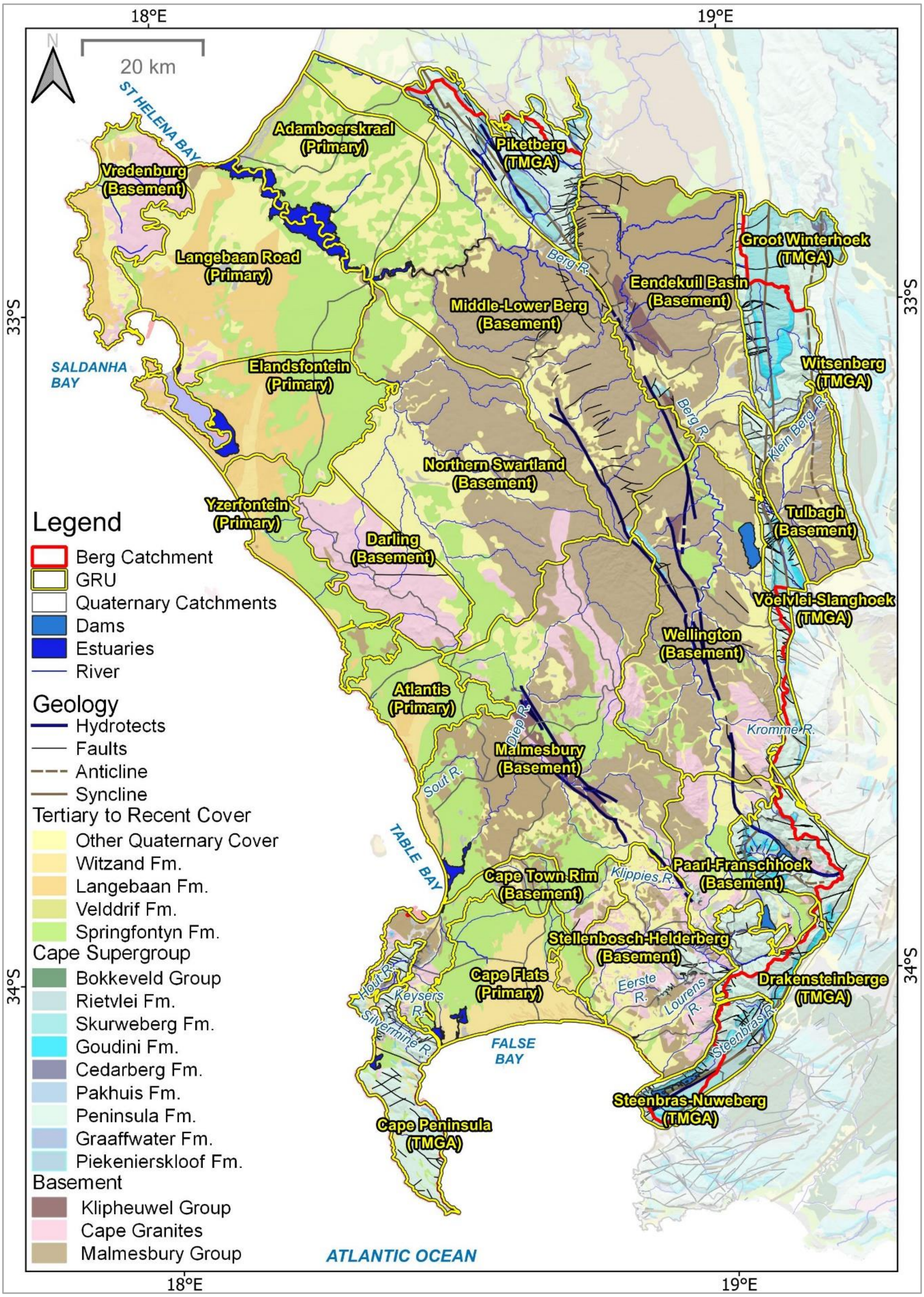

Figure 1 **Summary of revised Groundwater Resource Units (GRUs) extents for the Berg catchment with associated geological and structural features.**

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List of Abbreviations

<	-	Less than
BHN	-	Basic Human Needs
CD: WEM	-	Chief Directorate: Water Ecosystems Management
CFA	-	Cape Flats Aquifer
CoCT	-	City of Cape Town
DWA	-	Department of Water
DWAF	-	Department of Water Affairs and Forestry
DWS	-	Department of Water and Sanitation
e.g.	-	for example
EGSA	-	Ecological Goods, Services and Attributes
EIS	-	Ecological Importance and Sensitivity
Et al.	-	and others
etc.	-	etcetera
EWR	-	Ecological water requirements
Fm.	-	Formation
GIS	-	Geographic Information System
GRDM	-	Groundwater Resource Directed Measure
GRU	-	Groundwater Resource Unit
i.e.	-	that is
IUA	-	Integrated Unit of Analysis
IWRM	-	Integrated Water Resource Management
Km	-	Kilometres
l/s	-	Litres per second
Ltd.	-	Limited Liability
m	-	Metres
m^3	-	Cubic Meters
mamsl	-	Meters above mean sea level
MAP	-	Mean Annual Precipitation
mm	-	Millimetres
mm/a	-	Millimetres per annum
NWA	-	National Water Act
PES	-	Present Ecological Status
pg.	-	Page
Pr.1 -	-	Peninsula Recharge
Pty.	-	Proprietary
QGIS	-	Quantum Geographic Information System
Qr.1	-	Sandveld Recharge
RDM	-	Resource Directed Measures
RQO	-	Resource Quality Objective
RU	-	Resource Unit
SGWCA	-	Subterranean Government Water Control Area
Sr.1	-	Nardouw Recharge
SWSAgw	-	Strategic Water Source Areas for groundwater
TEC	-	Target Ecological Category
TMG	-	Table Mountain Group
TMGA	-	Table Mountain Group Aquifer
TOR	-	Terms of Reference
UTM	-	Universal Transverse Mercator
WAAS	-	Water Availability Assessment Study
WARMS	-	Water use Authorization and Registration Management System
WGS84	-	World Geodetic System (84)

WRC	-	Water Research Commission
WRCS	-	Water Resource Classification System
WRU	-	Wetland Resource Unit
WULA	-	Water Use Licence 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 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 the study site's geological and hydrogeological characteristics make it increasingly impossible to assess applications using a low confidence desktop groundwater Reserve.

Figure 1-1 outlines the Integrated Units of Analysis (IUAs) and associated Water Resource Classes that have been delineated for the Berg catchment (DWS, 2019b: 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 (hereafter referred to as DWS, 2016). The Gazette (DWS, 2019b: 121) included both recommendations for Water Classes for IUAs (in terms of Section 13(4)(a)(i)(aa) of the National Water Act (NWA), 1998) and RQOs for Resource Units (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 were 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 RUs & biophysical nodes which are observed in **Figure 1-1** and **Figure 1-2**:
    - Ecological Water Requirements (EWR) sites
    - Rivers
    - Estuaries
    - Dams
    - Wetlands
- In addition to this, the study also delineated Groundwater Resource Units (GRUs) and defined RQOs for priority sites (see **Figure 1-1** and **Figure 1-2**).

This current study will need to determine the required groundwater contribution, in terms of quantity and quality, to satisfy the Basic Human Needs (BHN) Reserve and EWR for the Berg catchment. It is understood from the Inception Report (DWS, 2022a), the outcomes from the DWS (2016) study will provide the framework for the socio-economic, surface water (rivers, dams, estuaries, and wetlands) and ecological understandings for this project.

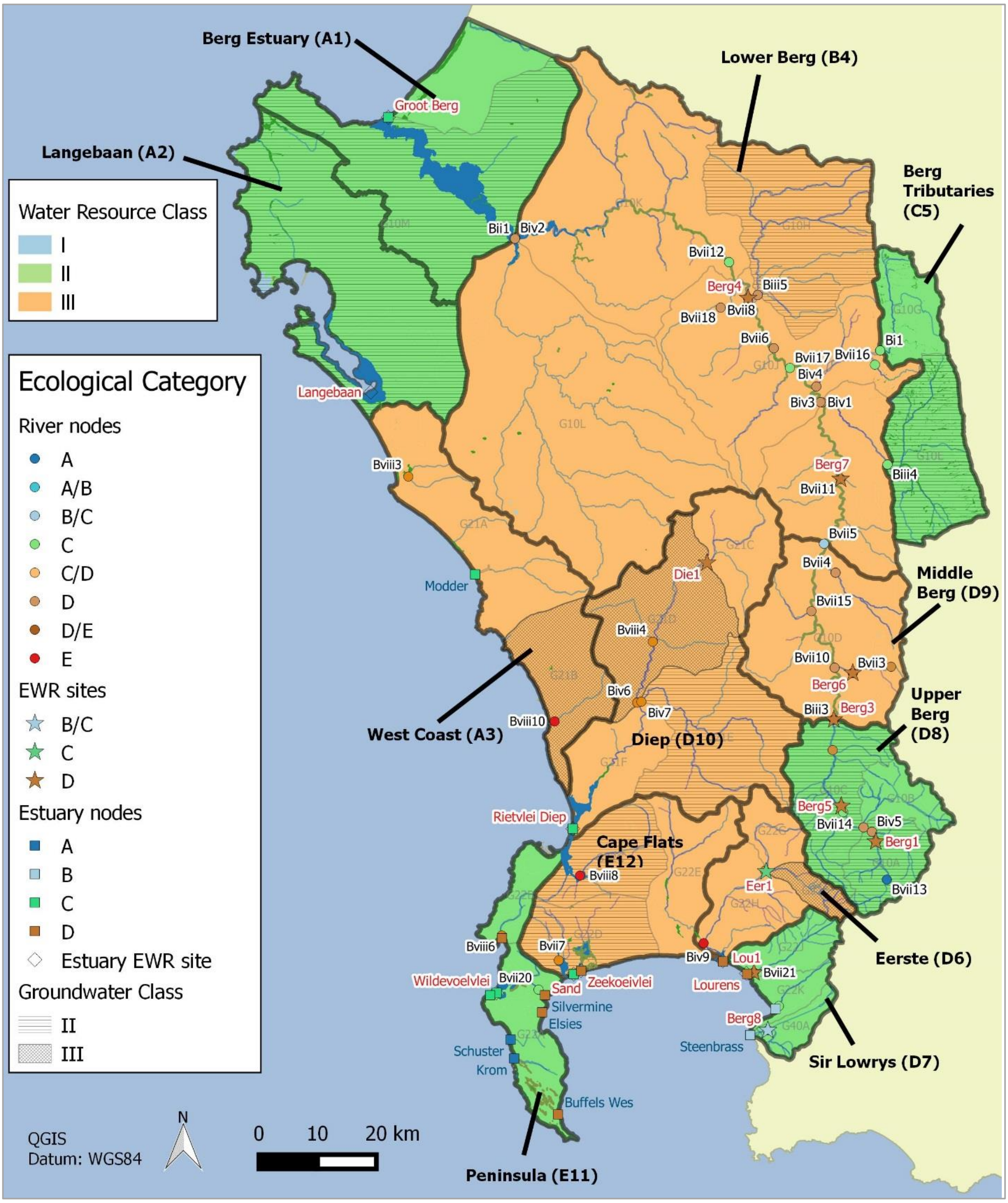

Figure 1-1 Water Resource Classes for the Berg catchment and associated ecological category for prioritised biophysical and allocation nodes (rivers, estuaries and dams), and the groundwater class for priority quaternary groundwater units (DWS, 2019b: 121).

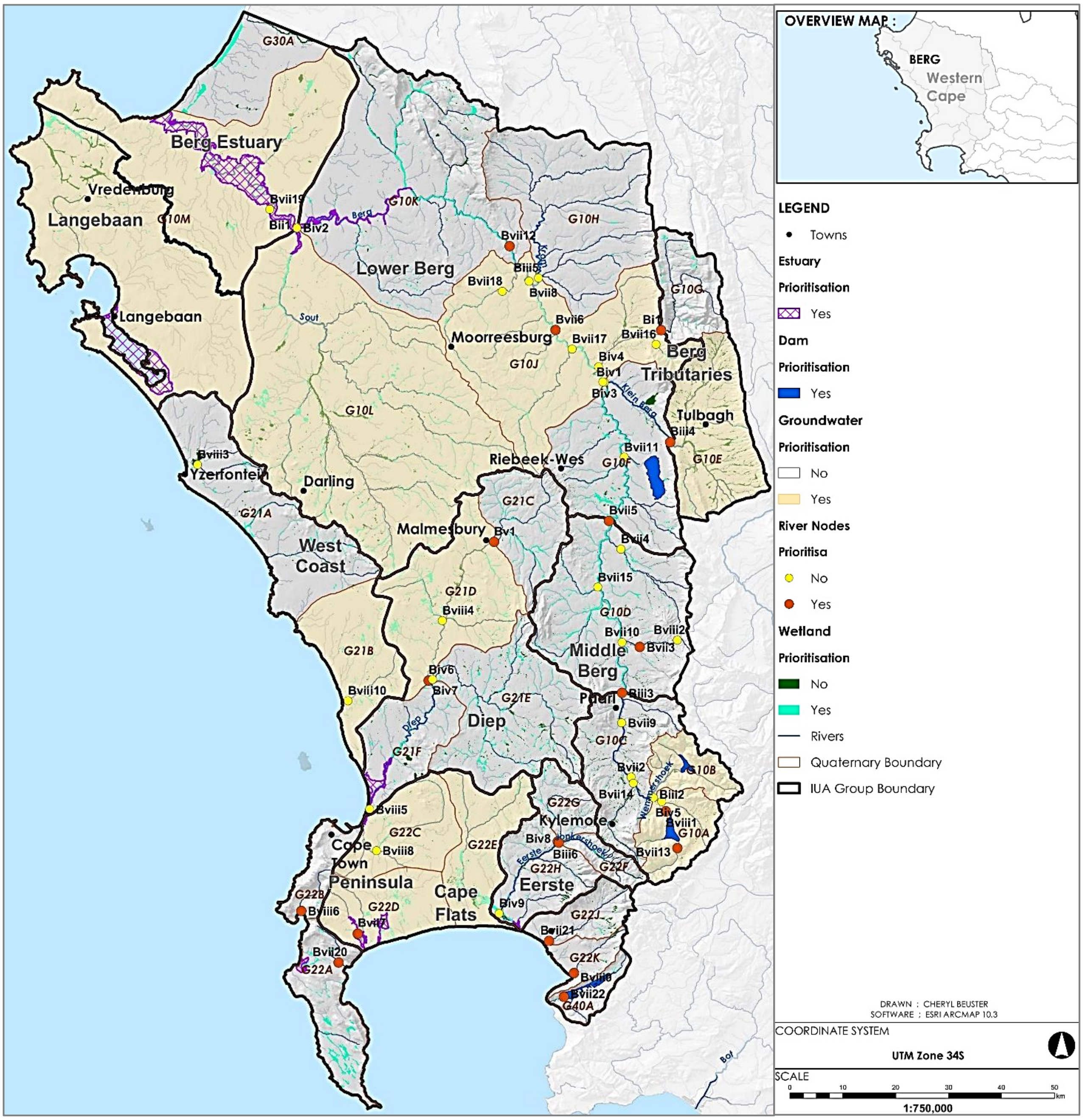

Figure 1-2 Summary of monitoring sites with defined Resource Quality Objectives (RQOs) for the Berg catchment including river nodes, estuaries, dams, wetlands, and quaternary groundwater units (DWS, 2019b: 121).

1.2. Terms of Reference

The Terms of Reference (TOR) for the study, as provided by the DWS CD: WEM, stipulates the 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, 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-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.

1.3. Aims 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) will be used. The GRDM manuals consulted for this report include WRC (2013), WRC (2007), as well as the preliminary findings from an ongoing review of RDM manuals by the Water Research Commission (WRC) to ensure GRUs are adequately assessed.

The aim of this report is to delineate aquifer-specific GRUs, select study sites (i.e., Step 2 of the eight-step GRDM: Reserve determination procedure) and, where appropriate, align with Step 1 of the 7 step GRDM: Water Resource Classification procedure set out in Regulation 2(4) and outlined in WRC (2013). **The Delineation of Groundwater Resource Units Report is Deliverable 3.1** of Phase 3 of this study (i.e., Reserve Determination). The report will provide an overview of the previously defined GRUs in the Berg catchment, outline the approach for delineating aquifer-specific GRU and provide detail around the criteria considered for selecting GRU boundaries and identifying areas for further investigation in the following Reserve determination steps. Selection criteria are outlined in **Section 3.1** and includes a description of the physical, management and functional criteria used to define GRU extents.

A detailed overview of the study approach and the scope of work is outlined in the projects Inception Report (DWS, 2022a) and summarised in **Table 1-1**.

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**
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

2. GROUNDWATER RESERVE DETERMINATION

2.1. Groundwater Reserve Determination Process

Regulation 2(4) of the NWA presents a legal framework for the effective and sustainable management of all significant water resources in South Africa (WRC, 2013). It must be noted that the NWA clearly includes groundwater in the definition of a "water resource" but the overall characteristics of groundwater may sometimes require a different resource management approach.

Through the implementation of the RDM and its obligation to achieve a balance between the protection, use, conservation, management and control of water resources, the RDM includes the Water Resource Classification Systems (WRCS), the Classification, the Reserve, and the Resource Quality Objectives (see **Figure 2-1**).

The Reserve (i.e., water "set aside" to provide for basic human needs and to sustain water ecosystems) is the only right to water in the NWA. It therefore has priority over all other water use and should be set as soon as the Class has been determined for each significant water resource. This is to say that the amount of water required for the Reserve *must* be met before water resources can be allocated to other water users. The requirements of the Reserve and all other demands on the water resource are covered by the determination of RQOs for priority sites (WRC, 2013).

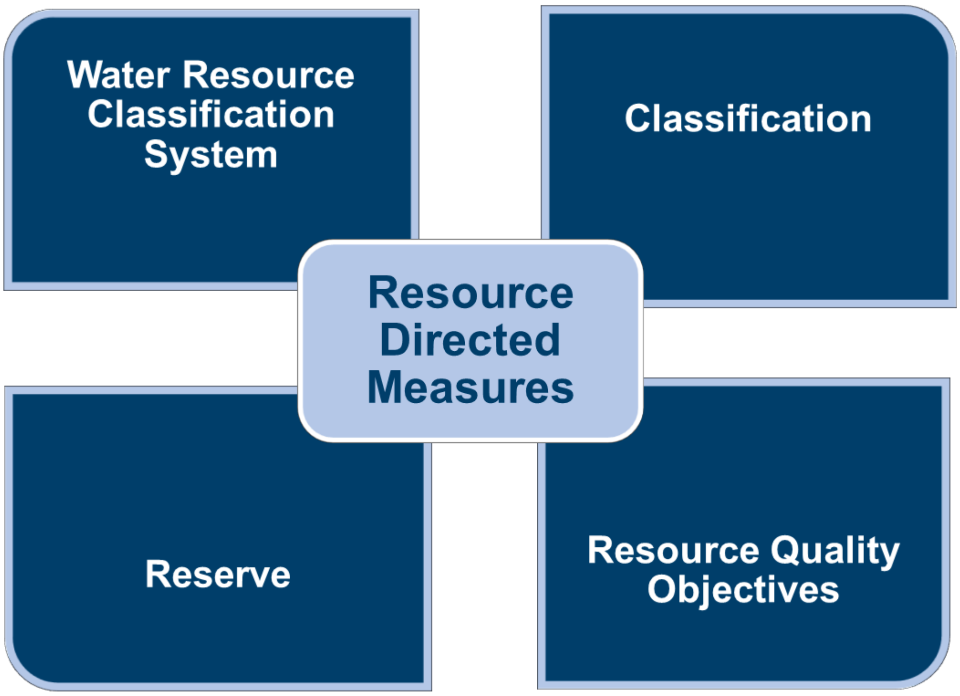

Figure 2-1 The four components of the Resource Directed Measures (RDM) as defined by Regulation 2(4) of the National Water Act (NWA; No. 36 of 1998).

2.2. Eight step procedure for determining the groundwater Reserve

The procedure for determining groundwaters contribution to the Reserve will follow the stepwise process outlined in the GRDM manual (WRC, 2013). This process is divided into eight steps (**Figure 2-2**) and is inter-linked with the GRDM: Classification procedure (**Figure 2-3**).

STEP 1	Initiate the BHN and EWR assessment.
STEP 2	Determine eco-regions, delineate RUs, select study sites and, where appropriate, align with Step 1 of the Water Resource Classification procedure set out in Regulation 2(4).
STEP 3	Determine the reference conditions, present ecological status (PES) and the ecological importance and sensitivity (EIS) of each of the selected study sites and, where appropriate, align with Step 2 of the Water Resource Classification procedure set out in Regulation 2(4).
STEP 4	Determine the BHN and EWR for each of the selected study sites and, where appropriate, align with Step 3 and 4 of the Water Resource Classification procedure set out in Regulation 2(4).
STEP 5	Determine operational scenarios and its socio-economic and ecological consequences, and, where appropriate, align with Step 5 of the Water Resource Classification procedure set out in Regulation 2(4).
STEP 6	Evaluate the scenarios with stakeholders and, where appropriate, align with Step 6 of the Water Resource Classification procedure set out in Regulation 2(4).
STEP 7	Design an appropriate monitoring programme.
STEP 8	Gazette and implement the Reserve.

Figure 2-2 **The 8-step procedure for determining the groundwater Reserve as defined by Regulation 2(4) of the National Water Act (NWA; No. 36 of 1998) and outlined in the Groundwater Reserve Determination Measures manual (GRDM; WRC, 2013).**

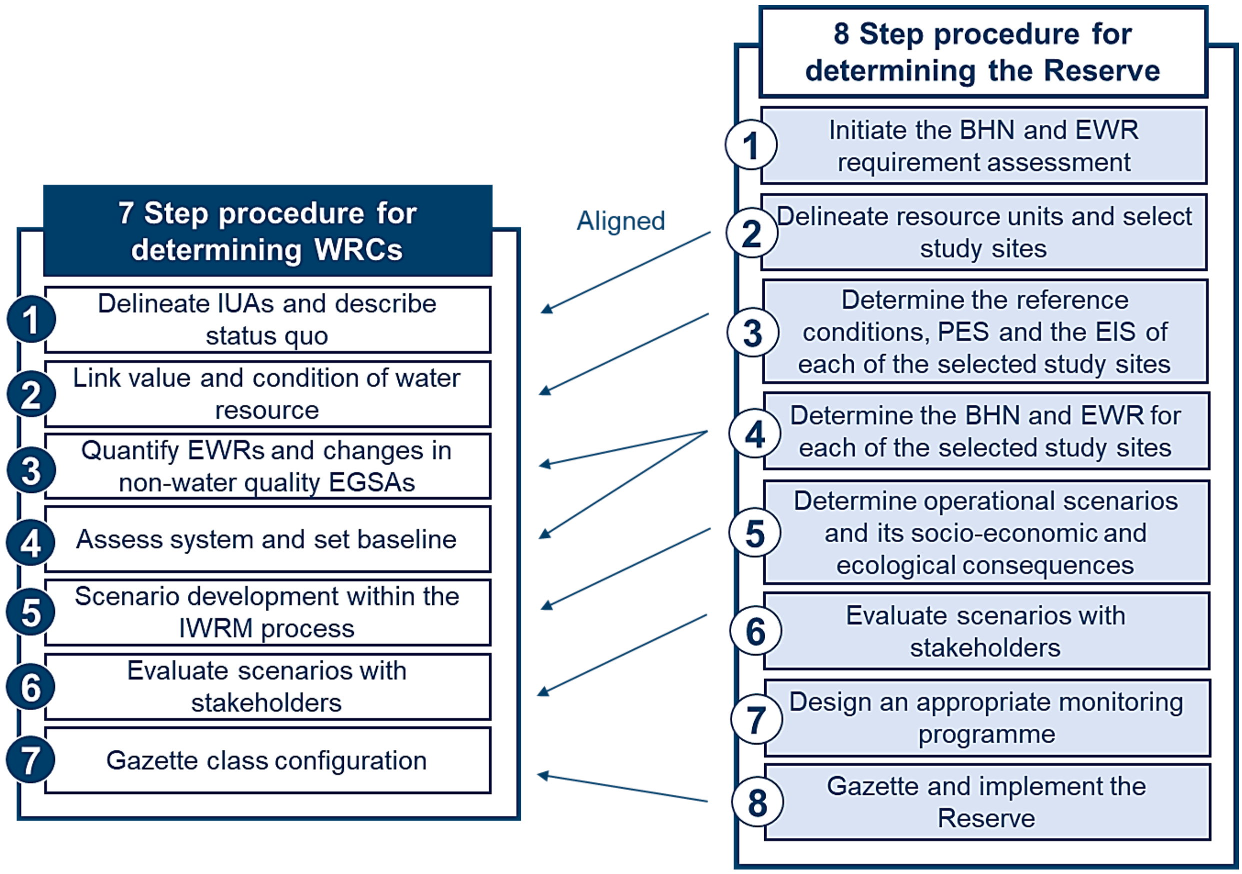

Figure 2-3 **The 8-step procedure for determining the groundwater Reserve and its alignment with the 7-step Water Resource Classification procedure as defined by Regulation 2(4) of the National Water Act (NWA; No. 36 of 1998) and outlined in WRC (2013).**

2.3. Previously Defined Groundwater Resource Units (GRUs)

As part of Step 1 of the 7-step GRDM procedure for the Water Resource Classification and the determination of RQOs for the Berg catchment (DWS, 2019b: 121), the GRU delineation approach considered previous hydrogeological delineations, as well as geological structures (fault zones, lithological contact zones and hydrostratigraphy), river systems, recharge and potential discharge zones, groundwater use, groundwater management (in terms of the size and extent of the units), and surface water divides on a quaternary and secondary catchment level scale.

The Berg Water Availability Assessment Study (WAAS) hydrogeological delineation (DWAF, 2007) was the largest contributor to the existing GRUs for the Berg catchment and formed the basis of the groundwater understanding in the DWS (2016) study in terms of GRU extents, aquifer types, aquifer characteristics, regional groundwater flow, recharge, and water quality and the overall conceptual understanding (see **Figure 2-4** and **Figure 2-5**).

Although DWS (2016d) considered geological controls, GRUs were primarily delineated according to surface water catchments with varying aquifer types grouped. A number of RUs were grouped into different sub-catchments in order to achieve the integration of both surface water and groundwater systems (see **Figure 2-5** and **Table 2-1**; DWS, 2016d). Additionally, important aquifers such as the Table Mountain Group Aquifers (TMGA) in the Steenbras area, that the City of Cape Town (CoCT) is currently developing, were not included in any of the existing GRUs defined as part of the DWS (2016) study.

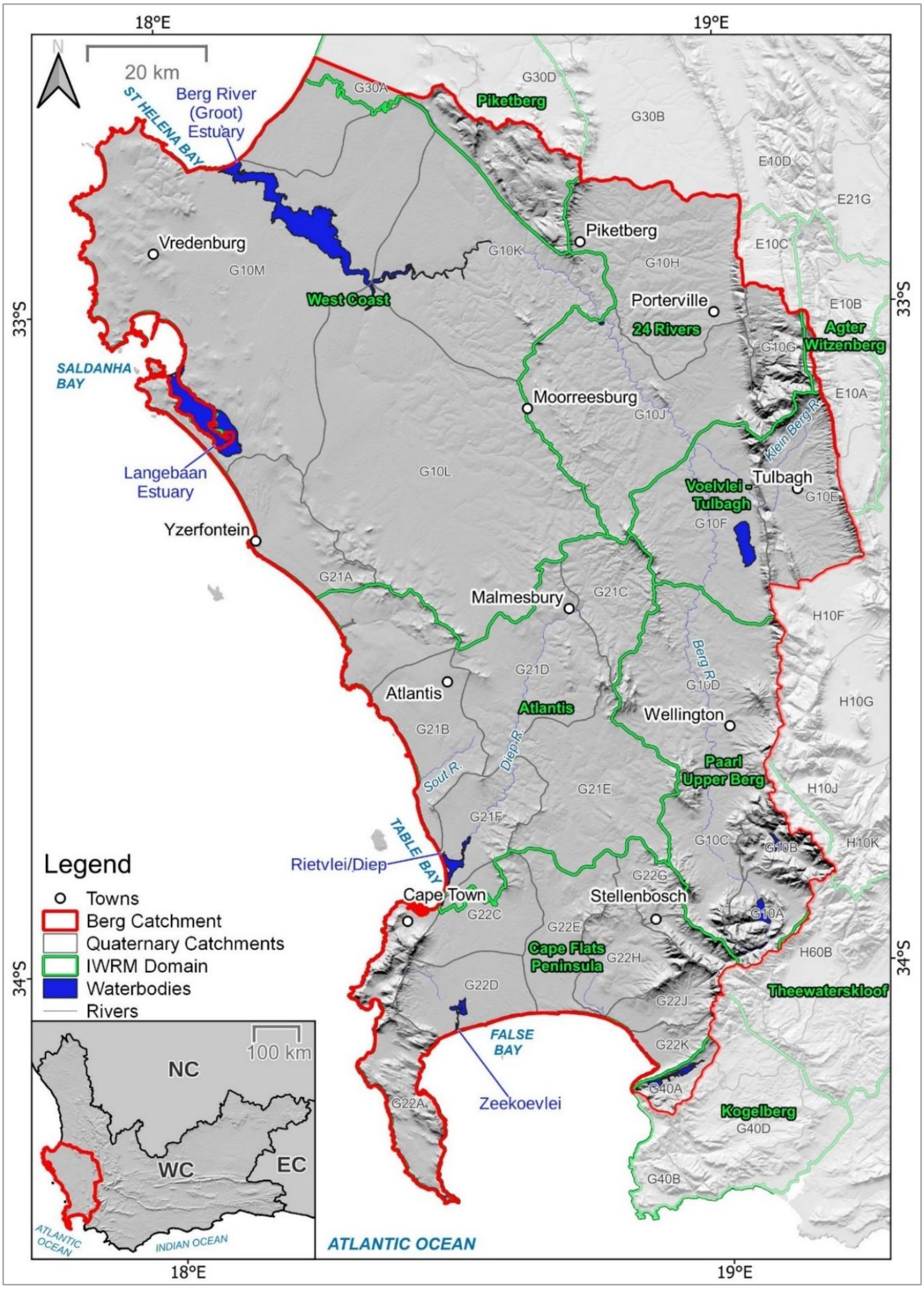

Figure 2-4 **Regional delineation of the Integrated Water Resource Management (IWRM) domains for the Berg catchment (from DWAF, 2007).**

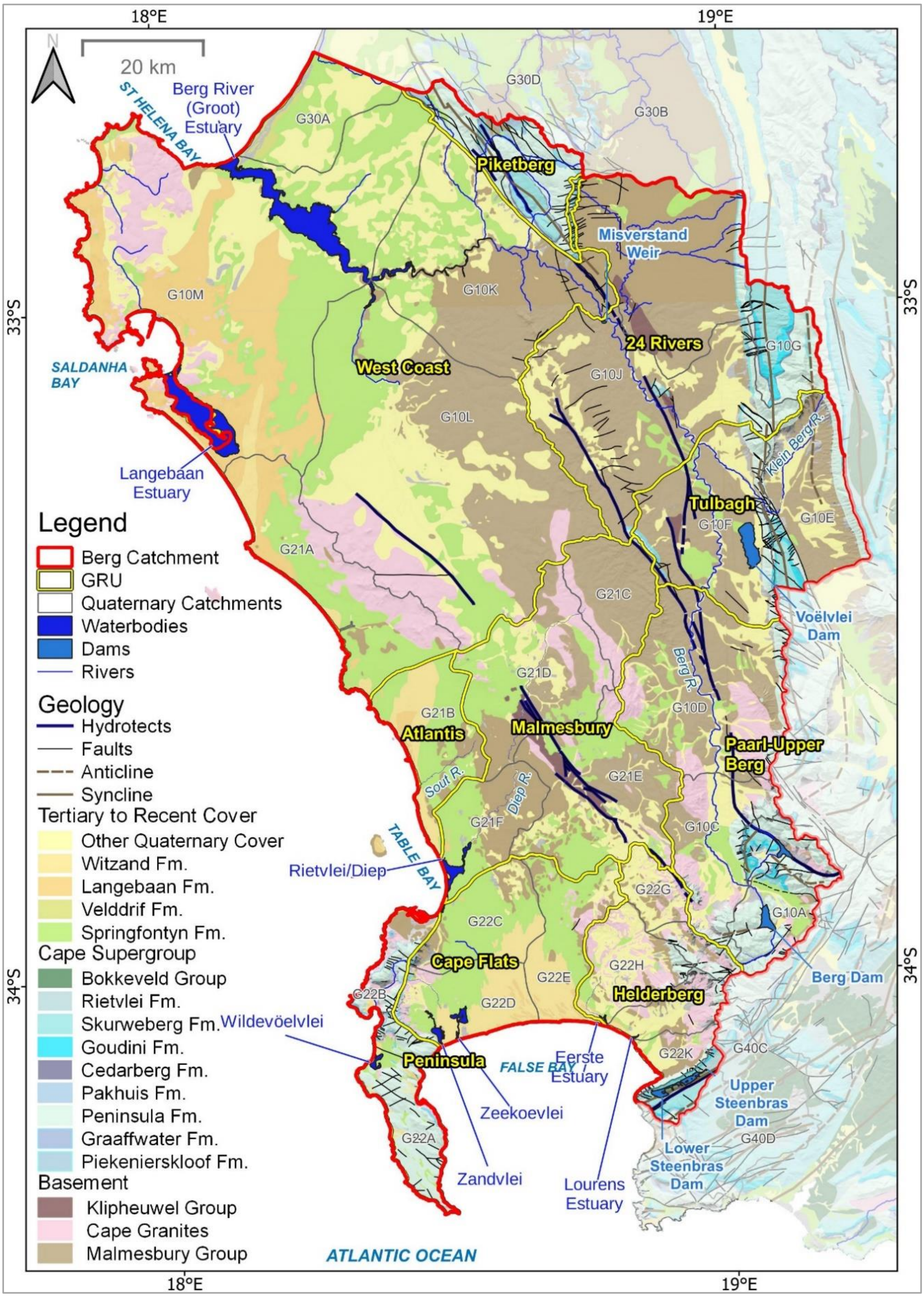

Figure 2-5 **Previously defined Groundwater Resource Units (GRUs) for the Berg catchment (from DWS, 2016d).**

Table 2-1 Summary of previously defined Groundwater Resource Units (GRUs) for the Berg catchment and the associated boundary-forming quaternary catchments (DWS, 2016d).

Sub-region	GRU	Associated Quaternary Catchment
Greater Cape Town	Peninsula	G22A and G22B
	Cape Flats	G22C; G22D and G22E
	Helderberg	G22G; G22H; G22K; G22J and G22F
Upper Berg	Paarl- Upper Berg	G10A; G10B; G10C and G10D
	Tulbagh Valley	G10E and G10F
	24 Rivers	G10G; G10H and G10J
Lower Berg	Piketberg	G30A; G30D and G10K
	West Coast	G10K; G10M; G10L; G21A and G30A
	Atlantis	G21B
	Malmesbury	G21C; G21D; G21E and G21F

3. GROUNDWATER RESOURCE UNIT DELINEATION

As noted in **Section 1.3**, the aim of this report is to delineate aquifer-specific GRUs, select study sites (Step 2 of the eight-step GRDM: Reserve determination procedure) and, where appropriate, align with Step 1 of the 7 step GRDM: Classification procedure outlined in WRC (2013).

3.1. GRU delineation and study site selection methodology

DWS (2019: 121) and the supporting study's reports (DWS, 2016a-e, 2017a-d, 2018a-e and 2019a) have identified social economic zones, IUAs and surface water RUs (i.e., Step 1 of the 7 step RDM: Classification), therefore this process will not be redone but will rather be used to build on the existing RU delineation understanding (see **Figure 1-1** and **Figure 1-2**). GRUs have also been delineated (see **Figure 2-5**) as part of the DWS (2016) study, but considering the high confidence requirements of this study and the TORs provided by the DWS CD: WEM, the current GRU delineation will be re-evaluated and refined (if required) to ensure that groundwater resources are fully encompassed and are aquifer specific. The geology of the Berg catchment is the dominating control on the topography, recharge (in terms drainage and the orogenic control over precipitation) and groundwater chemistry. Based on the complexity and varying geological characteristics of the different aquifers in the study area (i.e., the Sandveld Group, the Table Mountain Group (TMG) and the basement aquifers), as well as the strong compartmentalization of the TMG due to major faults or fault zones, most of the aquifers in the region cross quaternary catchment boundaries and therefore do not correlate with the existing GRU extents.

Three overarching criteria including, physical, management and functional criteria will be used to re-delineate aquifer specific GRUs for the Berg catchment to meet the high confidence requirements of this study. The overall approach involves delineating the physical aquifer geometry (which is predominantly controlled by geology), assessing recharge areas, using a conceptual understanding of the aquifer boundary conditions (i.e., where water enters, namely recharge, flows through, and exits the systems, such as springs, rivers, lakes and dams), as well as considering various functional and management criteria, including existing Water Resource Classes, existing RQO sites, Strategic Water Source Areas (SWSAs), groundwater use and aquifer reliance, and the contribution of groundwater to baseflow (see **Sections 3.1.1 - 3.1.3** below).

3.1.1. Physical Criteria

Geological and hydrogeological maps (1:50 000 to 1: 250 000) are the foundational input for the delineation of aquifer extents and therefore form the basis for delineating the aquifer-specific GRUs required for this study (see **Figure 3-1**). Most of the Berg catchment is underlain by the Klipheuwel and Malmesbury Groups, comprising of typically argillaceous greywackes and shales. These basement rocks were intruded by the Cape Granite Suite which mainly occurs as plutons such as the Paarl, Perdeberg and Darling plutons. Following the Cape Granite Suite intrusion, a long period of uplift and erosion resulted in the deposition of sandstones which form the TMG, particularly the Peninsula and Skurweberg formations that form the escarpments (Table Mountain, Hottentot Mountains etc.) of the area due to the erosion resistant quartzites. These formations form deep fractured rock aquifers (specifically the Peninsula and Nardouw [Skurweberg and Rietvlei formations] Aquifers). Further erosion of these formations, particularly the softer Malmesbury Group which forms eroded valleys, resulted in the deposition of sediments in the western and coastal portion of the catchment (see **Figure 3-1**). These sand deposits comprise the Bredasdorp Group, Sandveld Group and Quaternary age deposits that form major primary sedimentary / intergranular aquifers such as the Cape Flats Aquifer (CFA), Atlantis/Silwerstroom aquifers, and the West Coast aquifers (Yzerfontein, Adamboerskraal, Elandsfontein and Langebaan Road aquifers).

Based on the geology, three types of aquifers are encountered in the Berg catchment (see **Figure 3-2**), namely primary or intergranular aquifers (often extremely high yielding but are vulnerable to contamination due to their unconfined nature and high infiltration rates), fractured aquifers (often confined and high yielding with good water quality), and fractured and intergranular (basement) aquifers (often low yielding weathered aquifers with poor water quality, unless a particular fault/fracture (see the hydrotects denoted in **Figure 3-1**) is intersected with a higher groundwater potential (DWAF, 2008a, b; WRC, 2018).

Other physical criteria considered during the GRU delineation include existing aquifer boundaries from previous studies (see DWS, 2022b: Appendix A), topography, structural geology (**Figure 3-1**; major faults, folds and hydrotects), aquifer boundary conditions (i.e., where water enters, flows through and exits the groundwater systems), the orogenic control over precipitation (**Figure 3-3**), recharge (**Figure 3-4**), preferential groundwater flow directions and potential discharge points (**Figure 3-5** and **Figure 3-6**). The Berg WAAS study (DWAF, 2007) calculated recharge using various techniques (see DWAF, 2008b) which produced similar but nuanced results, particularly in the orographic (TMGA) and Sandveld coastal recharge regions. In these areas, varying models either overestimated or underestimated recharge. Recharge will be reassessed in steps 3 - 5 of this project (i.e., determining the reference conditions, PES and EIS, determining the BHN and EWR Reserve and, and determining operational scenarios and its socio-economic and ecological consequences for the study area).

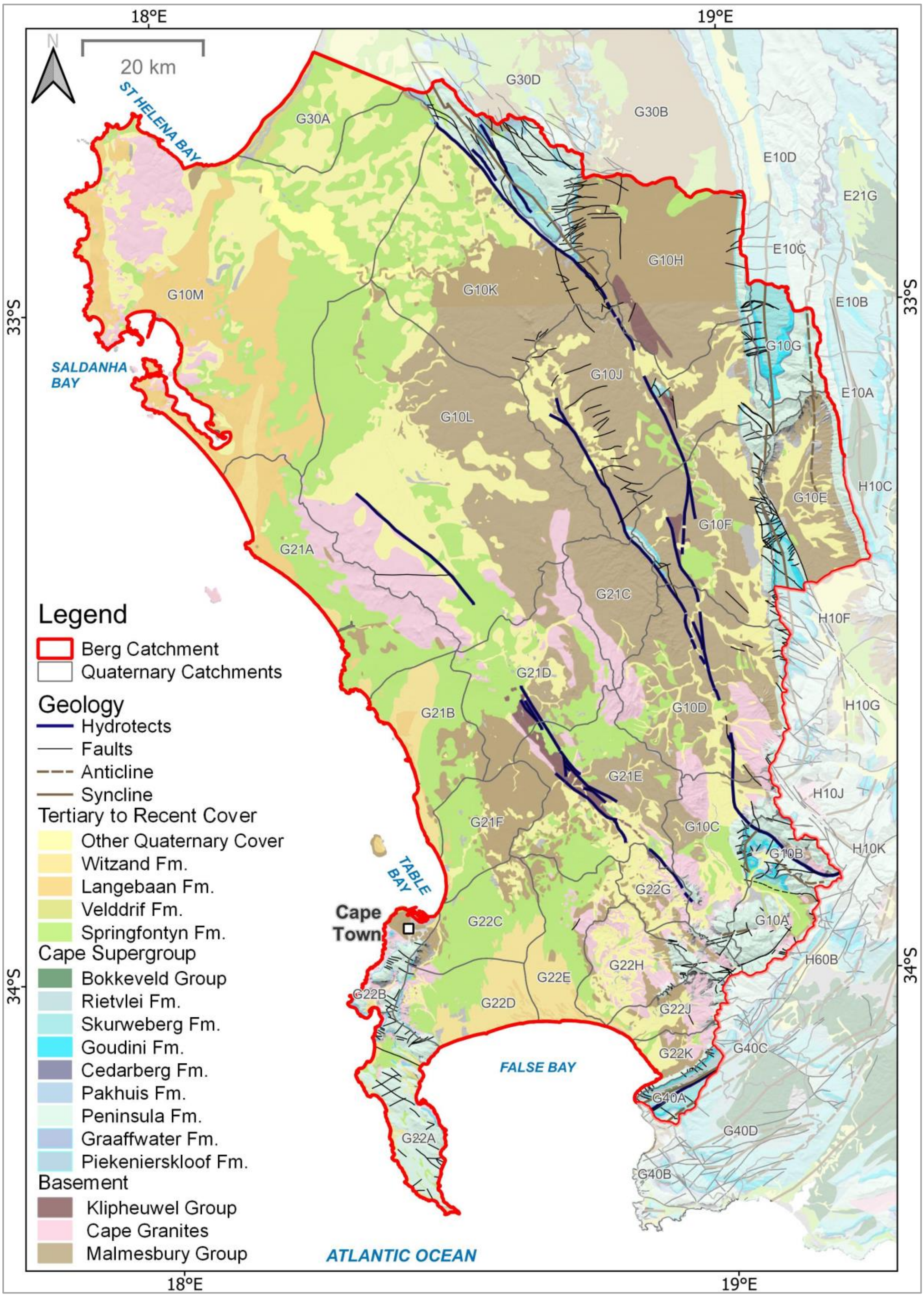

Figure 3-1 Geological map of the Berg catchment including major hydrogeologic structures (Theron et al., 1992).

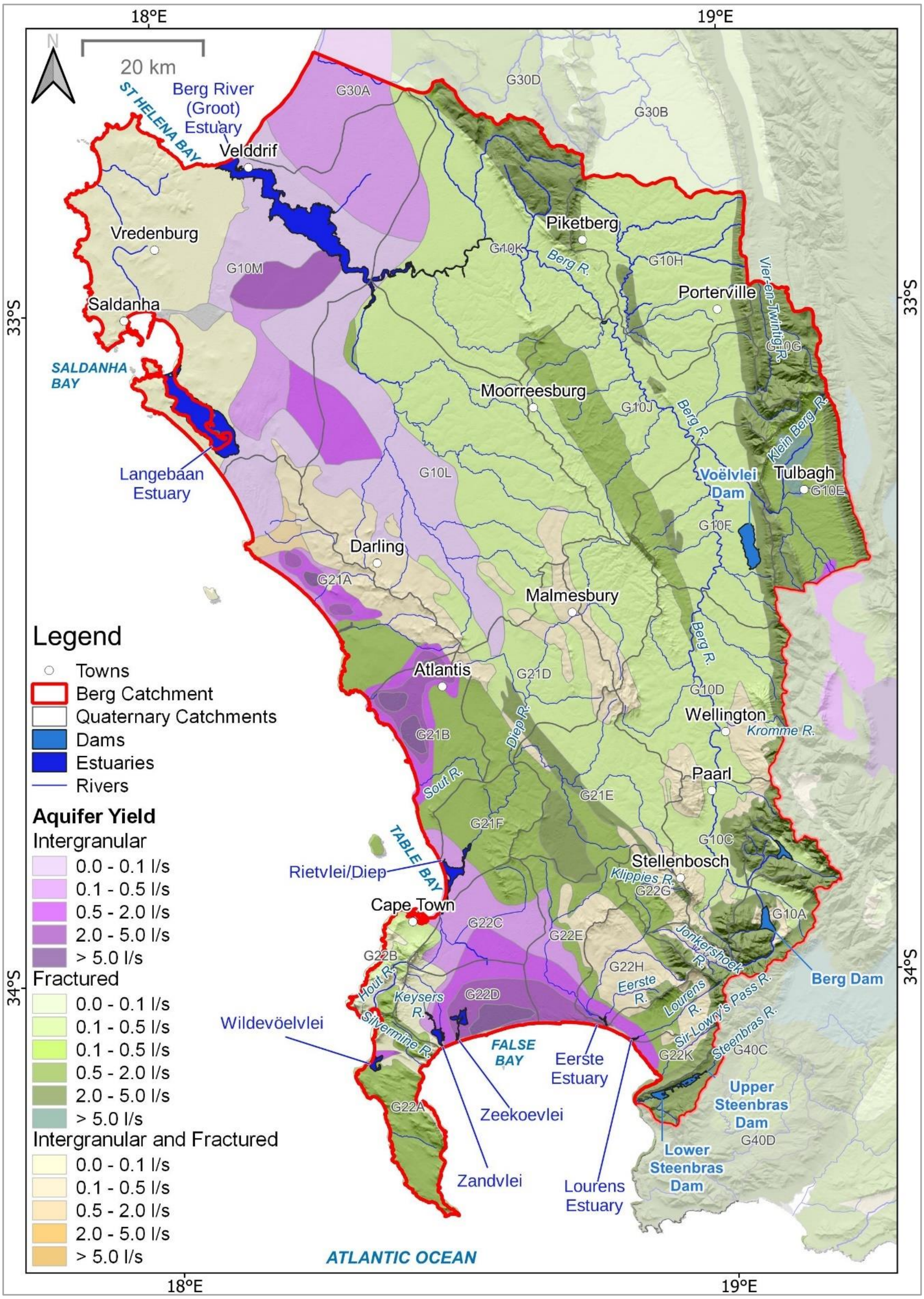

Figure 3-2 **Aquifer type and borehole yield class (median l/s, excluding dry boreholes). Coverage from the 1:500 000 Hydrogeological Map series of South Africa (DWAF, 2020), including major hydrological features for the Berg catchment.**

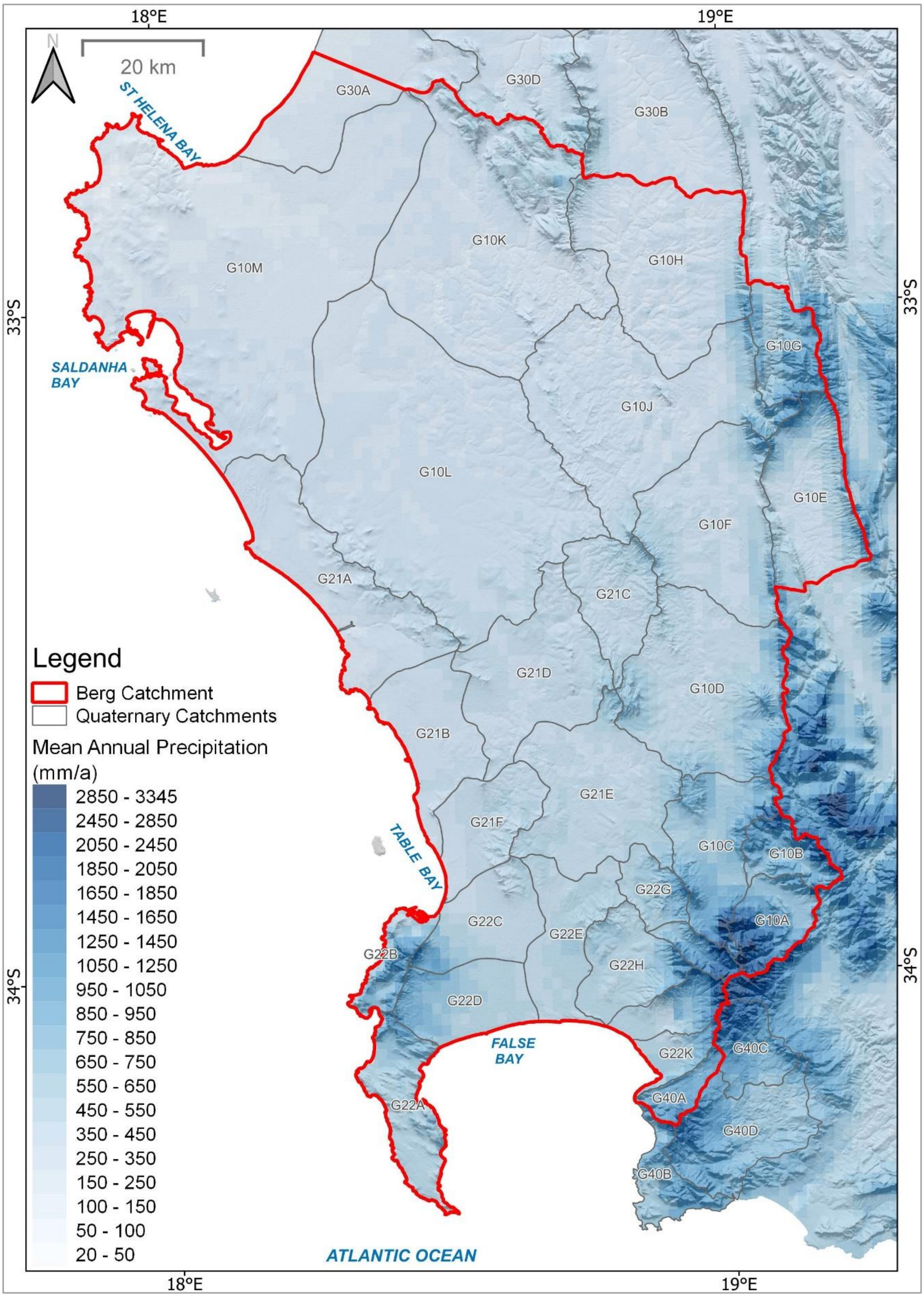

Figure 3-3 **Map of Mean Annual Precipitation (MAP) in and around the Berg catchment (from WRC, 2012).**

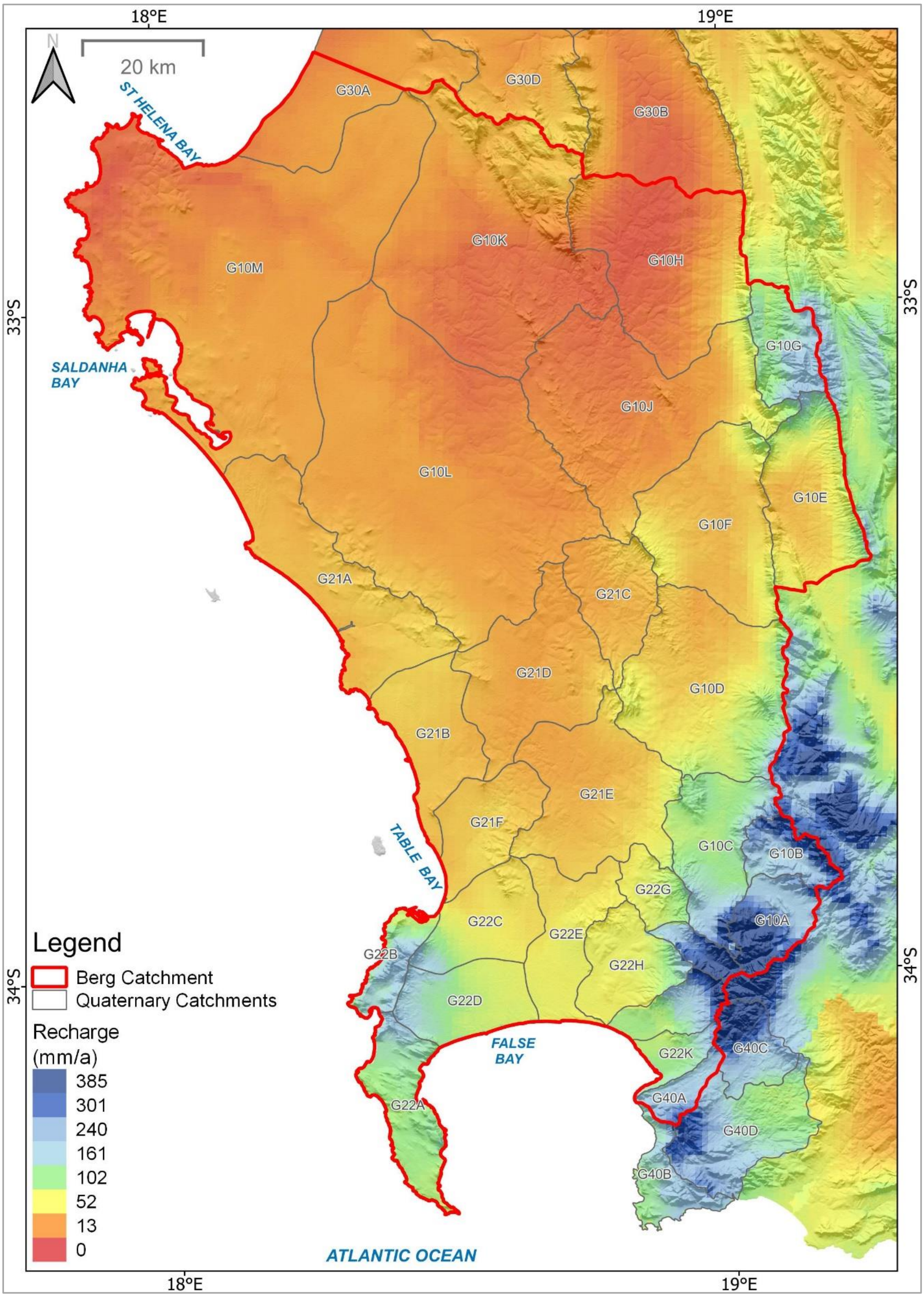

Figure 3-4 **Calculated recharge (mm/a) using the GRAII method for the Berg catchment (from DWAF, 2006).**

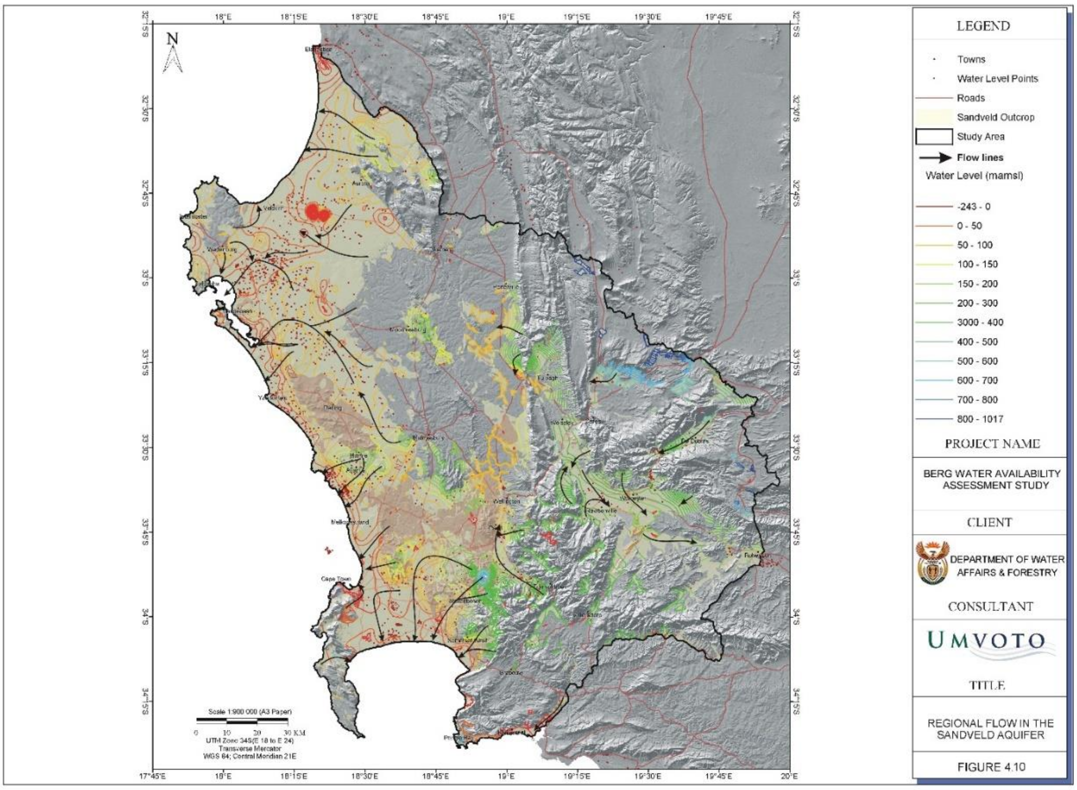

Figure 3-5 **Preferential groundwater flow paths for the primary / intergranular aquifers of the Berg catchment (DWAF, 2007).**

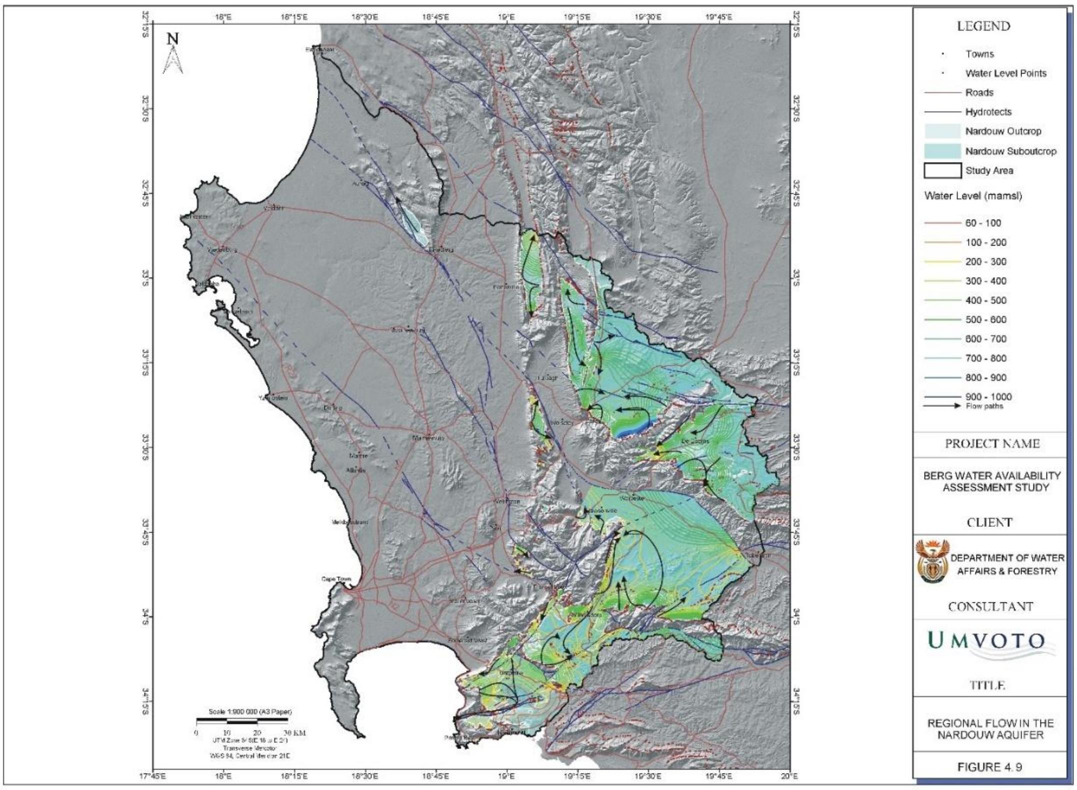

Figure 3-6 **Preferential groundwater flow paths for the Table Mountain Group Aquifers (TMGA) of the Berg catchment (DWAF, 2007).**

3.1.2. Management Criteria

The NWA clearly includes groundwater in the definition of a water resource, however, due to groundwaters characteristics, it requires a different management approach. Groundwater contributes to surface water flows and therefore the volume of groundwater that could sustainably be abstracted without impacting the ability of the groundwater to maintain or contribute to surface water RQOs must be considered when determining the groundwater Reserve.

In most cases, GRUs cannot be delineated based on physical criteria alone and must consider one or more groundwater management criteria, such as existing RQOs defined for prioritised surface water and groundwater resource units (see **Figure 3-7**; i.e., EWR sites and prioritised groundwater units), existing IUAs and Water Resource Classes (see **Figure 3-8**; Class I [high environmental protection and minimal utilization], Class II [moderate protection and moderate utilization], or Class III [sustainable minimal protection and high utilization]), Strategic Water Source Areas for groundwater (SWSAgw; see **Figure 3-9**) that are of national importance for South Africa, current and future aquifer reliance (**Figure 3-10**), Subterranean Government Water Control Areas (SGWCAs; see **Figure 3-10**), and overall groundwater use and inferred aquifer stress (**Figure 3-11**).

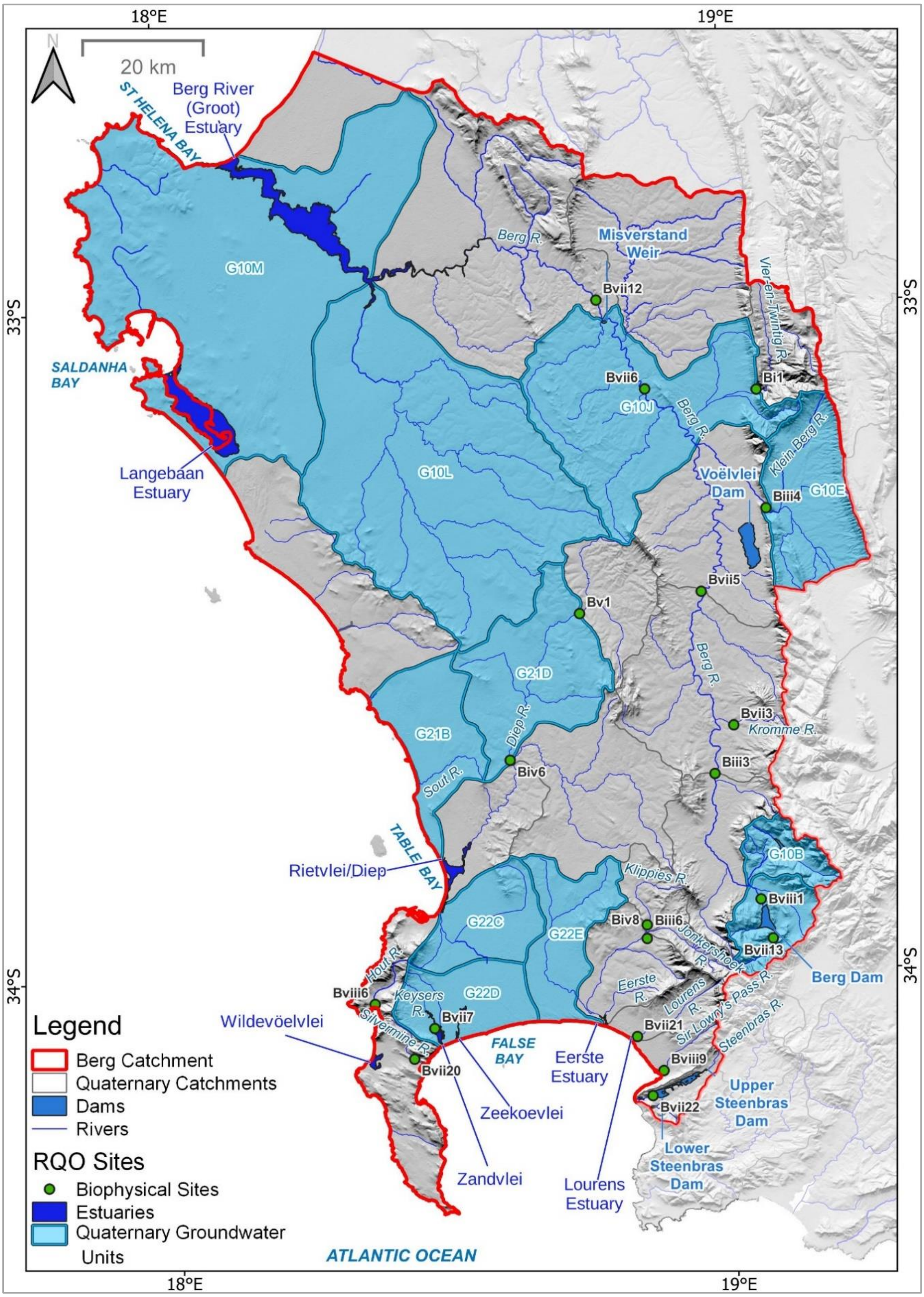

Figure 3-7 **Quaternary catchments with gazetted groundwater Resource Quality Objectives (RQOs) and biophysical sites (rivers nodes and estuaries nodes) with gazetted RQOs for the Berg Catchment (from DWS, 2019b: 121).**

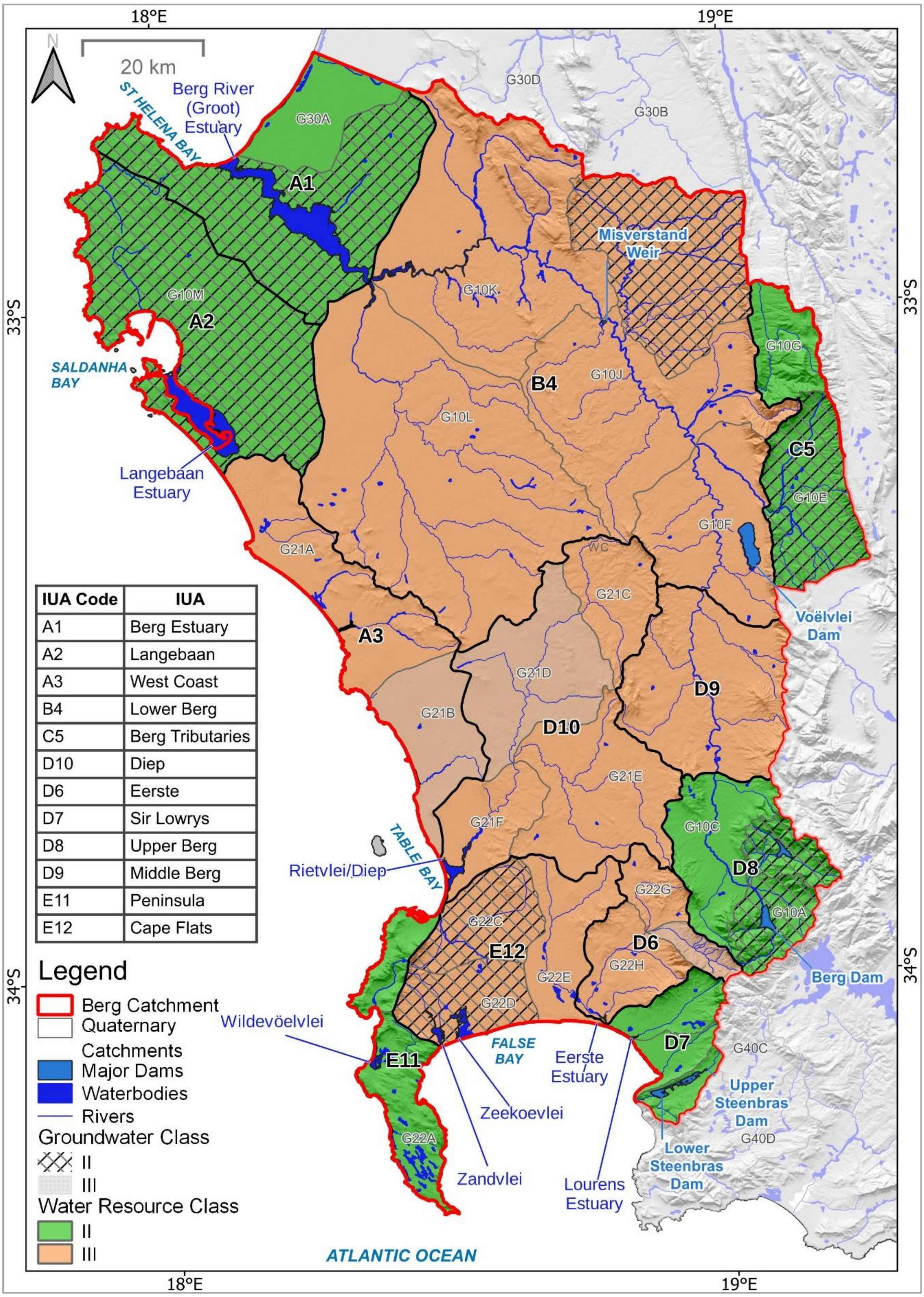

Figure 3-8 Integrated Units of Analysis (IUAs), Water Resource Classes and Groundwater Classes for the Berg catchment (DWS, 2019b: 121).

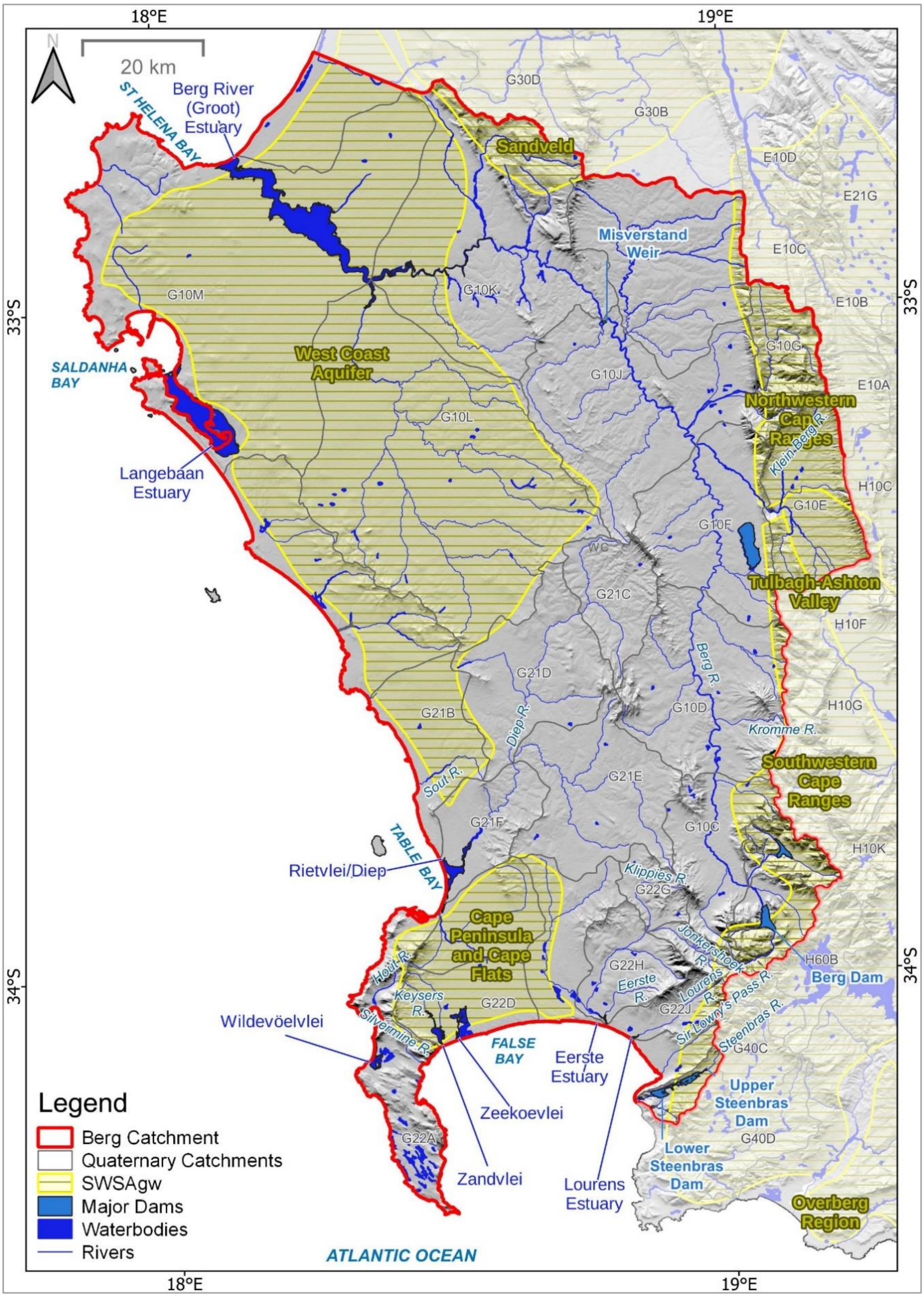

Figure 3-9 Outline of Strategic Water Source Areas for groundwater (SWSAgw) that are of national importance for South Africa (from WRC, 2018).

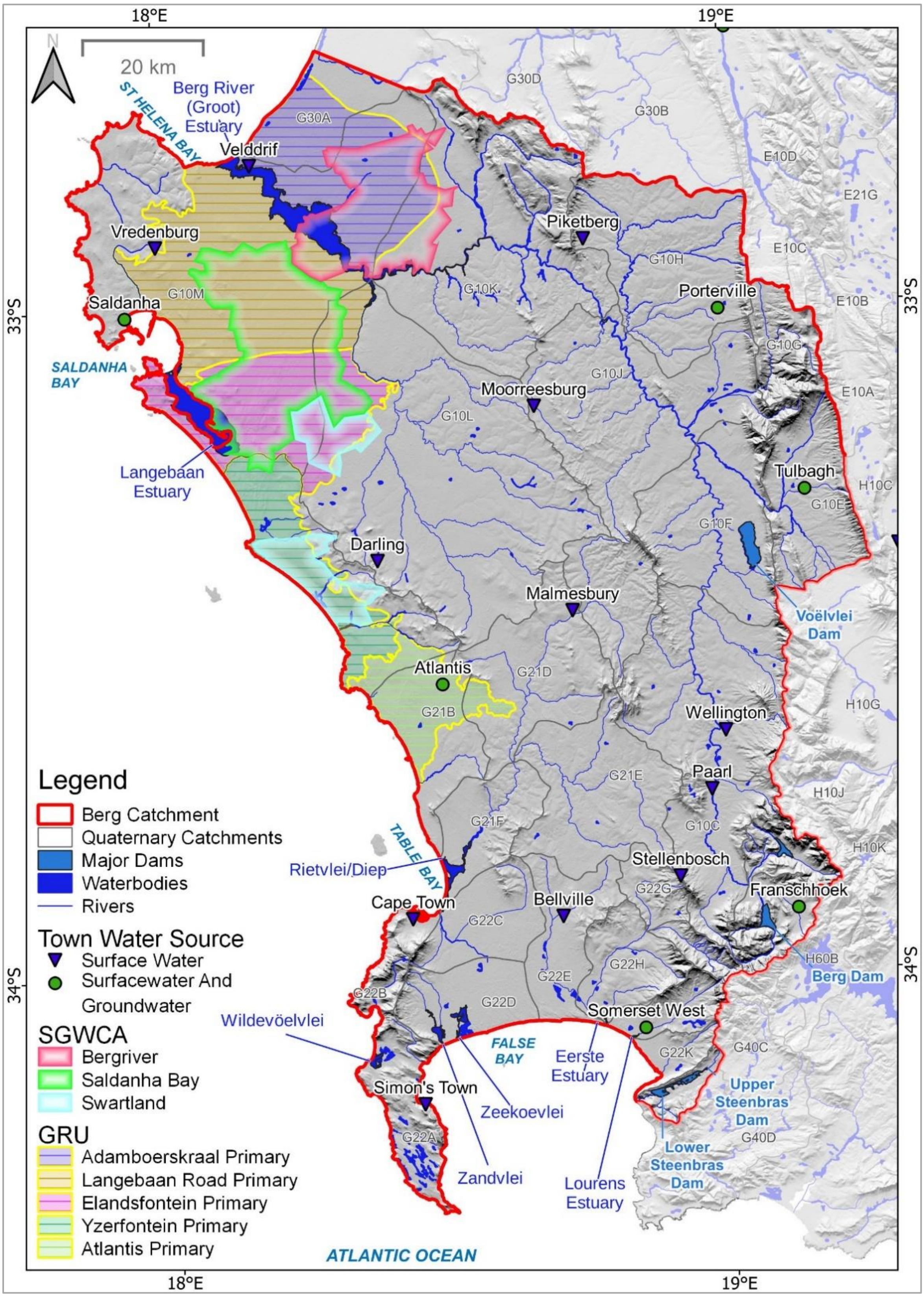

Figure 3-10 **Extents of utilised GRUs that are of current importance for the potable water supply in the Berg catchment which are indicated by the Subterranean Government Water Control Areas (SGWCA; from DWS, 2021).**

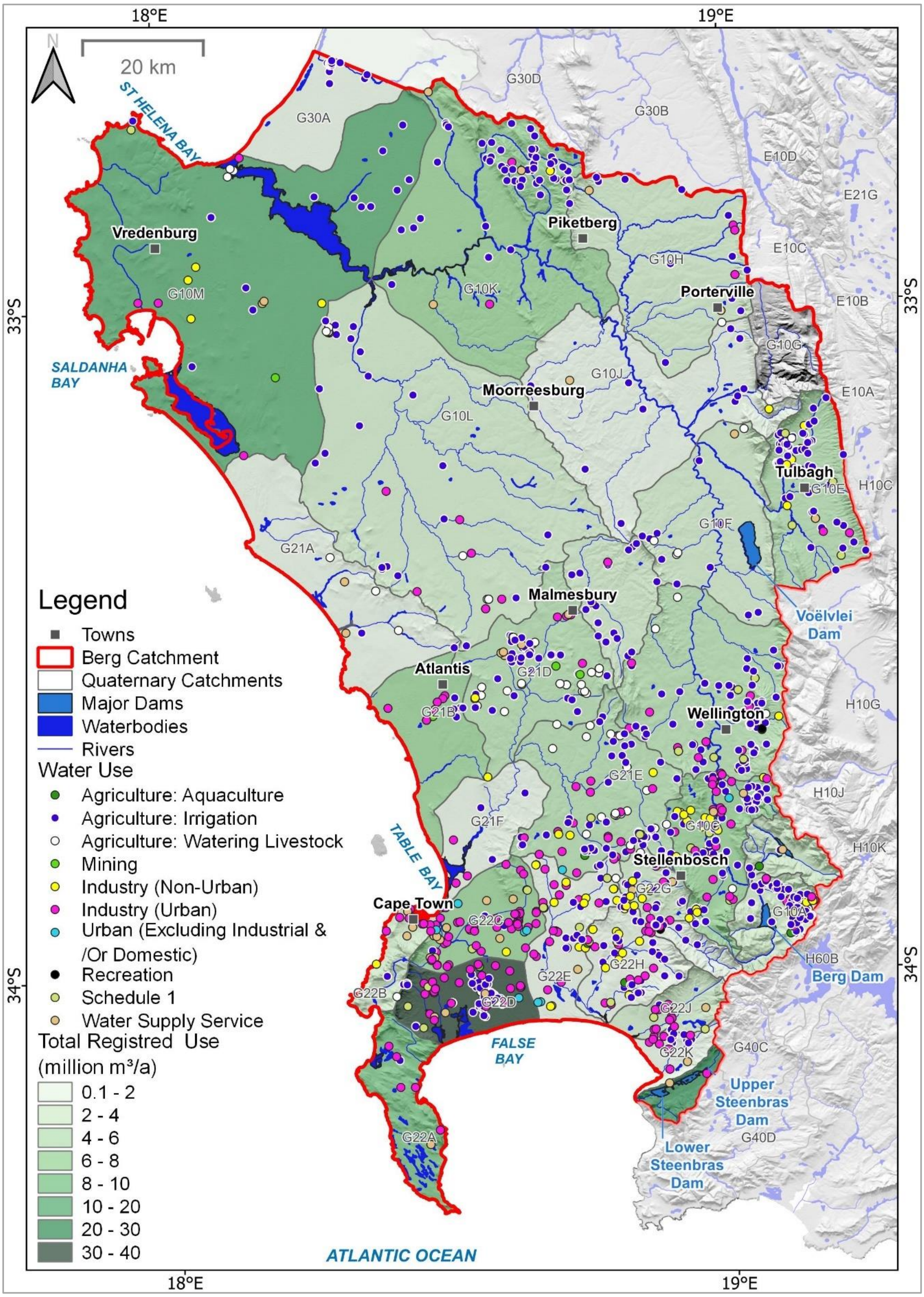

Figure 3-11 Map of all active/licenced WARMS groundwater registrations in the Berg catchment.

3.1.3. Functional Criteria

As part of the TORs provided by the DWS CD: WEM for this study, the Reserve determination must consider the requirements (in terms of quantity and quality) to satisfy BHN and to protect aquatic ecosystems in different priority RUs within the Berg catchment. It is therefore important to consider the role of groundwater in sustaining the hydrological and ecological functioning of the water resource systems by accounting for groundwater-surface water interactions (i.e., groundwater contribution to baseflow, and its role in maintaining hydrological integrity, discharge integrity and ecological conditions e.g., groundwater-dependent wetlands).

Although Wetland Resource Units (WRUs; DWS, 2016d) have been identified and were assessed as part of the DWS (2016) study, no distinction was made for groundwater fed wetlands, applicable to the groundwater contribution to the Reserve, and it seems that a number of smaller but ecologically sensitive and relevant wetlands (mainly associated with the TMGA) were not included in the assessment.

The hydrological controls and groundwater dependency of surface water bodies (i.e. rivers, wetlands and estuaries) have not yet been established at this phase of the project and therefore will not be used as part of the GRU delineation criteria. This will be addressed in steps 3 and 4 of the 8-step procedure for determining the groundwater Reserve (see **Section 2**).

3.2. Updated Groundwater Resource Units

The revised aquifer-specific GRUs are outlined per aquifer type (see **Figure 3-12**) in **Table 3-1** (Primary/ Intergranular), **Table 3-2** (Fractured TMG), **Table 3-3** (Fractured and Intergranular Basement). It is important to note that in defining new GRU extents, the study boundary now extends outside of the Berg catchment (a surface water catchment divide) to fully encompass the hydrogeological nature of all GRUs. **Table 3-4** and **Table 3-5** presents a summary of important management criteria, associated with each GRU, that need to be considered in the next steps of the groundwater Reserve determination.

Table 3-1 Summary of Primary/Intergranular GRUs for the Berg catchment. Areal extent of GRUs are shown in Figure 3-12.

GRU Name	Approximate Quaternary Catchment associations	Notes on boundaries
Cape Flats	G22C, G22D and G22E	The CoCT (2020a) aquifer model boundary was used to define the extent of the Cape Flats GRU. The aquifer model used a slope separation (<2 degree) of the Cape Flats and the adjacent hills and mountains, as well as an interpolated geological extent of the basement (i.e., the Cape Granite Suite and the Malmesbury Group) on the periphery of the GRU. The GRU is bound by the False Bay coastline in the south.
Atlantis	G21A, G21B and G21D	The CoCT (2020b) aquifer model boundary was used as the extent of the Atlantis GRU. The aquifer model boundary used areas of marginal thickness (0 m) (i.e., where the aquifer pinches out) as the basis of the aquifer extent. The boundary was then further refined using the outcrop extent of the low permeability basement lithologies (i.e., the Malmesbury Group and the Cape Granite Suite) in the northeast and southeast. The Modder and Louwskloof rivers bound the northern extent of the GRU, with the Sout River bounding the southwest extent, and the coastline bounding the western edge. Preferential flow directions (towards the coastline in the eastern edge of the GRU) were also considered when defining the boundary of the GRU.
Yzerfontein	G21A	The Yzerfontein GRU is bound by the CoCT (2020) Atlantis aquifer model boundary in the south, as well as the Cape Granite Suite outcrop and the Modder River along the south/south-eastern edge. The divide between the Yzerfontein GRU and the Elandsfontein GRU is between the G10M and G21A surface water quaternary catchment and considers the south-westerly preferential flow and discharge direction. It is noted that there is a hydraulic connection between the two aquifers. The coastline bounds the western edge of the GRU.
Elandsfontein	G10M and G10L	The Elandsfontein GRU is bound by the extent of the Springfontyn Formation in the east (including portions of the Sout River), as well as by an interpolated extent of the Cape Granite Suite outcrop to south. The Yzerfontein and Elandsfontein GRU share the surface water quaternary catchment divide at G10M and G21A, which considers the south-westerly preferential flow direction and discharge. The divide between the Elandsfontein and Langebaan Road GRU is based on an inferred basement high (i.e., Malmesbury Group and Cape Granite Suite) which extends from the eastern edge of the GRU towards the coast. However, it is noted that there might be a hydraulic connection between the Elandsfontein and Langebaan Road aquifers. The coastline bounds the western edge of the GRU.
Langebaan Road	G10M and G10L	The north-western extent of Langebaan Road GRU is bound by the interpolated extent of the Cape Granite Suite outcrop. The divide between the Elandsfontein and Langebaan Road GRU is based on an inferred basement high (i.e., the Malmesbury Group and the Cape Granite Suite) which extends from the eastern edge of the GRU towards the Saldanha Bay coast. The Berg and Sout River bound the eastern and south-eastern edge of the GRU, with the Saldanha Bay and St Helena Bay coastline's bounding the western and northern edge respectively. Preferential flow direction (towards Saldanha Bay) was also considered when defining the boundary for the GRU.
Adamboerskraal	G10M, G10K and G30A	The Adamboerskraal aquifer model boundary (SRK, 2004) was used as the extent of the GRU. The Berg River bounds the south-western edge, with the eastern/southern boundary defined by an interpolated basement lithology extent (i.e., the Malmesbury Group and the Cape Granite Suite overlain by a thin layer of the Springfontyn formation) as well as the north-westerly preferential flow direction (i.e., at the Berg River Estuary). The St Helena Bay coastline bounds the north/north-western edge of the GRU.

Table 3-2 Summary of fractured Table Mountain Group GRUs for the Berg catchment. Areal extent of GRUs are shown in Figure 3-12.

GRUs	Approximate Quaternary Catchment associations	Notes on boundaries
Cape Peninsula	G22A, G22B, G22C and G22D	The Cape Peninsula GRU is bound by the extent of the TMG outcrop (mostly Peninsula Formation, overlying the Cape Granite Suite along the length of the Cape Peninsula GRU, and the Malmesbury Group under the City Bowl and Devils Peak) which includes scree aprons occurring on the slopes of the mountains, especially around Table Mountain. The Atlantic and False Bay coastlines bounds the western and eastern extent of the GRU respectively.
Steenbras-Nuweberg	G40B, G40A, G40D, G22J, G22K, H60A and G40C	The CoCT (2021) aquifer model boundary was used as the extent of the Steenbras-Nuweberg GRU. It is bound by TMGA outcrop in the Steenbras and Theewaterskloof areas, the La Motte Fault in the northern recharge area (DWAF,2008a; CoCT, 2004), and the Kogelberg and Stettyns anticlines (including portions of the G40A surface water catchment boundary) on its eastern edge. The northern extent of the GRU is bound by the extent of interpolated basement lithologies (including the Malmesbury Group and the Cape Granite Suite outcrop) and the False Bay coastline in the west.
Drakensteinberge	G10A, G10C, G22F, G22J, H60A and H60B	The Drakensteinberge GRU is bound TMG outcrop (mostly Peninsula Formation, and portions of Skurweberg, Goudini, Cedarberg, and Pakhuis formations) as well as the Lourens River in the southwest. The La Motte Fault bounds the southern extent of the GRU (DWAF, 2008a; CoCT, 2004).
Wemmershoek	G10B, G10A, G10C, H10J, H60B and H10K	The Wemmershoek GRU is bound by the TMG extent and its contact with the basement lithologies (the Cape Granite Suite and the Malmesbury Group) of the Franschhoek valley and Stettyns anticline in the east. The GRU is also bounded by the Du Toits/Wellington fault (DWAF, 2008a) in the north (DWAF, 2008a) as well as the La Motte fault/basement aquitard in the south.
Voëlvlei-Slanghoek	G10E, G10J, G10D, G10F, H10E, H10F and H10J	The Voëlvlei-Slanghoek GRU is bound by the TMG extent and its contact with the basement lithologies (Klipheuwel Group, Cape Granite Suite, and Malmesbury Group) on both the western and eastern/north-eastern edge of the GRU. In the north, the Voëlvlei-Slanghoek GRU is separated from the Groot Winterhoek GRU by the Roodezandspas Fault. The eastern/south-eastern fringe is bound by the Stettyns and Koue Bokkeveld anticline and portions of the Du Toits/Wellington fault.
Witsenberg	G10E	The western extent of the Witsenberg GRU is bound by the extent of the TMG (predominantly Peninsula Formation) and its contact with the basement lithologies (Malmesbury Group). The extent of the Berg catchment bounds the eastern and southern fringe, with the G10G surface water quaternary catchment divide bounding the northern portion of the GRU.
Groot Winterhoek	G10J, G10E, G10H, E10C and G10G	The Groot Winterhoek GRU is bound by the extent of the TMG and its contact with the basement lithologies on its western flank (Malmesbury Group). The southern boundary, and its separation from Voëlvlei-Slanghoek and the Witsenberg GRUs, are defined by the Roodezandspas Fault line, the contact with the Malmesbury Group basement, and portions of the G10G surface water quaternary catchment divide. Sections of the E10C surface water quaternary catchment divide, and the extent of the Berg catchment marks the north-eastern edge of the GRU.
Piketberg	G10M, G30D, G10K, G30A and G10H	The Piketberg GRU is bound entirely by the extent of the TMG outcrop (predominantly the Peninsula, Rietvlei, Cederberg, Graafwaters and Piekenierskloof formations) and its contact with the surrounding basement lithologies (Malmesbury Group). The south/south-western edge of the GRU is bound by portions of the Aurora-Piketberg fault zone.

Table 3-3 Summary of fractured and intergranular Basement GRUs for the Berg catchment. Areal extent of GRUs are shown in Figure 3-12.

GRUs	Approximate Quaternary Catchment associations	Notes on boundaries
Cape Town Rim	G22C, G22E, G22B and G22D	Portions of the G21F, G21E, G22H and G22G surface water quaternary catchment divides form the northern and eastern edge of the GRU, with the extent of the basement lithologies (the Cape Granite Suite and the Malmesbury Group) and its contact with the TMG forming the boundary between the Cape Town Rim GRU and the Cape Peninsula GRU. Quaternary catchments were used because groundwater flow is often parallel to topography. The western/north-western fringe of the GRU is bound by the Table Bay and False Bay coastline.
Stellenbosch-Helderberg	G22G, G22H, G22F, G22J and G22K	Portions of the G22E and G21E surface water quaternary catchment divides as well as the CoCT (2018) aquifer model boundary (i.e., the Cape Flats GRU) forms the northern and western extent of the Stellenbosch-Helderberg GRU. The G10C surface water quaternary catchment divide, as well as the contact between an interpolated extent of the basement lithology (the Cape Granite Suite and the Malmesbury Group) and the TMG forms the eastern/south-eastern boundary of the GRU. The south-western edge of the GRU is bound by the False Bay coastline where preferential groundwater flow directions (towards the southwest) were also considered when defining the GRU boundary.
Paarl-Franschoek	G10C, G10A and G10B	The Paarl-Franschoek GRU is bound by the extent of the basement lithologies (the Cape Granite Suite and the Malmesbury Group) and its contact with the TMG on its eastern and southern edge. Portions of the G10D, G21E and G21D surface water quaternary catchment divides bound the GRU on its northern and western edge.
Malmesbury	G201E, G21C, G21D, G21F and G21B	The Malmesbury GRU is bound by a combination of an interpolated basement geology extent (i.e., the Klipheuwel Group, the Cape Granite Suite and the Malmesbury Group) and the G22G, G10D, G22C, G22E, G10C, G10J, G10L, G10F and G21A surface water quaternary catchment divides on its northern, eastern and southern fringe. Portion of the CoCT (2020) aquifer model boundary (i.e., the Atlantis GRU) and the Table Bay coastline were used as the western extent of the GRU.
Wellington	G10D and G10F	The Wellington GRU is bound by a combination of an interpolated basement geology extent (i.e., the Cape Granite Suite and Malmesbury Group), and the G21E, G21C, G10C and G10J surface water quaternary catchment divides on its western and southern edge (including portions of the Berg River). The contact between the TMG and the basement lithologies, as well as portions of the G10D surface water quaternary catchment divide on the eastern edge.
Tulbagh	G10E and G10G	The Tulbagh GRU is bound by the extent of the basement lithology and (i.e., the Malmesbury Group) and its contact with the TMG on its northern, eastern and western edge. The southern boundary is marked by the Berg catchment (i.e., the H10F surface water quaternary catchment divide).
Eendekuil Basin	G10H, G10J, G10F and G10K	The Eendekuil Basin GRU is bound by the extent of the basement lithologies (i.e., the Malmesbury Group) and its contact with the TMG outcrop on the eastern flank of the GRU and portions of the Aurora-Piketberg fault zone in the north. The Berg and Klein Berg rivers form the south/south-western boundaries. The preferential groundwater flow direction and inferred discharge directions towards both the north and south were considered to bound the GRU.
Middle-Lower Berg	G10J, G30A, G10K and G10M	The Middle-Lower Berg GRU is bound by portions of the G21C, G10L and G10F surface water quaternary catchment divides on its lower south-western to south-eastern edge. Portions of the Aurora-Piketberg fault zone and the Berg and Klein Berg rivers on the eastern edge. The TMGs contact with interpolated basement lithologies (the Malmesbury Group), as well as portions of the Berg catchment

GRUs	Approximate Quaternary Catchment associations	Notes on boundaries
		boundary separate the Middle-Lower Berg GRU from the Piketberg GRU on its north-eastern border. The Adamboerskraal aquifer model boundary (SRK, 2004) and the St Helena Bay coastline forms the north/north-western boundary.
Northern Swartland	G10L	The Northern Swartland GRU is bound by a combination of an interpolated basement lithology extent (the Cape Granite Suite and the Malmesbury Group) and portions of the G21C, G21D, G10J and G10K surface water quaternary catchment divides on its northern, eastern, and southern borders. Along the western edge of the GRU, the Colenso Fault, portions of the Modder River and the contact between Sprinfontyn Formation and the basement lithologies creates the south-western/western edge of the GRU. The Sout River marks western/north-western boarder of the Northern Swartland GRU.
Darling	G10L and G21A	The eastern flank of the Darling GRU is bound by the Colenso Fault, Modder River, and Groen River (i.e., the extent of Northern Swartland GRU). The extent of the Springfontyn Formation and its contact with the Cape Granite Suite forms the boundary between the Elandsfontein and Yzerfontein GRUs. Portions of the G21B surface water quaternary catchment divide and CoCT (2020) aquifer model boundary (i.e., the Atlantis GRU) was used as the Darling GRU boarder in the south.
Vredenburg	G10M	The Vredenburg GRU is bound by the Cape Granite Suite outcrop and its contact with the Springfontyn Formation on its eastern edge. A combination of an interpolated extent of Cape Granite Suite outcrops and the Bok River was used as the GRUs south-eastern boarder, with the Atlantic, Saldanha Bay, and St Helena Bay coastlines forming the northern, western, and southern extent.

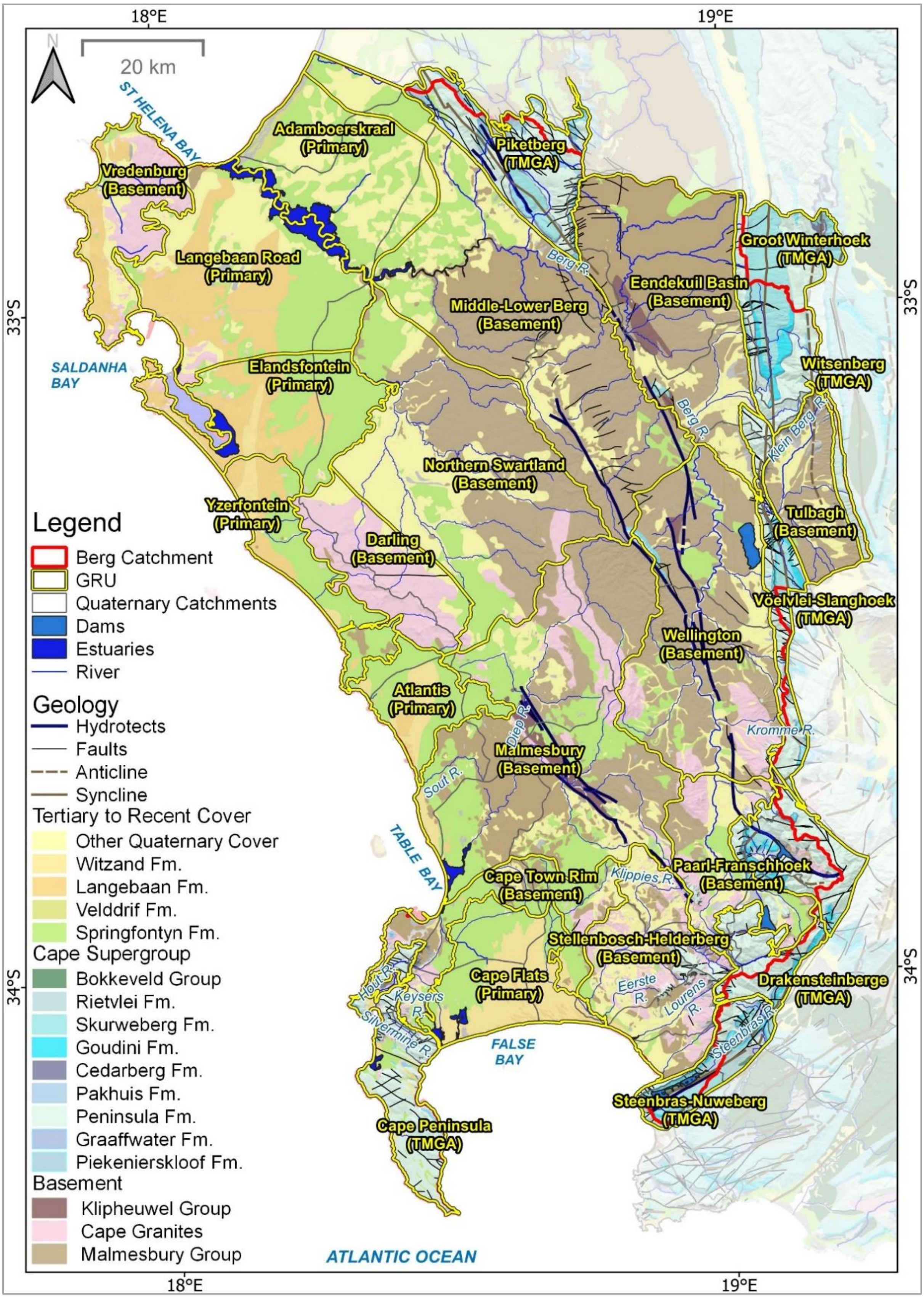

Figure 3-12 **Summary of revised Groundwater Resource Units (GRUs) extents for the Berg catchment with associated geology and structural features. GRUs are extended outside of the Berg catchment area to consider the full hydrogeological nature of the resource unit.**

Table 3-4 Summary of Groundwater Resource Units (GRUs) and gazetted Resource Quality Objectives (RQOs), including both biophysical sites (rivers nodes and estuaries nodes) and prioritised groundwater units (based on quaternary catchments) for the Berg Catchment (DWS, 2019b: 121).

GRU Name	Biophysical Monitoring Site	Estuary	Prioritised groundwater unit
Primary / Intergranular GRUs			
Adamboerskraal		Berg River (Groot) Estuary	G10M
Atlantis			G21B G21D
Cape Flats	Bvii7	Eerste Estuary Zeekoevlei Zandvlei	G22C G22D G22E
Elandsfontein		Langebaan Lagoon	G10M G10L
Langebaan Road		Langebaan Lagoon Berg River (Groot) Estuary	G10M G10L
Yzerfontein			
Fractured Table Mountain Group GRUs			
Cape Peninsula	Bviii6 Bvii20	Wildevoelvlei	G22C G22D
Drakensteinberge	Bvii13		G10A
Groot Winterhoek	Bi1		G10J G10E
Piketberg			G10M
Steenbras-Nuweberg	Bvii22		
Voëlvlei-Slanghoek	Biii4		G10E G10J
Wemmershoek			G10B G10A
Witsenberg			G10E
Fractured and Intergranular Basement GRUs			
Cape Town Rim		Rietvlei/Diep Zandvlei	G22C G22D
Darling			G10L
Eendekuil Basin			G10J
Malmesbury	Bv1 Biv6	Rietvlei/Diep	G21B G21D
Middle-Lower Berg	Bvii6 Bvii12	Berg River (Groot) Estuary	G10J G10M
Northern Swartland		Berg River (Groot) Estuary	G10L

GRU Name	Biophysical Monitoring Site	Estuary	Prioritised groundwater unit
Paarl-Franschhoek	Bviii1 Biii3		G10A G10B
Stellenbosch-Helderberg	Bvii21 Biv8 Biii6 Bviii9	Eerste Estuary Lourens Estuary	
Tulbagh			G10E
Vredenburg			G10M
Wellington	Bvii3 Bvii5		

Table 3-5 Summary of Groundwater Resource Units (GRUs) and associated SWSAgw (WRC, 2018), SGWCA (DWS, 2021), and the current groundwater use / registration (WARMS) per GRU.

GRU name	SWSAgw	SGWCA	Groundwater Use Total Volume (m^3)
Primary / Intergranular GRUs			
Adamboerskraal	West Coast Aquifer	Bergriver	2,133,000
Atlantis	West Coast Aquifer		6,764,909
Cape Flats	Cape Peninsula and Cape Flats		44,070,658
Elandsfontein	West Coast Aquifer	Saldanha Bay Swartland	1,201,813
Langebaan Road	West Coast Aquifer	Saldanha Bay	8,610,068
Yzerfontein	West Coast Aquifer	Swartland	353,180
Fractured Table Mountain Group GRUs			
Cape Peninsula	Cape Peninsula and Cape Flats		8,759,480
Drakensteinberge	Southwestern Cape Ranges		93,900
Groot Winterhoek	Northwestern Cape Ranges		1,639,200
Piketberg	Sandveld		5,985,281
Steenbras-Nuweberg	Southwestern Cape Ranges		25,024,422
Voëlvlei-Slanghoek	Northwestern Cape Ranges Southwestern Cape Ranges Tulbagh-Ashton Valley		130,000
Wemmershoek	Southwestern Cape Ranges		2,831,499
Witsenberg	Northwestern Cape Ranges Tulbagh-Ashton Valley		83,720
Fractured and Intergranular Basement GRUs			
Cape Town Rim			6,186,296
Darling			1,129,560
Eendekuil Basin			5,856,799
Malmesbury			15,124,312
Middle-Lower Berg			2,594,714
Northern Swartland			1,794,959
Paarl-Franschhoek			11,230,239
Stellenbosch-Helderberg			9,896,217
Tulbagh	Northwestern Cape Ranges Southwestern Cape Ranges Tulbagh-Ashton Valley		4,264,967
Vredenburg			1,157,362
Wellington			4,954,000

4. THE WAY FORWARD

The Delineation of Groundwater Resource Units Report is **Deliverable 3.1** of Phase 3 of this study (i.e., Reserve Determination) and forms the third of eleven deliverables that constitute the outcomes of this High Confidence Groundwater Reserve Determination study for the Berg catchment

Deliverable 3.2 (i.e., Step 3 of the groundwater Reserve procedure: the Ecological Reference Conditions Report) will evaluate the reference conditions, PES and EIS of each of the selected study sites. As outlined in DWS (2022a) the outcomes and associated data that informed the gazetted Water Resource Classes and RQOs (i.e., DWS, 2016) will be sufficient to determine surface water reference conditions. However, the reference conditions and present status for groundwater (e.g. aquifer stress, water quality, etc.) will be revaluated for all GRUs.

- Recharge: estimated as spatial distribution of % of MAP, total volume per GRU at 10, 25, 50, 75 and 90 percentile recurrence using different methods such as Chloride Mass Balance (CMB), Saturated Volume Fluctuation etc., will be undertaken depending on data availability. Recharge from through flow from adjacent aquifers will also be considered;
- Water use: estimated as spatial distribution and total annual volume per GRU, based on recent Water Use Allocation and Registration Management System (WARMS) data, reports and estimates of reasonable water consumption;
- Discharge: first order estimate of groundwater contribution to baseflow for each RU, with spatial distribution where sufficient data is available; to be updated as part of Step 4

The reference conditions and present status per GRU will be reported on as Deliverable 3.2.

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