High Confidence Groundwater Reserve Determination Study in the Berg Catchment

WP11398
BHN and EWR Requirement Report

Report Number: RDM/WMA19/02/CON/COMP/0123

April 2023

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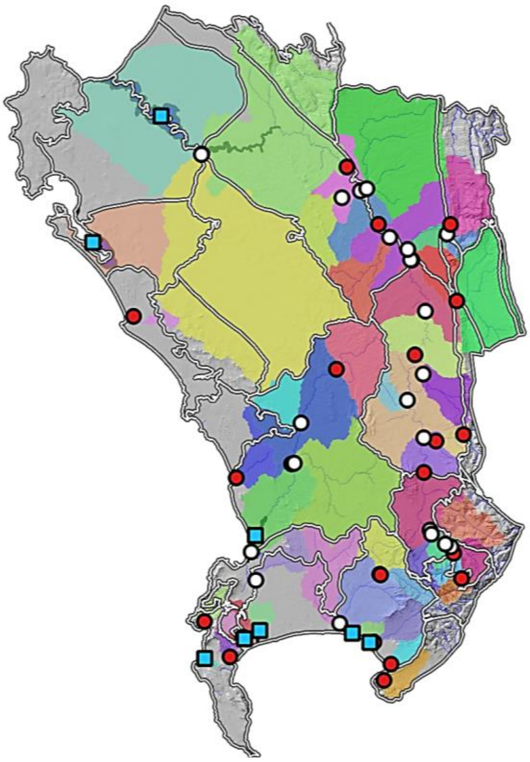

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Version 3 – Final

Prepared for:

Department of Water and Sanitation

Chief Directorate: Water Ecosystems Management

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

Following the eight-step Reserve determination procedure (WRC, 2013), this report aimed to determine the groundwater component of the Basic Human Needs (BHN) and Ecological Water Requirements (EWR) Reserves (i.e., Step 4 of the eight-step groundwater RDM) for aquifer-specific groundwater resource units (GRUs). The groundwater component of the BHN Reserve accounts for people who lack access to a formal water source and live beyond a minimum distance of 500 meters from a perennial river (hereafter referred to as the "Qualifying Population"). The Qualifying Population, estimated to be 257,331 individuals, was used to determine the daily water demand using a fixed value of 25 ℓ/p/d. The groundwater component of the **BHN Reserve was calculated as 2.35 Mm^3/a**. The highest groundwater BHN Reserve requirements were in the Cape Flats (0.70 Mm^3/a), Malmesbury (0.34 Mm^3/a), Stellenbosch-Helderberg (0.24 Mm^3/a), and Wellington (0.24 Mm^3/a) GRUs, which together account for approximately 65% of the total groundwater component of BHN Reserve (see Summary Table below).

The groundwater component of the EWR Reserve was quantified after considering various baseflow separation techniques, and ultimately, only selecting one method. Groundwater discharge was calculated using desktop-derived monthly flow data that was calibrated to meet the Target Ecological Categories (TECs) for all river nodes and priority estuaries in the study area. A "balancing and routing" tool was used to account for the cumulative flow in a downstream direction so that the consequences of changes in flow and TECs upstream could be calculated for downstream river nodes and estuaries. To accurately assess the contribution of groundwater to the EWR per GRU, a detailed GIS-based catchment analysis was used to re-evaluate the incremental catchments to the river and estuary nodes based on the local topography, flow direction, aquifer model extents, and available literature. A recharge ratio was then applied to the total dry-season contribution of groundwater to baseflow (per incremental catchment) to define the groundwater component of the EWR Reserve per GRU and associated aquifer types. The **EWR Reserve was calculated as 69.98 Mm^3/a**, with the Middle-Lower Berg (11.15 Mm^3/a), Wellington (6.75 Mm^3/a), Adamboerskraal (6.00 Mm^3/a), Elandsfontein (6.39 Mm^3/a), and Langebaan Road (5.52 Mm^3/a), Eendekuil Basin (6.95 Mm^3/a) GRUs accounting for approximately 61% of the total groundwater component of EWR Reserve (see Summary Table below).

The Reserve, which is the water set aside to provide for BHN and to sustain water ecosystems, is the only right to water in the NWA. Therefore, it has priority over all other water use and should be established as soon as the Class is determined for each water resource. This means that the amount of water required for the Reserve **must be met** before water resources can be allocated to other users. The determination of Resource Quality Objectives (RQOs) at priority sites in the Berg catchment covers the requirements of the Reserve and all other demands on the water resource.

Table: Summary of the Groundwater Reserve (Mm^3/a) per Groundwater Resource Unit (GRU), displaying both the groundwater component of the EWR Reserve (Mm3/a) and of the Basic Human Needs Reserve (Mm^3/a).

GRU	Groundwaters Contribution to EWR (Mm^3/a)	BHN (Mm^3/a)	GW Reserve (Mm^3/a)
Adamboerskraal	6.00	0.008	6.008
Atlantis	0.08	0.026	0.106
Cape Flats	0.51	0.701	1.211
Cape Peninsula	5.43	0.085	5.515
Cape Town Rim	0.87	0.195	1.065
Darling	0.03	0.015	0.045
Drakensteinberge	2.88	0.003	2.883
Eendekuil Basin	6.95	0.091	7.041
Elandsfontein	6.39	0.005	6.395
Groot Winterhoek	0.77	0.017	0.787
Langebaan Road	5.52	0.017	5.537
Malmesbury	1.18	0.343	1.523
Middle-Lower Berg	11.15	0.085	11.235
Northern Swartland	0.20	0.047	0.247
Paarl-Franschhoek	3.01	0.127	3.137
Piketberg	2.07	0.036	2.106
Steenbras-Nuweberg	1.16	0.016	1.176
Stellenbosch-Helderberg	2.34	0.242	2.582
Tulbagh	1.28	0.023	1.303
Voëlvlei-Slanghoek	1.62	0.007	1.627
Vredenburg	0.00	0.011	0.011
Wellington	6.75	0.235	6.985
Wemmershoek	3.59	0.002	3.592
Witzenberg	0.18	0.002	0.182
Yzerfontein	0.02	0.009	0.029
TOTAL	**69.98**	**2.35**	**72.33**

The NWA explicitly includes groundwater in its definition of a "water resource". However, due to its unique characteristics, managing groundwater often requires a different approach. Consequently, when calculating the Reserve, the amount of groundwater that can be abstracted without risking its capacity to maintain or contribute to surface water flow must be taken into account, given its significant role in this regard.

The portion of the groundwater resource that supports both the BHNs and EWRs is known as the Groundwater Reserve (**calculated to 72.33 Mm^3/a**). While groundwater is more widely distributed than surface water, this component is just a part of the larger geohydrological system considered under groundwater RDM. Once the volume of the Groundwater Reserve has been quantified and RQOs have been met, the remaining water resource can then be allocated to users. Since RQOs were defined for the Berg catchment prior to this high confidence groundwater Reserve project, it is likely that RQOs will have to be adjusted or updated to accommodate the updated Groundwater Reserve estimate.

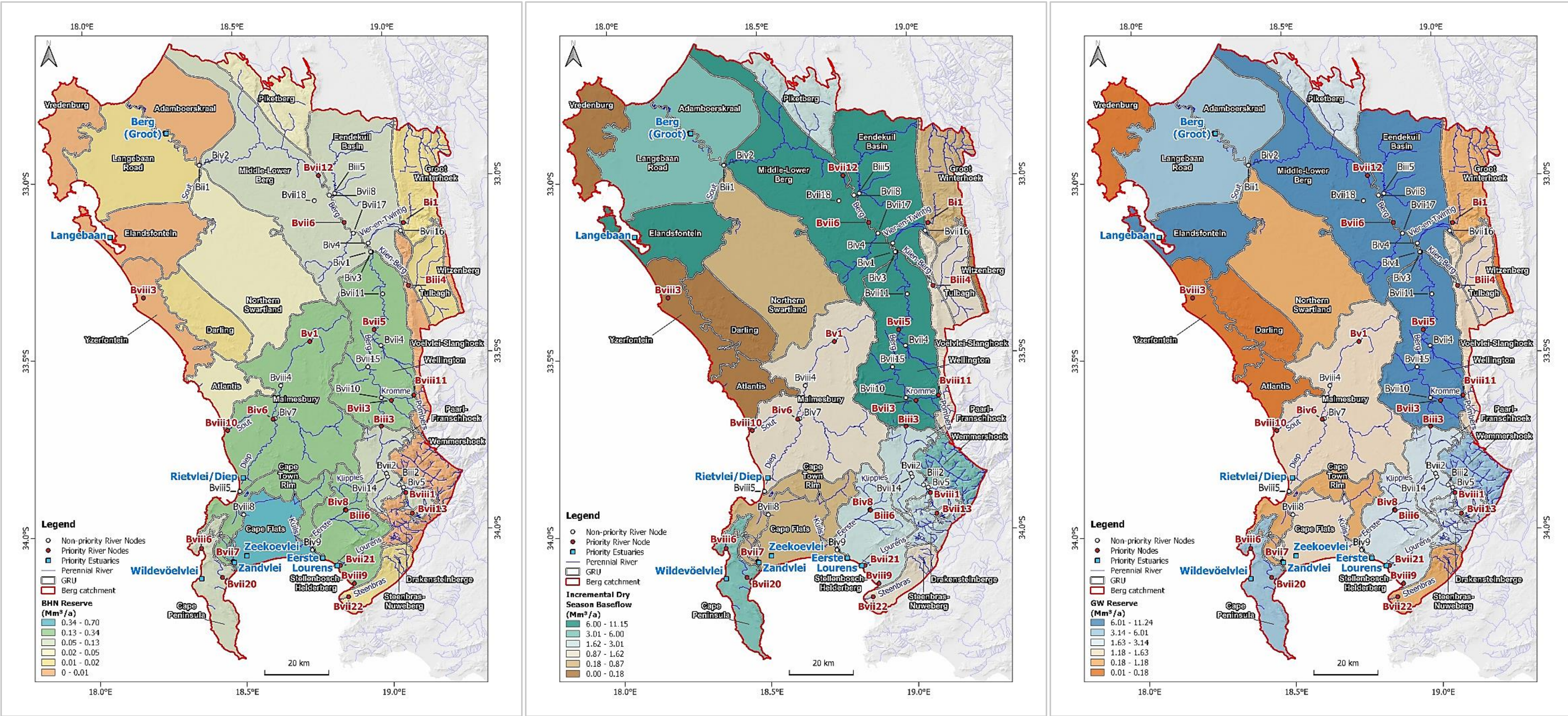

Figure: Left: Basic Human Needs (BHN) Reserve (Mm^3/a) per GRU; Middle: Ecological Water Requirement (EWR) Reserve (Mm^3/a) per GRU; and Right: Groundwater Reserve (Mm^3/a) per GRU for the Berg catchment.

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Abbreviations, acronyms, symbols and units of measurement

%	Percentage
~	Approximately
<	Less than
a	annum
BHN	Basic Human Needs
CD: WEM	Chief Directorate: Water Ecosystems Management
CFA	Cape Flats Aquifer
CoCT	City of Cape Town
CS	Community Survey
DEM	Digital Elevation Model
DWA	Department of Water
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category
EGSAs	Ecosystems Goods, Services and Attributes
e.g.	For example
Et al.	and others
etc.	etcetera
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
GIS	Geographic Information System
GRAII	Groundwater Resource Assessment (Phase II)
GRDM	Groundwater Resource Directed Measure
GRU	Groundwater Resource Unit
GWBF	Total groundwater contribution to baseflow
HH	Households
i.e.	That is.
IUA	Integrated Unit of Analysis
km	Kilometres
ℓ/p/d	Litres per person per day
l/s	Litres per second
LM	Local District Municipality
LRA	Langebaan Road Aquifer
Ltd.	Limited Liability
m	Metres
M m3	Million Cubic Metres
m3	Cubic Metres
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mm	Millimetres
mm/a	Millimetres per annum
N	North
NWA	National Water Act
PES	Present Ecological State
pg.	Page
PS	Present Status
PSP	Professional Service Provider
Pty.	Proprietary
QUAT	Quaternary
QGIS	Quantum Geographic Information System
Ref	Reference

REC	Recommended Ecological Category
RDM	Resource Directed Measure
RQO	Resource Quality Objective
RU	Resource Unit
SA	South African
SAWS	South African Weather Service
StatsSA	Statistics South Africa
SVF	Saturated Volume Fluctuation
TEC	Target Ecological Category
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TOR	Terms of Reference
WAAS	Water Availability Assessment Study
WARMS	Water Use Allocation and Registration Management System
WMA	Water Management Area
WR2012	Water Resources of South Africa 2012
WRC	Water Research Commission
WRCS	Water Resource Classification System
WRCs	Water Resource Classes
WWTW	Wastewater Treatment Works
WULA	Water Use Licence Application

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 within the Berg catchment, 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 (DWS, 2019b: 121) 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 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 are:
  - 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 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 were 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.

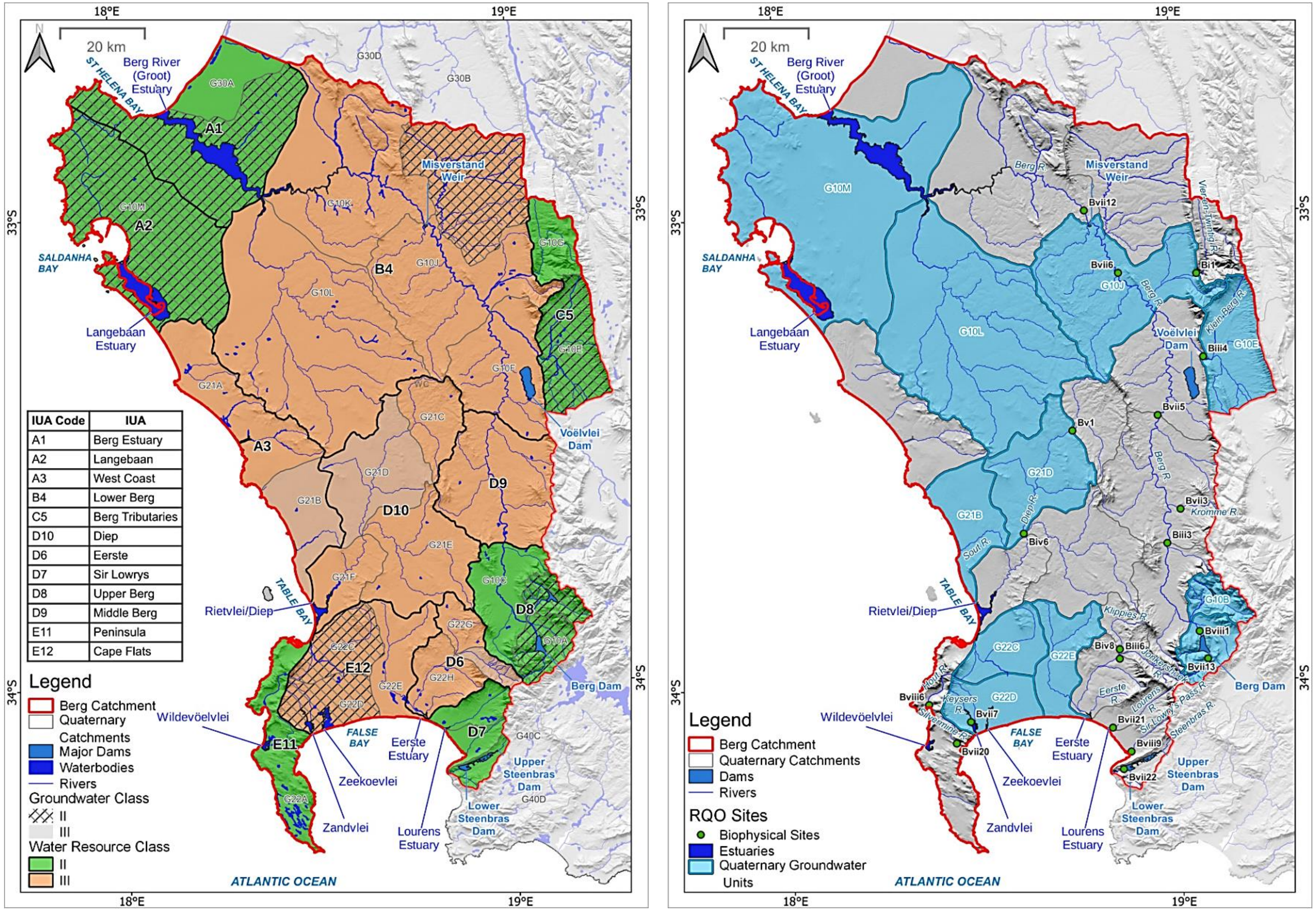


Figure 1-1 **Left: Integrated Units of Analysis (IUAs), Water Resource Classes (WRCs) and Groundwater Classes for the Berg catchment; Right: Priority quaternary catchments, biophysical sites (river and estuary nodes), and dams with gazetted Resource Quality Objectives (RQOs) (after DWS, 2019b: 121).**

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 high confidence groundwater Reserve requirements (quantity and quality) to satisfy basic human needs and to protect aquatic ecosystems of 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 (**Figure 1-2**). 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 is to determine the groundwater component of the BHN and EWR Reserve (i.e., Step 4 of the eight-step GRDM: Reserve determination procedure) for the aquifer-specific Groundwater Resource Units (GRUs) delineated as part of Step 2 of the Reserve determination process (see DWS, 2022d). A detailed overview of the study approach and the scope of work is outlined in the Inception Report (DWS, 2022a) and is summarized in **Table 1-1**.

This report describes the BHN requirements for the current population (accounting for reasonable population growth trends), who are reliant upon taking water from the groundwater resource for their essential needs of drinking water, food preparation, and personal hygiene. The BHN is based on the current population (i.e., 2022), of those either living within the catchment and directly dependent on the catchment or, more critically, not being supplied from a formal water supply scheme.

Groundwater's contribution to the EWR is described and compared to all draft (i.e., scenario-based) & gazetted EWRs for all river nodes and priority estuaries in the study area (DWS, 2016; DWS, 2019: 121). Where sufficient data is available, this determination is supported by analytical and existing numerical groundwater flow models. It is assumed that groundwater-dependent ecosystems were identified as part of the Berg catchment WRC and RQOs study (DWS, 2016). The BHN and EWR Requirement Report is Deliverable 3.3 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

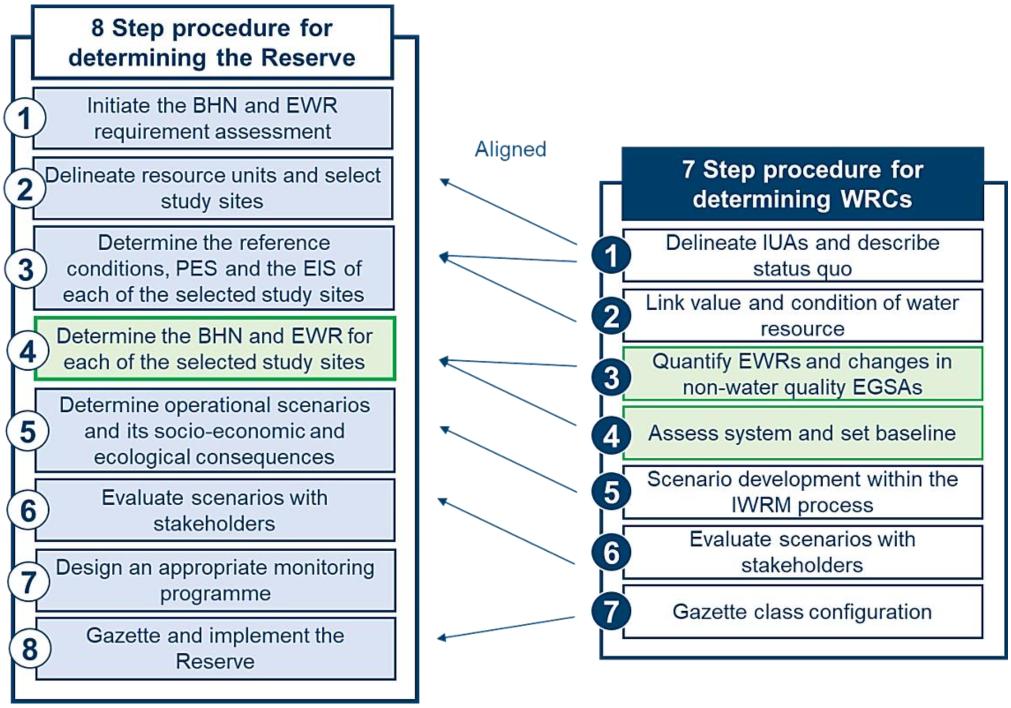


Figure 1-2 The eight-step procedure for determining the groundwater Reserve and its alignment with the seven-step Water Resource Classification procedure as defined by Regulation 2(4) of the National Water Act (NWA; No. 36 of 1998) and outlined in WRC (2013).

1.4. Overview

The NWA (No. 36 of 1998) provides a legal framework for the effective and sustainable management of all significant water resources in South Africa. 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 Classification, the Reserve, and RQOs.

The Reserve (i.e., water “set aside” to provide for BHN 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 is determined for each 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 water resources are covered by the determination of RQOs of priority sites in the Berg catchment.

The NWA clearly includes groundwater in the definition of a “water resource”, but the overall characteristics of groundwater sometimes require a different management approach. Therefore, because of the contribution of groundwater to surface water flow, the volume of groundwater that could sustainably be abstracted without impacting the ability of the groundwater to maintain or contribute to surface water must be considered when determining the Reserve.

In order to meet the TORs for this study, and ultimately determine high confidence groundwater Reserve requirements (quantity and quality), the previous GRUs delineated for the Berg catchment had to be re-evaluated and updated to ensure all groundwater resources were encompassed and were aquifer specific. The revised GRU extents are illustrated in **Figure 1-3** and were described in the Delineation of Groundwater Resource Units Report (DWS, 2022d). The boundaries of the GRUs may be updated as the project progresses, and as new information presents itself.

In terms of the overall GRDM process, and in order to correlate the results of this study to existing WRCs & RQOs outlined in the Gazette (DWS, 2019b: 121), the Present Status (PS) of groundwater, in terms of both quantity and quality, was re-assessed per GRU and associated aquifers. The approach and outcomes were outlined in the Ecological Reference Conditions Report (DWS, 2022e). In the context of this study, ‘ecological reference conditions’ refers to the ambient or natural state of a groundwater system while the ‘Present Status’ refers to the current status of the water resource in terms of utilization and water quality.

As outlined in **Section 1.3**, The BHN and EWR Reserve estimation process constitutes Step 4 of the eight-step GRDM: Reserve determination procedure, and will, where appropriate, align with Step 3 and Step 4 of the seven-step GRDM: Water Resource Classification procedure (**Figure 1-2**) as set out in Regulation 2(4) and outlined in WRC (2013). The report was organized into 5 main chapters including: 1) Introduction; 2) Population dependent on groundwater to meet BHN; 3) Groundwaters contribution to rivers and estuaries; 4) The Groundwater Reserve; and 5) Allocable groundwater. Each chapter includes a literature review, a thorough description of the methods and the calculated Reserves on a GRU scale.

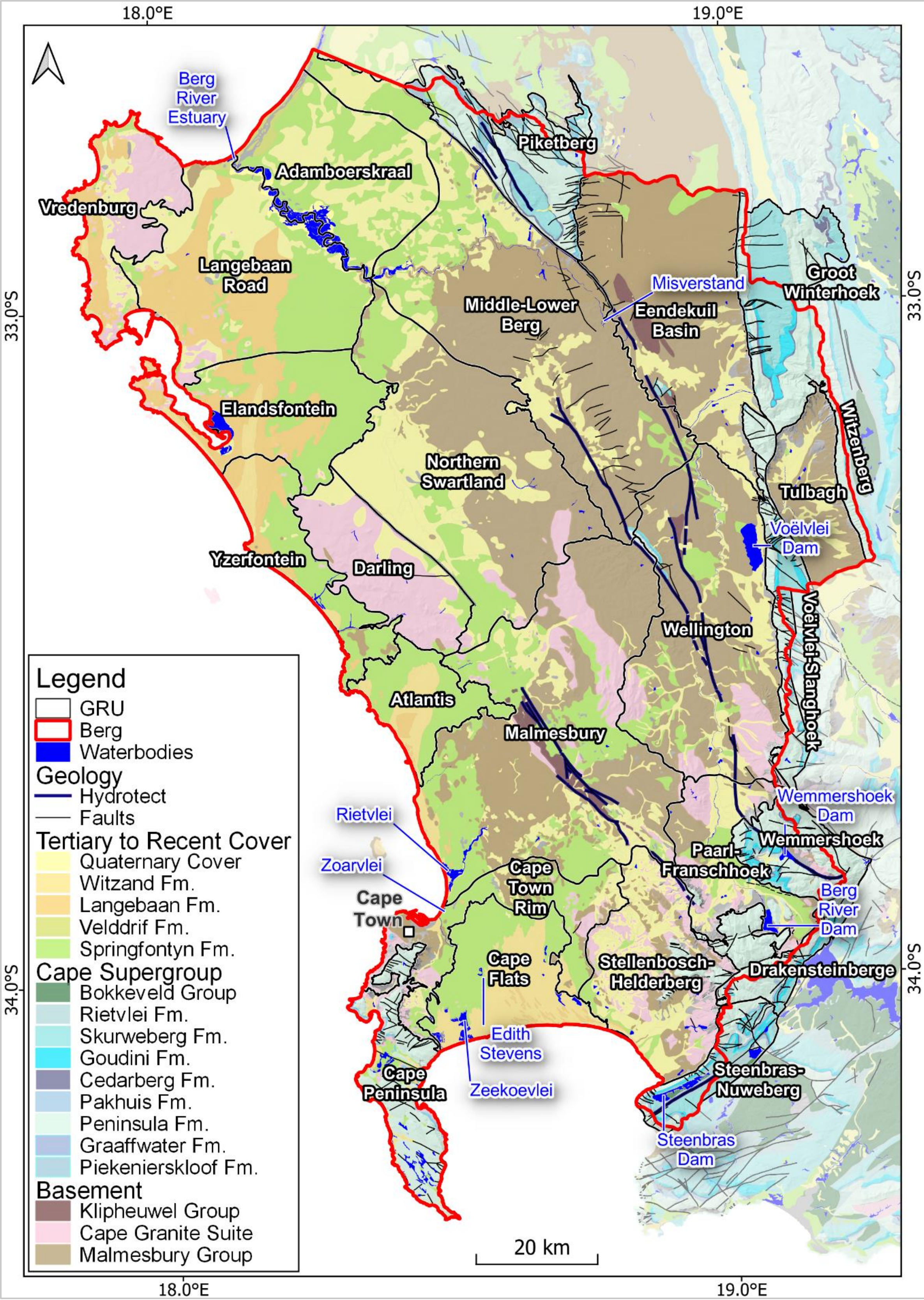


Figure 1-3 **Revised Groundwater Resource Units (GRU) extents for the Berg catchment with associated geology and structural features (including hydrotects).**

2. POPULATION DEPENDENCE ON GROUNDWATER TO MEET BHN

The BHN Reserve was determined for the current population (i.e., 2022) using various Census data and considered both currently accepted and projected population growth trends. The groundwater component of the BHN Reserve was calculated based on the current population, of those either living within the catchment and directly dependent on the catchment, or more critically, not being supplied with water from a formal water supply scheme, and not in close proximity (~500 m) to a perennial surface water source; hereafter referred to as the "Qualifying Population". To quantify the BHN Reserve, as mandated by the NWA (36 of 1998), the Qualifying Population is allocated a daily water requirement of 25 liters per person per day (ℓ/p/d) which is necessary to fulfill fundamental needs such as potable water, food preparation, and personal hygiene.

2.1. Previous BHN Reserve Review

All available studies relevant to the BHN Reserve in the Berg catchment were evaluated and reviewed. In addition to a literature review, statistics sourced from Statistics South Africa (StatsSA) were analysed to provide insights into population growth trends and water sources. The studies and data sources are listed and described below.

2.1.1. Pertinent Information from Relevant Studies

2.1.1.1. Berg Catchment WRCs and RQOs Study

The DWS (2016) study, and the resultant compilation of reports, provided results that supported the gazetted WRCs and RQOs for the Berg catchment (DWS, 2019b: 121). The initial phase included the delineation of IUAs (DWS, 2016d) and a status quo assessment of significant water resources of the Berg catchment (DWS, 2017b). Water requirements for BHN were included in the assessment which evaluated the number and percentage of households within each socio-economic zone that are reliant on rivers and streams as their main source of domestic water (**Table 2-1**). The study estimated a total of 4 819 households were reliant on surface water, with an estimated usage of 492 m^3/day based on StatsSA (2011) data hereafter referred to "Census (2011)". The number of households relying on rivers to meet their BHNs was forecasted to decrease over time.

Table 2-1 The number and percentage of households (HH) within each socio-economic zone that are reliant on water from rivers and streams (after DWS 2017b).

Socio-economic zone	IUA	No. HH relying on river water	Average HH size (people/unit)	Minimum daily flow required to meet BHN (m^3/day)
West Coast	Berg Estuary	237	4.05	24
	Langebaan	48	3.33	4
	West Coast	61	4.83	7
Lower Berg	Lower Berg	1,784	4.32	193
Tulbagh	Berg Tributaries	346	4.64	40
Winelands	Eerste and Sir Lowry's	593	3.82	57
	Upper Berg	217	4.48	24
	Middle Berg	613	4.61	71
	Diep	354	4.10	36
Cape Town	Peninsula	17	2.96	1
	Cape Flats	548	3.81	52
TOTAL		**4,819**	**4.09**	**492**

2.1.1.2. EWR and BHN for SW and GW in the Lower Orange River Catchment

The “Determination of Ecological Water Requirements for Surface Water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA” study was initiated in 2016 to determine the EWR and BHN Reserves for both groundwater and surface water sources in the Lower Orange River catchment (DWS, 2016f). The study employed the methodology outlined in GRDM (WRC, 2013) that used Geographic Information System (GIS) based techniques to allocate population enumeration areas to quaternary catchments. The study extrapolated the population to 2016, excluding those with no formal water supply, to estimate the “Qualifying Population” and associated BHN Reserve per quaternary catchment.

The methodology used in this report served as the foundation of the approach for estimating the BHN Reserve for the Berg catchment. However, this high confidence groundwater Reserve determination study aimed to take this a step further by allocating the extrapolated population (2022), and by extension the BHN Reserve, to a GRU scale (which required an additional layer of GIS-based calculations).

2.1.2. Pertinent Data Sources

2.1.2.1. StatsSA Census

Census data (sourced from StatsSA) used in this assessment was collated from all available enumeration years including Census (2001), Census (2011) and preliminary Census (2022) results (officially releasing at the end of July 2023). The data, formulated from a national statistical survey, collects demographic information of the population on a regional scale. Specific datasets were used to aid in the quantification of BHN Reserve, including the “total population” and the associated “water supply source” (both of which were used to confirm and re-calculate the currently accepted population growth rates), the number of individuals with no formal water supply, and the resultant “Qualifying Population” totals.

2.1.2.2. StatsSA Community Survey

Community Surveys (CS) and the resultant reports serve as a complementary source of information to fill data gaps in areas where the Census may not provide complete and accurate information. Both CS (2007) and CS (2016), which are based on a sample “enumeration area”, provided additional information on the population with no formal water supply. CS (2016) estimated that ~7.6% of the total population (or 131 158 of households) do not have access to safe drinking water. A comparative assessment of the percentage of households that have access to piped water for the Western Cape from both the Census and CS databases from 1996 – 2016 are displayed in **Figure 2-1**. In 1996, ~19.7% did not have access to piped water (i.e., formal water supply), which decreased to ~10.1% in 2016. The improvement was assumed to be due to infrastructural development.

2.1.2.1. Other Studies

Additional planning strategies also provided useful information pertaining to the BHN requirements including, the Reconciliation Strategies for All Towns in the Southern Planning Region (2016g) and Water Reconciliation Strategy for the WCWSS (2016h). Both these studies used Census (2011) and CS (2016) as the primary dataset to estimate population and associated future demands. The DWS has indicated that these studies are currently being updated and if the preliminary data is made available to the project team, it can be incorporated into Step-5: Operational Scenarios & Socio-Economic and Ecological Consequences Report.

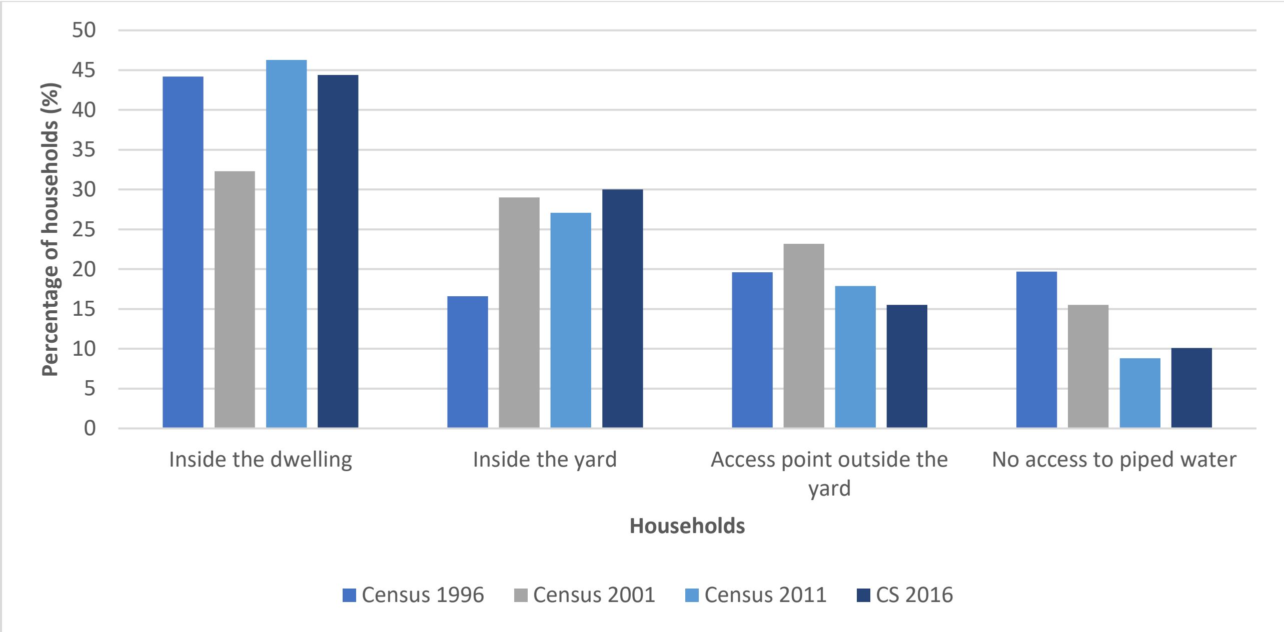
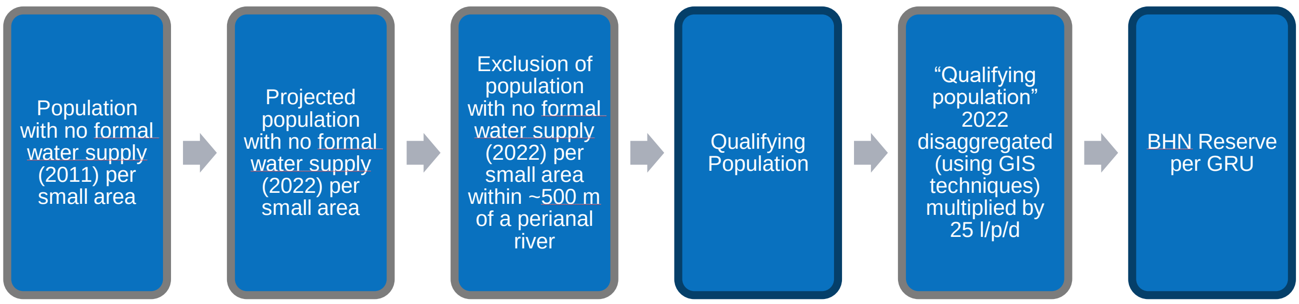


Figure 2-1 Percentage (%) of households with access to piped water[1] from various data sources (CS, 2016).

2.2. BHN Reserve Calculation Approach

The BHN Reserve was calculated using Census (2011) data which was spatially distributed using GIS-based techniques. These methods were used due to Census (2022) being incomplete (in terms of scale and the available information such as "water source", etc.).

The population with no formal water supply was identified and projected to 2022 using an average population growth rate (see **Section 2.2.2**). The projected population for 2022 was spatially distributed (on a "small area" scale, which is the smallest enumeration boundary provided by Census (2011), and those within 500 m of a perennial river were removed, as they were assumed to rely on surface water resources for their BHN requirements. The remaining population was called the "Qualifying Population" and the groundwater component of the BHN Reserve was estimated by multiplying the Qualifying Population by 25 ℓ/p/d (as per the NWA; see **Figure 2.2**Figure 2-2) This value is dependent on the projected population and may change in response to updated Census (2022) data.



[1] *Piped water from access point outside the yard includes piped water on community stand, neighbor's tap and communal tap. No access to piped water includes borehole in yard, rain-water tank in yard, water carrier/taker, borehole outside the yard, flowing water/stream/river, well, spring, other. CS (2016) asked households about their main source of water for drinking, whilst the Censuses asked whether the household had access to piped water.*

Figure 2-2 BHN Reserve calculation workflow

2.2.1. Population with No Formal Water Supply – 2011

The total population, which encompasses the demographic supplied and not supplied with water from a formal water supply scheme, was collated from the Census (2011) database. Population values were tabulated on a 'Local District Municipality' (LM) scale as shown in **Table 2-2** and **Figure 2-3**. The results show that of the total population (2011) of ~4.4 million people, approximately 95% were supplied with water from a formal water supply scheme.

Table 2-2 Summary of the population and associated water supply information per Local District Municipality (LM) based on Census (2011).

LM Name	LM Code	2011 Total Population	2011 Population with a formal water supply	2011 Population with no formal water supply
City of Cape Town	CPT	3,739,000	3,620,094	118,906
Cederberg	WC012	789	789	0
Bergrivier	WC013	53,147	36,429	16,718
Saldanha Bay	WC014	98,899	95,826	3,073
Swartland	WC015	113,712	82,218	31,494
Witzenberg	WC022	19,835	15,783	4,052
Drakenstein	WC023	251,197	214,425	36,772
Stellenbosch	WC024	155,640	130,386	25,254
Breede Valley	WC025	185	99	86
Theewaterskloof	WC031	26,739	25,179	1,560
TOTAL	**-**	**4,459,143**	**4,221,228**	**237,915**

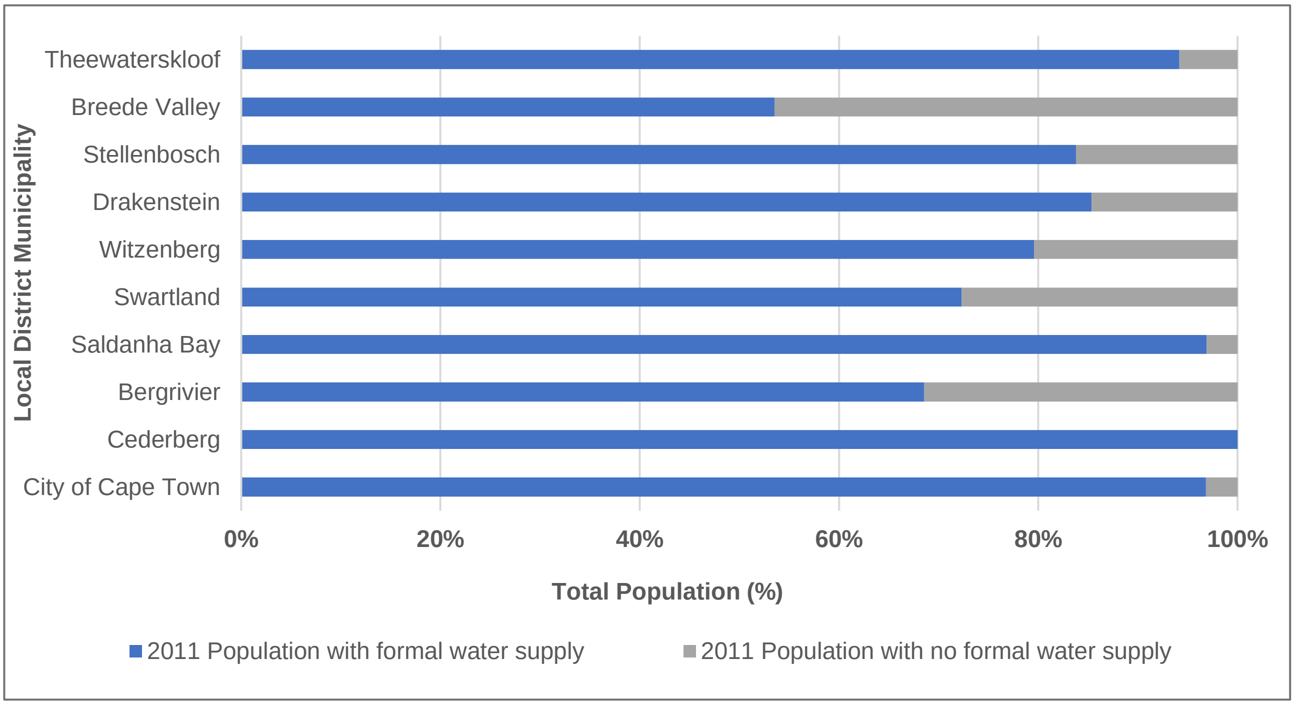


Figure 2-3 Population percentage (%) with their associated water supply per Local District

Municipality (LM) based on Census (2011).

2.2.2. Population Growth Rate

By assessing Census (2011) and preliminary Census (2022) databases, currently-accepted population growth rates were re-calculated and verified. The databases contained population data for all LMs within the study area from 2002 to 2022, except for the City of Cape Town (CoCT) which only had data up to 2021. Therefore, population statistics for CoCT were extrapolated to 2022 using an average annual growth rate of 1.6% (as presented by CS 2016) and applying that to the 2021 population.

The relative differences (%) in population were determined from 2011 to 2022 to indicate the population growth rate over this period as shown in **Table 2-3**, **Figure 2-4** and **Appendix A**. Even though LMs and GRU boundaries do not align, population growth rates were applied uniformly across the GRU. The results display an average population growth rate of ~24% from 2011, largely due to urban sprawl/migration in the CoCT, Stellenbosch and Saldanha Bay.

Table 2-3 Summary of population growth rates (%) per Local District Municipality (LM) from 2011 to 2022.

LM Name	LM Code	2011 Population	2022 Population	Relative growth rate (%)
City of Cape Town	CPT	3,792,657	4,756,255	25.41%
Cederberg	WC012	49,946	60,917	21.97%
Bergrivier	WC013	61,267	75,635	23.45%
Saldanha Bay	WC014	98,337	125,921	28.05%
Swartland	WC015	109,540	140,976	28.70%
Witzenberg	WC022	117,269	153,808	31.16%
Drakenstein	WC023	248,631	298,529	20.07%
Stellenbosch	WC024	156,635	199,704	27.50%
Breede Valley	WC025	169,306	196,590	16.12%
Theewaterskloof	WC031	106,372	124,341	16.89%
AVERAGE	**-**	**-**	**-**	**23.93%**

2.2.3. Population with No Formal Water Supply – 2022

This estimation does not consider aspects, such as the advancement of infrastructure, urbanisation, urban sprawl, migration patterns, etc. According to the Status Quo Report of the Berg catchment WRC and RQO study (DWS, 2016), the situation will likely improve in the future with regards to the provisioning of the formal water supply, which will likely lead to a reduction in the predicted number of individuals who with no formal water supply. The population with no formal water supply will be subject to revision and validation with the latest Census (2022) statistics. **Table 2-4** summarises the projected 2022 population per LM with no formal water supply.

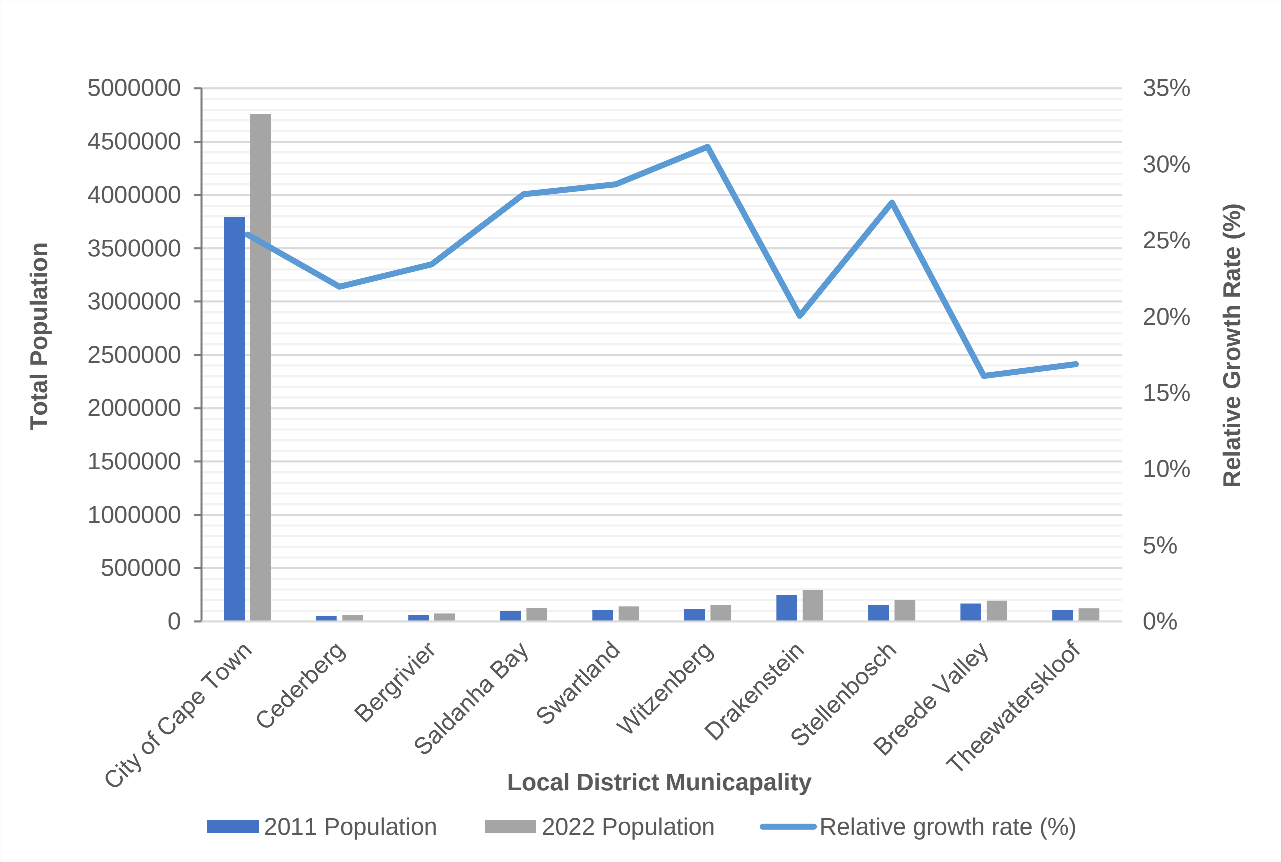


Figure 2-4 **Population statistic and associated growth rate per Local District Municipality (LM) within the Berg study area for 2011 and 2022.**

Table 2-4 **Summary of projected 2022 population per Local District Municipality (LM) with no formal water supply.**

LM Name	LM Code	2011 Population with no formal water supply	Relative growth rate (%)	2022 Population with no formal water supply
City of Cape Town	CPT	118,906	25.41%	149,116
Cederberg[2]	WC012	0	21.97%	0
Bergrivier	WC013	16,718	23.45%	20,638
Saldanha Bay	WC014	3,073	28.05%	3,934
Swartland	WC015	31,494	28.70%	40,532
Witzenberg	WC022	4,052	31.16%	5,314
Drakenstein	WC023	36,772	20.07%	44,152
Stellenbosch	WC024	25,254	27.50%	32,198
Breede Valley	WC025	86	16.12%	100
Theewaterskloof	WC031	15,60	16.89%	1,824
TOTAL	**-**	**237,915**	**-**	**297,809**

[2] *The Cederberg LM has a value of zero due to only 1.28% of the LMs total area falling within the Berg study area.*

2.2.4. Qualifying Population

The population with no formal water supply (2022) per 'small area' was aggregated to the LM and GRU scale using a basic area/distribution GIS technique. Thereafter, the population within 500 m of any perennial river was removed and "Qualifying Population" determined.

The resultant Qualifying Population was calculated to 257 331 people within the study area, which equates to approximately 4.6% of the total projected 2022 population of 5 562 979 people (**Table 2-5** and **Figure 2-5)**.

Table 2-5 Summary of Qualifying Population per Local District Municipality (LM) within the Berg study area.

LM Name	LM Code	2022 Population not on formal water supply	Population within 500 m from river	Qualifying Population
City of Cape Town	CPT	149,116	14,422	134,694
Cederberg[2]	WC012	0	0	0
Bergrivier	WC013	20,638	3,207	17,432
Saldanha Bay	WC014	3,934	63	3,872
Swartland	WC015	40,532	3,829	36,703
Witzenberg	WC022	5,314	1,055	4,259
Drakenstein	WC023	44,152	7,942	36,210
Stellenbosch	WC024	32,198	9,616	22,582
Breede Valley	WC025	100	21	79
Theewaterskloof	WC031	1,824	324	1,500
TOTAL	**-**	**297,809**	**40,478**	**257,331**

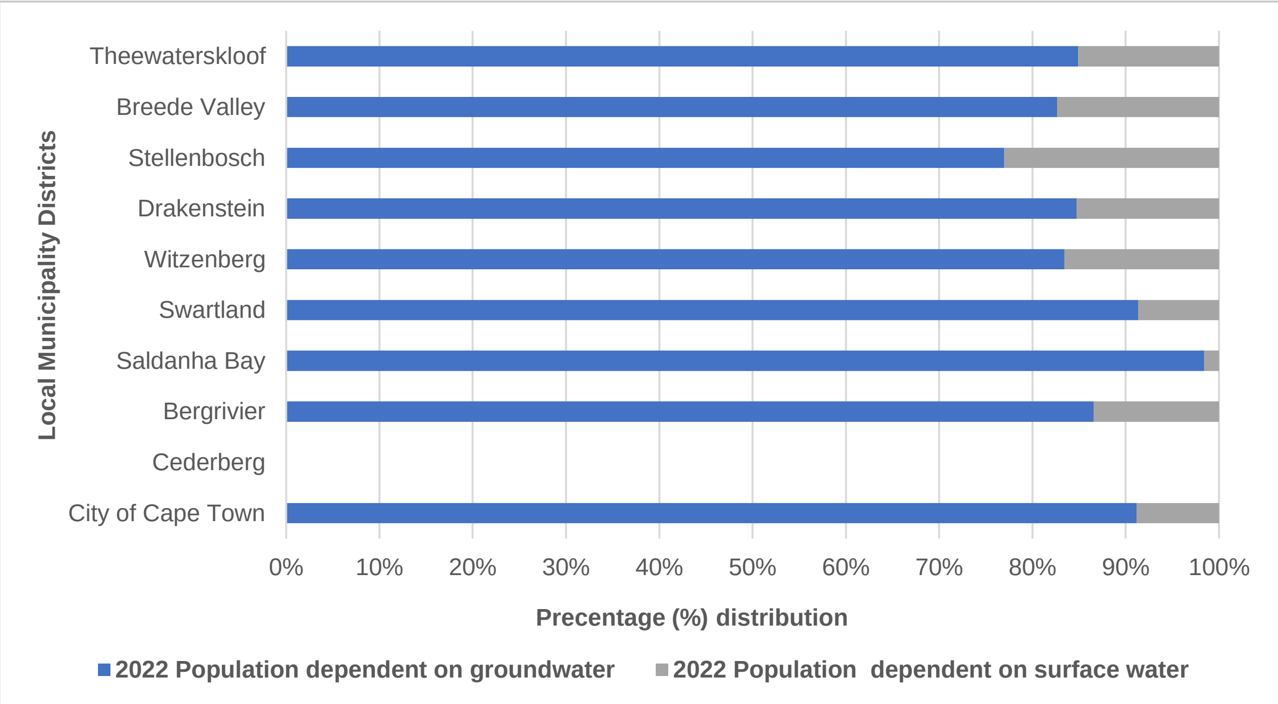


Figure 2-5 Qualifying population with no formal water supply and dependent on groundwater vs. those with no formal water supply and dependent on surface water per Local District Municipality (LM).

2.3. The Groundwater BHN Reserve

Based on the methods described in **Section 2.2**, the Qualifying Population was estimated to be **257 331** individuals. The Qualifying Population was multiplied by a daily water consumption rate of 25 ℓ/p/d, resulting in a groundwater BHN Reserve of **6,433,275 ℓ/d** or **2.35 Mm^3/a** (volumes per LM and GRU are tabulated in **Table 2-6** and **Table 2-7** respectively).

The highest groundwater BHN Reserve requirements were the Cape Flats, Malmesbury, Stellenbosch-Helderberg and Wellington GRU's, which make up ~65% of the BHN Reserve (**Table 2-8**, **Figure 2-7** and **Figure 2-8**), because of the high Qualifying Population density (**Figure 2-6**).

Below is a summary of the assumptions made to estimate the groundwater BHN Reserve:

- **Population estimate:** The calculation does not account for a 'groundwater dependency trend', which is a trend that informs whether areas are becoming more or less reliant on a formal water supply. Instead, the Qualifying Population was primarily based on the Census (2011) statistics, which were projected to 2022 based on confirmed population growth rates. The latest Census (2022) data give insight into this trend.
- **Consistency in consumption:** The calculation assumes that a daily water consumption of 25 ℓ/p/d remains relatively consistent across the population, with minimal variations due to factors such as age, gender, and location.
- **Water availability:**

  The calculation assumes the 2022 recharge rates per GRU (DWS, 2022e), together with the existing infrastructure in the Berg catchment, were sufficient to meet the estimated BHN Reserve.

Table 2-6 Summary of Qualifying Population per Local District Municipality (LM) in the study area and the associated groundwater Basic Human Needs (BHN) Reserve (Mm^3/a).

Local District Municipality	Local District Municipality Code	2011 Total Population	2011 Population with a formal water supply	2011 Population with no formal water supply	2022 Total Population	2022 Population with no formal water supply	2022 Population with no formal water supply within 500 m from River	Qualifying Population	GW-BHN Reserve (Mm^3/a)
City of Cape Town	CPT	3,731,822	3,620,094	118,906	4,679,963	149,116	14,422	134,694	1.23
Cederberg	WC012	88	789	0	107	0	0	0	0.00
Bergrivier	WC013	52,819	36,429	16,718	65,206	20,638	3,207	17,432	0.16
Saldanha Bay	WC014	98,075	95,826	3,073	125,585	3,934	63	3,872	0.04
Swartland	WC015	113,618	82,218	31,494	146,224	40,532	3,829	36,703	0.33
Witzenberg	WC022	16,144	15,783	4,052	21,175	5,314	1,055	4,259	0.04
Drakenstein	WC023	251,173	214,425	36,772	301,581	44,152	7,942	36,210	0.33
Stellenbosch	WC024	155,628	130,386	25,254	198,421	32,198	9,616	22,582	0.21
Breede Valley	WC025	160	99	86	186	100	21	79	0.00
Theewaterskloof	WC031	20,986	25,179	1,560	24,531	1,824	324	1,500	0.01
TOTAL		**4,440,514**	**4,221,228**	**237,915**	**5,562,979**	**297,809**	**40,478**	**257,331**	**2.35**

Table 2-7 Summary of the Qualifying Population per Groundwater Resource Unit (GRU).

Groundwater Resource Unit (GRU)	Local District Municipality Code	2011 Total Population	2011 Population with no formal water supply	2022 Total Population	2022 Population with a formal water supply	2022 Population with no formal water supply	2022 Population with no formal water supply within 500 m from River	Qualifying Population
Adamboerskraal	WC013, WC014	12,474	1,056	15,399	11,433	1,304	415	889
Atlantis	CPT, WC015	78,736	2,251	98,742	77,053	2,824	23	2,801
Cape Flats	CPT, WC024	2,377,671	67,527	2,981,765	2,310,569	84,684	7,822	76,862
Cape Peninsula		107,060	8,269	134,261	100,535	10,370	1,025	9,346
Cape Town Rim	CPT, WC024	642,525	19,390	805,881	624,151	24,379	3,031	21,348
Darling	CPT, WC015	14,196	1,279	18,195	12,917	1,643	4	1,640
Drakensteinberge	CPT, WC024, WC031	1,025	511	1,293	1,979	652	280	372
Eendekuil Basin	WC013, WC0156, WC022, WC023	38,541	9,084	47,247	29,692	11,194	1,226	9,968
Elandsfontein	WC014, WC015	3,861	430	4,947	3,431	553	8	545
Groot Winterhoek	WC012, WC013, WC022, WC023	2,756	2,004	3,509	1,614	2,552	691	1,861
Langebaan Road	WC013, WC014	51,514	1,493	65,948	50,121	1,911	19	1,891
Malmesbury	CPR, WC015, WC023, WC024	367,516	33,401	462,685	335,836	42,163	4,583	37,580
Middle-Lower Berg	WC013, WC014, WC014, WC023	27,158	8,660	34,750	18,502	11,020	1,665	9,355

Groundwater Resource Unit (GRU)	Local District Municipality Code	2011 Total Population	2011 Population with no formal water supply	2022 Total Population	2022 Population with a formal water supply	2022 Population with no formal water supply	2022 Population with no formal water supply within 500 m from River	Qualifying Population
Northern Swartland	CPT, WC013, WC014, WC015	6,820	4,127	8,769	2,692	5,310	161	5,149
Paarl- Franschhoek	WC023, WC024	128,538	16,677	156,788	111,873	20,351	6,475	13,875
Piketberg	WC013	6,234	3,807	7,695	2,507	4,700	735	3,965
Steenbras- Nuweberg	CPT, WC031	21,840	1,734	25,612	24,404	2,041	332	1,709
Stellenbosch- Helderberg	CPT, WC023, WC024	333,829	26,308	420,812	309,229	33,329	6,822	26,508
Tulbagh	WC022	13,619	2,435	17,863	14,220	3,194	626	2,568
Voëlvlei-Slanghoek	WC022, WC023, WC025	1,164	719	1,464	446	903	164	739
Vredenburg	WC014	41,751	959	53,463	41,516	1,227	0	1,227
Wellington	CPT, WC015, WC022, WC023	155,699	24,545	188,247	131,169	29,904	4,172	25,733
Wemmershoek	WC023, WC024, WC025	3,501	276	4,434	3,253	345	158	187
Witzenberg	WC022	473	213	621	754	279	35	243
Yzerfontein	CPT, WC014, WC015	2,012	759	2,589	1,332	976	6	970
TOTAL		**4,440,514**	**237,915**	**5,562,979**	**4,221,228**	**297,809**	**40,478**	**257,331**

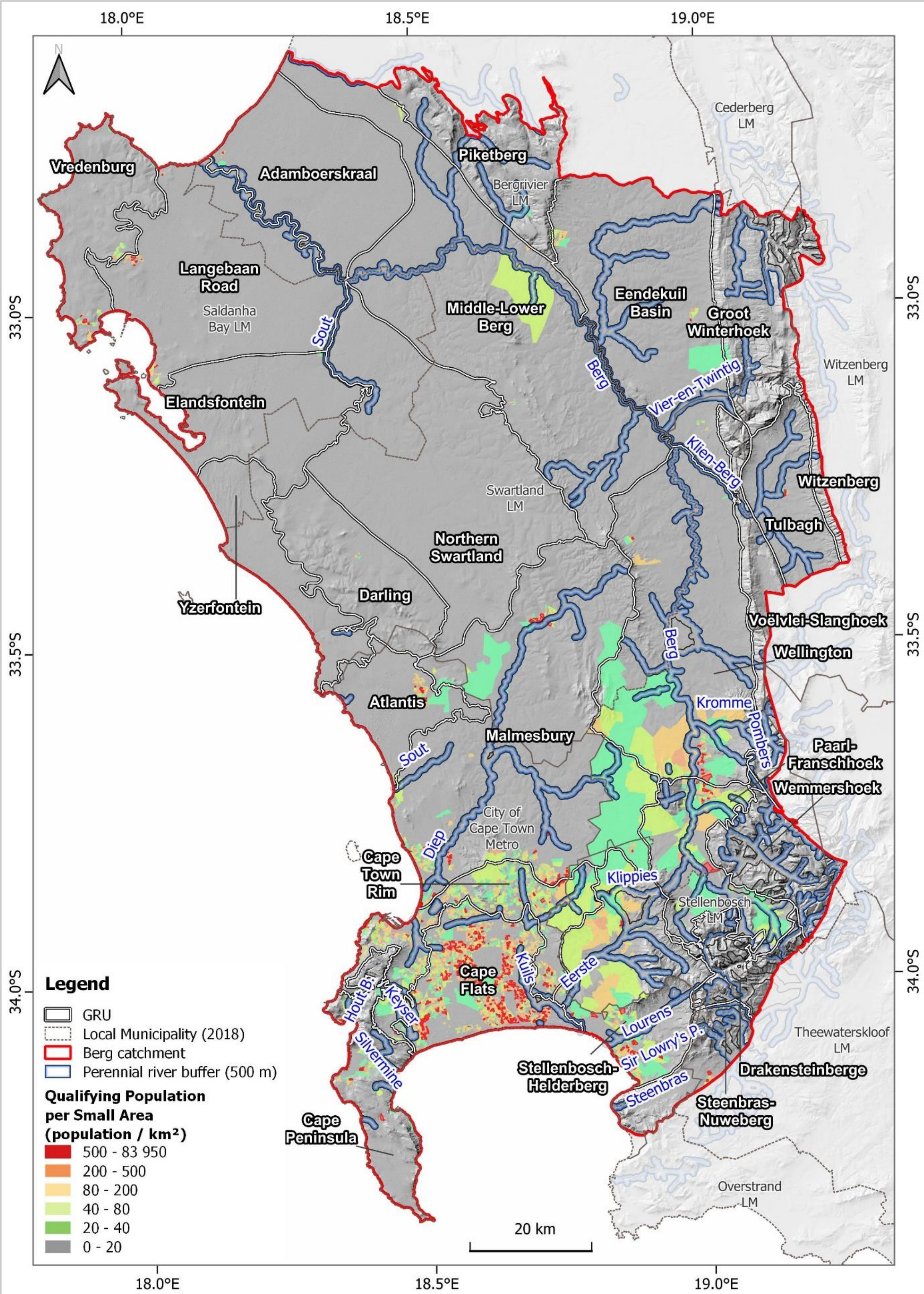


Figure 2-6 **Map of Qualifying Population (2022) density per 'Small Area' within the Berg study area.**

Table 2-8 Summary of the groundwater component of the Basic Human Needs (BHN) Reserve (Mm^3/a) per Groundwater Resource Unit (GRU).

GRU	GW-BHN Reserve (Mm^3/a)
Adamboerskraal	0.008
Atlantis	0.026
Cape Flats	0.701
Cape Peninsula	0.085
Cape Town Rim	0.195
Darling	0.015
Drakensteinberge	0.003
Eendekuil Basin	0.091
Elandsfontein	0.005
Groot Winterhoek	0.017
Langebaan Road	0.017
Malmesbury	0.343
Middle-Lower Berg	0.085
Northern Swartland	0.047
Paarl-Franschhoek	0.127
Piketberg	0.036
Steenbras- Nuweberg	0.016
Stellenbosch-Helderberg	0.242
Tulbagh	0.023
Voëlvlei-Slanghoek	0.007
Vredenburg	0.011
Wellington	0.235
Wemmershoek	0.002
Witzenberg	0.002
Yzerfontein	0.009
TOTAL	**2.348**

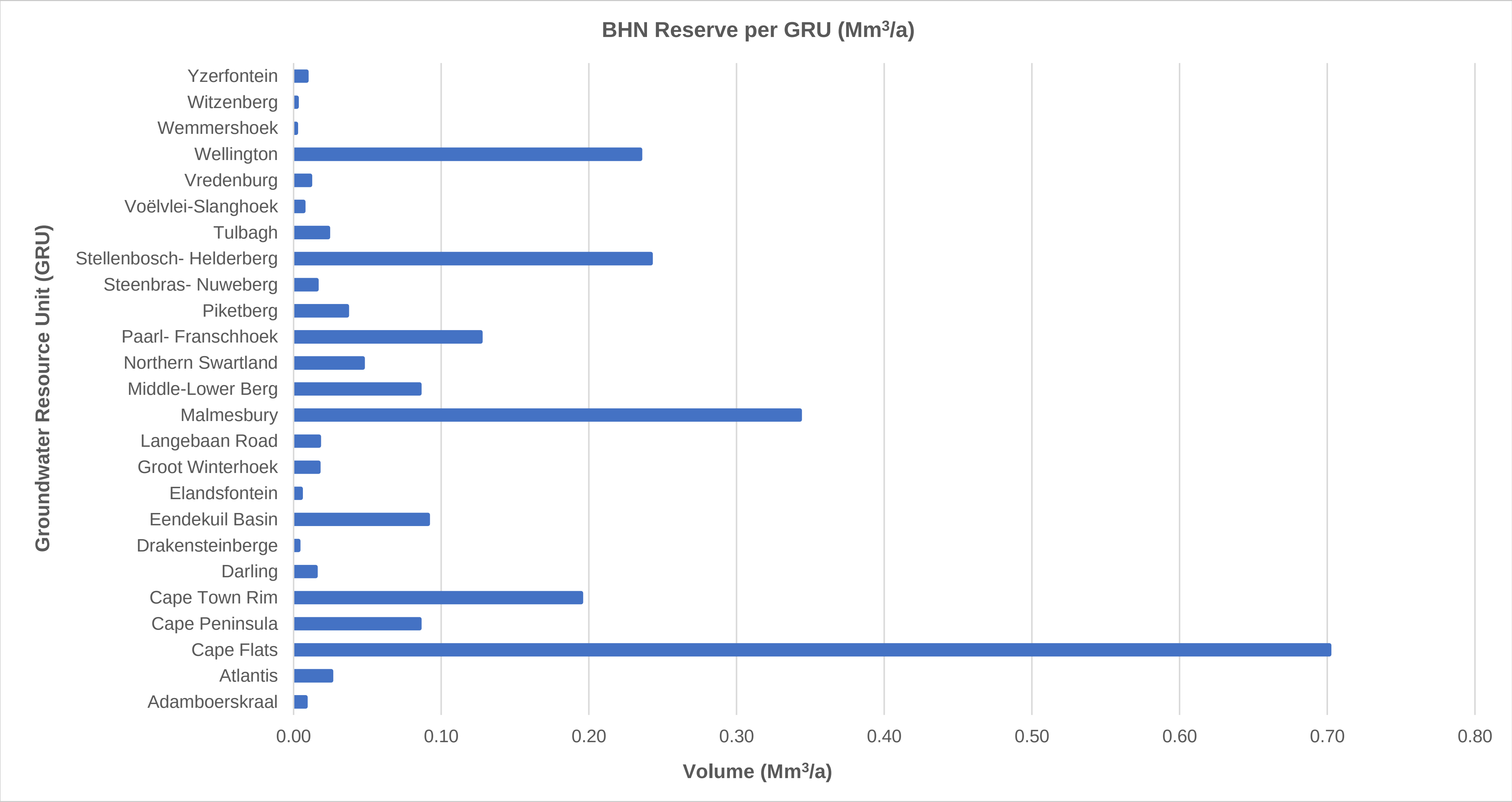


Figure 2-7 Summary of the groundwater Basic Human Needs (BHN) Reserve (Mm^3/a) per Groundwater Resource Unit (GRU) in the Berg study area.

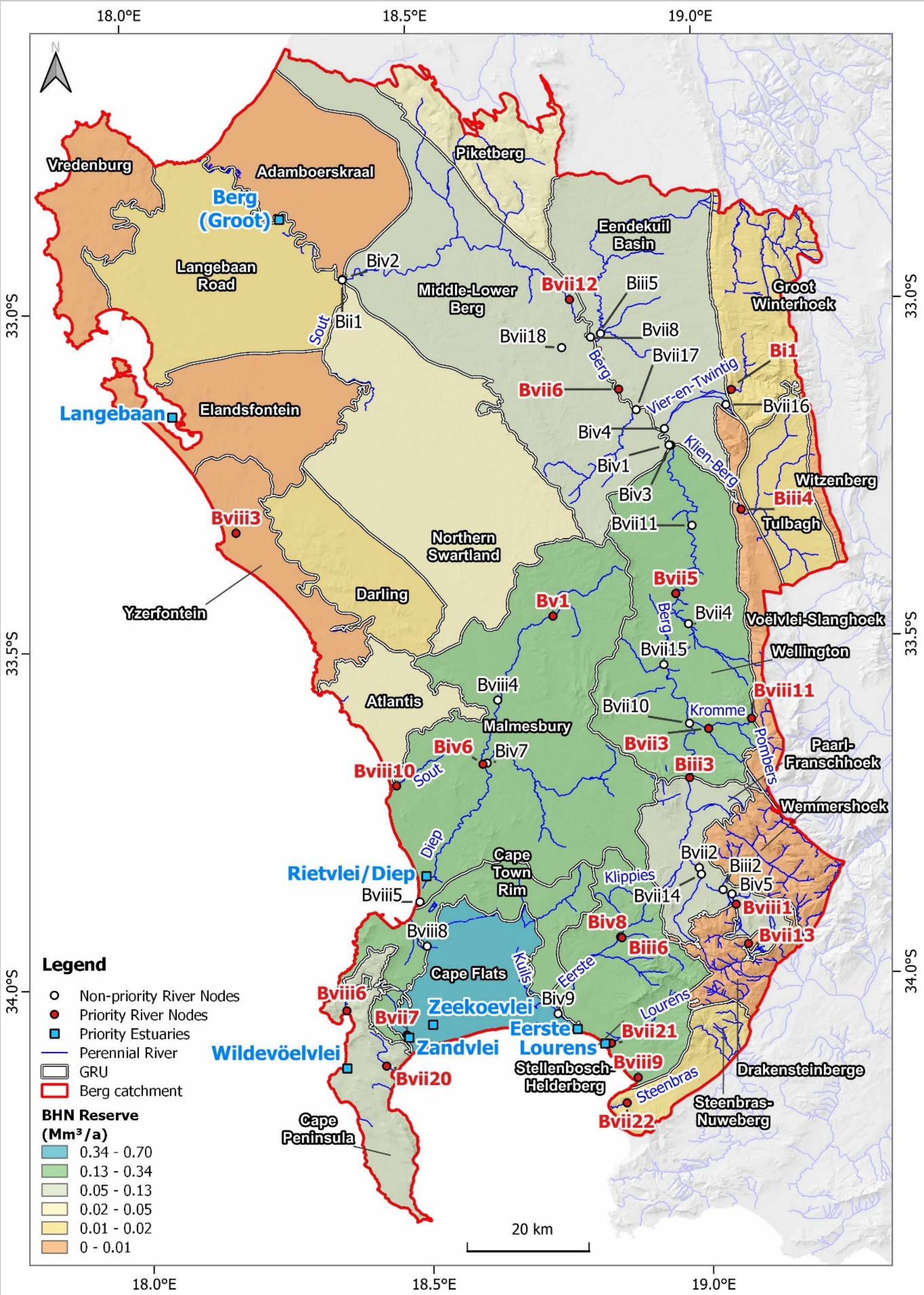


Figure 2-8 **Map of the groundwater BHN Reserve (Mm^3/a) per Groundwater Resource Unit (GRU) within the Berg study area.**

3. GROUNDWATERS CONTRIBUTION TO RIVERS AND ESTUARIES

The contribution of groundwater to the Ecological Water Requirement (EWR) per GRU was determined using a baseflow separation and a GIS-based spatial disaggregation technique. These results are described and compared to the draft (scenario-based) and gazetted EWRs (DWS, 2019: 121) for all river nodes and priority estuaries within the study area. Where sufficient data was available, the calculations were supported by existing analytical and numerical groundwater flow models.

Additionally, an overview of the previous EWR determination is presented to provide context with regards to data availability, criteria considered in terms of node selection and prioritization, and the approach used to identify groundwater dependent ecosystems.

The methodologies for determining the role of groundwater in the Reserve and conducting high confidence GRDM assessments have evolved over time and vary across studies, as noted by Parsons (1995), WRC (2007), and WRC (2013). The approaches were subject to simplifying assumptions that varied depending on the study area, data availability, and modeling challenges at the time. In some cases, only the groundwater Present Status (PS), based on use/recharge, was calculated, and the relationship between the Water Resource Classes (WRCs) and groundwater availability was not considered, leading to no specific calculation of allocable groundwater. This is acceptable in areas where surface-groundwater interactions are minimal, making the impact of groundwater use (and changing abstraction rates) on ecology (and meeting the EWR) minimal, thus simplifying the link between groundwater Class, Reserve and related RQOs.

In some cases, surface-groundwater interactions play a significant role, and it is assumed that maintaining their contribution to baseflow is necessary to meet the EWRs (DWA, 2013). However, this assumption oversimplifies things when dealing with altered systems, particularly estuaries, where interflow or return flows from wastewater treatment plants must be considered. In some cases, it may not be necessary to maintain all of the natural groundwater contribution to baseflow (GWBF) to maintain the EWRs for estuaries (Riemann, 2013).

However, this is not the case for rivers, as return flows from WWTW are not considered to contribute to EWRs since EWRs are defined based on natural patterns of discharge. For instance, too much or too little water can be problematic, particularly if it happens out of season.

The underlying theory for quantifying groundwaters contribution to EWR is summarized below:

- There are no separate WRCs for groundwater, as the primary emphasis is on the protection of water resources. WRCs are established per IUA based on the number of river nodes and the associated TECs. Groundwater therefore supports WRCs by contributing to baseflow (i.e., maintaining low flows) of the associated EWRs.
- The Present Status (PS) of groundwater is related to the alteration of the groundwater system from its natural state and is primarily linked to the level of use, which can influence groundwaters contribution to baseflow (Dennis et al, 2013).
- A TEC for groundwater can be established based on the WRCs, or WRCs may also be established based on conservation driven scenarios, in which case groundwater abstraction guidelines may be specified.
- The established WRCs dictates the TEC for groundwater, and in areas where groundwater has no contribution to baseflow, yet forms a significant resource, the TEC for groundwater may determine the WRCs for the entire IUA to protect groundwater resources.

3.1. Previous Studies

3.1.1. Berg catchment WRCs and RQOs study

The Berg catchment WRCs and RQOs Study (DWS, 2016) considered groundwater's potential role in the Classification by developing a groundwater balance model to establish the relationship between groundwater availability and groundwater's contribution to baseflow. Despite limitations (such as scale, data availability, etc.), the study described the analysis and simplifications in the Status Quo and Quantification of EWRs and changes in EGSAs Reports. Pertinent results from these reports are summarised below for surface flows of rivers and estuaries, groundwaters contribution to baseflow (GWBF) and availability, groundwater dependent ecosystems (GEDs) and wetlands.

3.1.1.1. Surface Flow for Rivers and Estuaries

The seven-step WRCs procedure was used for node selection and node elimination (**Figure 1-2**). Eleven tiers of information were assessed, and rules were applied to delineate various river nodes (DWS, 2016). A total of 47 river nodes were added and then rationalised to eliminate those without EWRs or with insufficient hydrological information (reduced to 45 river nodes). There were 7 previous EWR sites in the Berg River catchment (G1), of which some data was extrapolated to other nodes.

There were no existing EWRs for the G2 catchments, therefore 3 Rapid Level III Reserve sites were established on the Diep, Lourens and Eerste rivers. EWRs were calculated for all nodes using the Desktop Reserve Model (Hughes and Hannart, 2003) and calibrated with EWR data from existing Reserve sites.

22 estuary nodes were identified in the study area, 8 of which were deemed a priority and for which EWRs were determined. Specialist field visits were undertaken to determine the EWRs, PES and TECs for these 8 estuary sites (**Appendix B**).

3.1.1.2. GWBF and Availability

Two different EWRs were acquired from the Berg catchment WRCs and RQOs study: 1) those that excluded large inter-annual floods, and 2) those that included large inter-annual floods (or Total flows). EWRs that exclude large floods are better for management, because it is assumed that large floods, larger than the 1:2, take place naturally and cannot be managed because most dams in South Africa have no release mechanisms. Total flows are more useful when undertaking basin wide water resource planning because the hydrological models from which discharge time series are derived include the large floods.

The "balancing and routing” tool was used to balance the cumulative (Total) flow in a downstream direction and to calculate deficits and surpluses in volume, and the resulting changes in ecological condition at river nodes and estuaries. The results from the analysis were monthly flow volumes at all the nodes for a particular resulting "target" or “recommended” ecological condition (DWS, 2019b: 121; **Table 3-3**). The EWRs that exclude large floods were used to calculate baseflow separation (outlined in **Section 3.2.1**), because the primary interest were the low flows.

The nodes GWBF was then compared to the provisional EWRs as an indication of their relative importance in terms of surface-groundwater interaction (**Table 3-1** and **Table 3-2**). Nodes with estimated GWBF above 50% of the EWRs were considered groundwater dependent sites (discussed further in **Section 3.1.1**). Details around data collation and disaggregation can be reviewed in Berg catchment WRCs and RQOs study and resultant reports (DWS, 2016).

In terms of groundwater availability and the associated EWRs, the Berg catchment WRCs and RQOs study's groundwater availability assessment was based on the Capture Principal Approach described by Seyler et al. (2016). The underlying assumption was that recharge is comparable to (or an indicator of) groundwater availability and that the proportion of the recharge/availability being used is a direct indicator of "acceptable groundwater use" at a regional scale. This assumption was in line with the groundwater balance approach selected for this Reserve determination study, in which groundwater availability was set to some portion of recharge and includes GWBF, or its contribution to the EWR.

The methods used to generate the EWR data to construct the Ecological Category (EC) scenarios for the Berg catchment were described in the Quantification of EWR and changes to EGSA's Report (DWS, 2017b). Due to the significant diversity of regions within the Water Management Area (WMA), it was necessary to identify hydrological water resource zones with similar characteristics to generalize the EWR models.

3.1.1.3. GDEs and Wetlands

Wetlands with a link to a river node were identified in Berg catchment WRCs and RQOs study (DWS, 2016). The wetlands were either 1) dependent on river flow, or 2) influenced by discharge from upstream wetlands. River nodes near "Depression" or "Seep" wetlands were assumed to be locations where surface and groundwater interacted. Where applicable, the descriptions for each river node included significant relationships to wetlands (**Appendix B**).

The Water Resource Classification assessment (DWS, 2016) determined if groundwater was a source of baseflow, (whether ecology relies on groundwater), and what the potential consequences may be if there were changes to the system.

By quantifying the GWBF, the study provided a way to show a level of confidence and enable some integration with the surface water components of RDM. However, if RQOs and the associated EWRs are set without a comprehensive understanding of groundwater driven ecosystems, the RQOs and EWRs may be altogether ineffective in protecting the water resource, or they may fail the NWA by being too restrictive on groundwater abstraction when restrictions are not necessarily warranted.

Table 3-1 Groundwater balance, stress (Use/Recharge), groundwaters contribution to baseflow (GWBF), and present status (PS) per quaternary catchment (after DWS, 2017b).

Quaternary	Recharge (Mm³/a)	Use (Mm³/a)	GWBF (Mm³/a)	Balance (Mm³/a)	Use/ Recharge (%)	Water Resource Class
G10A	21.09	3.90	7.25	9.93	19%	I
G10B	12.27	0.36	5.34	6.57	3%	I
G10C	22.88	2.64	2.26	17.98	12%	I
G10D	31.03	3.87	5.00	22.15	12%	I
G10E	16.05	4.65	2.25	9.14	29%	II
G10F	15.05	0.98	4.33	9.74	7%	I
G10G	8.84	0.00	2.73	6.11	0%	I
G10H	17.18	1.62	3.28	12.28	9%	I
G10J	23.74	0.38	2.36	21.00	2%	I
G10K	39.34	7.50	1.18	30.66	19%	I
G10L	44.35	4.17	1.99	38.19	9%	I
G10M	55.50	1.97	5.70	47.83	4%	I
G21A	14.77	0.77	0.29	13.71	5%	I
G21B	7.50	6.33	0.53	0.64	84%	III
G21C	8.84	0.57	1.95	6.32	6%	I
G21D	14.25	6.97	3.27	4.02	49%	II
G21E	21.85	3.97	4.21	13.67	18%	I
G21F	5.07	0.13	1.71	3.23	3%	I
G22A	6.81	0.06	3.24	3.51	1%	I
G22B	4.22	0.04	0.65	3.52	1%	I
G22C	13.07	3.54	2.56	6.97	27%	II
G22D	13.08	7.31	2.40	3.37	56%	II
G22E	12.27	0.92	2.63	8.71	8%	I
G22F	8.54	0.50	2.41	5.63	6%	I
G22G	6.57	0.82	1.10	4.66	12%	I
G22H	14.03	1.25	2.08	10.70	9%	I
G22J	11.28	0.51	1.58	9.20	4%	I
G22K	4.78	0.24	1.06	3.48	5%	I
G30A	27.88	3.81	1.19	22.88	14%	I
G30D	15.61	8.23	0.62	6.76	53%	II
G40A	15.26	0.00	3.17	12.09	0%	I
TOTAL	**533**	**78.01**	**80.32**	**374.65**	**-**	**-**

Table 3-2 Groundwater contribution to baseflow (GWBF) for all river nodes in the Berg catchment which are compared to Ecological Water Requirements (EWR) and Natural Mean Annual Runoff (nMAR). Low to Moderate GWBF (<16%) at 22 nodes is highlighted blue, Moderate to high (17-75%) at 12 nodes highlighted green, and high (>75%) at 8 nodes highlighted orange.

Node Name	Quaternary	EWR (Mm^3/a)	EWR-MLF (Mm^3/a)	nMAR (Mm^3/a)	GWBF (Mm^3/a)	GWBF/ EWR	GWBF / EWR-MLF	GWBF/ nMAR
Bi1	G10G	125		125	2.7	2%		2%
Bii1	G10L	1.7		13.7	2	117%		15%
Biii2	G10B	12.5	6	85.6	5.3	43%	89%	6%
Biii3	G10C	92.2	65	418.1	1.8	2%	3%	0%
Biii4	G10E	18.7		84.2	2.3	12%		3%
Biii5	G10J	4.2	1.2	32.9	3.3	78%	274%	10%
Biii6	G22F	8.3	5.1	36.6	2.4	29%	47%	7%
Biv1	G10J	140.3		679	1.8	1%		0%
Biv2	G10L	223	155.8	924.5	1.1	1%	1%	0%
Biv3	G10J	14.4	6.3	96.8	0.8	5%	13%	1%
Biv4	G10J	24.1	11.5	165.5	0.5	2%	4%	0%
Biv5	G10A	5.3	2.9	34.9	1.5	27%	51%	4%
Biv6	G21D	1.3	0.6	9.3	2.6	201%	450%	28%
Biv7	G21E	4.3	1.8	30.3	4.2	98%	239%	14%
Biv8	G22G	4.3	1.4	30.3	1.1	26%	81%	4%
Biv9	G22E	0.6		20.3	2.4	389%		12%
Bv1	G21D	1.9	0.8	13.7	1.9	103%	250%	14%
Bvii10	G10D	101.8	71.8	461.6	0.9	1%	1%	0%
Bvii11	G10F	115.1	74	557	1.8	2%	2%	0%
Bvii12	G10K	217.5	151.9	901.8	0.3	0%	0%	0%
Bvii13	G10A	84.5		84.5	3.4	4%		4%
Bvii14	G10C	9.8	5.9	43.7	0.5	5%	9%	1%
Bvii15	G10D	0.6	0.3	3.8	0.3	57%	120%	9%
Bvii16	G10J	21.5		21.5	0.1	0%		0%
Bvii17	G10J	1.9	1	9.2	0.4	23%	41%	5%
Bvii18	G10J	0.5		3.3	0.4	78%		12%
Bvii20	G22A	3.5		3.5	0.3	8%		8%
Bvii21	G22J	15.8	7.9	70	1.6	10%	20%	2%
Bvii22	G40A	4.7	3.9	34.8	3.2	68%	83%	9%
Bvii3	G10D	2.6	1.1	18.2	0.4	14%	36%	2%
Bvii4	G10D	3.5	1.4	24.8	0.5	16%	37%	2%
Bvii5	G10D	177.4	83.1	534.3	2.8	2%	3%	1%
Bvii6	G10J	177.9	114.3	860.7	0.4	0%	0%	0%
Bvii7	G22D	0.7	0.3	4.5	0.2	28%	57%	4%
Bvii8	G10J	185.2	119.1	896.4	0.3	0%	0%	0%
Bviii1	G10A	44	27.4	141.7	2.4	5%	9%	2%
Bviii10	G21B	1		6.2	0.5	48%		8%
Bviii3	G21A	0.1	0.1	1	0	23%	0%	2%
Bviii4	G21D	0.3	0.1	2.3	0.7	218%	483%	28%
Bviii5	G21F	8.6		60.8	1.7	20%		3%
Bviii6	G22B	2.6	1.2	17.2	0.7	25%	56%	4%
Bviii8	G22C	3.6		23.2	1	28%		4%
Bviii9	G22K	11.8	8.1	48.7	1.1	9%	14%	2%
TOTAL	**-**	**1878.6**	**931.3**	**7635.4**	**63.6**	**-**	**-**	**-**

Table 3-3 Summary of priority river and estuary nodes in the Berg catchment, the associated Water Resource Classes (WRCs) for each Integrated Unit of Analysis (IUA), and the Target Ecological Category (TEC) (after DWS, 2019b: 121).

Integrated Unit of Analysis (IUA)	Water Resource Class for IUA	Resource Name	River and Estuary Node	Resource Type	TEC	% nMAR*
A1 Berg Estuary	II	Berg (Groot)	Bxi1	Estuary	C	52
A2 Langebaan	II	Langebaan	Bxi3[3]	Estuary	A	N/A
A3 West Coast	III	Yzerfontien	Bviii3	River	D	14.6
A3 West Coast	III	Sout	Bviii10	River	D	16.4
B4 Lower Berg	III	Berg	Bvii6	River	D	52
B4 Lower Berg	III	Berg	Bvii12	River	D	51
C5 Berg Tributaries	II	Klein Berg	Biii4	River	C	82
C5 Berg Tributaries	II	Vier-en-Twintig	Bi1	River	B/C	23
D10 Diep	III	Diep	Bv1	River	D	66
D10 Diep	III	Diep	Biv6	River	D	68
D10 Diep	III	Rietvlei/ Diep	Bxi7	Estuary	C	78
D6 Eerste	III	Eerste (Jonkershoek)	Biii6	River	C	93
D6 Eerste	III	Klippies	Biv8	River	D	77
D6 Eerste	III	Eerste	Bxi3[3]	Estuary	D	90
D7 Sir Lowry's	II	Lourens	Bvii21	River	D	114
D7 Sir Lowry's	II	Sir Lowry's Pass[4]	Bviii9	River	C	84
D7 Sir Lowry's	II	Steenbras	Bvii22	River	B/C	81
D7 Sir Lowry's	II	Lourens	Bxi4	Estuary	D	85
D8 Upper Berg	II	Berg	Bvii13	River	A	98
D8 Upper Berg	II	Berg	Bviii1	River	C	27
D8 Upper Berg	II	Berg	Biii3	River	D	53
D9 Middle Berg	III	Pombers	Bviii11	River	C	366
D9 Middle Berg	III	Kromme	Bvii3	River	D	89
D9 Middle Berg	III	Berg	Bvii5	River	D	49
E11 Peninsula	II	Hout Bay	Bviii6	River	D	97
E11 Peninsula	II	Silvermine	Bvii20	River	C	98
E11 Peninsula	II	Wildevöelvlei	Bxi14	Estuary	C	107
E12 Cape Flats	III	Keysers	Bvii7	River	D	93
E12 Cape Flats	III	Zandvlei	Bxi9	Estuary	C	93
E12 Cape Flats	III	Zeeköevlei	Bxi20	Estuary	D	N/A

[3] According to DWS (2019b: 121), the node name "Bxi3" is used for both the "Langebaan" and "Eerste" estuary. To avoid confusion, this report will refer to these water resources using the "resource name" and not the estuary node name.
[4] This is based on the estimated/simulated flow requirement in the system to meet downstream TECs as well as with current demands. This will differ from the minimum flow requirement to meet the EWR at any given node. In some cases, the flow is above 100% of natural due to the impact of releases to meet downstream demands.

3.1.2. Previous Reports from this current Study

3.1.2.1. Delineation of GRUs

DWS (2022d) provided an overview of the GRUs that had been previously defined in the Berg catchment, outlined the approach that was used to delineate aquifer-specific GRUs, and provided details about the criteria that were considered when selecting GRU boundaries. The approach that was followed was Step 2 of the eight-step groundwater Reserve determination procedure that was outlined in the Groundwater Reserve Determination Measures (GRDM) manual (WRC, 2013). Three overarching criteria were considered, including physical criteria, management criteria, and functional criteria.

The physical criteria that were considered included aquifer geometry, existing aquifer boundaries and associated boundary conditions, recharge, topography, structural geology, and potential discharge areas. The management criteria that were considered included 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. The functional criteria that were considered included groundwater-surface water interactions and their role in maintaining hydrological integrity, discharge integrity, and established ecological water requirements.

The revised aquifer-specific GRUs are presented in **Figure 1-3**. The study boundary extended beyond the Berg catchment to fully encompass the hydrogeological nature of all identified GRUs.

3.1.2.2. Ecological Reference Conditions

DWS (2022e) described the ecological reference conditions of aquifer-specific groundwater resource units (GRUs) and re-evaluated their Present Status (PS). It provided an overview of the previous groundwater status quo assessments and details on the criteria considered for a revised assessment. The re-assessment of the groundwater status quo for the Berg catchment was Step 3 of the eight-step RDM: groundwater Reserve determination procedure (WRC, 2013), and, where appropriate, aligned with Step 1 and Step 2 of the Water Resource Classification process set out in Regulation 2(4). Five key hydrogeological components were discussed in this report, viz. Recharge, Groundwater Use, Discharge, Groundwater Quality and Aquifer Stress; which are important considerations for the implementation of an effective water resource management strategy. **Table 3-4** presents a summary of both the groundwater availability and groundwater quality PS.

Although the groundwater Reserve does not address groundwater quality issues directly, these were addressed as part of the Water Resource Classification and RQOs in the Berg catchment (DWS, 2016). Additionally, as part of the Ecological Reference Conditions Report for the Berg catchment (DWS, 2022e), the groundwater quality Present Status (PS) was reassessed (**Table 3-4**). The report utilized data from various sources and conducted a basic hydrochemical assessment. Baseline groundwater quality was evaluated for each GRU and associated RUs, and potential sources of contamination were identified and investigated. Compliance with the DWS (2019b:121) RQOs was also assessed for select parameters, and water quality Classes were established per GRU. The evaluation of groundwater quality was based on a two-fold approach, including a baseline hydrochemical assessment, as well as a comparison of data to established preliminary RQOs for groundwater. Aquifer types were also considered, with water quality results assigned to the prevailing aquifer type in cases where borehole construction data and geological logs were not available (see DWS, 2022e for further details).

Additional groundwater quality data has recently been provided by DWS to supplement areas that previously had a shortage of data. The analysis of this data will be incorporated and reviewed in the Scenario Step i.e., Step 5 and 6 of the groundwater Reserve determination, see **Table 1-1**.

Table 3-4 Summary of Present Status (PS) Category per Groundwater Resource Unit (GRU) in the Berg catchment (after DWS, 2022e).

GRU	Groundwater Availability Present Status Category	Groundwater Quality Present Status Category
Cape Flats	C	D
Atlantis	B	C
Yzerfontein	A	A
Elandsfontein	B	B
Langebaan Road	C	B
Adamboerskraal	B	B
Cape Peninsula	B	B
Steenbras-Nuweberg	B	B
Drakensteinberge	A	-
Wemmershoek	A	A
Voëlvlei-Slanghoek	A	-
Witsenberg	A	-
Groot Winterhoek	B	-
Piketberg	C	-
Cape Town Rim	C	C
Stellenbosch-Helderberg	C	C
Paarl-Franschhoek	C	-
Malmesbury	C	B
Wellington	B	B
Tulbagh	C	-
Eendekuil Basin	C	C
Middle-Lower Berg	B	C
Northern Swartland	B	C
Darling	B	C
Vredenberg	B	-

3.2. EWR Reserve Calculation Approach

The EWR component dependent on groundwater discharge was calculated from hydrological data that was modelled to meet the EWRs predicted to maintain Target Ecological Categories (TECs) of river nodes and priority estuaries (DWS, 2016). As outlined in **Section 3.1.1**, the EWRs with no large floods were used for the baseflow separation.

A variety of baseflow separation techniques were evaluated and an appropriate method selected based on the hydrogeological complexities in the study area. To accurately assess the contribution of groundwater to the EWR per GRU, a detailed GIS-based catchment analysis was used to re-evaluate the extent of the incremental catchments based on the local topography, flow direction, aquifer model extents and available literature. A recharge ratio was then be applied to dry season baseflow per GRU and associated aquifer types to determine GWBF per GRU and the associated contribution to the EWR Reserve.

Figure 3-1 displays an overview of the EWR Reserve calculation workflow.

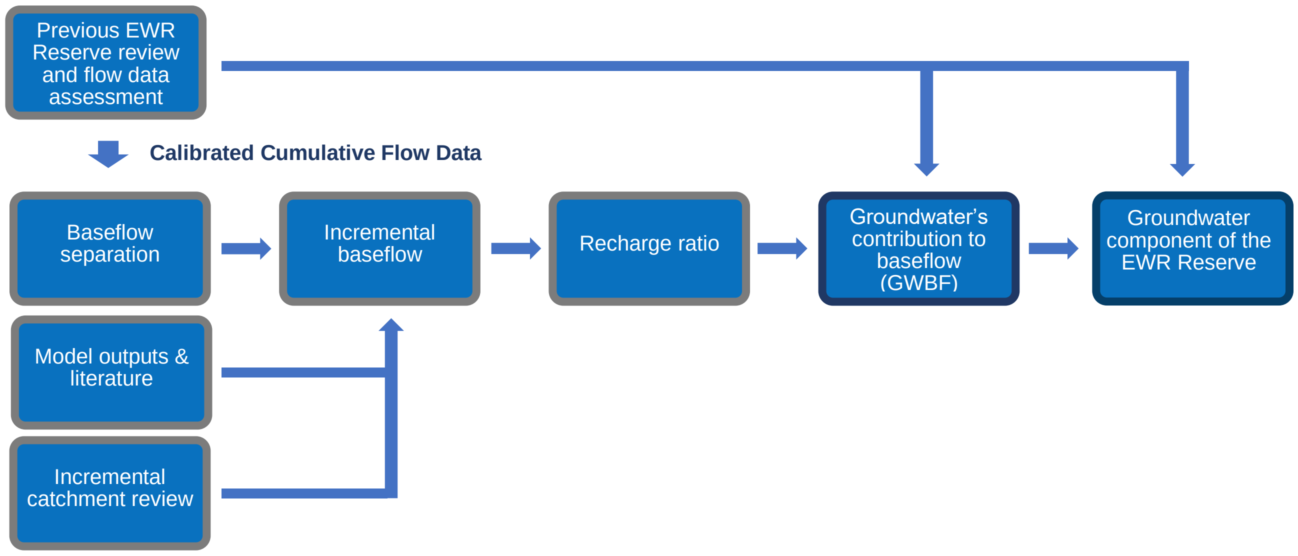


Figure 3-1 Groundwater contribution to the EWR Reserve calculation workflow

3.2.1. GWBF to Rivers: Baseflow Separation

Understanding the contribution of baseflow to rivers in the context of catchment-scale hydrology requires consideration of a range of aspects, including groundwater-surface water interactions, the influence of geology and topography on baseflow, and the calculation of groundwater recharge rates.

Hydrograph separation, also referred to as baseflow separation, can be a valuable supporting tool for groundwater Reserve determinations in terms of evaluating the effects of various environmental changes on both surface and groundwater. Conceptually, "baseflow" is the portion of the flow that has a different source other than surface runoff. Often, baseflow is considered to represent the sum of both deep and shallow subsurface contributions to flow. The two most commonly used baseflow separation techniques are 1) the Graphical Filter method, and 2) the Recursive Digital Filter method.

Graphical filter methods involve graphically estimating the baseflow component from the hydrograph. This method involves visually identifying the baseflow which is not deemed appropriate for this study.

Recursive digital filter methods are however based on mathematical algorithms that apply a set of equations to separate high-frequency fluctuations (streamflow) from low frequency fluctuations (baseflow) The most commonly used recursive digital filter methods for baseflow separation are the digital filters developed by Lyne and Hollick (1979), Chapman and Maxwell (1996), and Eckhardt (2005), all of which were done for all river nodes (**Appendix B**).

An advantage of using digital filters is their versatility, as they can be applied multiple times to separate flow into more than two components. This allows for attribution of the components to various sources of flow, such as surface runoff, delayed shallow flow, tile drain flow, and deep groundwater flow.

After a thorough review of separation methods, the associated results, and its applicability for use in the study area[5], the Chapman and Maxwell (1996) method, the most commonly used method in South Africa, was selected for use in this project. This "one-parameter" method involves the use of a digital filter with a single parameter that is adjusted to produce a desired level of smoothing in the

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[5] *In **Appendix C: Baseflow Separation**, a summary table (**Table C-1-1**) is presented along with the associated baseflow separation graphs (**Figure C-1-1**) for all river nodes in the Berg catchment. Parameters (Lyne & Hollick) = 0.75; alpha (Eckhardt) = 0.83; BFI Max (Eckhardt) = 0.75; and k (Chapman & Maxwell) = 0.1.*

hydrograph. The method assumes that the baseflow component of the hydrograph varies more slowly over time than the surface runoff component. A filter is then applied to the hydrograph repeatedly, with each successive iteration of the filter producing a smoother version of the hydrograph. The baseflow component is estimated by subtracting the smoothed hydrograph from the original streamflow hydrograph (see example in **Figure 3-2**).

Chapman & Maxwell (1996) - One parameter digital filter method

The Chapman and Maxwell hydrograph separation digital filter, introduced in 1996, can be viewed as a simplified version of that described by Boughton (1993).

$$bt = \frac{k}{2+C} \times b_{t-1} + \frac{1-k}{2-k} \times Qt$$

b - baseflow (m³/s)

Q - streamflow (m³/s)

t - the time (e.g., day) for which the baseflow is calculated

k - groundwater recession constant [values between 0 and 1]; set to 0.100

The Chapman & Maxwell (1996) method was applied to the total baseflow (Mm^3/a) during the dry season. As outlined in **Section 3.1.1**, monthly flow volumes (calibrated to the TEC) were used for baseflow separation of each river node. However, monthly flow data may not always be suitable for a robust baseflow separation due to the influence of periodic wet months and summer storm events. To address this issue, and to provide a more conservative value for baseflow, the study utilized the minimum baseflow for each year in the flow series and took the average over the entire data period.

The results are summarised in **Table 3-5**, which include summary statistics such as the maximum, mean, minimum, and standard deviation for both discharge (Q) and baseflow (b) values. Although the maximum and standard deviation values were not used in the graph (**Figure 3-2**), they provided crucial information about the central tendency, variability, and range of the data.

Table 3-5 Summary of the baseflow separation for all river nodes in the Berg catchment using the digital filter method Chapman and Maxwell (1996). The assessment of flow data covers the period from 1920 to 2002/2008/2012 (where data was available), and the results include a dry season average for both discharge (Q) and baseflow (b) in Mm³/annum. Note the values displayed are based on cumulative flow (Section 3.1.1.2).

Node Name	TEC	Flow Type	Q min	Q mean	Q max	Q std	Q dry season average	b min	b mean	b max	b stdev	b dry season average
Bi1	BC	Current	2.37	29.58	166.11	28.28	0.21	1.17	14.65	82.09	14.00	0.15
Bii1	C	Calibrated	1.00	3.08	4.72	0.90	0.03	0.50	1.54	2.36	0.45	0.01
Biii2	A	Natural	37.28	85.57	183.29	29.32	6.31	18.64	42.78	91.39	14.64	3.29
Biii3	D	Calibrated	82.50	137.98	163.54	19.84	17.16	41.26	68.99	81.75	9.92	8.90
Biii4	C	Calibrated	12.48	20.86	26.79	3.83	3.39	6.24	10.43	13.39	1.91	1.74
Biii5	B	Calibrated	3.47	9.45	12.76	2.13	0.07	1.73	4.72	6.38	1.07	0.04
Biii6	C	Calibrated	5.67	9.31	11.89	1.36	1.36	2.84	4.66	5.94	0.68	0.70
Biv1	B	Calibrated	229.40	458.12	928.37	151.98	44.75	114.84	229.06	463.39	75.92	23.07
Biv2	B	Calibrated	326.86	645.90	1309.33	216.57	61.52	163.33	322.95	653.51	108.19	31.86
Biv3	A	Natural	35.24	96.79	252.75	46.05	7.08	18.00	48.39	126.42	22.99	3.67
Biv4	B	Calibrated	27.30	55.36	69.27	9.08	9.78	13.63	27.68	34.64	4.53	5.02
Biv5	B	Calibrated	6.02	12.57	15.89	2.23	2.75	3.01	6.29	7.94	1.11	1.41
Biv6	D	Calibrated	2.06	4.58	6.06	1.02	0.69	1.03	2.29	3.03	0.51	0.35
Biv7	B	Calibrated	2.73	8.49	13.47	2.97	1.19	1.37	4.25	6.73	1.48	0.60
Biv8	D	Calibrated	1.57	3.51	4.36	0.53	1.10	0.79	1.76	2.18	0.27	0.56
Biv9	B	Calibrated	2.19	5.89	7.85	1.45	1.06	1.10	2.94	3.93	0.72	0.53
Bv1	D	Calibrated	0.96	2.33	3.13	0.56	0.32	0.48	1.17	1.56	0.28	0.16
Bvii10	B	Calibrated	157.29	333.54	624.54	101.31	28.53	78.65	166.77	311.72	50.62	14.75
Bvii11	D	Calibrated	83.91	121.76	151.64	18.28	25.52	41.95	60.88	75.81	9.14	13.04
Bvii12	D	Calibrated	123.45	217.89	271.66	37.82	46.69	61.67	108.94	135.80	18.90	23.89
Bvii13	A	Current	36.92	83.32	167.24	26.47	4.64	18.42	41.64	83.43	13.21	2.45
Bvii14	A	Natural	17.34	43.65	89.56	15.03	2.81	8.66	21.82	44.68	7.51	1.45
Bvii15	A	Natural	1.39	3.84	10.07	2.00	0.14	0.70	1.92	5.03	1.00	0.08

Node Name	TEC	Flow Type	Q min	Q mean	Q max	Q std	Q dry season average	b min	b mean	b max	b stdev	b dry season average
Bvii16	A	Calibrated	8.96	21.54	43.29	7.59	1.03	4.47	10.77	21.65	3.79	0.55
Bvii17	C	Calibrated	0.97	2.14	2.84	0.50	0.06	0.49	1.07	1.42	0.25	0.03
Bvii18	C	Calibrated	0.42	0.78	1.03	0.17	0.03	0.21	0.39	0.52	0.08	0.02
Bvii20	A	Current	0.70	3.22	9.62	2.20	0.28	0.36	1.61	4.81	1.10	0.14
Bvii21	D	Calibrated	7.77	12.38	15.50	1.76	1.98	3.88	6.19	7.75	0.88	1.00
Bvii22	BC	Calibrated	3.74	5.09	6.11	0.61	1.35	1.87	2.55	3.06	0.31	0.68
Bvii2	B	Calibrated	154.36	357.28	743.67	123.63	27.31	77.18	178.64	370.94	61.74	14.12
Bvii3	D	Calibrated	1.47	3.56	4.70	0.84	0.26	0.73	1.78	2.35	0.42	0.13
Bvii4	B	Calibrated	3.71	7.82	10.05	1.41	0.75	1.85	3.91	5.02	0.71	0.39
Bvii5	D	Calibrated	85.93	137.36	164.62	18.56	25.07	42.96	68.68	82.31	9.28	12.93
Bvii6	D	Calibrated	113.25	187.12	231.97	29.07	42.56	56.59	93.56	115.97	14.53	21.61
Bvii7	D	Calibrated	0.44	0.97	1.26	0.19	0.18	0.22	0.49	0.63	0.09	0.09
Bvii8	C	Calibrated	193.90	313.59	394.81	51.99	57.37	96.86	156.79	197.36	25.98	29.49
Bviii10	D	Calibrated	0.88	1.59	1.94	0.27	0.64	0.44	0.79	0.97	0.13	0.32
Bviii11	C	Calibrated	0.29	0.47	0.57	0.07	0.04	0.14	0.23	0.29	0.04	0.02
Bviii1	C	Calibrated	27.54	49.91	63.84	8.33	5.29	13.75	24.95	31.89	4.16	2.76
Bviii3	D	Current	0.18	0.58	3.92	0.52	0.08	0.09	0.29	1.96	0.26	0.04
Bviii4	B	Calibrated	0.27	0.74	1.00	0.18	0.12	0.14	0.37	0.50	0.09	0.06
Bviii5	D	Calibrated	5.01	11.19	15.04	2.64	1.78	2.50	5.59	7.52	1.32	0.89
Bviii6	D	Calibrated	1.80	3.46	4.43	0.58	0.50	0.90	1.73	2.22	0.29	0.25
Bviii8	D	Calibrated	2.83	5.42	6.83	1.03	1.38	1.41	2.71	3.41	0.52	0.69
Bviii9	C	Calibrated	7.29	13.44	16.95	2.04	2.38	3.64	6.72	8.46	1.02	1.21

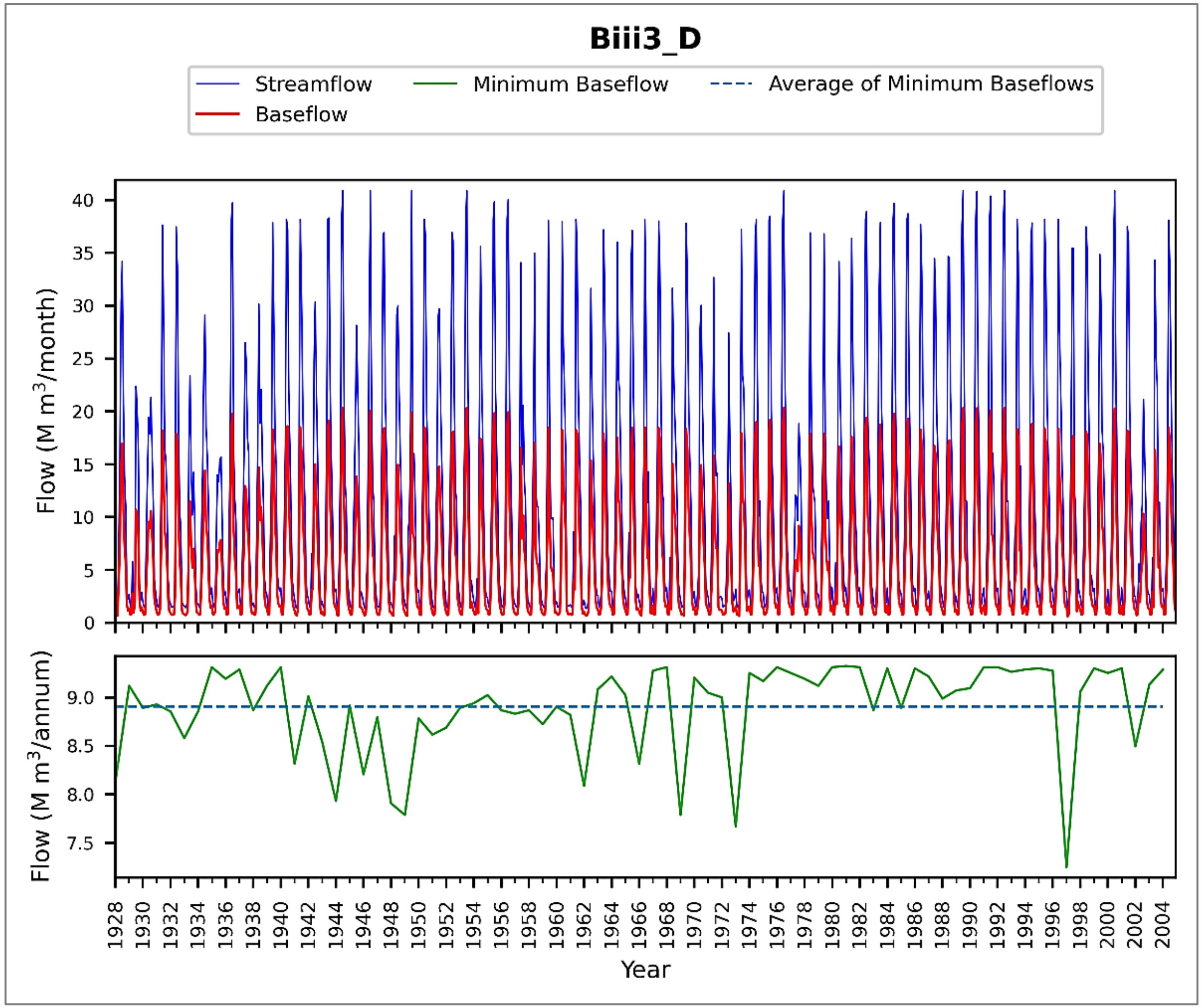

Figure 3-2 **Example of baseflow separation graph created for all river nodes in the Berg catchment after Chapman and Maxwell (1996). The upper graph displays the streamflow (Q) and baseflow (b) separation (Mm3/month) while the lower graph shows total dry season baseflow in Mm3/annum, which is the average minimum baseflow per year.**

3.2.2. GWBF to Estuaries: Model Outputs & Literature

This section presents an overview of groundwaters contribution to estuaries in maintaining the EWRs set in the Berg catchment WRCs and RQOs study DWS (2016). Eight priority estuaries were identified in the study area based on their type, biota, anthropogenic impacts, their current ecological health and conservation status, namely the: Berg River, Langebaan, Zandvlei, Zeeköevlei, Eerste, Lourens, Rietvlei/Diep and Wildevöelvlei Estuaries.

Estuaries were classified into five types based on the size of the tidal prism, mixing process, and salinity: (Whitfield, 1992): 1) estuarine bays, 2) permanently open estuaries, 3) estuarine river mouths, 4) estuarine lake, and 5) temporarily open estuaries. Of these, estuarine bays, permanently open estuaries, and estuarine river mouths remain open to the sea, while estuarine lakes and temporarily open/closed estuarine systems close periodically, sometimes for years. Of the eight estuaries, the Berg and Zeeköevlei estuaries are permanently open systems. Langebaan is an estuarine bay and the other five are temporarily open estuaries (**Table 3-6**).

The flow data provided by DWS (2016) accounted for inflow at the head of the estuary, and did not consider GWBF at the mouth or along its margins. The two estuaries where this is relevant are the Berg River and Langebaan Estuaries.

To quantify the volume of groundwater discharged into these two estuaries, existing numerical groundwater models (DWAF, 2008) were used, whereby the mass balances within their associated ‘incremental catchment’ were analysed. The analysis considered both the estuary inlet and the estuary margins. However, the associated EWRs only considered the flow from the inlet to the estuary, ignoring the groundwater input at the estuary margins. The methodology used to assess the groundwater contribution to these estuaries is outlined below and the revaluated groundwater catchments discussed in **Section 3.2.4** and displayed in **Figure 3-4**.

Based on the existing groundwater models, the Berg River Estuary has the largest groundwater inflow volume, estimated at approximately 11.27 Mm^3/a (**Table 3-8**) due to its large incremental catchment area that drives groundwater flow into the estuary. The Langebaan Estuary has the second-largest groundwater inflow, approximately 6.39 Mm^3/a, which is attributed to regional groundwater flows from the northeast towards the Lagoon (as illustrated in **Figure 3-3**).

3.2.2.1. The Berg River Estuary

The Berg River Estuary has a large incremental catchment, the river is ~285 km in length. As the river flows northwest past the towns of Paarl and Wellington, it traverses a predominantly flat coastal plain before reaching the town of Laaiplek, where it enters St Helena Bay. The estuary's gradient is very flat, and it extends ~69 km inland from the canalised mouth, with seawater penetration limited to ~40 km during low flow periods (DWS, 2017a).

The Berg River Estuary is a designated Ramsar site because it is one of the country's most significant coastal wetlands. The estuary forms the confluence of freshwater from its floodplain with marine water, resulting in a diverse environment that supports a wide range of habitats. Among these is the third-largest saltmarsh on the Cape Coast (Ramsar, 2022).

The Estuary's extensive floodplain, up to 4 km wide when inundated, makes the largest functional estuary zone in the study area.

3.2.2.2. Langebaan Estuary

The Langebaan Lagoon has been the subject of debate in terms of its classification due to its lack of a clear salinity gradient, despite it being larger than conventional lagoons. However, its characteristics, such as the presence of vegetation and groundwater input, suggest estuarine features. The lagoon is connected to Saldanha Bay and has tidal water exchange, but the influx of cooler, deeper marine water is prevented by thermal stratification.

The Langebaan Lagoon is ~16 km long and ~3-4 km wide, with channels ~5 m deep, making it the largest estuary channel within the study area and the second-largest estuarine functional area (DWS, 2017a). It is fed by groundwater rather than surface flows and therefore meets the definition of an Estuarine Bay (Whitfield 1992).

Langebaan Lagoon is ecologically important as a critical nursery area for several fish species, habitat for wintering and wading birds, housing the largest gull colony in South Africa, and with a diverse shoreline flora and fauna. The seasonal wetlands on the Saldanha Peninsula are saline and occur on neutral to alkaline sands or granite-derived soils. The lagoon is situated in the West Coast National Park and therefore should be safeguarded against land use changes that could pose significant risks to its ecology.

3.2.2.3. Zandvlei Estuary

GWBF contributions to maintain the Zandvlei Estuary are considered to be negligible, compared to river inflows that converge and enter the head of the estuary at river node Bvii7. The incremental catchments are approximately 1 km^2 and the estuary is a temporary open system. The estuary is located in the Zandvlei Nature Reserve managed by the CoCTs Biodiversity Management Branch. Marina da Gama, a housing development, is situated along canals that connect to the estuary. The mouth is canalized with low rubble weirs and tidal exchange of the estuary is artificially managed to protect property and maintain recreational activities.

3.2.2.4. Zeeköevlei Estuary

GWBF contributions to maintain the Zeeköevlei Estuary are considered to be negligible, compared to storm water and return flows from Waste Water Treatment Works (WWTW). The Zeekoe catchment encompasses the Big and Little Lotus Rivers (canals), Zeeköevlei, and Rondevlei, forming a crucial part of False Bay Nature Reserve. These wetlands are considered a Ramsar site and support a significant number of waterbirds, including pelicans and flamingoes. The estuary extends approximately 3 km inland. The Cape Flats WWTW discharges effluent into the estuary, severely limiting seawater penetration and polluting the water (DWS, 2017a).

3.2.2.5. Eerste Estuary

GWBF contributions to maintain the Eerste Estuary is negligible, compared to storm water and return flows from adjacent WWTWs. The Eerste Estuary is fed by the Kuils and Eerste Rivers. The Eerste River catchment mainly consists of agricultural land, while the Kuils River catchment consists of low-income urban areas, commercial and industrial zones, and informal settlements (DWS, 2017a). The estuary is an elongated lagoon that varies in size and location depending on outflow, wind, and wave action. Five WWTWs within the catchment contribute significantly to the estuary's water quality degradation. The estuary remains open due to the additional flow provided by the WWTWs, with limited tidal influence, thus there is no associated groundwater requirement.

3.2.2.6. Rietvlei-Diep estuary

GWBF contributions to maintain the Rietvlei/Diep Estuary are considered to be negligible, compared to storm water and return flows from the WWTWs. The estuary comprises of a large area of the Rietvlei and Milnerton Lagoons and enters Table Bay about ~5 km north of Cape Town CBD. The catchment is largely agricultural, with some urban residential and industrial areas. The estuary is a protected Nature Reserve managed by the CoCTs Biodiversity Management Branch. The Diep River catchment is the second largest in the study area, but its mean annual runoff is relatively low due to low rainfall and agricultural abstractions, resulting in the river sometimes drying up completely in the summer months (DWS, 2017a). The estuary used to be deeper and previously had two mouths, but presently, only one mouth remains open due to discharges from the Potsdam WWTW, resulting in reduced salinity of the estuary.

3.2.2.7. Wildvöelvlei Estuary

GWBF contributions to maintain the Wildevöelvlei Estuary are considered to be negligible, compared to storm water and return flows from adjacent WWTWs. The estuary comprises two connected vleis, a ~0.75 km estuary channel, and the backshore lagoon on the southern half of Noordhoek Beach. It was once a series of seasonal pans that were hypersaline and nearly empty, but since the construction of the municipal Wildevöelvlei WWTWs in 1976, the estuary has contained water perennially, with nearly all the summer inflow attributed to treated effluent. The catchment is mostly covered by natural vegetation (~74%) with the remaining portion covered by urban development (DWS, 2017a). The estuary has become increasingly freshwater-dominated, and the mouth still closes when a sandbar forms during the summer months, draining the estuary into the backshore lagoon.

Table 3-6 Summary of the surface water (SW) catchment and estuary dimensions, mean annual runoff (MAR) into the estuary, and estuary type (after Whitfield, 1992) of the eight priority estuaries within the study area. MAR excludes WWTW inputs (DWS, 2017a).

Estuary	SW Catchment size (km^2)	Functional Zone (ha)	Channel area (km^2)	Type	Reference MAR (Mm^3.yr-1)	Current MAR (Mm^3.yr-1)	Current as (% ref)	WWTW input (Mm^3.yr-1)	Current (% Ref Incl. WWTW)
Berg River Estuary	7 765	91.97	6.44	Permanently open	699	562	80		80
Langebaan Estuary	502	62.6	41.13	Estuarine Bay					
Rietvlei/Diep Estuary	1 522	8.34	2.29	Temporarily open	61	37	61	27	105
Wildevöelvlei Estuary	7	2.66	0.22	Temporarily open	6	6	94	3	147
Zandvlei Estuary	87	3.07	1.19	Temporarily open	32	30	93		93
Zeekoevlei Estuary	60	3.66	3.27	Permanently open	18	17	93	43	325
Eerste Estuary	628	0.55	0.09	Temporarily open	115	101	88	67	147
Lourens Estuary	27	0.38	0.02	Temporarily open	70	59	85		85

Table 3-7 Summary of groundwater discharge (Mm^3/a) to priority estuaries in the Berg catchment (after DWAF, 2008).

Estuary	Groundwater incremental catchment area (km^2)	Total GW discharge into estuary (Mm^3/a)
Langebaan Estuary	314	6.39
Berg River Estuary	1050	11.27

3.2.3. Incremental Catchment Delineation

The assessment of groundwater availability or the impact of groundwater use on discharge to water resources, whether conducted through a desktop assessment, water balance equations, or a numerical modelling exercise, should take place over a defined area that represents the boundaries of a specific water resource (DWS, 2017b). The areas within these boundaries can be considered to be in balance, in terms of both recharge and discharge, if the water resource is in dynamic equilibrium. The boundaries of the newly defined GRUs for the Berg catchment, outlined in the Delineation of Groundwater Resource Units Report (DWS, 2022d), and summarised in **Section 3.1.2**, follow hydrogeological boundaries, even though it is recognised that the DWS still manages both surface and groundwater resources based on surface water quaternary catchments.

While disaggregating quaternary catchment information to a GRU scale was found to be a fairly simple GIS-based exercise, Reserve estimations of significant water resources in the Berg catchment were still reported with reference to a surface water quaternary catchment. This, despite the fact that aquifers, which are important strategic water resources for the catchment, cross surface water catchment boundaries and may require a different management approach.

Given the limitations of quaternary scale Reserve outcomes from previous studies, it was no longer appropriate to view quaternary catchments as the all-inclusive boundary for both surface and groundwater results. Incremental catchments linked with the river nodes were therefore re-evaluated to establish groundwater's contribution to the EWR Reserve.

In order to define incremental catchment boundaries, a sub-catchment analysis was conducted for all river nodes in the Berg study area, utilizing the Advanced Land Observing Satellite (ALOS) Digital Elevation Model (DEM) (**Table 3-8**). ALOS provides comprehensive coverage of the area and high-resolution (30-meter) topographic data. The sub-catchments were generated through a GIS-based catchment analysis technique, which enabled the refinement of each of the sub-catchment's boundaries based on local topography, groundwater flow direction, groundwater elevation (water table), aquifer geometries, geological extents, existing analytical and numerical models, and available literature. The resulting sub-catchments were then grouped based on the river nodes they supply and now are regarded as the updated "incremental catchment" for those nodes (**Figure 3-4**).

The groundwater catchments for both the Berg River Estuary and the Langebaan Lagoon were informed by groundwater flow direction, groundwater levels, GRU extents, geologically no-flow boundaries, and aquifer extents (Whitfield, 1992; Woodford and Fortuin, 2003; Woodford, et at., 2003; du Plesis, 2008; DWAF, 2008). Analysis of the regional groundwater levels indicate that in the Langebaan Estuary the flow of groundwater entering the estuary predominantly follows a south-west to north-east direction (**Figure 3-3**). A groundwater divide was identified at the southern portion of the estuary, which diverts groundwater inflows to the eastern and southern regions (**Figure 3-3**). The water table analysis revealed a hydraulic head difference of ~70 meters, flowing from about 20 km inland in a south-westerly direction towards the estuary, which is influenced by the thick (over 100 meters) Cenozoic deposit that directs groundwater flow towards the estuary (**Figure 3-3**). The Langebaan Road Aquifer (LRA) has a perpendicular no flow boundary between the Langebaan Lagoon and Hopefield (**Figure 3-3**), and was also considered in defining the incremental catchment for the Langebaan Estuary, taking into account the hydrogeological conditions and aquifer extents informed by GRUs.

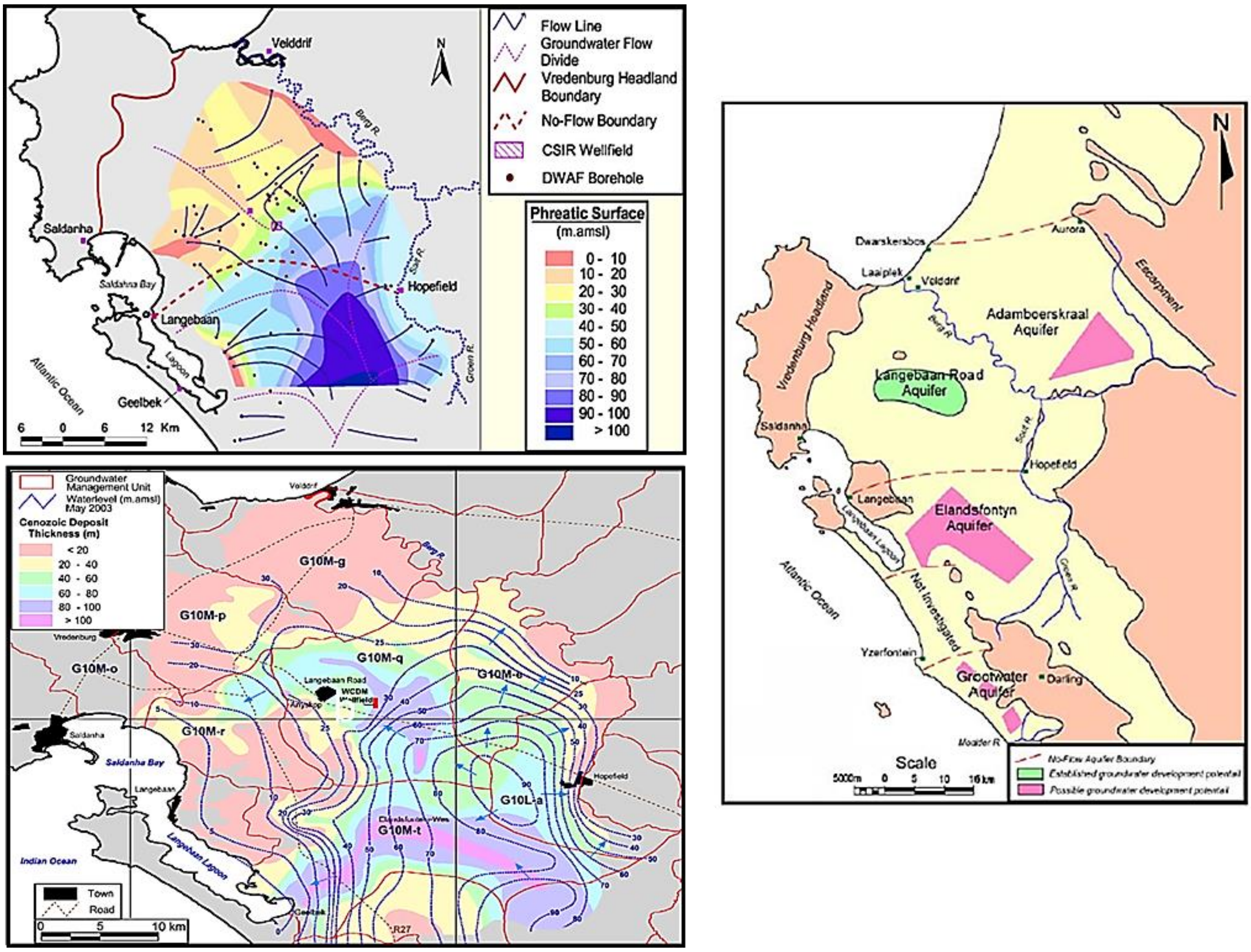

Figure 3-3 **Top left: Groundwater contours for the upper unconfined layer with flow directions (Woodford and Fortuin, 2003). Bottom left: Water level elevation and thickness of Cenozoic deposits in the Lower Aquifer Unit of the Langebaan Road Aquifer (LRA) and the Elandsfontein Aquifer (Woodford, et at., 2003; Woodford and Fortuin, 2003). Right: Extent and position of the aquifers in relation to other important formations, including no flow lines. (du Plesis, 2008).**

Groundwater contribution to the Berg River Estuary flows in a northerly direction from the LRA (**Figure 3-3**). Additional flow, from the Adamboerskraal Aquifer, drains southwards from the higher-lying escarpments toward the estuary. The incremental catchment area of the Berg River Estuary (**Figure 3-4**) was defined by the no-flow boundaries of the Adamboerskraal Aquifer in the north (between Aurora and Dwarskersboshelp towns) and south (along the LRA).

Table 3-8 A summary of the incremental catchments size (km²) for all river nodes and priority estuaries in the Berg catchment.

Node	TEC	Incremental Catchment Area (km²)	Comments (after DWS, 2016)
Bi1	B/C	185.33	At gauging weir G1H028, pristine wilderness 100%
Bii1	C	1752.60	U/s of confluence with Berg
Biii2	A	119.84	U/s of confluence with Berg
Biii3	D	245.95	At gauging weir G1H020
Biii4	C	391.11	At gauging weir G1H008
Biii5	B	671.22	At gauging weir G1H035
Biii6	C	65.84	At Lanzerac draw bridge
Biv1	B	226.69	U/s of confluence Klein-Berg, d/s Voëlvlei canal
Biv2	B	1110.26	U/s of confluence with Sout, head of estuary
Biv3	A	108.44	U/s of confluence with Berg
Biv4	B	49.42	U/s of confluence with Berg
Biv5	B	71.78	U/s of confluence with Berg
Biv6	D	391.43	
Biv7	B	531.55	
Biv8	D	112.27	
Biv9	B	230.47	U/s confluence Eerste
Bv1	D	245.67	D/s of Malmesbury
Bvii10	B	123.59	D/s of confluence Kromme, at gauging weir G1H015
Bvii11	D	211.03	U/s of Voëlvlei canal
Bvii12	D	119.27	3.5 km d/s of Misverstand reservoir, at EWR 5 - D
Bvii13	A	40.80	Gauge u/s Berg river dam, 100% MAR
Bvii14	A	60.45	Gauge
Bvii15	A	46.20	Gauge
Bvii16	A	36.79	Gauge, 100% MAR
Bvii17	C	153.76	Gauge
Bvii18	C	136.84	Gauge
Bvii2	D	47.20	Berg Water Project (BWP) pump station area
Bvii20	C	18.74	Town, 100% MAR
Bvii21	D	98.01	D/s of the N2
Bvii22	BC	66.36	At EWR 8, u/s of estuary mouth - B/C
Bvii3	D	47.40	North of Wellington, G1H037, d/s EWR 6 - D
Bvii4	B	122.83	At gauging weir G1H041
Bvii5	D	344.31	At gauging weir G1H036 and u/s of EWR 3 - C/D
Bvii6	D	265.65	D/s of EWR 4, above Misverstand Dam G1H013 - D
Bvii7	D	37.03	At EWR site
Bvii8	C	134.88	U/s Misverstand reservoir, d/s confluence with Matjies
Bviii1	C	40.04	D/s of Berg River dam at EWR 1 – C
Bviii10	D	102.84	Cumulative at outlet G21B
Bviii11	D	4.22	At EWR 7 u/s of confluence with Kromme - C
Bviii3	B	23.07	Inflow to Yzerfontein salt pan
Bviii4	D	109.10	U/s of confluence with Diep
Bviii5	D	262.92	
Bviii6	C	32.09	At EWR site
Bviii8	C	87.06	U/s of confluence Black
Bviii9	C	44.98	Cumulative at outlet G22K
Berg River Estuary	C	1050.44[6]	Berg River estuary EWR site, linked to river node Biv2; Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.

[6] *Re-evaluated groundwater catchment area as outlined in* ***Section 3.2.3.***

Node	TEC	Incremental Catchment Area (km^2)	Comments (after DWS, 2016)
Eerste Estuary[7]	D		Eerste estuary EWR site, linked to river nodes Biii6, Biv8 and Biv9; Floodplain wetlands.
Langebaan Estuary	A	313.96[6]	Langebaan estuary; Channelled Valley-bottom and Unchannelled Valley-bottom wetlands, significant groundwater contribution.
Lourens Estuary[7]	C		Lourens estuary, linked to river node Bvii21; Floodplain wetlands.
Rietvlei/Diep Estuary[7]	C		Rietvlei/Diep estuary EWR site, linked to river nodes Bv1, Bviii4, Biv6, Biv7; Floodplain and Valley bottom wetlands (Rietvlei) as well as Depression wetlands.
Wildevöelvlei Estuary[7]	D		Wildevöelvlei estuary; Depression wetlands (Noordhoek Salt Pan and Pick n Pay Reedbeds) as well as Valley-bottom wetlands.
Zandvlei Estuary[7]	C		Sand estuary EWR site, linked to river node Bvii7; Depression as well as Floodplain wetlands.
Zeekoevlei Estuary[7]	D		Zeekoevlei estuary; Depression (Zeekoevlei and Rondevlei) and Seep wetlands as well as Floodplain wetlands.

[7] *The estuary is linked to an inlet node or other wetlands (see comment) and has no groundwater EWR requirement at the estuary margins, therefore there is no catchment area displayed.*

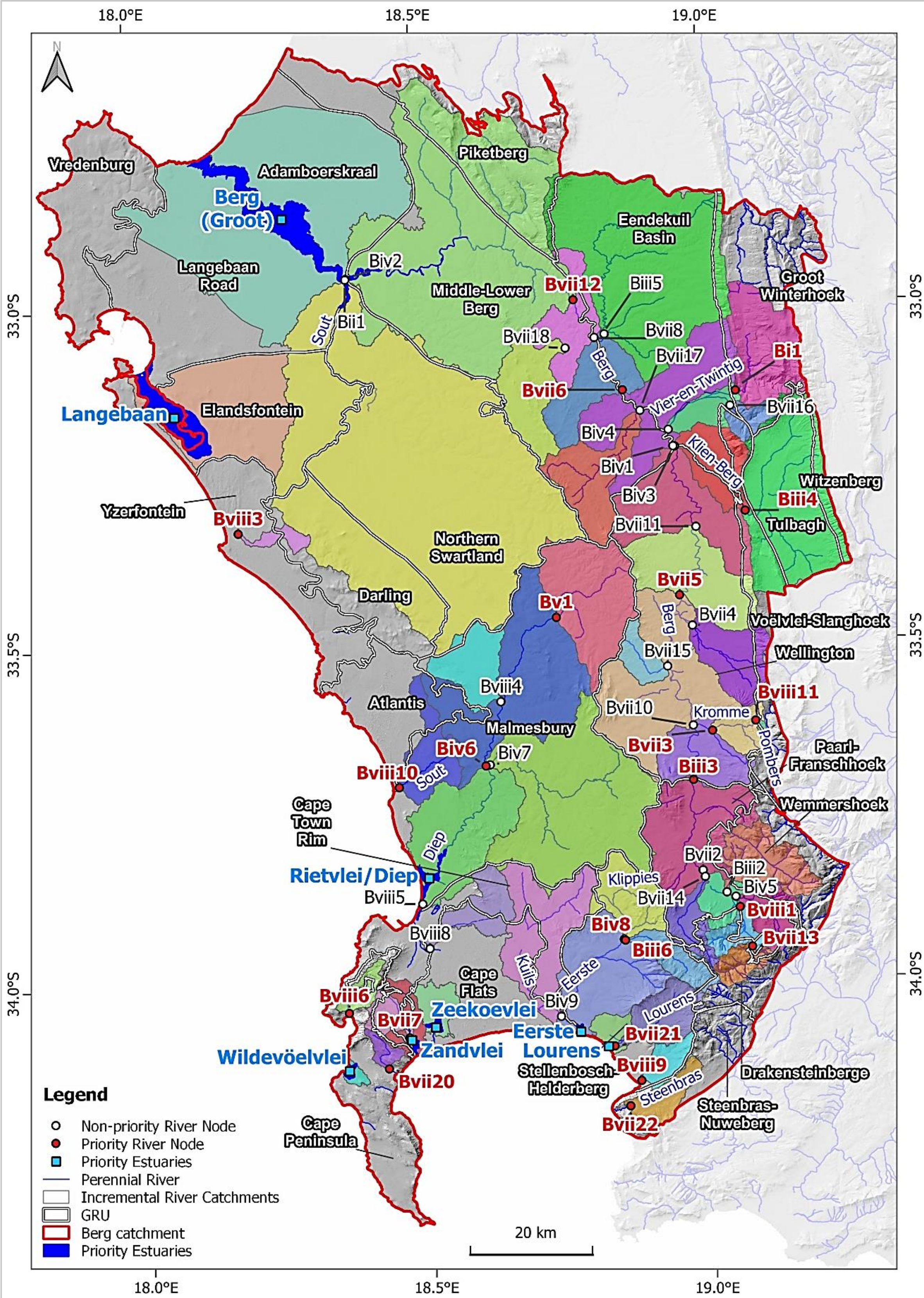

Figure 3-4 River and estuaries nodes and associated incremental catchments. Catchments were defined using a GIS-based catchment analysis technique to analyze local topography and flow direction.

3.2.4. Incremental GWBF to Rivers

As outlined in the EWR Reserve calculation approach (**Figure 3-1**), incremental dry season baseflow needed to be calculated in order to determine the groundwater's contribution to the EWR Reserve.

The contribution of groundwater from different Resource Units (RU) in an incremental catchment was calculated (based on the ratio of the RU recharge and the total recharge per incremental catchment) to apportion the dry season groundwater baseflow (GWBF) to each RU (see conceptual illustration a **Figure 3-5**.

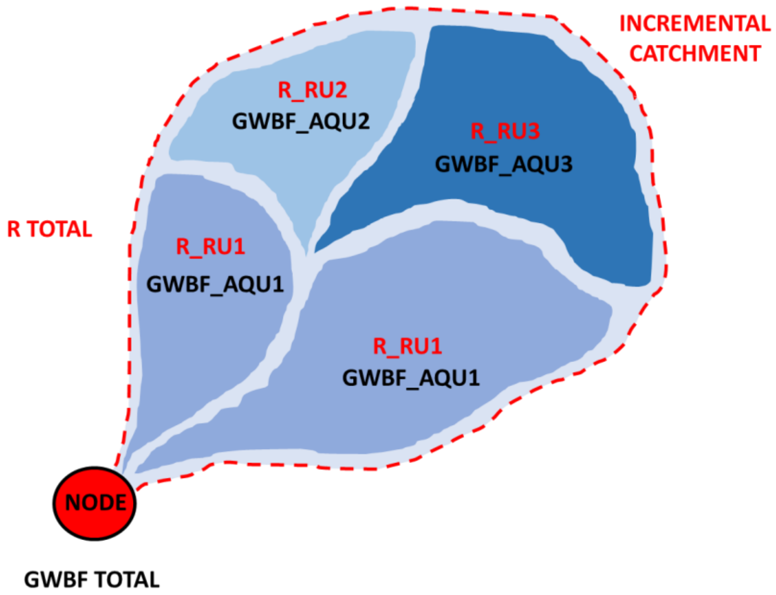

Figure 3-5 An illustration the contribution of groundwater from various Resource Units (RU) in a catchment using the ratio of each RU's recharge volume to the total recharge of the associated incremental catchment.

3.2.4.1. River Nodes

The flow analysis results from the Berg catchment WRCs and RQOs study (DWS, 2016) provided monthly flow volumes at all river nodes for a specific TEC on a river system (outlined in **Section 3.1.1**). Although the "balancing and routing" tool was used to account for ecological conditions downstream, the flow data itself remains cumulative. To account for groundwaters contribution to the EWR between two biophysical or river nodes, incremental volumes were calculated. This was done using an analytical tool where the river nodes were ordered, and their groundwater contributions calculated based on their position along the main stem of the river and associated downstream nodes (**Figure 3-6**). Only the Berg River and the Diep River had nodes along which incremental groundwater contributions needed to be calculated (see **Table 3-9**, **Table 3-10** and **Figure 3-7**). For nodes where there is no incremental contribution to the flow, the cumulative dry season baseflow value was used (see **Table 3-11, Table 3-12** and **Figure 3-7**).

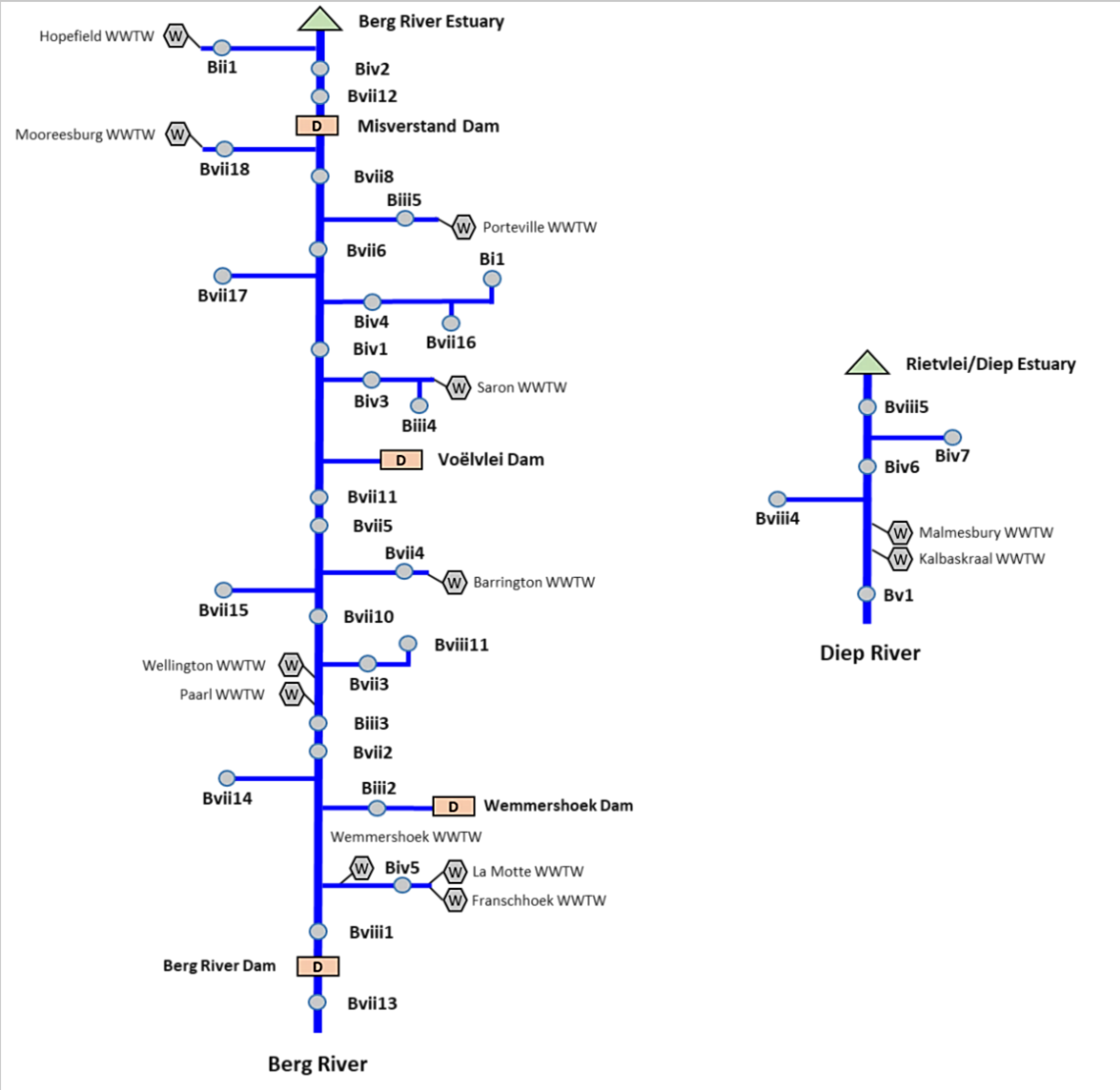

Figure 3-6 **Schematic diagram of biophysical and river nodes along the Berg River (left) and the Diep River (right) as well as the positions of important dams and wastewater treatment works.**

Table 3-11 presents a summary of the associated factor (%) applied per RU (as described above) based on the ratio of the recharge volume of each RU and the total recharge of the incremental catchment. Following that, **Table 3-12** presents a summary of the nodes and estuaries as well as the associated cumulative and incremental dry season contribution of groundwater to baseflow (Mm^3/a) per RU based on the factors listed in **Table 3-11**. Both the cumulative and incremental dry season contribution of groundwater to baseflow (Mm^3/a) per contributing catchment is displayed in **Figure 3-7**.

Table 3-9 Cumulative and incremental dry season baseflow (Mm³/a) for the Berg River. Red text indicates nodes where the baseflow is influenced by dam releases and therefore set to zero as this is not considered GWBF (see Table 3-11 and Table 3-14 for detail).

Berg River Nodes			Cumulative Dry Season Flow (Mm³/a)			Incremental Dry Season Flow (Mm³/a)		
Main Stem	Tributary 1	Tributary 2	Main Stem	Tributary 1	Tributary 2	Main Stem	Tributary 1	Tributary 2
Bvii13			2.451			2.451		
Bviii1			2.759			0.308		
	Biv5			1.405			1.405	
	Biii2			3.288			3.288	
	Bvii14			1.453			1.453	
Bvii2			14.116			5.211		
Biii3			8.905			0.000		
Bvii10	Bvii3	Bviii11	14.746	0.131	0.024	5.710	0.107	0.024
	Bvii15			0.077			0.077	
	Bvii4			0.390			0.390	
Bvii5			12.929			0.000		
Bvii11			13.037			0.108		
Biv1	Biv3	Biii4	23.069	3.667	1.738	6.365	1.929	1.738
		Bi1			0.152			0.152
		Bvii16			0.550			0.550
	Biv4			5.017			4.316	
	Bvii17			0.034			0.034	
Bvii6			21.605			0.000		
	Biii5			0.038			0.038	
Bvii8			29.492			7.848		
	Bvii18			0.017			0.017	
Bvii12			23.886			0.000		
Biv2			31.859			7.974		
	Bii1			0.015		0.015		

Table 3-10 Cumulative and incremental dry season baseflow (Mm³/a) for the Diep River. Red text indicates nodes where the baseflow is influenced by external factors and therefore set to zero (see Table 3-14 for detail).

Diep River Nodes			Cumulative Dry Season Flow (Mm³/a)			Incremental Dry Season Flow (Mm³/a)		
Main Stem	Tributary 1	Tributary 2	Main Stem	Tributary 1	Tributary 2	Main Stem	Tributary 1	Tributary 2
Bv1			0.160			0.160		
	Bviii4			0.061			0.061	
Biv6			0.348			0.126		
	Biv7			0.598			0.598	
Bviii5			0.893			0.000		

Table 3-11 River and priority estuaries nodes and the associated factor (%) applied per Resource Unit (RU) based on the ratio of the recharge volume of each RU and the total recharge catchment.

Node and Estuary Names	Fractured and Intergranular Basement	Nardouw Aquifer	Peninsula Aquifer	Primary/Intergranular	Fractured and Intergranular other
Bi1	1%	25%	51%	1%	22%
Bii1	46%	0%	0%	54%	0%
Biii2	2%	10%	55%	20%	14%
Biii3	30%	1%	14%	52%	2%
Biii4	34%	6%	21%	33%	5%
Biii5	83%	1%	7%	5%	4%
Biii6	23%	0%	43%	33%	1%
Biv1	67%	0%	10%	21%	2%
Biv2	28%	6%	27%	34%	5%
Biv3	28%	0%	33%	38%	0%
Biv4	20%	0%	14%	60%	5%
Biv5	13%	3%	30%	47%	6%
Biv6	62%	0%	0%	38%	0%
Biv7	55%	0%	0%	45%	0%
Biv8	35%	0%	2%	63%	0%
Biv9	23%	0%	0%	77%	0%
Bv1	98%	0%	1%	1%	0%
Bvii10	60%	0%	3%	37%	0%
Bvii11	48%	0%	10%	39%	3%
Bvii12	92%	0%	0%	7%	1%
Bvii13	2%	0%	92%	4%	1%
Bvii14	5%	0%	41%	53%	0%
Bvii15	77%	0%	0%	23%	0%
Bvii16	0%	0%	95%	5%	0%
Bvii17	84%	0%	1%	14%	1%
Bvii18	58%	0%	0%	42%	0%
Bvii2	6%	5%	29%	59%	0%

Node and Estuary Names	Fractured and Intergranular Basement	Nardouw Aquifer	Peninsula Aquifer	Primary/Intergranular	Fractured and Intergranular other
Bvii20	0%	0%	92%	8%	0%
Bvii21	34%	0%	15%	50%	1%
Bvii22	5%	69%	15%	0%	11%
Bvii3	55%	0%	14%	30%	0%
Bvii4	36%	0%	24%	36%	4%
Bvii5	68%	0%	0%	32%	0%
Bvii6	68%	0%	4%	26%	3%
Bvii7	18%	0%	16%	64%	2%
Bvii8	76%	0%	0%	22%	1%
Bviii1	3%	0%	71%	26%	0%
Bviii10	42%	0%	0%	58%	0%
Bviii11	14%	0%	71%	15%	0%
Bviii3	58%	0%	0%	42%	0%
Bviii4	7%	0%	0%	93%	0%
Bviii5	44%	0%	0%	56%	0%
Bviii6	11%	0%	55%	31%	3%
Bviii8	19%	0%	0%	81%	0%
Bviii9	51%	0%	13%	33%	3%
Berg River Estuary	1%	0%	0%	99%	0%
Langebaan Estuary	3%	0%	0%	97%	0%

Table 3-12 Cumulative and incremental groundwater contribution to baseflow (B) (Mm^3/a) for river and estuary nodes per Resource Unit (RU).

Node	TEC	Flow Type	Cumulative Baseflow	Incremental Baseflow	Fractured and Intergranular Basement	Nardouw Aquifer	Peninsula Aquifer	Primary/ Intergranular	Fractured and Intergranular other
Bi1	BC	Current	0.15	0.15	0.00	0.04	0.08	0.00	0.03
Bii1	C	Calibrated	0.01	0.01	0.01	0.00	0.00	0.01	0.00
Biii2	A	Natural	3.29	3.29	0.07	0.33	1.81	0.66	0.46
Biii3	D	Calibrated	8.90	0.00[8]	0.00	0.00	0.00	0.00	0.00
Biii4	C	Calibrated	1.74	1.74	0.59	0.10	0.36	0.57	0.09
Biii5	B	Calibrated	0.04	0.04	0.03	0.00	0.00	0.00	0.00
Biii6	C	Calibrated	0.70	0.70	0.16	0.00	0.30	0.23	0.01
Biv1	B	Calibrated	23.07	0.00[9]	0.00	0.00	0.00	0.00	0.00
Biv2	B	Calibrated	31.86	7.97	2.23	0.48	2.15	2.71	0.40
Biv3	A	Natural	3.67	1.93	0.54	0.00	0.64	0.73	0.00
Biv4	B	Calibrated	5.02	4.32	0.86	0.00	0.60	2.59	0.22
Biv5	B	Calibrated	1.41	1.41	0.18	0.04	0.42	0.66	0.08
Biv6	D	Calibrated	0.35	0.13	0.08	0.00	0.00	0.05	0.00
Biv7	B	Calibrated	0.60	0.60	0.33	0.00	0.00	0.27	0.00
Biv8	D	Calibrated	0.56	0.56	0.19	0.00	0.01	0.35	0.00
Biv9	B	Calibrated	0.53	0.53	0.12	0.00	0.00	0.41	0.00
Bv1	D	Calibrated	0.16	0.16	0.16	0.00	0.00	0.00	0.00
Bvii10	B	Calibrated	14.75	5.71	3.43	0.00	0.17	2.11	0.00
Bvii11	D	Calibrated	13.04	0.11	0.05	0.00	0.01	0.04	0.00
Bvii12	D	Calibrated	23.89	0.00[10]	0.00	0.00	0.00	0.00	0.00
Bvii13	A	Current	2.45	2.45	0.05	0.00	2.25	0.10	0.02
Bvii14	A	Natural	1.45	1.45	0.07	0.00	0.60	0.77	0.00
Bvii15	A	Natural	0.08	0.08	0.06	0.00	0.00	0.02	0.00
Bvii16	A	Calibrated	0.55	0.55	0.00	0.00	0.52	0.03	0.00

[8] *Several golf estates and significant water use from farming activities is assumed to be the cause of the reduction in baseflow at the river node.*
[9] *Incremental baseflow at the node is set to "0" due to its position downstream of the Voëlvlei Dam (dam release is not considered as baseflow).*
[10] *Incremental baseflow at the node is set to "0" due to its position downstream of the Misverstand Dam (dam release is not considered as baseflow).*

Node	TEC	Flow Type	Cumulative Baseflow	Incremental Baseflow	Fractured and Intergranular Basement	Nardouw Aquifer	Peninsula Aquifer	Primary/ Intergranular	Fractured and Intergranular other
Bvii17	C	Calibrated	0.03	0.03	0.03	0.00	0.00	0.00	0.00
Bvii18	C	Calibrated	0.02	0.02	0.01	0.00	0.00	0.01	0.00
Bvii2	B	Calibrated	14.12	5.21	0.31	0.26	1.51	3.07	0.00
Bvii20	A	Current	0.14	0.14	0.00	0.00	0.13	0.01	0.00
Bvii21	D	Calibrated	1.00	1.00	0.34	0.00	0.15	0.50	0.01
Bvii22	BC	Calibrated	0.68	0.68	0.03	0.47	0.10	0.00	0.08
Bvii3	D	Calibrated	0.13	0.11	0.06	0.00	0.01	0.03	0.00
Bvii4	B	Calibrated	0.39	0.39	0.14	0.00	0.09	0.14	0.02
Bvii5	D	Calibrated	12.93	0.0010	0.00	0.00	0.00	0.00	0.00
Bvii6	D	Calibrated	21.61	0.00[11]	0.00	0.00	0.00	0.00	0.00
Bvii7	D	Calibrated	0.09	0.09	0.02	0.00	0.01	0.06	0.00
Bvii8	C	Calibrated	29.49	7.85	5.96	0.00	0.00	1.73	0.08
Bviii1	C	Calibrated	2.76	0.31[12]	0.01	0.00	0.22	0.08	0.00
Bviii10	D	Calibrated	0.32	0.32	0.14	0.00	0.00	0.19	0.00
Bviii11	C	Calibrated	0.02	0.02	0.00	0.00	0.02	0.00	0.00
Bviii3	D	Current	0.04	0.04	0.02	0.00	0.00	0.02	0.00
Bviii4	B	Calibrated	0.06	0.06	0.00	0.00	0.00	0.06	0.00
Bviii5	D	Calibrated	0.89	0.00[13]	0.00	0.00	0.00	0.00	0.00
Bviii6	D	Calibrated	0.25	0.25	0.03	0.00	0.14	0.08	0.01
Bviii8	D	Calibrated	0.69	0.69	0.13	0.00	0.00	0.56	0.00
Bviii9	C	Calibrated	1.21	1.21	0.61	0.00	0.16	0.40	0.04
Berg River Estuary	C	Current	6.39	6.39	0.06	0.00	0.00	6.33	0.00
Langebaan Estuary	A	Current	11.27	11.27	0.34	0.00	0.00	10.93	0.00
TOTAL			**242.798**	**69.977**	**17.48**	**1.73**	**12.49**	**36.51**	**1.54**

[11] Significant farming areas along the river which is assumed to be the cause of the reduction in baseflow at the river node.
[12] Incremental baseflow at the node is low due to its position downstream of the Berg River Dam (dam release is not considered as baseflow).
[13] Limited groundwater contribution from basement aquifer and significant farming activity in the area is assumed to be the cause of the reduction in baseflow at the node.

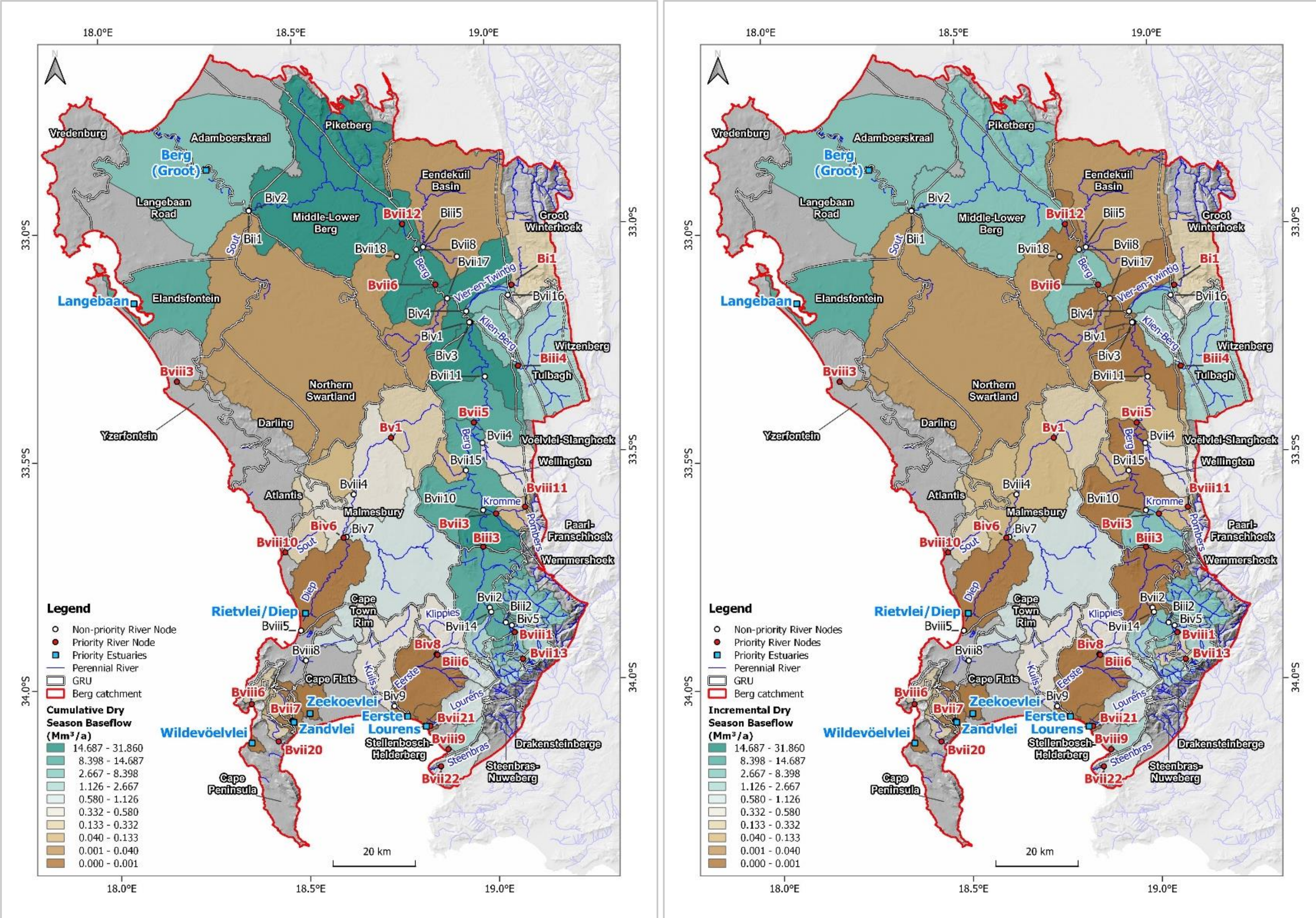

Figure 3-7 **Cumulative (Left) and incremental (Right) dry season GWBF (Mm^3/a) per incremental catchment for each river node and priority estuary.**

3.3. The Groundwater EWR Reserve

3.3.1. Groundwaters Contribution to the EWR per GRU

After calculating incremental baseflow per river and estuary node, these were aggregated for the individual incremental catchments to determine the total baseflow per GRU using a percentage area weighting. The percentage area weighting method assumes that the spatial distribution of baseflow is proportional to the incremental catchment area, where in reality it may vary. This is however the most conservative approach when apportioning baseflow.

As the calculated EWRs for each river and estuary node from the Berg catchment WRCs and RQOs study (DWS, 2016) (see **Section 3.1.1** and **Table 3-2**) are cumulative, these also had to be disaggregated into incremental values using the same analytical technique described in **Section 3.2.4.1** for river flow. The results are displayed **Table 3-14**.

The contribution of GWBF to EWRs per GRU can be seen in **Table 3-13**. The overall GWBF to EWRs is **69.98 Mm^3/a**. The Middle-Lower Berg GRU is the largest contributor with 11.15 Mm^3/a (16%), followed by the Eendekuil Basin GRU with 6.95 Mm^3/a (10%).

Table 3-13 The groundwater contribution to EWR (Mm^3/a) per Groundwater Resource Unit (GRU).

GRU	Groundwaters Contribution to EWR (Mm^3/a)
Adamboerskraal	6.00
Atlantis	0.08
Cape Flats	0.51
Cape Peninsula	5.43
Cape Town Rim	0.87
Darling	0.03
Drakensteinberge	2.88
Eendekuil Basin	6.95
Elandsfontein	6.39
Groot Winterhoek	0.77
Langebaan Road	5.52
Malmesbury	1.18
Middle-Lower Berg	11.15
Northern Swartland	0.20
Paarl-Franschhoek	3.01
Piketberg	2.07
Steenbras-Nuweberg	1.16
Stellenbosch-Helderberg	2.34
Tulbagh	1.28
Voëlvlei-Slanghoek	1.62
Vredenburg	0.00
Wellington	6.75
Wemmershoek	3.59
Witzenberg	0.18
Yzerfontein	0.02
TOTAL	**69.98**

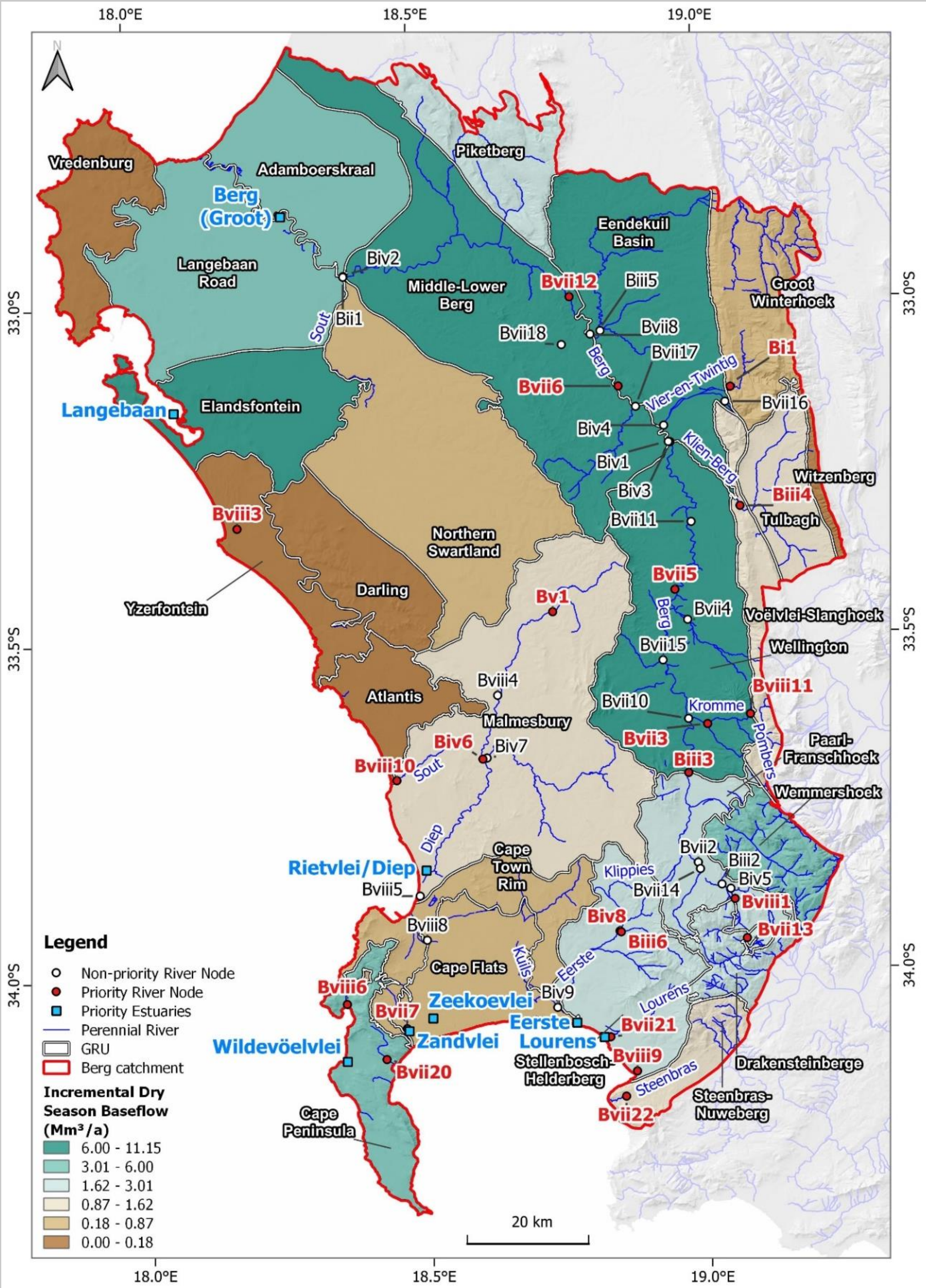

Figure 3-8 Map of groundwater contribution to EWR per Groundwater Resource Unit (GRU).

Table 3-14 River and estuary nodes and the associated Target Ecological Category (TEC), catchment size (km^2), Incremental Ecological Water Requirement (EWR) (Mm^3/a), groundwaters contribution to baseflow (GWBF) (Mm^3/a), Recharge per incremental catchment (Mm^3/a), and GWBF/EWR percentage (%).

Node / Estuary Name	TEC	Catchment Area (km^2)	Recharge in sub-catchment (Mm^3/a)	Incremental EWR (Mm^3/a)	Dry Season Incremental GWBF (Mm^3/a)	GWBF / EWR (%)
Bi1	B/C	185.33	8.81	125.00	0.15	0%
Bii1	C	1752.60	44.28	1.70	0.01	1%
Biii2	A	119.84	11.64	12.50	3.29	26%
Biii3	D	245.95	15.32	87.50	0.00	0%
Biii4	C	391.11	15.82	18.70	1.74	9%
Biii5	B	671.22	17.03	4.20	0.04	1%
Biii6	C	65.84	8.44	8.20	0.70	8%
Biv1	B	226.69	5.31	10.80	0.00	0%
Biv2	B	1110.26	37.51	5.50	7.97	145%
Biv3	A	108.44	2.88	0.00	1.93	0%
Biv4	B	49.42	1.27	0.00	4.32	0%
Biv5	B	71.78	5.97	5.30	1.41	27%
Biv6	D	391.43	12.21	0.00	0.13	0%
Biv7	B	531.55	21.83	7.60	0.60	8%
Biv8	D	112.27	6.88	18.50	0.56	3%
Biv9	B	230.47	10.40	0.61	0.53	88%
Bv1	D	245.67	8.91	1.91	0.16	8%
Bvii10	B	123.59	6.15	7.00	5.71	82%
Bvii11	D	211.03	6.97	0.00	0.11	0%
Bvii12	D	119.27	3.40	31.80	0.00	0%
Bvii13	A	40.80	6.70	84.50	2.45	3%
Bvii14	A	60.45	5.84	9.80	1.45	15%
Bvii15	A	46.20	1.43	0.60	0.08	13%
Bvii16	A	36.79	1.94	21.50	0.55	3%
Bvii17	C	153.76	4.28	1.90	0.03	2%
Bvii18	C	136.84	3.87	0.50	0.02	3%
Bvii2	B	47.20	4.63	0.00	5.21	0%
Bvii20	A	18.74	0.73	3.50	0.14	4%
Bvii21	D	98.01	9.78	8.50	1.00	12%

Node / Estuary Name	TEC	Catchment Area (km^2)	Recharge in sub-catchment (Mm^3/a)	Incremental EWR (Mm^3/a)	Dry Season Incremental GWBF (Mm^3/a)	GWBF / EWR (%)
Bvii22	BC	66.36	4.11	4.70	0.68	15%
Bvii3	D	47.40	2.40	1.60	0.11	7%
Bvii4	B	122.83	7.71	3.50	0.39	11%
Bvii5	D	344.31	13.10	71.50	0.00	0%
Bvii6	D	265.65	5.72	11.60	0.00	0%
Bvii7	D	37.03	1.82	3.20	0.09	3%
Bvii8	C	134.88	3.89	3.10	7.85	253%
Bviii1	C	40.04	6.51	0.00	0.31	0%
Bviii10	D	102.84	2.50	1.00	0.32	32%
Bviii11	C	4.22	0.30	1.00	0.02	2%
Bviii3	D	23.07	0.70	0.10	0.04	42%
Bviii4	B	109.10	2.37	0.60	0.06	10%
Bviii5	D	262.92	5.73	0.00	0.00	0%
Bviii6	D	32.09	1.80	8.60	0.25	3%
Bviii8	D	87.06	2.75	3.60	0.69	19%
Bviii9	C	44.98	3.23	11.80	1.21	10%
Berg River Estuary[14]	C	1050.44	10.78		6.39	
Langebaan Estuary[14]	A	228.11	34.63		11.27	

[14] *Estuary: modelled groundwater discharge under natural / current conditions – groundwater contribution to EWR not determined, as EWR not determined.*

4. THE GROUNDWATER RESERVE

The groundwater contribution to the BHN and EWR Reserves, which together make up the Groundwater Reserve for the Berg catchment, are provided in **Table 4-1** and illustrated in **Figure 4-1**. The data presented in **Table 4-1** shows that the EWR Reserve has an estimated annual volume of 69.98 Mm^3/a, while the BHN Reserve has an estimated annual volume of 2.35 Mm^3/a. The total estimated groundwater reserve for the catchment area is 72.33 Mm^3/a. The table also highlights the variability of groundwater reserves across different GRUs in the catchment.

The GRUs of Atlantis, Darling, Yzerfontein, and Vredenburg exhibit the lowest volumes of Groundwater Reserve, while the Middle-Lower Berg, Eendekuil Basin, Wellington and Elandsfontein have the highest volumes.

Table 4-1 The Groundwater Contribution to the Reserve (Mm^3/a) for the Berg catchment, displaying the EWR Reserve (Mm^3/a) and the Basic Human Needs Reserve (Mm^3/a) per Groundwater Resource Unit (GRU).

GRU	EWR Reserve (Mm^3/a)	BHN Reserve (Mm^3/a)	GW Reserve (Mm^3/a)
Adamboerskraal	6.00	0.008	6.008
Atlantis	0.08	0.026	0.106
Cape Flats	0.51	0.701	1.211
Cape Peninsula	5.43	0.085	5.515
Cape Town Rim	0.87	0.195	1.065
Darling	0.03	0.015	0.045
Drakensteinberge	2.88	0.003	2.883
Eendekuil Basin	6.95	0.091	7.041
Elandsfontein	6.39	0.005	6.395
Groot Winterhoek	0.77	0.017	0.787
Langebaan Road	5.52	0.017	5.537
Malmesbury	1.18	0.343	1.523
Middle-Lower Berg	11.15	0.085	11.235
Northern Swartland	0.20	0.047	0.247
Paarl-Franschhoek	3.01	0.127	3.137
Piketberg	2.07	0.036	2.106
Steenbras-Nuweberg	1.16	0.016	1.176
Stellenbosch-Helderberg	2.34	0.242	2.582
Tulbagh	1.28	0.023	1.303
Voëlvlei-Slanghoek	1.62	0.007	1.627
Vredenburg	0.00	0.011	0.011
Wellington	6.75	0.235	6.985
Wemmershoek	3.59	0.002	3.592
Witzenberg	0.18	0.002	0.182
Yzerfontein	0.02	0.009	0.029
TOTAL	**69.98**	**2.35**	**72.33**

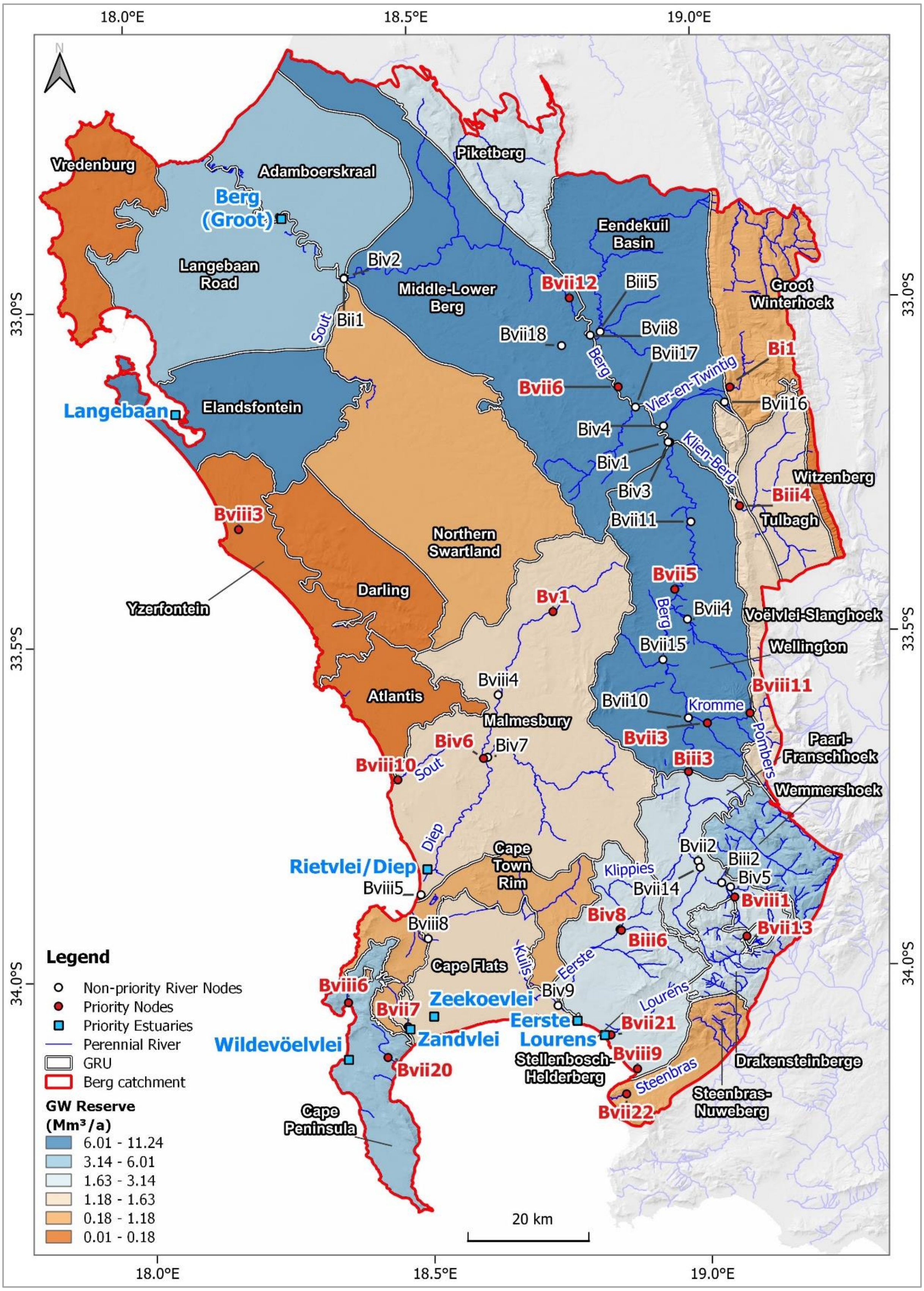

Figure 4-1 Map of the Groundwater Contribution to the Reserve per Groundwater Resource Unit (GRU).

5. ALLOCABLE GROUNDWATER

Groundwater allocations must be tightly managed to ensure that BHN and aquatic ecosystems are sustained. Currently, only a portion of the groundwater required to sustains the Reserve in the Berg catchment was considered in the Berg catchment WRC and RQOs study (DWS, 2016). As previously stated, groundwater is far more widespread geographically than surface water resources.

To calculate the allocable groundwater volume, the relationship between recharge from rainfall, groundwater inflow, groundwater outflow, BHN, and groundwater contribution to baseflow was considered. The determination of the volume of groundwater that can be allocated to users and potential users must be based on a comprehensive analysis of different scenarios (i.e., the next step in the determination process) that take into account the diverse environmental, social, and economic factors that affect groundwater availability and demand. This process will enable a more applicable estimation of the volume of groundwater needed to satisfy BHN and support the EWRs while also considering the requirements of other water use sectors. A first order "Allocable Groundwater" estimation is presented in **Table 5-1** (based on the results of this report), however, the results of the scenario analysis (i.e., Step 5 and 6 of the groundwater Reserve determination, see **Table 1-1**) will provide the basis for updating the final Groundwater Allocation and will require the integration of feedback from the client, stakeholders, and external reviewers.

Table 5-1 A summary of the current state of groundwater resources in the Berg catchments which includes Recharge (Mm^3/a), the Groundwater Reserve (Mm^3/a), the Allocable Groundwater Volume (Mm^3/a), and Current Water Use (Mm^3/a) per Groundwater Resource Unit (GRU).

GRU	Recharge (Mm^3/a)[15]	GW Reserve (Mm^3/a)	Allocable Volume (Mm^3/a)	Water Use (Mm^3/a)
Adamboerskraal	22.79	6.008	16.78	2.13[16]
Atlantis	6.20	0.106	6.09	1.65[17]
Cape Flats	20.91	1.211	19.70	12.00
Cape Peninsula	13.48	5.515	7.96	0.07
Cape Town Rim	20.04	1.065	18.97	6.21
Darling	9.95	0.045	9.90	0.76
Drakensteinberge	27.06	2.883	24.18	0.05
Eendekuil Basin	21.89	7.041	14.85	4.85
Elandsfontein	17.17	6.395	10.77	1.09
Groot Winterhoek	22.51	0.787	21.72	1.39
Langebaan Road	24.28	5.537	18.74	8.59
Malmesbury	52.90	1.523	51.38	14.75
Middle-Lower Berg	42.75	11.235	31.51	2.23
Northern Swartland	31.85	0.247	31.60	1.79

[15] Recharge has been updated for edge effect since DWS (2022e).
[16] Includes city municipal abstraction of 20 M m^3/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 M m^3/a (as a negative water use)
[17] Includes city municipal abstraction of 5 M m^3/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 5.11 M m^3/a (as a negative water use)

GRU	Recharge (Mm^3/a)[15]	GW Reserve (Mm^3/a)	Allocable Volume (Mm^3/a)	Water Use (Mm^3/a)
Paarl-Franschhoek	26.61	3.137	23.47	9.82
Piketberg	20.33	2.106	18.22	5.58
Steenbras-Nuweberg	18.60	1.176	17.42	9.13[18]
Stellenbosch-Helderberg	41.64	2.582	39.06	8.81
Tulbagh	10.87	1.303	9.57	3.78
Voëlvlei-Slanghoek	14.10	1.627	12.47	0.13
Vredenburg	8.76	0.011	8.75	1.16
Wellington	39.49	6.985	32.50	4.48
Wemmershoek	26.83	3.592	23.24	0.81
Witzenberg	2.78	0.182	2.60	0.08
Yzerfontein	9.60	0.029	9.57	0.26[19]
TOTAL	**553.38**	**72.33**	**481.01**	**101.60**

[18] *Includes city municipal abstraction of 9.13 M m^3/a in development (phase 1) as per NWA Section 21(a)*
[19] *The WARMS dataset places Yzerfontein's municipal abstraction of 0.26 M m^3/a in the Darling GRU. It has been updated to reflect for the Yzerfontein GRU.*

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APPENDIX A: POPULATION GROWTH

APPENDIX A-1: Population totals and growth rates per Local Municipality (LM)

Table A-1-1 Summary of the population for all Local District Municipalities (LM) based on preliminary 2022 data. The population values are presented in millions of people and refer to the entire extent of the LM, with only some portions falling within the Berg study area.

LM	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WC012	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
WC013	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08
WC014	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13
WC015	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14
WC022	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15
WC023	0.21	0.22	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.29	0.30
WC024	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.20	0.20
WC025	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.20
WC031	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12
CoCT	3.09	3.15	3.22	3.30	3.37	3.45	3.53	3.61	3.70	3.79	3.88	3.97	4.06	4.15	4.24	4.33	4.42	4.51	4.61	4.68	4.76
WC012	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
TOTAL	**4.82**	**4.91**	**5.00**	**5.10**	**5.20**	**5.30**	**5.41**	**5.53**	**5.66**	**5.79**	**5.91**	**6.04**	**6.17**	**6.29**	**6.42**	**6.55**	**6.68**	**6.81**	**6.94**	**7.04**	**7.15**

Table A-1-2 Annual percentage population growth rates (%) per Local District Municipality (LM) sourced from Census (2011) and preliminary Census (2022) data.

LM	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WC012	1.80	1.88	1.93	1.96	1.68	1.78	1.90	1.99	2.06	1.92	1.97	2.01	2.00	1.99	1.91	1.91	1.84	1.71	1.29	1.48	1.53
WC013	1.93	2.00	2.03	2.05	1.77	1.87	1.98	2.07	2.13	1.99	2.03	2.08	2.08	2.09	2.01	2.03	1.99	1.87	1.45	1.65	1.70
WC014	2.31	2.39	2.44	2.48	2.21	2.34	2.49	2.57	2.63	2.46	2.49	2.53	2.51	2.47	2.36	2.34	2.27	2.12	1.67	1.79	1.84
WC015	2.36	2.43	2.48	2.51	2.24	2.35	2.48	2.56	2.61	2.46	2.48	2.52	2.50	2.48	2.38	2.38	2.33	2.21	1.80	1.98	2.05
WC022	2.23	2.30	2.34	2.40	2.55	2.66	2.80	2.88	2.97	2.70	2.69	2.70	2.66	2.62	2.57	2.58	2.54	2.40	1.96	2.04	2.05
WC023	1.42	1.49	1.53	1.56	1.71	1.81	1.93	2.01	2.08	1.84	1.82	1.81	1.76	1.72	1.72	1.75	1.73	1.64	1.24	1.41	1.47
WC024	2.36	2.45	2.48	2.49	2.53	2.60	2.70	2.76	2.76	2.46	2.44	2.45	2.40	2.34	2.23	2.24	2.26	2.17	1.74	1.85	1.93
WC025	1.10	1.15	1.17	1.20	1.36	1.47	1.58	1.67	1.75	1.55	1.53	1.53	1.47	1.43	1.45	1.48	1.42	1.30	0.86	1.02	1.04
WC031	0.63	0.67	0.69	0.70	1.42	1.56	1.70	1.79	1.85	1.54	1.55	1.58	1.56	1.52	1.53	1.53	1.47	1.34	0.94	1.15	1.22
CoCT	2.18	2.24	2.27	2.30	2.19	2.28	2.39	2.47	2.53	2.34	2.30	2.28	2.20	2.13	2.11	2.11	2.12	2.05	1.59	1.64	No data
AVERAGE	**1.24**	**1.29**	**1.31**	**1.32**	**1.47**	**1.56**	**1.67**	**1.75**	**1.81**	**1.60**	**1.60**	**1.62**	**1.58**	**1.54**	**1.55**	**1.55**	**1.50**	**1.39**	**0.93**	**1.15**	**1.19**
TOTAL AVERAGE	**1.46%**																				

APPENDIX B: DWS (2016) NODE SELECTION

APPENDIX B-1: River nodes and estuaries selected for scenario analyses as part of the DWS (2016) study.

Table B-1-1 List of biophysical and river nodes selected for scenario analyses by DWS (2016) with associated node type and considerations (after DWS, 2017b). Estuaries are highlighted in blue and biophysical/river nodes with significant contribution from groundwater are highlighted green. Reserve sites are represented by blue text. IUA: Integrated Unit of Analysis, Quat: Quaternary Catchment, EIS: Ecological Importance and Sensitivity, and EC: Ecological Category.

IUA	NODE	QUAT	EIS	EC	Node type and considerations	Within conservation sites
A1	Bxi1	G10M	H	D	Berg River estuary EWR site, linked to river node Biv2; Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.	Berg River Estuary IBA
A2	Bxi3[20]	G10M	VH	B	Langebaan estuary; Channelled Valley-bottom and Unchannelled Valley-bottom wetlands, significant groundwater contribution.	West Coast National Park IBA
A3	Bxi12	G21A	M	C	Modder estuary	N/A
	Bviii3	G21A	H	D	Inflow to Yzerfontein salt pan; Depression wetland (Yzerfontein Salt Pan) as well as Unchannelled Valley-bottom wetlands.	N/A
	Bviii10	G21B	H	E	Sout River; Depression and Seep wetlands as well as Floodplain wetlands.	N/A
B4	Biv3	G10J	VH	D	Klein-Berg River, u/s of confluence with Berg; Channelled Valley-bottom wetlands.	N/A
	Biv1	G10J	M	D	Berg River, u/s of confluence Klein-Berg, d/s Voëlvlei canal; Seep wetlands as well as Channelled Valley-bottom and Floodplain wetlands.	N/A
	Bvii16	G10J	VH	A	Leeu River, gauge, 100% MAR.	N/A
	Bvii11	G10F	H	D	Berg River, u/s of Voëlvlei canal; Depression and Hillslope seep wetlands.	N/A
	Biv4	G10J	H	D	Vier-en-Twintig River, u/s of confluence with Berg; Depression wetlands as well as Channelled Valley-bottom, Unchannelled Valley-Bottom and Flat wetlands.	N/A
	Bvii17	G10J	M	C	Sandspruit River, gauge; Depression wetlands as well as Floodplain and Flat wetlands.	N/A
	Bvii6	G10J	H	D	Berg River, d/s of EWR 4, above Misverstand Dam; Depression wetlands as well as Floodplain wetlands.	N/A
	Biii5	G10J	M	D	Matjies River, gauge; significant groundwater contribution; Depression wetlands as well as Channelled Valley-bottom wetlands.	N/A
	Bvii8	G10J	M	D	Berg River, u/s Misverstand reservoir, d/s Matjies River; Depression wetlands as well as Floodplain wetlands.	N/A
	Bvii18	G10J	M	E	Morreesburg Spruit River, gauge; significant groundwater contribution; Depression wetlands as well as Flat and Channelled Valley-bottom wetlands.	N/A

[20] Note: According to DWS (2019b: 121), the node name "Bxi3" is used for both the "Langebaan" and "Eerste" estuary. To avoid confusion, this report will refer to these water resources using the "resource name" and not the node name.

IUA	NODE	QUAT	EIS	EC	Node type and considerations	Within conservation sites
	Bvii12	G10K	H	D	Berg River, 3.5 km d/s Misverstand reservoir, at EWR 5; Depression wetlands and Floodplain wetlands.	N/A
	Bii1	G10L	M	D	Sout River, u/s of confluence with Berg; Depression wetlands as well as Floodplain, Flat, Channelled Valley-bottom and Unchannelled Valley-bottom.	N/A
	Biv2	G10L	H	D	Berg River, u/s of confluence with Sout, head of estuary; Hillslope seep wetlands as well as Floodplain, Flat and Unchannelled Valley-bottom wetlands.	N/A
C5	Biii4	G10E	VH	C	Klein Berg River, gauge; Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands.	SWSA
	Bi1	G10G	VH	A	Vier-en-Twintig River, gauge, pristine wilderness 100%.	NFEPA Fish1; Winterhoek MCA
D6	Biii6	G22F	H	C	Jonkershoek River, Eer1 EWR site	N/A
	Biv8	G22G	H	D	Klippies River	N/A
	Biv9	G22H	H	E	Kuils River, u/s confluence Eerste; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain wetlands and Valley-bottom wetlands.	N/A
	Bxi3[20]	G22H	M	E	Eerste estuary EWR site, linked to river nodes Biii6, Biv8 and Biv9; Floodplain wetlands.	N/A
D7	Bvii21	G22J	H	C	Lourens River, Somerset West; Seep (Paardevlei) and Depression wetlands as well as Valley-bottom wetlands.	NFEPA Fish1, SWSA; Lourens River
	Bxi4	G22J	U	D	Lourens estuary, linked to river node Bvii21; Floodplain wetlands.	N/A
	Bviii9	G22K	H	C	Sir Lowrys Pass River; Depression and Seep wetlands as well as Valley-bottom wetlands.	NFEPA Fish1, SWSA
	Bxi5	G22K	U	E	Sir Lowrys Pass estuary EWR site, linked to river node Bviii9	N/A
	Bvii22	G40A	VH	C	Steenbras River, at EWR 8, u/s of estuary mouth; significant groundwater contribution; Seep wetlands as well as Valley-bottom wetlands.	SWSA; Hottentots Holland MCA
	Bxi6	G40A	U	B	Steenbras estuary EWR site, linked to river node Bvii22	Hottentots Holland MCA
D8	Bvii13	G10A	VH	A	Berg River, gauge u/s Berg River dam, 100% MAR.	NFEPA Fish2; SWSA
	Bviii1	G10A	H	C	Berg River, d/s of Berg River dam EWR 1	SWSA
	Biv5	G10A	H	D	Franschoek River, u/s of confluence with Berg.	N/A
	Biii2	G10B	VH	D	Wemmershoek River, u/s of confluence with Berg; significant groundwater contribution; Depression and Hillslope seep wetlands as well as Channelled Valley-bottom wetlands.	NFEPA Fish1; SWSA
	Bvii14	G10C	VH	C	Dwars River, gauge.	SWSA
	Bvii2	G10C	H	D	Berg River, Berg Water Project pump station; Depression wetlands as well as Floodplain and Channelled Valley-bottom wetlands.	SWSA
	Biii3	G10C	H	E	Berg River, gauge; Depression and Hillslope seep wetlands as well as Floodplain, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.	SWSA
D9	Bviii11	G10C	H	D	Pombers River, EWR 7 u/s of confluence with Kromme; Flat, Channelled Valley-bottom, Unchannelled Valley-bottom and Floodplain wetlands	N/A
	Bvii3	G10D	H	D	Kromme River, North of Wellington, EWR 6; Hillslope seep wetlands as well as Flat, Channelled Valley-bottom and Unchannelled Valley-bottom wetlands.	NFEPA Fish2; SWSA
	Bvii10	G10D	H	D	Berg River, d/s of confluence Kromme, gauge; significant groundwater contribution; Hillslope seep and Depression wetlands as well as Floodplain, Channelled Valley-bottom, Unchannelled Valley-bottom and Flat wetlands.	NFEPA Fish2; SWSA
	Bvii15	G10D	VH	D	Doring River, gauge; significant groundwater contribution; Depression wetlands as well as	SWSA

IUA	NODE	QUAT	EIS	EC	Node type and considerations	Within conservation sites
					Unchannelled Valley-bottom (Klein Sand vlei and Sand River vlei) and Floodplain wetlands.	
	Bvii4	G10D	H	D	Kompanjies River, gauge; Hillslope seep and Depression wetlands as well as Channelled Valley-bottom and Floodplain wetlands.	SWSA
	Bvii5	G10D	H	D	Berg River, gauge and u/s of EWR 3; Depression (Blouvlei) and Seep wetlands.	SWSA
D10	Bv1	G21D	H	D	Diep River; significant groundwater contribution; Depression and Seep wetlands as well as Flat wetlands.	NFEPA Fish2
	Bviii4	G21D	H	D	Swart River, u/s of confluence with Diep; significant groundwater contribution; Depression wetlands as well as Unchannelled Valley-bottom wetlands.	NFEPA Fish2
	Biv6	G21D	H	D	Diep River; significant groundwater contribution ; Depression and Seep wetlands as well as Valley-bottom wetlands.	NFEPA Fish2
	Biv7	G21E	H	D	Mosselbank River; significant groundwater contribution; Depression and Seep wetlands as well as Floodplain and Valley-bottom wetlands.	N/A
	Bxi7	G21F	H	D	Rietvlei/Diep estuary EWR site, linked to river nodes Bv1, Bviii4, Biv6, Biv7; Floodplain and Valley bottom wetlands (Rietvlei) as well as Depression wetlands.	N/A
E12	Bviii8	G22C	M	F	Elsieskraal River, u/s of confluence Black; Depression as well as Valley-bottom wetlands.	N/A
	Bvii7	G22D	H	D	Keysers River, at EWR site; Depression (Princessvlei) and Seep wetlands as well as Floodplain and Valley-bottom wetlands.	N/A
	Bxi9	G22D	H	D	Sand estuary EWR site, linked to river node Bvii7; Depression as well as Floodplain wetlands.	SWSA, False Bay Nature Reserve
	Bxi20	G22D	U	E	Zeekoevlei estuary; Depression (Zeekoevlei and Rondevlei) and Seep wetlands as well as Floodplain wetlands.	SWSA, False Bay Nature Reserve
E11	Bviii6	G22B	H	D	Hout Bay River, at EWR site; Seep wetlands as well as Floodplain and Valley-bottom wetlands.	SWSA, NFEPA Fish1
	Bxi10	G22B	U	E	Hout Bay estuary EWR site, linked to river node Bviii6	SWSA, Table Mountain National Park
	Bvii20	G22A	U	C	Silvermine River, Fish Hoek, 100% MAR; Seep wetlands.	NFEPA Fish1
	Bxi11	G22A	U	D	Silvermine estuary EWR site, linked to river node Bvii20	N/A
	Bxi13	G22A	M	D	Goeiehoop estuary	N/A
	Bxi14	G22A	M	D	Wildevöelvlei estuary; Depression wetlands (Noordhoek Salt Pan and Pick n Pay Reedbeds) as well as Valley-bottom wetlands.	Table Mountain National Park
	Bxi15	G22A	U	D	Bokramspruit estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands.	N/A
	Bxi16	G22A	U	A	Schuster estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands.	NFEPA Fish1, Table Mountain National Park
	Bxi17	G22A	U	A	Krom estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands.	Table Mountain National Park
	Bxi18	G22A	U	F	Buffels Wes estuary (micro-estuary); Seep wetlands as well as Valley-bottom wetlands.	Table Mountain National Park
	Bxi19	G22A	U	E	Elsies estuary (micro-estuary); Depression wetlands as well as Valley-bottom wetlands.	SWSA

APPENDIX C: BASEFLOW SEPARATION

APPENDIX C-1: Baseflow separation for all biophysical and river nodes in the Berg catchment.

Table C-1-1 Baseflow separation summary table for all biophysical and river nodes in the Berg catchment using Lyne & Hollick (1979), Eckhardt (2005) and Chapman & Maxwell (1996) recursive digital filter methods (including dry season statistics). Parameters: alpha (Lyne & Hollick) = 0.75; alpha (Eckhardt) = 0.83; BFI Max (Eckhardt) = 0.75; and k (Chapman & Maxwell) = 0.1. Streamflow (Q) and baseflow (b) in M m^3/a. Note the values displayed are based on cumulative flow.

Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
Bi1	BC	Current	Lyne & Hollick (1979)	2.37	29.58	166.11	28.28	0.21	0.60	9.40	55.56	9.61	0.21
			Eckhardt (2005)	2.37	29.58	166.11	28.28	0.21	1.02	14.27	82.49	14.10	0.21
			Chapman & Maxwell (1996)	2.37	29.58	166.11	28.28	0.21	1.17	14.65	82.09	14.00	0.15
Bii1	C	Calibrated	Lyne & Hollick (1979)	1.00	3.08	4.72	0.90	0.03	0.55	1.48	2.24	0.44	0.03
			Eckhardt (2005)	1.00	3.08	4.72	0.90	0.03	0.63	1.84	2.84	0.54	0.02
			Chapman & Maxwell (1996)	1.00	3.08	4.72	0.90	0.03	0.50	1.54	2.36	0.45	0.01
Biii2	A	Natural	Lyne & Hollick (1979)	37.28	85.57	183.29	29.32	6.31	20.42	44.53	85.93	14.30	6.21
			Eckhardt (2005)	37.28	85.57	183.29	29.32	6.31	23.98	53.06	106.99	17.45	6.03
			Chapman & Maxwell (1996)	37.28	85.57	183.29	29.32	6.31	18.64	42.78	91.39	14.64	3.29
Biii3	D	Calibrated	Lyne & Hollick (1979)	82.50	137.98	163.54	19.84	17.16	43.94	80.05	95.59	11.14	17.16
			Eckhardt (2005)	82.50	137.98	163.54	19.84	17.16	51.97	91.11	109.51	13.43	15.77
			Chapman & Maxwell (1996)	82.50	137.98	163.54	19.84	17.16	41.26	68.99	81.75	9.92	8.90
Biii4	C	Calibrated	Lyne & Hollick (1979)	12.48	20.86	26.79	3.83	3.39	6.57	12.37	16.08	2.43	3.38
			Eckhardt (2005)	12.48	20.86	26.79	3.83	3.39	8.04	13.80	18.10	2.66	3.12
			Chapman & Maxwell (1996)	12.48	20.86	26.79	3.83	3.39	6.24	10.43	13.39	1.91	1.74
Biii5	B	Calibrated	Lyne & Hollick (1979)	3.47	9.45	12.76	2.13	0.07	1.85	4.70	6.46	1.19	0.07

Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
			Eckhardt (2005)	3.47	9.45	12.76	2.13	0.07	2.14	5.78	7.88	1.38	0.07
			Chapman & Maxwell (1996)	3.47	9.45	12.76	2.13	0.07	1.73	4.72	6.38	1.07	0.04
Biii6	C	Calibrated	Lyne & Hollick (1979)	5.67	9.31	11.89	1.36	1.36	3.63	5.76	7.62	0.93	1.36
			Eckhardt (2005)	5.67	9.31	11.89	1.36	1.36	3.85	6.30	8.26	0.98	1.32
			Chapman & Maxwell (1996)	5.67	9.31	11.89	1.36	1.36	2.84	4.66	5.94	0.68	0.70
Biv1	B	Calibrated	Lyne & Hollick (1979)	229.40	458.12	928.37	151.98	44.75	126.01	248.05	463.99	73.55	43.49
			Eckhardt (2005)	229.40	458.12	928.37	151.98	44.75	148.84	290.26	562.10	91.04	42.35
			Chapman & Maxwell (1996)	229.40	458.12	928.37	151.98	44.75	114.84	229.06	463.39	75.92	23.07
Biv2	B	Calibrated	Lyne & Hollick (1979)	326.86	645.90	1309.33	216.57	61.52	165.50	348.58	643.31	104.23	60.15
			Eckhardt (2005)	326.86	645.90	1309.33	216.57	61.52	196.53	408.44	784.93	129.26	58.43
			Chapman & Maxwell (1996)	326.86	645.90	1309.33	216.57	61.52	163.33	322.95	653.51	108.19	31.86
Biv3	A	Natural	Lyne & Hollick (1979)	35.24	96.79	252.75	46.05	7.08	16.90	50.21	114.79	21.34	7.08
			Eckhardt (2005)	35.24	96.79	252.75	46.05	7.08	22.10	59.92	146.97	27.01	6.71
			Chapman & Maxwell (1996)	35.24	96.79	252.75	46.05	7.08	18.00	48.39	126.42	22.99	3.67
Biv4	B	Calibrated	Lyne & Hollick (1979)	27.30	55.36	69.27	9.08	9.78	16.75	33.78	44.23	6.10	9.72
			Eckhardt (2005)	27.30	55.36	69.27	9.08	9.78	18.02	37.04	47.56	6.48	9.04
			Chapman & Maxwell (1996)	27.30	55.36	69.27	9.08	9.78	13.63	27.68	34.64	4.53	5.02
Biv5	B	Calibrated	Lyne & Hollick (1979)	6.02	12.57	15.89	2.23	2.75	3.54	8.02	10.50	1.59	2.73
			Eckhardt (2005)	6.02	12.57	15.89	2.23	2.75	4.07	8.61	11.23	1.60	2.56
			Chapman & Maxwell (1996)	6.02	12.57	15.89	2.23	2.75	3.01	6.29	7.94	1.11	1.41
Biv6	D	Calibrated	Lyne & Hollick (1979)	2.06	4.58	6.06	1.02	0.69	1.03	2.67	3.44	0.53	0.69
			Eckhardt (2005)	2.06	4.58	6.06	1.02	0.69	1.22	3.01	3.94	0.64	0.61
			Chapman & Maxwell (1996)	2.06	4.58	6.06	1.02	0.69	1.03	2.29	3.03	0.51	0.35
Biv7	B	Calibrated	Lyne & Hollick (1979)	2.73	8.49	13.47	2.97	1.19	1.27	4.70	7.35	1.53	1.16

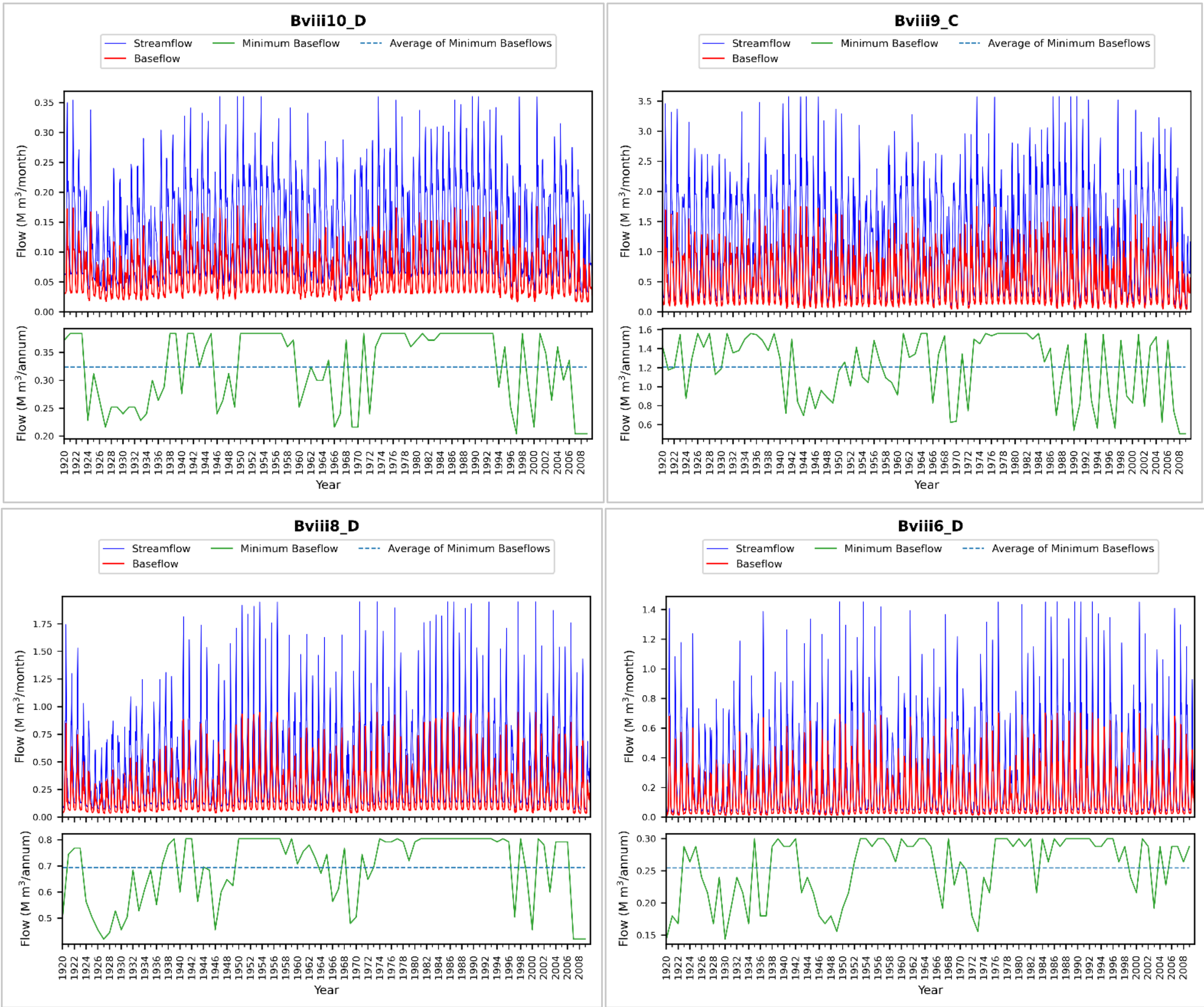
Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
			Eckhardt (2005)	2.73	8.49	13.47	2.97	1.19	1.72	5.45	8.61	1.87	1.08
			Chapman & Maxwell (1996)	2.73	8.49	13.47	2.97	1.19	1.37	4.25	6.73	1.48	0.60
Biv8	D	Calibrated	Lyne & Hollick (1979)	1.57	3.51	4.36	0.53	1.10	1.21	2.45	3.06	0.38	1.10
			Eckhardt (2005)	1.57	3.51	4.36	0.53	1.10	1.15	2.49	3.10	0.37	0.99
			Chapman & Maxwell (1996)	1.57	3.51	4.36	0.53	1.10	0.79	1.76	2.18	0.27	0.56
Biv9	B	Calibrated	Lyne & Hollick (1979)	2.19	5.89	7.85	1.45	1.06	1.10	3.48	4.60	0.85	1.04
			Eckhardt (2005)	2.19	5.89	7.85	1.45	1.06	1.31	3.90	5.24	0.97	0.96
			Chapman & Maxwell (1996)	2.19	5.89	7.85	1.45	1.06	1.10	2.94	3.93	0.72	0.53
Bv1	D	Calibrated	Lyne & Hollick (1979)	0.96	2.33	3.13	0.56	0.32	0.48	1.24	1.59	0.26	0.32
			Eckhardt (2005)	0.96	2.33	3.13	0.56	0.32	0.57	1.47	1.93	0.33	0.29
			Chapman & Maxwell (1996)	0.96	2.33	3.13	0.56	0.32	0.48	1.17	1.56	0.28	0.16
Bvii10	B	Calibrated	Lyne & Hollick (1979)	157.29	333.54	624.54	101.31	28.53	83.26	176.43	313.11	49.19	27.45
			Eckhardt (2005)	157.29	333.54	624.54	101.31	28.53	100.38	208.70	379.04	60.44	26.99
			Chapman & Maxwell (1996)	157.29	333.54	624.54	101.31	28.53	78.65	166.77	311.72	50.62	14.75
Bvii11	D	Calibrated	Lyne & Hollick (1979)	83.91	121.76	151.64	18.28	25.52	53.64	73.51	89.33	8.72	24.98
			Eckhardt (2005)	83.91	121.76	151.64	18.28	25.52	56.79	81.54	100.12	11.19	23.16
			Chapman & Maxwell (1996)	83.91	121.76	151.64	18.28	25.52	41.95	60.88	75.81	9.14	13.04
Bvii12	D	Calibrated	Lyne & Hollick (1979)	123.45	217.89	271.66	37.82	46.69	79.60	127.08	161.58	18.57	44.73
			Eckhardt (2005)	123.45	217.89	271.66	37.82	46.69	83.41	141.83	174.69	22.22	42.61
			Chapman & Maxwell (1996)	123.45	217.89	271.66	37.82	46.69	61.67	108.94	135.80	18.90	23.89
Bvii13	A	Current	Lyne & Hollick (1979)	36.92	83.32	167.24	26.47	4.64	16.42	42.69	85.65	14.26	3.79
			Eckhardt (2005)	36.92	83.32	167.24	26.47	4.64	21.33	50.98	100.40	16.39	3.94
			Chapman & Maxwell (1996)	36.92	83.32	167.24	26.47	4.64	18.42	41.64	83.43	13.21	2.45
Bvii14	A	Natural	Lyne & Hollick (1979)	17.34	43.65	89.56	15.03	2.81	10.30	22.27	46.89	7.31	2.49

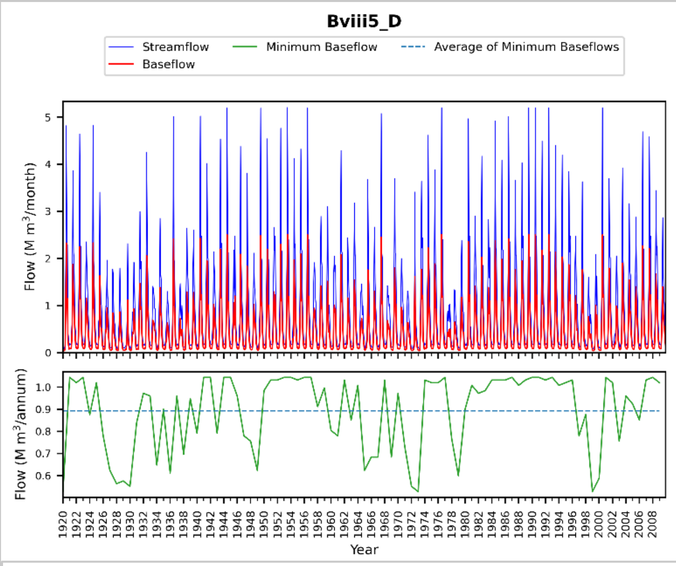
Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
			Eckhardt (2005)	17.34	43.65	89.56	15.03	2.81	11.67	26.82	54.95	8.94	2.51
			Chapman & Maxwell (1996)	17.34	43.65	89.56	15.03	2.81	8.66	21.82	44.68	7.51	1.45
Bvii15	A	Natural	Lyne & Hollick (1979)	1.39	3.84	10.07	2.00	0.14	0.67	1.85	4.39	0.82	0.14
			Eckhardt (2005)	1.39	3.84	10.07	2.00	0.14	0.83	2.29	5.69	1.10	0.14
			Chapman & Maxwell (1996)	1.39	3.84	10.07	2.00	0.14	0.70	1.92	5.03	1.00	0.08
Bvii16	A	Calibrated	Lyne & Hollick (1979)	8.96	21.54	43.29	7.59	1.03	3.36	11.03	22.92	3.92	0.97
			Eckhardt (2005)	8.96	21.54	43.29	7.59	1.03	4.62	13.23	26.52	4.64	0.99
			Chapman & Maxwell (1996)	8.96	21.54	43.29	7.59	1.03	4.47	10.77	21.65	3.79	0.55
Bvii17	C	Calibrated	Lyne & Hollick (1979)	0.97	2.14	2.84	0.50	0.06	0.50	1.13	1.50	0.27	0.06
			Eckhardt (2005)	0.97	2.14	2.84	0.50	0.06	0.60	1.35	1.81	0.32	0.06
			Chapman & Maxwell (1996)	0.97	2.14	2.84	0.50	0.06	0.49	1.07	1.42	0.25	0.03
Bvii18	C	Calibrated	Lyne & Hollick (1979)	0.42	0.78	1.03	0.17	0.03	0.23	0.44	0.59	0.10	0.03
			Eckhardt (2005)	0.42	0.78	1.03	0.17	0.03	0.26	0.50	0.67	0.11	0.03
			Chapman & Maxwell (1996)	0.42	0.78	1.03	0.17	0.03	0.21	0.39	0.52	0.08	0.02
Bvii20	A	Current	Lyne & Hollick (1979)	0.70	3.22	9.62	2.20	0.28	0.38	1.55	4.37	0.89	0.28
			Eckhardt (2005)	0.70	3.22	9.62	2.20	0.28	0.45	1.92	5.58	1.21	0.25
			Chapman & Maxwell (1996)	0.70	3.22	9.62	2.20	0.28	0.36	1.61	4.81	1.10	0.14
Bvii21	D	Calibrated	Lyne & Hollick (1979)	7.77	12.38	15.50	1.76	1.98	5.03	7.70	9.91	1.13	1.98
			Eckhardt (2005)	7.77	12.38	15.50	1.76	1.98	5.44	8.38	10.65	1.23	1.80
			Chapman & Maxwell (1996)	7.77	12.38	15.50	1.76	1.98	3.88	6.19	7.75	0.88	1.00
Bvii22	BC	Calibrated	Lyne & Hollick (1979)	3.74	5.09	6.11	0.61	1.35	2.43	3.40	4.06	0.37	1.35
			Eckhardt (2005)	3.74	5.09	6.11	0.61	1.35	2.70	3.59	4.33	0.41	1.25
			Chapman & Maxwell (1996)	3.74	5.09	6.11	0.61	1.35	1.87	2.55	3.06	0.31	0.68
Bvii2	B	Calibrated	Lyne & Hollick (1979)	154.36	357.28	743.67	123.63	27.31	81.78	185.52	361.42	60.31	25.43

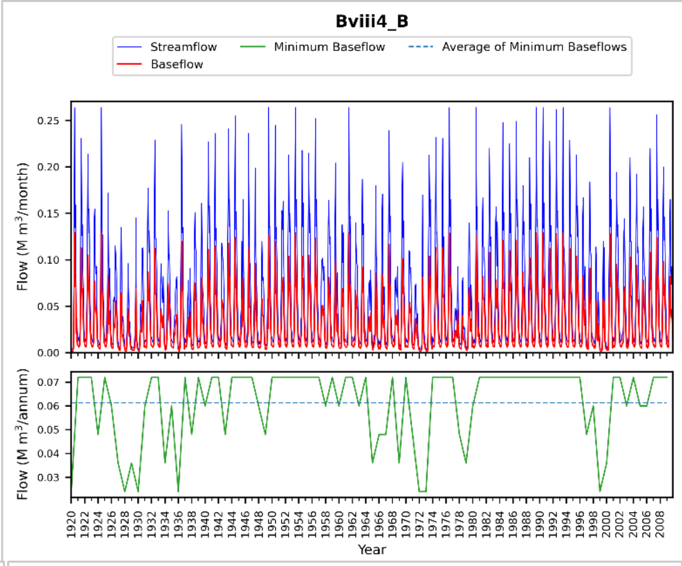
Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
			Eckhardt (2005)	154.36	357.28	743.67	123.63	27.31	98.48	221.28	443.42	73.60	25.15
			Chapman & Maxwell (1996)	154.36	357.28	743.67	123.63	27.31	77.18	178.64	370.94	61.74	14.12
Bvii3	D	Calibrated	Lyne & Hollick (1979)	1.47	3.56	4.70	0.84	0.26	0.71	1.97	2.69	0.54	0.26
			Eckhardt (2005)	1.47	3.56	4.70	0.84	0.26	0.87	2.29	3.08	0.58	0.24
			Chapman & Maxwell (1996)	1.47	3.56	4.70	0.84	0.26	0.73	1.78	2.35	0.42	0.13
Bvii4	B	Calibrated	Lyne & Hollick (1979)	3.71	7.82	10.05	1.41	0.75	1.94	4.19	5.62	0.81	0.74
			Eckhardt (2005)	3.71	7.82	10.05	1.41	0.75	2.23	4.93	6.50	0.93	0.69
			Chapman & Maxwell (1996)	3.71	7.82	10.05	1.41	0.75	1.85	3.91	5.02	0.71	0.39
Bvii5	D	Calibrated	Lyne & Hollick (1979)	85.93	137.36	164.62	18.56	25.07	49.52	82.41	96.08	10.02	24.98
			Eckhardt (2005)	85.93	137.36	164.62	18.56	25.07	55.71	92.21	109.95	12.51	23.38
			Chapman & Maxwell (1996)	85.93	137.36	164.62	18.56	25.07	42.96	68.68	82.31	9.28	12.93
Bvii6	D	Calibrated	Lyne & Hollick (1979)	113.25	187.12	231.97	29.07	42.56	79.80	114.09	136.92	13.41	41.61
			Eckhardt (2005)	113.25	187.12	231.97	29.07	42.56	78.46	125.46	152.13	17.59	37.72
			Chapman & Maxwell (1996)	113.25	187.12	231.97	29.07	42.56	56.59	93.56	115.97	14.53	21.61
Bvii7	D	Calibrated	Lyne & Hollick (1979)	0.44	0.97	1.26	0.19	0.18	0.24	0.58	0.74	0.10	0.18
			Eckhardt (2005)	0.44	0.97	1.26	0.19	0.18	0.28	0.64	0.83	0.12	0.15
			Chapman & Maxwell (1996)	0.44	0.97	1.26	0.19	0.18	0.22	0.49	0.63	0.09	0.09
Bvii8	C	Calibrated	Lyne & Hollick (1979)	193.90	313.59	394.81	51.99	57.37	116.01	186.82	244.14	31.39	55.47
			Eckhardt (2005)	193.90	313.59	394.81	51.99	57.37	124.77	207.24	260.29	34.45	53.18
			Chapman & Maxwell (1996)	193.90	313.59	394.81	51.99	57.37	96.86	156.79	197.36	25.98	29.49
Bviii10	D	Calibrated	Lyne & Hollick (1979)	0.88	1.59	1.94	0.27	0.64	0.69	1.18	1.45	0.20	0.64
			Eckhardt (2005)	0.88	1.59	1.94	0.27	0.64	0.66	1.15	1.41	0.19	0.56
			Chapman & Maxwell (1996)	0.88	1.59	1.94	0.27	0.64	0.44	0.79	0.97	0.13	0.32
Bviii11	C	Calibrated	Lyne & Hollick (1979)	0.29	0.47	0.57	0.07	0.04	0.18	0.27	0.33	0.04	0.04

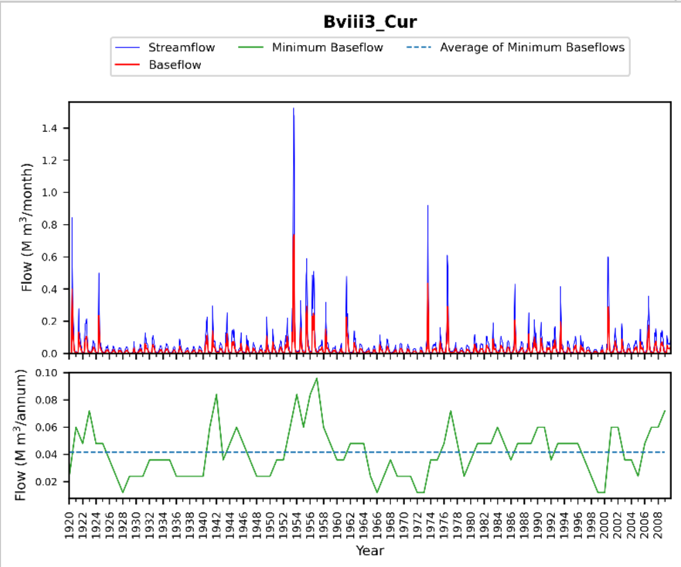
Node Name	TEC	Flow Type	Method	Q min	Q mean	Q max	Q std	Q Dry season average	b min	b mean	b max	b stdev	b Dry season average
			Eckhardt (2005)	0.29	0.47	0.57	0.07	0.04	0.20	0.31	0.38	0.05	0.04
			Chapman & Maxwell (1996)	0.29	0.47	0.57	0.07	0.04	0.14	0.23	0.29	0.04	0.02
Bviii1	C	Calibrated	Lyne & Hollick (1979)	27.54	49.91	63.84	8.33	5.29	14.81	26.88	33.24	3.84	5.06
			Eckhardt (2005)	27.54	49.91	63.84	8.33	5.29	17.49	31.65	39.15	4.73	4.87
			Chapman & Maxwell (1996)	27.54	49.91	63.84	8.33	5.29	13.75	24.95	31.89	4.16	2.76
Bviii3	D	Current	Lyne & Hollick (1979)	0.18	0.58	3.92	0.52	0.08	0.09	0.31	1.48	0.21	0.08
			Eckhardt (2005)	0.18	0.58	3.92	0.52	0.08	0.11	0.37	2.08	0.29	0.07
			Chapman & Maxwell (1996)	0.18	0.58	3.92	0.52	0.08	0.09	0.29	1.96	0.26	0.04
Bviii4	B	Calibrated	Lyne & Hollick (1979)	0.27	0.74	1.00	0.18	0.12	0.13	0.44	0.59	0.11	0.12
			Eckhardt (2005)	0.27	0.74	1.00	0.18	0.12	0.15	0.49	0.67	0.13	0.11
			Chapman & Maxwell (1996)	0.27	0.74	1.00	0.18	0.12	0.14	0.37	0.50	0.09	0.06
Bviii5	D	Calibrated	Lyne & Hollick (1979)	5.01	11.19	15.04	2.64	1.78	2.47	6.48	8.47	1.36	1.77
			Eckhardt (2005)	5.01	11.19	15.04	2.64	1.78	2.95	7.32	9.71	1.64	1.53
			Chapman & Maxwell (1996)	5.01	11.19	15.04	2.64	1.78	2.50	5.59	7.52	1.32	0.89
Bviii6	D	Calibrated	Lyne & Hollick (1979)	1.80	3.46	4.43	0.58	0.50	0.95	1.94	2.48	0.31	0.50
			Eckhardt (2005)	1.80	3.46	4.43	0.58	0.50	1.08	2.22	2.85	0.37	0.44
			Chapman & Maxwell (1996)	1.80	3.46	4.43	0.58	0.50	0.90	1.73	2.22	0.29	0.25
Bviii8	D	Calibrated	Lyne & Hollick (1979)	2.83	5.42	6.83	1.03	1.38	1.87	3.39	4.17	0.58	1.38
			Eckhardt (2005)	2.83	5.42	6.83	1.03	1.38	1.96	3.67	4.59	0.67	1.19
			Chapman & Maxwell (1996)	2.83	5.42	6.83	1.03	1.38	1.41	2.71	3.41	0.52	0.69
Bviii9	C	Calibrated	Lyne & Hollick (1979)	7.29	13.44	16.95	2.04	2.38	4.65	8.55	11.05	1.41	2.38
			Eckhardt (2005)	7.29	13.44	16.95	2.04	2.38	4.94	9.15	11.66	1.43	2.23
			Chapman & Maxwell (1996)	7.29	13.44	16.95	2.04	2.38	3.64	6.72	8.46	1.02	1.21

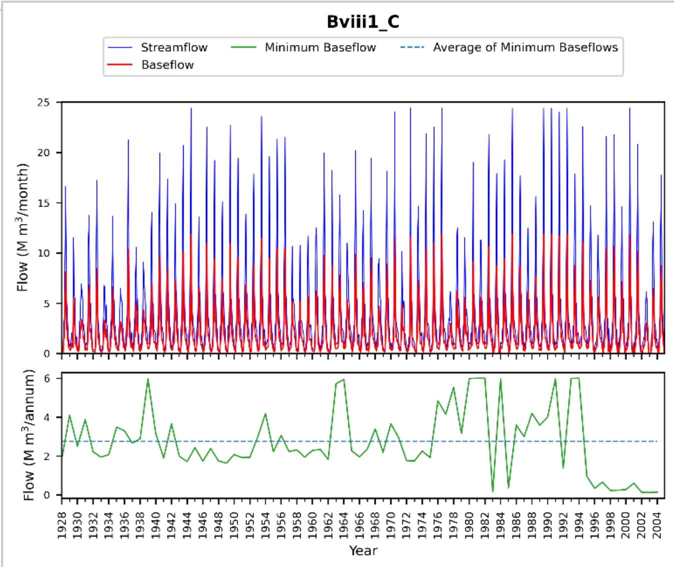
Figure C-1-1 Baseflow Separation graphs for all biophysical and river nodes in the Berg catchment using the Chapman & Maxwell (1996) recursive digital filter method. The upper graph displays the streamflow (Q) and baseflow (b) separation (M m^3/month) while the lower graph shows the mean dry season baseflow (M m^3/annum), which is the minimum baseflow of the year. It is important to note that these results are based on cumulative flow data and was done before incremental distribution.

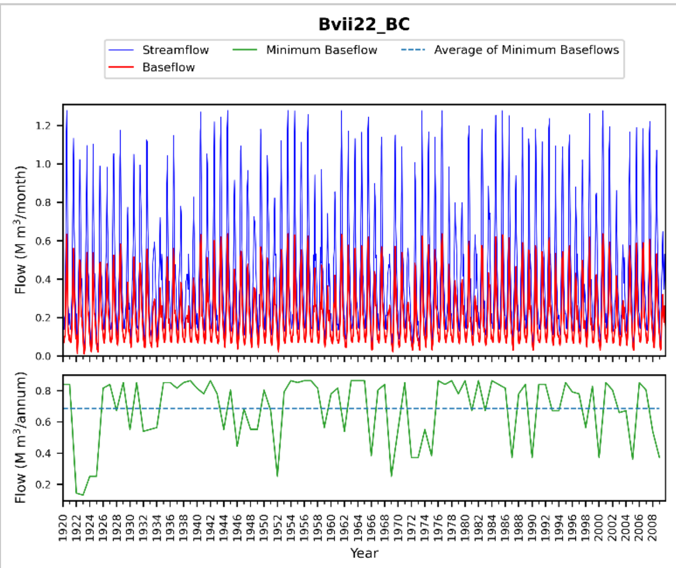


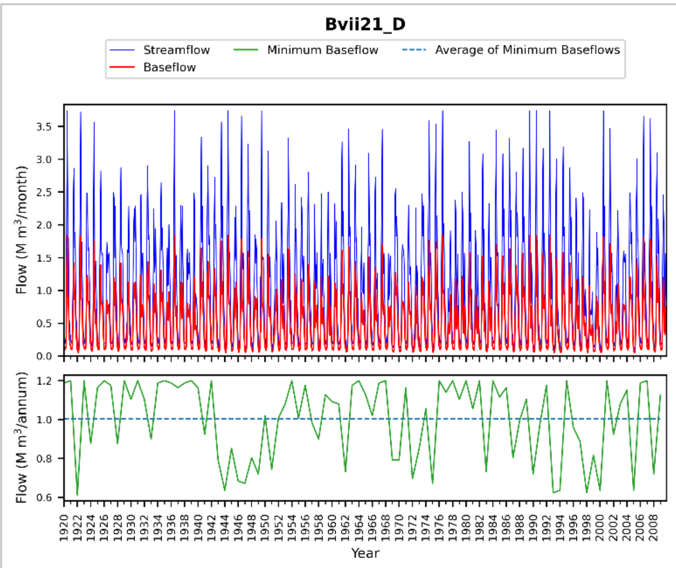

Bviii5_D
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

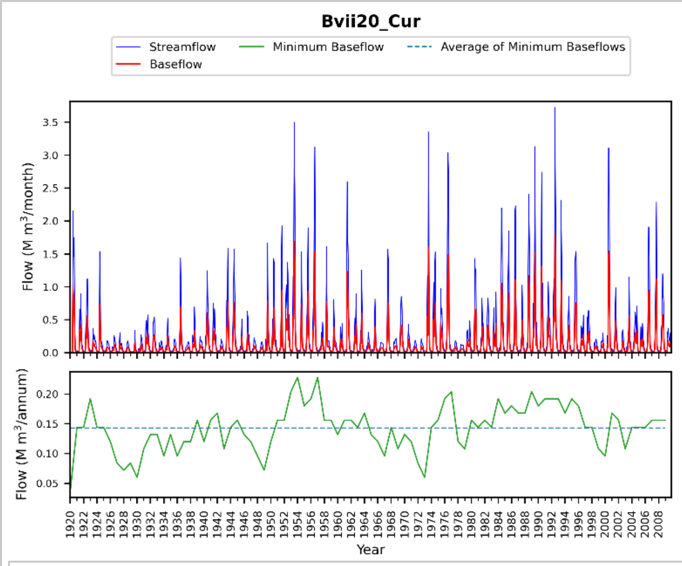

Bviii4_B
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

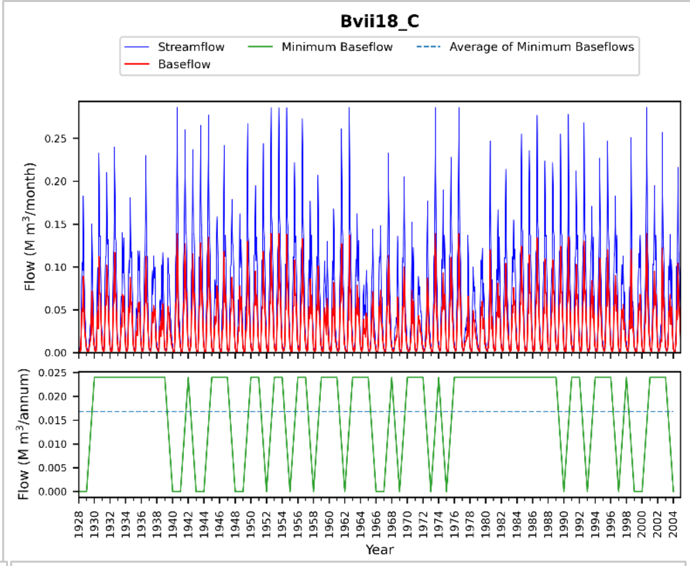

Bviii3_Cur
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

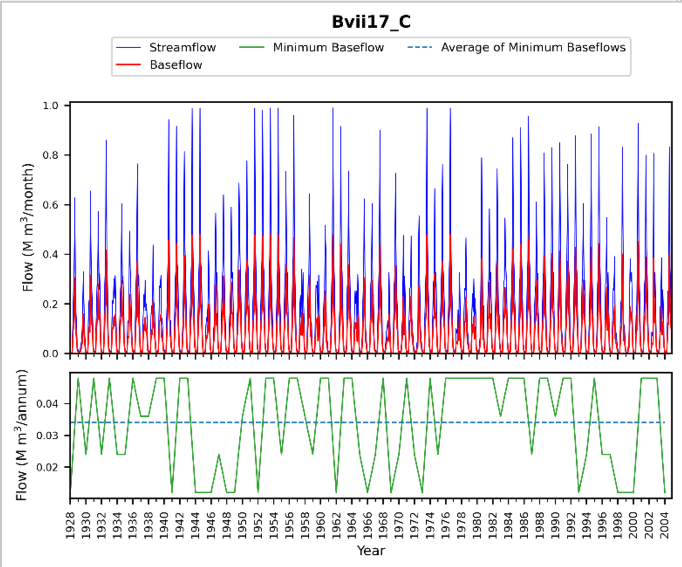

Bviii1_C
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

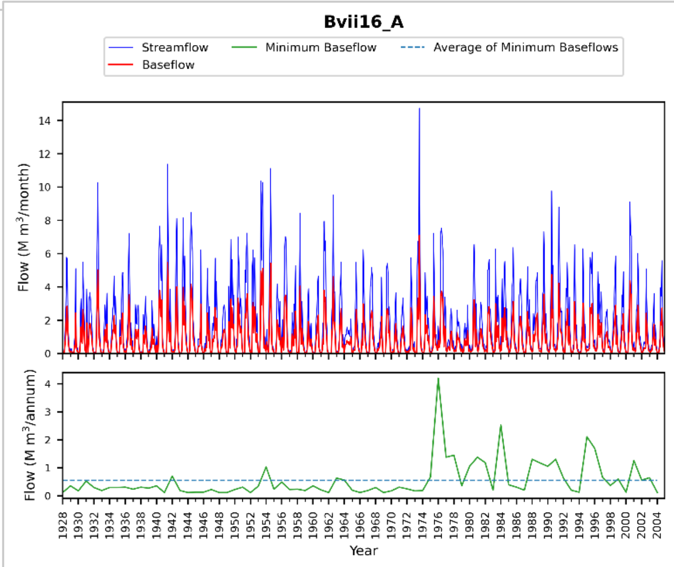

Bvii22_BC
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

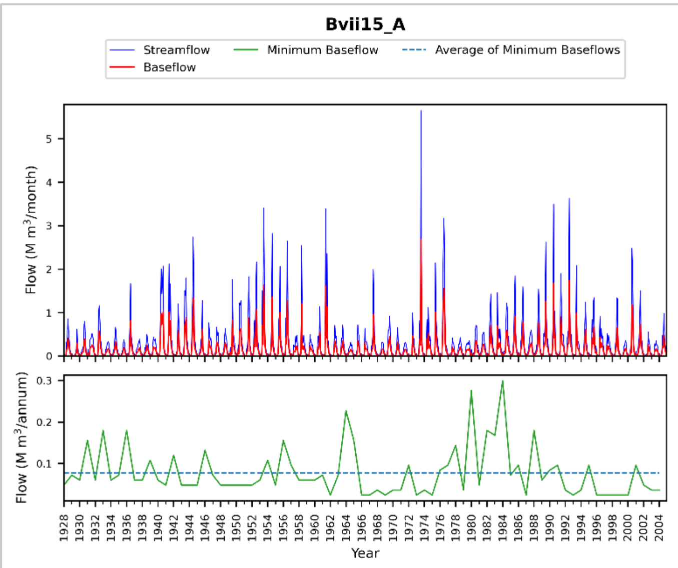

Bvii21_D
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year

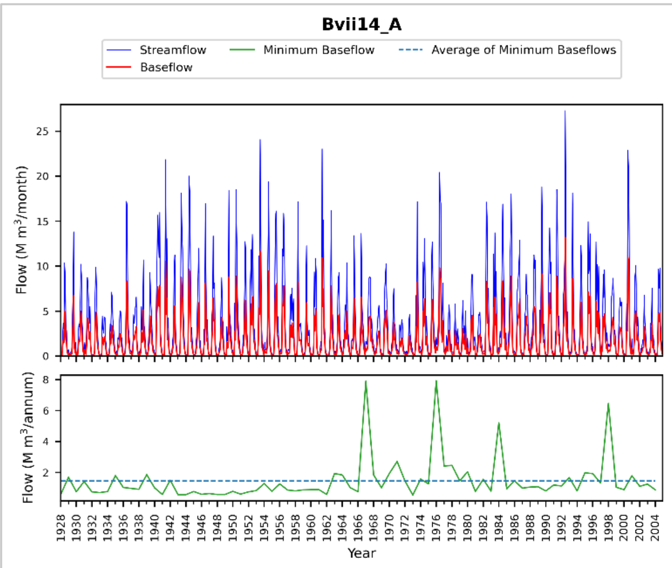

Bvii20_Cur
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

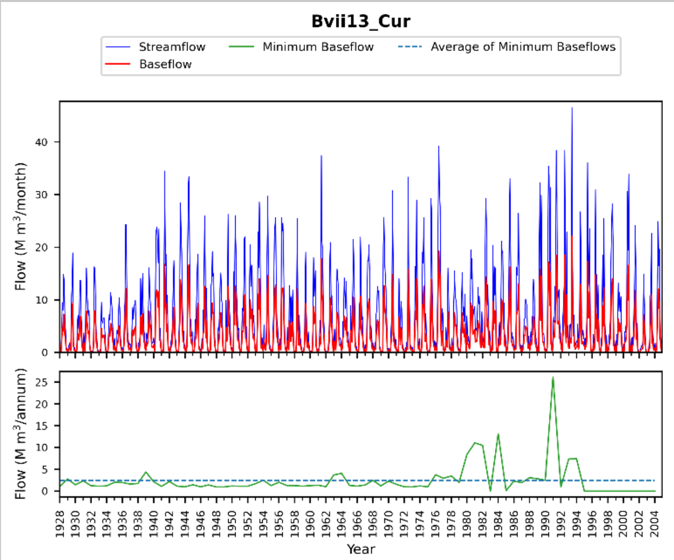

Bvii18_C
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

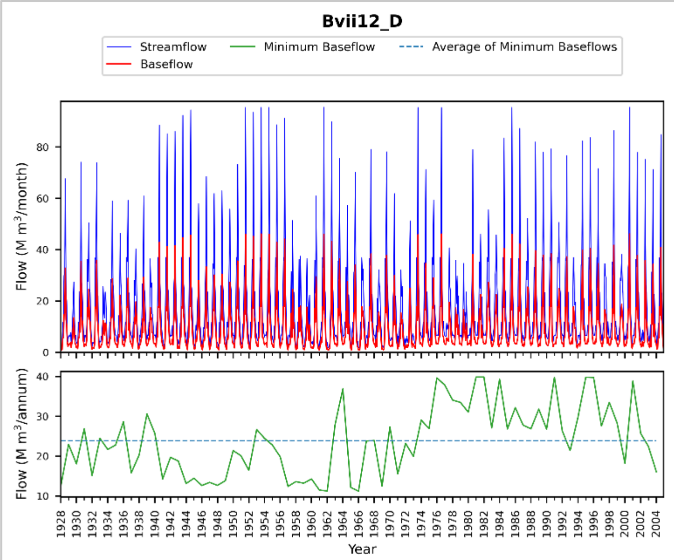

Bvii17_C
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

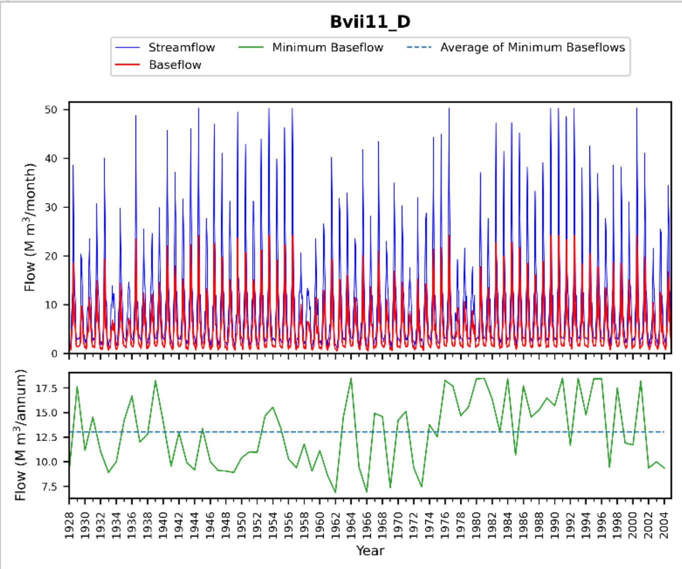

Bvii16_A
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

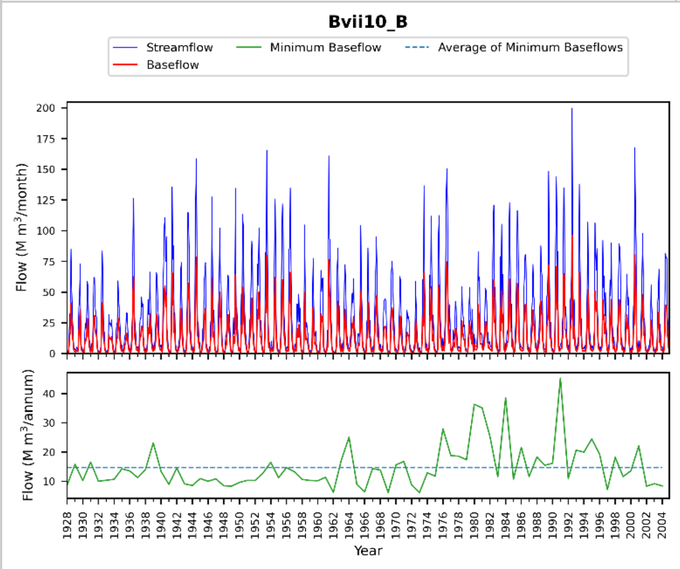

Bvii15_A
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

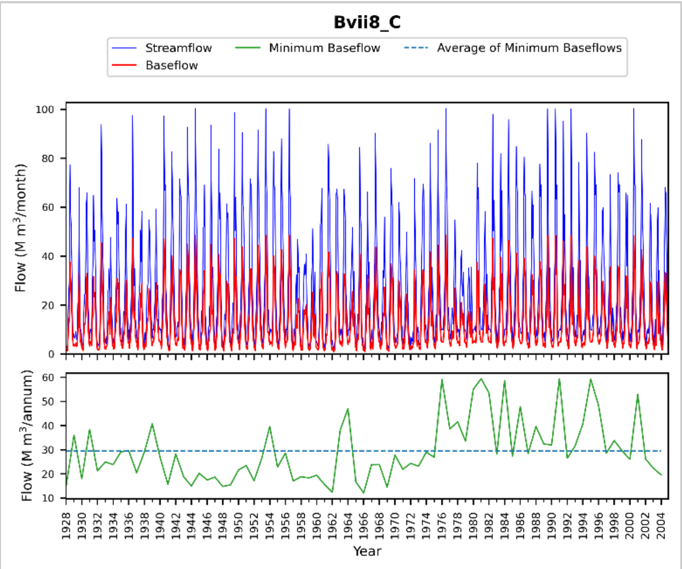

Bvii14_A
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

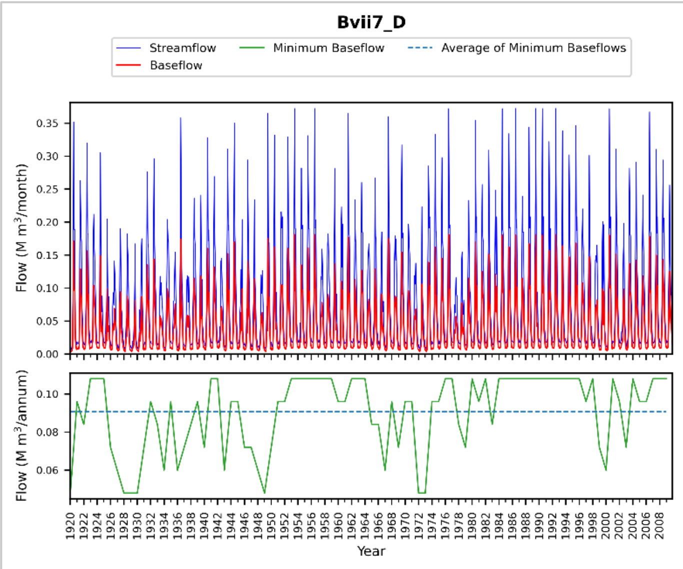

Bvii13_Cur
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

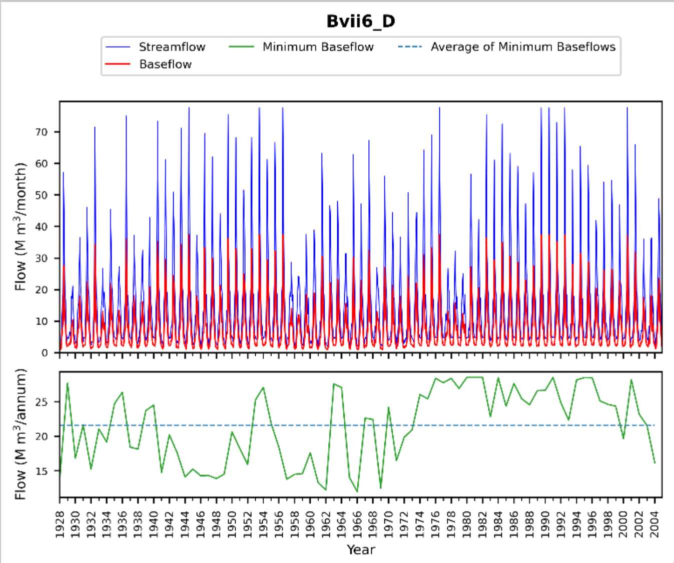

Bvii12_D
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

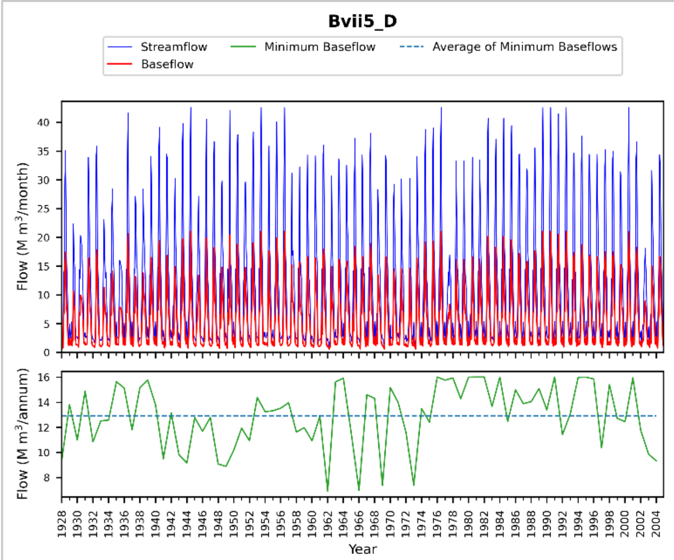

Bvii11_D
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

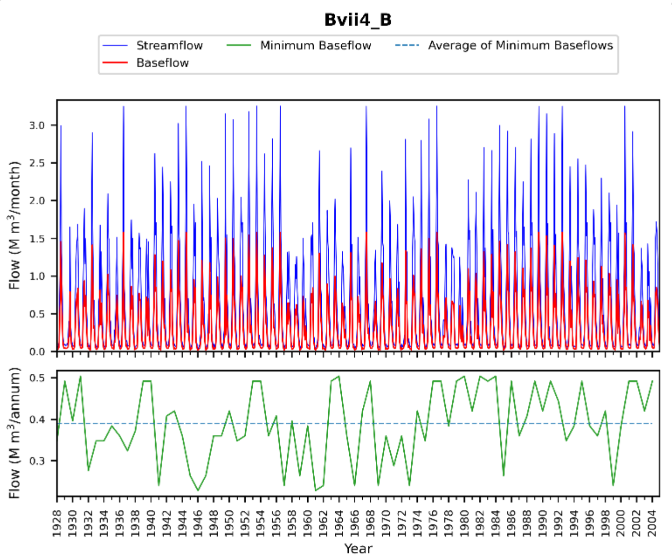

Bvii10_B
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

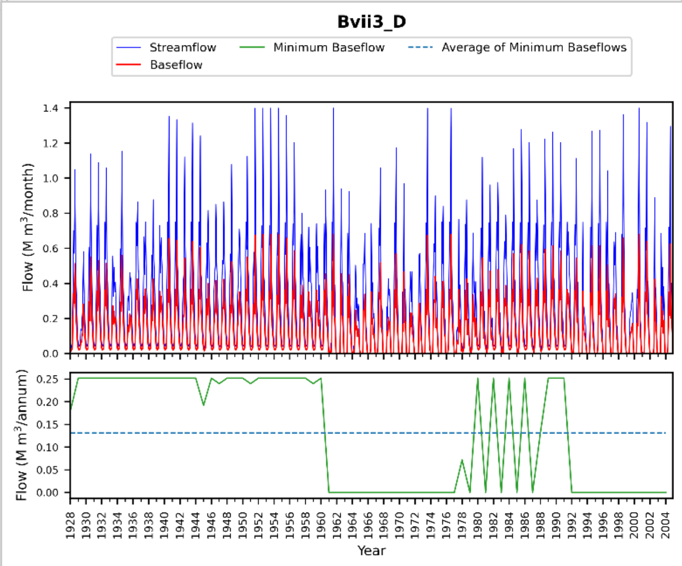

Bvii8_C
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

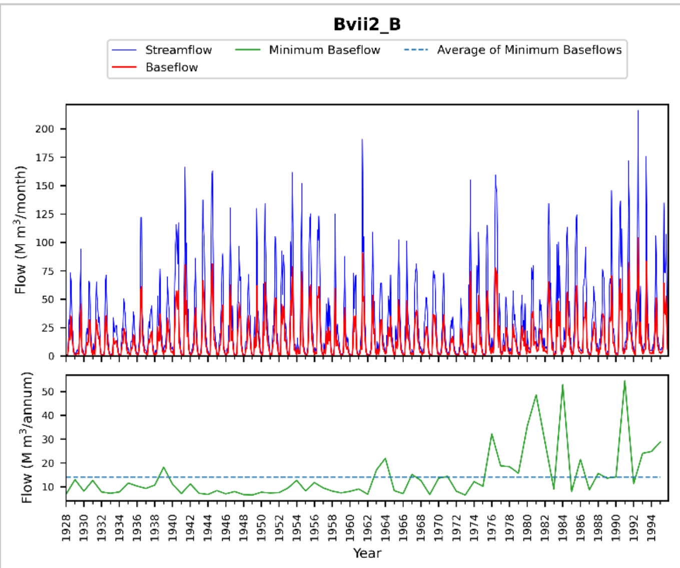

Bvii7_D
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m^3/month)
Flow (M m^3/annum)
Year

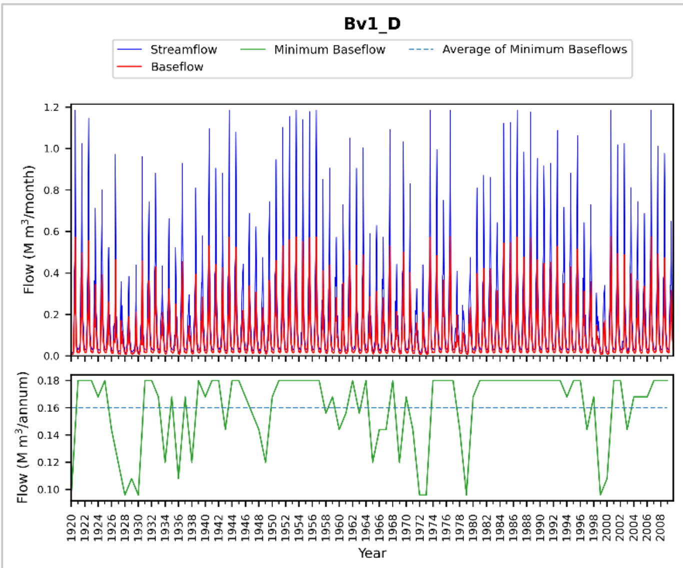

Bvii6_D
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

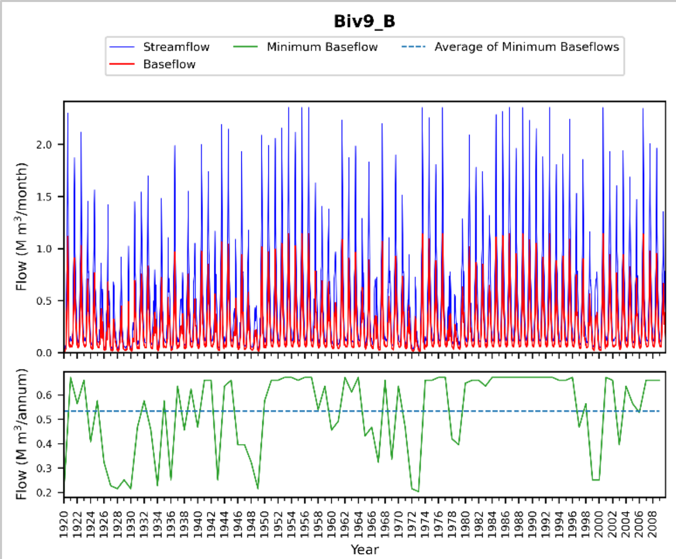

Bvii5_D
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

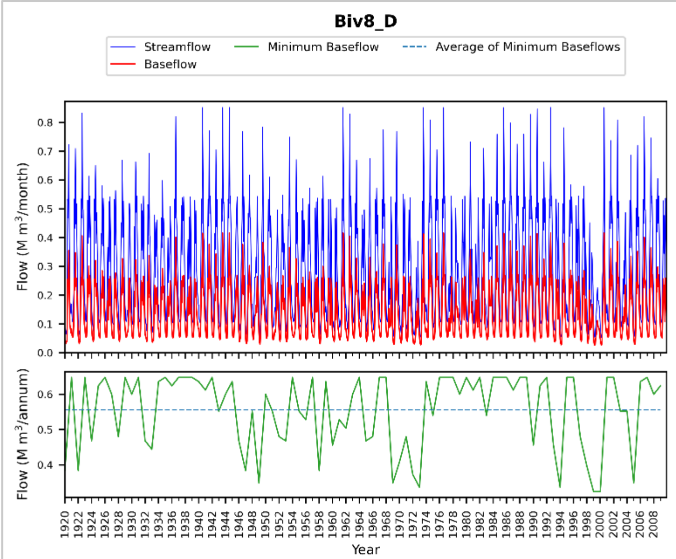

Bvii4_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

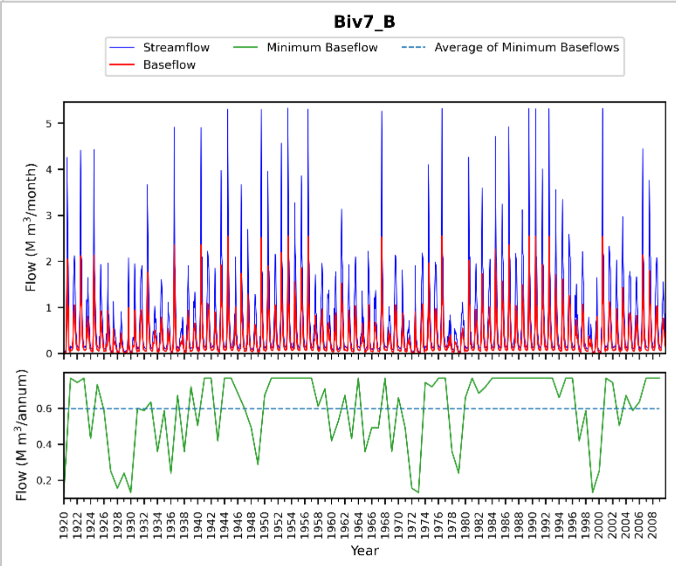

Bvii3_D
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year

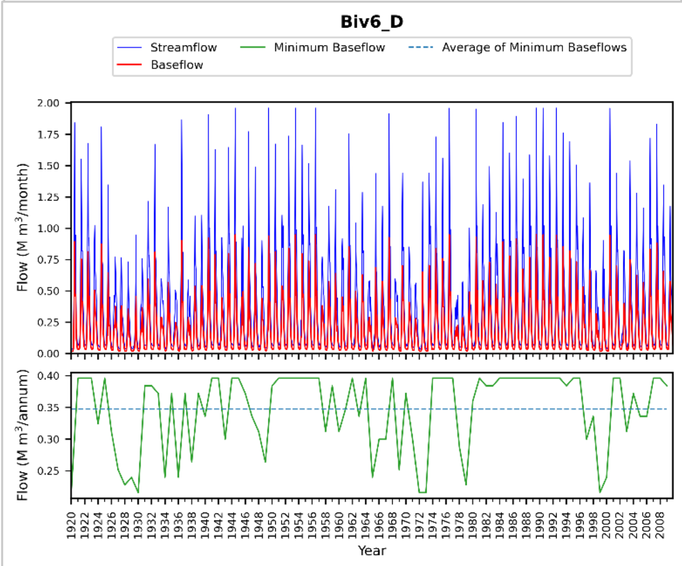

Bvii2_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year


Bv1_D
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m^3/month)
Flow (M m^3/annum)
Year


Biv9_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year


Biv8_D
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year


Biv7_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year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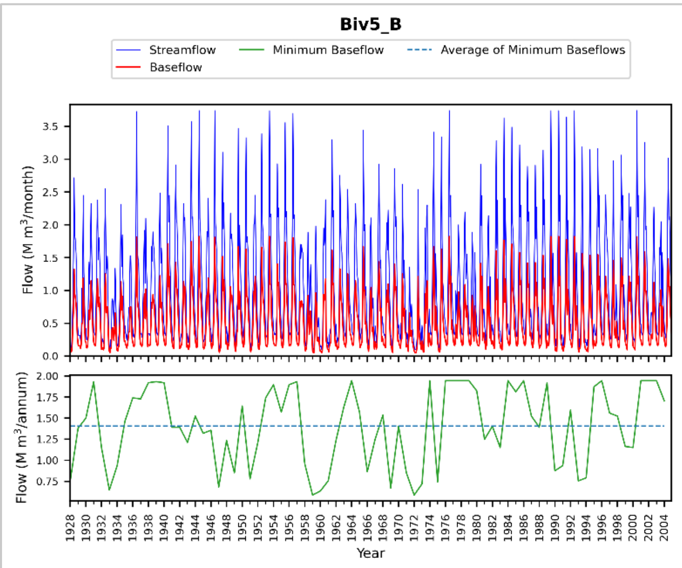
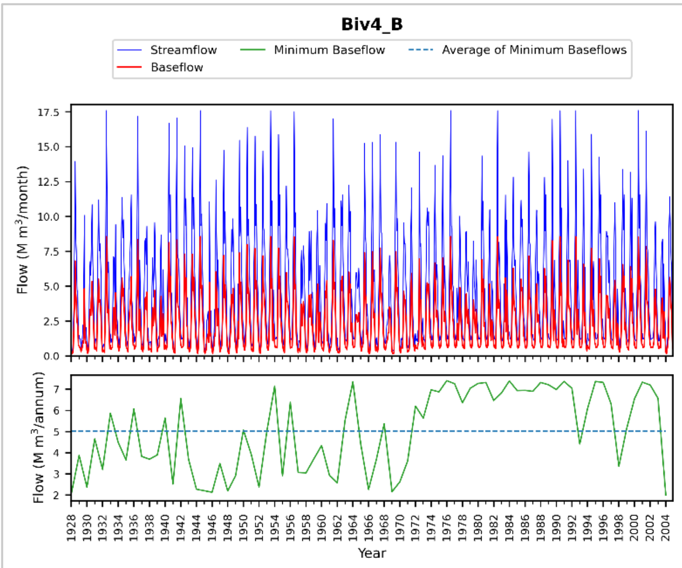
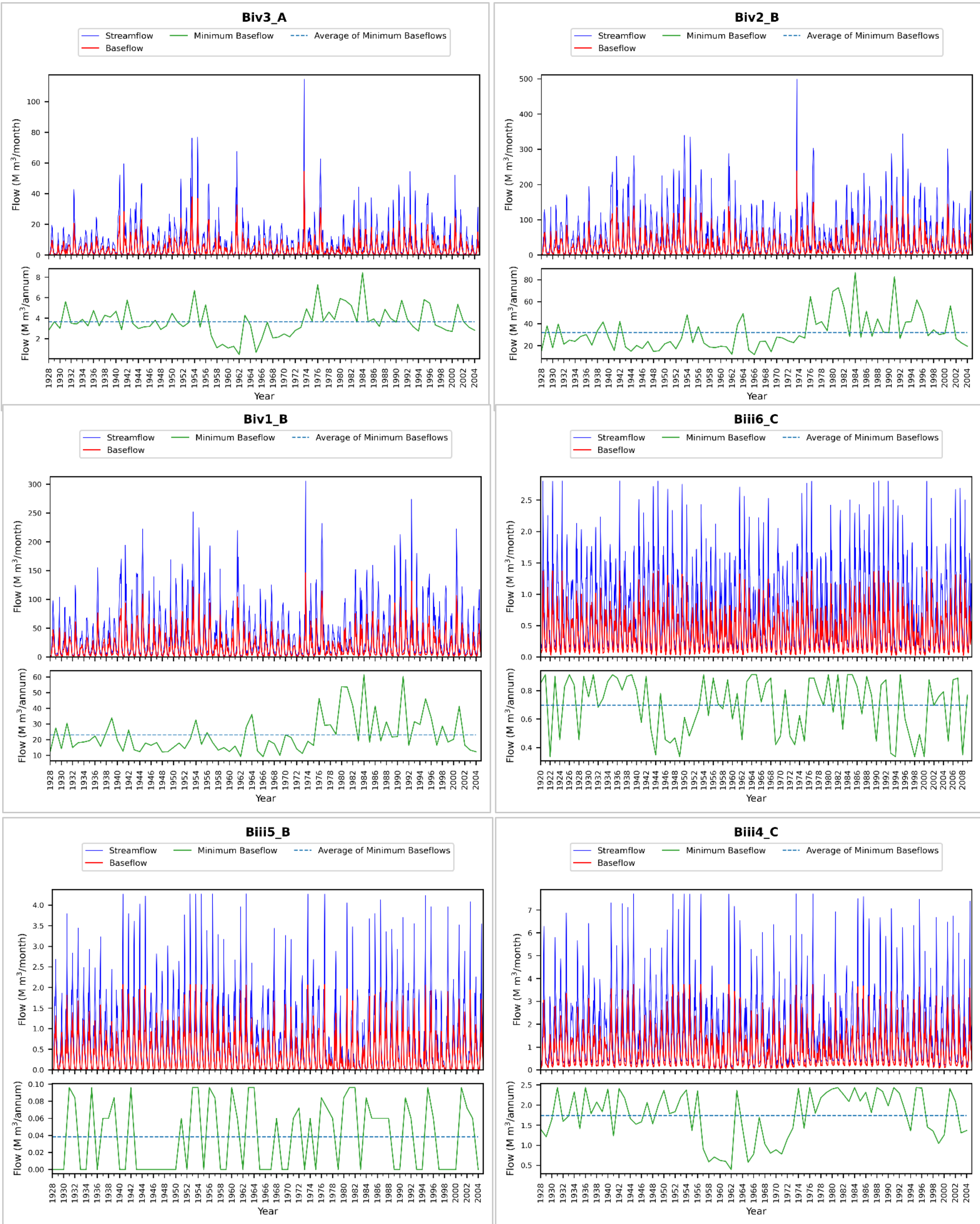
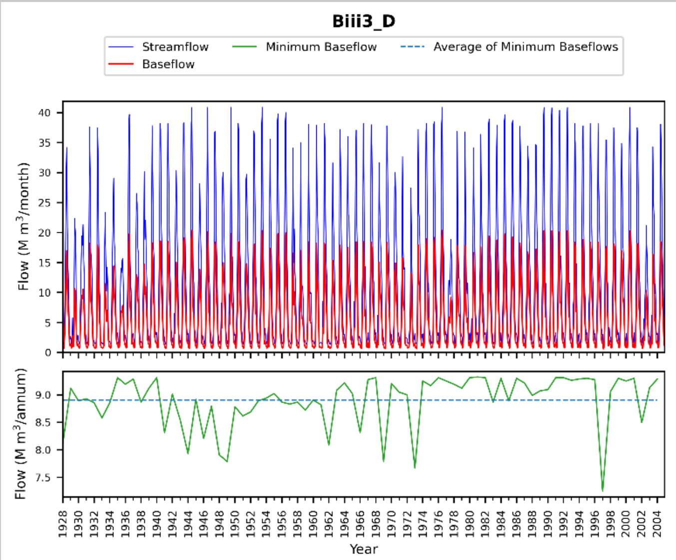
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year


Biv5_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year


Biv4_B
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year


Biv3_A
Streamflow
Minimum Baseflow
Average of Minimum Baseflows
Baseflow
Flow (M m³/month)
Flow (M m³/annum)
Year
Biv2_B
Biv1_B
Biii6_C
Biii5_B
Biii4_C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Baseflow
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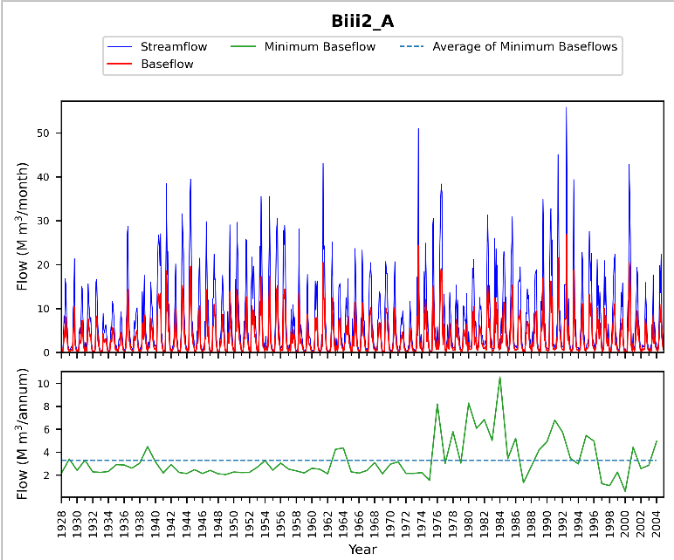
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year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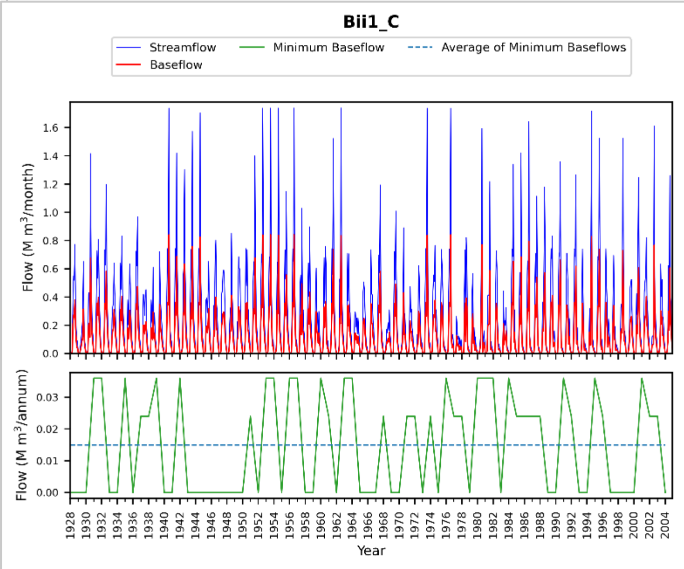
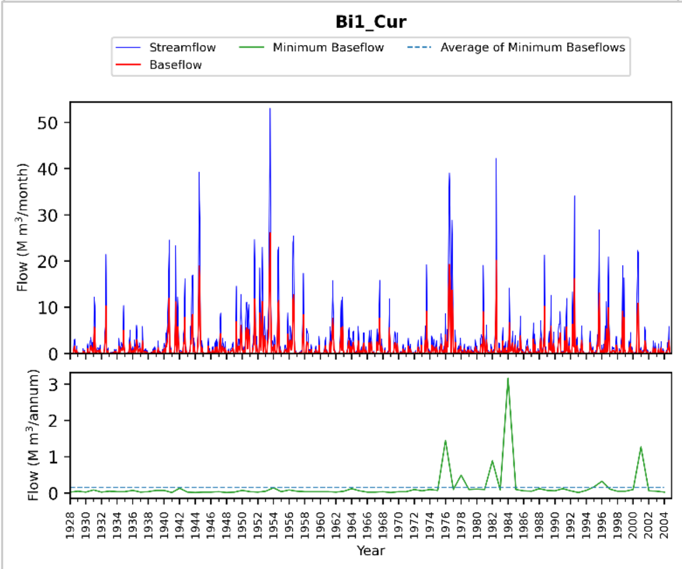
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year


Bii1_C
Streamflow
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year


Bi1_Cur
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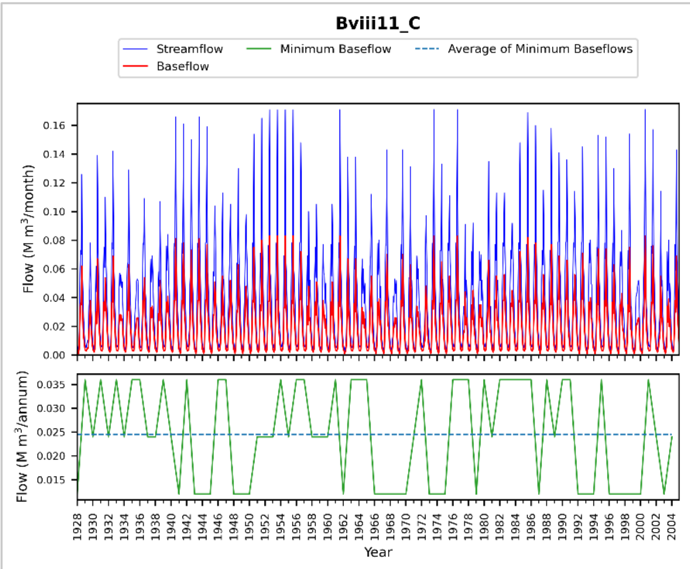
Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year


Bviii11_C
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Baseflow
Minimum Baseflow
Average of Minimum Baseflows
Flow (M m³/month)
Flow (M m³/annum)
Year