GROUNDWATER MANAGEMENT INSTITUTE

DETERMINING DEPENDENCY AND VULNERABILITY OF GROUNDWATER OF COASTAL CITIES (CAPE TOWN AND DAR ES SALAAM)

Groundwater Dependency Assessment: Cape Town

May 2025

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Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam)

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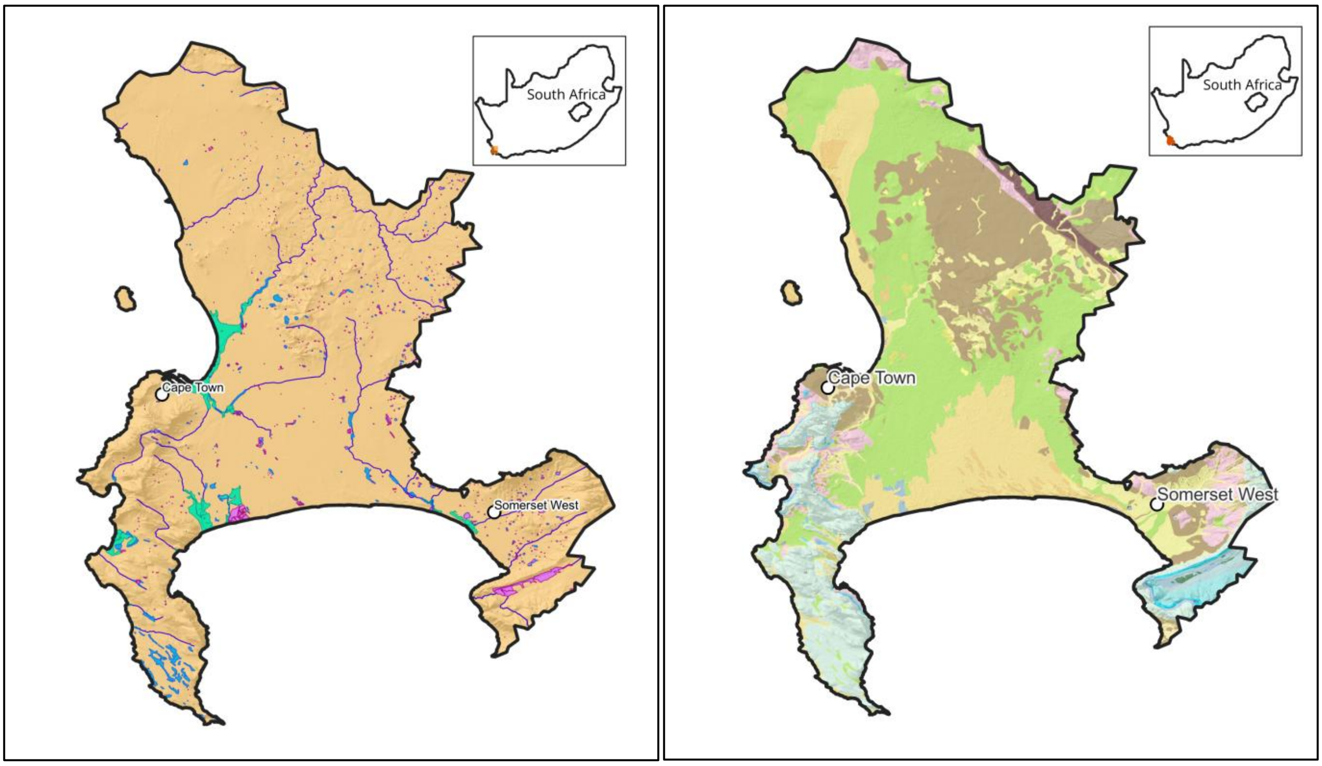

Version 1

Prepared for:

SADC-GMI

PROJECT	:	**Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam)**
REPORT TITLE	:	**Groundwater Dependency Assessment: Cape Town**
CLIENT	:	**SADC-GMI**
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REPORT STATUS	:	**Final**
VERSION	:	**Version 1**
UMVOTO REPORT NUMBER	:	**1074/3/1/2025**
CLIENT REPORT NUMBER	:	**ZA-SADC-GMI-418181-CS-CQS**
DATE	:	**May 2025**
APPROVED BY	:	

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Referencing

This report is to be referred to in bibliographies as:

SADC-GMI (2025). Groundwater Dependency Assessment (Cape Town), Determining Dependency and Vulnerability of Groundwater of Coastal Cities (Cape Town and Dar es Salaam). Prepared by E. Malijani, S. Stenzl, K. Woolf, K. Riemann and A. Benjamin of Umvoto Africa (Pty) Ltd., D. Brink and A. Modack of AIVIA (Pty) Ltd, M. Bollaert of Hydrologic Consulting (Pty) Ltd, and K. Snaddon of Freshwater Research Centre, on behalf of SADC-GMI. Final; Report No. 1074/2/4/2025, pg.51.

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Report Status

Version	Status	Reviewed By	Date
1	Draft	Keanan Woolf	27/05/2025
1	Final Draft	Kornelius Riemann	30/05/2025

Distribution List

Version	Name	Institution	Date
1	Kevin Pietersen	SADC-GMI	30/05/2025
1	James Sauramba	SADC-GMI	30/05/2025
1	Mampho Ntsekhe	SADC-GMI	30/05/2025

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List of Abbreviations

BOCMA	-	Breede-Olifants Catchment Management Agency
CBD	-	Central Business District
CCT	-	City of Cape Town
CFA	-	Cape Flats Aquifer
CMA	-	Catchment Management Agency
DAWASA	-	Dar es Salaam Water and Sewerage Authority
DM	-	District municipality
DWS	-	Department of Water and Sanitation
GESI	-	Gender Equity and Social Inclusion
GDE	-	Groundwater-dependent ecosystems
GRACE	-	Gravity Recovery and Climate Experiment
GWP	-	Global Water Partnership
Hydstra	-	Hydrological Data Management System
HSG	-	Hydrological soil group
IWRM	-	Integrated Water Resource Management
km	-	kilometre
m	-	metre
mamsl	-	metres above mean sea level
NGA	-	National Groundwater Archive
NWA	-	National Water Act
NWRS	-	National Water Resource Strategy
PHA	-	Philippi Horticultural Area
SADC	-	Southern African Developing Community
SADC-GMI	-	Southern African Developing Community-Groundwater Management Institute
SADC-GIP	-	Southern African Development Community- Groundwater Information Portal
SAWS	-	South African Weather Services
TBA	-	Transboundary Aquifer
TMG	-	Table Mountain Group
TOR	-	Terms of Reference
UNICEF	-	United Nations International Children's Emergency Fund
WMA	-	Water Management Area
WASH	-	Water and Sanitation Hygiene
WARMS	-	Water Authorisation and Registration Management System
WCWSS	-	Western Cape Water Supply System
WMS	-	Water Management System
WSA	-	Water Service Authorities
WSP	-	Water Service Providers
WUA	-	Water Use Associations
WUL	-	Water Use Licence

1. INTRODUCTION

1.1. Background

Southern Africa is home to approximately thirty (30) transboundary aquifers (TBAs) and numerous national strategic aquifers that support the primary water needs and livelihoods of a significant portion of the region's population. Because of climate change, reliance on groundwater has increased. Although there is a fair understanding of the strategic aquifers, increased data collection will enhance the capacity of institutions to sustainably manage groundwater resources. Furthermore, developing groundwater-specific data-sharing protocols among riparian states contributes to the integrated management of shared aquifers. There is a unique opportunity to establish groundwater monitoring networks and strengthen institutional frameworks for shared water management.

The Southern African Development Community Groundwater Management Institute (SADC-GMI), a subsidiary of the SADC Secretariat, is established as a Section 21 Not-for-Profit Company under South African law. The vision of the SADC-GMI is to ensure the equitable and sustainable use and protection of groundwater and be a Centre of Excellence in groundwater management and management of groundwater-dependent ecosystems in the region. The role of the SADC-GMI is to:

- Promote sustainable groundwater management and provide solutions to groundwater challenges in the SADC region through building capacity, providing training, advancing research, supporting infrastructure development, and enabling dialogue and exchange of groundwater information.
- Conduct and support the SADC Member States in groundwater research, and serve as a focal interlocutor with national, regional, and international groundwater initiatives.
- Promote the sustainable conjunctive use of surface and groundwater.

As part of their programme to provide solutions to groundwater challenges, SADC-GMI embarked on a project to investigate and provide management strategies for **Groundwater Dependency and Vulnerability in the Coastal Cities of Dar es Salaam and Cape Town.**

Groundwater Dependency and Vulnerability in Coastal Cities

The dependency and vulnerability of coastal cities stem from multiple factors. Rapid urban growth and population increases higher water demand, often met by groundwater due to insufficient surface water sources. Many urban authorities struggle to supply water through reticulated systems, leaving informal settlements reliant on shallow wells and boreholes.

Coastal cities are particularly susceptible to saltwater intrusion into aquifers, especially during dry seasons or due to excessive groundwater abstraction. Pollution from urban runoff, industrial activities, agricultural activities, and improper sanitation can degrade groundwater quality, making it unfit for consumption. Additionally, climate change has given rise to changing precipitation patterns, increasing temperatures and affecting groundwater recharge rates. These changes may increase water demand due to higher temperatures and evaporation, or reduced surface water availability, potentially leading to over-exploitation.

The urban sprawl in coastal cities, inadequate enforcement of regulations and improper management of groundwater resources can exacerbate these vulnerabilities. Given these challenges, this project aims to assess groundwater dependency and vulnerabilities of groundwater in the selected coastal cities of Cape Town and Dar es Salaam in the SADC region.

1.2. Project aims and objectives

The overall objective of this project is to determine the dependency and vulnerability of groundwater in coastal cities, using Cape Town and Dar es Salaam as case studies. This will involve engaging with stakeholders, conducting high-level hydrogeological and environmental assessments, identifying gaps in the current monitoring networks, assessing vulnerability factors, evaluating the impacts of pollution and climate change, and incorporating socio-economic and gender dynamics. As part of this, a conjunctive management strategic action plan will be developed to build resilience in each city. These strategic action plans will provide frameworks to guide sustainable groundwater use, mitigating risks and enhancing resilience to climate change and environmental stresses in coastal cities.

This groundwater dependency assessment is the first main technical task that assesses how municipalities, communities, industries and the environment rely on groundwater in Cape Town based on existing information. This report also includes relevant legislation and authorities responsible for groundwater management, a detailed hydrogeological assessment and an overview of how socioeconomics, gender equality and social inclusion factors influence groundwater dependency in Cape Town. This information is critical for understanding the city's reliance on groundwater and serves as a foundation for developing a conjunctive management strategic action plan that will guide the sustainable use of groundwater resources in Cape Town.

1.3. Definition of Terms

For the context of this project, the following terms are defined and described below:

Groundwater dependency refers to the reliance on groundwater for both human consumption and aquatic ecosystems (i.e. groundwater-dependent ecosystems, GDE's). In coastal cities like Cape Town and Dar es Salaam, increasing urbanisation and population growth increase water demand for human consumption, resulting in a reliance on groundwater due to inadequate surface water sources. Groundwater also plays a vital role in sustaining groundwater-dependent ecosystems, such as coastal wetlands and estuaries, which are crucial for maintaining biodiversity and ecological balance.

Groundwater vulnerability refers to how susceptible an aquifer is to the risks and threats affecting the groundwater resource itself, the ecosystems it supports, and its availability for human use. In the context of this study, the term also includes the vulnerability of the communities that depend on the groundwater resources.

Vulnerability can usefully be split into three main components, sensitivity (i.e. the extent of **dependency** of an ecosystem or water users on water resources, whether ground- or surface water), adaptive capacity or **resilience** (i.e. capacity or ability to respond to shifts in drivers, such as climate or water quality, and their consequences), and exposure to stressors or **hazards** (i.e. the probability of being exposed to a certain impact) (Stuart-Hill et al., 2012; Esterhuyse et al., 2014).

Resilience refers to the capacity of the affected ecosystem or community to deal with an impact, to "bounce back" (i.e. persist and recover) to status quo after a crisis or disaster, and potentially to "bounce forward" (i.e. adapt and transform) to something new that is better suited to emerging conditions.

Risk is usually defined as the product of likelihood and severity of adverse effects on the groundwater resource, water users and receiving environment due to the exposure to hazards. Key risks include contamination, over-abstraction, climate change impacts, seawater intrusion, and the degradation of groundwater-dependent ecosystems. These factors can compromise the availability and quality of groundwater for the people and ecosystems that depend on it.

Risk is also sometimes expressed as product of likelihood of a hazard occurring and vulnerability of the receiving environment, divided by coping capacity (or resilience).

2. Groundwater Management and Governance

2.1. Water related Legislation

2.1.1. National Water Act

The National Water Act (NWA), Act 36 of 1998, is the primary legal framework for water resource management in South Africa (Government of South Africa, 1998; WRC, 2011). It governs water resources, including rivers, streams, dams, and groundwater and mandates an Integrated Water Resource Management (IWRM) approach to ensure the consideration of all aspects of water resource management. The Act provides the legal framework for protecting, using, developing, conserving, managing, and controlling South Africa's water resources. The National Water Resources Strategy (NWRS) is the legal instrument for implementing and operationalising the National Water Act (NWA) (Act 36 of 1998).

The purpose of the National Water Act is to:

a) Meet the basic human needs of present and future generations

b) Promote equitable access to water

c) Redress the results of past racial and gender discrimination

d) Promote the efficient, sustainable, and beneficial use of water in the public interest

e) Facilitate social and economic development

f) Provide for the growing demand for water use

g) Protect aquatic and associated ecosystems and their biological diversity

h) Reduce and prevent pollution and degradation of water resources

i) Meet international obligations

j) Promote dam safety

k) Manage floods and droughts

The Act also redefines water as a unified national resource under the custodianship of the national government, replacing the previous system in which landowners of a property owned the rights to the underlying groundwater on their property and could abstract it with little to no regulations (WRC, 2014). This transition from previous groundwater legislation has led to vast improvements in groundwater management, protection and distribution (National Groundwater Strategy, 2016).

Chapter 14 of the NWA outlines the laws and requirements around the monitoring of water resources (what data is to be collected) and the management of collected data (storage and availability of data). The act mandates the establishment of national monitoring systems that collect data and information necessary to assess:

- The quantity of water in the various water resources;
- The quality of water resources;
- The use of water resources;
- The rehabilitation of water resources and compliance with resource quality;
- The health of aquatic ecosystems; and
- Atmospheric conditions that may influence water resources.

According to the Act, collected datasets must be stored in national information systems (e.g., Hydstra, NGA, WMS and WARMS) designed to support the protection, sustainable use, and management of water resources. These systems also serve to facilitate the development and implementation of the national water strategy and to provide data access for water management institutions, water users, and the public (Government of South Africa, 1998).

2.1.2. Water Services Act

The Water Services Act, Act 108 of 1997, deals mainly with water services or potable (drinkable) water and sanitation services supplied by municipalities to households and other municipal water users. It contains rules about how municipalities should provide water supply and sanitation services. The Act defines the municipal functions of ensuring water services provision and sets out guidelines for Water Services Authorities (WSA) as well as Water Services Providers (WSP).

Paragraph 4 of the Water Services Act sets out the conditions under which a WSP can operate, whereby paragraph 11 describes the duties of the WSA. The roles and responsibilities of the WSA and WSP in terms of water resource management are not explicitly stated but can be inferred from their different roles in the provision of water services.

2.1.3. Groundwater Use Authorisation and Registration

Once put in place, the NWA (No. 36 of 1998) mandated the registration of groundwater use for the improved management of groundwater resources. This information is stored on the departmental Water Use Authorisation and Registration Management System (WARMS) national register (defined in terms of Section 139 (2) (d). The national register is used to facilitate fair economic growth, development, and democracy within South Africa.

The NWA (No. 36 of 1998) stipulates that any water use requires authorisation from the Department of Water and Sanitation (DWS) or its appointed regulator (for example, a catchment management agency (CMA) such as the Breede-Olifants CMA for the City of Cape Town). This is to ensure that relevant groundwater data is collected and stored on the national databases to enable the DWS or appointed regulator to make effective decisions regarding the current state and future allocation/distribution of groundwater.

Groundwater authorisation is divided into three categories based on the type of groundwater use and associated volumes: Schedule 1 Use (as defined under Schedule 1 of the NWA), General Authorisation (GA), and Water Use Licenses (WULs). Schedule 1 water use is defined as reasonable domestic use, such as garden irrigation or potable water if outside an urban area on a farm with no water service provision. Schedule 1 water users are not required to register with the DWS, therefore registration is often lacking, resulting in data gaps, particularly in terms of groundwater abstraction volumes and the extent of groundwater users. Additionally, illegal groundwater use, which can be prompted by backlogs and delays in WUL applications, can also result in such gaps, as only 20% of groundwater use is verified in South Africa (WRC, 2022). Information on groundwater abstraction volumes and the extent of groundwater users in Cape Town is vital in determining the dependency of groundwater in the city and the vulnerability of the groundwater resources to over abstraction.

The different types of water use that require authorisation are defined in Section 21 of the NWA, as highlighted in the box below.

21. For the purposes of this Act, water use includes -

(a) taking water from a water resource;

(b) storing water;

(c) impeding or diverting the flow of water in a watercourse;

(d) engaging in a stream flow reduction activity contemplated in Section 36;

(e) engaging in a controlled activity identified as such in Section 37(1) or declared under Section 38(1);

(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;

(g) disposing of waste in a manner which may detrimentally impact on a water resource;

(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;

(i) altering the bed, banks, course or characteristics of a watercourse;

(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and

(k) using water for recreational purposes.

2.2. Relevant Environmental Legislation

2.2.1. National Environmental Management Act (Act 107 of 1998 as amended by Act 62 of 2008)

The National Environmental Management Act of 2008 (NEMA), outlines measures that "…prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."

Of particular relevance to this groundwater dependency report is Chapter 1(4r), which states that sensitive, vulnerable, highly dynamic or stressed ecosystems, such as coastal shores, estuaries, wetlands, and similar systems require specific attention in management and planning procedures, especially where they are subject to significant human resource usage and development pressure.

Section 24 of NEMA requires that the potential impact on the environment, socio-economic conditions and cultural heritage of activities that require authorisation or permission by law, must be considered, investigated and assessed prior to implementation, and reported to the relevant regulatory authority.

2.2.2. Western Cape Biodiversity Act (2021)

The Western Cape's Biodiversity Act aims to provide for "…the framework and institutions for nature conservation and the protection, management and sustainable use of biodiversity and ecosystems in the Province; and for matters incidental thereto." the objectives of the Act are to:

- Give effect to the obligation of the state in terms of national legislation to act as trustee in relation to the environment;
- Give effect to section 81(m) of the western cape constitution to protect and conserve the environment in the province, including its unique biodiversity, for the benefit of present and future generations;

- Ensure the long-term ecological sustainability and resilience of biodiversity, ecosystems, ecosystem services and ecological infrastructure through implementation of the principles of ecological sustainability contemplated in section 6 and the protection of priority biodiversity and ecological infrastructure;
- Ensure human well-being and the long-term resilience of society and the economy through the conservation of protected areas, biodiversity, ecosystems, ecosystem services and ecological infrastructure;
- Enable reasonable and sustainable access to benefits and opportunities emanating from the conservation of protected areas, biodiversity, ecosystems, ecosystem services and ecological infrastructure;
- Establish institutional structures and organisational capacity for the effective discharging of the conservation and management of biodiversity and nature in the province;
- Promote consultation, cooperation, integrated planning, decision-making and management in support of the conservation and sustainable use of biodiversity and ecosystem services in the province;
- Promote systematic biodiversity planning and the attainment of the biodiversity targets for conservation set in the biodiversity spatial plan and the provincial protected areas expansion strategy;
- Regulate certain activities to be undertaken in a manner that enhances and protects the integrity and health of the environment;
- Subject to section 231 of the constitution, implement and give effect to international agreements and best practices pertaining to the environment and conservation of biodiversity;
- Enable the financial and economic sustainability of the relevant institutions responsible for the conservation and management of biodiversity and nature in the province; and
- Enable and develop an equitable and sustainable biodiversity economy in the Province, including the promotion and development of eco-tourism in areas under the control of CapeNature.

2.2.3. National Environmental Management: Biodiversity Act (2004)

The purpose of the National Environmental Management: Biodiversity Act 10 of 2004 is to provide for the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act of **1998.** The focus of this act also includes:

- The protection of species and ecosystems that warrant national protection;
- The sustainable use of indigenous biological resources;
- The fair and equitable sharing of benefits arising from bio-prospecting involving indigenous biological resources;
- The establishment and functions of a South African National Biodiversity Institute.

2.2.4. Climate Change Bill (2018, 2022)

The vision of the Climate Change Bill (introduced to Parliament in February 2022) is to "…enable the development of an effective climate change response and a long-term, just transition to a low-carbon and climate-resilient economy and society for South Africa in the context of sustainable development; and to provide for matters connected therewith."

The objectives of the Act (when it is promulgated) are to:

- Provide for a coordinated and integrated response by the economy and society to climate change and its impacts in accordance with the principles of cooperative governance;
- Provide for the effective management of inevitable climate change impacts by enhancing adaptive capacity, strengthening resilience and reducing vulnerability
- To climate change, with a view to building social, economic and environmental resilience and an adequate national adaptation response in the context of the global climate change response;
- Make a fair contribution to the global effort to stabilise greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system;
- To ensure a just transition towards a low carbon economy and society considering national circumstances;
- Give effect to the republic's international commitments and obligations in relation to climate change; and
- Protect and preserve the planet for the benefit of present and future generations of humankind.

2.2.5. Western Cape Provincial Spatial Development Framework (March 2014)

Policies regarding the protection of biodiversity and ecosystem services in the Western Cape are:

- The Western Cape's Critical Biodiversity Area (CBA) mapping, together with the draft priority climate change adaption corridors, comprise the spatial extent of the Western Cape's biodiversity network. This must inform spatial planning and land use management decisions throughout the province.
- Using the latest available CBA mapping as a primary informant, regional, district and municipal SDFs must delineate Spatial Planning Categories (SPCs) that reflect suitable land use activities in the different CBA categories.
- To complement CapeNature's protected area expansion strategy and their Stewardship programme, SDFs should highlight priority areas outside the protected area network that are critical for the achievement of the province's conservation targets.

Policies regarding the management, repair and optimisation of inland water resources are:

- Given current water deficits, which will be accentuated by climate change, a 'water wise' planning and design approach in the W Cape's built environment is to be mainstreamed.
- Rehabilitation of degraded water systems is a complex inter-disciplinary intervention requiring built environment upgrading (i.e. infrastructure and the built fabric), improved farming practises, as well as the involvement of diverse stakeholders.
- Introduce and retrofit appropriate levels of water and sanitation systems technologies in informal settlements and formal neighbourhoods with backyard shacks as a priority.
- An overarching approach to water demand management is to be adopted – firstly efficiencies must be maximised, storage capacity sustainably optimised and ground water extraction sustainably optimised, with the last resort option of desalination being explored, if necessary.
- Protection and rehabilitation of river systems and high yielding groundwater recharge areas, particularly in areas of intensive land use (i.e. agricultural use, industry, mining and settlement interactions) should be prioritised.

- Regional Plans to be developed for Water Management Areas to ensure clear linkages and interdependencies between the natural resource base (including water resources) and the socio-economic development of the region are understood and addressed.
- Agricultural water demand management programmes to be developed with an emphasis on the Breede Valley and Oliphants / Doorn agricultural areas. Industrial water demand management programmes to be developed with an emphasis on Saldanha, Southern Cape and Cape Town. Settlement water demand management programmes to be developed with an emphasis on the Cape Town functional region.
- Government facilities (inclusive of education, health and public works facilities) to lead in implementing effective and efficient water demand management programmes.
- Continue with programmes (such as Working for Water) which reduce the presence of alien vegetation along river systems.

2.3. Role of Local Government in Groundwater Management

South Africa's legislative framework divides water governance between national resource management and local service provision. The NWA designates the national DWS and Catchment Management Agencies (CMAs) as custodians of water resources (including groundwater), while the Water Services Act (1997) tasks local governments (municipal Water Services Authorities, WSAs) with providing water services to communities.

2.3.1. Governance Structure

The NWA and the Water Services Act (Act No.108 of 1997) outline the authorities responsible for water management in South Africa. The main authorities involved in groundwater management and associated groundwater data collection are listed below (WRC, 2011; CCT, 2025):

- **National Government** – The role of the National Government is to draft and gazette water regulatory policies and laws.
- **Department of Water and Sanitation** (DWS) – is responsible for national legislation, planning the development of national groundwater resource policy, regulation and monitoring. DWS regional offices act as the effective proto-CMAs.
- **Catchment Management Agencies** (CMAs) are responsible for water resource management within their Water Management Area (WMA). They were established to address local water needs more effectively and develop tailored water management strategies specific to their WMAs. Their primary goal is to achieve integrated management within the catchment and facilitate stakeholder participation in decision-making and water resource management. Initially, nineteen (19) WMAs were defined with the intent for a CMA to be established within each WMA. However, delays in establishing these agencies led to a reduction first to nine WMAs and CMAs, which were later consolidated to just six. The City of Cape Town currently falls within the Breede-Olifants Water Management Area and is managed by the Breede-Olifants Catchment Management Agency since 2024, following its expansion from the Breede-Gouritz Catchment Management Agency established in 2013.
- **Water User Associations** (WUAs) are responsible for function at a local level, representing individual water users and providing vehicles for public participation to the CMA. They operate at a restricted localised level and are in effect co-operative associations of individual water users who wish to undertake water related activities for their mutual benefit (National Water Act 36 of 1998). WUAs are well placed to implement and manage conjunctive use of groundwater and surface water resources and the artificial recharge of local aquifers, reduce or prevent over-exploitation and degradation of the groundwater resource, implement water conservation measures and create awareness on resource availability and sustainability.

Figure 2-1 Powers and competencies of spheres of government (CCT, 2025)

- **Water Boards** – The eight (8) government owned water boards play a key role in resource management in the water sector of South Africa. The water boards operate bulk water supply infrastructure, wastewater systems, dams and supply infrastructure. Water boards which provide access to water service are referred to as Water Service Providers (WSP).
- **Water Service Authorities (WSAs)** are the designated municipal institutions responsible for ensuring water and sanitation services within their jurisdiction. Their duties include planning of water supply services, ensuring the operation and maintenance (O&M) of infrastructure, monitoring **water resources,** including **water levels, quantity, and quality,** and **analysing this data** to advise the WSP on necessary improvements. Some of these duties might be delegated to the WSP under a service provision contract (WSPC). In certain cases, such as in Cape Town, the WSA may also perform the role of the WSP. WSAs are also required to submit regular compliance reports to the CMA and DWS, including monitoring data (water level, water quality and quantity) and abstraction volumes. To support these functions, WSAs can make use of external organisations such as specialists and consultancies to assist in monitoring and reporting.
- **Water Service Providers** (WSPs) are appointed to provide water supply and sanitation services on behalf of the WSA. This also includes operating and maintaining infrastructure, monitoring (e.g., collecting, capturing, interpreting and analysing groundwater data) and submitting compliance reports to the WSA. The City of Cape Town Municipality functions as both a WSA and a WSP.

2.3.2. Local Government Function

Metropolitan municipalities, as WSAs, are responsible for delivering potable water, sanitation, and related infrastructure, but they have no explicit mandate for groundwater resource management under current law (Faragher and Carden, 2023). In practice, this means metros historically focused on distributing surface water supplied from regional dams, with groundwater governance largely left to national authorities.

Despite this division, municipal functions intersect with groundwater governance. Local authorities control land use planning, stormwater management, and pollution control, all of which affect aquifer recharge and quality (Faragher and Carden, 2023). Moreover, municipalities themselves may become significant groundwater users during droughts or as cities expand. The National Groundwater Strategy (DWS, 2016b) recognizes the need for a "bottom-up" co-management approach with local stakeholders (DWS, 2016b), but it provides little practical guidance on how local governments should engage in groundwater management (DWS, 2016b; Faragher and Carden 2023). This gap has resulted in a mismatch between policy and practice: local governments have traditionally not planned or budgeted for groundwater management, even as urban aquifers are increasingly tapped by residents and businesses. Current Practices in Metropolitan Municipalities include:

<u>Historically limited use and oversight:</u> In South Africa's metropolitan municipalities, groundwater use has generally been a small fraction of the total urban water supply. Nationally, only about 15% of the country's water supply comes from groundwater (DWS, 2016a; Riemann et al., 2012). Large metros like The City of Cape Town, Johannesburg, eThekwini (Durban), and Tshwane (Pretoria) have relied overwhelmingly on surface water from regional bulk suppliers, giving groundwater a peripheral role. As a result, most metros did not develop dedicated groundwater units or monitoring programmes. Very few cities employed hydrogeologists or maintained comprehensive borehole registers until recently. Groundwater was often seen as an "emergency" or supplementary source rather than part of the core supply mix (Riemann et al., 2012). This attitude is reflected in metropolitan water plans that, until the mid-2010s, made little mention of local aquifers.

Growing municipal groundwater use: In recent years, climate change and drought stresses have prompted some metros to reconsider groundwater. The severe 2015–2018 drought in the Western Cape was a turning point, especially for Cape Town that relied mainly on surface water. The City of Cape Town's Water Strategy (2019a) now projects about 7% of its bulk water supply to come from groundwater by 2040 (City of Cape Town, 2019a). During this drought, Cape Town fast-tracked the development of wellfields in the Table Mountain Group and Cape Flats aquifers to supplement its strained dams. Other metros have also begun modest groundwater initiatives, for instance, Mangaung (Bloemfontein) has developed wellfields to support its supply during dry periods, and Nelson Mandela Bay metro drilled emergency boreholes in the 2019–2020 drought. These efforts indicate a shift toward conjunctive use of surface and groundwater in cities. However, they remain the exception rather than the norm. Many metropolitan municipalities still have limited internal operational experience or capacity in groundwater development and management, and expertise is thus sourced from external specialists as needed.

Private groundwater use in cities: A significant aspect of current practice is that much urban groundwater use occurs outside the municipal supply system. In metropolitan areas, private individuals, industries, and other entities abstract groundwater via boreholes and wellpoints, often without active oversight by local government. For instance, in Cape Town the majority of registered groundwater use (by volume) is by agriculture (irrigation on the urban fringe) and industry, rather than the municipal utility (DWS, 2016b). Most metros require permits or registration for private boreholes in theory, but enforcement is patchy. Typically, these registrations are intended to prevent cross-connection with municipal water and to promote safety, rather than to actively monitor usage volumes. Monitoring of private abstractions is largely voluntary and compliance with reporting to the national WARMS database is low (World Bank, 2021). Consequently, metropolitan municipalities today face a situation where significant groundwater abstraction is happening within their boundaries with minimal data available at the local level. This poses challenges for integrated water resource management, as city-makers may be unaware of the stress on underlying aquifers.

Additional Responsibilities of Local Government

The key responsibilities of the local authorities, in terms of the constitution and water legislation that relate to IWRM, include ensuring provision of municipal services, municipal spatial development (land use), infrastructure planning and environmental management, including stormwater management, pollution control and waste management.

Local authority functions, such as environment, water services and air quality, should be dealt with as part of the **Integrated Development Plan (IDP)** process where they are relevant to the local priority issues. The **Water Services Development Plan (WSDP)** is seen as the water services component of the IDP. In addition, local authorities must set key performance indicators (KPIs) and targets related to their IDPs. The WSDP must be aligned with the Catchment Management Strategy (CMS) of the Catchment Management Agency (CMA), if in existence, or with the Internal Strategic Perspective (ISP).

The **Integrated Waste Management Plans (IWMP)** are considered as the waste management component of the IDP. It must include all streams of waste, solid and liquid, and provide for waste reduction, treatment and long-term disposal.

The **Spatial Development Framework (SDF)** deals with the growth and development scenarios of the municipality and the related spatial development and land use. The local SDF's feed into the Provincial Growth and Development Framework and in turn must be aligned with the guiding principles of it.

The legally required sectoral plans, namely IWMP and WSDP have IWRM gaps, which must be filled if a local authority is to simultaneously comply with its constitutional obligations for sustainable service delivery, socio-economic development and a safe and healthy environment. Hence, the local authority has to develop an **Integrated Water Resource Management Plan (IWRMP)** to facilitate the water use authorisation application process and local implementation of IWRM.

2.3.3. City of Cape Town Spatial Development Framework (April 2018)

The City of Cape Town's Municipal SDF (MSDF) sets out three spatial strategies, namely:

Spatial strategy 1: Build an inclusive, integrated, vibrant city.

Spatial strategy 2: Manage urban growth, and create a balance between urban development and environmental protection

Spatial strategy 3: Plan for employment and improving access to economic opportunities.

The spatial strategies inform submissions and motivations for development proposals and applications from the public and private sector, and directly affect the assessment of applications.

The MSDF sets out development directives based on environmental, risk and social factors that are likely to impact on the development potential of sites, and which may trigger additional legislative processes. Environmental development directives include the coastal edge, protected environmental or marine areas and wetlands. Biophysical assets are one of the elements that play a structuring role in shaping the urban and rural / natural form and quality of life enjoyed by citizens, mitigating climate change, providing food security for the city and region, and supporting the growing tourism economy.

At a metropolitan level, these biophysical assets include, *inter alia*:

- Biodiversity conservation areas, ecological support areas, natural vegetation, terrestrial and freshwater aquatic habitats within the city's extensive network of rivers and wetlands;
- Coastal areas and beaches which are important economic and recreational assets for the city; and
- Groundwater aquifers.

Wetlands and watercourses are mentioned in Spatial Strategy 2 (see above), and specifically in the sub-strategy that aims to "…appropriately manage the development impacts on natural resources and critical biodiversity networks". The policy statement pertinent to this sub-strategy is to "Reduce the impact of urban development on river systems, wetlands, aquifers, aquifer recharge areas and discharge areas" (Policy 24). This requires the City to ensure that the water flow regimes and quality of river systems and wetlands, as well as their ability to support their natural flora and fauna, are not unduly compromised, by:

- Identifying adequate flood lines and ecological buffers/setback lines to permit the full range of flow regimes and flood attenuation, and protect the integrity and functioning of adjacent aquatic ecosystems;
- Identifying adequate measures to reduce impacts such as quality impairment and erosion to all receiving surface and groundwater systems;
- Promoting the sustainable use and sourcing of water supply;
- Mapping all aquifer recharge areas;
- Policing of illegal water extraction; and
- Taking measures to accommodate changes in climate that predict lower water availability, extreme flood events and higher temperatures.

Furthermore, the development directives that address risk in the MSDF describe the principles that apply when considering the allocation of development rights and state that there needs to be "Careful management of development to avoid developing in high flood risk areas, to protect the environmental integrity of aquatic resources and to ensure that permitted development enhances the aesthetics and character of the adjacent watercourses/wetlands".

3. Description of Study Area

3.1. Locality

Cape Town is a coastal city in the Western Cape Province of South Africa. It is located at the southwestern tip of the African continent, along the Atlantic Ocean and covers an area of 2,461 km² (see Figure 3-1). Cape Town is South Africa's oldest city, the second-largest by population and represents the country's legislative capital (de Visser, 2016). It comprises urban, residential, commercial, industrial, agricultural, and natural conservation areas. Agriculture is the largest consumer of groundwater in Cape Town, with significant use in the Philippi Horticultural Area (PHA) and at various wine farms, particularly in Durbanville and Constantia.

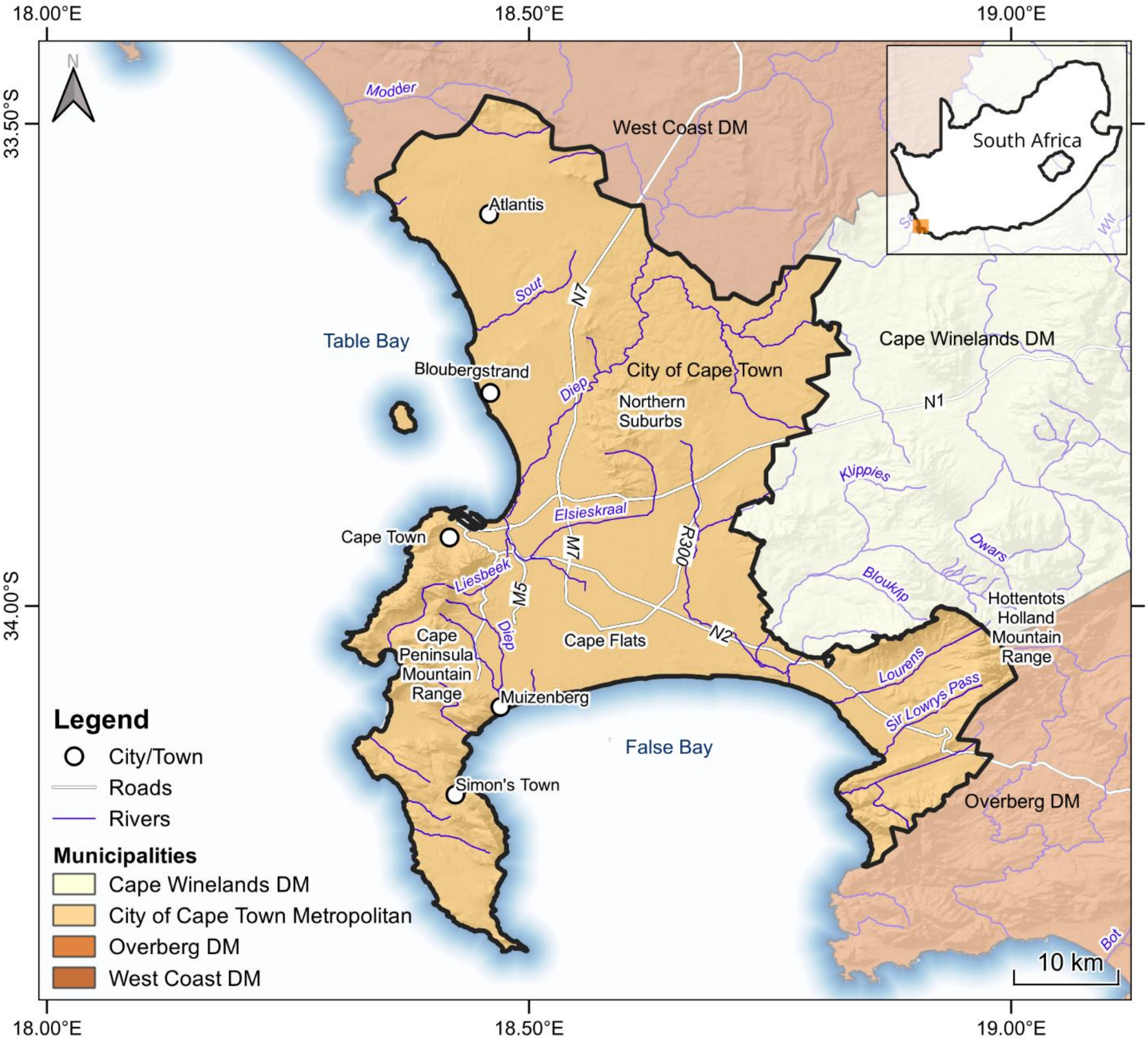

Figure 3-1: Locality map of the study area within the City of Cape Town municipal boundary.

The City of Cape Town's population has been growing exponentially at an unprecedented rate, with an estimated population growth rate of about 2.57% (Faragher and Carden, 2023). The population increased from approximately 3.7 million in 2011 to over 4.7 million people currently (Faragher & Carden, 2023). In 2011, 97.3% of the population relied on regional or local water schemes. By 2022, this reliance decreased to 96.9% (CCT, 2023b). Borehole registration increased from 0.48% (17,779) in 2011 to 1.35% (57,474) in 2022 (StatsSA, 2011; StatsSA, 2022). Other minor water reliance included rainwater storage tanks. The reliance on informal water sources (rainwater storage tanks, water tankers, springs, water vendors) decreased from 1.72% in 2011 to 0.82% in 2022, possibly due to improved access to formal water supplies (StatsSA, 2011; StatsSA, 2022).

Cape Town is a geographically expansive and diverse city with marked socioeconomic differences between its various areas. Affluence is concentrated in the City Bowl, southern suburbs, and the Atlantic Seaboard, where residents generally have better access to jobs, services, and infrastructure. In contrast, large areas such as the Cape Flats, including townships like Khayelitsha and Mitchells Plain, remain predominantly low-income and characterised by poor public amenities, limited employment opportunities, and access to quality services (Turok et. al., 2021). In low-income areas, many residents rely entirely on municipal water supply, particularly in informal settlements or townships like Khayelitsha where residents often have no direct household connections, accessing water from communal taps instead. In contrast, households in more affluent areas typically have secure municipal connections and the financial means to invest in private boreholes or wellpoints. This allows them to supplement or even replace municipal water, particularly during times of drought, reinforcing both their water security and their independence from the municipal system.

3.2. Climate

Cape Town experiences a Mediterranean climate, characterised by cold, wet winters and warm to hot, dry summers. According to the Köppen–Geiger climate classification system (Peel et al., 2007), the city is primarily classified as *Csa* (hot-summer Mediterranean) and *Csb* (warm-summer Mediterranean). The central and northern parts of the city, especially inland and low-lying areas, are classified as *Csa*, while those areas closer to the coast or at high elevations are classified as *Csb.*

Precipitation is predominantly linked to frontal systems coupled with the *Csa* westerly wind belt and the associated storm tracks that dominate the southwestern Cape in winter (June to August), while the South Atlantic high-pressure system (SAHP) dominates the austral summers (December to February), pushing the frontal systems further south, resulting in warm, dry and windy summers (du Plessis and Schloms, 2017). The continued offshore dominance of the SAHP system into the winter months is thought to be one of the main factors contributing to the 2015 – 2018 drought, Cape Town experienced.

Cape Town receives most of its rainfall during winter months from May to August, with annual rainfall typically ranging between 400 to 800 mm and a long-term average of 600 mm per year, as seen in **Figure 3-2** (Adelana, 2014). In summer (December to February), average maximum temperatures in Cape Town range between 25–30°C but can exceed 35°C, while minimum temperatures average between 15–18°C. In winter, temperatures drop to a maximum average between 16–19°C (June–August), while minimum temperatures average 7–9°C. Evaporation in most low-lying parts of Cape Town ranges between 1800 – 2000mm, and <1200-1300 mm in high elevation recharge areas like Steenbras (Bailey and Pitman, 2016). Estimated groundwater recharge rates for Cape Town range between 5% and 45 %, depending on various factors such as rainfall distribution across the city, land use cover and geology.

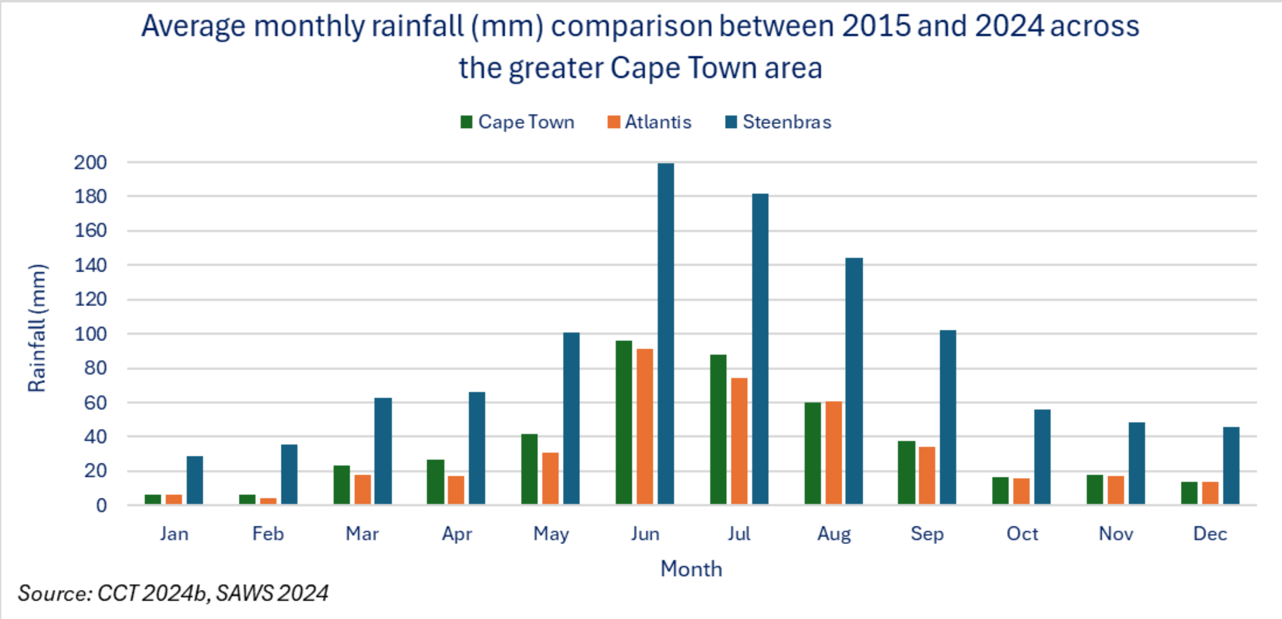

Figure 3-2: Average monthly rainfall (mm) between 2015 and 2024 across the greater Cape Town area comparing Cape Town (green bar), Atlantis (orange bar), and Steenbras (blue bar). The Mediterranean bell curve is clearly evident with peak rains in winter (June to August). As expected, the low-lying coastal areas (Atlantis and Cape Town) receive substantially less rainfall than the mountainous catchment recharge zone (Steenbras) where June rains range from 91 mm to 200 mm, respectively.

3.3. Topography

Topographically, the City of Cape Town Municipality encompasses several major features (see Figure 3-3). Along the southwestern portion of the municipality lies the Cape Peninsula Mountain chain, which includes Table Mountain, the highest point in this region, reaching an elevation of 1,086 m. The greater Cape Peninsula Mountain chain and its surrounding slopes house several key dams and reservoirs that form a critical part of Cape Town's water supply system.

East of the mountain base, the terrain transitions into the low-lying relatively flat expanse known as the Cape Flats. This area stretches eastward until it meets the base of the Hottentots Holland Mountain chain. These mountainous areas form part of the Cape Fold Belt which is characterised by dramatic ridges and steep slopes, gradually giving way to rolling hills and agricultural plains. Situated near the eastern edge of Cape Town's municipal boundary is the Steenbras Dam in the Hottentots Holland area, a major reservoir and a key source of water supply for the City of Cape Town.

To the north and northwest of the Cape Flats lies the Cape Town Central Business District (CBD), nestled between the base of Table Mountain and the Table Bay coast. Further north and northeast of the Cape Flats, the landscape becomes gently undulating, rising into foothills-an area referred to as the northern suburbs. North of these suburbs, towards the Swartland District Municipality, the topography transitions from foothills to rolling hills and plains. Agricultural land replaces the residential land of the northern suburbs, where several dams and the origins of the Diep River can be found. West of these foothills and the northern suburbs, the elevation gradually declines into a low-relief coastal plain, extending northward along the coast toward Atlantis.

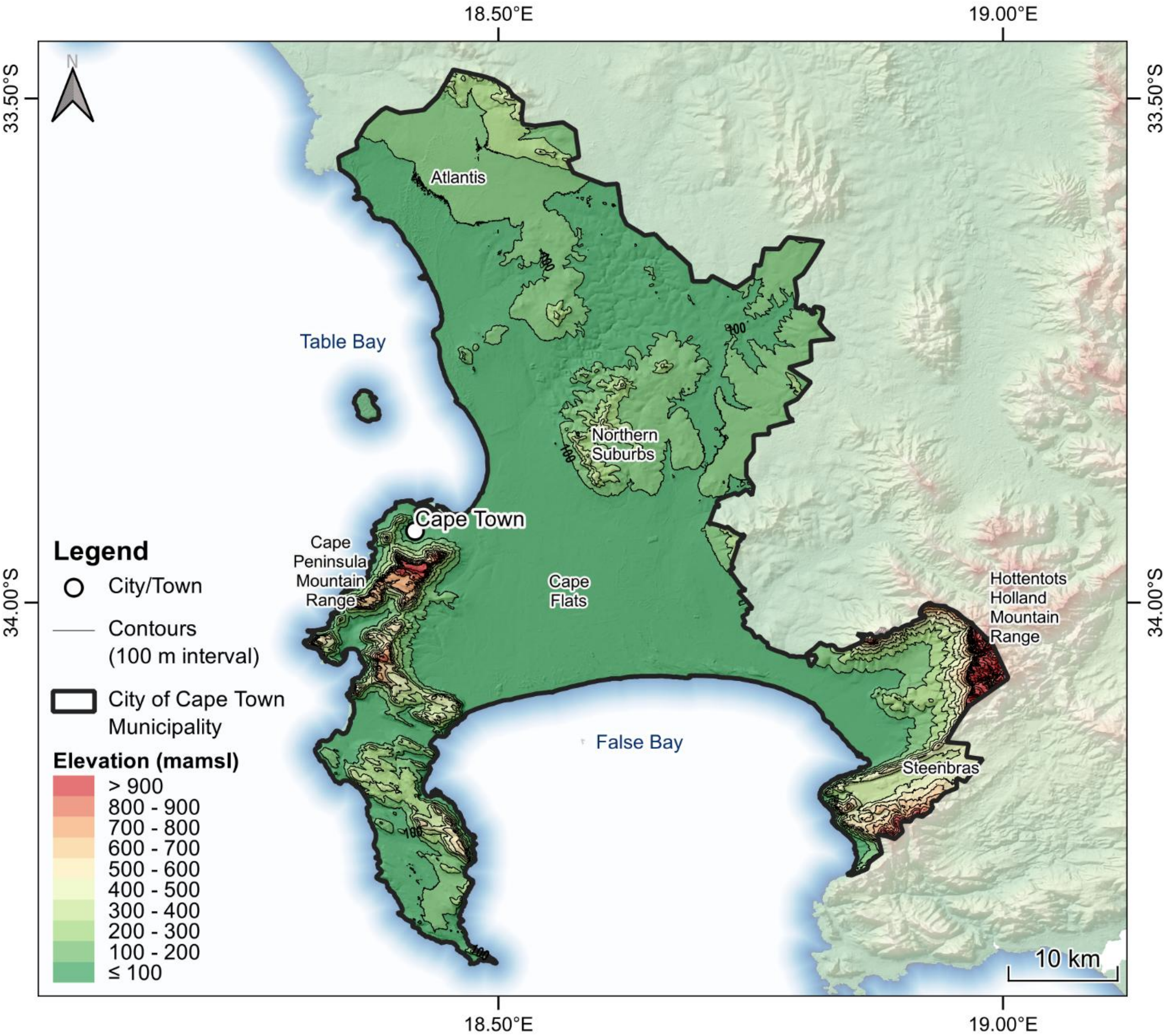

Figure 3-3: Topographical map of the City of Cape Town Municipality.

Different land cover types significantly influence rainfall recharge into groundwater systems. Cape Town, in particular, exhibits a diverse range of land cover types and associated activities (see Figure 3-4). Built environments often disrupt natural infiltration and recharge processes by diverting rainfall into drainage systems, where it is either channelled to the ocean or lost through evaporation.

Groundwater is also utilised by numerous land use activities, including industry, domestic supply, and irrigation. Areas where the subsurface geology facilitates groundwater movement and storage, particularly those with high recharge and infiltration rates, these activities can significantly impact both groundwater quality and availability. Consequently, regions where high dependency coincides with high susceptibility, there is a greater vulnerability to groundwater-related risks.

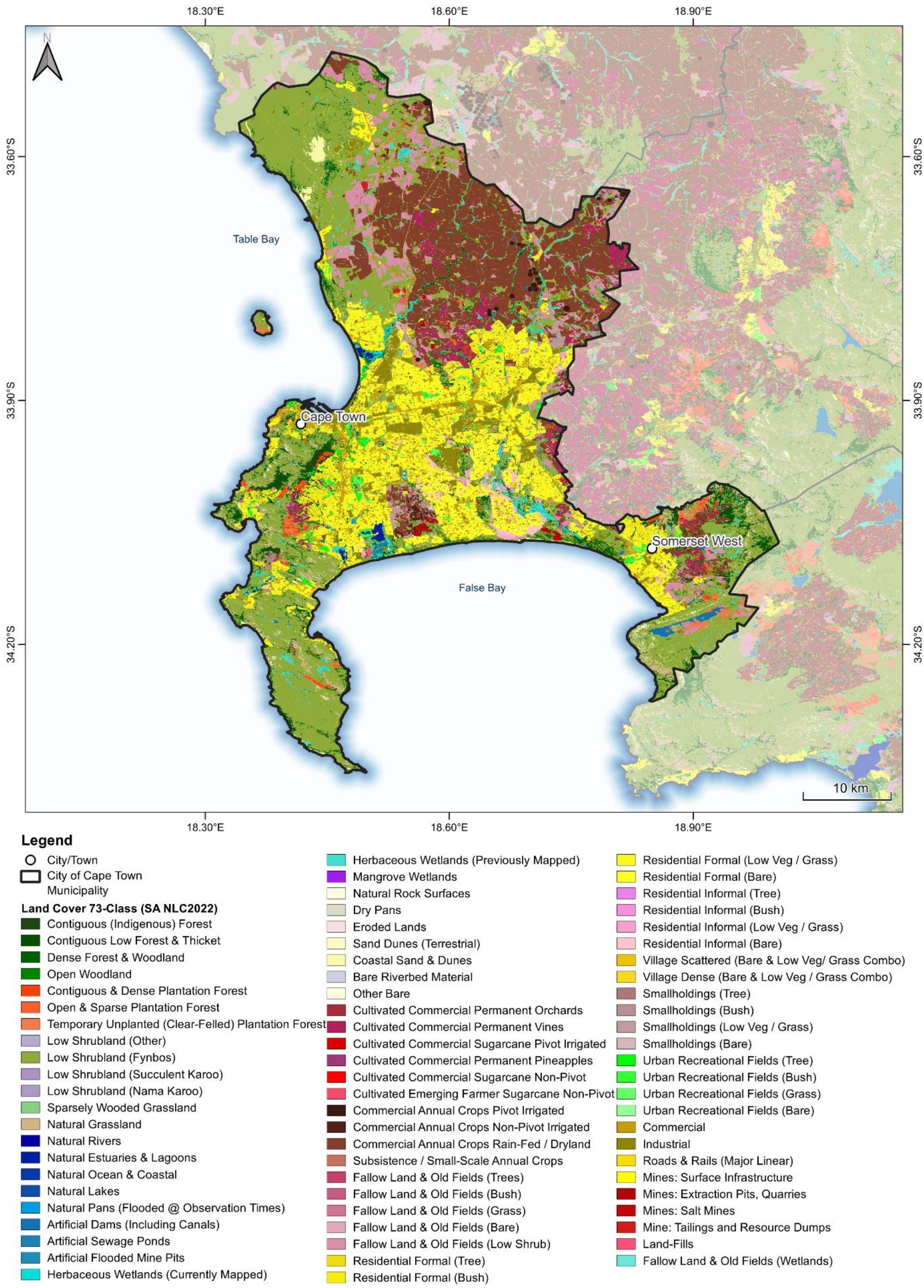

Figure 3-4: Land use map of the City of Cape Town Municipality using the Lan Cover 73-Class (SANLC, 2022).

3.4. Hydrology

The City of Cape Town is located in the Breede-Olifants Water Management Area (WMA), under the jurisdiction of the Breede-Olifants Catchment Management Agency (CMA). Its primary water catchment is classified as 'G' and consists of numerous quaternary catchment areas within the City of Cape Town Municipality boundary (See Figure 3-5). The quaternary catchments with their major rivers and or canals have been included in Table 3-1.

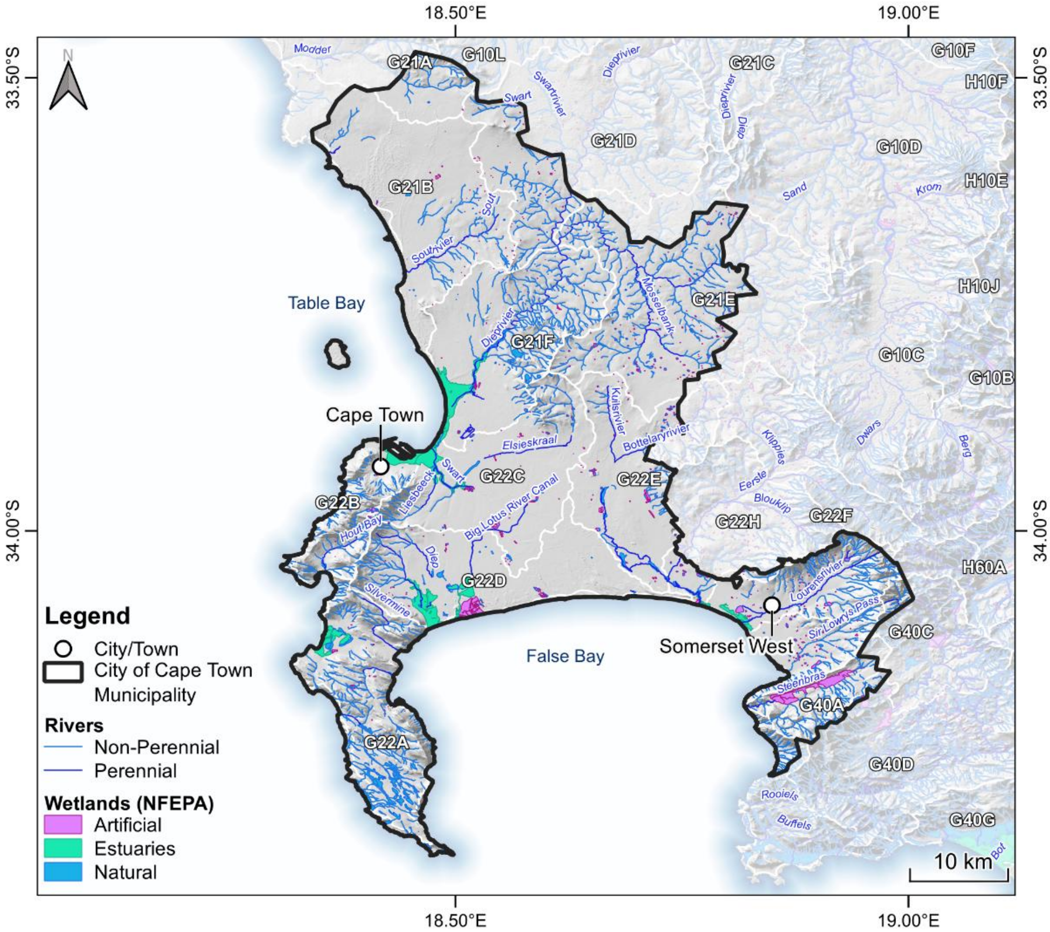

Figure 3-5: Hydrology map of the City of Cape Town Municipality.

The channels these rivers flow through are typically canalised in some part of their reaches, the extent of this canalisation is categorised in Table 3-1 as heavily modified, partially modified and unmodified. Unmodified describes a mostly natural river channel with the inclusion of minor concrete culverts. Partially modified channels refer to rivers which have parts of its reaches canalised. Heavily modified channels refer to the canalisation of whole reaches and often most of the river's extent. In addition, the flow regime has also been included to describe the nature of flow, whether flow is perennial or non-perennial, and if perennial whether this flow is natural or altered due to the release of stormwater and treated wastewater.

Rivers flowing through highly urbanised areas with high contamination risks can contribute significantly to groundwater pollution, particularly in sections where the river channels are not fully canalised. Many of these rivers also function as stormwater drainage systems, collecting and transporting polluted surface runoff. In sections of their reaches, where canals are not lined, this water can infiltrate into the subsurface and deteriorate groundwater quality.

Table 3-1: Major rivers and Canals within The City of Cape Town Municipality.

Catchment	River	Modification	Flow regime
G21B	Sout River	Unmodified	Non-Perennial
G21D/F	Diep River (Northern Suburbs)	Partially modified	Non-Perennial
G21E	Mosselbank River	Unmodified	Non-Perennial
G22A	Silvermine River	Unmodified	Perennial
G22B	Houtbay River	Partially modified	Non-Perennial (Altered)
G22C	Liesbeek River	Partially modified	Perennial (Altered)
G22C	Black River	Partially modified	Non-Perennial
G22C/D	Lotus River	Heavily modified	Non-Perennial (Altered)
G22D	Diep River (Southern Suburbs)	Partially modified	Non-Perennial
G22E	Kuils River	Heavily modified	Perennial (Altered)
G22E	Bottleay River	Unmodified	Perennial (Altered)
G22H	Eerste River	Partially modified	Perennial
G22J	Lourens River	Partially modified	Non-Perennial
G22C	Elsieskraal River	Partially modified	Non-Perennial
G22C	Vygekraal River	Partially modified	Non-Perennial

The Cape Peninsula mountain chain is also known for its many springs which feed into tributaries, major rivers, wetlands, surface water bodies and the ocean. Residential and agricultural areas located along its slopes and lower elevations make use of this water for drinking and irrigation.

The City's Quaternary catchments consist of several major rivers, their tributaries and canals. Along the Cape Peninsula Mountain chain Quaternary catchments G22A, G22B, G22C and G22D, house the Major Silvermine, Houtbay/Disa, Diep and Liesbeek rivers. Many of the pristine tributaries which feed these rivers are fed by TMG spring discharge from the Cape Peninsula slopes. These pristine systems are typically located in the upper reaches of the mountains, where riverine environments are largely unmodified. Further downstream, in their lower reaches forms of modification occur for the Houtbay/Disa and Liesbeek Rivers

Extending east towards the Cape Flats and north east towards the northern suburbs, G22C also contains the Black River, Lotus River, Vygkraal River and Elsieskraal River. Most of these rivers exhibit partial modification as they meander through several urbanised and high contamination risk areas. Parts of these rivers are without canalisation and therefore susceptible to groundwater contamination from stormwater and low quality wastewater. Numerous stormwater channels and retention / detention ponds are connected to the City's watercourses, which allow for the conveyance and storage of stormwater in the metropole.

Northeast of the Cape Flats and along the slopes and base of Hottentot Hollands Mountain Quaternary catchments G22E, G22H and G22J contain the Kuils River, Eerste River, Lourens River and Bottleray River. Similarly to the Cape Peninsula mountains, water from TMG springs and streams feed into the Lourens River and the tributaries that feed into the Eerste river. The upper reaches of these two rivers and their tributaries remain largely unmodified, while their lower reaches become more modified and urbanisation becomes more apparent. Contrast to the Bottleray and Kuils River, these two rivers each display a unmodified and heavily modified systems.

In the North near Atlantis and the northern suburbs the Sout, Diep and Mosselbank rivers are found in the Quaternary catchments G21B, G21D/F and G21E, respectively. The Sout and Mosselbank rivers remain largely unmodified, with the exception of localised concrete culverts and infrastructure in some agricultural locations. The Diep River in contrast is partially modified, with its upper reaches remaining largely natural through the agricultural hills and only becoming significantly modified in its lower reaches due to its use for stormwater management.

3.5. Geology

3.5.1. Malmesbury Group and Cape Granite Suite

Geologically, the Cape Town Municipality is underlain by late Neoproterozoic/Namibian basement rocks of the Malmesbury Group (Tygerberg Formation, ~800-550 Ma), with intrusions of the Cape Granite Suite (~550-510 Ma), as seen in Figure 3-6 and Table 3-2. These granitic intrusions formed as oceanic crust subducted beneath the African continent, generation plumes of magma that crystallised at depth. Over time, uplift and erosion of overlying material have exposed these plutons in areas such as the Cape Peninsula, Kuils River, Somerset West, Paarl, Darling and Velddrif. Within the municipality these plutons can be seen along the Cape Peninsula Mountain chain, Somerset West and Kuils River.

The Malmesbury Group is comprised of shales, siltstones, greywacke and feldspathic sandstone, while the Cape Granite Suite is characterised by its large alkali felspar crystals in a finer grained quartz matrix. Both rock formations were structurally deformed (faults and fractures) by Saldanian (~600-500 Ma) and Cape (~280-230 Ma) orogenies (i.e., mountain building events) resulting in the development of dominant northwest-southeast and northeast-southwest orientated structural trends. Break-up of the Gondwana supercontinent (~180-110 Ma) resulted in the re-activation and trans tensional (i.e. extensional/normal and strike-slip) faulting of existing, generally northwest-southeast orientated structural trends within the basement rocks. Opening of the South Atlantic during Gondwana break-up also resulted in the intrusion of the ~northwest-southeast orientated False Bay Suite dolerite dyke swarm at ~136 Ma, which intruded both basement rocks and the TMG in the City of Cape Town region. Weathering has resulted in the formation of a clay layer above the Tygerberg Formation and a similar alteration of Cape Granite Suite granite into kaolin clay.

3.5.2. Table Mountain Group

The Table Mountain Group (TMG) onlaps and unconformably (i.e. erosional time-break or hiatus) overlies the Namibian-Cambrian basement Malmesbury Group and Cape Granite Suite in the southwestern Cape. The TMG hosts the depositional interplay between fluvial and marine environments during a period of relatively stable large-scale subsidence. This subsidence allowed for the accumulation of mature and constantly reworked sandstones. These sedimentary rock deposits formed through the Cambrian to Devonian (~ 500- 416 Ma) periods to make up the TMG formations (see Table 3-2). The tectonic closure of the Agulhas Sea deformed these lithified layers creating the Cape Fold Belt, a chain of mountains extending 300 km north as the Cederberg Mountains and 800 km east along the coast towards Port Elizabeth.

Within the City of Cape Town Municipality, the spatial distribution of TMG formations are split into upper and lower TMG. The southwest Cape Peninsula is comprised of lower TMG (Graafwater, Peninsula, Pakhuis formations) while in the east of the municipality boundary, the Hottentots Hollands Mountain range and the adjacent Steenbras-Nuweberg area includes the upper TMG (Peninsula, Pakhuis, Cederberg, Goudini, Skurweberg and Rietvlei formations).

TMG deposition represents progressive fault-controlled failure and rift basin fill, with the earlier Graafwater Formation (~488-478 Ma) being absent in the Steenbras-Nuweberg area. Subsequent large-scale subsidence resulted in the thick quartz-rich sandstones of the Peninsula Formation and Nardouw Subgroup (Goudini, Skurweberg and Rietvlei Formations). The Peninsula Formation and Nardouw Subgroup are separated by the Pakhuis Formation (deposited during the Hirnantian glaciation from ~446-445 Ma) and Cedarberg Formation (mud-rich marine sediment deposited during glacial-rebound from ~445-440 Ma) (Rust, 1967; Rust, 1973; Hiller, 1992; Tankard, 2012). The overlying Bokkeveld Group preserves a conformable record of siliciclastic (i.e. quartz-rich) and argillaceous (i.e. mud-rich) sedimentation during a period of exaggerated subsidence (Tankard, 2012).

The City of Cape Town targets the TMG for bulk water supply within the steenbras wellfield in the Hottentot Hollands area. The City is currently undertaking exploration in the Nuweberg and Theewaterskloof areas, however these fall outside of the City's municipal boundary.

Graafwater Formation

The Early Ordovician (~488-478 Ma) Graafwater Formation forms the basal unit of the TMG within the City of Cape Town. It is present along the Cape Peninsula Mountain chain but is absent from the Hottentots Hollands Mountains. The Graafwater Formation unconformably overlies the Neoproterozoic/Namibian basement rocks of the Malmesbury Group and Cape Granite Suite. In the Cape Peninsula area, the Graafwater Formation reaches a thickness of ~70 m and comprises interbedded fine to medium grained sandstone, siltstone and mudstone layers (Flemming, 2016).

Peninsula Formation

The Early-Middle Ordovician (~480-460 Ma) Peninsula Formation overlies the Graafwater Formation in the Cape Peninsula area and forms the basal unit of the TMG in the Hottentots Hollands; however, it should be noted that thin and minor lenses of Graafwater Formation may occur locally underlying the Peninsula Formation and overlying Malmesbury Group (MacKellar, 1981). The Peninsula Formation ranges in thickness between 550-600 m thick in the Cape Peninsula area to over 1500 m north of Villiersdorp, with an estimated thickness of at least ~600-700 m in the Steenbras area (near Sir Lowry's Pass) to ~1,000-1,200 m in the Nuweberg and Theewaterskloof areas. The Peninsula Formation outcrops in the Steenbras-Nuweberg area as the high elevation and relief core and peaks of the Hottentots Holland Mountain range.

The Peninsula Formation is characterised by thickly bedded super-mature quartz sandstones (i.e. quartzites once slightly metamorphosed), the mature nature of which can be attributed to either recycling of sediment in a fluvial/shallow marine environment or chemical maturation (i.e. feldspar dissolution) during burial/diagenesis. The medium to very coarse-grained quartz sandstones (which occasionally coarsen to granule-fine pebble size grains) are interbedded with conglomerate lenses/ beds and rare silty mudstone beds (the latter representing marine incursions; Turner et al., 2011). The quartz sandstones and interbedded conglomerate beds and lenses show large scale planar and trough crossbedding. The whole Peninsula Formation tends to fine downwards.

The Peninsula Formation is overlain, with localised unconformable relationships in the zones of "syn-sedimentary folding" caused by ice movement of glaciogenic sediment (i.e. tillite; and heterogenous subaqueous interglacial sediments) of the Pakhuis Formation. The topmost units of the Peninsula Formation tend to interfinger and conformably grade into the Pakhuis Formation, indicative of a conformable gradual glacial palaeo-depositional shift (Turner et al., 2011).

Pakhuis Formation

The Late Ordovician (~446-445) Pakhuis Formation displays laterally undulating thickness variations (although generally <120 m thick) throughout the Steenbras-Nuweberg area, likely a result of laterally discontinuous depositional environments and variations in palaeo-relief (Rust, 1967). Within the Cape Peninsula, its glacial deposits can be found atop the Peninsula Formation in the form of pebbles and sandstone. The Pakhuis Formation is generally poorly sorted, massively bedded, folded and compact. The Pakhuis Formation in the Steenbras-Nuweberg area comprises of basal sandy tillite interfingered with quartzite lenses, intermittent, non-laterally persistent, interglacial quartzites, massive to laminated mudstones and rare breccia lenses, marine and glacial clay/muddy matrix tillite and dropstone (i.e. isolated rock fragment dropped into sediment) littered mudstones (Rust, 1967).

The Pakhuis Formation is unconformably overlain by the argillaceous Cedarberg Formation. Both the Pakhuis and Cedarberg Formations form a distinct, highly vegetated, negative weathering band (due to the erosivity of the argillaceous formations) on the downdip side of the high relief Peninsula Formation mountains in the Hottentots Holland Mountain.

Cederberg Formation

In the Steenbras-Nuweberg area, the Ordovician-Silurian straddling (~445-440 Ma) Cedarberg Formation shows relatively complete preservation, comprising of a thin basal layer of fining black carbonaceous (i.e. carbon bearing) shale, followed by a cyclic coarsening-down (becomes occasionally reverse graded toward the base of this layer) inter-bedded/laminated mudstone-siltstone sequence.

The thin basal layer comprises of the world-renowned Lagerstätte (fossiliferous) laminated shales (Aldridge et al., 1994; Gabbott, 1998). The abundance of diagenetic pyrite indicates saturated anoxic iron mineralisation conditions. The relatively incompetent basal shales often micro-folded quartz veining, clay smear and phyllosilicate alteration in the final ~3 m above the contact with the underlying Pakhuis Formation.

Mudstone-siltstone sequence gradually coarsens upwards along with thickening beds towards the overlying Goudini Formation, with horizontally laminated and interbedded siltstones, mudstones and shales present. This layer is typified by normal grading in beds coarsening from shale to silty shale to basal siltstones and/or silty sandstones. The depositional environment of this layer is thought to be due to a palaeo-environmental shift, from shoreline-shelf marine to fluvial-deltaic throughout the Cedarberg Formation.

Nardouw Subgroup

The fluvial sedimentation of the Nardouw Subgroup (~600-800 m thick on average) consists of three conformably and gradually transitioning, coarse-grained sandstone dominated formations (Malan and Theron, 1989), namely the Goudini, Skurweberg and Rietvlei Formations (from oldest to youngest, Early Silurian to Middle Devonian [~440-390 Ma]). The Nardouw Subgroup generally forms a secondary, high relief unit (although subdued in comparison to the Peninsula Formation), with the Skurweberg and Rietvlei Formations outcropping extensively in the Steenbras area.

Goudini Formation

The Silurian (~440-416 Ma) Goudini Formation forms the lower formation of the Nardouw Subgroup, and has a transitional, conformable contact with the underlying layer of the Cedarberg Formation. It is characterised by repeated normal graded sandstone-siltstone cyclicity, a distinct reddish-brown weathering due to iron-oxide content and a general upward coarsening trend.

Internally the interbedded coarse to fine sandstones become more quartzitic in nature and more thickly bedded as the beds coarsen up to the overlying Skurweberg Formation. Contrastingly, the siltstone and shale beds gradually thin out and become less abundant as one progresses up the stratigraphy. The sandstone beds show horizontal and planar crossbedding, with some fluvial influenced trough fills, minor fluvial lag conglomerate deposits (upper beds of the formation), ripple cross-laminae/bedding, mud drapes, mud clasts, and slump and dewatering structures.

Skurweberg Formation

The Silurian (~440-416 Ma) Skurweberg Formation forms the middle formation of the Nardouw Subgroup and consists of thick, cross-bedded quartzitic sandstones/quartzites (with occasional interbedded conglomerate lenses), and has a total thickness of up to ~300 m (Theron et al., 1992). The localised para-conglomeratic fluvial lag deposits include granular to pebble sized, rounded to sub-rounded clasts. The mature quartzitic sandstone beds are predominantly normally graded with planar and trough cross-bedding, as well as intraclast-rich lenses and laminae deposited in fluvial palaeo-environment (with occasional marine transgressions of minor argillaceous material). Alteration products within the quartzitic beds are predominantly comprised of fault-driven silica cementation and phyllosilicates (white micas, clay and chlorite).

Rietvlei Formation

The early-Middle Devonian (~416-390 Ma) Rietvlei Formation forms the uppermost formation of the Nardouw Subgroup (Theron et al., 1992), consisting of interbedded grey to light-grey feldspathic (i.e.

feldspar-bearing) sandstones, siltstones and micaceous shales. The Rietvlei Formation sandstones show a combination of fluvial to shallow marine planar cross-, trough cross-, herringbone, ripple cross- and hummocky cross-bedding. In addition to the interbedded and laminated siltstones, the beds also host flaser to lenticular bedding, ripple cross lamination with abundant mud clasts and soft sediment deformation structures. Localised lenses of conglomeratic lag deposits also occur more frequently toward the base of the formation.

3.5.3. Bokkeveld Group

The uppermost TMG contact represents a marine flooding surface recorded in the rapid, but conformable transition, from the Rietvlei Formation immature sandstones to the mudstone and shale rich lowermost Bokkeveld Group. The Bokkeveld Group (~390-375 Ma) is comprised of cyclic shales and sandstones (Penn-Clarke et al., 2018; Penn-Clarke, 2017), of which the basal Gydo Formation shales caps the TMG beneath both the upper and lower Steenbras Dams. The highly erosive nature of the shale-rich units of the Bokkeveld Group results in the developments of valleys, as evidenced in the Steenbras, Elgin-Grabouw and Theewaterskloof areas.

3.5.4. Sandveld Group

The surficial sediments overlaying much of the Cape Town Municipality is comprised of various Tertiary and Quaternary (~25-0 Ma) deposits of the Sandveld Group (see Figure 3-6). These sediments can consist of interbedded gravels, sands, clays, clayey sands, calcrete, sandstones and peat, deposited by either aeolian, marine and fluvial processes. The compilation and thickness of these layers vary amongst the group's formations. Within the Sandveld group, the Elandsfontyn, Varswater, Langebaan, Springfontyn and Witzand formations comprise its main geological units. Their colours vary, but are typically characterised as yellow, grey, beige, reddish-brown, maroon and white. The maroon and reddish-brown tones are often due to the presence of iron and manganese oxides.

Elandsfontyn Formation

Elandsfontyn Formation consists of an upper clayey sand and peat with lower gravels and gravelly sands which represent the deposition of a meandering river system (Roberts et al., 2006). Within the Cape Flats the Elandsfontyn Formation occupies palaeo-depressions (palaeochannel or old river channel) in the Precambrian bedrock, known as the Elsieskraal Paleochannel that extends north from the Strandfontein area through Philippi. Thickness varies but increases towards the north and centre of the palaeochannel. The Sandveld Group in Atlantis does not include the presence of the Elandsfontyn Formation.

Varswater Formation

The basal Varswater Formation is of marine origin and represents deposition in a shallow marine environment. It mostly consists of fine to medium, often silty or shelly, quarzitic, calcareous or phosphatic sands, and is overlain by coarse, shelly gravel sand. The Varswater Formation occupies the eroded space following the removal of the Elandsfontyn Formation by marine transgression (Rogers, 1980; Cole, 2003).

Langebaan Formation

The Langebaan Formation occurs in limited extent and consists of consolidated calcareous dune sand. The aeolian deposit accumulated during the last glacial lowering of sea level when vast tracks of unvegetated sand lay exposed on the emerging sea floor.

Springfontyn Formation

The Springfontyn Formation is also aeolian in origin and consists of quartzose aeolian sands, which are muddy and peaty in places (Roberts et al., 2006). Although Springfontyn and Witzand Formations are formed by similar processes, there is an absence of shell fragments in Springfontyn due to the decalcification of these sands as a result of the passage of acidic groundwater (Cole and Viljoen, 2001). The sands are well sorted, fine to medium grained near the coast. The formation is typically structureless (i.e., devoid of crossbedding) and attains a thickness of ~25m (Theron et al., 1992)

Witzand Formation

The Witzand Formation is aeolian in nature and is a product of sand deflation of modern beaches (Theron et al., 1992). The fine to coarse grained, unconsolidated sediments are shelly to calcareous in places, with a thickness of up to 28 m (Rogers, 1980). The uncemented, Holocene calcareous dunes, form the youngest subdivision of the Sandveld Group (Browning and Roberts, 2015). This unit unconformably overlies the Springfontyn and Langebaan Formations of the Sandveld Group as well as units of the Cape Granite Suite and Malmesbury Group. Witzand Formation is not overlain by any recognised formation.

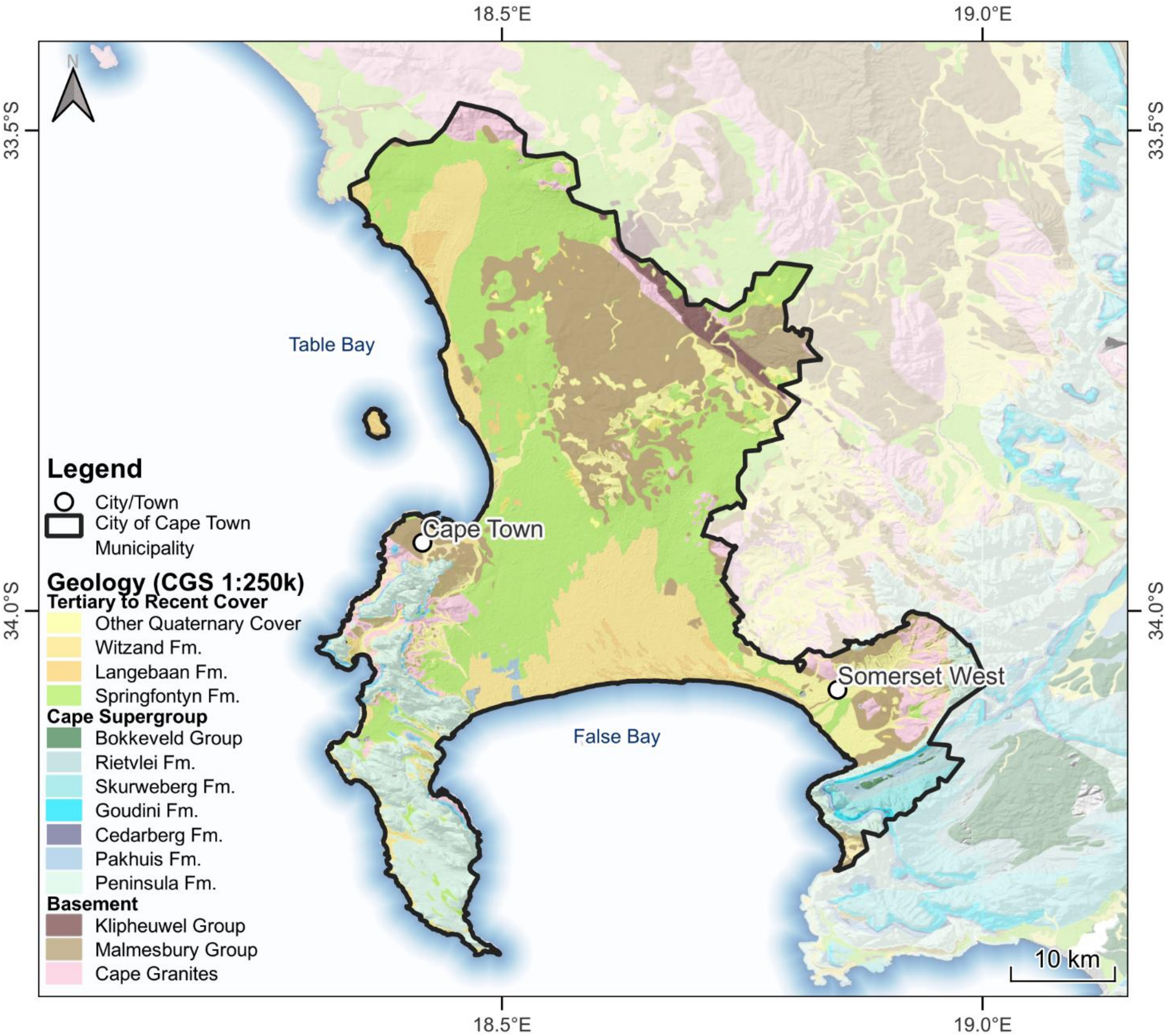

Figure 3-6: **Geological map of City of Cape Town and surrounding areas.**

3.6. Hydrogeology

Cape Town contains three main aquifer types, including the primary unconfined aquifers of the Sandveld Group, mainly the Cape Flats Aquifer (CFA) and Atlantis Aquifer, secondary fractured rock aquifers of the Table Mountain Group (TMG) and weathered and fractured basement rock aquifers of the Malmesbury Group and Cape Granite Suite. The CFA, Atlantis Aquifer and TMG aquifers are moderate to high-yielding and can supply significant volumes of water, hence, the City of Cape Town has developed groundwater schemes that involve the abstraction of groundwater from these aquifers to diversify bulk water supply in the city. In addition to municipal use, these aquifers are essential to other groundwater users such as farmers within the PHA, which depend on the CFA. Industries, private users, and groundwater dependent ecosystems across the municipality also rely on these aquifers.

The primary aquifers have high permeability and recharge rates but are more vulnerable to contamination due to their shallow, unconsolidated nature. In contrast, the deeper TMG Aquifer offers better water quality and is less prone to contamination, though it recharges more slowly and is at risk of over-abstraction.

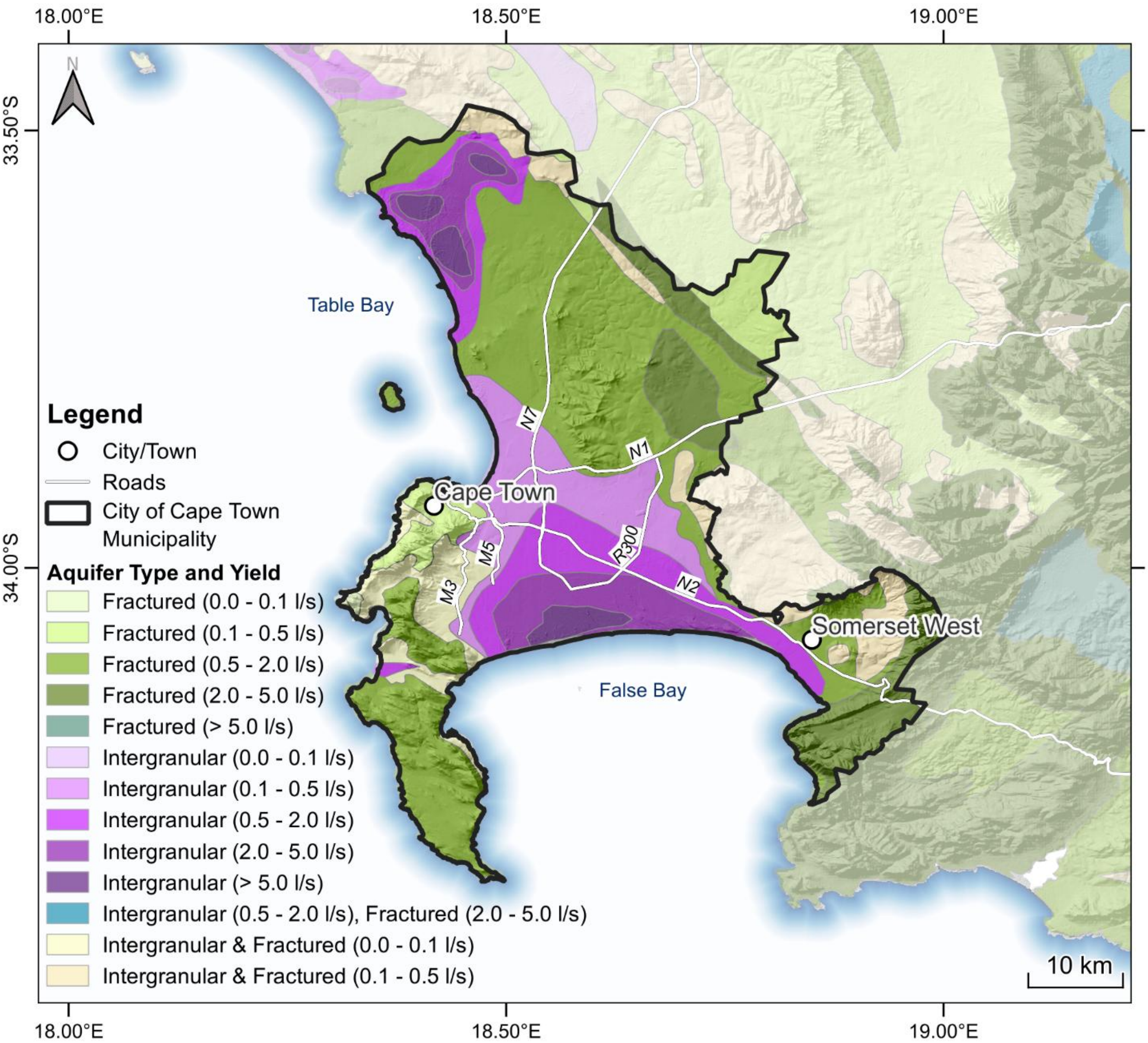

Figure 3-7: Hydrogeological map of City of Cape Town Municipality.

3.6.1. Primary Aquifers

Two major primary aquifer systems can be found in the Cape Town Municipality (see Figure 3-7), these include: the CFA and the Atlantis Aquifer (see Table 3-2).

Cape Flats Aquifer

The CFA is a major unconfined coastal aquifer system underlying the Cape Flats region. It consists of fluvial, marine and aeolian Tertiary and Quaternary sediments (interbedded gravels, sands, clays, clayey sands, calcrete, sandstones and peat) of the Sandveld Group which overly basement shales of the Malmesbury Group and granites of the Cape Granite Suite. The CFA reaches a maximum thickness of 50-60 m within a palaeochannel (Elsieskraal old river channel) within the central portion of the aquifer and towards the coast. The palaeochannel contains fluvial deposits of the Elandsfontyn Formation which has coarse grained sands and gravels and then towards the coastline these are replaced by gravels and shells of the Varswater Formation. The CFA's heterogeneity results in varying aquifer conditions across the region. In some areas, localised clay layers, peat deposits and calcrete formation create localised semi-confined to confined conditions. This stratification leads to a dual aquifer system in portions of the CFA, with distinct hydrogeological characteristics between the upper unconfined and lower semi-confined/confined units.

At the broadest scale, the aquifer is predominantly unconfined (with groundwater within a few metres below the surface), and rivers and wetlands are likely to be hydraulically connected to the relatively shallow groundwater. Where the aquifer is semi-confined (e.g., within the deep gravels in the palaeochannels), or at small local scale, where the aquifer is semi-confined by laterally discontinuous calcrete or clay lenses, rivers and wetlands are only likely to be in hydraulic connection with the shallow groundwater in the uppermost unconfined sand unit.

Hydrostratigraphically, the Elandsfontyn, Varswater and Springfontyn formations form the major aquifer units within the larger CFA, which is a large heterogeneous, stratified, intergranular or primary (i.e., porous sedimentary/sandy) aquifer within the Sandveld Group. The CFA transmits water relatively rapidly with an average hydraulic conductivity of ~15 - 50 m/day, and a transmissivity of ~30 - 600 m2/day (Adelana et al., 2010). Borehole yields range between 0.1 – 5 l/s yields but can be > 30 l/s in areas of high hydraulic conductivity (where the thickest Elandsfontyn Formation gravels and Varswater Formation shells are intersected) (see Figure 3-7). Additionally, the CFA is characterised by high infiltration rates of ~10 – 250 mm/day.

These favourable hydrogeological conditions have supported decades of groundwater use by farmers in the PHA, which supplies a significant portion of agricultural goods to the Cape Town metropolitan region. However, the unregistered and unregulated use by these farmers poses challenges to the sustainable groundwater management of the aquifer. Following the 2015–2018 drought, the City of Cape Town targeted the CFA for bulk water supply, with the addition of managed aquifer recharge to supplement its response in groundwater levels to bulk water abstraction.

While beneficial for water supply, the high infiltration rates and unconfined nature of the CFA's surface sediments create an environment where the groundwater system is highly vulnerable to surface contamination, particularly in an urbanised environment with a multitude of different land use activities (see Figure 3-4). Due to elevated levels salinity within the PHA some farmers in the PHA have opted to instead establish boreholes deeper into the Malmesbury Basement Aquifer. For the City of Cape Town, the quality of water in the CFA is still suitable for its abstraction and treatment. However, while there is a high dependency on the CFA for groundwater use, over-abstraction can result in salinisation of the aquifers groundwater due to seawater intrusion. Consequently, the CFA faces significant vulnerability from both pollution and salinisation.

Atlantis Aquifer

The Atlantis Aquifer represents another major unconfined sandy aquifer system in Cape Town. Situated along the west coast between Melkbosstrand and Silwerstroom, this intergranular aquifer has served as a critical groundwater resource, supplying the industrial town of Atlantis with water for the past 40 years. Consisting of Sandveld Group sediments, its basal layer forms part of the Varswater Formation with its overlying material comprised successively of the Langebaan, Springfontyn and Witzand Formations. These sediments were deposited in shallow marine and aeolian environments producing distinct layers of shelly, calcareous, and quartz-rich sands.

The Atlantis Aquifer has a general thickness of ~40-60 m and is mainly classified as unconfined, however, due to the presence of intermittent clay and calcrete lenses in the Springfontyn formation, semi-confined conditions may occur (Theron et.al.,1992).

The intergranular Atlantis aquifer is classified, using the 1:500 000 Cape Town 3317 hydrogeological map, as having varying yield potentials based on location. On the outer margins where the aquifer is thinner, a moderate yield potential (0.5-2.0 l/s) is seen. Where the aquifer becomes thicker, the yield potential increases to moderate-high (2.0-5.0 l/s) and high (>5.0 l/s), which is also verified through the last ~40 years of groundwater production by the City, with some boreholes yielding >20 l/s.

The basement topography of the Atlantis Aquifer is uneven due to the nature of the Pre-Cenozoic surface which it overlies. This also effects the depth, thickness and composition of the aquifer units intercepted at any given locality, as sub-terranean ridgelines and paleo channels exist within the basement. Generally, groundwater within the aquifer drains to the Atlantic Ocean in the southwest of the project area, with some exceptions in the northern and eastern extents (Vandoolaeghe and Bertram, 1980).

The Atlantis Aquifer exhibits high infiltration and recharge rates (10-30% of mean annual precipitation). Primary recharge zones occur where these sands are thickest, particularly in the Alantis dunes (see Figure 3-8). These favourable hydrogeological characteristics have made the Atlantis Aquifer an ideal site for managed aquifer recharge (MAR), which has supplemented water supply for Atlantis and, more recently, Cape Town’s municipal distribution network. Like the CFA, the Atlantis Aquifer’s unconfined portion, composed of unconsolidated sands and sediments, remains highly vulnerable to contamination. Although the Atlantis Aquifer is adjacent to the Atlantic Ocean, the underlying basement topography ensures that all boreholes targeting the aquifer have end depths above mean sea level, thereby mitigating the risk of seawater intrusion due to abstraction.

While the aquifer faces contamination risks from the Atlantis industrial zone, its overall risk to pollution is lower than for the CFA due to limited development across its extent, and both the aquifers geology and topography. The overlying land of the Atlantis Aquifer remains predominantly vegetated and undeveloped.

Minor primary aquifers

There are also minor primary localised aquifers exist within the greater City of Cape Town Municipality (see Figure 3-7). Along the eastern slopes of the Cape Peninsula Mountain chain, primary unconfined systems exist of late quaternary boulder-rich mountain scree, talus sediments, and or thin deposits of Quaternary alluvial/fluvial sediments, sands and calcareous soils that overly basement granites of the Cape Granite Suite.

Groundwater from these primary aquifers is primarily used for domestic purposes in more affluent areas of the City of Cape Town. Wellpoints are commonly installed to access shallow groundwater for irrigation, domestic use, and as a backup supply during municipal service disruptions caused by maintenance or drought. In addition to these areas, thin deposits of Quaternary cover, such as those found in parts of the City where the CFA begins to thin, also support shallow wellpoint abstraction for residential irrigation and domestic use.

The dependency on these minor aquifers and their vulnerability are relatively low, as municipal supply is the main source of water to these areas and land use is restricted to mainly residential developments with a low risk of contamination to groundwater. However, since domestic groundwater use falls under Schedule 1 of the NWA and does not require registration, managing and quantifying the dependency of these minor primary aquifers presents significant challenges.

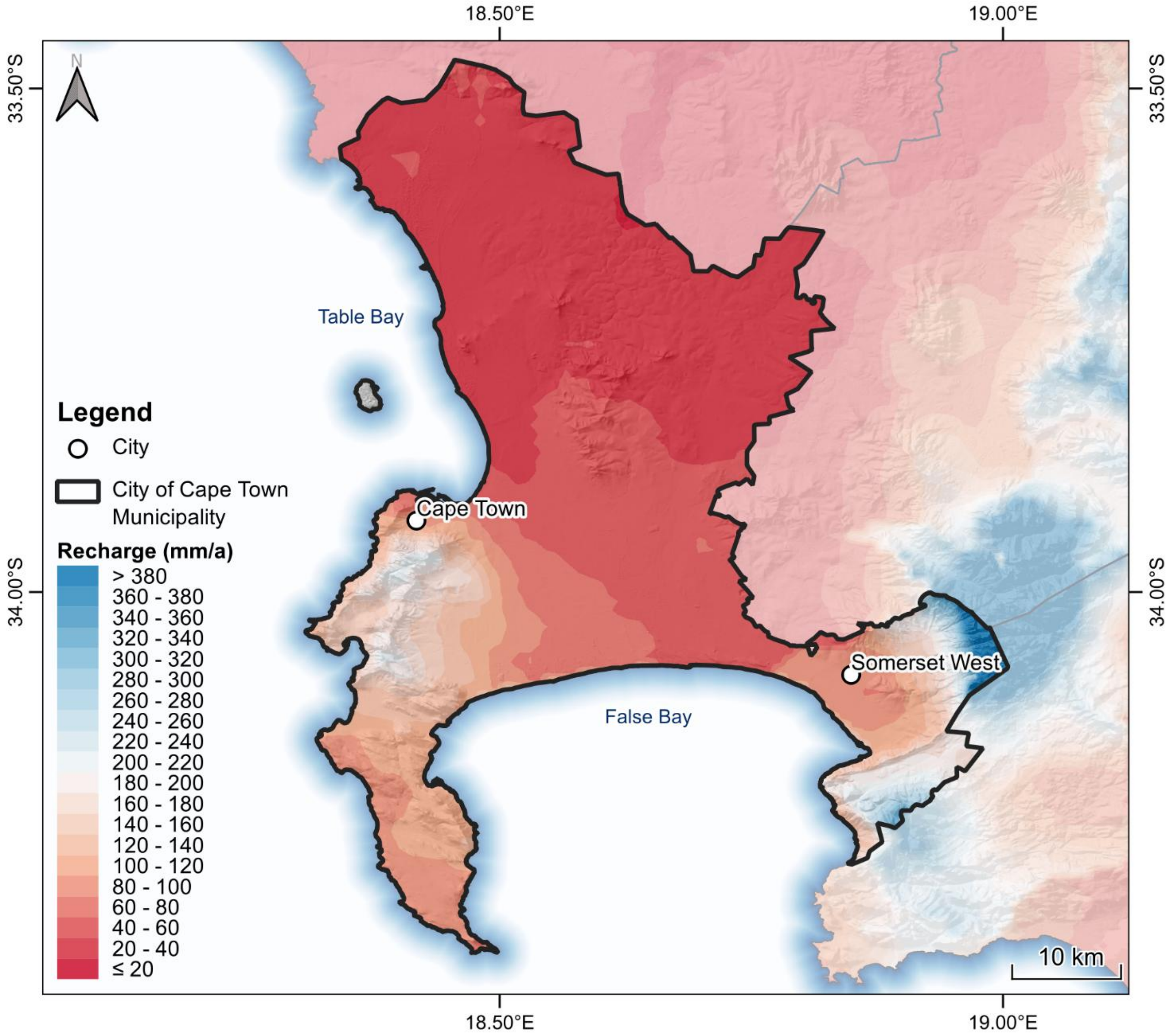

Figure 3-8 **Groundwater recharge zones for the aquifer systems in the City of Cape Town Municipality (DWAF, 2006).**

3.6.2. Secondary Fractured Rock Aquifers

The TMG aquifers, like the CFA and Atlantis Aquifer are major aquifers used to supply the City of Cape Town water supply network. Comprised of layered sandstone, the TMG consists of two main water bearing aquifers, the Peninsula Aquifer and Nardouw Aquifer (see Table 3-2). The locations of these aquifer units vary according to location within the City of Cape Town Municipality. The Peninsula aquifer is comprised of the Peninsula formation (lower TMG), while the Nardouw Aquifer is comprised of the Skurweberg and Rietvlei formations (upper TMG).

The Peninsula aquifer can be found along the Cape Peninsula mountain chain on the southwest of Cape Town and below the Winterhoek Mega-aquitard, a layer separating the Nardouw and Peninsula aquifers beneath the Steenbras dam on the south to south-east side of the Hottentot Hollands mountain range (see Figure 3-8).

TMG aquifers are characterised as fractured aquifer systems with medium to high yields (2 – 5l/s and > 5l/s). The fractured setting of TMG aquifers is defined by three main components, namely faults, joints and bedding. Highly connected and permeable structures within the TMG are largely attributable to bedding fractures and structural brittle faulting. These structures can result in high density fracture networks with preferential flow paths. Overall complex geological structures originating from primarily, mechanical and some chemical processes, have resulted in a major secondary fractured system.

Recharge of the TMG aquifers can be difficult to quantify due its variability and complex geological structures, however the main mechanism of recharge is thought to be by precipitation over fractured outcrops with high recharge potential, and spatially where its main water bearing formations are present and overlain by unconfined sediments.

Groundwater discharge features such as springs and seeps in the Cape Peninsula are closely linked to the structural and lithological controls within the TMG. Springs/seeps (groundwater dependent ecosystems) in the Cape Peninsula form primarily due to groundwater recharge in the fractured Peninsula Formation Aquifer, which occurs in high-relief areas through rainfall. The groundwater flows along faults and fractures, driven by topography, and interacts with underlying formations. Springs and seep zones form where the permeable Peninsula Formation meets the relatively impermeable Graafwater Formation aquitard or Cape Granite Suite aquiclude. This contact prevents further downward movement of groundwater, causing it to discharge at the surface. In some cases, vertical fractures allow groundwater to flow into the Graafwater Formation, saturating its permeable shale and siltstone layers. Water may then seep out along bedding planes or at contact points with the Cape Granite Suite. Groundwater from the Peninsula Formation may also recharge overlying alluvium, which can discharge at contact points with the Graafwater Formation or Cape Granite Suite. In rare cases, large faults or fractures may extend through the Graafwater Formation into the Cape Granite Suite, recharging deeper aquifers (Blake and Wise, 2023). Figure 3-9 presents a conceptual model illustrating these groundwater flow paths and discharge mechanisms.

The quality of water from TMG aquifers typically exhibit good water quality, however groundwater from TMG systems can be acidic and low in both nutrients and salinity. Elevated levels of iron and manganese have also been known to occur. Notably, during times of water decline, the quality of groundwater from these aquifers have remained relatively unchanged.

Both the Peninsula and Nardouw aquifers are targeted for water supply to the City of Cape Town water supply scheme. Groundwater from boreholes in the Steenbras wellfield are pumped into the Steenbras Dam, bringing in a factor of conjunctive management (surface and groundwater). Most groundwater abstracted from the TMG, by the City, is from the Steenbras wellfield. Which is in a critically protected biodiversity area, therefore no formal developments occur within this area, minimising the risk of contamination to these systems. Moreover, the topographic location and layout of these aquifers also minimize contamination from the surface and prevent saltwater intrusion.

Both the Peninsula and Nardouw aquifers are targeted for water supply for the City of Cape Town's water supply scheme. Groundwater from boreholes in the Steenbras Wellfield is pumped into the Steenbras Dam, enabling conjunctive use of both surface water and groundwater resources. The majority of groundwater abstracted from the TMG by the City is sourced from this wellfield. Located within a critically protected biodiversity area, the Steenbras Wellfield is safeguarded from formal development, significantly reducing the risk of contamination. However, the recent influx of people into Cape Town has led to the rapid expansion of informal settlements across the region, including areas near Grabouw, which may pose a potential contamination risk to the underlying aquifer systems.

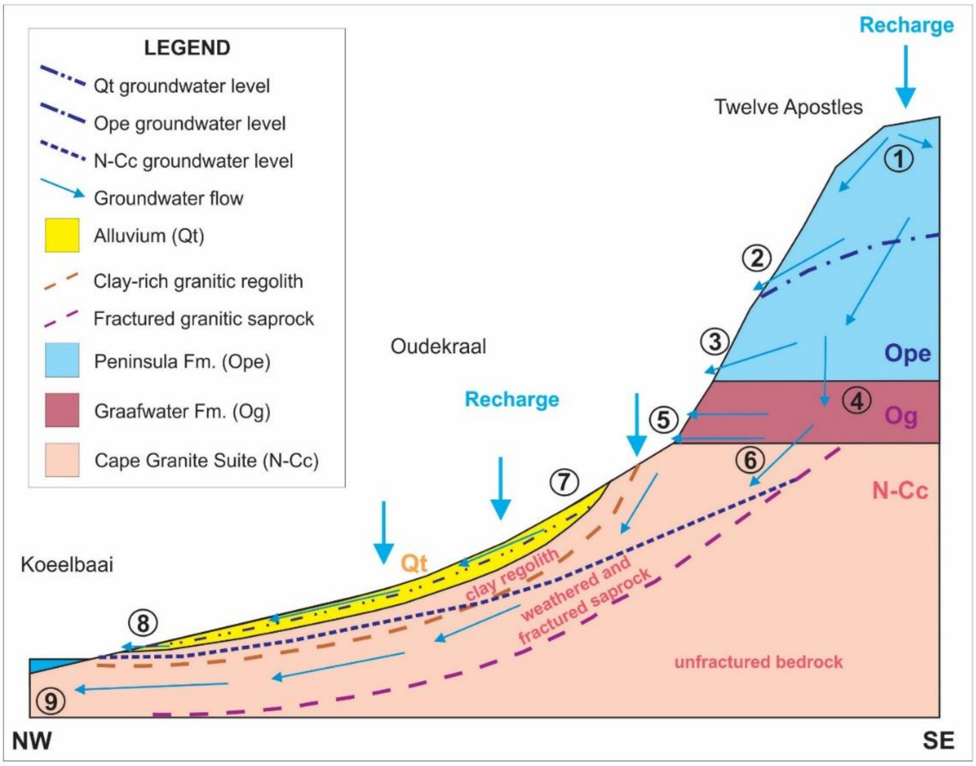

Figure 3-9: **Conceptual groundwater flow and surface water-groundwater interactions for the Cape Granite Suite basement aquifer, Peninsula Aquifer, and surface Quaternary primary aquifer within the Cape Peninsula area, resulting in spring or seep discharge (Blake and Wise, 2023).**

Water abstracted from the TMG along the Southern Peninsula is confined to private domestic use in residential areas and for irrigation in some few agricultural holdings. Domestic use of groundwater in some residential areas is limited to a back-up supply in instances where there are municipal disruptions or restrictions because of drought. Similarly to its counterpart in Steenbras and the surrounding areas, Vulnerability is quite low due to the land sue activities which take place and the geological structure of the aquifer's formations. The dependency on groundwater, from the TMG aquifer, in the southern peninsula is low. The Steenbras wellfield is the main access point to TMG groundwater.

3.6.3. Intergranular and Fractured Basement Aquifers

Malmesbury Group Aquifer

The Malmesbury basement aquifer forms the geological foundation underlying most primary aquifers in the Cape Town Municipality (see Figure 3-6, Figure 3-7 and Table 3-2). Composed of Tygerberg Formation sedimentary rocks, this system includes shales, phyllite, schist greywacke, limestone and quartzite. The faults and fractures in the basement rock create a secondary system, where groundwater is restricted to preferential flow along these pathways. However, the weathered area above the consolidated bedrock (consisting of saprolite and regolith) is typically the main water bearing zone. This portion of the aquifer forms an aquitard, storing water under semi-confined conditions.

Due to this dual structure, the Malmesbury Basement Aquifer is classified as both an intergranular and fractured aquifer system. Yields for the Malmesbury Basement aquifer range between low to moderate quantities (0.1 – 5 l/s). This is dependent on the thickness (controlled by the presence of weathered fracture zones) and clay content of the regolith/saprolite/saprock, as well as the presence of any major fault or fracture zones, intrusive contact zones (with the Cape Granite Suite) and/or intrusive dolerite dykes (with higher borehole yields possible in these zones of increased brecciation).

The high residence time of groundwater within the clay-rich regolith/saprolite (where present) and low transmissivity parent Tygerberg Formation shales usually results in relatively poor groundwater quality (due to the dissolution of natural salts present within the marine-deposited rock) e.g. high EC, high fluoride and high iron/manganese concentrations. Despite the general poor water quality, in some areas, such as the PHA, better water quality has been noted, which is potentially linked to recharge from dykes for faults propagating from the TMG, recharging the aquifer with better quality water. Overall, there is a relatively low dependency on its groundwater resources when compared to the primary aquifers in the region.

Natural recharge into the Malmesbury Group basement aquifer (through the thin overlying surface primary aquifer) is usually meteoric (rainfall), or via surface water (rivers, streams and wetlands) in areas with natural, non-urbanised cover. Lateral recharge may occur from the higher yielding, overlying Peninsula Aquifer into the basement aquifer, if large Saldanian/Cape Orogeny and Gondwana breakup-related regional structures such as fractures, faults and False Bay Suite dolerite dykes extend from the Cape Peninsula into the shales at depth (see Figure 3-9). Artificial recharge via unlined stormwater canals and domestic/sports field irrigation may also occur.

Cape Granite Suite

The hard-rock of the Cape Granite Suite is another source of groundwater from fractured basement aquifers in Cape Town. Located along the Southern Peninsula mountain chain, the northern suburbs and in east of the CBD, this system comprises of mostly gneiss and coarse grained porphyritic granites, with deformation structures forming its major water bearing zones (see Figure 3-6, Figure 3-7 and Table 3-2). Faults and fractures in the granites were formed during the Saldanian and Cape Orogenies, with the later break-up of the Gondwana supercontinent, resulting in the reactivation and normal faulting of these existing structures.

Similarly to the Malmesbury Basement Aquifer, most groundwater is found within the weathered regolith (residual soil and saprolite) and saprock (weathered, fractured rock) above the un-weathered granites, this water is typically stored under unconfined or semi-confined conditions depending on the thickness of overlying weathered material (typically clay). Fractures and faults along this interface can also sometimes be filled with weathered clays, inhibiting the movement of water and resulting in geological units with a low hydraulic conductivity.

The Cape Granite Suite can be characterised as either a fractured aquifer, or a combination of a fractured and intergranular aquifer, with yields ranging between 0.1 – 5 l/s within fractured zones and 0.1 – 0.5 l/s in intergranular and fractured zones. Recharge to basement granites is typically through overlying primary aquifers, by either precipitation or via surface water in non-urbanised areas, with little to no changes to the natural landcover. Where faults, fractures and dykes extend into the Cape Granite Suite, recharge may also occur. Additionally, zones where the TMG overly the Cape Granite Suite, recharge through fractures in the TMG geology may also occur (see Figure 3-9). The presence of these potential hydrotect systems could increase the groundwater potential of the granitic basement aquifer.

The relatively high residence time of groundwater within the clay-rich regolith, saprock and low transmissivity granitic parent rock can result in relatively poor groundwater quality (due to the dissolution of natural salts and elements present within the rock) e.g. relatively high electrical conductivities. Consistent fresh surface and lateral recharge via more transmissive fractured zones will improve groundwater quality within the granitic basement aquifer. Other hydrochemical constituents of concern that are known to occur in elevated quantities within the Cape Granite Suite are fluoride, iron, manganese and arsenic. The Cape Granite Suite Aquifer is less depended upon by groundwater users within Cape Town, and is typically utilised for domestic use and agriculture.

Due to location, landcover activities and their lithology, potentially contaminating activities are less likely to occur and reach its groundwater. The vulnerability and risk of contamination is therefore low.

Table 3-2: Stratigraphy and hydrostratigraphy of the City of Cape Town Municipality.

Age (Ma)	Period	Group	Formation	Origin	Description	Aquifer
25 - 0	Neogene / Quaternary	Sandveld	Witzand	Aeolian	Shelly calcareous sand	Primary/Sandy Unconfined (Atlantis and Cape Flats Aquifer)
			Springfontyn	Aeolian	Well Sorted and rounded fine to medium clean quartzose sand. Local lenses of calcrete, clay and peat	Major Primary/ Sandy Semi-confined to Unconfined (Atlantis and Cape Flats Aquifer)
			Langebaan	Aeolian	Calcrete and very calcareous sand	Primary/Sandy Semi-confined (Atlantis Aquifer and Cape Flats Aquifer)
			Varswater	Marine	Fine to Coarse, often silty, shelly, quartzose to calcareous and phosphatic sand and gravel.	Primary/Sandy Semi-confined (Atlantis and Cape Flats Aquifer)
			Elandsfontyn	Fluvial	Fluvial channel gravel	Major Primary/Sandy Semi-confined (Cape Flats Aquifer)
~~ Major Unconformity ~~~~						
~136	Cretaceous	False Bay Suite		Igneous	Dolerite dyke intrusions	Minor secondary/ Fracture aquifer.
~~Cape Orogeny (~280-230 Ma) and Major Unconformity / Gondwana break up (180-110 Ma) ~~~~						
~390-375	Devonian	Bokkeveld	Gydo	Marine	Shales and minor sandstone	Aquitard
~500-390		Table Mountain	Rietvlei	Fluvial	Felspathic sandstone, minor shale	Major Secondary / Fracture aquifer (TMG Nardouw Aquifer)
	Silurian		Skurweberg	Fluvial	Thickly bedded quartzite	
			Goudini	Fluvial	Reddish brown quartzitic sandstone	Winterhoek Mega-aquitard
			Cedarberg	Estuarine/ Marine	Dark grey shale and siltstone	
	Ordovician		Pakhuis	Glacial	Tillite and quartz sandstone	
			Peninsula	Fluvial/marine	Thickly bedded, fractured quartzitic sandstone	Major Secondary/Fracture Unconfined/Semi Confined (TMG Peninsula Aquifer)
	Cambrian		Graafwater	Marine	Purple siltstone, shale and sandstone	Aquitard
~~ Major Unconformity (Erosional Time Break) ~~~~						
~550-510	Namibian-Cambrian	Cape Granite Suite	Cape Peninsula Batholith	Igneous	Coarse grained, porphyritic granite	Basement/Regolith Aquifer/Aquitard
~800-550		Malmesbury	Tygerberg	Marine	Shale and sub-ordinate felspathic sandstone	Basement/Regolith Aquifer/Aquitard

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3.7. Surface Water and Groundwater Recharge Potential

Soil Infiltration Potential

The dependency of groundwater on surface water was assessed. This was centred on the concept of aquifer recharge potential and the hydrological aspects affecting this potential.

Of relevance is that recharge potential, as outlined in this section, excludes rainfall considerations which are discussed in **Section 3.2**. Where rainfall is higher, recharge potential would be higher (although it would be affected by the aspects discussed in this section). Figure 3-10 illustrates the datasets evaluated with regard to recharge potential.

Aquifer Recharge Potential

Aquifer types have the potential to (at a basic level) either be susceptible to recharge or resistant to recharge when they are either unconfined or confined, respectively. High soil infiltration potential with no impervious areas would not lead to recharge of a confined aquifer. To account for this, the aquifer susceptibility (per the Department of Water and Sanitation, 2013 dataset for Cape Town) was used as an input to estimate aquifer recharge potential. This dataset outlines aquifer susceptibility due to anthropogenic activities that may cause contaminants to enter an aquifer. As such, the dataset was used a analogous dataset for aquifer recharge potential. .

The Cape Flats are noted as an area of very high aquifer recharge potential. When considered in unison, the areas of highest recharge potential are noted to occur to the South of the Cape Flats and to the north around Atlantis.

Infiltration Potential

A primary determinant of recharge potential is that of infiltration potential, as the more infiltration that occurs, the higher the recharge (assuming aquifers aren't confined). To consider infiltration potential, the South African SCS Soil dataset was used, which defines hydrological soil groups (HSGs) according to the following runoff potential classification:

- **HSG A** - Low runoff potential. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures.
- **HSG B**- Moderately low runoff potential. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures.
- **HSG C** - Moderately high runoff potential. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures.
- **HSG D** - High runoff potential. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures.

South Africa has expanded the classification to increased soil detail, by using adjacent classes such that soils are defined into HSGs A, A/B, B, B/C, C, C/D and D.

As mentioned, the HSG is a classification relating to runoff potential. As such, infiltration potential can be determined according to the inverse of the HSG (e.g. an HSG A with low runoff potential would have a high infiltration potential).

Cape Town's primary HSG results in a high infiltration potential, with secondary areas of moderately high to low infiltration potential.

Impervious Areas

The Department of Forestry, Fisheries and the Environment (DFEE) 2022 land-cover dataset enabled the definition of impervious areas that would prevent infiltration and thereby recharge. Impervious areas were defined according to the presence of exposed rock, roads, residential, commercial or industrial areas. The impervious nature of these areas is not absolute, and some pervious portions remain. As such presents an assumed 'partly impervious surface'. Impervious areas are concentrated around the more developed portions of the city.

Sewage Treatment Plants

A likely minor addition to groundwater recharge is treated water from sewage treatment plants which serves to increase streamflow and thereby provide potential increases in groundwater recharge. The CCTs sewage treatment plants were plotted in Figure 3-10 to illustrate locations that may serve to increase or sustain streamflow and lead to localised increases in recharge (within the affected downstream river reach).

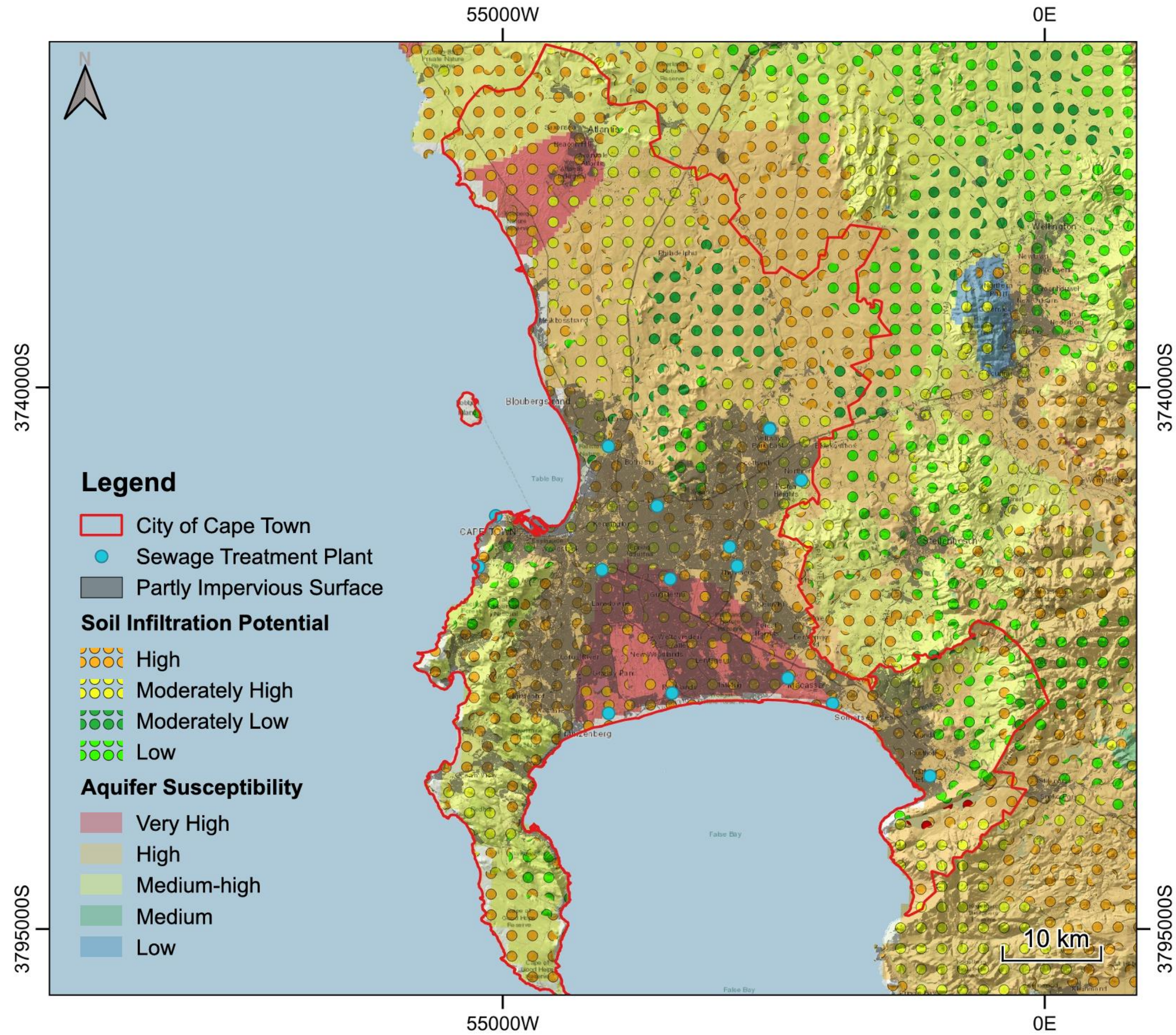

Figure 3-10: Aquifer recharge potential map across the City of Cape Town area. Aquifer recharge potential is shown as a function of aquifer susceptibility, soil infiltration capacity (based on HSGs), derived from hydrological soil group (HSG), impervious surface coverage from DFEE 2022 land-cover data, and locations of sewage treatment plants that may enhance streamflow and local recharge.

4. Groundwater Dependency in Cape Town

Cape Town lies in a water-scarce Mediterranean climate. Since 1996, the urban population has grown by approximately 56%, greatly intensifying water demand in the city. Climate projections for Cape Town indicate warmer, drier conditions with temperatures expected to increase by 1–1.8 °C, and rainfall expected to decrease by 20% by 2060 (Hofmann et al, 2024). Persistent droughts (e.g. 2015–2018) and climate change both reduce surface-water yield and groundwater recharge. This rising water demand and decreasing rainfall has forced the City of Cape Town to tap into groundwater as a buffer to climate risk.

The combined effect of growing water demand and a drying climate has led Cape Town to make groundwater a key part of its resilience strategy (Cape Town's Resilience Strategy, 2019b). Model-based analyses of the water–food nexus confirm that, even with planned augmentation, aquifer exploitation will rise sharply and must be managed to avoid over-abstraction (Hofmann et al, 2024). In response, the City's "New Water Programme" and Water Strategy call for diversified sources (reuse, desalination, and aquifer development) and explicit monitoring of groundwater use. In summary, Cape Town's groundwater dependency is increasing as urban and agricultural demand rises and surface water supplies decline, making the City's aquifers critical buffers in the city's water portfolios.

In the City of Cape Town, groundwater is utilised across multiple sectors, including municipal supply, agriculture, industry, and domestic use by communities. In addition to human use, the reliance of ecosystems on groundwater is also considered. The following section explores groundwater dependency across four key categories: Municipal Supply, Agricultural and Industrial Use, Communities, and Ecosystems.

4.1. Municipal Supply

Most of the water used by the City of Cape Town (96%) for urban and agricultural use is supplied by the Western Cape Water Supply System (WCWSS), an interconnected water supply network that supplies water from six main dams (Theewaterskloof Dam, Voëlvlei Dam, Berg River Dam, Wemmershoek Dam and Steenbras Upper and Lower Dams) that have a total storage of approximately 900 million kilolitres (Mauck & Winter, 2021; CCT, 2023a). Several of these dams are located outside of the Cape Town municipal boundary, as illustrated on Figure 4-1. The Steenbras Upper and Lower dams and the Wemmershoek dam are owned and operated by the City of Cape Town, while the others are owned and operated by the DWS.

The City of Cape Town Municipality compiled Cape Town's Water Strategy (2019a), which details a long-term plan designed to ensure water security, resilience, and sustainability following the City's severe drought crisis from 2015 to 2018. This severe drought was described as a 1 in 590-year event (CCT, 2023a; Faragher and Carden, 2023). Most global climate models predict lower rainfall for Cape Town and more frequent droughts. According to the City of Cape Town Outlook Report (CCT, 2023a), climate change is expected to reduce the city's available water by 25%. In light of this projection, continued reliance on rainfall-fed surface water dams is no longer a sustainable strategy. Additionally, Cape Town's water demands have increased steadily, increasing from approximately 950 million litres per day during the summer of 2021/2022 to an expected 1,200 million litres per day by the summer of 2024.

Although Cape Town's water supply is and will continue to rely mostly on rain-fed dams, primarily because it is cost-effective, the new water strategy recognises the need to diversify water supply to avoid extreme water shortages due to city's increasing water demands and droughts, which as climate models predict, are expected to increase due to climate change over time. A major commitment of this strategy is to provide a reliable and sufficient water supply to the City by increasing the available supply by more than 300 million litres per day over the next ten years.

The New Water Programme aims to diversify the City's water supply with alternative sources including aquifer development, desalination and water reuse (CCT, 2024a). As part of this, the City has established groundwater schemes to supplement the bulk water supply. This includes the Cape Flats Aquifer Management Scheme, the Table Mountain Group Aquifers Management Scheme and the refurbishment and upgrade of the Atlantis Water Management Scheme (see Figure 4-1). Through these groundwater schemes, the City of Cape Town Municipality now projects that about 7% of its bulk water supply will come from groundwater by 2040 (CCT, 2023a), increasing the city's dependency on the resource (see Figure 4-2).

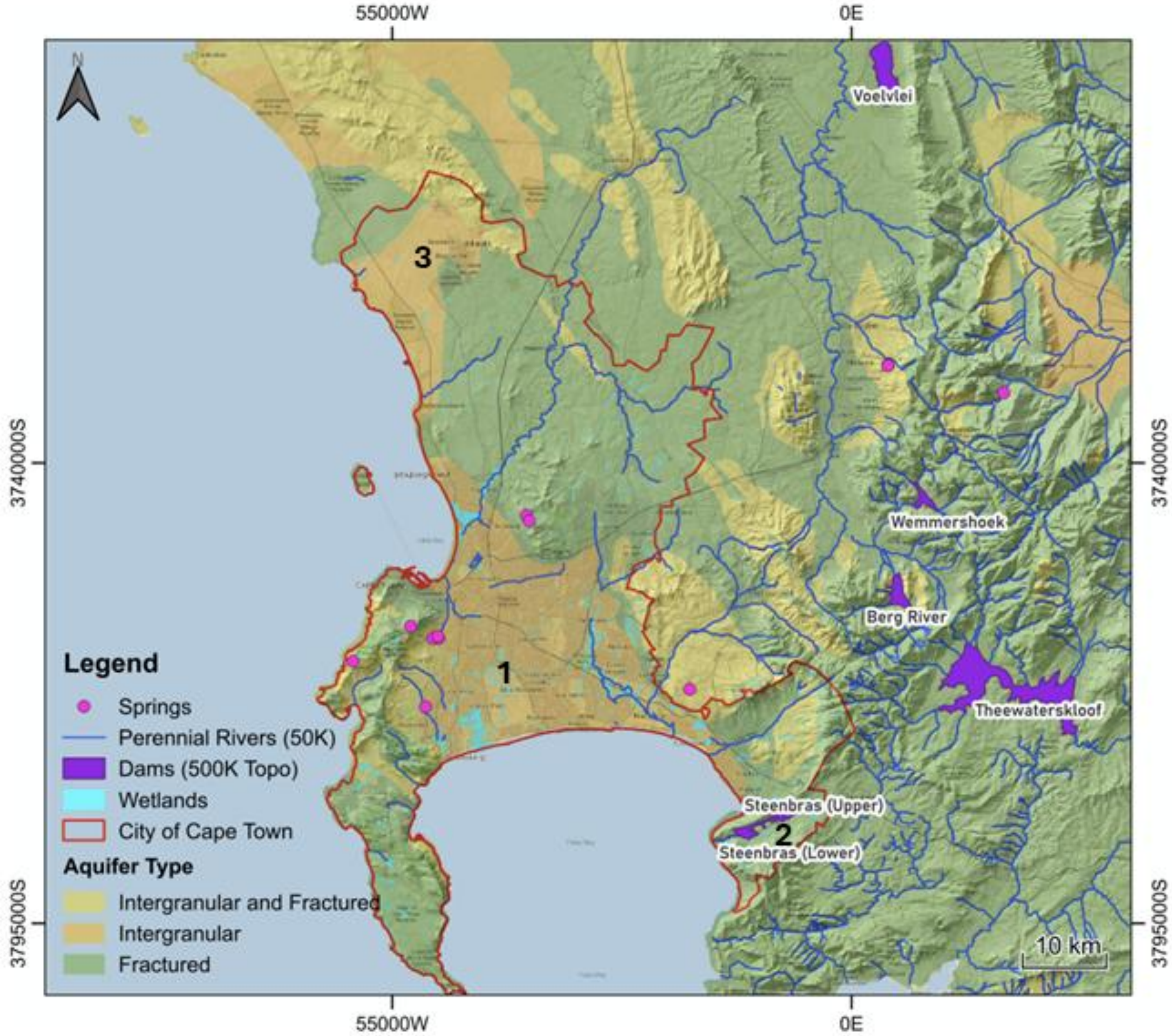

Figure 4-1: Hydrological features, springs, and aquifer types in Cape Town and surrounding areas. (The numbers on the map indicate the location of groundwater schemes; 1 – Cape Flats Aquifer Management Scheme; 2 – TMG Aquifers Management Scheme; 3 – Atlantis Water Resource Management Scheme).

It is also important to note that currently, a large portion of groundwater use in the City occurs outside of the municipal supply system. According to the Water Stressed Cities Project (2024), households are increasingly using water from the CFA, TMG Aquifer (Peninsula and Nardouw Aquifers), Atlantis Aquifer, and Malmesbury Group Aquifer. The registration of this private use is often lacking and unregulated, resulting in minimal data and unregulated groundwater use occurring within the municipal boundary. An increased reliance on groundwater necessitates effective groundwater management, including regular monitoring of both groundwater levels and quality. The over abstraction of groundwater can cause a significant decline in groundwater levels, which increases the risk of seawater intrusion, particularly in coastal aquifers. Seawater intrusion increases the vulnerability of groundwater to contamination and long-term degradation.

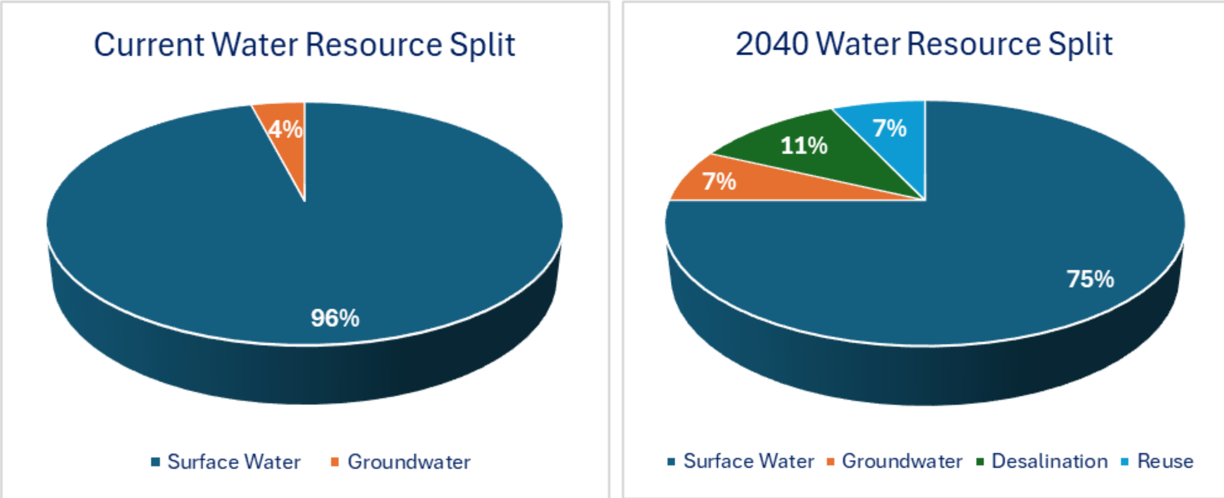

Figure 4-2: The shift from the current water resource split to that planned by the City of Cape Town by 2040.

4.2. Agricultural and Industrial Use

In Cape Town, the most groundwater-dependent sectors are irrigated agriculture, industry, and Schedule 1 domestic use. Other sectors, such as livestock farming, recreation, and aquaculture, also use groundwater but to a lesser extent. Among these, irrigated agriculture is the largest registered user, accounting for approximately 56% of total groundwater use in the City of Cape Town (WARMS database). This includes both commercial and subsistence farming operations. Figure 4-3 provides a visual representation of registered groundwater users, based on data from the National Department of Water and Sanitation (DWS) Water Use Authorisation and Registration Management System (WARMS).

The Irrigation Strategy for South Africa proposes expanding irrigated land by more than 50% (DWS, 2016b). This will likely intensify groundwater use and dependency in the agricultural sector which heightens the risk of aquifer over-abstraction and contamination. In addition to this planned expansion, unauthorised groundwater abstraction for irrigation purposes also increases the pressure on groundwater resources. Due to this unauthorised use, the true extent of groundwater dependency in the sector is unknown.

In Cape Town, the Philippi Horticultural Area (PHA), situated in the Cape Flats region, is an example of an area with a high reliance on groundwater. This region produces a significant proportion of Cape Town's fresh produce. Farmers in this area target the CFA for groundwater supply for irrigation purposes (WRC, 2020). This reliance is more pronounced during drought periods, leading to the risk of over-abstraction. The over-abstraction of groundwater in the CFA can result in salinisation of the aquifer due to seawater intrusion. Additionally, the unconsolidated nature of the CFA also makes it more susceptible to contamination from surrounding land uses, particularly agricultural activities, increasing its vulnerability. In summary, the dependency of the agricultural sector on groundwater in the CFA and its vulnerability to contamination by both anthropogenic activities and seawater intrusion are considered to be high.

The industrial sector is the second largest user of groundwater in the City of Cape Town, accounting for about 35% of all groundwater use. This sector uses groundwater for manufacturing processes and cooling, with registrations varying from general authorisation to licensed users. Industrial areas in Cape Town, such as Epping Industrial, which target the Malmesbury Group Aquifer, are suspected to have a high prevalence of private boreholes and a great dependency on groundwater for their operations. Due to chemical use in some industrial processes, there is a contamination risk to the surrounding and underlying environments (soils, groundwater and surface water). Groundwater quality monitoring is critical to ensure that any industrial-related activities do not contaminate the resource.

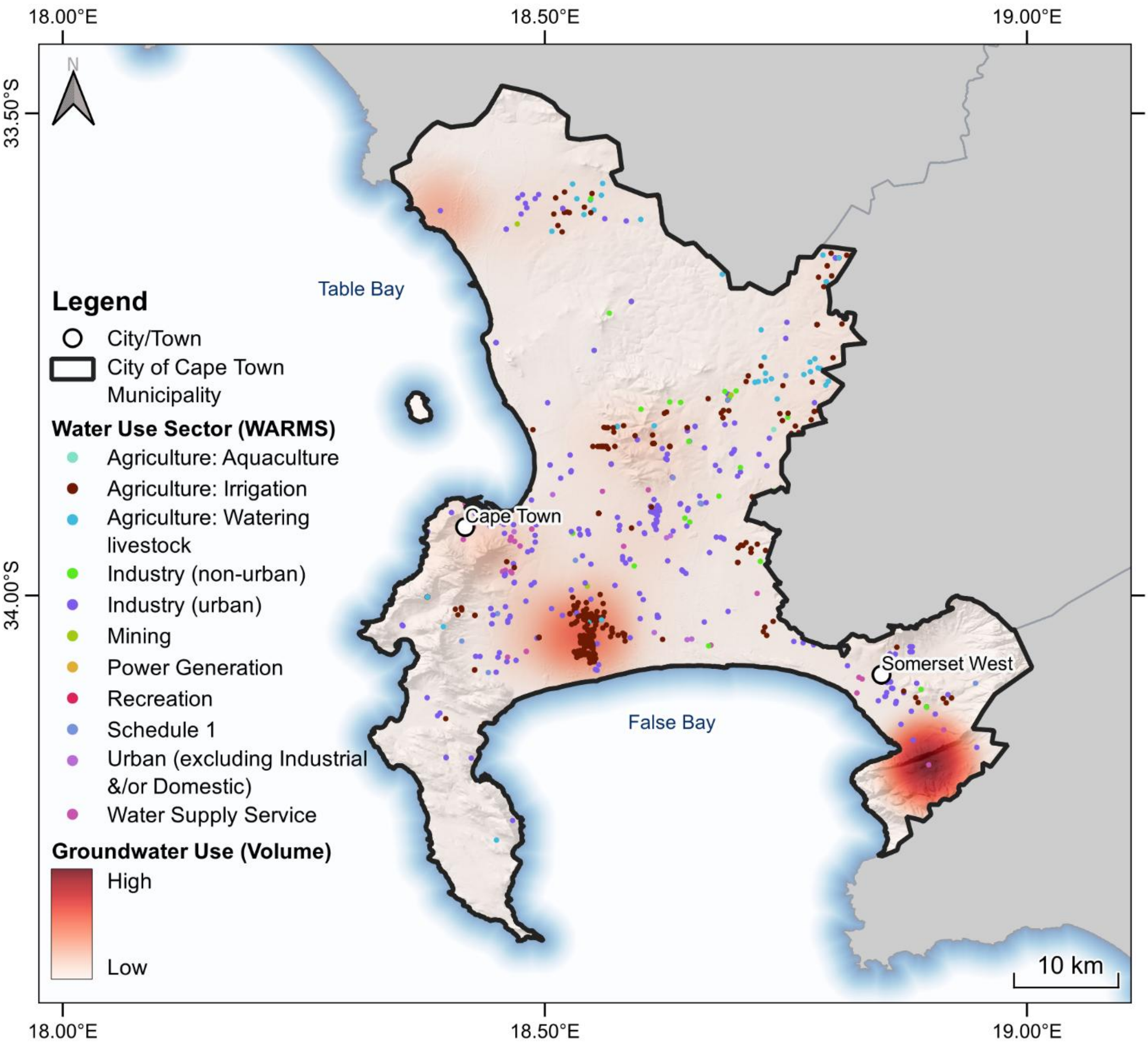

Figure 4-3: **Groundwater use and the distribution of authorised water uses, based on the WARMS database, including boreholes, wellpoints and springs, including the groundwater schemes of the City of Cape Town.**

4.3. Communities

Most communities in Cape Town primarily depend on municipal water supply, however, some communities also rely on groundwater as a supplementary water source, particularly during times of drought. This dependency became more apparent during the 2015 – 2018 drought when the number of private boreholes increased significantly to provide alternative water for both potable and non-potable uses (Faragher and Carden, 2023; Water Stressed Cities Project, 2024). This dependency on groundwater is expected to increase as global climate models project lower rainfall for Cape Town and more frequent droughts in the coming years. The City of Cape Town estimates that climate projections could reduce the city's available water by up to 25% by the year 2045 (CCT, 2023a). As the reliance on groundwater increases, so too does the risk of overexploitation and increased vulnerability of the resource.

4.3.1. Socioeconomic Influences on Groundwater Use in Cape Town

Cape Town is considered South Africa's most segregated city as it remains strongly divided by socioeconomic status, with these divisions often still linked to race. Despite this, a study on social inequality and spatial segregation in Cape Town conducted by Turok et al. (2021) noted a reduction in the degree of segregation in the city between 2001 and 2011. While the divisions that exist are no longer caused by apartheid laws, they are now driven by economic conditions and the job market. Job growth has not been strong enough to help many people escape poverty in the city. Where people live also affects their opportunities, for example, residents of townships in the Cape Flats have fewer opportunities and face very different living conditions compared to those in the more affluent southern and northern suburbs.

Access to clean and reliable water remains a significant challenge in informal settlements, largely driven by systemic inequalities in the distribution of water services (Chan, 2024). Cape Town's water supply system continues to reflect the impacts of apartheid-era socio-political decisions, which excluded Black and Coloured townships from the initial development of water and sanitation infrastructure. This has contributed to inequalities in access to water services today (Chan, 2024). Addressing these inequalities in access and utilisation remains central to sustainable groundwater governance in Cape Town.

Interview respondents in a recent study (Water Stressed Cities Project, 2024) explained that they find it unnecessary to use treated, potable water for gardening. All but one interviewee still uses municipal water, and only two respondents drink their groundwater. In other words, groundwater does not replace municipal water, but offsets some of their uses, providing a way for households to diversify their supply and be more resilient to future droughts (see **Figure 4-4**).

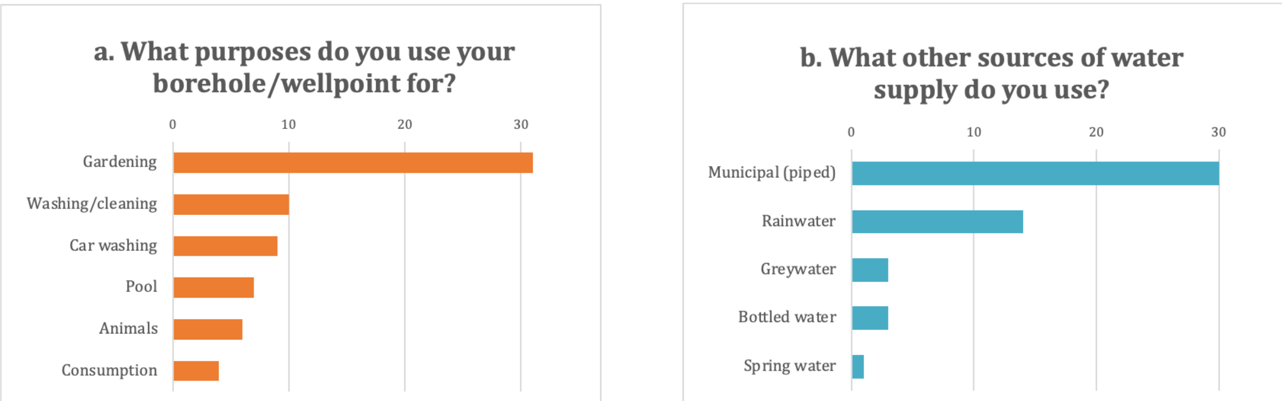

Figure 4-4: Results of interviews on how and why people use groundwater, alongside other water sources (Water Stressed Cities Project, 2024).

Many low-income/informal settlements such as Khayelitsha, Manenberg, and Hanover Park, located within the Cape Flats region, typically have limited access to groundwater due to the high costs associated with borehole drilling, groundwater licensing complexities, and limited means to access the technical capacity required. These areas are primarily dependent on access to water through municipal communal taps or public standpipes which is also often limited and unreliable in these areas due to challenges related to inadequate infrastructure, operational and maintenance challenges, and vandalism. These areas were severely impacted by the Day Zero drought, exacerbating existing vulnerabilities linked to water access, hygiene, and public health. Consequently, groundwater dependency is lower in these areas, even though the water security needs of lower income areas are greater.

According to Statistics South Africa (2022), 65% of the total number of groundwater users reside in formal settlements. High-income areas of Cape Town, such as Constantia, Bishopscourt, Newlands, and Claremont, often have greater access to groundwater resources. These suburbs typically have the financial means to invest in private boreholes and water storage infrastructure, reducing their reliance on the municipal water supply (see Figure 4-5) for the distribution of privately owned boreholes or wellpoints within the City of Cape Town). Affluent areas in Cape Town, located in the Table Mountain area also rely on springs that occur along mountain slopes (e.g. Newlands Spring which provided great relief not only for nearby communities but for many residents from all over Cape Town as well during the Day Zero Drought). Residents of these areas usually use springs for non-potable uses such as the watering of gardens and filling of swimming pools, even though the water from the springs is of good quality. These households are also more likely to use automated irrigation systems and water-intensive landscaping, increasing groundwater abstraction pressures in certain aquifer zones.

4.3.2. Gender and Social Inclusion in Groundwater Use and Management

Due to prevailing gender norms and roles, women, particularly in low-income and informal settlements, are often responsible for securing water for household use (Ntwana, 2021; iTorrent, 2023). Obtaining water for household use may require long travel distances to communal taps or water collection points. This has implications for safety, security and efficiency dependent upon the safety of route travelled, and the reliability of the water source. These areas generally lack access to groundwater due to the high cost of borehole drilling, as described above. During the Day Zero drought, women were disproportionately affected by the water crisis, spending increased time and effort collecting water, often waiting in long queues under unsafe conditions, and managing limited supplies for cooking, cleaning, and caregiving (iTorrent, 2023). This exposed underlying gender inequalities in water access in the city.

The National Water Act (NWA), Act 36 of 1998, which governs water resources in South Africa, including groundwater, aims to redress the results of past racial and gender discrimination in terms of the provision of water (Government of South Africa, 1998). To achieve this, gender equality and social inclusion are crucial to water resource management as they facilitate and promote inclusive decision-making. Despite policy commitments, women and socially marginalised groups, including youth, ethnic minorities, and informal settlement residents, are often underrepresented in key water governance platforms such as water user associations and catchment management forums (Elias, 2017). This exclusion limits the integration of diverse knowledge systems and lived experiences as well as the ability to advocate for sustainable and equitable groundwater use that addresses a diverse range of needs, weakening the effectiveness and equity of water governance processes.

Promoting inclusive groundwater governance is critical for climate resilience and sustainable development. Cape Town's conjunctive water management strategy must actively incorporate gender-responsive planning, including representation in water committees, targeted support for female-led water initiatives, and the integration of social indicators into the groundwater planning tool currently in progress. This will support more equitable, informed decision-making and reduce systemic barriers to water access.

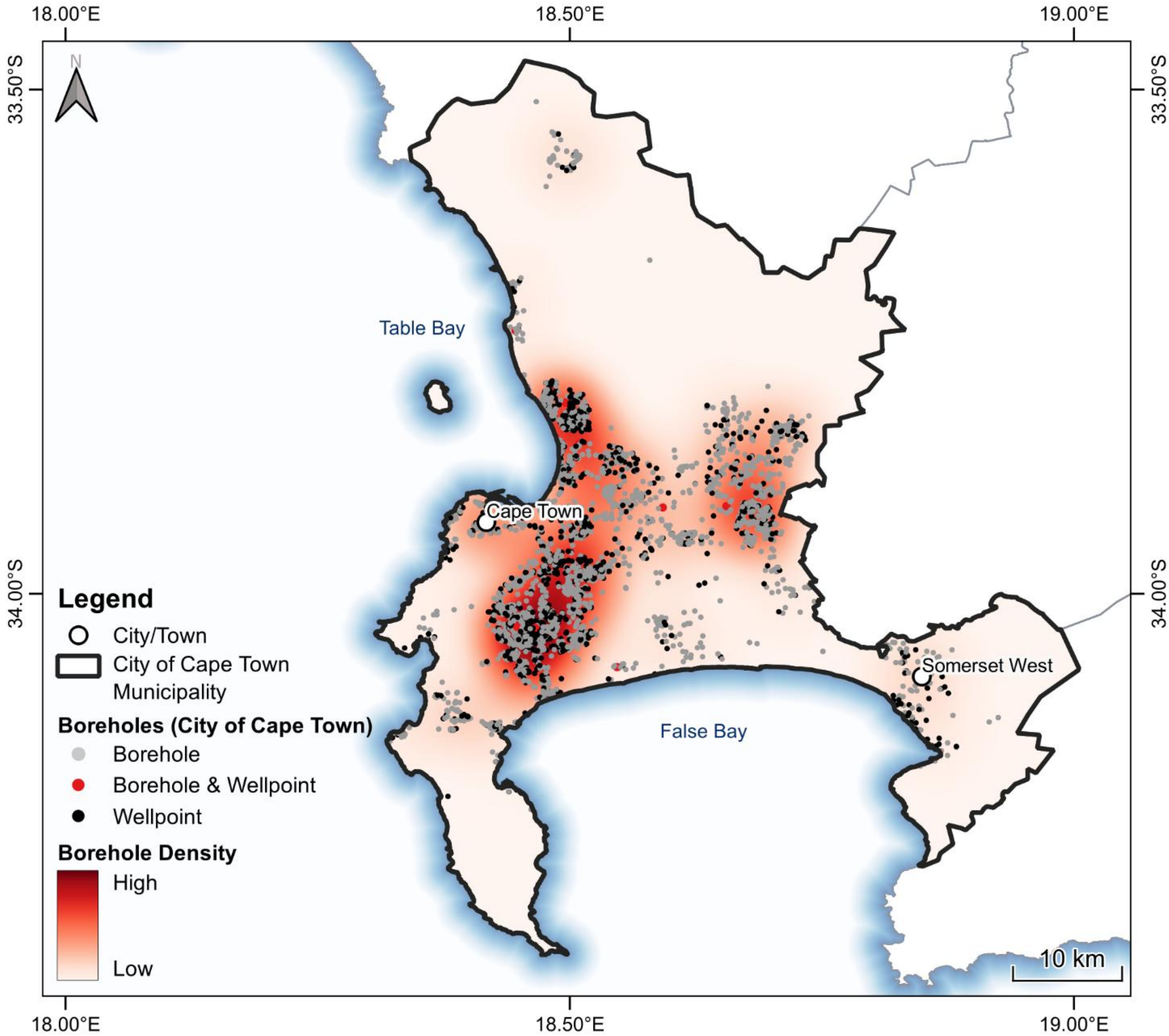

Figure 4-5: Distribution of private boreholes/wellpoints registered with the City of Cape Town.

4.4. Ecosystems

4.4.1. Wetlands

There are over 7,000 wetlands within the boundaries of the City of Cape Town (see Figure 4-7). These wetlands fall into five broad types, based on their hydrogeomorphic characteristics: seeps; depressions; floodplain wetlands; and channelled or unchannelled valley-bottom wetlands (Snaddon and Day 2009). The river catchments in which these wetlands occur are displayed in Figure 4-6.

Seeps (either connected to or disconnected from the riverine network) predominate in most of the City's 20 catchments. With the exception of the Zeekoe catchment, these catchments all include mountainous areas in which seeps tend to dominate. Many of these seeps are sustained by groundwater.

Depressions tend to occur in the lowlands, which represent a large proportion of several of the City's catchments, such as Atlantis, Eerste / Kuils River, Mitchell's Plain / Khayelitsha, Salt River and Sout River catchments. The Noordhoek Valley in the west of the Peninsula also supports a number of depression wetlands that are connected to a network of streams draining off the surrounding mountain slopes. Depressions tend to be fed by precipitation and sometimes groundwater.

Floodplain wetlands are dominant in the Diep River (Milnerton) and Sand River catchments, and are numerous in the Eerste / Kuils River catchment. The Diep and Sand rivers both have extensive floodplain flats associated with the lower reaches of the rivers, these are Rietvlei and Sandvlei respectively. Floodplain wetlands are sustained by surface flow from the lowland rivers associated with them. **Channelled** (with an obvious channel) **and unchannelled valley-bottom wetlands** are associated with rivers, and tend to form when water seeps out of the river channel, or overtops the channel's banks.

Estuaries (in the form of estuarine channels or depressions, and river mouths) are located in the Diep River, Eerste / Kuils River, Hout Bay River, Lourens River, Noordhoek, Sand River, Silvermine River, Sir Lowry's Pass River and South Peninsula catchments.

Large waterbodies in the City include Rondevlei and Zeekoevlei (Lotus catchment), Zandvlei and Princess Vlei (Sand catchment), and Rietvlei (Diep catchment).

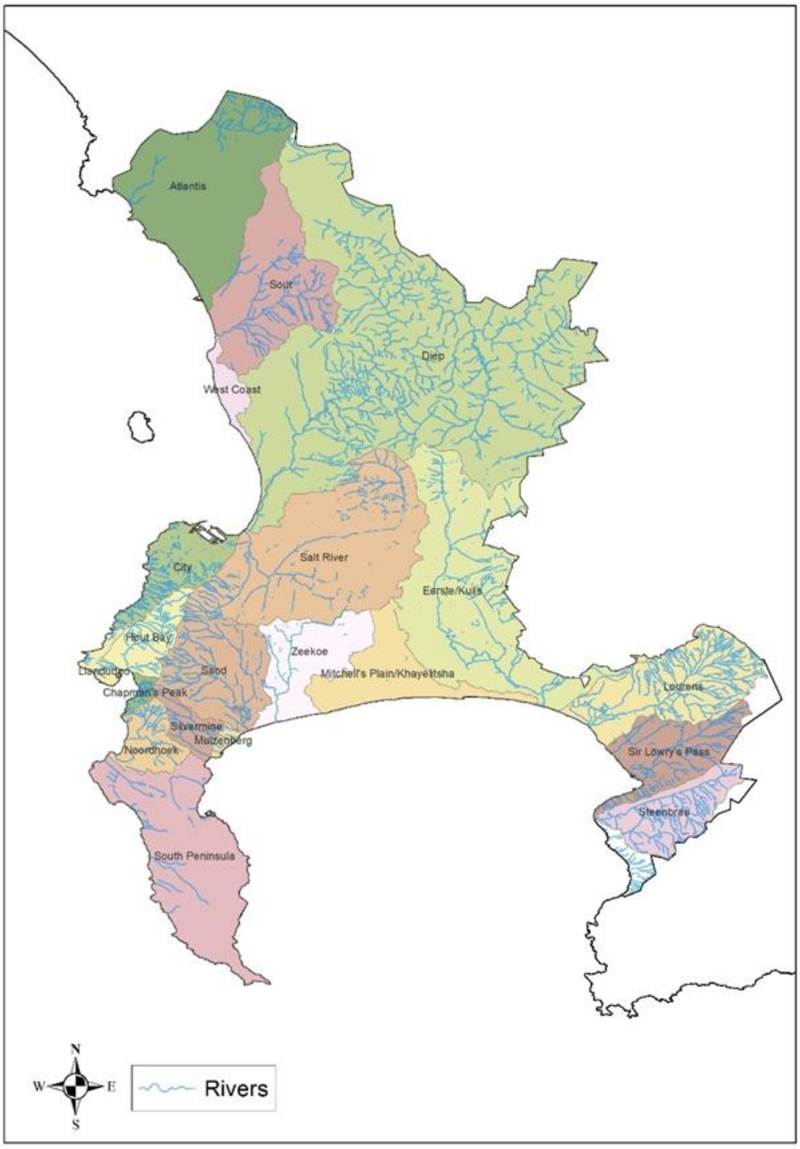

Figure 4-6: **Major river catchments in the City of Cape Town.**

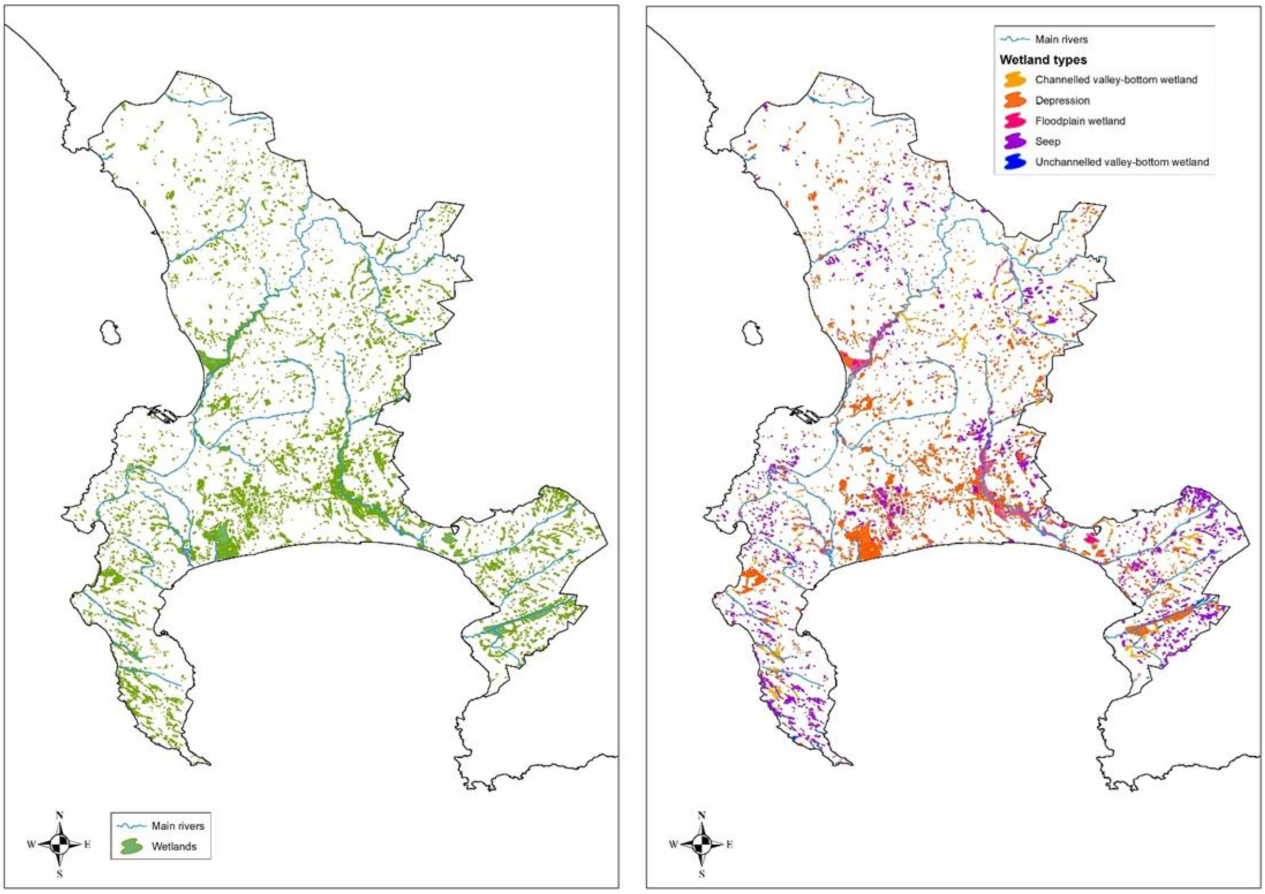

Figure 4-7: (Left) Wetlands in the City of Cape Town, and (Right) Wetland types.

4.4.2. Groundwater Dependent Ecosystems

Groundwater-dependent ecosystems (GDEs) rely on groundwater to meet some or all of their water and nutrient requirements (Rohde et al., 2017; Dabovic, 2024). In Cape Town, a significant number of GDEs are located within the Cape Flats Aquifer and Table Mountain Group Aquifer regions. Springs, rivers, and wetlands in these areas are sustained by groundwater, highlighting the ecological importance of these aquifer systems. According to Eamus et al. (2006) and Richardson et al. (2011), GDEs can be broadly categorised into three types:

1. Aquatic GDEs – ecosystems where groundwater discharges to the surface, such as rivers, wetlands, and springs.
2. Terrestrial GDEs – vegetation communities (referred to as "phreatophytic" species or communities) that depend on subsurface groundwater for survival, particularly during dry periods.
3. Subterranean GDEs – ecosystems occurring entirely below the surface, typically in saturated zones of aquifers.

Groundwater dependency can be analysed in terms of nature, extent and degree of dependency (Colvin et al. 2003). The degree to which GDEs depend on groundwater can be continuous or seasonal and may vary over time (Kløve et al., 2011). During dry seasons or droughts, when rainfall is limited and transpirational demands are at their highest, GDEs often become more reliant on groundwater compared to wetter months when surface water is more readily available to sustain or support these ecosystems (Eamus & Froend, 2006). Even an ephemeral or seasonal dependency on groundwater may be critical to the health or survival of an ecosystem (Colvin et al. 2003). This refers to the basic principle that where groundwater is accessible, the ecosystems (in particular, the biota) accessing the groundwater will develop some degree of dependency.

The extent of dependency can also vary depending on the type of aquifer, and due to the complex nature of the relationship between ground- and surface water, and can range from very localised to widespread. Sometimes, a GDE may be located some distance away from an aquifer, but still be dependent to some extent on the aquifer (Roets et al. 2008).

The nature of the dependency is probably the most complex aspect of GDEs. This may only become apparent when an ecosystem has been stressed beyond a critical threshold (Colvin et al. 2003). GDEs rely on groundwater for the maintenance of their ecological processes, structure, and function, particularly during dry periods. Systems that are completely fed by groundwater such as springs would not exist or persist without groundwater input (Kløve et al., 2011). Groundwater provides water, nutrients and relatively stable temperatures particularly to wetlands, streams and rivers, which help to maintain aquatic plant and animal communities that rely on groundwater for survival (Dabovic, 2024). Additionally, GDEs such as wetlands also absorb excess water during floods, reducing flood risk and can filter pollutants and sediments from surface water and shallow groundwater.

In addition to the ecological functions, GDEs also provide many other services, particularly in dry and semi-arid regions. Due to limited rainfall and the overall lack of fresh water in these regions, they serve as important sources of water for livestock, domestic purposes, and for the support of vegetation. These systems also have a notable economic value as they serve as important breeding grounds for fish, supporting commercial fishing. Additionally, they also generate revenue through eco-tourism.

The condition or health of GDEs is directly dependent on access to groundwater (Rohde et al., 2017). The growing demand for water due to climate change and a growing population in the city, poses a great threat to GDEs as it limits groundwater availability. The over extraction of groundwater limits the amount of groundwater discharge into wetlands, rivers and springs, disrupting ecosystem services, functions and structure (Eamus et al., 2006; Murray et al., 2006). This also limits the amount of water in the subsurface required by terrestrial GDEs (Kløve et al., 2011). Phreatophytic plant species are sensitive to the rate as well as the season of groundwater abstraction (Eamus et al. 2006).

Other threats such as changes in land use and the intensification of agriculture and urban development also result in habitat loss and pose a significant contamination risk, resulting in a change in groundwater quality. Land use activities such as urban development, mining and agriculture can lead to elevated metals, nutrients and pesticides in groundwater, altering its chemistry (Dabovic, 2024). Introducing these pollutants impacts these ecosystems' ability to perform their regular functions (e.g. water purification).

Given the critical reliance of GDEs on groundwater, implementing a conjunctive management strategic action plan can help prevent aquifer overuse and pollution, ensuring the protection of these valuable ecosystems. The protection of GDEs is particularly challenging due to their varying degree of groundwater dependence, which is not well understood, their diversity and unique ecological water requirements. For instance, our understanding of the relationship between groundwater levels and soil moisture dynamics in wetlands is minimal, but it is clear that the sustainable operation of any borehole or wellfield needs to take these kinds of interdependencies into account.

Researchers recently mapped the likely occurrence of GDEs in drylands, at roughly 30m resolution, which has shown the prevalence of GDEs in the drier regions of the world (Rohde et al. 2024). This map was used to infer groundwater dependency of the wetlands, rivers and estuaries within Cape Town, and these are shown in Figure 4-8.

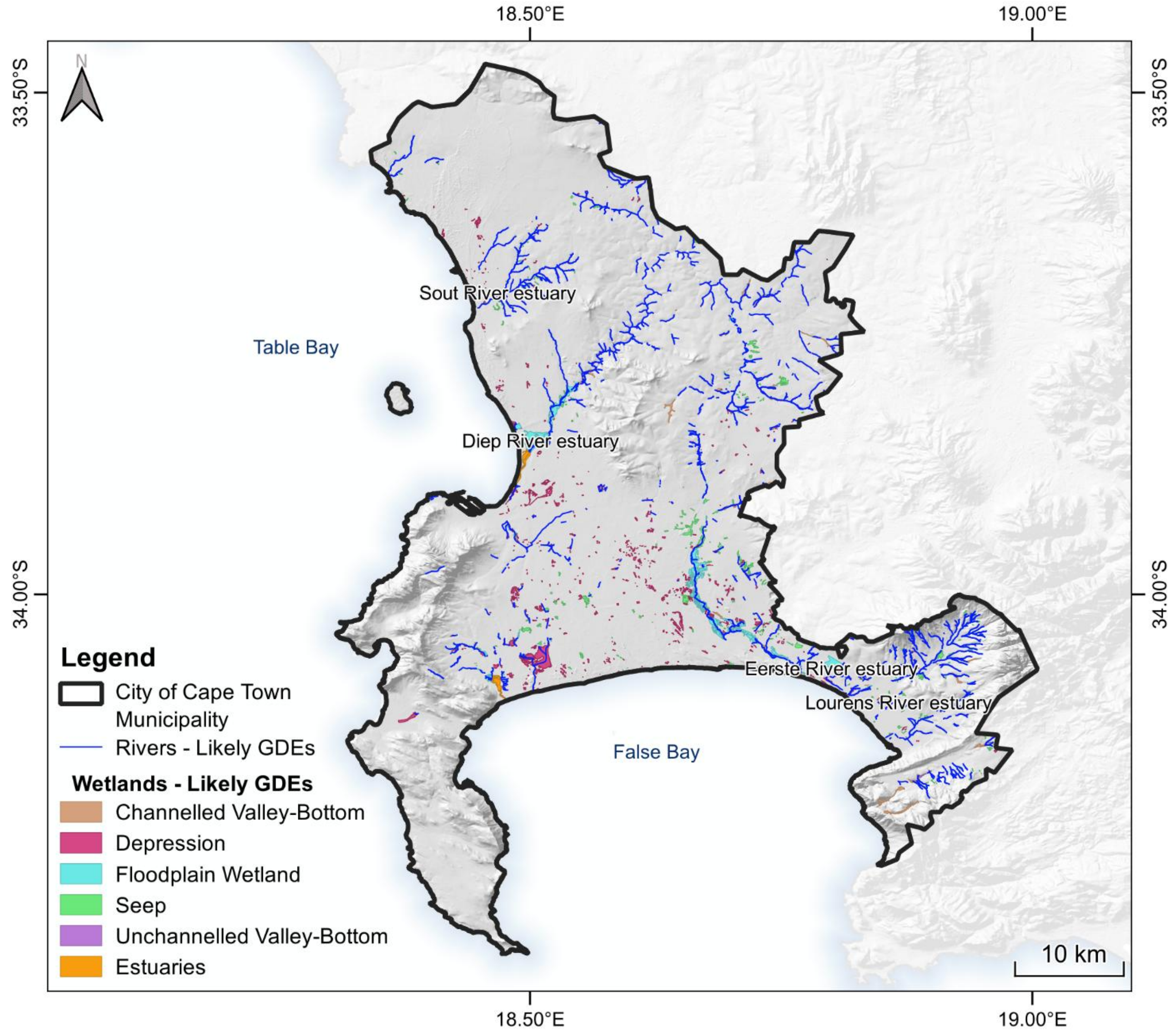

Figure 4-8: Surface water ecosystems that are likely to be GDEs.

4.5. Summary

This report presents a comprehensive assessment of groundwater dependency in the City of Cape Town, undertaken as part of the broader SADC-GMI initiative to evaluate groundwater dependency and vulnerability in coastal cities. The assessment highlights the role groundwater plays across multiple sectors, including municipal water supply, agriculture, industry, and domestic use, while highlighting the socioeconomic disparities in water supply for the City.

Cape Town's groundwater resources are hosted in three main aquifer types: the primary unconfined aquifers of the Sandveld Group (notably the Cape Flats and Atlantis Aquifers), the secondary fractured Table Mountain Group (TMG) aquifers, and the weathered and fractured basement aquifers of the Malmesbury Group and Cape Granite Suite. The City targets the CFA, Atlantis, and TMG aquifers for bulk water supply as part of its New Water Programme. However, there is a marked increase in groundwater use not only by the municipality but also by private individuals, industries, and agricultural users. This widespread and largely unregistered abstraction by private groundwater users poses growing risks to the sustainability and management of these aquifer systems.

In addition to human demand, groundwater-dependent ecosystems (GDEs), including wetlands and estuarine systems, are highly sensitive to fluctuations in groundwater levels and quality. The overlay of registered users and GDEs (see Figure 4-9) reveals key spatial hotspots where high levels of human dependency overlap with GDEs. This intersection highlights the need for integrated groundwater governance and the implementation of a conjunctive management approach, balancing surface and groundwater use, safeguarding ecosystem functions, and ensuring long-term water security for both people and nature.

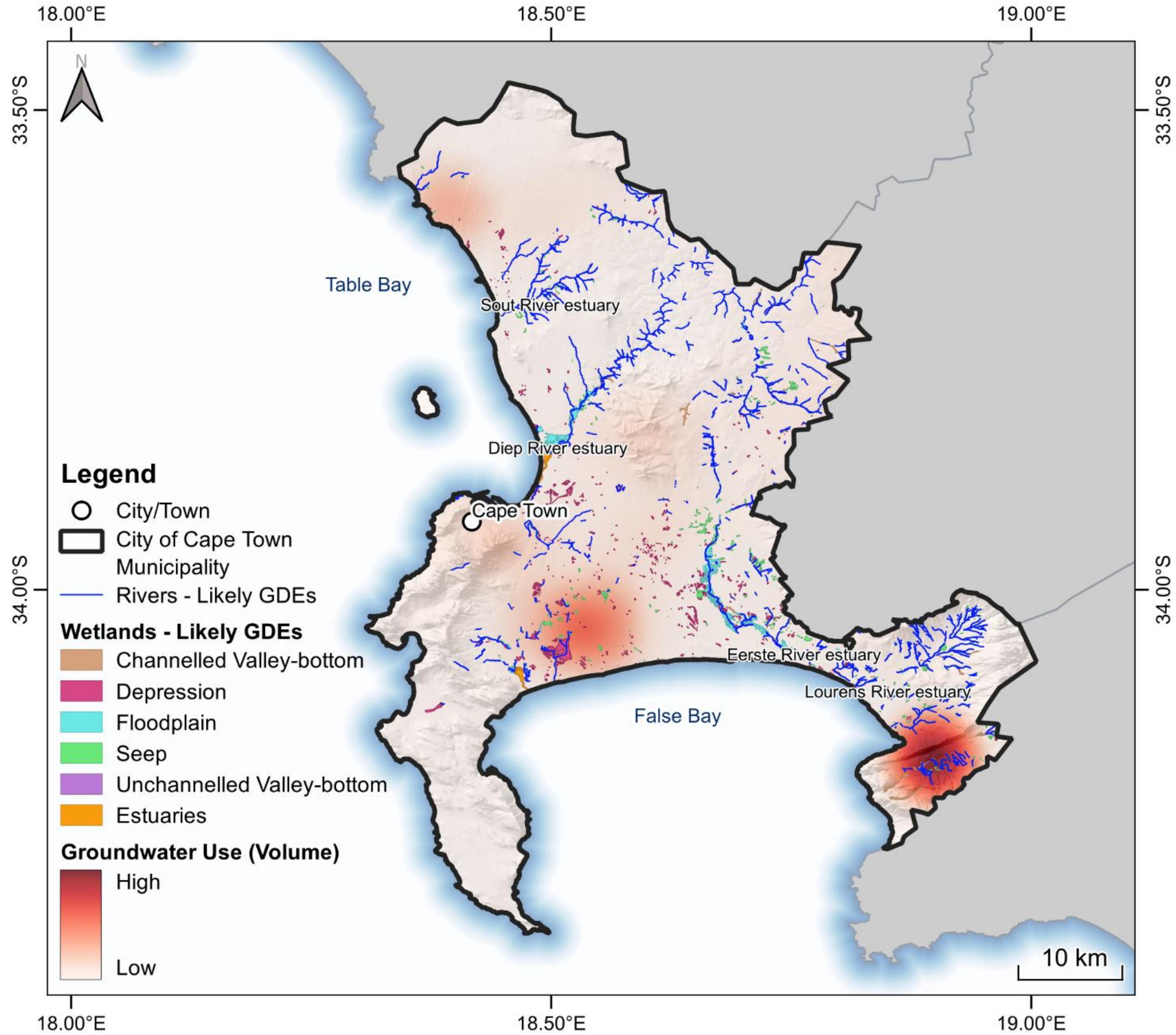

Figure 4-9: **Overlay of registered groundwater users and groundwater dependent ecosystems in the City of Cape Town Municipality, highlighting spatial hotspots of high groundwater dependency by overlaying registered users with mapped groundwater dependent ecosystems (GDEs).**

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