CHAPTER 4

Water Resources and Aquatic Ecology

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Executive Summary

E1 OVERVIEW

The Namakwa Region lies in the Northern Cape of South Africa in a region mostly characterised by very low rainfall, high evaporation rates and high levels of dependency on groundwater (Van Gend et al. 2021), with the entire study area being classified as either Hyper-Arid or Arid. Surface water resources are very limited, comprising mainly ephemeral streams and sporadic runoff events, mostly lasting for only a few days, with long dry periods in between events.

The region is however one of high biodiversity, with some areas supporting endemic flora and/or fauna of very high conservation importance. The only perennial river that flows through the area is the Orange River, the estuary of which enters the sea on the northwestern corner of the study area. Other rivers are seasonal to ephemeral, and although the area includes extensive pans and wetlands in places, surface water is generally sparse, both spatially and temporally.

In the context of the proposed Green Hydrogen Development (“GH_2”) with its required expansion of renewable energy generation and transmission infrastructure in the Namakwa Region (“the GH_2 supporting infrastructure”), the availability and quality of water for further development is likely to play a critical role in defining some of the opportunities for renewable energy expansion, and the direct and indirect impacts of such development on water demand.

At the same time, some of the proposed SEZ development interventions might increase the availability of fresh water in some areas, through desalination projects, changing current development constraints. Any new development in the region, particularly development at scale, including extensive linear infrastructure developments as well as impacts on flow regime and hydroperiod, could however impact on water resources from a biodiversity perspective, and need to be considered both locally and at a catchment level, when weighing up development opportunities and threats.

This Chapter considers the implications of regional expansion of renewable energy generation and transmission infrastructure on surface and groundwater resources, in terms of water quantity, quality and availability, both spatially and temporally, and the links between these systems. The ecological implications of such development on aquatic ecosystems are also considered, with a focus on inland aquatic ecosystems (e.g. rivers, wetlands, dams and pans) and estuaries. Three scenarios are considered – a baseline scenario (Sc0) with climate change and existing slowly increasing developments and populations; Green Hydrogen Development (GH_2) Scenario 1 (Sc1) (relatively small-scale renewable energy for GH_2 till 2035); and GH_2 Scenario 2 (Sc2) (upscaled renewable energy development, by 2050).

E2 GROUNDWATER SYSTEMS

E2.1 General

- Groundwater occurs in three different aquifer systems in the region namely:
    - Sandy/alluvial aquifers with direct recharge;
    - Fractured crystalline bedrock with indirect recharge from the primary aquifer;
    - Weathered zones or regolith (the layer of loose, weathered material overlying bedrock) and essential for the discharge from the alluvial aquifers and recharge to the fractured aquifers.

- Groundwater recharge is generally low (in the region 0.1 – 10 mm/a) and water quality as measured by electrical conductivity which is a function of the dissolved salts in the water, is relatively poor (70 – >1 000 mS/m).

E2.2 Current Trajectory and Anticipated Scenario 1 and Scenario 2 Impacts

- Climate change projections indicate that the Namakwa District will become hotter and drier; Mean Annual Precipitation (MAP) will decrease, and Mean Annual Potential Evapotranspiration (MAPE) will increase. A reduction in MAP is likely to decrease recharge to the alluvial aquifers, which consequently will impact recharge of basement aquifers. Shifting climate patterns are also likely to result in increased reliance on an already strained groundwater system.

- In a baseline scenario where no significant developments are anticipated to occur, population growth trends will result in increased strain on water supplies.

- Compounding the baseline scenario with further development (as per development of GH_2 and GH_2 supporting infrastructure) may result in a scenario where neither supply nor infrastructure is able to meet increasing demand.

E2.3 Main Sensitivities

- Given the high reliance of communities on groundwater, a number of Groundwater Resource Units have been identified as intermediate and high priority. Additionally, three Strategic Water Source Areas (SWSAs) have been delineated as of Very High Sensitivity in the study area: Port Nolloth, Kommagas and Kamiesberg SWSAs.
- Current Wastewater Treatment Works (WWTWs) and water treatment and distribution infrastructure are failing and require upgrades.
- The Department of Water and Sanitation (DWS) project lists indicate that the District Municipality (DM) is already struggling to meet current water demand and added pressure may have severe consequences.

E2.4 Key Recommendations

- High-risk activities (e.g. chemical storage and pipelines, treatment and processing facilities) should not take place in areas delineated as high and very high sensitivity from a groundwater perspective.
- Further GH_2 development planning would need to be informed by feasibility studies on costly mitigation measures, including investment into municipal infrastructure and management, and groundwater desalination.

E3 SURFACE HYDROLOGY

E3.1 Key Systems

Surface water resources in the interior are limited. Most drainage features drain westwards, with a few eastward draining channels in the east of the area. However, large areas in the central region are endoreic. Runoff in the drainage network is very scarce, with discharge events only occurring during infrequent heavy rains, and lasting only a few days. Runoff is limited to less than 10% of the time with long dry periods between events. The Orange River bounds the study area in the north, flowing westwards to discharge at Alexander Bay. Abstractions from the Orange River sustain much of the communities and industry in the north of the region.

E3.2 Current Trajectory and Anticipated Scenario 1 and 2 Impacts

The region is predicted to become warmer and drier in the near future, with some 18% of the area likely to change from Arid to Hyper-Arid, offering fewer development opportunities outside the Orange River supply network. Planned augmentation of the Orange River abstraction infrastructure and reticulation is aimed at supplying *inter alia* the anticipated needs for GH_2 Scenario 1. However, with the current system consistently yielding less than the design demand, future schemes will require improved operation and maintenance, with adequate funding and capacity.

E3.3 Main Sensitivities

The current abstractions from the Orange River and reticulation into the interior of the region are ageing and often do not yield their design demand, which continues to increase. Proposed new and augmented abstraction works and reticulated networks are considered extremely sensitive to poor management and maintenance, since they have been assessed as being the only viable source for sustaining water supply to the region. These systems may be supplemented by coastal desalination works, but there is some concern over the capacity of local operators to cope with the more sophisticated technology.

From a different perspective, with the very low occurrence of runoff events and long periods without runoff, all rivers and floodplains are also considered fragile to disturbance and river networks would be unable to reconfigure from disturbance (e.g. erosion) within periods of several decades.

E3.4 Key Recommendations

- Estimate the actual future water needs for Sc1 and Sc2 development and the extent to which, if any, these can be met through design and implementation of new and augmented water supply schemes from the Orange River, while providing for the ecological reserve for the lower Orange River and its estuary;
- Implement and adequately fund effective desalination plants for saline groundwater and seawater use to augment highly limited surface water supplies;
- Provide for adequate operation and maintenance of the abstraction, treatment, reticulation and storage works for water from the Orange River;
- Provide for expertise to operate desalination plants at proposed coastal locations;
- Prevent disturbance to river systems and floodplains, particularly at infrastructure crossings;
- Prevent encroachment of structures or dwellings into floodplains.

E4 INLAND AND ESTUARINE AQUATIC ECOSYSTEMS

E4.1 Key Systems

Aquatic ecosystems considered in this chapter include inland and estuarine ecosystems as well as micro-outlets. Wetlands are limited, due to the aridity of most of the study area. Inland aquatic ecosystems thus largely comprise ephemeral rivers and pans, although there are some areas (e.g. the Kamiesberg mountains) where there are seasonal and perennial wetlands that play important roles in the supply of livestock grazing areas and in erosion control and groundwater recharge. The Orange River is the only permanent river in the study area, and it receives most of its flows (outside of periodic local floods) from its upstream catchment. Endoreic areas in the study area support ephemeral pans. Pans are the most common aquatic ecosystem type in the study area, and many of these are classified as Critically Endangered or Endangered, depending on their Bioregion.

The Orange River Estuary is the largest and most ecologically important estuary in the study area. In addition to this, the study area includes four smaller Cool Temperate Arid Predominantly Closed (CTAPC) estuaries (the Buffels, Swartlintjies, Spoeg and Groen River Estuaries) and a few micro-outlets, where flows are too ephemeral to support estuarine habitat. Apart from the Orange River, eight mainstem ephemeral rivers flow into the Atlantic Ocean within the study area, while others dissipate inland and never reach the sea. Most rivers are in good ecological condition (PES Categories B/C), with notable exceptions including the Kwaganap, Bitter, and parts of the Groen River system. Pressures on these systems include road infrastructure, mining, invasive species, overgrazing, and groundwater abstraction.

E4.2 Current Trajectory and Anticipated Scenario 1 and 2 Impacts

In the Baseline Scenario, potential drivers of inland aquatic ecosystem degradation mainly comprise possible changes in pan ecosystem diversity; water quality deterioration (increasing salinity and nutrients); reduced riparian resilience as a result of reduced frequency of flows and extended no flow periods; increased vulnerability of ephemeral systems to erosion, grazing and trampling; and an increased likelihood of invasion of watercourses by alien plants, thus compounding surface and groundwater impacts.

Decreases in groundwater flows and increases in groundwater salinity would also be of concern for water quality in all four CTAPC estuaries in the study area. A reduction in the frequency and magnitude of floods in the lower reaches of ephemeral rivers with estuarine outlets would also potentially further impact on estuarine connectivity, by reducing breaching episodes and thus limiting fish recruitment into these systems.

Without active intervention, existing impacts on the Orange River Estuary would continue, and additional flood reduction impacts including changes in sediment regime, alien plant invasion and a general deterioration in river function and processes would be anticipated, if the proposed large dam upstream of the study area (Vioolsdrift Dam) is constructed.

In the context of large-scale expansion of linear, hardened infrastructure such as roads and pylons across the Namakwa Region, impacts such as concentrated flows into watercourses, erosion, changes in sediment regimes and ecosystem fragmentation are all likely, along with indirect impacts such as nutrient enrichment from variously treated or untreated effluent discharges and potentially expanding urban formal and informal settlement footprints.

Many of the inland aquatic ecosystems within the study area are Critically Endangered or Endangered ecosystems and any impacts to such systems would be significant. The Orange River Estuary and the four CTAPC estuaries in the study area are all rated as Endangered systems, of high conservation priority.

E4.3 Main Sensitivities

Inland and estuarine ecosystems in the study area are sensitive to the following key issues:

- Changes in water quality (increased or decreased salinities; nutrient enrichment);
- Changes in hydrology (increased water flows (e.g. from WWTW effluent discharges) as well as decreases in flow frequency and/or the magnitude of flood flows;
- Physical disturbance;
- Habitat fragmentation;
- Alien plant invasion.

E4.4 Key Recommendations

i. Measures to **avoid** impacts include the following:

- **a.** No new development should be located in areas mapped as Very High Sensitivity;
- **b.** Limited Low Risk activities (e.g. essential road crossings) might be considered in High Sensitivity areas, provided there is adequate mitigation;
- **c.** Only Low Risk activities should be located in buffer areas (Medium Sensitivity);
- **d.** High Risk activities should be located only in areas of Low Sensitivity;
- **e.** If Medium Risk activities are mitigated to low Risk, they could take place in areas of Low Sensitivity and some Medium sensitivity areas (excluding buffer areas);

ii. Measures to **mitigate against** impacts include design and implementation of appropriate stormwater management systems, appropriate management of buffer areas, attention to the design of existing and new road crossings over watercourses to minimise watercourse impacts, attention to construction disturbance and avoiding the passage of vehicles through pans, ephemeral watercourses and estuaries;

iii. Measures to **manage** impacts include pre-development implementation of the non-flow-related requirements for the Orange River Estuary to meet its REC; pre-development upgrading of WWTWs in areas likely to expand their urban populations; and upgrading of WWTWs that discharge treated or untreated effluent or enable irrigation within 500 m of any estuary so as to fall within the mesotrophic range for aquatic ecosystems, with regard to phosphorus and nitrogen nutrients.

E5 RESULTS OF SENSITIVITY ASSESSMENTS

Groundwater, surface water and aquatic ecosystem sensitivity layers are shown in **Figures E1-E3**. The layers have not been consolidated, since different activities / landuses may impact differently groundwater versus surface water and associated aquatic ecosystems.

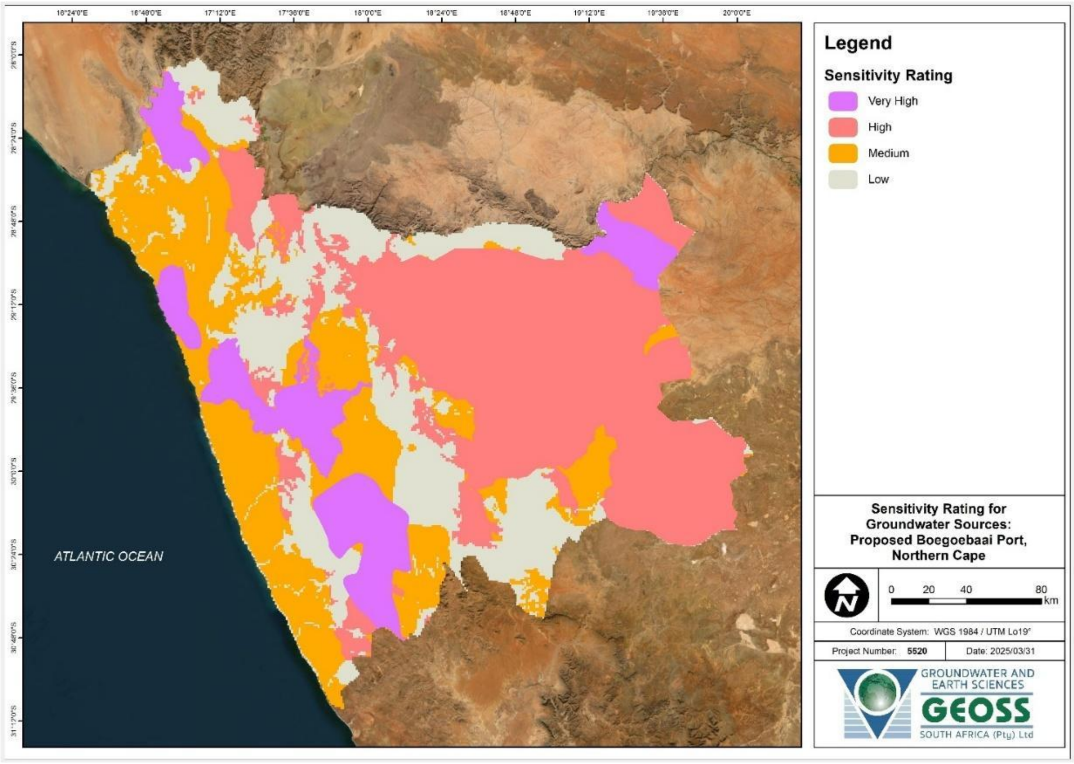

Figure E1
Results of application of the groundwater sensitivity classification

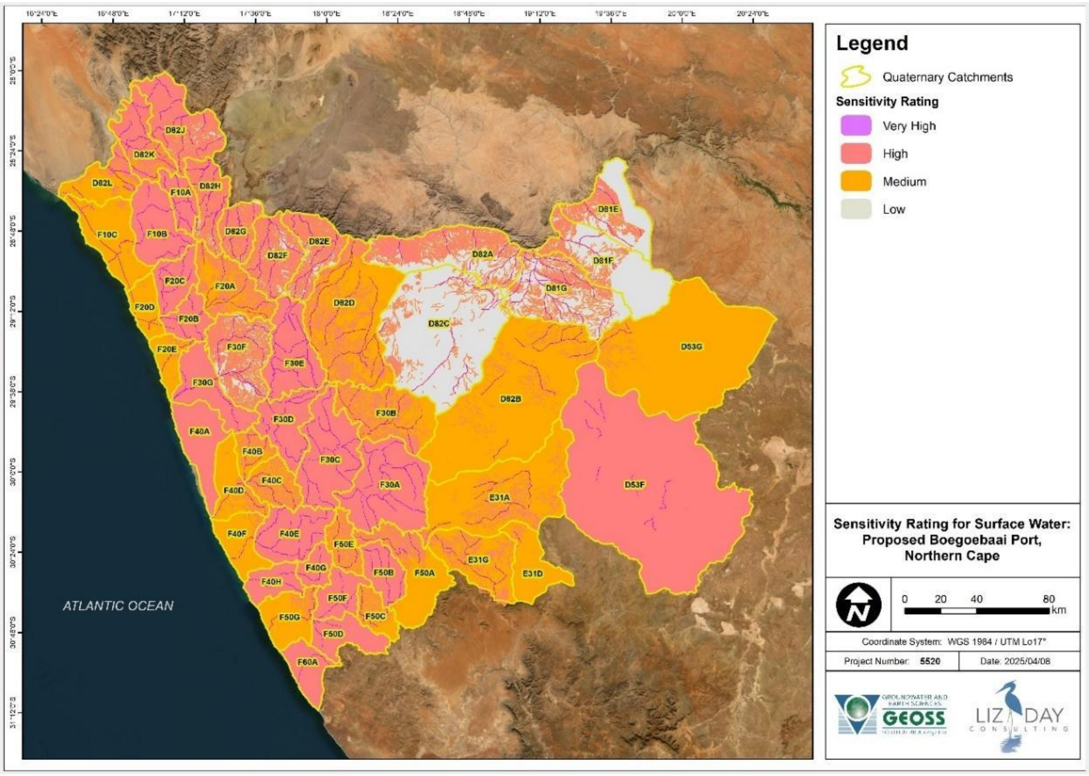

Figure E2
Results of application of the surface hydrology sensitivity classification

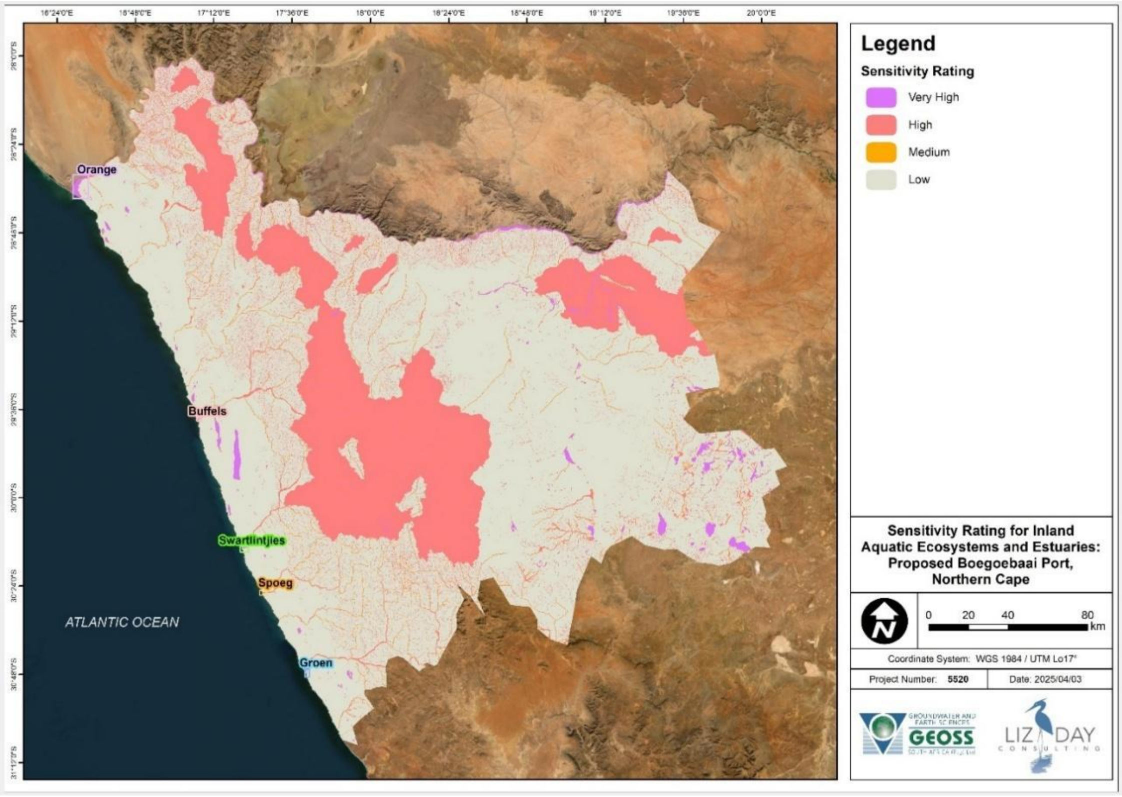

Figure E3
Results of application of the inland and estuarine aquatic ecosystem sensitivity classification

E6 POTENTIAL OPPORTUNITIES

The report acknowledges that, in addition to risks posed by the proposed development of GH_2 and its supporting infrastructure, such development could also bring with it opportunities for development in some areas, if the availability of fresh water increased as a result of affordable desalination projects, thus changing current development constraints. Such opportunities would however themselves be associated with increased risks from a biodiversity perspective, and their realisation would be contingent on meeting the challenges already highlighted around effective upgrading, expansion and maintenance of WWTW and water treatment infrastructure, and water reticulation.

E7 RECOMMENDED STRATEGIC MANAGEMENT ACTIONS

In addition to the recommendations already outlined, a number of strategic actions are also recommended if this project is to be taken forward. These comprise:

- Generally:
  - Ensuring that the additional water volume (and water quality) that would be required by the proposed development would in fact be available – this would require consideration by the DWS Water Resource Classification team, currently engaged in this assessment;
- From a groundwater perspective:

    - Investment in improvement in infrastructure and management of groundwater resources in the study area, including a focused investment in supplying treated, desalinised water to serve projected increased demand from domestic and industrial users in a GH_2 scenario;
    - Protection of groundwater quality from high-risk activities by implementing stricter regulations and requiring adherence thereto;
    - Investment in training schemes to enhance borehole management, in particular regarding mitigation of issues such as iron biofouling;
    - Investment in managed aquifer recharge schemes, including appropriate investment in training, human resources and infrastructure, to mitigate against possible natural increasing salinisation of groundwater;
- From a surface hydrology perspective:
    - Provision for (allowed-for) abstraction from the Orange River and reticulation to the level of Scenario 1 demand;
    - Provision for adequate operation and maintenance of (authorised) abstraction, treatment, reticulation and storage works;
    - Investment in the urgent development / out-sourcing of expertise to operate desalination plants at proposed coastal locations;
    - Ensuring that the water demand (volume and quality) for Scenarios 1 and 2 can be met, based on sustainable use of available surface and groundwater resources, including supplementation with groundwater and desalinated seawater sources as well as with treated WWTW effluent;
- From an inland and estuarine ecosystem perspective:
    - Avoidance of inland and estuarine aquatic ecosystems in any development context, given that these ecosystems are regionally rare, sensitive and of (generally) high ecological importance, as well as the fact that their degradation could result in multiple other impacts, including impacts on road infrastructure;
    - Implementation of the non-flow related rehabilitation requirements for the Orange River Estuary, as outlined in DWS (2017b and 2024b);
    - Consideration of the need for pro-active watercourse and terrestrial offset banking to ensure holistic biodiversity conservation across all habitat types;
    - Upfront investment in maintenance / improvement in road design, to ensure that flood flows into estuaries are not artificially attenuated, while also ensuring that flows under roads do not result in concentrated flows, channel narrowing and resultant erosion of river channels;
    - Ensuring that the recommended EWR for the lower Orange River and the Orange River Estuary can still be met, and is in no way jeopardised by the proposed development – this would require investment in desalination of both seawater and groundwater.

E8 CONCLUSIONS

This chapter considers water resources in the study area from both the perspective of the limitations this resource places on future development and the sensitivity of these systems themselves to some aspects of the proposed development. The greatest risks are posed by activities resulting in changes in water quality; reductions in water availability or predictability; and physical disturbance that reduces natural downstream flushing (e.g. estuaries) or increases channel erosion, especially in the vicinity of road crossings. Surface and groundwater flows and quality are interlinked, and changes in one can have impacts on the other. These resources are moreover already under threat as a result of climate change and existing demand.

Given the arid to hyper-arid character of the study area, water and its sustainable management are critical factors in any future development planning in the area. In this regard, it seems evident that the development of GH_2 and GH_2 supporting infrastructure should only be considered in a context where allowance is also made for large-scale desalination of seawater and/or groundwater to provide for the increase in direct and indirect water demand likely to be associated with such development. Such an approach would come at great potential ecological risk due to the inherent risks associated with brine generation and disposal as well as their energy requirements. Further, the naturally ephemeral watercourses and pans in the area have high biodiversity value and would be vulnerable to changes in hydroperiod, including receipt of additional (potentially nutrient enriched) water from ancillary developments such as expanded WWTWs and effluent outflows. Attention to creating a circular water economy that did not change aquatic ecosystem function would be important if the proposed development were to proceed.

Risk assessments presented in this chapter show that a high degree of avoidance of aquatic ecosystems and groundwater recharge areas is required, to reduce the high likelihood of major consequence for water resources including inland and estuarine aquatic ecosystems. Overall, it must be stressed that while solar and wind energy sources in the study area may be amply available, the limited availability of water resources and the high sensitivity of aquatic ecosystems in this particular region is a major constraint for such development at the outset, taking into account current and future demands and projected climate change impacts.

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Abbreviations

CTAPC	Cool Temperate Arid Predominantly Closed (estuary)
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	electrical conductivity
ETS	Ecological Threat Status
EWR	Ecological Water Requirements
FEPA	Freshwater Ecosystem Priority Area
GA	General Authorisation
GRU	Groundwater Resource Unit
ha	hectares
LM	Local Municipality
L/s	litres per second
m	metres
m^3	cubic metres
mamsl	metres above mean sea level
MAP	mean annual precipitation
MAPE	mean annual potential evapotranspiration
mbgl	metres below ground level
mm/a	millimetres per annum
mS/m	milli-Siemens per meter
NGA	National Groundwater Archive
NFEPA	National Freshwater Ecosystem Priority Area
NMP	Namaqua Metamorphic Province
NNMP	Namaqua-Natal Metamorphic Province
PES	Present Ecological State
PV	Photo-voltaic
EIS	Ecological Importance and Sensitivity
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
SEZ	Strategic Economic Zone
SWSA	Strategic Water Source Area
WARMS	Water Authorisation Registration Management System
WMA	Water Management Area

CHAPTER 4. WATER RESOURCES AND AQUATIC ECOLOGY

4.1 INTRODUCTION AND SCOPE

4.1.1 Background

Green hydrogen (GH_2), and its derivative products (e.g. green ammonia and green methanol) potentially provide an opportunity to decarbonise the South African energy economy, generate new revenues, create jobs and skills and facilitate a Just Energy Transition (Schreiner *et al.* 2024). As part of South Africa's ambition to become a player in the globally emerging green hydrogen (GH_2) market, a substantial programme of greenfield infrastructure has been proposed in the Northern Cape, consisting of three main components:

- A new deepwater port at Boegoebaai, with dry and liquid bulk berths as well as multi-purpose terminals;
- A mixed-use Special Economic Zone (SEZ), located in the region adjacent to the proposed Boegoebaai Port; and
- Expansive regional renewable energy (wind and solar PV) generation and transmission infrastructure.

The production of GH_2 at the scale envisaged could have multiple direct and indirect impacts, including on local economies, infrastructure, communities and natural ecosystems and resources. In order to consider these potential impacts, the Council for Scientific and Industrial Research (CSIR) has been appointed to undertake an independent Strategic Environmental Assessment (SEA). The overarching purpose of the SEA is to develop an integrated decision-making framework to guide the planning of the proposed Boegoebaai Port, Special Economic Zone, and wider Namakwa Region renewable energy development in a sustainable manner (Schreiner *et al.* 2024) (see **Figure 4-1.1**).

The SEA has two outputs:

- Boegoebaai Port and Special Economic Zone (SEZ) (Work Package 1): Local-scale SEA report, concerned with assessing the sensitivities of the receiving environment around the proposed port and SEZ;
- Namakwa Region SEA (Work Package 2): Regional-scale SEA report covering the main sustainability issues associated with expansion of renewable energy (wind and solar PV) generation and transmission infrastructure across parts of the Namakwa District, in response to the proposed development of the Boegoebaai Port and SEZ.

The present report falls under Work Package 2. It considers the implications and associated risks and opportunities of potential expansion of renewable energy generation and transmission infrastructure for surface and ground water resources, as well as for aquatic ecosystems and aquatic biodiversity.

4.1.2 Scope of work

The [1]Namakwa District lies in the Northern Cape of South Africa in a region mostly characterised by very low rainfall and high levels of dependency on groundwater (Van Gend *et al*. 2021). The region is also one of high biodiversity, with some areas supporting endemic flora and/or fauna of very high conservation importance. The only perennial river that flows through the area is the Orange River, the estuary of which enters the sea on the northwestern corner of the study area. Other rivers are seasonal to ephemeral, and although the study area includes extensive pans and some wetlands, surface water is generally sparse, both spatially and temporally. In

[1] Also referred to as Namaqualand

addition to the Orange River Estuary, the SEA area ("the study area") includes the Brak, Groen, Bitter, Spoeg, Swartlintjies, Buffels, Kwaganap and Holgat River outlets to the sea, classified variously as Cool Temperate Arid Predominantly Closed (CTAPC) estuaries and micro-outlets (Van Niekerk *et al.* 2024).

In the context of the proposed expansion of renewable energy generation and transmission infrastructure in the area, in support of the proposed Boegoebaai Port and SEZ development, the availability and quality of water for further development is likely to play a critical role in defining some of the opportunities for renewable energy expansion, and the direct and indirect impacts of such development on water demand.

At the same time, some of the proposed SEZ development interventions might increase the availability of fresh water in some areas, through desalination projects, thus changing current development constraints. Any new development in the region, particularly development at scale, and including extensive linear infrastructure developments, could also impact on water resources from a biodiversity perspective, and would need to be considered both locally and at a catchment level, when weighing up development opportunities and threats.

This is then the backdrop to the present chapter, produced as one of several inputs into Work Package 2. This chapter considers the implications of regional expansion of renewable energy generation and transmission infrastructure for surface and groundwater resources, in terms of water quantity, quality and availability, both spatially and temporally, as well as the links between these systems. The ecological implications of such development on aquatic ecosystems are also considered, with a focus on inland aquatic ecosystems (e.g. rivers, wetlands, dams and pans) and estuaries. Note that marine ecosystems are considered separately, in the Work Package 1 outputs of this project.

4.1.3 Project team

This input has been integrated from collaborative inputs provided by a multi-disciplinary team, including:

- Professor Simon Lorentz (hydrologist, SRK Consulting);
- Ms Zita Harilall (geohydrologist, GEOSS); and
- Dr Liz Day (aquatic (freshwater) ecologist, Liz Day Consulting).

Note that the original surface hydrology report has been appended to this report (Appendix F). Geohydrology and aquatic ecosystems reporting has been compiled directly into the present document.

4.1.4 Limitations and assumptions

- The findings of this chapter have been drawn from a focused desktop assessment, based on existing spatial and other data and available reports, the implications of which were required to be distilled into a concise document, for inclusion in final SEA reporting;
- This means that no new surface, groundwater or biophysical data were collected as part of this assessment, which was furthermore informed only by the existing knowledge of the specialist team of various parts of the SEA area ("the study area");
- With regard to groundwater impacts and their implications:
    - The regional groundwater maps in terms of yield, quality and vulnerability are of a regional scale and may not account for small-scale nuances and therefore only provide an indication of expected conditions;
    - No site visit was undertaken to the study area, and groundwater information was compiled from available databases and literature;

  - The WARMS 2025 database search only accounts for registered groundwater use. It is possible that there may be unregistered groundwater users, thus affecting the accuracy of current and projected groundwater use volumes;
  - The results yielded by the above database search may not be accurate and may not account for either newly commissioned boreholes that have yet to be incorporated into the database, and boreholes that no longer exist, as borehole records date back as far as 1914;
- From an aquatic ecosystems perspective:
  - The assessment has relied on existing watercourse and estuary spatial data, included in the NFEPA and NWM (ver 5) datasets. These data are useful to inform broad conservation planning, but have not been ground-truthed sufficiently for high-confidence information of environmental impact assessments and for detailed development planning. This is a significant limitation in this assessment – the mapped extent of watercourses in the above datasets is not necessarily accurate;
  - An important assumption is that the Resource Quality Objectives (RQOs) and Recommended Ecological Categories (RECs) for the Orange River and the estuaries within the study area remain unchanged, and remain legislated targets for aquatic ecosystem management in the area, and in the upstream Orange River Catchment (e.g. DWS 2016 2017a 2017b and 2024);
- Another assumption, relevant to the assessment of opportunities, constraints and impacts in this report is that it is assumed that no new water pipelines will be created to convey fresh water for domestic use inland from the SEZ, and that these areas will remain reliant on existing water resources – this may in fact not be correct, if desalination allows water production at scale;
- Finally, this project assumes that the expansion of green energy projects that would be a requirement for green hydrogen production at the proposed Boegoebaai Port and SEZ would be confined to the Namakwa Region. This is not necessarily true, and expansion of these activities further afield might in fact take place, but the implications of this have not been considered here.

4.1.5 Definitions

All references to wetlands and watercourses in this document are based on the following definitions, taken from the National Water Act (NWA) (Act 36 of 1998):

“**Watercourse**" means -

(a) a river or spring;

(b) a natural channel in which water flows regularly or intermittently;

(c) a wetland, lake or dam into which, or from which, water flows; and

(d) any collection of water which the Minister may, by notice in the Gazette, declare to be watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;

“**Wetland**" means -

Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

Government Notice (GN) 4167 of December 2023 furthermore defines:

“**Extent of a watercourse**” as:

(a) The outer edge of the 1 in 100 year flood line and/or delineated riparian habitat, whichever is the greatest distance, measured from the middle of the watercourse of a river, spring, natural channel, lake or dam; and

(b) Wetlands and pans: the delineated boundary (outer temporary zone) of any wetland or pan.

The National Environmental Management: Integrated Coastal Management Act 2008 (as amended: 2015) defines an estuary as follows:

"**Estuary**" means a body of surface water—

(a) that is permanently or periodically open to the sea;

(b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the body of surface water is open to the sea; or

(c) in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water;

Aquatic ecosystems are defined in Ollis *et al.* (2013)'s National Classification System for wetlands and other aquatic ecosystems as including

- Inland systems (i.e. watercourses (as defined above) comprising rivers, wetlands, springs and pans
- Estuarine systems (as defined above); and
- Marine systems.

This report is concerned only with Inland and Estuarine aquatic ecosystems, but includes non-estuarine "micro-outlets" as described in van Niekerk *et al.* (2020). These are defined in the latter paper as follows:

These are very small waterbodies (<1 ha in area or <50 m in length) that are ephemeral in nature (i.e. they can dry out during periods of low flow) or are elevated above mean sea level, with a perched outflow channel that does not facilitate tidal mixing of salt- and freshwater. They can, however, act as a limited conduit between the land and the sea during periods of elevated stream outflow or exceptionally high storm sea events.

4.1.6 Study area

The study area for this project encompasses an area of approximately 5.8 million hectares (ha), located in the Northern Cape Province of South Africa. It extends north and east from the coast, just north of the small town of Bitterfontein, including some 310 km of coastline and running inland up to about 260 km east. The South African boundary of the Orange River, from about 30 km east of Onseepkans to the coastal mining town of Alexander Bay, comprises the northern boundary. Within the study area are located both the Namakwa National Park in the south and the Richtersveld Transfrontier Park (extending over the Orange River into Namibia to the north).

4.1.7 Project approach

The findings of this Chapter have been driven by the Water Resources study team, with additional input from other specialists involved in different Chapters in the two SEA Workstreams, including input from the Socio-economics and Infrastructure and Planning Chapters.

Appendix A provides a listing of the datasets used in this Chapter, to generate the maps and overall findings.

4.2 MAJOR WATER RESOURCE DRIVERS

4.2.1 General

The major natural drivers of surface and groundwater resources, and the inland and estuarine ecosystems that depend on them, comprise climate, geology, soils and catchment geomorphology. These drivers determine the quantity and quality of water resources in the study area, as well as its spatial and temporal variation. Human interventions and activities are secondary drivers, also impacting on resource quality and quantity. This section provides a brief overview of these major drivers.

4.2.2 Climate

4.2.2.1 Rainfall

The rainfall in the study area is the lowest in the country, with Mean Annual Precipitation (MAP) varying from 60 mm to 215 mm as illustrated in **Figure 4-2.1**. MAP typically increases from west to east until the escarpment is reached, then decreases towards the interior. Higher lying areas within the study area receive much higher rainfall volumes than the surrounding lower lying areas and coastal plains.

The areas in the study area with the lowest rainfall include the north-western coastal region; the north -eastern section and along the Orange River. Rainfall increases towards the southern interior of the region, with highest values in the Kamiesberg mountains. Along the coastline, frequent fog occurs during winter, due to the cold Benguela current. These fogs contribute to moisture levels.

Mean annual values are, however, extremely deceptive, since the distribution of rainfall events is large, with some areas experiencing no rain for periods of years and rainfall often occurring in extreme events. This is reflected in the runoff analysis and particularly the number of dry days between runoff events.

Mean Annual Precipitation is predicted to decrease by 12% in the Near Future (2050). This result is derived from the average of six Global Climate Models (GCMs) applied to the study area. The maximum change GCM predicts a 24% decrease and the minimum a 5% increase.

The distribution of estimated Near Future changes in MAP is illustrated for the Average of 6 GCMs in Appendix C1 (**Figure C1.9**).

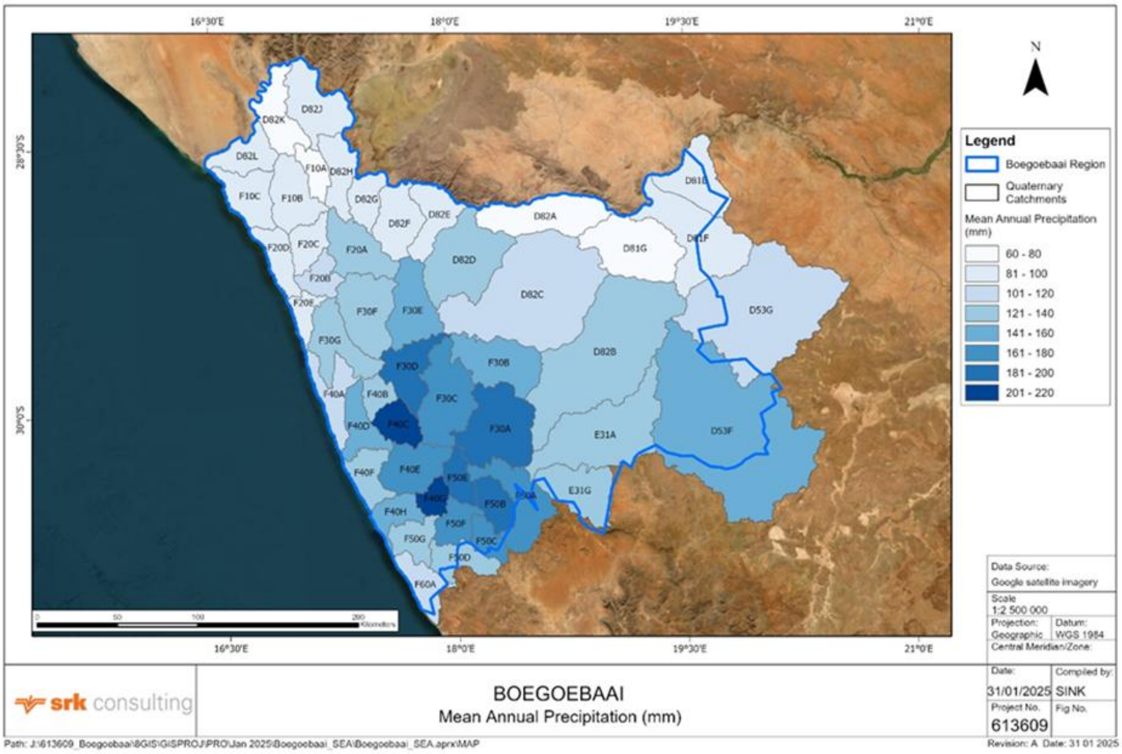

Figure 4-2.1: Distribution of the mean annual rainfall in the study area.

4.2.2.2 Temperature

The region has warm summers, with temperatures averaging around 30°C and occasionally peaking at 40°C, while winters are cooler, with daily averages ranging from 8 to 17°C. Observed average daily temperatures for Springbok (within the study area) are shown in **Figure 4-2.2**.

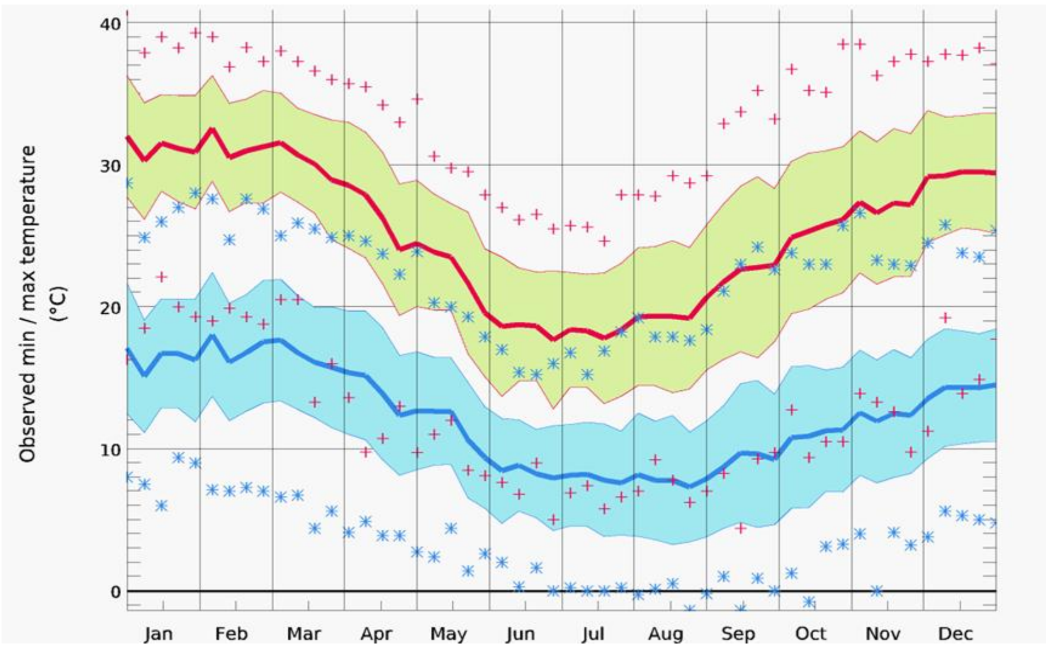

Figure 4-2.2: Mean daily maximum and minimum temperatures at Springbok.

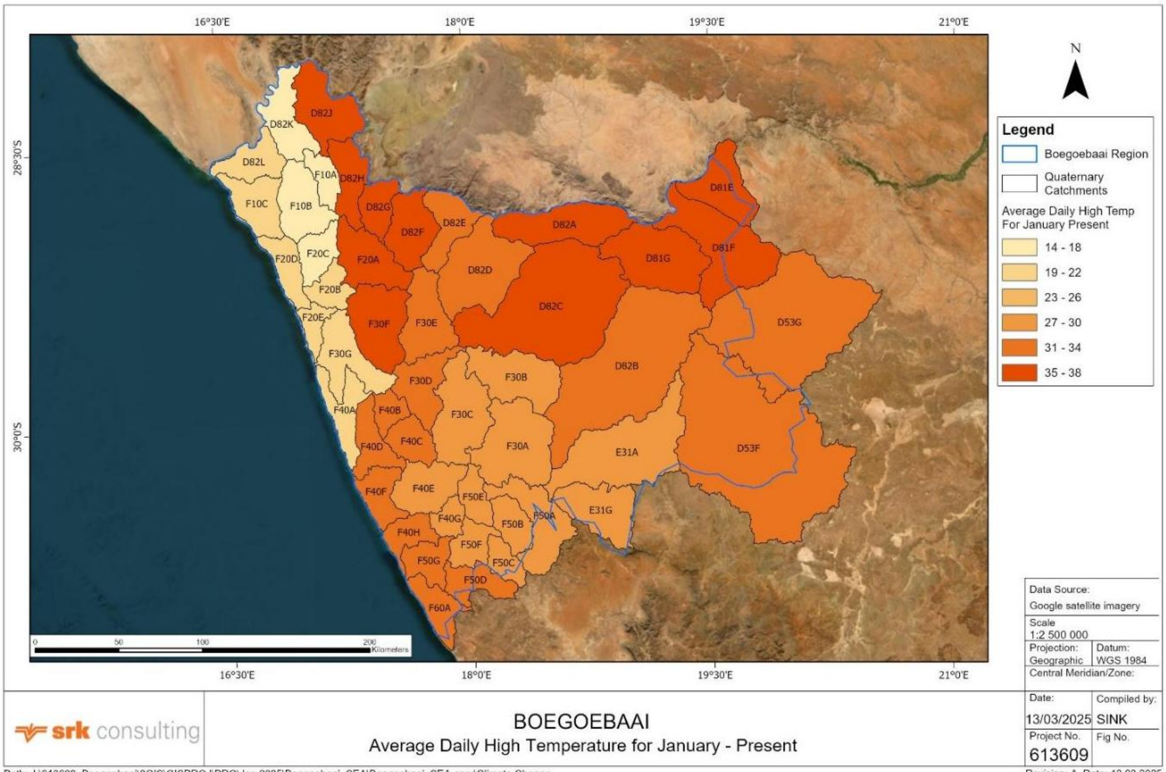

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Figure 4-2.3: Distribution of average Temperatures for January.

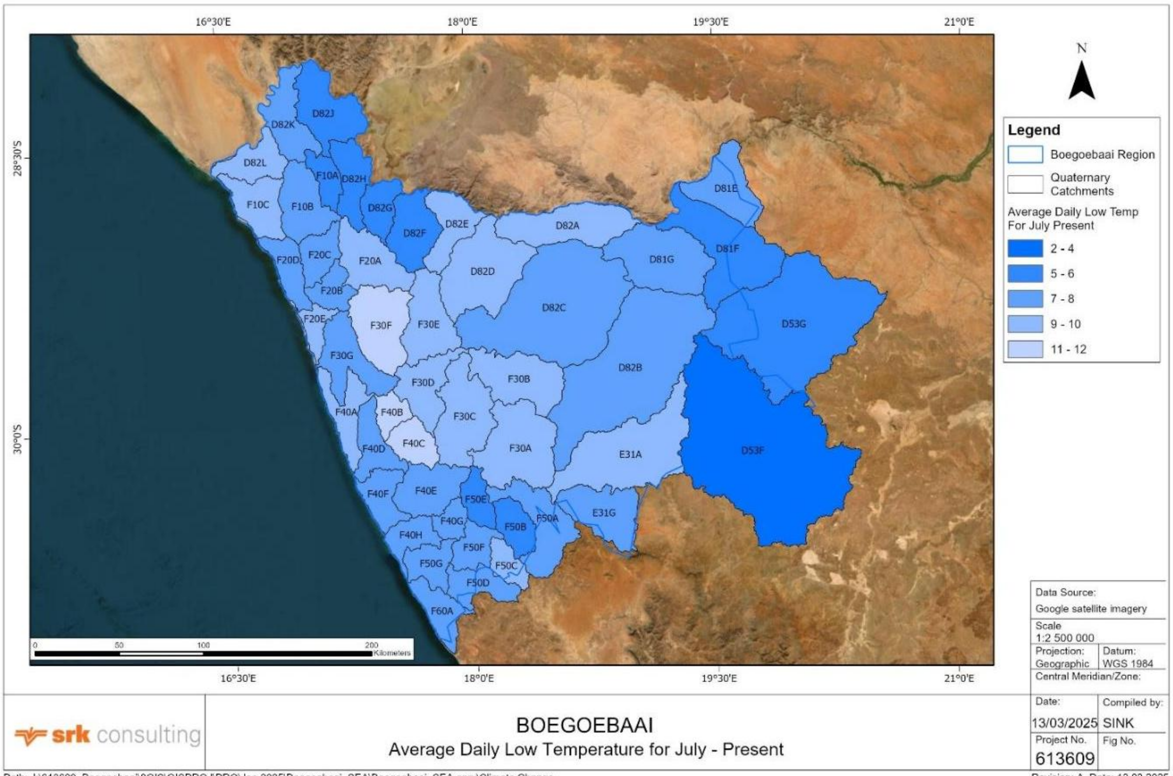

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Figure 4-2.4: Distribution of Average Temperatures for July.

4.2.2.3 Mean Annual Potential Evaporation and Potential Evapotranspiration

Potential evaporation tends to increase from the west to the east (Adams et. al., 2004

Mean Annual Potential Evaporation (MAPE) ranges between 611 mm and 2 680 mm (**Figure 4-2.5**) and exceeds the MAP by between 8 to 44 times. Evaporation rates are lowest in the northwest coastal areas of the region and increase towards the east and south.

The Aridity Index, defined as the ratio $\frac{MAPE}{MAP}$, is greater than 20 over 24% of the quaternary catchments, classifying these as Hyper-Arid (Gunkel and Lange 2017). The remainder are all classified as Arid, being less than 20, while 12% of the quaternaries have an Aridity Index less than 10. However, none of the quaternary catchments have an Aridity Index less than 5, which might classify these as Semi-Arid.

> Mean Annual Potential Evaporation is predicted to increase by 7% in the Near Future scenario (2050). This result is derived from the average of six GCMs applied to the study area (WRC 2023). With the predicted changes in MAP and MAPE in the Near Future scenario, some 18% of the quaternary catchments are likely to change from Arid to Hyper-Arid (estimated from Schütte et al., 2024; Gunkel and Lange, 2017),
>
> The distribution of estimated Near Future changes in MAPE is illustrated for the Average of GCMs in Appendix C1 (**Figure C1.10**). The Present and Near-Future distributions of Aridity Index are also presented in Appendix C1 (**Figures C1.7** and **C1.8**).

Annual potential evapotranspiration_(PET) ranges between 12 – 15 times the MAP. However, in certain quaternary catchments, this factor is as high as 22 (Adams et al., 2004). Studies found actual evapotranspiration is much higher in areas of dense vegetation and shallow water levels than in areas of sparse vegetation and deeper water levels (Van der Sommen and Geirnaert, 1988), Campbell et al., (1992) further reported that evaporation occurred to a depth of 91 cm in the subsurface of the alluvium cover.

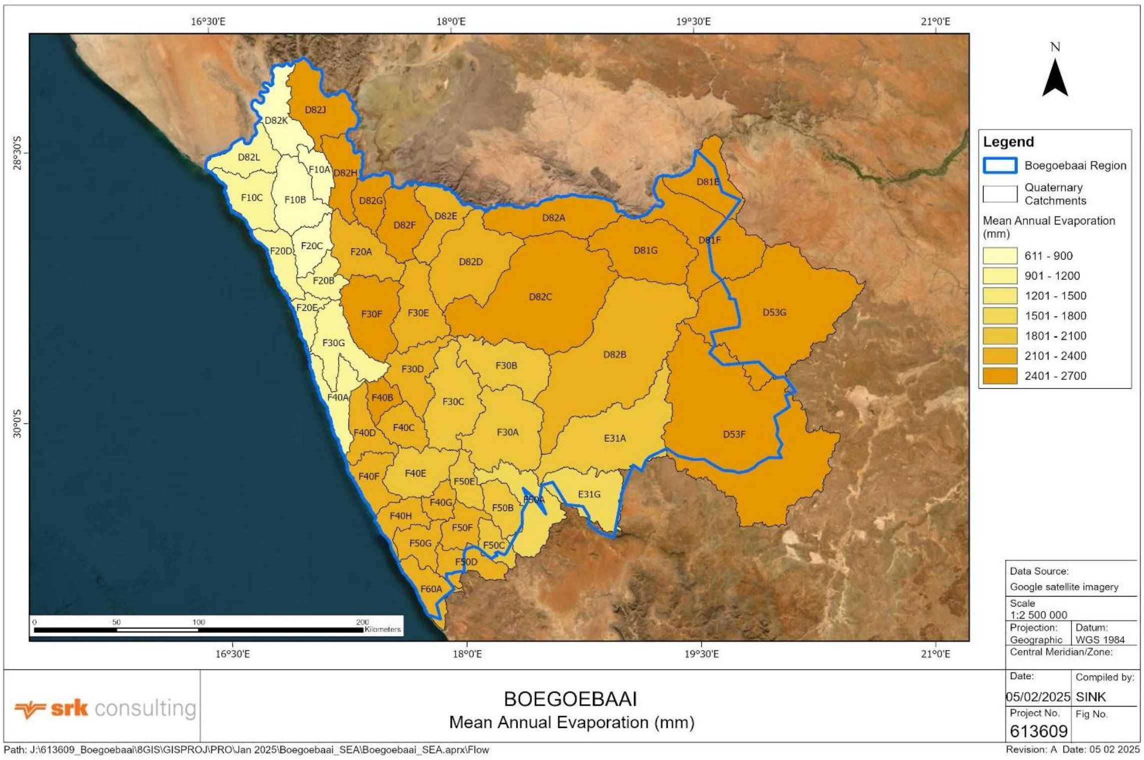


Figure 4-2.5: Distribution of Mean Annual Potential Evaporation

4.2.3 Geology

Namaqualand geology is subdivided into three geological provinces, the Namaqua Metamorphic Province (NMP), the Gariep Complex and the Phanerozoic Cratonic cover (Tankard et al., 1982; Visser, 1989). The NMP, composed of deformed and metamorphosed sedimentary and igneous rocks, forms part of the Namaqua-Natal Metamorphic Province (NNMP) of southern Africa. The NNMP is a high-grade metamorphosed orogenic belt that developed along the southern and southwestern margins of the Kaapvaal Craton (Nke et al., 2020). The NNMP is composed of meta-igneous and meta-sedimentary rocks formed or metamorphosed during the Namaqua Orogeny at ~1 200 to 1 000 Ma. It is understood to be one of several orogenic belts involved in the assembly of the supercontinent, Rodinia (Dalziel et al., 2000). These geological units crop out extensively in the Northern Cape (100 000 km^2) and KwaZulu-Natal (20 000 km^2) geographical provinces of South Africa and are referred to as the Namaqua and Natal Sectors of the Namaqua-Natal Province respectively (Cornell et al., 2006; Nakwafila, 2015) (see **Figure 4-2.6**).

The main lithological units of the NMP are meta-volcano-sedimentary units intruded by multiple granitoid intrusions (Blignault et al., 1983). The NMP rocks display evidence of four metamorphic events (Robb et al., 1999; Clifford et al., 2004). D1 deformation (greenschist-facies) occurred during the Orange River Orogeny, dated at 1 700 – 1 900 Ma (Blignault et al., 1983). D2 and D3 metamorphism occurred during the polyphase Namaquan Orogeny, dated at 1 020 – 1 220 Ma (Robb et al., 1999; Clifford et al., 2004). D2 deformation occurred during the main phase of the Namaquan Orogeny during which time, the Namaqua domains were intensely deformed and then juxtaposed along major thrust zones to form a regional-scale SW-vergent thrust stack, resulting in the present-day geological setting (Macey et al., 2022). D4 deformation occurred after the Namaquan Orogeny and is understood to be a result of tectonic relaxation (958 – 1 005 Ma) (Macey et al., 2022; Thomas et al., 1996; Colliston and Schoch, 2003).

The NMP is subdivided into several tectono-stratigraphic domains (or subprovinces) which are bounded by major shear zones. These subprovinces are the Richtersveld, Bushmanland, Gordonia and Kheis tectonic Subprovinces (Tankard et al., 1982; Hartnady et al., 1985). With the exception of the Richtersveld Subprovince, all of these subprovinces experienced polyphase deformation, metamorphism and plutonic activities during the Namaquan Cycle (~1 200 – 1 000 Ma) (Thomas et al., 1996). These subprovinces are further subdivided into terranes which are categorised according to changes in lithostratigraphy across structural discontinuities (Cornell et al 2009; Nakwafila 2015) (**Figure 4-2.7**).

The regional geology is of particular economic value and has given rise to the presence of many mines, particularly alluvial diamond and copper mining. The basement rocks are covered by Cenozoic alluvial cover, primarily shoreline terrace along the coast and surficial sandy and aeolian soils in the interior (CGS 2011).

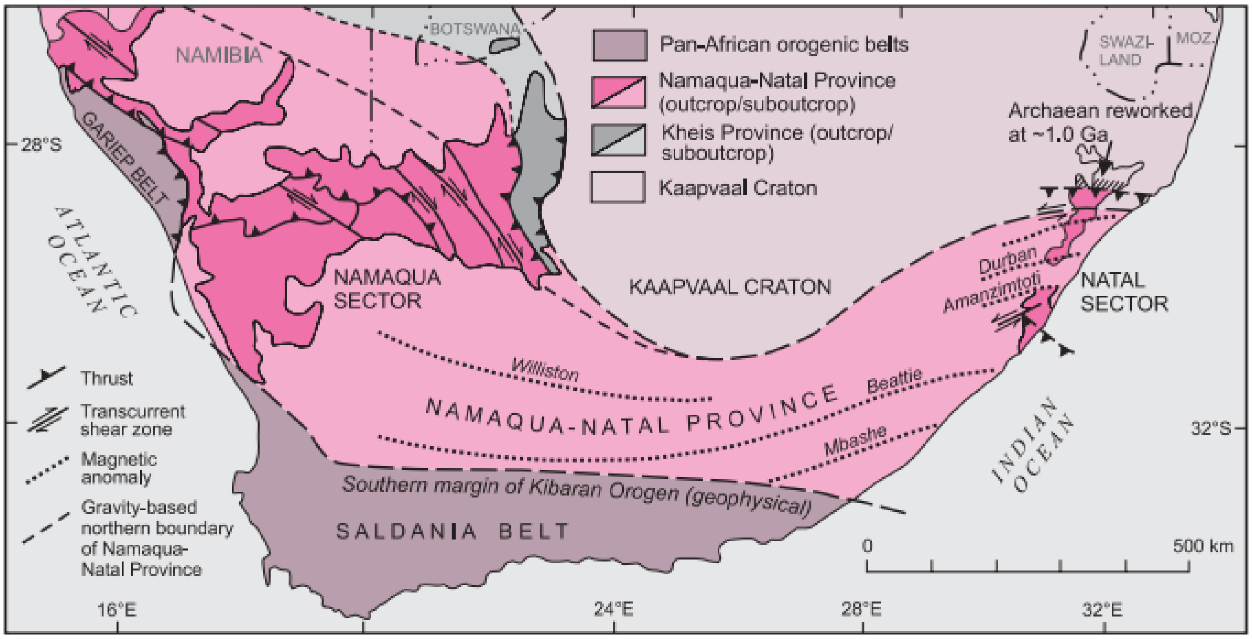


Figure 4-2.6: Geological setting of the Namaqua-Natal Province (Cornell et al. 2006).

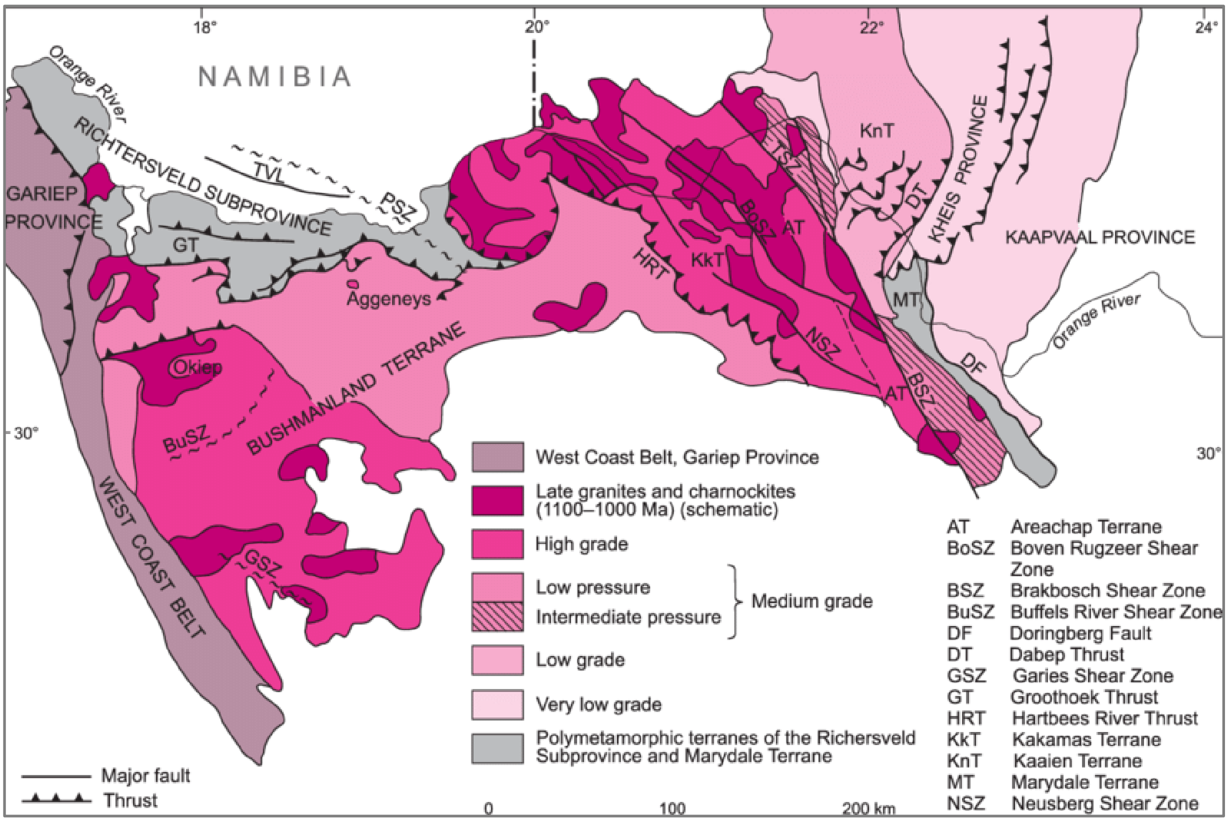


Figure 4-2.7: Geological terrains of the Namaqua Sector of the NMP (Cornell et al., 2006).

4.2.4 Geomorphology

Three geomorphological zones exist in Namaqualand: (1) the western coastal lowland or plain which is characterised by crystalline basement rocks overlain by younger sedimentary rocks and sands; (2) the escarpment zone of exposed granitic domes, interspersed with thick layers of weathered material cut by alluvial palaeochannels; and (3) the gently undulating Bushmanland Plateau consisting of erosional and aggradational phases (Adams et al., 2004; Titus et al., 2009; Van Gend et al., 2021).

The Orange River has preferentially eroded bedrock fractures, joints and foliations to form multiple channels which divide large (up to ~15 km long, ~2 km wide), numerous , stable islands formed of alluvium and/or bedrock. Notable changes in channel-bed gradient occur along the river which strongly controls anabranching - a river pattern which is characterised by multiple channels which divide and rejoin around semi-permanent ridges or islands (Tooth and McCarthy, 2004). Much of the groundwater abstracted from the alluvium near the river, is actually recharged from the river itself. The bedrock aquifer systems are mainly limited to fault-controlled valleys that occur throughout the study area and are traditionally targeted for the development of groundwater resources (Titus et al., 2009).

4.2.5 Land use and anthropogenic activities

The aridity of much of the study area means that large areas are rural with sparse settlements and little development, and includes large areas of natural vegetation, some of which overlie Strategic Groundwater Source Areas (see Section 4.7.2.5). Mining and agriculture are the main commercial activities in the study area, with the latter concentrated along the main stem of the Orange River. Mining occurs primarily along the West Coast and the lower reaches of the Orange River, and mining expansion is noted as a threat to the condition of some of the important estuaries along this coast (e.g. Groen and Spoeg estuaries – see Section 4.5.3.3). The larger towns in the area (Springbok, Garies and Port Nolloth) service both the mining and agricultural industries. Most of the smaller towns / urban settlements occur along the Orange River or near to mines (DWS, 2024) (**Figure 4-2.8**).

The area has an exceptionally high biodiversity (Rundel and Cowling 2013) and is known for its annual production of indigenous (including highly endemic) spring flowers in particular, which support a growing tourism industry. While these extend over large parts of the Namakwa Region (Namaqualand) during spring flowering, the main nodes of tourism are the Namakwa National Park in the southwestern portion of the study area and the Richtersveld Transfrontier Park (extending over the Orange River into Namibia to the north).

Livestock grazing takes place in many areas, often at a subsistence level or supporting often impoverished small rural communities. Over-grazing is a problem in many areas, reflecting in changes in sediment type and load in many of the watercourses including the lower Orange River (DWS 2024). Grazing is often focused along ephemeral river beds, which provide more consistent water sources and foraging for livestock, but in places exacerbates erosion and degradation of these fragile systems (see Section 4.5.2.5).

With the very low rainfall over much of the area, surface water storage is limited and there are very few dams in the study area, and no big ones. **Figure 4-2.9** maps dam density, and shows that most of the study area has < 26 dams per quaternary catchment. Higher densities of dams occur in the wetter Kamiesberg Mountains of the Namaqua Highlands ecoregion, discussed in Section 4.5.2.1 and mapped in **Figure E1** (Appendix 1).

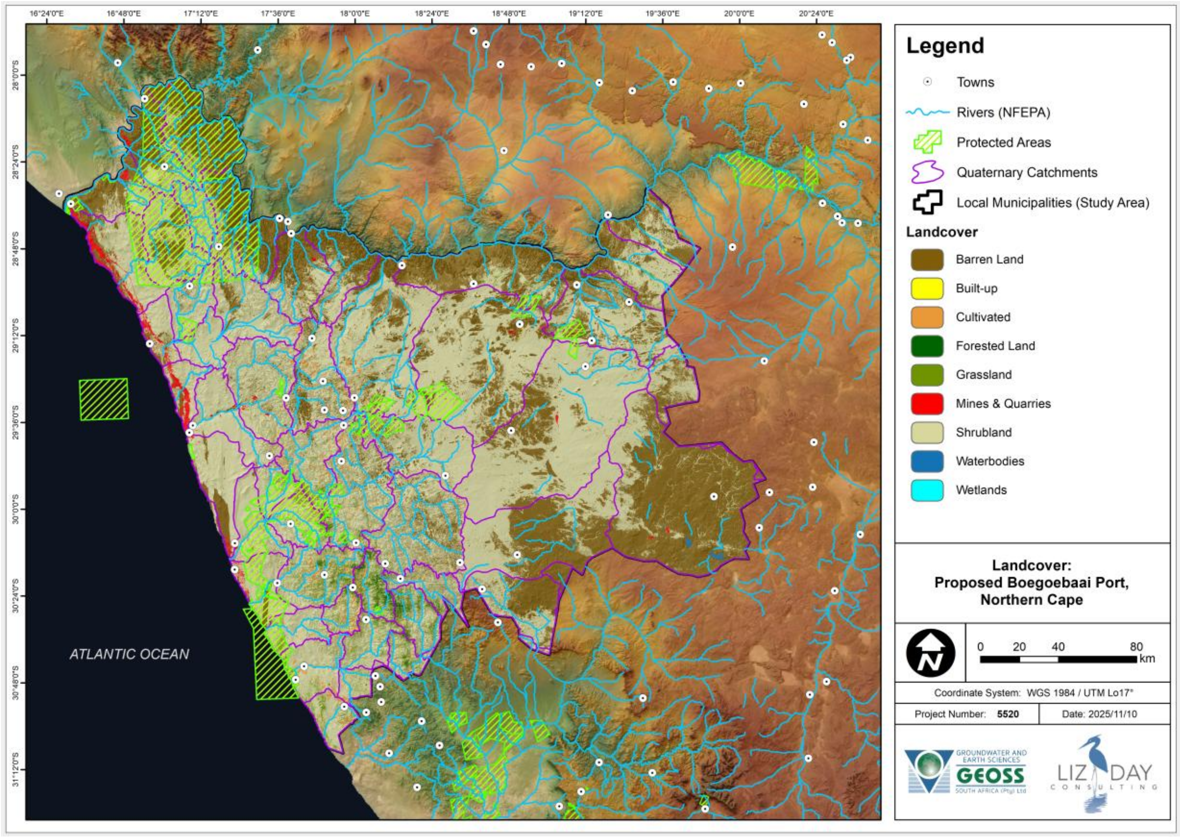


Figure 4-2.8: Distribution of Land-Use in the study area (SA Land-Use (2022))

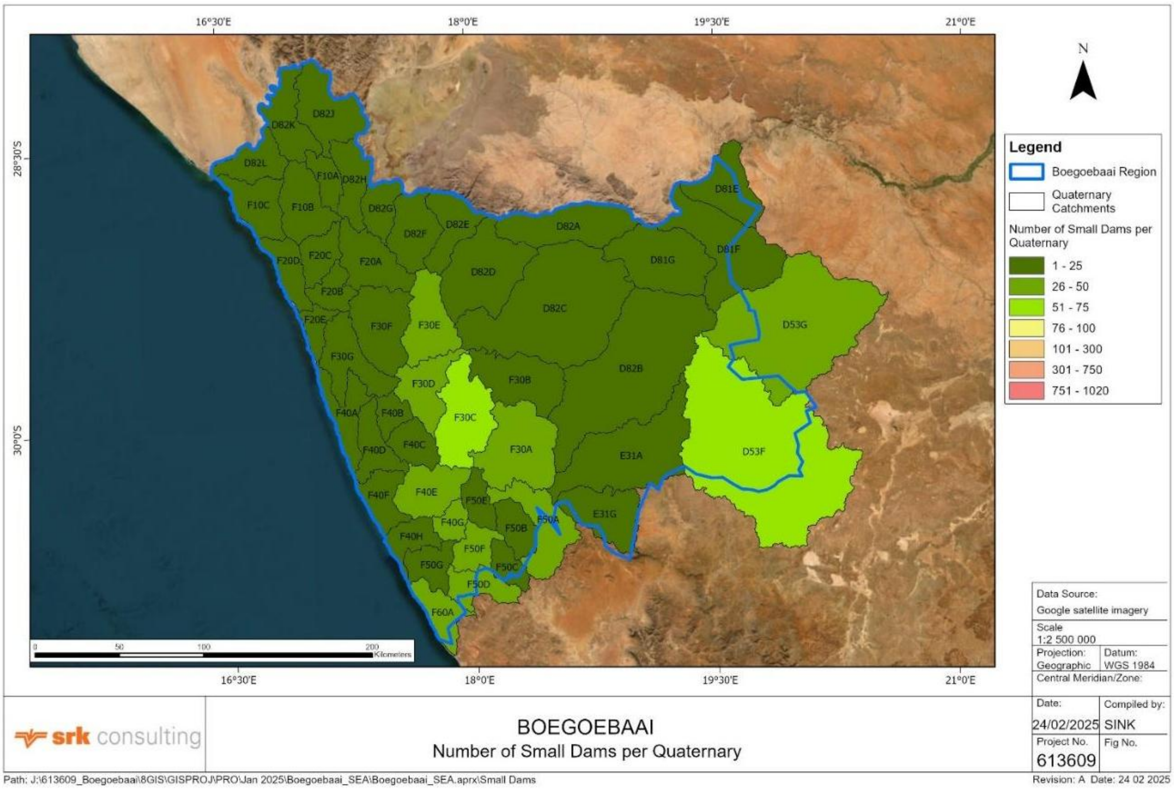


Figure 4-2.9: Distribution of the number of small dams per quaternary.

4.3 HYDROGEOLOGY

4.3.1 Groundwater occurrence

Groundwater occurs in three different aquifer systems in the region (Pietersen et. al. 2009), namely:

- Sandy/alluvial aquifers;
- Weathered zone or regolith;
- Fractured crystalline bedrock

Alluvial aquifers are closely interlinked with deeper fractured bedrock aquifer systems via weathered zones that serve as pathways for subsurface intergranular flow from the shallow alluvial aquifers to the deeper granitic, gneissic and bedrock aquifers (Benito et al., 2011; Marais et al., 2001a and 2001b; Van Gend et al., 2021). The granitic and gneissic host rocks, however, are associated with low primary porosity and groundwater is hosted in fractures and joint planes, though the effective porosity is variable as these fractures are not always interconnected. Consequently, the granitic and gneissic host rocks are associated with very low hydraulic conductivities in comparison to the alluvial aquifer systems (Watson et al., 2021).

4.3.2 Yield

Immediately beneath the proposed port zone, a fractured aquifer with an average borehole yield of 0.0 – 0.1 L/s is mapped (**Figure 4-3.1**). This fractured aquifer is mapped along the banks of the Lower Orange River between the towns of Sendelingsdrif and Alexander Bay, and extends along the coast from the South African-Namibian border before tapering out at Kleinsee. As one moves east and south from the aforementioned aquifer, intergranular aquifers are mapped to overlie fractured aquifers. From Kleinsee to the southern extent of the Greater Namakwa Region, both an intergranular and fractured aquifer are identified with similarly low yields, ranging between 0.0 – 0.1 L/s. Aquifer yields in the study area are generally poor along the borders of the larger study area, not exceeding an average yield of 0.5 L/s in the various aquifers. Towards the southeast, however, higher yields (0.5 – 2.0 L/s) are generally encountered in the intergranular and fractured aquifers spanning between Springbok, Garies and Kliprand (**Figure 4-3.1**).

4.3.3 Quality

Groundwater quality in the region is variable, but generally poor. The regional groundwater map indicates that the aquifers in the area have electrical conductivity values ranging between 70 mS/m to more than 1 000 mS/m (DWAF, 2001) (**Figure B6** in Appendix B). Groundwater in the area is often highly saline and unsafe to consume without treatment. The best quality water is observed in the higher-yielding aquifer located in the area spanning between Springbok, Garies and Kliprand. In this area, EC ranges between 70 – 300 mS/m which can be considered good to marginal quality in terms of domestic water standards (DWAF, 1998). Along the coast in the southern region of the greater study area (from Hondeklip Bay southwards), the poorest water quality is observed, mapped to exceed 1 000 mS/m. The groundwater quality observed in the rest of the greater study area ranges between 300 – 1 000 mS/m. It must be noted, however, that varying water quality can be encountered within a region due to stratification. Groundwater in different layers can exhibit distinctly different chemical compositions due to variations in composition of the host geology, mineral interactions, and the presence of contaminants.

The groundwater quality across the Namaqualand region is generally quite similar in composition, exhibiting a dominant Na-Cl signature throughout the various aquifers. The Na-Cl nature of the groundwater is either a result of the direct infiltration of Na-Cl-type precipitation, or the preferential dissolution and leaching of more soluble evaporitic salts during the infiltration process (Titus et al., 2009). Salt dissolution occurs as water infiltrates through the weathered overburden. Alternatively, the direct evaporation of precipitation results in the dry deposition of salts. Lower salinity water tends to be encountered in the alluvial aquifers and limited to the higher lying regions of the catchment, and higher salinity water in the basement aquifers as a consequence of mineral dissolution (Titus et al., 2009; Pietersen et al., 2009). Due to the stratification of better quality water in the alluvial aquifers overlying poorer water quality in the basement aquifers, abstraction over time could result in a deterioration in the quality of fresher aquifers.

The poorer quality groundwater encountered in the region has often been attributed to high rates of evaporation. Analysis of stable hydrogen and oxygen data, however, suggests that evaporation does not play a major role in salinisation of the groundwater (Van Gend et al., 2021). Major ions and strontium ratios indicate that salts present in the groundwater are linked to dry deposition of marine aerosols and ion-exchange reactions in soils in the alluvial aquifer systems. The hydrochemical variability of the groundwater in the basement aquifer systems suggest that there are strong local controls linked to weathering processes in individual basement rock types (Van Gend et al., 2021). The region is also known for its high density of heuweltjies. Heuweltjies are large circular mounds associated with paleo and modern termite activity, and are generally up to 30 m in diameter, but may be as wide as 50 m, and up to 3 m in height. These structures are prominent throughout the region and have increased permeability due to biological activity of various endemic animal species (Lovegrove and Siegfried 1989). Heuweltjies occupy between 14 – 25% of the landscape (Lovegrove and Siegfried 1986; McAuliffe et al., 2019a; Picker et al. 2007) and contain elevated levels of micro and macro elements, including salts, in comparison to the surrounding soils (Kunz et al., 2012; McAuliffe et al., 2019a 2019b; Midgley and Musil, 1990; Midgley et al., 2012). Electromagnetic scanning and measurement of water-soluble soil EC values on and off heuweltjies show that the structures are saline, with salinity increasing with depth. Level of measured groundwater salinity correlates with level of heuweltjie salinity (Van Gend et al., 2021). Rainfall records from the last 150 years provide support for the hypothesis that accumulated salts, particularly heuweltjie salts, are flushed into the groundwater system during sporadic, large volume rainfall events. Heuweltjies could therefore, potentially represent a previously unrecognized contributor to groundwater salinisation across Namaqualand (Van Gend et al., 2021).

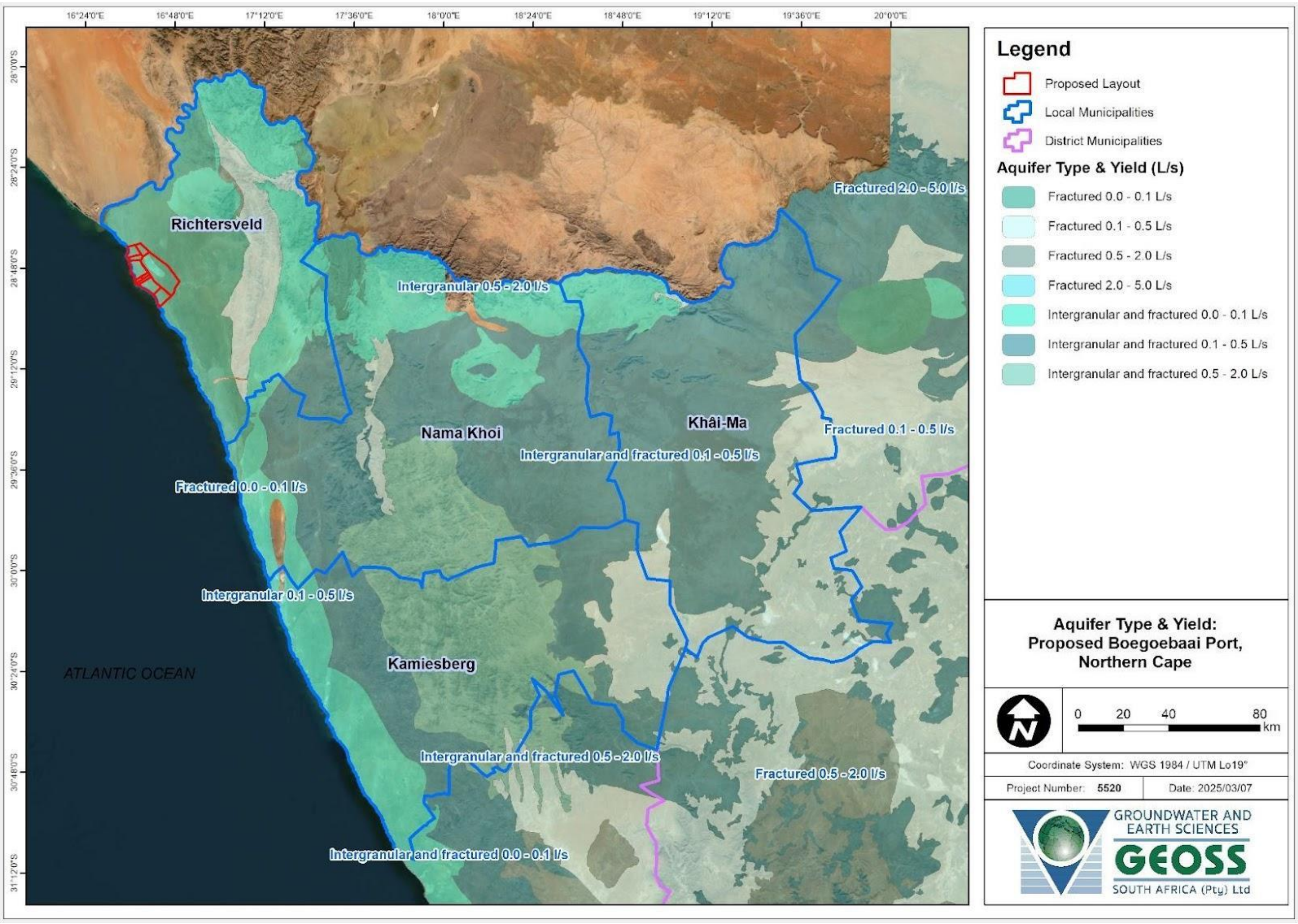


Figure 4-3.1: Regional aquifer yield (L/s) (DWAF 2001).

4.3.4 Recharge

Various estimation methods were undertaken by Adams et. al., (2004) in an attempt to estimate groundwater recharge across catchments F30, F40 and F50. Methods included: the chloride mass balance (CMB) method; cumulative rainfall departures (CRD) method; saturated volume fluctuation (SVF) method; statistical approaches and GIS analytical approaches. Results indicate that recharge rates to the basement and alluvial aquifers in the region are estimated to be within the range of 0.1 – 10 mm per annum, with higher values being associated with alluvial aquifers and high altitude sites, and the lower limits to the fractured rock aquifers (Adams et al., 2004; DWS, 2016). Groundwater recharge decreases from the escarpment zone to the coastal zone, i.e. from east to west (Adams et al.. 2004; DWS. 2016). Further, stable oxygen and hydrogen isotopes indicate that indirect recharge is dominant in the region, involving the infiltration of surface runoff as well as discharges from springs and adjacent aquifers. Direct recharge only dominates in the mountainous areas as a result of higher rainfall volumes over these areas due to the orographic effect (Adams et al., 2004). Alluvial aquifers are easily recharged on account of their hydraulic characteristics and position within the landscape. Flood events also produce significant recharge to these aquifers. The structural control on the ephemeral drainage systems is evident in their alignment along fracture systems that are associated with the underlying bedrock (Adams et al., 2004). Alluvial aquifer systems are important pathways for groundwater recharge to the weathered and bedrock zone aquifers (Adams et al., 2004). Isotope data for the groundwater indicates variable mean residence times, ranging from very young (<50 years) to very old (>30 000 years). Intermediate ages are an indication of active mixing of younger and older water (Adams et al., 2004)

4.4 SURFACE WATER RESOURCES

4.4.1 Catchment context

Most of the study area lies in the Vaal- Orange Water Management Area (WMA) – the largest WMA in South Africa, which includes the whole of the Orange River's catchment within the country. Parts of the southern boundary of the study area do however extend into the Breede-Olifants WMA – a large and complex WMA including the catchments of the Olifants, Berg, Breede and Gouritz Rivers, as well as numerous smaller river catchments that drain into the Atlantic and Indian Oceans via estuaries or other outlets.

Within the present study area, the above WMAs are in turn made up of four secondary catchments, comprising the Coastal Orange, Orange and Orange Tributaries sub-WMAs within the Vaal-Orange WMA, and the Knersvlakte sub-WMA, in the Breede-Olifants WMA.

Fifty-nine quaternary catchments have been mapped in these sub- WMAs, and form the basis for much of the surface and aquatic ecosystems catchment descriptions and assessments provided in this section. The quaternaries and the four sub-WMAs are shown in Figure 4-4.1. Of the watercourses shown in the figure, only rivers within the Orange sub-WMA flow into the Orange River itself, and in this region, many of these only flow occasionally and some never reach the river at all. The Orange River receives most of its runoff from upstream(Upper Orange WMA).

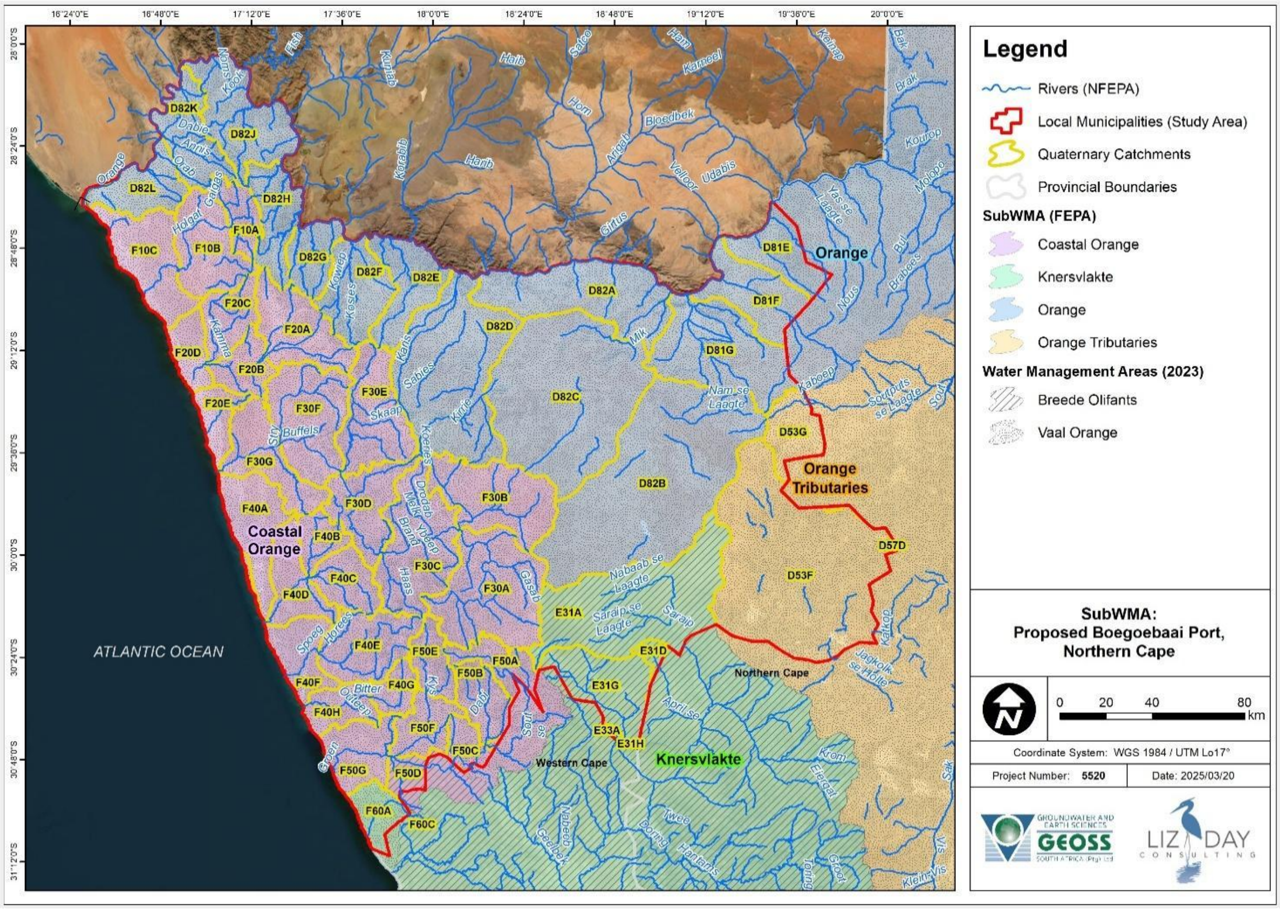


Figure 4-4.1: Study area in the context of DWS Water Management Areas and Sub Water Management Areas (SubWMA) from the NFEPA programme (Driver et al., 2011).

4.4.2 *Surface water hydrology*

The entire study area is classified as either Hyper-Arid or Arid, with no Semi-Arid catchments. The surface water resources are therefore very limited, with ephemeral streams and sporadic runoff events, mostly lasting for only a few days, with long dry periods in between events. The surface water runoff has been assessed on a Quaternary catchment basis.

4.4.2.1 <u>Quaternary Runoff</u>

4.4.2.1.1 Endoreic Areas

Two large Quaternary catchments (D82B and D82C) are completely endoreic as illustrated in **Figure 4-4.2**. This means that no surface runoff or stream discharge leaves these catchments, and all internal surface runoff terminates in internal pans or groundwater recharge zones. A few other Quaternaries have a portion of their area defined as endoreic, but otherwise most have drainage features that leave the Quaternary.

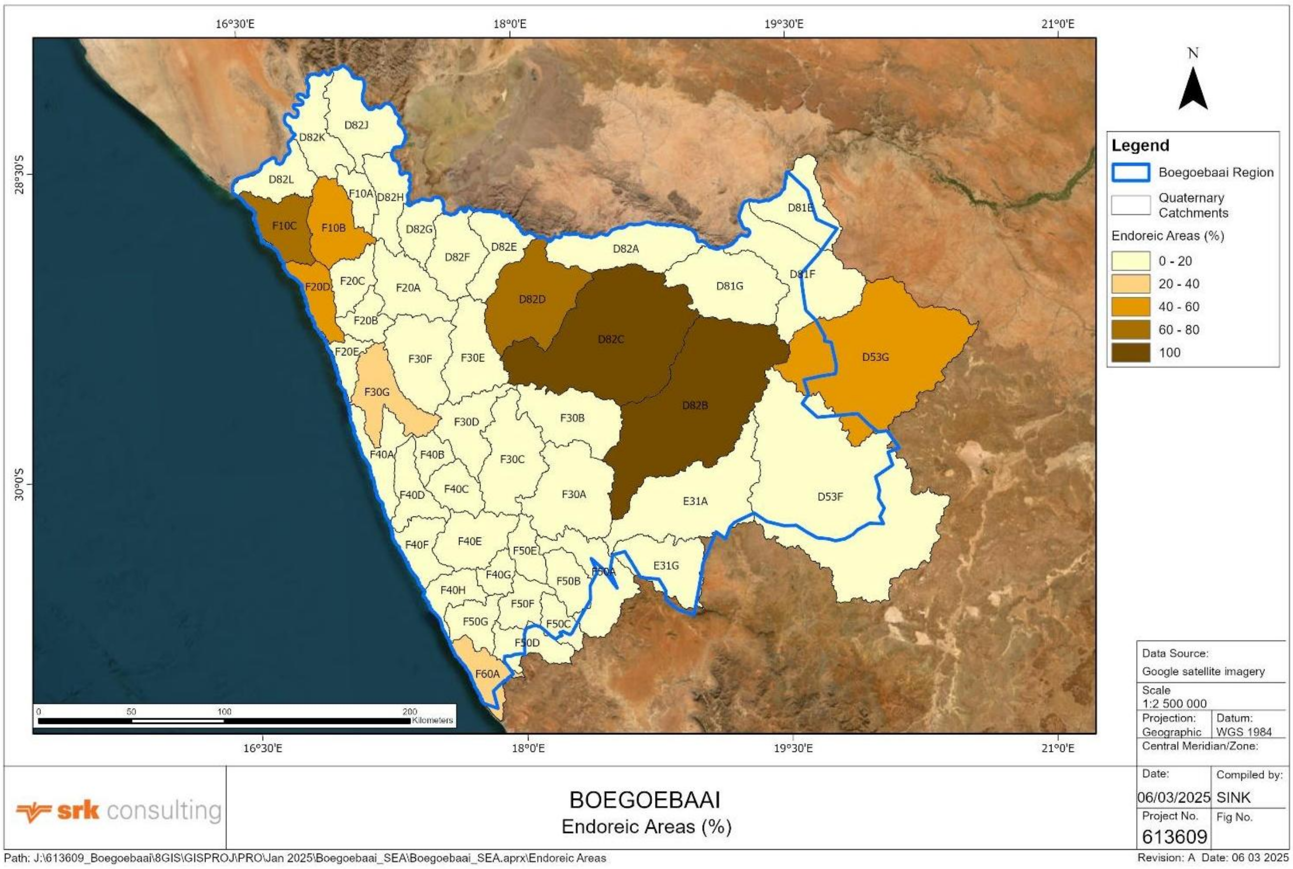


Figure 4-4.2: Distribution of endoreic areas (Mantel and Hughes 2023).

The Mean Annual Runoff (MAR) for the Quaternary catchments in the study area has been estimated in WR2012. These estimates reveal mean annual quaternary runoff varying from a minimum of 0 (completely endoreic) to a maximum of 1.24% of the average annual precipitation, with the average of all Quaternaries without endoreic areas reporting MAR of 0.57% of MAP. However, average annual estimates of runoff are misleading in areas with such sporadic runoff regimes. An effort was therefore made in this project to estimate the distribution and magnitude of runoff events and dry periods between these.

Simulations of the quinary catchments making up the quaternaries in the study area have been modelled using the ACRU agro-hydrological model, with daily meteorological inputs (Schütte *et al.* 2023). These simulations were calibrated using observed daily runoff data from two stations, F5H001 and F5H002 as well as a daily runoff record derived from a study on the Buffels river (Benito *et al*. 2011). The stations and contributing catchments are illustrated in **Figure C2.2** (Appendix C).

The simulated and observed flow regimes for the Buffels river catchment indicate the sporadic nature of runoff, with all discharge events occurring over less than 10% of the time (**Figure 4-4.3**).

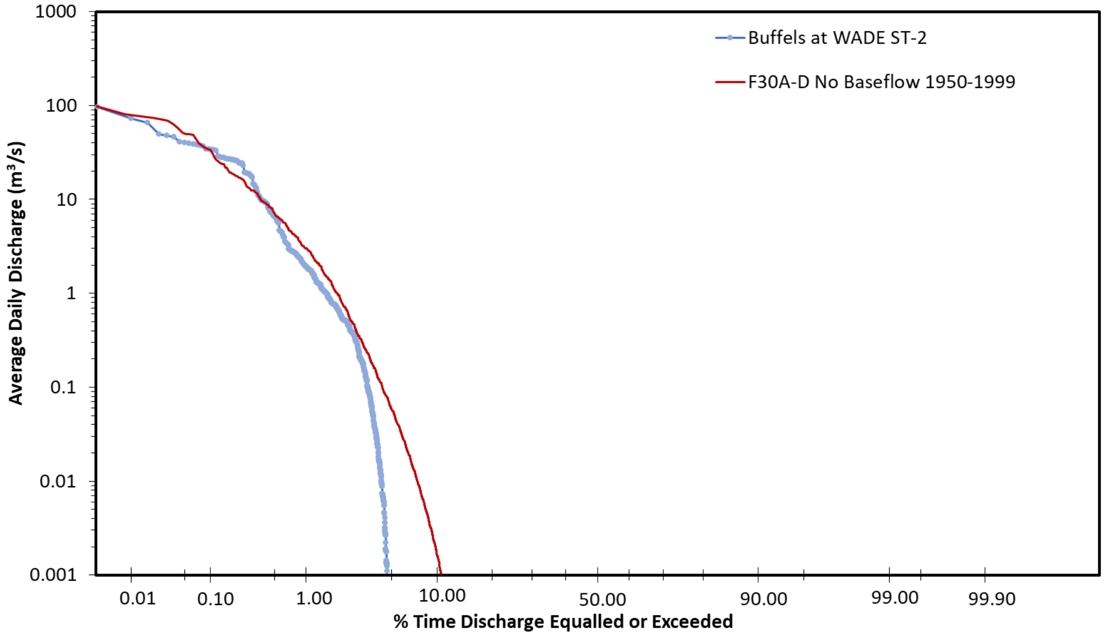


Figure 4-4.3: Comparison of simulated and observed flow regimes for the Buffels river (ZADE station 2 in Figure C2.2 (Appendix C)).

The simulated runoff for all quaternaries resulted in similar flow regimes and very low annual runoff. The MAR is predominantly less than 2 mm per annum, with the lowest MAR along the coast, increasing towards the east, particularly in the high lying interior, decreasing again, eastwards on the leeward side of the mountains and finally increasing again in the far east of the region and far north along the Orange River (**Figure C2.3** (Appendix C2)). The Quaternary MARs are generally less than 1% of the MAP, except in the far east and north, where the Quaternary MARs are some 2% of MAP (**Figure C2.4** (Appendix C2)).

Mean Annual Runoff is predicted to decrease by 20-40% over most of the region in the Near Future (2050). A few Quaternaries in the coastal north and in the far east of the region are predicted to increase (up to 20%) in the Near Future (**Figure C2.5** (Appendix C2)).

This result is derived from the average of six GCMs applied to the study area. (Schütte, *et al*. 2023). The highest of the GCMs predicts mostly increasing MAR, while the lowest GCM predicts decreasing MAR everywhere (**Figures C2.6** and **C2.7** (Appendix C2)).

Long periods without any flow occurring (No-Flow periods) are particularly prevalent throughout the region. The average duration of No-Flow periods ranges from 334 to 365 days (**Figure C2.8** (Appendix C2)), while the longest period of No-Flow in the 50-year simulated record, ranges from 3 to 7 years over most of the region, with maximum No-Flow durations reaching 16 years in the north coastal region (**Figure C2.9** (Appendix C2)).

No-Flow periods are predicted to decrease in number but increase in duration in the Near Future (2050) (**Figures C2.10** to **Figure C2.13** (Appendix C2)).

4.4.3 Water quality

4.4.3.1 General

The study area includes two very different kinds of surface aquatic systems, the one (the Orange River) driven by upstream flows and subject to high levels of water use for agriculture, industry and domestic use throughout its reaches in South Africa, and the other, comprising ephemeral to seasonal rivers and other watercourses, some of which feed into the Orange River while others flow into the Atlantic Ocean on the West Coast via estuaries (classified by Van Niekerk *et al.* 2020 as Cool Temperate Arid Predominantly Closed Estuaries) or micro-outlets, or simply dissipate into the surrounding landscape or the underlying aquifer.

4.4.3.2 Overview of water quality in the Lower Orange River (current study area)

The DWS monitors water quality in important mainstream rivers. The only DWS water quality monitoring sites in the present study area are located along the Orange River and comprise six sites, between Onseepkans in the east and Alexander Bay in the west. Summary water quality data for these sites, extracted from DWS (2024a) are presented in **Table D1** (Appendix D). These data, which cover variable time periods between 1965 and 2023, suggest that:

- River salinities (measured by electrical conductivity (EC) data) are variable, but increase with distance downstream, while also showing high inter seasonal variability;
- Median orthophosphate data suggest that the river lies within the mesotrophic range of DWAF (1996) and in a Present Ecological State (PES) Category C (as per DWAF (2008b) thresholds), although the range of data indicate at least periodic increases in enrichment of this nutrient to well over hypertrophic thresholds, at at least some of the sites in this dataset;
- Median nitrogen nutrient data also suggest that the river over the reflected monitoring period was generally in an oligotrophic condition (PES Category C to A/B in terms of DWAF (2008b)), although maximum concentrations per site indicate at least periods when nitrogen enrichment fell into a Category D for this variable (again, as per DWAF 2008b);
- Median total ammonia concentrations were low at all sites. However, maximum concentrations at times would have fallen within the range where concentrations of the un-ionised component of this variable (NH_3) would have exceeded thresholds of concern for acute or chronic ecosystem toxicity (as per DWAF 1996 at the cited pH levels and assumed temperatures of 20°C).

DWS (2016a) summarises water quality data for the two Ecological Water Requirement (EWR) sites located along the Orange River, indicating water quality in a PES Category C/D at EWR04 (Vioolsdrift) and PES C at EWR05 (Sendelingsdrift), and citing agricultural return flows, abstraction and mining activities as the main causes of concern along these reaches.

Coleman and van Niekerk (2007), drawing on the above datasets for the period up until 2004, provide summary data that illustrate a deterioration in water quality in the lower reaches of the Orange River (Vioolsdrift site) from an irrigation perspective, with just over 50% of samples only lying within the "Ideal" range for irrigation (< 40 mS/m), although the rest remained in the Acceptable range. These compared with over 75% of samples being in the Ideal range at the nearest assessed monitoring site at Upington. Sulphate and orthophosphate concentrations at Vioolsdrift were also elevated compared with the upstream site, with more than 35% lying in the "Tolerable" range and the rest in the Acceptable range. These authors suggested largescale mining activities to be the key source of sulphates, while return flows from irrigation areas contribute salinity and nutrients to the river. Salinity is exacerbated by high rates of evaporation.

Elevated orthophosphates have resulted in a history of cyanobacterial blooms in the lower river, leading at times to odour and colour problems in the river and affecting the intake water to various water treatment plants (Coleman and van Niekerk 2007).

4.4.3.3 Water quality in ephemeral rivers and arid estuaries

DWS (2017a) comments that water quality in at least some of the ephemeral watercourses and small estuaries and micro-outlets south of the Orange River Estuary mouth was also affected by:

- Groundwater abstraction for mining, which reduces flows and leads to increased salinities in groundwater fed systems (e.g. Groen River Estuary);
- Discharges of nutrient-enriched and otherwise contaminated water from WWTWs;
- Nutrient inflows (often as seepage) from areas irrigated with treated effluent from WWTWs and from ablution facilities at resorts located near to watercourses (e.g. Groen River Estuary);
- Inflows of suspended sediments (during flood conditions), from catchment scale erosion, exacerbated by mining, poorly designed road culverts, poor livestock farming practices and overgrazing.

That said, the above report also notes that water quality in the small estuaries in the present study area generally remained in a fairly good condition, compared with their reference state.

4.4.3.4 Impacts of waste water treatment works

Table D2 (Appendix D) summarises Critical Risk Ratings (CRRs) for the WWTWs in the four municipalities making up the present study area. The CRRs presented were obtained from the DWS 2024 Green Drop Report (DWS, 2023). Of the 16 WWTWs assessed in the report, 14 had a CRR of 100%, reflecting the highest possible risk rating ("Critical"), indicative of systemic failures throughout the works that resulted in complete failure to achieve physical or chemical compliance. The remaining two WWTWs assessed had CRRs of 80 – 90%, rated as High Risk. All 16 WWTWs showed major declines in performance since 2011, when three were rated as Low Risk; two as Medium Risk; and only two of the (then assessed 13 WWTWs) were rated Critical.

Data regarding individual effluent disposal methods from these WWTWs are limited. Where treated effluent is used for industry, agriculture, irrigation of golf courses and other amenities, and/or discharged into watercourses or allowed to infiltrate into the water table, the quality of final effluent for such uses is important in determining its impacts. Where WWTWs are dysfunctional, all of these uses could present an increasing risk of contamination of groundwater as well as of surface water courses, including the Orange River, which receives effluent from three of the listed WWTWs within the study area (Appendix D). Poorly treated effluent would contribute to the elevated nutrients already noted as a problem in the Orange River and affecting some of the ephemeral tributaries and their estuaries.

4.4.4 Surface and groundwater interactions

The Namakwa region experiences low rainfall and high potential evaporation rates, which have a significant impact on the net recharge of local aquifers (Nakwafila, 2015). The only perennial river system in the region is the Orange River, along which only two catchments are listed as contributing baseflow; neither of which fall within the study area. Consequently, groundwater plays a minimal role in maintaining baseflow in rivers in the region (DWS, 2016). Watercourses in the region are ephemeral and only flow after heavy rainfall events that occur once every several years (Makubalo and Diamond, 2020).

In the study area, alluvial aquifers have been associated with ephemeral rivers, paleochannels and coastal plains. Ephemeral surface water provides recharge to alluvial groundwater systems through typically dry riverbeds. The aquifers associated with ephemeral river systems have generally been observed to be shallower than those associated with the coastal plain (Pietersen et al., 2009). Groundwater-surface water interaction has not been sufficiently studied in the Northern Cape due to limited surface water, however, surface water fed alluvial aquifer systems are considered to be important pathways for groundwater recharge to the weathered and bedrock zone aquifers (Adams et al., (2004).

4.5 AQUATIC ECOSYSTEMS

4.5.1 Overview

Aquatic ecosystems considered in this chapter include inland and estuarine ecosystems, as defined in Section 4.1.5. Included among the latter are the small, highly ephemeral micro-outlets, described in Van Niekerk *et al.* (2020), while the inland ecosystems include rivers, wetlands, pans and springs, variously connected to surface and/or groundwater sources. **Figure 4-5.1** shows the main rivers and estuaries within the study area, in the context of regional topography. The figure highlights the extensive north-south running mountain ranges just inland from the coast with its undulating dunes and sandy soils. The mountain ranges include the Kamiesberg, within the western section of the Namaqua National Park. In the north of the study area, the Orange River Canyon includes the Orange River and the Richtersveld area, with its steep, rocky terrain that drops down to the fertile Orange River floodplain below. For the rest, the topography is generally flat with undulating sands and some areas characterised by large pans or endoreic areas.

This section (Section 4.5) provides an overview of these systems, to inform subsequent considerations of the ecological implications of the proposed Boegoebaai Port development and associated likely regional expansion of renewable energy in the Namakwa region. The section deals with inland and estuarine aquatic ecosystems separately.

4.5.2 Inland aquatic ecosystems

4.5.2.1 <u>Ecoregions</u>

Ecoregions are areas within which groups of rivers share similar physiography, climate, geology, soils and potential natural vegetation. An ecoregional classification produced by Kleynhans *et al.* (2005) divided South Africa's rivers into 31 distinct ecoregions. These are shown in **Figure E1** (Appendix E), in the context of the present study area.

The study area straddles four ecoregions, namely the Western Coastal Belt ecoregion, which runs in a relatively narrow band parallel with the coast; the Namaqua Highlands ecoregion, which coincides with the north-south mountains and hills described above and includes part of the Richtersveld National Park; the Nama Karoo ecoregion, which covers the largest part of the study area; and the Orange River Gorge ecoregion, which includes the Orange River and its rocky gorge, as well as sections within the Richtersveld National Park.

These ecoregions are all characterised by very low and highly variable rainfall, with the Nama Karoo and Western Coastal Belt ecoregions generally having few river watercourses, compared with medium to high drainage density and stream frequency in the other two ecoregions. Rain, when it does fall, tends to occur in late summer to winter in the Orange River Gorge ecoregion, versus winter rainfall in the other ecoregions. These subtle differences as well as differences in geology and geomorphology (see Section 4.2) help to account for differences in aquatic biodiversity in rivers through these areas and are the basis on which Ecosystem Threat Status is assigned to different groups of rivers in the National Biodiversity Assessment (Van Deventer *et al.,* 2019).

Table 4-5.1 summarises the relative Threat Status of different river types in the above ecoregions. Of the various river types, perennial /seasonal lowland rivers in the Western Coastal Belt, and all perennial /seasonal rivers in the Namaqua Highlands ecoregion are the most threatened (Critically Endangered or Endangered).

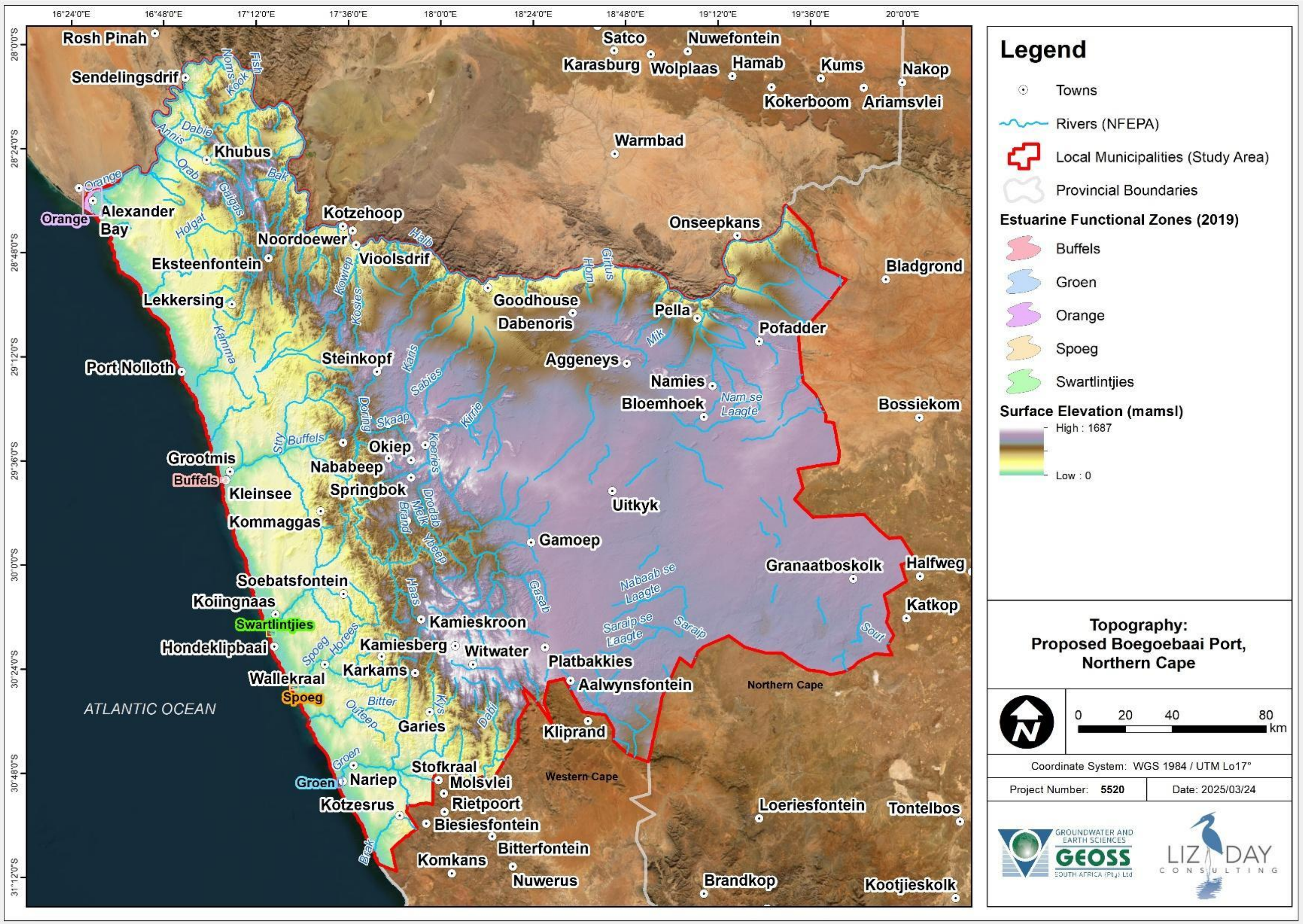


Figure 4-5.1: Main (1:500 000) rivers and mapped estuaries within the study area, in the context of regional topography

Table 4-5.1: Threat Status of different river types per ecoregion. Data from Van Deventer *et al.* (2019).
See Appendix E, Figure E1 for ecoregion map. Critically Endangered systems highlighted in red.

Level 1 ecoregion	Flow variability	River type	ETS	EPL
Western Coastal Belt	Ephemeral	Lowland river	LT	WP
		Lower foothill	LT	WP
		Mountain stream	VU	PP
		Upper foothill	LT	MP
	Perennial/Seasonal	**Lowland river**	**CR**	**NP**
		Lower foothill	LT	WP
Nama Karoo	Ephemeral	Lowland river	LT	NP
		Lower foothill	EN	NP
		Mountain stream	LT	PP
		Upper foothill	LT	NP
	Perennial/Seasonal	**Lowland river**	**CR**	**PP**
		Lower foothill	EN	NP
		Mountain stream	**CR**	**NP**
		Upper foothill	**CR**	**NP**
Namaqua Highlands	Ephemeral	Lowland river	LT	NP
		Lower foothill	LT	PP
		Mountain stream	LT	MP
		Upper foothill	LT	MP
Orange River Gorge	Ephemeral	Lowland river	LT	WP
		Lower foothill	LT	WP
		Mountain stream	LT	PP
		Upper foothill	LT	WP
	Perennial/Seasonal	Lowland river	LT	MP
		Lower foothill	LT	NP
		Upper foothill	LT	WP

4.5.2.2 River FEPA status

The National Freshwater Ecosystem (NFEPA) Programme (Driver *et al.*, 2011) includes rated Freshwater Ecosystem Priority Areas (FEPAs). These are described and their spatial extent in the study area illustrated in extent in Appendix E (Section E1 and **Figure E2**). The latter figure indicates that:

- Most of the sub-quaternaries in the Orange River Gorge ecoregion have been accorded **FEPA** status, recognising the importance of this river system and its associated wetlands;

- Other parts of the study area that have FEPA status include least-impacted sub-quaternaries in the Spoeg, Groen and Swartlintjies catchments, all of which support important downstream estuaries on the West Coast (See Section 4.5.3.3) as well as ephemeral to seasonal wetlands within the mapped FEPA sub-catchments;

- The sub-quaternaries of the upper reaches of the ephemeral Holgat River have also been mapped as river FEPAs, along with the sub-quaternary of the ephemeral Kwaganap River, which is too ephemeral to support any functional estuary but is relatively unimpacted along its river reaches;

- Large areas of the study area have been accorded **Upstream FEPA** status. These sub-quaternaries lie mostly in the Namaqua Highlands ecoregion, and feed into the important Holgat, Swartlintjies and Buffels River systems but include the Goob se Laagte sub-quaternary, which is one of the few rivers that flow (albeit ephemerally) into the Orange River near the northeastern site boundary. Management of these systems in good condition is intended to protect important downstream ecosystems – in this case, the Orange River;

- Six sub-quaternaries along the Orange River just upstream of its estuary have been rated as Fish Corridors that are important for the protection of vulnerable or near-threatened indigenous fish species, in this case, [2]*Barbus hospes* (Namaqua barb);

- Phase 2 FEPA status has been assigned to the lower reaches of the Groen and Swartlintjie subcatchments, as well as to the sub-quaternary in the northwestern corner of the site, associated with and draining into the Orange River. The Orange River estuary has been accorded Ramsar wetland status, indicative of a wetland with extremely high conservation importance, at an international level, and rehabilitation of areas surrounding the estuary and its associated wetlands would support its conservation;

- Many subcatchments in the study area have no River FEPA status – these are largely areas that drain towards the west, but in which there are no watercourses or those that occur are too ephemeral to support downstream ecosystems of ecological importance. Sub-catchments within the largely to wholly endoreic quaternary catchments D82B-D are included among these (see **Figure E3** in Appendix D). These areas do not support any river systems – but include important ephemeral pans, discussed later in this section.

4.5.2.3 Regional conservation planning data (Northern Cape Biodiversity Planning data)

Regional conservation planning data from the Northern Cape Biodiversity Planning dataset (Northern Cape Department of Environment and Nature Conservation 2018) were accessed for this assessment and overlain as GIS data over the study area and surrounds. These data do not differentiate between aquatic and terrestrial ecosystems, as shown in **Figure E4** (Appendix E). However, the overlays of rivers and NBA (2018) wetlands do show where aquatic ecosystems may contribute to high conservation status in some areas. The data show that virtually the whole study area has some level of status in biodiversity planning, with large areas in the central and east to south eastern parts of the study area being mapped as "Other Natural Areas" (indicating relatively low levels of development overall in this region), while extensive Critical Biodiversity Areas (CBAs) level 1 and level 2 extend along the Orange River Gorge, Namaqua Highlands and Western Coastal Belt ecoregions. These areas include rivers, wetlands and pans, within a broader terrestrial matrix.

The numerous pans that occur in the southeastern corner of the site have been rated as "Other Natural Areas" only, with the exception of a few of the larger ones, rated as Ecosystem Support Areas.

[2] Note that *B. hospes* has subsequently been re-named *Enteromius hospes* – this species is rated as Least Threatened and is likely to have benefited from more continuous base flows (from dam releases) compared with natural conditions (SANBI data: https://speciesstatus.sanbi.org/assessment/last-assessment/47/, Accessed November 2025)

Parts of the western portion of the study area, particularly along the coastal area in the north, have not been included among conservation priorities, presumably due to extensive mining and other development in these areas.

4.5.2.4 Wetland bioregions

Data from the National Biodiversity Assessment (NBA) of aquatic ecosystems (Van Deventer *et al.* 2018) show that aquatic ecosystems within the study area fall within the following bioregions:

- Bushmanland Bioregion, which comprises the dry inland quaternaries that slice from south of the Orange River in the centre of the site, across to the south western site boundary and including the endoreic areas mapped in **Figure E3** (Appendix E) – most of the mapped wetlands (pans) are wetland depressions, rated as Critically Endangered wetland types (see **Table 4-5.2**);
- Richtersveld Bioregion, comprising wetlands in the Richtersveld area, south of the Orange River, within the Orange River Gorge ecoregion;
- Gariep Desert Bioregion, comprising wetlands (pans) in the northeastern part of the site;
- Namaqualand Sandveld Bioregion, including wetlands (pans) along the entire coastal strip within the site;
- Namaqualand Cape Shrublands Bioregion, comprising wetlands in the southern section of the high-lying Namaqua Highlands;
- Namaqualand Hardeveld Bioregion (with only one “wetland seep” mapped in this area;
- Southern Namib Desert Bioregion, including a few wetlands just south of the Orange River Estuary.

The conservation status of different wetland types within these bioregions is summarized in **Table 4-5.2** and the distribution of mapped wetlands is illustrated in **Figure E5** in Appendix E. It must however be noted that in some instances there is evidence of extensive historical mining / disturbance within mapped CBA regions. Nevertheless, the CBA status of the above areas remains, and even disturbed areas may contribute towards the maintenance of ecological corridors, particularly along the coastal zone.

Note that the wetlands of the Orange River estuary itself are classified as estuarine ecosystems and discussed in Section 4.5.3.2.

Table 4-5.2: Distribution (by quaternary catchment) and conservation status of different wetland types within the study area, classified using the hierarchical classification system of Ollis *et al.* (2013) and the bioregions and Ecological Threat Status provided in NBA (2018). DEP=Depression; VBW=Valley bottom wetland; FLOOD=floodplain wetland; Seep=seep wetland. Cr=Critically Endangered; EN=Endangered; V=Vulnerable; LC=Least Concern

Bioregion	Quaternaries in Study Area (with wetlands)	Wetland Ecosystem Threat Status			
		Dep	VBW	Flood	Seep
Bushmanland Bioregion	D82B, D82C, D82D, D53F, D53G, E31A, E31G	CR	CR	CR	V
Gariep Desert Bioregion	d82A, d82E, d82F, d82g, d82g, d82g, d81E, D81g	LC	CR	-	CR
Namaqualand Sandveld Bioregion	f40D, f40E, f40F, f40H, f50G, f60A	CR	CR	-	LC
Namaqualand Cape Shrublands Bioregion	f30A, f30C, f50E, f30C, f30C, f30C,	CR	CR	LC	LC
Namaqualand Hardeveld Bioregion	F50A, F50B, F50E, F50B,	LC	CR	-	CR
Southern Namib Desert Bioregion	D82L	LC	-	-	-
Richtersveld Bioregion	D82a, d82c,	EN	V	-	LC

4.5.2.5 Description of main inland aquatic ecosystems in the study area

Inland aquatic ecosystems in the study area can usefully be separated out into those associated with the Orange River, which is the only large, perennial river that passes into and through the site, driven primarily by upstream flows from its inland catchment; and the ephemeral rivers, pans and wetlands that occur in the remainder of the site, and which are characterised by an arid climate, with low, unpredictable rainfall and at times long periods (months to several years) of no rainfall (see Section 4.2). **Figure E7** (Appendix E) suggests that, over a 30-year period (based on modelled data derived from Schütte *et al.* 2023), there would be:

- At least four periods where there was no rainfall within 200 days;
- At least five periods where there was no rainfall within two years;
- At least two periods where there was no rainfall within three years;
- At least one period where there was no rainfall within six years.

The above data highlight the aridity of the study area and illustrate the conditions to which natural ecosystems are adapted. **Figure E7** also highlights how these figures will alter in a climate change scenario, with at least one period in 30 years where there would be no rainfall for six years.

4.5.2.6 The Orange River and its tributaries

Within the study area, none of the tributaries of the Orange River contribute significantly to flows in the river or its estuary. In fact, the RSA tributaries entering the Lower Orange Sub-WMA (an area much larger than the present study area) account for only about 1.9% of total flows in the Lower Orange River (DWS 2016a).

DWS (2016a) summarises ecoclassification results for the Lower Orange River, drawing on previous studies (e.g. Louw and Koekemoer (2010) and Louw *et al.* (2013)). Of the four riverine EWR sites used to determine ecological flow requirements in the Lower Orange River, two are located within the study area (EWR 04 and EWR 05, at Vioolsdrift and Sendelingsdrift, respectively). Ecoclassification results for these sites indicate a Present Ecological State (PES) (at least at the time of these studies) of Category C (moderately modified) and Category B/C (largely natural to moderately modified) for these sites respectively, suggesting improvement with distance downstream. Both sites were accorded Ecological Importance and Sensitivity (EIS) ratings, and the report notes that degradation from natural conditions at both sites is the result of loss of frequency of large floods; agricultural return flows; higher low flows than natural in the dry season; decreased low flows at other times; sediments from dam releases; the presence of alien fish; mining activities; alien vegetation; and grazing and trampling by livestock.

EIS was rated as High for both sites, and this contributed to the Recommended Ecological Categories (REC) for the sites of Category B/C and B respectively, implying a need for improvement in river condition. These recommendations are also in line with requirements for improvement in the Orange River Estuary condition, rated as of Very High EIS (see Section 4.5.3).

Measures to improve watercourse condition in the above reaches so as to achieve their respective RECs should focus on increasing wet season base flows; clearing of alien vegetation; controlling grazing and trampling (EWR04); and reinstating dry season droughts (EWR05) (DWS 2016a).

Five resource units (RUs) along the Orange River reaches within the study area have been included as Priority Resource Units for the development of Resource Quality Objectives (RQOs) in the Lower Orange River Water Resource Classification Project (DWS 2024b). These comprise the river in its reaches from Augrabies Gorge to Pella (that is, including all the river reaches in the study area as far as Pella); Pella to Vioolsdrift weir; Vioolsdrift weir to quaternary D82H; the downstream river reaches within the Richtersveld National Park; and the upstream portion of quaternary D82L to the start of the estuary. These units all received prioritisation scores >0.7 (0.87 - 1.00) and were thus included among priority RUs. The prioritisation scores were derived from a number of rated criteria. Of relevance to the present study were the high scores (1.00) accorded to Threats Posed to Users (dependent on water use) and Threats Posed to Ecological Components (that is, the level of ecological threat posed by human activities) for all of these RUs, with the exception of the (protected) Richtersveld river reaches, where these threats were scored 0.5 only.

Note that the Orange River Estuary itself is a Ramsar wetland – this important system is discussed in Section 4.5.3.

4.5.2.7 Other river systems

[3]Eight mainstem ephemeral watercourses in the study area flow into the Atlantic Ocean via estuaries or micro-outlets, while others (e.g. the Kamma River and numerous other unnamed systems) dissipate into deep sands or pans, and never flow into the sea. These watercourses lie in the Coastal Orange Sub-WMA. DWS (2016a) indicates that their condition is generally good, with all of these rivers categorized as PES Category B/C or B, with the exception of the Kwaganap River (PES Category C), the Bitter River (PES Category C to D) and tributaries of the Groen (Hartbees into the Swart-Doring River) (PES Category C). The main impacts affecting rivers in these catchments comprise (variously and in no order of scale) road infrastructure that traps ephemeral water flows and changes flood patterns; mining; alien vegetation; over-grazing that increases erosion and sediment loads; groundwater abstraction and other forms of human disturbance (DWS 2017a).

[3] These rivers (excluding the perennial Orange River) comprise the Holgat, Kwaganap, Buffels, Swartlintjies, Spoeg, Bitter, Groen and Brak Rivers (see Figure 5.1).

The REC for the above rivers is the same as their PES, reflecting generally good condition, although the REC for the Kwaganap and Bitter Rivers requires an improvement from PES Category C to an REC Category B /C.

Ephemeral rivers in the Namaqua National Park in the south western portion of the study area have been described in a little more detail in SANParks (2024) and include the upper and middle reaches of the Swartlintjies River and the lower/ estuarine reaches of the Spoeg, Bitter and Groen Rivers (Figure E6, Appendix E). The latter document notes the lack of ground-truthing of mainly desk-top classified and modelled watercourses (an issue presumed to be applicable to most watercourses in the study area as a whole). The report also identifies five key pressures on rivers in the park, namely:

- Modifications to the natural variation of hydrological regime;
- Impacts to water quality;
- Loss of natural habitat, habitat degradation and fragmentation;
- Spread of invasive (plant) species; and
- Over-exploitation of (plant) species.

Poorly monitored and poorly understood degradation in watercourse condition in these areas is also highlighted in this study. These changes would be expected to be exacerbated under climate change conditions (Van Deventer *et al.* 2019). It is assumed for the purposes of this report that if watercourses in protected areas are undergoing degradation, it is likely that this is occurring to at least the same if not greater degrees in unprotected areas.

It is however noted that ephemeral rivers in arid areas are less likely to be impacted to the same degree by issues that plague perennial and lower salinity systems elsewhere in rural areas, where abstraction, impoundment and nutrient enrichment impact on these systems to a much greater degree, because the water resources are often of better quality from a livestock and irrigation perspective and thus are more likely to be exploited.

4.5.2.8 Pans

Endorheic pans are the most common wetland type in arid and semi-arid environments (Allan et al. 1995), and are generally thought to form as a result of the synergy of a number of factors and processes, including low rainfall, sparse vegetation, flat to gently sloping topography, disrupted drainage, geology, grazing and deflation. The present study area indeed includes numerous ephemeral pans, classified as depression wetlands in the NWM (v5). The largest of these are located in the south eastern corner of the site (quaternaries D53F and E31A in Figure E3 (Appendix E), where they comprise sometimes extensive areas of occasionally (sometimes only after years) inundated wetland, where water perches on a hardpan substrate. These wetlands lie west of large pans such as Grootvloer and Verneukpan, and although much smaller, are assumed to be important biodiversity features. Other (generally smaller) ephemeral pans are located in the (100% endoreic) areas of quaternaries D82B and D82C, and in fact, ephemeral pans occur throughout the study area, generally driven by impermeable near-surface layers that allow perching of infrequent rainfall over periods of weeks to months. In some areas (e.g. in the proposed Boegoebaai Port SEZ area), some pans associated with areas of perennial water and characterised by stands of *Phragmites australis* reeds and (salt-tolerant) *Sarcocornia cf. perenne* dominated margins are believed to comprise coastal salinas - that is, lagoons that have their own natural supply of ground water, usually in the form of sea water seepage (or vestigial sea water lenses from past sea levels) rather than rain runoff, and usually have local encrustations of gypsum or common salt. They would have been formed originally at higher sea levels, and were then abandoned as sea levels fell (see Desmet 1996).

The ephemeral pans and pools in the study area are likely to support communities of invertebrate fauna that are adapted to life in transient aquatic conditions, with adaptations commonly including rapid hatching under inundated conditions, fast development, high fecundity, and short life spans. Such fauna could include branchiopod crustaceans, with taxa from four orders all associated with temporary freshwater habitats (Conchostraca (clam shrimps); Cladocera (water fleas – e.g. daphnia); Notostraca (tadpole shrimps of the genus *Triops* (Rayner 1996)); and Anostraca (fairy shrimps)). Species richness in temporary waterbodies relates to the size and habitat diversity of the water body and to habitat duration (Ebert and Balko (1987); Hamer and Rayner (1996); and Mabidi *et al.* (2016)).

4.5.2.9 Wetlands excluding ephemeral pans

The aridity of most of the study area means that wetlands other than the ephemeral pans described above are limited to areas along the perennial Orange River and some seasonal, rather than ephemeral seeps, wetlands and rivers, mostly occurring in the Kamiesberg area, in the southern portion of the Namaqua Highlands Ecoregion. None of the "High" and "Very High" priority wetlands identified in DWS (2016b) lie within the present study area – these priority areas were however identified in that study from the perspective of their potential to contribute to water resource availability for non-ecological requirements. The study notes that wetlands in the Lower Orange WMA that were identified as ecologically important were mostly those with **low water resource use importance.** Those with high water resource use importance were confined to the Orange River. This aspect is considered further in this chapter, with regard to the assignation of aquatic ecosystem versus water resource use sensitivity (see Section 4.7.4).

The valley bottom wetlands and hillslope seeps in the Kamiesberg uplands and surrounds (south western portion of the study area, quaternaries F50E, F30C and F30A) provide a critical support system for livestock, owing to their ability to continue to retain water and quality forage throughout the dry summer months of the year (Samuels 2013; Kotze *et al.* 2010, Black *et al.* 2016). These wetlands, located on shallow soils in often steep terrain with high run-off from the upper catchments of the Kamiesberg act to reduce flow velocities, allowing water to permeate through the underlying soil and recharge shallow sub-surface water, the presence of which is vital to the existence of springs and water levels that are accessible to livestock in excavated wells (Kotze et al. 2010 and Black *et al.* 2016). Despite their high importance for sustaining local livelihoods, over 60 per cent of these wetlands have been severely degraded by the removal of indigenous vegetation, over-burning, cultivation, overgrazing, roads, over-abstraction of water and alien vegetation (Helme and Desmet 2006). These wetlands are furthermore highly vulnerable to climate change where it affects the frequency of rainfall events in areas such as these, where average no-flow days/annum are already 336 to 345 days per year (**Figure E7** Appendix E).

Note that the Ramkamp and Xharas wetlands in the Kamiesberg Uplands have been rated as particularly important and least impacted wetlands and are the only wetlands within the present study area that have been prioritised for the development of Resource Quality Objectives (RQOs) in the Lower Orange River Water Resource Classification Project (DWS 2024b).

4.5.3 Estuaries

4.5.3.1 General

The largest and most ecologically significant estuary in the study area is the Orange River Estuary, which enters the Atlantic Ocean on the northern boundary of South Africa and Namibia, forming the northwestern boundary of the study area. In addition to this estuary, described in more detail below, the study area includes the Brak, Groen, Bitter, Spoeg, Swartlintjies, Buffels, Kwaganap and Holgat River outlets to the sea, classified variously as Cool Temperate Arid Predominantly Closed (CTAPC) estuaries and micro-outlets (Van Niekerk *et al.* 2020). These are all indicated in **Figure 4-5.2**.

4.5.3.2 The Orange River Estuary

The Orange River Estuary, with an area of some [4]2 298 ha (DWS 2024), straddles the South African / Namibian border, and lies between the towns of Alexander Bay (RSA side) and Oranjemund (Namibian side). The estuary outlet is described in DWS (2024b) as a delta type river mouth, made up of a braided channel system located between sandbanks covered with pioneer vegetation; a 2 to 3 m deep tidal basin; and extensive areas of salt marsh along the southern bank. It extends some 14 km upstream, with its upper boundary extending some 3 km

[4] Note that the NBA (2018) (Van Deventer et al., 2019) shows the estuary as an area of 3019.5 ha

upstream of the Sir Ernest Oppenheimer Bridge crossing (as shown in the 2018 NBA (van Niekerk *et al*., 2019). The estuary mouth is now almost permanently open.

This estuary is of international importance, having been declared a Ramsar Wetland site in 1991 (South African side) and 1995 (Namibian side). It is also of national importance in both Namibia and South Africa, being one of only two estuaries along the Namibian coastline and having been ranked as the seventh most important estuary in South Africa in terms of its conservation importance (Turpie *et al.* 2002). Van Niekerk *et al.* (2013) scored its Ecological Importance as 99 out of 100, associated with High importance, with the highest scores allocated for its size, habitat diversity and functional importance. The latter relates mainly to the importance of the estuary as a supply of sediment to beaches north of the river mouth and for the provision of near-shore sandy habitat for West Coast sole (*Austroglossus microlepis*) (DWS 2017b).

The estuary was however placed on the [5]Montreux Record in 1995, in recognition of the severely degraded condition of the saltmarsh wetland on the southern bank. [6]Degradation is attributed largely to the impacts of adjacent mining, upstream flow regulation and the construction of an embankment through the estuary, causing a substantial decrease in the amount of fresh water entering the saltmarsh, which has dried out substantially. Moreover, regulated water flows entering the estuary as a result of upstream hydro-electric and irrigation releases from dams result in more constant water flows, less frequent flooding and a reduction in sediment input, in contrast to its more natural hydro-regime when the river mouth would dry out temporarily during dry periods (August-September) before being re-flooded in wet periods.

REASONS FOR RAMSAR STATUS

The estuary supports more than 1% of the world population of three species of waterbirds that are endemic to southern Africa (Cape Cormorant, Hartlaub's Gull and Damara Tern) as well as more than 1% of the Southern African populations of six species of waterbirds (Black-necked Grebe, Lesser Flamingo, Chestnut-banded Plover, Curlew Sandpiper, Swift Tern and Caspian Tern).

It is regarded as one of the most important coastal wetlands in southern Africa in terms of the number of birds supported, at times supporting more than 20,000 waterbirds of between 50 and 57 species and is thus also recognized as an Important Bird Area. (data from http://www.saramsar.com/, downloaded April 2025).

Van Niekerk *et al.* (2013) highlighted the following major impacts affecting the condition of the estuary, namely:

- Significant freshwater flow modification (loss of floods and increased dry season baseflows);
- Lack of mouth closure and associated back flooding of salt marshes with fresher water;
- Road infrastructure in the estuary;
- Nutrient enrichment from upstream;
- Gill netting of indigenous fish species;
- Levees preventing back flooding of riparian areas;
- Grazing and hunting;
- Mining activities; and
- Wastewater disposal (sewage and mining effluent).

Based on the above, the Present Ecological State (PES) of the estuary was assessed as Category D (highly modified) (Van Niekerk *et al.* 2013). DWS (2024b) notes however that, given the high ecological importance of the estuary, its Recommended Ecological Category (REC) should ideally be set at Category A. Achieving this condition was however considered unfeasible, and the REC was thus set at Category C – a condition that would

[5] The Montreux Record is a listing of Ramsar wetlands that are in a degraded condition. Wetlands placed on this list are expected to undergo focused rehabilitation, in order to retain their status

[6]Source: Ramsar wetland site datasheets [https://rsis.ramsar.org/RISapp/files/119/documents/ZA526lit.pdf]

still require significant intervention to achieve. The Ecosystem Threat Status (ETS) for this estuary is Endangered (Van Niekerk et al. 2019).

4.5.3.3 Other estuaries

In addition to the Orange River Estuary, four CTAPC estuaries occur within the study area within the Coastal Orange Sub-WMA, namely the Groen, Spoeg, Swartlintjies and Buffels River estuaries. Estuary condition, functional and estuarine importance, the main sources of impact, PES and REC have all been assessed for these systems (see DWS 2017a), while Van Niekerk *et al.* (2019) include Conservation Priority and Ecosystem Threat Status (ETS) ratings for estuaries in the 2018 National Biodiversity Assessment (NBA). These data are summarized in **Tables 4-5.3** and **4-5.4**.

Note that estuarine functional importance ratings for these systems were largely driven by their contribution to a very limited wetland habitat type for estuarine and coastal birds along the coast.

Table 4-5.3: Summary data relating to condition, PES, REC, ETS and Conservation Priority for the Cool Temperate Arid Predominantly Closed (CTAPC) estuaries within the SEA study area (data from DWS 2017a)

Estuary	PES (DWS 2017a)	Functional importance (DWS 2017a)	Estuarine importance (DWS 2017a)	REC (DWS 2017a)	Conservation priority (NBA 2018)	ETS (NBA 2018)
Groen	B	Important	Average importance	B	Priority – "No Take" estuary	Endangered
Spoeg	A/B	Very important	Average importance	A/B	Priority – "No Take" estuary	Endangered
Swartlintjie	B	Important	Average importance	B	Not a priority estuary	Endangered
Buffels	D (deteriorating)	Very important	Average importance	D	Not a priority estuary	Endangered

Table 4-5.4: Main causes of impacts to estuary condition (from DWS 2017a)

Rated High, Moderate, none

Estuary	Groen	Spoeg	Swartlintjie	Buffels
Groundwater abstraction resulting in loss of freshwater inflows	Moderate	Moderate		High
Road infrastructure / embankments trapping river flows	Moderate	Moderate	High	High
Mining activities incl. dust and salinisation	[future threat]	[future threat]	High	High
Roads in the EFZ	Moderate		Moderate	High
Floodplain development (e.g. golf courses, houses	Moderate			High
Diffuse sewage runoff (irrigation, ablutions)	Moderate			High
Grazing in catchment affecting sediment structure through erosion	Moderate	Moderate	Moderate	Moderate
Invasive alien plants				High
Human disturbance	High			High
Saltworks				
Artificial; breaching / mouth manipulation				High

4.5.4 Micro-outlets

The Brak, Bitter, Kwaganap and Holgat Rivers are all small, ephemeral rivers that flow into the sea after major storms. Their flows are, however, too rare to sustain functional estuaries and they are instead classified as micro-outlets (Van Niekerk *et al.* 2020). Moreover, although the catchments of several of these systems have been rated as near-natural (e.g. the Holgat River), their outflows in many cases have been highly altered by mining-associated activities.

Other rivers such as the Kamma, which also flow towards the sea, never in fact reach it, with their ephemeral flows dissipating into the sands, where they contribute to groundwater recharge or evaporate from pans.

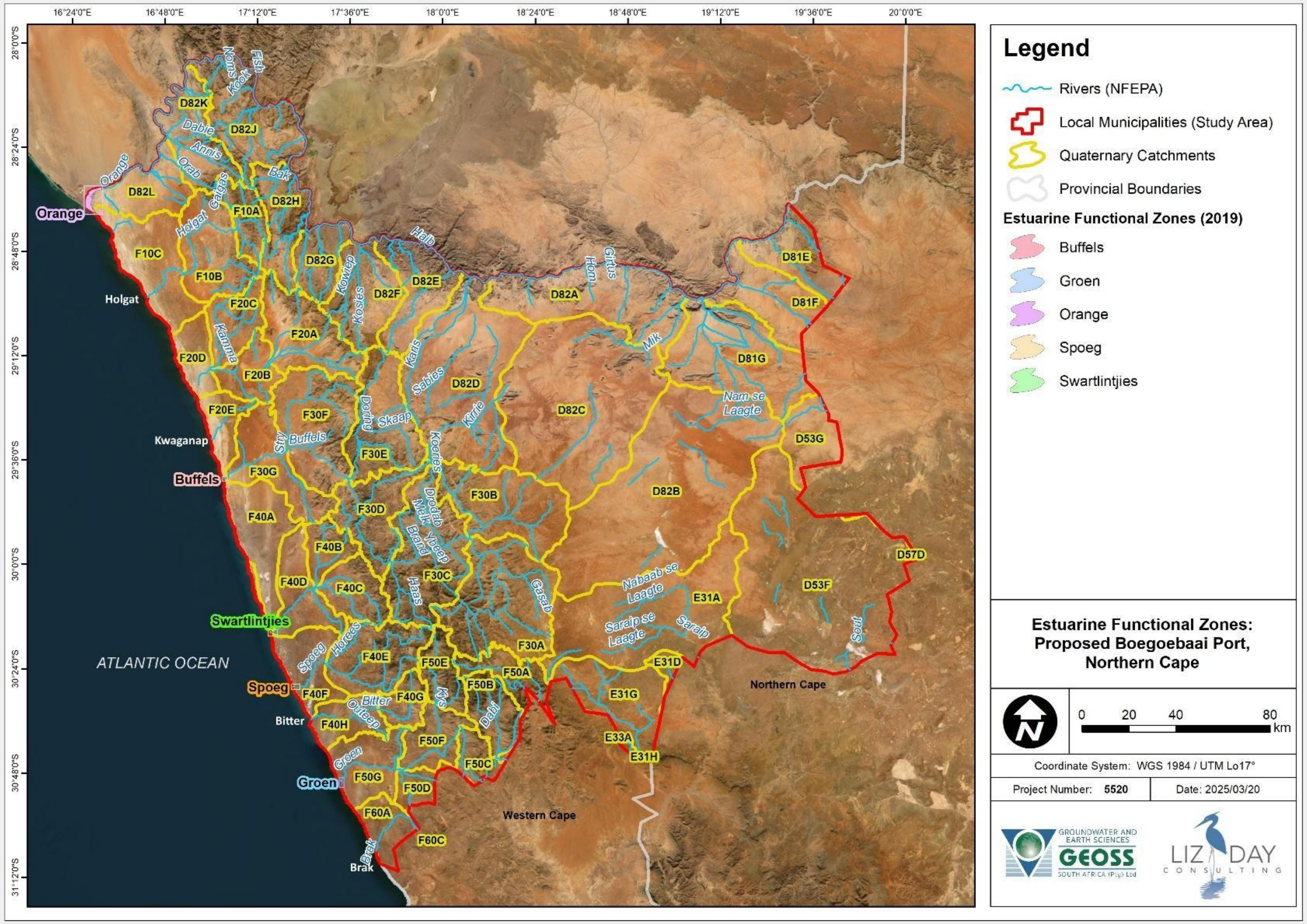


Figure 4-5.2: Study area showing estuaries (mapped as Estuarine Functional Zones (EFZ) and micro-outlets of highly ephemeral watercourses that lack estuary function (Van Niekerk et al. 2020) (labelled in white)

4.6 WATER RESOURCE AVAILABILITY AND DEMAND

4.6.1 Water users

The main water users in the study area are the irrigated agriculture sector (mainly along the lower Orange River), mining (extraction of alluvial diamonds and a number of minerals), domestic and industrial water supply and recreational purposes, with the lower Orange River supporting tourist activities such as canoe safaris. These water uses are supported by a combination of surface water supplies from the Orange River, driven primarily by flows entering from the Upper Orange River catchment; groundwater abstraction; and some desalination schemes.

4.6.2 Main current and planned water sources

4.6.2.1 Groundwater use

The low MAP for the Namaqualand region combined with limited surface water resources means that the area is strongly dependent on groundwater to support human populations and economic activities (Van Gend et al., 2021). The Greater Namakwa Region that is being evaluated in this assessment covers a vast number of quaternary catchments, falling within the Lower Orange and the Olifants-Doorn Water Management Areas. Invariably, due to the aridity of the region, all of these quaternary catchments have a general authorization (GA) of 0 m^3/ha/a for groundwater use and all groundwater use needs to be registered. The primary source of water supply across the Richtersveld, Kamiesberg and Nama Khoi Local Municipalities (LMs) is groundwater pumped from municipal boreholes, but the primary source of water supply for Khai-Ma Municipality is not stated (DFFE, 2023).

Registered water use is available on national databases, namely the Water Authorisation and Registration Management System (WARMS) Database and the National Groundwater Archive (NGA). The latest accessible version of the WARMS Database has been updated in 2025. Water use on the WARMS database is categorised by resource type: rivers/streams, dams, surface water schemes, springs/eyes and boreholes. A total of 48 registered boreholes were found to be registered on the WARMS database in the study area (the four delineated LMs), and a total volume of 2 975 902 m^3 per annum has been allocated for groundwater use (see **Figure B8** (Appendix B)). Water use is predominantly for water supply (56%) as many towns are reliant on groundwater as a sole source (Conrad et al., 2003). Other water uses include mining (26%), agricultural irrigation (10%), industrial use (4%), power generation (3%) and livestock watering (1%). A breakdown of the water use in the area is presented below.

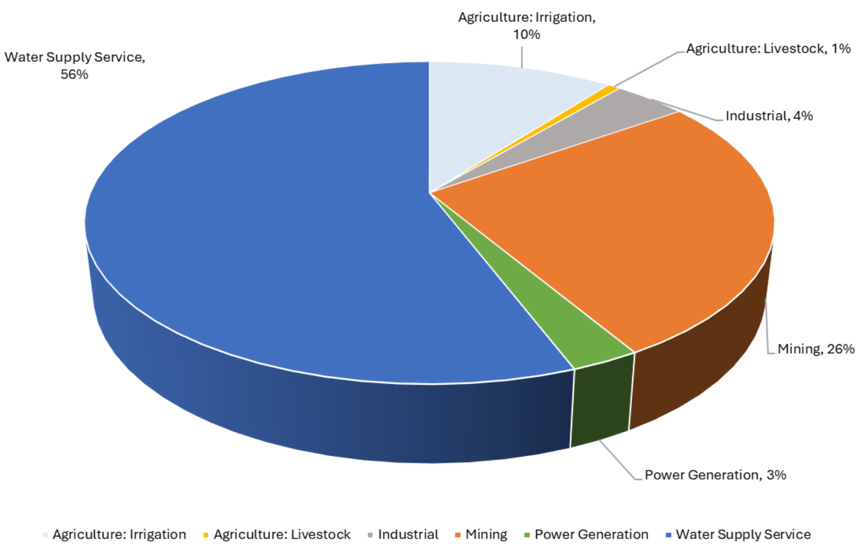


Figure 4-6.1: Breakdown of registered groundwater use in the 2025 WARMS database for the four LMs.

The NGA Database indicates a total of 5 693 boreholes present in the study area, installed into various aquifers across the region. The database does not contain information on the groundwater volume used and therefore, groundwater use is likely much higher than what is reported. It is, however, important to note that the number of groundwater users in the area may not be entirely accurate. There may be more groundwater users in the area as not all groundwater use tends to be registered. The number of boreholes retrieved from the NGA database date back to as far as 1914, and some of these holes may no longer be used or yielding water.

4.6.2.2 Surface water use

Surface water use is essentially limited to the Lower Orange River, with water use elsewhere in this arid study area being largely reliant on groundwater or desalination.

The simulated Mean Annual Runoff contributing to the Orange River, without abstractions, is 24 400 Mm3/annum (Schütte et al. 2023). However, considerable abstractions occur. The current urban, industrial and mining abstractions from the Orange River overall are estimated to be 360 Mm3/annum, while future abstractions (2040) could reach 479 Mm3/annum (DWS 2012). Average annual river losses between the Vanderkloof Dam and the river mouth are estimated at 615 Mm3/annum, mainly due to evaporation from the river surface area, but also include seepage losses and evapo-transpiration from riparian and instream vegetation. In the EFR study of Louw et al. (2013), the in-stream MAR was estimated at 11 306 Mm3/annum, so considerable additional abstractions are evident.

4.6.3 Other water sources: Desalination

Desalination / reverse osmosis technologies are currently used in some areas to supplement water supply, including the Kamiesberg Municipality, which is implementing a desalination plant in Garies to improve groundwater quality (Kamiesberg Municipality 2017).

4.6.4 Water supply schemes

While most of the domestic, urban and mining requirements for water in the study area come from the Lower Orange River mainstem sub-area (ORASECOM 2020), water is also transferred from the Orange River to the Coastal Orange Sub-WMA. Water demand in these areas is generally relatively low and associated with small towns such as Springbok, Steinkopf and Port Nolloth as well as the mines in the area (DWS 2024).

Water demand in Port Nolloth, which escalated from 2020 to 2040, is planned to be supplied by the Alexander Bay Bulk Water Scheme. The Springbok Regional Water Supply Scheme is also relevant to the current project, supplying the towns of Springbok, O'Kiep, Carolusburg and Kleinsee as well as local mines (DWS 2024). The planned Namakwa Bulkwater Scheme would extend this scheme further south and serve additional small towns and mining areas (DWS 2012).

Figure 4-6.2 (after DWS 2024) shows irrigation and water supply schemes and the main irrigation areas in the Lower Orange Catchment, as produced in DWS (2004), while Figure 4-6.3 shows updated bulkwater and other supply schemes (after DWS 2023).

4.6.5 Irrigation schemes

Linked to the water supply schemes are various irrigation schemes, of which those relevant to the present study area are (data from DWS 2024):

- The Onseepkans Irrigation Scheme, which supplies water from the Orange River to some 314 ha of irrigation land;
- The Namakwaland Irrigation Area, which is supplied with water from the Orange River, released from the Vanderkloof Dam (upstream of the study area), allowing for irrigation of some 2 439 ha;

- The Vioolsdrift Irrigation Scheme, which receives water via a canal system fed by the Vioolsdrift Weir on the Orange River within the study area. This allows for irrigation of some 600 ha and also supplies Namibia with irrigation water in the Noordoewer area, for some 284 ha.

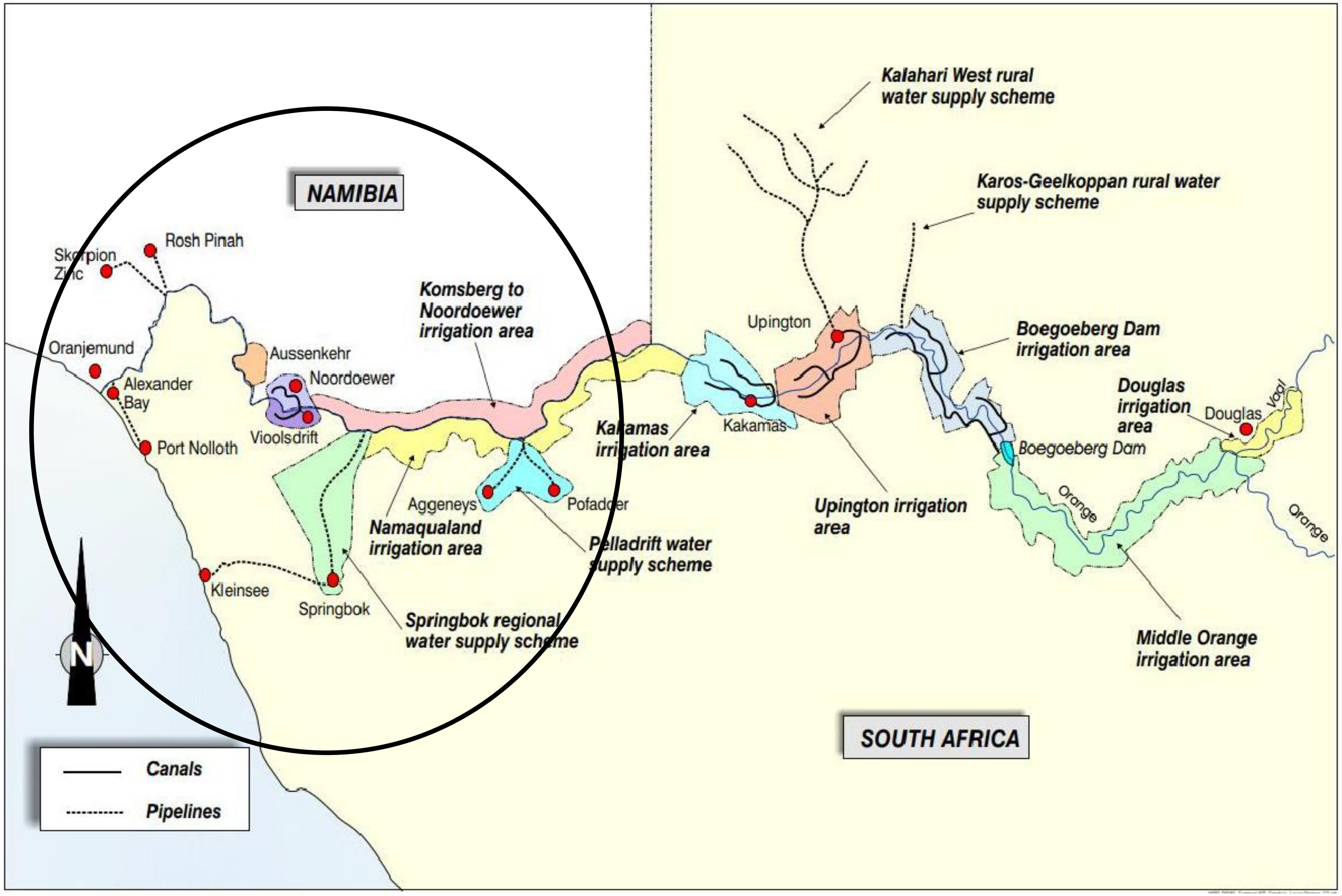
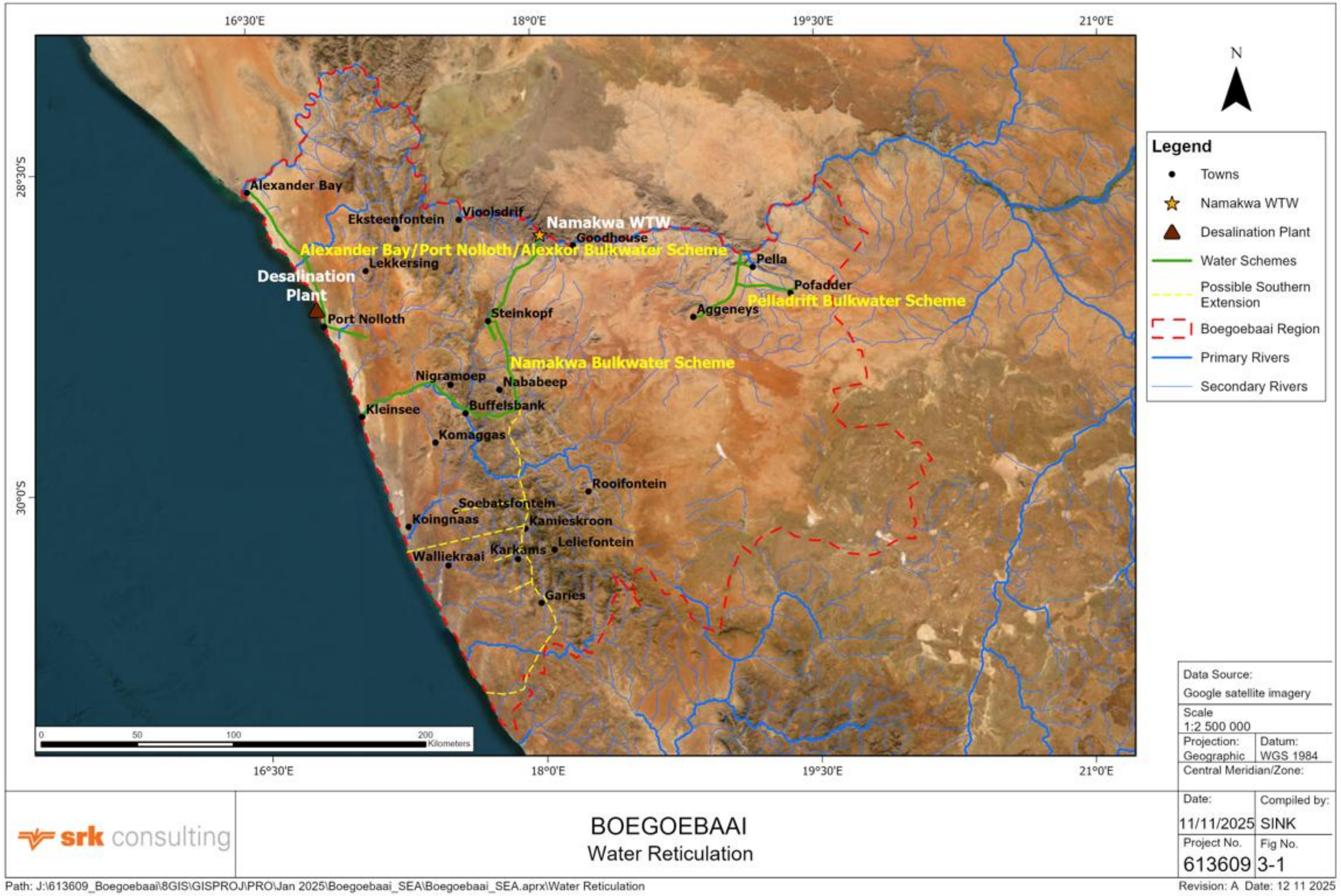


Figure 4-6.2: Irrigation and water supply schemes and the main irrigation areas in the Lower Orange Catchment, as shown in DWS (2004) (Figure after DWS 2024). Schemes relative to the current study area are roughly circled.



1 Figure 4-6.3: Updated existing and planned bulkwater and other supply schemes (after DWS 2023).

4.7 SENSITIVITY CLASSIFICATION

4.7.1 Approach

An important part of this project is defining particular water resource sensitivities in a development context. This will allow early differentiation of different areas, on the basis of their sensitivity to development associated with expansion of green energy and associated infrastructure, in response to the proposed Green Hydrogen development at the proposed Boegoebaai Port.

It is important to note however that not all activities associated with the proposed development would necessarily impact on all areas mapped as sensitive. That is, the "sensitivity" mapping included in this project includes an element of ecological importance, and not all activities associated with the proposed development(s) would be incompatible with maintaining these important areas, which in some cases would not be sensitive to the actual impacts associated with those activities.

The following sections outline the various criteria used in identification of different levels of sensitivity of different areas to (unspecified) activities. These are unpacked more usefully in Section 4.9, with regard to actual projected activities and their impacts in different areas.

4.7.2 Groundwater Sensitivity Classification

4.7.2.1 Background

Groundwater is vulnerable to contamination from a wide range of anthropogenic activities, with groundwater sensitivity being dependent on factors such as geological characteristics, landscape, importance to people, etc. These factors are discussed in the sections below, and used to delineate overall areas of groundwater sensitivity. It is also recognised that some aquifers are more vulnerable to contamination than others. A distinction is thus made between aquifer vulnerability and aquifer susceptibility. Vulnerability describes the likelihood of surface-based contaminants reaching the groundwater system whereas susceptibility indicates both resource importance and vulnerability (Parsons and Conrad, 1998).

4.7.2.2 Aquifer System Management Classes

Aquifer system management classes are categorised by evaluating resource accessibility in comparison to its exploitability. Aquifer management classes speak to the importance of the resource and are described in **Table 4-7.1** and **Table 4-7.2** below. Aquifers with high exploitability and accessibility are classified as major aquifer systems whereas aquifers with low accessibility and exploitability are considered as poor or non-aquifer systems. Descriptions of these aquifer systems are described in **Table 4-7.2**.

Table 4-7.1: Application of the aquifer system management classification to the borehole prospecting map of Vegter (1998).

Accessibility	Exploitability					
	<10%	10% - 20%	20% - 30%	30% - 40%	40% - 50%	> 50%
>60%	Poor	Minor	Minor	Major	Major	Major
40% - 60%	Poor	Poor	Minor	Minor	Major	Major
<40%	Poor	Poor	Poor	Minor	Minor	Major

Table 4-7.2: Definitions of aquifer management classes (Parsons and Conrad, 1998).

Aquifer	Description
Major Aquifer System	Highly permeable formations, usually with a known or probable presence of significant fracturing. This may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable.

4.7.2.3 Aquifer Vulnerability Classification

The national scale groundwater vulnerability classification, which was developed according to the DRASTIC methodology (Conrad and Munch 2007), indicates that the study area has varying vulnerabilities to surface-based contaminants. The DRASTIC method considers the following factors:

D = depth to groundwater (5)
R = recharge (4)
A = aquifer media (3)
S = soil type (2)
T = topography (1)
I = impact of the vadose zone (5)
C = conductivity (hydraulic) (3)

The number indicated in parenthesis after each factor description is the weighting or relative importance of that factor.

4.7.2.4 Aquifer Susceptibility Classification

The aquifer contamination susceptibility map (see **Figure B7** (Appendix B)) is a product of the aquifer system management classification map and the aquifer vulnerability map. The classes used for each base map were used to develop susceptibility classes as indicated in **Table 4-7.3** below. Poor groundwater regions with a low vulnerability are defined as having a low susceptibility to contamination. Conversely, major aquifer regions with a high vulnerability are regarded as having a high susceptibility to contamination (Parsons and Conrad, 1998).

Aquifer susceptibility generally ranges from “low” to “medium” along the West Coast and “very low” to “low” along the South African-Namibian border. As one moves inland from the coast and the Orange River (Namibian border), groundwater vulnerability tends to be more variable, ranging between medium to very high. “Very high” vulnerability is mapped for the high-yielding aquifer located between Springbok, Garies and Kliprand (see **Figure B7** (Appendix B).

Table 4-7.3: Basis for assigning aquifer contamination susceptibility classes (Parsons and Conrad, 1998).

Aquifer System Management Class	Vulnerability Class		
	Low (1)	*Medium (2)*	*High (3)*
Poor Groundwater Region (1)	Low susceptibility (1)	Low susceptibility (1)	Medium susceptibility (3)
Minor Aquifer Region (2)	Low susceptibility (2)	Medium susceptibility (4)	High susceptibility (6)
Major Aquifer Region (3)	Medium susceptibility (3)	High susceptibility (6)	High susceptibility (9)

4.7.2.5 Strategic Water Source Areas (SWSAs)

Strategic Water Source Areas (SWSAs) are defined as areas of land that either: (1) supply a disproportionately large quantity of mean annual surface water runoff in relation to their size and are therefore, considered nationally important; or (2) have high groundwater recharge and where groundwater forms a nationally important resource; or (3) areas that meet both criteria (1) and (2). SWSA aquifers sustain baseflow, contribute to runoff and, especially, contribute to dry season flows. Sustained river flows are important as they support people and communities who depend directly on rivers for their water, especially during the dry season and droughts. (CSIR, 2017).

Groundwater SWSAs cover approximately 9% of South Africa's land surface. They account for up to 42% of the river baseflow generated by these water source areas and play a key role in sustaining surface water flows during the dry season (CSIR 2017). Three sub-national groundwater SWSAs have been identified in the study area, namely the Port Nolloth, Kamieskroon and Komaggas SWSAs which make up 2.65% of national SWSAs. These SWSAs are indicated in **Figure B9** (Appendix B) and have been further classified as areas of very high sensitivity in this study.

4.7.2.6 Groundwater Resource Units (GRUs)

A number of GRUs have been delineated in the Lower Orange WMA. A GRU, classified as a groundwater body that has been delineated or grouped into a single significant water resource, is based on one or more characteristics that are similar across that unit. Classification is based on a number of factors, including: topography (primary delineation by quaternary catchment boundary), aquifer type, interaction with surface water bodies (pans and baseflow) and possibly dependent ecosystems, recharge, resource accessibility and exploitability, quality and resource dependence.

In order to identify and prioritise the most important GRUs, the following assessment criteria were used: (1) importance of the GRU to users (degree of groundwater dependence); (2) threat posed to water resource quality for users (aquifer vulnerability); (3) threat posed to water resource quality for the environment (baseflow) and (4) degree of use (stress index). Using the aforementioned criteria, a number of GRUs were categorised as intermediate and high priority. These GRUs are indicated in **Figure B9** (Appendix B) and will subsequently be identified as high and very high sensitivity areas, respectively. In-depth analyses and assessment of the various GRUs are presented in the Lower Orange Reserve Determination Report (2016).

4.7.2.7 Sensitivity Classification

Based on the above sections, descriptions of groundwater sensitivity areas are presented in **Table 4-7.4** below. These are mapped in **Figure 4-7.1.**

Table 4-7.4: Groundwater sensitivity classifications

Sensitivity	Description
Low	Classified as having very low to low vulnerability according to DRASTIC methodology; typically falling within a poor groundwater region or minor aquifer system with low accessibility and exploitability. Low susceptibility to surface-based contamination.
Medium	Classified as having low/medium to medium vulnerability according to DRASTIC methodology; typically falling within a minor to major aquifer system with moderate accessibility and exploitability. Medium susceptibility to surface-based contamination.
High	Classified as having high vulnerability according to DRASTIC methodology; typically falling within a major aquifer system with good accessibility and exploitability. High susceptibility to surface-based contamination. Possibly also classified as an intermediate priority GRU as per DWS (2016).
Very High	Classified as having high vulnerability according to DRASTIC methodology; typically falling within a major aquifer system with high accessibility and exploitability. High susceptibility to surface-based contamination. Possibly also classified as a Strategic Water Source Area or a high priority GRU as per DWS (2016).

4.7.3 Surface Water Sensitivity Classification

Surface water sensitivity has been assessed for linear and distributed criteria. Linear features subject to impacts are the drainage network (river system) and the Orange River abstraction and reticulation network. Distributed features include aridity levels and the density of farm dams, all mapped at a quaternary level.

4.7.3.1 Drainage Networks

Although surface water discharge only occurs occasionally in the drainage network, the responses are generally rapid and can be intense when they do occur. The drainage networks are particularly sensitive to disturbance (road crossings, bridges, encroachment into the flood plain) and the alluvial flood plains are critical for groundwater recharge, which occurs mainly during flood events.

Disturbances and restrictions in the drainage network (ephemeral rivers) could give rise to extensive upstream flooding and, if breaches occur, downstream damage could result. Restrictions in watercourses could also give rise to increased velocities and scour damage to stream banks and beds. Where riverbeds comprise mostly sands and floodplains mostly silts, disturbances are likely to cause significant changes in sediment transport and scour.

With the very low occurrence of runoff events and long periods without runoff, all rivers and floodplains are considered fragile to disturbance, being dry most of the time and unable to resist disturbance when it does occur. It is also considered that river networks would be unable to reconfigure from disturbance within periods of several decades (Fryirs 2017).

4.7.3.2 Water Supply Reticulation

The extensive use of groundwater in the area has stretched the resource to a limit and further groundwater exploitation in the region is limited. The current abstractions from the Orange River and reticulation into the interior of the region are also aging and often do not yield their design demand, which continues to increase (DWS 2012; BVI 2023a). These abstraction works and reticulated networks, including planned extensions and improvements, are considered extremely sensitive, since they have been assessed as being the only viable source for sustaining water supply to the region.

These systems may be supplemented by coastal desalination works, but there is some concern over the capacity of local operators to cope with the more sophisticated technology.

4.7.3.3 Aridity

All quaternary catchments in the study area are categorised as either arid or hyper-arid. It is considered that hyper-arid areas would be insensitive to water supply impacts as the yield is negligible. These areas are considered unsuitable for crops or grazing. In arid regions, some grazing systems may be supported, but no crops would be viable without irrigation. Aridity indices (defined as the ratio between average annual evapotranspiration to precipitation) above 20 are classed as hyper-arid and those between 5 and 20 as arid. It is deemed that the quaternaries with low aridity indices (5 to 10) would be highly sensitive to disturbance, since these would be the most suited to cattle farming. Quaternaries with aridity indices between 11 and 20 would be considered having medium sensitivity (see **Figure C1.1** (Appendix C).

4.7.3.4 Farm Dams

In a similar way to the aridity indices, areas with small farm dams are also considered sensitive (see **Figure 4-2.9**). Disturbances in these areas that might restrict replenishment of the dams would impact on their capacity to water livestock.

4.7.3.5 Sensitivity Classification

Linear and areal sensitivity criteria are summarised in Table 4-7.5 and mapped in Figure 4-7.2.

Table 4-7.5: Sensitivity rating categories for surface water resources

Sensitivity	Sensitivity Feature	Motivation
Very High	• Orange River and buffer area • Water supply reticulation pipeline from the Orange River and desalination plants, including towns they supply • NFEPA river systems	DWS current and future supply schemes (Figures 4-6.2 and 4-6.3) River systems (Figure 4-5.1)
High	• Areas with more than 50 farm dams per quaternary or • Areas classified as Arid, but with Aridity index less than 10 • 1:50 000 rivers layer	Mantel and Hughes 2023 Gunkel and Lange 2017.
Medium	• Areas with fewer than 50 farm dams per quaternary or • Aridity Index greater than 10, but in Arid classification (Aridity Index less than 20) • [7]River buffers	Mantel and Hughes 2023 Gunkel and Lange 2017. Impacts
Low	• Areas classified as Hyper-Arid (Aridity Index greater than 20). • No surface water supply or storage	Schütte, *et al*. 2024; Gunkel and Lange 2017 (While these areas may be sensitive to hyper-arid ecosystems, they are not considered sensitive to surface water supply).

[7] In discussion between the project hydrologist and the freshwater ecologist, it was agreed that appropriate buffers would comprise: 20 m around dams and artificial wetlands / pans; 50 m around all wetlands; 100 m for NFEPA rivers and EFZs

4.7.4 Aquatic ecosystem sensitivity classification

4.7.4.1 Sensitivity defined

This section considers inland aquatic and estuarine ecosystems in the context of their likely sensitivity to the various activities associated with the proposed development. Although aquatic sensitivity is generally defined as the capacity of an aquatic ecosystem (inland or estuarine) to tolerate disturbance, “sensitivity” in the present context includes an element of ecological importance. That is, although some aquatic ecosystems may be “sensitive” (i.e. respond directly) to certain impacts, if they are of low ecological value, their sensitivity rating would not correspond to their actual response rating. Thus in this assessment, the term “sensitivity” includes elements of both the ecological importance and the sensitivity of the impacted system.

4.7.4.2 Inland aquatic ecosystem sensitivities

The inland aquatic ecosystems described in Section 4.5.2 are likely to be particularly sensitive to the following changes, some of which have a bearing on the kinds of impacts that might be anticipated as a result of climate changes and/or the direct and indirect effects of the proposed Boegoebaai Port and SEZ developments and their associated roll-out of green energy production areas and associated infrastructure:

- Changes in hydroperiod:
  - Increases in hydroperiod – that is, increased duration and frequency of inundation of naturally seasonal systems that could result in significant changes to habitat type and the biota that they support, potentially (and subject to water quality) increasing dominance by *Phragmites australis* reedbed, at the expense of biota including temporary pan zooplankton assemblages, adapted to life in ephemeral systems. Such increases in hydroperiod would be most likely to result from discharges of WWTW effluent into watercourses;
  - Decreases in hydroperiod – these would potentially also alter existing established aquatic ecosystems, drying out existing sources of relatively fresh water and the plants that they sustain, and thus impacting on food and/or water sources for both terrestrial and aquatic fauna – disruption of existing water sources could stem from surface hardening (particularly of sand dunes that act as local aquifers); diversion of stormwater from watercourses and pans usually linked to upstream seepage and flows; and changes in climate involving a reduced frequency of rainfall events;
- Changes in water quality:
  - Artificial “freshening” of inflows into pans, wetlands or other ephemeral watercourses (i.e. decreasing salinities) would potentially impact on natural / existing plant and animal communities that have adaptations to ecosystems that are characterised by brackish to saline conditions, increasing in some systems to hypersaline late-season periods. Freshening would be likely to favour increasing dominance by freshwater-adapted species such as *Phragmites australis* at the expense of existing plant communities, particularly along the margins of the few permanent and seasonally inundated systems. Freshening could be associated with managed stormwater flows into pans and wetlands from hardened surfaces such as roads and development platforms for new infrastructure;
  - Nutrient enrichment: All aquatic ecosystems would be assumed to have high sensitivity to pronounced and sustained nutrient enrichment, particularly in the forms of phosphorus and ammoniacal nitrogen, potentially associated with receipt of seepage or runoff from septic tanks, soakaways and treated sewage effluent;
  - Physical disturbance: The natural pans, wetlands, springs and ephemeral drainage lines that occur in the study area all have high sensitivity to physical disturbance, which could disrupt existing flows into adjacent areas. These could result in subtle differences in topography,

affecting inundation regime and also potentially exposing accumulations of organic material in seasonal wetland / spring areas, affecting rates of decomposition, nutrient cycling and aquatic ecosystem interactions. In the arid study area, physical disturbance (e.g. the creation of ruts and churning of surface sediments by machinery) would be unlikely to be re-set by natural processes such as flooding and could result in permanent changes. In rocky outcrops, activities such as blasting or rock harvesting could destroy locally or regionally important ephemeral aquatic habitats and their biota;

Given their creation through excavation, artificial pans and depressions are assumed to have lower sensitivity to physical disturbance, although even artificial systems may support important biota – Bird and Malan (2010) for example found rare invertebrate fauna typical of ephemeral wetland habitat even in artificial roadside borrow pits in the region (e.g. notostracans of the genus *Triops*);

- Changes in surface runoff patterns:
    - All pans and other watercourses would be sensitive to changes in surface runoff velocities, potentially stemming from stormwater management systems for hardened surfaces including roads. Increased velocities would potentially lead to localised erosion and changes in aquatic ecosystem hydroperiod and habitat quality;
- Fragmentation from other watercourses and supporting terrestrial areas:
    - Hydrological fragmentation: New roads, built infrastructure and other development on a large scale could contribute to hydrological fragmentation, where this interrupts surface or groundwater inflows into aquatic ecosystems or seepage or flows from them, or disrupts aquifer recharge areas;
    - Physical (surface) fragmentation: The study area is currently relatively undeveloped and it is assumed that there is faunal movement between watercourses, at least at times, and particularly in areas such as the Kamiesberg, where moisture-retention in wetlands provides dry-season foraging material and water. Extended linear and concentrated non-linear development could potentially isolate some systems, disrupting ecological corridors.

4.7.4.3 Estuary sensitivity and importance

4.7.4.4 The Orange River Estuary

The Orange River Estuary has high importance and would be sensitive to activities / impacts that resulted in:

- Changes in freshwater flows (as a result of increased demand for fresh water, with water demand in Alexander Bay being met at least in part by flows from the Orange River upstream of the estuary (Hattingh 2016)) - such demand could increase with an increased population in Alexander Bay, as a result of actual and perceived increases in local employment opportunities;
- Increased road infrastructure across the estuary, affecting flows into the estuarine saltmarshes (such impacts seem unlikely);
- Increased nutrient input – this could be associated with increased treated sewage effluent discharge from the Alexander Bay Waste Water Treatment Works (WWTW), as a result of local population increases;
- Increased fishing, as a result of a locally increased population, leading to increases in gill netting of indigenous fish species and fishing effort in the estuary;
- Increased grazing and hunting activities, particularly linked with a likely influx of population into the Alexander Bay area as a result of perceived or real employment opportunities;

- Increases in physical disturbance as a result of vehicle and other traffic into the estuary for bird viewing and other recreational activities – if such activities resulted in increased traffic across saltmarsh areas and increased localised dumping of solid waste in a seemingly largely unpoliced area, then significant estuarine degradation could accrue.

4.7.4.5 Ephemeral estuaries along the West coast

These estuaries are rated as very important to important from a functional perspective, largely as a result of the rarity of estuarine systems along this part of the West Coast, particularly from the perspective of coastal birds (DWS 2017a), although their ecological importance is rated only "average" (see Section 4.5.3.3). These estuaries would be sensitive to activities / impacts that resulted in:

- Any deterioration in condition;
- Increased nutrient inputs (e.g. from WWTW discharges or septic tanks);
- Disruptions to surface inflows during storm events (e.g. as a result of upstream impoundments, stormwater attenuation or berms /other barriers to flows), leading to reduced frequency of breaching and reduced efficacy of fish recruitment;
- Reduced freshwater inflows, potentially as a result of increased groundwater abstraction;
- Roads or other infrastructure within or through estuaries;
- Alien invasion;
- Vehicle traffic / trampling / compaction.

4.7.4.6 Micro outlets along the West coast

These are considered less sensitive to changes in flows in their catchment, as they are by definition too ephemeral to support estuarine conditions. They would however be sensitive to:

- Physical disturbance, including activities that resulted in concentrations of flows into these outlets, potentially triggering erosion;
- Pollution from water quality inflows;
- Sustained sources of treated or other effluent, that created permanently to seasonally inundated to saturated conditions, resulting in a major change in ecosystem type;
- Invasion by alien vegetation.

Table 4-7.6: Sensitivity rating categories for surface water resources

Sensitivity rating categories for inland aquatic ecosystems and estuaries

Sensitivity	Sensitivity Feature	Data
Very High (no development area)	• Critically Endangered (CR) and Endangered (EN) wetland types from the NBA (Van Deventer *et al.* 2019a) • CBA1 and CBA2 wetlands (NWM_5) • NFEPA rivers • Critically Endangered (CR) and Endangered (EN) estuaries (NWM-2)	NBA (2018a) NFEPA rivers NWM 5 (aquatic) NWM-v5.2
High	• All other wetlands included in the NWM 5 • FEPA sub-catchments • Upstream sub-catchments as identified in the NFEPA programme • All watercourses as mapped in 1:50 000 rivers layer and NFEPA river layer • Artificial pans • Dams • All other estuaries (Estuary Functional Zones)	NWM-v5 River FEPA 1:50 000 layers NBA(2018c): artificial
Medium	• All watercourse buffers / development setback areas • Micro-outlets into the sea (as per Van Niekerk *et al.* 2020)	20 m buffer round dams / artificial wetlands 50 m buffer for 1:50 000 rivers 50 m buffer for all wetlands 100 m buffer for NFEPA rivers EFZ data (NBA 2018b)
Low	• Rest of site – i.e. non aquatic areas <u>outside of recommended aquatic ecosystem buffer zones</u>	

4.7.5 Results of Sensitivity assessments

Figures 4-7.1 to 4-7.3 illustrate the results of geohydrological, surface water resources and aquatic ecosystems sensitivity mapping, applied as per the rules / logic outlined in Sections 4.7.1 to 4.7.4.

The sensitivity layers have been developed separately for each of these disciplines, on the basis that some activities might affect groundwater resources but not surface resource use or availability or aquatic ecosystems and *vice versa*, and that to overlay all of them on one map would suggest greater sensitivity and the need for avoidance of large areas than would otherwise be the case.

In this regard it is further noted that while the maps have denoted "sensitive areas", not all areas mapped as sensitive would necessarily be sensitive to all activities in the proposed development scenarios.

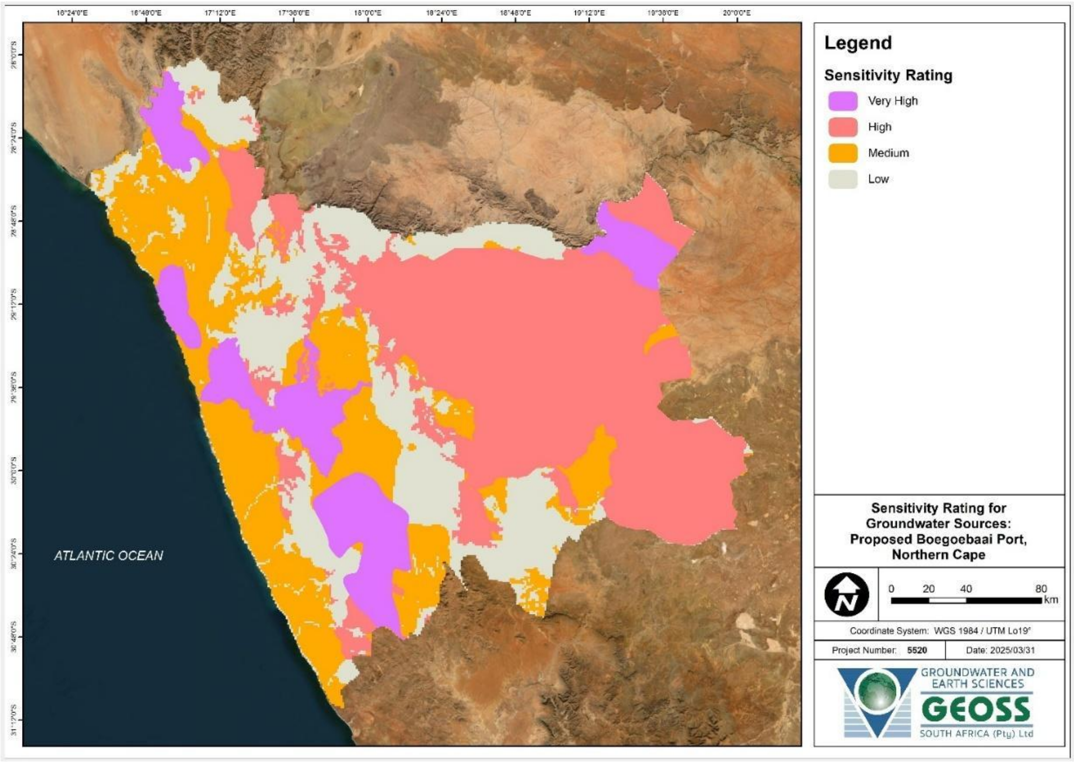


Figure 4-7.1: Results of application of the groundwater sensitivity classification presented in Table 4-7.4 , in the SEA study area

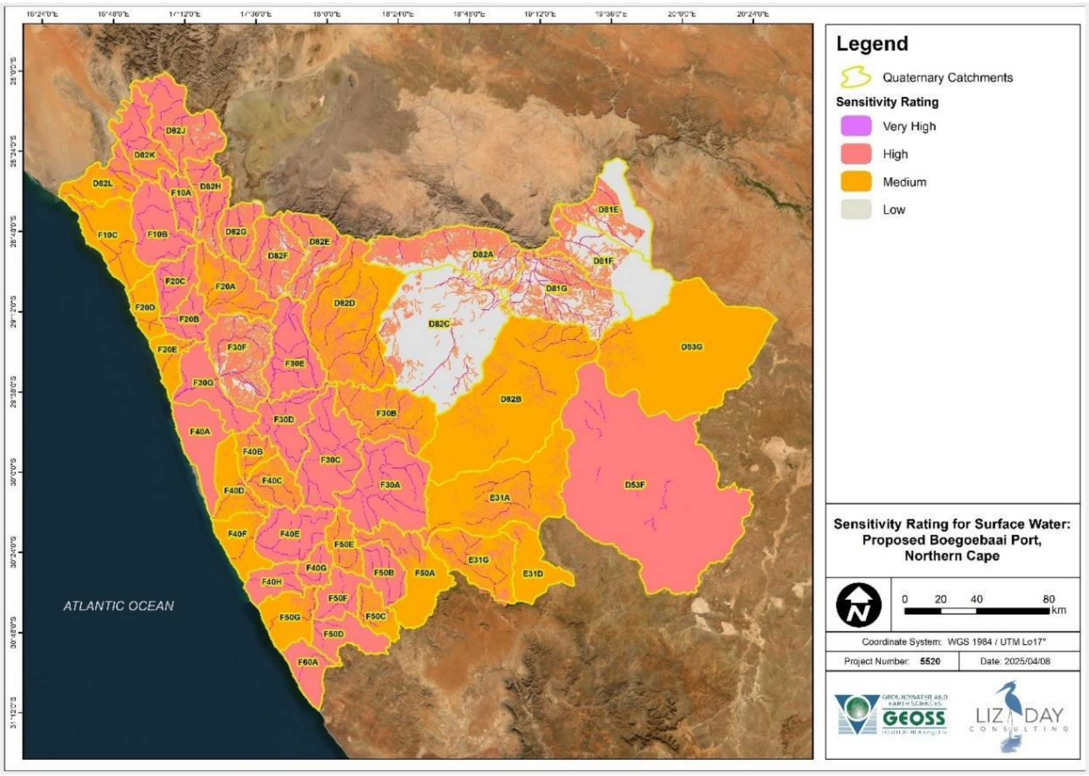


Figure 4-7.2: Results of application of the surface hydrology sensitivity classification presented in Table 4-7.5, in the SEA study area

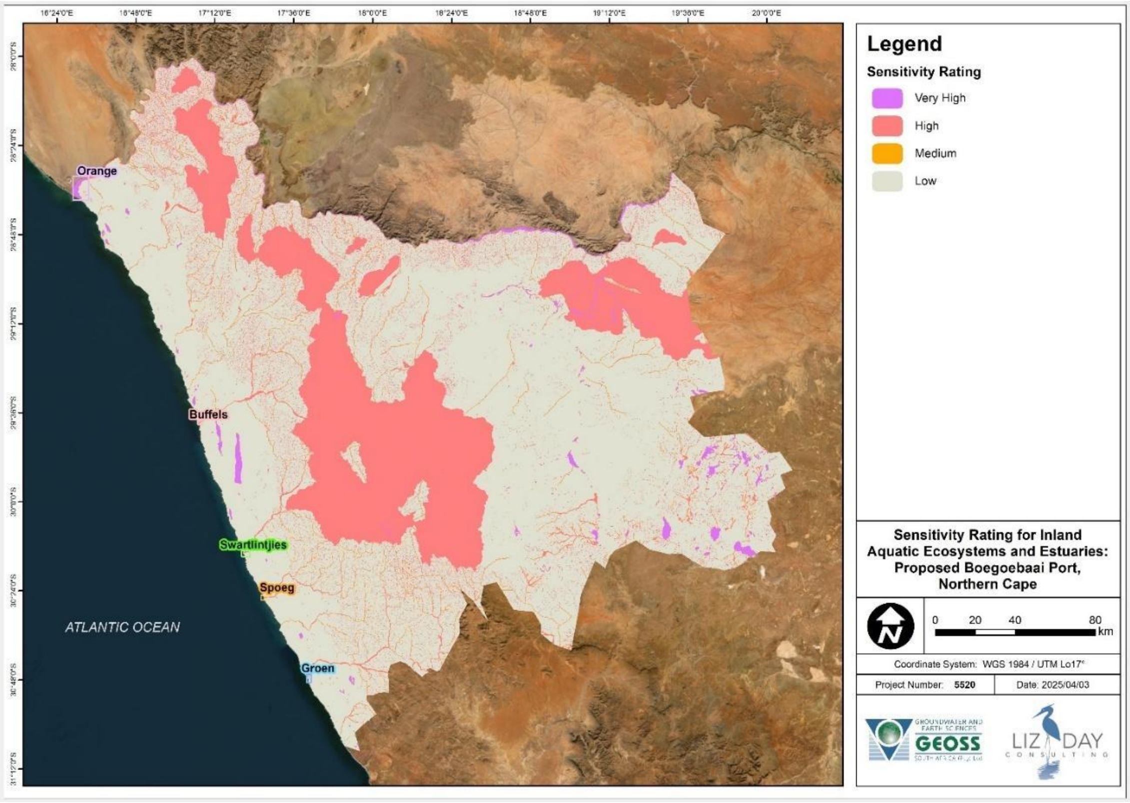


Figure 4-7.3: Results of application of the inland and estuarine aquatic ecosystem sensitivity classification presented in Table 4-7.6 in the SEA study area

4.8 IMPLICATIONS OF DEVELOPMENT SCENARIOS FOR WATER RESOURCES

4.8.1 Assessed development scenarios

Assessment of the implications of a large Northern Cape Green Hydrogen-driven economy has been assisted in this study by consideration of three development scenarios, namely:

- Scenario 0 - A dynamic baseline, over the period 2023-2050, that considers climate change but assumes no green hydrogen development in the Northern Cape. This scenario does assume current development trends, including renewable energy development;
- Scenario 1 - Small green hydrogen development (by 2035) and associated expansion of renewable energy generation and transmission infrastructure in the area, in support of the proposed Boegoebaai Port and SEZ development;
- Scenario 2 -Upscaled green hydrogen development (by 2050) and associated expansion of renewable energy generation and transmission infrastructure in the area.

The likely development infrastructure and other aspects of the two development scenarios are detailed in CSIR (2024).

Table 4-8.1: Explanation of symbols used in this section, to indicate resource trajectory.

Trend direction	Explanation
↓	Evidence/experience suggests a substantial decrease in the driver or its quality
↘	Evidence/experience suggests a moderate decrease in the driver or its quality
→	Evidence/experience suggests no change in the driver or its quality
↗	Evidence/experience suggests a moderate increase in the driver or its quality
↑	Evidence/experience suggests a substantial increase in the driver or its quality
?	Insufficient Evidence/experience to predict the direction of the driver or its quality, or evidence/experience is conflicting

4.8.2 Projected impacts for regional groundwater

4.8.2.1 Baseline Scenario (Scenario 0)

Evidence suggests that temperatures in Namaqualand have been increasing over the last century, and that the rate of warming has been increasing, most notably over the last two decades. There has been an increase in the frequency of hot days and a corresponding decrease in the frequency of cool days (Davis et al. 2016). Climate change projections for the Namakwa District indicate increasing temperatures and shifting rainfall patterns resulting in drier, hotter conditions in the region. It is predicted that the region will experience a 3 – 4°C increase in temperature (Christensen et al., 2007) and a 10 – 20% decrease in annual runoff by 2041 – 2060, relative to the period 1900 – 1970 (Milly et al., 2005). Mean Annual Precipitation (MAP) is projected to decrease by between 10 – 20% in most places, but between 0 – 10% in other locations (WRC 2024). It is also projected that Mean Annual Potential Evapotranspiration (MAPE) will increase by 6 – 10% (WRC, 2023).

These projected climate trends are expected to significantly increase pressure on water resources, exacerbating water scarcity (Bourne et al., 2015). Overutilisation of the already stressed Orange River is anticipated to add additional pressure on the groundwater resources in the region. Consequently, groundwater abstraction is anticipated to increase, as many towns in the region rely on groundwater for sole supply (Conrad et al., 2003). There will be reduced groundwater availability in the alluvial aquifers due to decreased rainfall (CSIR, 2023), particularly a decrease in rainfall events that will be able to sufficiently infiltrate into the aquifer systems to provide recharge. Increased extreme runoff events are unlikely to improve or lessen recharge to riparian aquifers. Reduced recharge to alluvial aquifers will result in reduced recharge to dependent fractured aquifers. Groundwater recharge, however, is a complex hydrological process affected by many conditions such as precipitation, evaporation, soil, vegetation, topography, geology (Fu et al., 2019; Moeck et al., 2020). Groundwater recharge threshold conditions which are defined as the necessary conditions required and the specific values that these conditions must reach to trigger a groundwater level rise (Moeck et al., 2020), requires further investigation in the region. Limited studies from the area indicate that with a rainfall threshold of >20 mm, less than 1% to seldom more than 10% of precipitation can infiltrate the subsurface to reach the groundwater (DWAF, 2008a).

In a baseline scenario where no significant developments are anticipated to occur, populations of the four local municipalities are anticipated to increase by 25 – 86% of the 2021/2022 surveyed populations by 2050. In many cases, aquifers are already stressed due to over-abstraction for various reasons, including high demand, poor infrastructure and improper management (Pietersen et al., 2009). Heavy reliance on groundwater in the region has already resulted in declines observed in water levels of monitoring boreholes between 1990 – 2008 (DWS 2008a). Increased development and settlement will exacerbate this.

Basic access to water is calculated to be 25 L/p/day (The Strategic Framework for Water Services 2003) whereas 'sufficient' access to water is considered to be in the range of 42 – 50 L/day (UCT, 2017). These estimates, however, are considered to be highly conservative and sufficient for survival, not taking into account actual water use. Governmental data released for the 2020/2021 water use reports indicate that the actual average water consumption per capita for Namakwa District Municipality is 147 L/day (DWS, 2023). Assuming groundwater usage per capita remains constant, water use will increase by the same percentage range. The area will become increasingly water stressed under the baseline scenario.

Marine aerosols contribute to increased groundwater salinity through dry deposition in coastal areas. Additionally, the presence of salt-rich heuweltjies in the region has been linked to elevated groundwater salinity (Francis et al., 2022). Projected increase in runoff extremes may result in the flushing of concentrated salts from these mounds, into the groundwater, exacerbating salinization (Van Gend et al., 2021). Increased salinity in the alluvial aquifers is likely to affect basement aquifers which are dependent for indirect recharge, possibly leading to increasing salinisation of groundwater in the region over time.

Table 4-8.2 presents the assumed key drivers of groundwater resources, and their trajectory over the time frames considered in this SEA (by 2030 and up to 2050), in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure in the Namakwa area. These assumed trajectories form the basis for assessment of the likely impacts of Scenarios 1 and 2.

Table 4-8.2: Assumed key drivers of groundwater resources, and their trajectory over the time frames considered in this SEA (2025 to 2050), in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure.

Symbols as per Table 4-8.1. All of these drivers would be exacerbated in Scenarios 1 and 2 (Sc1 and Sc2).

Theme/Driver Groundwater resources	Trend	Explanation Scenario 0
Water Use	↗	Climate change projections for the Namakwa District indicate drier, hotter conditions, heightening water demand. This trend is expected to significantly increase pressure on water resources, with rising temperatures and reduced rainfall exacerbating water scarcity (Bourne et al., 2015). Groundwater abstraction is anticipated to increase, as many towns in the region rely on groundwater for sole supply (Conrad et al., 2003).
Water Demand	↑	Increasing MAPE, reduction in average rainfall and rainfall frequency (WRC 2023) will intensify the pressure on existing and future water resources. Consequently, over-utilisation of water sources like the Orange River will likely increase surface water scarcity in the region. The depletion of surface water in the region will result in increased demand on groundwater resources (CSIR, 2023).
Water Quality	↘	Marine aerosols contribute to increased groundwater salinity through dry deposition in coastal areas. Additionally, the presence of salt-rich heuweltjies in the region has been linked to elevated groundwater salinity (Francis et al., 2022). Projected increase in runoff extremes may result in the flushing of concentrated salts from these mounds, into the groundwater, exacerbating salinization (Van Gend et al., 2021). Increased salinity in the alluvial aquifers is likely to affect basement aquifers which are dependent for indirect recharge.
Water Availability and Recharge	↘	Reduction in groundwater availability in the alluvial aquifers due to decreased rainfall (CSIR, 2023), particularly a decrease in rainfall events that are able to sufficiently infiltrate into the aquifer systems to provide recharge. Higher extreme runoff events are not likely to improve or lessen recharge to riparian aquifers. Reduced recharge to alluvial aquifers will result in reduced recharge to dependent fractured aquifers. In many cases, aquifers are already stressed due to over-abstraction for various reasons, including: high demand, poor infrastructure and improper management (Pietersen et al., 2009). Increased development and settlement will exacerbate this. Heavy reliance on groundwater in the region has already resulted in declines observed in water levels of monitoring boreholes between 1990 – 2008 (DWS, 2008a).

4.8.2.2 Further Development (Boegoebaai Port) (Scenarios 1 and 2)

It has been proposed that incoming residents would be accommodated in two of the larger towns, namely Alexander Bay and Port Nolloth (see SEA Infrastructure chapter). Based on the assumption of an average household size of 4.3 people, Alexander Bay would gain between 2 573 to 3 048 people while Port Nolloth would gain between 4 780 to 5 663 people over the long-term operation of the port. These additional residents may result in increased groundwater demand of 1.081– 1.281 ML/a. These numbers could be significantly higher should more employees bring their families.

Such a significant increase in population in conjunction with the population projections for the baseline scenario may lead to water shortages in the area if there is insufficient and appropriate planning for bulk supply. The Port Nolloth area is categorised as both a high priority GRU (F20D) as well as a groundwater SWSA, indicating that the area hosts important groundwater resources that are stressed, requiring careful management. East of Alexander Bay, between Sanddrift and Sendelingsdrift, another high priority GRU (D82K) is delineated. This is a possible indication that the groundwater resources are insufficient to sustain the growing demand at the current consumption rate.

Due to lack of available funding, the state of the DM's bulk water supply network is under strain and refurbishments are needed. Further development is also identified in a number of areas. Examples include Kharkams, which is mostly reliant on groundwater, but supply is already unable to meet peak demand with refurbishment of bulk water supply infrastructure underway. Groundwater development is earmarked for the settlements of Hondeklip Bay, Lekkersing, Eksteenfontein and Kuboes. Additionally, there has been upgrade and refurbishment of the existing boreholes in Kamiesberg and Richtersveld LMs (DWS 2025). Consultation of the DWS project list for the DM indicates that the municipality is struggling to meet current water demand and added pressure may have severe consequences.

4.8.3 Projected impacts for surface water resources

4.8.3.1 Baseline Scenario (Scenario 0)

Both groundwater withdrawals and the reticulated supply from the Orange River are severely stressed in the region. Assessment studies point to augmenting the abstractions and reticulation of supply from the Orange River (BVI 2023a; DWS 2012). Desalination of ocean water and borehole water has been assessed as a supplementary option, but studies warn of the lack of current capacity to operate this sophisticated technology.

With expected growth remaining at 1.68% per annum in the Port Nolloth Bulk Water supply scheme, the current system will require augmentation to supply some 917 000 kL/annum (based on consumption of 125L/person/day plus losses and municipal use, making 145 L/person/day). The Alexander Bay pipeline is designed to deliver approximately 504 000 kL/annum, and even this is not systematically delivered. Groundwater may yield some 345 000 kL/annum, but this is increasingly subject to desalination prior to household consumption.

4.8.3.2 Further Development (Boegoebaai Port) (Scenario 1 and 2)

The predicted increase in population to include the Boegoebaai SEZ in the Port Nolloth supply area amounts to some 76% by 2040, being a population increase from 7 078 to 12 503. Other areas may also see significant increases in population.

A combination of Orange River abstractions from the Port Nolloth Bulk Water Supply scheme, Namakwa Supply scheme as well as desalination of borehole and ocean water will be required to meet the expected increase in demand in the region.

Table 4-8.3 presents the assumed key drivers of surface water resources, and their trajectory over the time frames considered in this SEA (by 2030 and up to 2050) in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure in the Namaqua area. These assumed trajectories form the basis for assessment of the likely impacts of Scenarios 1 and 2.

Table 4-8.3: Assumed key drivers of surface water resources, and their trajectory over the time frames considered in this SEA (2025 to 2050), in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure.

Symbols as per Table 4-8.1. All of these drivers would be exacerbated in Scenarios 1 and 2 (Sc1 and Sc2).

Theme/Driver	Trend	Explanation
Surface Water resources		
Evapotranspiration	↗	Projected increase in Mean Annual Potential Evapotranspiration (MAPE) of 6 to 10% (WRC 2023). Increased vegetation uptake will impact agriculture and ecosystems. Human comfort levels will deteriorate, and water demand will increase. Stored open water bodies will experience higher losses.
Rainfall	↘	Mean Annual Precipitation (MAP) has reduced from 100 years ago, but over the past 50 years has been stable (Benito 2011). MAP is projected to decrease between 10-20% in most places, but some locations between 0 -10% (WRC 2024). Less local water in quaternary catchments.
Mean Runoff	↓	Runoff has been dropping marginally over the past 50 years in Namaqualand (Benito *et al*. 2011). Mean Annual Runoff (MAR) is projected to reduce by up to 50% in most quaternary catchments but may increase by up to 25% in a few places. The sporadic nature of runoff events offers very limited opportunity for usable storage. Some small farm dams are concentrated in the mountainous areas of the Buffels river and in the salt pan areas of quaternaries D53F and D53G.
Runoff Extremes	→	Flood events are not likely to increase in intensity. Present to Near-Future Climate change GCMs predict a 20% reduction in maximum discharge. Riparian areas will be subjected to reduced flood levels and crossings exposed to ongoing flood damage.
Dry Periods	↑	The current average duration of runoff-free periods is 350 days, with some places reporting dry periods of several years (SRK Quaternary Runoff Analysis). These dry intervals are likely to increase (Climate change GCMs predict slight increase in average duration – 1%, but large increases in the maximum dry periods up to 45%). Nine of the quaternary catchments are likely to change classification from Arid to Hyper-Arid in the near future. Extended runoff-free dry periods will impact ecosystems and agriculture.
Water Demand	↑	Increasing MAPE, reduction in average rainfall and decrease in rainfall frequency (WRC 2023) will intensify the pressure on existing and future water resources.
Water Scarcity	↑	Within quaternary catchments, higher MAPE and lower MAP will increase water scarcity. Higher extreme runoff events are not likely to improve or lessen recharge to riparian aquifers, although salinity may increase due to the higher MAPE (Benito 2011). However, predicted increase in flows in the Orange River due to future MAP increase in Lesotho and eastern RSA may allow for increased abstractions, depending on upstream water use in the Orange-Vaal system.
Bulk Water Supply	↗	Increase in demand will be met from Orange River abstractions due to projected increase in Orange River MAR at points of abstraction due to predicted Climate Change increases in runoff in Lesotho and eastern RSA (WRC 2023). However, availability for abstraction will depend on upstream water use in the Orange-Vaal systems.

4.8.4 Projected impacts for inland and estuarine aquatic ecosystems

4.8.4.1 Baseline Scenario (Scenario 0)

The changes in geohydrology and surface hydrology predicted above would have implications for aquatic ecosystems, even in the absence of the escalated development associated with a green hydrogen economy in the study area. Although the area is characterised by ephemeral rivers and pans, adapted to infrequent and unpredictable inundation, there are assumed to be (unquantified) thresholds of inundation frequency and, more particularly, duration, beyond which natural faunal and plant life cycles cannot be completed. This would be particularly applicable to the ephemeral pan systems, which are infrequently inundated but, when they are inundated, retain water for days to several weeks, and long enough for often complex invertebrate communities to complete their life cycles (e.g. Allan *et al*. 1995). If reduced frequency of rainfall, coupled with increased temperature-driven evaporation rates resulted in inundation periods that are too short for invertebrate and plant life cycles, there may be significant biodiversity loss in these systems, many of which are poorly studied.

Other ecological impacts associated with decreased rainfall frequency and extended periods of no rainfall would be deterioration in the condition of riparian vegetation along many watercourses, as access to shallow groundwater or periodic rainfall decreased, making these systems increasingly vulnerable to erosion in sandy areas.

Changes in water quality are also likely, as a result of increased evapotranspiration and decreased surface water, affecting aquatic habitat quality and, in estuarine areas in particular, increasing salinity in systems that are already subject at times to hypersalinity (e.g. the Swartlintjies and Groen) (DWS 2017a). Decreases in groundwater flows and increases in groundwater salinity would be of even more concern for water quality in all four CTAPC West Coast estuaries, where fresher groundwater inflows support sedge and reedbed habitat in their upper reaches.

A reduction in the frequency and magnitude of floods in the lower reaches of ephemeral rivers with estuarine outlets would also potentially further impact on estuarine connectivity, by reducing breaching episodes and thus limiting fish recruitment into these systems. Recruitment success is currently also limited by excessive estuarine salinity, at least at times (DWS 2017a), and this too would be likely to be increasingly experienced going forwards.

Other water quality impacts would be associated with population increases, and increased sewage effluent production in affected areas, adding to already generally inefficient and overloaded WWTWs in the study area (see **Table D3**, Appendix D).

Without active intervention, existing impacts on the Orange River Estuary would continue and additional flood reduction impacts including changes in sediment regime are also possible, if the proposed large dam upstream of the study area (Vioolsdrift Dam) is constructed (DWS 2017b). However, if the non-flow related remedial measures outlined in DWS (2017b) were in fact implemented, some improvement in estuary condition towards its REC might also occur. The confidence in such measures being implemented is however low – 14 years have elapsed since they were first mooted in Van Niekerk *et al.* 2013).

Table 4-8.4 presents the assumed key drivers of aquatic ecosystem condition and extent, and their trajectory over the time frames considered in this SEA (by 2030 and up to 2050) in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure in the Namakwa Region. These assumed trajectories form the basis for assessment of the likely impacts of Scenarios 1 and 2. It is noted however that these ecosystem drivers are tightly linked to the predicted ground- and surface water resource trajectories, outlined in **Tables 4-8.2 and 4-8.3**.

Table 4-8.4: Assumed key drivers of inland aquatic ecosystem and estuarine ecosystems (including micro-outlets) and their trajectory over the time frames considered in this SEA (2025 to 2050), in the absence of the proposed Green Hydrogen project and its associated Boegoebaai Port development, SEZ and associated expansion of renewable energy developments and infrastructure. Symbols as per Table 4-8.1.

All of these drivers would be exacerbated in Scenarios 1 and 2 (Sc1 and Sc2).

Theme Aquatic ecosystems: Inland and Estuarine ecosystems	Trend	Explanation
Water quality	↓	Water quality in aquatic ecosystems is expected to be on a deteriorating trajectory, with increasing salinities associated with predicted decreased rainfall (Benito 2011). Increases in populations in some local municipalities means increased loads of sewage, and associated increased risks of nutrient enrichment and possible microbial and other contamination of local watercourses, depending on WWTW efficacy (see Table D3 in Appendix D).
Ephemeral pans	↘	Reduced rainfall will be compounded by increased evapotranspiration. Pan hydroperiod may decrease – if it decreases over thresholds of concern (e.g. inundation period is too short for temporary pan-adapted fauna to complete lifecycles) then aquatic biodiversity will be impacted, while terrestrial fauna dependent on pans for water for parts of the year would also be impacted. Plants in and around pans could also be impacted if conditions become hotter, drier and more saline. If plants die back, this will impact on the value of some pans for provision of grazing material.
Seasonal and temporary rivers	↘	Where extended dry periods result in loss of riparian vegetation, ephemeral and seasonal rivers will be more vulnerable to erosion when flooding occurs, particularly at road crossings, where episodic flows are concentrated. These systems are already impacted in some areas by over-grazing, focused along riverine channels, and this would be expected to be ongoing, with its impacts exacerbated by vegetation under increasingly water-stressed conditions.
Wetlands	↓	Extended dry periods and reduced MAP will impact on wetland condition, shifting permanently saturated and seasonally wetlands towards seasonal to ephemeral systems. Although such wetlands are limited in the study area they do occur (e.g. Kamiesberg mountains) where wetlands retain water and allow drinking and foraging by indigenous biota and livestock throughout the year (Samuels 2013; Kotze *et al.* 2010) and provide other benefits, such as erosion control and flow regulation (Kotze et al. 2010, Black and Turpie 2016). Changes in wetland condition and type may trigger erosion and reduce crucial wetland ecosystem services in these areas.
Orange River and estuary	↓	Increased water stress may increase abstraction from the Orange River near Alexander Bay and (potentially) in its upstream river reaches (possibly offset by increase in MAP in upper catchment). Increased salinity in the lower estuarine salt marshes may be exacerbated by increased MAP and MAPE, in the absence of remedial measures (see DWS 2017b). Upstream dam construction would lessen flood flows into the estuary and change sediment regime in the lower river (DWS 2017b). Shifts in the river / estuarine interface could also occur, including estuary shrinkage, with implications for estuarine productivity as well as faunal community assemblages and distribution and, importantly, habitat availability for estuarine fish species.
Other estuaries	↓	Estuaries already impacted by hypersalinity (e.g. the Groen River Estuary) would be further impacted by increasingly saline surface and (especially) groundwater inflows, and reduced groundwater flows as a result of increased abstraction. Fish recruit into the Arid Predominantly Closed estuaries in the study area when peak flow periods overtop the estuary and link it to the sea – but hypersalinity in these estuaries affects fish survival (DWS 2024). Reduced flood frequency would lessen breaching events and thus impact on estuary flushing periodicity and fish recruitment opportunities. Such changes would potentially impact on habitat quality and estuarine macrofauna, in turn impacting on habitat quality for coastal and migratory birds. Reduced MAP and increased MAPE, leading also to increased pressure on water resources, may further threaten ground-water dependent systems (e.g. upper Spoeg and Groen estuaries), leading to loss of reedbed habitat, associated with inflows of lower salinity groundwater.

4.8.4.2 Further Development (Boegoebaai Port) (Scenarios 1 and 2)

The Scenario 1 and 2 developments would include development of Boegoebaai Port and SEZ, the implications of which have already been unpacked from an inland aquatic ecosystem and estuarine perspective in Day (2025). In addition to the intense development in the Boegoebaai area associated with the proposed port and SEZ, the associated roll-out of green energy production and transmission installations across the study area could have significant effects on aquatic ecosystems, with the following being the main considerations:

- Locally increased concentrations of flows from hardened surfaces, when rainfall occurs, resulting in the possible localised creation of eroded gullies in watercourses;
- Barriers to flood flows in the form of inappropriately designed roads and culverts over watercourse crossings, affecting downstream watercourse condition including estuarine flushing and water quality;
- Encroachment of new built infrastructure into watercourses, including construction of roads, pylons and pipelines through these systems – these might extend hundreds of kilometers across the study area;
- Fragmentation of sensitive ecosystems as a result of road construction – overall biodiversity (terrestrial and aquatic) would be negatively impacted by fragmentation that interrupts mosaic terrestrial and ephemeral aquatic systems;
- Impacts associated with expanding human populations and both formal and informal settlements, with such impacts including:
    - Increased sources of solid waste into open spaces including watercourses;
    - Increased volumes of variously treated sewage effluent, potentially discharged into watercourses but also irrigated, from where it can reach aquatic ecosystems via groundwater or flushing (DWS (2017a) note that the Buffels River Estuary is already impacted by golf course irrigation with treated sewage water);
    - Increased threats of sewage and solid waste associated with informal settlements – the latter are likely to expand with the expectation of improved job opportunities in the area;
    - Increased pressure on estuaries as recreational nodes for a growing population, and associated increases in fishing pressure, at least in the Orange River;

The above impacts are expected to be relevant to Scenario 1 and to be sharply ramped up in Scenario 2 (as a guide, the former would be associated with a 21 082 ha infrastructure footprint and the latter with a 142 240 ha footprint (CSIR 2024)).

4.9 RISK / OPPORTUNITIES ASSESSMENT

4.9.1 General approach

A systematic risk / opportunity assessment is required in this chapter. Risk and opportunity are determined by estimating the **likelihood** of occurrence of different impacts or trends, in relation to their **consequences**. A structured assessment of these two components is provided in **Figure 4-9.1**. Note that in this chapter, the term "likelihood" refers to the likelihood of an impact occurring, if it is located within each of the variously rated sensitive areas. It does not refer to the likelihood that there would be desirability to locate an activity with its associated impacts in areas of differing sensitivity.

In order to provide a transparent and consistent approach to consequence ratings, these have been defined in this chapter for each of groundwater, surface hydrology and aquatic ecosystems (inland and estuarine ecosystems), as shown in **Table 4-9.1**. Risk and opportunity categories (Very Low to Very High) are defined in CSIR (2024).

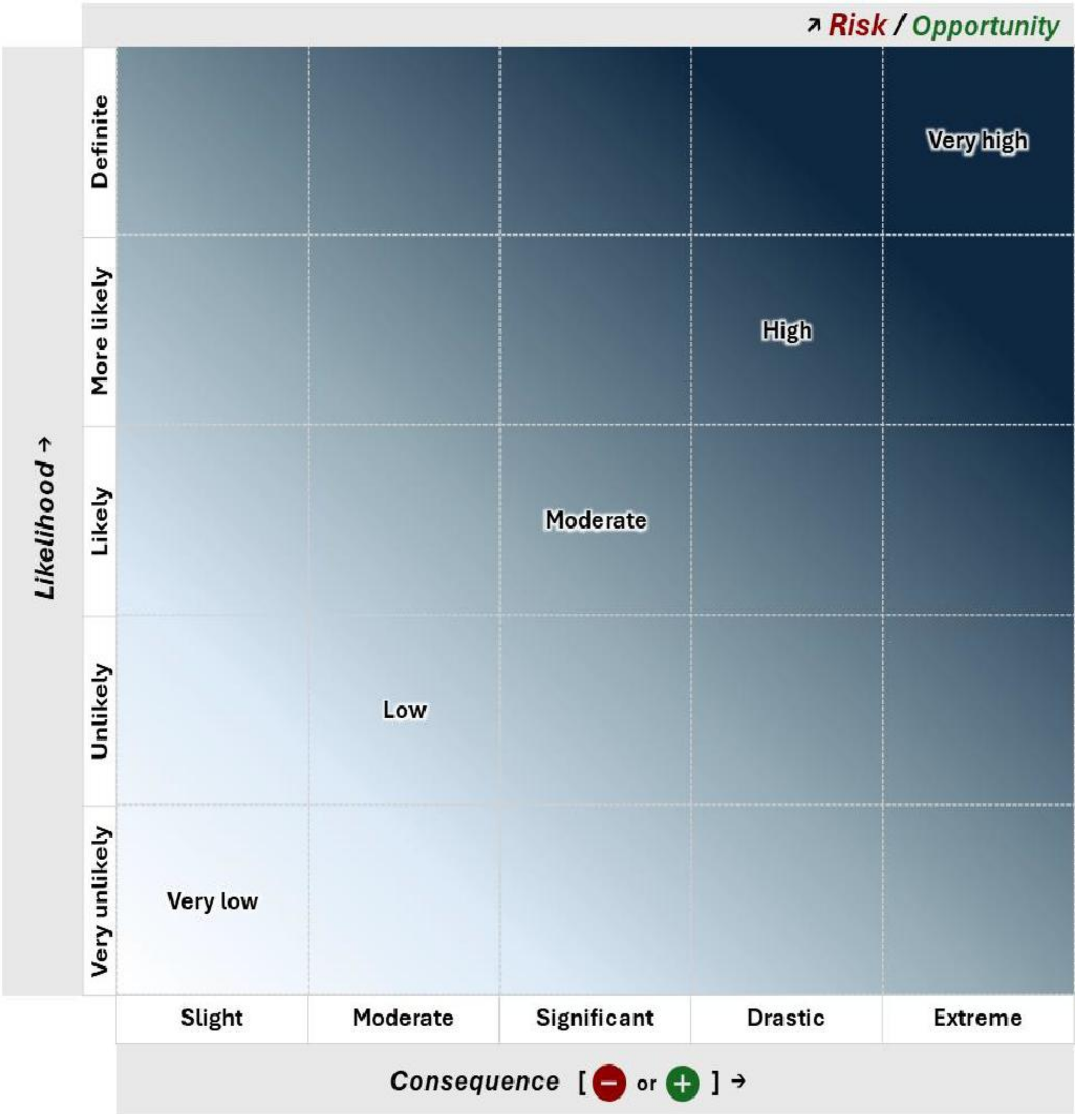


Figure 4-9.1: Schematic showing qualitative derivation of Risk and Opportunity by multiplying the likelihood of an impact (positive or negative) by the severity of the consequences for a particular theme. Figure after CSIR (2014).

Table 4-9.1: Description of Consequences (positive and negative) as defined for geohydrology, surface hydrology and inland and estuarine aquatic ecosystems, based on expert judgement. Consequence categories as per CSIR (2024) requirements.

		Geohydrology	Surface Hydrology	Inland and estuarine aquatic ecosystems
	Nature of Consequence	Consequence Description		
	Negative (-)	Impacts would harm the receiving (groundwater) environment (including people).	Impacts would reduce surface water availability, reliability or quality, affecting socio economic activities and /or human health and well being	Impacts would degrade aquatic ecosystem condition (compared to natural) and /or decrease resilience
	Positive (+)	Impacts would benefit the receiving (groundwater) environment (including people).	Impacts would improve surface water availability, reliability or quality, affecting socio economic activities and /or human health and well being	Impacts would improve aquatic ecosystem condition (compared to natural) and /or improve resilience
	Consequence	**Geohydrology**	**Surface Hydrology**	**Inland and estuarine aquatic ecosystems**
Negative	Slight	The effect on groundwater resources or human wellbeing (as a consequence of environmental change) would be minimal; impacts would be well within environmental quality standards or targets (RQOs), or legal requirements (determined threshold limits). There would be no need for mitigation.	Current flow regimes would largely remain constant. • Low rainfall-runoff intensity and duration of no-runoff increase at local extent and persist for medium term • Low rainfall-runoff intensity and duration of no-runoff increase at medium extent and persist for short term • Low to medium rainfall-runoff intensity and duration of no-runoff increase at local extent and persist for a short term. • Slight change to discharge or access of Orange River abstractions.	These would comprise: • No change in resource ecostatus class, although some reduction in resource quality or aspects of resource quality could be discernible. • No reduction in capacity to meet RQOs (compared to present); • Effects would be limited in extent (site specific) and would be readily reversible at any time and/or of short-term duration. • The impact should not have an influence on, or require to be significantly accommodated in the development design.
	Moderate	There would be little material effect on the resource or human wellbeing; impacts would be well within environmental quality standards or	• Moderate change to flow regimes • Manageable impacts to ecosystems,	• Some degradation in resource ecostatus / possible change in PES class;

<table>
<tr><th></th><th>Consequence</th><th>Geohydrology</th><th>Surface Hydrology</th><th>Inland and estuarine aquatic ecosystems</th></tr>
<tr><td></td><td></td><td>targets (RQOs), or legal requirements (threshold limits). Minor mitigation measures may be required to manage potential impacts. The extent of the impact would likely be site-specific and duration would be short-term.</td><td>drainage crossings, access points
Moderate reduction in discharge or abstraction potential of Orange River flows.</td><td>Reduced capacity to meet all RQOs (compared to present);
Impacts however readily reversible once activity ceases;
Impacts well within the tolerance levels or adaptive capacity of aquatic ecosystems relying on the resource;
The impact should not have an influence on development decision-making, provided that recommended measures to mitigate negative impacts are implemented.</td></tr>
<tr><td></td><td>Significant</td><td>There would be a material effect on the receiving resource (including people). Legal requirements would still be met but thresholds of potential concern with regard to environmental quality may be crossed. Mitigation measures (avoidance, minimization, rehabilitation/restoration, and in some cases offsets/ compensation) would be needed to reduce the impact significance. The extent of the impact would likely be local and duration would be medium-term.</td><td>Substantial change to flow regimes.
Higher extreme events and longer dry periods result in substantial deterioration of ecosystems, drainage crossings and access points.
Substantial reduction in discharge or abstraction potential of Orange River flows.</td><td>Marked degradation in resource ecostatus (deterioration by one or two classes)
Capacity to meet RQOs compromised (meeting REC unlikely)
Beyond the adaptive capacity of aquatic ecosystems to maintain key biotic elements
Impacts potentially reversible once activity ceases
The impact could have an influence on the environment and would require modification of the development design; alternative mitigation; and/or ecological offsets.</td></tr>
<tr><td></td><td>Drastic</td><td>There would be major effects on the receiving resource to the extent where environmental quality standards or targets may be exceeded, legal requirements may not be met, and the health, safety, livelihoods and/or wellbeing of affected people could be endangered. Mitigation measures (avoidance/impact prevention, minimization, rehabilitation/restoration, and offsets/ compensation) are essential to</td><td>Severe changes to flow regimes.
Increase in extreme events and longer dry periods between events lead to loss of income in agriculture and hardships in health, livelihoods and income.
Severe reduction in discharge or abstraction potential of Orange River flows.</td><td>Considerable degradation in resource ecostatus (more than two classes);
Impacts reversible only with human intervention over decades;
System unable to meet RQOs and REC thus permanently compromised, unless impacts reversed;</td></tr>
</table>

	Consequence	Geohydrology	Surface Hydrology	Inland and estuarine aquatic ecosystems
		substantially reduce the impact significance. The extent of the impact would likely be regional and duration would be long-term.		• The impact could have a no-go implication for the development or a component of the development, regardless of any possible mitigation).
	Extreme	There would be severe effects on the receiving resource to the extent where environmental quality standards or targets would be exceeded, there would be non-compliance with legal requirements, and the health, safety, livelihoods and/or wellbeing of affected people would be jeopardized. Unmitigated impacts would be considered to be irreversible. Mitigation measures – avoidance or prevention of impacts as a priority would be required, since impacts are unacceptable. The extent of the impact would likely be regional and duration would be long-term to permanent.	• Extreme flow regime changes. • Increase in extreme events and extension of dry periods between events lead to irreversible, severe effects to income in agriculture and hardships in health, livelihoods and income for urban communities. • Extreme reduction in discharge or abstraction potential of Orange River flows.	• Extreme degradation in resource status (more than two classes); • Resource impacts irreversible and remediation impractical; • The level of impact should strongly influence decision-making and further steps should be investigated to avoid impacts.
Positive	Slight	The effect on the groundwater resource or human wellbeing (as a consequence of environmental change) would be minimal; impacts would remain within expected environmental quality standards (RQOs) or targets, or legal requirements (threshold limits). There is little to no appreciable benefits.	• Perturbations to flow regimes would not impact ecosystem, agriculture and human demand. • No shortfall in Orange River discharge and access.	• Impacts would reduce risk to aquatic ecosystems – but resource ecostatus class would not change; • Limited in extent (site specific); • Reversible at any time and/or of short-term duration (so not necessarily long-lived); • The impact would be positive but would not drive decision-making.
	Moderate	There would be little positive material effect on the resource or human wellbeing, and available quantities and qualities of the resource would be well within baseline/historical ranges for the resource. There is little appreciable benefit to human wellbeing. The extent of the impact would likely be site-specific, and duration would be short-term.	• Perturbations to flow regimes marginally improve supply to agriculture, ecosystems and human demand. Drainage systems remain intact and riparian system benefit. • Moderate improvement in discharge and abstraction potential of Orange River flows.	• Measurable improvement in resource ecostatus / possible change in PES class; • Improved capacity to meet all RQOs; • Positive impacts associated with the lifetime of the project – thus reversible once activity ceases; • The impact would be positive and should not drive decision-making but would be a

	Consequence	Geohydrology	Surface Hydrology	Inland and estuarine aquatic ecosystems
				factor to consider.
	Significant	There would be a material positive effect on the receiving resource (or human wellbeing), and available quantities and qualities of the resource may be within baseline/historical ranges for the resource, but are typically improved beyond what is considered 'normal'. There would be tangible benefits to human wellbeing. The extent of the impact would likely be local and duration would be medium-term.	• Substantial improvement to flow regimes. • Lower extreme events and shorter dry periods result in substantial improvement to ecosystems, drainage crossings and access points. MAR increase. • Substantially improved discharge and abstraction potential in Orange River flows.	• Marked improvement in resource ecostatus (improvement by one or two classes); • Capacity to meet RQOs markedly improved (meeting REC likely); • Positive impacts could be reversible once activity ceases; • The positive impact should have an influence on decision-making (for local or regional activities).
	Drastic	There would be major positive effects on the receiving resource to the extent where historical environmental quality ranges and available quantities would be improved beyond baseline/historical ranges leading to general improvement in quality and availability of the resource. The health, safety, livelihoods and/or wellbeing of affected people could be improved. The extent of the impact would likely be regional and duration would be long-term.	• Severe improvements to flow regimes. • Decrease in extreme events and shorter dry periods between events lead to access of quaternary catchment water and improvement to agriculture productivity, health, livelihoods and income. • Severe increase in discharge and abstraction potential of Orange River flows.	• Considerable improvement in resource ecostatus (more than two classes)' • Long-term conservation status secured at least locally' • System able to meet RQOs and REC' • The impact should influence decision-making.
	Extreme	There would be excessively positive effects on the receiving resource to the extent where historical environmental quality ranges and available quantities would be vastly improved beyond baseline ranges, leading to overall abundance. The health, safety, livelihoods and/or wellbeing of affected people would be vastly improved. The extent of the impact would likely be regional and duration would be long-term to permanent.	• Extreme improvements in flow regimes. • Decrease in extreme events and reduction of dry periods between events lead to improvements to income in agriculture and livelihoods and income for urban communities. Surface water storage becomes possible in quaternary catchments. • Extreme improvement in discharge and abstraction potential of Orange River flows satisfy all demands and provide excess for storage.	• Major improvement in resource status (at least two classes); • Long-term conservation status in perpetuity secured at locally to regionally; • The level of impact should strongly influence decision-making.

4.9.2 Risk and opportunity (impact) assessments

This section identifies broad impacts to water resources that are likely to be associated with the proposed Boegoebaai Port, SEZ and associated at-scale green energy production and infrastructure that would be rolled out in the Namakwa Region. The comments and identified issues outlined in Section 4.8 form the basis for the thinking in this section, which seeks to amalgamate multiple potential impacts into more general themes for risk and opportunity assessment.

It should be stressed that the impacts identified here are not intended to be all-encompassing but only to highlight major issues and opportunities that would have a bearing on decision-making regarding the feasibility and acceptability of the proposed development. More detailed impact identification, assessment and description of auditable impact avoidance, mitigation and management measures would be required on a site-by-site and project-specific basis, in the event that the principle of this development is supported.

Drawing on the above, **Table 4-9.2** broadly categorises some of the main activities likely to be associated with impacts to water resources within the study area, in terms of the level of "risk" posed by each. These risk categories are then assessed in the individual geohydrology, surface hydrology and aquatic ecosystem assessment sections that follow.

Table 4-9.2: Identification of development-related activities likely to be associated with different levels of risk to water resources (groundwater, surface and aquatic ecosystems)

Degree of Risk	Associated Activities
High	This grouping includes development aspects affecting recharge, surface water velocities and flow paths; encroaching into watercourses and estuaries; and water quality contaminants of serious concern (e.g. toxins, corrosives) namely: All hardened surfaces (buildings, roads, paving, loading and parking areas) for development of railways and portside access paths (port and SEZ area) as well as additional regional access roads; hardened surfaces for internal roads, wind turbine access roads, solar panel arrays and associated electrical infrastructure (e.g. pylons, BESS, substations and other buildings); storage of bulk liquid items such as green ammonia and diesel and the dispensing of these products via pipeline; water treatment facilities for green hydrogen production which includes nitrogen, hydrogen and oxygen storage and pipelines (port and SEZ area)
Medium	Disposal of treated and untreated sewage and other effluent from expanding settlements, and sewage pipelines
Low	Installation of bulk water supply pipelines; transmission lines; fences

4.9.3 Potential Groundwater Impacts

4.9.3.1 Impact description

The biggest risk associated with the development is likely to be the strain that additional groundwater users will have on the water supply system in an already water-stressed arid environment.

Two key impacts are identified on groundwater resources in the region:

- **Reduced groundwater availability and security:** Activities such as extensive development of hardened surfaces for roads are likely to reduce direct recharge to alluvial aquifers;
- **Reduced groundwater quality: Changes** in climate trends as well as the existing physical features in the region (e.g. heuweltijies) are likely to result in increased salinity of the groundwater with time. High-risk activities such as storage of bulk liquid items such as green ammonia and diesel, and the dispensing

thereof via pipeline, as well as facilities for green hydrogen production which include, nitrogen, hydrogen and oxygen storage and pipelines, pose a high risk to groundwater quality should contamination occur. Some categories of land use have higher associated risks as they may affect the groundwater recharge and quality more so than others. Categories of activities associated with the development are categorised in **Table 4-9.2**.

4.9.3.2 Mitigation measures

Mitigation measures would need to include preventing high risk development-associated activities in areas of high to very high sensitivity. High risk activities would need to be confined to areas of Low sensitivity, while Medium risk activities could potentially be applied in areas of High and Medium sensitivity, provided they included impact mitigation. Low risk activities could be applied in all areas, provided they were carried out with attention to Best Practice and a view to avoid or minimize contamination and disturbance.

Mitigation for the potential impacts identified in this chapter would be likely to prove complex and costly, as the main impacts are driven by the natural environment. Mitigation measures would probably require significant financial investment, as they might include support to municipal structures to assist in improving infrastructure and the management of groundwater resources in the area. Despite groundwater resources not being optimally managed at present, it remains that supply is limited. Additional measures to address water scarcity, albeit very costly, may include supplying treated, desalinised water to nearby communities. The ecological, practical and financial feasibility of this mitigation measure, however, would need to be investigated as the activity itself has a number of associated risks and impacts if not appropriately managed, especially to marine ecosystems.

Groundwater quality can be protected by ensuring that groundwater resources are protected from high-risk activities by implementing stricter regulations and requiring adherence thereto. Deterioration of water quality due to poorly functional water treatment facilities, as well as industrial and agricultural activities can be prevented. Investment into the current water supply infrastructure and into training schemes for municipal staff may improve wastewater quality released from treatment facilities. The use of appropriately treated wastewater can be considered as an alternative source of water in the area. Training schemes may also enhance borehole management, mitigating certain issues such as iron biofouling. With the exception of the introduction of a managed aquifer recharge schemes, the possible natural increasing salinisation of groundwater (baseline scenario and both development scenarios) may not, however, be mitigable.

4.9.3.3 Impact assessment

Tables 4-9.3 and **4-9.4** provide formal ratings of the above impacts, considering their application to areas of different groundwater sensitivity (Very High to Low sensitivity, as mapped in **Figure 4-7.1**) , for the Baseline Scenario (Sc0) and the two development scenarios (Sc1 and Sc2).

The ratings are carried out separately, with and without the recommended mitigation and management measures outlined above. **Table 4-9.3 Assessment of potential impacts on groundwater availability and security**

Table 4-9.3: Assessment of potential impacts on groundwater availability and security

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With Management (Financial and Legislative Intervention: policies, investment, training)		
			Consequence (-)	Likelihood	Risk	Consequence (-)	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Drastic	Likely	High	N/A	N/A	N/A
	S1: Small GH2		Drastic	Likely	High	Significant	Likely	Moderate
	S2: Big GH2		Extreme	Likely	Very High	Drastic	Likely	High
	S0: Baseline	High Sensitivity	Moderate	More Likely	Moderate	N/A	N/A	N/A
	S1: Small GH2		Drastic	Likely	High	Significant	Likely	Moderate
	S2: Big GH2		Drastic	Likely	High	Significant	Likely	Moderate
	S0: Baseline	Medium Sensitivity	Moderate	Likely	Low	N/A	N/A	N/A
	S1: Small GH2		Significant	Likely	Moderate	Slight	Likely	Very Low
	S2: Big GH2		Significant	Likely	Moderate	Moderate	Likely	Low
	S0: Baseline	Low Sensitivity	Slight	Likely	Very Low	N/A	N/A	N/A
	S1: Small GH2		Moderate	Likely	Low	Slight	Likely	Very Low
	S2: Big GH2		Moderate	Likely	Low	Slight	Likely	Very Low
Impact	**Scenario**	**Spatial receiving environment or receptor**	**Without Management**			**With Management (Physical Intervention: desalination, MAR)**		
			Consequence (+)	**Likelihood**	**Opportunity**	**Consequence (+)**	**Likelihood**	**Opportunity**
Positive	S0: Baseline	Very High Sensitivity	N/A	N/A	N/A	N/A	N/A	N/A
	S1: Small GH2		N/A	N/A	N/A	Significant	Likely	Moderate
	S2: Big GH2		N/A	N/A	N/A	Significant	Likely	Moderate
	S0: Baseline	High Sensitivity	N/A	N/A	N/A	N/A	N/A	N/A
	S1: Small GH2		N/A	N/A	N/A	Significant	Likely	Moderate
	S2: Big GH2		N/A	N/A	N/A	Significant	Likely	Moderate
	S0: Baseline	Medium Sensitivity	N/A	N/A	N/A	N/A	N/A	N/A
	S1: Small GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S2: Big GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S0: Baseline	Low Sensitivity	N/A	N/A	N/A	N/A	N/A	N/A
	S1: Small GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S2: Big GH2		N/A	N/A	N/A	Moderate	Likely	Low

Table 4-9.4: Assessment of potential impacts on groundwater quality

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With Management		
			Consequence (-)	Likelihood	Risk	Consequence (-)	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Moderate	Likely	Low	N/A	N/A	N/A
	S1: Small GH2		Drastic	Unlikely	Moderate	Significant	Unlikely	Low
	S2: Big GH2		Extreme	Unlikely	Moderate	Drastic	Unlikely	Moderate
	S0: Baseline	High Sensitivity	Moderate	Likely	Low	N/A	N/A	N/A
	S1: Small GH2		Drastic	Unlikely	Moderate	Significant	Unlikely	Low
	S2: Big GH2		Extreme	Unlikely	Moderate	Drastic	Unlikely	Low
	S0: Baseline	Medium Sensitivity	Moderate	Likely	Low	N/A	N/A	N/A
	S1: Small GH2		Significant	Unlikely	Low	Moderate	Unlikely	Low
	S2: Big GH2		Significant	Unlikely	Low	Moderate	Unlikely	Low
	S0: Baseline	Low Sensitivity	Slight	Unlikely	Very Low	N/A	N/A	N/A
	S1: Small GH2		Moderate	Likely	Low	Slight	Likely	Very Low
	S2: Big GH2		Moderate	Likely	Low	Slight	Likely	Very Low

4.9.4 Potential impacts to surface water resources

4.9.4.1 Impact description

The entire study area is classified as either arid or hyper-arid. Water for life and livelihoods is limited and is likely to become increasingly scarce, without effective alternative water supplies. Potential impacts to surface water resources include:

- Increasing stresses on a limited water supply from the Orange River, for an increasing population;
- Increasing shortage of water to sustain life and livelihoods where areas change from arid to hyper-arid in the future.

4.9.4.2 Mitigation measures

Mitigation measures, particularly in the north-west of the delimited area, would need to include:

- Appropriate estimation of future needs, design and implementation of new and augmented water supply schemes from the Orange River, in alignment with the EFR and RQOs for the estuary and lower Orange River;
- Implementation of effective desalination plants to meet additional water demand;
- Effective capacity building and proper operation and maintenance of abstraction works, reticulation and local water supply infrastructure;
- Prevention of pollution to the abstraction works, where Orange River water is drawn from riparian subsurface (to allow for abstraction of filtered Orange River yield).

4.9.4.3 Impact assessment

Table 4-9.5 provides formal ratings of the above impacts, considering their application to areas of different surface water sensitivity (Very High to Low sensitivity, as defined in Section 4.7.3 and mapped in **Figure 4-7.2**) , for the Baseline Scenario (Sc0) and the two development scenarios (Sc1 and Sc2).

The ratings are carried out separately, with and without the recommended mitigation and management measures outlined above.

Table 4-9.5: Assessment of potential impacts on surface water resource availability, quality and security

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With Management		
			Consequence (-)	Likelihood	Risk	Consequence (-)	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Severe	More likely	Very High	Substantial	Less Likely	Moderate
	S1: Small GH2		Extreme	Likely	Very High	Substantial	Less Likely	Moderate
	S2: Big GH2		Extreme	Likely	Very High	Substantial	Less Likely	Moderate
	S0: Baseline	High Sensitivity	Substantial	More likely	High	Moderate	Unlikely	Low
	S1: Small GH2		Severe	Likely	High	Moderate	Unlikely	Low
	S2: Big GH2		Severe	Likely	High	Moderate	Unlikely	Low
	S0: Baseline	Medium Sensitivity	Moderate	More likely	Moderate	Moderate	Unlikely	Low
	S1: Small GH2		Substantial	Likely	Moderate	Moderate	Unlikely	Low
	S2: Big GH2		Substantial	Likely	Moderate	Moderate	Unlikely	Low
	S0: Baseline	Low Sensitivity	Slight	Likely	Low	Slight	Unlikely	Very Low
	S1: Small GH2		Moderate	Unlikely	Low	Slight	Unlikely	Very Low
	S2: Big GH2		Moderate	Unlikely	Low	Slight	Unlikely	Very Low
Positive	S0: Baseline	Very High Sensitivity	N/A	N/A	N/A	Substantial	Less Likely	Moderate
	S1: Small GH2		N/A	N/A	N/A	Substantial	Likely	Moderate
	S2: Big GH2		N/A	N/A	N/A	Substantial	Likely	Moderate
	S0: Baseline	High Sensitivity	N/A	N/A	N/A	Moderate	Less Likely	Low
	S1: Small GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S2: Big GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S0: Baseline	Medium Sensitivity	N/A	N/A	N/A	Moderate	Less Likely	Low
	S1: Small GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S2: Big GH2		N/A	N/A	N/A	Moderate	Likely	Low
	S0: Baseline	Low Sensitivity	N/A	N/A	N/A	Slight	Less Likely	Very Low
	S1: Small GH2		N/A	N/A	N/A	Slight	Likely	Very Low
	S2: Big GH2		N/A	N/A	N/A	Slight	Likely	Very Low

4.9.5 Potential impacts to inland aquatic ecosystems

4.9.5.1 Impact description: Degradation of inland aquatic ecosystems

The discussions in Section 4.8.4 and **Table 4-8.4** highlight a number of potential drivers of inland aquatic ecosystem degradation, both in the Baseline Scenario (Sc0) and in Scenarios 1 and 2. In the Baseline Scenario, these mainly comprise possible potential changes in pan ecosystem diversity; possible water quality deterioration (increasing salinity and nutrients); reduced riparian resilience as a result of reduced frequency of flows and extended no flow periods; increased vulnerability of ephemeral systems to erosion, grazing and trampling; and increased vulnerability of naturally ephemeral systems to the receipt of additional flows from treated and/or untreated effluent.

In the context of large-scale expansion of linear, hardened infrastructure such as roads across the Namakwa Region, with development likely to require new roads, widening and upgrading of existing roads, and new internal roads for wind farms in particular, as well as potentially hundreds of kilometers of pylons and transmission lines, impacts such as concentrated flows into watercourses, erosion, changes in sediment regimes and ecosystem fragmentation are all likely, along with indirect impacts also discussed, such as nutrient enrichment from variously treated or untreated effluent discharges and potentially expanding urban formal and informal settlement footprints.

Many of the aquatic ecosystems within the study area are, moreover, Critically Endangered or Endangered ecosystems (**Table 4-5.1**), and any impacts to such systems would be significant.

4.9.5.2 Avoidance, mitigation and management measures

The following broad measures would be recommended to reduce concerns around aquatic ecosystem degradation:

i. Measures to **avoid** impacts:

- No new development should be located in areas mapped in **Figure 4-7.3** (see also **Table 4-7.6**) as Very High Sensitivity;
- No new development should ideally take place in any areas mapped in **Figure 4-7.3** as High Sensitivity – however, limited Low Risk activities might be considered, provided there is adequate mitigation. In the case of (essential) road crossings, design mitigation could potentially reduce risks to Medium or Low, with significant input into design and construction phase mitigation, but such crossings should be minimised;
- Only Low Risk activities should be located in buffer areas (mapped as Medium Sensitivity);
- High Risk activities should be located only in areas of Low Sensitivity;
- Medium Risk activities may be mitigated to low, and could take place in areas of Low Sensitivity and some Medium sensitivity areas (excluding buffer areas);

ii. Measures to **mitigate against** impacts:

- WWTWs that discharge treated or untreated effluent into any watercourse or areas within 500 m of any watercourse should be required to treat such effluent to better than the DWS Special Effluent Limits (GN 383 of 2019), and rather to standards that are in line with the DWAF (1996) water quality guidelines for aquatic ecosystems, for mesotrophic systems, with regard to phosphorus and nitrogen nutrient;

- Developments or parts of developments entailing hardening of surfaces should be subject to meeting the requirements of a stormwater management plan that allows for recharge and appropriately attenuated runoff into the buffers of natural watercourses, and (where appropriate) requires separation of clean and polluted water on site, and treatment of the latter to ecologically acceptable standards;
- Buffer areas should be managed free of activities likely to impact negatively on their associated watercourses – thus there should be no hardening of surfaces in buffer areas, or disturbance likely to render these areas less effective as buffers;
- Road crossings over watercourses should be designed to allow for natural flows (including flood flows) to pass under or over the roads without concentration of flows downstream (e.g. as a result of passing through narrow culverts that result in narrower channels downstream) – culverts under road crossings should allow for the full width of flows in all watercourses to pass under the road, without creating concentrated flow paths;
- Where water pipelines are routed through areas of High sensitivity, construction measures must be managed to reduce disturbance, and final levels over the pipelines should be set to pre-development levels (i.e. without raised mounds over pipelines);
- The passage of vehicles through pans and ephemeral watercourses, particularly during construction phases, should be stringently avoided;

iii. Measures to **manage** impacts:

- Attention must be paid to the pre-development upgrading of WWTWs in areas likely to expand urban populations in response to perceived and actual opportunities associated with the proposed development – since many of these WWTWs are poorly performing at present, attention must also be paid to upskilling of WWTW management and staff, particularly in the larger urban areas. This is a strategic management action, and is included in Section 4.10.

4.9.5.3 Impact assessment

This impact is rated in **Table 4-9.6**, considering its application to areas of different inland aquatic ecosystem sensitivity (Very High to Low sensitivity, as mapped in **Figure 4-7.3**) , for the Baseline Scenario (Sc0) and the two development scenarios (Sc1 and Sc2).

The ratings are carried out separately, with and without the recommended mitigation and management measures outlined above.

4.9.6 Potential impacts to estuaries

4.9.6.1 Impact description: Degradation of estuarine ecosystems and resultant potential biodiversity impacts

Section 4.8.4 and **Table 4-8.4** highlight the following key impacts on estuarine ecosystems and micro-outlets that would be associated with the Baseline Scenario (Sc0):

- Increased salinity: Projected increases in evapotranspiration and reductions in surface water inputs are likely to elevate salinity levels in estuarine environments. Systems already prone to hypersalinity, such as the Swartlintjies and Groen estuaries, are expected to be particularly vulnerable;
- Changes in groundwater quality and quantity: Lower groundwater flows and rising groundwater salinity pose significant risks to estuarine water quality, particularly in the four CTAPC West Coast estuaries,

where fresher groundwater inflows support critical sedge and reedbed habitats in upper estuarine reaches;

- Altered flood regimes and estuarine connectivity: A projected reduced frequency of flooding in ephemeral rivers may reduce the frequency of breaching of estuary mouths, decreasing opportunities for fish recruitment. Existing recruitment challenges, already constrained by elevated salinity levels, are thus expected to be further exacerbated;
- Deterioration in water quality as a result of urban expansion: Population growth and associated increases in sewage effluent volumes are anticipated to further strain wastewater treatment works (WWTWs), many of which are already operating beyond capacity and with limited efficiency;
- Impacts on the Orange River Estuary: Without active intervention, current degradation of the Orange River Estuary is expected to persist and would be heightened by construction of the proposed Vioolsdrift Dam.

In the context of Scenarios 1 and 2, the above impacts would be expected to be exacerbated, as demand for groundwater increases, and in the light of likely increases in effluent discharges, impacting on surface and groundwater quality. Road upgrades for the construction of windfarm and solar plant installations are furthermore likely, and could perpetuate and worsen existing estuarine impacts in the form of attenuated floods upstream of road berms and barriers, that reduce the frequency and duration of estuary breaching that is necessary for fish recruitment and water quality maintenance in the estuaries.

At the same time, however, the potential need for road upgrades in the river reaches upstream of the CTAPC estuaries could provide opportunities to remedy existing impacts to these estuaries, particularly those associated with artificially attenuated flood flows.

4.9.6.2 Impact avoidance, mitigation and management measures

The following broad measures would be recommended to reduce concerns around estuarine degradation:

i. Measures to **avoid** impacts:

- No new development including roads should be located in areas mapped in **Figure 4-7.3** (see also **Table 4-7.6**) as Very High Sensitivity – all four CTAPC estuaries have been rated as Very High sensitivity, given their Endangered ETS;
- Only Low Risk activities should be located in buffer areas and micro-outlets (mapped as Medium Sensitivity);
- The discharge of treated or untreated effluent into any estuary in the study area, or into their upstream river reaches, should be avoided – this is because these systems have high sensitivity to changes in water quality and quantity and furthermore because treatment of effluent to the required quality is unlikely to be achievable, given the current performance of WWTWs.

ii. Measures to **mitigate against** impacts:

- Developments or parts of developments entailing hardening of surfaces should be subject to meeting the requirements of detailed stormwater management plans that allow for recharge and appropriately attenuated runoff into estuaries and micro-outlets and (where appropriate), should require separation of clean and polluted water on site, and treatment of the latter to ecologically acceptable standards – attenuation should be aimed at mirroring natural conditions and should not impact on the frequency or duration of estuary breaching;
- No new road crossings should be allowed through estuaries;
- The passage of vehicles through estuarine saltmarsh and other areas during construction (and other) phases, should be stringently avoided;

- Where existing roads through estuarine areas would require upgrading or widening to accommodate windfarm and/or solar installations or other activities associated with the proposed overall development, existing impacts to estuaries associated with upstream road berms and inadequate culverts that attenuate flood flows and thus reduce estuary mouth breaching frequency and duration should be addressed, and road crossings should be re-configured to allow more natural passage of flows into downstream areas – this measure provides an opportunity to improve existing conditions;
- The non-flow-related requirements for the Orange River Estuary to meet its REC should be implemented as a pre-requisite for any further development in this area (as per DWS 2017b);

iii. Measures to **manage** impacts:

- Where discharge of treated effluent into an estuary is unavoidable or is required to meet the Ecological Reserve for that estuary, such effluent (including irrigation water within 500 m of any estuary) must be treated to better than the DWS Special Effluent Limits (GN 383 of 2019), and rather to standards that are in line with the DWAF (1996) water quality guidelines for aquatic ecosystems, for mesotrophic systems with regard to phosphorus and nitrogen nutrients. This stipulation is made because the DWS effluent limits assume a degree of dilution by receiving aquatic ecosystems, which is not the case in ephemeral watercourses and arid, predominantly closed estuaries. Alternatively, where these are available, effluent may be discharged within gazetted or otherwise stipulated RQOs for that estuary;
- Again, attention must be paid to the pre-development upgrading of WWTWs in areas likely to expand urban populations in response to perceived and actual opportunities associated with the proposed development – since many of these WWTWs are poorly performing at present, attention must also be paid to upskilling of WWTW management and staff, particularly in the larger urban areas. This is a strategic management action, and is included in Section 4.10.

4.9.6.3 Impact assessment

This impact is rated in **Table 4-9.7**, considering its application to areas of different estuarine ecosystem sensitivity (Very High to Low sensitivity, as mapped in **Figure 4-7.3**) , for the Baseline Scenario (Sc0) and the two development scenarios (Sc1 and Sc2).

The ratings are carried out separately, with and without the recommended avoidance, mitigation and management measures outlined above.

Table 4-9.6: Assessment of the impacts of degradation of inland aquatic ecosystems (rivers, wetlands and pans). Assessment of the Scenario 0 (S0) assumes current development trajectory (without specific mitigation) and climate change. S1 and S2 assessments are based on the development impacts only.

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With recommended management and mitigation, and assuming avoidance		
			Consequence (-) for inland aquatic ecosystems	Likelihood	Risk	Consequence (-) for inland aquatic ecosystems	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Drastic	Likely	Moderate to high	N/A	N/A	N/A
	S1: Small GH2		Extreme	More likely	High	None – avoided	Likely	Very Low
	S2: Big GH2		Extreme	More likely	High	Drastic	Likely	Moderate to High
	S0: Baseline	High Sensitivity	Drastic	Likely	Moderate to high	N/A	N/A	N/A
	S1: Small GH2		Extreme	More likely	High	Significant (with major avoidance)	Likely	Moderate
	S2: Big GH2		Extreme	More likely	High	Drastic	Likely	Moderate to High
	S0: Baseline	Medium Sensitivity	Significant	Likely	Moderate	N/A	N/A	N/A
	S1: Small GH2		Significant	Likely	Moderate	Moderate	Likely	Low to Moderate
	S2: Big GH2		Drastic	Likely	Moderate to high	Significant	Likely	Moderate
	S0: Baseline	Low Sensitivity	Moderate	Likely	Low to Moderate	N/A	N/A	N/A
	S1: Small GH2		Moderate	Likely	Low to Moderate	Slight	Likely	Very Low
	S2: Big GH2		Significant	Likely	Moderate	Moderate	Likely	Low to Moderate

Table 4-9.7: Assessment of the impact of degradation of estuaries (including the Orange River Estuary) and micro-outlets. Assessment of the Scenario 0 (S0) assumes current development trajectory (without specific mitigation) and climate change. S1 and S2 assessments are based on the development impacts only. Impacts to estuaries would stem largely from catchment activities.

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With recommended management and mitigation, and assuming avoidance		
			Consequence (-) for estuaries	Likelihood	Risk	Consequence (-) for estuaries	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Drastic	Likely	Low to Moderate	N/A	N/A	N/A
	S1: Small GH2		Extreme	More likely	High	None – avoided	Likely	Very Low
	S2: Big GH2		Extreme	More likely	High	Drastic	Likely	Moderate to High
	S0: Baseline	High Sensitivity	Significant	Likely	Moderate to high	N/A	N/A	N/A
	S1: Small GH2		Extreme	More likely	High	Significant (with major avoidance)	Likely	Moderate
	S2: Big GH2		Extreme	More likely	High	Drastic	Likely	Moderate to High
	S0: Baseline	Medium Sensitivity	Moderate	Likely	Moderate	N/A	N/A	N/A
	S1: Small GH2		Significant	Likely	Moderate	Moderate	Likely	Low to Moderate
	S2: Big GH2		Drastic	Likely	Moderate to high	Significant	Likely	Moderate
	S0: Baseline	Low Sensitivity	Moderate	Slight	Low to Moderate	N/A	N/A	N/A
	S1: Small GH2		Moderate	Likely	Low to Moderate	Slight	Likely	Very Low
	S2: Big GH2		Significant	Likely	Moderate	Moderate	Likely	Low to Moderate

4.9.7 Potential opportunities

The previous sections focused on risks to water resources associated with the proposed development of GH2 and GH2 supporting infrastructure in the study area. It must however also be noted that such development could bring with it opportunities for development in some areas, if the availability of fresh water increased as a result of affordable desalination projects, thus changing current development constraints. Such opportunities would however themselves be associated with increased risks from a biodiversity perspective, and their realisation would be contingent on meeting the challenges already highlighted around effective upgrading, expansion and maintenance of WWTW and water treatment infrastructure; improved water reticulation; and management of human populations, and the likely expansion of informal settlements in particular.

In addition to increasing fresh water supplies, GH2 development and its supporting infrastructure could also contribute positively towards upgrading of water supply networks and improved training opportunities that result in better maintenance and operational services at WWTWs, Orange River abstraction points and desalination plants.

4.9.8 Recommended Strategic Management Actions

The previous section included various high-level avoidance, mitigation and management measures to address the key impacts associated with the kinds of activities and interventions that would be anticipated in a GH_2 development scenario in Boegoebaai and the Namakwa Region. There are, however, a number of strategic actions that should also be considered, in taking this project further towards a sustainable outcome from a water resources perspective.

These comprise:

- Generally:
    - Ensuring that the additional water volume (and associated water quality) that would be required by the proposed development would in fact be available – this would require consideration by the DWS Water Resource Classification team, currently engaged in this assessment;
- From a groundwater perspective:
    - Investment in improvement in infrastructure and management of groundwater resources in the study area, including a focused investment in supplying treated, desalinised water to serve projected increased demand from domestic and industrial users in a GH_2 scenario;
    - Protection of groundwater quality from high-risk activities by implementing stricter regulations and requiring adherence thereto;
    - Investment in currently poorly functional WWTWs, including training to upskill municipal management and other staff and infrastructure upgrades – if successful, such measures could allow for WWTW effluent to be used as an alternative water source;
    - Investment in training schemes to enhance borehole management, in particular regarding mitigation of issues such as iron biofouling;
    - Investment in managed aquifer recharge schemes, including appropriate investment in training, human resources and infrastructure, to mitigate against possible natural increasing salinisation of groundwater;
- From a surface hydrology perspective:
    - Provision for (allowed-for) abstraction from the Orange River, in keeping with the Ecological Reserve and RQOs for the estuary, and reticulation to the level of Scenario 1 demand;

  - Provision for adequate maintenance of the (authorised) abstraction, treatment, reticulation and storage works;
  - Provision for the protection of abstraction works and reticulation pipelines;
  - Investment in the urgent development / out-sourcing of expertise to operate desalination plants at proposed coastal locations;
  - Minimisation of disturbance to river systems and floodplains, particularly at infrastructure crossings;
  - Prevention of encroachment of structures or dwellings into the 1:100-year floodplains of watercourses;
  - Ensuring that the water demand (volume and quality) for Scenarios 1 and 2 can be met, based on sustainable use of available surface and groundwater resources, including supplementation with groundwater and marine water sources;

- From an inland and estuarine ecosystem perspective:
  - Avoidance of inland and estuarine aquatic ecosystems in any development context, given that these ecosystems are regionally rare, sensitive and of (generally) high ecological importance, as well as the fact that their degradation could result in multiple other impacts, including impacts on road infrastructure (e.g. as a result of erosion and/or sedimentation);
  - Upfront investing in improved WWTW management and infrastructure and ensuring that all municipal WWTW effluent in areas likely to expand urban populations in response to perceived and actual opportunities associated with the proposed development meet their required (licensed) limits before embarking on any development that will exert greater stresses on such infrastructure – since many of these WWTWs are currently poorly performing, attention must also be paid to upskilling of WWTW management and staff;
  - Investment in enhanced wastewater treatment facilities so that effluent can be re-used beneficially without resulting in nutrient enrichment of surface or groundwater or changing natural watercourse function (e.g. changing from ephemeral to seasonal or perennial waste conveyance systems);
  - Implementation of the non-flow related rehabilitation requirements for the Orange River Estuary, as outlined in DWS (2017b and 2024b);
  - Considered assessment of the practical implications of any required need for aquatic ecosystem offsets (i.e. where the post mitigation residual impact is greater than a Low significance) – such assessment should consider the availability, affordability and practical manageability of offset receptor sites, and should also consider pro-active watercourse offset banking, in combination with terrestrial offset requirements to ensure holistic biodiversity conservation across all habitat types;
  - Upfront investment in maintenance / improvement in road design, to ensure that flood flows into estuaries are not artificially attenuated (e.g. by upstream berms), while also ensuring that flows under roads do not result in concentrated flows, likely to cause channelisation, narrowing and resultant erosion of river channels;
  - Ensuring that the recommended EWR for the lower Orange River and the Orange River Estuary in particular can still be met, and is in no way jeopardised by the proposed development – this would require investment in desalination of both seawater and groundwater.

4.10 CONCLUSIONS

This chapter has considered water resources in the study area from both the perspective of the limitations these resources place on future development and the sensitivity of these systems themselves to some aspects of development. The greatest risks are posed by activities resulting in changes in water quality; reductions in water availability or predictability; and physical disturbance that reduces natural downstream flushing (e.g. estuaries) or increases channel erosion, especially in the vicinity of road crossings. Surface and groundwater flows and quality are interlinked, and changes in one can have impacts on the other. These resources are moreover already under threat as a result of climate change and existing demand.

Given the arid to hyper-arid character of the study area, water and its sustainable management must thus be recognized as critical factors in any future development planning in the area. In this regard, it seems evident that the Boegoebaai Port, SEZ and the associated (required) large-scale roll-out of renewable energy in the region should only be considered in a context where allowance is also made for large-scale desalination of seawater and/or groundwater to provide for the increase in direct and indirect water demand likely to be associated with such development. Such an approach would come at great potential ecological risk, as the naturally ephemeral watercourses and pans in the area have high biodiversity value and would be vulnerable to changes in hydroperiod, including receipt of additional (potentially nutrient enriched) water from ancillary developments such as expanded WWTWs and effluent outflows, as well as increased salinities from brine disposal from desalination works. Attention to creating a circular water economy that does not change aquatic ecosystem function would be important if the proposed development were to proceed. At the same time, it is possible that such development could be used in part to redress existing impacts to aquatic ecosystems, such as the impacts of roads and effluent outflows on some of the estuaries – there is however very low confidence attached to the reality of any such outcome being achieved.

Risk assessments presented in this chapter show that a high degree of avoidance of aquatic ecosystems, their floodplains and groundwater recharge areas would be required, to reduce the high likelihood of major consequence for water resources including inland and estuarine aquatic ecosystems.

Overall, it must be stressed that while solar and wind energy sources in the study area may be amply available, the limited availability of water resources and the high sensitivity of aquatic ecosystems in this particular region is a major constraint for such development at the outset, taking into account current and future demands and projected climate change impacts.

4.11 REFERENCES

Adams, A., Titus, R. and Xu, Y. (2004). Groundwater Recharge Assessment of the Basement Aquifers of Central Namaqualand.. WRC Report No. 1093/1/04. Water Research Commission, Pretoria.

Allan, D.G., Seaman M.T. and Kaletja, B. 1995. The endorheic pans of South Africa. In: Cowan, GI. (ed), Wetlands of South Africa. Department of Environmental Affairs and Tourism, Pretoria, South Africa. Pp 75-101. Aller, L., Bennet, T., Lehr, J.H. and Petty, R. J. (1987). DRASTIC – a standardised system for evaluating groundwater pollution potential using hydrogeologic settings; United States Environmental Protection Agency Report EPA/600/2-87/035.

Benito, G., Botero, BA., Thorndycraft, VR., Rico, M., Sanchez-Moya, Y., Sopena, A., Machado, MJ. And Dahan, O. 2011 Rainfall-runoff modelling and palaeoflood hydrology applied to reconstruct centennial scale records of flooding and aquifer recharge in ungauged ephemeral rivers. Hydrol. Earth Syst. Sci. 15(1185-1196).

Bird, M. and Malan, H. 2010. Aquatic invertebrates as indicators of human impacts in South Arican Wetlands. Report to the Water Research Commission. WRC Report No TT 435/09. Pretoria. South Africa.

Black, D., Turpie, J. and Rao, N. 2016. Evaluating the cost-effectiveness of ecosystem-based adaptation: Kamiesberg Wetlands case study. SAJEMS Asset research NS 19 (2016) No 5:702-713

Blignault, H. J., Van Aswegen, G., Van Der Merwe, S. W., and Colliston, W. P. 1983. The Namaqualand geotraverse and environs: part of the Proterozoic Namaqua Mobile Belt. Geological Society of South Africa, Special Publication, 10, 1–29

Bourne, A, P. de Abreu, C. Donatti, S. Scorgie, and S. Holness. 2015. A Climate Change Vulnerability Assessment for the Namakwa District, South Africa: The 2015 revision. Conservation South Africa, Cape Town.

BVI Consulting Engineers. 2023a. Feasibility Study – Port Nolloth Bulkwater Supply. Project Ref 34141.

BVI Consulting Engineers. 2023b. Feasibility Study – Port Nolloth Bulkwater Supply. Annexure H: Water demand till 2040 assuming Boegoebaai and Special Economic Zone. Project Ref 34141.

Campbell, E. E., Parker-Nance, T. and Bate, G. C. 1992. A Compilation of the information on the magnitude, nature and importance of coastal aquifers in Southern Africa. WRC Report No 370/1/92. Water Research Commission, Pretoria.

CGS (2001). 1:250 000 Geological Map. Springbok 2916.

CGS (2007). 1:250 000 Geological Map. Onseepkans 2818.

CGS (2007). 1:250 000 Geological Map. Pofadder 2918.

CGS (2010). 1:250 000 Geological Map. Garies 3017.

CGS (2010). 1:250 000 Geological Map. Loeriesfontein 3018.

CGS (2011). 1:250 000 Geological Map. Alexander Bay 2816. Zoomed-in map.

Christensen, J H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I.., Jones, R., Kolli, R K., Kwon, W T., Laprise, R., Rueda, V., Mearns, L., Menendez, C G., Raisanen, J., Rinke, A., Sarr, A., Whetton, P. 2007. 'Regional Climate Projections', Chapter 11, The Physical Science basis, United Kingdom. https://www.osti.gov/etdeweb/biblio/20962141

Clifford, T., Barton, E., Stern. R., Duchesne, JC. 2004, ' U–Pb Zircon Calendar for Namaquan (Grenville) Crustal Events in the Granulite-facies Terrane of the O'okiep Copper District of South Africa', Journal of Petrology, Volume 45, Issue 4, Pages 669–691, https://doi.org/10.1093/petrology/egg097

Coleman, T. and van Niekerk, A. 2007. Orange River Integrated Water Resources Management Plan. Water Quality in the Orange River. Report submitted to the Orange Senqu River Commission (ORASECOM) ORASECOM 007/2007.

Colliston, W.P., Schoch, A.E. 2003, 'A mid-Proterozoic Volcano-Sedimentary sequence in the Aggeneys Hills Duplex, Namaqua Metamorphic Complex' ;*South African Journal of Geology* Volume 106 (4): 343–360. https://doi.org/10.2113/106.4.343

Conrad, J., Adams, S. and Titus, R. 2003. GIS based assessment of groundwater recharge in the fractured rocks of Namaqualand, South Africa. International Conference on Groundwater in Fractured Rocks. Conference Proceedings. Prague, Czech Republic.

Cornell, D. H., Thomas, R. J., Moen, H. F. G., Reid, D. L., Moore, J. M. and Gibson, R. L. 2006. The Namaqua-Natal Province. The Geology of South Africa. Geological Society of South Africa. 352-379.

Cornell, D.H. Thomas, R..J. Gibson, R. Moen, H.F.G. Moore J.M. and Reid D.L. 2006, 'Namaqua-Natal Province', in Johnson, M.R., Anhauesser, C.R., Thomas, R.J (eds) The Geology of South Africa. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, 325-379

Cornell, D.H., Pettersson, A,. Whitehouse, M.J., A. Scherstén. 2009, 'A New Chronostratigraphic Paradigm for the Age and Tectonic History of the Mesoproterozoic Bushmanland Ore District, South Africa'. Economic Geology Volume 104 (3): 385–404 https://doi.org/10.2113/gsecongeo.104.3.385

Cornell, D.H., Robert, T., Moore, J.M., Jacobs, J. 1994, 'Crustal evolution of the Namaqua-Natal Metamorphic Province',Southern Africa. South African Journal of Geology. 97. 8-14. https://www.researchgate.net/publication/265058631_Crustal_evolution_of_the_Namaqua-Natal_Metamorphic_Province_southern_Africa

CSIR. 2017. Strategic Water Source Areas of South Africa. Available at: https://www.csir.co.za/strategic-water-source-areas-south-africa/

CSIR. 2023. Namakwa District Municipality Risk Profile Report based on the GreenBook. Available at: https://greenbook.co.za/

CSIR. 2024. Strategic Environmental Assessment for the proposed Boegoebaai Port, SEZ and Namakwa Region. Briefing note for research partners.

Dalziel, I. W. D., Mosher, S. and Gahagan, L. M. 2000. Laurentia-Kalahari collision and the assembly of Rodinia. The Journal of Geology. 108(5), 499–513.

Dalziel, I. W., Mosher, S., & Gahagan, L. M. 2000, 'Laurentia-Kalahari collision and the assembly of Rodinia', The Journal of Geology, Volume 108 (5), 499-513.

Davis, C. L., Hoffman, M. and Roberts, W. 2016. Recent trends in the climate of Namaqualand, a megadiverse arid region of South Africa. South African Journal of Science.112(3/4), Art. 2015-0217, 9 pages. http://dx.doi.org/10.17159/sajs.2016/20150217.

Day, E. (Liz). 2025. Strategic Environmental Assessment for the proposed Boegoebaai Port and Strategic Economic Zone, Northern Cape, South Africa. Work Package 1. Aquatic Ecosystems Assessment: Inland Aquatic Ecosystems And Estuaries. Report To CSIR.

Department of Forestry, Fisheries and the Environment (DFFE). 2023. Namakwa District Municipality: Final Integrated Waste Management Plan (2023 – 2027).

Department of Water Affairs and Forestry (DWAF). 1996. South African Water Quality Guidelines (second edition), Volume 7: Aquatic Ecosystems

Department of Water Affairs and Forestry (DWAF). 1998. Quality of Domestic Water Supplies. Volume 1: Assessment Guide. Second Edition. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2004. Development of Internal Strategic Perspectives: Groundwater Overview for Lower Orange Catchment Management Area. Prepared by: Pretorius, J.A. and Dennis, I.

Department of Water Affairs and Forestry (DWAF). 2008a. Groundwater Resources in the Northern Cape Province: 2008. Authored by Van Dyk, G. S., Makhetha, J., Potgieter, D., Zikali, T., Leeme, V., Moletsane, F., and Vonya, T. Department of Water Affairs and Forestry, Kimberley.

Department of Water Affairs and Forestry (DWAF). 2008b. Methods for determining the Water Quality component of the Ecological Reserve. Second Draft. Prepared by P-A Scherman of Scherman Consulting.

Department of Water and Sanitation (DWS), South Africa. 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Groundwater EWR report. Prepared by: WSM Leshika Consulting (Pty) Ltd. Authored by Sami, K. DWS Report No: RDM/WMA06/00/CON/COMP/0416.

Department of Water and Sanitation (DWS), South Africa. 2017a. Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. *Report on consequences of scenarios*. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0117.

Department of Water and Sanitation (DWS), South Africa. 2017b. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. *Ecological Specifications and monitoring report*. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0217.

Department of Water and Sanitation (DWS). 2001. 1:500 000 Hydrogeological Map. 2714 Upington and 2718 Alexander Bay.

Department of Water and Sanitation (DWS). 2012. Namaqua Water Supply Scheme. Sedibeng Water and BVI Consulting Engineers DWS report to DWS regional Bulk Infrastructure Grant. Feasibility and Implementation Readiness Study: Phase 3, November 2012.

Department of Water and Sanitation (DWS). 2013. Development of Reconciliation Strategies for Large Bulk Water Supply Systems Orange River: Current and Future Urban/Industrial Water Requirements. Report prepared by: WRP Consulting Engineers, Aurecon, Golder Associates Africa, and Zitholele Consulting. Report No. P RSA D000/00/18312/4

Department of Water and Sanitation (DWS). 2023. Green Drop Progress Report 2023. https://ws.dws.gov.za/iris/releases/GDP AT_2023_Report.pdf

Department of Water and Sanitation (DWS). 2024a. National monitoring data. Resource Quality Information Services. Department of Water and Sanitation. 2024-09-20 10:29:59 using NEMP TimeLine.R ver 2.3 under R version 4.4.1 (2024-06-14 ucrt). https://www.dws.gov.za/iwqs/wms/data/WMS_WMA_txt.asp.

Department of Water and Sanitation (DWS). 2024b. Determination of Water Resource Classes and associated Resource Quality Objectives in the lower Orange River Catchment. Resource Units Prioritisation Report. WP11438. Draft Report. No RDM/WMA04/00CON/CLA/0424. August 2024.

Department of Water and Sanitation (DWS). 2025. Department of Water and Sanitation Project List: Namakwa [DC6]. Online: https://ws.dws.gov.za/pmd/projects/default.aspx?enc=62GZREEewybvdRpJjo5P/NPsy6IkVZCF6BpOSI2rnFDuj2+PUcDPdHITm/0+LcL0WTSPgf3b10PwhIC8LGPbyxVw1AiGNH4ZWzHqpXCWzLc=#! Accessed: 7 March 2025.

Department of Water and Sanitation (DWS). 2002. 1:500 000 Hydrogeological Map. 2916 Springbok.

Department of Water and Sanitation (DWS). 2016a. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Groundwater EWR report. Prepared by: WSM Leshika Consulting (Pty) Ltd. Authored by Sami, K. DWS Report No: RDM/WMA06/00/CON/COMP/0416.

Department of Water and Sanitation (DWS). 2016b. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Wetland EWR Report. Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0616.

Department of Water and Sanitation (DWS). 2017a. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Buffels, Swartlintjies, Spoeg, Groen and Sout Estuaries Ecological Water Requirement. Authored by CSIR: L. van Niekerk, J. Adams, SJ Lamberth, S. Taljaard for Rivers for Africa DWS Report No: RDM/WMA06/00/CON/COMP/0316.

Department of Water and Sanitation (DWS). 2017b. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Report on Consequences of Scenarios. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0117.

Department of Water and Sanitation (DWS). 2023. Status of Water and Sanitation in Northern Cape. Northern Cape Province, South Africa

Desmet, P. 1996. The vegetation and restoration potential of the coastal belt between Port Nolloth and Alexander Bay, Namaqualand, South Africa. Masters Thesis. University of Cape Town.

Driver, A, Nel, J.L., Snaddon, K., Murray, K., Roux, D., Hill, L., Swartz, E.R., Manuel, J. and Funke, N. 2011. *Implementation Manual for Freshwater Ecosystem Priority Areas*. WRC Report No. 1801/1/11. ISBN 978-1-4312-0147-1. Pretoria.

Ebert, T. and Balko, M. 1987. Temporary pools as islands in space and in time: the biota of vernal pools in San Diego, Southern California, USA. Arch. Hydrobiol. 110. Pp101-123.

Eglington, B.M. 2006, 'Evolution of the Namaqua-Natal Belt, southern Africa – A geochronological and isotope geochemical review', Journal of African Earth Sciences, Volume 46, Issues 1–2,Pages 93-111, https://doi.org/10.1016/j.jafrearsci.2006.01.014.

Francis, M. L., Clarke, C. E., Van Gend, J., Vermooten, M., Maponya, M. G., Mashimbye, E., Palcsu, L., Watson, A. P., Van Rooyen, J. D. and Miller, J. A. 2022. The Relationship between Heuweltjies and Saline Groundwater along the West Coast of South Africa. WRC Report No. 2825/1/22.

Francis, M. L., Fey, M. V., Prinsloo, H. P., Ellis, F., Mills, A. J. and Medinski, T. V. 2007. Soils of Namaqualand: compensations for aridity. *Journal of Arid Environments*, *70*(4), 588-603.

Fryirs, K.A. 2017. River sensitivity: a lost foundation concept in fluvial geomorphology. Earth Surf. Process. Landforms 42:550-70.

Fu, G., Crosbie, R. S., Barron, O., Charles, S. P., Dawes, W., Shi, X., Van Niel, T., Li, C. 2019. Attributing variations of temporal and spatial groundwater recharge: a statistical analysis of climatic and non-climatic factors. *Journal of Hydrology*. DOI:10.1016/j.jhydrol.2018.11.022

Gunkel, A. and Lange, J. 2017. Water scarcity, data scarcity and the Budyko curve – An application in the lower Jordan river basin. Journal of Hydrology: Regional Studies 12(2017):136-149.

Hamer, M., Rayner, N.A. 1996. A note on the unusual crustacean community of a temporary pool in the Northern Cape. *South African Journal of Aquatic Science* 22(1): 100–104. doi:10.1080/10183469.1996.9631376

Hartnady C., Joubert P., Stowe C. 1985. 'Proterozoic Crustal Evolution in Southwestern Africa' ,Journal of international Geoscience Volume 8:236-244. https://doi.org/10.18814/epiiugs/1985/v8i4/003

Hattingh, J. 2016. *Surface and Groundwater Assessment.* Report to PHS Consulting for VAST Mineral Sands (Pty) Ltd.

Helme, N., Desmet, P.G. 2006. 'A Description of the Endemic Flora and Vegetation of the Kamiesberg Uplands, Namaqualand, South Africa', Report for CEPF/SKEP. https://www.cepf.net/sites/default/files/helme_desmet.pdf

Herold, C. and Bailey, A. 2016. Water Resources of South Africa. 2012 Study (WR2012). Water Research Commission. Pretoria, South Africa.

Joubert P. 1986. 'Namaqualand - a model of Proterozoic accretion', Geological society of South Africa, Volume 89, issue 2,Pages 1-18, https://hdl.handle.net/10520/EJC-1bb4925612

Kamiesberg Municipality. 2017. Integrated Development Plan. 2017-2022. Kamiesberg Municipality 4th Generation IDP.

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N.J., and Rowntree, K. 2005. *River EcoClassification: Manual for EcoStatus determination* (Version 1). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05

Kotze, D., Malan, H., Ellery, W., Samuals, I. and Saul, L. 2010. Assessment of the environmental condition, Ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands. Report to the Water Research Commission (WRC).

Le Maitre, D.C., Seyler, H., Holland, M., Smith-Adao, L.B., Nel, J.L., Maherry, A. and Witthüser, K. 2018. Strategic Water Source Areas for groundwater (Vector data). One of the outputs of the identification, delineation and importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater, WRC Report No TT 754/1/18, Water Research Commission, Pretoria, South Africa.

Lovegrove,B. G., Siegfried,W. R. 1986. 'Distribution and formation of Mima-like earth mounds in the western Cape Province of South Africa', South African Journal of Science, Volume 82 (432–436) https://www.semanticscholar.org/paper/Distribution-and-formation-of-Mima-like-earth-in-of-Lovegrove-Siegfried/2f1459b375a8031c6fecbef4d45bfd5bcf491af9

Lovegrove,B. G., Siegfried,W. R. 1989. 'Spacing and origin(s) of Mima-like earth mounds in the Cape Province of South Africa'., (1989), English, Journal article 1996-7489 0038-2353, 85, (2), South African Journal of Science, (108–112) https://www.cabidigitallibrary.org/doi/full/10.5555/19891935424

Mabidi A., Bird, M.S., Perissinotto, R., Rogers, D.C.. 2016. Ecology and distribution of large branchiopods (Crustacea, Branchiopoda, Anostraca, Notostraca, Laevicaudata, Spinicaudata) of the Eastern Cape Karoo, South Africa. *ZooKeys* 618: 15–38. doi: 10.3897/zookeys.618.9212

Macey, P.H., Thomas, R.J., Kisters, A.F.M., Diener, J.F.A., Angombe, M., Doggart, S., Groenewald, C.A., Lambert, C.W., Miller, J.A., Minnaar, H. and Smith, H. 2022. A continental back-arc setting for the Namaqua belt: Evidence from the Kakamas Domain. Geoscience Frontiers, 13(4), p.101408.

Makubalo, S. S. and Diamond, R. E. 2020. Hydrochemical evolution of high uranium, fluoride and nitrate groundwaters of Namakwaland, South Africa. *Journal of African Earth Sciences*, *172*, 104002.

Mantel, S. and Hughes, D. 2023. Farm Dams in Southern Africa: Balancing Environmental and Socio-Economic Sustainability (in): Dam Engineering – Design, Construction, and Sustainability, DOI: 10.5772/intechopen.113930

Marais, J. A. H., Agenbacht, A. L. D., Prinsloo, M. and Basson, W.A. 2001a. The Geology of the Springbok Area. Explanation: Sheet 2916. Pretoria.

Marais, J. A. H., Agenbacht, A. L. D., Prinsloo, M. and Basson, W.A. 2001b. The Geology of the Springbok Area.

McAuliffe, J.R., Hoffman, M.T., McFadden,L.D., Bell, W., Jack, S., King, M.P., Nixon, V. 2019, 'Landscape patterning created by the southern harvester termite, Microhodotermes viator: Spatial dispersion of colonies and alteration of soils', Journal of Arid Environments, Volume 162, Pages 26-34, https://doi.org/10.1016/j.jaridenv.2018.11.010.

Midgley, J.J., Harris, C., Harington, A., Potts, A.J. 2012, 'Geochemical perspective on origins and consequences Of Heuweltjie Formation In The Southwestern Cape, South Africa', South African Journal of Geology, Volume 115 (4): 577–588 https://doi.org/10.2113/gssajg.115.4.577

Midgley,G.F., Musil,C.F. 1990, 'Substrate effects of zoogenic soil mounds on vegetation composition in the Worcester – Robertson valley, Cape Province', South African Journal of Botany, Volume 56, Issue 2, Pages 158-166 https://doi.org/10.1016/S0254-6299(16)31083-3.

Moeck, C., Brunner, P., Hunkeler, D., 2016. The influence of model structure on groundwater recharge rates in climate-change impact studies. Hydrogeology Journal, 24(5): 1171 - 1184. DOI:10.1007/s10040-016-1367-1

Moen, H.F.G., Armstrong, R.A. 2008. 'New age constraints on the tectogenesis of the Kheis Subprovince and the evolution of the eastern Namaqua Province', South African Journal of Geolog, Volume 111 (1): 79–88. https://doi.org/10.2113/gssajg.111.1.79

Moen,H. F. G. 1999. 'The Kheis tectonic subprovince, Southern Africa; a lithostratigraphic perspective', South African Journal of Geology ,Volume 102 (1): 27–42, https://pubs.geoscienceworld.org/gssa/sajg/article/102/1/27/88061/The-Kheis-tectonic-subprovince-Southern-Africa-a

Nakwafila, A. N. 2015. Salinisation source(s) and mechanism(s) in shallow alluvial aquifers along the Buffels River. MSc Thesis. Stellenbosch University.

Nke, A. Y., Bailie, R. H., Macey, P. H., Thomas, R. J., Frei, D., Le Roux, P., Spencer, C. J. (2020). The 1.8 Ga Gladkop Suite: The youngest Palaeoproterozoic domain in the Namaqua-Natal Metamorphic Province, South Africa. Precambrian Research, Volume 350, 105941. ISSN 0301-9268. https://doi.org/10.1016/j.precamres.2020.105941.

Northern Cape Department of Environment and Nature Conservation. 2018. Northern Cape Critical Biodiversity Areas.

Ollis, D.J., Snaddon, C.D., Job, N.M. and Mbona, N. 2013. *Classification System for Rivers and other Aquatic Ecosystems in South Africa.* User Manual: Inland Systems.

Parsons, R. and Conrad, J. 1998. Explanatory Notes for the Aquifer Classification Map of South Africa. Water Research Commission Report No KV 116/98.

Pettersson A., Cornell D.H., Moen H.,Reddy S., Evans, D. 2007. 'Ion-probe dating of 1.2Ga collision and crustal architecture in the Namaqua-Natal Province of southern Africa' ,Precambrian Research,Volume 158, Issue 1-2, Pages 79-92 https://doi.org/10.1016/j.precamres.2007.04.006

Pettersson, Å. 2008. Mesoproterozoic crustal evolution in Southern Africa. Doctoral dissertation, Gothenburg University.

Picker, M.D., Hoffman, M.T., Bronwyn 2006, 'The density of Microhodotermes viator (Hodotermitidae) mounds in Southern Africa in relation to rainfall and productivity gradients', Journal of Zoology, Volume 271 Pages 37 - 44. https://www.researchgate.net/publication/230486293_The_density_of_Microhodotermes_viator_Hodotermitidae_mounds_in_Southern_Africa_in_relation_to_rainfall_and_productivity_gradients

Picker, M.D., Hoffman, M.T. and Leverton, B. 2006, 'The density of Microhodotermes viator (Hodotermitidae) mounds in Southern Africa in relation to rainfall and productivity gradients', Journal of Zoology, Volume 271 Pages 37 - 44. https://www.researchgate.net/publication/230486293_The_density_of_Microhodotermes_viator_Hodotermitidae_mounds_in_Southern_Africa_in_relation_to_rainfall_and_productivity_gradients

Pietersen, K., Titus, R. and Cobbing, J. 2009. Effective Groundwater Management in Namaqualand: Sustaining Supplies. WRC Report No. TT 418/09. Water Research Commission, Pretoria.

Rayner N.A. and Bowland, A.E. 1985. Notes on the taxonomy and ecology of *Triops granaries* (Lucas) (Notostraca: Crustacea) in South Africa. *South African Journal of Science* 81:500–505 .

Reid, D. L., Welke, H. J., Smith, C. B., Moore, J. M. 1997. 'Lead isotope patterns in Proterozoic stratiform mineralization in the Bushmanland Group, Namaqua Province, South Africa', *Economic Geology* Volume 92 (2): p248–258. https://doi.org/10.2113/gsecongeo.92.2.248

Reid, D., Barton, E.S. 1983. 'Geochemical characterization of granitoids in the Namaqualand geotraverse', The Geological Society of South Africa, Issue 10 206 https://inis.iaea.org/records/8w0eh-7qc19

Robb, L.J., Armstrong, R.A., and Waters, D.J. 1999. The History of Granulite-Facies Metamorphism and Crustal Growth from Single Zircon U–Pb Geochronology: Namaqualand, South Africa. Journal of Petrology, 40, 1747-1770.

Rundel, P. and Cowling, R. 2013. Biodiversity of the Succulent Karoo. Encyclopedia of Biodiversity (Second Edition). Pages 485-490. https://doi.org/10.1016/B978-0-12-384719-5.00226-4

Samuels, M. 2013. 'Pastoral mobility in a variable and spatially constrained South African environment', University of Cape Town https://open.uct.ac.za/items/66546d4b-7714-47c2-8104-783a97f62690

SANParks. 2024. Namaqua National Park Management Plan. SANParks. Pretoria. Similarly, the wetlands are mostly dry. Some wetlands are groundwater fed with the soil moist for longer periods

Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P., Louw, H., Modise, S., Ruthenavelu, M., Zukulu, T. and Maluleke, J. 2024. Strategic Environmental Assessment for the proposed Boegoebaai Port, SEZ and Namakwa Region: Briefing note for research partners. CSIR briefing report.

Schütte, S., Schulze, RE. and Clark, DJ. 2023. A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa: Report 1 - Methodology and Results. WRC Report No. 2833/1/22. Water Research Commission, Pretoria, South Africa.

South African National Biodiversity Institute (SANBI). 2022a. Red List of Ecosystems (RLE) for terrestrial realm for South Africa - remnants [Vector] 2021. Available from the Biodiversity GIS website, downloaded on Tuesday, January 21 2025

South African National Biodiversity Institute (SANBI). 2022b. Red List of Ecosystems (RLE) for terrestrial realm for South Africa - Original extent [Vector] 2021. Available from the Biodiversity GIS website, downloaded on Tuesday, January 21 2025

Stats SA. 2016. GHS Series Volume VIII: Water and Sanitation, in-depth analysis of the General Household Survey 2002–2015 and Community Survey 2016 data. Report 03-18-07(2002-2015).

Tankard, A. J., Jackson, M. P., Eriksson, K. A., Hobday, D. K., Hunter, D. R. and Minter, W. E. L. 1982. Crustal Evolution of South Africa: 3.8 Billion Years of Earth History. Springer-Verlag, New York.

Thomas, R.J., De Beer, C.H., and Bowring, S.A. 1996. A comparative study of the Mesoproterozoic late orogenic porphyritic granitoids of southwest Namaqualand and Natal, South Africa. J. Afr. Earth Sci.23, 485–508.

Titus, R.A., Beekman, H., Adams, S. and Strachan, L. 2009. The Basement Aquifers of Southern Africa. WRC Report K5/1418. Water Research Commission, Pretoria.

Titus, R.A., Pietersen, K.C., Williams, M.L., Adams, S., Xu, Y., Colvin, C., and Saayman, I.C. 2002. Groundwater assessment and strategies for sustainable resource supply in arid zones – The Namaqualand case study. WRC Report 721/1/02. Water Research Commission, Pretoria.

Tooth, S. and McCarthy, T. S. 2004. Anabranching in mixed bedrock-alluvial rivers: the example of the Orange River above Augrabies Falls, Northern Cape Province, South Africa, *Geomorphology,* 57 (3–4), pp 235-262. DOI: 10.1016/S0169-555X(03)00105-3.

Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty B.M., Maree, R.C., Whitefiled A.K., Wooldridge T.H., lamberth, S.J., Taljaard, S. and Van Niekerk, L. 2002. 'Assessment of the conservation priority status of South African estuaries for use in management and water allocation', Water SA, vol. 28(2), p 191-206 https://researchspace.csir.co.za/server/api/core/bitstreams/77cc0554-b65d-42cb-9330-7e616f1e61bb/content

University of Cape Town (UCT). 2017. Future Water: Can you use less than 42L a day? ((https://futurewater.uct.ac.za/activities/can-you-use-less-42l-day). Accessed on: 12 February 2025.

Van der Sommen, J. J. and Geirnaert, W. 1988. On the continuity of aquifer systems on the crystalline basement of Burkina Faso. I. Simmers (ed): Estimation of Natural Groundwater Recharge. 29-45. D. Reidel Publishing Company.

Van Deventer, H., Smith-Adao, L., Mbona, N., Petersen, C., Skowno, A., Collins, N.B., Grenfell, M., Job, N., Lötter, M., Ollis, D., Scherman, P., Sieben, E. and Snaddon, K. 2018. *South African National Biodiversity Assessment 2018: Technical Report*. Volume 2a: South African Inventory of Inland Aquatic Ecosystems (SAIIAE). Version 3, final released on 3 October 2019. Council for Scientific and Industrial Research (CSIR) and South African National Biodiversity Institute (SANBI): Pretoria, South Africa. Report Number: CSIR report number CSIR/NRE/ECOS/IR/2018/0001/A; SANBI report number. http://hdl.handle.net/20.500.12143/5847

Van Deventer, H., Smith-Adao, L., Nel, Jeanne L. & Petersen, C. 2019. Chapter 6: Ecosystem Assessment for the Inland Aquatic Realm. In: Van Deventer *et al.* South African National Biodiversity Assessment 2018: Technical Report. Volume 2b: Inland Aquatic (Freshwater) Realm. CSIR report number CSIR/NRE/ECOS/IR/2019/0004/A. South African National Biodiversity Institute, Pretoria. http://hdl.handle.net/20.500.12143/6230

Van Gend, J., Francis, M. L., Watson, A. P., Palcsu, L., Horváth, A., Macey, P. H., Le Roux, P., Clarke, C. E. and Miller, J. A. 2021. Saline groundwater in the Buffels River catchment, Namaqualand, South Africa: A new look at an old problem. *Science of the Total Environment*, *762*, p.143140.

Van Niekerk, H. S. 2006. The origin of the Kheis Terrane and its relationship with the Archean Kaapvaal Craton and the Grenvillian Namaqua Province in southern Africa. Doctoral dissertation, University of Johannesburg.

Van Niekerk, L., Adams, J., James, N., Lamberth, S., MacKay, C., Turpie, J., Rajkaran, A., Weerts,S. and Whitfield, A. 2020. An Estuary Ecosystem Classification that encompasses biogeography and a high diversity of types in support of protection and management. *African Journal of Aquatic Science* 45:1-2 199-216, DOI: 10.2989/16085914.2019.1685934.

Van Niekerk, L., Adams, J.B., Bate, G.C., Forbes, N., Forbes, A., Huizinga, P., Lamberth, S.J., MacKay, F., Petersen, C., Taljaard, S., Weerts, S., Whitfield, A.K. and Wooldridge, T.H. 2013. Country-wide assessment of estuary health: An approach for integrating pressures and ecosystem response in a data limited environment. Estuarine, Coastal and Shelf Science 130: 239-251.

Van Niekerk, L., Adams, J.B., Fernandes, M., Harris, L., Lamberth, S.J., MacKay, CF.,Petersen, C., Ramjukhad, C.-L., Riddin, T., Van Deventer, H. & Weerts, S.P. 2019, ' Chapter 4: Extending the Estuary Functional Zone to include key habitats and processes', South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm. South African National Biodiversity Institute, Pretoria. Report Number: SANBI/NAT/NBA2018/2019/Vol3/A

Visser, D. J. L. 1989. Explanation of the 1:1.000.000 geological map, fourth edition 1984. Department of Mineral and Energy Affairs, Government Printer.

4.12 APPENDICES A - F

SEPARATE DOCUMENT

APPENDIX A: DATA ACCESSED IN DEVELOPMENT OF THE WATER RESOURCES CHAPTER

APPENDIX B: GEOHYDROLOGY MAPS

APPENDIX C: SURFACE HYDROLOGY APPENDICES

APPENDIX D: WATER QUALITY

APPENDIX E: AQUATIC ECOSYSTEMS

APPENDIX F: SPECIALIST HYDROLOGICAL REPORT