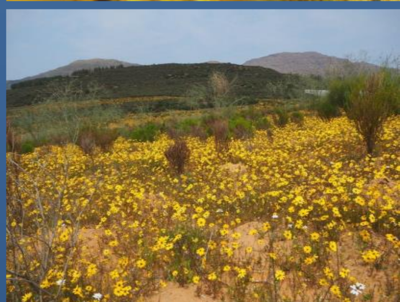
RESERVE DETERMINATION STUDY FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE F60 AND G30 CATCHMENTS WITHIN THE BERG-OLIFANTS WMA

SCENARIO REPORT

April 2023



Department of Water and Sanitation

Chief Directorate: Water Ecosystem Management

DEPARTMENT: WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEM MANAGEMENT

RESERVE DETERMINATION STUDY FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE F60 AND G30 CATCHMENTS WITHIN THE BERG-OLIFANTS WMA

WP11340

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ACRONYMS AND ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit
CSIR	Council for Scientific and Industrial Research
D:RDM	Directorate: Resource Directed Measures
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EcoStatus	Ecological Status
EISC	Ecological Importance and Sensitivity Category
EI-ES	Ecological Important and Ecological Sensitivity
EWR	Ecological Water Requirements
GIS	Geographic Information System
GRU	Groundwater Resource Units
l/s	Litre per second
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
NWA	National Water Act
PES	Present Ecological State
PESC	Present Ecological Status Class
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQO	Resource Quality Objective
WMA	Water Management Area
WR2012	Water Resources 2012
WRSM	Water Resources Simulation Model
WRC	Water Research Commission

GLOSSARY

ANTHROPOGENIC	Caused by human activity.
AQUATIC	Relating to water.
AQUIFER	Underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt)
BASEFLOW	That part of stream flow contributed by groundwater and discharged gradually into the channel.
BIOTA	The living organisms occupying a place together, e.g. plants, animals, bacteria, etc in the aquatic biota, or terrestrial biota.
CATCHMENT	The area from which any rainfall will drain into the watercourse or watercourses, through surface or subsurface flow.
ECOCLASSIFICATION	The term used for Ecological Classification refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers compared to the natural or close to natural reference condition. The purpose of EcoClassification is to gain insights into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints have to be considered.
ECOLOGICAL HEALTH	A descriptive non-specific term for the combination of all factors, biotic and abiotic, that make up a particular environment and its organisms
ECOREGIONS	Areas of similar ecological characteristics.
ECOSYSTEM	A community of animals, plants and bacteria with its physical and chemical environment.
EPHEMERAL	An ephemeral stream has flowing water only during, and for a short duration after, precipitation events in a typical year
ENVIRONMENT	All of the external factors, conditions, and influences that affect the growth, development, and survival of

	organisms or a community. This includes climate, physical, chemical, and biological factors, nutrients, and social and cultural conditions.
ESTUARY	A partially or fully enclosed body of water that is open to the sea permanently or periodically, and within which the sea water can be diluted, to a measurable extent, with fresh water drained from land.
FLOW REGIME	Recorded or historical sequence of flows used to create a hydrological profile of the water resource.
HABITAT	The environment or place where a plant or animal is most likely to occur naturally.
HYDRAULICS	Of, involving, moved by, or operated by a fluid, especially water, under pressure.
HYDROLOGY	The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.
IMPACTS	The measurable effect of one thing on another.
INDIGENOUS	Living or growing naturally in a particular area, but not naturally confined only to that area or any resource consisting of (a) any living or dead animal, plant or other organisms of an indigenous species, (b) any derivative of such animal, plant or other organisms; or (c) any genetic material of such animal, plant or other organisms.
LEGISLATION	A law or a series of laws
MANDATE	The authority to do something, given to an organisation or government, by the people who support it.
MODIFIED	Changed, altered.
POLICY	A plan of action, statement of ideals, etc. proposed by an organization, government, etc.
PRISTINE	Remaining in a pure or natural state.
PREDATION	A predator is an animal that kills and eats other animals. Predation is the capturing of prey as a means of maintaining life.
PRESENT ECOLOGICAL STATE	The current state or condition of a resource in terms of its various components, i.e., drivers (physico-chemical, geomorphology, and hydrology) and biological response

	(fish, riparian vegetation and aquatic invertebrates). The prequel to recommended ecological category.
QUATERNARY CATCHMENT	A fourth-order catchment in a hierarchical system in which the primary catchment is the major unit.
RIPARIAN	Of, on, or relating to the banks of a water course, including the physical structure and associated vegetation. The area of land adjacent to a stream or river that is influenced by stream-induced or related processes.
SPECIES	A kind of animal, plant or other organisms that does not normally interbreed with individuals of another kind, and includes any sub-species, cultivar, variety, geographic race, strain, hybrid or geographically separate population
TERTIARY CATCHMENT	A third-order catchment in a hierarchal classification system in which a primary catchment is a major unit.
SURFACE WATER	All water that is exposed to the atmosphere, e.g., rivers, reservoirs, ponds, the sea, etc.
VARIABILITY	The tendency to vary i.e., to change.
WATERCOURSE	"A natural channel or depression in which water flows regularly or intermittently" (definition in the NWA)
WATER QUALITY	The value or usefulness of water, determined by the combined effects of its physical attributes and its chemical constituents and varying from user to user
WETLANDS	"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" (definition in the NWA)

1. INTRODUCTION

1.1 Background

The Chief Directorate: Water Ecosystems Management of the Department of Water and Sanitation (DWS) has embarked on a preliminary Reserve determination study for the G30 and F60 catchments (Figure 1). These are the two remaining Tertiary Catchments of the Berg Olifants Water Management Area (WMA) that still require a higher level of confidence Reserve determination. The Verlorevlei within the study area was designated as a Wetland of International Importance (Ramsar Site) on 28 June 1991 under the Ramsar Convention on Wetlands of International Importance, especially as Waterfowl Habitat. In addition, peat wetlands have been identified to occur in the area that is associated with the Verlorevlei that provide important ecological services but are under severe threat and require urgent protection. It is therefore crucial that the Reserve calculations are revisited and the water resources with the Sandveld catchments addressed holistically, with a clear understanding of the surface and groundwater interactions and interdependencies as well as the rainfall and flow patterns being well researched and documented.

1.2 Objectives

This study aims to identify gaps in previous Reserve Determination Studies and to determine the Reserve at a high level of confidence to yield results that could be gazetted and provide legal protection specifications. The following objectives are listed:

1. Determination of the water quantity and quality for the protection of rivers at various Ecological Water Requirement (EWR) sites;
2. Determination of the water quantity and quality for the protection of priority wetlands, pans and lakes;
3. Determination of the water quantity and quality of estuarine freshwater requirements for the protection of various identified estuaries;
4. Determination of the groundwater quantity and quality requirements for the protection of groundwater resources; and
5. Determination of the quantity and quality of water required for the provision of Basic Human Needs.

1.3 Purpose of this Report

The purpose of this report is to define operational scenarios and to identify scenarios for analysis, as well as the context of the scenarios and how they may impact water availability in the G30 and F60 catchments (Figure 1) of the Olifants-Doorn WMA. Scenarios, in the context of water resource management and planning, are plausible definitions (settings) of all the factors (variables) that influence the water balance and water quality in a catchment and the system as a whole.

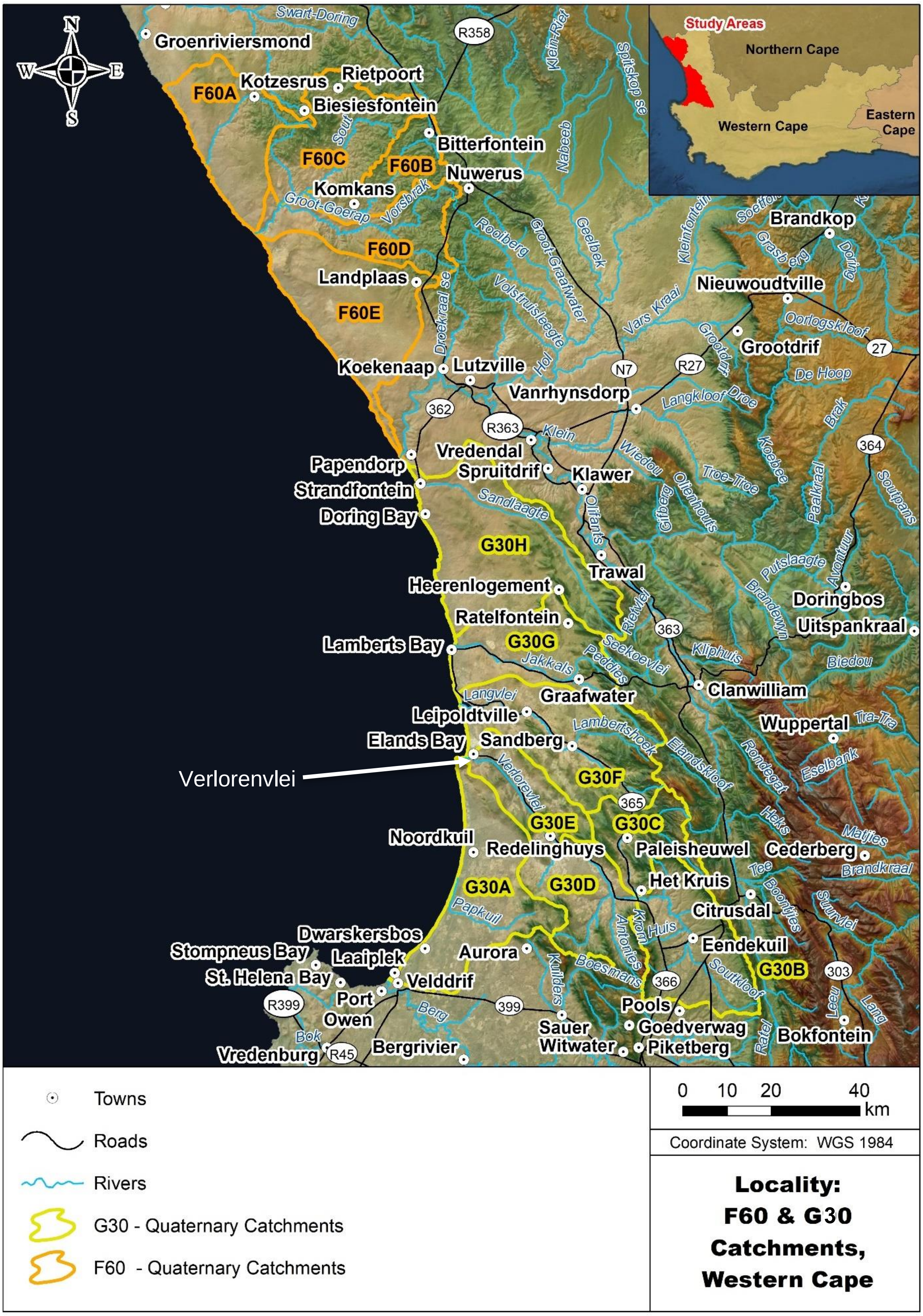

Figure 1: Map of the study area with the location of the G30 and F60 Catchments and main aquatic features shown

1.4. The Study Area

The study area comprises two Tertiary Catchments, the G30 (Sandveld) and the F60 (Knersvlakte) Catchments. The majority of the G30F60 Catchment Area falls within the Western Cape Province, with a small section of the most northerly section of the catchment falling within the Northern Cape Province.

The Sandveld consists of the coastal plain along the west coast of South Africa, bordered by the Olifants River catchment in the north and east, the Berg River catchment in the south and the Atlantic Ocean coastline in the west. The area contains the following seasonal river and wetland systems:

- Verlorenvlei River System with its main tributaries, the Kruismans, Bergvlei, Krom Antonies and Hol Rivers, as well as the Verlorenvlei Estuary;
- Langvlei River with the Wadrif wetland and pan;
- Jakkals River and Jakkalsvlei Estuary;
- Sandlaagte River;
- Rosherpan and Papkuil River; and
- Several smaller wetland areas along watercourses, coastline and on hillslopes.

The Ramsar-designated Verlorenvlei estuarine and wetland system is the best-known of the systems and has a clear responsibility of actively conserving the unique wetland and the biological diversity that it supports. Several rare species have been recorded in the estuarine and wetland system including the white pelican and eight other threatened birds. Over multiple surveys more than 75 different species have been recorded with numbers of individual birds exceeding 6 500. The site is one of the most important wetlands for wading birds in the Western Cape as it provides feeding, nesting and resting habitats to a large variety of birds.

The Groot Goerap/Sout and Brak River Catchments to the north of the Sandveld are in the even more arid Knersvlakte region. The area comprises ephemeral rivers and wetlands, including:

- Sout River System with its main tributaries, the Groot and Klein Goerap Rivers and the South Estuary;
- Brak River and Estuary; and
- Several mostly isolated depression wetlands.

Groundwater in the G30 (Sandveld) catchment enables extensive agricultural activity and is the sole source of freshwater for most of the towns and settlements within the catchments. Groundwater also plays a significant role in sustaining surface water ecosystems. The catchments contain both fractured and intergranular areas. Average yields range from very low (0.5 l/s) to high yielding (> 5 l/s), with identified paleochannels and other geological pathways, producing boreholes of a yield higher than 25 l/s. Groundwater quality is described as being good across the G30 catchments, however, where Malmesbury Group formations occur, the main aquifer can be identified as yielding groundwater of poor quality. The main recharge areas have been identified as the mountainous areas towards the east of the study area that form part of the Cederberg and Piketberg Mountain ranges. The Graafwater aquifer management area coincides largely with the Jakkals River Catchment in the larger G30 catchment.

Groundwater availability in the F60 catchments is much lower than in the G30 catchments. The geological setting of the area is also more complex. The area has been classified as containing both intergranular and fractured aquifers (DWAF 2005). The regional expected yields are very low (0.1 - 0.5 l/s) with higher-yielding boreholes (up to 2 l/s) at the most southern point of the F60 catchments. Groundwater quality across the catchment is generally categorised as being poor, with EC values of over 1000 mS/m.

Land use in the area consists largely of livestock farming (sheep and goats), with small areas being used for dryland farming. fishing and ecotourism around the coastal resort towns. Intensive irrigation of citrus and potatoes is undertaken in the G30 Catchment.

Urban and rural areas are small, with the main towns being Redelinghuys, Elands Bay, Eendekuil, Leipoldtville, Graafwater, Lamberts Bay, Strandfontein and Bitterfontein. Water use in the urban areas is supplied by coastal aquifers where seasonal peaks relating to tourism influx need to be provided for.

There is very little quantitative knowledge of surface groundwater interaction in the study area. Concerns have been raised about the impact of groundwater abstraction on the surface water ecosystems in the G30 Catchment where water abstraction from surface and groundwater in the southern portion of the study area has significantly modified the flow of the aquatic ecosystems, particularly in summer. Modified flows have reduced the habitat integrity and, consequently, the goods and services provided by these ecosystems.

Baseflow is low to zero in the regolith dominated sub areas of the F60 Catchment, indicating a very low, negligible groundwater contribution to surface water bodies.

1.5. Study Methodology and Approach

The river, wetland, estuarine and groundwater components of the Reserve determinations will use the latest RDM recommended methodologies. While the standard methodologies for the determination of the Basic Human Needs and ecological Reserve are followed in the study, the need for a slightly adapted approach for the Sandveld and Knersvlakte Rivers has been recognised. This adapted approach is deemed to be necessary to address the following:

- Most of the surface water features within the study area are non-perennial with a hydrological regime that has high variability in flow both spatially and temporally with a highly unpredictable surface water flow;
- Surface water ecosystems in these systems are primarily groundwater fed during the dry season. They thus have a strong wetland character and are often confined to isolated pools towards the end of the dry season. The aquatic biota associated with these habitats comprises hardy species with low diversity, although both the habitat and biota may be of high ecological importance;

- The estuaries within the area comprise mostly coastal lakes or estuarine salt pans, with a low diversity of hardy species. These systems are mostly nearly permanently closed and also have very little freshwater inflow from their associated river systems. As a result, they tend to be hypersaline;
- Very close integration occurs between the surface water ecosystems (rivers, wetlands and estuarine habitats) as well as with the groundwater. Integration of these two specialist fields and the recommended ecological Reserve (quantity and quality) was thus critical; and
- The products from the groundwater specialists have provided an improved understanding of the surface water ecosystems and the delineation of the river reaches and wetland regions as well as the water supply to those ecosystems. The Wetland component in particular needed to provide inputs to and rely on inputs from the Rivers and Groundwater specialists.

The revised generic procedure is provided in Figure 2 (DWAF, 2008), which shows the process for the determination of the Ecological Water Requirement in the context of the larger Resource Directed Measures process, with possible links to issues such as the stakeholder process, classification, implementation and operation, indicated as suggested ways to integrate the Reserve determination process.

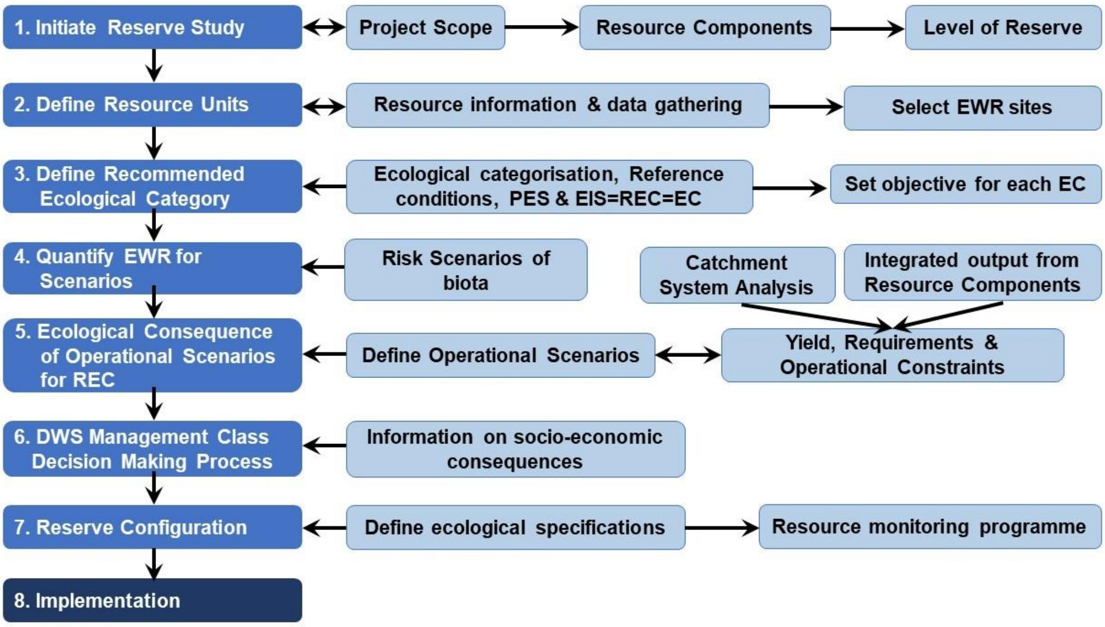

Figure 2: The Reserve Determination Process (adapted from DWAF, 2008)

This report documents the outcome of the first five steps of the above Reserve determination process. Possible flow and water use variables that make up scenarios have been identified for the F30 and G30 Catchments. These variables have been combined into different scenarios, which are described in this document. The scenarios are based on flow and water quality-related aspects and not on non-flow-related aspects. Mitigation measures to address non-flow-related aspects will be identified and will be addressed as part of the EWR Implementation Plan that forms part of the Final EWR Integrated Report (RDM/WMA09/00/CON/0132).

2. INFORMANTS TO THE OPERATIONAL SCENARIOS

2.1 Hydrology

The F60 and G30 catchments were configured in the WRSM2000 Pitman model, a rainfall-runoff model with monthly rainfall time series data as the primary input. Other hydro-meteorological data which is significant to the model are the evaporation data and observed streamflow data which can be used to calibrate the model or validate the results of the model output.

2.1.1. Natural Hydrology

The naturalised hydrology forms the baseline against which all scenarios will be assessed. Hydrology for the study area was updated from the Water Resources 2012 (WR2012) hydrology using rainfall data obtained from the catchment, as there are no active streamflow gauges in the study area. This allowed for the natural hydrology to be modelled to 2020 and, in so doing, including the recent severe drought in the Western Cape. The modelled flows were validated against the observed flows at G3H001 (DWS flow gauge on the Kruismans River at Tweekuilen for the period 1971 to 2005) and at E3H001 (DWS flow gauge on the Troe-Troe River from 1982 to 2022).

Groundwater contribution to baseflow was also incorporated into the modelling of the hydrology to account for the significant volume of groundwater that would naturally have sustained these arid surface water systems.

The historic hydrology data was generally available at a quaternary level resolution and was then updated and scaled to sub-catchments delineated according to differing hydrological characteristic as well as to the catchment areas of the EWR study sites.

The reader is referred to the EWR Report (Report no. RDM/WMA09/00/CON/0126) and to the hydrology assessment report for the study that is included as an attachment to the Main Integrated Report (Report No. RDM/WMA09/00/CON/0132) for further information in this regard.

2.1.2. Present Day Hydrology

The WRSM2000 Pitman model was updated with the latest land-use information available (Western Cape Department of Agriculture Crop Census 2017/18 and Department of Environmental Affairs Land Cover dataset) in order to produce the best possible estimates of present-day flow. Land-use components included: Irrigation and return flows, Afforestation, alien invasive plants and urban/rural water requirements.

The large dams and smaller farm dams were also included in the WRSM2000 Pitman model setup. The smaller dams were incorporated to include the effect of irrigation from farm dams, as well as the effect of multiple small dams' regulation in streamflow and loss of water by evaporation from the dam surfaces. The subsequent result is a reduction in water yield from water resource developments downstream of these dams. The present-day flows were then generated using the configured model with all the catchment development information incorporated at the required resolution.

2.2 Water Resource Units

Below are lists of the groundwater resource units (GRUs) and surface water EWR sites in the G30 and F60 catchments. The resource units largely coincide with the quaternary catchments within the study area, with the EWR sites being located at the existing point of the associated watercourse in the quaternary catchment. The delineated resource units and EWR sites are shown in Figures 3 - 5.

2.2.1. Groundwater Resource Units

G30 Catchments (Figure 3):

- **Papkuils (G30A GRU)**: Comprises the G30A catchment, including the Papkuils River and Rosherpan.
- **Verlorenvlei & Tributaries (Southern G30D GRU)**: Comprises the upper reaches of the Krom Antonies and Hol River catchments.
- **Verlorenvlei & Tributaries (Northern G30D GRU)**: Comprises the lower reaches of the Hol, Krom Antonies and Kruismans Rivers to their confluence with the Verlorenvlei River.
- **Verlorenvlei & Tributaries (G30B GRU)**: Comprises the upper Kruismans River between the Citrusdal and Piketberg Mountain ranges.
- **Verlorenvlei & Tributaries (G30C GRU)**: Comprises the Bergvallei Valley.
- **Verlorenvlei & Tributaries (G30E GRU)**: Comprises the Verlorenvlei area and includes the Kruisfontein Springs.
- **Langvlei-Wadrift (Northern G30F GRU)**: Langvlei has two "paleochannel type structures" running through the valley, a northern and a southern valley. This GRU comprises the northern one.
- **Langvlei-Wadrift (Southern G30F GRU)**: This GRU lies south of the Northern G30F GRU and includes the Wadrif aquifer.
- **Jakkals (G30G GRU)**: Comprises the Jakkals River catchment, and includes the Graafwater aquifer
- **Northern Sandveld (G30H GRU)**: Comprises the Sandlaagte catchment and is referred to as the Northern Sandveld.

F60 Catchments (Figure 4)

- **Namaqualand (Southern F60E GRU)**: The GRU is situated on the coast in the area north of the Olifants River Estuary. There are no watercourses within this unit, only depression wetlands.
- **Namaqualand (Northern F60E GRU)**: Comprises the northern portion of the F60E catchment. As for the Southern Namaqualand GRU, there are no watercourses within this unit, only depression wetlands.
- **Groot-Goerap & Sout (F60D GRU)**: The groundwater unit falls within the F60D catchment and includes the Groot Goerap and lower Sout Rivers.
- **Klein-Goerap (F60B GRU)**: The groundwater unit falls within the F60B quaternary catchment boundaries and includes the Klein Goerap River.
- **Sout (F60C GRU)**: The groundwater unit falls within the F60C quaternary catchment boundaries and includes the Sout River (before it joins with the Groot-Goerap), and

- **Brak (F60A GRU)**: The groundwater unit falls within the F60A quaternary catchment boundaries and includes the Brak River Catchment.

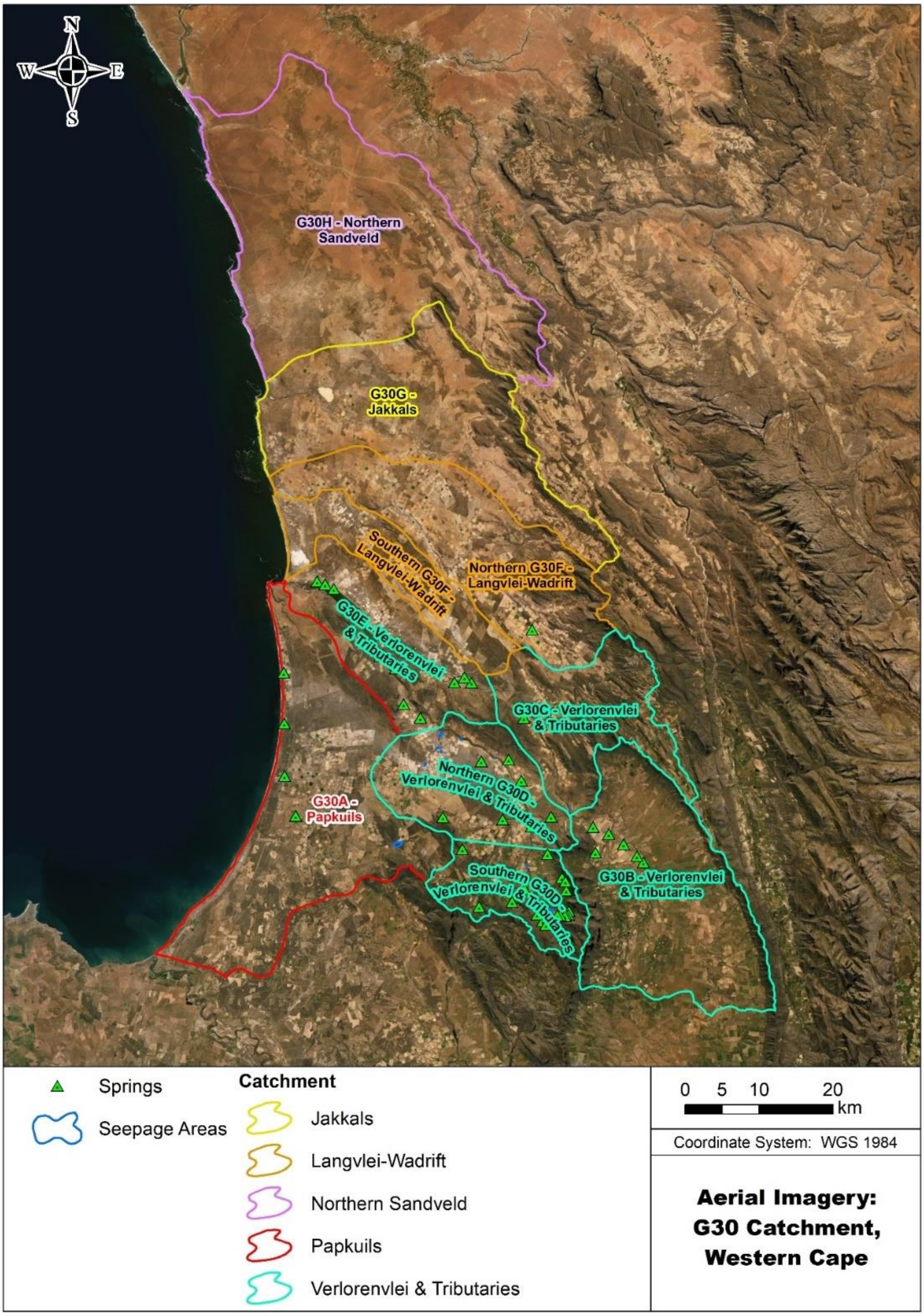

Figure 3: Combined map of delineated GRUs for the G30 catchments

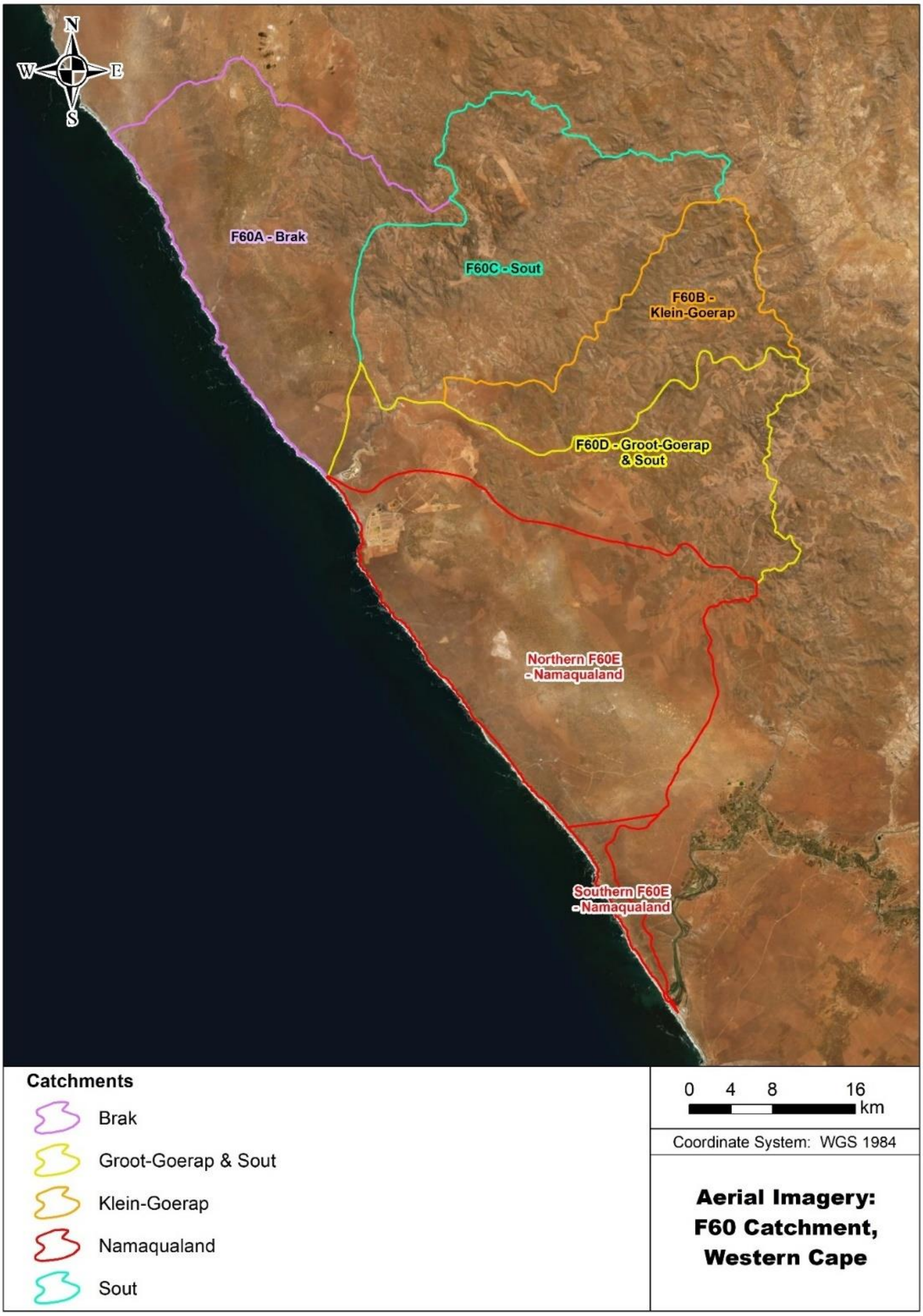

Figure 4: Combined map of delineated GRUs for the F60 catchments

2.2.2. River and Wetland EWR sites:

- **EWR1 RW-F60A BRAK STRAN** Brak River and Valley Bottom Wetland
- **EWR2 W-F60A DEPR NUWEB** North West Fynbos Depression Wetland
- **EWR3 RW-F60B GRGO KOMKA** Sout/Groot-Goerap River
- **EWR4 W-F60C DEPR ADOON** Knersvlakte Depression Wetland
- **EWR5 W-F60E DEPR ELSIE** Sandveld Depression Wetland
- **EWR6 RW-G30H SAND HOLLE** Sandlaagte River
- **EWR7 RW-G30G JAKK KOOKF** Jakkals River and Valley Bottom Wetland
- **EWR8 RW-G30F LANG BRAND** Langvlei River and Valley Bottom Wetland
- **EWR9 W-G30F WADR WAGEN** Wadrift Valley Bottom Wetland
- **EWR10 RW-G30D KRUI EENHE** Lower Kruismans River and Valley Bottom Wetland
- **EWR11 RW-G30D KROM GOERG** Krom Antonies River and Floodplain Wetland
- **EWR12 RW-G30E VERL WITTE** Lower Verlorenvlei River and Floodplain Wetland
- **EWR13 W-G30A DUNE FA277** Isolated depression/duneslack wetland
- **EWR14 W-G30A ROCH FA272** Rocherpan Wetland
- **EWR15 RW-G30A PAPK BOOKR** Papkuils River and Valley Bottom Wetland
- **EWR16 W-G30A PAPK RIETF** Upper Papkuils Seep Wetland

2.2.3. Estuary Resource Units

- Verlorenvlei Estuarine Lake (G30E)
- Wadrif Arid, Predominantly Closed Estuary (G30F)
- Jakkals Temporary Closed Estuary (G30G)
- Sout Arid, Predominantly Closed Estuary (F60D)

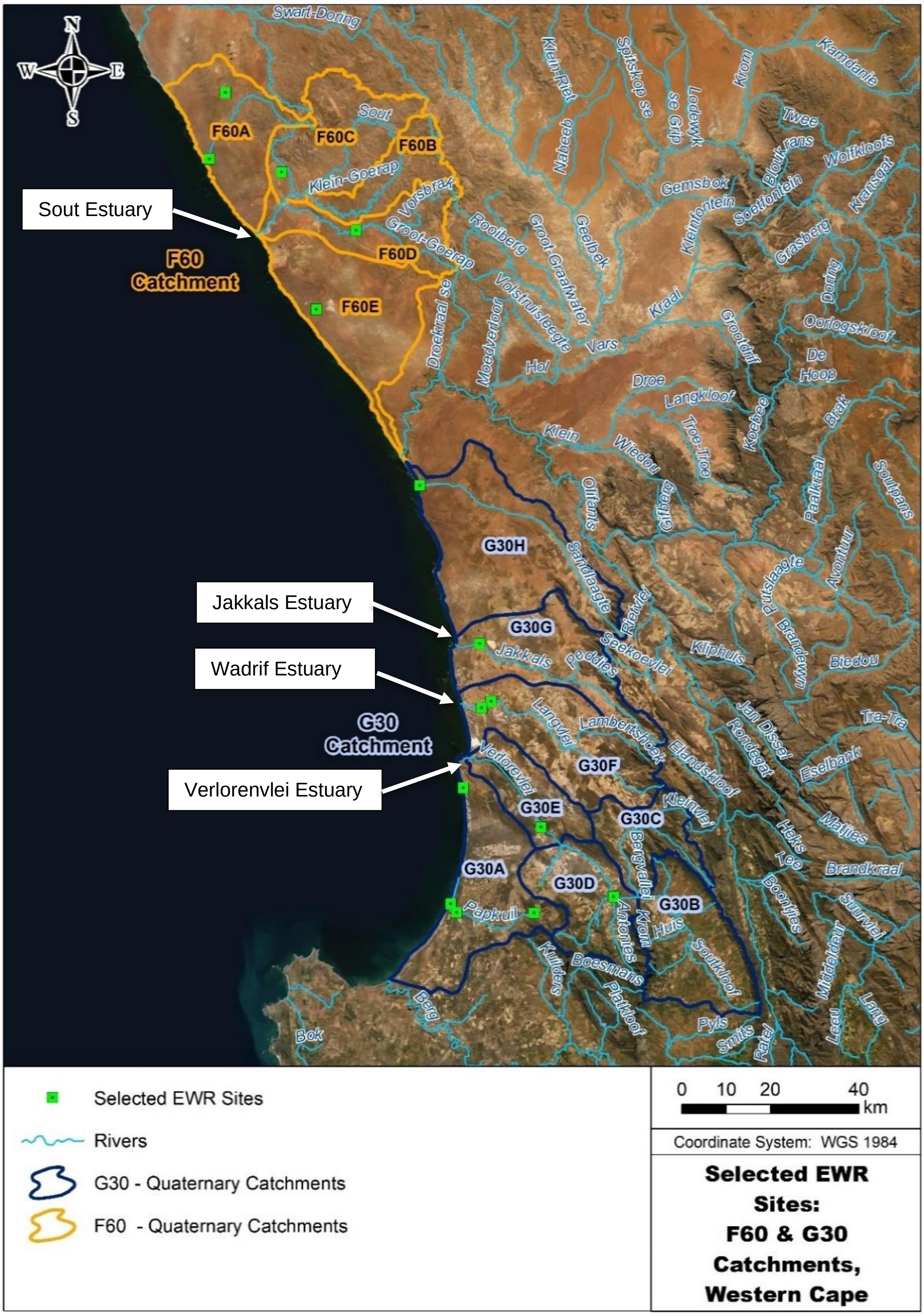

Figure 5. Map of the proposed EWR sites for rivers and wetlands, as well as the location of the Estuary Resource Units in the F60 and G30 Catchments

3. SCENARIOS

3.1. Scenario Descriptions

Scenarios identified during the project, consideration of the present-day hydrology and discussions with various stakeholder groups are as follows:

- **Reference scenario** – this represents the study catchment in the natural condition. It is assumed that baseflows contribute to surface flow in catchments where the Table Mountain Group aquifer is dominant, with about 30% of annual surface flow being baseflow contribution.

- **Current-day scenario** represents the current-day development in the study catchment, which is primarily agriculture. Irrigated agriculture is supplied by both surface water and groundwater sources. It was assumed that baseflows are reduced by 50% from natural under the current day scenarios. It was further assumed that there was no spring flow contribution to baseflow except for Papkuils (G30A), Kruisfontein (G30E), Matrosefontein (G30D) and these were reduced by 50% from natural.

- **Sustainability scenario** (Scenario 1) – this is the least amount of water that should remain in the water resources within the study area to ensure the long-term sustainability of the associated aquatic ecosystems. Current or present-day flows and assessment of the aquatic ecosystems indicate that there are several of the aquatic ecosystems within the study area where the sustainability scenario is not being met. This scenario was developed to represent an improvement from the current day as a quasi-sustainable case in which surface water abstraction (irrigation and farm dam storage) was reduced by 50% from the present day, baseflows were reduced by 25% from natural and all spring flows reduced by 50% from natural.

- **Climate change scenario** (Scenario 2) - The anticipated impact of global climate change for the area is that more extreme precipitation events will occur, and temperatures will increase, with a resulting increase in veld fires and a change in the water availability in areas where water is exploited. The increase in drying up and burning of significant wetlands in the study area is already an impact of concern. This scenario considered the potential flow change and the associated change needed in terms of the EWR recommendations.

  The climate change scenario was based on the results of the National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa (Schutte *et al*, 2022; Schulze and Davis, 2021).

The climate change predictions for the Berg-Olifants WMA show **air temperature** increases, with mid-summer increases of ~1.2 to 1.4°C along the coast and increase up to 1.8°C in the interior. Note that into the more distant future of the 2080s, the average increases from 4-5°C across the WMA. Mid-winter minima are projected to increase by less than mid-summer maxima, viz. from 0.8°C to 1.2°C, with the lowest increases in the western mountains (where the highest mid-summer maxima occur), and the highest projected increases occurring along the west coast (where the lowest mid-summer maximum changes are projected to occur).

Change in **mean annual precipitation** shows that in a dry year, most of the WMA will have reductions in Mean Annual Precipitation (MAP) of 10 to 20%, while in average years, projected reductions are somewhat lower at 10-15% while in wet years, the east of the WMA is even projected to getting more rainfall than at present. All of these projected changes have possible repercussions on runoff.

Mean annual streamflow during a low flow year shows reductions of 20 to 60%, while in a year of average flows, reductions of 20-40% are foreseen, but with some flow increases possible in the extreme east of the WMA, with these eastern increases expanding in a 1:10 high flow year with the positive being that the east is the source of several important rivers in the Berg-Olifants WMA.

To generate the hydrology for the climate change scenario, the climate projections mentioned above were considered and the daily rainfall and temperature projections were bias corrected to the quinary catchment database and run through the ACRU model to determine the hydrological responses. The statistics of the projected changes are presented from the present (1961-1990) to the near future (2015-2044) and from the present to the distant future (2070-2099). The assessment of climate change impacts in the F60 and G30 catchments were made by extracting the results of mean annual rainfall and mean annual A-Pan equivalent evapotranspiration for the quaternary catchments in the study area.

3.2. Scenario Hydrology

Below is a summary of the modelled natural mean annual runoff (MAR), the present-day flows for each of the quaternaries in the study area (Table 1) and for the EWR sites (Table 2).

Table 1. Summary of simulated MARs (cumulative) for the quaternary catchments for the scenarios considered

Quaternary	Natural MAR	Current MAR	Scenario 1 MAR	Scenario 2 MAR
	million m^3/a			
F60A	0.07	0.07	0.07	0.04
F60B	0.07	0.07	0.07	0.06
F60C	0.25	0.25	0.25	0.21
F60D	0.46	0.46	0.46	0.40
F60E	0.05	0.05	0.05	0.00
G30A	1.24	1.19	1.19	0.65

Quaternary	Natural MAR	Current MAR	Scenario 1 MAR	Scenario 2 MAR
	million m^3/a			
G30B	15.82	10.71	12.45	7.00
G30C	10.94	8.26	9.64	6.09
G30D	46.45	34.67	39.63	23.82
G30E	48.13	31.83	23.74	9.11
G30F	4.75	3.2	3.64	1.99
G30G	1.41	0.96	0.99	0.53
G30H	1.36	1.36	1.36	0.82

Table 2. Summary of the simulated MARs at the EWR sites for the scenarios considered. The percentage of natural flow for each scenario is provided in brackets

EWR Site	Description	Natural	Current	Scenario 1	Scenario 2
		Million m^3/a			
EWR1	Lower Brak River	0.07	0.07 (100%)	0.07 (100%)	0.04 (57%)
EWR2,4,5	Isolated depression wetlands	-	-	-	-
EWR3	Lower Groot Goerap River	0.11	0.11 (100%)	0.11 (100%)	0.06 (55%)
EWR6	Lower Sandlaagte River	1.36	1.36 (100%)	1.36 (100%)	0.82 (60%)
EWR7	Lower Jakkals River	2.315	1.24 (58%)	1.32 (61%)	0.77 (35%)
EWR8	Lower Langvlei River	8.955	7.08 (73%)	3.83 (82%)	2.18 (46%)
EWR9	Wadrif Wetland	4.75	3.2 (67%)	3.64 (77)	1.99 (42%)
EWR10	Lower Kruismans River	27.813	18.97 (71%)	22.1 (83%)	13.09 (49%)
EWR11	Lower Krom Antonies River	7.318	5.14 (73%)	6.03 (86%)	3.43 (49%)
EWR12	Lower Verlorenvlei River	47.58	33.36 (70%)	39.31 (83%)	23.21 (49%)
EWR13	Isolated depression/duneslack wetland	-	-	-	-
EWR14	Rocherpan	-	-	-	-
EWR15	Lower Papkuils River	1.378	1.19 (96%)	1.19 (96%)	0.65 (52%)
EWR16	Papkuilsvlei	-	-	-	-

3.3. Water Quality Consequences

The reference condition represents the study catchment in the natural condition. There are no long-term water quality data available at any of the EWR sites but based on the water quality data from the G3H001 - Kruis River at Tweekuilen/Eendekuil, (the only long-term water quality monitoring site in the G30 catchment) the water quality is very variable from year to year although there seems to be a slight seasonal trend. It was not possible to determine reference conditions for any of the EWR sites.

The current or present-day condition represents the current-day development in the study catchment, which is primarily agriculture. Water quality samples were collected to represent the wet and dry seasons to get some indication of the current water quality status in the G30 catchment.

The lack of water quality data makes it challenging to determine reference and present-day conditions and even more challenging is the fact that both G30 and F60 tertiary catchment have non-perennial rivers linked to wetlands with definite wet and dry rainfall seasons with and without interaction with the groundwater and springs in the study areas.

The fact that the rivers are fed from different water resources (groundwater, surface water runoff and springs) does not enable the confident extrapolation of water quality characteristics from one site to the next.

The two possible future scenarios were investigated, and certain predictions were made, but with low confidence as there are no historical data or present-day data to validate expected outcomes.

3.3.1. Scenario 1 - 50% reduction in surface water abstraction

Scenario 1 was developed to represent an improvement from the present-day as a sustainable option in which surface water abstraction (irrigation and farm dam storage) was reduced by 50% from the current day, baseflows were reduced by 25% from natural and all spring flows reduced by 50% from natural.

Based on the limited water quality samples collected (one to two at an EWR river site), one cannot quantify expected outcomes if Scenario 1 was implemented. However, as most of the rivers are non-perennial rivers linked to wetlands with definite wet and dry rainfall seasons with and without interaction with the groundwater and springs in the study areas, high variability in quality is expected to continue. Some rivers, such as the Jakkals River, seem to have naturally high salinities and as it is also one of the least impacted parts of the G30 catchment, Scenario 1 will probably not make a big difference in the water quality.

The water quality in the Kruismans and Krom Antonies Rivers, however, can be expected to improve for Scenario 1 and would be of benefit to the downstream users. Even though the rivers in G30 are currently in a degraded condition, it is expected that the systems are still sensitive to increases and decreases in freshwater inflows and abstractions, and more freshwater input (less abstraction) will benefit and improve the water quality in the rivers.

3.3.2. Scenario 2 - Impacts of climate change

Potential climate changes

An increase in **air temperature** will lead to an increase in water temperature. Water temperature can be estimated from the air temperature using relationships developed for South Africa perennial rivers by Dallas & Rivers-Moore (2019). Increased water temperatures could affect, inter alia, the quality of water for irrigation, dissolved oxygen content of water, and the rates of chemical and biological reactions in water, as well as have wide-ranging repercussions in the health sector through the creation of favourable conditions for the incubation and transmission of waterborne diseases. Heat waves can lead to severe short-term water quality impacts and increased fish mortality due to low oxygen concentrations brought about by a rapid increase in decomposition processes and temperature stress on fish and other aquatic biota.

Water temperature affects evaporation, which in turn affects the concentration of the salts in the water. Wide fluctuations in salinity are already a characteristic of the non-perennial rivers in the study area. An increase in water temperature would aggravate this, resulting in an increase in the occurrence of high salt concentrations in rivers and pools.

Elevated water temperatures can affect the rate at which compounds dissociate from suspended sediment particles. Enhanced dissociation of sediment-bound agrochemicals, metals, and nutrients can have an impact on aquatic biota.

Water temperature, in the presence of sufficient nutrients, often triggers algal blooms in rivers and pools. The dependence of the algal growth rate on water temperature is controlled with the parameter Θ, the temperature adjustment coefficient, which typically has a value between 1.01 and 1.2. A value of 1.072 corresponds to a doubling of the growth rate for every 10°C increase in water temperature (Bowie *et al*., 1985). An increase in surface water temperature could extend the growing season of free-floating and filamentous algae (blooms could occur earlier in the season and extend later into autumn).

An increase in water temperature creates more favourable conditions for bacterial growth. Studies have shown a strong correlation between the outbreak of waterborne diseases and above-normal water temperatures. Although wastewater effluents are not a major concern in the study area, local impacts of seepage from pit latrines and septic tanks, and degraded sewerage infrastructure, will be aggravated by high water temperatures. However, an increase in water temperature could also lead to a more rapid die-off of bacteria in water. This could restrict the duration and spatial extent of waterborne disease outbreaks.

The solubility of oxygen in water is indirectly related to water temperature. The saturation decreases as temperature increases. In freshwater, the dissolved oxygen concentrations range from 14.6 mg/L in at 0°C to 7.6 mg/L at 30°C. An increase in water temperature would therefore result in lower DO in the water to the detriment of dissolved oxygen sensitive organisms. The decomposition of organic matter consumes dissolved oxygen. The rate of decomposition is temperature dependent and an increase in water temperature would increase the incidence of oxygen depletion in the study and the negative impacts on aquatic biota.

Enhanced evaporation is the additional evaporation, over and above that under present climatic conditions, from open water bodies such as dams and wetlands as well as from the soil and plant systems. Evaporation has the effect of concentrating salts and other constituents in an open water body when the water volume is reduced. It can also concentrate salts and other constituents in the soil when the soil moisture is reduced as a result of evaporation at the surface and water losses by evapotranspiration from plants.

Enhanced evaporation leads to the concentration of nutrients in a smaller volume of water. Free-floating algae, attached algae, and rooted water plants will respond to the increased nutrient concentrations.

Enhanced evaporation would also have the effect of concentrating organic matter into a smaller volume of water. This could increase the impacts of processes that affect dissolved oxygen in water. Aquatic organisms may therefore experience wider diurnal fluctuations in dissolved oxygen as photosynthetic processes dominate during daytime and respiration/decomposition processes dominate during night-time.

Enhanced evaporation would concentrate agrochemicals and other toxic substances into a smaller volume of water, thereby increasing the concentration that aquatic organisms are exposed to.

Mean annual streamflow during a low flow year shows reductions of 20 to 60%, while in a year of average flow reductions of 20 to 40% are foreseen. A reduction in streamflow will have serious impacts on water quality because it would decrease the introduction of good-quality runoff. This reduces dilution of poor-quality water in rivers and pools in the study area. There is an inverse relationship between salinity and the suspended sediment concentrations in turbid rivers. An increase in salinity promotes the coagulation of sediment particles, causing them to settle out. This clearing of the water promotes deeper light penetration of the water column, thereby increasing the heating up of the water.

3.4. Ecological Consequences

3.4.1. Rivers and Wetlands

The revised Present Ecological Status (PES) data and the Ecological Important and Ecological Sensitivity (EI-ES) data from the PES/EI-ES results, as well as the Classification and Resource Quality Objective (RQO) projects, were used to derive the Recommended Ecological Category (REC) for the river and wetland systems within the study area. These are summarised in Table 3. An analysis of the outcome of the scenario assessments and the resulting ecological category for each scenario for the key EWR sites is included.

Table 3. Summary of the Recommended Ecological Categories for the study area

Quat	River/ Wetland	EISC	Surface Water PESC	Groundwater PESC	Trend	REC
G30A	Papkuils	High	C/D: Moderately to Largely Modified	CLASS C: MODERATELY MODIFIED	Negative	Class C: Moderately modified
G30B	Kruismans	High	D: Largely Modified	CLASS D: LARGELY MODIFIED	Negative	Class C: Moderately Modified

Quat	River/ Wetland	EISC	Surface Water PESC	Groundwater PESC	Trend	REC
G30C	Bergvallei	High	D/E: Largely to Seriously Modified	CLASS E - F: NOT AN ACCEPTABLE	Negative	Class C: Moderately Modified
G30D	Verlorenvlei	High	D: Largely Modified	CLASS D: LARGELY MODIFIED	Negative	Class C: Moderately Modified
G30E	Verlorenvlei	High	D/E: Largely to Seriously modified	CLASS D: LARGELY MODIFIED	Negative	Class B/C: Largely natural to Moderately Modified
G30F	Langvlei	High	D/E: Largely to Seriously modified	CLASS E - F: NOT AN ACCEPTABLE	Negative	Class D: Largely Modified
G30G	Jakkals	Moder ate	C: Moderately Modified	CLASS D: LARGELY MODIFIED	Negative	Class C: Moderately Modified
G30H	Sandlaagte	Low	C/D: Moderately to Largely Modified	CLASS B LARGELY NATURAL	Negative	Class C: Moderately Modified
F60A	Brak	High	B: Largely Natural	CLASS A: UNMODIFIED, NATURAL	Neutral	Class B: Largely Natural
F60B	Klein Goerap	High	C: Moderately Modified	CLASS B: LARGELY NATURAL	Neutral	C: Moderately Modified
F60C	Sout	High	C: Moderately Modified	CLASS A: UNMODIFIED, NATURAL	Negative	C: Moderately Modified
F60D	Groot Goerap	Moder ate	C: Moderately Modified	CLASS A: UNMODIFIED, NATURAL	Negative	Class C: Moderately Modified
F60E	Depression	High	C: Moderately modified	CLASS A: UNMODIFIED, NATURAL	Neutral, negative in places	Class C: Moderately Modified

Table 4. Summary of the Ecological Category for the different runoff scenarios at each of the Intermediate EWR sites

EWR site No.	Description	Scenario			
		Current	Scenario 1	Scenario 2	REC
EWR7	Lower Jakkals River	C/D	C	D	C
EWR8	Lower Langvlei River	E	D	E/F	D
EWR10	Lower Kruismans River	D	C	E	C
EWR11	Lower Krom Antonies River	C/D	C	D	C
EWR12	Lower Verlorenvlei River	D	C	E	C
EWR15	Lower Papkuils River	D	C/D	E	D

Many of the impacts on the rivers and wetlands are non-flow related; thus, improving flow will not necessarily result in an improvement of the ecological condition of the rivers and wetlands. It can, however, be expected that Scenario 1 will result in some improvement in ecological conditions while Scenario 2, the climate change scenario, results in a substantial reduction in flow and can be expected to result in a noticeable decline in the ecological integrity of the aquatic ecosystems.

3.4.2. Estuary Consequences

The scenarios have been considered for the three estuaries within the study area. Table 5 is a summary of the estuarine assessment of the estuary health index and corresponding ecological category.

Table 5. Summary of the Estuary Health Index score and corresponding Ecological Category for the different runoff scenarios

Estuary	Scenario		
	Current	Scenario 1	Scenario 2
VERLORENVLEI			
Estuary Health Score	50	60	39
Ecological Status	D*	C/D	D/E*
WADRIF			
Estuary Health Score	46	53	33
Ecological Status	D	D	E
JAKKALSVLEI			
Estuary Health Score	53	56	37
Ecological Status	D	D	E

**The current observed condition of the Verlorenvlei Estuary is deemed to be lower (E category) than the evaluation of the 101-year present simulation scenario as a result of the extended drought and the associated lake acidification that has taken place*.

The Best Attainable State determined for the Verlorenvlei Estuary is a C Category without significant restoration interventions. Attaining the REC would require restoring flow to the system and improving the water quality, as well as addressing some of the existing non-flow-related issues affecting the estuary such as preventing the illegal artificial breaching of the estuary and reducing the levels of inorganic nutrients in inflowing water from the catchment. The flow requirements for the estuary are the same as those described for Scenario 1.

The REC for the Wadrift Estuary is a C representing a significant improvement on the PES. Attaining this state would require restoring a certain amount of flow to the system as well as addressing some of the existing non-flow-related issues affecting the estuary. The flow requirements for the estuary are the same as those described for Scenario 1.

The REC for the Jakkals Estuary is a D Category which requires the maintenance of its present state, i.e. PES D Category. Thus, the flow requirements for the estuary are the same as those described for the Present or Current-day scenario.

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