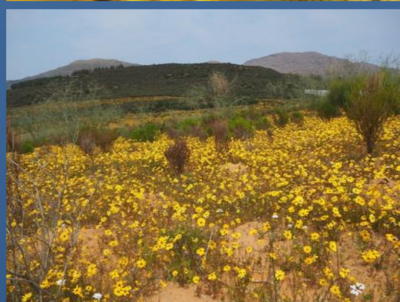
RESERVE DETERMINATION STUDY FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE F60 AND G30 CATCHMENTS WITHIN THE BERG-OLIFANTS WMA

ECOCLASSIFICATION REPORT

2022



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

ECOCLASSIFICATION REPORT

REPORT NUMBER: RDM/WMA09/00/CON/0125

NOVEMBER 2022

REFERENCE

This report is to be cited as:

DEPARTMENT OF WATER AND SANITATION (DWS). JUNE 2022. RESERVE DETERMINATION STUDY FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE F60 AND G30 CATCHMENTS WITHIN THE BERG-OLIFANTS WMA: ECOCLASSIFICATION REPORT. *(FINAL)* RDM/WMA09/00/CON/0125.

Prepared by:

BlueScience (Pty) Ltd, Editors: Belcher, T and Grobler, D
In association with: GEOSS (Pty) Ltd, Zutari (Pty) Ltd, CSIR, Nelson Mandela University, University of Stellenbosch, Dr Linda Rossouw & Mr N Rossouw, Mr Dean Ollis, Mr Dean Impson and Dr Charles Boucher.

TITLE:	EcoClassification Report
PROJECT NUMBER:	WP11340
AUTHORS:	Belcher, T and Grobler, D (eds)
CONTRIBUTING AUTHORS:	J Conrad, L Dobinson, D Impson, D Ollis, L Rossouw, N Rossouw, L Smit, S Taljaard, A Watson and L van Niekerk
STUDY NAME:	Reserve Determination Study for Selected Surface Water, Groundwater, Estuaries and Wetlands in the F60 and G30 Catchments within the Berg-Olifants WMA
REPORT STATUS:	Final
DATE:	November 2022
DWS REPORT No.:	RDM/WMA09/00/CON/0125

APPROVED BY

Blue Science (Pty) Ltd Director **Daniel Grobler**	Blue Science (Pty) Ltd Technical Reviewer **Toni Belcher**
Department of Water and Sanitation Chief Directorate: Water Ecosystems Management Project Manager **Gladys Makhado**	Department of Water and Sanitation Chief Directorate: Water Ecosystems Management Scientific Manager **Barbara Weston**
Department of Water and Sanitation Chief Directorate: Water Ecosystems Management Director **Yakeen Atwaru**	

DOCUMENT INDEX

Reports as part of this project:

Bold type indicates this report.

REPORT INDEX	REPORT NUMBER	REPORT TITLE
1.0	RDM/WMA09/00/CON/0121	Inception Report
2.0	RDM/WMA09/00/CON/0122	Gap Analysis Report
3.0	RDM/WMA09/00/CON/0123	Groundwater Delineation Report
4.0	RDM/WMA09/00/CON/0124	Surface Water Delineation Report
5.0	**RDM/WMA09/00/CON/0125**	**EcoClassification Report**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
BHN	Basic Human Needs
CSIR	Council for Scientific and Industrial Research
CMA	Catchment Management Agency
CWAC	Coordinated Waterbird Counts
DEA	Department of Environment Affairs
DEADP	Department of Environmental Affairs and Development Planning (Western Cape Government)
DFFE	Department of Forestry, Fisheries and the Environment
DRIFT	Downstream Response to Imposed Flow Transformation
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
EcoSpecs	Ecological Specifications
EcoStatus	Ecological Status
EGSA	Ecosystem Goods, Services and Attributes
EIS	Ecological Importance and Sensitivity
EISC	Ecological Importance and Significance Category
EMC	Ecological Management Category
EMP	Estuary Management Plan
EWR	Ecological Water Requirements
FBIS	Freshwater Biodiversity Information System
FEPA	Freshwater Ecosystems Priority Areas
GDP	Gross Domestic Product
GIS	Geographic Information System
GRDM	Groundwater Resource Directed Measures

GRU	Groundwater Resource Unit
HDI	Human Development Index
HGM	Hydrogeomorphic
HRU	Hydrological Resource Unit
IFR	Instream Flow Requirement
IHI	Index of Habitat Integrity
IUCN	International Union for Conservation of Nature
l/s	Litre per second
mamsl	meters above mean sea level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MIRAI	Macro Invertebrate Response Assessment Index
mm/a	millimetre per annum (precipitation)
mS/m	milliSiemens per meter (measurement of the electrical conductivity of water)
MRU	Management Resource Unit
MSL	Mean Sea Level
NBA-2018	National Biodiversity Assessment 2018
NCMP	National Chemical Monitoring Programme
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Area
NGA	National Groundwater Archive
NMU	Nelson Mandela University
NWA	National Water Act
NWM5	National Wetland Map 5
PAI	Physico-Chemical Assessment Index
PES	Present Ecological State
PESC	Present Ecological Status Class

ppt	parts per thousand (measurement of salinity)
PMC	Project Management Committee
PSA	Potato South Africa
PSC	Project Steering Committee
PWR	Preliminary Water Requirements
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REI	River Estuary Interface
REMP	River EcoStatus Monitoring Programme
RQO	Resource Quality Objective
RU	Resource Units
RWQO	Resource Water Quality Objective
SANBI	South African National Biodiversity Institute
TEC	Target Ecological Category
TMG	Table Mountain Group
VEGRAI	Vegetation Response Assessment Index
WCBSP	Western Cape Biodiversity Spatial Plan
WMA	Water Management Area
WMS	Water Management System
WR2012	Water Resources 2012
WRC	Water Research Commission
WULA	Water use licence application

GLOSSARY

ABIOTIC	Without life, inanimate; physical environment like temperature, rainfall.
AESTHETIC	The overall scenic attraction of the setting, including amongst other things; natural beauty of banks and waters, or any unusual natural phenomena; the appeal of wildlife and aquatic plants; desirable natural landscape for home sites on the shores etc.
ANISOTROPIC	Properties that vary according to the direction from which they are observed.
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).
ATTENUATION	To make something weaker or have less effect.
BASEFLOW	That part of stream flow contributed by groundwater and discharged gradually into the channel.
BENTHIC	Organisms that inhabit the shallow, bottom habitat of water.
BIOTA	The living organisms occupying a place together, e.g. plants, animals, bacteria, etc in the aquatic biota, or terrestrial biota.
BIOMONITORING	Monitoring of living organisms, usually as indicators of habitat integrity.
CALCAREOUS	Composed of, containing, or characteristic of calcium carbonate, calcium, or limestone.
CATCHMENT	The area from which any rainfall will drain into the watercourse or watercourses, through surface or subsurface flow.
CONTAMINANT	A foreign agent that is present (e.g. in water, sediment) that may produce a physical or chemical change but may not cause an adverse biological effect.
DIFFUSE SOURCE	A general source (e.g. of pollution), the exact location of which is difficult to pinpoint.
DISTURBANCE REGIME	The pattern of natural variability of physical and biological processes, incorporating the return time to a stable condition from extreme conditions.

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.
EROSION	The wearing away and removal of materials of the earth's crust by natural means. Running water, waves, moving ice, and wind currents are examples of erosion.
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.
EUTROPHICATION	The process whereby high levels of nutrients result in the excessive growth of plants.
FLOW REGIME	Recorded or historical sequence of flows used to create a hydrological profile of the water resource.
GEOMORPHOLOGY	The branch of geology that deals with, amongst other things, the form of the earth and the changes that take place in the process of development of landforms.

GRADIENT	The degree of slope or incline. In the context of this course, it refers to the slope of a stream bed or the vertical distance that water falls while travelling a horizontal distance downstream.
GYPSIFEROUS	Containing or yielding gypsum.
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.
HYPERSALINE	An environment that has salinities greater than that of normal seawater.
HYPORHEOS	water flowing over streambeds in lotic environments.
IMPACTS	The measurable effect of one thing on another.
IMPOUNDMENT	To retain water artificially by means of a weir or dam.
INDICATOR SPECIES	A species that has been extensively studied to the point that the effect of environmental changes upon its distribution and lifecycle are well known so that knowledge of its status provides information on the overall condition of the ecosystem, and of other species in that ecosystem.
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.
INDIGENOUS SPECIES	A species that occurs, or has historically occurred, naturally in a free state, in nature within an ecologically similar area, but excludes a species that has been introduced from another area or continent as a result of human activity.
INTERGRANULAR AQUIFER	An aquifer in which groundwater flows in openings and void space between grains or weathered rock
INVERTEBRATE	Animal without a backbone.
KARST AQUIFERS	Aquifers that occur within limestone geology, where the limestone (or other easily dissolved rock) has been partially

	dissolved so that some fractures are enlarged into passages that carry the groundwater flow.
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.
METASEDIMENTARY	A sedimentary rock that shows evidence of having been subjected to metamorphism.
MODIFIED	Changed, altered.
NUTRIENTS	Elements required for life processes: nitrogen, phosphorus and potassium are probably the most important nutrients.
POINT SOURCE	A definable or precise location or source e.g., of pollution
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.
RIVER ESTUARY INTERFACE	That part of an estuary where the river and estuarine waters mix, and where the vertically integrated salinity is usually less than 10 ppt.
SEDIMENTATION	The act or process of depositing sediment. Sediment comprises fragments of inorganic or organic material that are carried and deposited by water.
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.
STAKEHOLDER	May be (a) a person, an organ of state or a community or (b) an indigenous community.
TAXON	Biological category (e.g. species) or its name
TERTIARY CATCHMENT	A third-order catchment in a hierarchal classification system in which a primary catchment is a major unit.
SUBSTRATE	The surface to which a plant or animal is attached or on which it grows.
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 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 describe and document the status quo for the water resources in the G30 and F60 catchments (Figure 1) of the Olifants-Doorn Water Management Area, based on current information and data from previous studies undertaken. This task, therefore, describes the physical template and information for decision-making regarding the different levels of investigation for Reserve determination and guides the selection of where Ecological Water Requirements (EWRs) should be determined.

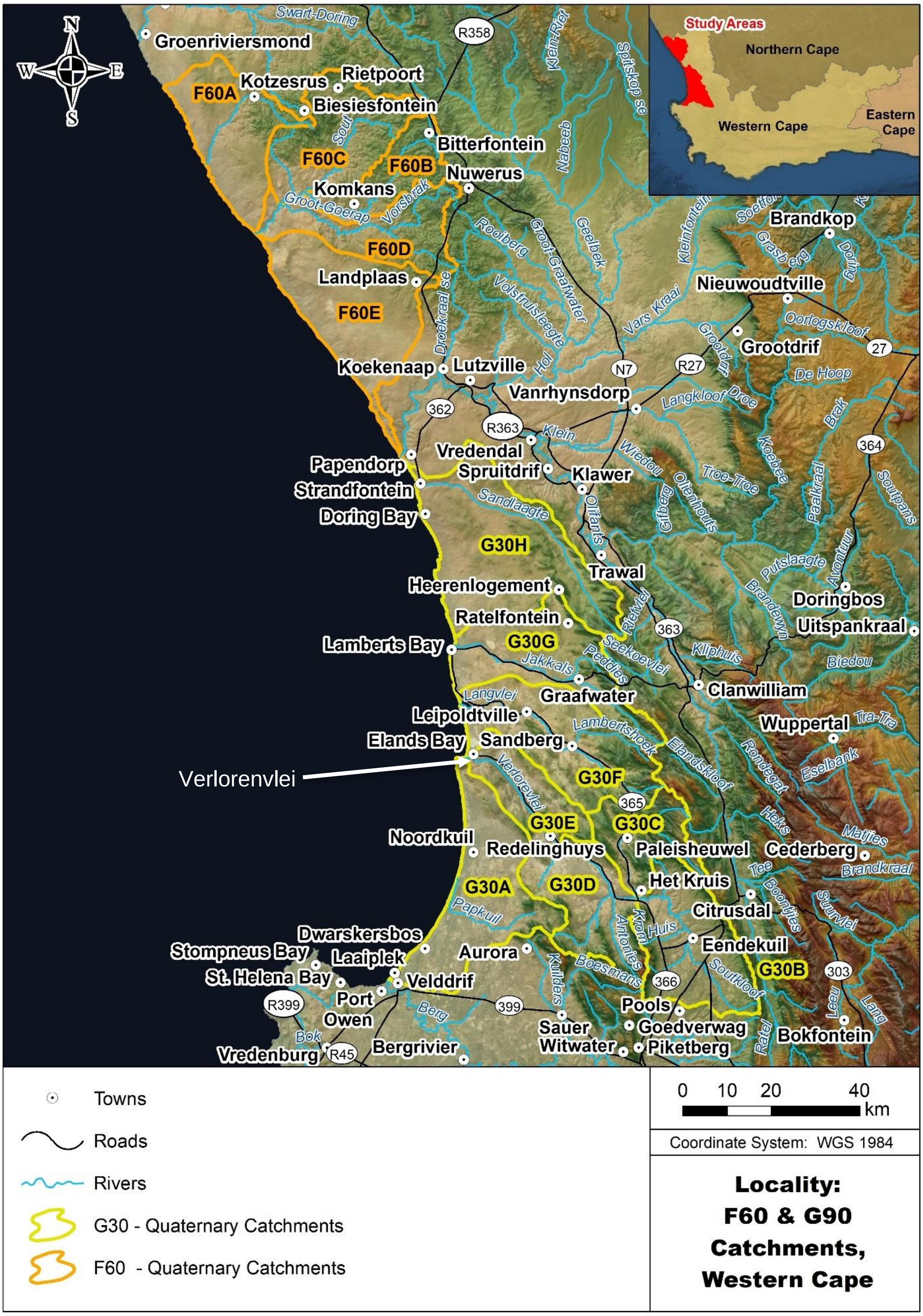


Figure 1: Map of the study area with the location of the G30 and F60 Catchments and main aquatic features shown

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 three local municipalities located within the West Coast District Municipality in the Western Cape Province, namely:

- Berg River Local Municipality.
- Cederberg Local Municipality.
- Matzikama Municipality

A small section of the most northerly section of the catchment falls within Kamiesberg Local Municipality 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 comprises mainly the three parallel seasonal river and longitudinal wetland systems, namely Jakkals, Langvlei and Verlorenvlei. The catchments drain westwards through the Sandveld and consist of a combination of rivers, pans and wetland/vlei systems.

While the seasonal Langvlei, Jakkals and Verlorenvlei longitudinal wetlands are the main wetlands of note in the study area, other relatively large wetland areas comprise Rocherpan near the Berg River Estuary; Valley bottom wetland habitats associated with the Papkuil River in G30A; and Several pans in the upper Verlorenvlei Catchment. These wetland areas occur within an arid landscape that has been significantly modified by agriculture and provides valuable habitat for birdlife as well as amphibians.

The Ramsar-designated Verlorenvlei estuarine and wetland system is the best-known of the systems. The Ramsar treaty falls under the aegis of the United Nations and the International Union for the Conservation of Nature (IUCN) and member nations - of which South Africa is one and thus has acceded to the Ramsar treaty with its clearly defined responsibility of actively conserving the unique wetland and the biological diversity that it supports.

The Verlorenvlei Estuary is naturally a nearly permanently closed and only breaches to the sea during periods of high inflow. Other estuaries within the G30 catchment comprise the Wadrift Estuary, a small estuarine system of low to average biodiversity importance at the mouth of the Langvlei River; and the Jakkalsvlei Estuary, another small estuarine system of low to average biodiversity importance that is located at the mouth of the Jakkals River.

The Groot Goerap/Sout and Brak River Catchments to the north of the Sandveld are in the even more arid Knersvlakte region that comprises low, undulating hills with isolated patches of white quartz stone and saline soils. The hypersaline Sout River Estuary is classified as an Arid, Predominantly Closed System that is nearly always closed to the sea. The estuary is a highly transformed system due to the presence of a salt works, which occupies much of the system. In general, the Sout River estuary is not acknowledged as a functional estuary or a noteworthy ecosystem. Due to the poorly developed soils and the low agricultural potential of the area, only a small percentage of the area is cultivated and that is mostly in the southeast portion of the catchment.

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. Only the towns at the northern tips of the catchments (Strandfontein and Doringbaai) can obtain additional sources through the Olifants River canal system. Although surface water plays a significant role in the study area, particularly for the aquatic ecosystems, groundwater plays a more significant role in sustaining these systems.

The catchments contain both fractured and intergranular areas. The average yield ranges from very low (0.5 l/s) to high yielding (> 5 l/s), with identified paleochannels producing boreholes of a yield higher than 25 l/s. Groundwater quality is described as being good across the G30 catchments (DWAF, 2005). 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 F60 catchments are overall drier and groundwater availability is much lower than in the G30 catchments. Furthermore, the geological setting of the area is more complex. Quaternary deposits are still present toward the coast but include calcareous and gypsiferous units as well as thick calcrete beds within the deposits. These sediments are underlain by igneous formations that form part of the Bushmanland and Richtersveld Sub-province, which in turn falls under the Namaqua Metamorphic Province. 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 poor, with EC values of over 1000 mS/m.

Water abstraction from surface and groundwater has significantly modified the flow of the aquatic ecosystems, particularly by reducing low flows in summer. Modified flows have reduced, amongst others, the habitat integrity and consequently the goods and services provided by these ecosystems. Land use in the area consists largely of livestock farming (sheep and goats), with small areas being used for dryland farming. Intensive irrigation of citrus and potatoes is undertaken in the south. Urban and rural areas are small, with the main towns being Redelinghuys, Elands Bay, Eendekuil, Leipoldtville, Graafwater, Lamberts Bay, Strandfontein and Bitterfontein.

1.5. Study Methodology and Approach

A Reserve determination study endeavours to provide information at the highest level of confidence possible within the defined time, data availability and financial constraints of the project. These constraints dictate the spatial and temporal extent to which data can be collected and inform the understanding of aquatic ecosystem responses to flow volume and pattern changes. Within such a study, with a one- or two-year data collection period, a picture of the conditions in the ecosystems at the time of the study is formed that may provide greater confidence that the conditions at the time of the study (i.e. PES of the water resource at the

EWR site) are accurately recorded and represented. This is of utmost importance to set a management condition for the system (REC) that would remain at the PES or would improve. The data collected will, however, not indicate the ecological condition or responses at another time under different conditions, i.e. drier or wetter periods.

The Terms of Reference called for a high-confidence reserve determination process. However, a lack of data for the water resources in the study area is likely to result in the generic requirements recommended for a Comprehensive Ecological Reserve determination not being met, and thus, the level of confidence in the assessment may be lower than comprehensive. Clear recommendations with regard to future monitoring of the water resources must be included in the outcomes of this study to rectify this shortcoming.

The river, wetland, estuarine and groundwater components of the Reserve determinations will use the latest RDM recommended methodologies. While standard methodologies for the determination of the Basic Human Needs and ecological Reserve will be followed in the study. Recognition of the need for a slightly adapted approach for the Sandveld and Knersvlakte Rivers in the G30 and F60 Tertiary Catchments is proposed to be undertaken. 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 often confined to isolated pools that eventually dry up. 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) thus needs to take place; and
- The sequencing and interaction between the tasks and disciplines on this project are critical. The products from the groundwater specialists will provide an improved understanding of the surface water ecosystems and the delineation of the river reaches and wetland regions. Enough time must be set aside to allow for integration. The wetlands component will especially need to provide inputs to and rely on inputs from the Rivers and Groundwater specialists. Once the priority wetlands have been determined, a key step will be to interact with the specialists to obtain assistance in determining EWRs. The River specialists would also need to have input into the wetland priorities chosen.

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.

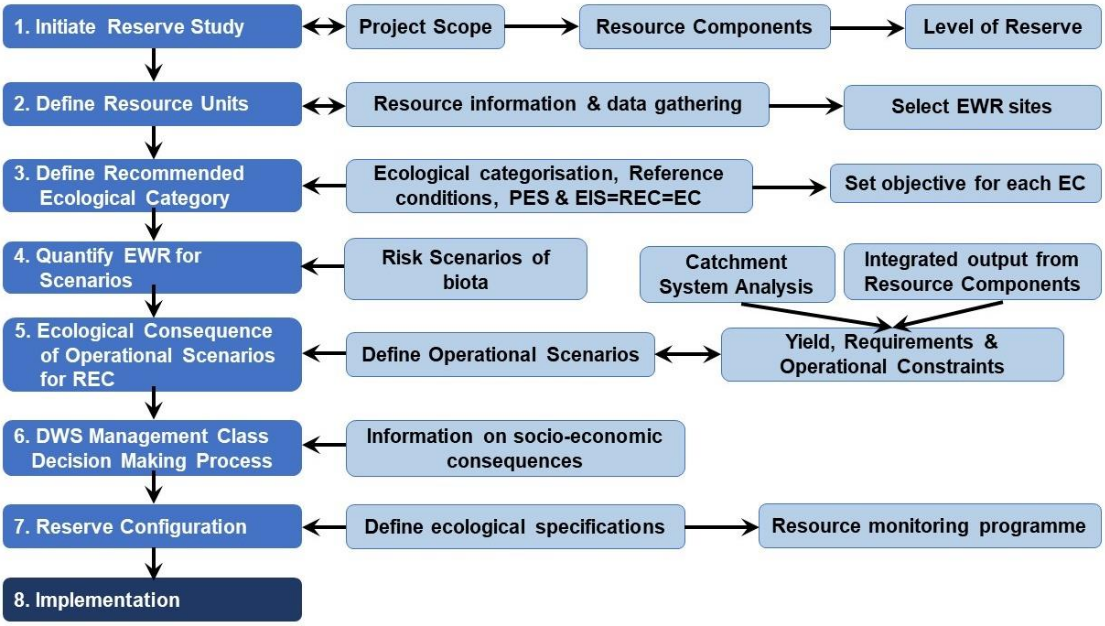


Figure 2: The Reserve Determination Process (adapted from DWAF, 2008)

The steps followed in EcoClassification (Kleynhans and Louw, 2007) are as follows:

- Determination of the reference conditions for each water resource component.
- Determination of the PES and Ecostatus for each component.
- Determination of the trend.
- Determination of reasons for the PES (whether these are flow or non-flow related).
- Determination of the Ecological Importance and Sensitivity (EIS) for the biota and habitat.
- Proposing an attainable Recommended Ecological Category (REC).
- Determination of alternative Ecological Categories (ECs).

2. STATUS QUO ASSESSMENT OF THE WATER RESOURCES

2.1. Geohydrology

2.1.1. Overview of the G30 Catchments

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. Groundwater in the G30 (Sandveld) Catchments plays an essential role in environmental functioning. It enables extensive agricultural activity and is the sole source of freshwater for most of the towns and settlements within the catchments. Only the towns at the northern tips of the catchments (Strandfontein and Doringbaai) can obtain additional sources through the Olifants River canal system.

Distinct variations in water quality and plant species occur throughout the study area. Although surface water plays a significant role in the study area, particularly for the aquatic ecosystems, groundwater plays a more significant role in sustaining these systems. The main recharge areas have been identified as the mountainous areas towards the east of the study area that form part of the Cederberg, Citrusdal and Piketberg Mountain ranges (GEOSS, 2019). These mountains are made up of the Table Mountain Group (TMG) formations, located in some instances outside the study area.

For the G30 catchments, geology is not as complex as for the F60 catchments (Table 1). The Malmesbury Group Formations are shale rich and seen as the basement rocks of the area. This is overlain by the Table Mountain Group formations. The TMG generally produces good quality water and is seen as good aquifers (Peninsula and Piekenierskloof), although some formations are shale rich (Graafwater) and generally yields poorer quality water. For most of the G30 catchments, these hard rock units are covered by thick sand deposits. TMG formations outcrop towards the eastern boundaries of the main Sandveld area and form the mountains found in the G30D, G30B and G30C catchment areas. The Geology is displayed in Figure 3.

Table 1: General Geology for G30 catchments

Code	Formation	Group	Description
	-	Quaternary to Tertiary Deposits	Alluvium
Q1	Springfontein Formation		Sandy Soil
Q2	-		Sand and sandy loam from the hillocky veld
Q5	Witzand Formation		Dune sand, highly calcareous in places
QP	Varswater Formation		Consolidated and unconsolidated phosphatic sand, clay and shelly gravel
C1Q1	Peninsula Formation	Table Mountain Group	Quartzitic sandstone with minor shale and conglomerate lenses
C1S1	Graafwater Formation		Reddish brown shale, sandy shale and siltstone
C1Q1R	Piekenierskloof Formation		Quartzitic sandstone and conglomerate
Kl	Klipheuwel Formation	Malmesbury Group	Brightly coloured shale, sandstone, greywacke and conglomerate,
MaQg	Piketberg		Chlorite schist, calcareous schists, phyllite, greywacke layers with meta-carbonate lenses
MaS	Porterville Formation		Phyllitic shale, schist and greywacke, with scattered thin grit lenses
MaQw2	Moorreesburg Formation		Greywacke, phyllite and quartz schist with thin lenses of limestone and grit

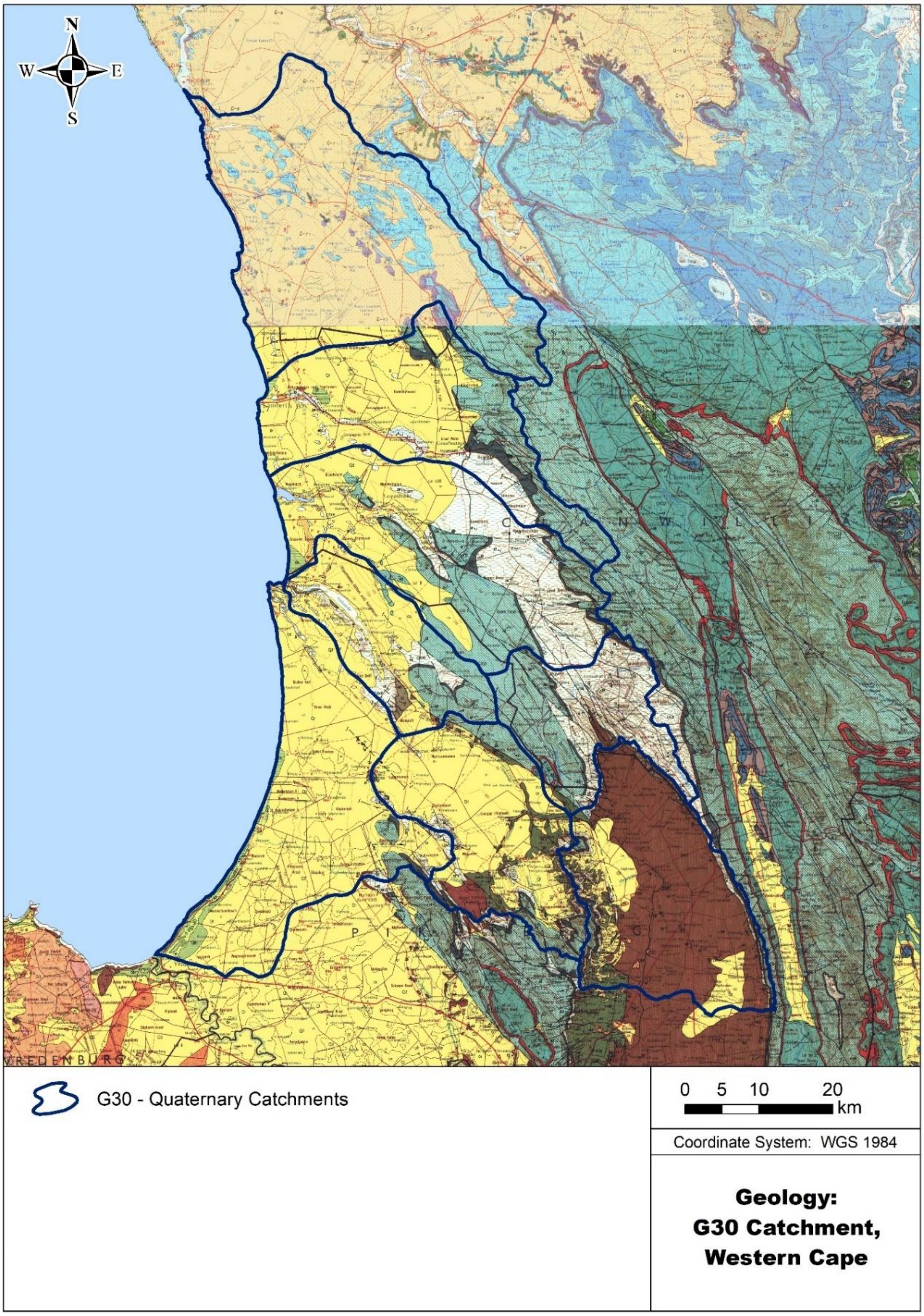


Figure 3: Geological setting of the G30 catchments (Clanwilliam,3218 & Calvinia, 3118) (CGS, 1973 & CGS, 2001)

With regards to hydrogeology, in the more mountainous catchments where hard rock is exposed or sand cover is shallow, boreholes are drilled mostly into the fractured hard rock aquifer. In the coastal areas, where thick sand deposits are found, boreholes are drilled into the sand. These zones of alluvium are generally parallel to the larger rivers, in this case, the Verlorenvlei. The sandy overburden is generally underlain by unconsolidated to semi-consolidated sand, clay and sometimes beach gravel. The Quaternary age deposits were identified by Vandoolaeghe (1982) as the optimum source of groundwater. The properties of the Quaternary deposits vary significantly.

Within the sand, yields differ from dry to very high (> 20L/s). Historically, these areas were referred to as paleochannels (Jolly, 1992). Paleochannels refer to an old or ancient channel that continues to act as a groundwater conduit, even if the actual river path on the surface changes or meanders. In the Sandveld, these are in some areas very distinctly visible from the air as bands of lighter sand areas that are generally northwest-southeast trending. High-yielding boreholes and seepage areas are found within these areas, although at irregular intervals. From data collection and general field observations, a hypothesis has been proposed that links these groundwater-rich saturated sands with discontinuous groundwater upwelling from faults underlying the sand in some areas, while in other, more typical paleochannel structures occur.

The catchments thus contain both fractured and intergranular areas (Figure 4) (DWAF, 2005). The average yield ranges from very low (0.5 L/s) to high yielding (> 5 L/s), with identified paleochannels producing boreholes of a yield higher than 25 L/s. Groundwater quality (Figure 5) is described as being good across the G30 catchments (DWAF, 2005). This needs to be checked with more recent water quality data. Fewer monitoring boreholes exist in the upper reaches of the catchments.

As mentioned, groundwater forms the only source of freshwater for the vast majority of the human settlements located within these catchments. Groundwater abstraction for agricultural irrigation use is the main groundwater use in the area. The Sandveld has, over time, transitioned from integrated livestock and rainfed crop production systems to irrigated vegetable production systems within the last 30 years. Although still an important potato-producing area, the crops have diversified to include the production of other irrigated vegetables and, in recent years, citrus. These crops are labour-intensive and have contributed to the economic growth of the towns in the catchments. The growth of the town and the changing agricultural water uses have placed an increase in the groundwater demand for the area and thus stress the water resources.

Monitoring data is available in the form of water level readings from DWS, individual farms and the Potato SA monitoring project (GEOSS, 2019). Data reflecting the actual use for agricultural purposes is lacking. The distribution of these monitoring boreholes is towards the coast. Much development has occurred in the last 20 years that the Validation and Verification (V & V) process has not accounted for. This gap in data has been highlighted recently when across the G30 catchments, the V & V process was finalised and showed that most of the farmers are using more groundwater than what has been calculated during the V & V.

Springs and seepage points were incorporated into the delineation process and will act as focal points within the GRUs. Some of the springs have been visited, and for some, comprehensive data is available (flow and chemistry data available for the Matroosfontein seepage area that supplies Redelinghuys), while other springs have not been verified with the location being supplied by farmers in the area. Most of these spring sites are minor and are used up completely for domestic and agricultural uses.

Springs/Seepage points that are still relatively strong and likely still contribute to surface water are:

- Papkuils Seepage Area (G30A);
- Sandfontein Spring (G30F);
- Kruisfontein Springs (G30E);
- Seepage Areas at Matroosfontein and Uitvlug (G30D);
- Seepage Areas at Moutonshoek (G30D); and
- The minor springs next to the Verlorenvlei in G30E (Klaarfontein Spring), although these are minor and flow is being impacted from boreholes nearby.

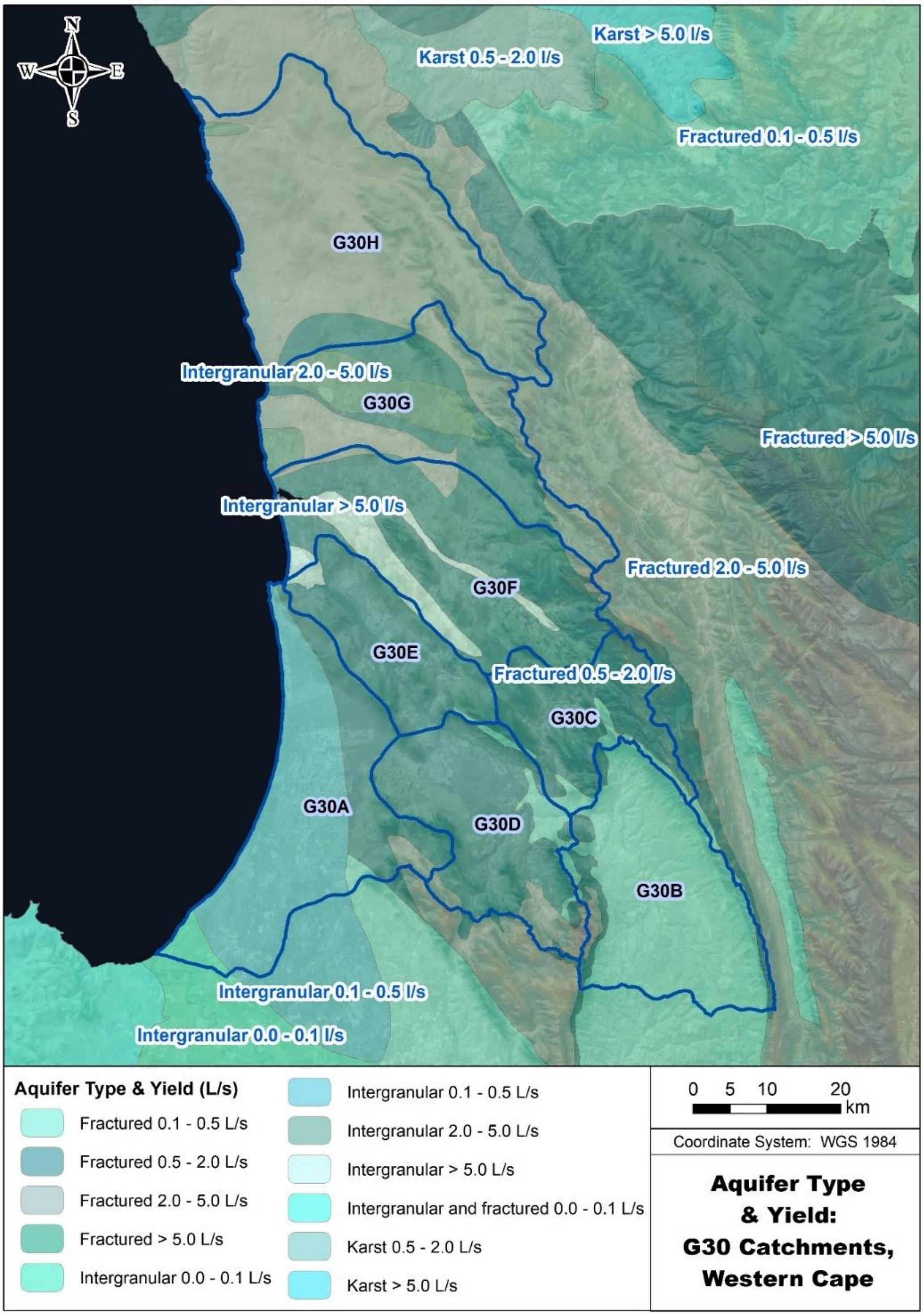


Figure 4: Regional aquifer yield for the G30 Catchments from the 1:1 000 000 scale groundwater map (DWAF, 2005)

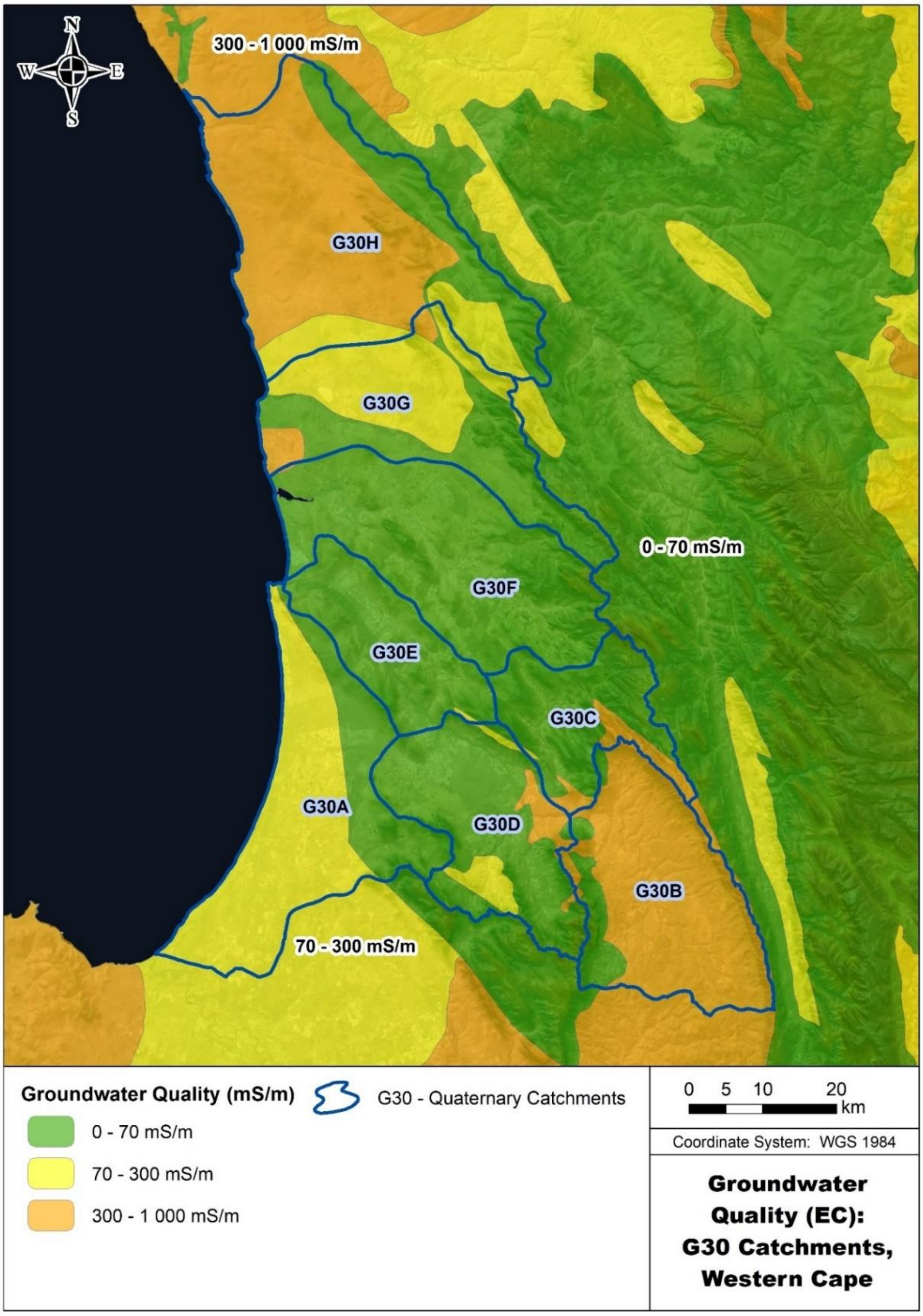


Figure 5: Regional groundwater quality (EC in mS/m) from (DWAF, 2005), for the G30 Catchments

2.1.2. Overview of the F60 Catchments

The F60 catchments are overall drier and groundwater availability is much lower than in the G30 catchments. Furthermore, the geological setting of the area is more complex (Figure 6).

The geology is dominated by igneous and metamorphic rock units that are overlain by quaternary deposits. Quaternary deposits are still present toward the coast but include calcareous and gypsiferous units as well as thick calcrete beds within the deposits. The only sedimentary units found within the F60 catchment area refer to the Peninsula Formation that underlies the sand deposits at the most southern point of G60E and the Flaminkberg Formation in F60B.

The area is mostly underlain by different age granite and gneiss variants of the Koegel Fontein Complex, Spektakel Granite Suite, Little Namaqualand Suite and Kamiesberg Group. There are several younger dike intrusions mapped, with some being unmapped. These dykes, as well as faults (mostly northwest-southeast) are targeted during groundwater exploration. The poor quality in the area is linked to the lack of recharge but also to the geology. Some faulted areas provide groundwater that cannot be used due to the poor quality of the groundwater that had reacted to the host rocks high in salts and minerals. It has also been reported that although water can be found if drilling in or near dry riverbeds, the water found here is, in some cases, very saline. For such areas, groundwater exploration is sometimes moved away from drainage channels and are drilled against hillsides and away from riverbed to target dykes or fracture zones.

Very few hard rock formations are exposed in areas towards the coast and geological boundaries between rock formations and faults are not defined. These coastal sedimentary deposits host some of the richest placer deposits in the world. They are targeted and mined for heavy minerals, such as zircon, garnet, ilmenite, rutile and magnetite. Because of this, there is interest in opening more mines in the area. These could potentially impact the very limited groundwater resource.

Boreholes drilled along the coast target saturated sand or weathered rock overlying hard rock units, while boreholes inland target the fractured hard rock formations or the dykes as mentioned above.

With the number of mines increasing across the catchment, local interested parties have raised concerns regarding the increased demand being placed on a very scarce natural resource.

Table 2 discusses the geology in more detail as well as displays the chronological order of the geology units in the area.

The poor quality in the area is linked to the lack of recharge but also to the geology. Some faulted areas provide groundwater that cannot be used due to the poor quality of the groundwater that had reacted to the host rocks high in salts and minerals. It has also been reported that although water can be found if drilling in or near dry riverbeds, the water found here is, in some cases, very saline. For such areas, groundwater exploration is sometimes moved away from drainage channels and are drilled against hillsides and away from riverbed to target dykes or fracture zones.

Very few hard rock formations are exposed in areas towards the coast and geological boundaries between rock formations and faults are not defined. These coastal sedimentary deposits host some of the richest placer deposits in the world. They are targeted and mined for heavy minerals, such as zircon, garnet, ilmenite, rutile and magnetite. Because of this, there is interest in opening more mines in the area. These could potentially impact the very limited groundwater resource.

Boreholes drilled along the coast target saturated sand or weathered rock overlying hard rock units, while boreholes inland target the fractured hard rock formations or the dykes as mentioned above.

With the number of mines increasing across the catchment, local interested parties have raised concerns regarding the increased demand being placed on a very scarce natural resource.

Table 2: General Geology for F60 catchments

Code	Formation/Unit	Group/Suite	Description
	-	Quaternary to Tertiary Deposits	Alluvium, colluvium, eluvium
Q-r$_2$	-		Calcareous and gypsiferous soil
Q-t	-		Quarts Scree
Qwi	Witzand Formation		Dune sand, highly calcareous in places
E-si	-		Silcrete
E-c	-		Calcrete
Δ Δ	-		Scree
E-s/Qkk	-		Red aeolian sand
Qh	Hardevlei Formation		Pale-red to red dune sand
Qpa	Panvlei Formation		Granitic soil with calcrete and dorbank, sometimes gypsiferous
Tdt	De Toren Formation		Silicified scree, sandstone and duricrust
Tbf	-	Bietjies Fontein Suite	Olivine melilitite and nephelinte plug
Kr	Rietpoort Granite	Koegel Fontein Complex	Alkali feldspar leucogranite
Kzr	Zout River Basalt/dykes		Tholeiitic basalt plug
Krb	Ribbokrug Alkali Syenite		Aegerine syenite and/or fenite
Ksa	Sandkop Syenite		Quartz-hornblende syenite, quartz-biotite syenite
Op	Peninsula Formation	Table Mountain Group	Quartzitic sandstone with minor shale and conglomerate lenses
Nfl	Flaminkberg Formation	Vanrhyndorp Group	Blue, white and red sandstone with subordinate conglomerate, shale and arkose
Nat	Aties Formation	Gariep Supergroup	White quartzite, graphitic phyllite, iron gossans
Nwi	Widouw Formation		Limestone and dolomitic marble
Nkr	Karoetjes Kop		Conglomerate, diamictite, quartzite, biotite schist
Nhf	Hangsfontein Granite	Spektakel Suite	Quartzo-feldspatic granite with biotite and minor garnet
Nbk	Bloukop Granite		Blueish-grey, reddish-brown weathering megacrystic granite
Nstf	Strandfontein Granite		Charnockitic, megacrystic, gneissic granite
Njk	Jakkalshoek Granite		Leucocratic, megacrystic granite to gneissic granite
Nnu	Nuwerus Gneiss	Little Namaqualand Suite	Biotite augengneiss
Nlp	Landplaas Gneiss		Medium-grained pink quartz-feldspar-biotite gneiss, medium- to fine-grained quartz-feldspar gneiss, minor quartz-feldspar-amphibole gneiss
Nme	Mesklip Gneiss		Pink augen gneiss, equigranular gneiss and leucogneis
Nhb	Hunboom Gneiss		Grey leucogneiss and biotite gneiss, augen gneiss
Mks	-		Quarts-muscovite-biotite-garnet

Code	Formation/Unit	Group/Suite	Description
Mbt	Bitterfontein Formation	Kamiesberg Group	Metapsammitic cordite-garnet gneiss, lenses and bands of calc-silicate rock and mafic granulite
Mru	Ruiter-se-Berg Formation		Feldspathic quartzite, garnet bearing quartzite
Mkg	-		Meta-psammitic gneiss
Mkq	-		Metaquartzite (feldspatic, glassy, ferruginous) Leucogneiss
Mbm	Boegoekom Formation		Schistose biotite gneiss
Mja/Mkq	Jakkalsfontein Formation		Flaggy feldspathic quartzite with thin laminae of iron oxides
Mst	Stoffelskop		Quartz-muscovite schist (kyanite bearing), feldspathic and glassy
Mlr/Nlek	Louisrus Formation		Fine to medium-grained grey quartz-feldspar gneiss, quartz-feldspar-sillimanite gneiss, quartz-feldspar-biotite gneiss; lenses and bands of glassy quartzite, pelitic biotite-garnet-sillimanite gneiss, calc-sillicate gneiss, amphibolite and rare biotite-cordierite-hypersthene gneiss

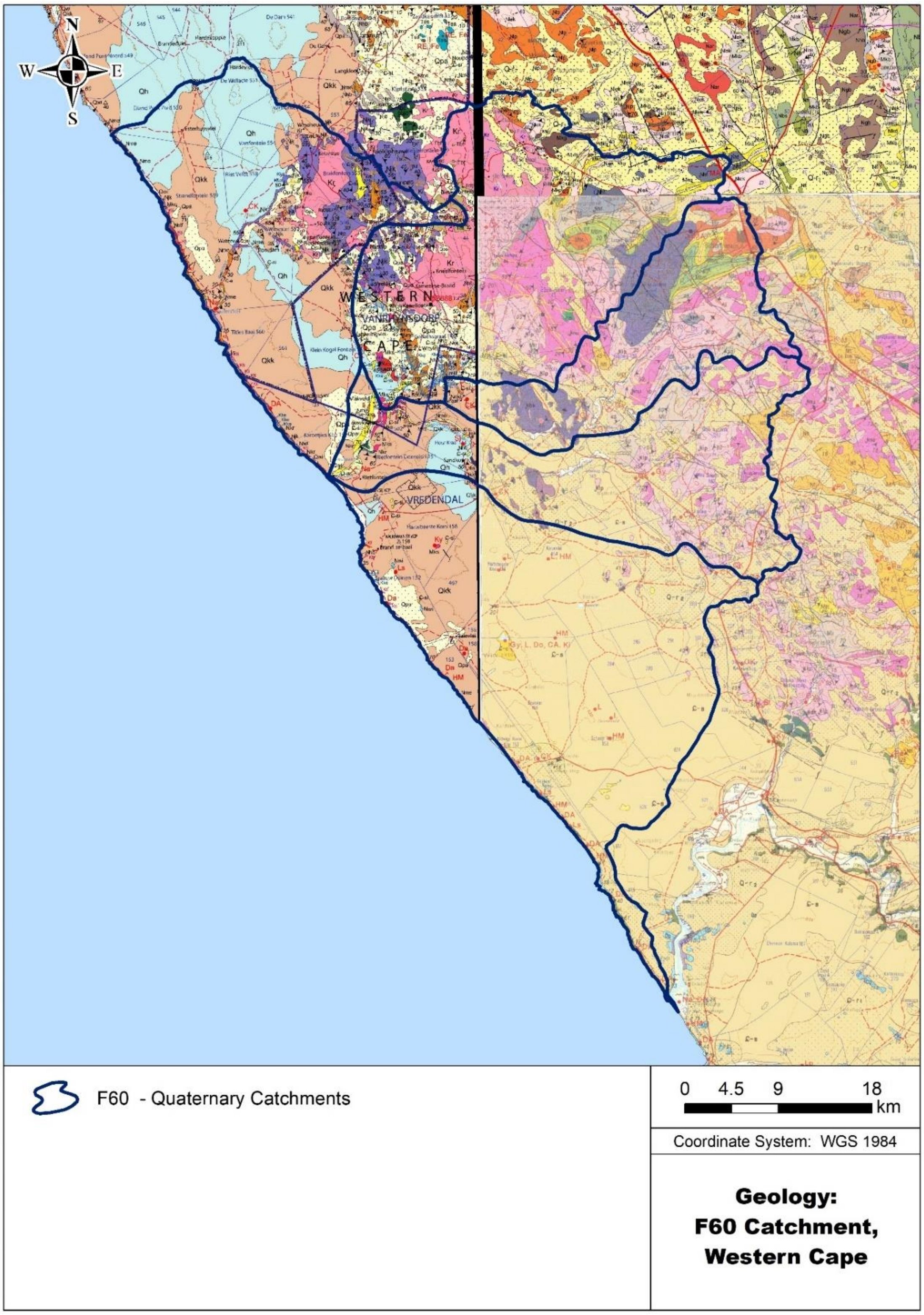


Figure 6: Geological setting of the F60 catchments (Calvinia, 3118, Garies, 3017 & Loeriesfontein, 3018) (CGS, 2001; CGS, 2010 & CGS, 2010)

Groundwater is the only reliable source of freshwater in the area and all the human settlements are completely reliant on groundwater and rainwater collection. Farms are mainly livestock focussed and are reliant on the groundwater for domestic use as well as for human and animal consumption. This is mainly due to the lack of good quality groundwater.

The regional expected yields are very low (0.1 - 0.5 L/s) (Figure 7). The area has been classified as containing both intergranular and fractured aquifers (DWAF, 2005). Higher yielding boreholes have been found at the most southern point of the F60 catchments, along the coast where calcareous and gypsiferous layers within the quaternary deposits create karst aquifers with an average yield potential of 0.5 – 2 L/s. Higher-yielding boreholes have also been drilled into dykes and fracture plains in the Bitterfontein area.

A karst aquifer exists in calcareous areas which possess a topography peculiar to and dependent upon the underground solution as well as the diversion of surface waters to underground routes. Usually, in the Western Cape, intergranular (water moving through sand grains) and fractured (water moving through faults and fracture plains in hard rock) is more common.

Groundwater quality across the catchments is generally categorised as being poor, with EC values of over 1 000 mS/m expected across the different quaternary catchments within the F60 cluster (Figure 8) (DWAF, 2005). The best quality seems to be found around certain areas around Bitterfontein, where some boreholes yield water with an EC value ranging between 120 - 500 mS/m. The Peninsula formation found under the sand deposits in the southern portion of G60E could potentially also produce better-quality water, but boreholes have not been drilled to verify this hypothesis.

Bitterfontein has a desalination plant that treats groundwater to drinking water standard. The treated water from Bitterfonetin boreholes is then piped to the Nuwerus, Rietpoort, Stofkraal, Molsvlei and Put-se-kloof, as well as being used in Bitterfontein itself. Most of the Bitterfontein boreholes are situated in the neighbouring quaternary catchment, E33D. Kliprand makes use of its own boreholes for town supply.

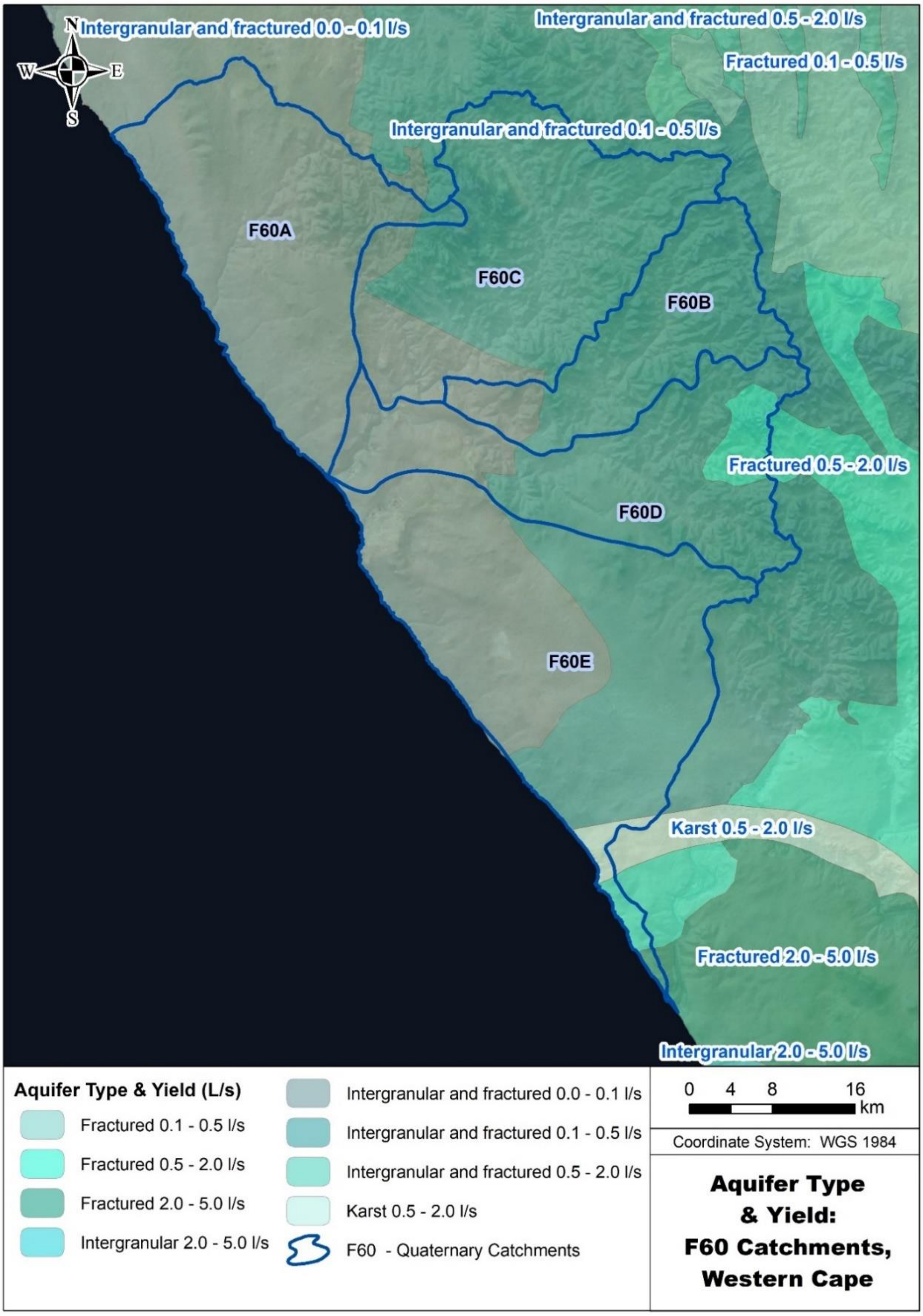


Figure 7: Regional aquifer yield for the F60 Catchments from the 1:1 000 000 scale groundwater map (DWAF, 2005)

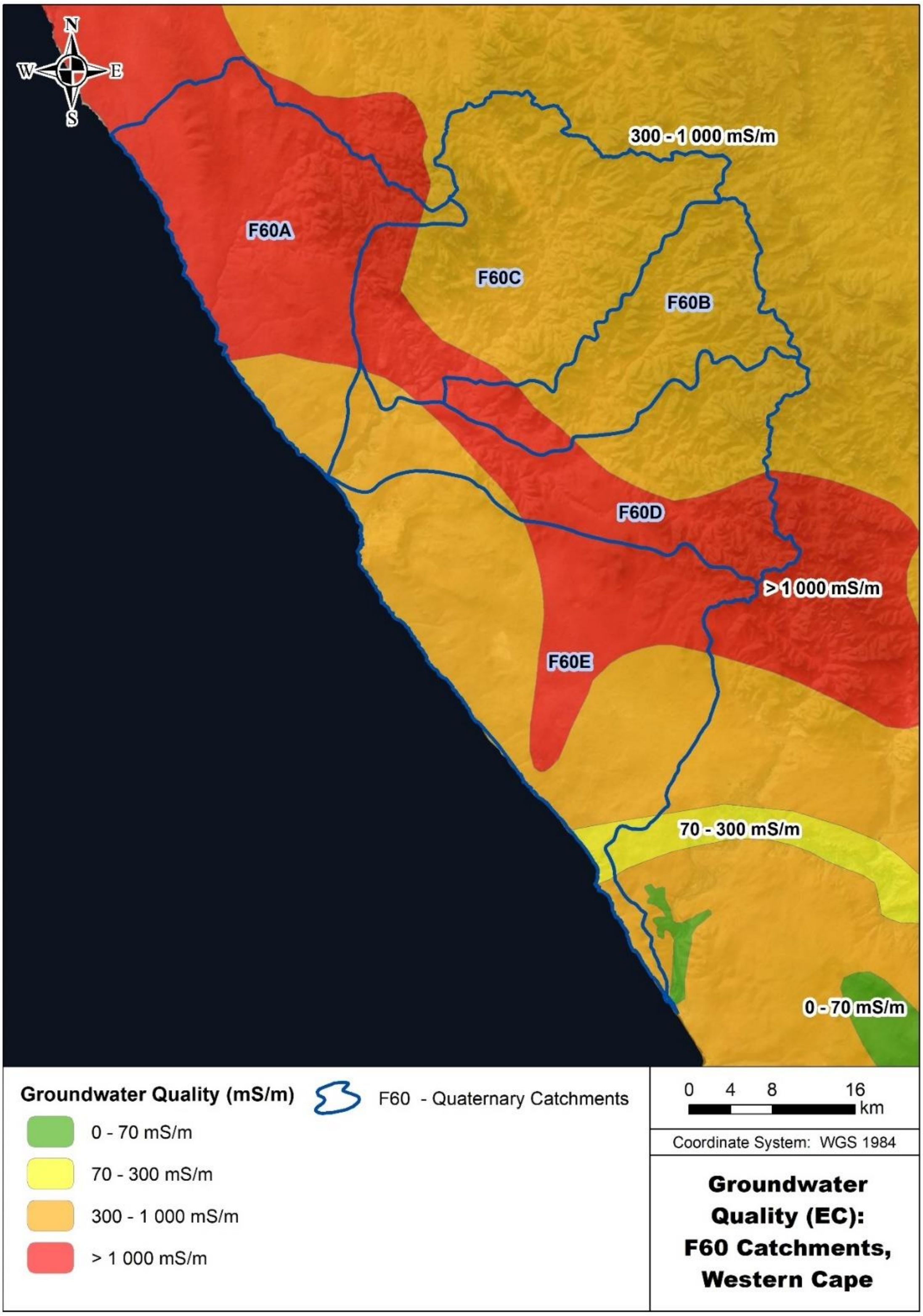


Figure 8: Regional groundwater quality (EC in mS/m) from (DWAF, 2005), for the F60 Catchments

2.1.3. Description of the Groundwater Resource Units

Below is a more detailed discussion for each of the groundwater resource units (GRUs) in the G30 (Figure 9) and F60 (Figure 10) catchments, according to their groundwater quality, water level, use, groundwater-surface water interaction and geological structures.

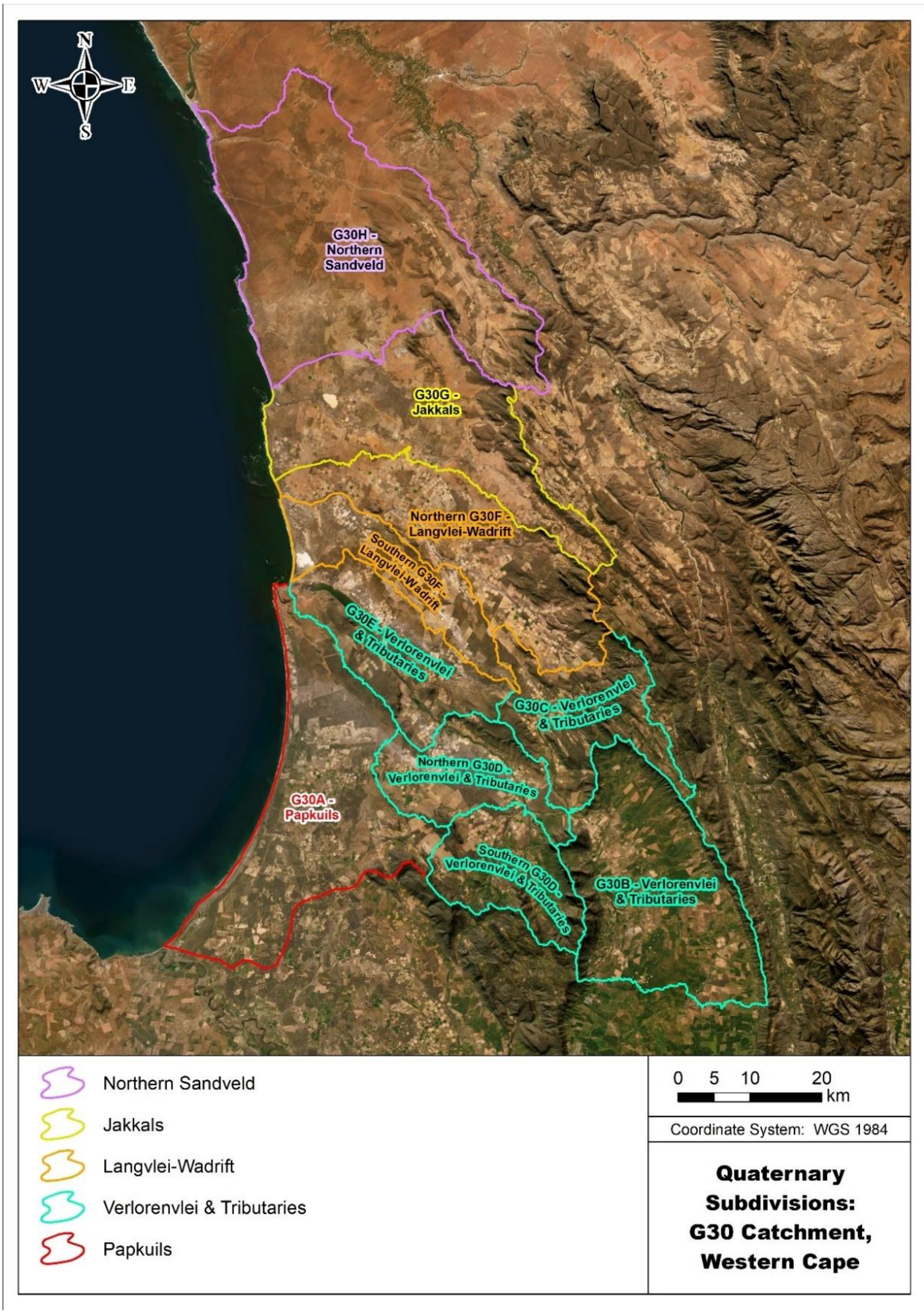


Figure 9: Combined map of delineated GRUs for the G30 catchments

Papkuils (G30A GRU)

Groundwater Use: Moderate to high (in areas with available groundwater).

The groundwater unit falls within the quaternary catchment boundaries. The Papkuils seepage area forms the only significant observed groundwater/surface water interaction site in this unit, and this spring site is a significant one.

The majority of the GRU is low-lying coastal flats. Thick sand is underlain by TMG formations and Malmesbury shales, although boundaries between formations are undefined due to thick sand cover. Boreholes are drilled into the alluvial sand. Water quality is good around the Papkuils seepage area and along the eastern area of the GRU, where a "paleochannel type structure" has been observed.

It has been hypothesized that these saturated sand zones could be caused by discontinuous groundwater upwelling from fault zones. It has been observed that where sand is underlain by TMG sandstone, water quality in the sand is generally better than where the sand is underlain by Malmesbury shales. This can also be observed in aerial photography, with the darker red sand areas indicating areas where sand is underlain by clay.

Borehole yields are below 2 L/s and groundwater abstraction is moderate, with areas of higher abstraction being focused on areas with better quality and higher yields, like around the seepage area (yield of > 25L/s and EC < 60mS/m). Rainfall is between 330 and 230 mm/a.

Verlorenvlei & Tributaries (Southern G30D GRU)

Groundwater Use: Extensive.

This unit comprises the upper reaches of the Krom-Antonies and Hol River catchments. Contact springs are still found up against mountainsides where TMG meets Malmesbury Group shales, Graafwater and other TMG group formations. The Graafwater is more 'aquitard' in nature than the TMG formations found in the area (e.g., Peninsula, Piekenierskloof).

Seepage areas exist along fault lines in the upper reaches of the Mountonshoek Valley. Rainfall ranges between 340 and 560 mm/a, including TMG mountain areas of higher recharge and water levels are generally shallow (<17mbgl), except in large-scale production boreholes, where water levels have been lowered (50 - 70mbgl).

Boreholes are drilled into hard rock mostly, although a few high-yielding boreholes have been recorded to have been drilled into the sand in the southwestern portion of the valley. This sandy area also contains seepage areas that could provide baseflow to the Krom-Antonies catchment.

Groundwater abstraction in the area is extensive. The quality of the groundwater is very good in the most southern parts of the valley, closest to the mountains. The quality then deteriorates towards the north and especially the northeast. The area has also been highlighted as an area where preliminary ELU volumes exceed the final ELU volumes determined. Some farms have continued to drill and build dams to get to their "preliminary ELU".

Verlorenvlei & Tributaries (Northern G30D GRU)

Groundwater Use: Moderate to high.

The groundwater unit is made up of the lower reaches of the Hol, Krom-Antonies and Kruismans rivers and well as where the rivers meet to form the Verlorenvlei river. Malmesbury shales and TMG are overlain by quaternary sands.

The Matroosfontein spring/seepage area to the northern end of this unit is the only major spring observed, although seepage areas within the Verlorenvlei river have also been reported in the northern portion of this unit. It has been hypothesized that discontinuous groundwater upwelling along inferred and mapped fault lines could be introducing older water from the fractured rock aquifer into the sand deposits overlying it.

Rainfall for this catchment ranges between 280 and 300mm/a, and is still much higher than the coastal resource units. Faulted contact between the shale-rich Piketberg and sandstone-dominated Peninsula Formations has been mapped along the western bank of the Verlorenvlei river valley. This change in geology results in groundwater quality on the eastern side of the Verlorenvlei being much better than on the western side.

Groundwater abstraction in the area is extensive towards the northern portion of this GRU.

A decrease in flow at the Matroosfontein has been reported and is being linked to an increase in upstream dams and additional boreholes being drilled into the Matroosfontein section of the GRU. Springs and seepage areas in this GRU are largely being used up completely or are being channelled into dams (Uitvlug and Matroosfontein have dams or boreholes in close proximity).

Verlorenvlei & Tributaries (G30B GRU)

Groundwater Use: Moderate to high (the south-western portion of GRU).

The groundwater unit falls within the quaternary catchment boundaries. The GRU lies between the Citrusdal and Piketberg Mountain ranges. The area is dominated by the Porterville Formation, which forms part of the Malmesbury Group.

Water quality is generally poor and yields low (around 1-5 L/s) for much of the valley. Boreholes are drilled into the hard rock, although a few sand boreholes with higher yields (>5L/s) and good quality have been recorded and are located in the pockets of deeper quaternary sands found in the valley, overlying the Porterville Formation.

A few high yielding (16 – 18 L/s) boreholes have been reported towards the southwestern corner against the Piketberg mountains. Contact and fault springs have been reported along the Piketberg Mountains, as well as some on the Citrusdal side, where TMG formations meet the Porterville formation. The yields of these springs vary, but the quality is usually good. Most of these springs are used for domestic or irrigation supply and no longer contribute to surface water flow (Kruismans river). Some springs have also been reported along the bank of the Kruismans river.

Groundwater abstraction is moderate, with mostly dryland crops in the basin area of the unit and large-scale groundwater and spring water use in the southwestern portion of the GRU, along the Piketberg mountain. In this portion, it is reported that the farms use spring water as well as high-yielding boreholes drilled near fault zones. This will be investigated. Rainfall varies between 300 - 500 mm/a.

Verlorenvlei & Tributaries (G30C GRU)

Groundwater Use: Extensive.

The groundwater unit falls within the quaternary catchment boundaries and is made up of the area known as the Bergvallei valley.

Rainfall varies from 460 mm/a in mountainous areas to as low as 300 mm/a around the Het-Kruis area in the northwest. Groundwater use is extensive in the area, and a drop in water levels has been observed in this unit. The entire valley is underlain by the TMG formations. Borehole yields in the area are high (> 20 L/s in some cases), and quality is good.

The upper reaches of the valley have boreholes drilled into the river valley into the shallow hard rock aquifer. Lower down in the valley, the boreholes target the sand deposits overlaying the fractured aquifer.

There are large-scale northwest-southeast trending faults in the area. Farmers lower down in the catchment have reported that their water levels are dropping due to increased abstraction in the upper reaches of the valley. This claim will have to be investigated.

The upper reaches of the Bergvallei valley have completely been transformed, and little of the old river channel remains visible. The Het Kruis wetland area has subsequently, with the increased abstraction in the upper reaches of the GRU, also dried up progressively in the last 15 years.

Verlorenvlei & Tributaries (G30E GRU)

Groundwater Use: Extensive

The groundwater unit comprises the Verlorenvlei area. The geology is characterised by TMG formations and the Klipheuwel Formation (Malmesbury Group) being overlain by thick quaternary sediments. The Klipheuwel Formation is seen as the basement rock for the area and outcrops to the western side of the Verlorenvlei wetland. The groundwater found on this side of the wetland is usually of poor quality with low yields. Boreholes drilled on the eastern side of the wetland in some areas produce very high-yielding boreholes (>20L/s) with very good quality (EC<60mS/m). These boreholes are located in close proximity to the inferred large northwest-southeast trending inferred fault that lies towards the east of the wetland and runs along it.

It has been hypothesized that these saturated sand zones could be caused by discontinuous groundwater upwelling from fault zones. Borehole yields drop significantly when going past the Vensterklip farm and the road that leads to Leipoldtville. The old Graauwe Duynen wellfield is situated to the north of Elandsbay but is only minimally being used for town supply due to poor quality and low yields. Rainfall decreased from around 300mm/a at the top of the catchment to as low as 230mm/a near Elandsbay.

Kruisfontein Springs are most likely completely groundwater-fed and likely fault related. Some smaller springs occur along the wetland area, but these are used for domestic or irrigation uses and do not contribute a significant amount to the wetland at this stage. Boreholes are also drilled along the wetland and spring areas.

Langvlei-Wadrift (Northern G30F GRU)

Groundwater Use: Extensive.

The groundwater unit falls within the quaternary catchment boundaries and makes use of geological and hydrological boundaries to separate this GRU from the Southern G30F GRU. Whereas other quaternary catchments within the Sandveld generally incorporate one valley area that usually has a "paleochannel type structure" running through the valley, G30F has two, a northern and a southern valley.

In this GRU, groundwater abstraction is extensive. The highest yields and best quality water is found from boreholes in the upper reaches of the GRU, between Sandfontein and Sandberg. Passing Sandberg, groundwater quality deteriorates and becomes more saline. Boreholes are drilled into the primary sand and, in some cases, into bedrock. The bedrock in this area is made up of thick sandstone units from the Peninsula Formation (TMG). The sand layer becomes thicker towards the coast and is underlain by TMG formations that outcrop towards the upper reaches of the GRU.

Rainfall varies from a maximum of around 400 mm/a in the upper reaches of the GRU to as low as 180 mm/a on the coast. It was reported that historically, the area had more springs. Currently, the only significant one that has been observed is Sandfontein. Depth to groundwater is around 20 mbgl and shallower in the upper reaches of GRU (< 5 mbgl).

Langvlei-Wadrift (Southern G30F GRU)

Groundwater Use: Extensive.

The groundwater unit falls within the quaternary catchment boundaries and makes use of geological and hydrological boundaries to separate this GRU from the Northern G30F GRU. In this GRU, groundwater abstraction is extensive. The highest yields and best quality water is located towards the sea, in what is known as the upper-Wadrif area. The lower-Wadrif aquifer was historically also a good aquifer. A wellfield was installed around Wadrif wetland. The wellfield comprised several boreholes that were abandoned when the aquifer was damaged during over-abstraction. This also resulted in drying up the adjacent wetland. With the desiccation of the wetland, salt accumulated, and after a few big rain events, the salt infiltrated into the aquifer, making the water too saline to use. Peat fires also damaged the wetland. All of the boreholes have been abandoned. This situation outlines the sensitivity of the area`s aquifer system and emphasizes the importance of managing an aquifer system.

This GRU falls within the Wadrif Subterranean Government Water Control Area (SGWCA). Current groundwater abstraction is focused in the upper Wadrif aquifer, and boreholes are drilled into the thick sand cover overlaying the TMG formations. Groundwater quality in the upper-Wadrif is very good (< 40 mS/m), and high yields (> 12 L/s) can be obtained in certain areas where saturated sand is identified. Dry boreholes are also drilled, and this is important in highlighting that the aquifer is confined to certain areas to form a typical paleo-channel. No large faults have been linked to this high-yielding saturated sand aquifer, unlike some of the other paleochannel structures in the Sandveld.

Lamberts Bay uses this wellfield for town supply, and a large volume is also being pumped for agricultural uses. Municipal monitoring data has displayed a decline in water level for the past ten years, and this is concerning as vegetation die-off has also been noticed in the old riverbed. Rainfall decreased from around 280 mm/a at the top of the catchment to as low as 200 mm/a near the coast.

Jakkals (G30G GRU)

Groundwater Use: Extensive in certain areas and Low in others.

The groundwater unit falls within the quaternary catchment boundaries and can be referred to as the Jakkals River catchment. Rainfall decreased from around 340 mm/a at the top of the catchment to as low as 190 mm/a near Lamberts Bay. This GRU falls within the Graafwater Subterranean Government Water Control Area.

A “paleo channel type structure" exists and has been well documented (Jolly, 1992). Best groundwater yields (12 - 20 L/s) and quality (90 - 130 mS/m) are found towards the bottom of the GRU, north of the Jakkals River and about 7- 12 km east of Lamberts Bay, in the area known as Kookfontein and Varsfontein. Boreholes drilled around the Jakkals river or to the south of the river provide poor yields (<2L/s) and poor-quality water with elevated levels of chloride and iron. Towards the upper reaches of the GRU and around Graafwater, high yields can be obtained, but the quality is generally much lower than in other areas of the Sandveld. This is most likely due to the Graafwater Formation. This formation is a shale unit within the TMG and, unlike the Piekenierskloof and Peninsula, is linked to poor quality, iron and chloride-rich water. The formation is usually a relatively thin formation, but it dominates the geology around Graafwater and where it underlies the sand deposits into which boreholes are drilled, yields moderate-poor quality water, although yields can still be good (10 – 12 L/s).

For the town of Graafwater, new boreholes drilled cased-off portions of the sand deposits, which were the most clay-rich and through this found a useable supply of water, although it is still chloride rich. None of the springs in the lower Jakkals river GRU is reportedly still flowing, but this can be investigated. Water levels generally range between 3 – 23 mbgl, but 60 – 70 mbgl have been recorded at some production boreholes. Groundwater use is extensive in areas that are groundwater rich. Much less water is being abstracted in areas north of Graafwater and to the south of Lamberts Bay. In such areas, dryland crops are mostly cultivated as well as livestock farming.

Northern Sandveld (G30H GRU)

Groundwater Use: Low

The groundwater unit falls within the quaternary catchment boundaries and can be referred to as the Northern Sandveld. Groundwater usage in this area is much lower than for the rest of the Sandveld. Groundwater quality is generally poor, with EC values higher than 1 000 mS/m being normal for large areas.

Borehole yields are very varied (0.2 - 5 L/s), although some high-yielding boreholes have been drilled towards the upper portions of the GRU (8 - 15 L/s). These boreholes are most likely linked to the large northwest-southeast trending fault that runs along the Sandlaagte River. This site also had relatively good quality for the area (360 mS/m) but still had elevated levels of Sodium (500 mg/L) and Chloride (1 000 mg/L). Agriculture is focused on dryland crops and animal farming.

Recently, multiple requests for exploration for heavy minerals along the coast have been submitted. Concerns have been raised about how mining could impact the limited groundwater supply.

As with the rest of the Sandveld, coastal sand deposits are underlain by TMG and Klipheuwel, although sand deposits are shallower in some areas than for the rest of the Sandveld. Resting water levels are much deeper than what is found in the rest of the Sandveld, with water levels getting deeper going from the southeast portion (30 mbgl) to the northern portion (50 mbgl) of the GRU. Some winter seepage areas have been reported towards the upper reaches of the catchment, and this will need to be investigated.

Rainfall ranges from 270 mm/a towards the southwest portion of the GRU to 170 mm/a in the north-western portion around Strandfontein and Doringbaai. Reportedly, these towns are the only ones in the Sandveld that do not use groundwater as their only water supply due to poor water quality.

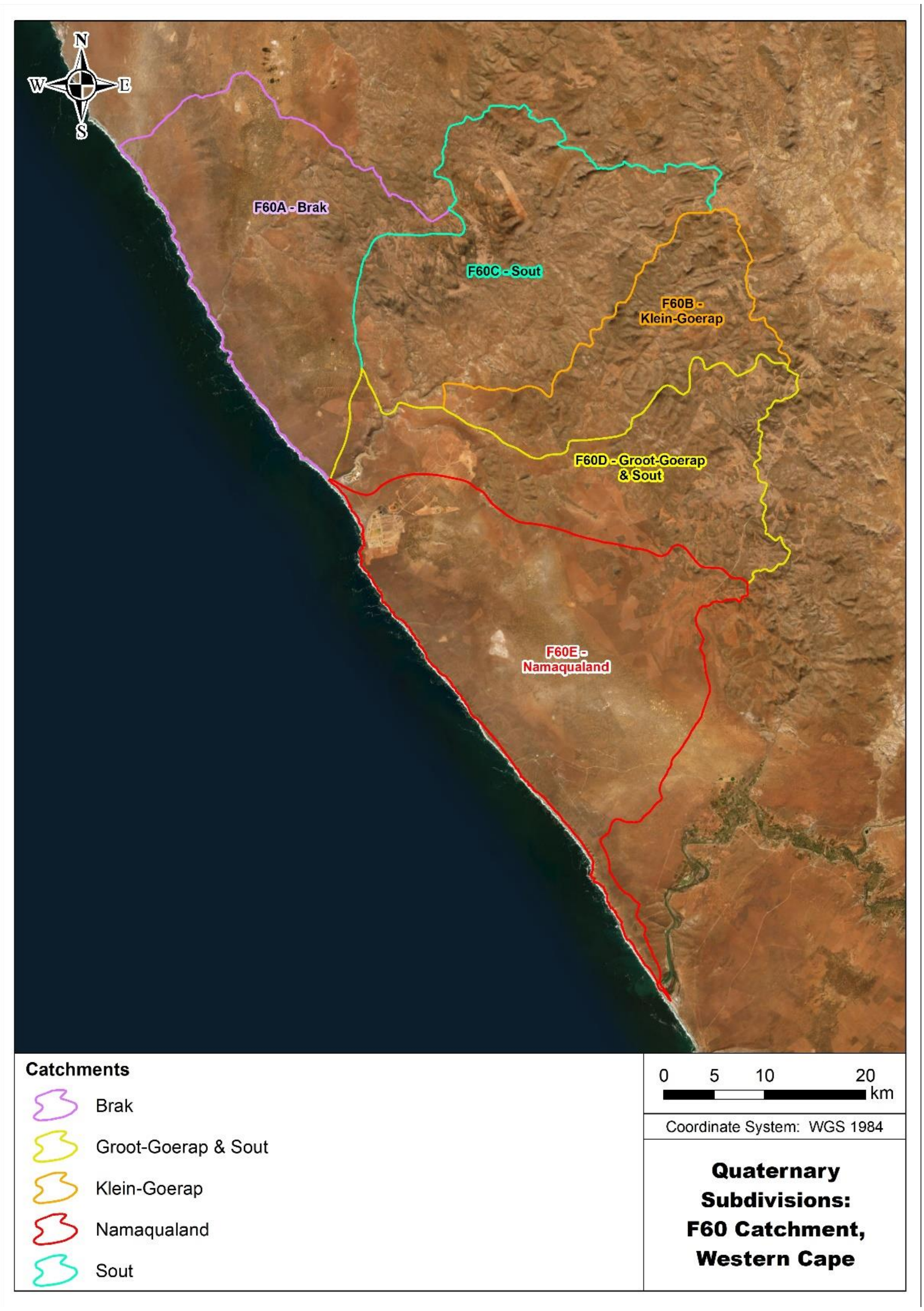


Figure 10: Combined map of delineated GRUs for the F60 catchments

Namaqualand (F60E GRU)

Groundwater Use: Very Low.

The groundwater unit falls within the F60E quaternary catchment boundary. This area hosts karst aquifers as well as intergranular and fractured aquifers. A karst aquifer exists in limestone and dolomite areas which possess a topography peculiar to and dependent upon the underground solution as well as the diversion of surface waters to underground routes. Usually, in the Western Cape, intergranular (water moving through sand grains) and fractured (water moving through faults and fracture plains in hard rock) is more common. The geology underlying the southern portion of the GRU has been mapped as calcareous and gypsiferous soil, silcrete and other alluvial deposits overlying the metamorphosized units of the Gariep Supergroup and in the southern most point, the sandstone Peninsula Formation (TMG).

The geology in the north of the GRU is characterised as gneiss and granite formations from the Little Namaqualand Suite being overlain by quaternary sand deposits. Very few hard rock formations are exposed in this area and geological boundaries between rock formations and faults are not defined. The Namaqua Sand Mine is situated to the north of the GRU, where heavy minerals are being mined, such as zircon, garnet, ilmenite, rutile and magnetite. These naturally occurring deposits are some of the richest placer deposits in the world. Because of this, there is interest in commissioning more mines in the area. This could potentially impact the very limited groundwater resource.

Extremely little groundwater is abstracted. The only known groundwater user that has been identified is Tormin mine. They use borehole water for dust suppression. At Namaqua Sands mine, water levels are generally deep (40mbgl) and the mine does not use groundwater but rather sea water. A numerical model has been set up and is updated regularly with monitoring data from the mine to model the pollution plume. Drinking water for both mines is trucked or piped in. The groundwater quality for the region is classified as “poor” in the northern section of the GRU (300 – 1 000 mS/m) and “marginal” in the southern section (70 – 300 mS/m). Yields of 0.5 - 2 L/s are expected.

Groot-Goerap & Sout (F60D GRU)

Groundwater Use: Low.

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Groot Goerap and lower Sout River.

There is very little perceived groundwater abstraction. Mostly dryland and livestock farming and some mining activity (Namaqua Sands) towards the coast. NGA database does note multiple very low-yielding boreholes with poor quality. These boreholes are likely used for animal drinking water and, where possible, domestic uses. Rainfall is highest in the upper catchment (150 mm/a and drops to around 100 mm/a at the coast. Groundwater levels are between 30 and 18 mbgl.

The underlying geology is very complex and characterised by Quaternary age material consisting of sand and calcareous and gypsiferous soil, underlain by igneous and metamorphic formations. The area is mostly underlain by different age granite and gneiss variants of the Little Namaqualand Suite and Kamiesberg Group. The sandstone Flaminkberg Formation also overlays the older igneous rock units towards the north-eastern corner of the GRU. There are also northwest-southeast trending fault structures cross-cutting the igneous formations towards the eastern portion of the GRU.

It has been noted groundwater intersected in drainage channels sometimes yields extremely salty water. Groundwater quality varies between 800 – 3 000 mS/m, although the southeastern corner of the GRU has been reported to yield better quality water (200 – 500 mS/m). Yields generally vary between 0.1 and 1 L/s.

Klein-Goerap (F60B GRU)

Groundwater Use: Low to moderate (around Bitterfontein).

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Klein Goerap River.

There is very little perceived groundwater abstraction. Mostly dryland and livestock farming. Rainfall is around 140 mm/a across the GRU. Groundwater levels are between 17 and 40 mbgl (although NGA noted water levels as shallow as 3 mbgl and as deep as 72 mbgl). Yields are generally very low (< 0.3 L/s), although some higher-yielding boreholes (3 – 5 L/s) have been documented in the northeast section of the GRU, around Bitterfontein.

Water quality is very poor (> 1 000 mS/m), especially in the northern portion of the GRU. Good quality for the area is around 200 - 500 mS/m and is found in the upper reaches of the GRU. The fractured hard rock aquifer is targeted as the main aquifer in this GRU.

Bitterfontein has a desalination plant that treats groundwater to drinking water standards. The treated water from Bitterfontein boreholes is then piped to the Nuwerus, Rietpoort, Stofkraal, Molsvlei and Put-se-kloof, as well as being used in Bitterfontein itself. Most of the Bitterfontein boreholes are situated in the neighbouring quaternary catchment, E33D. Kliprand uses its own boreholes for town supply. It has been reported that some of the production boreholes at Bitterfontein have been over-abstracted. This claim will need to be investigated.

Like with other GRUs, geology is dominated by igneous and metamorphic rock units. In this GRU, less of the catchment is covered by quaternary deposits and thus, geological units, boundaries and structures are easier to distinguish. Granites and gneisses from the Little Namaqua Suite and Kamiesberg Group are overlain by quaternary deposits. These igneous formations have experienced multiple phases of deformation and the units have been folded. Syncline and anticline structures are evident. Northwest-southeast trending fault structures also cross-cut the igneous formations.

Sout (F60C GRU)

Groundwater Use: Low.

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Sout River (before it joins with the Groot-Goerap).

There is very little perceived groundwater abstraction. Some dryland farming is evident, although most of the GRU does not display any signs of cultivation and livestock farming is assumed to be the predominant activity in the area. Villages situated in this area receive water (piped) from the treatment plant at Bitterfontein.

The regional geology comprises Quaternary age material consisting of sand and calcareous and gypsiferous soil, underlain by igneous and metamorphic formations. The area is mostly underlain by different age granite and gneiss variants of the Koegel Fontein Complex, Spektakel Granite Suite, Little Namaqualand Suite and Kamiesberg Group. There are several younger dike intrusions mapped within the GRU, such as the Zout River Basalt plug that can clearly be seen from above as a large dark shape towards the southern border of the GRU. There are also northwest-southeast trending fault structures that cross-cut the igneous formations towards the southwest of the GRU.

These fault structures are targeted during groundwater exploration. Rainfall is around 120 - 130 mm/a across the GRU. Groundwater levels are between 12 and 40 mbgl. Yields are generally very low (< 0.3 L/s), although some higher-yielding boreholes (2 – 3 L/s) have been documented in the north section of the GRU, around Rietpoort. Water quality is poor (around 1 000 mS/m) at the bottom portion of the GRU, but improves towards the north of the catchment. Relatively good quality (around 200 mS/m) can be found in this area and NGA also records the majority of the boreholes found in F60C in this section of the GRU. These boreholes are mostly drilled into the Louisrus Formation (Kammiesberg Group). This formation is the oldest in the area and is characterised by fine to medium-grained quartz-rich gneisses.

Brak (F60A GRU)

Groundwater Use: Very Low to non-existent.

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Brak River.

Very little to non-existent groundwater abstraction is evident. Mostly dryland and livestock farming and some possible mining activity towards the north. Rainfall is very low (100 - 120 mm/a), and very little recharge is evident.

NGA has recorded a few boreholes in the catchment. Matzikama Municipality has not confirmed the water supply for Kotzesrus and Lepelsfontein, but it is suspected to be groundwater. This will be investigated.

Groundwater levels are deep (> 35 mbgl), with some shallower water levels having been documented around Lepelsfontein. Documented yields are very low (< 0.2 L/s) for most of the catchment, although NGA reported a few higher-yielding boreholes on the southern coastline of the GRU. Water quality data for these boreholes are not available. Therefore, it is unclear if water from these boreholes can be used without intensive treatment. Boreholes target saturated sand areas, although it is hypothesized that faults mapped along the coast would be the most likely source of recharge to the sands due to low rainfall.

Most of the GRU is covered by quaternary aeolian sand deposits, with hard rocks only outcropping towards the north-eastern corner and along the coastal terraces. In these areas, the geology is dominated by the granites and gneisses of the Spektakel Suite, as well as the younger Koegel Fontein Complex (mostly the Rietpoort Granite) that intruded the Spektakel units.

Faults have been mapped along the coast, cross-cutting the geology perpendicular to the coastal terraces.

2.3. River and Wetlands

2.3.1. Hydrology

The hydrology of the G30 and F60 catchments was previously modelled as part of the Olifants-Doring WMA. The WR2012 hydrology covers the period 1920 to 2009 and does not cover the recent drought period. The current study has refined and extended the WR2012 hydrology to the 2020 hydrological year (up to September 2021). A summary of the mean annual runoff (MAR) for the quaternary catchments in the study area is shown in Table 3.

Table 3: Mean annual runoff modelled for the quaternary catchments in the study area (WR2012)

Quaternary catchment	Catchment area (km^2)		MAR WR90 (1920-1989)	MAR WR2005 (1920-2004)	MAR WR2012 (1920-2009)	MAR Current Study (1920-2020)
	Gross area	Net area	Million m^3/a			
G30A	761	761	1.60	9.84	8.51	1.24
G30B	658	658	18.90	15.25	16.07	15.82
G30C	351	351	11.30	17.50	14.49	10.94
G30D	534	534	11.90	14.10	13.69	19.69
G30E	352	352	1.90	6.79	5.92	2.13
G30F	780	780	4.00	13.26	11.76	4.75
G30G	652.6	333	1.80	5.33	4.43	1.06
G30H	1077	1077	3.30	6.84	5.86	1.36
Tertiary G30	*5165.6*	*4846*	*54.70*	*88.91*	*80.73*	60.57
F60A	572	386	0.10	0.19	1.42	0.07
F60B	320	320	0.20	0.16		0.07
F60C	622	622	0.20	0.35		0.25
F60D	481	481	0.20	0.28		0.16
F60E	795	120	0.00	0.10		0.05
Tertiary F60	*2790*	*1929*	*0.70*	*1.08*	1.42	0.60

There are no active flow gauging stations in the study area. Historically observed flows are available on the Kruismans River at Tweekuilen (DWS flow gauge G3H001) for the period 1971 to 2005. This weir is the only streamflow gauge in the Verlorenvlei catchment and has been used as a means to calibrate rainfall/runoff models in the region (Watson *et al*., 2019, 2018). The gauge has data between 1970 to 2006, shown in Figure 11 and was decommissioned after a flood in November 2006. The data from the gauge was used during this study to validate the modelled flows.

The data show two distinct periods of hydrological characteristics: a period from 1986-1993, which has sharp monthly streamflow peaks and a period from 1994-2006 where the peaks are completely flattened. The cause of these changes has yet to be identified but could be related to a leaking gauge, streamflow impacts due to irrigation (farm dams and river abstraction) or the natural variability of precipitation.

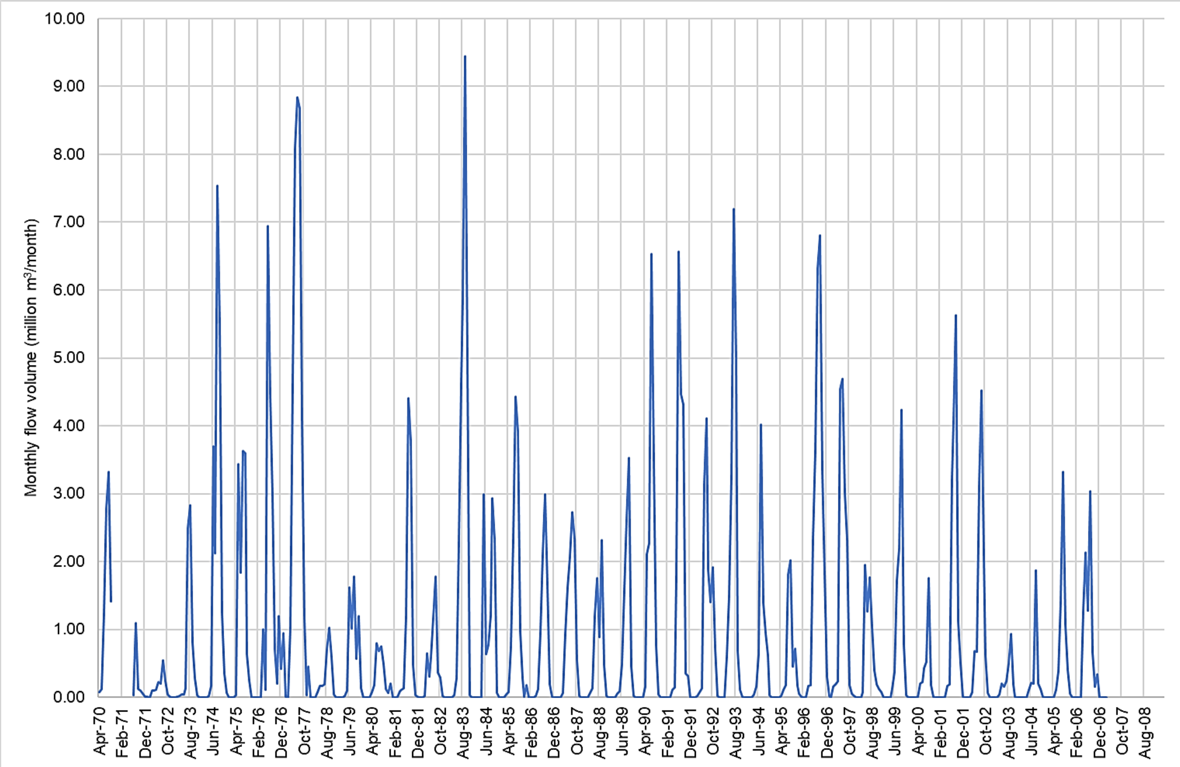


Figure 11. Observed monthly flows at G3H001 (April 1970 to Dec 2006)

According to the WR2012 study, the G30 tertiary catchments have low rainfall along the coast with a MAP of approximately 200 mm, increasing from the west to south-east of the study area. The MAP increases up to 500 mm in the Banghoek mountains. Overall, the Sandveld MAP is approximately 290 mm/a. The catchment is characterised by endorheic areas in the Papkuils (G30A) and the Langvlei (G30F) catchments, and most runoff is generated in the Kruismans (G30B), the Bergvallei (G30C) and the Krom Antonies and the Hol Rivers in G30D.

In the WR2012 study, the F60 tertiary catchments have a relatively uniform rainfall distribution with mean annual precipitation (MAP) of 115 mm/a. The runoff characteristics are uniform, with an estimated mean annual runoff of less than 2.5 mm. More than half the catchment area is considered endorheic and does not contribute to surface water runoff. The WR2012 characteristics have been retained in the current study because there is no data on which to verify the modelled flows.

Table 4 summarises the delineation of catchments for the hydrological resource units.

Table 4: Summary of the delineated hydrological resource units

Runoff module ID	Sub-Catchment	Quaternary catchment	Name	MAP	Area (km^2)	MAP (mm)
1	G30A1	G30A	Papkuils	Low	131.1	292
2	G30A2	G30A	Papkuils Lower	Low	10.0	292
3	G30B1	G30B	G30B High	High	23.7	505
4	G30B1	G30B	G30B Low	Low	92.4	300
30	G30B2	G30B	Soutkloof	High	17.8	415
5	G30B2	G30B	Soutkloof	Low	194.5	300

Runoff module ID	Sub-Catchment	Quaternary catchment	Name	MAP	Area (km^2)	MAP (mm)
6	G30B3	G30B	Huis tributary	High	53.8	505
7	G30B3	G30B	Huis tributary	Low	288.5	300
8	G30C1	G30C	Kleinvlei	High	64.3	404
9	G30C2	G30C	Jansekraal	High	62.6	404
10	G30C3	G30C	Bergvallei	Low	218.2	383
11	G30D1	G30D	KA upper	High	64.8	517
12	G30D1	G30D	KA lower	Low	55.1	366
13	G30D2	G30D	Hol upper	High	51.7	517
14	G30D2	G30D	Hol lower	Low	102.6	366
15	G30D3	G30D	Matroosfontein	Low	128.2	347
16	G30D4	G30D	Verlorenvlei	Low	151.8	347
17	G30E1	G30E	Kruisfontein	Low	90.4	286
18	G30E2	G30E	Verlorenvlei	Low	44.9	286
19	G30E3	G30E	Verlorenvlei	Low	35.3	286
20	G30E4	G30E	Verlorenvlei	Low	190.5	286
21	G30F1	G30F	Langvlei	Low	194.2	352
22	G30F2	G30F	Lambertshoek	Low	98.9	352
23	G30F3	G30F	Middle Langvlei	Low	397.8	236
24	G30F4	G30F	Lower Langvlei	Low	30.2	212
25	G30G1	G30G	Jakkals	Low	134.4	268
26	G30G2	G30G	Peddies	Low	49.4	268
27	G30G3	G30G	Jakkals (middle)	Low	317.5	208
28	G30G4	G30G	Jakkals (lower)	Low	21.7	138
29	G30H1	G30H	Sandlaagte	Low	580.8	204
31	F60A	F60A	Brak	Low	386	103
33	F60B	F60B	Klein-Goerap	Low	320	129
34	F60C	F60C	Sout	Low	622	114
32	F60D	F60D	Groot-Goerap	Low	481	120
35	F60E	F60E		Low	120	116

2.3.2. Water quality

The Present Ecological Status was determined on a desktop level in 2011 and based on the results, the PES for the F60 catchment is a B (Largely natural). However, the PES for the G30 catchment is a D (Largely modified) (DWS, 2012).

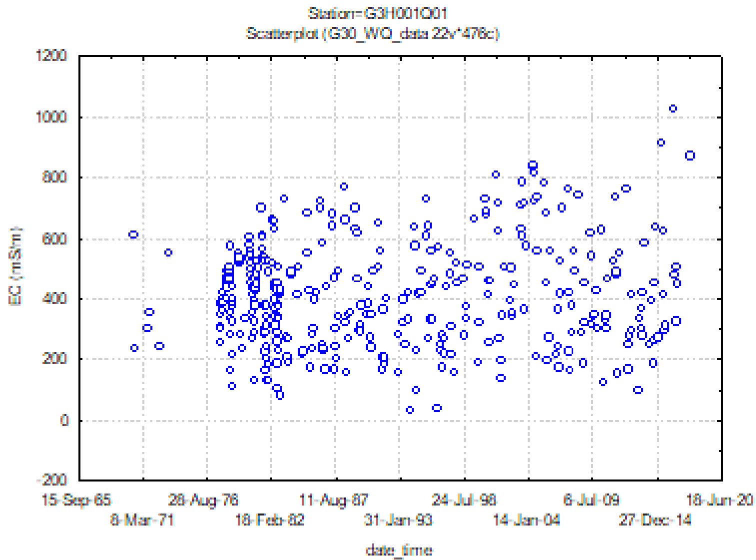
The lack of water quality data also makes it challenging to determine reference conditions and even more challenging is the fact that both G30 and F60 quaternary catchments have non-perennial rivers linked to wetlands with definite wet and dry rainfall seasons, with and without interaction with the groundwater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

Reference conditions will have to be determined by following the non-perennial river methodology described in Seaman *et al.,* 2010, in which the catchment, and not only the EWR site, is included in the evaluation of the reference condition.

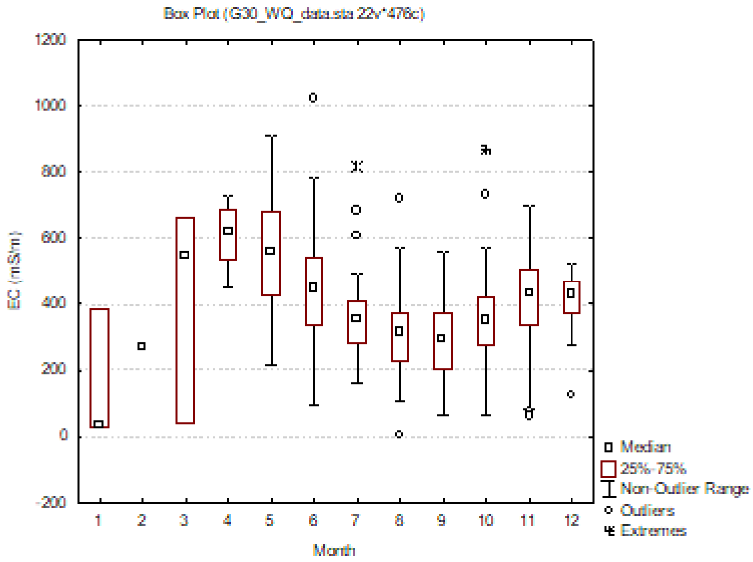
The only monitoring points in the G30 tertiary catchment where there is a longer data record are the gauging sites on the Kruis River at Tweekuilen/Eendekuil (G3H001) and the Hol River at Wittewater Papkuilsvlei (G3H005). At the G3H001 sampling site (Kruis River at Tweekuilen/Eendekuil), 374 samples were collected from 1970 to 2017, while 102 samples were collected at G3H005 (Hol River at Wittewater Papkuilsvlei) between 1978 and 1990 and one in 2017. Sampling frequency started at monthly intervals but was later reduced to *ad hoc* sample collection. The historical data record at both sampling stations was therefore examined for long-term trends and for seasonal changes to determine if there are differences in water quality between the wet and dry seasons. However, these sites cannot be used to determine reference conditions as they are not close to any EWR sites and extrapolation in non-perennial systems is not recommended because of the high variability in physical, chemical, and biological attributes.

The water quality data from the G3H001 (Kruis River at Tweekuilen/Eendekuil) and G3H005 (Hol River at Wittewater Papkuilsvlei) sampling sites are presented in graph format. A limited number of constituents were examined (pH, Electrical conductivity, Total Inorganic Nitrogen (TIN) and Orthophosphates for G3H001 and only EC for G3H005 (due to the limited data in this record and the lack of data from 1990 onwards)) to get some understanding of long-term trends and seasonality at these two DWS gauging stations. The constituents selected are the ones that are mostly also monitored in groundwater sampling programmes, so that one could compare surface and groundwater sampling data, should that be available.

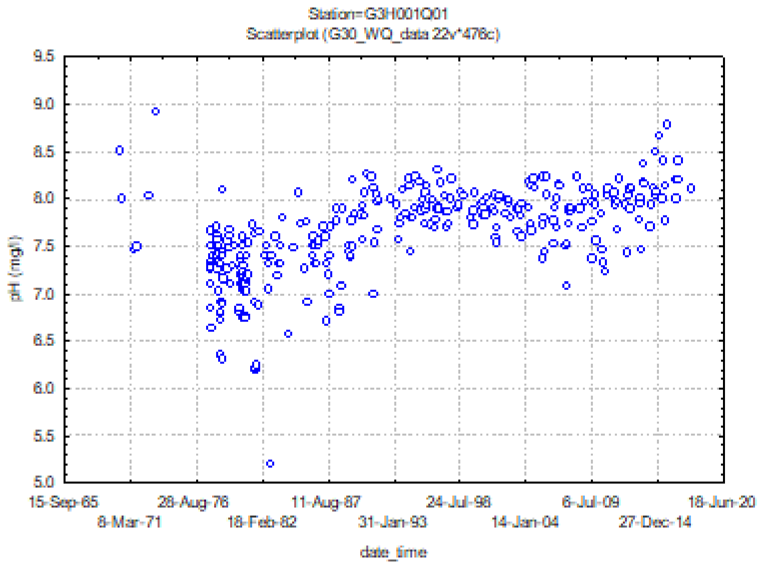
G3H001 (Kruis River at Tweekuilen/Eendekuil)



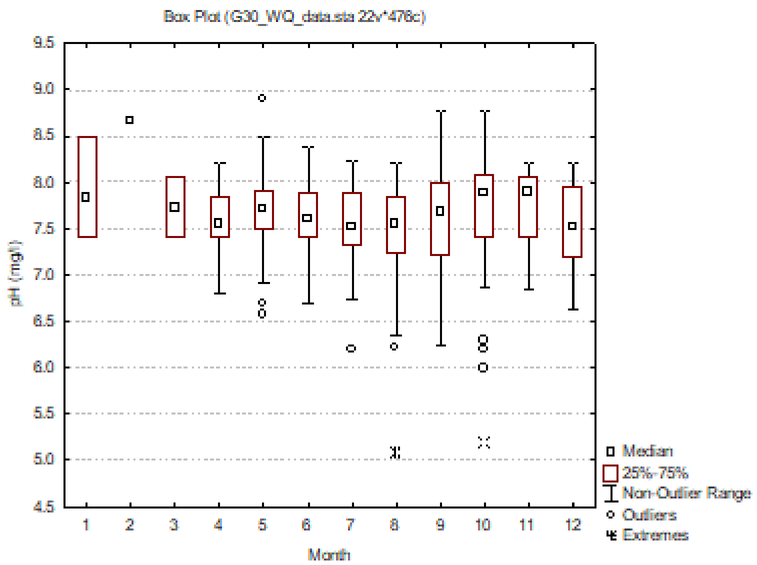
The EC varies over a range from less than 200 to more than 800 mS/m. There does not seem to be a specific increasing or decreasing trend, except for the latter part of the record, there may be an increasing trend. However, looking at the raw data for 2016, the EC ranged from as little as 325mS/m in February to as high as 1024 mS/m in July. This is an indication that with increased runoff, there is an increase in EC in the surface water for this particular year.



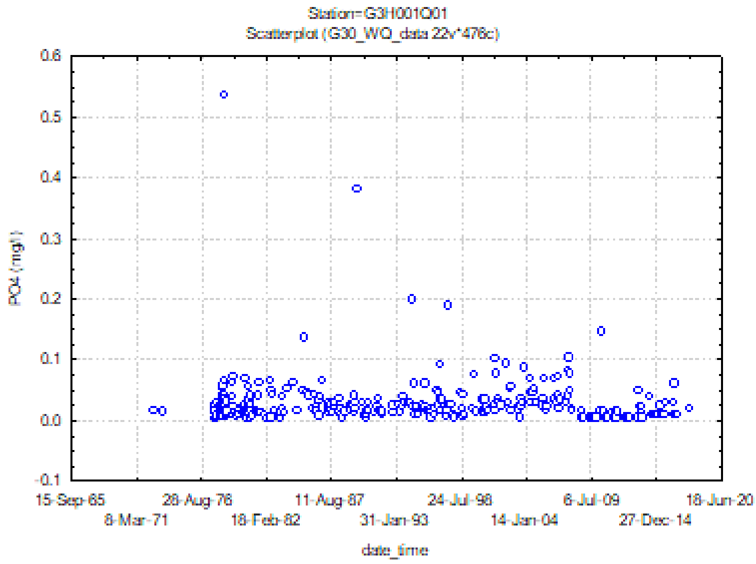
In general, there seems to be a definitive seasonal trend with the highest salt concentrations at the end of the dry season, March and April, when low to no flows occur, and the start of the wet season (first seasonal flushing), decreasing during the rest of the wet season and then again increasing during the dry season. This was not supported by the 2016 data and illustrated the variability in the system.



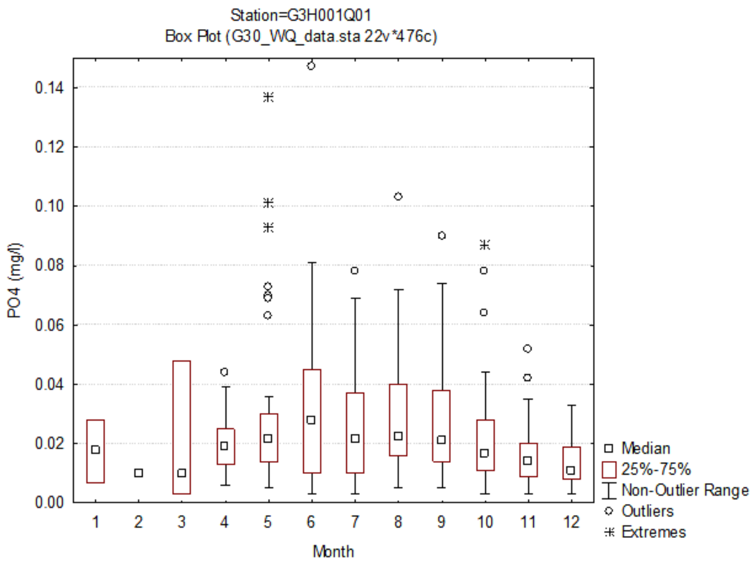
The pH varies over a range from about 6.5 to about 8.5. There seems to be an increasing trend. Looking at the raw data, the pH range was mostly above 7.5 to just less than 8.5. All the pH values for 2016 and 2017 were above 8.



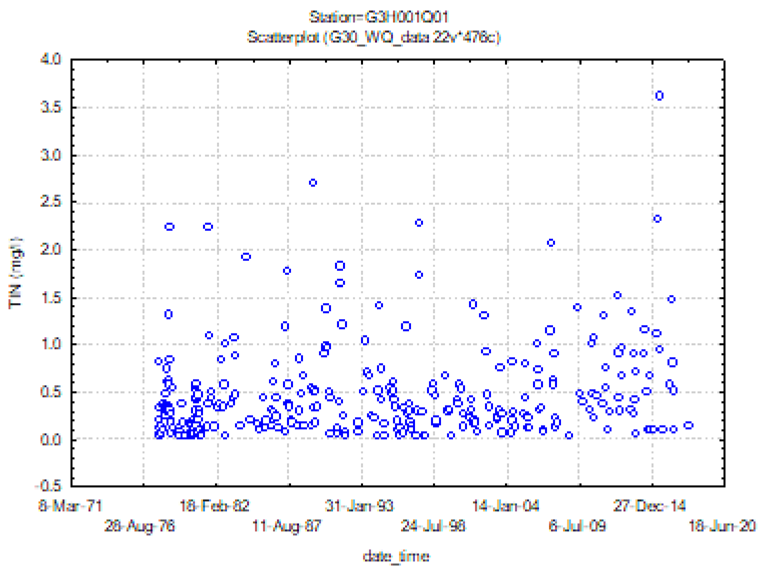
In general, there seems to be a slight seasonal trend, with the highest pH values recorded during the dry season (low to no flows) and the beginning of the wet season (first wet season flushing), decreasing slightly during the rest of the wet season and then again increasing during the dry season. However, the December median value is similar to the wet season values.



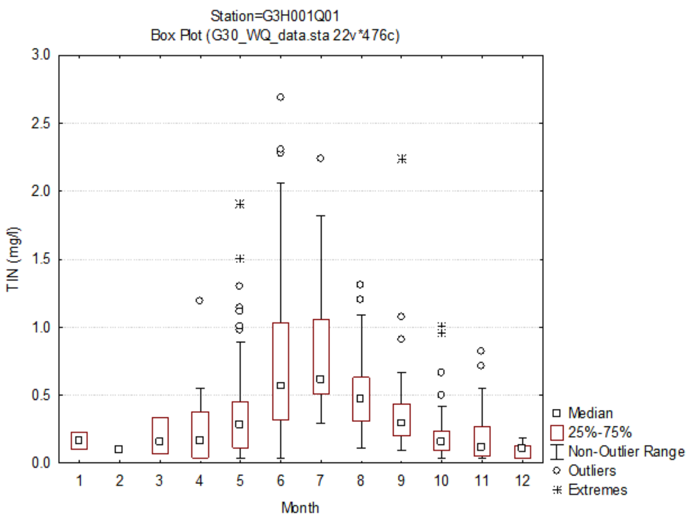
The orthophosphate (PO_4-P) concentrations vary over a range from 0.003 to 0.147 mg/l. During the 2016 and 2017 sampling, values of 0.01 to 0.06 were measured. It is difficult to determine if there is any trend as the concentrations vary from year to year.



In general, there seems to be a slight seasonal trend, with the highest PO_4-P concentrations recorded during the wet season, decreasing slightly during the dry summer season.

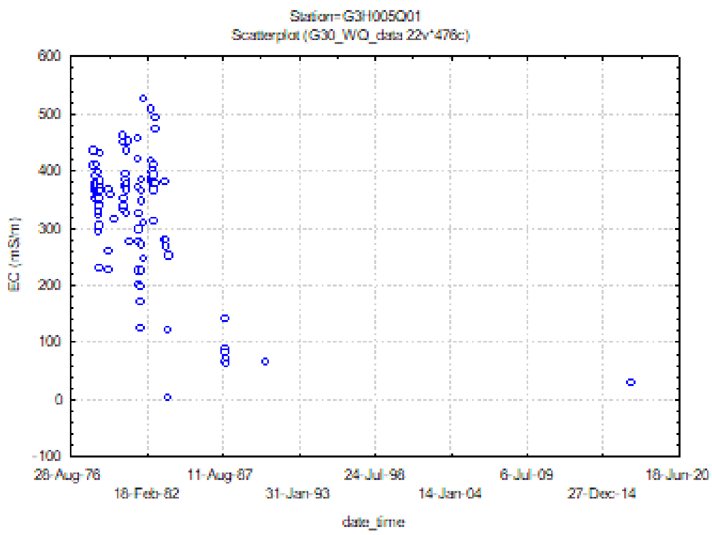


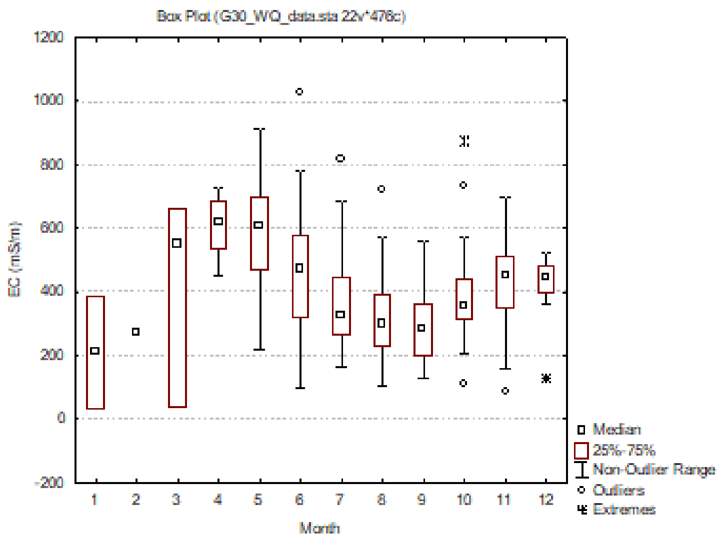
The Total Inorganic Nitrogen (TIN (calculated by adding the NH_4-N and NO_3+NO_2-N concentrations) varies over a range from very low to more than 2 mg/l. It is difficult to determine if there is any trend as the values vary from year to year. An example is the 2016 sampling year when the concentrations measured were as low as 0.1 mg/l (in August) to as high as 1.47 mg/l (in July).



The TIN concentrations exhibit a strong seasonal pattern, with the highest TIN values recorded during the wet season and decreasing during the dry season. Similar patterns in nitrogen were observed in the Berg and the Breede Rivers (DWS, 2018a)

G3H005 (Hol River at Wittewater Papkuilsvlei)





The EC varies over a wide range from less than 100 to more than 500 mS/m, but generally seems to be in the 300 to 400 mS/m range. There does not seem to be a specific increasing or decreasing trend, except for the latter part of the record there seems to be a decreasing trend. However, since no data were collected from 1990 and only one sample in 2017, drawing any conclusions based on the current information is not recommended.

In general, there seems to be a seasonal trend, with the highest salt concentrations observed at the end of the dry season (low to no flows) and the beginning of the wet season (first seasonal flushing).

No recent surface water quality samples were collected in the study area after 2017 for the National DWS Monitoring System. However, the Western Cape Regional Office has been monitoring water quality in the Sandveld since 2013 in key rivers in the G30 catchment (Twelve sites). The sampling frequency varies from monthly to quarterly, and often, there is no surface water to sample as the river would be dry during a sampling event. This resulted in data records with many “missing” results, which is typical of sampling programmes in non-perennial river systems.

A summary of some of the data is presented in box-and-whisker plots to illustrate the spatial change in Electrical Conductivity, pH and nutrients (nitrates and orthophosphate) from the mouth of the river at the Verlorenvlei Estuary (SAND05 at 1 km, Figure 12) upstream to the furthest main stem sampling point on the Kruismans River at SAND006 at 78.3km.

Table 5: Western Cape Regional office sampling points used to examine the longitudinal changes in water quality along the Kruismans/Verlorenvlei river.

Code	River distance (km)	Description
SAND015	1	SAND015- Verlorenvlei Estuary at Elands Bay Town- Railway Line Crossing Over the Point
SAND014	18	SAND014- Verlorenvlei River the Point IS Low Water Crossing on Grootdrif Farm
SAND013	26.6	SAND013- Verlorenvlei River downstream of Redelinghuys Town
SAND012	46.6	SAND012- Verlorenvlei Point E downstream of Hol River on Farm Skrik van Rondom
SAND011	52.2	SAND011 - Verlorenvlei Bridge 2 Located Under a Bridge on R365
SAND008	55.9	SAND008- Kruismans River 1 below R365 Bridge- adjacent to a Railway Line
SAND006	78.3	SAND006- Kruismans River Point IS downstream of Eendekuil Town

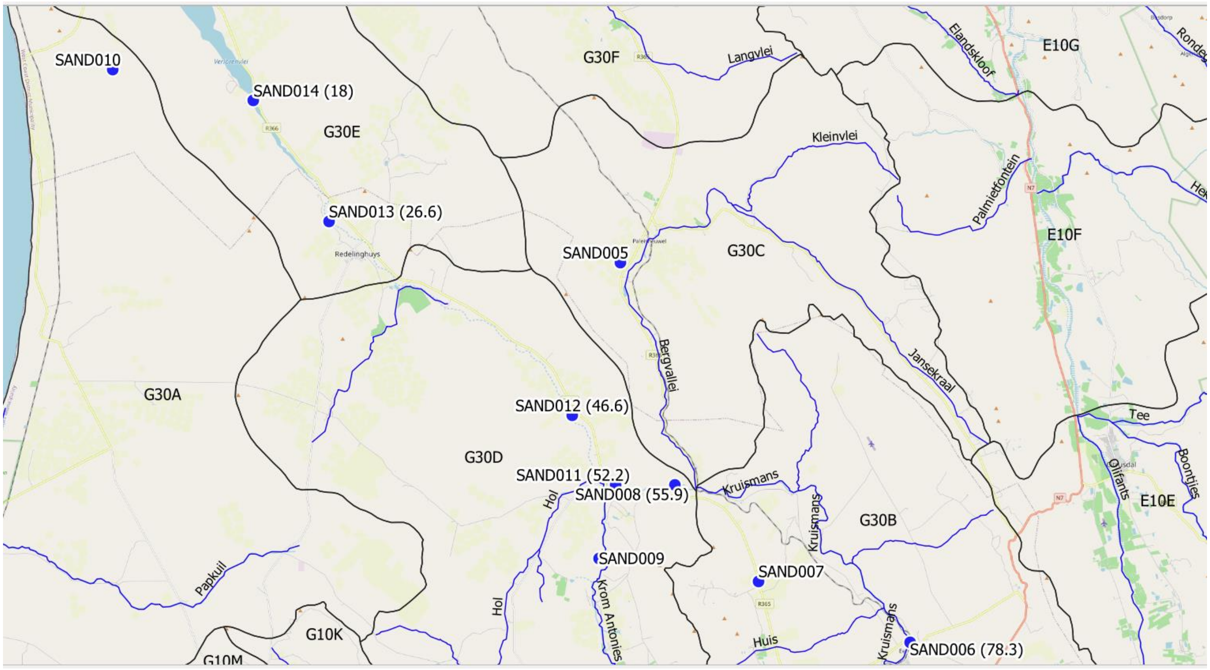
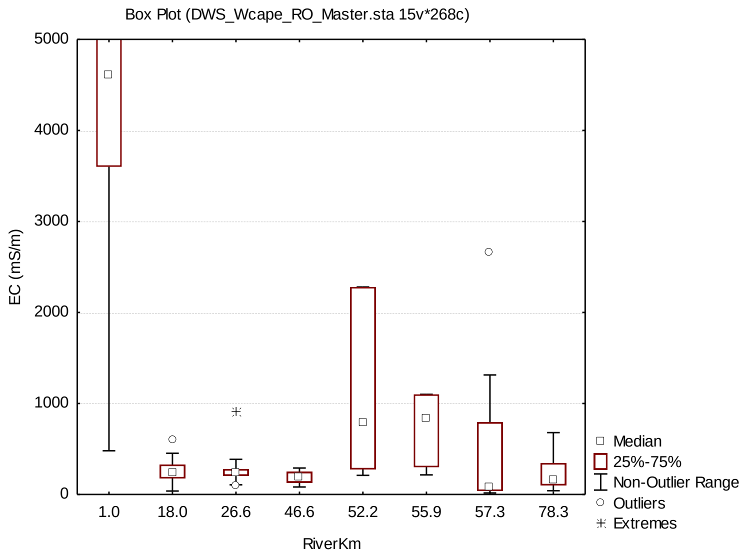
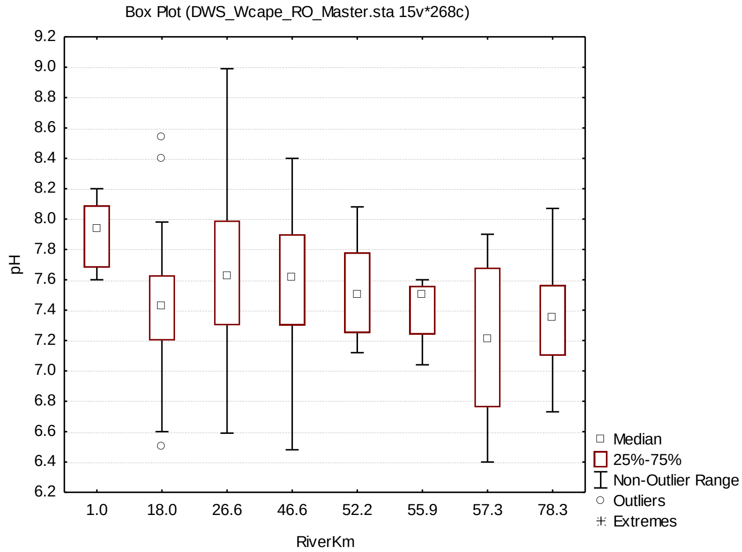


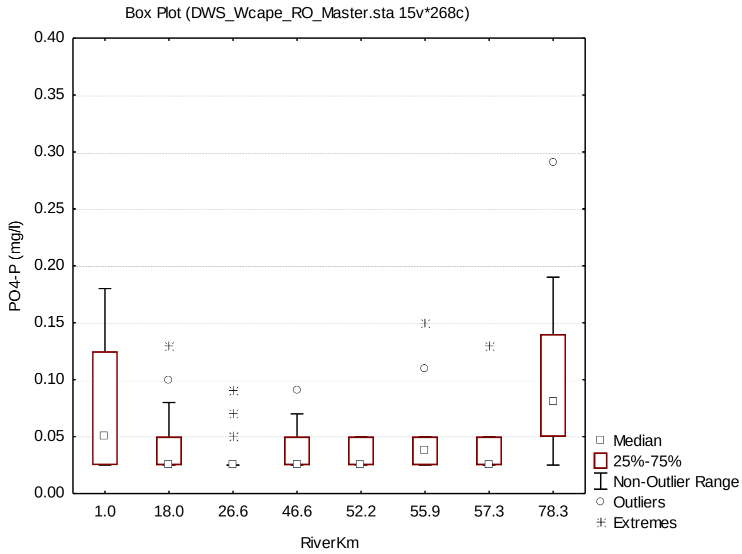
Figure 12: Map showing the location of the Western Cape Regional Office sampling points and their river distance from the Verlorenvlei Estuary



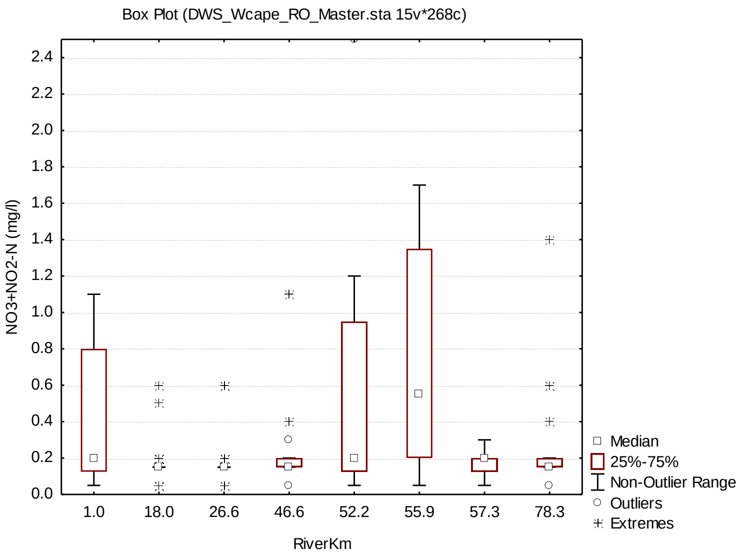
The Krom Antonies River, a tributary of the Verlorenvlei River, flows into the Kruismans River between the sampling points at the Verlorenvlei Bridge (52.2km) and the Verlorenvlei River downstream of the Hol River confluence (46.6km). There is a large decrease in EC values downstream of the confluence of the Krom Antonies River with the Verlorenvlei River.



There seem to be a gradual increase in pH values from SAND006 at 78.3km up to sampling point SAND013 at 26.6km near the village of Redelinghuys. The pH values in the upper reaches of Verlorenvlei at Grootvlei farm, SAND014 at 18km were slightly lower. The highest median pH values were recorded at the estuary sampling site. However, the median pH values over distance vary within a narrow range of 7.4 to 7.6, excluding the estuary values.



The PO_4-P concentrations were the highest in the upper (78.3) and lower (55.9) Kruismans River and in similar ranges further downstream. The inflow from the Krom Antonies River does not seem to have an impact on the PO_4-P concentrations, as was evident with the EC values.



The NO_3+NO_2-N concentrations increased in a downstream direction, with the highest concentrations being recorded in the lower Kruismans River at 52.2km (SAND011) and 55.9km (SAND008). Downstream of the Hol and Krom Antonies confluences, the nitrogen concentrations were low, probably the result of uptake by the extensive reedbeds that cover this reach of the Verlorenvlei River.

There are no long-term water quality monitoring data available in the F60 tertiary catchment.

Water Quality at the EWR Sites

The river catchments that are discussed below are the Papkuils, Verlorenvlei, Langvlei/Wadrif, Jakkals and Sandlaagte in the G30 catchment and the Sout and Brak in the F60 catchment.

It is important to note that all the systems, particularly within their lower wetland sections, are largely groundwater driven or are groundwater-dependent ecosystems. Thus, although the discussions below describe these systems as rivers, they comprise a mix of river and wetland systems and are fed from both ground and surface water. In their lowest reaches, the habitat changes quickly from riverine to wetland and then to estuarine. This implies that the ecological Reserve recommendations for these systems need to take cognizance of the aquatic habitat type, the associated water required to maintain that habitat and to **understand where the water originates from; ground or surface water or a combination thereof depending on the season**. To further challenge our understanding of the system is the seasonal interactions between surface and groundwater, although river flows in the hot, dry summer months become negligible, and surface river water can become isolated pools with a lack of surface flow continuity, which can be maintained by groundwater. This is particularly important for the water quality as there are limited data available and the water quality information gathered from the water quality sampling undertaken in this study are snapshots of the current surface water but not explain where it comes from.

Sources and potential sources of groundwater and surface water pollution need to be considered to better understand the current water quality situation within the study area. Two main potential sources of groundwater pollution were identified in the Sandveld Reserve study (DWAF, 2006). The first is from the application of fertilizer and nutrients to mainly potato crops through centre-pivot irrigation systems. However, it was found that very little nitrate or irrigation water itself actually reached the water table beneath these centre pivots (REF). Very little increase in nitrate levels in groundwater is observed within the Sandveld, although the nitrate levels vary considerably. The highest elevated nitrate in groundwater is in the Redelinghuys area and may be due to the use of septic tank systems and pit latrines, the agricultural activities in the area and the natural accumulation of nitrates in the area. Additional potential sources of pollution will be associated with standard agricultural practices, such as the use and storage of herbicides and pesticides, leakages from storage tanks (diesel) and improper management of domestic waste.

Potential surface water pollution sources also include the application of fertilizers, herbicides and pesticides to irrigated crops and cattle grazing (nutrient and bacteriological contamination) activities in and around the wetland/river systems. Land clearing and erosion also contribute to the suspended sediments (turbidity) and salinity increases that can be experienced when natural areas are cleared for dryland or irrigation activities.

The water quality information collected during the two site surveys at the EWR sites will be evaluated based on the snap-shot water quality sampling results, the trends from the G3H001 water quality gauging station, and the current land use activities. Only the electrical conductivity (EC), total dissolved solids (TDS) and pH will be discussed, as the nutrient values were all less than the laboratory detection limits (0.2 mg/l P for orthophosphate and 0.2 mg/l for NO_3-N and for NO_2-N, and 0.1 mg/l for NH_4-N). Only Langvlei at EWR 8 had an elevated TIN concentration of 1.98 mg/l during the wet season. All the results from the two site surveys are presented in Appendix A in the Wet and Dry Season Survey report (DWS, September 2022).

To determine the ecoclassification for the surface water quality, input from the groundwater, wetland and vegetation component are also required as all the riverine sites are a mix of wetlands and riverine systems with inputs from surface and groundwater.

Papkuils catchment

The most southern catchment, G30A, is situated between Piketberg in the east and the coast. The catchment is largely flat, with a number of small water bodies, the most important being Rocherpan and the Papkuilsvlei that feeds the Papkuils River. The river itself comprises largely a longitudinal wetland that has been significantly modified by the surrounding agricultural activities. The river is classified as ephemeral.

Landuse activities in this catchment are mainly natural areas with planted pastures/crops and groundwater abstraction.

Four EWR sites were selected within this quaternary catchment, and the one on the lower Papkuils River was the only river/wetland EWR site. The other three (Rosherpan, Papkuilsvlei and an isolated depression along the coast) were assessed as wetlands. Water quality samples were collected at the lower Papkuils River (EWR 15-G30A PAPK BOOKR) and at the Papkuilsvlei (EWR 16-G30A PAPK RIETF) towards the end of the wet season in September 2022. There was no water at the EWR 15 site during the dry season.

EWR 16 RW-G30A PAPK RIETF

Water Quality Variable	Results from sample collected on 8 September 2022
pH (at 25°C)	7.63
Electrical Conductivity (mS/m)	129
Total Dissolved Solids (mg/l)	868

The electrical conductivity is relatively low and using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline the water is fit for use for most crops, except for low salt-tolerant crops. The water quality is acceptable for livestock watering (DWAF, 1996b).

The Papkuils seepage area forms the only significant observed groundwater/surface water interaction site in the G30A quaternary catchment, and this spring is a significant one, feeding the Papkuilsvlei and the upper Papkuils River. Water quality is good around the Papkuils seepage area (DWS, August 2022). Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Papkuils River is probably no better than a C at a low confidence level.

Verlorenvlei Catchment

Quaternary catchments G30B (Kruismans River) and G30C (Bergvallei River) form the upper catchment of Verlorenvlei. The catchment of the Kruismans River (G30B) is basin-shaped and surrounded by high mountains, with the Piketberg Mountains to the west and the Olifantsrivierberg to the east. The Kruismans River flows to the north and west, where it cuts through the Piketberg Mountains and is joined by the Bergvallei, Krom Antonies, and Hol rivers to form the Verlorenvlei River. The Verlorenvlei River flows from catchment G30D into G30E, through a well-defined catchment that is rectangular in shape with a northwest/southeast orientation. Only the Verlorenvlei River is classified as seasonal. The others are classified as perennial, although this study has found evidence that they might have changed to non-perennial rivers due to over-abstractions in the catchment.

Landuse activities in catchment G30B (Kruismans River) include natural areas with dryland (wheat) and irrigated (grapes) agriculture, livestock, surface and groundwater abstraction and farm dams. Landuse activities in catchment G30C (Bergvallei River) are natural areas with dryland (rooibos) and irrigated (grapes, citrus, potatoes) agriculture, surface and groundwater abstraction and farm dams. Landuse in catchment G30D (Krom Antonies River) is natural areas with dryland (pastures) and irrigated (grapes, citrus, potatoes) agriculture, surface and groundwater abstraction and farm dams. Landuse in catchment G30E (Verlorenvlei River) are natural areas with dryland (rooibos) and irrigated (grapes, citrus, potatoes) agriculture, surface and groundwater abstraction and groundwater abstraction for Elands Bay.

The lower reaches of the Verlorenvlei, Langvlei and Jakkals Rivers comprise extensive longitudinal wetlands with localised and weak riverine components. Short sections of morphologically distinct river channels exist in the upper catchments (e.g. Upper Kruis, Bergvallei, Krom Antonies Rivers and the headwaters of the Langvlei tributaries – the Alexandershoek and Lambertshoek). Important secondary characteristics are the presence of multiple freshwater springs, or ‘eyes’, occurring along the length of all three systems. Lateral intrusions of brackish to saline water also occur, which results in distinct variations in water quality and plant species throughout the study area. In essence, portions of these systems exist as a series of wetlands, connected by surface channels in places but mostly by flow through the hyporheos zone.

With respect to groundwater/surface water interaction, the Krom Antonies Tributary is regarded as the largest, in terms of area-weighted flow contribution, with the Table Mountain Group (TMG) playing a critical role in terms of baseflow. While the Hol Tributary is saline

(Watson *et al*., 2020a), it is significant that baseflow is more sustained due to the dominance of slow groundwater flow from the Malmesbury shale aquifer.

To give an indication of the complexity of the groundwater/surface water interaction, the recharge of Verlorenvlei is an example, as can be seen from the groundwater chapter in the Draft Ecoclassification Report (DWS, June 2022). The use of isotope dating techniques conducted for the catchment essentially shows three distinct aquifer systems which are mixed before reaching the Verlorenvlei itself (Miller *et al*., submitted scientific paper for publication). These mixing relationships suggest and show the connection between the TMG and primary alluvial aquifer, as well as the connection between the TMG and Malmesbury shale aquifer. The fractured TMG aquifers receive the highest amount of direct recharge (~22-25% of MAP) (Umvoto, 2021).

The quality of the groundwater is very good in the most southern parts of the valley, closest to the mountains. The quality then deteriorates towards the north and especially the northeast (DWS, August 2022).

Three river/wetland EWR sites are located within the Verlorenvlei Catchment, one on the lower Kruismans (EWR 10 RW-G30D KRUI EENHE), one on the lower Krom Antonies (EWR 11 RW-G30D KROM GOERD) Rivers and one on the lower Verlorenvlei River (EWR 12 RW-G30E VERL WITTE), just upstream of the estuary. Water quality samples were collected during the dry and wet seasons from EWR 10 and EWR 11 and a wet season sample was collected from EWR 12 in September 2022. An additional sample was taken in the upper reaches of the Krom Antonies River at Moutonshoek, and although the site is not pristine, that is the nearest to a reference site one could get for this river. A water quality sample was also collected on the Hol River in September 2022 and the results are also presented below.

EWR 10 RW-G30D KRUIS EENHE

Water Quality Variable	Dry Season	Wet Season	Change
pH (at 25°C)	7.35	7.19	↓
Electrical Conductivity (mS/m)	990	650	↓
Total Dissolved Solids (mg/l)	6800	4400	↓

The electrical conductivity is lower during the wet season but still high. Using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline, the water can still be used for irrigation of selected crops provided sound irrigation management is practised and yield decreases are acceptable. The water can be used for livestock watering (both wet and dry seasons), and although there may be an initial reluctance to drink, this will be temporary with no adverse effects (DWAF, 1996b).

A few high yielding (16 – 18 L/s) boreholes have been reported towards the southwestern corner against the Piketberg mountains in the G30 B quaternary catchment. Contact and fault springs have been reported along the Piketberg Mountains, as well as some on the Citrusdal side, where TMG formations meet the Porterville formation. The yields of these springs vary, but the quality is usually good. Most of these springs are used for domestic or irrigation supply and no longer contribute to surface water flow (Kruismans river). Some springs have also been reported along the bank of the Kruismans river (DWS, August 2022).

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Kruismans River is probably no better than a C/D at a low confidence level.

EWR 11 RW-G30D KROM GOERG

Water Quality Variable	Dry Season	Wet Season	Change
pH (at 25°C)	7.65	7.78	↑
Electrical Conductivity (mS/m)	157	28.8	↓
Total Dissolved Solids (mg/l)	1044	202	↓

The electrical conductivity is much lower during the wet season, but both the wet and dry season values indicate a good water quality suitable for irrigation and livestock watering (DWAF, 1996a; DWAF, 1996b).

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Lower Krom Antonies River is probably no better than a C at a low confidence level.

KROM ANTONIES RIVER AT MOUTONSHOEK

Water Quality Variable	Results from sample collected on 7 September 2022
pH (at 25°C)	8.49
Electrical Conductivity (mS/m)	12.3
Total Dissolved Solids (mg/l)	78

The electrical conductivity in the upper reaches of the Krom Antonies River is within the ideal water quality ranges for all water users and as expected, the EC in the upper reaches is lower than the EC in the lower reach at the EWR site.

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Upper Krom Antonies River is probably a B at a low confidence level.

EWR 12 RW-G30E VERL WITTE

Water Quality Variable	Results from sample collected on 8 September 2022
pH (at 25°C)	7.62
Electrical Conductivity (mS/m)	194
Total Dissolved Solids (mg/l)	1300

The electrical conductivity is relatively low and using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline the water can be used for moderately salt-tolerant crops by using a low-frequency application system. Wetting of the foliage of salt-sensitive crops should be avoided. The water quality is acceptable for livestock watering (DWAF, 1996b).

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Lower Verlorenvlei River is probably a C/D at a low confidence level.

HOL RIVER

Water Quality Variable	Results from sample collected on 8 September 2022
pH (at 25°C)	6.98
Electrical Conductivity (mS/m)	720
Total Dissolved Solids (mg/l)	4820

The electrical conductivity is high. Using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline, the water can still be used for irrigation of selected crops provided sound irrigation management is practised and yield decreases are acceptable. The water can be used for livestock watering, and although there may be an initial reluctance to drink, this will be temporary with no adverse effects (DWAF, 1996b).

Langvlei Catchment

To the north of the Verlorenvlei catchment (G30E) is the Langvlei catchment (G30F), which is the largest in the area and extends from the Swartberg in the east to the coast. The Alexandershoek and Lambertshoek Rivers drain these mountains and join to form the Langvlei River. In the lower Langvlei, extensive wetland areas occur up until the Wadrif area. Downstream from the Wadrif wetland is the Wadrif saltpan which extends down to the coastal dune system. The river is classified as ephemeral.

Landuse in catchment G30F (Langvlei River) are natural areas with dryland (rooibos) and irrigated (pastures, wheat, potatoes) agriculture, livestock, surface and groundwater abstraction and groundwater abstraction for Leipoldtville and Lamberts Bay.

Two EWR sites are located in this catchment, one in the lower Langvlei (EWR 8 RW-G30F LANG BRAND), a river/wetland EWR site and a second in the Wadrif Wetland (wetland assessment site only). Water quality samples were collected during the dry and wet seasons from EWR 8.

EWR 8 RW-G30F LANG BRAND

Water Quality Variable	Dry Season	Wet Season	Change
pH (at 25°C)	6.83	6.9	↑
Electrical Conductivity (mS/m)	1501	1214	↓
Total Dissolved Solids (mg/l)	12400	7998	↓

The electrical conductivity is lower during the wet season but still very high. Using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline, the water can still be used for irrigation of selected crops (> 540 mS/m) provided sound irrigation management is practised and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive, and the likelihood of sustainable irrigation decreases rapidly. The water cannot be used for livestock watering (both wet and dry seasons) on a long-term basis (DWAF, 1996b).

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Langvlei is probably a D at a low confidence level.

Jakkals Catchment

To the north of the Langvlei/Wadrif catchment is the Jakkals catchment (G30G). It is bounded in the east by the rugged Langeberg and Uitkomsberge mountains, with the town of Graafwater at the base of these mountains. At the coast, the Jakkals River terminates with the Jakkalsvlei. The Jakkals River is classified as ephemeral.

Landuse in catchment G30G (Jakkals River) are natural areas with dryland (pastures, rooibos) and irrigated (wheat) agriculture, livestock, and groundwater abstraction.

Groundwater/surface water interaction: For the Jakkals River catchment (G30G), in the area around Graafwater to 8 km downstream from Graafwater, there is no perceived contribution from groundwater to surface water flow, and the river system is a losing system (recharging groundwater) (GEOSS, 2005). Although historically, springs did occur (Kookfontein) towards the coast along the Jakkals River, these dried up many years ago. The only gaining section on the Jakkalsvlei River is situated midway between Graafwater and Lamberts Bay.

A single river/wetland EWR site (EWR 7 RW-G30G JAKK KOOKF) is located in the lower reaches of this system. Water quality samples were collected during the dry and wet seasons from EWR 7 at the pool of water close to the road. An additional sample was collected at the SASS collection site during the wet season sampling and is some distance (a couple hundred metres) upstream of the road sampling site.

EWR 7 RW – G30G JAKK KOOKF

Water Quality Variable	Dry Season	Wet Season	Change
pH (at 25°C)	7.39	7.12	↓
Electrical Conductivity (mS/m)	10100	2200	↓
Total Dissolved Solids (mg/l)	61200	14600	↓

The electrical conductivity is lower during the wet season but still very high. Using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline, the water can still be used for irrigation of selected crops (> 540 mS/m) provided sound irrigation management is practised and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly. The water cannot be used for livestock watering (both wet and dry seasons) on a long-term basis (DWAF, 1996b).

Based only on the snapshot water quality data, the land use and the groundwater input, the water quality Ecoclassification of the Jakkals River is probably a C/D at a low confidence level.

EWR 7 RW – G30G JAKK KOOKF - water quality sample taken at the SASS sampling site

Water Quality Variable	Results from sample collected on 6 September 2022
pH (at 25°C)	6.57
Electrical Conductivity (mS/m)	1225
Total Dissolved Solids (mg/l)	8200

The electrical conductivity is very high. Using the South African Water Quality Guideline for Agricultural use (DWAF, 1996a) as a guideline, the water can still be used for irrigation of selected crops (> 540 mS/m) provided sound irrigation management is practised and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly. The water cannot be used for livestock watering on a long-term basis (DWAF, 1996b).

When comparing the data from the two sampling sites on the Jakkals River during the wet season, there are considerable differences between the EC of the two sites, although they are only a couple of hundred meters apart. This once again illustrated the danger of extrapolation in these non-perennial systems.

Sandlaagte catchment

The most northern catchment of the study area, G30H, consists of the coastal plain south of the Olifants River mouth. The Sandlaagte River is classified as ephemeral and there are no significant surface water bodies within this catchment and land use development is limited to natural areas with dryland (pastures) agriculture, and groundwater abstraction

A single EWR site has been selected in the lower Sandlaagte River that will be assessed as a desktop-based assessment, with possible field verification. In terms of water quality, no samples were collected due to the absence of any no surface water, and no historical water quality data are available.

Sout catchment

To the north of the Olifants River Estuary is the Sout River Catchment that comprises the Groot Goerap (F60D), Klein Goerap (F60B) and the Sout River (F60C). The rivers drain westwards from the high-lying hills along the N7, draining down to the deep sands on the coast. The towns of Rietpoort, Nuwerus and Bitterfontein lie within the upper reaches of this catchment. Due to the arid nature of this area, the surface water features are largely ephemeral and land use activities are limited to largely natural, with some livestock and some groundwater abstraction.

A single EWR site was selected within this catchment, on the lower Groot Goerap River, that will be assessed as a desktop-based assessment, with possible field verification. In terms of water quality, no water quality samples were collected due to the absence of natural surface water, and no water quality data are available.

Brak catchment

The Brak River is a small catchment (F60A) in the northern portion of F60. Like the Sout River to the south, the river drains the higher-lying Ribbokberg, draining westwards through the deep sands on the coast. Significant surface water bodies (the Brak River is classified as ephemeral) within this catchment and land use development are limited to largely natural, with some livestock.

A single river/wetland EWR site has been selected in the lower river that is still to be assessed by means of a desktop-based assessment, with possible field verification. In terms of water quality, no samples were collected (no surface water) and no water quality data are available.

2.3.3. River Ecological Assessments

The study area comprises seven river catchments (Papkuils, Verlorenvlei, Langvlei/Wadrif, Jakkals and Sandlaagte in the G30 catchment and the Sout and Brak in the F60 catchment). Figure 13 shows these catchments that are described further below.

Verlorenvlei Catchment

Quaternary catchments G30B (Kruismans River) and G30C (Bergvallei River) form the upper catchment of Verlorenvlei. The catchment of the Kruismans River (G30B) is basin-shaped and surrounded by high mountains, with the Piketberg Mountains to the west and the Olifantsrivierberg to the east. The Kruismans River flows to the north and west, where it cuts through the Piketberg Mountains and is joined by the Bergvallei, Krom Antonies, and Hol rivers to form the Verlorenvlei River.

The Bergvallei River (G30C) drains the Swartberg Mountains (which reach an elevation of 1153 m above mean sea level (mamsl)) to the east and flows in a southerly direction into the Kruismans River. There are no major towns in this catchment and it is mainly an agricultural area with extensive use of groundwater. The catchment is an important recharge area for the Sandveld aquifers.

The Kruismans River drains into quaternary catchment G30D on the northwestern side of the Piketberg Mountains. The Piketberg Mountains are steeply sided dropping off over a short distance into a catchment that is rather flat and featureless. It is a catchment of extensive agriculture, due to its relatively flat relief. It is also within this catchment that alien plant infestation is at its greatest along the course of the Verlorenvlei River. The Krom-Antonies and Hol tributaries contribute from the southern part of the G30D catchment. The Verlorenvlei River flows from catchment G30D into G30E, through a well-defined catchment that is rectangular in shape with a northwest / southeast trend. It is a hilly and scenic catchment with a significant amount of agricultural activity and contains the Verlorenvlei wetland.

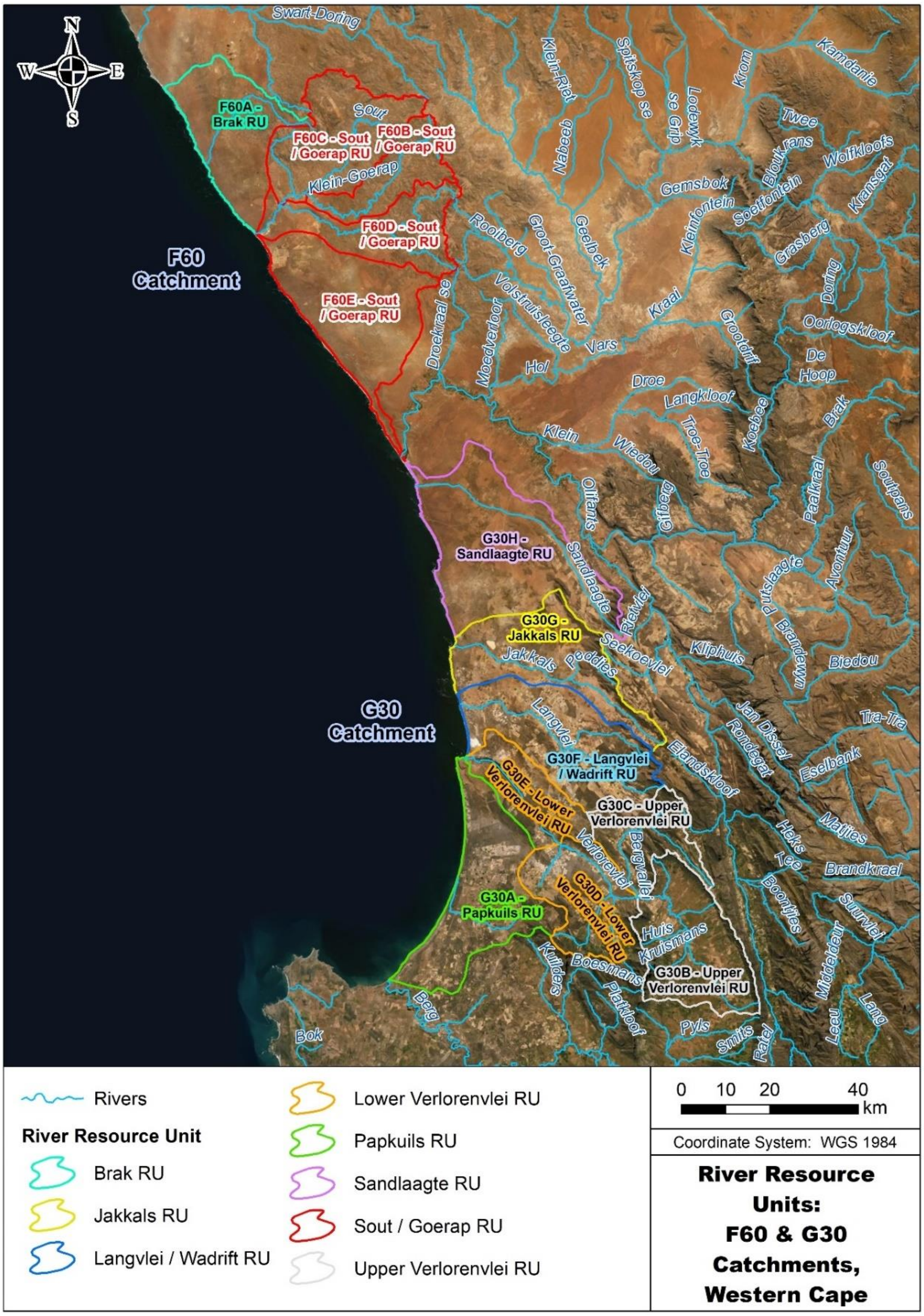


Figure 13. Map showing the River Resource Units within the study area

Langvlei Catchment

To the north of the Verlorenvlei catchment (G30E) is the Langvlei catchment (G30F), which is the largest in the area and extends from the Swartberg (1153 mamsl) in the east to the coast. The Alexandershoek and Lambertshoek Rivers drain these mountains and join to form the Langvlei River. This catchment is quite rugged, yet agricultural activity is the greatest here in the entire study area. To the south of the Langvlei River is a mountain ridge called the Bobbejaansfonteinberge, Olifantsberg and Grootberg, which do not form the catchment boundary, as to the south of this ridge is another wide and almost secluded valley, which contains the Wadrif aquifer.

The town of Leipoldtville is situated near the Bobbejaansfonteinberge and Langvleiberge. In the Brandwag area, extensive wetland areas occur up until the Wadrif area and the Lambert's Bay wellfield. The Wadrif Wetland, however, is now desiccated and permanently damaged due to the underground fire that burnt there for approximately two years. Downstream from the Wadrif wetland is the Wadrif saltpan which extends down to the coastal dune system.

Jakkals catchment

To the north of the Langvlei/Wadrif catchment is the Jakkals catchment (G30G). It is bounded to the east by the rugged Langeberg and Uitkomsberge mountains that drop off quite rapidly to the west. The town of Graafwater is at the base of these mountains. From Graafwater to the coast, the topography is relatively flat and featureless. At the coast, the Jakkals River terminates with the Jakkalsvlei. Agricultural activity occurs only to a limited extent within this catchment.

Sandlaagte catchment

The most northern catchment of the study area G30H consists of the coastal plain south of the Olifants River mouth. There are no significant surface water bodies within this catchment and land use development is limited.

Papkuils catchment

The most southern catchment, G30A is situated between Piketberg on the west and the coast. It is also largely flat, with a number of small water bodies, the most important being Rocherpan and the Papkuilsvlei that feeds the river. The river itself comprises largely a longitudinal wetland that has been significantly modified by the surrounding agricultural activities. To the south of the catchment lies the Berg River Estuary.

Sout catchment

To the north of the Olifants River Estuary is the Sout River Catchment that comprises the Groot Goerap (F60D), Klein Goerap (F60B) and the Sout River F60C). The rivers drain westwards from the high-lying hills along the N7, draining down to the deep sands on the coast. The towns of Rietpoort, Nuwerus and Bitterfontein lie within the upper reaches of this catchment. Due to the arid nature of this area, the surface water features are largely ephemeral and land use activities are limited.

Brak catchment

The Brak River is a small catchment (F60A) in the northern portion of F60. The smaller settlements of Kotzerus and Lepelfontein are located within this catchment. Like the Sout River to the south, the river drains the higher-lying Ribbokberg, draining westwards through the deep sands on the coast. The surface water features are ephemeral, with limited land use that comprises largely livestock.

The primary classification of rivers is a division into Ecoregions. Ecoregions are groups of rivers within South Africa that share similar physiography, climate, geology, soils and potential natural vegetation. For this study, the ecoregional classification presented in DWAF (1999), which divides the country's rivers into ecoregions, was used. Ecoregions within the study area are:

- South Western Coastal Belt (most of the G30 catchment);
- Western Coastal Belt (most of the F60 catchment);
- Western Folded Mountains (eastern extent of the G30 catchment); and
- Namaqua Highlands (north eastern extent of the F60 catchment).

Rivers within an ecoregion are further divided into sub-regions. Sub-regions (or geomorphological zones) are groups of rivers, or segments of rivers, within an ecoregion, which share similar geomorphological features, of which gradient is the most important. The use of geomorphological features is based on the assumption that these are a major factor in determining the distribution of the biota. The Ecoregion and Geomorphological zone characteristics for the study area are included in Table 8.

The lower reaches of the Verlorenvlei, Langvlei and Jakkals Rivers comprise extensive longitudinal wetlands with localised and weak riverine components. Short sections of morphologically distinct river channels exist in the upper catchments (e.g. Upper Kruis, Bergvallei, Krom Antonies Rivers and the headwaters of the Langvlei tributaries – the Alexandershoek and Lambertshoek). Important secondary characteristics are the presence of multiple freshwater springs, or 'eyes', occurring along the length of all three systems. Lateral intrusions of brackish to saline water also occur, resulting in distinct variations in water quality and plant species throughout each of the three systems. In essence, portions of these systems exist as a series of wetlands, connected by surface channels in places but mostly by flow through the hyporheos.

All the systems, particularly within their lower wetland sections, are largely groundwater driven or are groundwater-dependent ecosystems. Thus, although the discussions below describe these systems as rivers, they comprise rather a mix of river and wetland and are fed from both ground and surface water. In their lowest reaches, the habitat changes quickly from riverine to wetland and then to estuarine. This implies that the ecological Reserve recommendations for these systems need to take cognisance of the aquatic habitat type, the associated water required to maintain that habitat and to understand where the water supply comes from, ground or surface water or a combination thereof depending on the season. This requires good integration between the various disciplines contributing to this Reserve study.

The previous Ecological Reserve (Rapid Level), undertaken by Southern Waters for the G30 Catchment in 2003, comprised assessments of the Kruismans Tributary of the Verlorenvlei River, the lowest reach of the Verlorenvlei River, the lowest reach of the Langvlei River and the lowest reach of the Jakkals River (Figure 14).

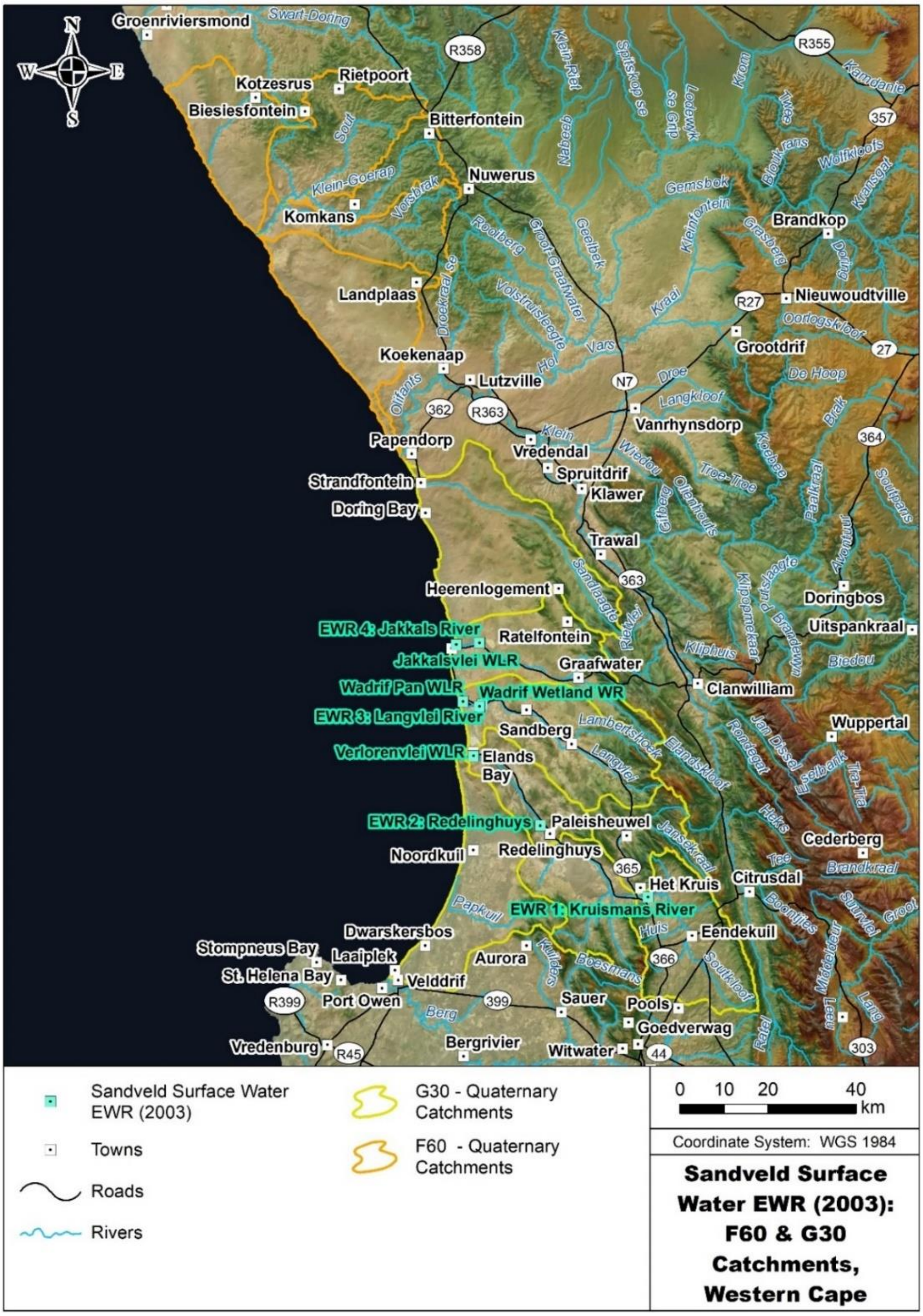


Figure 14. Map of surface water EWR sites for the Sandveld Reserve determination undertaken in 2003

A PESC assessment was undertaken at each site that included water quality, macroinvertebrates and habitat integrity assessments. The EISC was also determined for each site. The result from the assessments is provided in Table 6.

Table 6. Summary of the PESC and EISC for the Sandveld Ecological Reserve Determination in 2003

EWR Location	Quaternary	PES	EIS	REC
Langvlei River	G30F	E/F	Moderate	C
Wadrif Wetland	G30F	F	High	C
Wadrif Pan	G30F	E	Moderate	C
Jakkals River	G30G	D	Moderate	C
Jakkalsvlei/Estuary	G30G	E	Moderate	C
Verlorenvlei (Kruis)	G30D	C	High	C
Verlorenvlei (Redelinghuys)	G30E	C	High	B
Verlorenvlei Lake/Estuary	G30E	C	High	B

In 2006 a State of Rivers Report was completed for the Olifants/Doring and Sandveld Rivers (DWA, 2006) that included an assessment of the habitat integrity, geomorphology, riparian vegetation, macroinvertebrates, fish and water quality at five sites in the Verlorevlei River System (upper and lower Kruismans, Bergvallei, Krom Antonies and the Verlorenvlei at Redelinghuys), and one site each on the Langvlei and Jakkals Rivers. The Ecological Importance (EI) and Ecological Sensitivity (ES) were also assessed, and a desired ecological state was recommended. An additional site was also included in the Sout/Goerap River that comprised habitat integrity and riparian vegetation assessments.

The seven River Eco-status Monitoring sites (indicated as Macroinvertebrate sites in Figure 19) have been sampled between three and ten times over the period between 2004 and 2015. There are an additional 17 fish once-off sampling sites sampled primarily in the Verlorenvlei River but also in the Langvlei, Jakkals and Papkuils Rivers. Eight once-off sampling sites for adult dragonflies have also been undertaken in the Sandveld Rivers. The Freshwater Biodiversity Information System (FBIS) also displays the Odonata (dragonfly and damselfly) data from the OdonataMap Virtual Museum, FitzPatrick Institute of African Ornithology at the University of Cape Town. Eight records of dragonfly observations occur within the study area on the FBIS.

The desktop Present Ecological Status (PES), Ecological Importance (EI) and Ecological Sensitivity (ES) has been determined in the various river reaches within the study area, following the procedures in Kleynhans and Louw (2007). The Desktop PES, EI and ES are available at the sub-quaternary level (DWA, 2013) and are summarised in Table 7. The desktop assessment of the PES, EI and ES (DWS, 2014) was undertaken for 28 river reaches in the G30 Catchment, and 14 river reaches in the F60 Catchment. Also of significance is the National Freshwater Ecosystem Priority Area (NFEPA) and mapped aquatic Critical Biodiversity Areas. These have been included in Table 8 and Table 12.

The outcomes of these assessments, which included the results from the River Eco-status assessments, were incorporated into the Water resources classification for the Olifants Doorn Water Management Area (including the rivers of the G30 and F60 catchments at a quaternary catchment level), which was completed in 2012 and gazetted in 2014. Resource quality objectives (RQOs) were gazetted for these rivers in 2015 (Notice No. 609 of 2015 published in Government Gazette 39001 dated 17 July 2015) and included RQOs for the lower Verlorenvlei, Langvlei, Jakkals and Sandlaagte Rivers.

The Water Resource Classification Study for the larger Olifants-Doorn Water Management Area was then completed in April 2012, followed by the Determination of Resource Quality Objectives (RQO) completed in March 2013. The categories for the quaternary catchments in the Olifants-Doorn WMA recommended by the Classification project (DWA 2012) and updated in the RQO project are provided in Table 7.

Table 7. Summary of PES and Recommended Ecological Categories from the Classification and RQO projects for the F60 and G30 catchments (DWA, 2013)

Quaternary	PES (2011)	REC - Incremental	REC - Cumulative
F60A	B	B	B
F60B	B	B	B
F60C	B	B	B
F60D	B	B	B
F60E	B	B	B
G30A	C	C	C
G30B	C	C	C
G30C	C	C	C
G30D	C	C	C
G30E	C	C	B
G30F	C	C	C
G30G	C	C	C
G30H	C	C	C

Based on the dry and wet season surveys undertaken as part of this study, the Ecostatus of the rivers at the EWR sites has been revised. Assessments of the drivers (hydrology, water quality geomorphology) and biotic responses from vegetation (instream and riparian), macroinvertebrates and fish were included. In addition, level 4 Index of Habitat Integrity (IHI) assessments for the G30 Catchment rivers (excluding Sandlaagte River). Rapid-level IHI assessments were undertaken for the remaining rivers. A summary of the results from the assessments is provided in Section 2.3.6, where the results have been integrated with the findings of the wetland assessment.

Table 8: Summary of the main characteristics of the River Resource Units within the F60 Catchment

RIVER RESOURCE UNIT	QUATERNARY	ECOREGION	MAIN RIVER	HYDROLOGICAL INDEX	GEOMORPHIC	ALTITUDE (M)	BIOREGION	GEOLOGY	LANDUSE	EI&ES	PES	REC	RESERVE REGION
Brak RU	F60A	Western Coastal Belt; Namaqua Highlands	Brak	Ephemeral	Mountain Stream to Lower foothill	0-500	Northwest Fynbos, Namaqualand Sandveld & Hardeveld	Marine terrace gravel & sand, red dune sand, loamy & granitic sand, calcrete, dorbank, white calcareous sand	Largely natural with some livestock	High/ High	B	B	West Karoo
Sout/Goerap RU	F60B	Western Coastal Belt; Namaqua Highlands	Klein-Goerap	Ephemeral	Mountain Stream to Lower foothill	0-500	Namaqualand Hardeveld	Aeolian material overlying granites & gneisses of Namaqualand Metamorphic Complex and marine sediments	Largely natural with some livestock; groundwater abstraction at Bitterfontein	High/ High	B	B	West Karoo
	F60C	Namaqua Highlands; Western Coastal Belt	Sout	Ephemeral	Mountain Stream to Lower foothill	0-450	Knersvlakte & Namaqualand Hardeveld	Aeolian material overlying granites & gneisses of Namaqualand Metamorphic Complex and marine sediments	Largely natural with some livestock	High/ High	B	B	West Karoo
	F60D	Western Coastal Belt	Groot Goerap	Ephemeral	Mountain Stream to Lowland	0-500	Knersvlakte, Namaqualand Sandveld & Hardeveld	Aeolian material overlying granites & gneisses of Namaqualand Metamorphic Complex and marine sediments	Largely natural with some livestock	High/ High	B	B	West Karoo
	F60E	Western Coastal Belt	None	N/A	N/A	0-350	Northwest Fynbos, Namaqualand Sandveld & Hardeveld	Aeolian material overlying granites & gneisses of Namaqualand Metamorphic Complex and marine sediments	Largely natural with some livestock; mining activities	N/A	N/A	N/A	West Karoo

Table 9: Summary of the main characteristics of the River Resource Units within the G30 Catchment

RIVER RESOURCE UNIT	QUATERNARY	ECOREGION	MAIN RIVER	HYDROLOGICAL INDEX	GEOMORPHIC	ALTITUDE (M)	BIOREGION	GEOLOGY	LANDUSE	EI&ES	PES	REC	RESERVE REGION
Papkuil RU	G30A	South Western Coastal Belt	Papkuil	Ephemeral	Upper foothill to Lowland	0-550	West Strandveld & Northwest Fynbos	Aeolian sand with underlying greywacke and phyllite and lenses of quart schist, limestone and grit of the Moorreesburg Formation; Malmesbury Group.	Natural areas with planted pastures/crops and groundwater abstraction	Moderate/ High	D	C	West Karoo
Upper Verlorenvlei RU	G30B	South Western Coastal Belt; Western Folded Mnts	Kruismans	Perennial	Mountain Stream to Lower foothill	0-1400	West Coast Renosterveld & Northwest Fynbos	Phyllitic shale, schist, greywacke with limestone and quartzitic sandstone and conglomerate beds of the Porterville Formation; Malmesbury Group.	Natural areas with dryland (wheat) and irrigated (grapes) agriculture; livestock; surface and groundwater abstraction; farm dams	Moderate/ High	D	C	W Cape (dry)
	G30C	South Western Coastal Belt; Western Folded Mnts	Bergvallei	Perennial	Upper foothill to Lowland	0-1250	Northwest Fynbos	Quartzitic sandstone with grit, conglomerate and shale of the Piekenierskloof Formation; Table Mountain Group and shale, schist and greywacke of the Porterville Formation; Malmesbury Group	Natural areas with dryland (rooibos) and irrigated (grapes, citrus, potatoes) agriculture; surface and groundwater abstraction; farm dams	Moderate/ Very High	D	C	W Cape (dry)

RIVER RESOURCE UNIT	QUARTER NARY	ECOREGION	MAIN RIVER	HYDROLOGICAL INDEX	GEOMORPHIC	ALTITUDE (M)	BIOREGION	GEOLOGY	LANDUSE	EI&ES	PES	REC	RESERVE REGION
Lower Verlorenvlei RU	G30D	Western & South Western Coastal Belt	Krom Antonies	Perennial	Mnt headwater to Lowland	0-200	West Coast Renosterveld & Northwest Fynbos	Aeolian sand with some feldspathic grit, greywacke, quartz schist, conglomerate and limestone beds with lenses of phyllite of the Piketberg Formation; Malmesbury Group	Natural areas with dryland (pastures) and irrigated (grapes, citrus, potatoes) agriculture; surface and groundwater abstraction; farm dams	Moderate/ Very High	D	C	W Cape (dry)
	G30E	Western & South Western Coastal Belt; Western Folded Mnts	Verlorenvlei	Seasonal	Mnt headwater to Lower foothill	0-500	Northwest Fynbos & West Strandveld	Aeolian sand with mainly quartzitic sandstone and shale of the Piekenierskloof and Graafwater Formations	Natural areas with dryland (rooibos) and irrigated (grapes, citrus, potatoes) agriculture; surface and groundwater abstractions: Elands Bay abstraction	Moderate/ Very High	D	B	W Cape (dry)
Langvlei/ Wadrif RU	G30F	Western & South Western Coastal Belt; Western Folded Mnts	Langvlei	Ephemeral	Mnt Stream to Lower foothill	0-1200	Northwest Fynbos & West Strandveld	Aeolian sand with mainly quartzitic sandstone and shale of the Piekenierskloof and Graafwater Formations	Natural areas with dryland (rooibos) and irrigated (pastures, wheat, potatoes) agriculture; livestock; groundwater abstractions; Leipoldville and Lamberts Bay groundwater abstraction	Moderate/ Very High	D	C	West Karoo
Jakkals RU	G30G	Western & South Western Coastal Belt; Western Folded Mnts	Jakkals	Ephemeral	Mnt Stream to Lower foothill	0-800	Northwest Fynbos & Namaqualand Sandveld	Aeolian sand with underlying marine sediments with quartzitic sandstone	Natural areas with dryland (pastures, rooibos) and irrigated (wheat) agriculture; livestock; groundwater abstraction	Moderate/ Very High	D	C	West Karoo
Sandlaagte RU	G30H	Western & South Western Coastal Belt	Sandlaagte	Ephemeral	Mountain Stream to Lower foothill	0-700	Northwest Fynbos & Namaqualand Sandveld	Aeolian sand with underlying marine sediments with quartzitic sandstone	Natural areas with dryland (pastures) agriculture; groundwater abstraction	Moderate/ Very High	D	C	West Karoo

2.3.4. Wetlands

Very little information is available for wetlands in Quaternary Catchments G30 and, especially, F60. Firstly, the coverage and accuracy of the mapping of wetlands in these study areas are not particularly good. Except for the bigger, more well-known systems (such as Wadrift wetland, Verlorenvlei, Langvlei and Jakkalsvlei), most of the wetlands have been mapped at a low level of confidence only based on desktop-based information. The most recent comprehensive coverage of wetlands in the study area is the desktop-based National Wetland Map 5 (NWM5) (see Figure 15 and 16), produced as part of the South African Inventory of Inland Aquatic Ecosystems (Van Deventer *et al*., 2018), which formed the basis of the wetland component of the National Biodiversity Assessment 2018 (NBA-2018) (Van Deventer *et al*., 2019).

The earlier NFEPA project (Nel *et al*., 2011) also mapped wetlands in the study area and identified FEPA wetlands considered to be of particular conservation importance, while the WCBSP (after Pool-Stanvleit *et al*., 2017) includes wetlands that have been mapped in the study area and categorised as regionally important Aquatic CBAs.

The mapping of wetlands by NWM5 and NFEPA did include desktop-based information on the types of wetlands (as shown on the maps of NWM5 wetlands in Figures 15 and Figure 16), while NFEPA and the NBA-2018 also included some modelled estimates of the Present Ecological State (PES) of the wetlands based on available land cover data (as explained by Nel *et al*., 2011 and Van Deventer *et al*., 2019, respectively). Information on the hydrology, geomorphology and water quality of wetlands in the F60 and G30 catchments is, however, severely lacking, as is information on the biota associated with the wetlands.

No EWR studies have been completed for wetland ecosystems in Quaternary Catchment F60. The most detailed information collected to date for wetlands in Quaternary Catchment G30, especially in relation to EWR studies, is that which was collected for the Sandveld Preliminary (Rapid) Reserve Determinations for the Langvlei, Jakkals and Verlorenvlei systems (DWAF, 2003). All three systems are essentially extensive longitudinal wetlands with localised and weak riverine components, according to the Reserve report (Southern Waters, 2003). Despite this reality, the only Resource Unit that was dealt with as a "wetland" in this study was the Wadrift wetland, forming part of the Langvlei system. The other units were treated as estuarine or river ecosystems.

The Wadrif Wetland is a small wetland at the point of discharge of the Langvlei River onto the coastal plain, immediately upstream of and grading into the Wadrif Pan. As such, the wetland was classified as a floodplain wetland system by Southern Waters (2003), but with a high degree of riverine character in its upper reaches and pan shoreline at the downstream end where it grades into the Wadrift Pan (estuarine ecosystem). The wetland has a very high degree of groundwater dependence, according to Southern Waters (2003).

Figure 15. Wetlands in the F60 catchments, categorised according to HGM type, as mapped and categorised by National Wetlands Map 5

Figure 16. Wetlands in the G30 catchments, categorised according to HGM type, as mapped and categorised by National Wetlands Map 5

In the absence of readily available and tested methods for Wetland RDM studies at the time, the following pilot approach was employed by Southern Waters (2003) for the preliminary determination of the water requirements for the Wadrif wetland:

1. Identification and description of the reference conditions;
2. Identification of the key drivers, cause and effect functions and stressors that underpin the ecological, functional and socio-economic functioning of the wetland;
3. Undertaking of preliminary level hydrology, hydraulics, water quality and biotic (floral and faunal – inclusive of sediments) verification of the condition of the wetland and its (transect-based) association with its upland (terrestrial) environment, and longitudinal connections up-and downstream;
4. Determination of the Present Ecological Status Class (PESC) using the Wetland Rehabilitation and Assessment Protocol (WRAP) that was in development by Southern Waters at the time of the study;
5. Determination of the Trajectory of Change of the identified key components of system functionality;
6. Determination of the Ecological Importance and Significance (EISC) of the system – using a specialist workshop process and other pertinent information;
7. Identification of key indicators that support the identification of water levels and durations of inundation;
8. Determination of the desired Ecological Management Category (EMC);
9. Determination of the (preliminary) water requirements (PWR) to meet the EMC;
10. Comparison and contrasting of the PWR with the availability of water from the IFR assessment to link the PWR to the system hydrology;
11. Specification of the degree of confidence in the recommendations and identify such further work as may be required to develop the required level of understanding.

In the study to determine RQOs for the Olifants Doorn WMA (DWA 2013), narrative and numeric RQOs were included for the Wadrift wetland (discussed above in relation to the EWR), and some narrative RQOs were included for the Sandlaagte wetlands in Catchment G30H. No RQOs have been set to date for any other wetlands in Quaternary catchments G30 or F60 due to a lack of sufficiently detailed information at this point in time. It was recommended by DWA (2013) that additional Priority Resource Units should be identified in the broader Olifants Doorn WMA, for which RQOs will then need to be determined. This is particularly important for wetland ecosystems in Quaternary Catchments F60 and G30.

During the Wetland Resource Unit (RU) selection process, which was explained in detail in the Surface Water Delineation Report for the current project (DWS Report Number: RDM/WMA09/00/CON/0124), four Wetland RUs were selected in Catchment F60 and ten in Catchment G30. A list of the Wetland RUs that were selected is provided in Table 10, and maps showing the location of the Resource Units in Tertiary Catchments F60 and G30 are presented in Figure 17 and Figure 18, respectively. Table 10 gives the name of each Wetland RU, together with an indication of the Quaternary catchment and Bioregion group that each RU falls into as well as the HGM type of the RU. In addition, the modelled PES of each Wetland RU, as derived on a desktop-basis by the NFEPA-2011 and NBA-2018 assessments, is given together with an indication of the FEPA status (from NFEPA) and ETS (from NBA-2018) of each RU.

Table 10: List of Wetland Resource Units (RUs) selected in Tertiary catchments F60 and G30, together with the desktop-based PES (from NFEPA and NBA-2018) and the FEPA status and Ecosystem Threat Status (ETS) for each RU

Tertiary catchment	Quaternary catchment	Wetland RU name	Site	Bioregion group	HGM type*	PES_NFEPA (FEPA status)	PES_NBA'18 (ETS**)
F60	F60A	Lower Brak River VB wetland	Above EFZ on Farm RE/559 Strandfontein	Sandveld_ F6	CVB	A/B (non-FEPA)	- (CR)
	F60A	NW Fynbos depression	On Farm RE/641 Nuwe-Begin	NW Fynbos	DEP	A/B (FEPA)	A/B (EN)
	F60C	Knersvlakte depression	On Farm RE/145 Adoonsvlei	Hardeveld-Knersvlakte	DEP	A/B (FEPA)	A/B (LC)
	F60E	Sandveld depression	On Ptn 18/20 of Farm 158 Elsie Erasmus Kloof	Sandveld_ F6	DEP	C (non-FEPA)	A/B (CR)
G30	G30G	Lower Jakkals River VB wetland	Above EFZ on Ptn 3 of Farm 88 Kookfontein	NW-SW Fynbos	CVB	C (FEPA)	D/E/F (CR)
	G30F	Lower Langvlei VB wetland	On Ptn 23 of Farm 226 Branswacht	West Strandveld	UVB	C (FEPA)	D/E/F (CR)
	G30F	Wadrift VB wetland (Lower Langvlei)	On Farm RE/230 Wagendrift	West Strandveld	UVB	C (FEPA)	- (CR)
	G30D	Upper Verlorenvlei River VB wetland	Above R366 bridge on Ptn 1 of Farm 42 Eenheid	W-Coast Renosterveld	CVB	C (FEPA)	D/E/F (CR)
	G30D	Krom-Antonies River FP wetland	u//s Verlorenvlei R confl. on Farm RE/40 Goergap	W-Coast Renosterveld	FP	C (FEPA)	D/E/F (CR)
	G30E	Lower Verlorenvlei River FP wetland	Edge of EFZ on Ptn 4 of Farm 4 Wittedrift	NW-SW Fynbos	FP	C (FEPA)	- (CR)
	G30A	West Strandveld duneslack wetland	Above tar road on Ptn 27 of Farm 277	West Strandveld	DEP	C (FEPA)	D/E/F (CR)
	G30A	Rocherpan	Within Nature Reserve on Farm 272	West Strandveld	DEP	A/B (FEPA)	D/E/F (CR)
	G30A	Lower Papkuils FP wetland	Above railway line on Ptn 1 of Farm 30 Bookram	NW-SW Fynbos	FP	C (FEPA)	D/E/F (CR)
	G30A	Upper Papkuils seep	On Ptn 3 of Farm 18 Rietfontein	NW-SW Fynbos	SEEP	C (FEPA)	D/E/F (VU)

** HGM types: FP = Floodplain wetland;; CVB = Channelled valley-bottom wetland; UVB = Unchannelled valley-bottom wetland; SEEP = Seep; DEP = Depression; FLAT = Wetland Flat*

*** Ecosystem Threat Status (ETS) rating categories: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern*

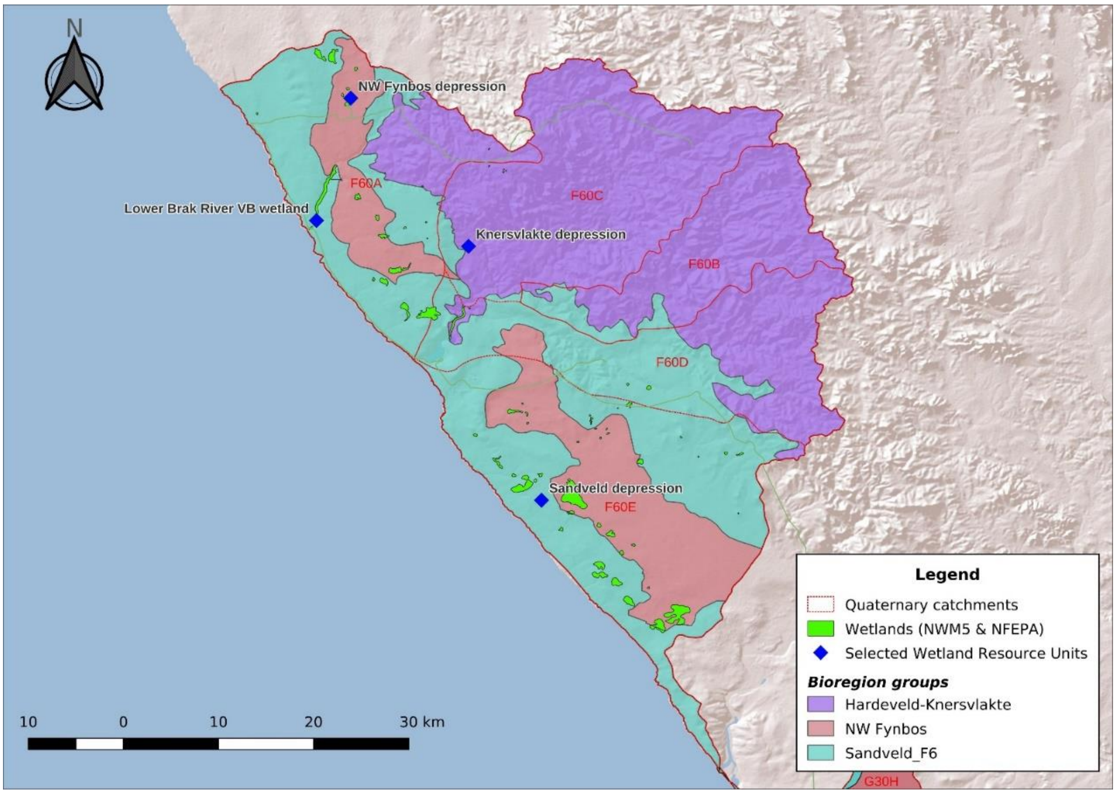


Figure 17. Map of selected Wetland Resource Units in Tertiary Catchment F60, shown in relation to the Bioregion Groups in the Catchment

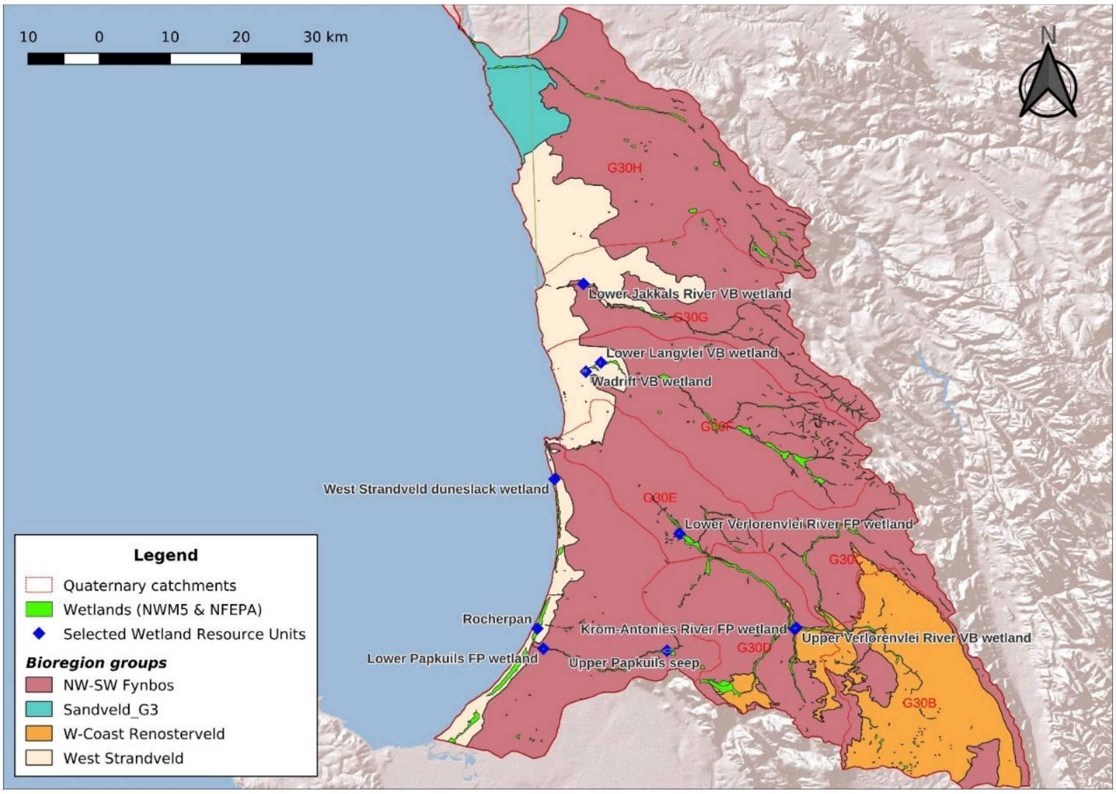


Figure 18. Map of selected Wetland Resource Units in Tertiary Catchment G30, shown in relation to the Bioregion Groups in the Catchment

As for the river assessment, dry and wet season survey data was utilised to determine the wetland PES at the EWR sites. A summary of the results from the assessments is provided in Section 2.3.6.

2.3.5. Freshwater biota

Aquatic Vegetation

The arid river systems within the northern half of the study area tend to be dry for most of the year, with intermittent flow only after good rains. The rainfall is low, with a MAP of around 150mm and most rainfall occurs between June and August. The rivers typically occupy broad river valleys with sandy alluvial soils with some clayey depressions and sandstone, granite or shale bedrock. These systems also tend to be slightly saline in places. The dominant vegetation type is Azonal Namaqualand River vegetation (AZi 1). The vegetation type is characterised by a mix of succulent shrubs and patches of grasses and, in places, a narrow band of medium to tall trees – usually *Vachellia karroo,* along the edge of the active riverbed.

To the south, the lower river systems are associated with Cape Inland Salt Pans or Marshes. This vegetation type is dominated by small succulent shrubs like *Sarcocornia* spp., common reeds (*Phragmites australis*), rushes such as *Juncus kraussii* and grasses such as *Cynodon dactylon*. The botanical diversity within the river riparian zones is low.

Surveys of riparian and instream vegetation have been undertaken as part of the 2003 Reserve Determination for the Jakkals, Langvlei and Verlorenvlei Rivers by Coastec. Assessments of the riparian vegetation of the above rivers were also undertaken at seven sites as part of the River Eco-status Monitoring Programme and, in particular, informed the Olifants/Doring and Sandveld Rivers: State of Rivers Report, dated 2006. These assessments were before the development of the VEGRAI. A single eco-status assessment of the riparian vegetation of the Sout/Goerap River within the F60 Catchments was undertaken. From 2006 (2013 to 2019), follow-up surveys of the riparian vegetation in the Verlorenvlei, Langvlei and Jakkals Rivers have been undertaken and reference conditions as well as the present state of the riparian vegetation at the sites described.

In the dry and wet season surveys, the vegetation at the EWR sites in the G30 Catchment was assessed, and a PES was derived for vegetation using the level 4 VEGRAI method. Detailed survey results are included in the EWR survey report. A summary of the PES results is provided in Section 2.3.6.

Macroinvertebrates

Because the rivers within the study area are primarily non-perennial, flowing for only part of the year, the macroinvertebrate communities occurring in these watercourses tend to have a low diversity that comprises mainly of less sensitive taxa. This becomes increasingly so as one travels from the south and the Verlorenvlei Catchment northwards into the Sout and Brak Rivers. In addition, most of the river systems, such as the Langvlei River, comprise wetland habitat that has low dissolved oxygen levels and flow and thus inherently does not contain a diverse population of sensitive macroinvertebrates and is poorly suited to the macroinvertebrate sampling technique developed in South Africa for rivers (South African Scoring System version 5 or SASS5).

The rivers in the F60 catchment tend to flow for very short periods, and as a result, there is no available macroinvertebrate data available for the rivers. Within the G30 catchment, seven river ecostatus monitoring sites exist that have been sampled for macroinvertebrates (SASS5) more than twice (Figure 19). Only three of the sites within the Verlorenvlei River Catchment contain data from which reference conditions can be derived. These are in the upper Kruismans River (G30B), the lower Kruismans at the flow gauging weir (G3H001) and in the Verlorenvlei at Redelinghuys.

SASS5 assessments of macroinvertebrates at seven sites in the Jakkals, Langvlei and Verlorenvlei Rivers were undertaken from 2004 until recently as part of the River Eco-status Monitoring Programme. The assessments informed the Olifants/Doring and Sandveld Rivers: State of Rivers Report, dated 2006. Follow-up sampling has been done at most of these since then.

As defined by the SASS5 Score and Average Score per taxa, the expected reference conditions range from more than 150 and 7, respectively, in the upper Kruismans River to more than 115 and 6.4 in the Verlorenvlei at Redelinghuys (DWS generated MIRAI for the River Ecostatus monitoring sites; March 2022).

In the dry and wet season surveys, sampling of macroinvertebrates was undertaken within the river at the EWR sites in the G30 Catchment using SASS5 sampling techniques. A PES was then derived for macroinvertebrates using the level 4 MIRAI method. As expected for the non-perennial rivers within the study area, relatively low numbers of hardy species were sampled. As such, an adapted assessment that places more emphasis on invertebrate flow preferences and less on water quality and habitat has been applied. Detailed survey results are included in the EWR survey report. A summary of the PES results is provided in Section 2.3.6.

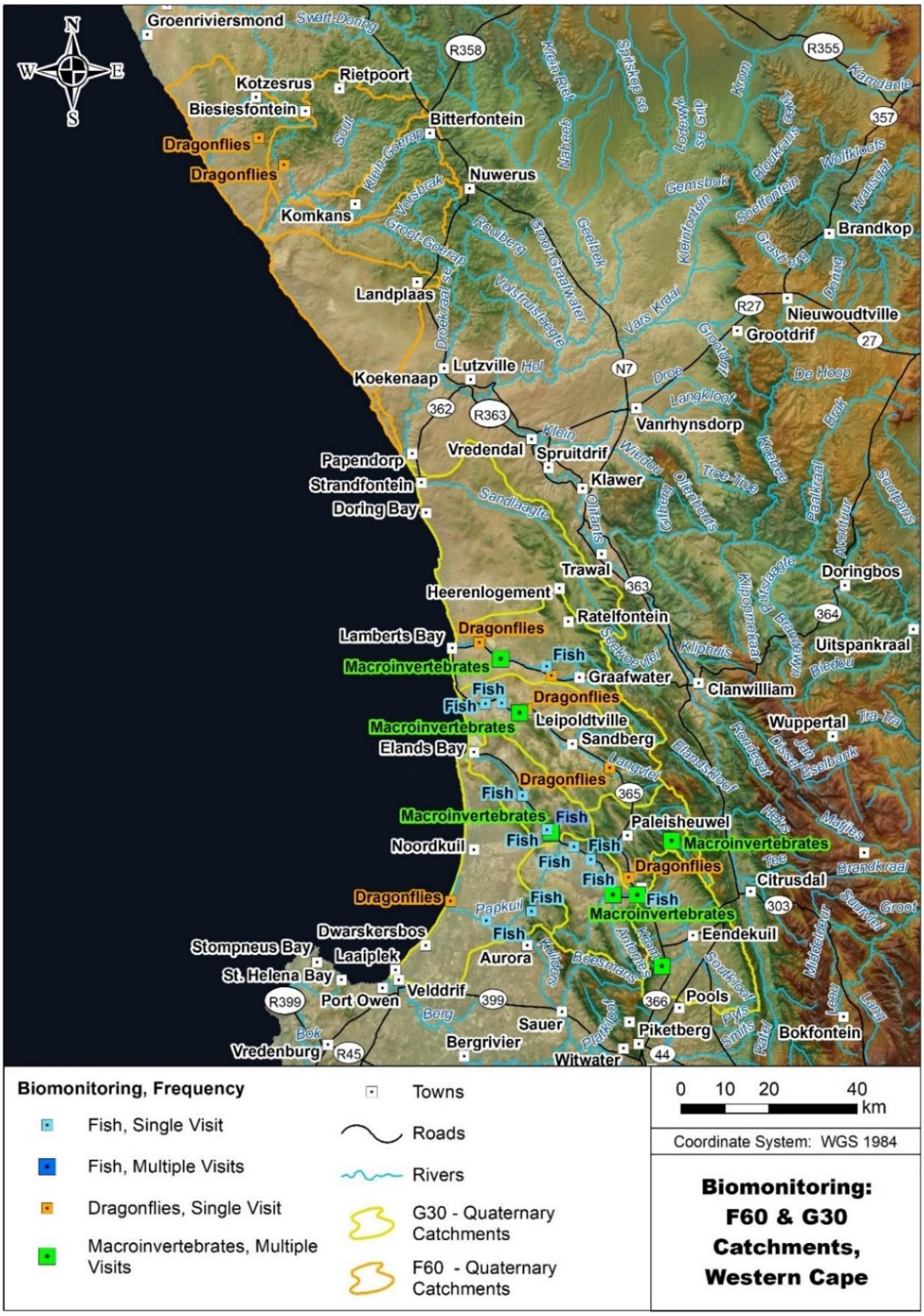


Figure 19. Map of surface water biomonitoring points in F60 and G30 Catchments

Fish

The study area, especially the Verlorenvlei River System, has been surveyed for fish several times, mainly by the staff of CapeNature, the provincial conservation agency, focusing on the river sections, but also by the staff of the Department of Forestry, Fisheries and the Environment (DFFE) undertaking fisheries surveys in the Verlorenvlei. This vlei is situated very close to the sea, and estuarine-dependent fishes such as mullet enter the vlei for recruitment purposes.

An intensive fish survey was undertaken of the Verlorenvlei River System in 2015 (Chakona *et al*., 2019), providing accurate and up-to-date knowledge of the diversity of freshwater fish fauna of this key river system. This publication also provided valuable information on the densities of the native fishes in this system and highlighted which river areas are especially important for the conservation of the endangered native fishes. Knowledge of the distribution of the Galaxias and Sandelia lineages in the other and much smaller river systems is patchier, and it would be valuable to have several sites in each system, to improve knowledge of fish distribution in them. Figure 20 provides a map of the potential distribution of indigenous fish populations.

The Verlorenvlei redfin was described as a new species recently (Chakona *et al*., 2014) and is listed as endangered by the IUCN (Chakona *et al*., 2017a). The species has its strongest population in the Krom Antonies River, a perennial tributary of the Verlorenvlei River System. Its major threats are well known, which include excessive water abstraction (surface and groundwater), habitat degradation, pollution and invasive non-native fishes (carp, banded tilapia, Mozambique tilapia) (Chakona *et al*., 2017a).

The unique Galaxias lineage was recently listed as endangered by the IUCN and had its strongest population in the Kruismans River, a tributary of the Verlorenvlei River System (Chakona *et al*., 2017b). Its key threats are the same as for the Verlorenvlei redfin.

The Cape kurper present in the study area has been identified as *Sandelia* sp. ‘capensis west coast’, which is largely confined to the Langvlei, Verlorenvlei, Diep and Berg River Systems (Bronaugh *et al*., 2019). The conservation status of this taxon has not been assessed yet (Chakona *et al*., 2019). It would appear to be most common in the Upper Krom Antonies and lower Verlorenvlei rivers (Chakona *et al*., 2019).

The fish surveys undertaken as part of this study were undertaken slightly differently and slightly later than the combined river and wetland team surveys due to the fact that the conditions at the time of the surveys were not ideal for the fish surveys. The PES assessment also needed to be adapted as FRAI has major limitations as an index when used in seasonal rivers in South Africa, where fish communities generally consist of a few hardy species

The Fish Scores for sites in the Verlorenvlei River System, including for river stretches very close to the two EWR sites on the river, were mostly in a C category (moderately modified). This is because two of the three expected fish species mentioned above were found to be present, there was evidence of recruitment, the fish were in good health and invasive fishes were either lacking or present in low numbers. Detailed survey results are included in the EWR survey report. A summary of the PES results is provided in Section 2.3.6.

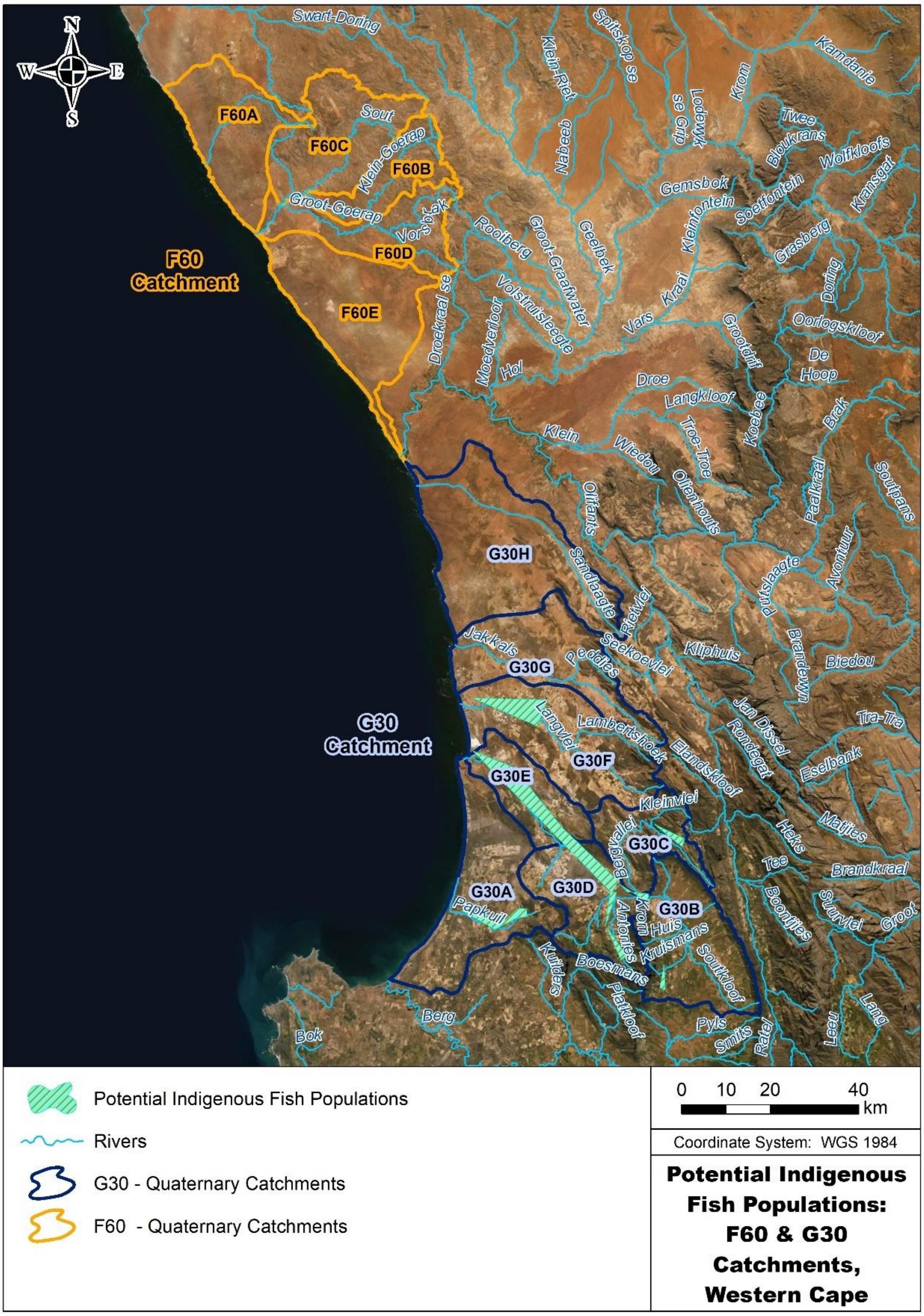


Figure 20. Map indicating the potential indigenous fish populations in the F60 and G30 Catchments

Amphibians

Some data exists for the area. As the study area is a relatively dry region, it has a low amphibian species richness. A total of 11 frog species are known or expected to occur in this area. Of the 11 frog species in the study area, eight are reliant on the annual inundation of wetland habitats. The three *Breviceps* species breed independently of wetland habitats.

The amphibians of the study area can be roughly grouped into two guilds, i.e. terrestrial and aquatic lifestyles. The terrestrial guild can be further subdivided according to wetland types that these frogs are specifically associated with, as has been indicated in Table 11 below.

Table 11: List of amphibian species known or likely to occur in the study area, with their respective IUCN conservation status and ecological guild category

Family	Genus	Species	Common name	IUCN status	Endemic	Guild*
Brevicipitidae	*Breviceps*	*gibbosus*	Cape Rain Frog	Near Threatened	WC	AG1e
Brevicipitidae	*Breviceps*	*namaquensis*	Namaqua Rain Frog	Least Concern	SA	AG1e
Brevicipitidae	*Breviceps*	*rosei*	Sand Rain Frog	Least Concern	WC	AG1e
Bufonidae	*Sclerophrys*	*capensis*	Raucous Toad	Least Concern	SA	AG1abcd
Bufonidae	*Vandijkophrynus*	*angusticeps*	Cape Sand Toad	Least Concern	WC	AG1abd
Bufonidae	*Vandijkophrynus*	*gariepensis*	Karoo Toad	Least Concern	0	AG1abd
Pipidae	*Xenopus*	*laevis*	Common Platanna	Least Concern	0	AG2abcd
Pyxicephalidae	*Amietia*	*fuscigula*	Cape River Frog	Least Concern	SA	AG1abcd
Pyxicephalidae	*Cacosternum*	*capense*	Cape Caco	Near Threatened	WC	AG1ad
Pyxicephalidae	*Strongylopus*	*grayii*	Clicking Stream Frog	Least Concern	SA	AG1abd
Pyxicephalidae	*Tomopterna*	*delalandii*	Cape Sand Frog	Least Concern	SA	AG1abcd

** The various guilds listed are described below*

Terrestrial (AG1): The terrestrial amphibian guild is comprised of frogs that spend the majority of their lives outside of water. Most members of this guild typically forage and live away from water bodies when not breeding but tend to congregate at water bodies during the breeding season. They may shelter under rocks, logs, amongst vegetation and underground, with many species aestivating during the dry season. Although some members of this guild (e.g. *Amietia* species) have strong affinities with wetlands throughout the year, they are still considered to be terrestrial because they spend most of their lives on land as opposed to in the water. Some species (e.g. *Breviceps*) breed independently of wetland habitats, i.e. through direct development without free-swimming tadpoles.

Aquatic (AG2): Aquatic amphibians are species that typically live in water for almost all of their lives, only emerging onto land during dispersal events, and even then usually in wet conditions. Aquatic frogs call, breed, feed and shelter beneath the water surface. During dry spells when wetlands may dry up, these frogs can aestivate underground until the wetlands fill up again.

Endorheic (a): These systems are depressions that fill up seasonally (rainwater or seepage) and are depleted by evaporation or absorption into the atmosphere (i.e. pans, pools and ponds).

Riverine (b): Systems that are generally contained in a channel but may flood during periods of excessive rainfall (i.e. permanent rivers, dry river beds, floodplains, temporary streams, perennial streams and mountain torrents).

Lacustrine (c): Systems that are larger than 8 ha in topographic depressions with the majority of the water surface open without emergent vegetation (i.e. dams and lakes).

Palustine (d): Shallow marshland systems dominated by emergent vegetation (i.e. vlei, hill slope seepage, inundated grassland).

Terrestrial (e): These are systems with no obvious standing or flowing water (i.e. forest floor, rocky outcrops, sand dunes, open grassland, savannah). Species in this sub-guild do not need standing water to breed and are therefore of rare occurrence in amphibians.

2.3.6. Combined River and Wetland PES

As the inland surface water ecosystems of the G30 study area depend on both surface and groundwater supply, they contain elements of both river and wetland habitats. The assessment of the PES for these rivers/wetlands has thus been combined. Below are the summary tables for the more detailed PES assessments undertaken at the EWR sites in the G30 Catchment.

Where the ecological categories and colour code shown below have been used:

Ecological Categories	Score (%)
Natural (A)	90-100
Largely Natural (B)	80-89
Moderately modified (C)	60-79
Largely modified (D)	40-59
Seriously modified (E)	20-39
Critically modified (F)	0-19

Verlorenvlei Catchment

Site: Kruismans	
ECOSTATUS COMPONENT	METRIC GROUP: CALCULATED RATING (%)
Hydrology	39.0
Water Quality	60.0
Geomorph	63.0
Driver score	**50.9**
Vegetation	37.0
Macroinvertebrates	49.0
Fish	70.0
Biotic Responses Score	**49.3**
Combined Ecostatus for Separate Component Assessments	**50.2**
River Habitat Integrity	**54.5**
Wetland Integrity	**59.0**
Overall Ecostatus Score	**54.6**
Overall Ecostatus Category	**D**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

Site: Krom Antonies	
ECOSTATUS COMPONENT	METRIC GROUP: CALCULATED RATING
Hydrology	55.0
Water Quality	70.0
Geomorph	56.8
Driver score	**59.0**
Vegetation	44.0
Macroinvertebrates	58.0
Fish	70.0
Biotic Responses Score	**54.8**
Combined Ecostatus for Separate Component Assessments	**57.3**
River Habitat Integrity	**58.1**
Wetland Integrity	**59.0**
Overall Ecostatus Score	**58.1**
Overall Ecostatus Category	**C/D**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

Site: Verlorenvlei	
ECOSTATUS COMPONENT	METRIC GROUP: CALCULATED RATING
Hydrology	43.5
Water Quality	70.0
Geomorph	61.5
Driver score	**55.0**
Vegetation	57.8
Macroinvertebrates	44.0
Fish	70.0
Biotic Responses Score	**58.0**
Combined Ecostatus for Separate Component Assessments	**60.1**
River Habitat Integrity	**55.0**
Overall Ecostatus Score	**57.6**
Overall Ecostatus Category	**D**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

The combined ecostatus for the Kruismans and downstream Verlorenvlei Rivers is a D Category (largely modified) while the integrity of the Krom Antonies River is slightly better and is a C/D Category (moderately to largely modified). The confidence in the results is medium to low due to a general shortage of data. All the rivers show a decreasing trend.

Langvlei Catchment

Site:Langvlei	
ECOSTATUS COMPONENT	**METRIC GROUP: CALCULATED RATING**
Hydrology	36.0
Water Quality	50.0
Geomorph	46.0
Driver score	**42.2**
Vegetation	37.7
Macroinvertebrates	28.0
Fish	10.0
Biotic Responses Score	**27.5**
Combined Ecostatus for Separate Component Assessments	**36.3**
River Habitat Integrity	**41.5**
Wetland Integrity	**42.0**
Overall Ecostatus Score	**39.9**
Overall Ecostatus Category	**D/E**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

The combined ecostatus for the Langvlei River is a D/E Category (largely to seriously modified). The confidence in the results is medium to low due to a general shortage of data. All the rivers show a decreasing trend.

Jakkals Catchment

Site: Jakkals	
ECOSTATUS COMPONENT	**METRIC GROUP: CALCULATED RATING**
Hydrology	68.0
Water Quality	70.0
Geomorph	55.0
Driver score	**64.8**
Vegetation	55.0
Macroinvertebrates	37.0
Biotic Responses Score	**45.5**
Combined Ecostatus for Separate Component Assessments	**57.0**
River Habitat Integrity	**56.3**
Wetland Integrity	**78.0**
Overall Ecostatus Score	**63.8**
Overall Ecostatus Category	**C**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

The combined ecostatus for the Jakkals River is a C Category (moderately modified). The confidence in the results is medium to low due to a general shortage of data. All the rivers show a decreasing trend.

Papkuils Catchment

Site: Papkuils	
ECOSTATUS COMPONENT	**METRIC GROUP: CALCULATED RATING**
Hydrology	66.5
Water Quality	70.0
Geomorph	58.2
Driver score	**64.9**
Vegetation	45.9
Fish	60.0
Biotic Responses Score	**45.8**
Combined Ecostatus for Separate Component Assessments	**57.3**
River Habitat Integrity	**59.0**
Overall Ecostatus Score	**58.1**
Overall Ecostatus Category	**C/D**
Trajectory of change	**Negative**
Confidence	**Medium/Low**

The combined ecostatus for the Papkuils River is a C/D Category (moderately to largely modified). The confidence in the results is medium to low due to a general shortage of data. All the rivers show a decreasing trend.

Sandlaagte, Sout and Brak Rivers

River	Instream Integrity Score	Riparian Integrity Score	Ecostatus	Ecological Category
Brak	82	82	82	B
Klein Goerap	77	75	76	C
Groot Goerap	74	73	74	C
Sout	71	69	70	C
Sandlaagte	61	54	58	C/D

The rivers in the F60 Catchment are in a largely natural to moderately modified ecological condition, with mostly just localised impacts. There is, however, significant agricultural activity and groundwater use in the upper Sandlaagte River in G30H that has modified the river, particularly in its upper reaches.

2.4. Estuaries

2.4.1. Verlorenvlei

The Verlorenvlei is classified as an Estuarine Lake (Van Niekerk *et al*., 2020) located in the Cool temperate region of the Western Cape near the town of Elandsbay (Figure 21). The geographical boundaries of the estuary are defined as follows:

Downstream boundary (mouth):	32°18'59.14"S; 18°19'58.18"E
Upstream boundary:	32°28'21.27"S; 18°32'25.17"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

Historically the system breaches to sea at an annual timescale (every 2 - 5 years), with mouth opening coinciding with periods of high rainfall. Over the last decades, heavy utilisation of freshwater resources has decreased opportunities for marine connectivity. Salinity varies from hypersaline to fresh in the system. This system is heavily modified. Table 12 provides a summary of the ecosystem classification, importance (biodiversity and conservation, and ecosystem threat status of the estuary. Table 13 provides the results of the PES determined in this study. The Verlorenvlei PES (2022) is an E Category.

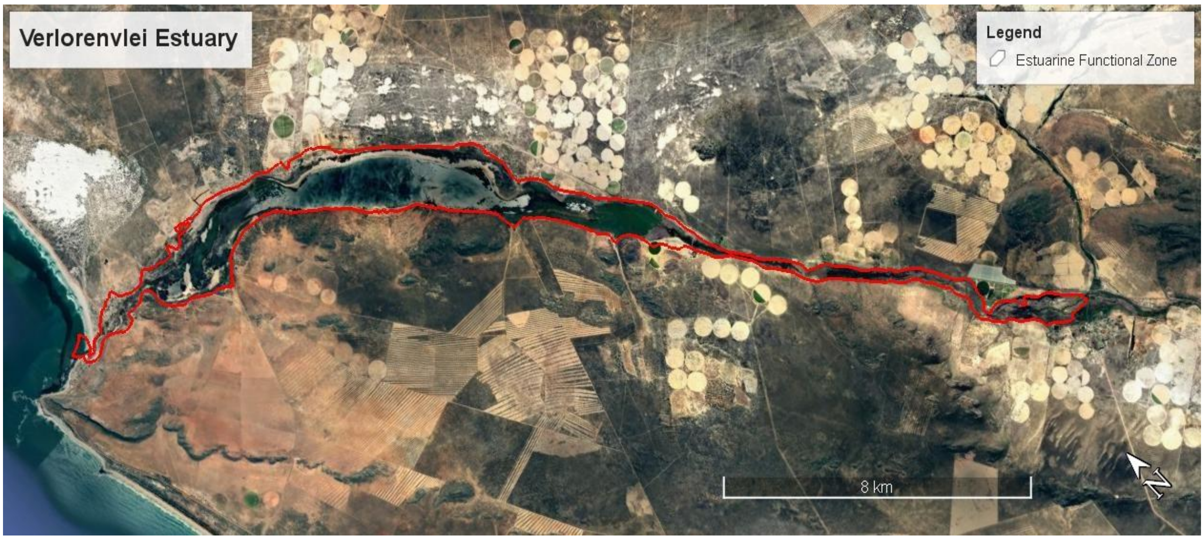


Figure 21: Geographical Boundary of Verlorenvlei Estuary

Table 12: Summary of the Verlorenvlei Estuary ecosystem classification, importance (biodiversity and conservation), and ecosystem threat status

Name	Verlorenvlei
NBA 2019 Ecosystem type (Van Niekerk *et al*., 2019b)	Cool Temperate - Estuarine Lake
Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie *et al*., 2002, Turpie & Clark, 2009)	Important
Biodiversity Conservation Priority (Van Niekerk & Turpie, 2012, Turpie and Clark, 2007 (CAPE))	South African (NBA), Western Cape
In Marine Protected Area (MPA) or priority area	-
Adjacent terrestrial Protected Area	-
Ramsar status	Yes
Important Bird Area (IBA)	Yes
Ecologically or Biologically Significant Marine Areas (EBSAs)	Adjacent
DFFE Important Fish Nurseries (Very High - Medium = Priority)	Medium
NBA 2019 Ecosystem Threat Status (Van Niekerk *et al*., 2019b)	Endangered
NBA 2019 Ecosystem Condition Status (Van Niekerk *et a*l., 2019b)	Heavily

Table 13: PES assessment for the Verlorenvlei Estuary

Verlorenvlei	Present (2022)	Pres (Sim)
Hydrology	40	70
Hydrodynamics and mouth condition	30	53
Water quality	22	45
Physical habitat alteration	30	65
Habitat health score	31	58
Microalgae	23	43
Macrophytes	45	55
Invertebrates	10	50
Fish	5	30
Birds	30	40
Biotic health score	23	44
ESTUARINE HEALTH SCORE	27	51
PRESENT ECOLOGICAL STATUS	**E**	**D**

2.4.2. Wadrift

The Wadrift is classified as an Arid, Predominantly Closed estuary (Van Niekerk et al., 2020) located in the Cool temperate region of the Western Cape near the town of Lambertsbaai (Figure 22). The geographical boundaries of the estuary are defined as follows:

Downstream boundary (mouth)	32°12' 15.54"S; 18°19' 32.43"E
Upstream boundary	32°12' 49.87"S; 18°22' 37.15"E
Lateral boundaries	5 m contour above Mean Sea Level (MSL) along each bank

There is no record of the Wadrift estuary being open to the sea in recent times. However, regular overwash from the sea results in a marine to hypersaline salinity regime in the section of Wadrift facing the sea. The landward side of Wadrift is generally fresher. This system is deemed to be severely/ critically modified due to the Sishen-Saldanha railway track bisecting it and the severe over-abstraction of surface and groundwater flowing into it. Table 14Table 12 provides a summary of the ecosystem classification, importance (biodiversity and conservation, and ecosystem threat status of the estuary. Table 15 provides the results of the PES determined in this study. The Wadrift Estuary PES (2022) is a D Category.

Figure 22: Geographical Boundary of Wadrift Estuary

Table 14: Summary of the Wadrift Estuary ecosystem classification, importance (biodiversity and conservation), and ecosystem threat status

Name	Wadrift
NBA 2019 Ecosystem type (Van Niekerk *et al*., 2019b)	Cool Temperate - Arid Predominantly Closed
Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie *et al*., 2002, Turpie & Clark, 2009)	Low to Average Importance
Biodiversity Conservation Priority (Van Niekerk & Turpie 2012, Turpie & Clark, 2007 (CAPE))	-
In Marine Protected Area (MPA) or priority area	-
Adjacent terrestrial Protected Area	-
Ramsar status	-
Important Bird Area (IBA)	-
Ecologically or Biologically Significant Marine Areas (EBSAs)	Adjacent
DFFE Important Fish Nurseries (Very High - Medium = Priority)	Low
NBA 2019 Ecosystem Threat Status (Van Niekerk *et al*., 2019b)	Endangered
NBA 2019 Ecosystem Condition Status (Van Niekerk *et al*., 2019b)	Severely/Critical

Table 15: PES assessment for the Wadrif Pan

Wadrift	Present
Hydrology	68
Hydrodynamics and mouth condition	62
Water quality	44
Physical habitat alteration	60
Habitat health score	58
Microalgae	56
Macrophytes	40
Invertebrates	40
Fish	25
Birds	45
Biotic health score	41
ESTUARINE HEALTH SCORE	50
PRESENT ECOLOGICAL STATUS	**D**

2.4.3. Jakkals

The Jakkals Estuary or Jakkalsvlei is classified as a Large, Temporarily Closed estuary (Van Niekerk *et al*., 2020) located in the Cool temperate region of the Western Cape near the town of Lambertsbaai (Figure 23). The geographical boundaries of the estuary are defined as follows:

Downstream boundary (mouth):	32° 5' 5.39"S; 18°18' 48.25"E
Upstream boundary:	32° 5' 26.89"S; 18°20' 1.32"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

The estuary seasonally opens to the sea during periods of higher rainfall. The salinity regime in the system varies from fresh to marine, depending on the runoff from the catchment. This system is deemed to be heavily modified. Table 16 provides a summary of the ecosystem classification, importance (biodiversity and conservation, and ecosystem threat status of the estuary. Table 17 provides the results of the PES determined in this study. The Jakkalsvlei PES (2022) is a D Category.

Figure 23: Geographical Boundary of Jakkals Estuary

Table 16: Summary of the Jakkals Estuary ecosystem classification, importance (biodiversity and conservation), and ecosystem threat status

Name	Jakkals
NBA 2019 Ecosystem type (Van Niekerk *et al*., 2019b)	Cool Temperate - Large Temporarily Closed
Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie *et al.,* 2002, Turpie & Clark, 2009)	Low to Average Importance
Biodiversity Conservation Priority (Van Niekerk & Turpie, 2012, Turpie & Clark, 2007 (CAPE))	-
In Marine Protected Area (MPA) or priority area	-
Adjacent terrestrial Protected Area	-
Ramsar status	-
Important Bird Area (IBA)	-
Ecologically or Biologically Significant Marine Areas (EBSAs)	-
DFFE Important Fish Nurseries (Very High - Medium = Priority)	Low
NBA 2019 Ecosystem Threat Status (Van Niekerk *et al*,. 2019b)	Critically Endangered
NBA 2019 Ecosystem Condition Status (Van Niekerk *et al*., 2019b)	Heavily

Table 17: PES assessment for the Jakkals Estuary

Jakkalsvlei	Present
Hydrology	37
Hydrodynamics and mouth condition	49
Water quality	56
Physical habitat alteration	60
Habitat health score	51
Microalgae	49
Macrophytes	60
Invertebrates	50
Fish	50
Birds	55
Biotic health score	53
ESTUARINE HEALTH SCORE	52
PRESENT ECOLOGICAL STATUS	**D**

2.4.4. Sout (Noord)

The Sout (Noord) is classified as an Arid, Predominantly Closed estuary (Van Niekerk *et al*., 2020) located in the Cool temperate region of the Western Cape near the town of Lambertsbaai (Figure 24). The geographical boundaries of the estuary are defined as follows:

Downstream boundary (estuary mouth):	31°14' 38.40"S 17°50' 57.36"E
Upstream boundary:	31°12' 36.28"S 17°53' 28.41"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

This estuary is largely transformed as it is used to produce salt, with saltworks infrastructure (e.g. roads, channels and berms) resulting in several disconnected sections, with a PES = E (Table 18). There is no record of the Sout (Noord) estuary being open to the sea in recent times. However, saltwater is pumped into various parts of the system artificially, resulting in a marine to hypersaline salinity regime.

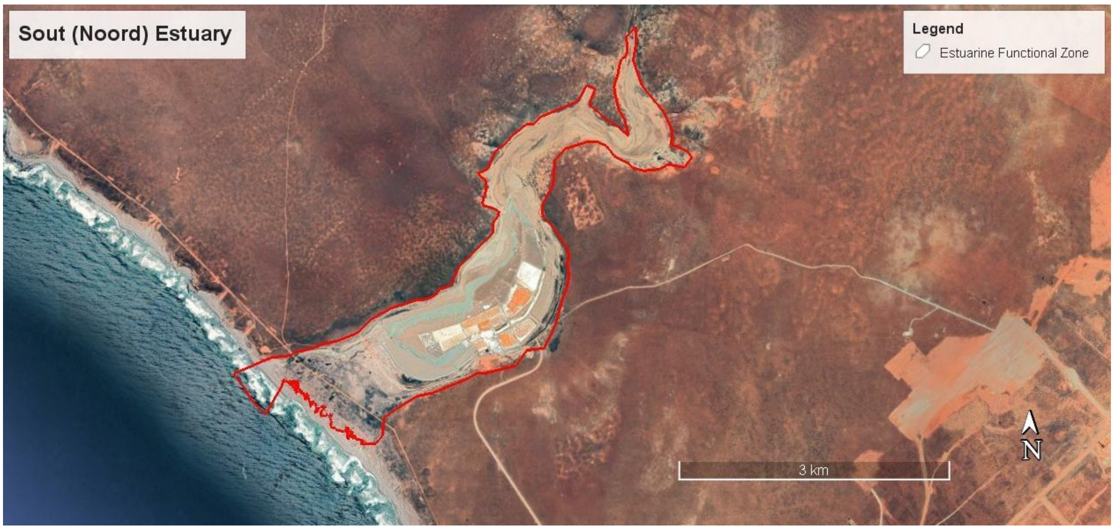


Figure 24: Geographical Boundary of Sout (Noord) Estuary

Table 18: Summary of the Sout (Noord) Estuary ecosystem classification, importance (biodiversity and conservation), and ecosystem threat status

Name	Sout (Noord)
NBA 2019 Ecosystem type (Van Niekerk *et al*., 2019b)	Cool Temperate - Arid Predominantly Closed
Biodiversity Importance Rating (>80 =High Importance, 60 - 80=Important >60 = Average Importance) (Turpie *et al*., 2002, Turpie & Clark, 2009)	Low to Average Importance
Biodiversity Conservation Priority (Van Niekerk & Turpie, 2012, Turpie & Clark, 2007 (CAPE))	-
In Marine Protected Area (MPA) or priority area	-
Adjacent terrestrial Protected Area	-
Ramsar status	-
Important Bird Area (IBA)	-
Ecologically or Biologically Significant Marine Areas (EBSAs)	Adjacent
DFFE Important Fish Nurseries (Very High - Medium = Priority) (Van Niekerk *et al*., 2019b)	Low
NBA 2019 Ecosystem Threat Status	Endangered
NBA 2019 Ecosystem Condition Status	Severely/Critical
PES	E

2.5. Groundwater/Surface Water Interaction

There is seasonal interaction between surface water and groundwater, although river flows in the hot, dry summer months become negligible. Based on an assessment of groundwater levels (in the summer months), a number of comments can be made. For the Jakkals River catchment (G30G), in the area around Graafwater to 8 km downstream from Graafwater, there is no perceived contribution from groundwater to surface water flow, and the river system is a losing system (recharging groundwater) (GEOSS, 2005). Although historically, springs did occur (Kookfontein) towards the coast along the Jakkals River, these dried up many years ago. The only gaining section on the Jakkalsvlei River is situated midway between Graafwater and Lamberts Bay. In the Langvlei, the gaining reaches within the catchment are short.

For the Verlorenvlei, the gaining sections are thought to be of significant length, with the longest gaining reach being downstream of the confluence of the Hol, Krom Antonies and Kruismans Rivers. At Redelinghuys and at the headwaters of Verlorenvlei, there are also stretches of gaining river. The Kruismans Tributary is regarded as the largest tributary and is mainly derived from surface runoff (Watson *et al*., 2019). Thus far, the Bergvallei Tributary is regarded as the largest groundwater flow contributor using the J2000 rainfall/runoff model, with strontium isotope ratios confirming this (Sigidi, 2017). Decreasing water levels have been recorded towards the bottom area of these catchments and it is known that many additional boreholes and dams have been constructed over the last 20 years.

The Krom Antonies Tributary is regarded as the largest, in terms of area-weighted flow contribution, with the TMG playing a critical role in terms of baseflow. While the Hol Tributary is saline (Watson *et al*., 2020a), it is significant that baseflow is more sustained due to the dominance of slow groundwater flow from the Malmesbury shale aquifer. Areas with clear groundwater-surface water interactions can be seen where seepage areas occur.

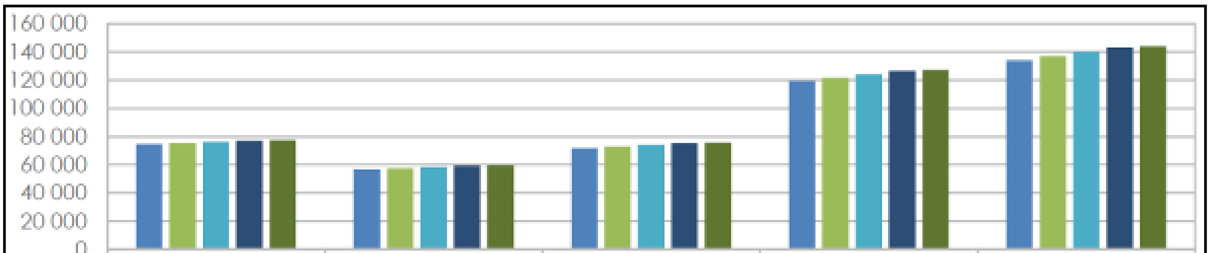
The recharge in Verlorenvlei is mainly generated in the TMG aquifer, which is a secondary porosity aquifer system and water is held in the fracture network. The recharge rates into the TMG aquifer have been estimated to be 37.6 to 50 mm/year using the Chloride Mass Balance (CMB) (Watson *et al*., 2020a) and agree with bulk rainfall/runoff modelling estimates (Watson *et al*., 2018). The fractured TMG aquifers receive the highest amount of direct recharge (~22-25% of MAP) (Umvoto, 2021). Isotope data has been used to understand dominant groundwater flow paths and was instrumental in identifying groundwater mixing relationships between the upper, middle and lower Krom Antonies sub-basin (Watson *et al*., 2020a). Furthermore, the use of isotope dating techniques conducted for the catchment essentially shows three distinct aquifer systems which are mixed before reaching the Verlorenvlei itself (Miller *et al*., submitted a scientific paper for publication). These mixing relationships suggest and show the connection between the TMG and primary alluvial aquifer, as well as the connection between the TMG and Malmesbury shale aquifer.

The connection between the Malmesbury and alluvial aquifer is not clear, but these two systems must interact as pumping data shows that water can move between the alluvial and Malmesbury aquifer, although this is an interpretation of a single observation borehole, which could have multiple sourced water (Watson *et al*., 2020a). In terms of the dating outputs, the results show that the TMG and the alluvial aquifer are actively recharged, comprised of young water (34-57 years), with the Malmesbury aquifer being mainly comprised of very old groundwater but has not yet been successfully isolated due to mixing.

For the F60 catchments, groundwater/surface water interaction is much less understood and due to a lack of springs and seepage areas, it is very difficult to delineate such areas. It has been noted that in some of the coastal areas, the overlying sand deposits could be receiving lateral recharge from fault and fracture systems within the hard rock.

2.6. Socio-Economics

The majority of the study area falls within the Matzikama, Cederberg and Berg River Municipalities. Socio-economic information for these municipalities is available from the Western Cape Provincial Government 2019 Socio-economic Profile for each of the municipalities. The population of the Matzikama, Cederberg and Bergrivier Municipalities in 2022 is estimated to be 77 007, 59 210 and 75 397, respectively (Figure 25). Growth rates for the municipalities range between 0.9% (Matzikama) and 4.6% (Cederberg).



	Matzikama	Cederberg	Bergrivier	Saldanha Bay	Swartland
2019	74 636	56 782	71 518	119 132	133 813
2020	75 448	57 599	72 804	121 641	136 854
2021	76 226	58 408	74 088	124 137	139 936
2022	77 007	59 210	75 397	126 600	143 042
2023	77 425	59 432	75 630	127 278	143 785

Figure 25: Population Municipalities in West Coast District Municipality

The United Nations uses the Human Development Index (HDI) to assess the relative level of socio-economic development in countries. Indicators that measure human development are education, housing, access to basic services and health. There has been a general increase in the HDI in the municipalities within the study area between 2015 and 2018. The HDI figures are similar to the district and provincial HDI. Although there was an improvement in the HDI between 2015 and 2018, these gains are likely to have been impacted by the COVID-19 pandemic of 2020-2021.

In 2017, the two main contributors to the economy and employment in the area were the agriculture, forestry, and fishing sector, followed by the wholesale & retail trade, catering and accommodation sector and manufacturing sector. The manufacturing sector is closely linked to and supported by the agriculture, forestry, and fishing sector.

Table 19 provides a socio-economic overview of the relevant wards within which the study area is located -Matzikama Municipality Ward 8, 5 and 2; Cederberg Municipality Ward 5; Berg River Municipality Ward 6 and Kamiesberg Municipality Ward 3. Figure 26 contains a map of the municipality boundaries and the relevant wards.

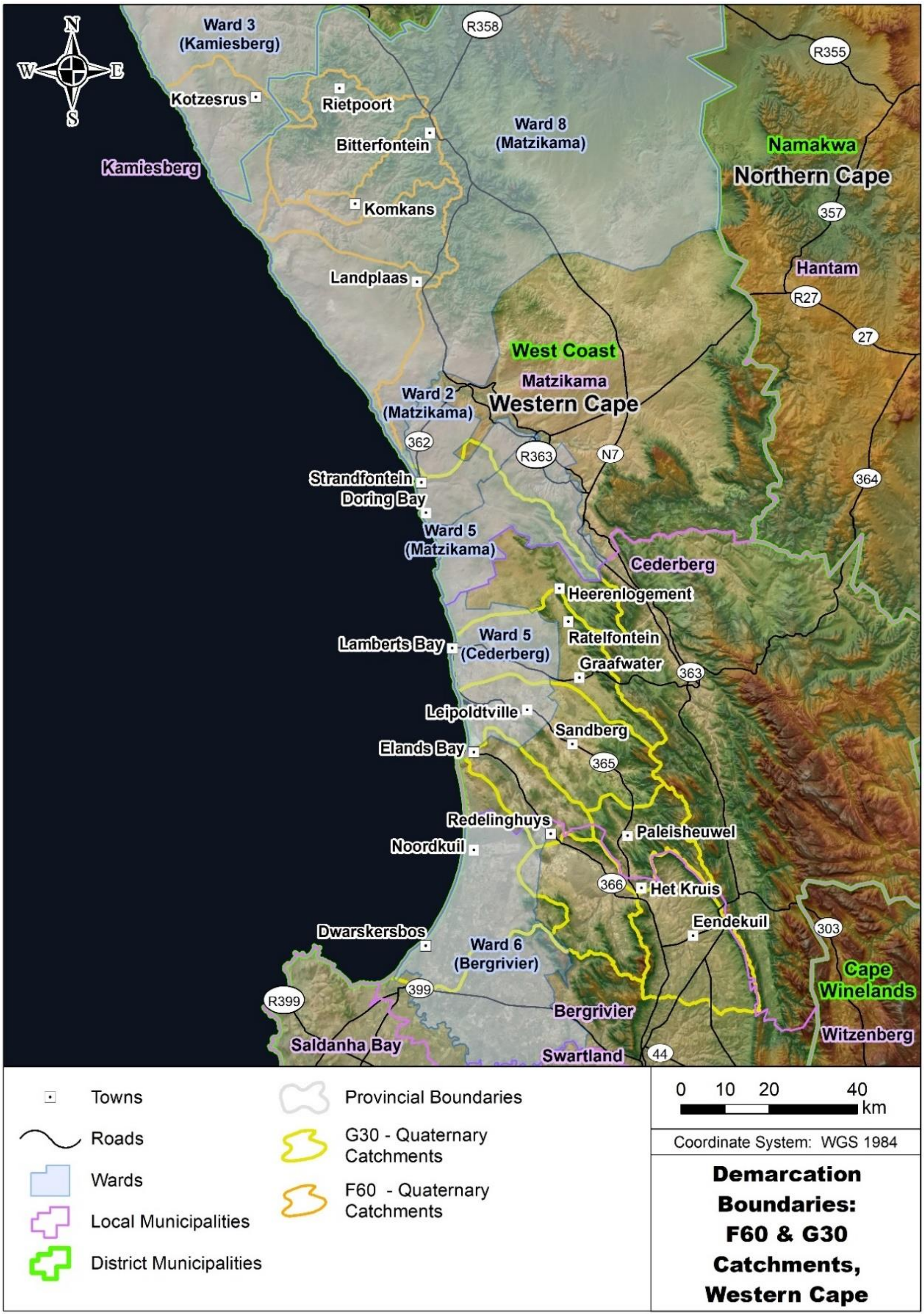


Figure 26. Map of the demarcation boundaries within the F60 and G30 Catchments

Table 19. Socio-economic overview of the relevant wards within the study area

Category	Matzikama			Cederberg	Bergrivier	Kamiesberg
	Ward 8	Ward 5	Ward 2	Ward 5	Ward 6	Ward 3
Population (2011)	8 050	8 595	7 298	9 141	9 428	3 240
Age						
U 18	32.3%	28.1%	31.8%	29.4%	30.4%	29.2%
18-64	59.5%	63.4%	61.3%	61.6%	63.2%	60.2%
65-	8.2%	8.5%	6.9%	9.0%	6.5%	10.7%
Population Group						
Black African	8.5%	5.5%	4.7%	12.4%	13.8%	5.9%
Coloured	77.7%	55.2%	83.7%	71.8%	73.1%	77.45
White	13.1%	38.0%	11.1%	15%	11.9%	15.55
Indian/Asian	0.5%	0.7%		0.5%	0.6%	0.3%
Language						
Afrikaans	92.2%	91.2%	92.5%	85.8%	83.4%	87.9%
IsiXhosa	1.3%	1.7%	0.8%	6.6%	8.3%	0.5%
English	1.8%	2%	1.5%	2.1%	2.2%	0.7%
Education						
None	7.3%	5.7%	0.0%	4.8%	5.2%	4.2%
Matric	17.5%	29.8%	0.0%	24.4%	21%	22.2%
Employment						
Employed	43.1%	68.3%	48.7%	46.3%	51.2%	46.1%
Unemployed	12.1%	2%	13.7%	10.5%	9.7%	14.5%
Households						
Households (2011)	2 373	2 823	2 025	2 654	2 979	987
House	76.8%	83%	89.9%	83.6%	76.2%	87.9%
Shack			1.9%	7.8%	4.4%	
Annual Income						
Under R4800	14.8%	4.6%	12.5%	13.9%	18.9%	9.1%
R5K – R20K	28.3%	15%	21.9%	20.7%	19.6%	20.6%
R20 – R40K	23.7%	22.9%	26.5%	24.3%	22.7%	23.2%
Water Supply						
Service Provider	74.3%	61.3%	87.1%	87.2%	81.4%	84.3%
Borehole/Dam	12.8%	27.7%	7.5%	10.5%	10.3%	8.4%
Sanitation						
Flush toilet	59.2%	56.3%	62.8%	87.9%	86.2%	72.8%
Bucket	9.3%	1.4%	5.4%	3.9%	2.7%	1.7%
Refuse						
Service	70.5%	48.2%	65%	82.4%	80.3%	85.5%
Own dump	24.2%	41.3%	20.8%	12.9%	15%	12.4%

2.7 Land and Water Use

The main activity within the G30 catchment is cultivation (potatoes, wheat, mealies, vegetables, rooibos and citrus). In the F60 catchment, cultivation is primarily restricted to the southeastern portion of the catchment, in the upper Groot Goerap Catchment. Farming with livestock occurs more in the F60 catchment. The 2020 landcover map is included in **Figure 27**.

The expansion of centre-pivot irrigation followed the introduction of Eskom power lines to the area in the mid-1980s. The unconsolidated sands of the Sandveld are particularly well-suited to the cultivation of potatoes; however, these sands are nutrient-poor, with low moisture retention capacity. Thus significant input of water and nutrients are required for the growing of potatoes.

Between 5 000 and 7 500 ha of potatoes are planted annually in the Sandveld (Potatoes SA regional information for the Sandveld for the period 2013-2018) for the production of seed potatoes, potatoes for the fresh market and potatoes for the processing industry (French fries, crisps and frozen products). A farmer wanting to cultivate 20 hectares of seed potatoes would need to clear four 20-ha circles (80 ha) and cultivate one circle per year, moving the centre pivot to the appropriate field each year.

Natural indigenous vegetation, mostly Strandveld, is being cleared to cultivate potatoes. The total number of centre pivots in the potato production area of the Sandveld has been calculated as 1 773 (with a combined area of 30 740 ha) using satellite imagery (2003/4). Analysis of the trend of expansion of the industry between 2000 and 2010 showed that in the core of the production area (Wadrif to Paleisheuwel to Moutonshoek to Elandsbaai), the number of centre pivot fields increased from 599 to 1 355 and the area from 12 384 ha to 22 871 ha. This was an increase of 84 % in size and 126 % in the number of circles. Over more recent years, the area has shown a trend to change from potatoes to citrus, particularly in the upper parts of the catchment.

Water use by the potato industry in the Sandveld has conservatively been estimated at 46.9 Mm^3/a (Knight *et al.*, 2007; Conrad and Helme, 2007), which equates to about 20% of the (groundwater) recharge for the area. The G30F catchment is the largest but is also the most intensively cultivated and the fastest-growing agriculture area in the Sandveld.

Towns in the Sandveld are all small, and most are supplied from local sources via infrastructure owned and operated by local authorities. The exceptions are Strandfontein and Doringbaai, where there is a transfer of 0.4 million m^3/a of water from the Olifants River Canal near Ebenhaezer via a pipeline from the Lower Olifants Government Scheme to these towns and rural domestic consumers in the vicinity. The other potable water supply schemes in the Sandveld are Graafwater (0.21 million m^3/a from boreholes), Elandsbaai (0.07 million m^3/a from 7 boreholes) and Lambert's Bay (0.8 million m^3/a from a groundwater wellfield). There are no major dams in the area. However, there are many smaller storage dams throughout the area, including both in-channel and off-channel storage dams. The dams are used entirely for agriculture, and there are no dams for town water supply purposes.

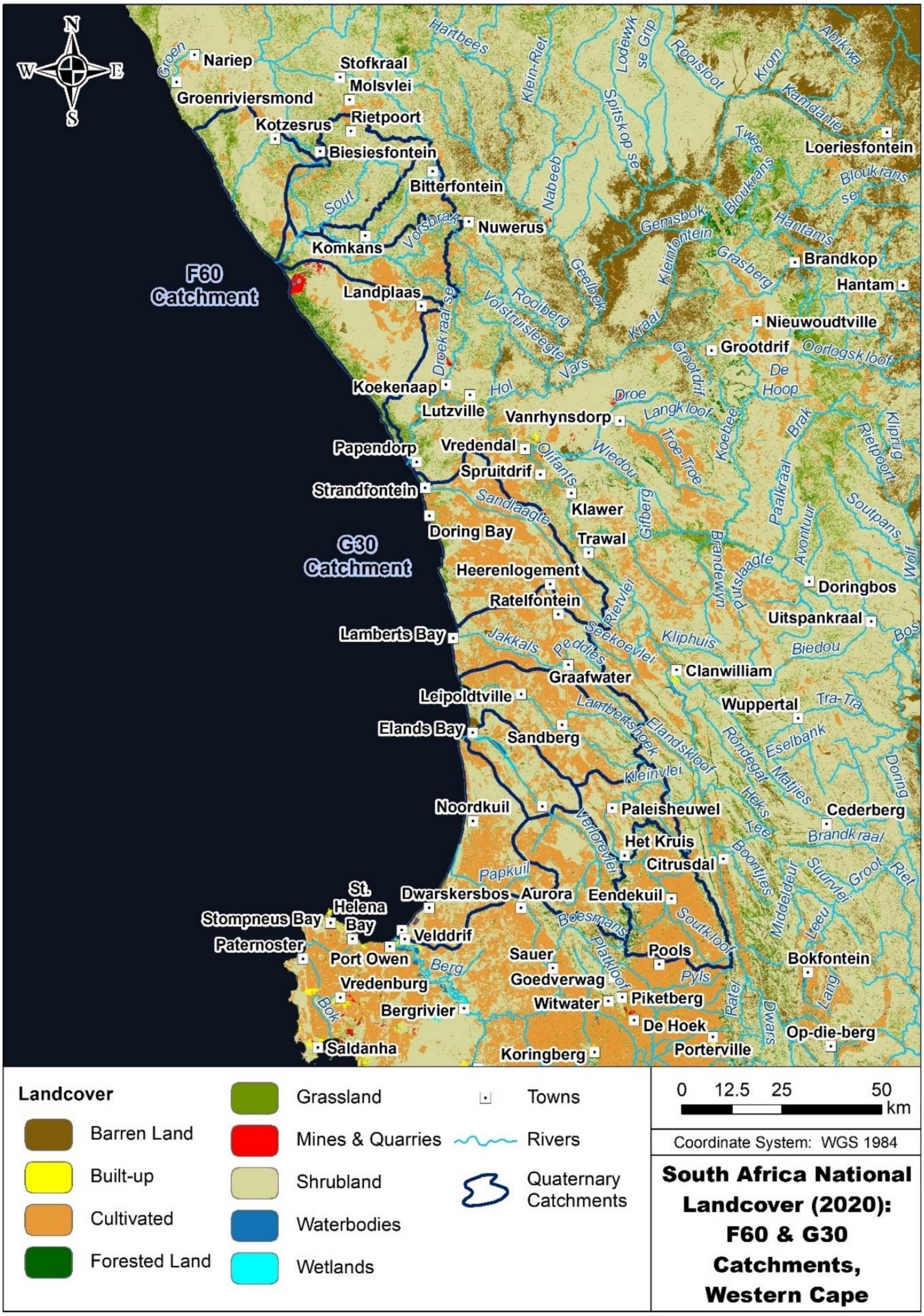


Figure 27. Landcover map (2020) for the F60 and G30 Catchments

3. RECOMMENDED ECOLOGICAL CATEGORY

An analysis of the revised PES data and EI-ES data from the PES/EIS results, as well as the Classification and RQO projects, were used to derive the Recommended Ecological Category (REC).

Table 20.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	Moderate	D: Largely Modified	CLASS D: LARGELY MODIFIED	Negative	Class C: Moderately Modified
G30C	Bergvallei	Moderate	D/E: Largely to Seriously Modified	CLASS E - F: NOT AN ACCEPTABLE	Negative	Class C: Moderately Modified
G30D	Verlorenvlei	Moderate	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	Moderate	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	Moderate	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

4. REFERENCES

ADAMS, JB, S TALJAARD, L VAN NIEKERK and DA LEMLEY. 2020. Nutrient enrichment as a threat to the ecological resilience and health of microtidal estuaries. African Journal of Aquatic Science, 45: 23-40.

BREDIN, I.P., AWUAH, A., PRINGLE, C., QUAYLE, L., KOTZE, D.C. AND MARNEWECK, G.C. 2019. A procedure to develop and monitor wetland resource quality objectives. WRC Report No TT 795/19. Water Research Commission, Pretoria.

BRONAUGH, W.M., SWARTZ, E.R. & SIDLAUSKAS, B.L. 2019. Between an ocean and a high place: coastal drainage isolation generates endemic cryptic species in the Cape kurper *Sandelia capensis* (Anabantiformes: Anabantidae), Cape Region, South Africa. Journal of Fish Biology 96 (5): 1087-1099.

BROWN, CA, AR JOUBERT, J BEUSTER, A GREYLING & JM KING. 2013. DRIFT: DSS Software Development for Integrated Flow Assessments. WRC Report No. 1873/1/13.

CHAKONA, A., JORDAAN, M. & KADYE, W. T. 2019. Distributions and summer habitat associations of three narrow-range endemic fishes in an intermittent southern temperate Mediterranean river system. Fundam. Appl. Limnol. 193/1 (2019), 65–77.

CHAKONA, A., JORDAAN, M., KADYE, W. T. & VAN DER WALT, R. 2017a. *Pseudobarbus verloreni*. The IUCN Red List of Threatened Species, 2017: http://dx.doi.org/10.2305/IUCN.UK.

CHAKONA, A., JORDAAN, M., KADYE, W. T. & VAN DER WALT, R. 2017b. *Galaxias* sp. nov. 'Verlorenvlei'. The IUCN Red List of Threatened Species, 2017: http://dx.doi.org/10.2305/IUCN.UK.

CHAKONA, A., SWARTZ, E. R. & SKELTON, P. H. 2014. A new species of redfin (Teleostei, Cyprinidae, Pseudobarbus) from the Verlorenvlei River system, South Africa. *ZooKeys, 453*(453), 121–137.

CSIR, 2009 Development of the Verlorenvlei estuarine management plan: Situation assessment. Report prepared for the C.A.P.E. Estuaries Programme. CSIR Report No. CSIR/NRE/CO/ER/2009/0153/B Stellenbosch.

DALLAS, HF, RIVERS-MOORE NA, ROSS-GILLESPIE V, EADY B, MANTEL S. 2012. Water temperatures and the ecological reserve. Water Research Commission report 1799/1/12. Pretoria: Water Research Commission.

DEPARTMENT OF WATER AFFAIRS (DWA), 2013. Determination of Resource Quality Objectives for the Olifants Doorn Water Management Area - Report No. 3 - RQO Determination Report. Prepared by Umvoto Africa (Pty) Ltd in association with Southern Water Ecological Research and Consulting cc (Authors: K Riemann. A Joubert, C. Brown) on behalf of the Directorate : RDM Compliance.

DESMET, P. & MARSH, A. 2008. Namakwa District Biodiversity Sector Plan.

DWA 2012a. Final Project Report for the Classification of significant water resources in the Olifants-Doorn WMA, Department of Water Affairs, South Africa, Belcher A. and Grobler D. 2012.

DWA 2012b. Integrated Socio-Economic and Ecological Specialist Report for the Classification of significant water resources in the Olifants-Doorn WMA, Department of Water Affairs, South Africa.

DWA 2012c. Guideline for identifying levels of Resource Protection Measures for Inland Wetlands: Version 1.0. Joint Department of Water Affairs and Water Research Commission report, prepared by M. W. Rountree, B. Weston and J. Jay. Department of Water Affairs, Pretoria.

DWA 2012d. DRAFT: Review and update of the 1999 Ecological Importance-Sensitivity and the Present Ecological Status (EIS/PES) of South African rivers including expansion to priority tributaries and wetlands according to quaternary catchment: Group 5 - Western Cape WMAs: Breede/Overberg, Berg, Gouritz and Olifants/Doorn. Draft report prepared by Southern Waters for Department of Water Affairs.

DWA. 2010. Directorate Water Resources Planning Systems: Water Quality Planning. Resource Directed Management of Water Quality. Planning Level Review of Water Quality in South Africa. Sub-series No WQP 2.0. Pretoria, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). 2003. Sandveld Preliminary (Rapid) Reserve Determinations. Langvlei, Jakkals and Verlorenvlei Rivers. Olifants-Doorn WMA G30. Surface Volume 1: Final Report Reserve Specifications. DWAF Project Number: 2002-227.

DWAF, 2005. A Practical Field Procedure for Identification and Delineation of Wetlands and Riparian Areas. Department of Water Affairs and Forestry, Pretoria.

DWAF 2008. Methods for determining the Water Quality component of the Ecological Reserve. Prepared by Scherman Consulting.

DEPARTMENT OF WATER AND SANITATION (DWS). 2014. Determination of Resource Quality Objectives in the Upper Vaal Water Management Area (WMA8): Resource Unit Prioritisation Report. Report No.: RDM/WMA08/00/CON/RQO/0213. Chief Directorate: Water Ecosystems. Study No.: WP10535. Prepared by the Institute of Natural Resources (INR) NPC. INR Technical Report No.: INR 493/14.(i). Pietermaritzburg, South Africa.

DWS. 2016. Development of Procedures to Operationalise Resource Directed Measures. Water quality tool analysis and standardisation Report. Prepared by Scherman, P-A and Koekemoer, S for: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0816.

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.

DWS. 2017b. Development of Procedures to Operationalise Resource Directed Measures. Main Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0117.

DWS. 2018a. Determination of Water Resource Classes and Associated Resource Quality Objectives in the Berg Catchment: Resource Units Prioritisation Report. Project Number WP10987. DWS Report NO: RDM/WMA9/00/CON/CLA/0517.

DWS 2018b. Determination of Water Resources Classes and Resource Quality Objectives in the Breede-Gouritz Water Management Area: Resource Unit Prioritisation Report. Report No: RDM/WMA8/00/CON/CLA/0517.

GEOSS, 2005. Groundwater Reserve Determination required for the Sandveld, Olifants-Doorn Water Management Area. GEOSS Report Number: 2005/04-20. GEOSS - Geohydrological & Spatial Solutions International (Pty) Ltd. Stellenbosch, South Africa.

GRESSE, F (2017). Working for Wetlands Rehabilitation Programme, Western Cape. Basic Assessment Report. Aurecon Report No: 113223/11664. Prepared by Aurecon South Africa (Pty) Ltd.

GRUNDLING A, GRUNDLING P-L AND VAN ROOYEN L 2018. National peatland database. *The Water Wheel*, May/June 2018, pp. 39-40.

KLEYNHANS CJ, THIRION C AND MOOLMAN J. 2005. A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria.

KOTZE D, MACFARLANE D, EDWARDS R, MANDER M, COLLINS N, TEXEIRA-LEITE A, LAGESSE J, PRINGLE C, MARNEWECK G, BATCHELOR A AND LINDLEY D. 2020. WET-EcoServices Version 2.0: A technique for rapidly assessing ecosystem services supplied by wetlands and riparian areas. WRC Report No. TT 833/20. Water Research Commission, Pretoria, South Africa.

LOUW D, BIRKHEAD, D, EWART-SMITH J, HUGGINS G, KOEKEMOER S, LOTTER A, MACKENZIE J, MULLINS W, SAMI, K, SCHERMAN P, VAN NIEKERK L, VAN ROOYEN P. 2017. Development of Procedures to Operationalise Resource Directed Measures. Main Report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Report no RDM/WE/00/CON/ORDM/0117. Department of Water and Sanitation, South Africa.

OLLIS DJ, SNADDON CD, JOB NM AND MBONA N. 2013. Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria.

MACFARLANE DM, OLLIS DJ AND KOTZE DC, 2020. WET-Health (Version 2.0). A refined suite of tools for assessing the Present Ecological State of wetland ecosystems. Technical Guide. WRC Report No. TT 820/20. Water Research Commission, Pretoria.

MUCINA L AND RUTHERFORD MC (eds) 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

NEL, J. 2005. Assessment of the Geohydrology of the Langvlei Catchment. Report No: GH 4000.

NEL JL, DRIVER A, STRYDOM WF, MAHERRY A, PETERSEN C, HILL L, ROUX DJ, NIENABER S, VAN DEVENTER H, SWARTZ E AND SMITH-ADAO LB 2011. Atlas of Freshwater Ecosystem Priority Areas in South Africa: Maps to support sustainable development of water resources. WRC Report No. TT 500/11. Water Research Commission, Pretoria.

NEL L, MURRAY KM, MAHERRY AM, PETERSEN CP, ROUX DJ, DRIVER A, HILL L, VAN DEVENTER H, FUNKE N, SWARTZ ER, SMITH-ADAO LB, MBONA N, DOWNSBOROUGH L AND NIENABER S. 2011. Technical Report for the National Freshwater Ecosystem Priority Areas project. WRC Report No. 1801/2/11. Water Research Commission, Pretoria.

NEL J, COLVIN C, LE MAITRE D, SMITH J AND HAINES I 2013. South Africa's Strategic Water Source Areas. CSIR Report no. CSIR/NRE/ECOS/ER/2013/0031/A.

POOL-STANVLIET R, DUFFELL-CANHAM A, PENCE G AND SMART R 2017. The Western Cape Biodiversity Spatial Plan Handbook. Stellenbosch: CapeNature.

REINECKE K, MAGOBA R, BROWN C AND JOUBERT A 2018. A Conceptual Framework for Using Historical Information When Monitoring Resource Quality Objectives. WRC Report No.2345/1/18. Water Research Commission, Pretoria.

REPUBLIC OF SOUTH AFRICA. DEPARTMENT OF WATER AND SANITATION. 2015. Proposed Classes of Water Resources and Resource Quality Objectives for Catchments of the Olifants Doorn Government Gazette no. 39001, Government Notice No 609, 17 July.

ROOSEBOOM, A., VERSTER E, ZIETSMAN HL, LOTRIET HH. 1992. The Development of the New Sediment Yield Map of Southern Africa. Report to the WRC by Sigma Beta. WRC Report No 297/2/92.

ROUNTREE MW AND KOTZE DC 2013. Specialist Appendix A3: EIS Assessment. In: Rountree MW, Malan HL and Weston BC (eds.); Manual for the Rapid Ecological Reserve Determination of Inland Wetlands (Version 2.0). WRC Report No. 1788/1/13. Water Research Commission, Pretoria, pp. 42-46.

ROSSOUW, J.N., 2009. Riviera Tungsten Environmental Impact Assessment: Present water quality status and scoping report. Draft report as part of the Environmental Impact Assessment Report for the Riviera Tungsten Deposit, Pieketberg.

RUTHERFORD MC, MUCINA L AND POWRIE LW 2006. Biomes and bioregions of Southern Africa. In: Mucina L & Rutherford MC (eds), The vegetation of South Africa, Lesotho and Swaziland: 30-51. SANBI, Pretoria.

SNADDON K & DAY L 2009. Prioritisation of City Wetlands. Report prepared for the City of Cape Town by the Freshwater Consulting Group.

SNADDON, K. & NIEUWOUDT, H. 2019. Working For Wetlands: Western Cape. Provincial Strategic Plan: 2019 - 2024. Version 1, August 2019. Prepared for Department of Environmental Affairs; Environmental Programmes: Natural Resource Management.

SEAMAN, M.T., M.F., WATSON, M., KING, J., ARMOUR, J., BARKER, C.H., DOLLAR, E., DU PREEZ, P.J., HUGHES, D., ROSSOUW, L., VAN TONDER, G., 2010. Developing a method for determining the environmental water requirements for non-perennial systems. WRC Report No TT 459/10.

SIGIDI, N.T., 2017. Geochemical and isotopic tracing of salinity loads into the RAMSAR listed Verlorenvlei freshwater coastal estuarine lake, Western Cape, South Africa. Unpublished MSc thesis, Department of Earth Sciences, Stellenbosch University.

TALJAARD, S, VAN NIEKERK, L, HUIZINGA, P AND JOUBERT, W. 2003. Resource monitoring procedures for estuaries for application in the Ecological Reserve determination and implementation process. Water Research Commission Report No. 1308/1/03. Pretoria.

TURPIE. J.K. AND CLARK, B.M. 2007. Development of a conservation plan for temperate South African estuaries on the basis of biodiversity importance, ecosystem health and economic costs and benefits. Anchor Environmental Consulting report prepared for C.A.P.E. Regional Estuarine Management Programme.

VAN DEVENTER, H., SMITH-ADAO, L., COLLINS, N.B., GRENFELL, M., GRUNDLING, A., GRUNDLING, P-L., IMPSON, D., JOB, N., LÖTTER, M., OLLIS, D., PETERSEN, C., SCHERMAN, P., SIEBEN, E., SNADDON, K., TERERAI, F. & VAN DER COLFF, D. 2019. 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.

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. & 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 NIEKERK, L, ADAMS JB, JAMES, N, LAMBERTH S, MACKAY F, RAJKARAN A, TURPIE J, WEERTS S, WHITFIELD AK. 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: 199-216.

VAN NIEKERK L, ADAMS, JB, LAMBERTH, SJ, TALJAARD, S, & VAN ROOYEN P 2016. Development of Procedures to Operationalise Resource Directed Measures. Estuaries and Marine tool analysis and standardisation Report. Prepared by: CSIR for Rivers for Africa. Report no RDM/WE/00/CON/ORDM/0716. Department of Water and Sanitation, South Africa, October 2016.

VAN NIEKERK, L AND TALJAARD, S. 2003. Recommendations on a framework for cooperative governance in South African estuaries. Report in preparation for the Water Research Commission as part of the Eastern Cape Estuaries Management Programme. CSIR Report ENV-S-C 2003-077.

VAN NIEKERK, L AND TALJAARD, S. 2007. Proposed generic framework for Estuarine Management Plans. C.A.P.E. Estuaries Management Programme.

VAN NIEKERK, L. AND TURPIE, J.K. (EDS) 2012. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B. Council for Scientific and Industrial Research, Stellenbosch.

NIEKERK L; TALJAARD S; ADAMS JB; FUNDISI D; HUIZINGA P; LAMBERTH SJ; MALLORY S; SNOW GC; TURPIE JK; WHITFIELD AK; WOOLDRIDGE TH (2015). Desktop provisional eco-classification of the temperate estuaries in South Africa. WRC K5/2187. WRC Report number 2187/1/15.

WATSON, A., EILERS, A., MILLER, J., 2020a. Groundwater characterisation and recharge estimation using CMB and environmental isotopes in a semi-arid agricultural region and implications for sustainability of the Verlorenvlei estuarine system, South Africa. Water (Switzerland) 12, 1–26. https://doi.org/10.3390/w12051362.

WATSON, A., KRALISCH, S., KÜNNE, A., FINK, M., MILLER, J., 2020b. Impact of precipitation data density and duration on simulated flow dynamics and implications for ecohydrological modelling in semi-arid catchments in Southern Africa. J. Hydrol. 590, 125280. https://doi.org/10.1016/j.jhydrol.2020.125280.

WATSON, A., MIDGLEY, G., KÜNNE, A., KRALISCH, S., HELMSCHROT, J., 2021. Determining Hydrological Variability Using a Multi-Catchment Model Approach for the Western Cape, South Africa. Sustain. 13, 1–26. https://doi.org/https://doi.org/10.3390/.

WATSON, A., MILLER, J., FINK, M., KRALISCH, S., FLEISCHER, M., DE CLERCQ, W., 2019. Distributive rainfall-runoff modelling to understand runoff-to-baseflow proportioning and its impact on the determination of reserve requirements of the Verlorenvlei estuarine lake, west coast, South Africa. Hydrol. Earth Syst. Sci. 23, 2679–2697. https://doi.org/10.5194/hess-23-2679-2019.

WESTERN CAPE GOVERNMENT: DEPARTMENT OF ENVIRONMENT AND DEVELOPMENT PLANNING AND DEPARTMENT OF AGRICULTURE, 2018. Sandveld Environmental Management Framework.