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

GROUNDWATER RESERVE REPORT

AUGUST 2023

Department of Water and Sanitation

Chief Directorate: Water Ecosystem Management

DEPARTMENT: WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEM MANAGEMENT

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

WP11340

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DOCUMENT INDEX

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Bold type indicates this report.

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ABBREVIATIONS

BAS	Best Attainable State
BH	Borehole
BHN	Basic Human Needs
CGS	Council for Geoscience (Est 1993 formerly the Geological Survey of South Africa)
CSIR	Council for Scientific and Industrial Research
CMA	Catchment Management Agency
DEA	Department of Environment Affairs
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
EWR	Ecological Water Requirements
Fe	Iron
GA	General Authorisation
GCM	General Circulation Models
GIS	Geographic Information System
GRDM	Groundwater Resource Directed Measures
GRU	Groundwater Resource Unit
ha	hectare
HDI	Human Development Index
HDAI	Hydrological Driver Assessment Index
HGM	Hydrogeomorphic
HRU	Hydrological Resource Unit

km	kilometre
l/s	Litre per second
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
m	metres
m^3/a	cubic metres cubed per annum
$m^3/ha/a$	cubic metres cubed per hectare per annum
mbgl	metres below ground level
mg/L	milligrams per litre
mm	millimetre
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
NGA	National Groundwater Archive
NWA	National Water Act
PES	Present Ecological State
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
RQO	Resource Quality Objective

RU	Resource Units
RWQO	Resource Water Quality Objective
SANAS	South African National Accreditation System
SANS	South African National Standard
TMG	Table Mountain Group
TT	Task Team
V & V	Validation and Verification (of existing water use)
WARMS	Water Use Authorisation and Registration Management System
WCBSP	Western Cape Biodiversity Spatial Plan
WGS84	World Geodetic System 1984
WL	Water Level
WMA	Water Management Area
WMS	Water Management System
WR2012	Water Resources 2012
WRC	Water Research Commission
WULA	Water use licence application

GLOSSARY OF TERMS

AQUIFER A geological formation, which has structures or textures that hold water or permit appreciable water movement through them [from National Water Act (Act No. 36 of 1998)].

BASEFLOW The flow component of streamflow which is comprised of groundwater and discharges gradually into the channel.

BOREHOLE : Includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer [from National Water Act (Act No. 36 of 1998)].

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

ECOSYSTEM A community of animals, plants and bacteria with its physical and chemical environment.

EPHEMERAL An ephemeral stream has flowing water only during, and for a short duration after, precipitation events in a typical year.

ENVIRONMENT All of the external factors, conditions, and influences that affect the growth, development, and survival of organisms or a community. This includes climate, physical, chemical, and biological factors, nutrients, and social and cultural conditions.

ESTUARY A partially or fully enclosed body of water that is open to the sea permanently or periodically, and within which the sea water can be diluted, to a measurable extent, with fresh water drained from land.

EXOGENENOUS RECHARGE The lateral migration of groundwater from adjacent aquifers.

FAULT A break or crack in the earth's crust, and can range from a few centimetres long to many kilometres. Faults can conduct groundwater in certain cases, whilst in others they can stop the flow of groundwater.

FRACTURED AQUIFER Fissured and fractured bedrock resulting from decompression and/or tectonic action. Groundwater occurs predominantly within fissures and fractures.

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.

GROUNDWATER water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

GYPSIFEROUS Containing or yielding gypsum.

INTERGRANULAR AQUIFER The intergranular aquifer is the primary aquifer and is described as an aquifer in which groundwater is stored within the flows through open pore spaces in the unconsolidated Quaternary deposits.

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.

MODIFIED Changed, altered.

PALEO CHANNEL A paleo channel

PERMEABILITY The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as m3/m2·d or m/d). It is an intrinsic property of the porous medium and is independent of the properties of the saturating fluid; not to be confused with hydraulic conductivity, which relates specifically to the movement of water.

SPRING (EYE) A spring (eye) is a point specific discharge of groundwater to the surface and can form a wider seepage area that contribute to surface water runoff and the formation and maintenance of wetlands and freshwater ecosystems.

QUATERNARY CATCHMENT A fourth-order catchment in a hierarchical system in which the primary catchment is the major unit.

RECHARGE The addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water.

REGOLITH A layer of loose, weathered material covering solid rock. It usually forms from the breakdown or weathering of the underlying solid rock and it can hold large amounts of groundwater

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.

SATURATED ZONE The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere.

STORATIVITY The volume of water released from storage per unit of aquifer storage area per unit change in head.

SURFACE WATER All water that is exposed to the atmosphere, e.g., rivers, reservoirs, ponds, the sea, etc.

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 no. 36 of 1998).

YIELD (of a borehole) Borehole yield is the volume of water that can be abstracted from a borehole. This is the maximum rate of abstraction from the borehole and can be expressed as l/s, m^3/hr, m^3/d or m^3/a.

1 INTRODUCTION

1.1 Background

The Chief Directorate: Water Ecosystems Management of the Department of Water and Sanitation (DWS) has embarked on a Reserve determination study for the G30 and F60 catchments (**Map 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 Verlorenvlei 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 within the study area that are associated with estuaries, i.e., the Verlorenvlei, that provide important ecological services, but are under severe threat and require urgent protection. It is therefore important that the low confidence Reserve calculations are revisited and that the water resources with the Sandveld catchments are assessed holistically, with a clear understanding of the groundwater – surface water interactions and that the interdependencies thereof are being well researched and documented.

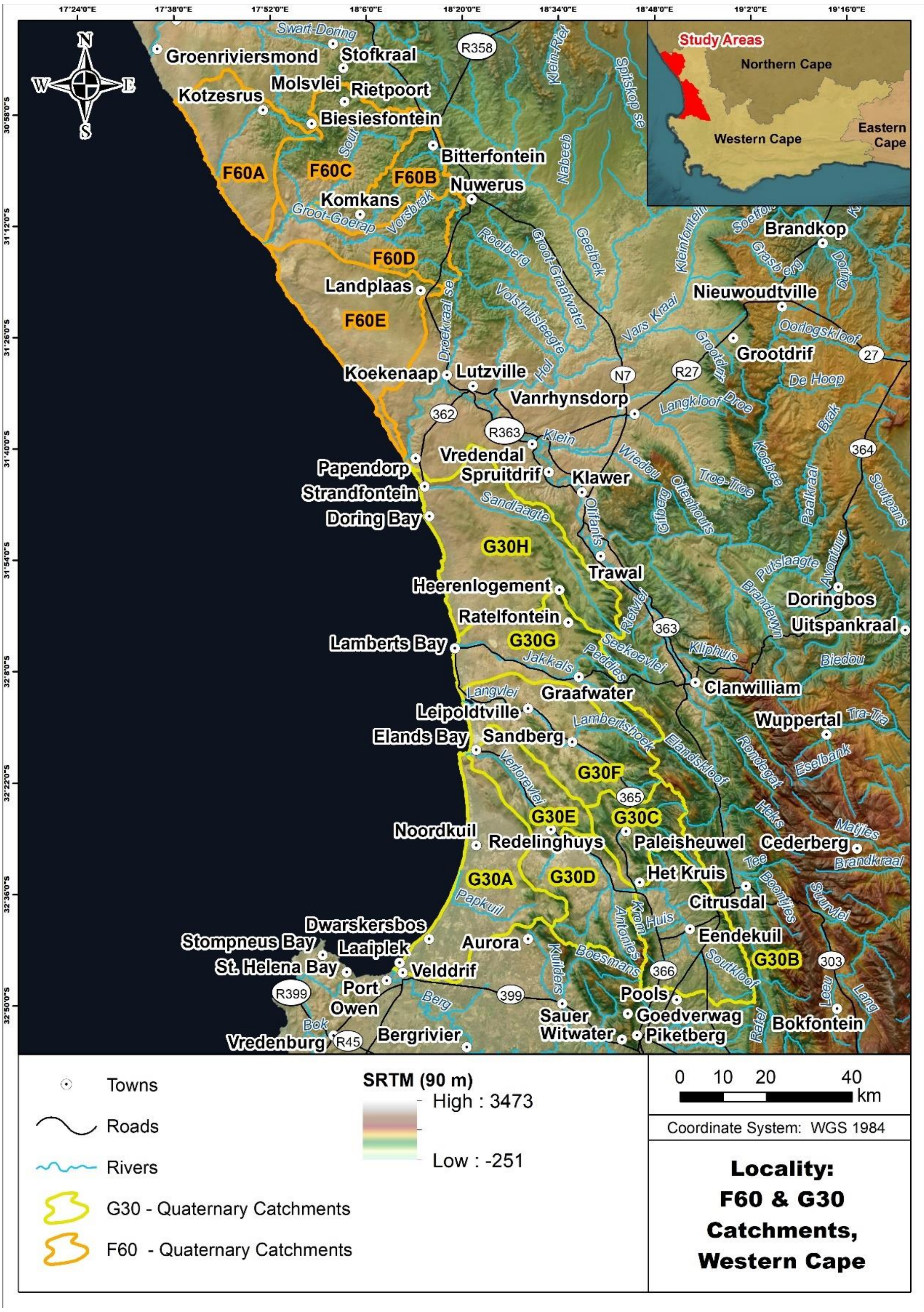
1.1 Objectives

This study aims to identify gaps in previous Reserve Determination Studies and to determine the Reserve with a high level of confidence that could be gazetted and provide a basis for decision-making and sustainable use of the resource. The following tasks are listed:

1. Complete a review of available hydrogeological data (hydraulic [i.e., groundwater levels] and hydro chemical) from literature, internal GEOSS datasets as well as existing Department of Water and Sanitation (DWS) databases and reports;
2. Characterize and describe the groundwater systems within the catchments.
3. Delineate relevant groundwater resource units (GRUs);
4. Determine the groundwater input into surface water systems within these catchments;
5. Calculate the groundwater balance per quaternary catchment;
6. Delineate important groundwater zones/aquifers that require protection;
7. Provide groundwater monitoring recommendations within the Tertiary G30 and F60 catchments;
8. Determine the groundwater Reserve

1.2 Purpose of this Report

The purpose of this report is to characterise the groundwater system, analyse the available data and calculate the groundwater reserve for the tertiary G30 and F60 catchments respectively, located within the Olifants-Doorn Water Management Area (**Map 1**).



Map 1: Map of the study area with the location of the Tertiary G30 and F60 Catchments

1.3 The Study Area

The study area comprises two Tertiary Catchments, the G30 (Sandveld) and the F60 (Knersvlakte) catchments. Both areas are considered semi-arid and receive generally low rainfall. The highest rainfall regions are located within the mountainous areas of the G30 catchment or adjacent to the southeast of the G30 catchment. In general, rainfall decreases from the south towards the north. The predominant land use is agriculture and there is limited urban or industrial development within the F60 catchment, however, there is some mining activity within the area.

The majority of the G30 and F60 Catchment Areas fall within the jurisdiction of three local municipalities part of the West Coast District Municipality in the Western Cape Province, namely:

- The Berg River Local Municipality;
- Cedarberg Local Municipality; and
- Matzikama Municipality.

A small section of the F60 catchment towards the far north falls within the borders of the Kamiesberg Local Municipality in the Northern Cape Province.

1.3.1 G30 Catchments (Sandveld)

The G30 catchments are known locally as the Sandveld and consist of the coastal plain along the west coast of South Africa, bordered by the Olifants River catchment to the north and east, the Berg River catchment in the south and the Atlantic Ocean coastline to the west. The study area is bound by the prominent Piketberg Mountains to the south, the Olifantsrivier and Cederberg Mountains (>500 metres above mean sea-level [mamsl]) to the east, with the low-lying coastal plains of the Sandveld dominating the eastern and central areas (<200 mamsl) (Umvoto, 2021).

Groundwater is considered an essential resource in the G30 tertiary catchment, where it is the sole freshwater source for neighbouring towns and rural water supply but also agricultural activities. It plays a major role in maintaining the functionality of the natural environment. Towns reliant on groundwater include Lamberts Bay, Elands Bay, Graafwater, Leipoldtville, Paleisheuwel, Redelinghuys and Eendekuil. Only the towns at the northern tips of the catchments (Strandfontein and Doringbaai) can obtain additional sources through the Olifants River canal system. Groundwater contributes to the surface water systems through baseflow, seepage areas and springs.

Groundwater plays a major role in maintaining and sustaining important aquatic ecosystems. This is evident as plant species, which are sensitive to distinct variations in water quality, occur more frequently in area known for low EC groundwater. The good quality groundwater is associated with recharge from 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. These areas are also where the highest rainfall in the area occurs and it has been found that recharge from these mountains then flows eastward towards the coast, following fault structures that act as water conduits.

1.3.1.1 G30 Geology

The geology for the G30 catchments is presented in **Table 1**. The Malmesbury Group (~800-550 Ma) of the Neoproterozoic Saldanian Belt forms the oldest geological formations in the region, upon which the younger sediments of the Cambrian (~500 Ma) Klipheuwel Group, Cambrian-Devonian (~500-390 Ma) Table Mountain Group (TMG) from the Cape Supergroup and Cenozoic (~160 Ma in the area) Sandveld Group are unconformably (i.e., erosional time-break/hiatus) overlain (Johnson et al., 2006; Rozendaal and Gresse, 1994, and Umvoto, 2019). For most of the G30 catchments, the hard rock units are covered by thick Cenozoic 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 TMG is generally associated with good quality groundwater and is considered good aquifers (Peninsula and Piekenierskloof). However, some formations which form part of the TMG are shale-rich (Graafwater) and generally have poorer quality in terms of dissolved ions, specifically higher salinity.

The three prominent TMG formations occurring within the study area are the Piekenierskloof, Graafwater and Peninsula formations.

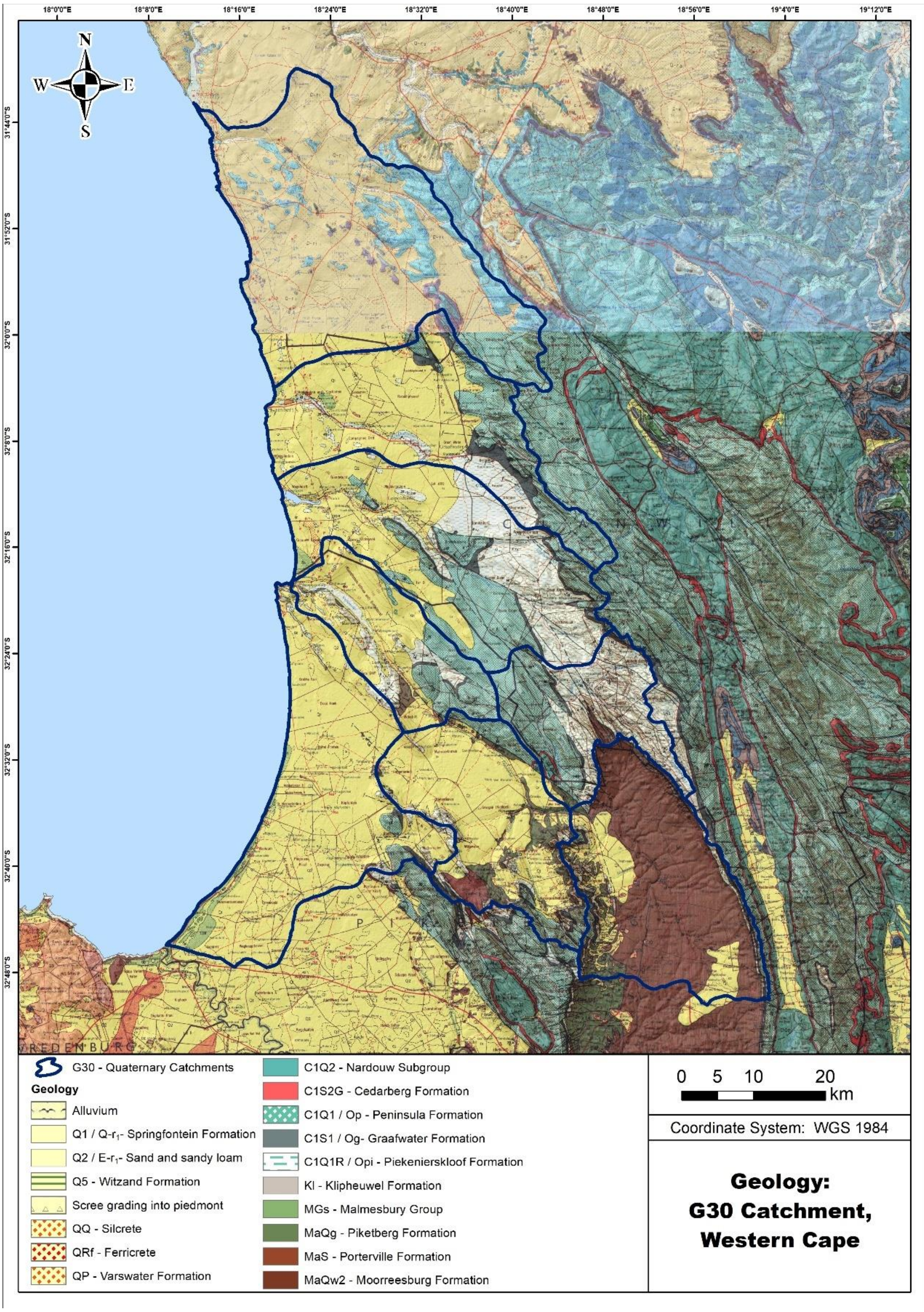
The Piekenierskloof Formation (10-150 m thick) (C1Q1R) consist of quartzitic sandstones and conglomerates. This formation is stratigraphically overlain by the thin-bedded, fine-grained, red-brown; siltstone to sandy shales of the Graafwater Formation (25 – 65 m thick). The other Table Mountain Group rock type in the area is the Peninsula Formation (575 – 2000 m thick), which stratigraphically overlies the Graafwater Formation. The Peninsula Formation consists of sandstone, with lenses of shale and conglomerate rarely present.

The distinct elevation changes between the Sandveld plains and the Cederberg and Piketberg mountain ranges are due to displacement and erosion along major southeast-northwest (SE-NW) striking faults. Similarly, these faults form deeply incised valleys within the mountain ranges, such as Moutonshoek, with the large Piketberg Syncline (i.e., U-shaped fold structure) forming the Wolfkloof Valley. Between the Olifantsrivierberge and the Piketberg Mountains is the low-lying Eendekuil Basin (Umvoto, 2021).

The Geological Survey of South Africa (now the Council for Geoscience) has mapped the area at a 1:250 000 scale (3218, Clanwilliam)(CGS,1973). The main geology of the area is listed in Table 3 and the geological setting is shown in **Table 1**. The Geology is displayed in **Map 2**.

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
C1Q2)	Rietvlei	Table Mountain Group	Grey feldspathic sandstones, siltstone and shale.
C1Q2	Skurweberg		Whitish grey, coarse-grained, thickly bedded quartzitic sandstone and conglomerates.
C1Q2	Goudini (Nardouw Sgp. with Skurweberg and Rietvlei Fm. not sub-divided on map)		Reddish-weathering sandstone with interbedded shale and siltstone~
C1S2G	Cedarberg		Grey to dark grey, fine sandstone and siltstone (upper Disa Mb.) / dark grey to black shale (basal Soom Mb.)
C1S2G	Pakhuis (with Cedarberg Fm., not sub-divided on map)		Grey tillite, sandstone and conglomerate~
C1Q1	Peninsula Formation		Quartzitic sandstone with minor shale and conglomerate lenses
C1S1	Graafwater Formation		Purple to maroon, thinly bedded sandstone, siltstone, mudstone, and shale
C1Q1R	Piekenierskloof Formation		Thickly bedded, pinkish-white quartzite and conglomerate
Kl	Magrug / Populiersbos	Klipheuwel	Reddish-purple conglomerate and sandstone (basal Magrug Fm.) / shale (upper Populiersbos Fm.)
-	Cape Granite Suite	Riviera Pluton	Granodiorite and porphyritic granite
MaQg	Piketberg	Malmesbury Group	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



Map 2: Geological setting of the G30 catchments (Clanwilliam, 3218 & Calvinia, 3118) (CGS, 1973 & CGS, 2001)

1.3.1.2 G30 Hydrogeology

The geological setting of the G30 tertiary catchment is associated with both fractured and intergranular aquifers (**Map 3**) (DWAF 2005). The TMG rocks are largely anisotropic and do not display uniform aquifer characteristics. The infiltration, transmissivity and storage of groundwater are therefore controlled primarily by the occurrence of faults, fractures, fissures and joints. The abundance of fractures, as well as the generally high rainfall of the higher-lying areas, results in a setting favourable for groundwater recharge. It is believed that the TMG offers the most favourable opportunities for groundwater development from fractured aquifers in the south-western Cape region (Meyer, 2001). The quality of groundwater from the TMG is generally excellent for use, with Electrical Conductivities (ECs) ranging between 5 and 70 mS/m. The presence of shale layers, however, can occasionally increase the ECs up to 180 mS/m (Meyer 2001). The fractured aquifer also includes the Malmesbury Group formations. It must be noted that water obtained from drilling into the shale rich Malmesbury generally provides groundwater of poorer quality than what is found within the TMG. Quaternary age deposits overlying the bedrock towards the coast were identified by Jolly (1992) and Vandoolaeghe (1982) as a second optimum source of groundwater, apart from drilling directly into the TMG. The properties of the Quaternary deposits vary significantly.

The average borehole yield ranges from very low (0.5 L/s) to high yielding (> 5 L/s) (DWAF, 2005), with identified paleochannels producing boreholes of a yield higher than 25 L/s. Groundwater quality (**Map 4**) is described as being good across the G30 catchments (DWAF 2005). Reports exist of deteriorating water quality in the Sandberg area (GEOSS, 2022a) and the DWS monitoring has also indicated a few very high EC values at one of the coastal Elandsbay monitoring boreholes (DWS, 2022). Fewer monitoring boreholes exist in the upper reaches of the catchments.

With regards to the 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(**Map 3**). In the coastal areas, where thick sand deposits are found, boreholes are drilled into the unconsolidated sand, primary sand aquifers. 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 gravels, which is in turn underlain by residual bedrock. The Quaternary age deposits were identified by Vandoolaeghe (1982) as the optimum source of groundwater. The properties of the Quaternary deposits vary significantly. Yields of up to 20 L/s can be expected in the coarser-grained sand deposits, whilst limited yields of around 3 L/s are common in the finer sand deposits. In general, the high porosity and extreme horizontal permeability of this primary aquifer greatly enhance flow dynamics over that of hard rocks.

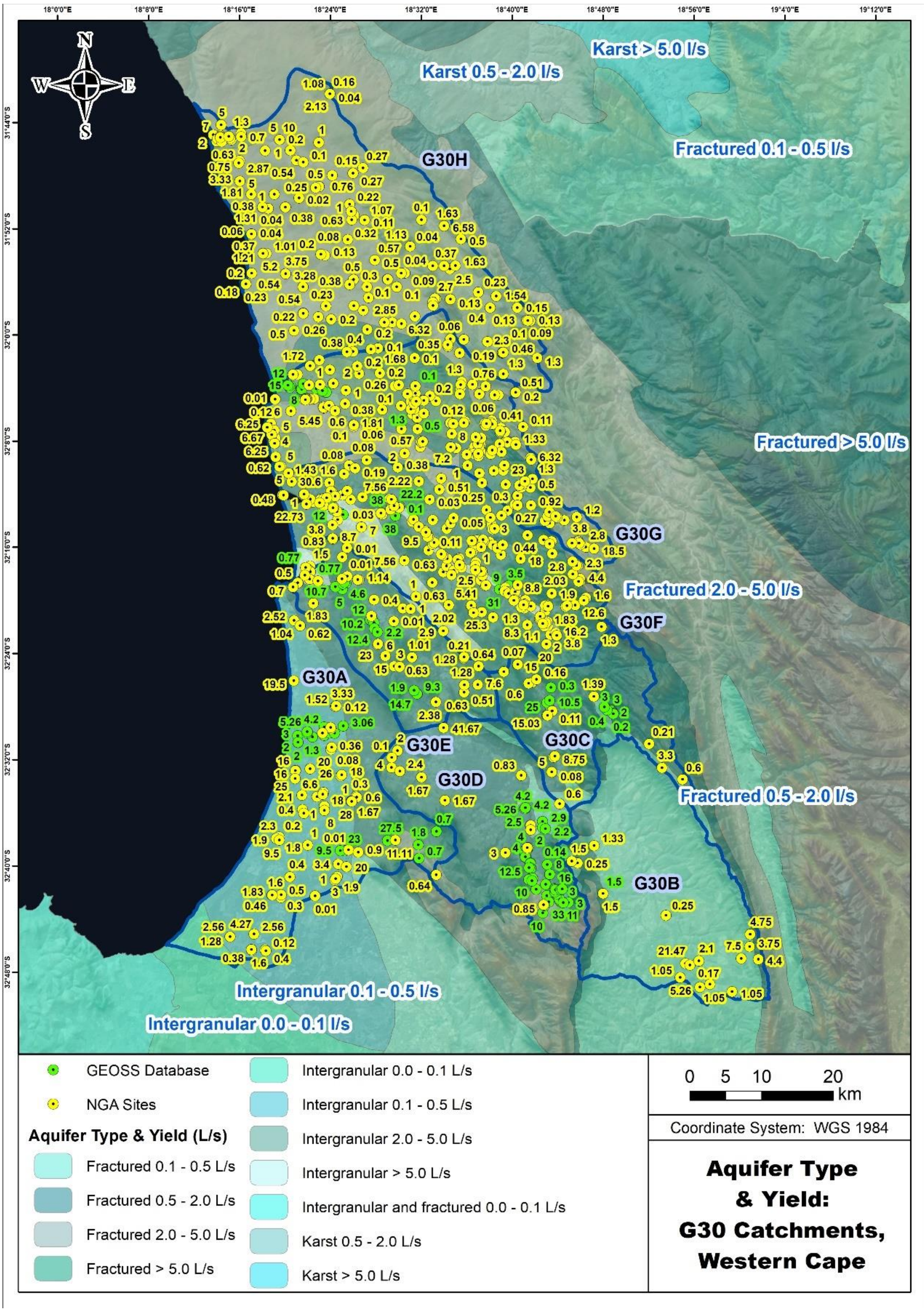
Within the primary sand aquifer, yields vary from low (dry) to very high (<20 L/s) (**Map 3**). High-yielding boreholes were typically drilled into coarse-grained sands and gravels, often referred to as Paleo channel environments (Jolly, 1992). Paleo channels are referred to as old channels that act as conduits for groundwater flow. These were typically filled through the deposition of coarse-grained material (sand or gravels) during high-flow events. The rivers were meandering and do not always conform to a linear deposition pattern, therefore, resulting in highly variable borehole siting success. In the Sandveld, these are in some areas very distinctly visible from the air as bands of lighter sand areas that are generally SE-NW trending. High-yielding boreholes and seepage areas are found within these areas, although at irregular intervals. From data collected 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. This hypothesis does not contradict the paleo-channel theory, as the paleo-rivers would have exploited the zones of weakness along the fault lines.

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 the last 30 years transitioned from integrated livestock and rainfed crop production systems to irrigated vegetable and fruit production systems. 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 towns and agricultural water uses has increased the groundwater demand in the area and thus increased the stress on the water resources.

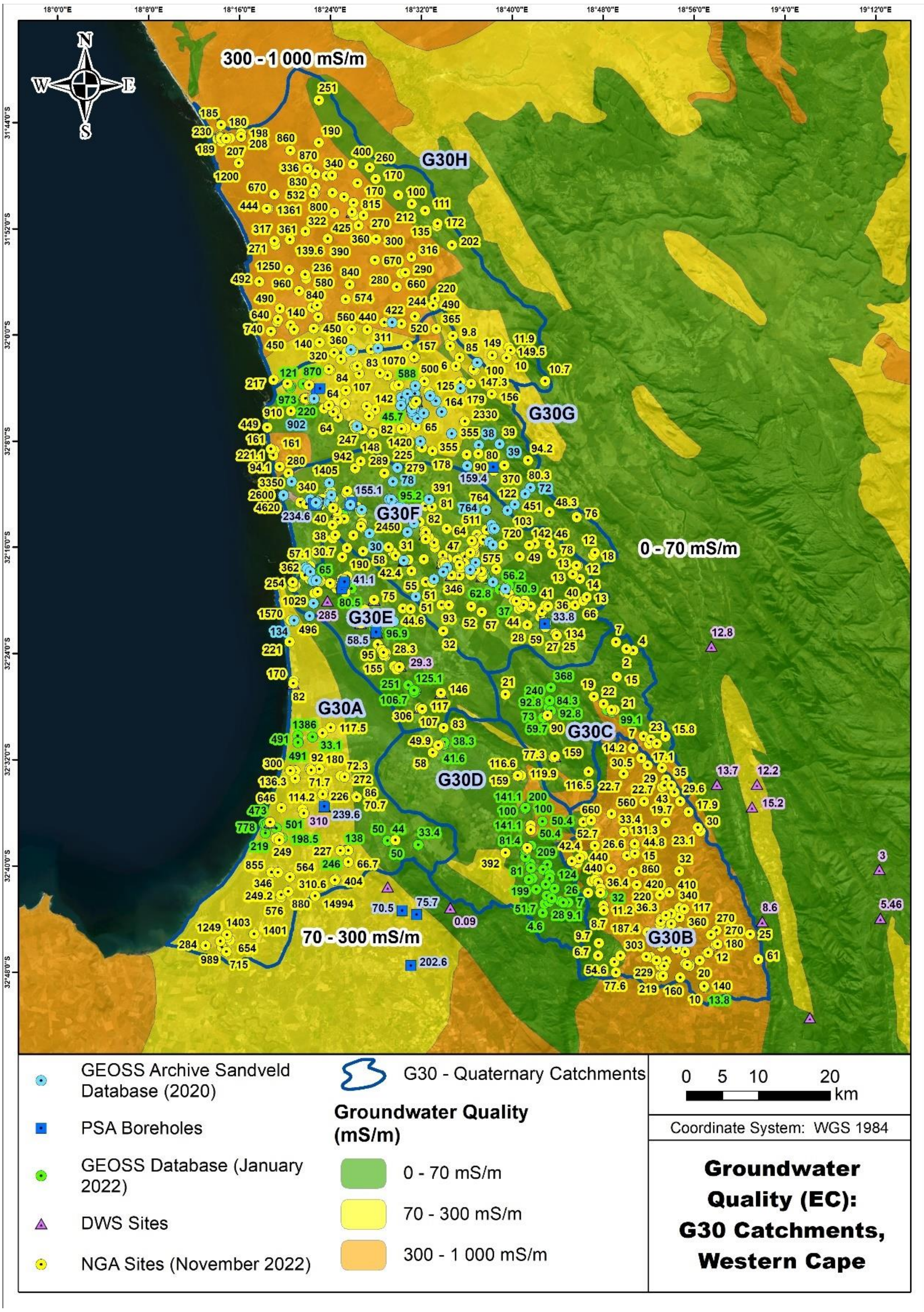
Monitoring data is available in the form of water level readings from DWS (DWS, 2022), municipalities (Cederberg Local Municipality, 2019a), individual farms (GEOSS, 2022b and GEOSS, 2023) and the Potato SA monitoring project (GEOSS, 2022a). Data reflecting the actual abstraction for agricultural purposes is lacking, as the Government Gazette (2018) directive to install flowmeters across the Olifants catchment and send actual abstraction volumes to DWS has to a large extend not been implemented or enforced. The distribution of Potato SA and DWS monitoring boreholes is towards the coast, with limited monitoring being conducted in the upper reaches of these catchments.

From consulting with the local DWS officials currently working to finalise the V&V the Validation and Verification (V&V) process, it was noted that they have picked up development that has occurred since the early 2000`s, that will not be categorised as Existing Lawful Use and that will need to be dealt with after the V & V process has been finalized. The Department is working to finalise the V&V this year (2023). Further departmental processes will then follow to deal with water users that use more than what is authorised.

Springs and seepage points were incorporated in the delineation process for the reserve study and act as focus points within the GRUs. Some of the springs have been visited and for some, comprehensive data is available (flow and chemistry data available for Matroozefontein 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, with the full yield being taken for domestic and agricultural uses.



Map 3: Regional aquifer yield for the G30 Catchments from the 1:1 000 000 scale groundwater map (DWAF, 2005)



Map 4: Regional groundwater quality (EC in mS/m) from (DWAF, 2005), for the G30 Catchments

1.3.2 F60 Catchments (Knersvlakte)

The F60 catchments are in general drier and the groundwater availability is much lower than in the G30 catchments (**Map 6**). The quality of the groundwater restricts the use of the groundwater as it is not considered fit for human consumption in large areas (**Map 7**) within these catchments. Groundwater is abstracted for municipal supply around the town of Bitterfontein, although it should be noted that most of the production boreholes fall within quaternary catchment E33D, outside of the F60 catchments.

During a hydrocensus, conducted for this project in April 2022, it was found that groundwater is used for non-drinking domestic uses as well as supplying water to livestock. Drinking water is mostly supplied by rainwater and mist collection. Springs are found in the F60 catchments and although generally found to be very low yielding (<1L/s), local wildlife and people are reliant on these water resources. Most low-yielding springs are still flowing, with locals noting that they have not seen a drop in water levels and spring flows for at least the last 20-30 years. It is observed that this area is still close to reference conditions, where the use of the groundwater resource is constrained due to the occurrence and quality of the groundwater.

1.3.2.1 Geology

The geology is dominated by igneous and metamorphic rock units that are overlain by quaternary deposits **(Map 5)**. 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.These dykes as well as faults (mostly SE-NW) are targeted during groundwater exploration. The chronological order of the geology units ranges from the youngest formation including Quaternary and Tertiary Deposits while the oldest is the Kamiesberg Group (**Table 2**).

The geometries of the aquifer systems in the F60 catchments have been largely controlled and influenced by the underlying geology of igneous and metamorphic rocks (such as granites and gneisses) and their deformation history or structural evolution. Another influence on aquifer geometry has been the geomorphic development of the Namaqualand region, including weathering (Pieterson *et al*., 2009). The groundwater can be found in 4 different aquifers:

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

The poor groundwater 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 igneous rocks high in salts and minerals. It has also been reported that although water can be found if drilling in or near dry river-beds, 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 (Watson et al., 2021a; Benito et al., 2011a and Benito et al., 2011b).

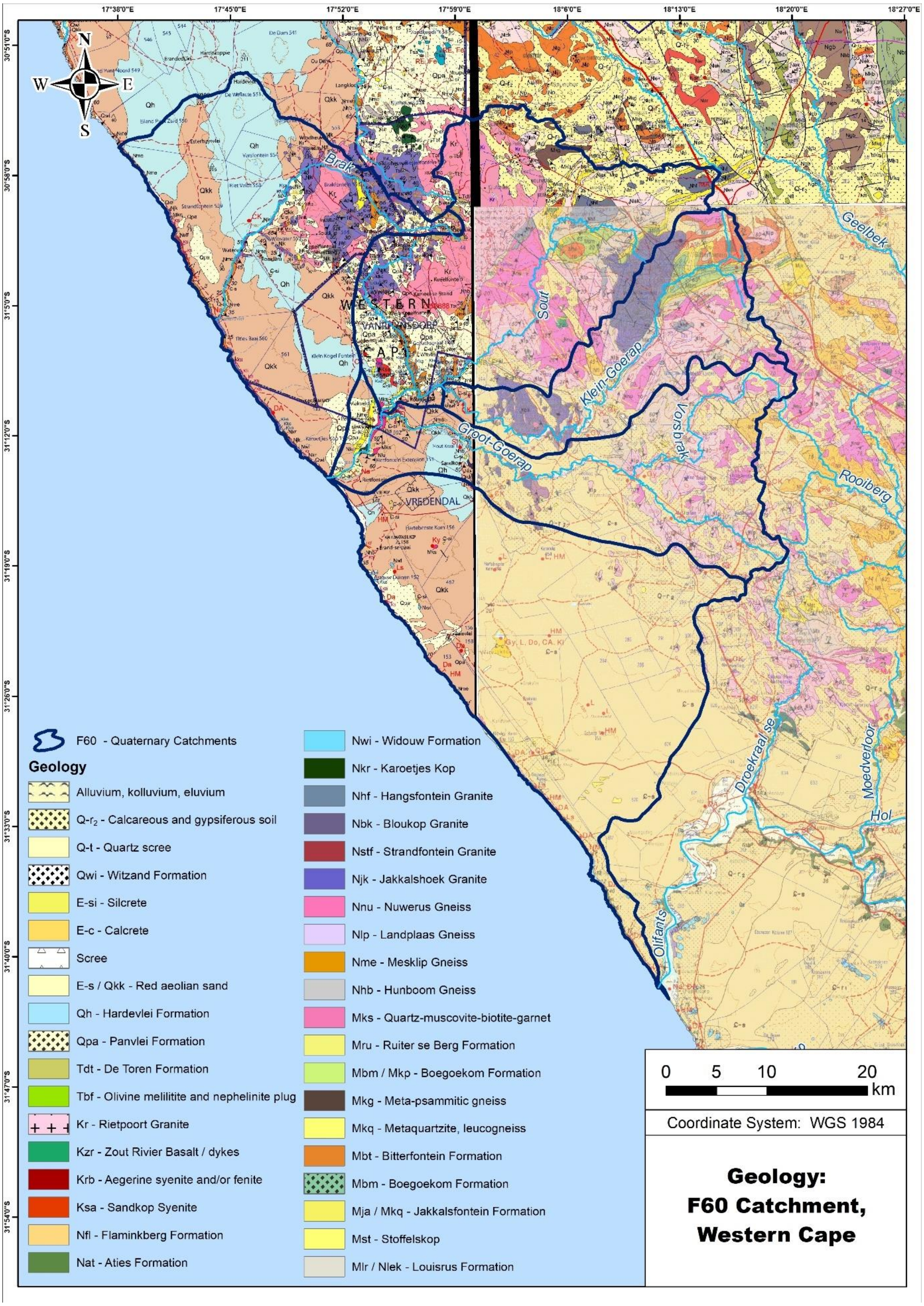
Very few hard rock formations are exposed in areas towards the coast and geological boundaries are covered by sand deposits. These coastal sedimentary deposits host some of the richest placer deposits in the world. They are targeted and mined for heavy minerals, such as zircon, garnet, ilmenite, rutile and magnetite. 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.

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.

Table 2: General Geology for F60 catchments

Code	Formation/Unit	Group/Suite	Description
~	-	Quaternary to Tertiary Deposits	Alluvium, colluvium, eluvium
Q-r2	-		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		Biotite augengneiss

Code	Formation/Unit	Group/Suite	Description
Nlp	Landplaas Gneiss	Little Namaqualand Suite	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	-	Kamiesberg Group	Quarts-muscovite-biotite-garnet
Mbt	Bitterfontein Formation		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



Map 5: Geological setting of the F60 catchments (Calvinia, 3118, Garies, 3017 & Loeriesfontein, 3018) (CGS, 2001; CGS, 2010 & CGS, 2010)

1.3.2.2 F60 Hydrogeology

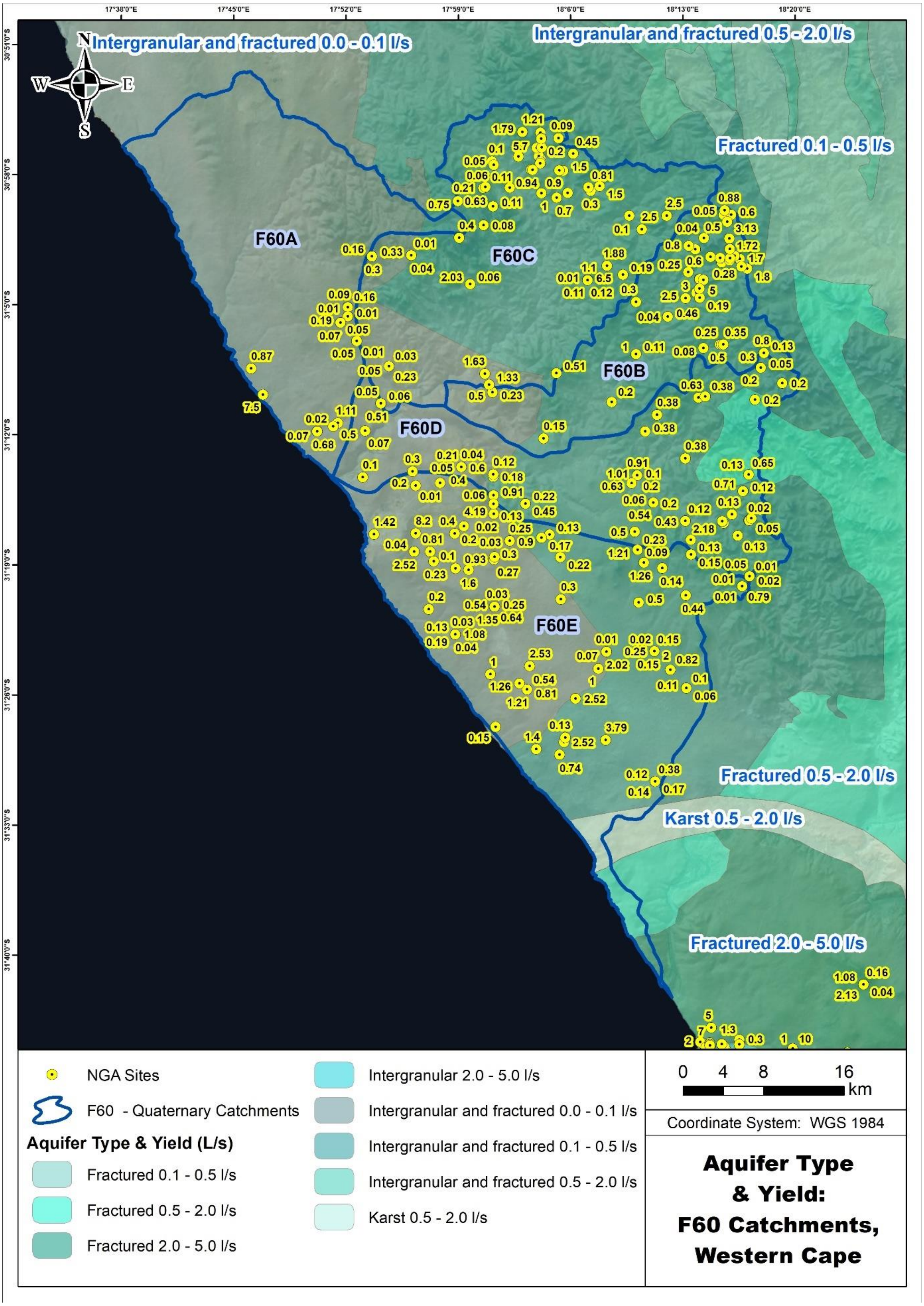
Groundwater is the only reliable source of freshwater in the area and all the human settlements are completely reliant on groundwater and rainwater collection. Farms are mainly livestock focussed and are reliant on the groundwater for domestic use as well as for human and animal consumption. This is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

The regional expected yields are very low (0.1 - 0.5 L/s) (**Map 6**). 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.

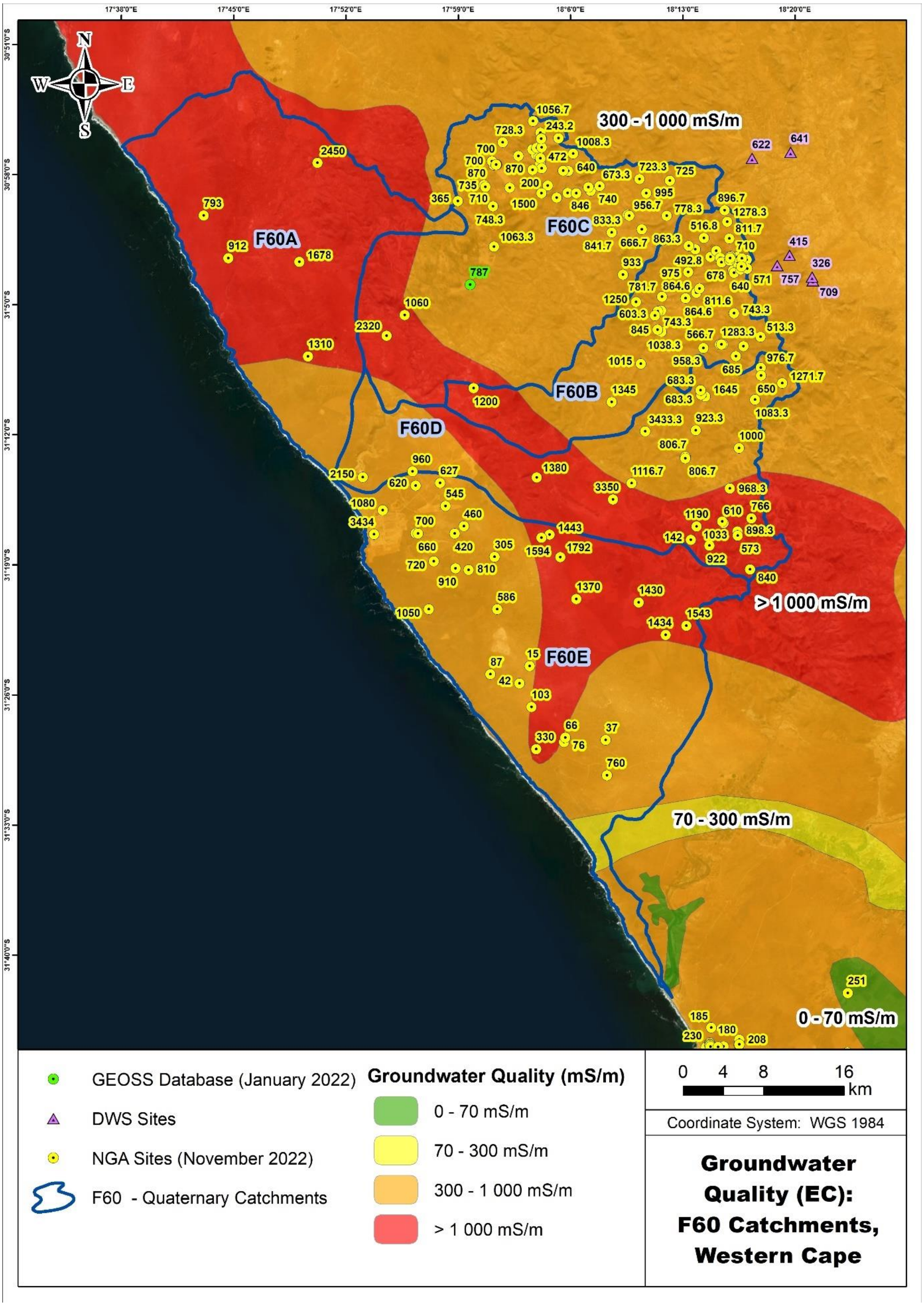
A karst aquifer exists in calcareous areas which possess a structure peculiar to and dependent upon underground solutions as well as the diversion of surface waters to underground routes. Usually in the Western Cape, intergranular (water moving through sand grains) and fractured aquifers (water moving 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 (**Map 7**) (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 F60E 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 standards. The treated water from Bitterfontein boreholes is then piped to the Nuwerus, Rietpoort, Stofkraal, Molsvlei and Put-se-kloof, as well as used in Bitterfontein itself. Most of the Bittefontein boreholes are situated in the neighbouring quaternary catchment, E33D. Kliprand makes use of its own boreholes for town supply.



Map 6: Regional aquifer yield for the F60 Catchments from the 1:1 000 000 scale groundwater map (DWAF, 2005



Map 7: Regional groundwater quality (EC in mS/m) from (DWAF, 2005), for the F60 Catchments

1.4 Study Methodology and Approach

A Reserve determination study endeavours to provide information at the highest level of confidence possible within the defined time and data availability. 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 is formed that may provide greater confidence (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 or BAS) 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 study. However, a lack of data for the water resources in the study area resulted in lower confidence results than what would be the requirement of a Comprehensive Ecological Reserve determination study. Clear recommendations with regard to future monitoring of the water resources has been included in the outcomes of this study to rectify this shortcoming. The monitoring will in the assist with the management and curve unsustainable use as well as improving the analytical model that has been produced during this study.

The river, wetland, estuarine and groundwater components of the Reserve determinations has used the latest RDM recommended methodologies (DWS, 2018a). While standard methodologies for the determination of the Basic Human Needs and ecological Reserve would 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 and ephemeral, 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 of hardy species with low diversity, although both the habitat and biota may be of high ecological importance;
- The estuaries within the area comprise mostly of 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).
- 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. 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 1** (DWAF, 2008) that 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.

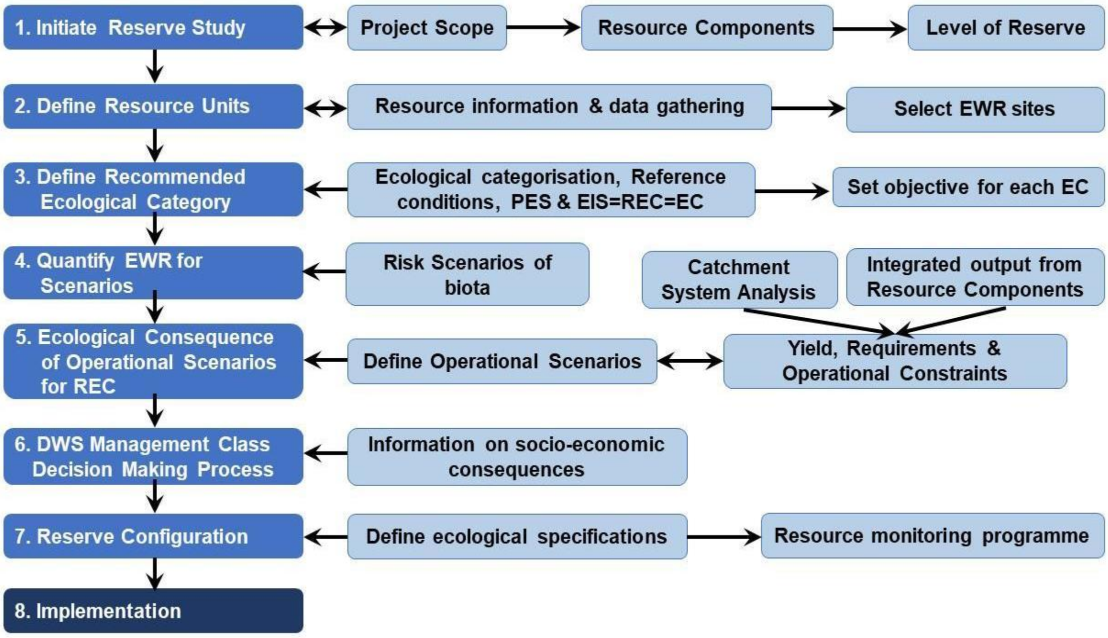


Figure 1: The Reserve Determination Process (adapted from DWAF, 2008)

2. GROUNDWATER RESOURCE UNIT DELINEATION

The delineation of Groundwater Resource Units (GRUs) was done at a desktop level and is based on findings and data from previous studies. Geological, hydrological and meteorological data were combined with general knowledge of the area and comments from land owners.

The occurrence of groundwater, aquifer characteristics and site-specific groundwater-related phenomena were taken into account during the process of delineation of the GRUs within the F60 and G30 catchments.

Because the groundwater reserves and RQOs that are linked to them will ultimately have to be linked to surface water RQOs and the quaternary catchments, it was decided to use these boundaries where possible.

For the F60 catchments, the quaternary boundaries were used.

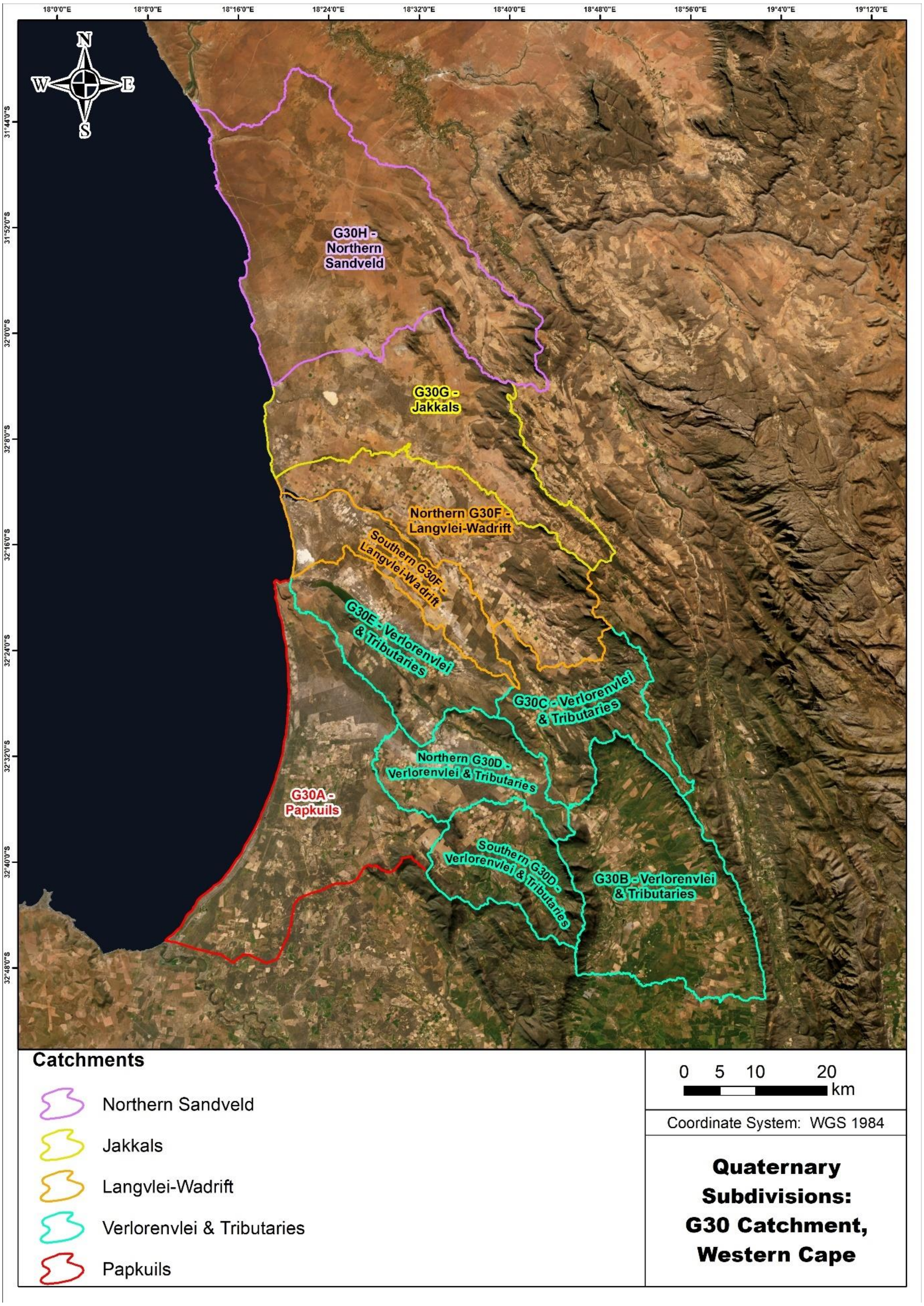
2.1 G30 Resource Unit Delineation

Taking into account the nature of the groundwater system within the G30 catchments, it was decided to mostly stick to the existing quaternary boundaries as they do tend to each incorporate a single valley that relates well with perceived groundwater flow and surface water contribution. The boundaries only extend to the coastline and do not presume that groundwater or surface water is unable to flow into the ocean.

The G30D quaternary catchment was split into a northern and southern GRU. This was based on a large difference in the rainfall received evidently increasing from north to south. The southern portion of the quaternary catchment experiences much higher rainfall (>450 mm/a) in comparison to that of the north (<300 mm/a). Where the southern mountainous area comprises of sedimentary bedrock cross-cut by fault structures and fractured zones, linked to higher percentages of recharge.

G30F has also been split into a northern and southern GRUs along the topographic high as this quaternary catchment includes two valleys that each have a separate paleochannel type feature.

Delineation areas in G30 catchments are displayed on **Map 8**.

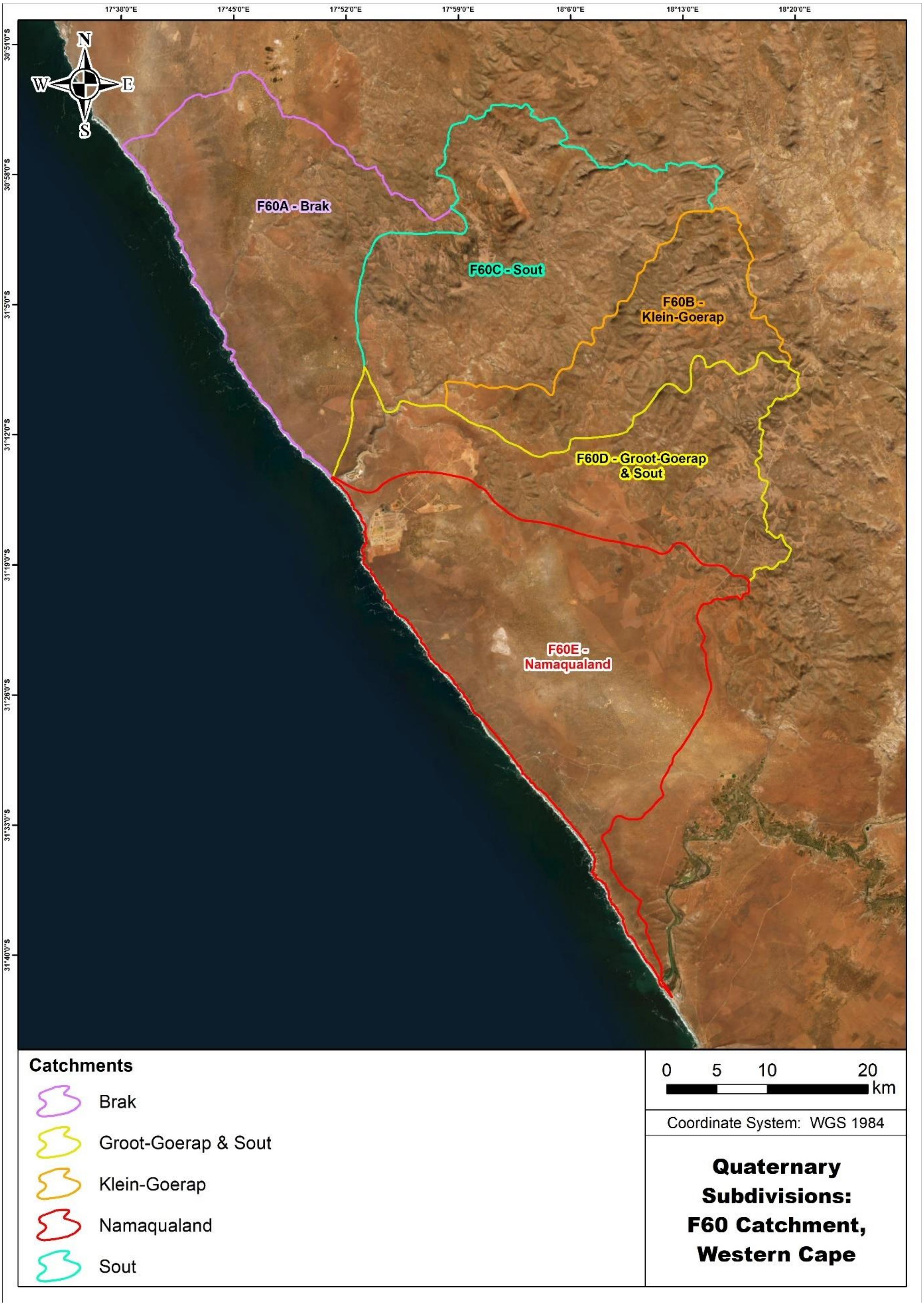


Map 8: Groundwater Resource Units delineated for G30 catchments

2.2 F60 Resource Unit Delineation

Taking into account the nature of the groundwater system within the F60 catchments, it was decided to keep to the existing quaternary boundaries as they do tend to each incorporate a single surface water system and as the RQOs will be on that level, the quaternary boundaries will act as sufficient separation.

Due to the presence of karst type aquifers in F60E`s coastal areas, it was attempted to divide the catchment. Due to a lack of data that could indicate exactly how far up the coast the karst aquifers stretch, it was decided to ultimately leave the boundaries of the GRU as is until sufficient data becomes available. Delineation areas in F60 catchments are displayed on **Map 9**.



Map 9: Map displaying Groundwater Resource Units delineated for F60 catchments

3. AVAILABLE DATA

Data were obtained through various sources. The DWS long-term monitoring data formed the base of the assessment with regard to water levels in the catchments, and trends within that dataset were checked against other datapoints from other sources, located nearby. The main data sources included:

- The National Groundwater Archive (NGA), Updated up till November 2022, when it was downloaded;
- The Department of Water and Sanitation`s monitoring database for the Berg, Sandveld, Cederberg and Bitterfontein Monitoring Networks (DWS, 2022);
- Municipal monitoring data (Cederberg Local Municipality, 2019b and Matzikama Local Municipality, 2022);
- The internal GEOSS database for work done within the F60 and G30 catchments for current (GEOSS, 2020a; GEOSS, 2020b; GEOSS, 2022b and GEOSS, 2023) and archived projects (pre-2020);
- The Stellenbosch University work that has been done in the G30 catchments (Eilers, 2018; Eilers et al., 2017; Harilall, 2020 ; Miller et al., 2022; Watson et al., 2018; Watson et al., 2019; Watson et al., 2020a; Watson et al., 2020b; Watson et al., 2021a and Watson et al., 2021b);
- The Potato South Africa monitoring project, although only limited access was granted to this database (GEOSS, 2019 and GEOSS, 2022a); and
- Namaqua Sands Mine (Tronox Mineral Sand, 2022).

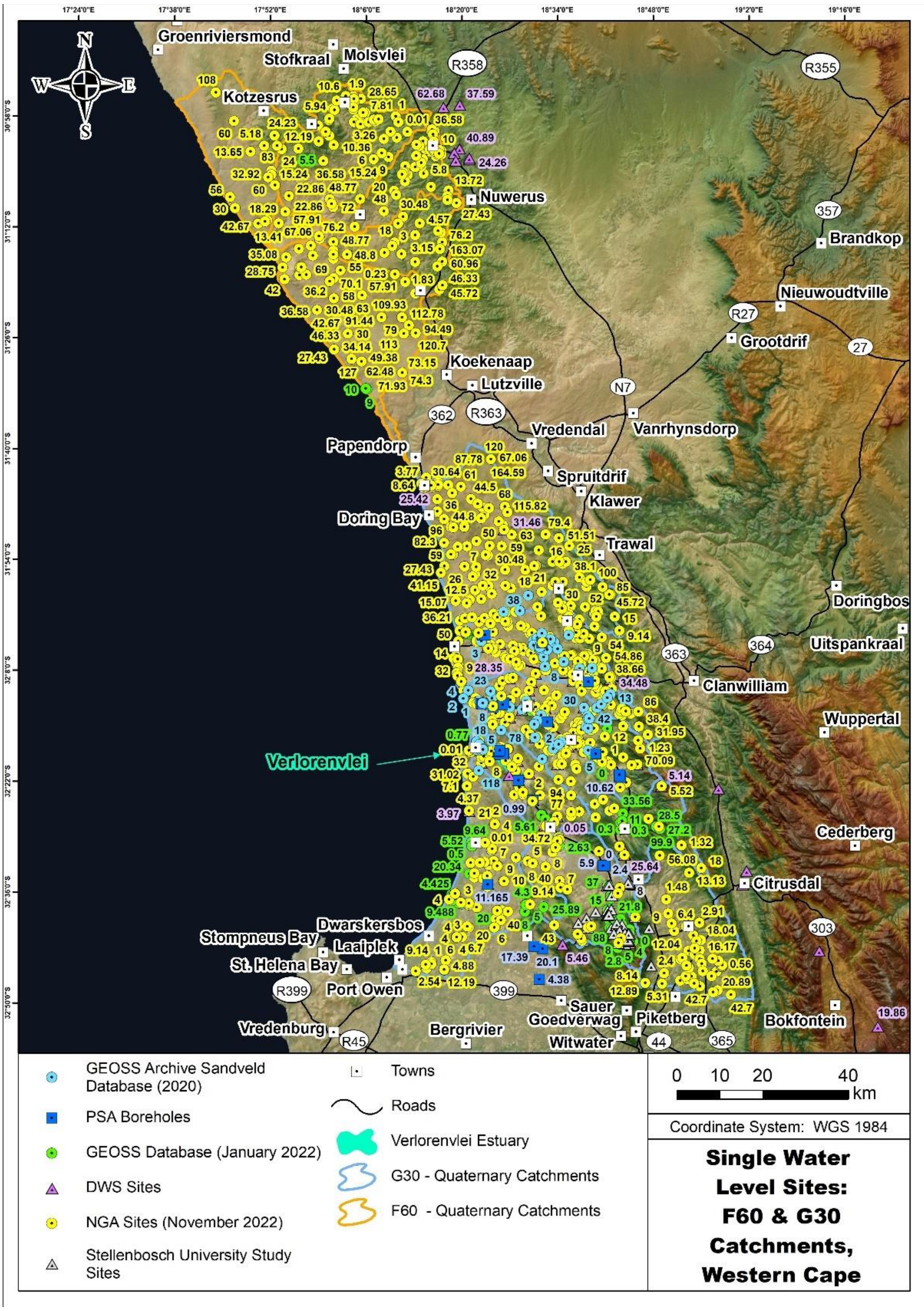
3.1 Water Level Data

3.1.1 Single Water Level Points

The biggest source of water level data was obtained from single event measurements taken, the majority of which came from NGA database (updated until November 2022, when it was downloaded). This provides an indication of groundwater levels within a certain area. However, long-term monitoring of water levels is essential to accurately assess the status and behaviour of a groundwater system.

It should be noted that some of the databases used did not specify if water levels were pumping or static water levels. For databases that did specify this, preference was given to static water levels as it is more representative of the transient state of the aquifer. Groundwater levels have been reported as meters below ground level (mbgl). The single water level values measured within the study areas are shown in **Map 10**.

The water level data that was obtained per GRU is presented in **Annexure A: Single Water levels, EC values, Borehole Yields, WARMS and NGA per GRU**.



Map 10: Map displaying single water level observations found in G30 and F60 catchments

3.1.2 Water Level Monitoring

The only available long-term monitoring data is in the central Sandveld region (DWS, 2022 and GEOSS, 2022a). This includes long-term DWS monitoring, monitoring data from the GEOSS database, studies completed by the Stellenbosch University and the Namaqua Sands Mine database. For some areas within the F60 and G30 catchments, no long-term water level monitoring data could be obtained. The DWS monitoring data was mostly used and supplemented with other available datasets.

The water level data that was obtained per GRU is displayed in **Annexure B: Water Level and EC Monitoring Data.**

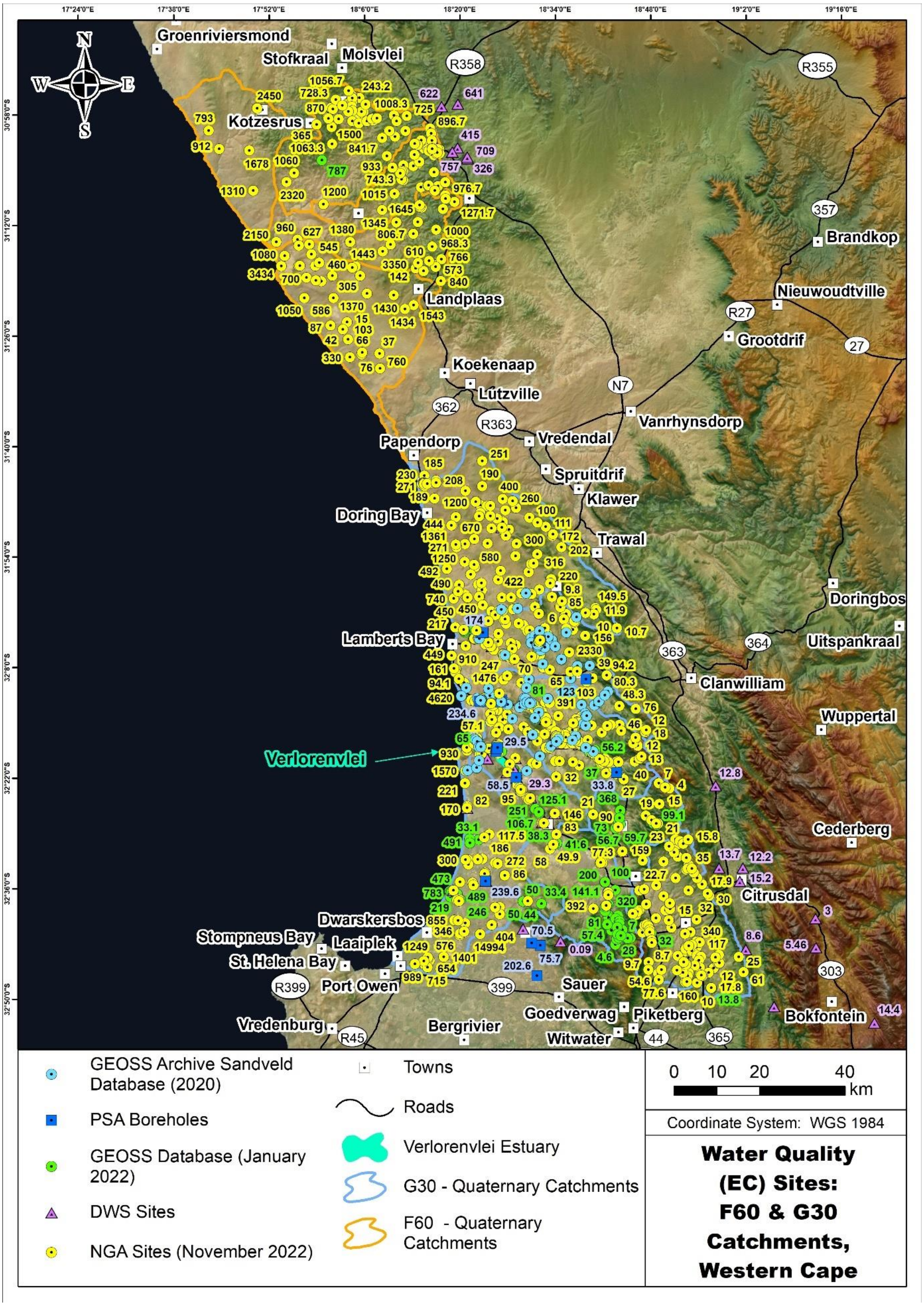
3.2 Water Quality Data

3.2.1 Single EC Points

Electrical conductivity (EC) is a measure of the ability of the groundwater to conduct electricity and this is directly related to the concentration and type of ions in the water. This parameter is used as a bulk indication of groundwater quality.

In some cases, this is the only data available that could provide an indication of the groundwater quality for a certain area. It should be noted that although groundwater with a low EC value would generally be associated with “good quality” water this is not always the case. The potability of water largely depends on the chemical composition, concentrations of certain elements and microbial constituents. Should some of these be evident in elevated concentrations this can be harmful to humans and animals, and detrimental to crops.

The EC value data that was obtained per GRU is shown in **Map 11** and in **Annexure A: Single Water levels, EC values, Borehole Yields, WARMS and NGA per GRU**. Time series data for EC monitoring was very limited within the study area, but what could be obtained is presented in **Annexure B: Water Level and EC Monitoring Data.** These Annexures are in the form of Excel Spreadsheets.



Map 11: Map displaying EC values (mS/m) per site, found in G30 and F60 catchments

3.2.2 Water Quality: Laboratory analysis

Detailed groundwater quality data was sourced from laboratory testing analysis results from work that GEOSS has done in the area(GEOSS, 2020a; GEOSS, 2020b; GEOSS, 2022b and GEOSS, 2023), what was provided by the local DWS office that relates to their monitoring of the area (DWS, 2022). In June 2023, the DWS head office also provided additional data obtained from the Water Management System (WMS) (DWS, 2023). All data obtained was analysed according to the DWS water quality reserve spreadsheet that reworks the data to show number of sample sites and to display the 5^{th} and 95^{th} percentiles as well as the average and median of the values obtained and to compare it to the limits set by the reserve team at DWS Head Office (**Table 3**). The value reported is the statistical median of the parameter. The spreadsheet with all the data combined (WMS, DWS local office and GEOSS data), can be found **Annexure A: Single Water levels, EC values, Borehole Yields, WARMS and NGA per GRU**.

Table 3: Classification table for specific limits, as provided by DWS National Office

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**

3.3 Groundwater abstraction and borehole yield data

3.3.1 Groundwater abstraction

Groundwater abstraction data along with rainfall data is a crucial component required to accurately calculate the water balance for a study area. This forms part of the component that accounts for losses from the source catchment.

The 2018 land cover map (DFFE, 2018) indicates that cultivated land is the predominant land use type in the G30 catchment. Where groundwater is considered to be the sole resource (no rivers or dams) cultivated lands are expected to be irrigated and considered a large groundwater user. Another important user of groundwater is municipalities for the towns located in the study areas. This confirmed that for G30 catchments, the main groundwater uses are for water abstracted for irrigation and municipal supply. For the F60 catchments, registered groundwater use was much lower.

In January 2018 the Department of Water and Sanitation released a Government Gazette published that: “All water use sector groups and individuals taking water from any water resource (surface or groundwater) regardless of the authorization type, in the Berg, Olifants and Breede Gouritz Water Management Area, shall install electronic water recording, monitoring or measuring devices to enable monitoring of abstractions, storage and use of water by existing lawful users and establish links with any monitoring or management system as well as keep records of the water used" (Government Gazette, 2018).

Even through the monitoring requirement was published in 2018, it was found that this directive has not been adhered to by the majority of the water users in the F60 and G30 catchments. Because of this, the "actual monitored water abstraction data" could not be considered during this study. It is be strongly suggested that as part of the outcomes of this study, this directive is enforced and that the records of actual abstraction data for the basis of any future investigations.

In the absence of this dataset, WARMS and V&V datasets were studied, but because not all water uses are registered on WARMS and because the V&V process is still ongoing and thus still developing, 2017/2018 Crop Census data obtained from the Department of Agriculture was used (Western Cape Department of Agriculture, 2018).

The Crop Census data is the total use per quaternary catchment and there is no clear divide between groundwater and surface water allocation/use. Where the V&V data clearly distinguishes between groundwater and surface water use within the study areas. Because of this, the V&V data was used to calculate the ration between groundwater and surface water use, for each catchment. An average irrigation factor of 7000 m^3/ha/a to calculate the volumes being abstracted for irrigation use. This factor is considered an average value used in the G30 catchment by DWS (**Table 4**).

Municipal abstraction data could partially be obtained from recent Water Use License applications that were submitted for the towns located within the G30 catchments. An estimated volume for groundwater use for towns located in the F60 catchments is based on groundwater use monitoring data for the town of Bitterfontein (Matzikama Municipality, 2022). This is water abstracted from the Bitterfontein wellfield is treated and piped to other settlements within the F60 catchment. The Lepelsfontein settlement also located in the F60 catchment, in the Northern Cape province, does rely on groundwater for its supply, however, there is no abstraction data from which volumes could be calculated. The towns identified that do abstract groundwater, together with an average annual abstraction volume, were summarised in **Table 5**.

Table 4: Estimated irrigation areas and registered allocations

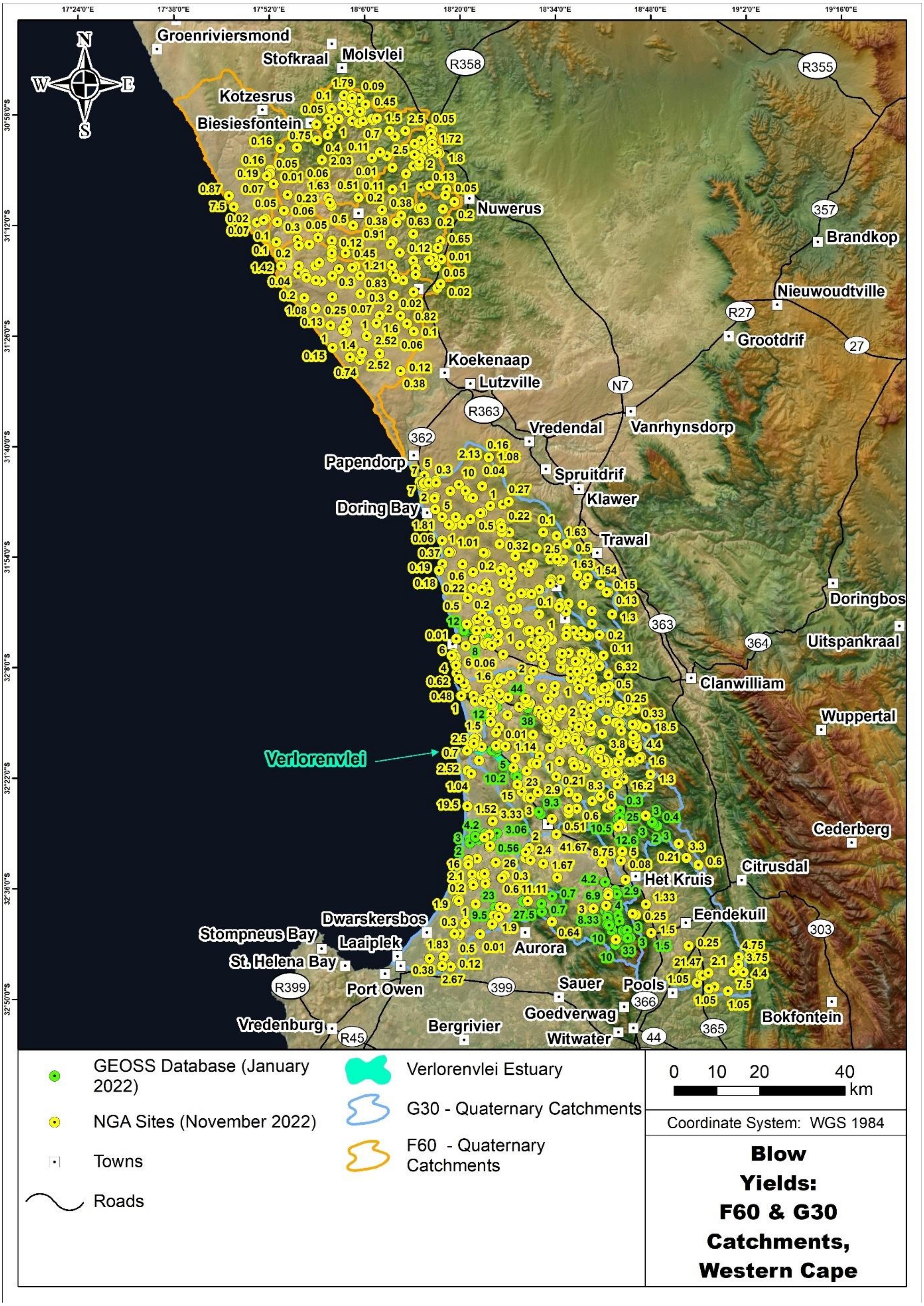
Quaternary Catchments	Crop Census	V&V Data used to estimate % breakdown between groundwater and surface water use						Final irrigation areas from GW (km^2)	Final irrigation areas from GW (ha)	Average Crop irrigation value used by DWS for the catchment (m^3/a/ha)	Estimated GW abstraction for irrigation (m^3/a)	Estimated GW abstraction for irrigation (Mm^3/a)
	Crops 2017/18 (CFM) (km^2)	Irrigation area from V&V (km^2)	V&V Total irrigation volume (Mm^3/a)	V&V Taking of Surface Water for Irrigation (Mm^3)	V&V Taking of Ground Water for Irrigation (Mm^3)	Calc: V&V SW+GW for irrigation	Assumed %GW irrigation based on V&V registrations					
G30A	10.29	27.19	11.98	0.48	8.09	8.57	94%	9.71	971	7 000	6 799 564	6.80
G30B	9.1	25.23	12	7.88	4.02	11.89	34%	3.08	307	7 000	2 153 692	2.15
G30C	14.45	33.93	14.55	4.76	7.98	12.75	63%	9.04	904	7 000	6 330 800	6.33
G30D	18.87	76.39	29.96	6.01	23.71	29.72	80%	15.05	1 505	7 000	10 537 866	10.54
G30E	5.72	35.14	11.61	3.06	8.52	11.59	74%	4.20	420	7 000	2 943406	2.94
G30F	27.08	100.87	33.97	0.92	32.44	33.36	97%	26.33	2633	7 000	18433232	18.43
G30G	6.25	29.22	10.62	1.84	8.73	10.56	83%	5.17	516	7 000	3 616 832	3.62
G30H	3.39	3.7	2.02	0.05	1.97	2.02	97%	3.31	330	7 000	2 314 262	2.31
Total G30	**95.16**	**331.67**	**126.71**	**25.01**	**95.45**	**120.46**	**79%**	**75.90**	**7 589**		**53 129 657**	**53.13**

Table 5: Towns that abstract groundwater located in the F60 and G30 catchments

Quaternary Catchments	Town	Water Source	Annual Abstraction Volume (m^3/a)	Data Source
F60A	Lepelsfontein	Groundwater: Boreholes	-	No data could be obtained on the abstraction volumes for the boreholes at Lepelsfontein
F60B	Bitterfontein (Water abstracted is treated through and RO plant and then piped to other towns.)	Groundwater: Boreholes	183 146	Abstraction metered between 12 Jan 2021 and 12 Jan 2022. From municipal monitoring sheets. Matzikama Local Municipality, (2022)
G30B	Eendekuil	Groundwater: Spring	53 676	2020 metered use. Obtained from Bergriver Local Municipality
G30C	Paleisheuwel	Groundwater: Boreholes	74 207	Municipal meter data. Obtained from Cederberg Local Municipality, (2019a)
G30D	Redelinghuys	Groundwater: Matroosfontein Spring	37 988	Average annual use between 2016-2019. Obtained from Bergriver Local Municipality, (2019)
G30E	Elands Bay	Groundwater: Boreholes	443 172	2018 Abstraction volume. Obtained from Cederberg Local Municipality, (2019)
G30F	Leipoldtville	Groundwater: Boreholes	121 920	2018 Abstraction volume. Obtained from Cederberg Local Municipality, (2019)
G30F	Lamberts Bay (Town situated in G30G, but boreholes are in G30F)	Groundwater: Boreholes	864 000	2018 Abstraction volume. Obtained from Cederberg Local Municipality, (2019)
G30G	Graafwater	Groundwater: Boreholes	203 213	Municipal meter data. Obtained from Cederberg Local Municipality, (2019)

3.3.2 Borehole Yields

Borehole yield data was used to provide an indication of the exploitation potential of groundwater for a certain area, and measured in litres per second. It is also relates to hydraulic conductivity, so even if no actual hydraulic parameters can be found, this can give an indication of the change in hydraulic conductivity across an area. The yield value data that was obtained per GRU is shown in **Map 12** and in **Annexure A: Single Water levels, EC values, Borehole Yields, WARMS and NGA per GRU**.



Map 12: Map displaying borehole yields (L/s) found in G30 and F60 catchments

3.4 Hydrologic Parameter Data

3.4.1 Groundwater Recharge

The global hydrological cycle is a complex system controlled by the processes of inflow (from precipitation and snow melt), recharge and outflow (from runoff and evapotranspiration) of which groundwater and surface water are two of many components of this system (Freeze and Cherry, 1979). Groundwater is recharged through precipitation, snow, rivers, large water bodies and often through anthropogenic activities such as return flow from irrigation. Recharge is therefore defined as the hydrologic process where the downward flow of water, through infiltration and percolation, contributes to the permanent water table (Eilers *et al*., 2017 and Eilers, 2018).

Lerner *et al*. (1990) characterised recharge into three principal mechanisms, 1) direct recharge, 2) indirect recharge, and 3) localised/focused recharge. The first mechanism is the direct infiltration of precipitation/rainfall, where water percolates vertically through the vadose zone into the groundwater, and will only occur where the additional water is greater than evapotranspiration and the soil-water deficit in the unsaturated zone. The Table Mountain Group formations outcropping in the mountainous areas of G30 catchments has been linked to displaying high direct recharge values. This is due to the higher rainfall (>400 mm/a) found in these areas and due to the fractured nature of the sandstones evident in these mountains, which promotes direct recharge.

Indirect recharge is associated with river beds and defined channels, where water percolation contributes to the recharge of the local water table (Beekman and Xu, 2003). This type of recharge within the study area can be observed in the fractured shale-rich Malmsbury Formations. The Malmesbury Group basement aquifer receives limited direct recharge, but it can receive indirect recharge from overlying fractured TMG bedrock and Sandveld Aquifers or alluvial aquifers (Eilers, 2018).

Localised or focussed recharge is a form of indirect recharge, where large water bodies with an absence of channels, such as lakes, act as the hosts for localised recharge, and concentrated infiltration and percolation transfers water through the vadose zone (Robins, 1998). For the F60 catchments, it was observed that water users would target hillsides, against granite and other igneous rock hilly outcrops known locally as “koppies”. After rain events, the water from these shallow boreholes has been reported to experience a dramatic improvement in quality, a day or two after the rain event occurred. The water quality would then slowly deteriorate over time, but still considered the “freshest” water to be found in the area. It is thus hypothesized that these hill-side boreholes target the water found in the uppermost fractured zone or the shallow weathered zone associated with exfoliation-type weathering. The residence time of water within this zone is very short and therefore of good quality. As the water then seeps into the fractured zones and matrix of the crystalline rocks over time, minerals associated with the host rock are dissolved, which then typically increases the concentration of dissolved minerals in the groundwater.

An aquifer comprising of weathered material has been used to describe groundwater systems in the northern Namaqualand (Titus, 2003, Friese et al., 2006 Pieterson et al., 2009) and seems to also describe the systems observed during this study in the southern Namaqualand (F60), in these sources, this type of aquifer is referred to as a regolith aquifer. Although this type of recharge is not generally seen as localised recharge, for the purpose of this study, these areas will be termed as "recent localised recharge".

While such simplified definitions enable scientists to contextualise recharge processes, they focus on vertical percolation and largely ignore lateral subsurface recharge (Lerner et al., 1990). For the catchments observed in the study areas, the lateral migration of groundwater from one aquifer to another across quaternary catchment boundaries is extremely important and especially for the coastal G30 catchments, this type of recharge is seen as the dominant source of groundwater.

No single estimation technique can be used to accurately estimate recharge across a range of environments (Van Tonder and Bean, 2003), but combining physical and natural tracer techniques, as well as numerical modelling, has proven to be a powerful tool for estimating recharge (Scanlon et al., 2002).

For the central G30 catchments, isotope dating has linked the groundwater found in the low-lying coastal regions with rainwater sampled in the higher-lying mountainous regions of the Piketberg and Citrusdal mountains (GEOSS, 2019 and Miller et al., 2022), although most of the studies have been focused on the Piketberg Mountains and the Verlorenvlei Catchment. Groundwater recharge in the Verlorenvlei catchments has been determined using rainfall/runoff modelling (Watson et al., 2018), a natural tracer technique using Chloride Mass Balance (CMB) (Watson et al., 2020 and GEOSS, 2019) and a GIS−based modelling approach (Conrad et al., 2004). Recharge dominantly occurs in areas of high elevation, such as the Piketberg Mountains, and therefore into the TMG aquifer. Thus, it can be noted that aquifer-specific recharge values are available for the G30 catchments that make up the Krom-Antonies and Verlorenvlei system (G30D and G30E), but not for other G30 catchments and not for the F60 catchments.

Similar to that of all quaternary catchments in South Africa, the Groundwater Resource Assessment II (DWAF, 2005), calculated groundwater recharge values for each of the G30 and F60 catchments. These values were calculated per catchment and are not aquifer specific, but if no other recharge values are available, these could be used.

The recharge values obtained from various sources are displayed in **Table 6**. After using several variations of the values in the Pitman model to model the hydrology, it was possible to not use the DWAF (2005) values catchments. It was thus decided to use aquifer-specific recharge, assigning representative recharge values per aquifer. These representative values were obtained from the latest studies done by Stellenbosch University: TMG: 23%, Malmesbury Shales: 5% and Sand Aquifer: 3.5% of MAP. Although these values were calculated for the specific systems surrounding the Verlorenvlei system, it was found that these estimated recharge values are more representative of some of the other G30 catchments than the GRAII values. The high recharge rates found within the Table Mountain Group Formations in high-elevation areas were evident in the recent studies completed on the area (Eilers et al.; 2017; Eilers, 2018; Watson et al. 2018b; Watson et al.; 2019; Miller et al 2018 and Miller et al 2022). It is hypothesized that the high recharge is potentially linked to the fractured nature of the geology in these areas and that although the actual recharge would be highly variable across unfractured and fractured outcrops, the >20% is representative of the overall nature of this system.

To use calculated recharge on a more localised scale and link the Pitman surface water model with the groundwater reserve calculations, a surface water delineation of the catchments was used. These catchments are smaller than the groundwater delineated GRU`s, but both sets of delineations are linked. **Map 13** shows how the surface water catchments fit into the larger groundwater GRUs. The surface water catchments were also further subdivided in the upper G30 quaternary catchments with high MAP and low MAP characteristics as well as whether their baseflows were dominated by shale, sand or TMG aquifers. Thus, recharge was calculated on a small scale where possible and then added up to represent the complete groundwater resource units.

A recharge calculation was also done of the portion of the Piketberg Mountain range that falls outside the G30 catchment (G10K), to provide an indication of what volumes can be expected to recharge the G30A, G30D and G30E catchments through lateral recharge from outside of the G30 catchment system. Because only limited isotope dating had been done between the most northern G30 catchments and the Olifantsrivier and Cederberg Mountains, and the exact extent of the recharge zone is not evident, these E10 catchments could not be included in the recharge calculations during this study. It is recommended that isotope and inorganic sampling commences to investigate the link between the E10 and the coastal G30 catchments of the northern Sandveld. It is hypothesized that the same system of lateral recharge from the mountainous areas towards the coastal areas occurs here as well.

It should be noted that for this study, the perceived dominant geology, linked to the aquifer`s recharge, was used to calculate the recharge for that specific area. It is understood that the three aquifers are interconnected to some extent (Watson et al., 2018a) and groundwater mixing may play an important role in the catchment groundwater evolution. The interplay between these aquifers is still poorly understood and a more detailed study of the similarities and differences between the different groundwater systems is required in order to understand these mixing relationships (Miller et al., 2022).

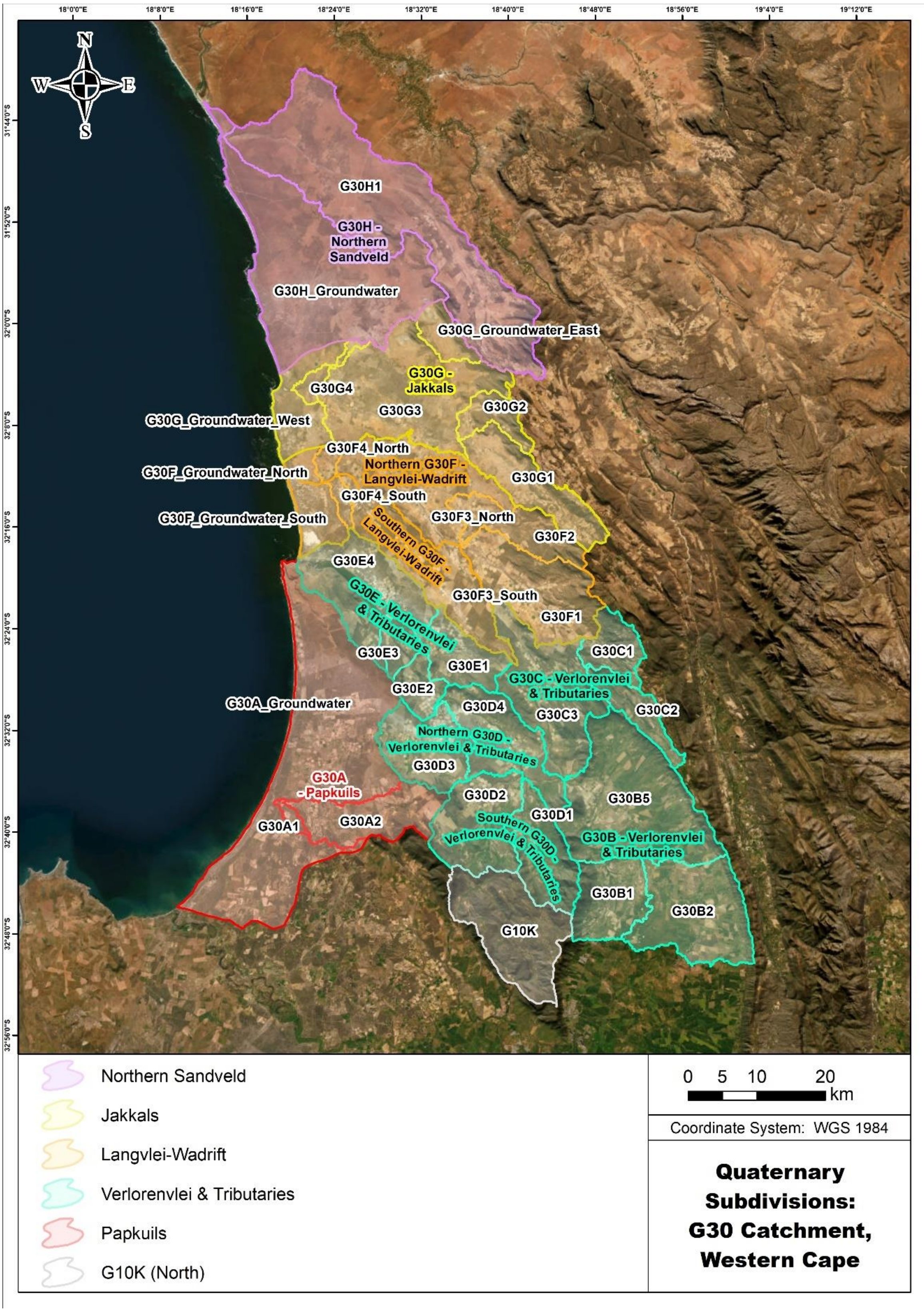
Table 6: Groundwater Recharge Values sourced from DWAF (2005), GEOSS (2019), Watson et al. (2020), Watson et al. 2018b, Miller et al. (2022) and Umvoto (2021)

Quaternary Catchment	Borehole ID	River	Sample Location: Latitude	Sample Location: Longitude	Geological Unit	Aquifer	Recharge Percent of MAP	Source
G30A	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	5.4	(DWAF, 2005) (AFYM, WRC, 2012)
G30B	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	3.8	(DWAF, 2005) (AFYM, WRC, 2012)
G30C	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	5.7	(DWAF, 2005) (AFYM, WRC, 2012)
G30D	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	5.7	(DWAF, 2005) (AFYM, WRC, 2012)
G30E	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	4.9	(DWAF, 2005) (AFYM, WRC, 2012)
G30F	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	4.7	(DWAF, 2005) (AFYM, WRC, 2012)
G30G	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	3.3	(DWAF, 2005) (AFYM, WRC, 2012)
G30H	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	1.9	(DWAF, 2005) (AFYM, WRC, 2012)
F60A	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	0.7	(DWAF, 2005) (AFYM, WRC, 2012)
F60B	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	1.2	(DWAF, 2005) (AFYM, WRC, 2012)
F60C	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	1.4	(DWAF, 2005) (AFYM, WRC, 2012)

Quaternary Catchment	Borehole ID	River	Sample Location: Latitude	Sample Location: Longitude	Geological Unit	Aquifer	Recharge Percent of MAP	Source
F60D	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	0.9	(DWAF, 2005) (AFYM, WRC, 2012)
F60E	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	0.8	(DWAF, 2005) (AFYM, WRC, 2012)
G10K	BH1	Not Specified	-32.72263566	18.57090479	Peninsula Formation	Fractured TMG	15.88	GEOSS (2019)
G10K	BH2	Not Specified	-32.78404	18.705248	Peninsula Formation	Fractured TMG	8.75	GEOSS (2019)
G30A	BH3	Not Specified	-32.635931	18.491057	Unconsolidated Sand	Unconsolidated Sand	7.38	GEOSS (2019)
G30E	BH5	Not Specified	-32.47312	18.530764	Unconsolidated Sand	Unconsolidated Sand	1.42	GEOSS (2019)
G30E	BH6	Not Specified	-32.364888	18.454683	Unconsolidated Sand	Unconsolidated Sand	3.44	GEOSS (2019)
G30B	BH7.2	Not Specified	-32.62947359	18.94811277	Piekenierskloof Formation	Fractured TMG	2.84	GEOSS (2019)
G30F	BH8	Not Specified	-32.367947	18.715105	Unconsolidated Sand	Unconsolidated Sand	1.86	GEOSS (2019)
G30F	BH10	Not Specified	-32.222521	18.401269	Unconsolidated Sand	Unconsolidated Sand	6.53	GEOSS (2019)
G30G	BH11	Not Specified	-32.081222	18.371305	Unconsolidated Sand	Unconsolidated Sand	2.24	GEOSS (2019)
G30G	BH12	Not Specified	-32.089969	18.520792	Unconsolidated Sand	Unconsolidated Sand	2.28	GEOSS (2019)

Quaternary Catchment	Borehole ID	River	Sample Location: Latitude	Sample Location: Longitude	Geological Unit	Aquifer	Recharge Percent of MAP	Source
E10G	BH13	Not Specified	-32.30268938	18.82054555	Peninsula Formation	Fractured TMG	6.33	GEOSS (2019)
E10E	BH14	Not Specified	-32.63232	19.09176	Peninsula Formation	Fractured TMG	28.67	GEOSS (2019)
G30D	KA1-KA3 (KA-R2)	Upper Krom-Antonies	Not Specified	Not Specified	Not Specified	Not Specified	5.7	Watson et al 2020
G30D	KA1-KA3 (M-R)	Upper Krom-Antonies	Not Specified	Not Specified	Not Specified	Not Specified	13.8	Watson et al 2020
G30D	KA4-KA18 (KK-R & M-R)	Middle Krom Antonies	Not Specified	Not Specified	Not Specified	Not Specified	1.1	Watson et al 2020
G30D	KA19-KA25 (VL-R)	Lower Krom Antonies	Not Specified	Not Specified	Not Specified	Not Specified	1.7	Watson et al 2020
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Unconsolidated Sand	0.2-3.5	Umvoto 2021
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured Malmesbury	4.0-6.0	Umvoto 2021
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured TMG	22-25	Umvoto 2021
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured TMG	6.0-11	Watson et al 2018b
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured TMG	22-25	Watson et al 2018b
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Unconsolidated Sand	1.0-5	Watson et al 2018b

Quaternary Catchment	Borehole ID	River	Sample Location: Latitude	Sample Location: Longitude	Geological Unit	Aquifer	Recharge Percent of MAP	Source
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured TMG	up to 29 (20-50 mm/year)	Miller et al 2022
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Unconsolidated Sand	3.0-4	Miller et al 2022
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Fractured Malmesbury	(2-8 mm/year)	Miller et al 2022
Verlorenvlei Catchments	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Unconsolidated Sand	1–5 (2 and 10 mm/year)	Miller et al 2022



Map 13: Map displaying delineation of groundwater resource units as well as the smaller localised surface water delineations on which the recharge was calculated, displayed on satellite imagery

3.4.2 Groundwater Baseflow

The term groundwater baseflow contributions refers to the groundwater`s component of river flow, and groundwater is likely to contribute to surface flow during low rainfall periods. Baseflow may also contribute to wetlands, springs and seeps (Vegter and Pitman, 2003), and provide a minimum estimate of groundwater recharge. High groundwater abstraction near streams (inside riparian zone) can result in reversing the gradient from the stream to groundwater, causing induced riverbed infiltration, otherwise reduction of groundwater contribution to baseflow (Chen, 2001).

For the G30 river systems, it must be noted that fault zones have been mapped parallel or in close proximity to the river/wetland systems. As noted earlier in this study, the current hypothesis is that these fault systems act as preferred pathways for groundwater flow and that at discontinuous sections along these structural faults, there is an upwelling of groundwater into the unconsolidated sands. These areas are where seepage zones and springs are present and also where groundwater exploration is targeted. It could be assumed that these areas would contribute to the baseflow of these systems, at certain points along the system. There have not been detailed studies done on the potential baseflow contribution of these groundwater upwelling zones and it was difficult to assign specific baseflow contributions for this, although steps were taken to include this assumption.

The baseflow calculations for the F60 and G30 catchments are based on data from the GRAII (2012) and a recent study completed by Watson (2019) where the groundwater component within the JAMS/J2000 model was distributed to calculate baseflow and streamflow estimates (**Figure 2**).

Baseflow and streamflow estimates were calculated for the four main tributaries; 1) Bergvallei, 2) Kruismans, 3) Hol and 4) Krom Antonies. These tributaries make up 81% of the streamflow into the Verlorenvlei. It was also found that of the water entering the Verlorenvlei, ~56% of the total flow is surface runoff, with groundwater baseflow and interflow contributing ~40% and ~4%, respectively (Watson et al., 2019). This percentage breakdown provided site-specific baseflow estimations that took into consideration the nature of the system. It was decided that these estimated baseflow percentages could be used to describe the flow systems of the other river systems in the G30 catchments. It is understood that the Papkuils, Langvlei and Jakkals systems would each be unique, however, due to a lack of baseflow and streamflow data, the average separation between groundwater and surface water for the Verlorenvlei system is considered to be the most accurate to be applied at this time for catchments were surface-groundwater interaction has been identified. It is however recommended that each of these systems must be monitored so that similar baseflow calculations can be done in the future.

For those not linked to the Verlorenvlei system (G30H and the F60 systems), the GRAII (2012) values were used. Baseflow estimations obtained from the GRAII model as well as the estimated baseflow percentage of total flow calculated by Watson (2019) are summarised in **Table 7**.

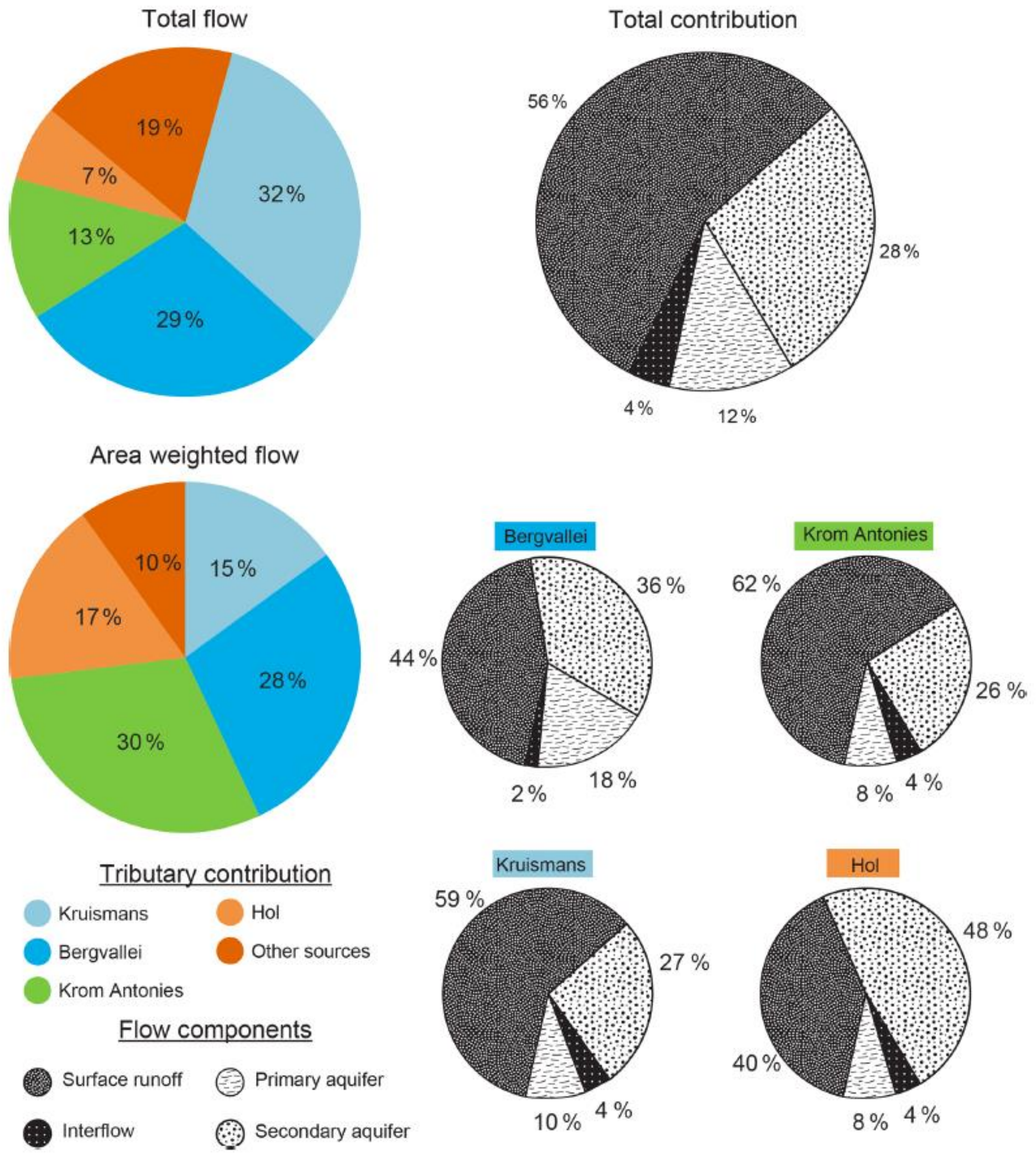


Figure 2: The Verlorenvlei flow contributions (total flow and area-weighted flow) of Kruismans, Bergvallei, Krom Antonies and Hol as well as flow component separation into surface runoff, interflow, primary aquifer flow and secondary aquifer flow (Watson, 2019)

Table 7: Baseflow estimations obtained from the GRAII model (2012) and estimated baseflow % calculated by Watson (2019)

Quaternary Catchment	River	Geological Unit	Aquifer	Baseflow (% of total flow)	Baseflow (Mm^3/a)	Source	Comments
G30A	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	Not very accurate to site specific conditions.
G30B	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	
G30C	Not Specified	Not Specified	Not Specified	Not Specified	0.56	(DWAF, 2005) (AFYM, WRC, 2012)	
G30D	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	
G30E	Not Specified	Not Specified	Not Specified	Not Specified	9.43	(DWAF, 2005) (AFYM, WRC, 2012)	
G30F	Not Specified	Not Specified	Not Specified	Not Specified	12.62	(DWAF, 2005) (AFYM, WRC, 2012)	
G30G	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	
G30H	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	
F60A	Not Specified	Not Specified	Not Specified	Not Specified	10.61	(DWAF, 2005) (AFYM, WRC, 2012)	
F60B	Not Specified	Not Specified	Not Specified	Not Specified	7.83	(DWAF, 2005) (AFYM, WRC, 2012)	
F60C	Not Specified	Not Specified	Not Specified	Not Specified	10.02	(DWAF, 2005) (AFYM, WRC, 2012)	
F60D	Not Specified	Not Specified	Not Specified	Not Specified	0.81	(DWAF, 2005) (AFYM, WRC, 2012)	
F60E	Not Specified	Not Specified	Not Specified	Not Specified	0	(DWAF, 2005) (AFYM, WRC, 2012)	

Quaternary Catchment	River	Geological Unit	Aquifer	Baseflow (% of total flow)	Baseflow (Mm^3/a)	Source	Comments
G30C	Bergvallei	TMG and Malmesbury	Fractured Aquifer	36	Not Specified	Watson et al 2019	The adaptation of the J2000 rainfall–runoff model was used to understand the flow contributions of the main feeding tributaries, the proportioning of baseflow-to-surface runoff as well as how often the inflows exceed the lake evaporation demand.
G30C	Bergvallei	Unconsolidated sand	Unconsolidated Aquifer	18	Not Specified	Watson et al 2019	
G30C	Bergvallei	Unconsolidated sand	Interflow	2	Not Specified	Watson et al 2019	
G30D	Krom Antonies	TMG and Malmesbury	Fractured Aquifer	26	Not Specified	Watson et al 2019	
G30D	Krom Antonies	Unconsolidated sand	Unconsolidated Aquifer	8	Not Specified	Watson et al 2019	
G30D	Krom Antonies	Unconsolidated sand	Interflow	4	Not Specified	Watson et al 2019	
G30D	Hol	TMG and Malmesbury	Fractured Aquifer	48	Not Specified	Watson et al 2019	
G30D	Hol	Unconsolidated sand	Unconsolidated Aquifer	8	Not Specified	Watson et al 2019	
G30D	Hol	Unconsolidated sand	Interflow	4	Not Specified	Watson et al 2019	
G30B	Kruismans	TMG and Malmesbury	Fractured Aquifer	27	Not Specified	Watson et al 2019	
G30B	Kruismans	Unconsolidated sand	Unconsolidated Aquifer	10	Not Specified	Watson et al 2019	
G30B	Kruismans	Unconsolidated sand	Interflow	4	Not Specified	Watson et al 2019	

3.4.3 Isotopes

GEOSS (2019) and Stellenbosch University (Eilers, 2018 and Watson et al., 2020) have completed some isotope studies in the G30 catchments, and thus this data was used to draw conclusions on recharge areas and interconnectivity of specific systems. The Stellenbosch Universities completed studies in the Krom Antonies river system and in some areas associated with the other Verlorenvlei tributaries. Studies completed by GEOSS formed part of a larger study driven by Potato South Africa with sites located throughout the central Sandveld. These studies focus on using the stable isotope data in water (oxygen-18 or ^{18}O and deuterium or ^{2}H) and applying the chloride mass balance methods.

Eilers (2018) established the connection of groundwater between the primary Sandveld Aquifer, Malmesbury Group basement aquifer and fractured TMG aquifers, focusing predominantly on the Krom Antonies river.

3.4.3.1 Stable Isotopes

The stable isotope ratios of hydrogen and oxygen have been widely used to understand broad hydrological processes. The applications are based on the isotopic variation in water as a result of the ratio change between the heavier and lighter isotopes. This ratio is affected by the energy difference between the chemical bonds during phase changes between water vapour, liquid water and ice. Heavier and lighter isotopes naturally fractionate and their signatures can be used to identify altitude, temperature and evaporation trends. In hydrology, stable isotopes are conventionally reported at per mil (‰) deviation from a standard using the δ (delta) notation (Eq. 1). R is the isotope ratio of the heavier over the lighter isotope (ex. $^{2}H/^{1}H$ and $^{18}O/^{16}O$).

$$\delta\ (‰) = \frac{R_{sample} - R_{standard}}{R_{standard}} \cdot 10$$

Equation 1

Applications for hydrogeological studies are concerned with the isotopic variation in water that results from evaporation and condensation. It is important to note that isotopic signatures of water are reported in terms of the heavier isotopes i.e. 2H and 18O. During evaporation, the light molecule of water ($^{1}H_2{}^{16}O$) is more volatile than the heavier molecule of water ($^{2}H_2{}^{18}O$). As a result, vapour that evaporates from the ocean is depleted in heavier isotopes. This enrichment in the light isotope provides an isotopically negative signature. When this vapour undergoes cooling, the precipitation is enriched in heavier isotopes. The lighter isotopes preferentially remain in the vapour phase therefore the condensation (liquid phase) is isotopically positive. Given this information, successive precipitation events from the same initial vapour mass will be more and more isotopically negative (**Figure 3**).

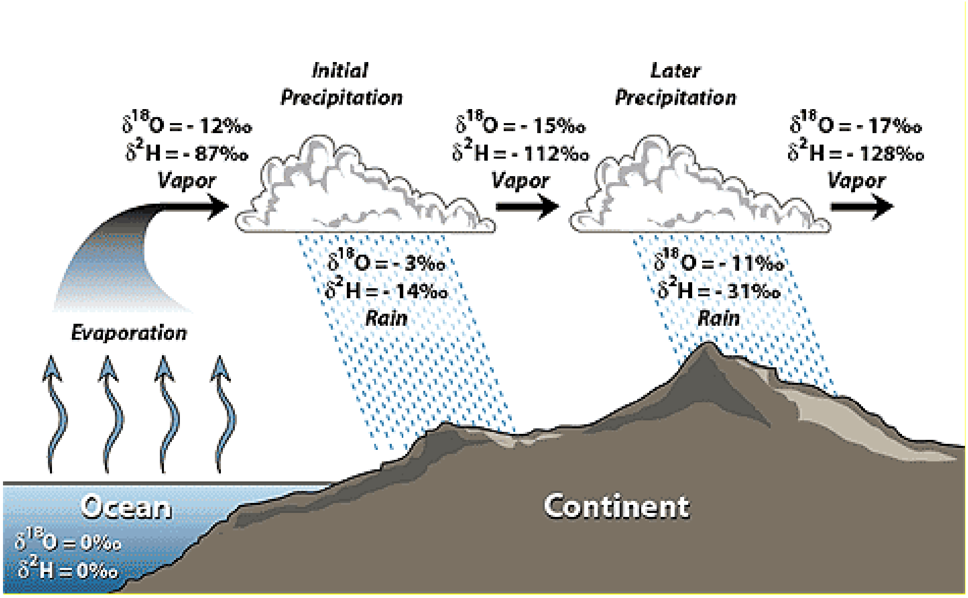


Figure 3: Stable isotope composition of rainwater with progressive rainfall events (GEOSS, 2019, after Craig, 1961)

Long-term studies of the isotopic composition of rainfall have been carried out by the International Atomic Energy Agency (IAEA). Observations have indicated a linear trend between δ^2H and $\delta^{18}O$ (Eq 2) which is referred to as the Global Meteoric Water Line (GMWL) (Craig 1961). Localized stable isotope ratios can be used as a comparative tool against the GMWL in order to better understand kinetic and temperature controls on localized rainfall. The linear trend of rainfall in a localized area is referred to as the local meteoric water line (LMWL).

$$\delta^2 H = 8 \cdot \delta^{18} O + 10$$

Equation 2

The LMWL is affected by two main factors; temperature and the amount of rainfall. Changes in these factors result in variation in the slope and y-intercept of the LMWL (**Figure 4)**. Precipitation that deviates from this trend indicates that evaporation has taken place.

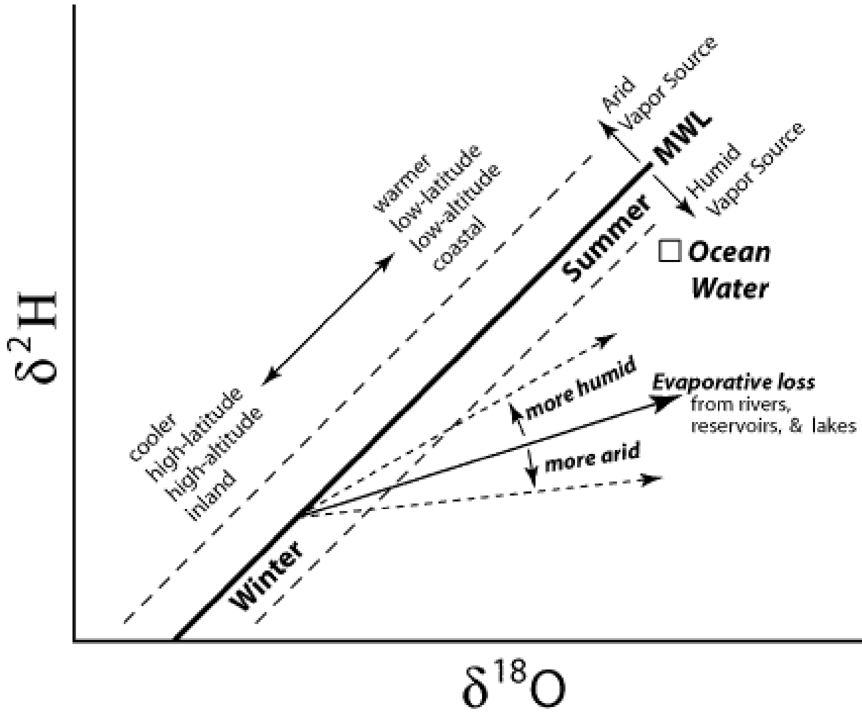


Figure 4: Factors that lead to variation in the stable isotope values of precipitation

In most aquifers when precipitation infiltrates to recharge groundwater, the δ^2H and $\delta^{18}O$ values remain fairly constant. The isotopic composition of groundwater is therefore related to that of precipitation in the recharge area at the time of recharge. Thus, the groundwater stable isotope composition can be used to infer the source of groundwater recharge as well as the climatic conditions during recharge. Groundwater may also be recharged by surface waters; in which case the stable isotope composition of the groundwater should reflect that of the surface water body.

3.4.3.2 Chloride Mass Balance

The Chloride Mass Balance (CMB) method for recharge estimation incorporates the chloride concentrations of the vadose zone or groundwater system as well as that of the precipitation within an area. It is defined by the following equation:

$$R = \frac{P \text{ x } Cl_p}{Cl_{gw}}$$

Equation 3

Where R is recharge (mm/a), P is annual precipitation (mm), Cl_p is chloride concentration in rainwater, and Cl_{gw} is chloride concentration in groundwater.

However, when using this method, one assumes that the following holds true:

1. Chloride in the groundwater is directly derived from precipitation and only precipitation;
2. Chloride in the aquifer is conservative and can therefore completely be recovered;
3. The chloride-mass flux has been consistent over time; and
4. Chloride is not recycled, added or concentrated in the aquifer.

In the case of the Sandveld, which can be characterised as a semi-arid area, potential evaporation rates exceed the precipitation rates during most months of the year. In cases like this, salts (containing large amounts of chloride) are often concentrated in the upper meter of the vadose zone. With rainfall events, these salts are flushed into the groundwater system. Continuous wetting and drying together with dry deposition of marine aerosols are the largest causes of salt accumulation in groundwater systems in semi-arid coastal areas. The extent of these processes is exacerbated by high energy waves and strong onshore winds such as those experienced along the west coast of South Africa. Due to this phenomenon, the CMB recharge estimation is most likely to be distorted and will not provide a true representation of the actual recharge (GEOSS, 2019).

3.4.3.3 Isotope Studies in the G30 catchments

Using stable water isotope data (oxygen-18 or ^{18}O and deuterium or ^{2}H), Eilers (2018) and Watson (2020) established the connection of groundwater between the primary Sandveld Aquifer, Malmesbury Group basement aquifer and fractured TMG aquifers, focusing predominantly on the Krom Antonies River.

In the upper and middle Krom Antonies River, the primary unconsolidated sand and fractured TMG aquifers have a similar isotopic composition (**Figure 5** and **Figure 6**). This suggests that the TMG aquifer recharges the unconsolidated sand aquifer (Eilers et al., 2017 and Eilers, 2018). Eilers also noted that the upper Krom Antonies is a gaining stream because of the baseflow contribution from these aquifers.

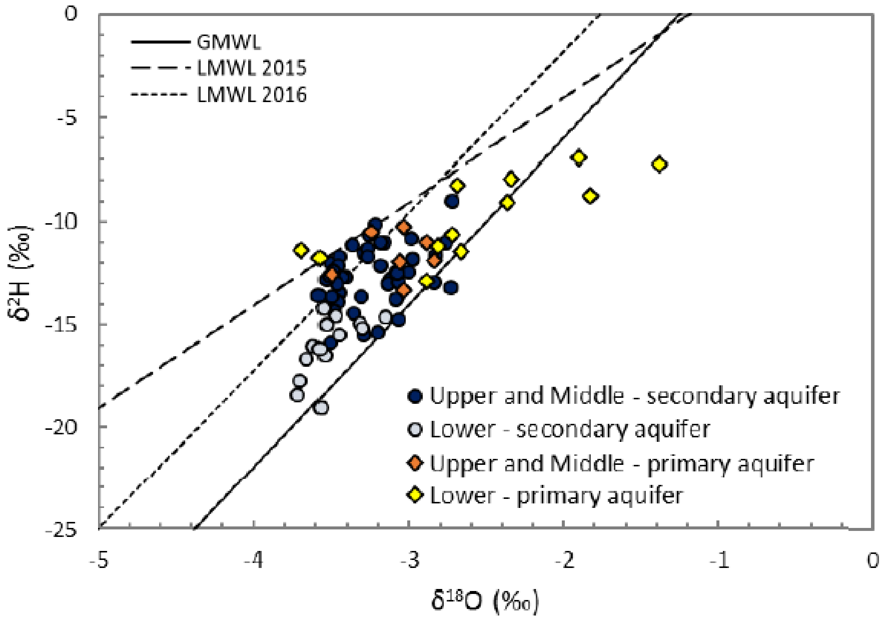


Figure 5: Comparison of the stable Isotope compositions between the fractured TMG aquifers (in the middle and upper portions of the river), Malmesbury Group basement aquifer (in the lower portions of the river) and primary Sandveld Aquifer along the Krom Antonies River, in comparison to the Local Meteoric Water Line (LMWL) and Global Meteoric Water Line (GMWL) (from Sigidi et al., 2017, Eilers, 2018 and Umvoto, 2021)

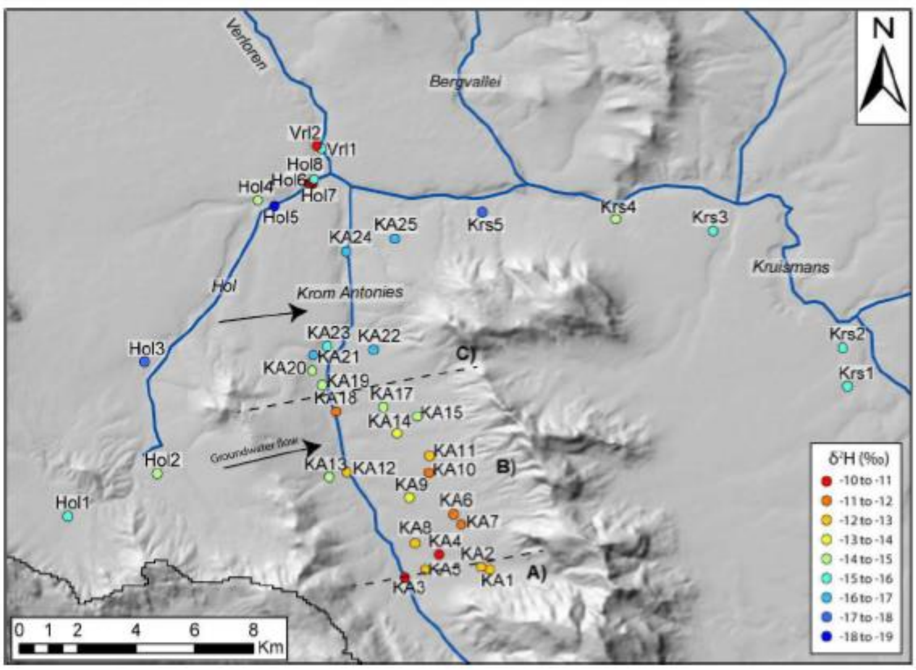


Figure 6:Delineation of groundwater zones along the Krom Antonies based on groundwater 2H, where A is the upper Krom Antonies, B the middle Krom Antonies and C the lower Krom Antonies (from Watson et al., 2020)

The isotope dating (GEOSS, 2019) investigation, funded by Potato South Africa, sampled various boreholes across the central Sandveld , within the G30 catchments (**Figure 7)** in order to identify the groundwater recharge areas.

The two main conclusions of the study (GEOSS, 2019):

- The groundwater isotopic data plots in a cluster with rainfall that is possibly derived from a higher altitude and inland areas. These waters typically plot towards the more negative end of the graph. This can be compared to sample RG4 which clearly has a less negative isotopic signature which is typical of rainfall closer to the coastal zone. Due to the clustering of groundwater and the higher altitude waters, it can be said that recharge occurs in the higher altitude inland areas (**Figure 8**).
- At Verlorenvlei extensive evaporation contributes largely to the increased salinity seen on the western side of the wetland. The fact that there is no significant variation between the deeper and shallower samples taken in the same location indicates that there is no significant groundwater influx from the base of the wetland. However, the wetland receives an influx of groundwater on the eastern side and the water becomes more saline towards the west.

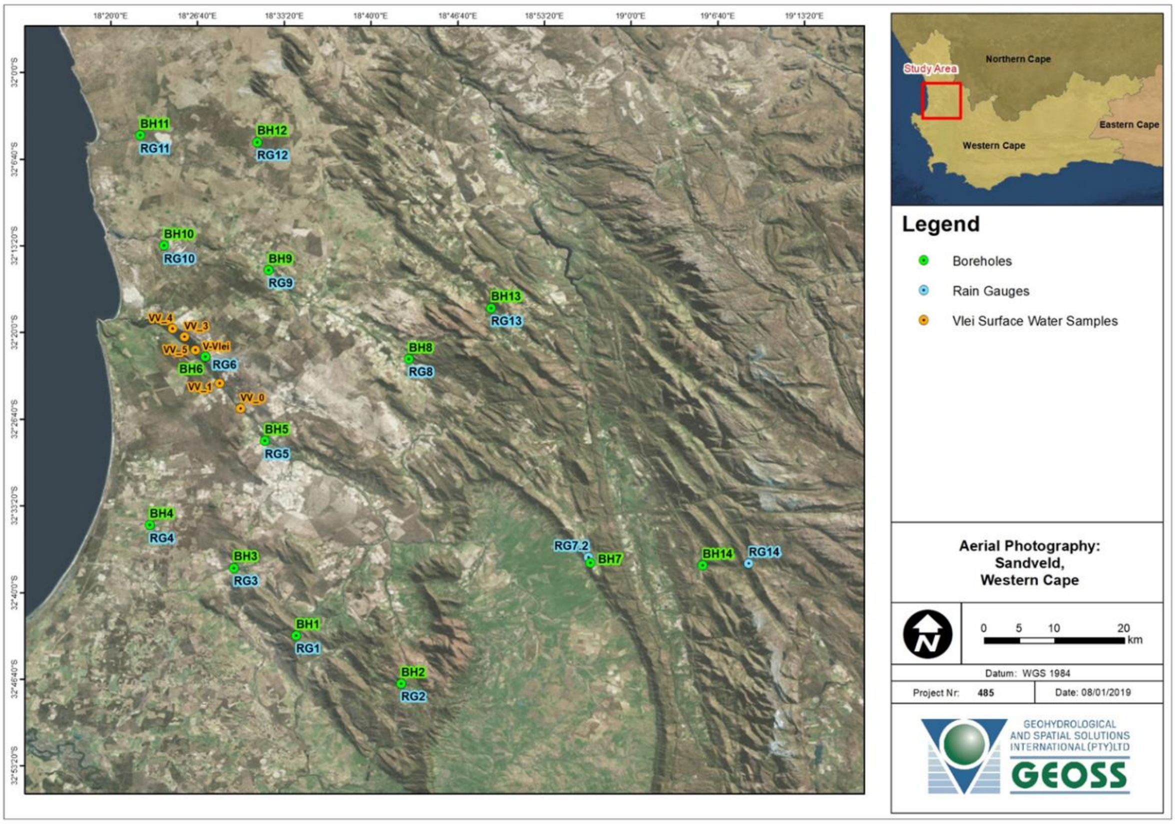


Figure 7: Map displaying isotope sampling locations within the Sandveld for the GEOSS 2019 study, taken from report (GEOSS, 2019).

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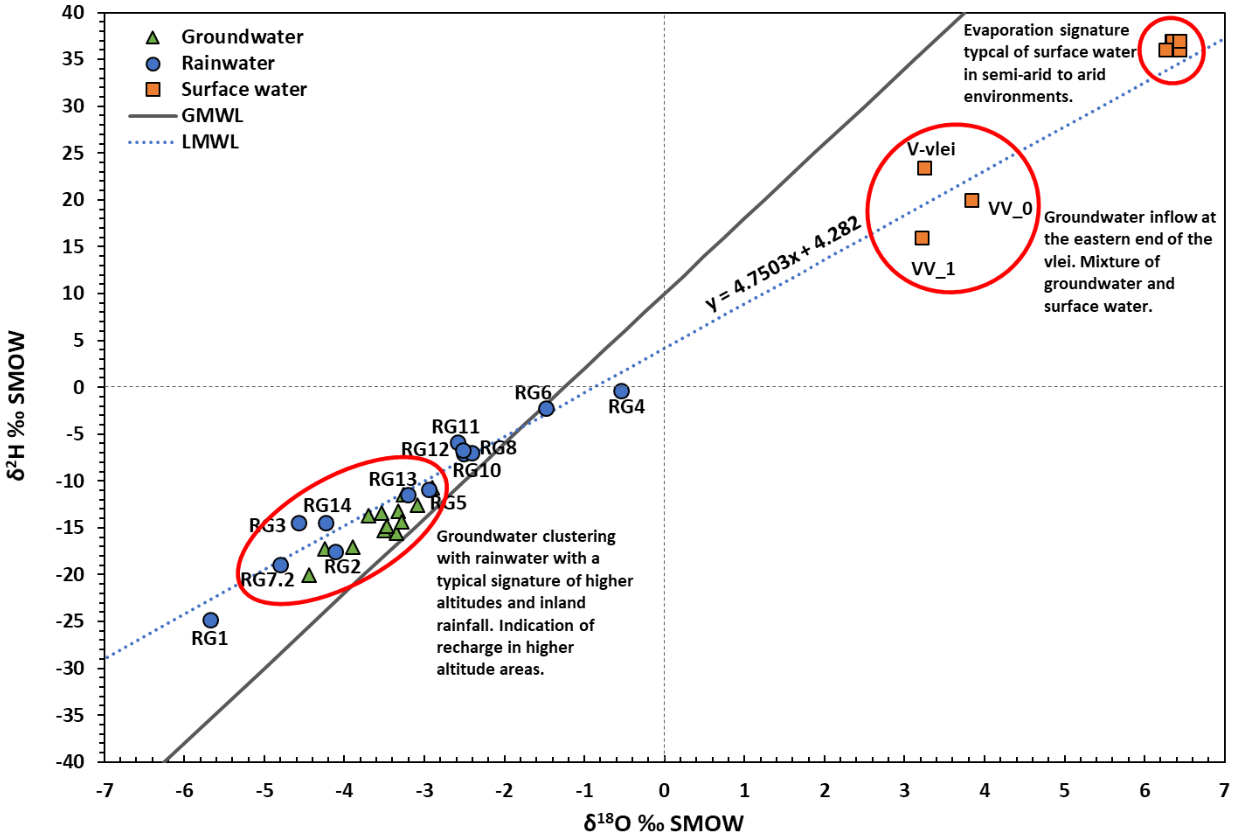


Figure 8: Comparison of the stable Isotope compositions taken during the GEOSS (2019) study displaying similarities between the link between groundwater abstracted in the lower coastal regions of the Sandveld with the rainwater from the Piketberg Mountain range

3.5 Spring Data

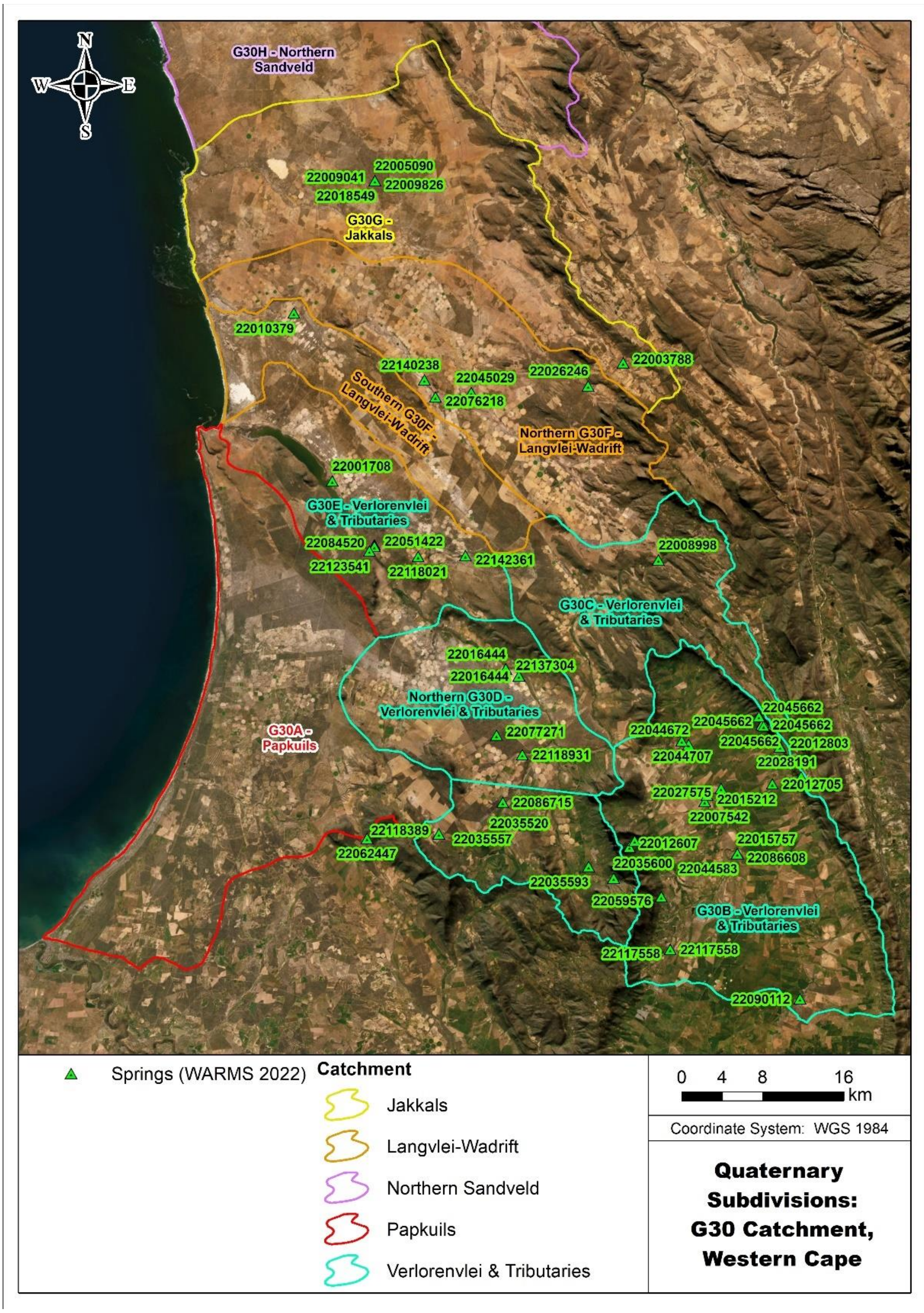
Very little data could be found on the springs in the F60 and G30 catchments during the course of this study and a main recommendation for this study is that important springs need to have flow monitoring systems installed.

For the F60 catchments, very little data on springs existed and during April 2022, a hydrocensus was done in the F60A and F60C catchments to investigate groundwater use and the occurrence of springs. Low-yielding (reported yield of <0.1 - 0.5 L/s) springs were identified. According to the local water users, some of the springs are used by animals and for non-drinking domestic purposes. The springs have reportedly not decreased in yield in the last few decades and this is attributed to the overall low groundwater abstraction for that area.

For the G30 catchments, some major springs have been identified. Most of these springs can be classified as seepage zones, rather than springs, although the term spring is used by most.

All the springs identified have been impacted and have reportedly displayed a decrease in yield in the past 20 years, and in some cases, have dried up (this was reported during the community engagement meeting held throughout the course of this study). Of these springs, only the Matroozefontein is equipped with a flow monitoring system that was installed on the 15th of December 2021 by the Bergrivier Municipality, because the spring supplies the town of Redelinghuys. The flow measuring system was installed because the municipality is concerned about the drop in yield in recent years. The farm on which the seepage area is located is responsible for ensuring continuously supplying the town (and some farms downstream) with a constant supply of 18 L/s. Because the spring stopped being able to sustain this demanded yield entirely by its self around 20 years ago, two boreholes were drilled in the proximity of the seepage area and discharge water in the seepage area to supplement the supply during months when the spring cannot sustain this yield. Before the drought, around 2014, the farm reported that the spring could still sustain the necessary supply until late summer, but since then, they have had to start using the boreholes to supplement spring flow earlier into the dry season each year. In the last two years, the boreholes had to be switched on in early August and continued to be used to supplement the supply until earlier winter (May or June). This indicates a sharp decrease in spring flow. The two boreholes that are supplementing the spring flow are now also being monitored so that the volumes can be subtracted from the spring flow to get an accurate spring flowrate. When this was done, the actual flow in December 2022 was reported as being 2 L/s. If the reports that the spring had been able to sustain this flow in 2014 are true, that would mean a decrease in the December months` flow of 88%. An increase in drilling and damming upstream of the Matroozefontein seepage area has been observed and is most likely linked to the flow reduction. The local DWS office is aware of this and are committed to engage with the water users to resolve this issue.

None of the other springs or seepage areas in the G30 catchments is monitored with regard to flow or quality. Some of these are still important in regard to inflows into the Verlorenvlei or Rocherpan wetlands and are also important sources of domestic and irrigation water. To get some indication of the significance of these springs, WARMS data was used. Although this dataset cannot be seen as actual spring flow data, spring abstraction registered through WARMS did at least indicate the potential yield of a specific spring or seepage area. Registered use from springs within the G30 catchments is available in **Table 8** and on **Map 14**.



Map 14: Map displaying registered WARMS springs (WARM, 2022), displayed on satellite imagery

Table 8: WARMS data on springs and seepage areas in the G30 catchments, updated until 14 July 2022 (provided by Bellville DWS Office)

Register No.	Drainage Region Code	Resource Type	Resource Name	Latitude	Longitude	Registered Volume Start Date	Registered Volume	Volume MU	Interval Type
22001708	G30E	SPRING/EYE	GROUNDWATER	-32.362666	18.45548	01/04/2002	90 000	CUBIC METRES	PER YEAR
22003788	G30G	SPRING/EYE	GROUNDWATER	-32.258506	18.76049	01/02/1982	12 750	CUBIC METRES	PER YEAR
22005090	G30G	SPRING/EYE	FOUNTAIN	-32.09578	18.501472	01/02/1995	162 000	CUBIC METRES	PER YEAR
22007542	G30B	SPRING/EYE	GROUNDWATER (ONBRENT FOUNTAIN)	-32.648764	18.845209	01/03/1996	15 000	CUBIC METRES	PER YEAR
22008998	G30C	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.433924	18.796819	01/03/1997	398 000	CUBIC METRES	PER YEAR
22009041	G30G	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.09578	18.501472	01/03/1976	50 000	CUBIC METRES	PER YEAR
22009826	G30G	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.09578	18.501472	01/03/1983	32 800	CUBIC METRES	PER YEAR
22010379	G30G	SPRING/EYE	DIE OOG	-32.213233	18.416039	01/12/1999	6 000	CUBIC METRES	PER YEAR
22012607	G30B	SPRING/EYE	GROUNDWATER(FOUNTAIN)	-32.689041	18.766046	01/03/1994	79 000	CUBIC METRES	PER YEAR
22012705	G30B	SPRING/EYE	GROUNDWATER(FOUNTAIN)	-32.633255	18.916171	01/04/1993	130 000	CUBIC METRES	PER YEAR
22012803	G30B	SPRING/EYE	GROUNDWATER(FOUNTAIN)	-32.600157	18.924382	01/09/1997	21 024	CUBIC METRES	PER YEAR
22015212	G30B	SPRING/EYE	GROUNDWATER (KRUIS RIVER EYE)	-32.643214	18.847709	01/04/1993	16 396	CUBIC METRES	PER YEAR
22015757	G30B	SPRING/EYE	GROUNDWATER	-32.695152	18.87948	01/05/1986	432 000	CUBIC METRES	PER YEAR

Register No.	Drainage Region Code	Resource Type	Resource Name	Latitude	Longitude	Registered Volume Start Date	Registered Volume	Volume MU	Interval Type
22016444	G30D	SPRING/EYE	C58-0-14-0-FI	-32.53041	18.6366	01/11/2003	7 000	CUBIC METRES	PER YEAR
22016444	G30D	SPRING/EYE	C58-0-14-0-F2	-32.5368	18.65041	01/11/2003	7 000	CUBIC METRES	PER YEAR
22018549	G30G	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.09578	18.501472	01/05/1995	275 940	CUBIC METRES	PER YEAR
22026246	G30F	SPRING/EYE	FOUNTAIN (KOOK FOUNTAIN)	-32.279062	18.723818	01/11/1999	12 000	CUBIC METRES	PER YEAR
22027575	G30B	SPRING/EYE	GROUNDWATER	-32.637043	18.862268	01/01/1993	21 000	CUBIC METRES	PER YEAR
22028191	G30B	SPRING/EYE	GROUND WATER	-32.626825	18.946322	01/07/1995	8 800	CUBIC METRES	PER YEAR
22035520	G30D	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.680711	18.619372	01/10/1998	20 000	CUBIC METRES	PER YEAR
22035557	G30D	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.668212	18.642433	01/01/1971	10 000	CUBIC METRES	PER YEAR
22035593	G30D	SPRING/EYE	GROUNDWATER	-32.70648	18.722855	01/01/1991	162 000	CUBIC METRES	PER YEAR
22035600	G30D	SPRING/EYE	GROUNDWATER	-32.71682	18.749375	01/12/2013	64 973	CUBIC METRES	PER YEAR
22044583	G30B	SPRING/EYE	FOUNTAIN	-32.695152	18.87948	01/11/1995	77 400	CUBIC METRES	PER YEAR
22044672	G30B	SPRING/EYE	DE OOG PLAAS HANDELAARSKRAAL	-32.598146	18.828349	01/01/1976	109 500	CUBIC METRES	PER YEAR
22044707	G30B	SPRING/EYE	AGTER DAM	-32.594856	18.821288	01/01/1985	350 000	CUBIC METRES	PER YEAR
22044716	G30B	SPRING/EYE	EYE	-32.695152	18.87948	01/10/1999	153 300	CUBIC METRES	PER YEAR

Register No.	Drainage Region Code	Resource Type	Resource Name	Latitude	Longitude	Registered Volume Start Date	Registered Volume	Volume MU	Interval Type
22045029	G30F	SPRING/EYE	BERGFONTEIN	-32.284571	18.601274	01/12/1991	5 000	CUBIC METRES	PER YEAR
22045662	G30B	SPRING/EYE	C58-0-59-0-F2	-32.57847	18.90634	01/04/2002	5 000	CUBIC METRES	PER YEAR
22045662	G30B	SPRING/EYE	C58-0-59-0-F3	-32.5805	18.90573	01/04/2002	5 000	CUBIC METRES	PER YEAR
22045662	G30B	SPRING/EYE	C58-0-59-0-F4	-32.58076	18.90515	01/04/2002	5 000	CUBIC METRES	PER YEAR
22045662	G30B	SPRING/EYE	C58-0-59-0-F5	-32.58173	18.9073	01/04/2002	5 000	CUBIC METRES	PER YEAR
22045662	G30B	SPRING/EYE	C58-0-59-0-F1	-32.57333	18.90211	01/05/2013	5 000	CUBIC METRES	PER YEAR
22051422	G30E	SPRING/EYE	GROUNDWATER (HANSIESFONTEIN)	-32.419603	18.49937	01/10/1998	20 000	CUBIC METRES	PER YEAR
22051422	G30E	SPRING/EYE	GROUNDWATER (KLAARFONTEIN)	-32.419603	18.49937	01/10/1998	50 000	CUBIC METRES	PER YEAR
22059576	G10H	SPRING/EYE	WABOOMKLOOF - FONTEIN	-32.733455	18.799377	01/01/1964	75 686	CUBIC METRES	PER YEAR
22062447	G10M	SPRING/EYE	GROUNDWATER (MATROOSFONTEIN OOG)	-32.680556	18.49	01/01/1998	46 500	CUBIC METRES	PER YEAR
22076218	G30F	SPRING/EYE	GROUNDWATER (FOUNTAIN /GROOTDAM)	-32.288503	18.563817	01/10/1998	39 600	CUBIC METRES	PER YEAR
22077271	G30D	SPRING/EYE	NAMAQUASFONTEIN	-32.589356	18.626573	01/04/2002	25 000	CUBIC METRES	PER YEAR
22084520	G30E	SPRING/EYE	GROUNDWATER	-32.420996	18.49937	01/04/2002	232 000	CUBIC METRES	PER YEAR
22086608	G30B	SPRING/EYE	GROUNDWATER	-32.695152	18.87948	01/04/2002	266 000	CUBIC METRES	PER YEAR

Register No.	Drainage Region Code	Resource Type	Resource Name	Latitude	Longitude	Registered Volume Start Date	Registered Volume	Volume MU	Interval Type
22086715	G30D	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.649042	18.632955	01/09/2003	137 970	CUBIC METRES	PER YEAR
22090112	G30B	SPRING/EYE	FOUNTAIN	-32.824246	18.945281	01/03/2004	50 000	CUBIC METRES	PER YEAR
22117558	G30B	SPRING/EYE	GROUNDWATER(FOUNTAIN)	-32.780306	18.8085	01/01/2003	5 595	CUBIC METRES	PER YEAR
22117558	G30B	SPRING/EYE	GROUNDWATER	-32.780306	18.808556	01/04/2002	1 865	CUBIC METRES	PER YEAR
22118021	G30E	SPRING/EYE	GROUNDWATER	-32.4301	18.5451	01/12/2011	300 000	CUBIC METRES	PER YEAR
22118389	G30D	SPRING/EYE	GROUNDWATER (FOUNTAIN)	-32.676901	18.56572	01/04/2012	2 000	CUBIC METRES	PER YEAR
22118931	G30D	SPRING/EYE	GROUNDWATER	-32.606655	18.653573	01/04/2012	150 000	CUBIC METRES	PER YEAR
22123541	G30E	SPRING/EYE	GROUNDWATER	-32.425163	18.494092	01/08/2012	30 600	CUBIC METRES	PER YEAR
22128582	G30B	SPRING/EYE	GROUNDWATER (SEWEFONTEIN)	-32.683482	18.771596	01/08/2012	25 814	CUBIC METRES	PER YEAR
22137304	G30D	SPRING/EYE	SPRING/EYE	-32.53041	18.6366	01/01/2004	7 000	CUBIC METRES	PER YEAR
22140238	G30F	SPRING/EYE	FOUNTAIN	-32.273231	18.552433	01/10/2017	71 800	CUBIC METRES	PER YEAR
22141914	G30B	SPRING/EYE	GROUNDWATER	-32.695152	18.87948	01/06/2010	24 000	CUBIC METRES	PER YEAR
22142361	G30E	SPRING/EYE	GROUNDWATER (KRUISFONTEIN)	-32.429603	18.594653	01/06/2017	48 000	CUBIC METRES	PER YEAR

4. GRONDWATER RESOURCE UNITS

4.1 G30 Catchments

4.1.1 Papkuils-G30A GRU

Grouping: Papkuils

GRU Name: G30A

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

Description:

The groundwater unit falls within the quaternary catchment boundaries. Papkuils seepage area (**Figure 9**) forms a significant observed groundwater/surface water interaction site in this unit, and this spring site is a significant one and still contains some areas of important wetland habitat and species. Another area of importance has been delineated towards the northeast of the Rosherpan wetland, as springs popping up in these areas also feeds the wetland. This area has been identified as a significant aquifer.

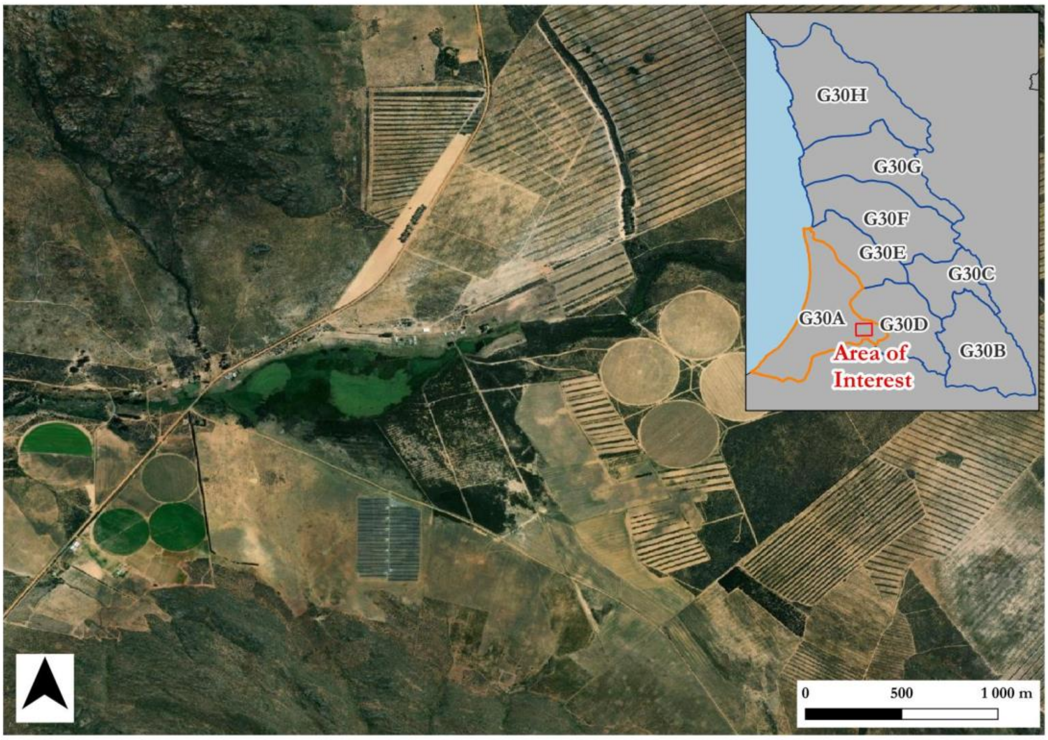


Figure 9: Papkuils Seepage Area

The majority of the GRU is low-lying coastal flats (**Map 16**). 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.

With regards to the DWS monitoring, there are 3 sites being monitored, 2 of which display a slight decline. The G33940 site is located close to the Rosherpan EWR site and displays a decline of less than 1 meter between 2015 and 2021 (**Figure 10**). G33256 is located towards the north of the catchment and has been monitored since 1985. Since then, a drop in static water level has been observed of approx. 10 meters (it is assumed that the deeper WLs refer to the impact of a nearby production borehole. The data is displayed in **Figure 11** and more detail is available in **Annexure B**. This is a very good example of displaying the drop in water level that occurred since the mid-1990s, when groundwater exploration and use increased in the Sandveld area.

Single water levels are displayed in **Map 14** which shows that water levels are generally shallow (<15 mbgl), except for a few deeper levels measured that can be contributed to either being production boreholes, or to their proximity to production boreholes.

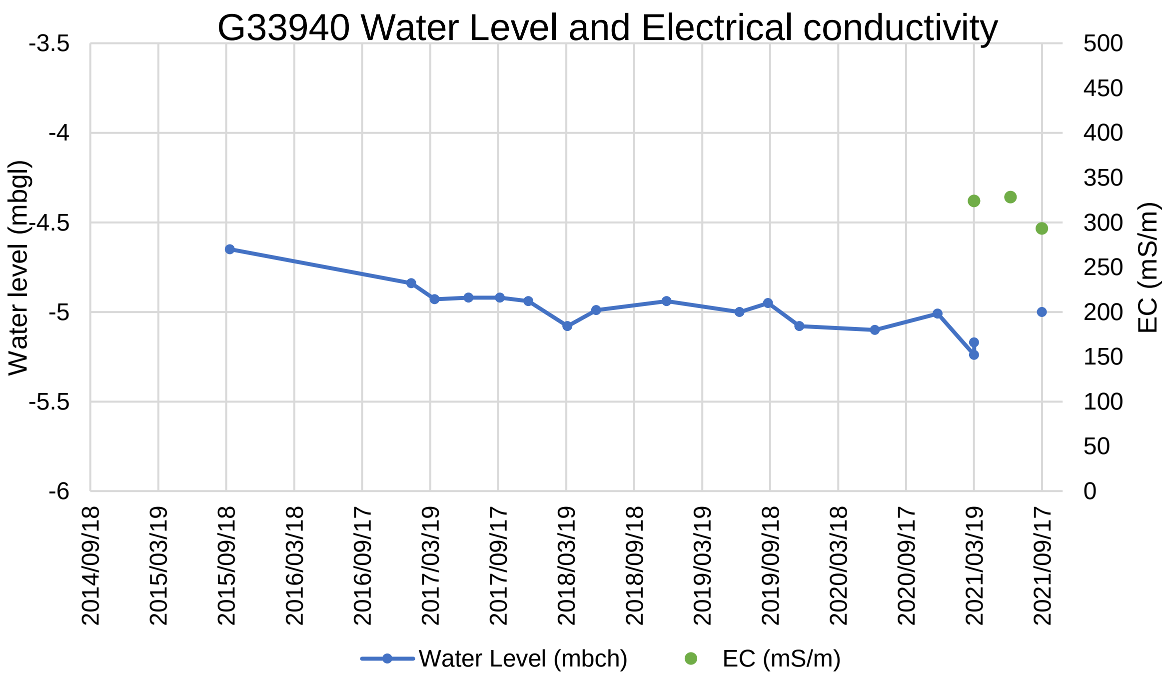


Figure 10: G33940 WL and EC monitoring, located close to Rosherpan EWR site

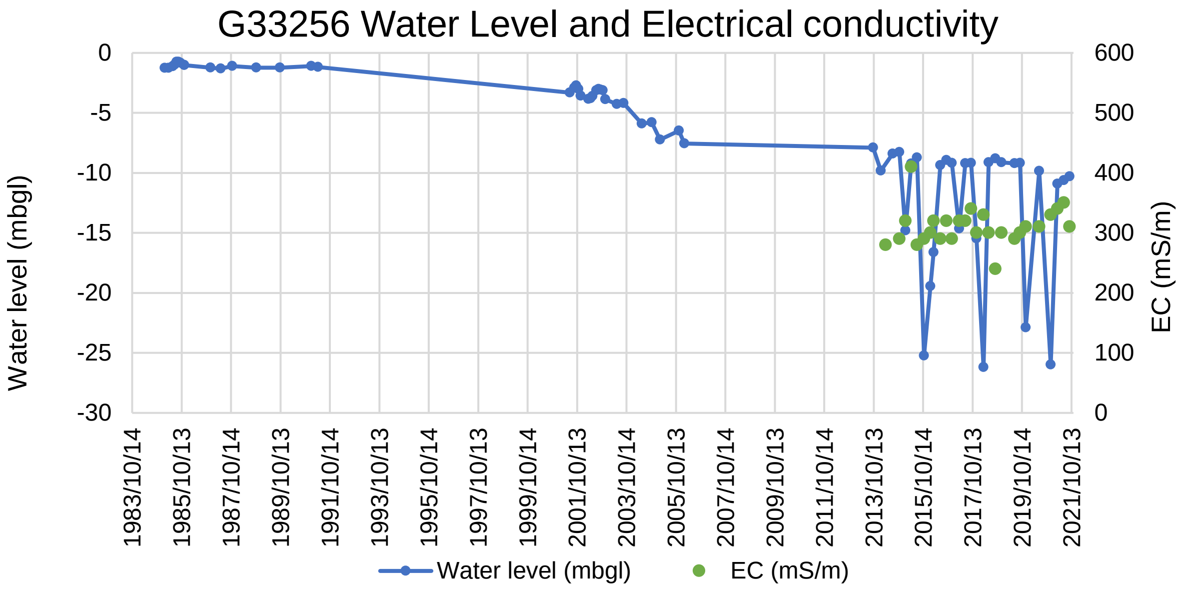


Figure 11: G33256 WL and EC monitoring

With regards to EC and yield measurements, it could be noticed that the better-quality water and higher yields seem to plot in the central area of the GRU (**Map 15**), supporting the hypothesis of the water from the G10K (Piketberg Mountains) draining along NW trending structures or conduits towards the coast.

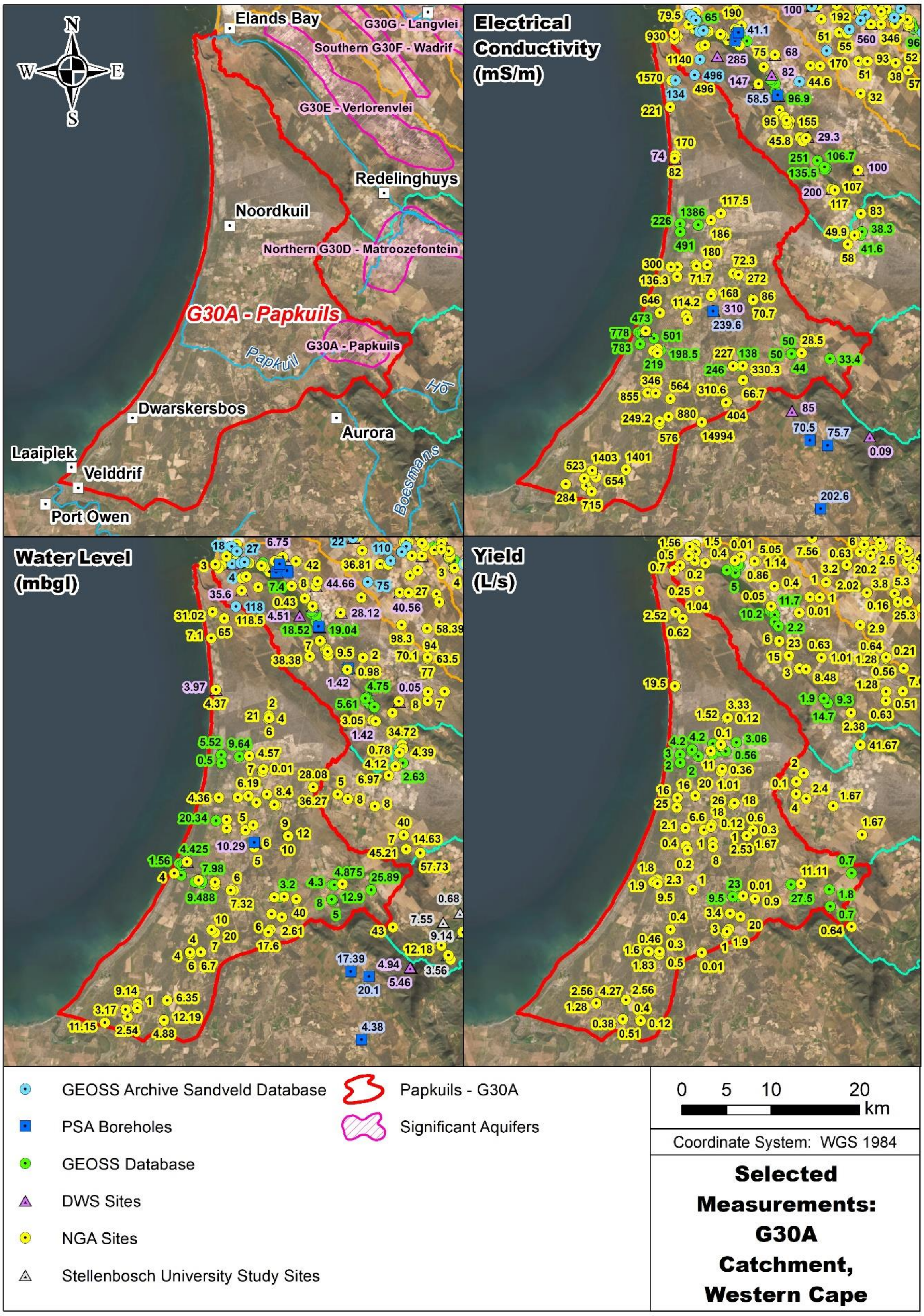
A borehole located approximately 160 meters from the Papkuils river and 800 m downstream from the Papkuils seepage area had undergone sampling in an investigation done by GEOSS in 2020. The landowner has supplied the data for this study, but asked that the exact location of the site not be included in the maps. The data is displayed in **Table 9**.

With regards to the quality of the groundwater found in G30A, the data that could be obtained from the GEOSS Database (2022) and DWS (DWS, 2022 and DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 9**). Water quality varies, with the best groundwater quality located around the seepage areas and springs. Average CL and EC is high and falls within Class 3 of the DWS classification.

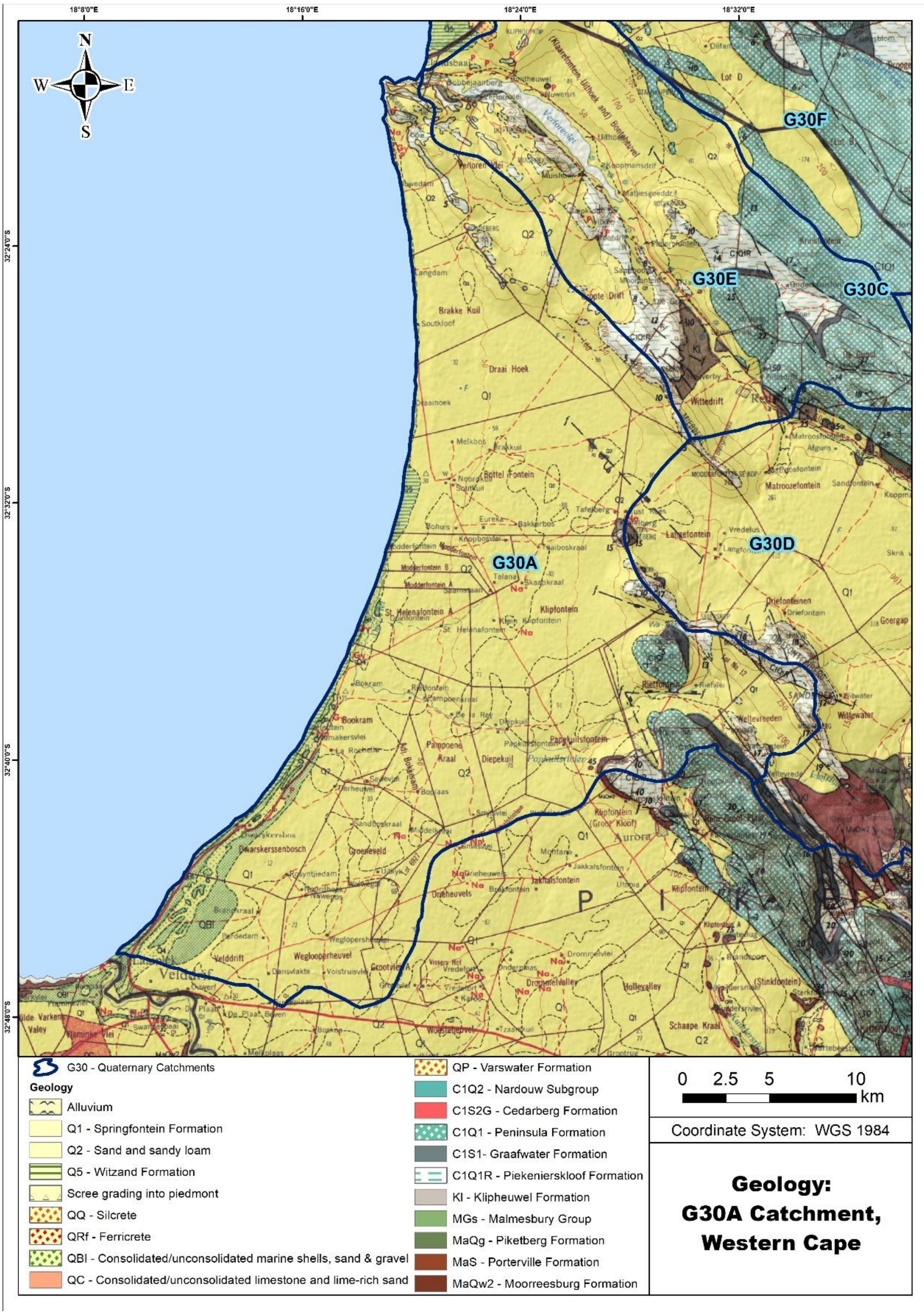
With regards to spring flow data, no actual data is available and when the WARMS spring registrations found around the seepage area are added up, a value of 124 000 m^3/a has been registered to be abstracted from this seepage area. Because the spring is still there with a wetland, the actual yield/spring flow is considered to be much more than this. It has been reported that since drilling increased around the seepage area and along the Papkuils river, the stream being generated from the seepage area and rain is not flowing as it used to and has dried up in sections.

Table 9: Groundwater Quality analyses for G30A, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023)

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	46	46	46	46	46	46	46	46	46	46
Median	**38.90**	**928.60**	**325.50**	**0.41**	**79.55**	**0.09**	**510.55**	**105.00**	**59.55**	**6.71**
Average	66.81	1329.66	429.74	0.70	112.32	5.87	718.18	215.99	83.26	6.68
95.00	186.33	3593.05	1119.08	1.69	288.35	5.26	1981.13	794.60	269.80	7.60
5.00	7.83	201.52	86.45	0.11	13.77	0.02	118.30	17.08	2.00	4.83



Map 15: Delineation of the Papkuils-G30A GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 16: Geological setting of the G30A Catchment (Clanwilliam, 3218) (CGS, 1973)

4.1.2 Verlorenvlei & Tributaries-Southern G30D GRU

Grouping: Verlorenvlei & Tributaries

GRU Name: Southern G30D

Groundwater Use: Extensive

Description:

This unit comprises the upper reaches of the Krom-Antonies and Hol river catchments and is known as the Moutonshoek and Goergap areas. Contact springs are still found 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). Data obtained for the area is presented in **Map 17** and more detail is available in **Annexure A.**

Due to the occurrence of Tungsten in the Riveria Pluton located in the Moutonshoek valley, the geology has been studied in detail. The Piketberg Formation in the Moutonshoek Valley has been mapped as a succession of phyllites, schist and greywacke layers, interbedded with meta-carbonate lenses. The metasedimentary formation is relatively easily eroded and forms the central-lying valley floor of the Krom-Antonies basin. The formation is characterised by a high degree of fracturing and an increasing level of metamorphism moving towards the granite pluton. Meta-Carbonate lenses occur throughout the formation and were observed during exploration drilling (**Map 18**).

The Piketberg Formation has been intruded upon by the Riviera Granite Pluton, which is part of the Cape Granite Suite. North-westerly trending faults in this basement induced the intruding of the Riviera Granite Pluton in at least one part of the study area (Rozendaal et al, 1994). The Riviera Pluton is an I-type monzogranite, granite and alkali feldspar granite, and later A-type granite, which is per-aluminous to met-aluminous in composition (Rozendaal & Boshoff, 2010). The Riviera Pluton intruded into a sequence of greenstone beds in a dome-shaped interference structure (Rozendaal & Moyen, 2009) between 507 Ma and 516 Ma.

The Riviera Pluton was discovered by Union Carbide Exploration Company in 1975. After forming a joint venture with Anglo American Corporation, the ore zone was outlined and a feasibility study was concluded by the end of 1983 by extensive core drilling. The latest published ore description was done by SRK in 2013. They stated that: *"Mineralization of economic significance consists entirely of disseminated scheelite ($CaWO_4$, <1 % Mo) and minor disseminated molybdenite with trace amounts of chalcopyrite and sphalerite. Most of the tungsten mineralization is associated with potassic and endoskarn alteration with the veins making a minor contribution to the overall resources. The phyllic-altered host is of very low grade in the order of 0.015-0.05 % WO_3 with minor amounts of molybdenite present. The potassic zone with its areas of endoskarn is well mineralized with grades from 0.10 % WO_3 up* *to 2 % WO3 and averaging 0.35 % WO3. Vein style mineralization is extremely variable with grades of up to 10 % WO3 and 5 % Mo."*

The report also detailed the presence of Sulphur (1-2% S) as well as trace amounts of uranium (U) and thorium (Th). The richest ore zone occurs along the eastern edge of the Riviera Granite Dome (Rozendaal, et al, 1994).

The Riviera Pluton consists of at least three intrusive phases (SRK, 2013):

- Early quartz monzonite porphyry (QMP);
- Biotite monzogranite (BMG); and
- Late-stage aphanitic granite-monzogranite (AGM).

Subsequent Mesozoic tensional tectonics have resulted in a swarm of steep dipping northwest-trending normal faults (Rozendaal, et al, 1994). Erosion exposed the roof of the granite pluton, which was subsequently covered by superficial deposits of clay and alluvium. For this reason, the granite pluton is not visible on the geological map. The granite pluton is terminated on its western edge by a major fault, called the Krom-Antonies Fault, which has a downthrow of ~ 450 m to the west (Rozendaal et al, 1994). The Plutons northern edge is also sharply terminated by a fold system (Rozendaal, et al 1994).

The study area is bounded in the east, west and south by hills and mountains formed by quartzitic sandstones of the Table Mountain Group (TMG), namely the Piekenier-, Graafwater- and Peninsula Formation (Belcher & Kisters, 2003; Visser, 2009). Two southwest-northeast geological sections have been included in **Figure 14** to assist with the geohydrological understanding of the Moutonshoek Valley. These were taken from a GEOSS study (2022a), and were included to display the assumed geological setting for the upper and lower reaches of the Moutonshoek Valley. The geological setting is important as the area is being continually targeted for mining.

With regards to hydrogeology, both primary and secondary aquifers exist, although the unconsolidated sands are not deep enough in most areas to host extensive primary sand aquifers, and the abstraction of groundwater is targeted to the fractured aquifer. Studies done on the relationship between the primary and secondary aquifers within the Moutonshoek area also pointed to a strong relationship between the two aquifers, and in turn the baseflow of the river (Eilers et al., 2017 and Eilers, 2018). Eilers also suggested that this relationship was highlighted by the similarities in the stable isotope and chemistry results between groundwater samples (both from the primary aquifer and secondary aquifer) and surface water (rainwater and river samples). The research suggests that the thin primary aquifer found in the study area is recharged from the TMG, and direct recharge to the secondary aquifer is likely to be the primary mechanism. Comparison between groundwater of the secondary and primary aquifer originating in the upper Krom-Antonies indicate that the primary and secondary aquifers have a similar composition. This suggests that the high recharge to the secondary aquifer in the vicinity of the study area recharges the primary aquifer, thus contributing to baseflow in the form of a gaining stream (Eilers, 2018, Watson 2020).

Because isotope dating (Eilers, 2018) has linked groundwater from the secondary and primary aquifers in the upper reaches of the Krom-Antonies, with the baseflow of the Krom-Antonies

River, the proposed mining could have serious impacts on the groundwater in the valley, as well as downgradient towards the coast. A large-scale dewatering project in that specific location pose a real risk of detrimentally impacting the groundwater and surface water (baseflow to the river) on a regional scale.

Reported seepage areas exist along fault lines in the upper reaches of the Mountonshoek Valley. Due to the occurrence of the seepage zones as well as the studies connecting the upper Krom-Antonies with surrounding aquifers, the upper Moutonshoek Valley has been delineated as an important aquifer. The same could not be done for the Hol upper catchment due to a lack of data, but it can be assumed that a similar system exists.

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 (near the mountainside). The groundwater quality data that could be obtained from the GEOSS Database (2022) and DWS (DWS, 2022 and DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 10**).

Table 10: Groundwater Quality analyses for Southern G30D, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023)

	Ca (mg/l)	**Cl (mg/l)**	**EC (mS/m)**	**F (mg/l)**	**Mg (mg/l)**	**NO3+NO2 (mg/l)**	**Na (mg/l)**	**SO4 (mg/l)**	**TAL**	**pH**
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	42	42	42	42	42	42	42	42	42	42
Median	**42.70**	**181.60**	**83.75**	**0.19**	**18.35**	**0.04**	**94.05**	**36.45**	**79.10**	**7.66**
Average	58.16	322.70	130.02	0.19	31.88	1.22	143.71	59.50	86.13	7.55
95.00	152.74	1027.36	333.30	0.41	94.49	5.88	459.58	231.98	189.52	8.36
5.00	4.35	48.93	33.15	0.05	5.15	0.02	31.41	8.40	2.10	6.60

It is important to note that <u>NO groundwater monitoring is being done in this GRU by DWS</u>. As the area has been identified as an important recharge area, it is suggested that monitoring commences, especially in the upper reaches of the valley and on top of the mountain in the area known as the Piket-Bo-Berg (located within G10K catchment).

Some groundwater users are monitoring the water levels and EC in the production boreholes they use. One land owner located in the lower section of the Moutons Valley, just before the Krom-Antonies joins the Hol, did provide access to their data, but asked that the specific location of these sites not be identified (GEOSS, 2022b). From the data that could be obtained, it was noted that EC values are generally constant (**Figure 12**). The one borehole that did display change can be contributed to that specific borehole being located and interacting with the dam. With regards to the water level monitoring, it should be noted that the one borehole`s data only goes up to January 2022. The monitoring data dates from 2018 to the end of 2022 and although all the boreholes display good recovery during non-pumping periods, a slight drop in water level can still be observed (**Figure 13**). Because the data only goes back to 2018, one has to assume that the water levels before pumping began many years ago, would likely have been much shallower.

Yield for the area varies, but the average yield is much higher here than in the other G30 catchments. Generally, the highest yields have been recorded in the upper reaches of the valley and in close proximity to the upper Krom-Antonies. It should also be noted that the crops being irrigated in the Moutons Valley, although they do still include potato crops, also include citrus and table grapes. Although water levels have reportedly not dropped a lot in the area, some springs on the mountain ridge have dropped in flow and some deeper water levels have been reported at some of the main production boreholes.

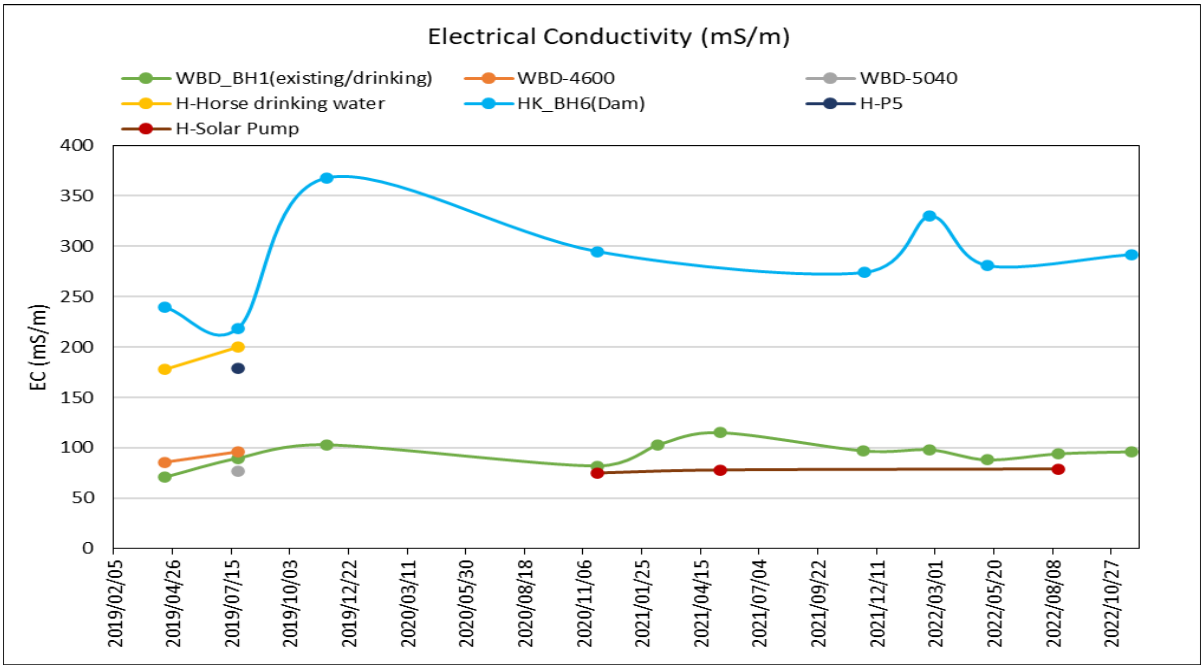
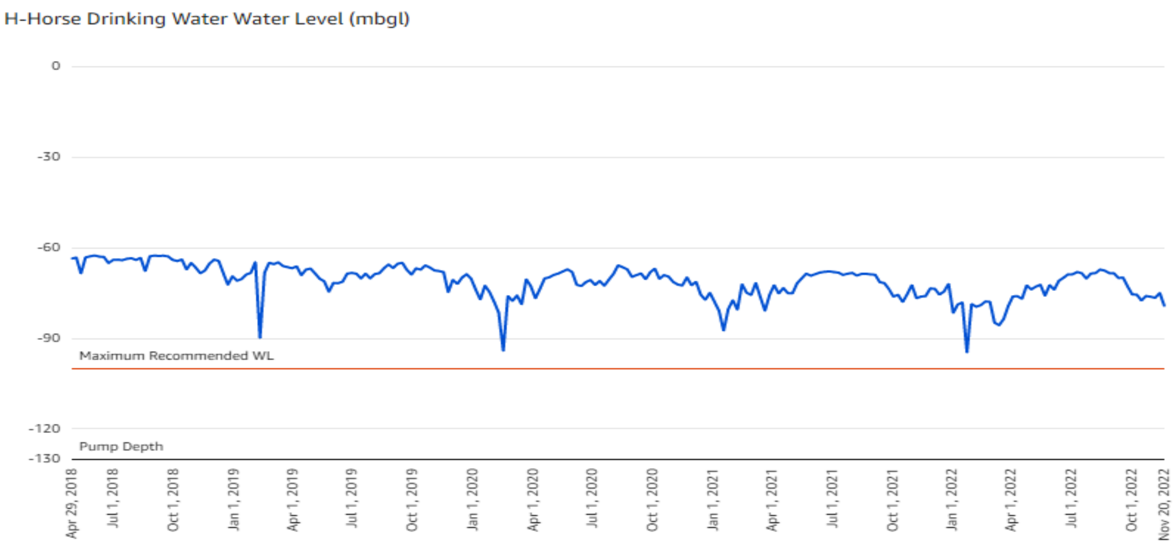
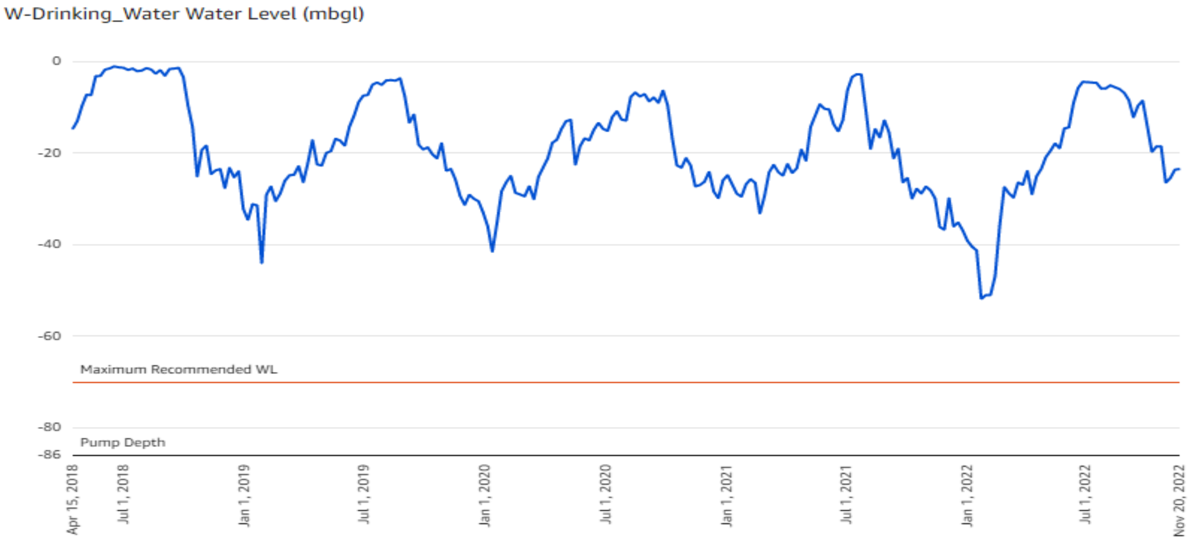


Figure 12: EC monitoring done for production boreholes on farm located in G30D





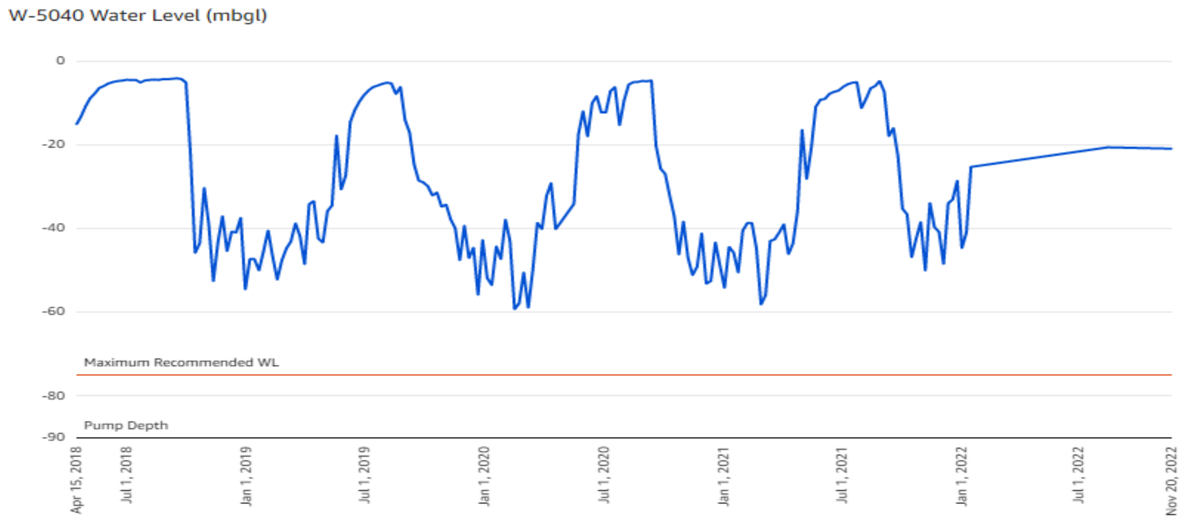
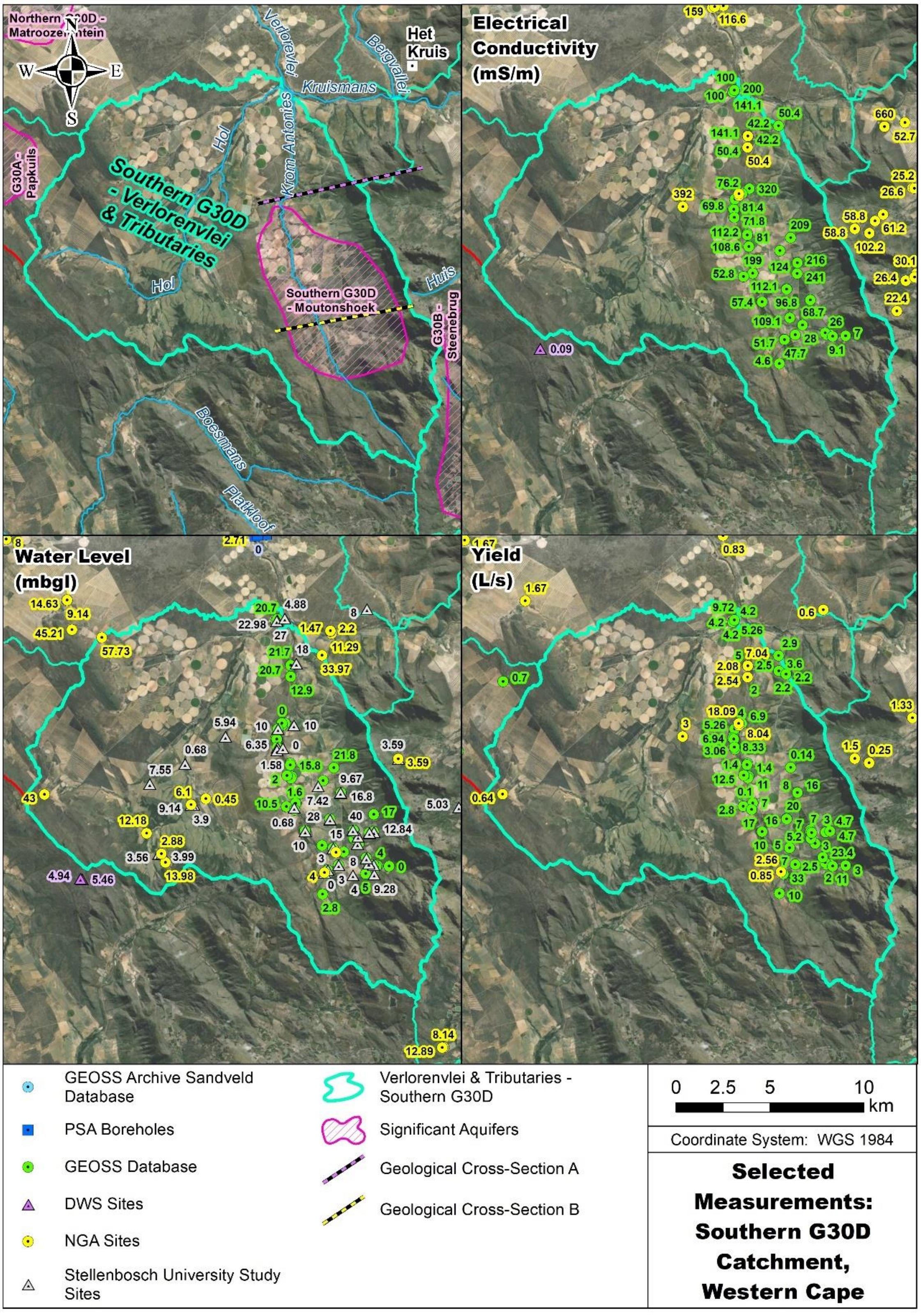
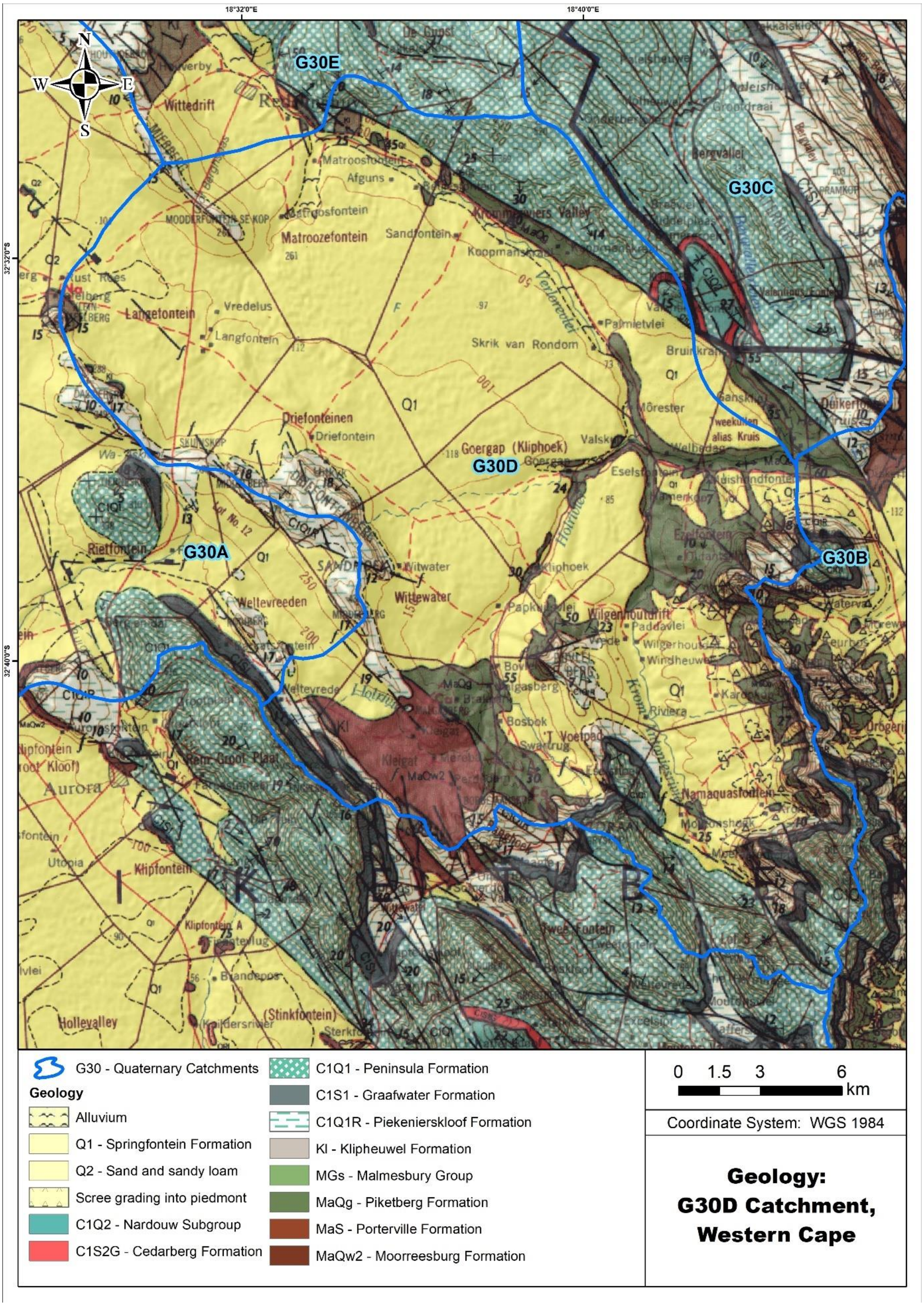


Figure 13: Groundwater water level monitoring in 3 production boreholes located in G30D



Map 17: Delineation of the Verlorenvlei & Tributaries-Southern G30D GRU, on satellite imagery and displaying EC, WL and yield values, where data was available .



Map 18: Geological setting of the G30D Catchment (Clanwilliam, 3218) (CGS, 1973)

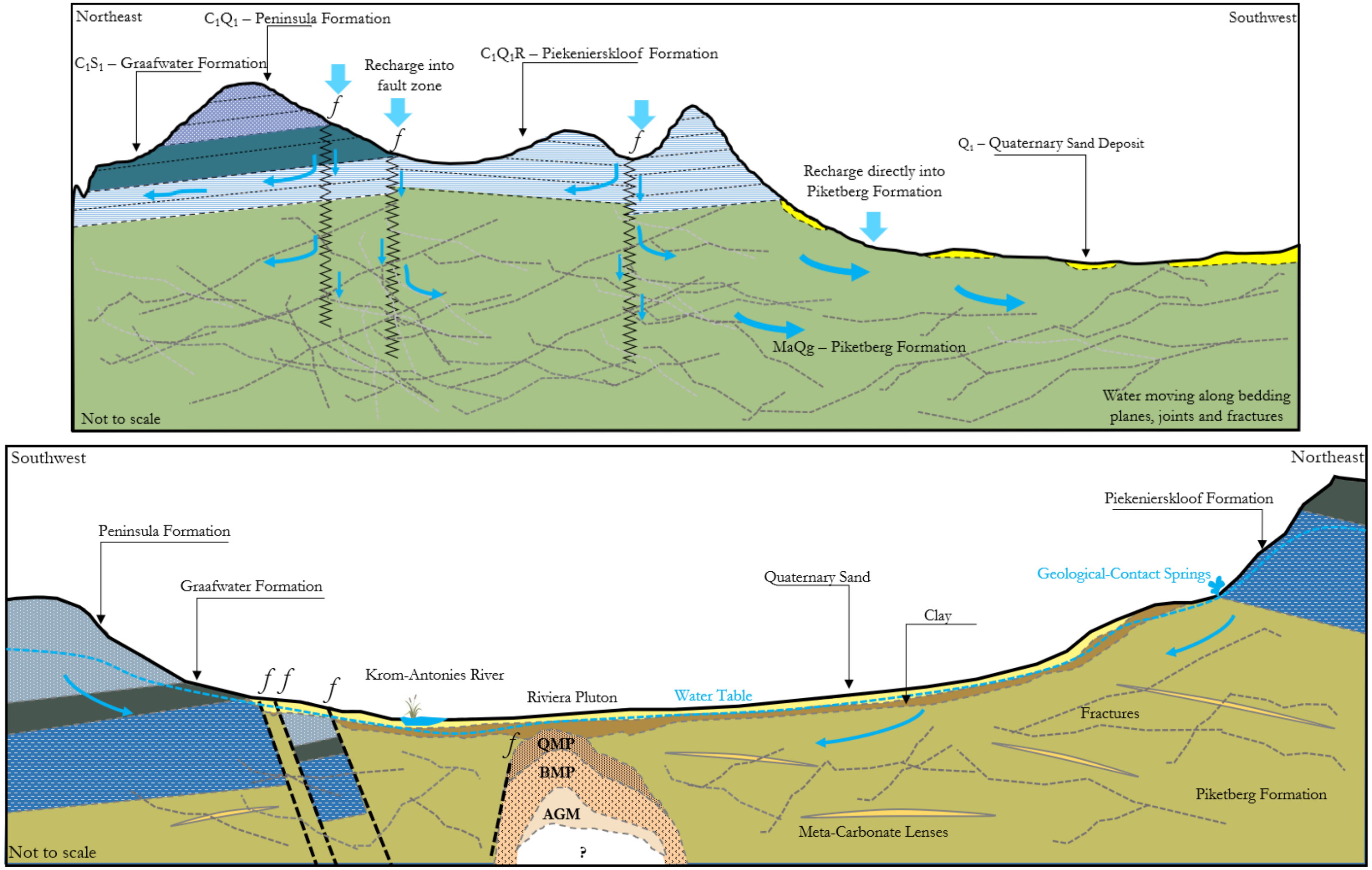


Figure 14: Schematic Southwest-Northeast geological cross-sections of the Moutonshoek Area. The top cross-section (A) represents the bottom represents the lower portion of the valley and bottom cross-section (B) the upper reaches of the valley and. Taken from GEOSS 2020a report

4.1.3 Verlorenvlei & Tributaries-Northern G30D GRU

Grouping: Verlorenvlei & Tributaries

GRU Name: Northern G30D

Groundwater Use: Moderate to high

Description:

Groundwater unit made up of the lower reaches of the Hol, Krom-Antonies and Kruismans rivers as well as where the rivers meet to form the Verlorenvlei river. Malmesbury shales and TMG are overlain by quaternary sands (**Map 18**). Data obtained for the area is presented in **Figure 32** and more detail is available in **Annexure A.** Because of the significance of the Matroozefontein seepage area and the other reported small seepage areas in the main channel of the Verlorenvlei river, this area has been delineated as an important aquifer. This is also an area of assumed groundwater-surface water interaction.

The Matroozefontein spring/seepage area to the northern end (**Figure 15**) of this GRU 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 water from the fractured rock aquifer into the sand deposits overlying it. The seepage area is targeted during groundwater exploration and some of the seepage areas in the upper reaches of this spring area have dried up. The spring area also acts as the only water supply for the town of Redelinghuys.

Matroozefontein is equipped with a flow monitoring system that was installed on the 15th of December 2021 by the Bergrivier Municipality, because the spring supplies the town of Redelinghuys. The flow measuring system was installed because the municipality is concerned about the drop in yield in recent years. The farm on which the seepage area is located, is responsible to continuously supply the town (and some farms downstream) with a constant supply of 18 L/s of water. Because the spring stopped being able to sustain this demanded yield around 20 years ago, two boreholes were drilled in the proximity of the seepage area to supplement the supply during months when the spring cannot sustain this yield. Before the drought, around 2014, the farm reported that the spring could still sustain the necessary supply until late summer, but since then, they have had to start using the boreholes to supplement spring flow earlier in the summer each year. In the last two years, the boreholes had to be switched on in early August, and continued to be used to supplement the supply until early in winter (May or June). This indicates a sharp decrease in spring flow. The two boreholes that are supplementing the spring flow are now also being monitored so that the volumes can be subtracted from the spring flow to get an accurate spring flowrate. When this was done, the actual flow in December 2022 was reported as being 2 L/s. If the reports that the spring had been able to sustain this flow in 2014 are regionally representative, that would mean a decrease in the December months` flow of 88%. An increase in drilling and damming upstream of the Matroozefontein seepage area has been reported and is most likely linked to the flow reduction.

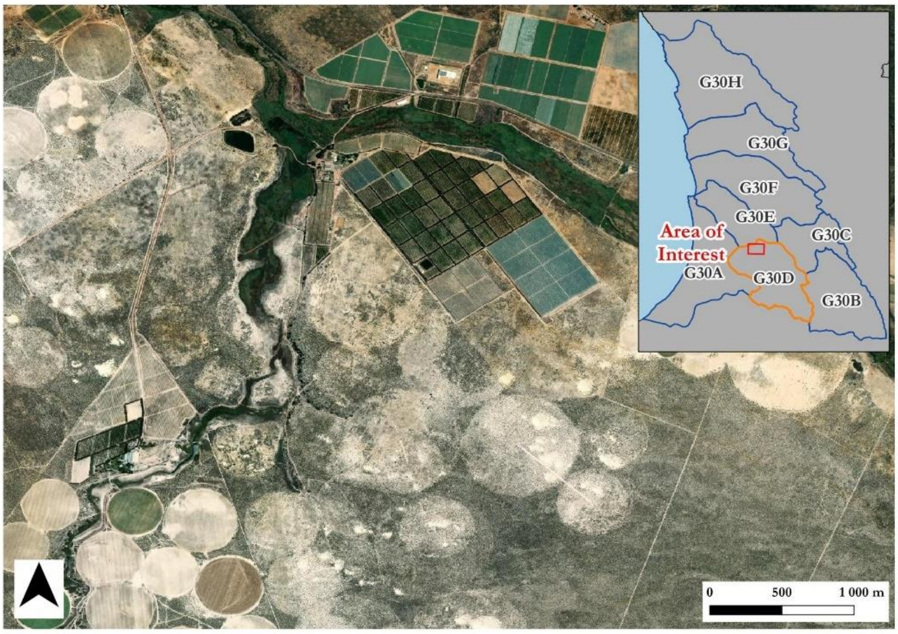


Figure 15: Matroozefontein Seepage Area

It is important to note that NO groundwater monitoring is being done in this GRU by DWS. Some groundwater users are monitoring the water levels in the production boreholes they use. One land owner located in the property adjacent to the Matroozefontein seepage area, did provide access to their data, but asked that the specific location of these sites not be identified (GEOSS, 2023).

From the data (dating back to 2005), a drop of <5 m in water levels can be observed (**Figure 16**). Because these boreholes are near a major seepage area (where the water level should be 0 mbgl in some areas) it could explain the decrease in flow.

With regards to the quality of the groundwater found in Southern G30A, the data that could be obtained from the GEOSS Database (2022) and DWS (DWS, 2022 and DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 11**).Water quality varies, but is generally considered to be good, though some isolated high nutrient values have been observed. With regards to the quality of the spring/seepage area, Bergrivier Municipality does monitor the quality of the raw spring water. This data was obtained from the municipality (Bergrivier Local Municipality, 2020) and incorporated with the other groundwater samples in **Table 11**.

Very little data is available on borehole yields, but reported yields are generally low, apart from the area surrounding the Matroozefontein Seepage Area. Very high yields have been attributed to this area by NGA, with yields between 18 and 40 L/s being observed, although these are mostly blow yields (**Map 19**).

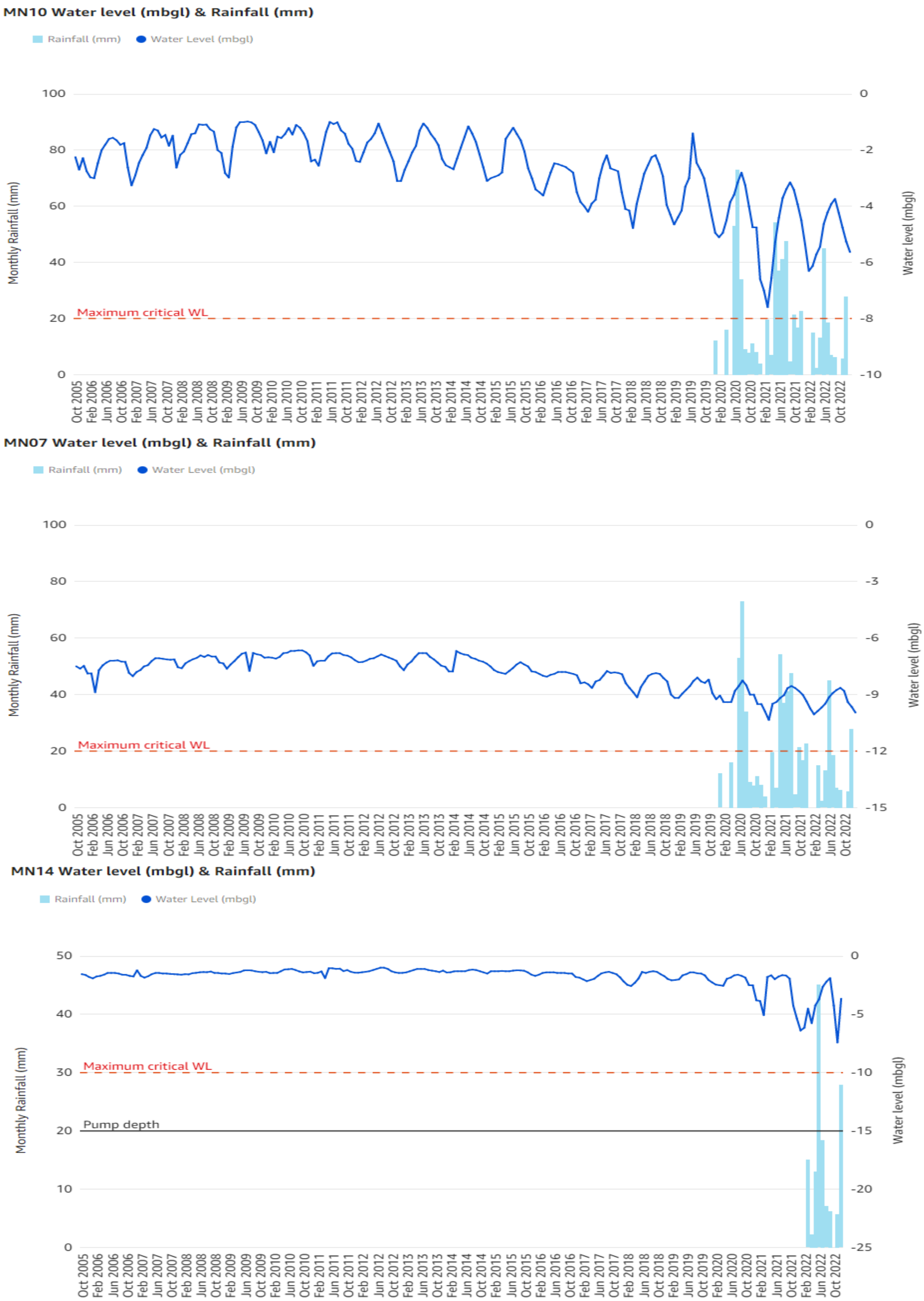
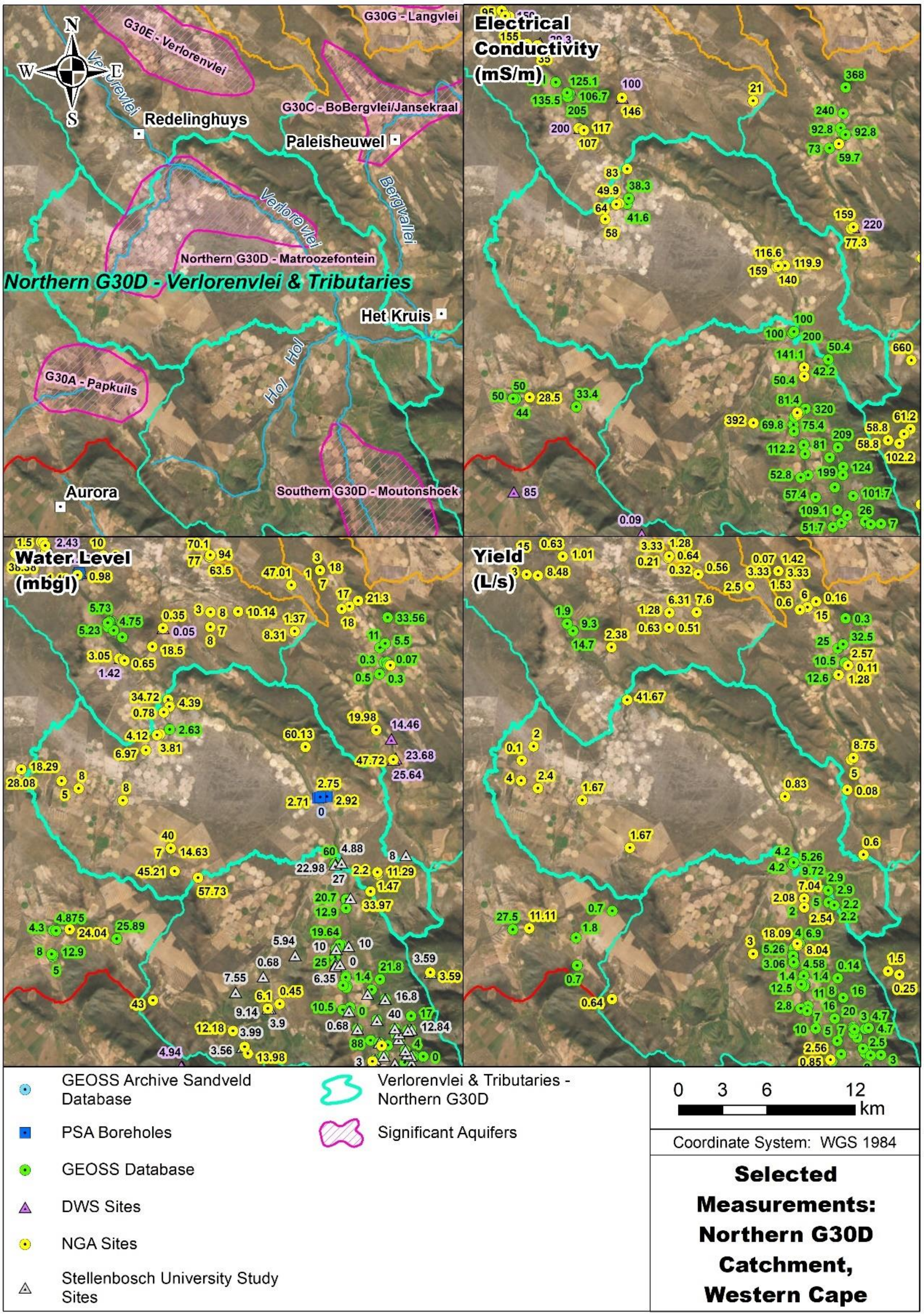


Figure 16: Groundwater water level monitoring in 3 production boreholes located in located near Matroozefontein Seepage Area

Table 11: Groundwater Quality analyses for Southern G30D, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	18	18	18	18	18	18	18	18	18	18
Median	**12.75**	**141.80**	**65.63**	**0.13**	**13.93**	**1.35**	**78.65**	**21.40**	**19.70**	**6.83**
Average	13.45	170.18	71.14	0.20	14.92	2.99	91.82	22.25	34.35	6.86
95.00	34.30	329.31	129.59	0.50	31.14	8.07	174.11	46.10	107.76	7.66
5.00	4.62	81.86	38.88	0.05	4.27	0.02	44.64	2.00	7.19	6.24



Map 19 Delineation of the Verlorenvlei & Tributaries- Northern G30D GRU, on satellite imagery and displaying EC, WL and yield values, where data was available

4.1.4 Verlorenvlei & Tributaries-G30B GRU

Grouping: Verlorenvlei & Tributaries

GRU Name: G30B

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

Description:

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 (**Map 21**). Not a lot of data is available for this area and thus the assumptions had to be based on what has been made available and on reports from local groundwater users. Data obtained for the area is presented in **Map 20** and more detail is available in **Annexure A**.

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, but could not be identified during the course of this study.

With regards to the quality of the groundwater found in G30B, the data that could be obtained was analysed according to the DWS water quality reserve template (**Table 12**). Some high nutrient (NO3 +NO2) levels were picked up and the catchment displayed an average Cl (mg/L) enrichment of 717.41, which would burn plants if used for irrigation. This was also noted by some of the land owners, who noted only the farm located near the mountain had groundwater of a good enough quality to be used for large scale irrigation.

Table 12: Groundwater Quality analyses for G30B, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	71	71	71	71	71	71	71	71	71	71
Median	**26.50**	**460.40**	**191.00**	**0.29**	**37.60**	**1.62**	**273.40**	**41.60**	**73.40**	**7.49**
Average	40.59	717.41	259.11	0.37	62.68	5.76	380.60	82.59	89.55	7.38
95.00	154.65	2602.60	817.00	0.90	237.55	20.13	1279.85	253.45	204.35	7.92
5.00	3.95	25.78	22.20	0.12	3.86	0.02	16.11	5.85	10.57	6.66

Yields are low (around 1 - 3 L/s) for much of the valley. Boreholes are drilled into the hard rock, although a few sand boreholes with higher yields (>5 L/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. The Oliviersfontein Spring has been reported to exist in this south-eastern corner of the GRU, but access to the spring could not be obtained during this study.

A few high yielding (16 – 18 L/s) boreholes have been found towards the southwestern corner against the Piketberg mountains. Although multiple attempts to access these boreholes were made, permission to visit boreholes could not be obtained during the course of this study. It is widely reported in the area, that these farms abstract very high volumes of groundwater, as well as build dams to store runoff from the streams and spring flow off of the mountains. Reports have been made by farm owners downgradient of these streams, that they relied on for water for their animals, are no longer flowing. Drilling rigs were also observed on these farms during the course of this study, thereby substantiating at least the report of increased groundwater exploration and indicating an increase in demand.

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. Because of the reports of very high groundwater abstraction, and the reports of groundwater users downstream being impacted, it was decided to delineate this area as an important aquifer (**Figure 17**).

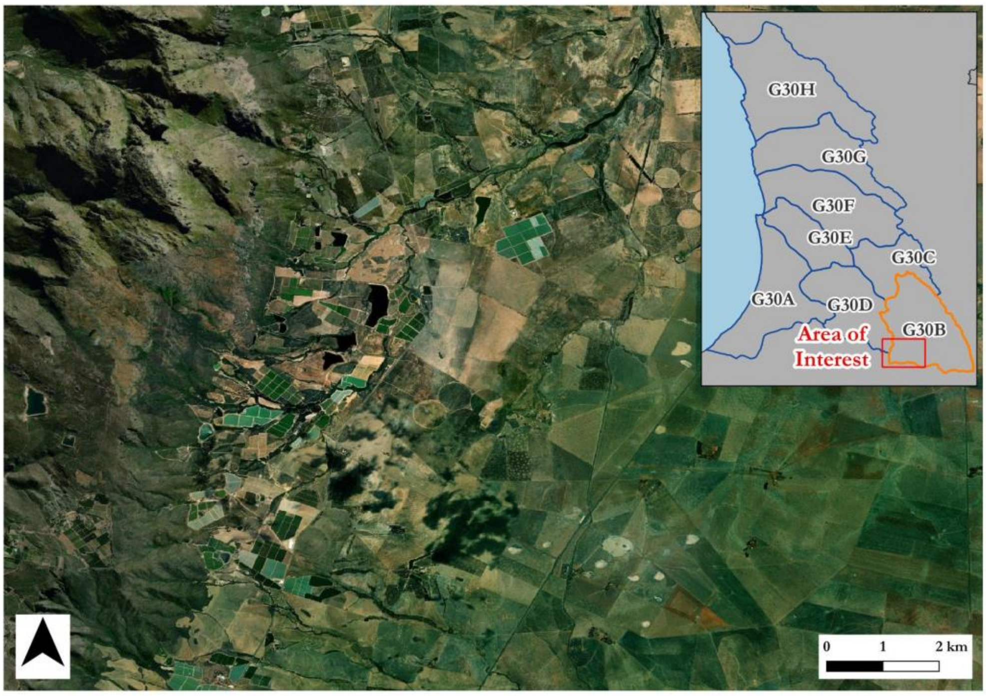
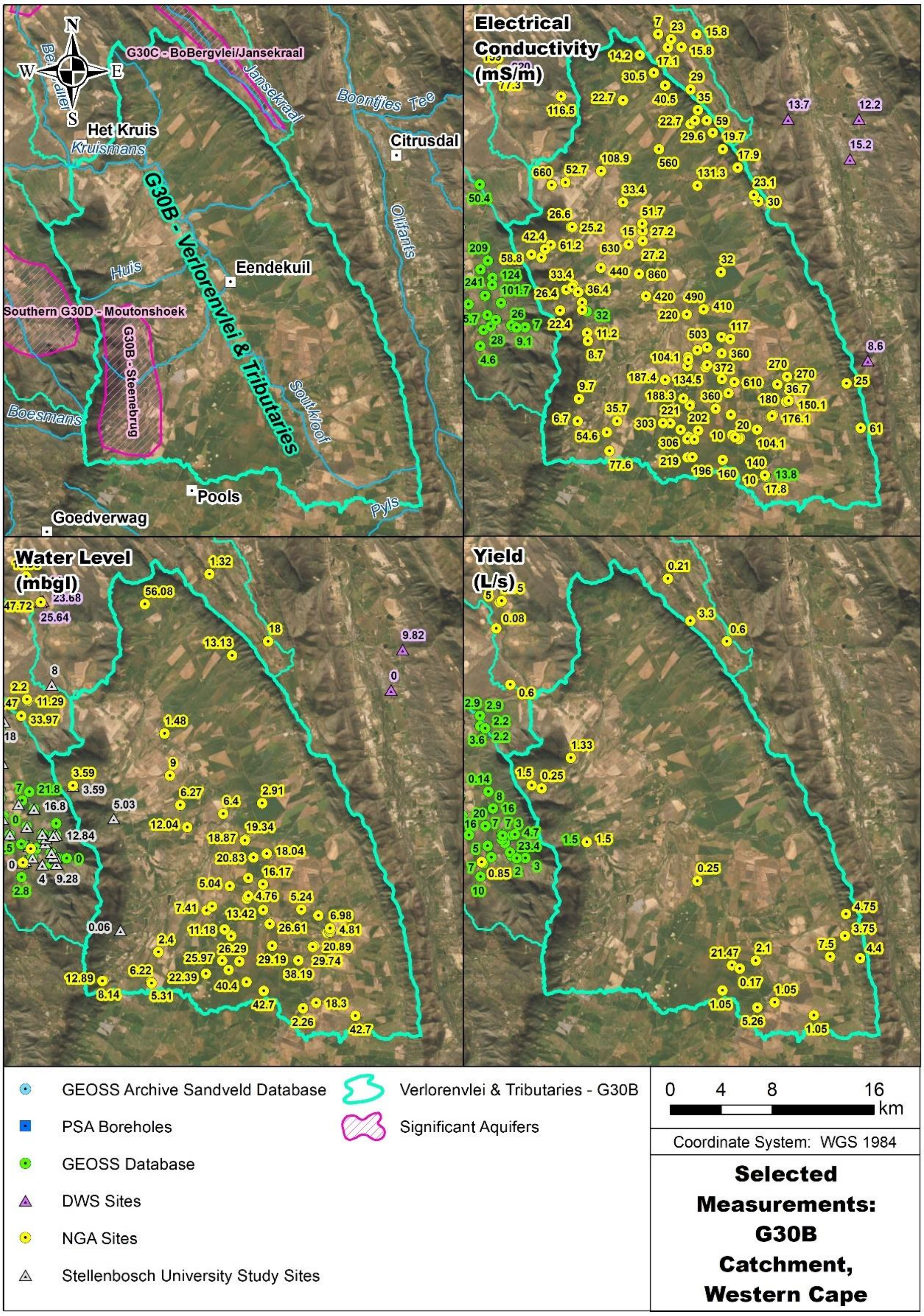


Figure 17:Significant groundwater area in the southwestern corner of G30B

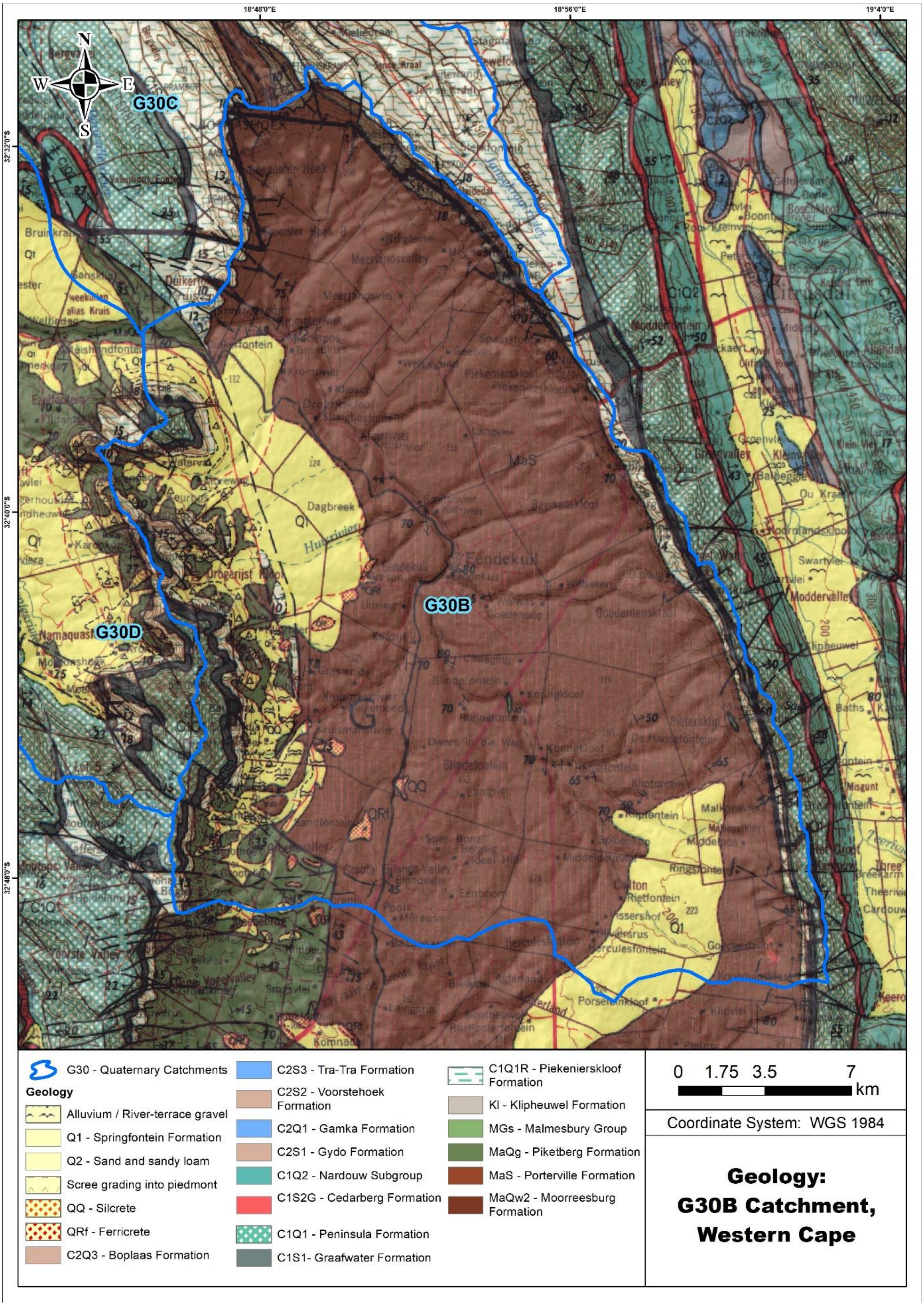
The town of Eendekuil falls in this GRU and is depended upon a spring located 10 km southwest of the town at the base of the Piketberg mountains (**Figure 18**), which delivers a steady supply of domestic water to the town. In recent years, the spring has been supplemented with use from a privately owned borehole, 2.5 km north of the spring. In winter, when there is excess runoff from the mountain, spring flow is higher and the water is channelled to the dams below (Bergrivier Local Municipality, 2020). Currently, the spring flow is not being monitored and it is recommended that a flow meter be installed on the 63 mm pipe between the spring collection box and the dam.

It is important to note that NO groundwater monitoring is being done in this GRU by DWS. It is recommended that monitoring sites be identified in the delineated important aquifer area.

Figure 18: Spring that supplies Eendekuil in G30B



Map 20: Delineation of the Verlorenvlei & Tributaries- G30B GRU, on satellite imagery and displaying EC, WL and yield values, where data was available .



Map 21: Geological setting of the G30B Catchment (Clanwilliam, 3218) (CGS, 1973)

4.1.5 Verlorenvlei & Tributaries-G30C GRU

Grouping: Verlorenvlei & Tributaries

GRU Name: G30C

Groundwater Use: Extensive

Description:

The groundwater unit falls within the quaternary catchment boundaries and is made up of the area known as the Bergvallei. Not a lot of data is available for this area and thus the assumptions had to be based on what has been made available and on reports from local groundwater users. Data obtained for the area is presented in **Map 22** and more detail is available in **Annexure A**.

Groundwater use is extensive in the area, and a drop in water levels has been observed in this unit. This could be observed in the boreholes being monitored by DWS. Borehole 3218BD2050 is located in the upper reaches of the valley and BLI026 is located in the lower reaches, next to the settlement of Paleisheuwel and the Bergvallei river. The data is displayed in **Figure 19** and **Figure 20** and more detail can be seen in **Annexure B** (Sandveld monitoring). Not all of the DWS monitoring sites display a drop in water level, but when speaking to the land owners, the overarching consensus was that water levels are dropping in the area.

The entire valley is underlain by the TMG formations (**Map 23**). This valley has also been noted to have been a very important contributor to the Verlorenvlei system, although recent studies display almost no water reaching the Verlorenvlei system from this region (Watson, 2020 and Watson 2019). Borehole yields in the area are high (> 20 L/s in some cases), and quality is good (<100 mS/m) for the upper reaches of the valley and lower in the central low-lying regions where EC of higher than 200 mS/m have been measured (**Map 18**).

The upper reaches of the valley have boreholes drilled into the shallow hard rock aquifer. Lower down in this area, boreholes target the sand deposits overlaying the fractured aquifer. There are large-scale SE-NW 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. Although access to boreholes in the upper reaches of the Bergvallei was denied, landowners did note that they are having to redrill their 100 m deep boreholes to depths of >300 m to allow them to lower their pumps as the water levels have dropped to such an extent that some boreholes have run dry.

The upper reaches of the Bergvallei have completely been transformed, and little of the old river channel remains visible. Citrus and fruit trees are planted across the riparian zone and a high number of in-stream dams have also been noted. Off-channel dams are also built that direct mountain streams and runoff into the dams rather than the old stream beds. 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. This is discussed in more detail in the wetlands report.

With regards to the quality of the groundwater found in G30A, the data that could be obtained was analysed according to the DWS water quality reserve template (**Table 13**).Water quality is very good in this catchment, with the 95th percentile EC being only 284.05 mS/m. The overall good quality is attributed by the TMG being the dominant geology in this catchment.

Because access was denied to boreholes in the upper reaches of this catchment, some water users were contacted to get more information on the situation. In interviews held with some of the landowners in April 2022, some comments were raised:

- The building of dams (both instream and other dams) has increased significantly since 1996, with multiple dams having been built in the last 10 years;
- The Jansekraal river flowed throughout the entire year, although the flow would be very low from February to March. For the last 10 years, flows have dropped and then the river stopped flowing in the summer 6 years ago. It only flows now in winter months of June to August or after large rainfall events; and
- Kleinvlei river area is less exploited, but the spring areas at the top of this river have recently been targeted by drilling boreholes next to spring areas. Because of this, flow in the Kleinvlei river is also substantially reduced.

Because of the concerning reports with regard to a steep increase in groundwater abstraction and surface water use in the upper reaches of the Bergvallei GRU and the finding that it was historically an important contributor to the Verlorenvlei system, a large portion of this GRU has been delineated as an important aquifer (**Map 18**).

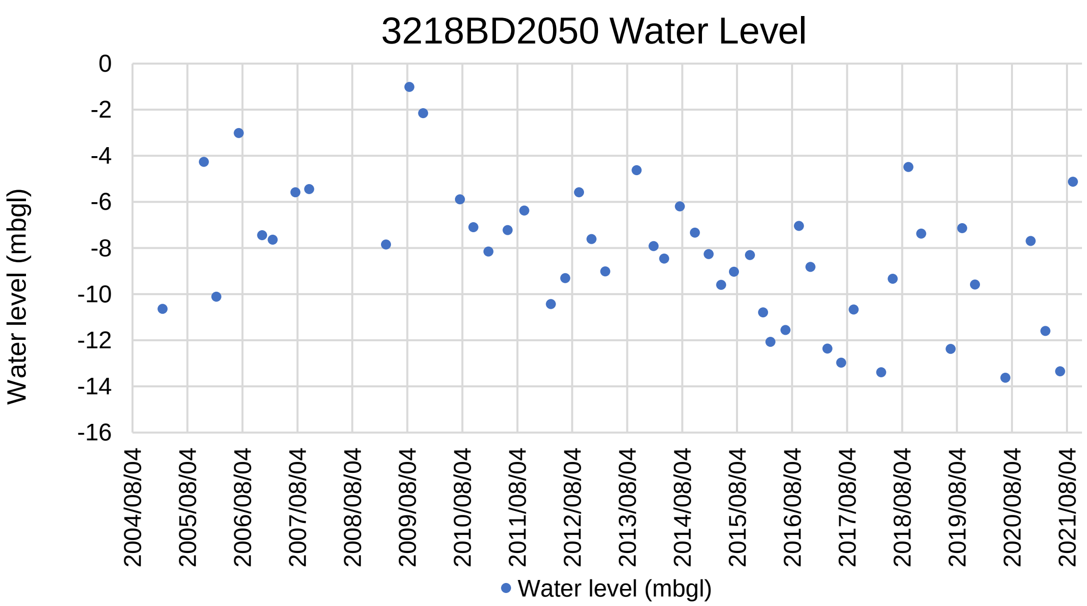


Figure 19: Water level monitoring of 3218BD2050 in G30C

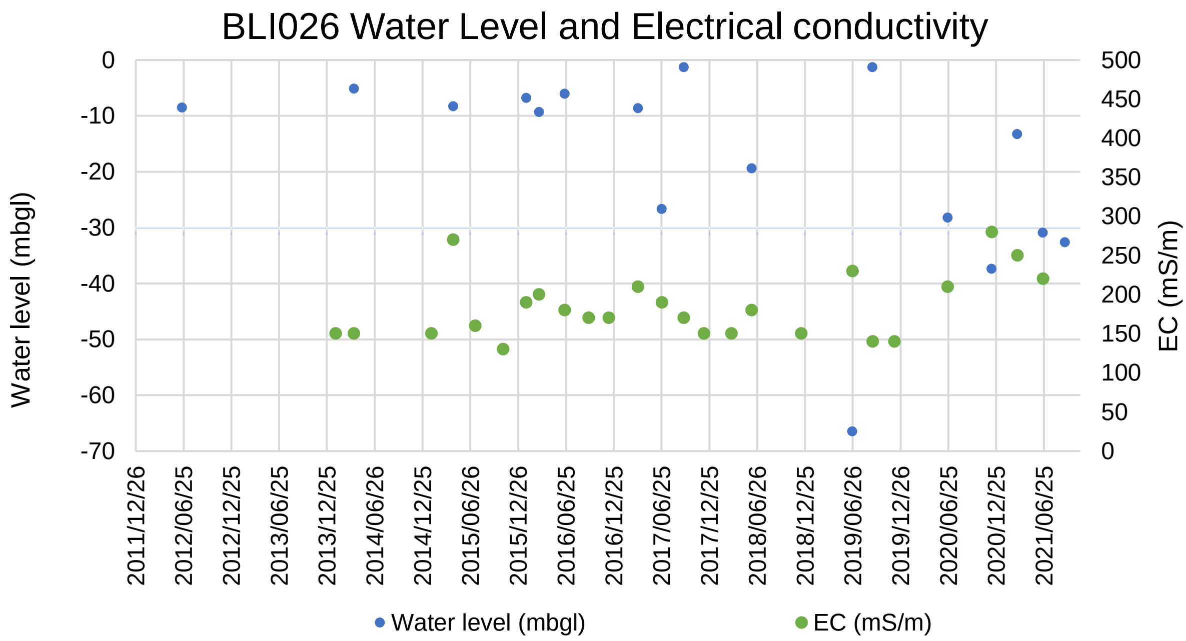
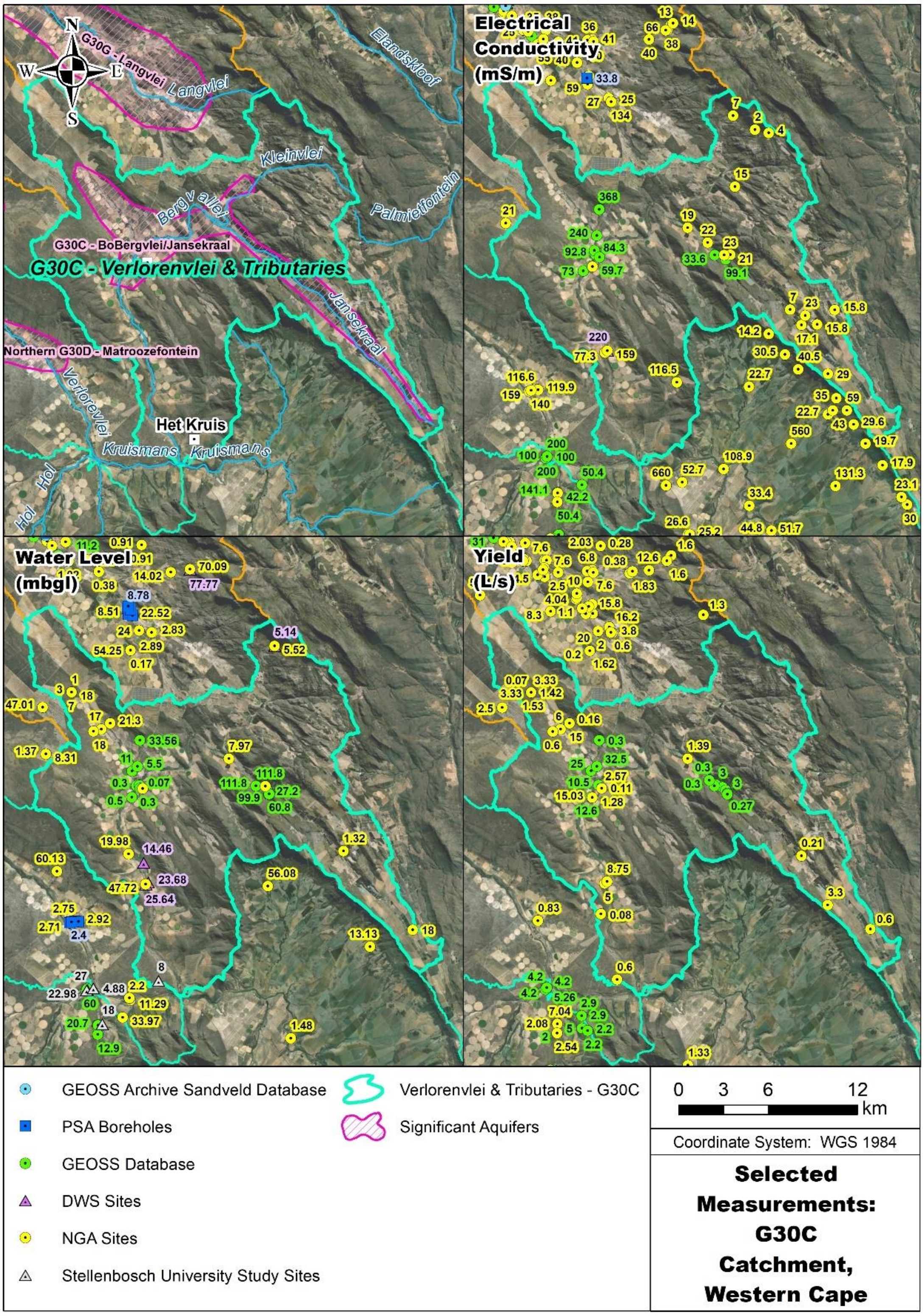


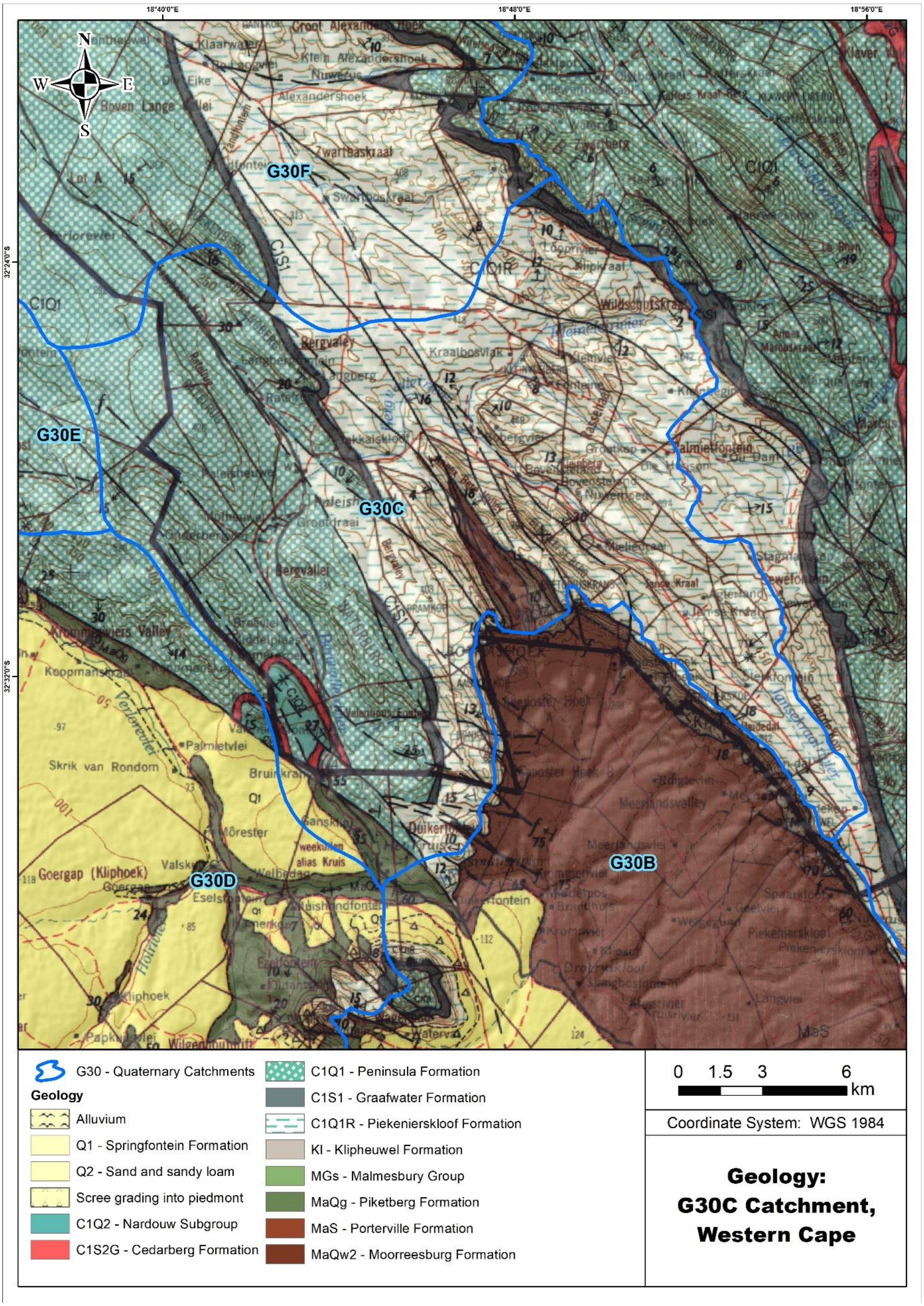
Figure 20: Water level and EC monitoring of BLI026 in G30C

Table 13: Groundwater Quality analyses for G30C, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	**Cl (mg/l)**	**EC (mS/m)**	**F (mg/l)**	**Mg (mg/l)**	**NO3+NO2 (mg/l)**	**Na (mg/l)**	**SO4 (mg/l)**	**TAL**	**pH**
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	23	23	23	23	23	23	23	23	23	23
Median	**5.60**	**102.60**	**45.60**	**0.10**	**9.60**	**2.90**	**52.50**	**10.30**	**5.80**	**6.24**
Average	7.49	126.45	51.19	0.12	11.67	3.40	65.37	15.65	13.14	6.12
95.00	23.81	284.05	107.01	0.25	25.61	8.40	145.83	31.95	52.89	7.44
5.00	1.51	32.22	17.80	0.05	3.00	0.31	16.99	2.00	0.00	4.90



Map 22:Delineation of the Verlorenvlei & Tributaries- G30C GRU, on satellite imagery and displaying EC, WL and yield values, where data was available .



Map 23: Geological setting of the G30C Catchment (Clanwilliam, 3218) (CGS, 1973)

4.1.6 Verlorenvlei & Tributaries-G30E GRU

Grouping: Verlorenvlei & Tributaries

GRU Name: G30E

Groundwater Use: Extensive

Description:

The groundwater unit falls within the quaternary catchment boundaries and is made up of the area known as the Verlorenvlei (**Map 24**).

The geology is characterised by TMG formations and the Klipheuwel Formation (Malmesbury Group) being overlain by thick quaternary sediments (**Map 25**). 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 lower yields and historically drilling has been focused on the eastern side of the wetland. Boreholes drilled on the eastern side of the wetland in some areas are very high-yielding (>15L/s) with very good quality (EC<60mS/m). These boreholes are located in close proximity to the inferred large SE-NW 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. This area has been delineated as an important aquifer.

Borehole yields drop significantly towards the coast. The old Graauwe Duynen wellfield is situated to the north of Elands Bay but is only minimally being used for town supply due to poor quality and low yields. The town`s main wellfield is located on the farm of Waaihoek, about 7 km inland from the town.

The groundwater isotope signatures from samples taken in this GRU are very similar to rainfall derived from the higher altitudes (Piketberg Mountains) and thus it is assumed that direct vertical recharge is not the main source of groundwater recharge from this area. The Verlorenvlei isotope values are significantly different to groundwater and the water has undergone extensive evaporation. There is an indication of groundwater inflow into the upper reaches (eastern portion) of the Verlorenvlei – in the vicinity of the Klaarfontein spring (GEOSS, 2019). Another possibly very important area of groundwater-surface water interaction, where groundwater is introduced to the Verlorenvlei system is the Kruisfontein Springs (**Figure 21**), located towards the northeast of Redelinghuys. These spring areas are not being monitored and it is strongly recommended that the flow be monitored. The water from the various springs flows into one channel that drain and joins the Verlorenvlei River at Redelinghuys. It is recommended that a flow measuring and monitoring system be installed just before the streams join and where the Kruisfontein stream flows underneath the road. The springs are being heavily used with a planned increase in abstraction to plant citrus trees. Water from these areas thus only gets to the Verlorenvlei River during the winter, as the summer flows are used by local landowners. Currently, this is one of the last seepage area/spring areas in the Verlorenvlei system that is still flowing the entire year and that is still contributing to the system during the winter. It was observed during 2021 and 2022, that this was the first water being introduced into the Verlorenvlei in early winter, as flows from the Kruisfontein stream were noticed draining into the Verlorenvlei channel before the water from the upper tributaries had been able to reach the Redelinghuys area. Even though no flow information is available, it was noticed that on WARMS database, 408 000m^3/a has been registered to be abstracted from these springs, indicating that this is a substantial historical inflow of groundwater into the system. This is thus considered a very important future monitoring site.

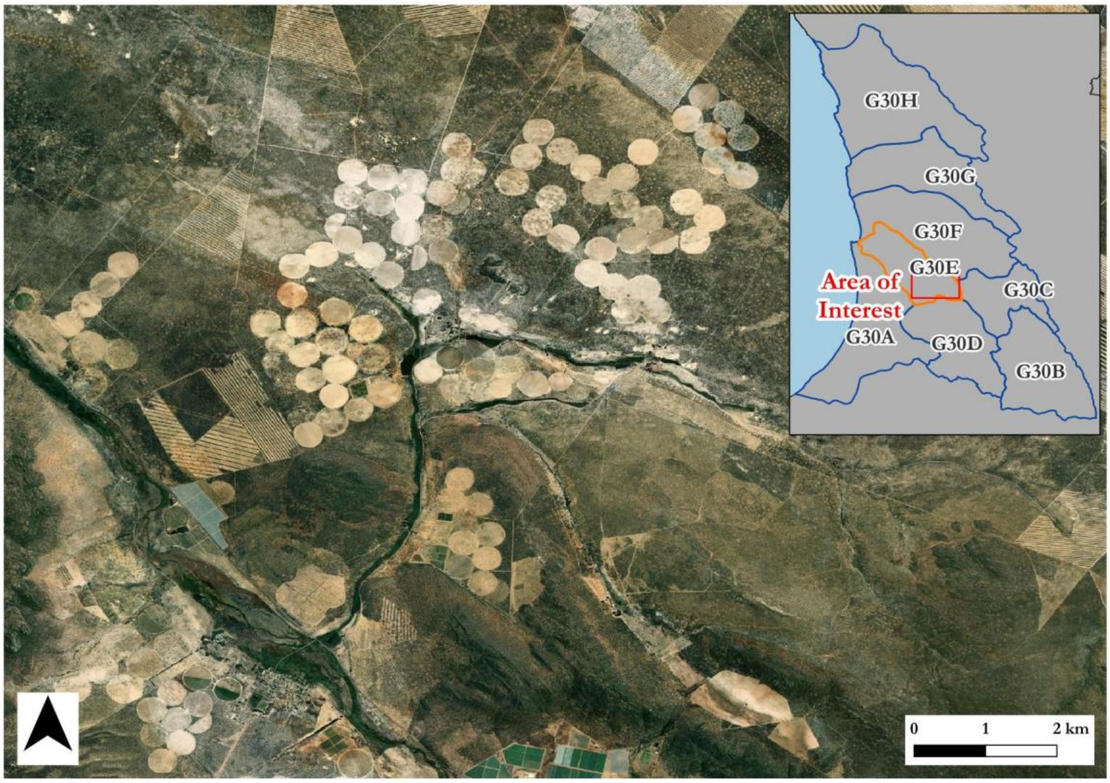


Figure 21: Kruisfontein Spring areas in G30E

With regards to the quality of the groundwater found in G30E, the data that could be obtained was analysed according to the DWS water quality reserve template (**Table 14**).Water quality varies good to very poor in respect to elevated levels of Cl, Na and SO_4. The poor water quality has historically been associated with the western bank of the Verlorenvlei Wetland, where the sand is underlain by the Klipheuwel Formation, while the eastern banks hosts better quality groundwater where the TMG underlies the sand. Salinity also increases closer towards the coast.

Table 14: Groundwater Quality analyses for G30E, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	54	54	54	54	54	54	54	54	54	54
Median	**30.12**	**327.38**	**131.23**	**0.28**	**24.55**	**3.07**	**179.92**	**45.15**	**47.90**	**7.25**
Average	88.56	2385.89	588.31	0.32	168.75	5.33	1283.71	316.20	89.15	7.03
95.00	395.78	14167.74	3614.14	0.86	1026.97	16.32	7557.27	1947.53	277.88	8.28
5.00	5.71	53.67	30.92	0.06	5.57	0.05	32.23	4.66	2.00	4.36

DWS monitors 16 boreholes in the GRU and the full dataset can be viewed in **Annexure B** (Sandveld monitoring). Some graphs have been included in this report to highlight trends on which assumptions have been made. Going from sites located inland towards the coast, the following was noted from the DWS monitoring data, as well as boreholes being monitored through a project funded by Potato South Africa.

The monitoring site known as V11 displayed a drop in water level of approx. 2 meters since 1995, the borehole has however been displaying a rise in water level since 2019 (**Figure 22**). A rise in Nitrates has also been observed at this borehole (**Figure 23**) and could be linked to over-fertilization or irrigation of the pivot crops located up-gradient of this borehole. Another borehole is located a few meters away and is being monitored through the Potato South Africa project and this data confirms the trends observed in V11. Although the actual location of sites may not be presented, access to the data was provided to use the data to confirm or reject trends for DWS monitoring boreholes.

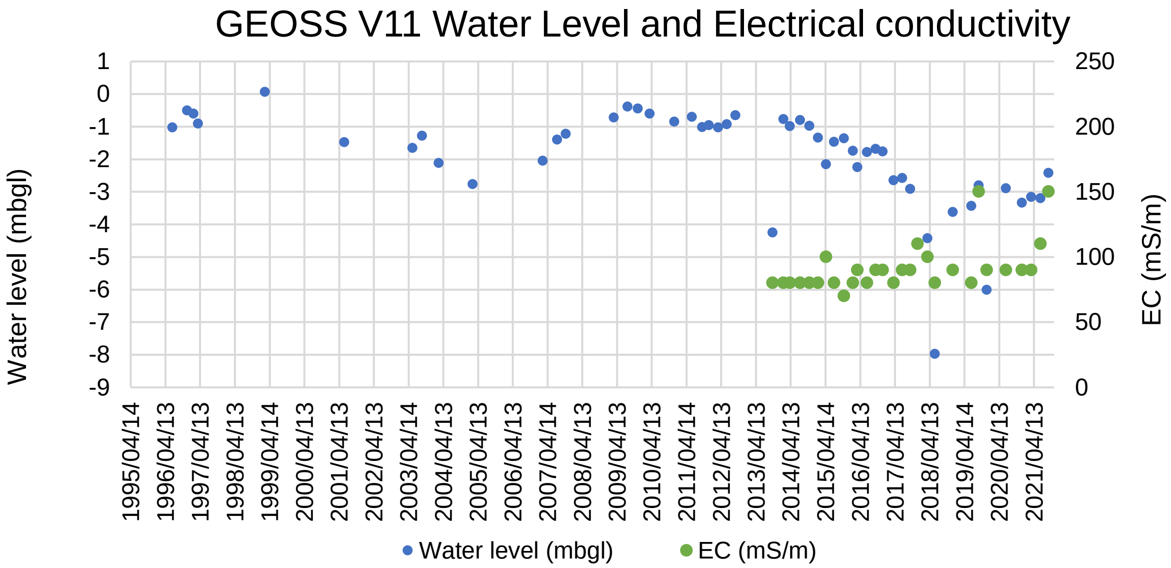


Figure 22: Water level and EC monitoring of V11 in G30E

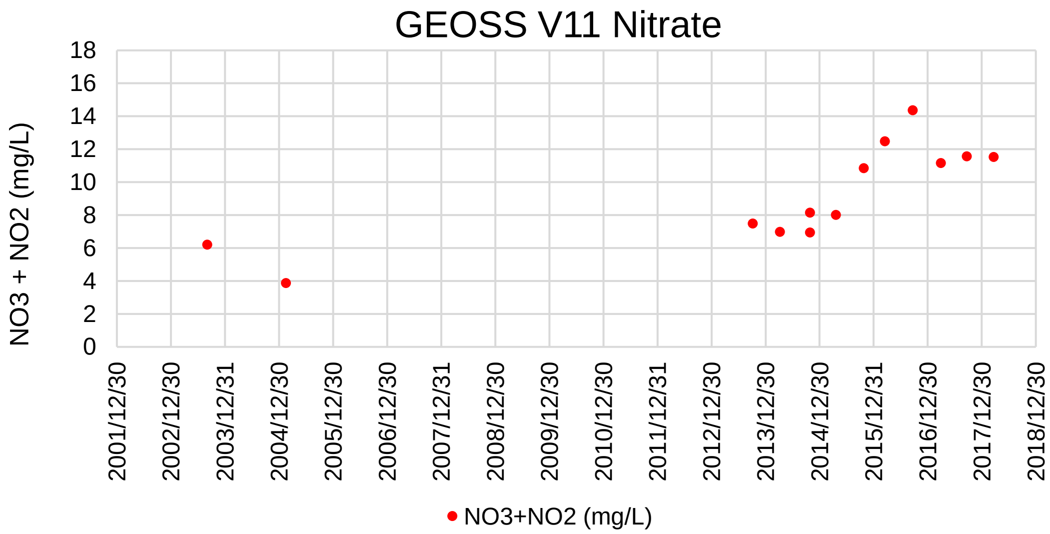


Figure 23: Nitrates monitoring of V11 in G30E

Boreholes MK1 and G33651 are located on either side of the Verlorenvlei wetland, just before it opens up into the main water body. The boreholes both show a slight decrease in water level (**Figure 23** and **Figure 24**) of 2 to 2.5 meters. The V10-GEOSS borehole, located 800m away from G33651 also displays a similar drop in water level, as well as an increase in nitrates (**Figure 25**). This borehole is notably also located close to pivot circle crop areas and this could be linked to the nitrate increase. Boreholes located further from the wetland on higher lying areas such as G33568 (**Figure 27**) and G33659 (**Figure 28**) are not showing a drop in water level, with G33568 showing a rise in water level. This is likely due to the fact that these boreholes are far from any production boreholes or their proximity to saturated sand overlying the fault. The presence of irrigation could also be increasing the vertical recharge.

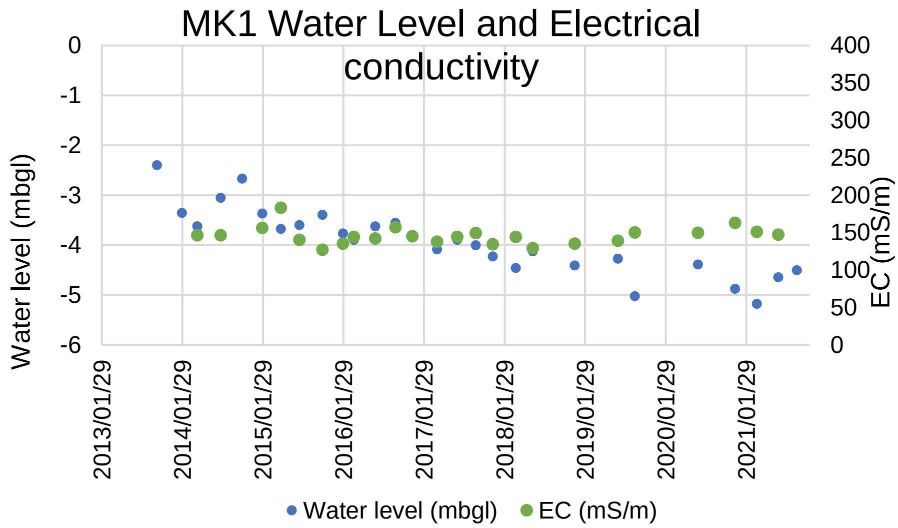


Figure 24: Water level and EC monitoring of MK1 in G30E

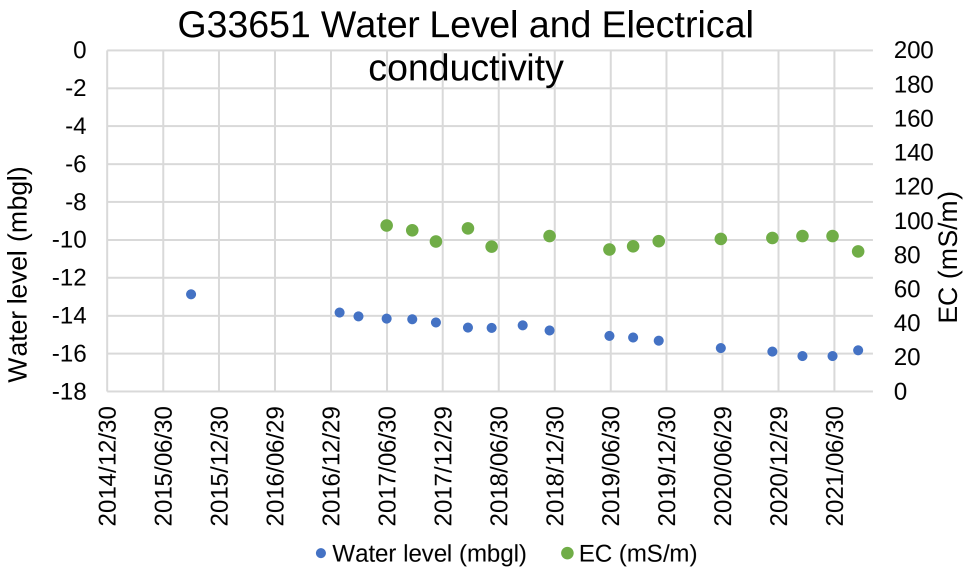


Figure 25: Water level and EC monitoring of G33651 in G30E

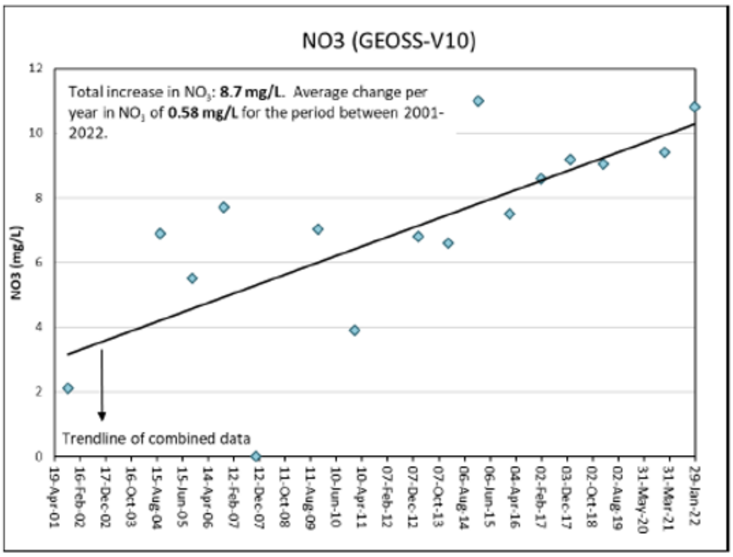


Figure 26: Nitrate monitoring of GEOSS-V10 in G30E, taken from GEOSS (2022a)

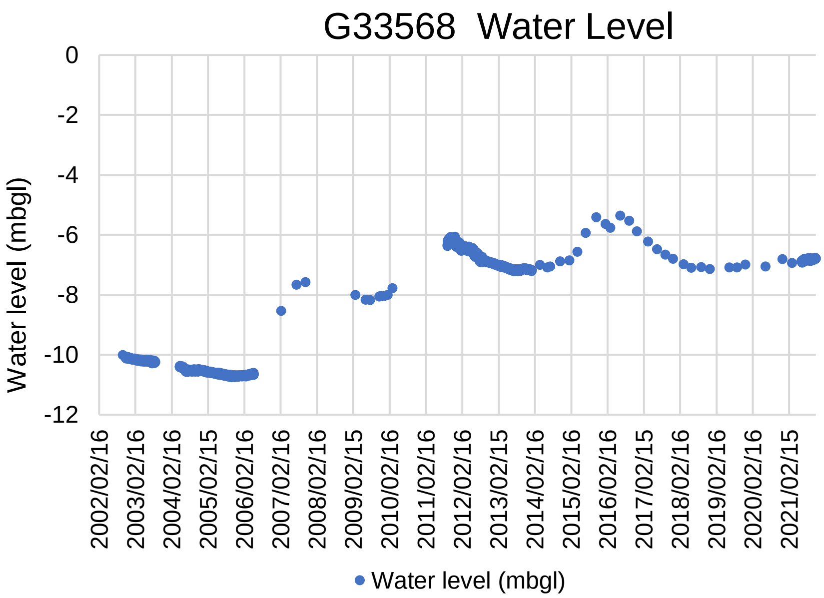


Figure 27: Water level monitoring of G33568 in G30E

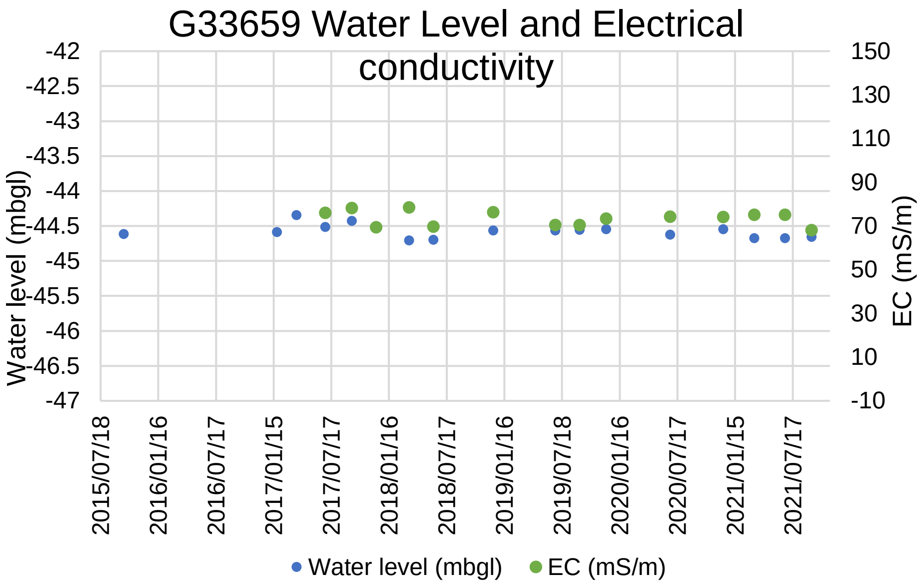


Figure 28: Water level and EC monitoring of G33659 in G30E

The GEOSS-V8 borehole (**Figure 29**) displays a drop in water level of 3 meters since the early 2000s, although it does display a rise in water level since 2019. This borehole is also monitored through the Potatoes South Africa project and from the GEOSS annual monitoring report (2022), EC and Nitrate monitoring data could be obtained, which also displayed an increase in EC and Nitrate concentration.

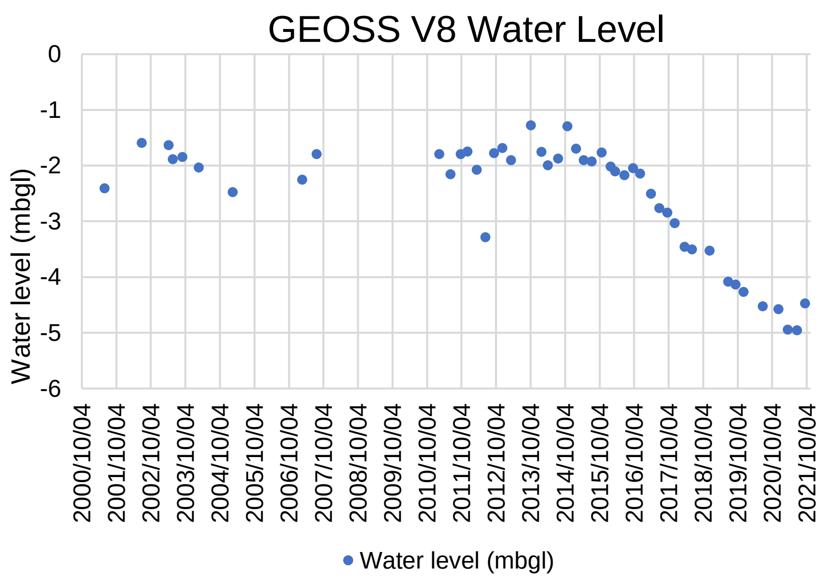


Figure 29: Water level monitoring of GEOSS-V8 in G30E

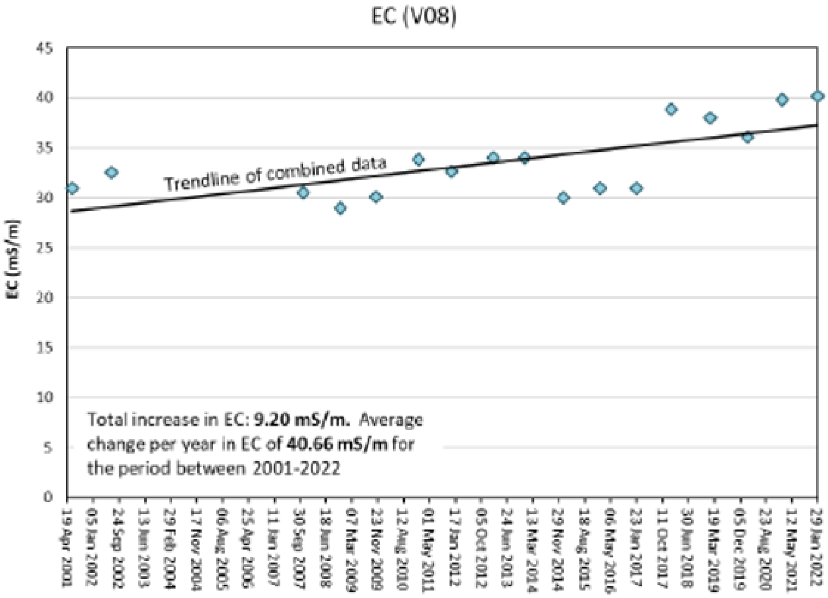


Figure 30: EC monitoring of GEOSS-V8 in G30E, taken from GEOSS (2022a)

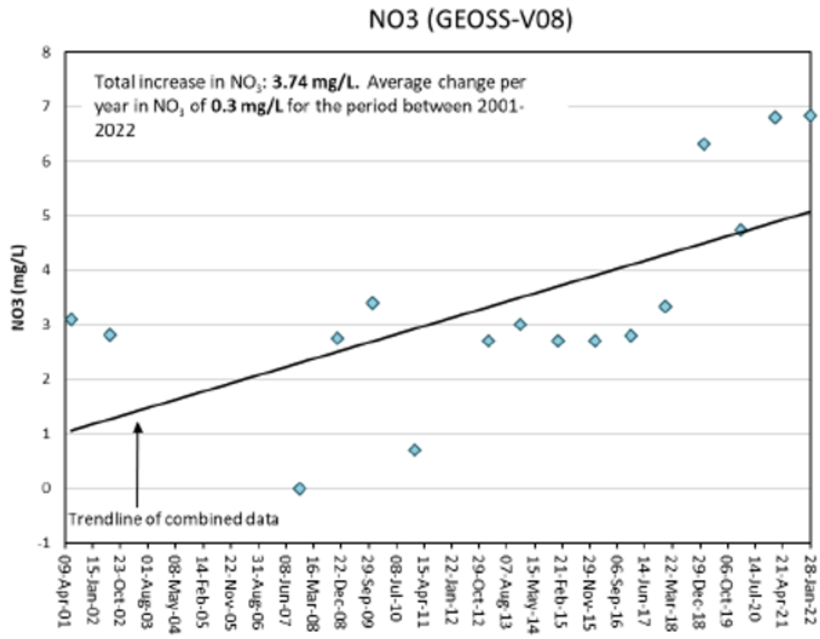


Figure 31: Nitrate monitoring of GEOSS-V8 in G30E, taken from GEOSS (2022a)

The G33948 borehole, located in the Graauwe Duynen municipal wellfield north of Elands Bay displayed two severe EC spikes in 2021 and 2022 that are concerning (**Figure 32**), where EC levels jumped from between 200 - 300 mS/m to >1000 mS/m when water was sampled in December 2021 and October 2022. Between these two high readings, the water was sampled in March, June and September 2022, with EC readings of 350-400 mS/m. It is important to note that the water level has not changed much since 2002 (**Figure 33**).

Municipal monitoring data for boreholes nearby was obtained, but there is only data to 2019, thus the spike could not be confirmed through their monitoring data. The municipality does monitor both the Graauwe Duynen and Waaihoek wellfields, and their data was obtained from the municipality during a different project (Cederberg Local Municipality, 2019b). The data is displayed in **Figure 34** and **Figure 35**. From the data, it could be observed that with regard to the water levels, a small decrease could be noted, in the range of 1-2 meters, similar to what has been noted in other boreholes being monitored around the Verlorenvlei wetland. The EC monitoring does not display spikes in EC to the degree that was noticed in the DWS monitoring, but it does highlight the difference in general quality for the two municipal wellfields. Although new municipal data could not be obtained during the course of the study, the municipal technical team at Lamberts Bay did confirm that the water quality has deteriorated at the one Graauwe Duynen borehole.

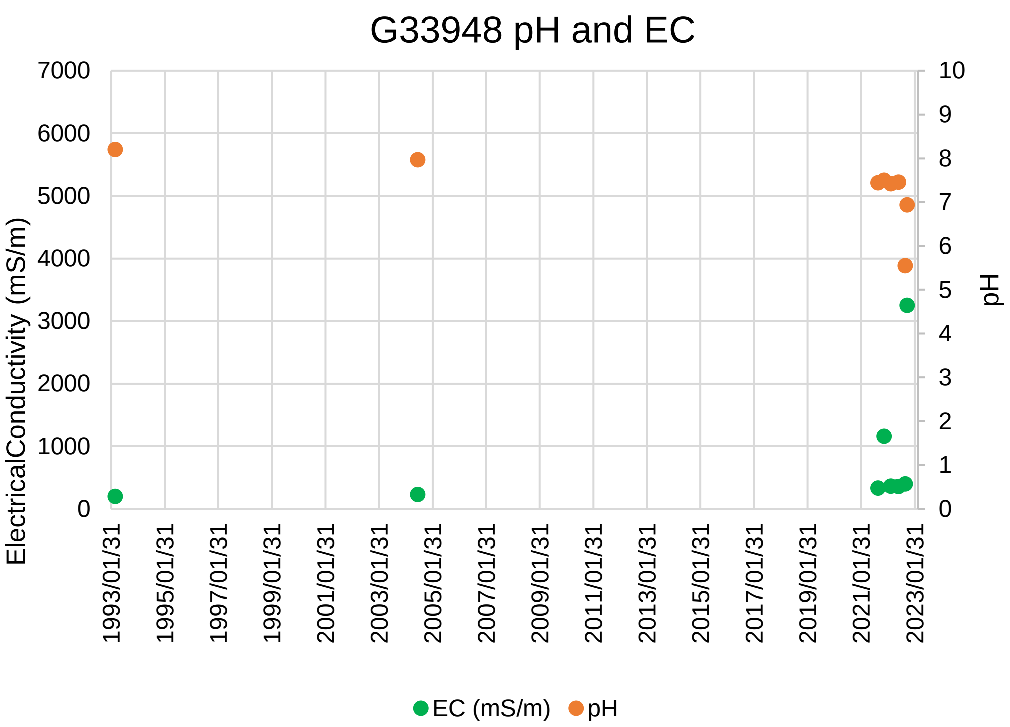


Figure 32: EC and pH monitoring of G33948 in G30E

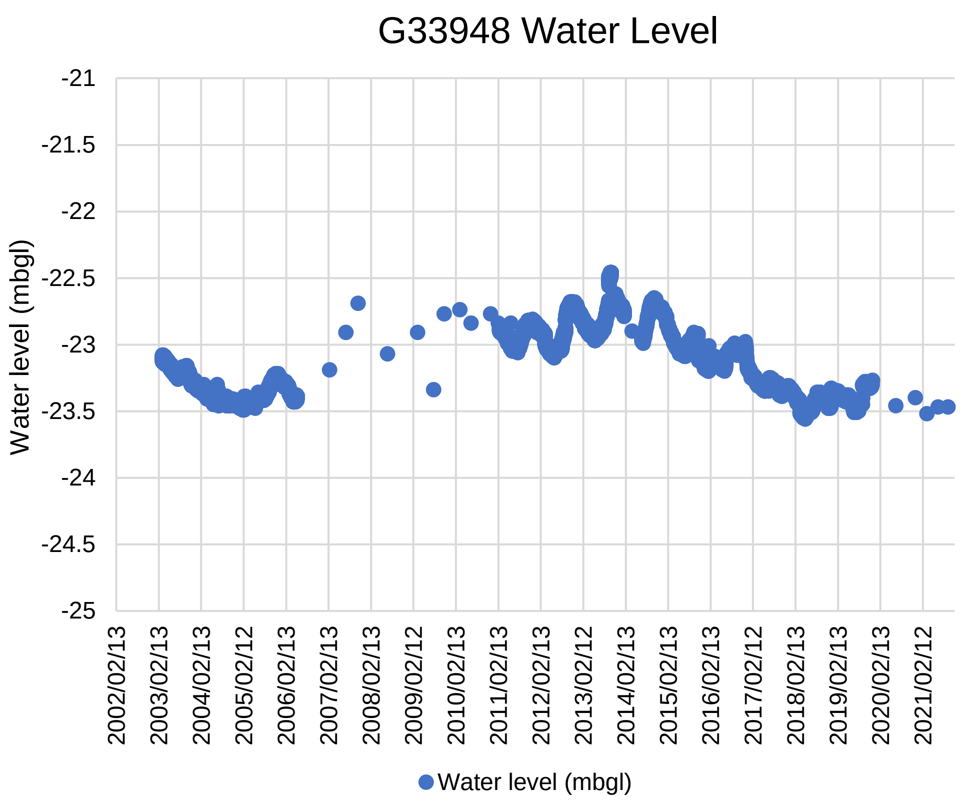


Figure 33: Water level monitoring of G33948 in G30E

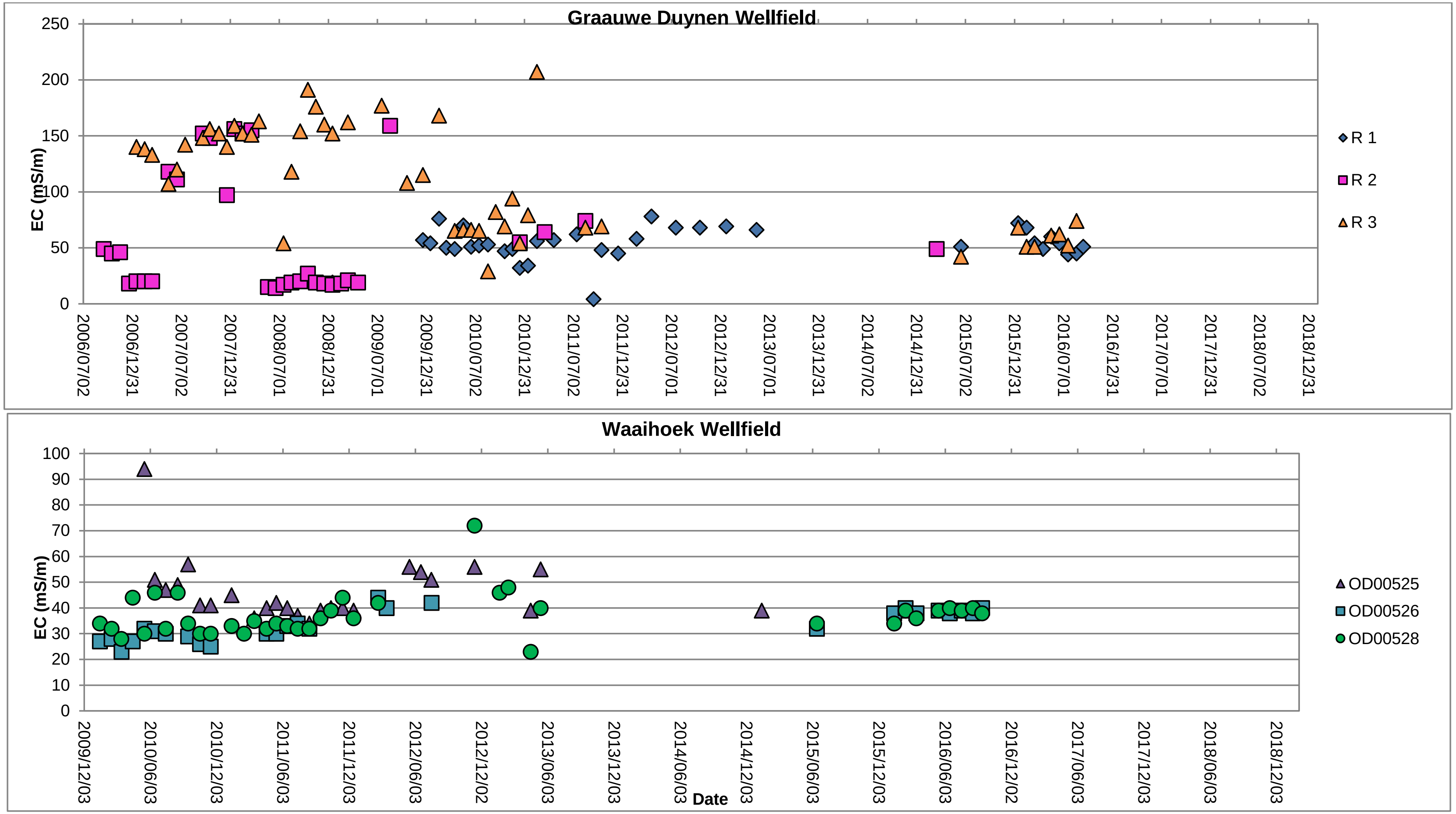


Figure 34: EC monitoring of Elands Bay municipal boreholes (2009-2019) in G30E (Cederberg Local Municipality, 2019b)

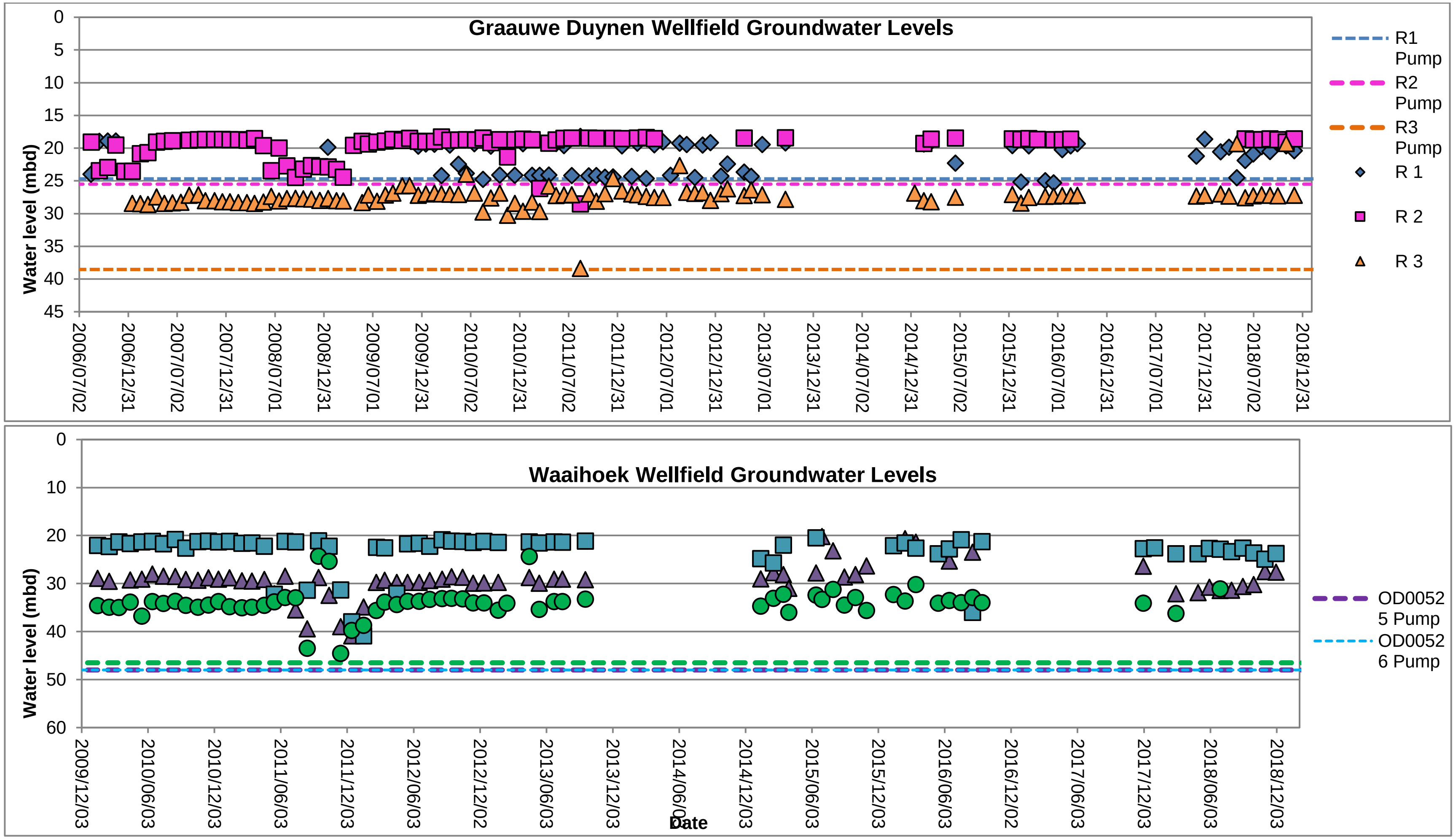


Figure 35: Water level monitoring of Elands Bay municipal boreholes (2009-2019) in G30E

From all the single water level data and yield data that could be obtained and that is presented on **Map 24**, it is evident that the yields and water levels are highly variable in this GRU. Some water levels are very shallow <3 mbgl, while other water levels further away from the wetland and that are around or are production boreholes are lower >30 mbgl. Many have pointed to the groundwater abstraction adjacent to the main Verlorenvlei water body being responsible for the wetland drying up, but the situation is more complex than that. As was observed in the previous Verlorenvlei & Tributaries GRU sections, groundwater abstraction and damming have increased significantly in the last 20 years around the tributaries and recharge areas or the Verlorenvlei system. In some of these GRUs, reports of dropping water levels and springs drying up must also be considered.

From the chemistry and isotope data obtained in the GEOSS study, funded by Potato South Africa (GEOSS, 2019), a change in the chemistry of the surface water was documented. Moving from Redelinghuys towards the coast, the wetland starts to open up into the main water body. Surface water at this point appeared to contain less chloride and was less saline than towards the west. Similarly, the stable isotope signature of the surface water suggested that the samples taken towards the wetland inflow (the eastern side of the wetland) are much different from that of the western side. Because of the EC difference between the VV_0 and VV_1 (**Table 15**), it was noted that there must be a groundwater inflow between these areas, around the Klaarfontein spring (GEOSS, 2019).

Table 15: Chloride and EC surface water samples taken from GEOSS (2019) study

Sample Site	Chloride as CL dissolved (mg/l)	Electrical Conductivity (mS/m)
VV-O	757	255
VV-1	647	230
V-Vlei	4420	1460
VV-5	5065	1550
VV-3	5000	1550
VV-4	4987	1600

The Klaarfontein spring`s flow is not monitored and it is not seen as one of the significant springs or seepage areas for this GRU, but a WARMS water use has been registered to the spring of 50 000 m^3/a (1.5 L/s). The current flow is assumed to be lower, but the groundwater contribution could be entering the wetland in different ways than just from the spring. During the drought of (2016-2018), it was reported that when this area of the wetland dried up completely, a small pool of water in the centre of the wetland area kept getting wet during the night and then dried during the day. This report could not be investigated as that portion of the wetland did not completely dry up during 2021 and 2022, but it would be recommended that if this occurs again, the pool is sampled. It would be difficult to sample (because of the mud layer), but could possibly be done with a drone.

Groundwater inflows were not observed further down into the wetland during the 2019 GEOSS study, but as the conclusions for that study were only based on a few samples, and because of the effect of evaporation on the water quality, groundwater could potentially enter the system downstream of the Klaarfontein.

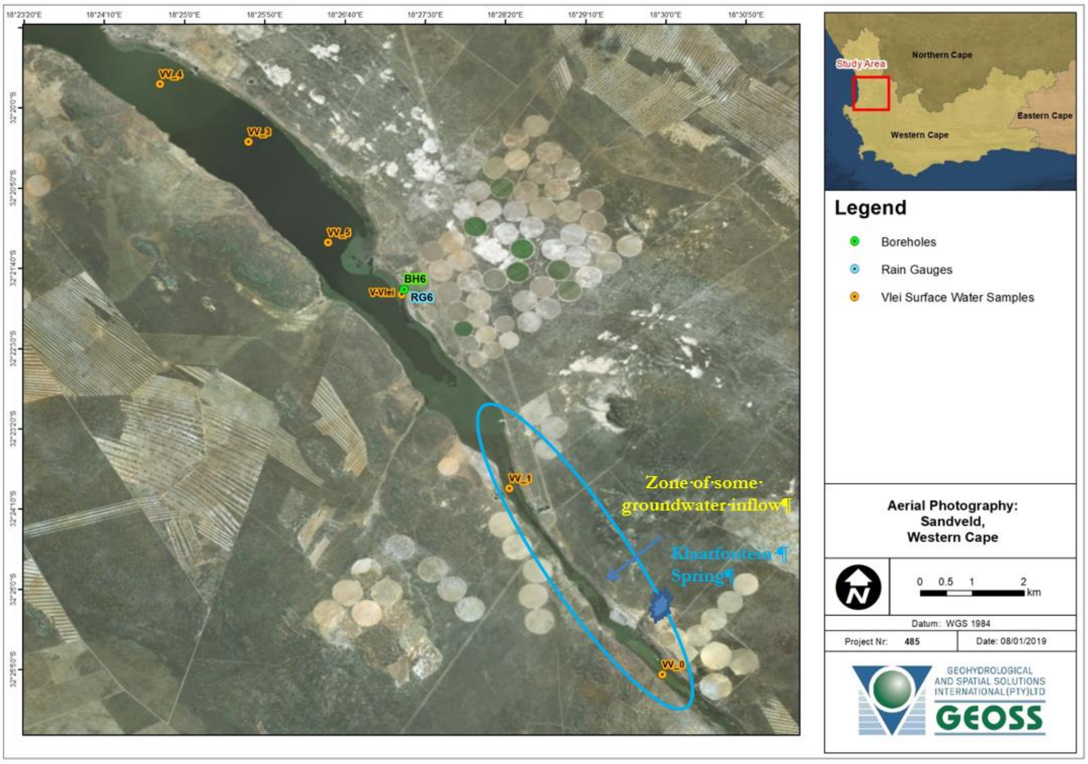


Figure 36: Figure indicating the distribution of surface water samples (GEOSS, 2019)

When a hydro chemical isotope analysis of 18O and 2H stable water isotopes was conducted for production boreholes adjacent to the main water body of the wetland and compared to a sample of the Verlorenvlei wetland, it was noted that the two samples displayed different isotopic signatures (GEOSS,2020b).

Based on the Deuterium/Oxygen-18 ratios of the boreholes, the boreholes are all linked to the same source and follow the Global meteoric water line. The sample from the Verlorenvlei is distinctly different from the isotopic signal of the boreholes and plots to the right of the meteoric water line (**Figure 36**). The sample from the Verlorenvlei is enriched in both Oxygen-18 and Deuterium compared to the borehole samples. The isotopic signature of the Verlorenvlei shows a strong evaporation trend, which is expected. Because this study only included a few samples, there is uncertainty in interpreting the results.

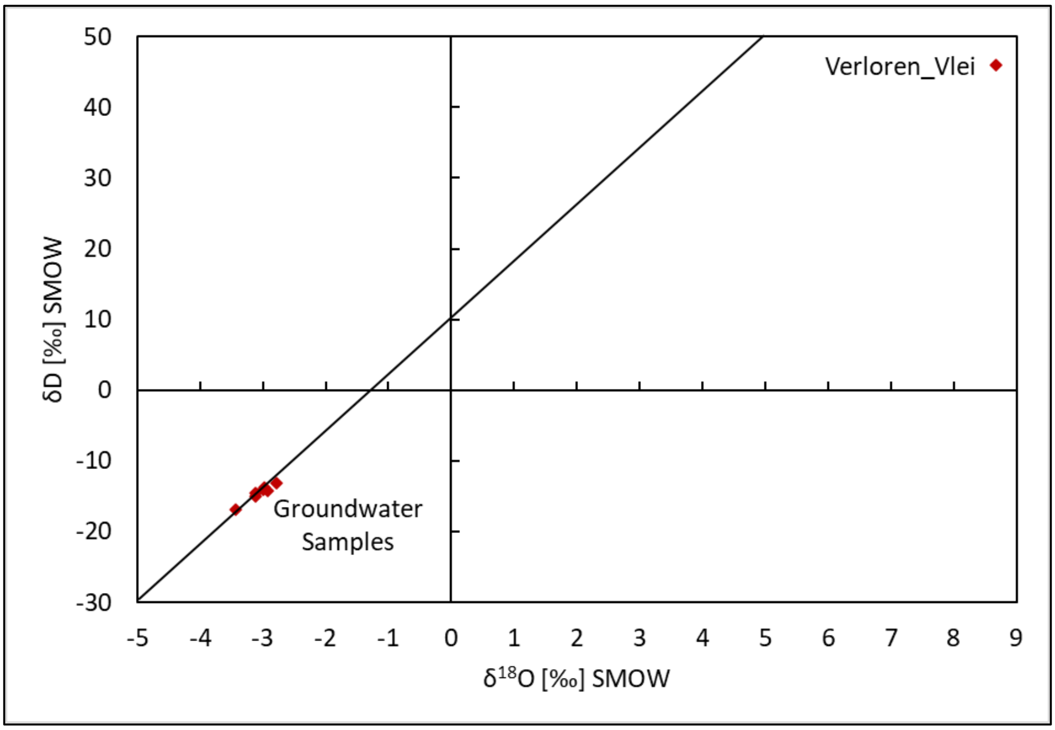


Figure 37: Isotope analysis of boreholes located adjacent to the Verlorenvlei and a surface water sample (GEOSS, 2020b)

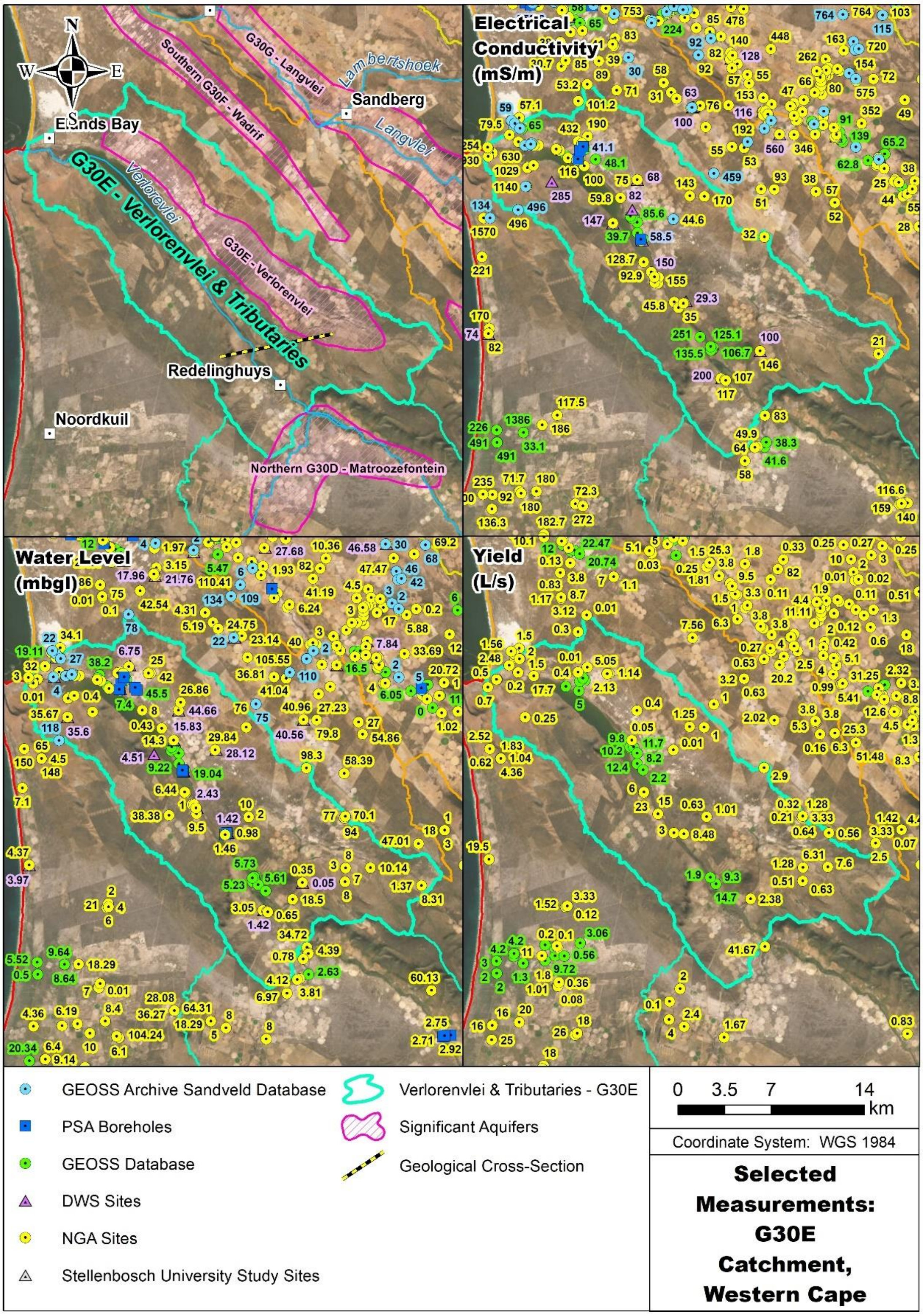
Based on these results, it was concluded that the groundwater abstracted from the production boreholes does not originate from the Verlorenvlei, but it was noted that it could not be disproven that the abstraction from these boreholes might abstract groundwater which would have otherwise discharged into the wetland. Because abstraction at current production boreholes has been taking place for decades, it is not possible to accurately predict the pre-industrial environmental conditions.

When these boreholes were yield tested, no constant head boundary conditions were observed, as would have been expected when a nearby surface water source starts to feed the aquifer during a pumping test. The test-pumping results indicated that a delayed yield (Neuman) water level response was observed in several of the boreholes in question, indicating that the primary aquifer into which the production boreholes are drilled has an unconfined signature (GEOSS, 2020b and UMVOTO, 2021).

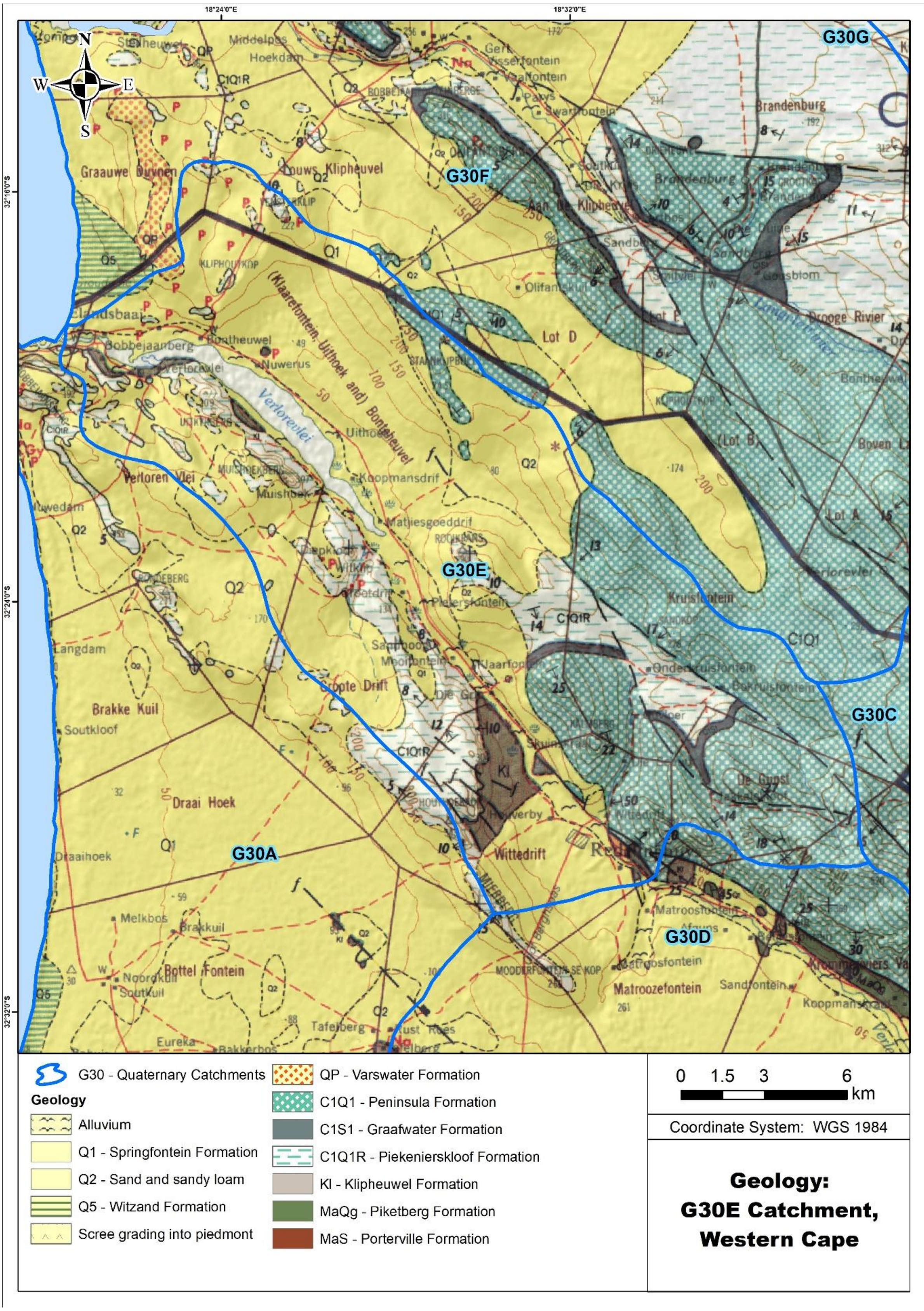
This could be seen to disprove previous assumptions that an impermeable clay layer separated the Verlorenvlei from the aquifer surrounding it. Based on the borehole logs generated for boreholes adjacent to the wetland, collected and compiled post-drilling, it is evident that several of these boreholes contain such a clay layer. The clay layer is, however, not present at all of the boreholes. In the boreholes where the clay layer was observed it was also seen that the elevation of the clay layer is above the water level of the Verlorenvlei. (**Figure 38**). Thus, it could be concluded that although the production boreholes directly adjacent to the main Verlorenvlei wetland are not seen to be abstracted from the wetland, it cannot be definitively stated that water being abstracted at these boreholes could have historically been linked to the wetland.

Still within the G30E GRU, north of the main Verlorenvlei wetland body, groundwater-surface water interaction has been observed through springs and seepage areas (Kruisfontein and Klaarfontein) and through a chemical change in the surface water (**Table 15**). To indicate the conceptional understanding of this area and to show how the groundwater and surface water systems could be potentially linked, a Southwestern-North-eastern cross section has been constructed (**Figure 39**).

With regards to the boreholes adjacent to the main water body of the Verlorenvlei, a drop in water level of about 2 meters has been observed in the last 20 years. This change in water level is by itself, not a significant change, but because it is unknown if groundwater was historically introduced lower in the Verlorenvlei system than what is currently observed, it is unknown what the real impact of the 2 m change in water level could be. A much larger concern for the lower portion of the G30E GRU is the change in quality observed in some of the boreholes. Although the general quality of the water is still very good on the northern side of the wetland, an increase in nitrates has been observed in boreholes located in close proximity to pivot circles and two very high EC spikes was observed in one of the DWS monitoring sites north of Elands Bay. More sampling and analysis are needed to link these changes with the specific activities and/or specific hydrogeological processes, but increased water quality monitoring is recommended for this GRU. It is also vital that the Kruisfontein spring flows are monitored.



Map 24: Delineation of the Verlorenvlei & Tributaries- G30E GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 25: Geological setting of the G30E Catchment (Clanwilliam, 3218) (CGS, 1973)

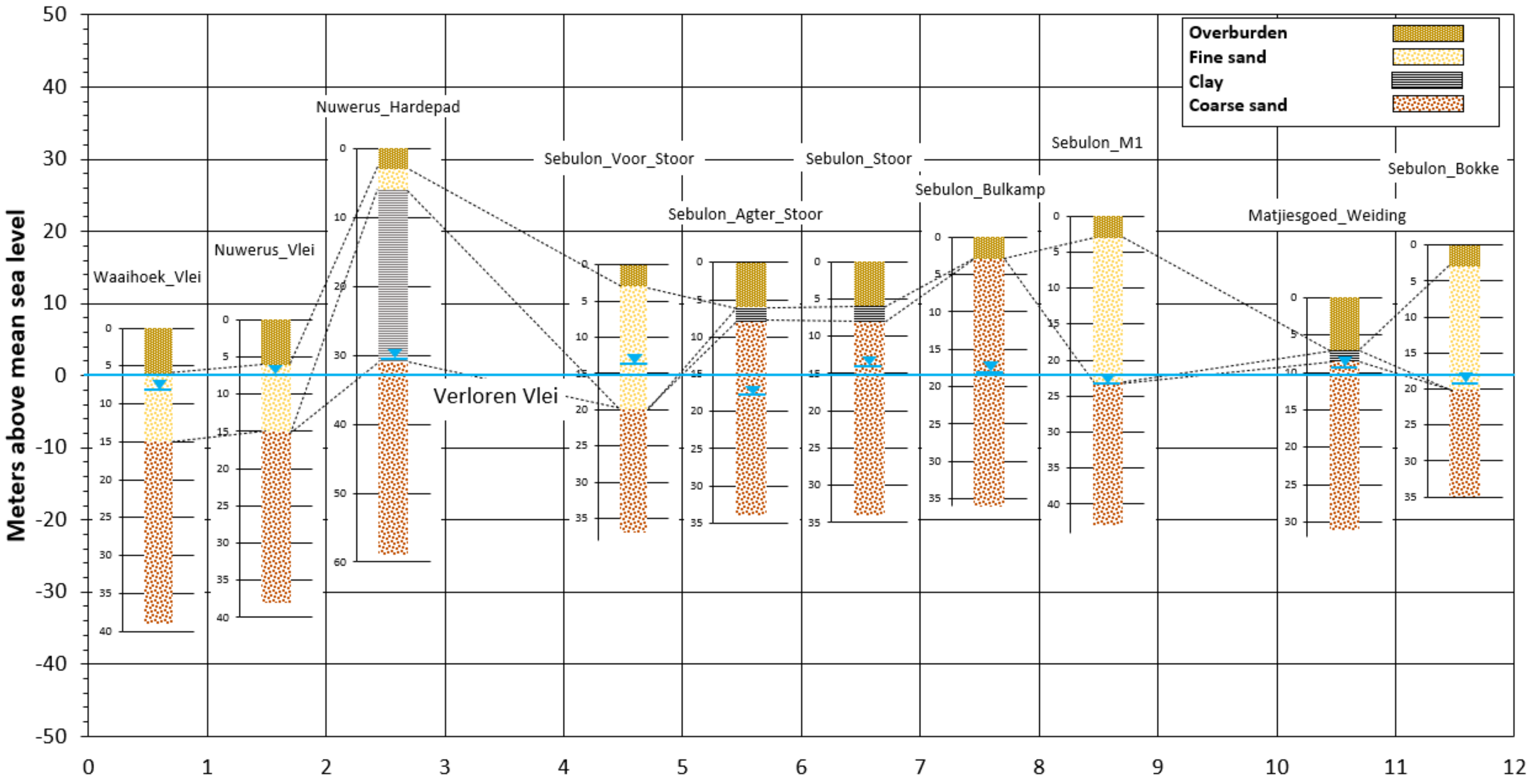


Figure 38: Borehole logs for boreholes located adjacent to the wetland in relation to the Verlorenvlei. Taken from GEOSS (2020b) report

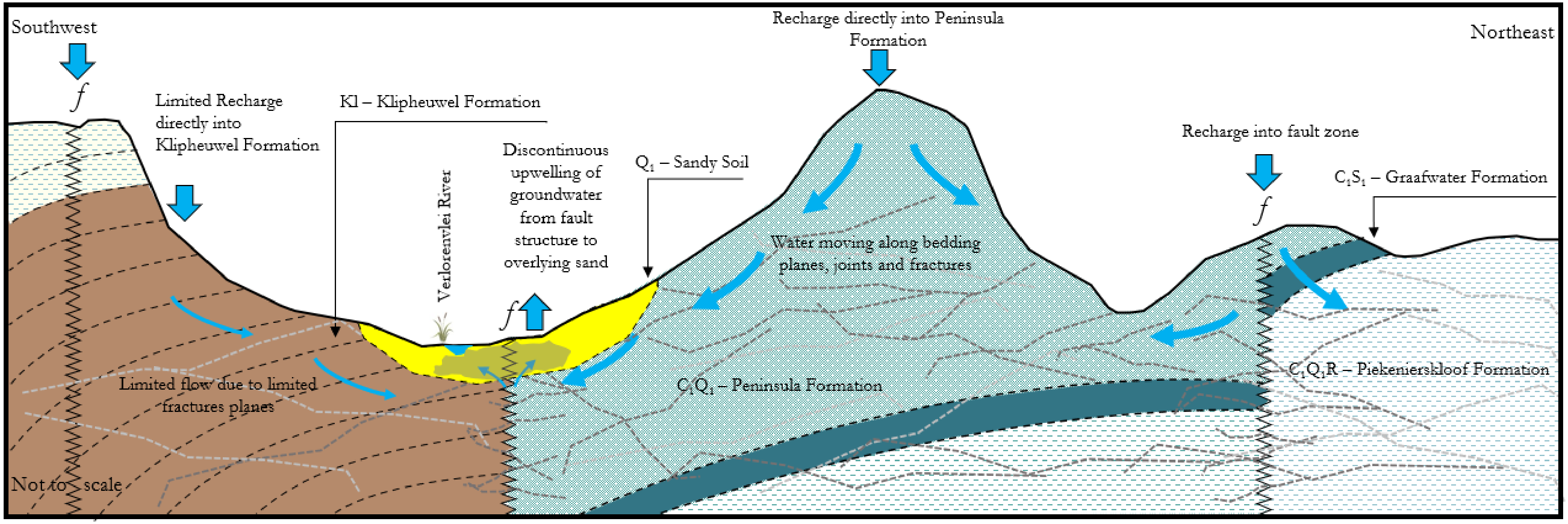


Figure 39: Schematic Southwest-Northeast geological cross-sections of the valley below Redelinghuys, near the Verlorenvlei EWR site

4.1.7 Langvlei-Wadrift - Southern G30F GRU

Grouping: Langvlei-Wadrift

GRU Name: Southern G30F

Groundwater Use: Extensive

Description:

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. This was done because two separate “paleo channel” type structures were observed in this quaternary catchment. SE-NW faults have been mapped in this area and although the exact location of fault lines under the quaternary sand is not known, enough evidence could be obtained to split the two GRUs from the larger quaternary catchment. This GRU falls within the Wadrift Subterranean Government Water Control Area (SGWCA). Data obtained for the area is presented in **Map 26** and more detail is available in **Annexure A**.

In this GRU, groundwater abstraction is extensive towards the coast. The highest yields and best quality water is located here in what is known as the upper-Wadrift area. The lower-Wadrift aquifer was historically also a good aquifer, but the quality degraded to such an extent that the agricultural boreholes and the Lamberts Bay municipal boreholes that were all drilled in this area were abandoned and the municipal boreholes moved to the upper-Wadrift wellfield. Boreholes were situated around the now-extinct Wadrift wetland. This wellfield holds a large number of boreholes that were abandoned when the aquifer was damaged, possibly due to over-abstraction. **Figure 40 - Figure 44** display the wetland in a historical and present context.

Figure 40: Wadrift wetland in 1997, located in G30F

Figure 41: Wadrift wetland in the 1990`s, located in G30F

Figure 42: Wadrift wetland in 2010, located in G30F

Figure 43: Wadrift wetland in 2019, located in G30F

Figure 44: Wadrift wetland in 2020, located in G30F

It has been hypothesized that as the wetland dried up, 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 the boreholes have been abandoned.

As part of the Potato South Africa ongoing monitoring project, GEOSS monitors boreholes in this abandoned wellfield and some water level and EC graphs were taken from the 2022 annual report to display the increase in EC and drop in water level that was observed, although it should be noted that monitoring only started here after the water quality had deteriorated. The upper wellfield still has an average EC of <50mS/m and it is assumed that the lower Wadrift wellfield would have originally had an EC close to this. In **Figure 45**, the water level monitoring of the LO2 borehole displays the original drop in water level and the sudden rise in 2008, when most of the boreholes were abandoned due to low quality and then the slow drop again over time. An increase in upstream abstraction to overcome the shortfall from the abandoned wellfield is linked to this second slow drop in water levels. In **Figure 46**, the EC monitoring data displays the same trends, although the EC only started to drop in 2011 and was still in 2022 (approx. 290 mS/m) measured as more than double what was noted in 2001 (approx. 90 mS/m). This situation outlines the sensitivity of the area`s aquifer system and emphasizes the importance of managing an aquifer system.

As noted, the current abstraction is focused on the upper Wadrift aquifer, approx. 3 km southeast of the old wellfield. This aquifer seems to follow the same NW-SW trend as the other coastal aquifer. From the data available, this “paleochannel-like structure” has been delineated and identified as an important aquifer (**Map 26**).

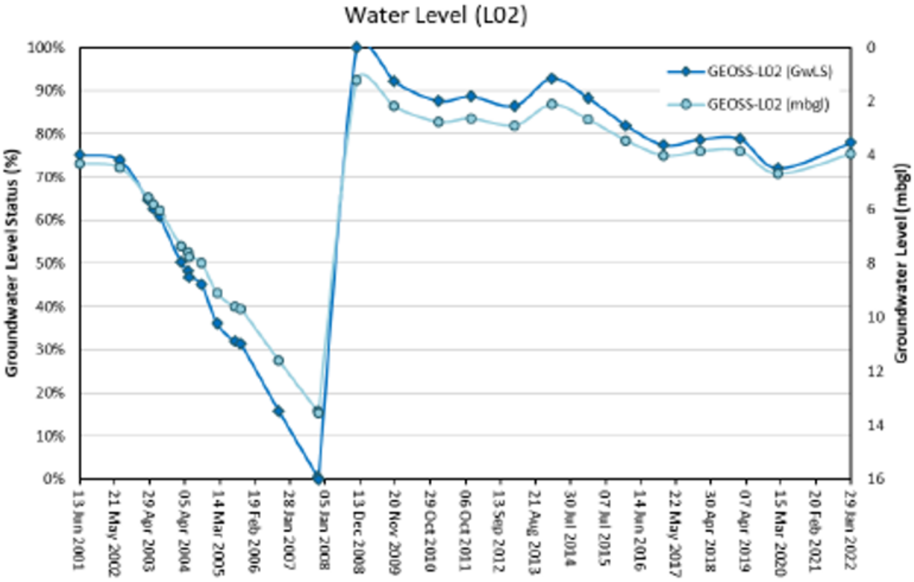


Figure 45: Water level monitoring of LO2 borehole, in G30F, taken from GEOSS (2022a)

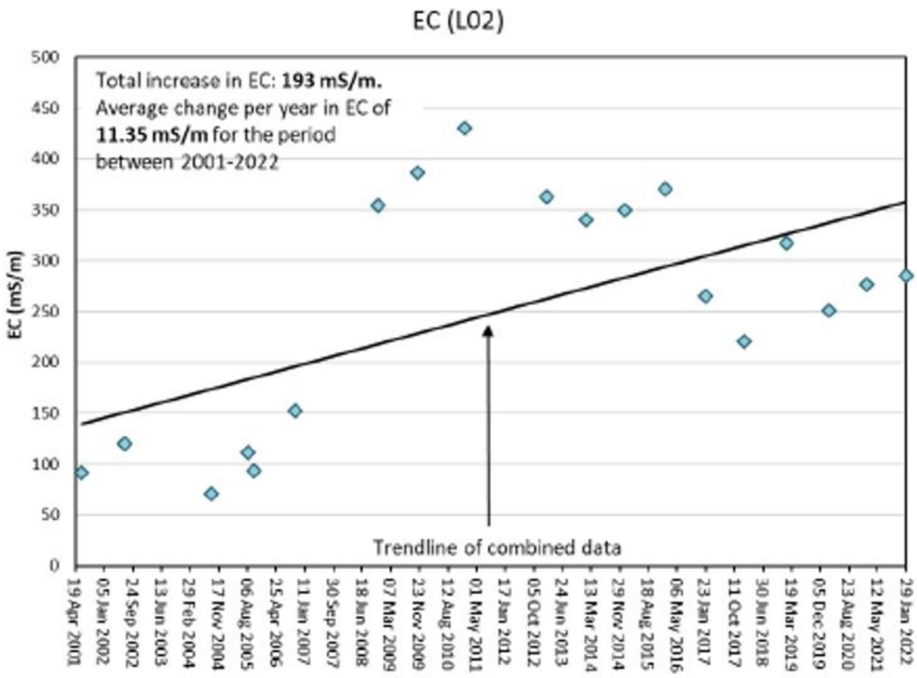


Figure 46: EC monitoring of LO2 borehole, in G30F, taken from GEOSS (2022a)

DWS does monitor eight boreholes in this GRU, the data and all the graphs compiled are displayed in **Annexure B.** G33942, one of the monitoring boreholes further away from the lower-Wadrift wellfield, but still within the delineated important aquifer, displays a rise in water level from 1994 until 2017, when water levels start dropping again (**Figure 47**). **Figure 48** displays the EC and water level monitoring from a borehole located nearby. Not many water levels exist, but the EC monitoring displays a rise in EC until around 2016 when it started dropping again. As water levels in the borehole nearby were rising at this stage, it would have been expected that the EC would potentially lower, but these parameters are not always linked and a decrease in quality is not always linked to the over-abstraction of the aquifer.

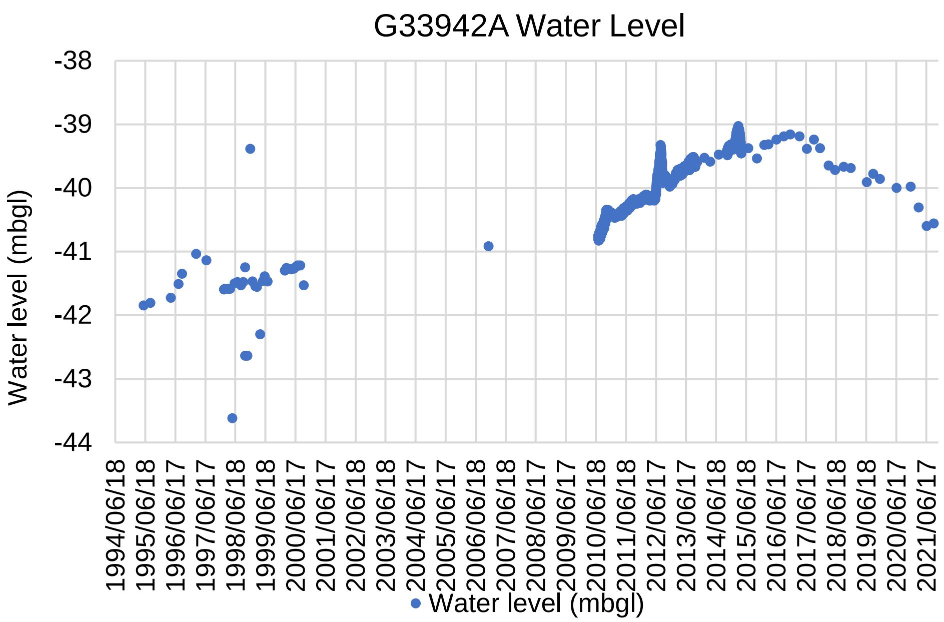


Figure 47: Water level monitoring of G33942A borehole, in G30F

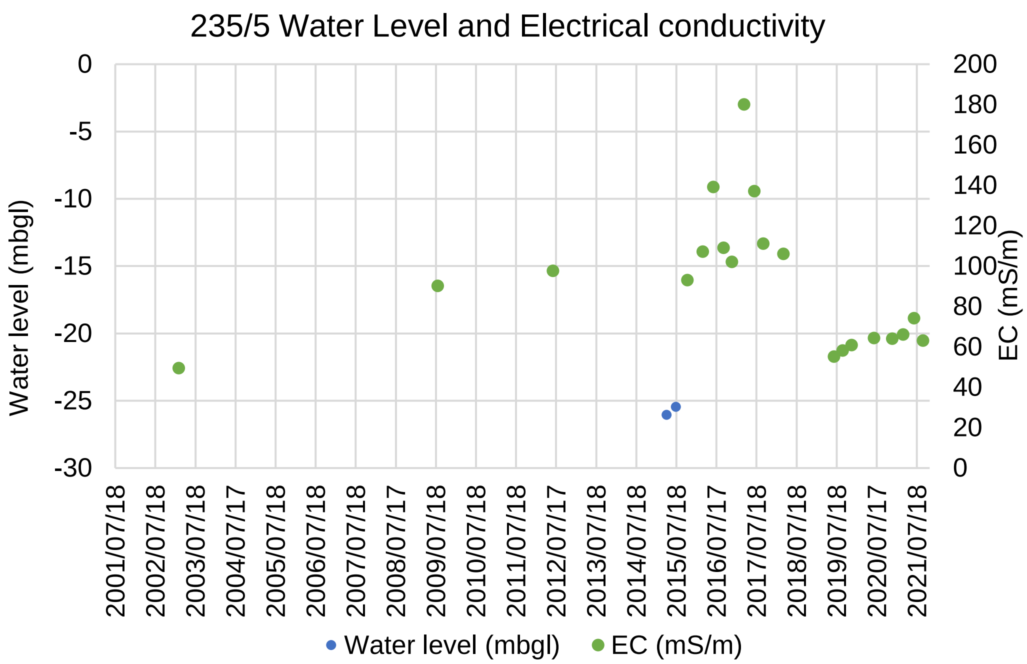


Figure 48: Water level and EC monitoring of 235/5 borehole, in G30F

Boreholes G33945A and G33947 are located closer to the majority of the production boreholes, in what is known as the upper-Wadrift aquifer. Both of these boreholes display a drop in water level, which can be observed in **Figure 49** and **Figure 50** respectively, although it was positive to note that the water levels in G33947 seem to be rising again.

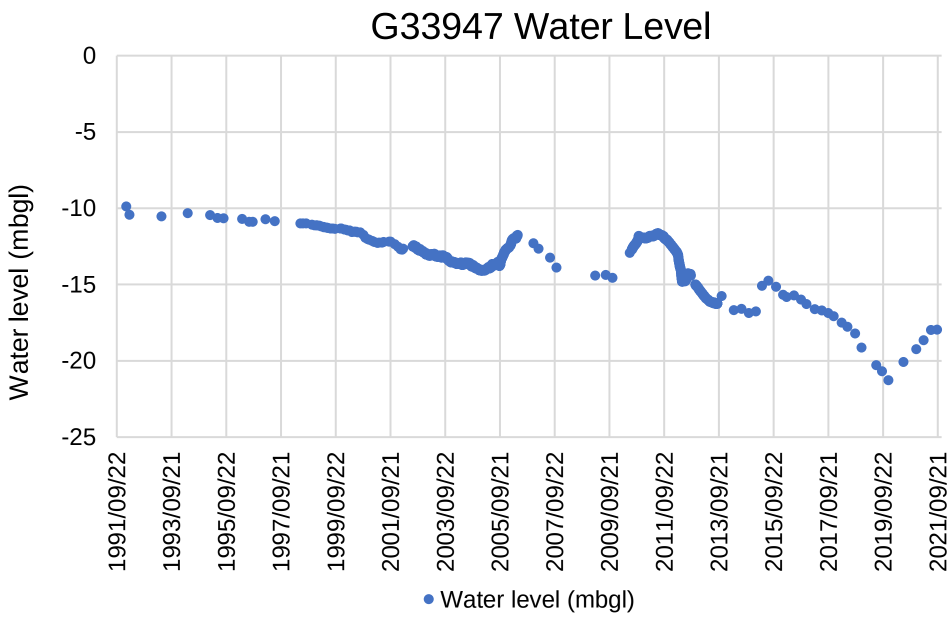


Figure 49: Water level monitoring of G33947 borehole, in G30F

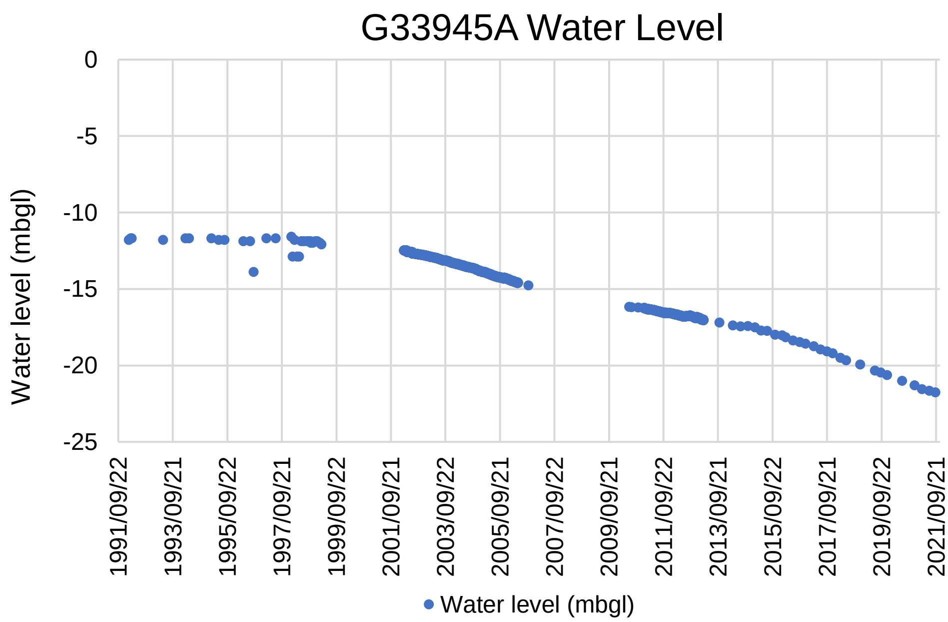


Figure 50: Water level monitoring of G33945A borehole, in G30F

These boreholes are located 2km and 4 km upgradient from the current Lamberts Bay municipal wellfield. Lamberts Bay uses this wellfield for town supply and although they are currently abstracting more than the sustainable yield of these wellfields, additional sources of water are being explored to decrease the demand on this stressed aquifer. Municipal monitoring data has displayed a decline of about 1m per year in water level for the past ten years (**Figure 52**) together with a slight increase in EC (**Figure 51**). Although a link between the surface water and groundwater has not been confirmed at the point where this aquifer meets the lower Langvlei river, the assumed impact of possible over-abstraction of the lower-Wadrift aquifer linking to the drying up of the wetland could indicate that historically, this aquifer discharged into the Langvlei river in this area. This area was also identified as an EWR site because this was one of the few remaining wet areas in the Langvlei system until recently.

The quality of the groundwater in the catchment (**Table 16**) varies, but is generally better than what has been observed in the northern G30F GRU. When considering the history of the lower-Wadrift aquifer and the drop in water levels observed in the monitoring boreholes, it is vital that water level and quality monitoring continue in this area. The concern with regards to sea-water intrusion must be mitigated by regular monitoring. As noted, the more inland areas of this aquifer have seemingly not been targeted to the extent at which the lower portions have been and this could explain the relatively good quality still, even though water levels have dropped to a relatively deep level (>40mbgl) in some areas of the GRU (**Map 20**).

Table 16: Groundwater Quality analyses for Southern G30F, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023)

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	46	46	46	46	46	46	46	46	46	46
Median	**8.64**	**183.70**	**62.45**	**0.14**	**13.65**	**1.84**	**98.68**	**21.22**	**13.10**	**6.58**
Average	30.22	444.90	144.07	0.22	31.82	2.47	240.65	64.97	35.55	6.51
95.00	146.28	1464.35	514.30	0.49	95.80	5.61	768.10	232.93	134.08	7.69
5.00	3.88	84.55	34.78	0.05	5.83	0.03	44.95	5.98	2.55	5.00

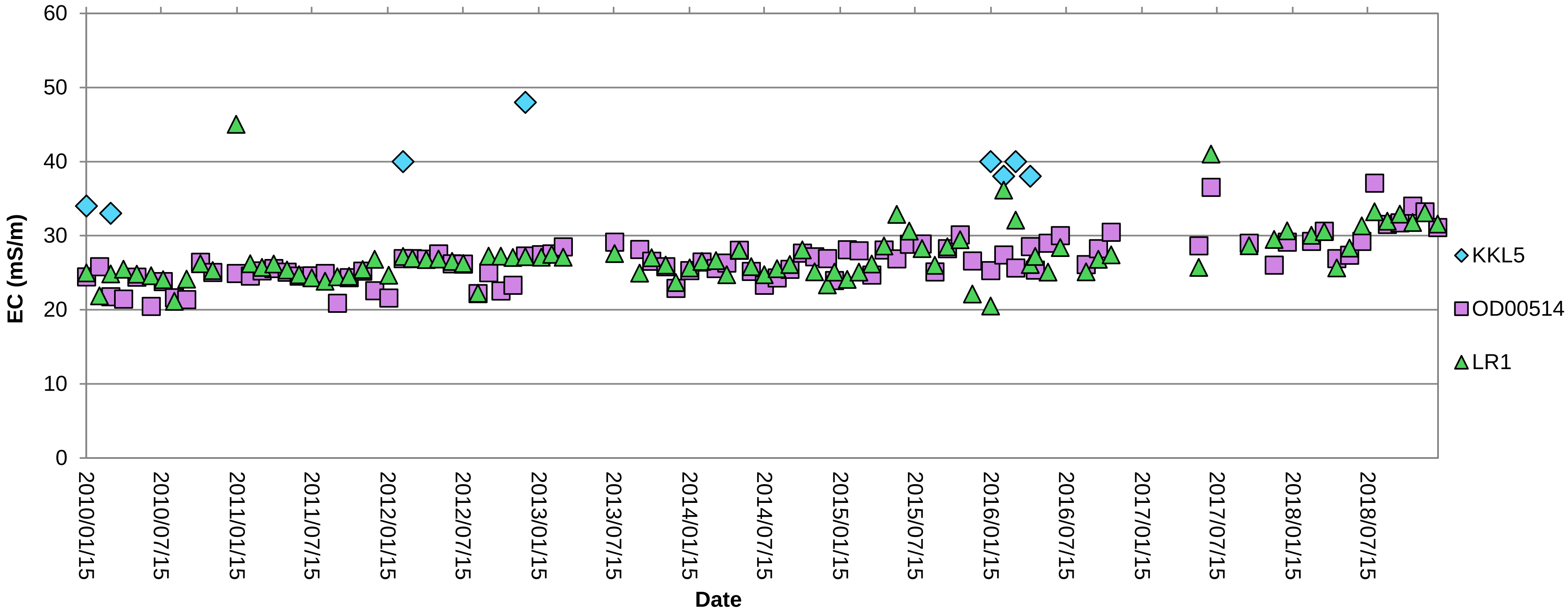


Figure 51: EC monitoring of Lamberts Bay municipal boreholes (2010-2019) in G30F (Cederberg Local Municipality, 2019b)

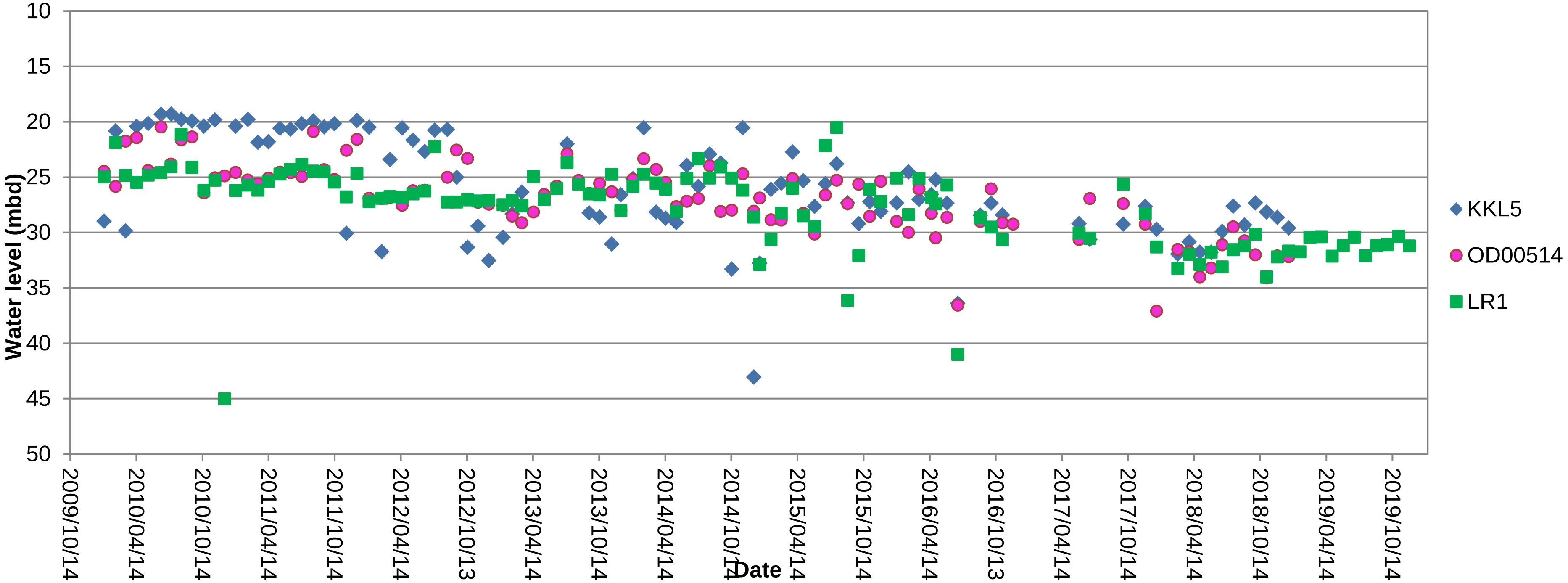
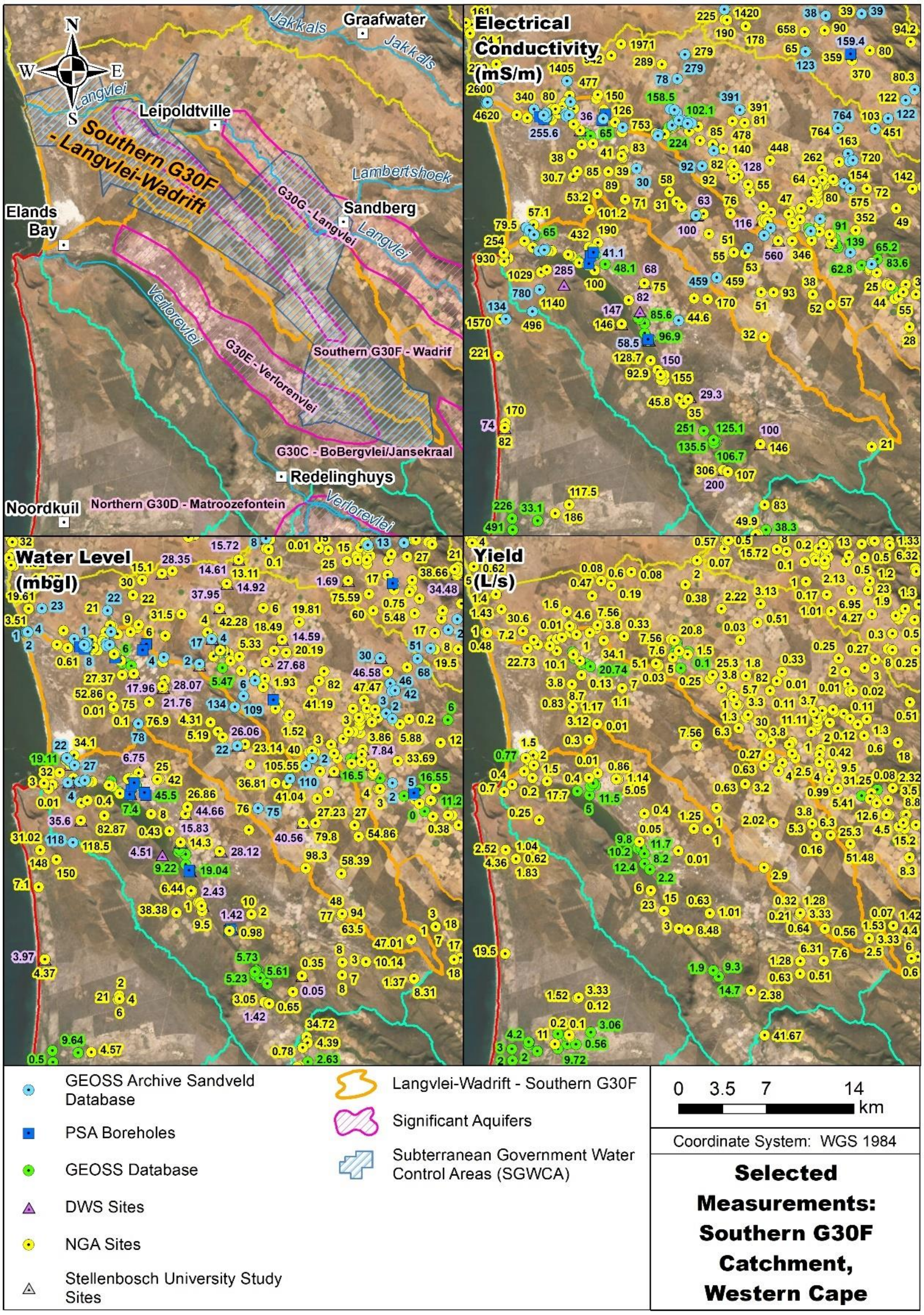
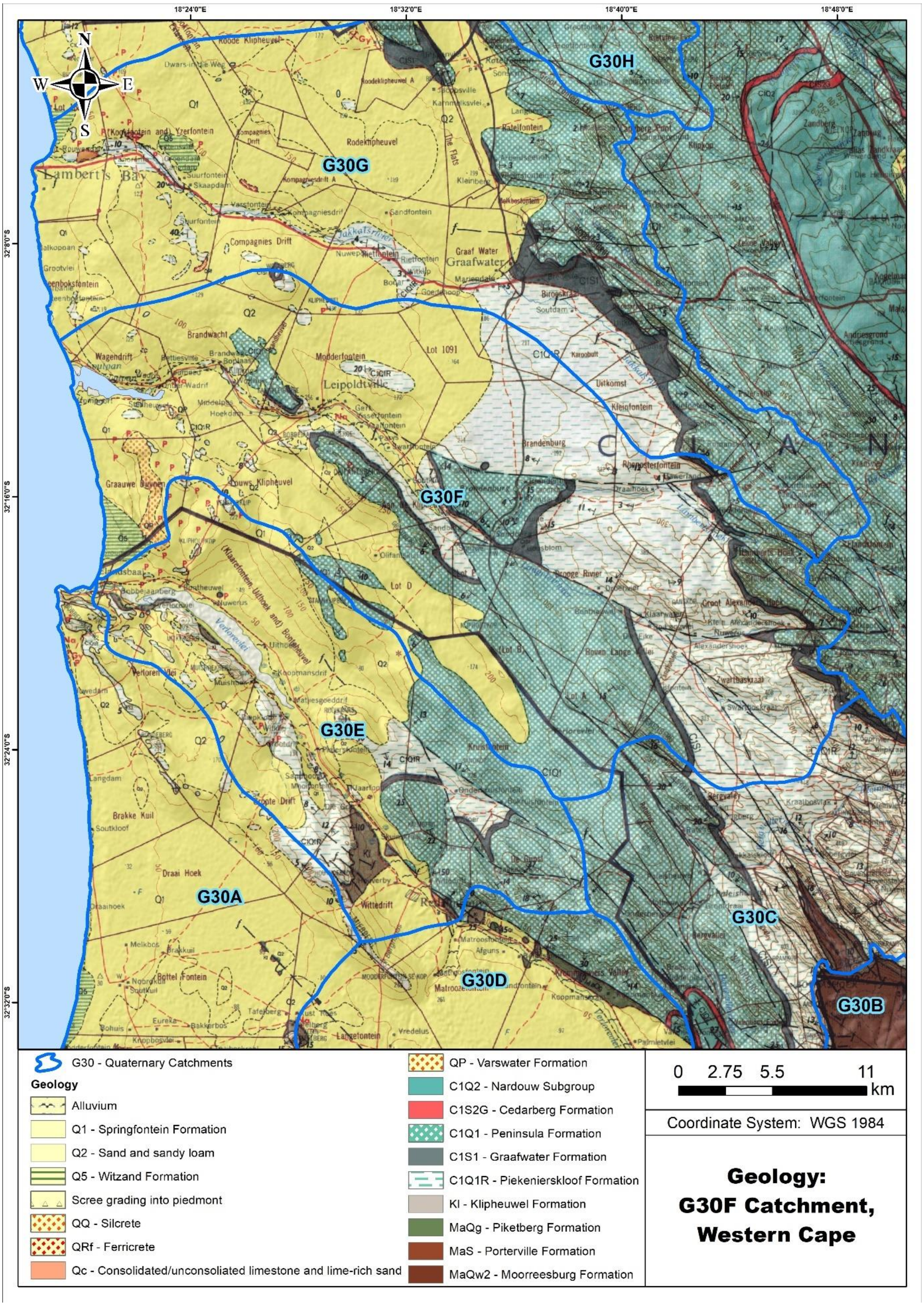


Figure 52: WL monitoring of Lamberts Bay municipal boreholes (2010-2019) in G30F (Cederberg Local Municipality, 2019b)



Map 26: Delineation of the Langvlei-Wadrift - Southern G30F GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 27: Geological setting of the G30F Catchment (Clanwilliam, 3218) (CGS, 1973)

4.1.8 Langvlei-Wadrift - Northern G30F GRU

Grouping: Langvlei-Wadrift

GRU Name: Northern G30F

Groundwater Use: Extensive

Description:

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. The Langvlei river flows in a north-westerly direction towards Leipoldtville from its source in the Swartberg. This GRU includes exposed TMG formations that outcrop towards the eastern boundary and elevated areas on either side of the Langvlei valley (**Map 27**). It has been observed that groundwater is readily available along the valley floor from the eastern boundaries of the GRU until the Paleisheuwel. The valley is underlain by a 7km wide anticline which extends from the south-east towards Graafwater in the northwest. As for other geological settings in this area, the dominant structural orientations in the Langvlei valley are towards the northwest, this being supported by the orientation of the major drainage channels in the area and the mapping of fault structures (Havenga, 1989 and Rasmussen, 1999).

The bedrock directly below this valley comprises the thick-bedded quartzose sandstone and conglomerate of the Piekenierskloof Formation of the TMG. In the hills to either side of the valley, the Piekenierskloof Formation can be seen to be overlain by the younger Graafwater Formation, comprising thin-bedded, red and brown sandstone, subordinate mudrock, small-pebble conglomerate and grit. The Peninsula Formation (TMG) overlies the Graafwater Formation and due to its very hard, resistant nature comprises the upper layers of the adjacent hills. Because the bedrock underlying this valley has been defined clearly, it could be derived from the data obtained that the groundwater occurrence and quality are directly linked to the geology of the valley. More detail on the data collected can be observed in **Annexure A**. This area has been delineated as an important aquifer.

In this GRU, groundwater abstraction is extensive, but restricted to very specific areas along the valley, where water quality is best. 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. The quality of water also deteriorates from the valley floor up towards the hills that contain the Langvlei valley (**Map 28**).

Boreholes are drilled into the primary sand and, in some cases, into the Piekenierskloof Formation. The sand layer becomes thicker towards the coast. It was reported that historically, the area had more springs. Currently, the only significant one that has been observed is Sandfontein, located adjacent to the mapped fault and likely the result of an upwelling of groundwater from the fault. (**Figure 53**). The reported spring could not be visited during the course of this study, but it is reportedly still flowing and being used. No WARMS abstraction points have been registered for this spring, although it is known to be used for domestic and agricultural use. No water from this spring could be observed to reach the Langvlei system anymore. It has been assumed that this is the status of any remaining springs found in the GRU that are not located in the actual Langvlei riverbed.

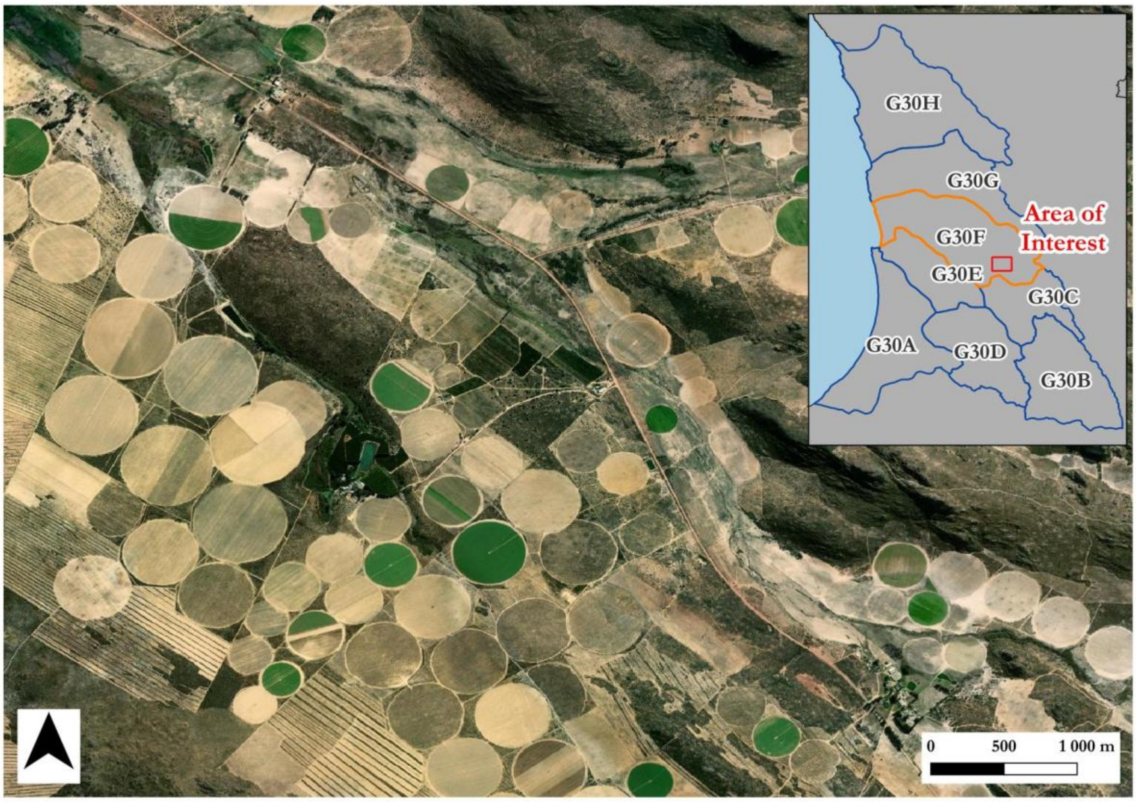


Figure 53: Reported Sandfontein Spring, located in G30F, on google earth imagery

Boreholes are being monitored in this GRU by DWS and through the Potato South Africa Project. Not all the graphs were included in this report, but all the DWS data obtained has been graphed and is included in **Annexure B** (Sandveld monitoring), which is in the form of a separate spreadsheet. Going from the upper reaches of the GRU towards the coast, the following was noted.

The only monitoring site that could be obtained from a borehole located within the TMG in the mountainsides that border the GRU, was G47865. This borehole displayed a drop in water level since 2012, after an initial rise between 2005 and 2010 (**Figure 54**). The water levels observed are also deep for the area (>70 mbgl), with these boreholes being drilled into the fault zone. Nitrate levels have increased slightly and EC values measured have increased very slightly (**Figure 55**).

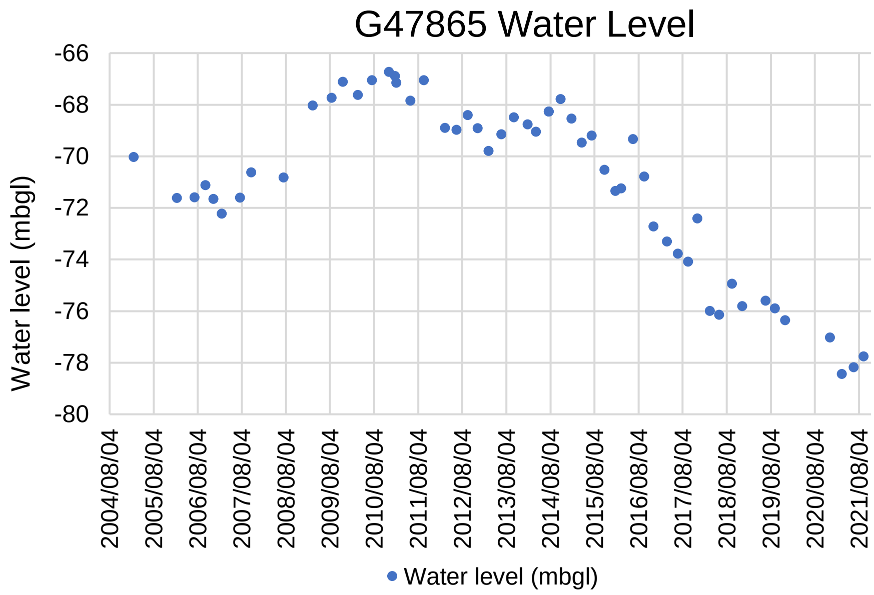


Figure 54: Water level monitoring data for G47865, located in G30F

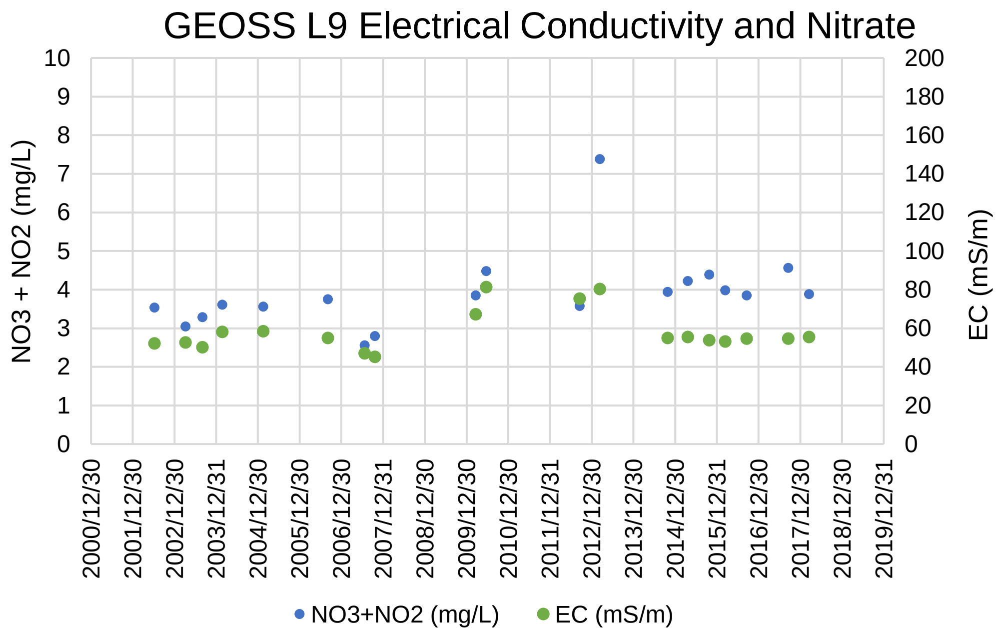


Figure 55: EC and nitrate monitoring data for G47865, located in G30F

Located on the valley floor near the G47865, some boreholes are monitored through the Potato South Africa project. It has been asked that the exact position of boreholes not be identified, but that the data could be used to draw conclusions and verify or disprove assumptions. Two of these boreholes are located very close to each other, with one borehole being situated near a pivot circle and one 300 m downgradient towards the river bed. The borehole located nearest to the pivot circle displayed elevated nitrate levels (**Figure 56**), while a very slight decrease was observed in the borehole located downgradient (**Figure 57**). This highlights the localised nature of the elevated nitrate levels that has been monitored and thus it would not be recommended to extrapolate the increase in nitrate that has been observed in certain boreholes across large areas until additional sampling is done. It is recommended that in areas where high nitrates have been observed, surrounding boreholes be sampled to measure the extent of the higher nitrate area.

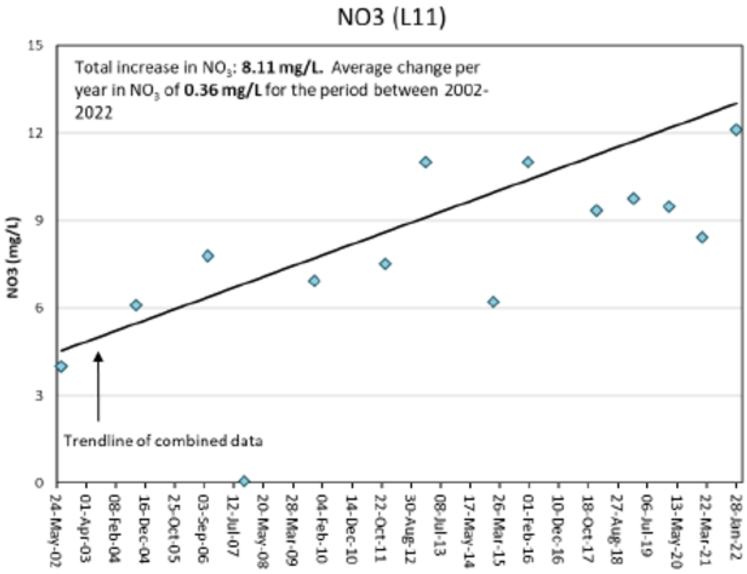


Figure 56: Nitrate monitoring data for L11 borehole located in G30F (GEOSS, 2022a)

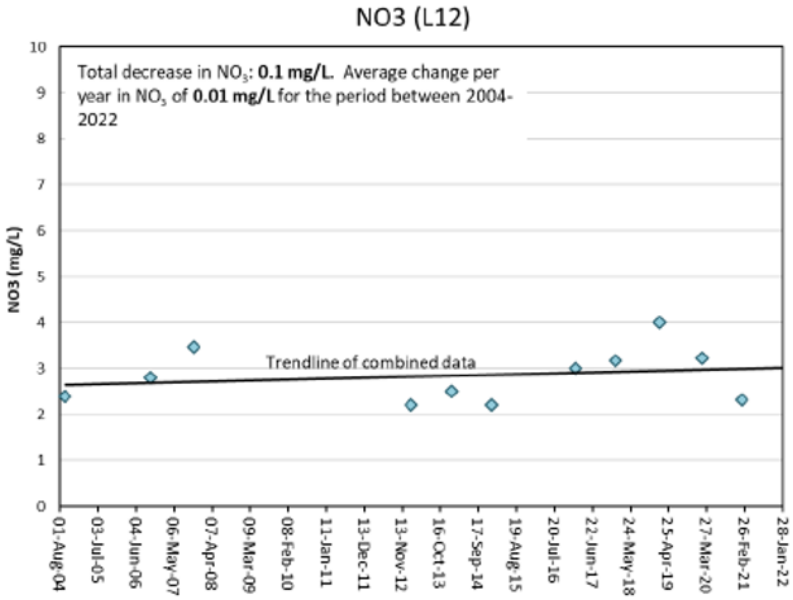


Figure 57: Nitrate monitoring data for L12 borehole located in G30F (GEOSS, 2022a)

With regards to water level, L12 has been monitored since 2001 and displays very good recovery of water levels between 2007 and 2010, after which water levels dropped again until 2019. Between 2019 and 2022, water levels have been rising again and this has been attributed to the increase in rainfall since the most recent drought (**Figure 58**). This borehole was originally artesian and the way in which it responds to abstraction shows how vulnerable the aquifers in these areas are to over-abstraction.

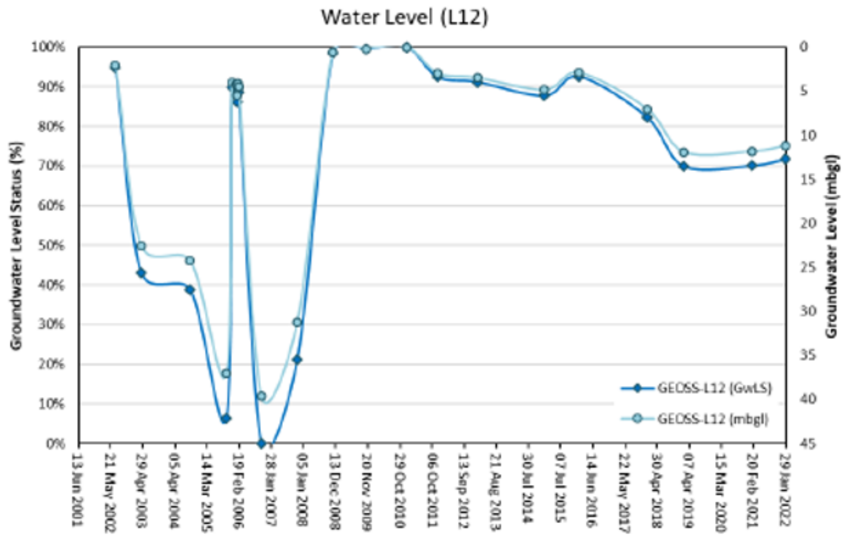


Figure 58: Water level monitoring data for L12 borehole located in G30F (GEOSS, 2022a)

Moving down the valley towards Leipoldtville, a couple of boreholes are monitored, and although some display a clear drop in water levels over time (**Figure 59**), other boreholes do display water levels shallower than what was measured in the early 2000s (**Figure 60**). Most boreholes also displayed a rise in water level since 2019, after the most recent drought ended. Most boreholes do show a drop in water level, but the drop is not as persistently displayed in all boreholes in the valley as what was viewed in the other G30F GRU, in the lower-Wadrift area. This could however be related to the reports that most abstraction occurs at very specific points along the Langvlei valley, which could explain why some boreholes display a more defined drop in water level. It should also be noted that there are reports of continued drilling in this area and an increase in groundwater exploration.

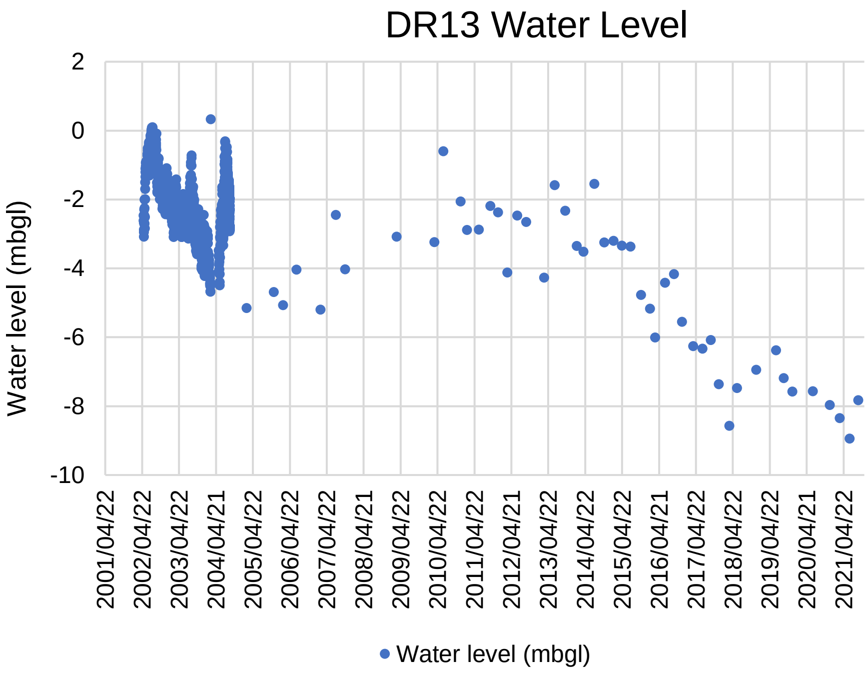


Figure 59: Water level monitoring data for DR13, located in G30F

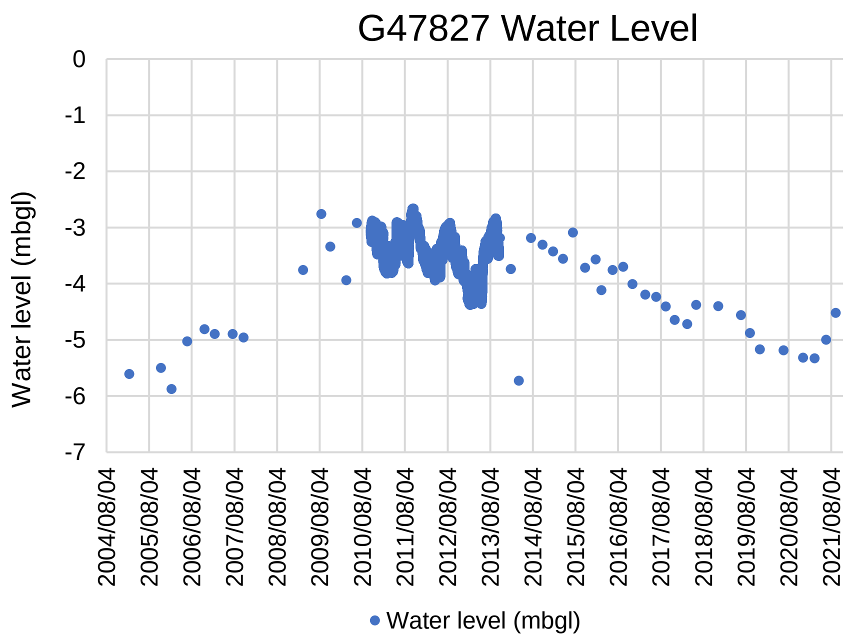


Figure 60: Water level monitoring data for G47827, located in G30F

The settlement of Leipoldtville is located 15km inland (east) of the coast and has always been reliant on groundwater for its only supply of water. The production borehole is located 1km east of the town and is known as LPP01A. A DWS monitoring borehole is located 70m away from this borehole and the water level monitoring data for this borehole is displayed in **Figure 61**. The data displays water levels between 3 and 9 meters and also shows a rise in water level for the last couple of years, most likely reflecting the effect of increased rainfall.

The Leipoldtville municipal borehole is being sampled yearly as part of the Potato South Africa project and the results are displayed in **Figure 62** – **Figure 64**. The data shows increasingly high EC values, with a slight decrease in pH and nitrates remaining mainly stable.

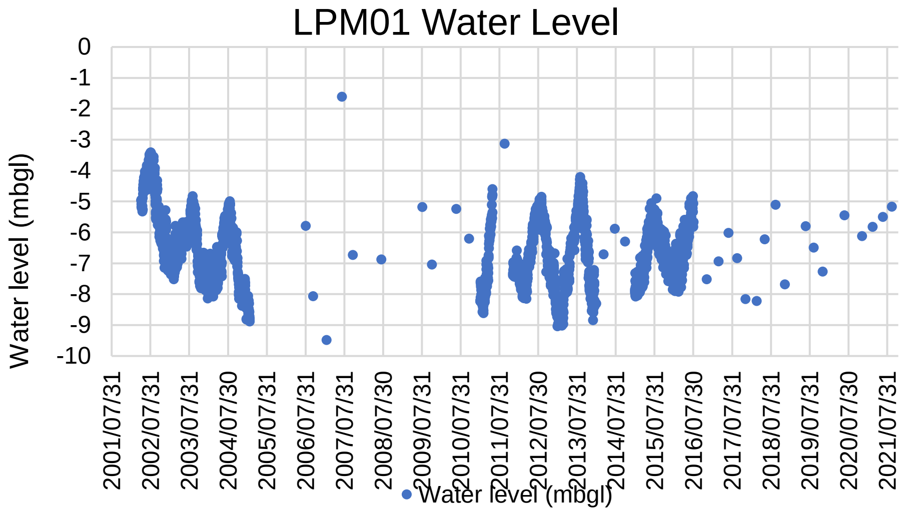


Figure 61: Water level monitoring data for LPM01, located in G30F

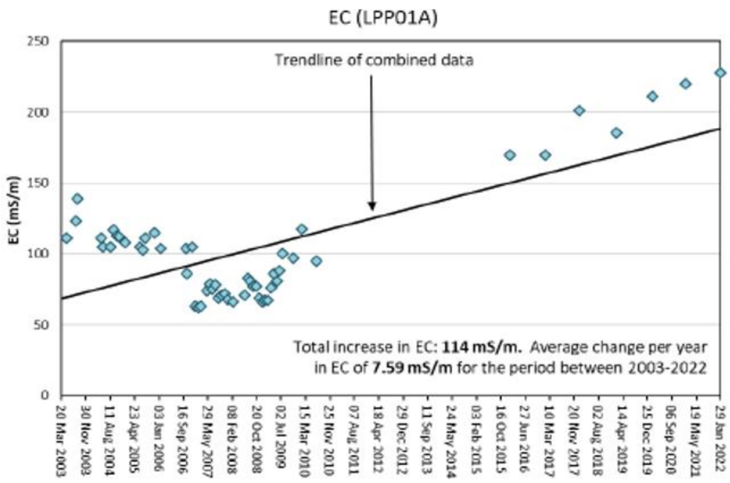


Figure 62: EC monitoring data for LPP01A borehole located in G30F (GEOSS, 2022a)

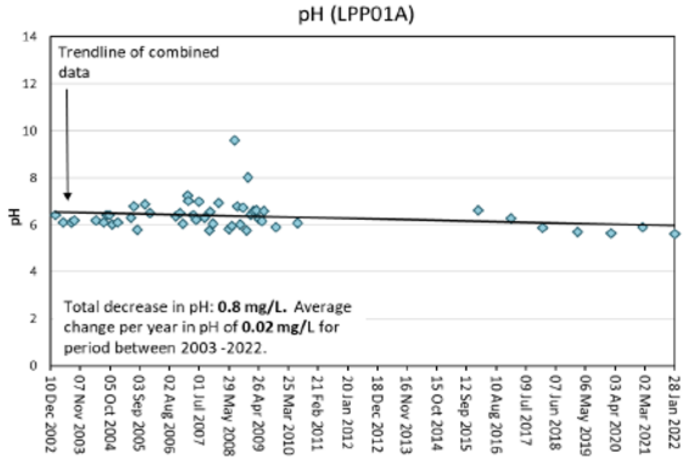


Figure 63: pH monitoring data for LPP01A borehole located in G30F (GEOSS, 2022a)

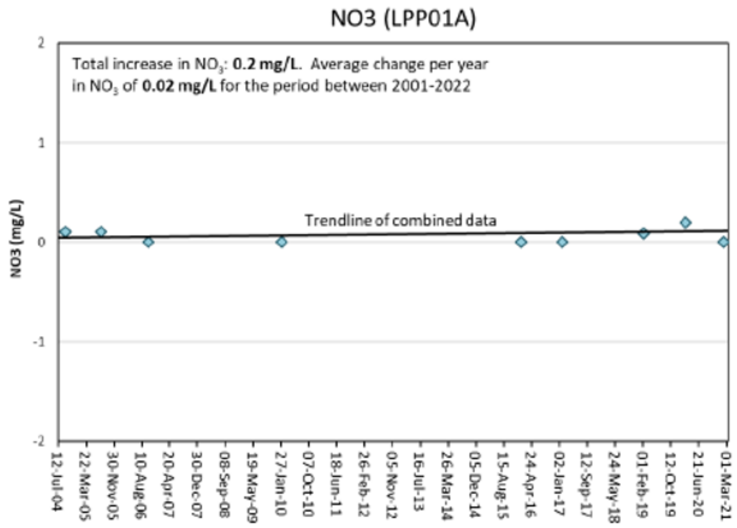
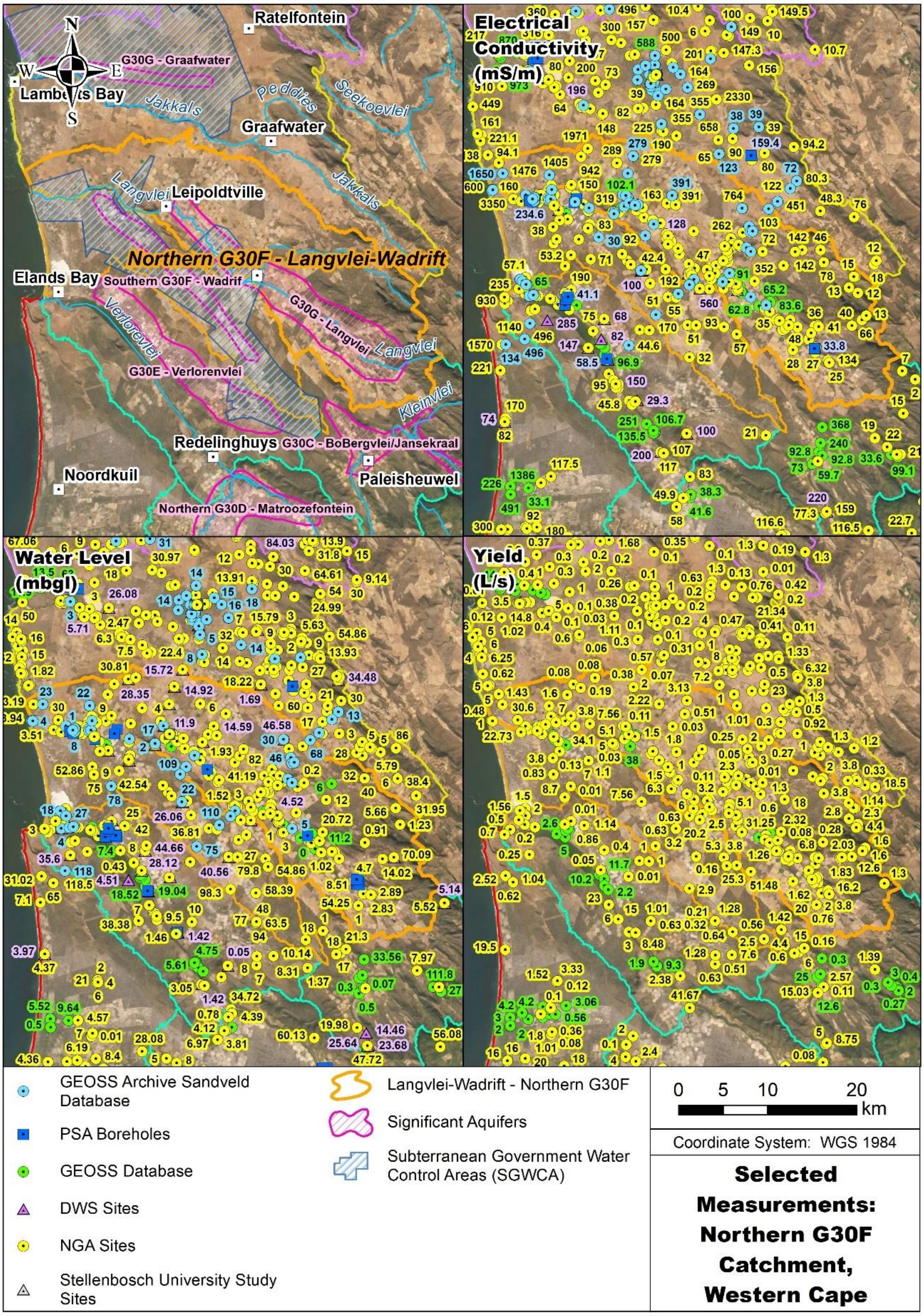


Figure 64: Nitrate monitoring data for LPP01A borehole located in G30F (GEOSS, 2022a)

With regards to the quality of the groundwater found in northern G30F area, the data that could be obtained from the GEOSS Database (2022) and DWS (DWS, 2022 and DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 17**).Water quality is poorer than in the Southern G30F Gru, with some very high chloride levels being observed. The elevated levels of chloride having been linked to the presence of the Graafwater Formation (Conrad et al., 2004 and Meyer, 2001).As was noted above, some areas display elevated nutrient levels that could be linked to fertilizers.

Table 17: Groundwater Quality analyses for Northern G30F, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023)

	Ca (mg/l)	**Cl (mg/l)**	**EC (mS/m)**	**F (mg/l)**	**Mg (mg/l)**	**NO3+NO2 (mg/l)**	**Na (mg/l)**	**SO4 (mg/l)**	**TAL**	**pH**
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	56	56	56	56	56	56	56	56	56	56
Median	**9.28**	**223.45**	**85.83**	**0.12**	**18.65**	**2.27**	**113.80**	**12.65**	**6.80**	**5.99**
Average	27.06	602.75	191.99	0.14	57.26	3.31	282.44	52.73	14.46	5.97
95.00	80.48	3112.52	911.10	0.27	247.96	10.24	1470.47	244.35	54.43	7.17
5.00	2.13	55.95	23.75	0.05	4.43	0.06	32.05	2.00	2.00	4.65



Map 28: Delineation of the Langvlei-Wadrift - Northern G30F GRU, on satellite imagery and displaying EC, WL and yield values, where data was available

4.1.9 Jakkals- G30G GRU

Grouping: Jakkals

GRU Name: G30G

Groundwater Use: Extensive in certain areas and Low in others

Description:

The groundwater unit falls within the quaternary catchment boundaries and can be referred to as the Jakkals river catchment. The Graafwater Subterranean Government Water Control Area Graafwater (SGWCA) falls within this GRU. Typically, within a Government Subterranean Water Control Area, such an area is protected for municipal supply. The area is also seen as the start of the northern Sandveld and displays the transition from potato and other irrigated crops to dryland crops and animal farming operations. The town of Graafwater is located in the upper Jakkals river system, on the eastern side of the GRU, while the town of Lamberts Bay is located on the western side, on the coast. The geology of the GRU is as with the other coastal G30 catchment, dominated by quaternary sand deposits, with the Peninsula Formation and the Graafwater Formation outcropping in the elevated areas and mountains that border the GRU. The Piekenierskloof formation also outcrops along the river bed (**Map 30**).

As noted previously, Lamberts Bay gets its water supply from the upper-Wadrift aquifer, located in G30F. Because of an observed drop in water level at the production boreholes, other water sources are being explored to supplement the water supply. Work has been done on a Desalination plant, but it has never been completed or put into production. If this could be brought into production, it would be used to supplement the groundwater that is being used. The drilling of boreholes in the area north of Lamberts Bay has also been proposed, and borehole sites have been provided to the municipality. The aim would be to drill and develop boreholes to supplement the other water resources.

The town of Graafwater is also solely reliant on groundwater and pumps water from a wellfield, located approximately 11 km north-west of Graafwater on the farm Rodeklipheuvel 1/84. This area was identified as an optimum source of groundwater by Vandoolaeghe (1982) and was characterised as a paleochannel by Jolly (1992). Although suitable areas for groundwater abstraction have been located (areas with deep paleo-channels) the water quality is problematic with regard to iron concentrations within the groundwater. The presence of the Graafwater Formation has been linked to the elevated concentrations of chloride and iron in the groundwater (Meyer 2001).

DWS monitors boreholes in this GRU, the data was obtained from DWS in July 2022 and graphed. Not all graphs were included in this report, but are presented in **Annexure B** (Sandveld). Potato South Africa (PSA) also monitors a couple of boreholes in this GRU and although the exact position of the boreholes has not been identified, some graphs have been used to display changes in water level or quality.

For the upper reaches of the Jakkals river system, no boreholes are being monitored, but multiple NGA boreholes have been registered for this area, displaying varying yields (1 - 18L/s) and water levels (3 – 38 mbgl) (**Map 29**). It is recommended that at least one of these boreholes be included in the monitoring system as it would be useful to monitor groundwater in this area.

The G47869 borehole is a 203 m deep borehole drilled into the fault zone of the Peninsula formation, located next to the R364 road, 8 km east of Graafwater. The water levels observed in this borehole have remained overall stable since monitoring began in 2004, although there was a drop and subsequent rise in water level noted between the years 2010 and 2013 (**Figure 65**). Moving toward Graafwater, Potato SA monitors a couple of boreholes about 5km east of Graafwater. The boreholes are located near the main Jakkals River channel. Since monitoring started in 2001, the water levels have risen and fallen (from 0 to 35 mbgl), but it was very interesting to note that in 2022, the water level was slightly shallower than what was measured in 2001 (**Figure 66**). Because this fluctuation has been measured at a production borehole, the most likely reason for the fluctuations would be related to the actual pumping of the borehole. It is however a positive fact that the water levels have not consistently been dropping and that current levels being measured are mostly the same as what was measured in 2001. Another DWS monitoring borehole, G47828, located 3.7 km west and downstream of the JO5 borehole also displays a generally stable water level (**Figure 67**).

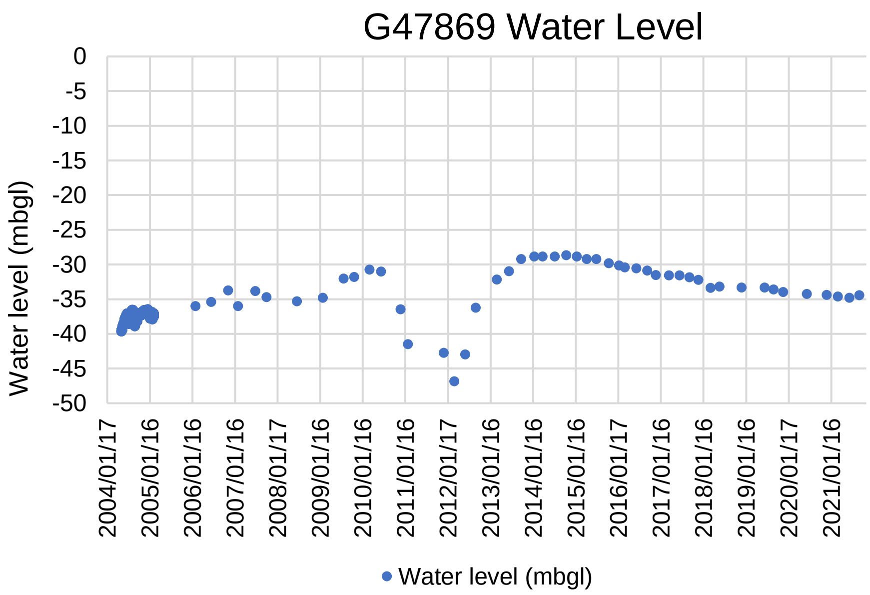


Figure 65: Water level monitoring data for G47869 borehole located in G30G

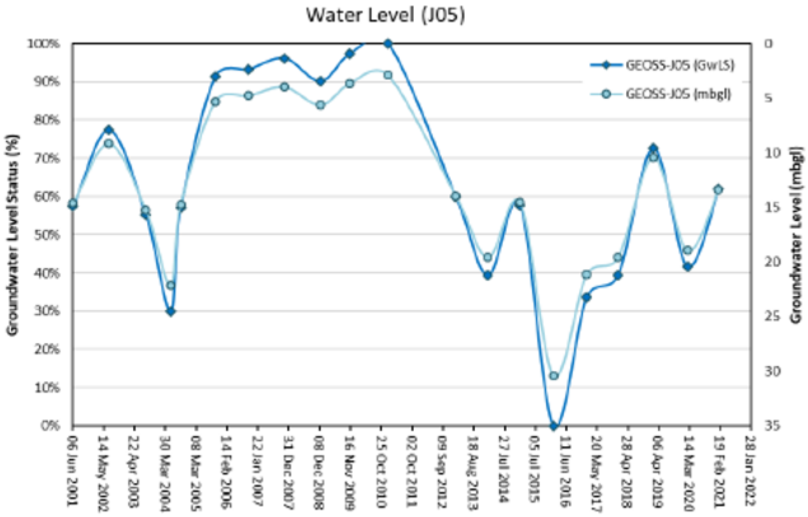


Figure 66: Water level monitoring data for JO5 borehole located in G30G (GEOSS, 2022a)

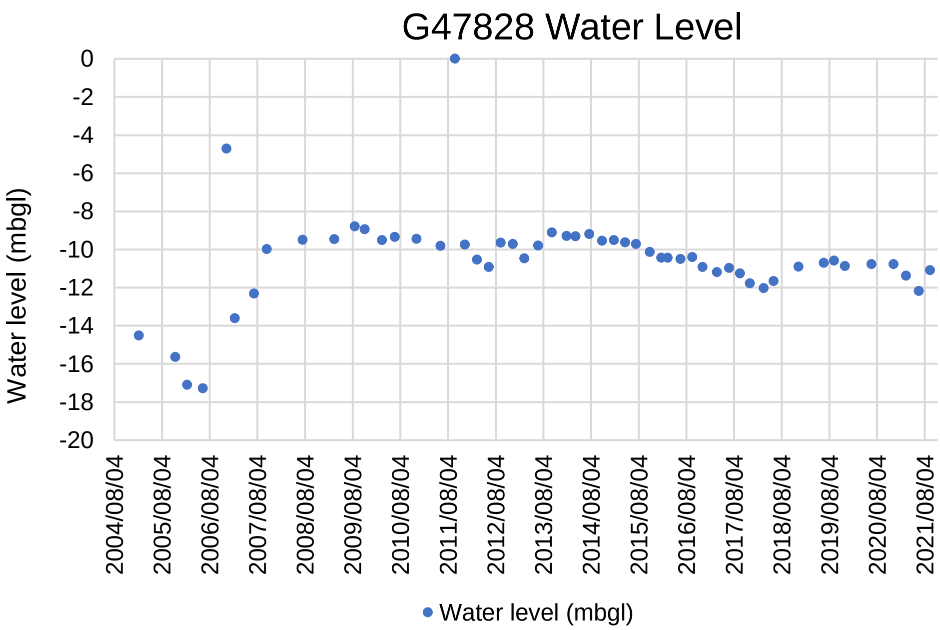


Figure 67: Water level monitoring data for G47828 borehole located in G30G

The Graafwater wellfield is located 11 km northwest of the town. As noted, a paleochannel has been identified in this area during the 1980s and 1990s and apart from one of the existing production boreholes being redrilled in 2021, has remained the only source of water for the town and has been pumped almost continuously since the 1980s. In 1992, Jolly described the paleochannel from drill logs and from what geology had been mapped in the area. This cross-section has been included in **Figure 68**. With regards to the hypotheses that has been put forward previously in the report, describing "*lateral movement of groundwater from mountainous areas via faults acting as water conduits, across catchment boundaries, in a generally northwest direction towards the coast and discharging groundwater in a* *discontinuous manner along these faults"*, it is currently not clear if this conceptual model fits with the Graafwater paleochannel. The subsurface lithologies that constitute an aquifer in the Graafwater setting are associated with coarse-grained sand matrix deposited in a steep valley-like setting where conduit zones are located towards the centre of the valley structure. Considering the regional geological setting, the formation of these "valleys" could still be fault related. This is also evident in the drill logs (Jolly, 1992). With regards to the boreholes at Graafwater, obtaining relatively high yields (10 L/s) could be achieved relatively easily, but the biggest issues are related to the quality. When the G33747B was redrilled, the shallower clay-rich water associated with high iron, was cased off. The water still contained high iron concentrations, but the water was still useable as the town has a treatment plant.

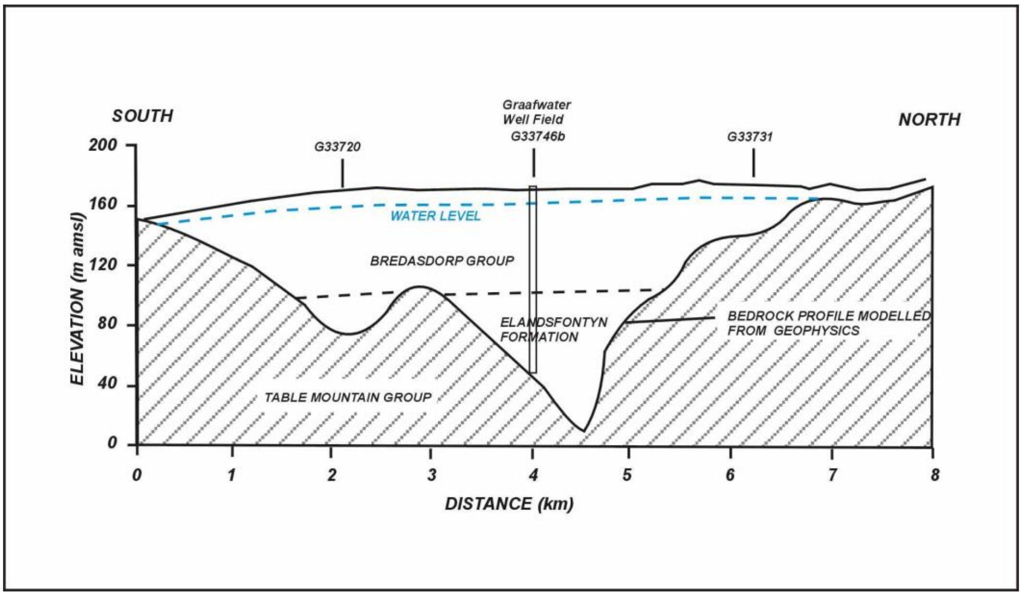


Figure 68: Geohydrological cross-section through the Graafwater well field (After Jolly 1992)

There are multiple boreholes around this wellfield being monitored by DWS. G33747A display EC readings taken between 2014 and 2021, indicate an increase (**Figure 69**). G33722 displays a drop in water level of approx. 5m since the monitoring started in 1989 (**Figure 70**), while G33732A displays a drop of 2 meters between 1989 – 2021 (**Figure 71**). The change in water level is remarkably small considering that the wellfield has been in continuous use since the 1980s.

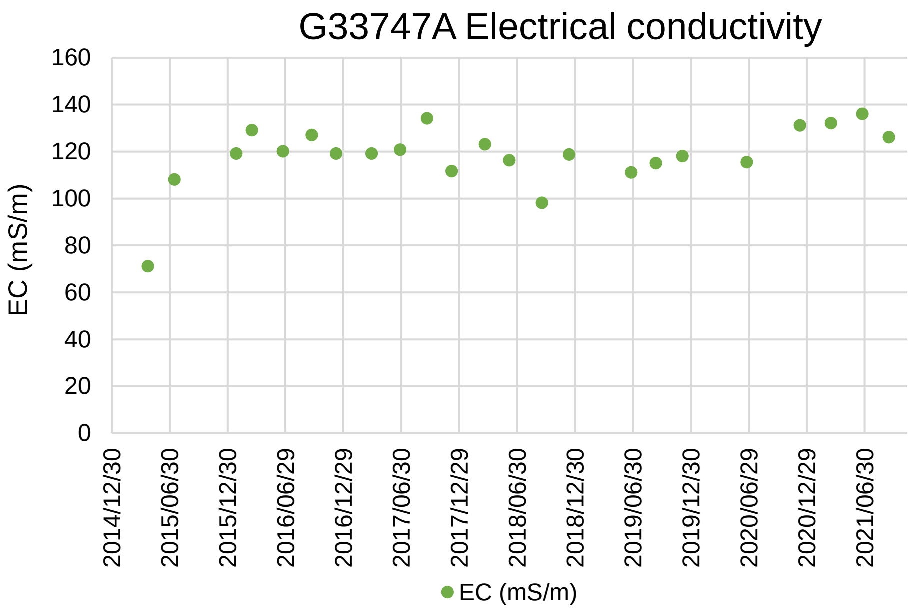


Figure 69: EC monitoring data for G33747A borehole located in G30G

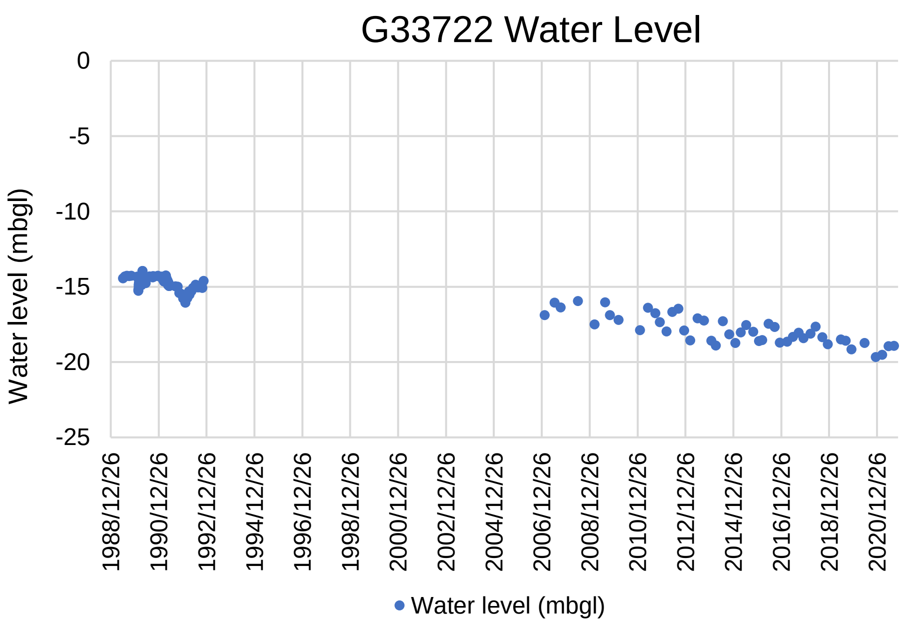


Figure 70: Water level monitoring data for G33722 borehole located in G30G

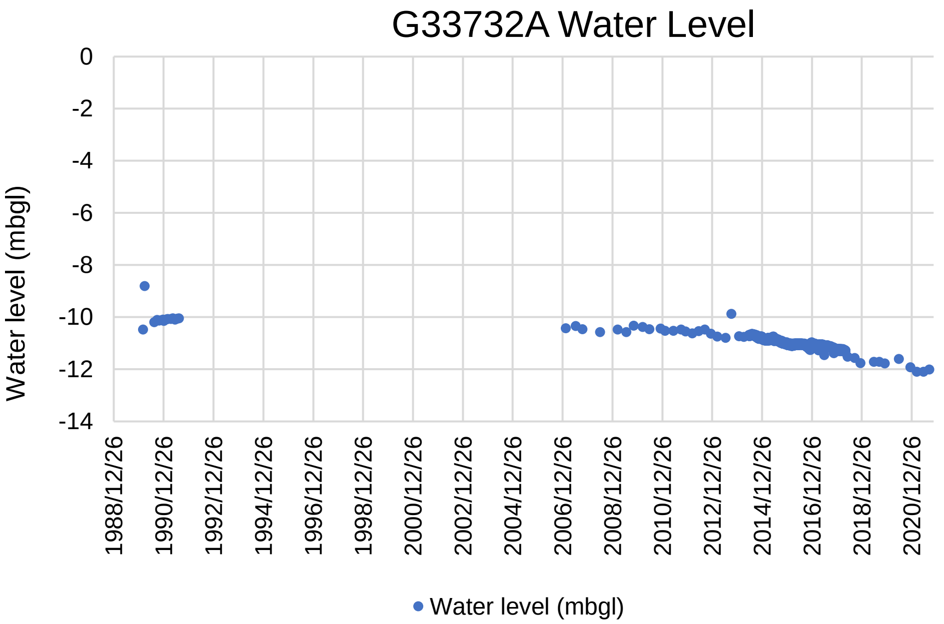


Figure 71: Water level monitoring data for G33732A borehole located in G30G

Moving towards the coast, another area has been identified that yields relatively good quality water and very high yields ranging between 16 and 31 L/s (**Annexure A),** in the area known as Kookfontein. No springs that currently still flow could be identified, but because this section of the Jakkalsvlei River is one of the only remaining wet areas, it is postulated that some groundwater could still be entering the system at this point. The clay banks along the northern side of this small wetland have been found wet during the summer, and it is hypothesized that groundwater in the primary aquifer may still be discharging where it meets the clay bank.

A small dune field is located in this area, with very high-yielding boreholes found on either side of the dune field. The G33749 borehole is located to the east of the dune field and the water levels monitored here display a drop in water level of approx. 15 meters since monitoring started in 2003 (**Figure 73**). The G33748 borehole is located to the west of the dune field and the water levels monitored here do not display a significant change, but the water levels are very deep (around 60 mbgl) (**Figure 73**). It should however be noted that G33748 is located at an elevation of 170 mamsl, while G33749 is only 93 mamsl, which could explain the difference in water levels.

Like the northern wellfield, quality rather than yield is the main issue in these aquifers. The main concern for the groundwater around Graafwater is the high concentrations of iron and other metals found in the water, while chloride and sodium are seen to increase towards the coast. It has been reported that groundwater outside of the paleochannel structures are much poorer in quality, although the NGA database displays varying quality, in term of EC, for the area (**Map 29**). With regards to more comprehensive water quality data, only 5 sample results could be obtained from the various databases obtained (GEOSS Database (2022) and DWS local and WMS databases (DWS, 2022 and DWS, 2023)) (**Table 18**). The reported very high EC boreholes area clearly not displayed in this dataset as the 95th percentile is only 444.6 mS/m.

Due to the focus on groundwater abstraction and the occurrence of high-yielding boreholes, the Kookfontein and Graafwater wellfields have been used to delineate an important aquifer for this GRU. Due to the lack of isotope and inorganic analysis data for this portion of the Sandveld, as well as for the adjacent mountains, it is recommended that isotope sampling be done and analysed to investigate whether the northern Sandveld does obtain its recharge from the Cederberg and Swartberg Mountains as is assumed. The GEOSS (2019) isotope sampling did not include many sampling sites in the north of the Sandveld or in the Cederberg and such data would be vital to outline recharge areas.

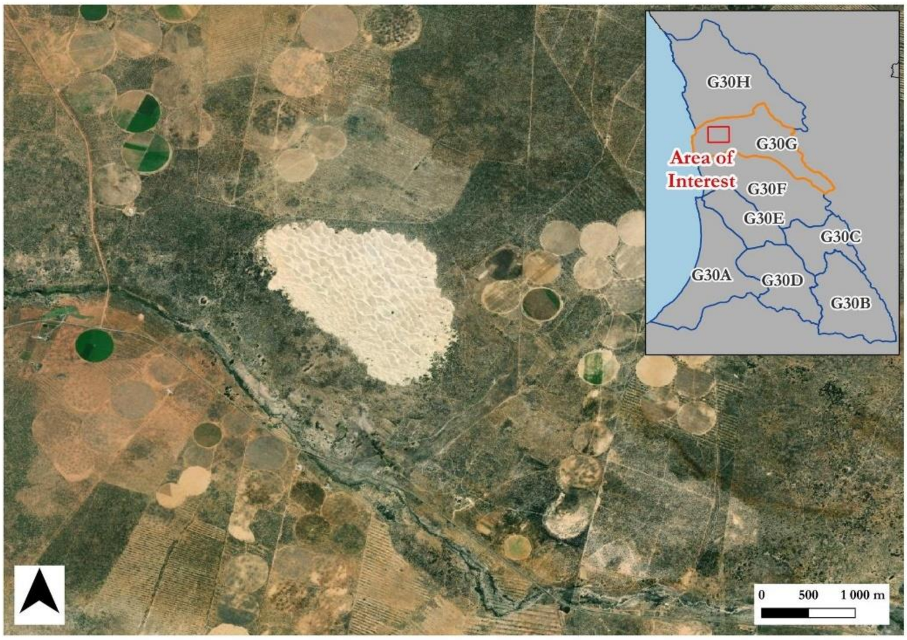


Figure 72: Kookfontein, located in G30G, on google earth imagery

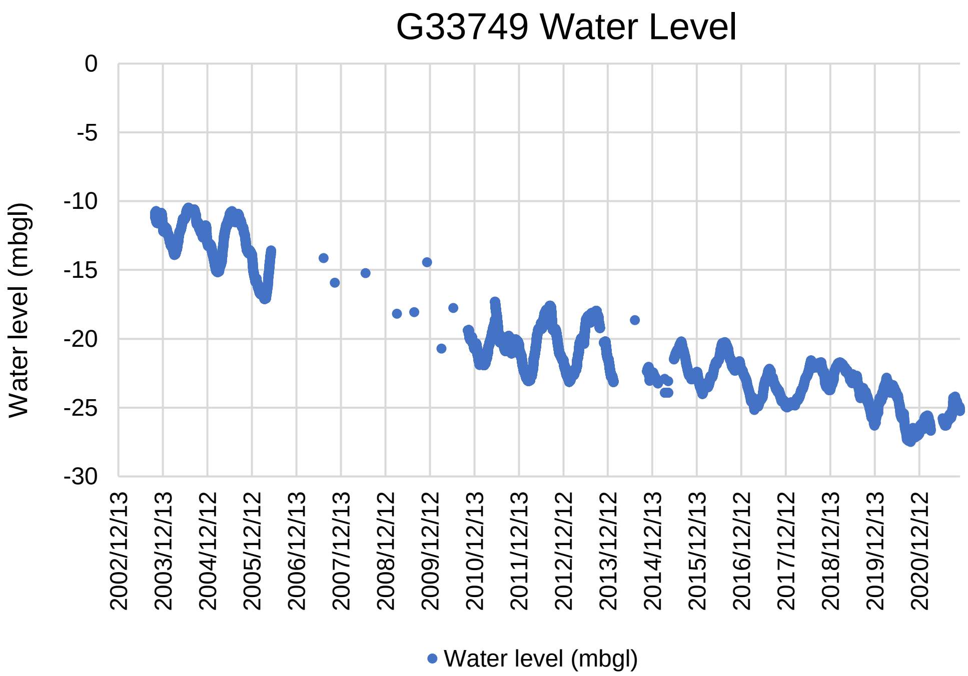


Figure 73: Water level monitoring data for G33749 borehole located in G30G

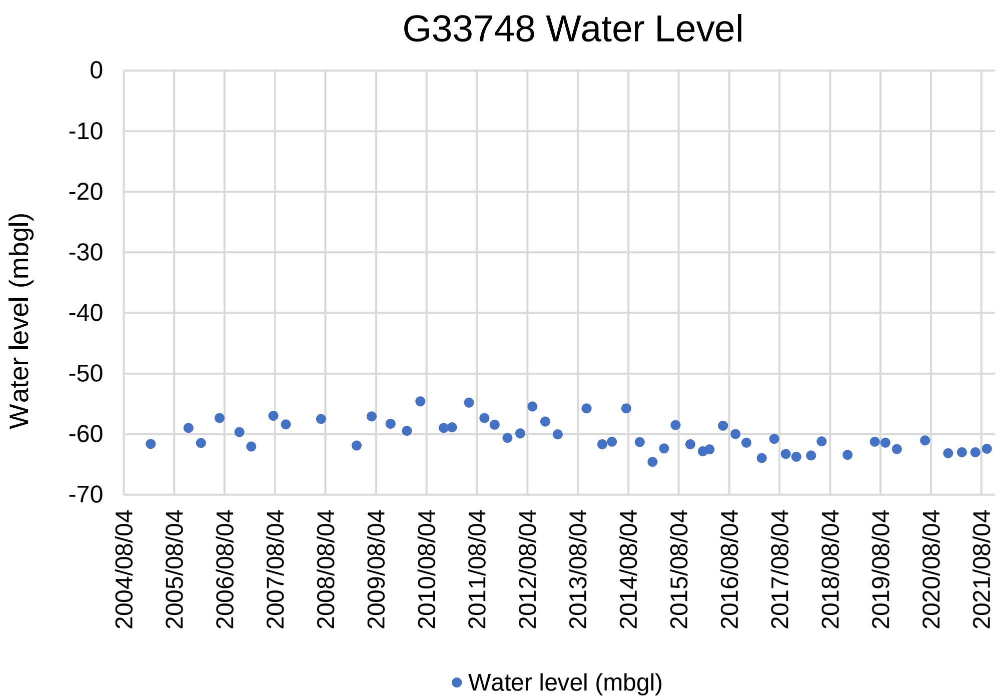
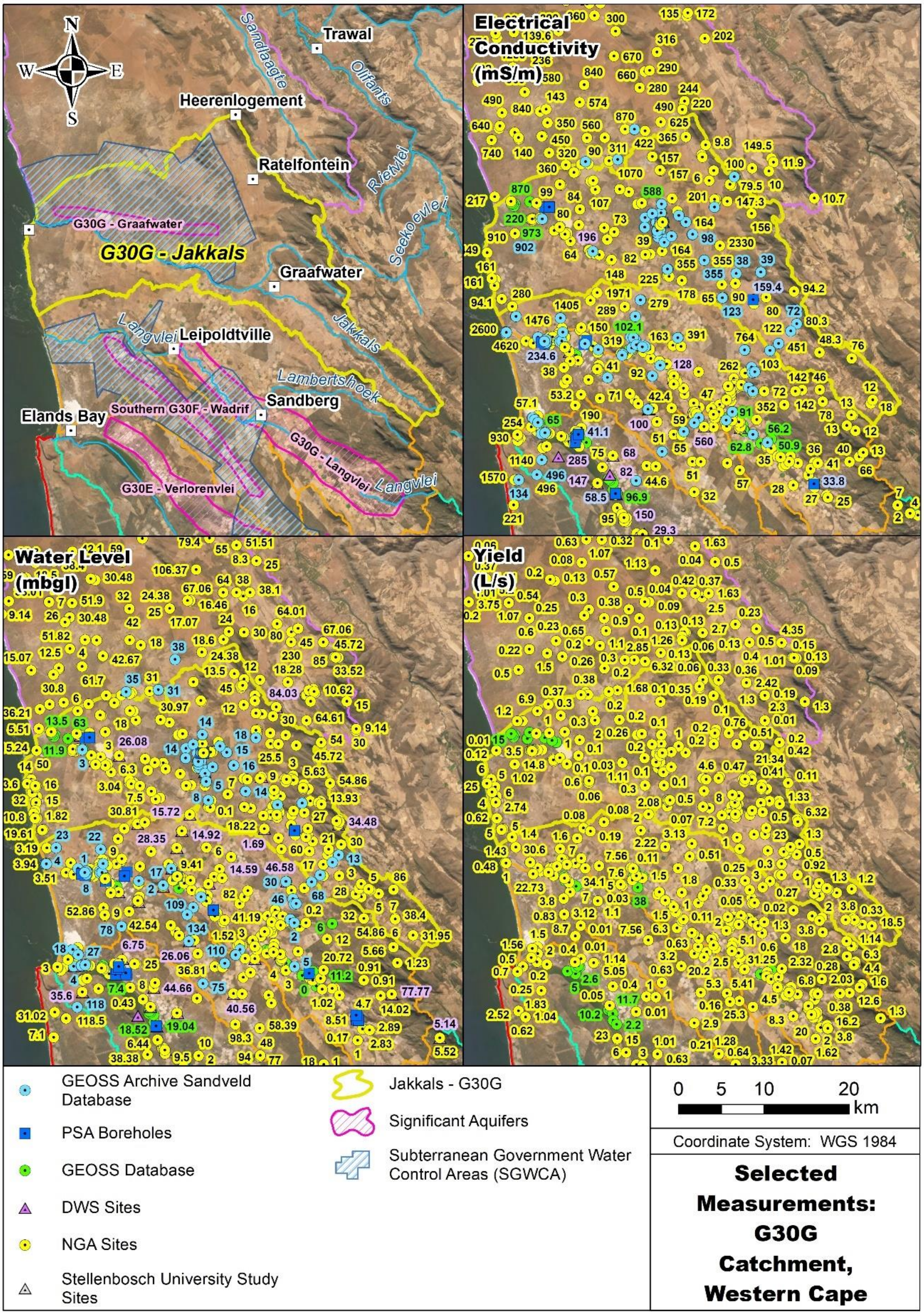


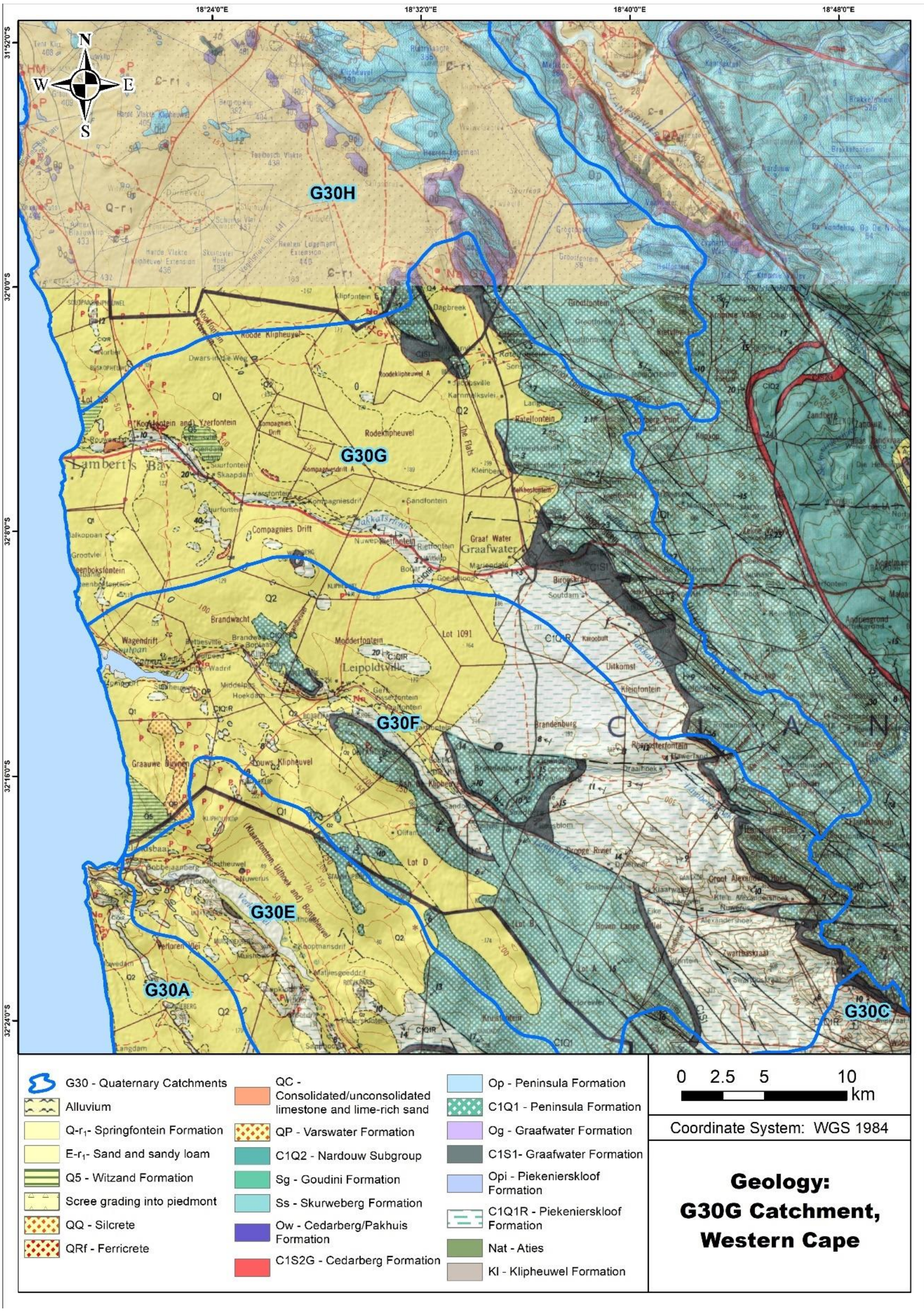
Figure 74: Water level monitoring data for G33748 borehole located in G30G

Table 18: Groundwater Quality analyses for G30G, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		5-6 & 9-9.5
Class II	300	600	370	3.5	200	20	400	600		4-5 & 9.5-10
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		<4 & >10
No of samples	5	5	5	5	5	5	5	5	5	5
Median	**32.03**	**512.90**	**183.00**	**0.23**	**40.42**	**0.89**	**251.50**	**69.74**	**35.21**	**6.21**
Average	33.41	730.79	258.90	0.32	59.55	3.44	387.15	90.54	56.29	6.55
95.00	57.16	1359.69	444.60	0.78	107.83	11.60	704.34	140.85	134.29	7.54
5.00	11.78	284.64	110.10	0.10	26.04	0.13	139.85	48.66	17.48	6.01



Map 29: Delineation of the Jakkals- G30G GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 30: Geological setting of the G30G Catchment (Clanwilliam, 3218c & Calvinia, 3118) (CGS, 1973 & CGS, 2001)

4.1.10 Northern Sandveld - G30H GRU

Grouping: Northern Sandveld

GRU Name: G30H

Groundwater Use: Low

Description:

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. Agriculture is reportedly focused on dryland crops and animal farming. Not many groundwater projects have been completed in this area, and only a few boreholes are being monitored. As with the rest of the Sandveld, coastal sand deposits are underlain by TMG and Klipheuwel, although sand deposits are reportedly thinner in some areas than for the rest of the Sandveld (**Map 32**). Local water users reported that some of their wind pumps are drilled into hard rock and not just into sand deposits. The data that could be obtained are presented on **Map 31**, with more detail available in **Annexure A**. The long-term monitoring data is available in **Annexure B** (Sandveld Monitoring).

Groundwater quality is generally poorer than groundwater in the other G30 catchments with EC values generally ranging between 300 – 800 mS/m, although outliers to this are found (EC values as low as 60 mS/m and high as 1000 mS/m has also been observed) (**Table 19**). The average chloride level observed is high (1187.42 mg/l), limiting the use of the available groundwater as irrigating with such high chloride levels would burn the leaves of plants.The best water quality has been observed in the southeast corner of the GRU. This area is also the highest elevated area in the GRU and is bordered by mountains made up of the TMG formations. Rest 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 (8 mbgl) to the northern portion (164 mbgl) of the GRU (**Map 31**). Some winter seepage areas have been reported towards the upper reaches of the catchment, but these sites could not be visited during the course of this study.

Borehole yields are low (0.1 – 1.1 L/s), although some high-yielding boreholes have been drilled towards the upper portions of the GRU (4 - 6 L/s). It has been reported that the boreholes are drilled into and are abstracting from both a primary sand aquifer as well as the deeper boreholes being drilled into the hard rock of the TMG formations. The reportedly high-yielding boreholes have also been linked to the two mapped NW trending faults. One fault cross-cuts the centre of the GRU, while another has been mapped along the Sandlaagte River and TMG mountainous area

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.

For the boreholes being monitored in the GRU, all data with regard to the water level and quality monitoring has been graphed and is available in **Annexure B** (Sandveld Monitoring). Some graphs have been included in this report to highlight trends or changes observed.

The KK7 borehole is located in the centre of the GRU, next to the turn-off road that leads to Doringbaai. The borehole monitoring data reflects a stable water level at around 31 mbgl and EC values of around 400 mS/m (**Figure 75**). There are two proposed production boreholes located 700 south-east of the KK7 borehole. Both boreholes are drilled to a depth of 50 m and the recommended abstraction is 15 and 8 L/s for a 14-hour pump cycle with a 10 hour recovery. These yields were calculated from a pumping test run according to SANS 10299-4:2003 standards and thus the high yields should not be attributed to blow yields, proving that high-yielding boreholes can be drilled in this GRU. The boreholes are located close to one of the faults mapped in this area and it is hypothesized that the high yields would be restricted to sand deposits adjacent to one of the fault structures.

Some irrigation use is expected in the south-eastern corner, where some pivot circles have been mapped, but it is not expected that this GRU would ever be as irrigation intensive as the central G30 catchments, due to the lack of suitable groundwater volumes and quality.

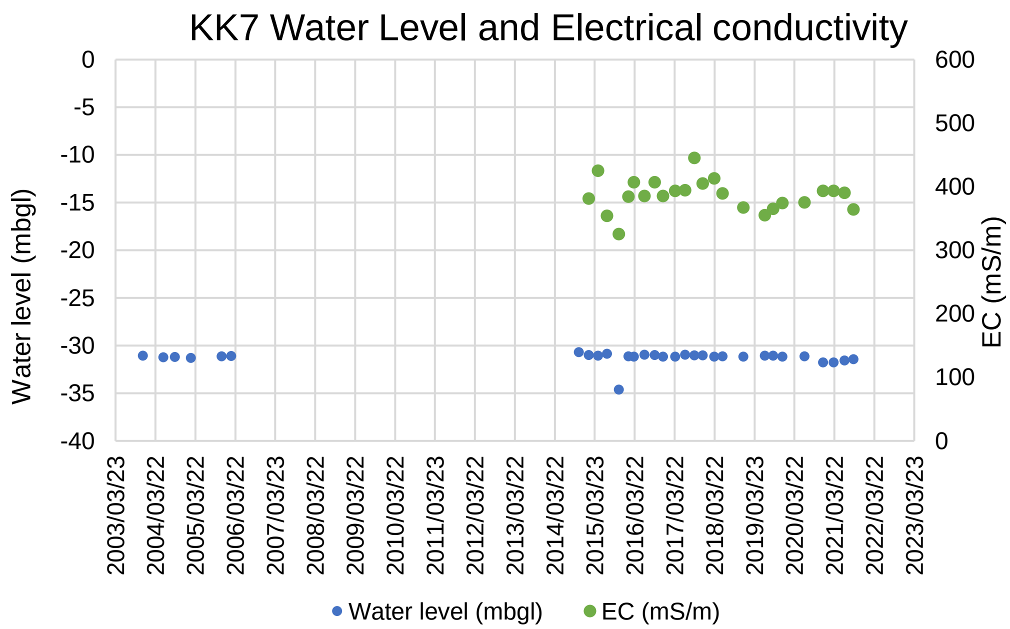


Figure 75: Water level and EC monitoring data for KK7 borehole located in G30H

For the other two DWS monitoring sites, G47857 is located on the boundary between the G30H and G30G catchment. The borehole has been monitored since the early 2000s and displays stable water levels at between 34 and 34.5 mbgl. The data is presented in **Figure 76**.

The other monitoring site is located near the town of Strandfontein. The data is presented in **Figure 77**. This borehole has been monitored by DWS since 1994 and although the data has generally remained very stable, a drop in water level was observed between 2016 and 2021 of just over 2 meters. When the depth of the water level is compared to nearby NGA boreholes, the water levels measured at G33953 are not deep for that area, but the borehole is located adjacent to the Sandlaagte River and thus could potentially be linked to baseflow. The depth of the borehole is 48 meters. The drop in water level at this borehole could not be linked to a specific activity in the area, as according to reports, the town of Strandfontein does not use the boreholes that were drilled for town supply and instead, Strandfontein and Doringbaai receive their water supply from the Olifants River Canal system (Matzikama Municipality, 2020). No WARMS abstraction points have been registered around the town, but it is not improbable that groundwater abstraction is taking place near the borehole.

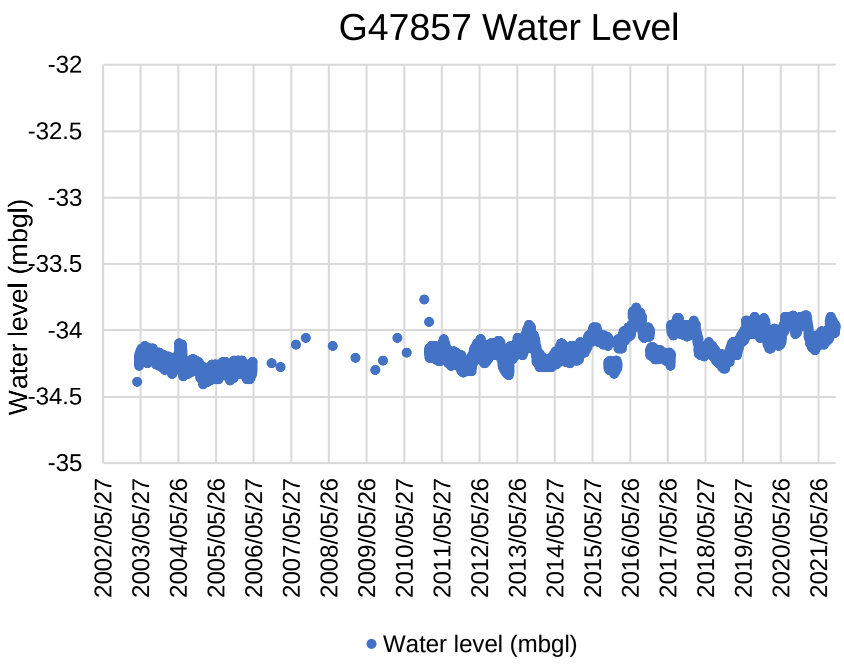


Figure 76: Water level monitoring data for G47857 borehole located in G30H

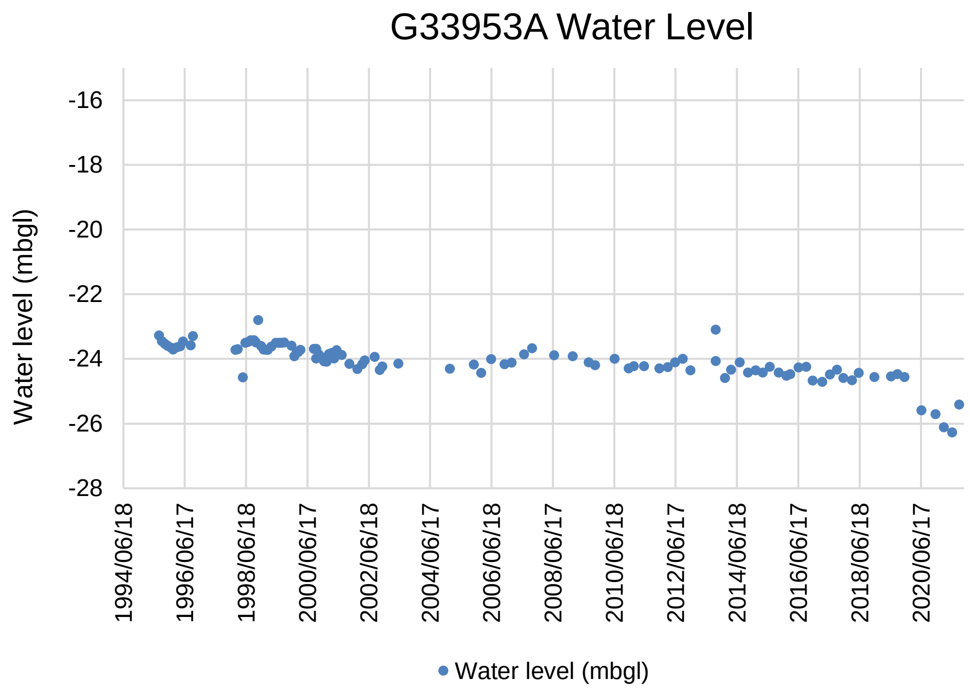
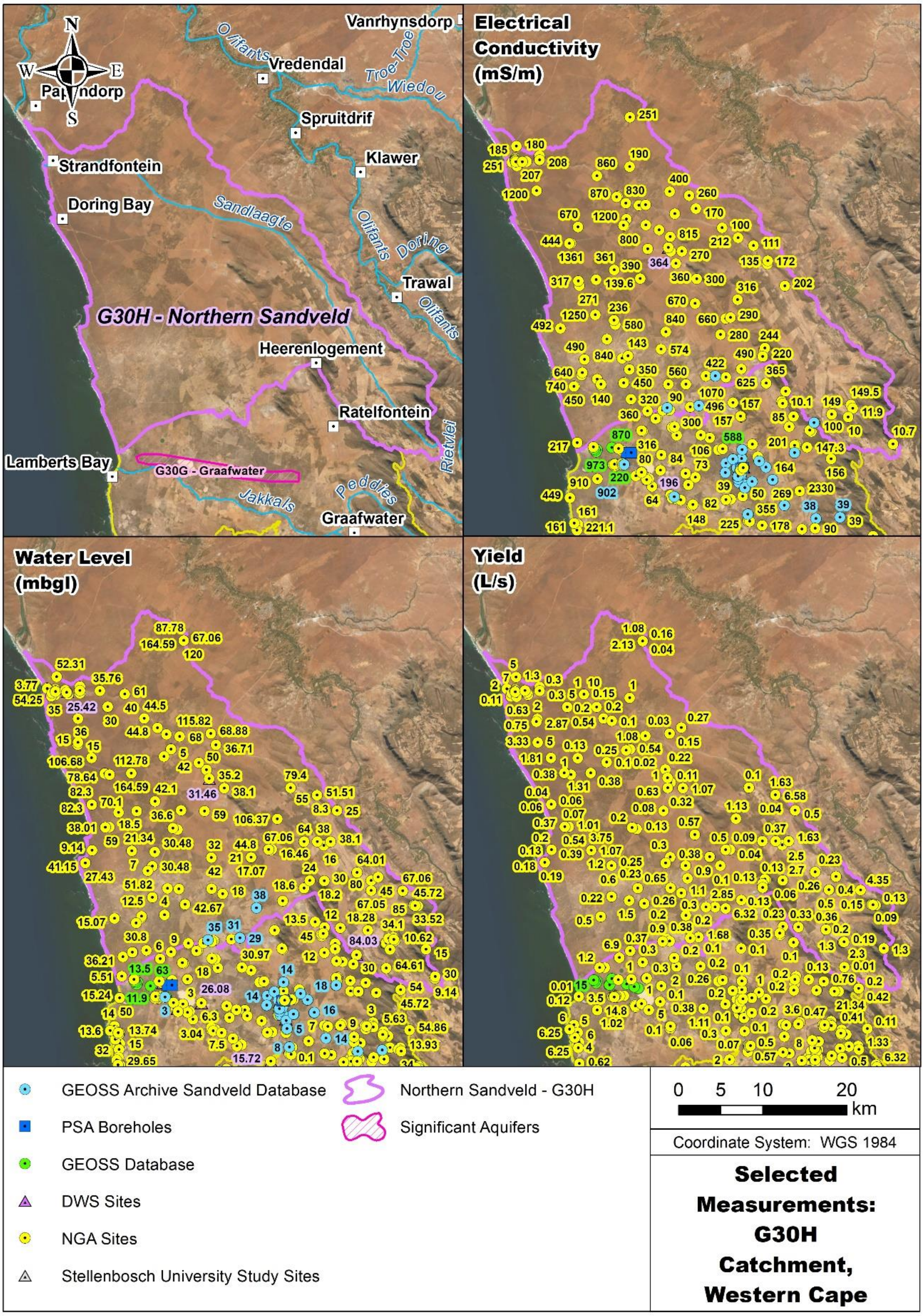


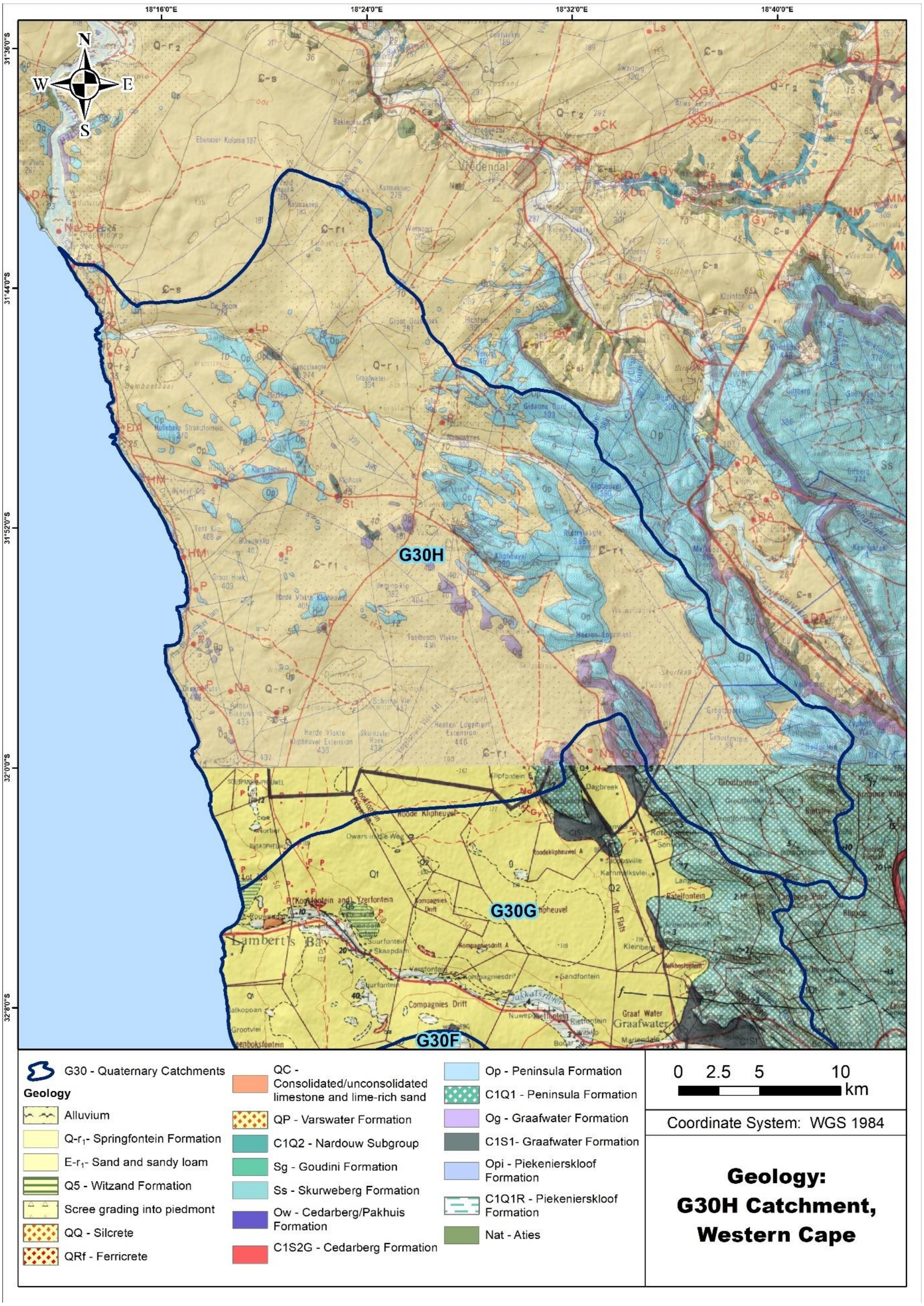
Figure 77: Water level monitoring data for G33953A borehole located in G30H

Table 19: Groundwater Quality analyses, using DWS template (GEOSS Database (2022); DWS data (DWS, 2022 and DWS, 2023))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		5-6 & 9-9.5
Class II	300	600	370	3.5	200	20	400	600		4-5 & 9.5-10
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		<4 & >10
No of samples	36	36	36	36	36	36	36	36	36	36
Median	**42.60**	**853.35**	**268.50**	**0.27**	**66.15**	**2.20**	**424.70**	**95.65**	**44.65**	**7.14**
Average	64.71	1187.42	362.73	0.37	98.79	2.54	580.05	140.10	48.27	6.87
95.00	203.58	3309.05	1013.55	0.80	306.88	6.62	1628.68	367.85	114.85	7.78
5.00	9.15	203.70	64.30	0.10	17.35	0.05	128.25	24.93	2.00	4.09



Map 31: Delineation of the Northern Sandveld - G30H GRU, on satellite imagery and displaying EC, WL and yield values, where data was available .



Map 32: Geological setting of the G30H Catchment (Clanwilliam, 3218 & Calvinia, 3118) (CGS, 1973 & CGS, 2001)

4.2 F60 Catchments

4.2.1 Namaqualand F60E GRU

Grouping: Namaqualand

GRU Name: F60E

Groundwater Use: Very Low

Delineation:

The groundwater unit falls within the quaternary catchment boundaries. 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) are more common.

The geology underlying the GRU has been mapped as calcareous and gypsiferous soil, silcrete and other alluvial deposits overlying the igneous and metamorphosized units of the Gariep Supergroup and the Little Namaqualand Suite in certain areas and the sandstone Peninsula Formation (TMG) in the most southern areas of the GRU (**Map 34**). Very few hard rock formations are exposed in this area and geological boundaries between rock formations and faults are not defined, because of being covered by the quaternary deposits. This GRU displays the transition from sedimentary deposits found in the G30 catchments to the intrusive and metamorphic rock units that dominate the geology of the F60 catchments.

The area is known for heavy minerals, 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. Namaqua sands mine is located in the northern coastal section of the GRU, while the Tormin mine is located in the southern coastal section. Both mines use water for dust suppression and as part of the mining process, but Namaqua Sands uses seawater for this function, while Tormin reportedly uses groundwater. Access to Tormin mine was denied during this study, but Namaqua Sands mine did approve a site visit in April 2022 and made their monitoring data available for this study. Both mines truck or pipe in drinking water.

With regard to other water users, no settlement is located in this GRU. No WARMS sites have been registered, but one farm was identified through the V & V process that noted that they use about 2 200 m^3/a for animal feedlots. No irrigation has been identified, and water is likely mostly only used for animal drinking water and for domestic use where the quality is good enough.

Data on EC, water levels and borehole yields were obtained from the NGA database and is presented in **Map 33**. With regards to water levels, although some shallow water levels have been measured, the reported water level is usually > 40 mbgl and the expected yield is very low > 1 L/s (NGA, 2022).

With regard to the monitoring being done by Tronox Mineral Sands (Pty) Ltd, **Figure 81** displays the positions of the current monitoring boreholes around the mining site. Because the mine is not actively dewatering or abstracting groundwater, the focus of the monitoring is to monitor the potential leachate chemistry of contaminant sources, along with recommended groundwater chemical indicators to define the extent of the contaminant plume, associated with the use of seawater. Trends in water levels are relevant for all contamination plumes where rising water levels over a long period indicate increased groundwater recharge (or hydraulic pressure), likely to be coming from the contaminant source.

The monitoring network of the Mine includes 17 boreholes. Although a few of these are no longer in existence or are dry, most are included in the regular quarterly monitoring round (from 1993 to 2020) when water levels and samples are taken (SRK, 2020). Not all the monitoring data was included in this report, but the data obtained from the mine in April 2022 is available in **Annexure B** (Namaqua Sands). Water levels range from 12 mbgl for boreholes located near the beach wells to around 50 mbgl in the main mining areas. An increase in EC has been observed in some boreholes and the SRK model predicts that the pollution plume would move towards the west, but is expected to remain within the approved mining rights area, and that which extends beyond it has very low concentrations (slightly above background EC).

The GNS3 borehole is located near the Groot Goerap River and the data is displayed in **Figure 78**. The sporadic increases and decreases in EC have been attributed to the mining and backfilling occurring 500 m of the borehole. Water levels have dropped slightly over time, and EC has increased since 2015 quite dramatically, but this increase does correspond well with what has been modelled (SRK, 2020). The situation is however sensitive, and it is imperative that the mine continue its scheduled monitoring and updating its numeric model.

The GNS12 borehole is located in the east mine area and the data is presented in **Figure 79**. Water levels remain fairly consistent, displaying a slight drop of 2 m from 2005 to 2020. It has been noted by SRK (2020) that borehole GNS12 has low concentrations when compared to some of the other boreholes and is thought to be representative of background water concentration.

The GNS9 borehole is located in the west mine area and the data is presented in **Figure 80**. Borehole GNS9 was drilled to monitor groundwater mounding and contaminant plume migration from these mining activities and seawater introduction in the mining area located closest to the coast and where the evaporation bonds are held. Water levels in this borehole remain relatively consistent, displaying an average 1 m change from 2005 to 2020. EC has increased by approx. 1000 mS/m over the past 15 years, now obtaining similar salinity levels to that of seawater. SRK (2020) noted that EC concentrations are expected to remain consistent or decrease over time due to the dilution effect from natural recharge.

Some water quality results have been obtained from Tronox Mineral Sands in April 2022 and is presented in **Annexure B** (Namaqua Sands). The groundwater sampling results was also was analysed with the other water quality datasets obtained through DWS and the GEOSS database to display the range of water quality that can be expected in this area (**Table 20**). The natural water quality is very poor and extremely enriched in multiple elements such as chloride, sodium, and sulphate (**Table 20**).

As noted above, some of the boreholes monitored by the mine is located near the Groot Goerap River. Because no samples are available for the surface water of the river (due to it reportedly not having flowed since the start of the mine), the surface and groundwater could not be compared.

EC values for the boreholes being monitored by the mine range from 545 – 4310 mS/m. The 545 mS/m is the lowest observed in all the monitoring boreholes from the data the mine provided. GNS 12 is located in the east mine, while GNS 9, GNS 11S and GNS 14 are all located near the west mine. All of the boreholes display water quality of very poor water quality that could cause health problems if consumed. Some of the boreholes display water salinity levels similar to that of seawater. Although the background salinity levels are very high, the pollution plume created by the mining activities and the use of seawater is noticeable. However, the mine is following the conditions listed in its Water Use Licence to continue to monitor and update its numerical model to allow DWS to manage the extent of the activity. In areas such as these, although water levels could be below the proposed mining activities and even though the background quality of the water is poor, mining activities still have the capacity to detrimentally impact the groundwater.

It is thus vital that any mining activity in these areas must if approved, continually monitor, and model the groundwater and their effects on it. It is recommended that any proposed mining activity, or any other proposed activity that could impact the groundwater, be closely evaluated, based on site-specific conditions, before any decision is made to approve such an activity.

Table 20: Groundwater Quality analyses for F60E, using DWS template (WMS database) (DWS, 2023) and (SRK, 2020))

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		5-6 & 9-9.5
Class II	300	600	370	3.5	200	20	400	600		4-5 & 9.5-10
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		<4 & >10
No of samples	13	13	13	5	13	13	13	13	5	13
Median	**461.00**	**8812.80**	**2565.00**	**3.08**	**620.00**	**1.13**	**4289.90**	**1264.40**	**112.50**	**7.50**
Average	486.63	9206.66	2595.85	2.74	724.12	2.54	4568.46	1340.04	123.20	7.69
95.00	1047.80	17630.12	4686.00	3.64	1546.60	9.96	8138.70	2409.52	190.78	8.74
5.00	40.80	2537.42	802.58	1.27	82.40	0.01	1328.22	333.98	50.20	7.02

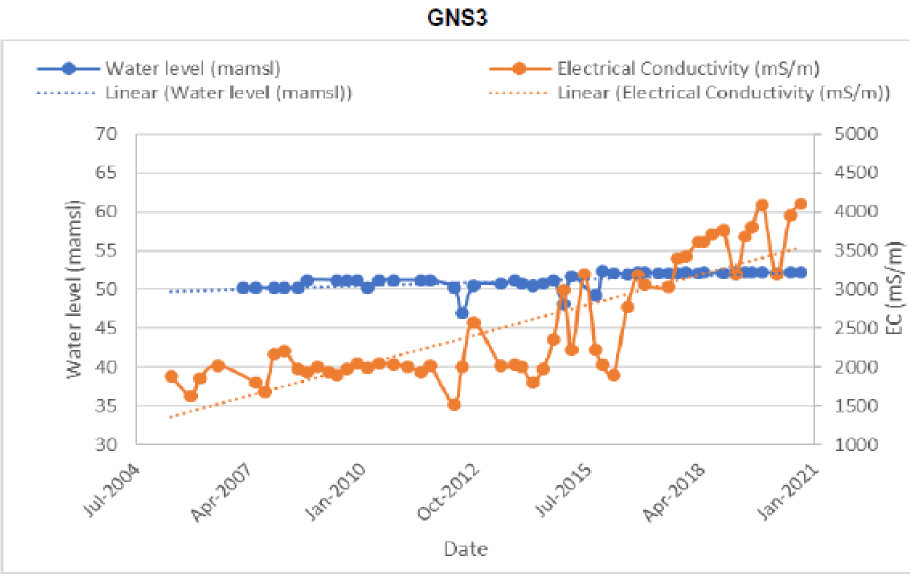


Figure 78: Water level and EC monitoring data for GNS3 borehole located in F60E (SRK, 2020)

GNS 3 is located next to the Groot Goerap River and is actually located in the F60E GRU, but it was decided to discuss the main mining activities and monitoring in one GRU section, and because the majority of the activities occur in F60E, the data was included in this GRU discussion.

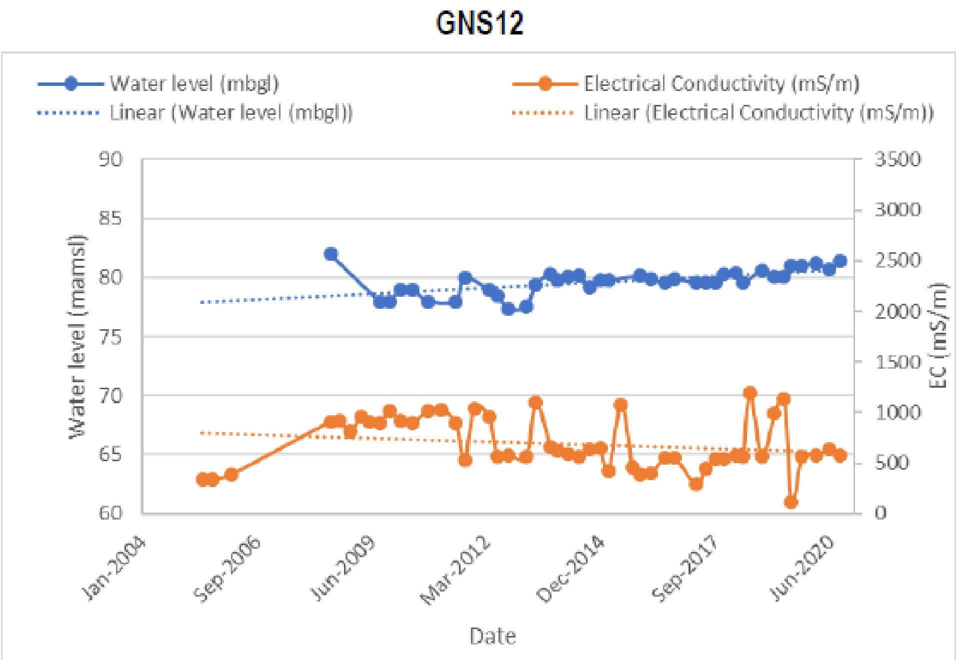


Figure 79: Water level and EC monitoring data for GNS12 borehole located in F60E (SRK, 2020)

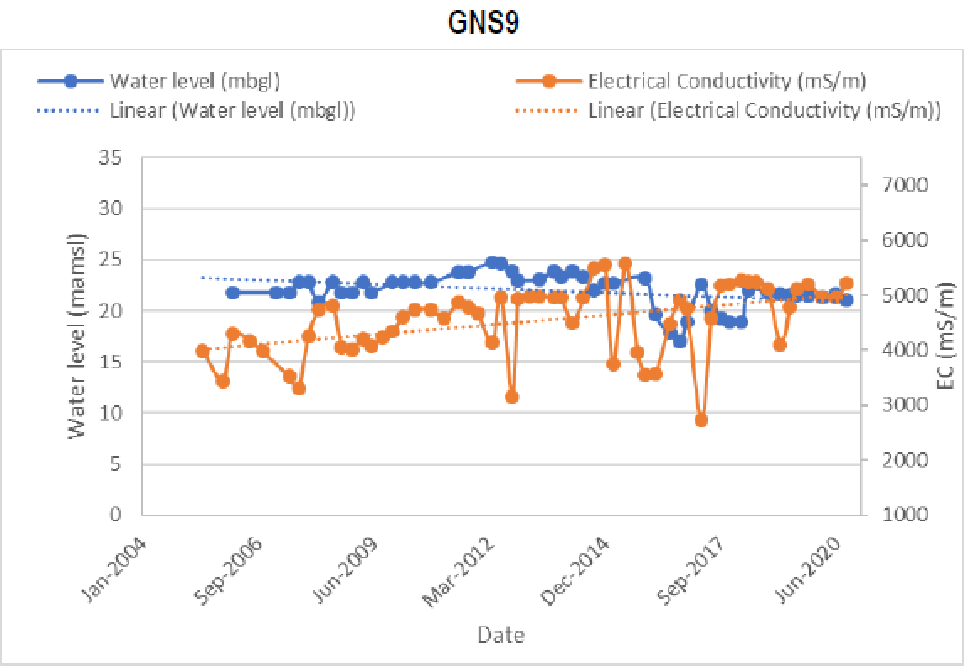


Figure 80: Water level and EC monitoring data for GNS9 borehole located in F60E (SRK, 2020)

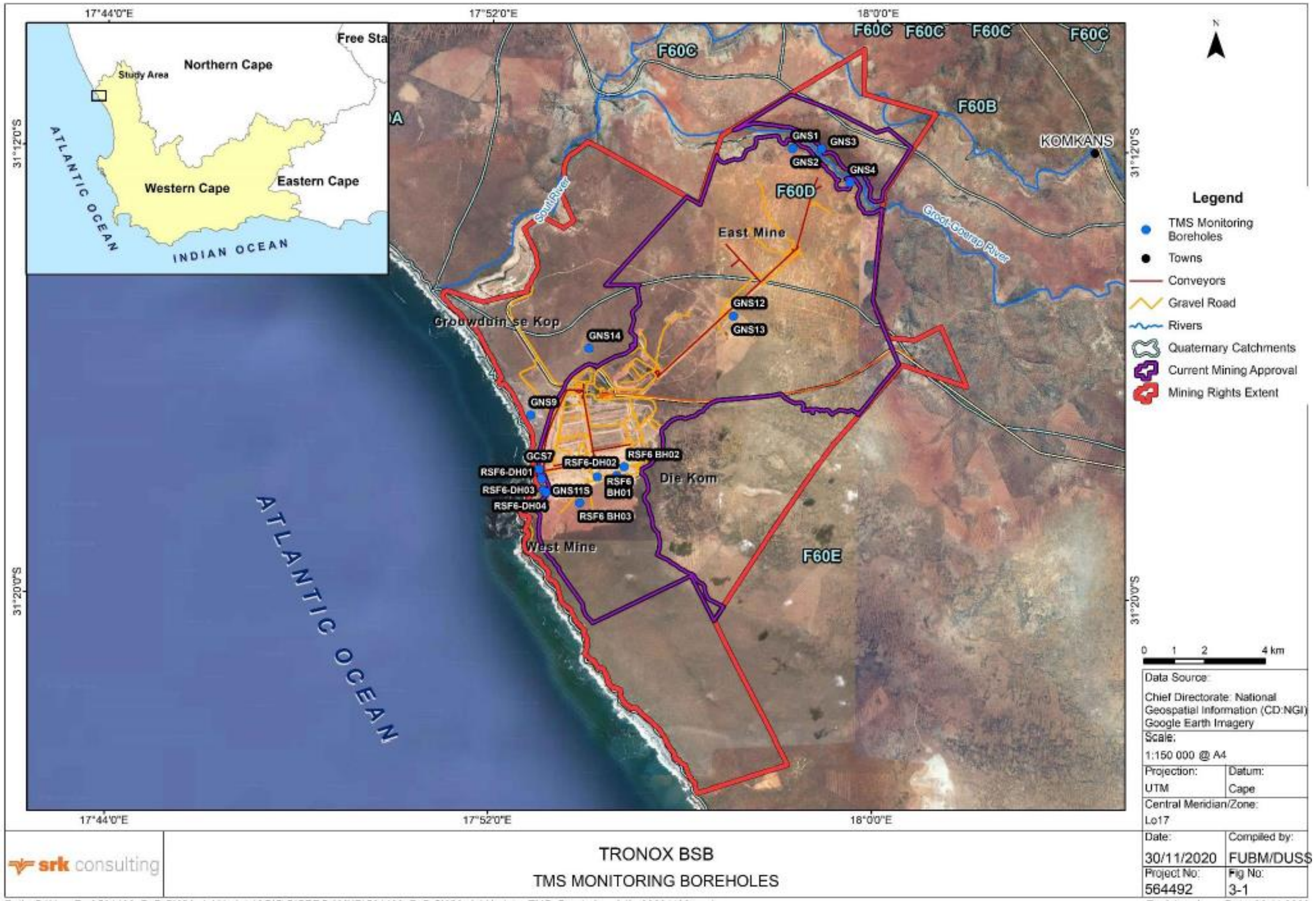
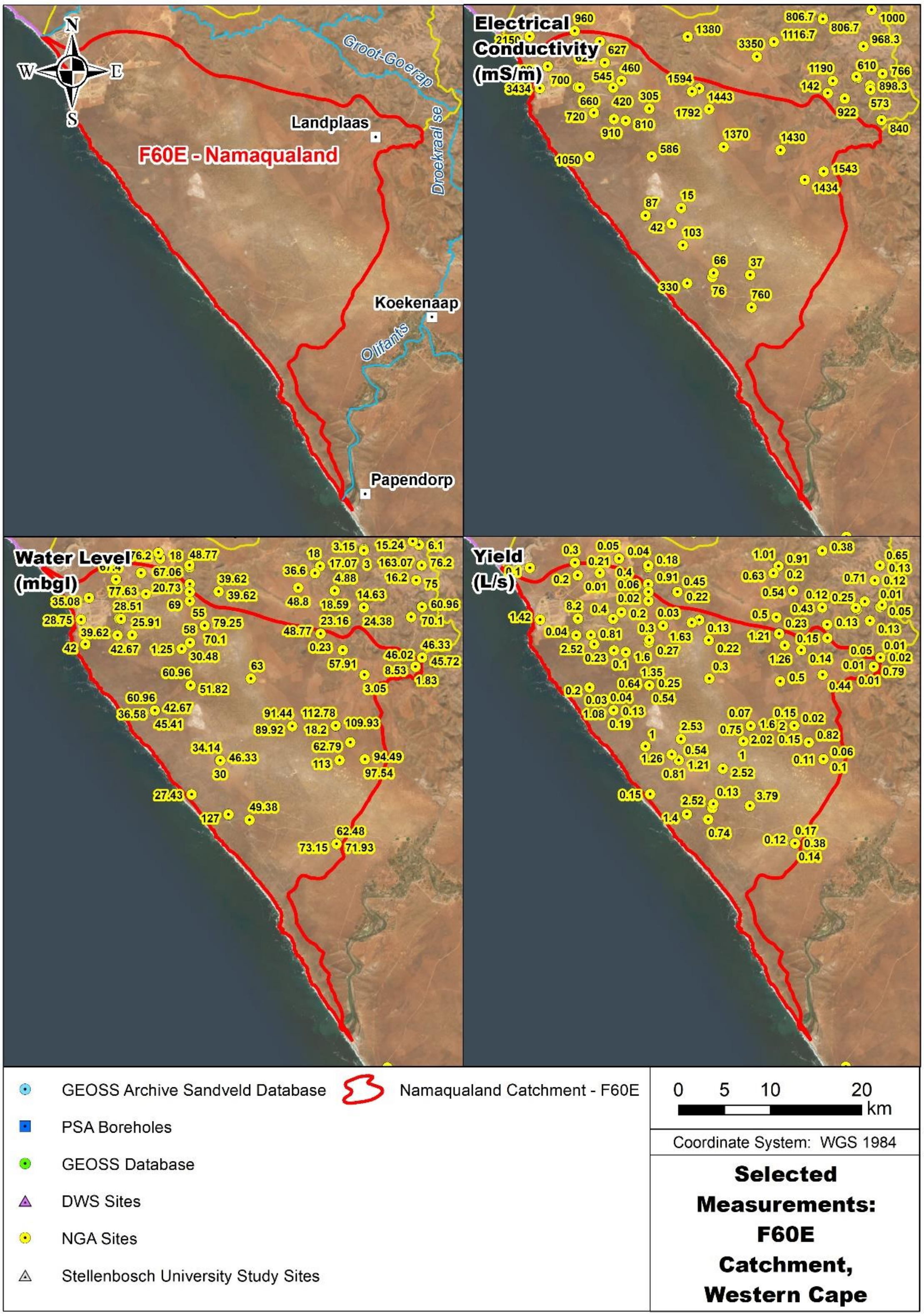
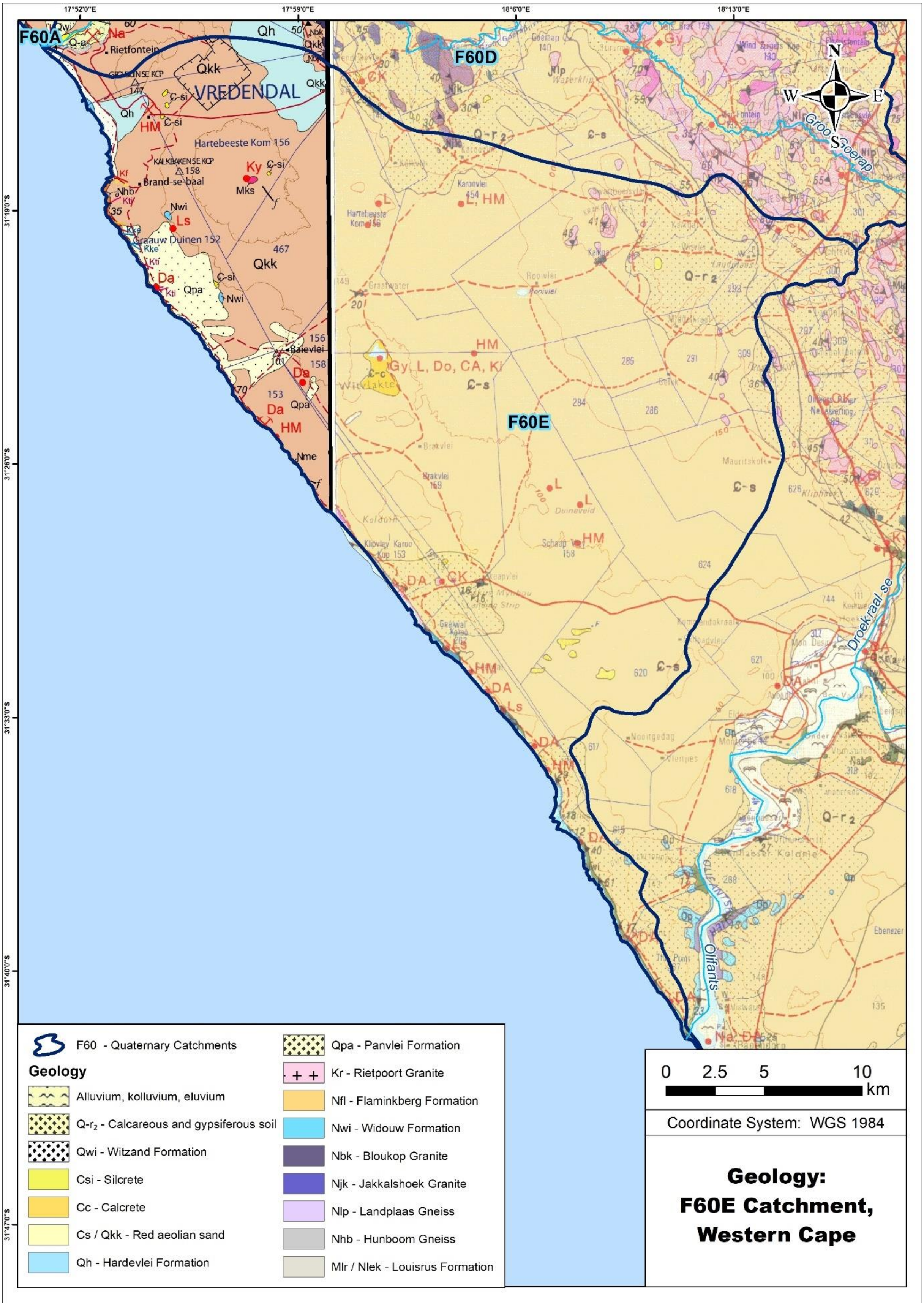


Figure 81: Tronox Mineral Sands monitoring network around the Namaqua Sands mine, located in F60E



Map 33: Delineation of the Namaqualand- Southern F60E GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 34: Geological setting of the F60E Catchment (Calvinia, 3118 and Garies, 3017) (CGS, 2001 and CGS, 2010)

4.2.2 Groot-Goerap & Sout - F60D GRU

Grouping: Groot-Goerap & Sout

GRU Name: F60D

Groundwater Use: Very Low

Delineation:

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Groot Goerap and lower Sout River. 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 (**Map 36**). There are also SE-NW trending fault structures cross-cutting the igneous formations towards the eastern portion of the GRU.

There is very little perceived groundwater abstraction. Mostly dryland and livestock farming and some mining activity (Namaqua Sands) towards the coast. As noted in the F60E GRU discussion, some of the GNS monitoring boreholes as well as a portion of the east mine does fall in F60D, but the graphs and water quality data were included in the F60E GRU discussion. Please see the previous section for the relevant data that could be obtained for boreholes located near the Groot Goerap River.

The NGA database does note multiple very low-yielding boreholes with poor quality. The data that could be obtained is displayed on **Map 35**. Groundwater levels range between 10 – 163 mbgl, with an average water level of 37.63 mbgl. Borehole yields are very low, with an average of 0.3 L/s. The only groundwater abstraction registered on WARM is linked to the mine, which noted that they do not actively abstract groundwater, but seawater from a borehole located on the beach.

With regards to the quality of the groundwater found in F60D, the data that could be obtained from the Water Management System (WMS) (DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 21**).Only 5 samples have been included for this catchment, but from the data it was clear to note that the natural groundwater quality for this area, can be classified as poor in terms being used for human consumptions. Even the 5th percentile for EC and chloride is high and this would limit the groundwater`s potential uses, nether the less, this is the natural groundwater quality on which the ecosystem is dependent on and should be protected against contaminations and water depletion.

Table 21: : Groundwater Quality analyses for F60D, using DWS template (WMS database) (DWS, 2023)

	Ca (mg/l)	**Cl (mg/l)**	**EC (mS/m)**	**F (mg/l)**	**Mg (mg/l)**	**NO3+NO2 (mg/l)**	**Na (mg/l)**	**SO4 (mg/l)**	**TAL**	**pH**
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	5	5	5	5	5	5	5	5	5	5
Median	**288.70**	**4249.60**	**1255.00**	**2.00**	**270.70**	**0.59**	**2136.50**	**592.20**	**180.40**	**7.83**
Average	254.56	3955.46	1189.60	1.99	284.48	3.93	2079.22	606.46	161.60	7.80
95.00	372.24	4786.36	1432.00	2.53	429.14	12.95	2609.34	763.10	204.50	8.04
5.00	116.84	2664.02	808.00	1.58	161.86	0.02	1454.82	407.30	97.66	7.56

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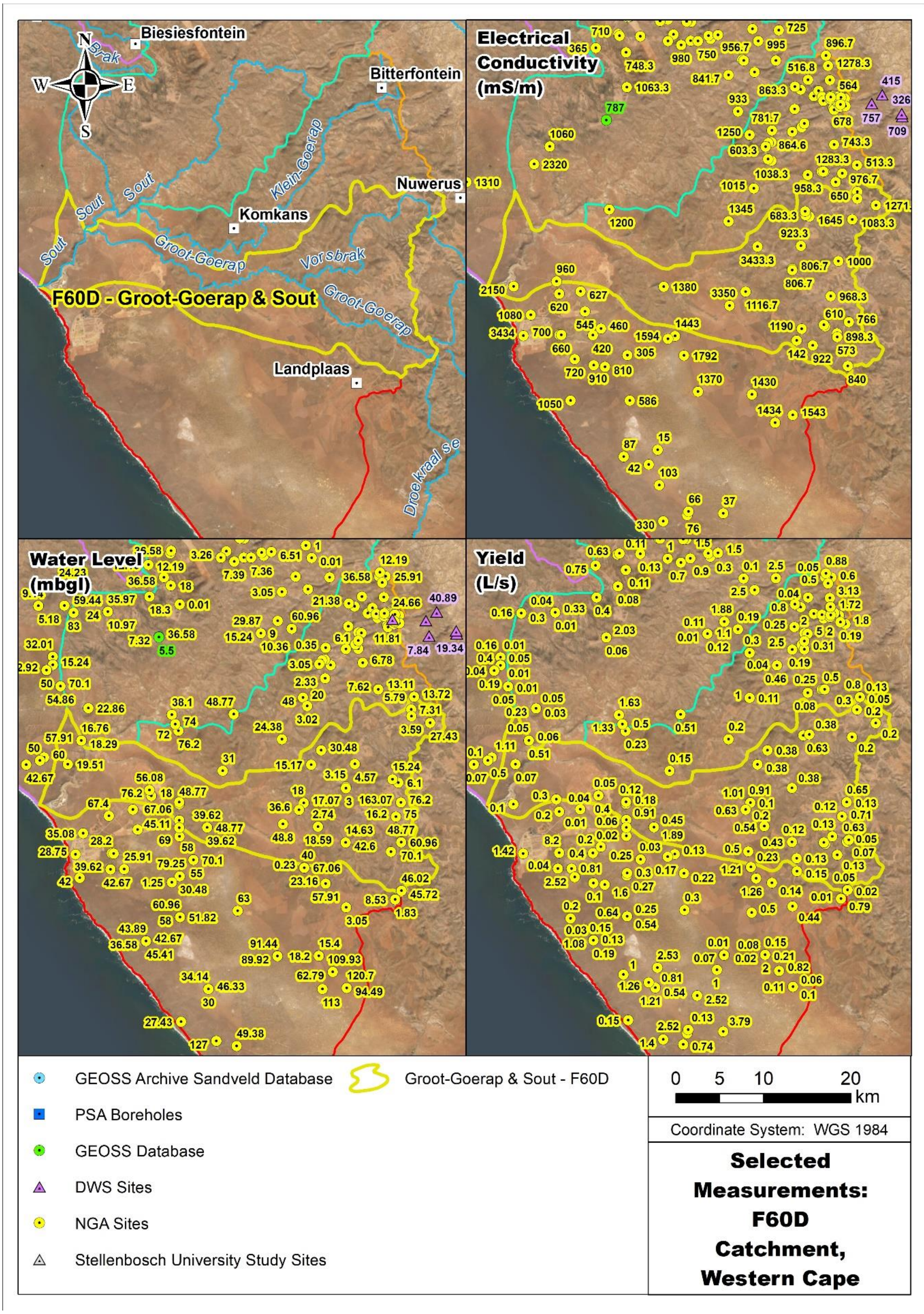
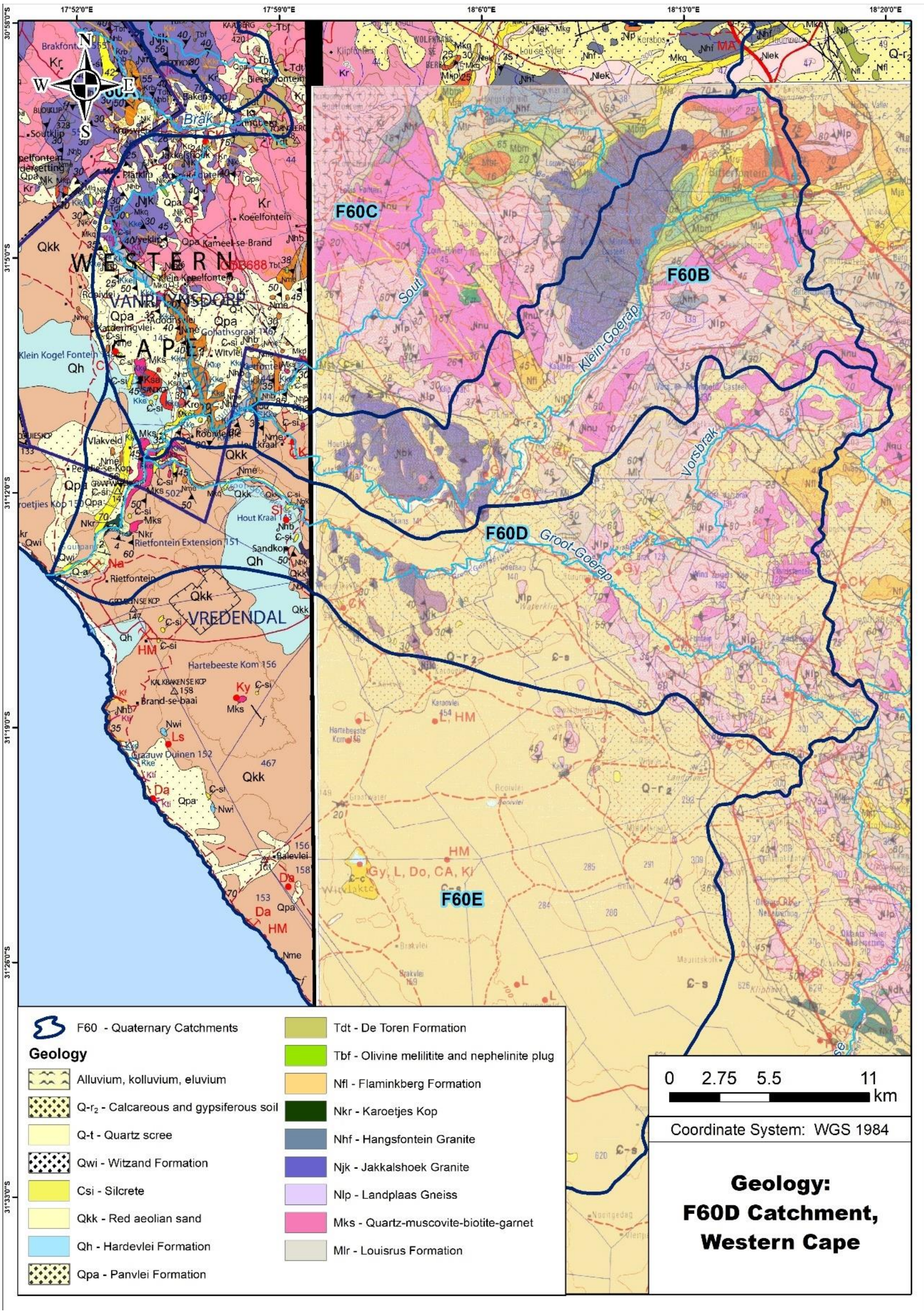


Map 35: Delineation of the Groot-Goerap & Sout- F60D GRU, on satellite imagery and displaying EC, WL and yield values, where data was available .



Map 36: Geological setting of the F60D Catchment (Calvinia, 3118, Garies, 3017 & Loeriesfontein, 3018) (CGS, 2001; CGS, 2010 & CGS, 2010)

4.2.3 Klein-Goerap - F60B GRU

Grouping: Klein-Goerap

GRU Name: F60B

Groundwater Use: Low to moderate (around Bitterfontein)

Delineation:

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Klein Goerap River. Like with other F60 catchments, the 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. SE-NW trending fault structures also cross-cut the igneous formations (**Map 38**).

There is very little perceived groundwater abstraction and no abstraction has been registered on WARMS. The area is dominated by dryland and livestock farming. When visiting the area in April 2022, it was noted that only sheep farming could be observed in this area. Some data for this area is available through the NGA database and the information that could be obtained has been displayed in **Map 37**. The data is also available in **Annexure A**.

The average water level was 21 mbgl, while the average yield observed from the NGA data was 0.77 L/s (**Annexure A**). The true yield of the aquifers for most of this GRU is expected to be lower as when water users were contacted in 2022, they reported that any boreholes with a yield exceeding 0.01 L/s are seen as a successful borehole.

The main abstraction occurs in the northeast corner of the GRU and across the quaternary boundary in E33D. This group of boreholes are known as the Bitterfontein boreholes and groundwater is pumped from the boreholes, to the desalination plant at Bitterfontein. 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. According to the municipality, they historically had 11 production boreholes, with most yields varying between 0.5 and 3 L/s and with 3 boreholes that have a yield exceeding 6 L/s (Matzikama Local Municipality, 2022). From those, 7 are currently being used. The exact reason behind not using some boreholes could not be confirmed with the municipality, although they did note that some borehole are “dry” and they also noted that they are currently only able to use one of the reportable higher-yielding boreholes.

DWS does monitor water levels at boreholes near the Bitterfontein boreholes, and although not all the graphs generated from this data have been included in this report, they are available in **Annexure B** (Bitterfontein Monitoring). It is important to note that some of the production boreholes are currently installed with some form of telemetry water level data logging, but the data could not be obtained from the Matzikama Municipality during the course of this study. With regards to the sites being monitored by DWS, the only borehole still located within the F60B GRU is G37382. The data is displayed in **Figure 82** and the borehole has been monitored since 1985 and displays a rise in water level from approx. 16 mbgl to 8 mbgl.

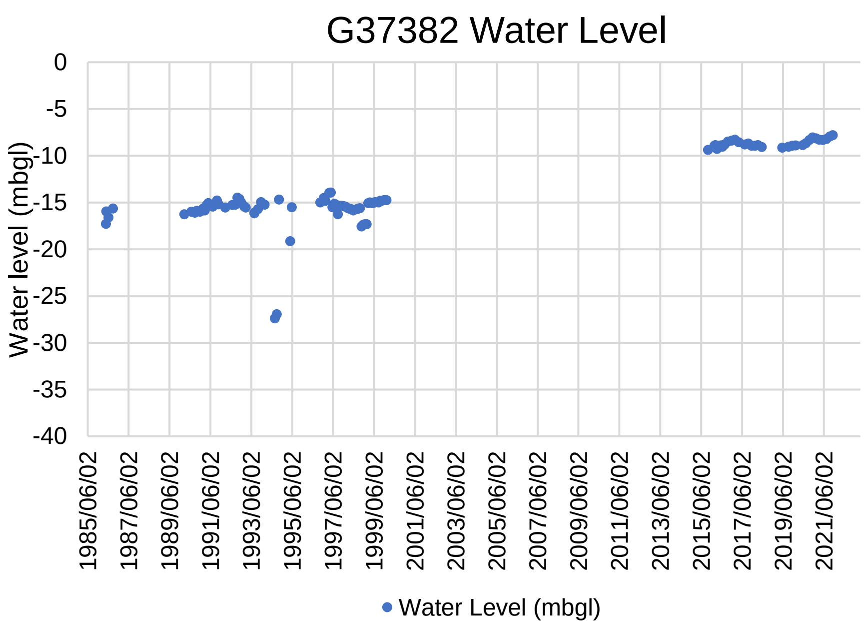


Figure 82: Water level monitoring data for G37382 borehole located in F60B

G31317 and G31281 fall in the E33D. Water levels have remained very stable in G31317 since 2015, when monitoring at this borehole started (**Figure 83**), while G31281 displays a drop in water level (**Figure 84**). The trends observed in the DWS boreholes could not clearly be linked to the production boreholes for the municipality, as the municipality noted that they do have issues with some of the boreholes (Matzikama Local Municipality, 2022). It is recommended that the monitoring data from the actual production boreholes be obtained and incorporated into the DWS monitoring system. Because these boreholes and the desalination plant supply all the settlements and small towns in the area with their only source of water, it is vital that the sustainability of the system be monitored.

A last recommendation for this municipal setup would be to monitor groundwater quality surrounding the evaporation dams linked to the desalination plant. The municipality noted that this is currently not being done and it would be recommended that sampling in a up to 1km radius around these dams should be done to monitor the potential pollution risk these dams pose.

With regards to the quality of the groundwater found in F60B, the data that could be obtained from the Water Management System (WMS) (DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 22**). The average EC for this GRU is 792mS/m, although some samples show a much better quality (EC <200 mS/m). These areas are targeted for domestic supply, but for large portions of this GRU, the natural groundwater cannot be used for human consumption. People outside of settlements make use of rainwater as their main drinking water supply, while the settlements use the Bitterfontein wellfield as discussed above.

Table 22: Groundwater Quality analyses for F30B, using DWS template (WMS database) (DWS, 2023)

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	71	71	71	71	71	64	64	71	71	71
Median	**152.20**	**2005.30**	**656.00**	**1.42**	**187.10**	**1.54**	**1034.44**	**394.00**	**174.60**	**7.77**
Average	200.12	2484.78	792.93	1.47	237.07	5.51	1304.90	460.51	166.79	7.63
95.00	507.85	4896.65	1415.00	2.55	551.00	25.22	1926.47	911.93	285.55	8.39
5.00	50.45	445.00	146.00	0.53	54.50	0.02	698.06	60.00	52.40	6.98

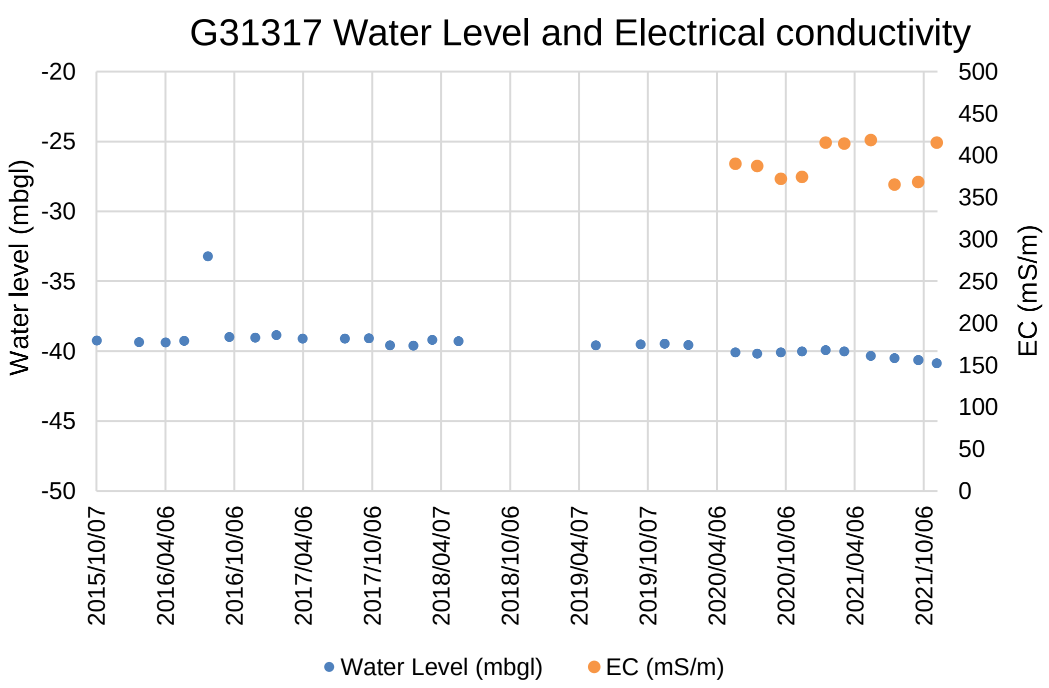


Figure 83: Water level and EC monitoring data for G31317 borehole located in E33D

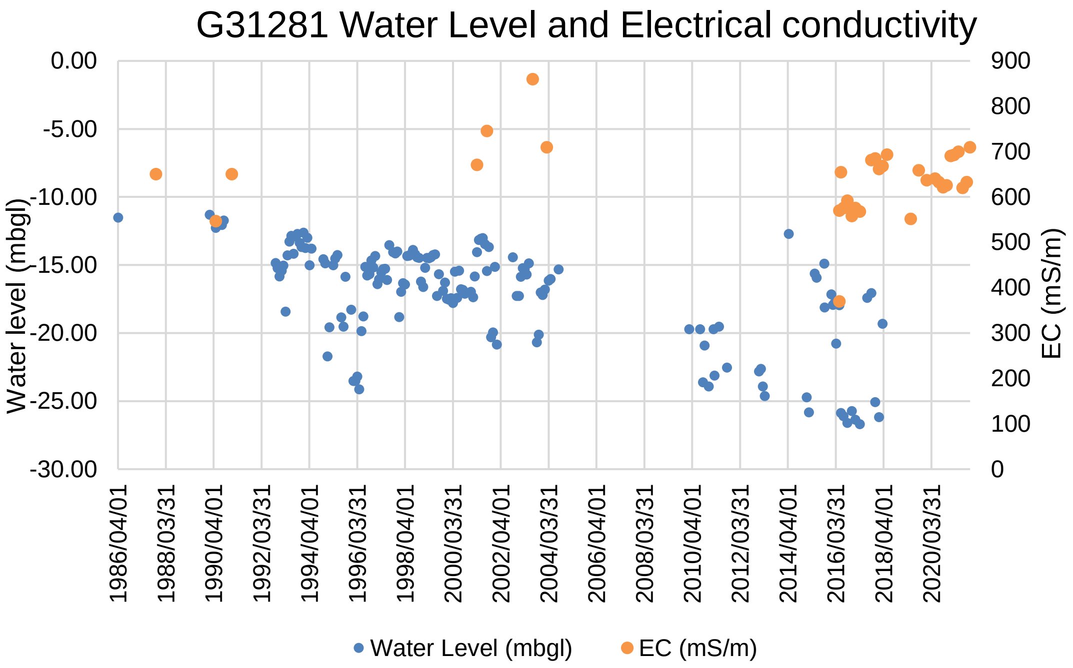
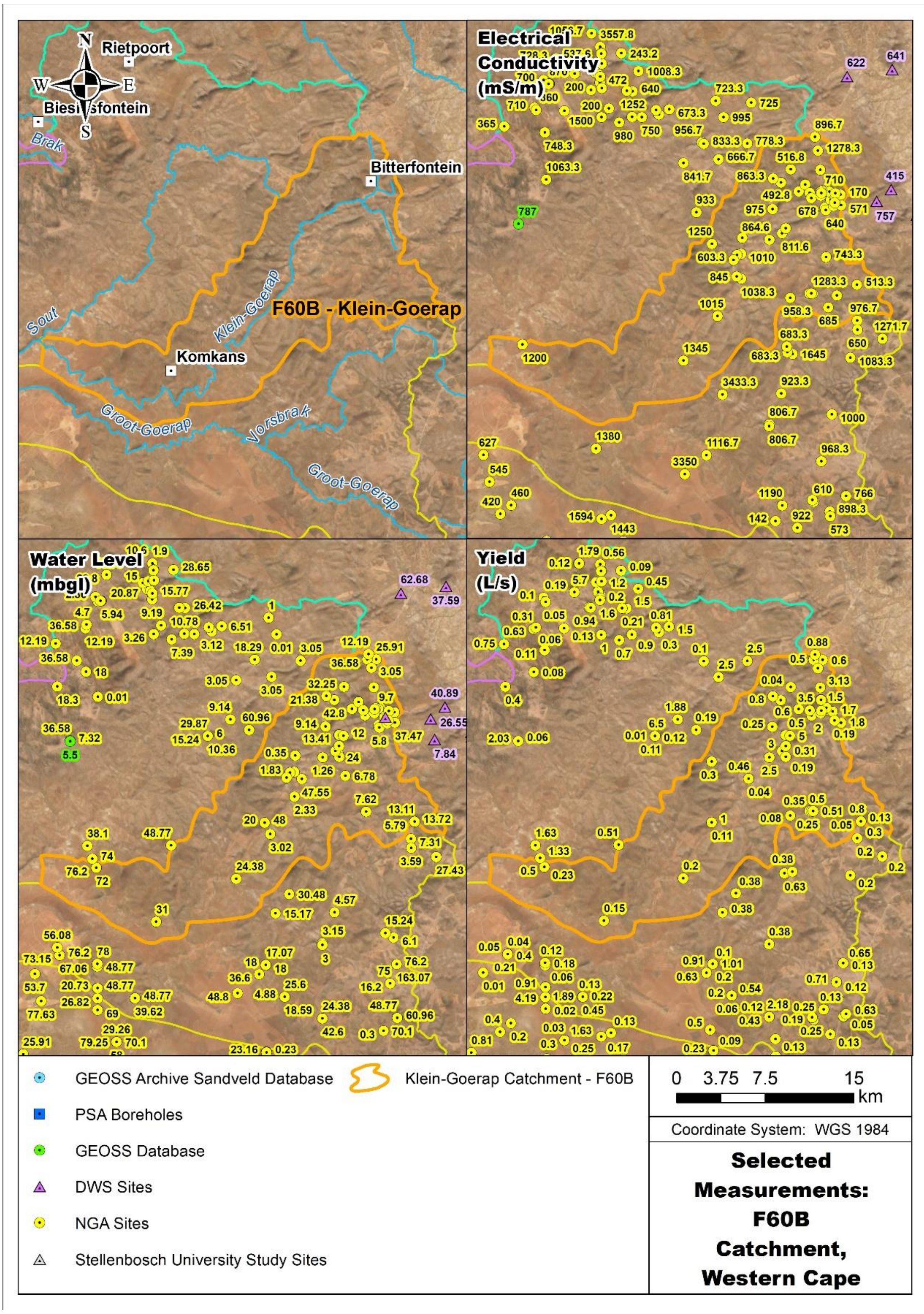
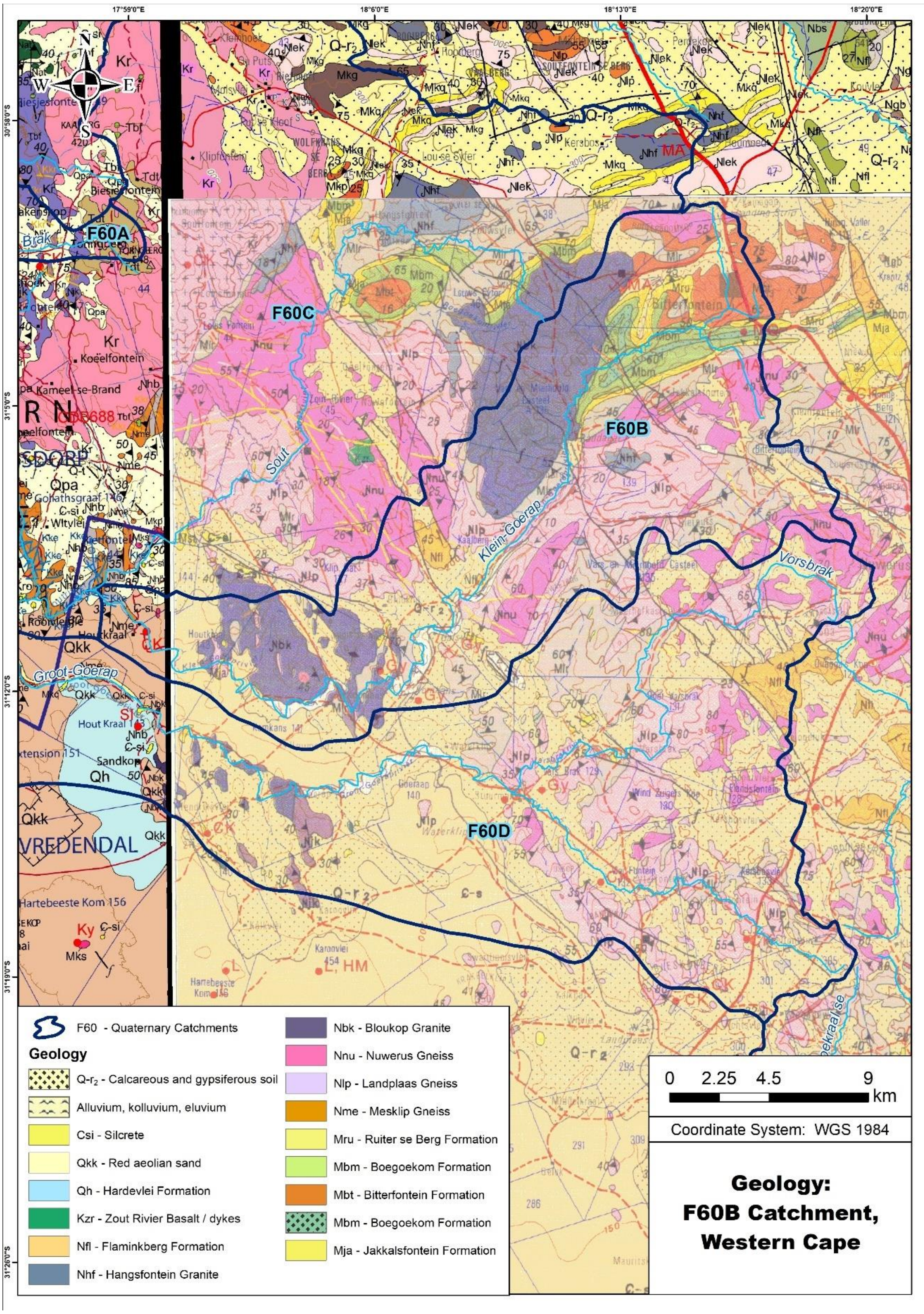


Figure 84: Water level and EC monitoring data for G31281 borehole located in E33D



Map 37: Delineation of the Klein-Goerap - F60B GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 38: Geological setting of the F60B Catchment (Calvinia, 3118, Garies, 3017 & Loeriesfontein, 3018) (CGS, 2001; CGS, 2010 & CGS, 2010)

4.2.4 Sout - F60C GRU

Grouping: Sout

GRU Name: F60C

Groundwater Use: Very Low

Delineation:

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 SE-NW trending fault structures that cross-cut the igneous formations towards the southwest of the GRU (**Map 40**).

No DWS monitoring sites are found within this area and the information obtained came from the NGA database. The information that could be obtained has been displayed in **Map 39**. The data is also available in **Annexure A**. The data displays generally shallow water levels, with an average of 15.3 mbgl, although some boreholes with water levels deeper than 60 mbgl were observed. The average yield from the NGA boreholes was 0.88 L/s and the average quality was 853 mS/m. The general yield is expected to be lower, because most boreholes display very low yields (< 0.3 L/s), but because some higher-yielding boreholes (2 – 3 L/s) have been documented in the north section of the GRU, around Rietpoort, it skews the average. The water quality information is also clustered in the northern section of the GRU, and quality in the central and southern sections is reportedly poorer.

Because such limited information is available for this area, a hydrocensus of the F60 catchments was done in April 2022. The Bitterfontein and Namaqua Sands mines were visited, but the main focus was to obtain more information for the F60C and F60A areas.

During the hydrocensus, it was found that groundwater abstraction in the central and southern portions of F60C is indeed very low. All farms that were visited noted that the groundwater cannot be used for drinking purposes, although it is used for animal drinking water if the quality permits as well as for non-drinking domestic purposes. Drinking water for animals and people is obtained from rainwater and mist collected. Rainwater capturing systems were observed for most structures, including sheds and chicken coops, on these farms. Water is also abstracted from natural indentations in the granite hills (**Figure 85**).

Figure 85: Rain and mist water harvesting from granite indentations in F60C

Farmers in this area confirmed that a successful borehole is seen as anything exceeding 0.1 L/s and that water levels vary between very shallow and deep (>60 mbgl). Quite a few springs were also observed. Some were used for drinking water for animals, while others were termed "too salty". When the springs were discussed, people in the area reported that they have not observed a drop in spring flow for at least the last 30 years, although spring flow decreased during years of drought (**Figure 86**). Some springs had crab shells in the water, proving that aquatic life is also found in these wetlands. Because these natural springs are still mostly undisturbed when compared to those in the G30 catchment, it can be assumed that the groundwater natural flow regimes are still close to reference conditions in these areas.

Figure 86: Natural springs in F60C, spring on left used for animal drinking water, while spring on right did not display any signs of being used even by local wildlife

With regards to the quality of the groundwater found in F60C, the data that could be obtained from the Water Management System (WMS) (DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 23**). From the results, it is clear that the natural groundwater quality for this area is enriched in chloride and sodium and EC values exceeding 1000 mS/m should be expected. Some high nutrient levels were also observed, but these seem isolated and potentially linked to human activity and not the natural systems.

Table 23: Groundwater Quality analyses for F30C, using DWS template (WMS database) (DWS, 2023)

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		**5-6 & 9-9.5**
Class II	300	600	370	3.5	200	20	400	600		**4-5 & 9.5-10**
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		**<4 & >10**
No of samples	32	32	32	32	32	32	32	32	32	32
Median	**142.30**	**2462.85**	**765.00**	**1.08**	**195.45**	**0.16**	**1280.50**	**361.90**	**103.40**	**7.18**
Average	184.09	2705.69	838.17	1.22	220.45	3.30	1344.30	404.71	101.19	7.20
95.00	385.55	5112.41	1543.60	2.33	435.82	13.71	2453.87	670.39	202.94	7.83
5.00	48.39	635.55	223.76	0.38	53.96	0.02	336.22	109.31	11.15	6.57

During the hydrocensus, multiple farmers reported that the best quality water is found against granite and other igneous hillsides, known as "koppies". They noted that although higher yields can be obtained when drilling along drainage valleys or dyke structures, the quality is usually to poor to allow the water to be used. For boreholes drilled against hillsides, the yield is usually poor (reportedly around 0.1 L or less), but the quality is usually acceptable for domestic and agricultural use. After rain events, the water in these shallow boreholes has been reported to experience a dramatic change in quality a day or two after the rain event occurred. The water quality would then slowly degrade over time, but would still represent the "freshest" water to be found in the area. It is thus hypothesized that these hill-side boreholes target the water found in the uppermost unconsolidated material, known as the regolith, thus abstracting water before it could enter deeper into the crystalline rock aquifer, where the flow slows down allowing for increased interacting with the surrounding minerals, creating more mineral rich, "salty" water. This aquifer comprised of weathered material has been used to describe groundwater systems in the northern Namaqualand (Titus, 2003, Friese et al., 2006 Pieterson et al., 2009) and seems to also describe the systems observed during this study in the southern Namaqualand (F60). Although this type of recharge (runoff from koppies recharging the regolith) is not generally seen as localised recharge, for the purpose of this study, these areas will be termed as "recent localised recharge".

Pieterson et al. (2009) noted that for the Namaqualand aquifers systems, although they are controlled and influenced by the underlying geology of igneous and metamorphic rocks and its deformation history or structural evolution, the weathering of those units plays a very important role. Together with Karst, intergranular and fractured crystalline bedrock aquifers, the regolith can also be classified as an aquifer (Titus, 2003, Friese et al., 2006 Pieterson et al., 2009). They noted that weathered regolith is known to extend to greater depths in strongly fractured terrain and that arid regions, like Namaqualand, are characterized by relatively thin saturated regolith, which is generally present just above deeper groundwater levels. This aquifer system is presented in **Figure 87**. Although these regolith aquifers are not high yielding, they are very important to the local water users, as apart from rain and mist water collection, these boreholes are their only other source of usable water.

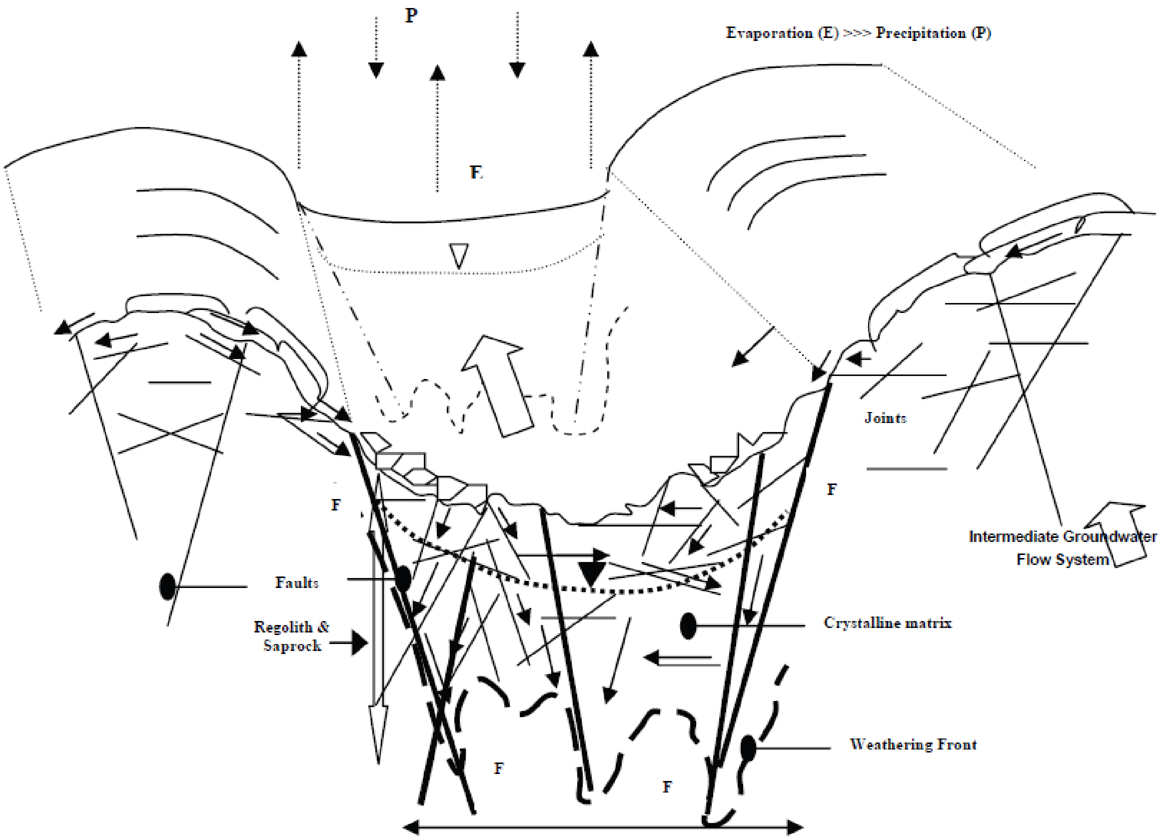
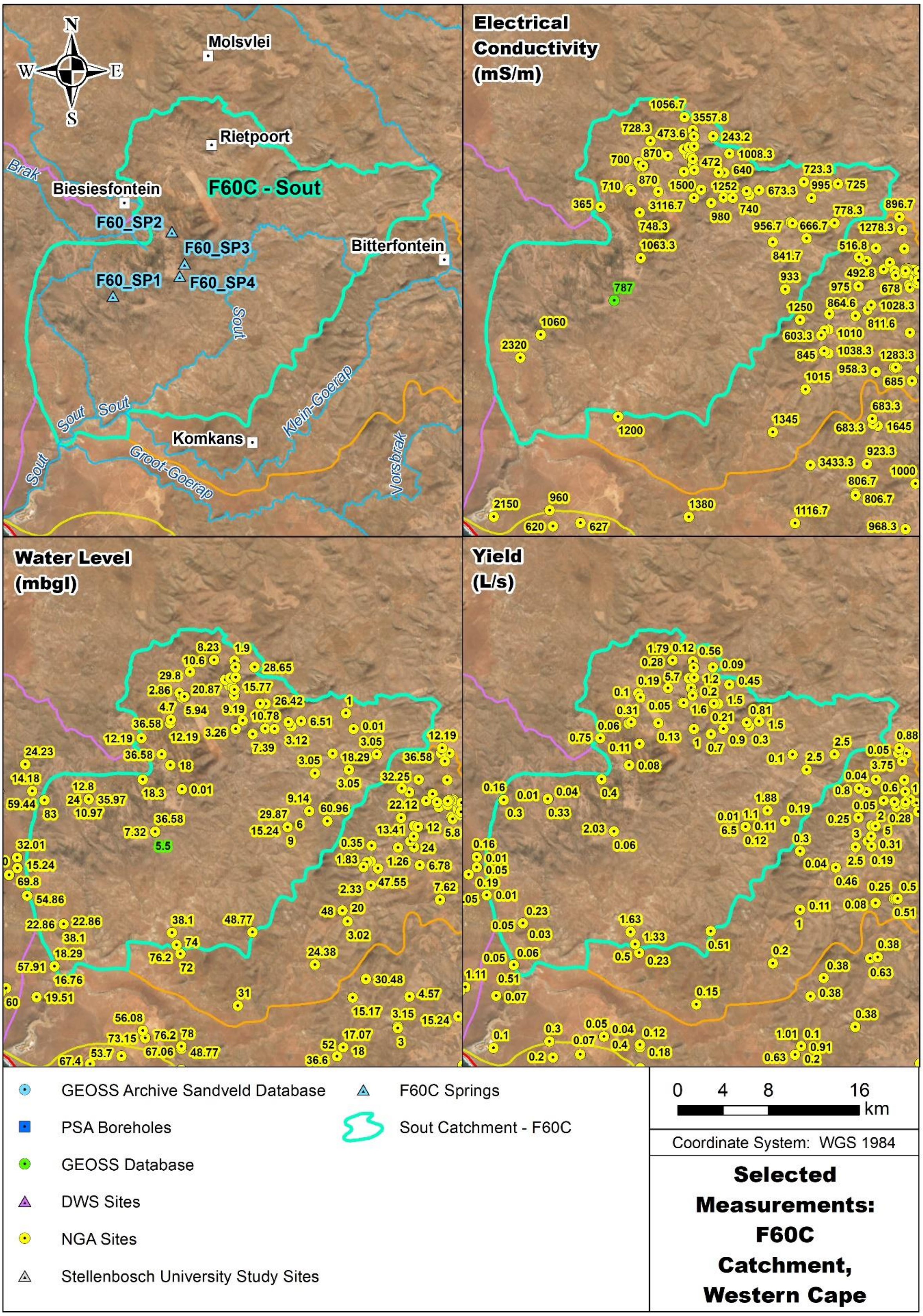
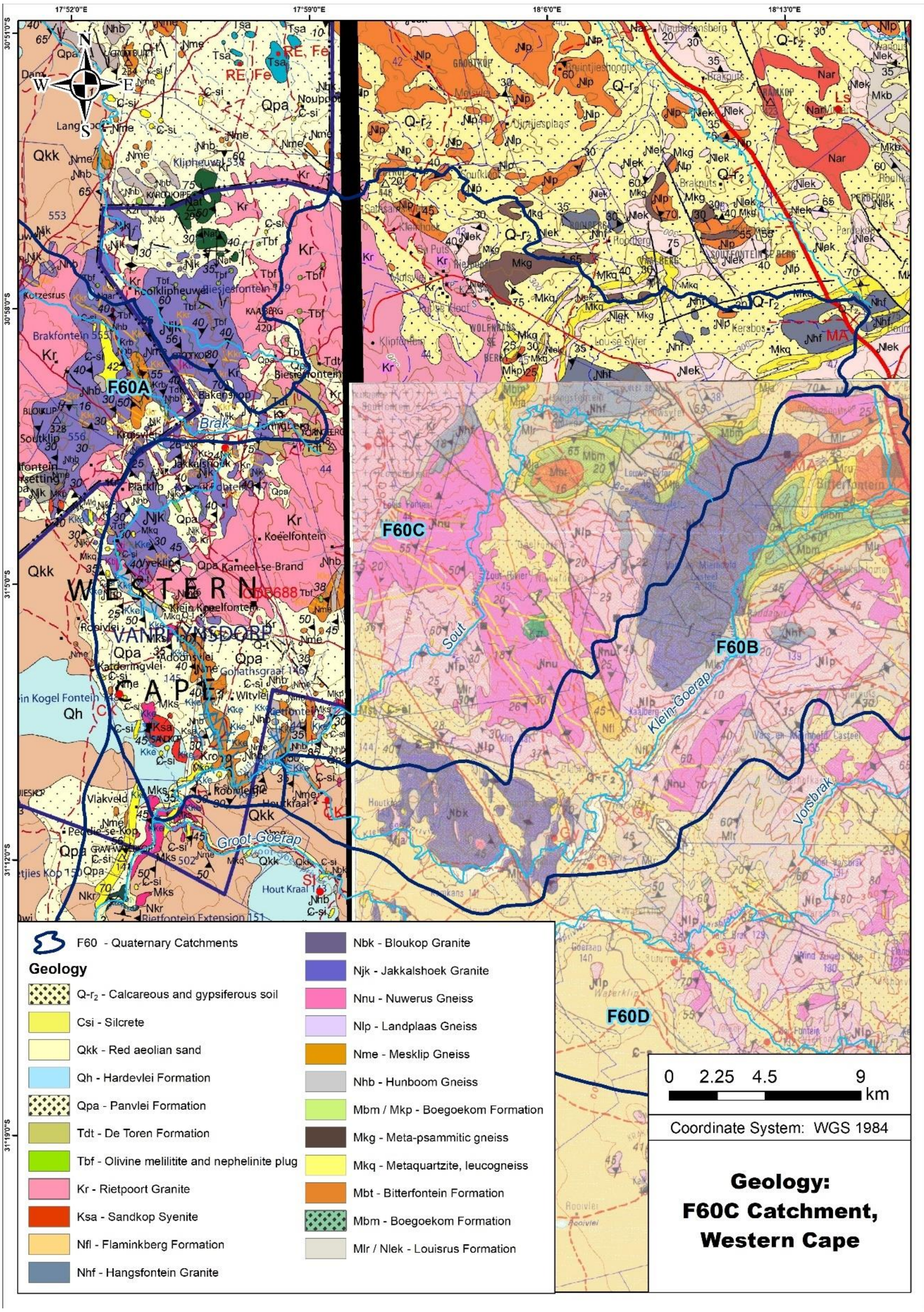


Figure 87:Proposed aquifer flow regimes for a typical structurally controlled valley within secondary drainage catchment F30 (Titus, 2003)



Map 39: Delineation of the Sout - F60C GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 40: Geological setting of the F60C Catchment (Calvinia, 3118, Garies, 3017 & Loeriesfontein, 3018) (CGS, 2001; CGS, 2010 & CGS, 2010)

4.2.5 Brak - F60A GRU

Grouping: Brak

GRU Name: F60A

Groundwater Use: Very Low to non-existent

Delineation:

The groundwater unit falls within the quaternary catchment boundaries and includes the areas surrounding the Brak River. 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 (**Map 42**). Faults have been mapped along the coast, cross-cutting the geology perpendicular to the coastal terraces

Very little to non-existent groundwater abstraction is evident and no WARMS abstraction points have been registered. Only livestock farming was observed in this GRU and not very many NGA sites are found in the area. The information that could be obtained has been displayed in **Map 41**. The data is also available in **Annexure A**. Groundwater levels are deep (average is 43 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 high-yielding borehole (7.5 L/s) on the southern coastline of the GRU. Water quality data for this borehole is not available.

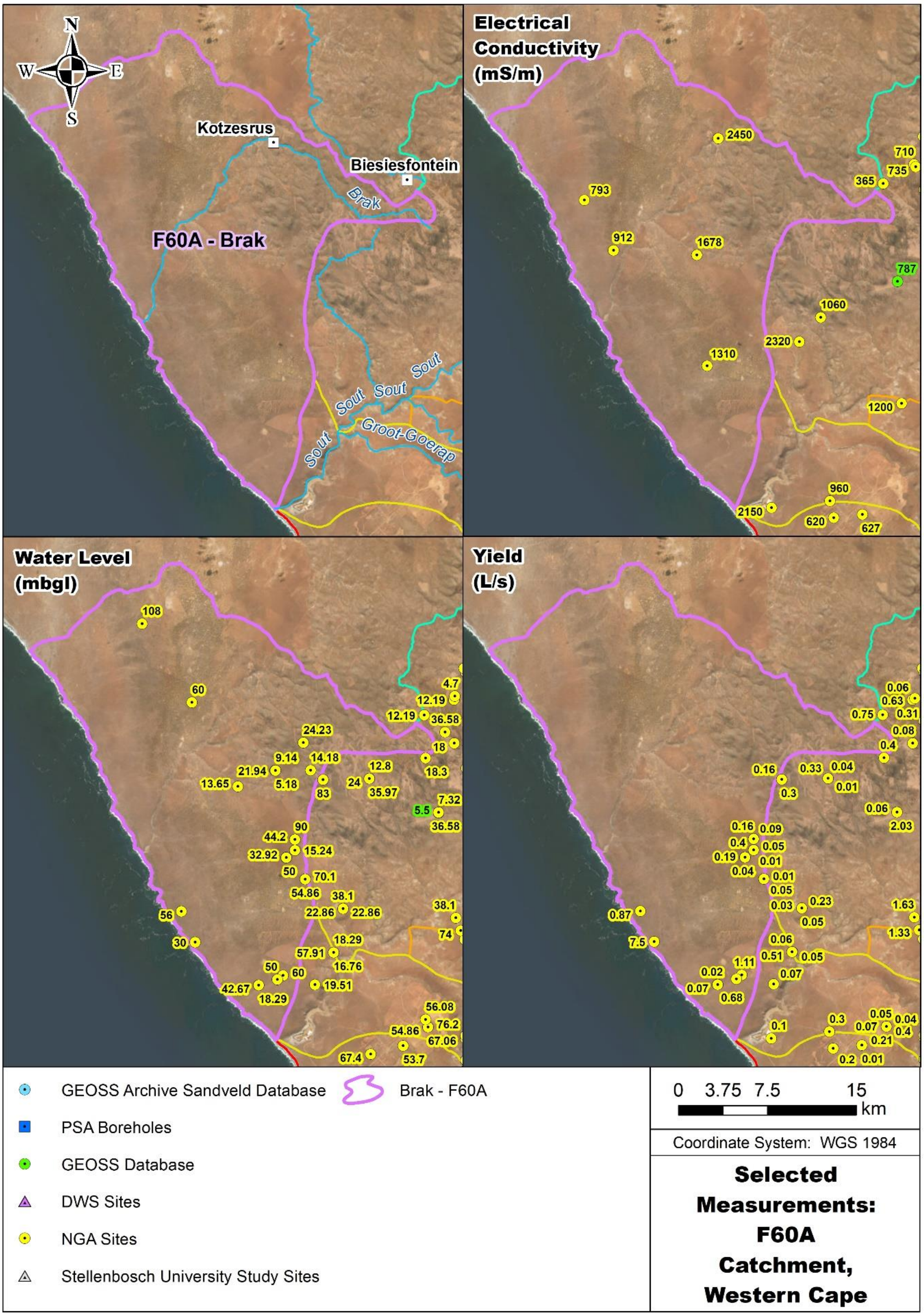
Two settlements are found in the area, Kotzesrus and Lepelsfontein. Kotzesrus residents confirmed that water is trucked in as there is no suitable water source near the settlement. Lepelsfontein residents confirmed that they have a small treatment plant to treat water abstracted from 4 boreholes, but access to the boreholes or any information regarding the boreholes could not be obtained during the course of this study, although both the Kamiesberg Local and Namakwa District Municipalities were contacted.

When a large farm was visited, it was noted that they have drilled a high-yielding borehole near the coast, but that the quality was extremely poor. They also reported that they have drilled more than 20 boreholes across their expansive farm in order to obtain useable water quality, but that ultimately, they found better quality water when they drilled on the border with the F60C catchment, against a hillside, in an assumed regolith aquifer.

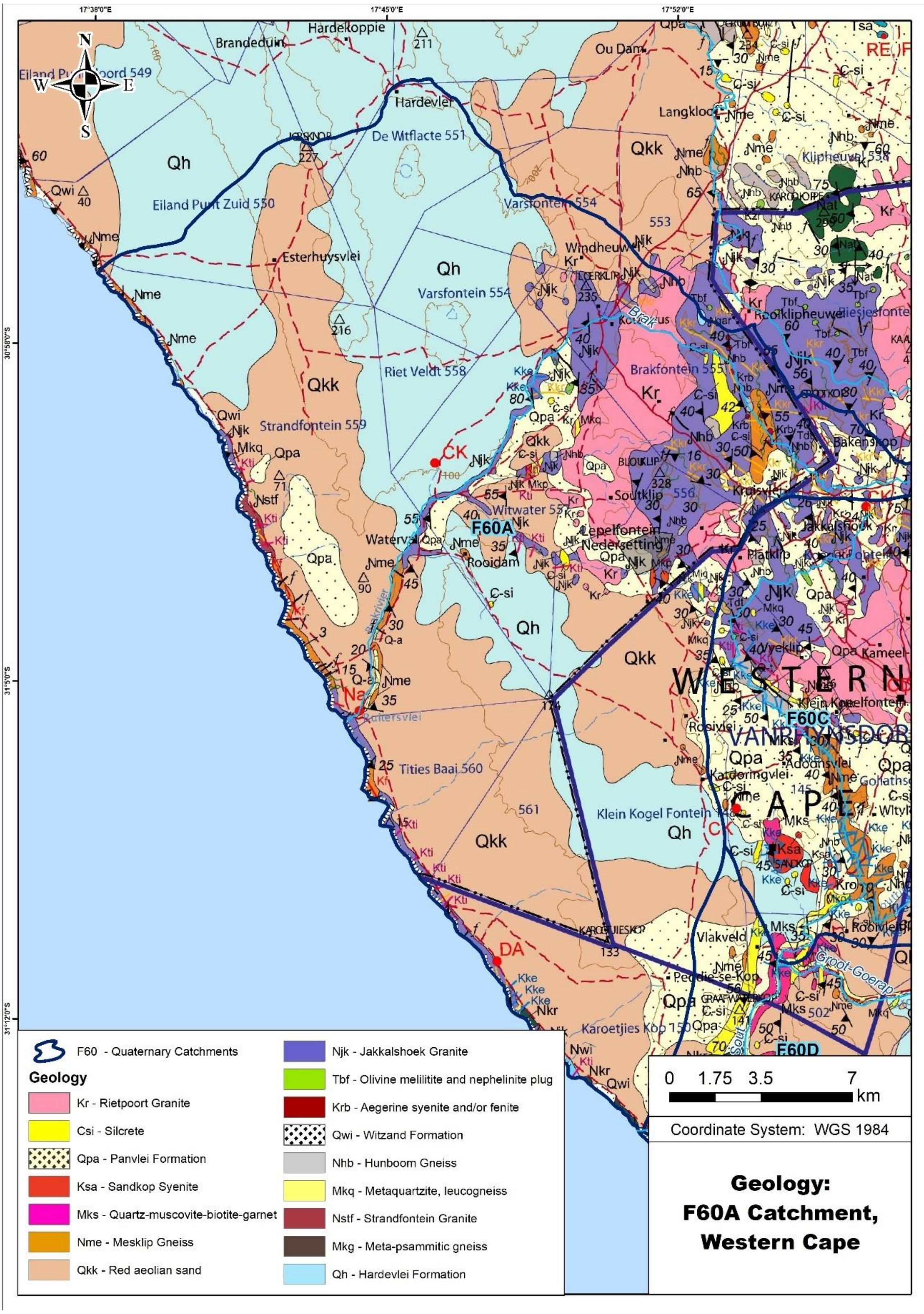
With regards to the quality of the groundwater found in F60A, the data that could be obtained from the Water Management System (WMS) (DWS, 2023), was analysed according to the DWS water quality reserve template (**Table 24**). From the results, it is clear that the natural groundwater quality for this area is enriched in chloride, sodium and EC. It should be noted that although groundwater quality for most of this GRU can be classified as "poor" according to any drinking water standards, this is the natural water quality. Thus, any potential sources of groundwater pollution, such as mines, could still have an impact on groundwater resources.

Table 24: Groundwater Quality analyses for F30A, using DWS template (WMS database) (DWS, 2023)

	Ca (mg/l)	Cl (mg/l)	EC (mS/m)	F (mg/l)	Mg (mg/l)	NO3+NO2 (mg/l)	Na (mg/l)	SO4 (mg/l)	TAL	pH
Class 0	80	100	70	0.7	70	6	100	200		6-9
Class I	150	200	150	1	100	10	200	400		5-6 & 9-9.5
Class II	300	600	370	3.5	200	20	400	600		4-5 & 9.5-10
Class III	>300	>600	>370	>3.5	>200	>20	>400	>600		<4 & >10
No of samples	10	10	10	10	10	10	10	10	10	10
Median	**121.25**	**3386.00**	**1058.50**	**0.64**	**210.50**	**0.31**	**1848.60**	**514.95**	**152.10**	**7.60**
Average	135.08	3405.97	980.80	0.92	218.11	0.77	1896.43	466.39	153.24	7.52
95.00	315.03	8000.02	2088.25	2.35	537.91	2.67	4385.30	1067.57	229.75	8.28
5.00	15.80	314.35	112.75	0.20	27.18	0.02	159.39	22.58	57.20	6.45



Map 41: Delineation of the Brak - F60A GRU, on satellite imagery and displaying EC, WL and yield values, where data was available



Map 42: Geological setting of the F60A Catchment (Garies, 3017) (CGS, 2010)

5. GROUNDWATER - SURFACE WATER INTERACTION

During the course of this study, the interaction between groundwater and surface water systems was investigated for each groundwater resource unit. For the F60 catchments, because all the rivers can be classified as episodic or ephemeral and very little data is available, it was difficult to establish the ground and surface water interaction for these systems. Springs were observed to be completely groundwater dependent. Although the flow of these springs is low and the quality is too poor to be used for drinking water, some springs are used by wildlife and livestock. These springs are vital sources of water and thus need to be protected. At Namaqua Sands Mine, boreholes adjacent to the Groot Goerap river do form part of their monitoring and sampling network and it would thus be recommended that the river must be sampled when it next flows to compare the surface water quality to that of borehole water for those boreholes drilled in the riparian zone of the river. It was also observed that some of the production boreholes at Bitterfontein seem to be drilled near drainage channels, and although these boreholes are located across the quaternary boundary in the E33D quaternary catchment (Olifants Doring river catchment), it would be recommended that isotope and inorganic sampling and analyses be done during surface water flow periods to investigate the relationship between these boreholes and the surface water systems in these areas.

For the G30 GRUs, studies have been done in certain areas, especially with regard to the Verlorenvlei system. Watson *et al* (2019) calculated, and on average, groundwater makes up 40% of the total annual flow of the four main tributaries (Bergvallei, Kruismans, Hol and Krom Antonies) of the Verlorenvlei system. For the Krom Antonies river, Eilers (2018) concluded that the upper river sections can be classified as a gaining stream. 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 rivers (GEOSS, 2019). The Kruismans tributary is regarded as the largest tributary and is mainly presumed to be derived from surface runoff (Watson et al., 2019). Thus far, the Bergvallei tributary is regarded as the largest groundwater flow contributor using the JAMS/J2000 rainfall/runoff model, with strontium isotope ratios confirming this (Sigidi, 2018). 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 in their upper catchments. The possible over-abstraction in the catchment will need to be investigated further. 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 contribution to baseflow. While the Hol tributary is saline (Watson et al., 2020a), its flow contribution is significant in 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*., 2022). These mixing relationships suggest and show the connection between the TMG and the 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 show 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 have not yet been successfully isolated due to mixing.

Getting a better idea of the composition of the Malmesbury aquifer is a critical part to understand this aquifer's flow contribution, therefore identifying a borehole that shows limited mixing is important. While this has already been done in the Berg River (Harilall, 2020), a more in-depth selection is required for Verlorenvlei.

For surface systems in the G30 catchments, other than the Verlorenvlei system, no studies could be found that specifically investigate the interaction between the surface water and groundwater systems, but for this study, some assumptions could be made based on observations that do speak to the interaction. It should however be noted that it is strongly recommended that additional studies with regard to these systems are undertaken to confirm the assumptions made in this report.

For the G30A Papkuils system, no spring flow data, apart from what has been registered through WARM was available. This volume has been used to represent the spring, but it is thought that the actual spring flow of this system is much higher. A borehole located approximately 160 meters from the Papkuils river and 800 m downstream from the Papkuils seepage area had undergone sampling in an investigation done by GEOSS in 2020. From the chemical results of the rainwater, surface water and groundwater, it was found that the surface water sample displayed a much higher mineral content than that of the rainfall and groundwater samples. The Papkuils river is characterised by relatively high sodium, magnesium, chloride, sulphate, manganese and iron. These levels are not observed in the rainfall and groundwater samples. From this analysis, it was not possible to clearly link the groundwater abstracted from this borehole to the surface water in the river and it was thus unlikely that the borehole is abstracting from the river. It could however not conclusively be proven that the water being abstracted by the borehole, is linked to the baseflow in the river. Because of this, no groundwater baseflow contribution has been added to the surface water modelling for this river, although the volume registered for the spring has been added to the Pitman model for the river. The volume has also been used in the groundwater balance.

For the G30F Langvlei and Wadrift systems, although no specific studies have been done to link the surface water in the Langvlei river with the groundwater from the two "paleochannel-like" structures in the area, some observations point to interaction. Firstly, the assumed impact of possible over-abstraction of the lower-Wadrift aquifer and the subsequent drying up of the wetland, could indicate that historically, this aquifer discharged into the Langvlei river. The Langvlei EWR site has been chosen adjacent to where the upper Wadrift aquifer meets the river channel, because the site is where one of the few remaining wet areas in the Langvlei system occurred until recently. It is most likely that groundwater could be discharging into this area, although additional sampling should be done to confirm this. In the upper Langvlei system, shallow water levels in boreholes drilled near the river channel and reports of some boreholes becoming artesian could also be linked to groundwater and surface water interaction along the system. Because of this assumed interaction, the same baseflow percentage was used as has been used for the Verlorenvlei tributaries.

For the G30G (Jakkals) and G30H (Sandlaagte) systems, no area-specific studies have been done. For the G30H area, the limited data available did not make it possible to clearly link the groundwater and the surface water in this system. For the Jakkals system, not enough information is available at this time. No perceived contribution from groundwater to surface water flow has been documented and this stream has historically been classified as a losing system (recharging groundwater) (GEOSS, 2005). It does seem that observations made during the course of this study as well as reports from locals on the historical setting could refute the hypothesis of a "losing stream. Historically, springs did occur (Kookfontein) towards the coast along the Jakkals River, but no springs that currently still flow could be identified. However, because this lower section of the Jakkalsvlei river, where the EWR site is located, is one of the only remaining wet areas, it is postulated that some groundwater could still be entering the system at this point. The clay banks along the northern side of this small wetland have been found to be wet during the summer, and it is hypothesized that groundwater in the primary aquifer may still be discharging where it meets the clay bank. Sampling of the vegetation and water quality at the EWR site also supports this hypothesis.

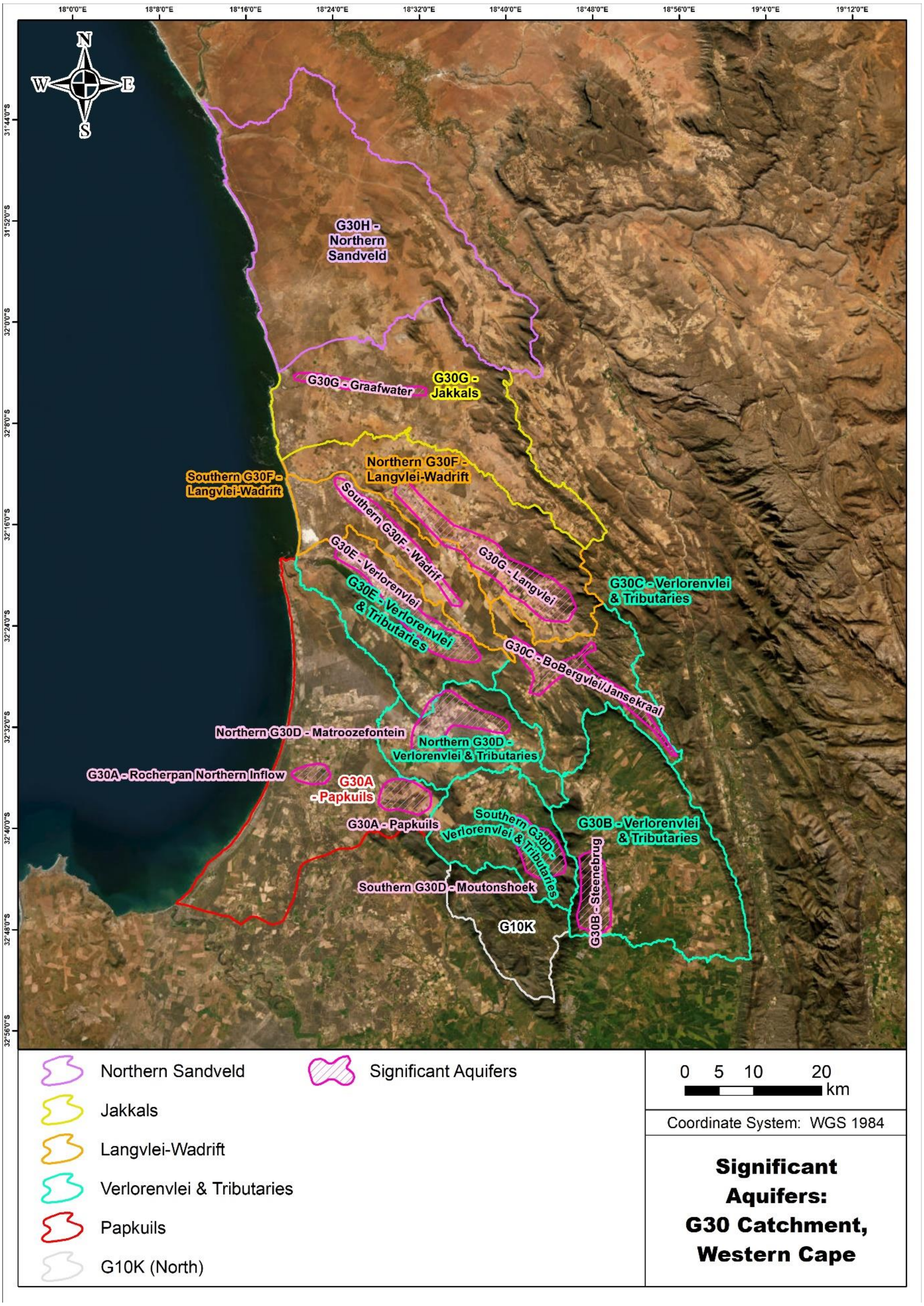
6. IMPORTANT GROUNDWATER AQUIFERS

Important aquifers have been delineated for the G30 catchments. Where possible, delineation was done on existing data. **Map 43** displays the delineated important aquifers. For two of the delineated areas, G30C_Bobergvlei and Jansekraal and G30B_Steenebrug, reports of declining water levels and very high abstraction amounts could not be verified due to a lack of access granted to existing boreholes.

These areas can be seen to represent places where groundwater availability and groundwater quality are the best in the study. Subsequently, these areas have also been targeted during groundwater exploration and currently these are the areas that host the highest-yielding boreholes as well as the highest reported groundwater abstraction volumes. Some of these areas, like the G30D_Moutonshoek area, have been linked to the baseflow of the local rivers (Eilers et al., 2017 and Eilers, 2018). While others, like the G30D_Matroozefontein and G30A_Papkuil, are linked to extensive seepage areas that form an important contribution to surface water systems.

The remaining four important aquifers are linked to coastal catchments and the hypothesis of an uncontinuous upwelling of groundwater along fault zones that create paleochannel type of environments. The four that have been delineated are: G30E_Verlorenvlei, G30F_Wadrift, G30F_Langvlei and G30G_Graafwater.

It is recommended that groundwater monitoring should be focused on in these areas, as well as the investigation of the current abstraction of groundwater impacting the baseflow of rivers in these systems. These important aquifers should be protected against over-abstraction as these are the most vulnerable due to their good quality and high groundwater availability.



Map 43: Delineation of important aquifers in the G30 catchments on satellite imagery

7. GROUNDWATER BALANCE FOR F60 AND G30 CATCHMENTS

7.1 Current Groundwater Balance for G30 and F60 catchments

For the data that could be obtained throughout the study, a groundwater balance calculation was done for each of the G30 and F60 delineated groundwater resource units. The summarised results are presented, together with the DWS reserve results done for the Olifants Doorn Catchments (DWA, 2012), in **Table 25**. A more detailed table for the current groundwater balance is displayed in **Table 26**, with the full spreadsheet available in **Annexure C** (Groundwater Reserve Calculations_Current).

From the data, it was observed that currently only G30F came out with a negative water balance. Although this area has been flagged as a potentially over-abstracted area, other areas of concern have displayed a positive water balance. G30B, G30C and G30D all calculated higher recharge values than what was calculated in 2012 and this is likely due to the high recharge value that was used for sub-catchments dominated by the TMG formations, which have displayed high recharge values during the latest studies done in the area (Eilers et al., 2017 and Eilers, 2018; Watson et al 2018b, Watson et al., 2019 and Miller et al 2022). Although these studies were focused on the Moutonshoek (G30D) catchment, it was decided that the higher recharge linked to the fractured TMG outcrops displayed through these studies is more accurate than the regional GRA2 (2005) recharge values. It is however possible that the recharge for the TMG outcrops outside of the G30D and G10K mountains can be lower and it is thus suggested that the calculations be updated once additional recharge studies, are completed. The recharge calculations are presented in multiple spreadsheets within **Annexure C**, to allow DWS to continually update the calculations as more data becomes available. Here follows a short discussion on all catchments where there may be contributing factors that affect the accuracy of the specific groundwater balance:

G30A (Papkuils): Localised groundwater abstraction is perceived to be high and the spring flow for the Papkuils seepage area obtained from WARM is likely much lower than the actual spring flow. Abstraction for irrigation is mostly used for cultivating potatoes and the 7000 m^3/ha/a is considered a representative irrigation rate for this crop, so abstraction data should be correct. Although some boreholes displayed a drop in water levels, others stayed more or less stable, pointing to localised drawdown due to high abstraction volumes. More boreholes are reportedly being drilled near the Papkuils river channel, so abstraction could be targeting surface water and baseflow. The balance calculated for this area could be turned into a more significant negative value if the spring flow monitoring proves the assumption of a significant spring flow.

G30B (Upper Kruismans): Localised groundwater abstraction is perceived to be high in the southwestern corner of this catchment. The abstraction data for this catchment is linked to table grapes, which are known to have a potentially high irrigation value and thus the 7000 m^3/ha/a could be considered conservative for this area. All the abstraction is also focused on one area and could be affecting the baseflow of the upper Kruismans tributaries much more than accounted for in this catchment. Just because of the large area, this catchment will have a large recharge value, although a large portion of the groundwater would not be usable for irrigation and human consumption due to the poor quality. More groundwater data is needed to confirm potential groundwater over-abstraction and abstraction from baseflow for the southwestern corner of this catchment.

G30C (Bergvallei):: Localised groundwater abstraction is perceived to be high for this catchment. The abstraction data for this catchment is linked to potatoes, but also to Citrus and Stone Fruit orchards, which are known to have a potentially high irrigation value and thus the 7000 m^3/ha/a could be considered conservative for this area. Also, boreholes are drilled into the stream bed and large orchards are planted within the riparian zone and drainage. Abstraction seems to be focused on the baseflow and thus even though the water balance gave a positive value for this catchment, the current abstraction could likely be impacting the baseflow and surface water systems to a negative degree. It has been reported that boreholes are being drilled deeper and deeper in the upper Bergvallei area and the latest studies from Stellenbosch University note that no trace of Bergvallei water is being picked up in new mixing models (studies are still ongoing, but Andrew Watson noted that these results are being picked up), thus the baseflow component for this catchment could already be completely abstracted through the current abstraction.

G30D (Lower Kruismans): Localised groundwater abstraction is perceived to be high for this catchment. The abstraction data for this catchment is linked to table grapes, which are known to have a potentially high irrigation value and thus the 7000 m^3/ha/a could be considered conservative for this area. The upper Krom-Antonies have been linked to the surrounding aquifers and thus the abstraction could be impacting the baseflow as many of the production boreholes are reported to be located adjacent to the river or seepage areas. Because of high rainfall and the proven high recharge in the TMG, this catchment could still have a positive water balance even though abstraction is high. The concern, however, is that groundwater linked to baseflow is being targeted and thus having an impact on the surface water. Also, some deep-water levels have been reported in the area, pointing to localised decreased water levels creating long-lasting cones of influence due to high volumes being abstracted in wellfields.

G30E (Verlorenvlei): The water balance for this area is positive, but only by a small margin. The abstraction volumes linked to town supply and the irrigation of potatoes should be correct, although high nitrates in certain areas could be seen as an indicator of over-irrigation due to high summer temperatures and wind. If more accurate abstraction figures are obtained, the irrigation figure used could be termed conservative. Another point of note is that the Kruisfontein Springs does not have any flow values, and the WARMS values used could be found to be very conservative. An average drop in the groundwater levels of about 2m could also be observed in the long-term monitoring data for boreholes located around the wetland. Abstraction in this catchment is focused on one paleo channel type structure that includes the Kruisfontein spring. Because this aquifer has the best quality when compared to other areas, the abstraction of this aquifer could also be linked to the increase in EC values observed due to the impact of poorer-quality water being drawn in.

G30F (Langvlei and Wadrift): This area has been calculated as having a negative water balance in the current study as well as the previous reserve calculated in 2012. This is mainly due to the large areas of irrigation as well as the high volume (when compared to the rest of the Sandveld) linked to the Lambertsbay`s town supply. Water levels for this area do show a drop and with the drying up of the lower Wadrift wetland having been linked to over-abstraction of groundwater, the negative water balance could be shown to be accurate for the area.

G30G (Jakkals): This catchment displays a high positive water balance. This is due to the high recharge of the TMG observed in G30D being used for the upper Peddies and Jakkals catchments. It is recommended that studies be done for the Langvlei, Jakkals and Papkuils to investigate baseflow and recharge for these systems. When more site-specific recharge values become available, this calculation should be updated. Because of the potential of the recharge to have been over-estimated, this value does carry a low confidence. When observing water levels from the monitoring data that was available, it was found that for the upper Jakkals, water levels seem very stable, although a drop in water level was observed towards the coast.

G30H (Sandlaagte): Groundwater abstraction in this area is focused in the upper reaches of the GRU and is linked to potatoes and the abstraction volume should be more or less accurate. Monitoring sites are not abundant, but the data available do display stable water levels, apart from one borehole located adjacent to the Sandlaagte river and just upstream of Strandfontein. The town reportedly does not use groundwater, but the drop could be linked to a potential abstraction nearby or be linked to the baseflow of the river. As for the other G30 catchments, a positive water balance may be misleading as the abstraction of groundwater does seem to be focused on rivers and springs and thus could be impacting the baseflow and surface flow of systems, even though the water balance is positive.

F60 catchments (Namaqualand/Sout and Brak): For all of these water balances, the perceived abstraction is very low. Data could not be obtained to link the groundwater and surface water systems and it is recommended that sampling must occur to investigate these systems. Although the data was very limited, low-flowing springs are still present and inhabitants noted that they have not observed a drop in water level. Although groundwater availability and quality are considered to be much lower and poorer than the G30 catchments, the local communities are still reliant on the groundwater for non-drinking domestic purposes and animal drinking water for most areas. Because abstraction and use are linked to very low-yield boreholes and springs, any drop in water level and change in quality could have a detrimental effect across the area. It is thus recommended that any proposed mining activity, or any other proposed activity that could impact the groundwater, be closely evaluated, based on site-specific conditions, before any decision is made to approve such an activity.

G10K (Lower Berg) and other potential recharge areas in the Olifants catchment: An exercise was undertaken to determine what the potential recharge would be for the remainder of the Piketberg Mountain range, located in catchment G10K. This was because this mountain range has been linked to exogenous recharge into the G30D, G30E and potentially G30A catchments. Because no water use and baseflow contribution data were available for the G10K catchment and the area falls outside of the study area, an exact value could not be calculated. Determination of this recharge has value non the less in displaying what large values of recharge could potentially be linked to the mountains that border the G30 catchments. It is recommended that studies investigating the Swartberg, Citrusdal and Cederberg Mountains with the coastal catchments be undertaken to delineate a recharge area for the G30 catchment more accurately. Monitoring must also be extended into these recharge areas.

Table 25: Summarised results for the Current Groundwater Balance, together with comparative results from the groundwater balance done in 2012 by the Department of Water and Sanitation (DWA, 2012)

Quaternary Catchment	Recharge (Mm^3/a) (DWA, 2012)	Recharge (Mm^3/a) (Current Study)	Total Usage (Mm^3/a) (DWA, 2012)	Total Usage (Reserve + Irrigation use) (Mm^3/a) (Current Study)	Water Balance (Mm^3/a) (DWA, 2012)	Water Balance (Mm^3/a) (Current Study)
G30A (Papkuils)	10.73	6.94	2.77	7.05	7.96	-0.11
G30B (Upper Kruismans)	15.62	19.32	0.49	5.71	15.13	13.61
G30C (Bergvallei)	8.48	14.72	2.78	7.95	5.70	6.77
G30D (Lower Kruismans)	12.38	20.14	4.00	13.86	8.38	6.27
G30E (Verlorenvlei)	4.45	4.43	2.90	4.17	1.55	0.25
G30F (Langvlei and Wadrift)	13.80	14.47	14.03	21.13	-0.23	-5.10
G30G (Jakkals)	11.06	17.37	6.74	4.49	4.32	12.87
G30H (Sandlaagte)	4.52	6.53	0.035	2.37	4.49	4.16
F60A	-	1.39	-	0.00106	-	1.39
F60B	-	1.44	-	0.19	-	1.25
F60C	-	2.48	-	0.004	-	2.48
F60D	-	2.02	-	-	-	2.02
F60E	-	0.49	-	0.00056	-	0.487
G10K_Groundwater_North	-	23.40	-	unknown XYZ§	-	23.4-XYZ

§ Unknown Baseflow (x) and Spring flow (Y) contribution and unknown irrigation abstraction (Z)

Table 26: More detailed results for the Current Groundwater Balance, calculated for G30 and F60 catchments, during this study

Sub-catchments used to calculate recharge	River System	Area (km2)	MAP (mm)	Estimated Recharge (% of total annual flow)	Calculated recharge (Mm3)	Total calculated baseflow (million m3)	Total calculated springflow from WARMS 2022 (million m3)	Total abstracted for Town supply (million m3)	Basic Human Need (2011)	Reserve (BHN + Springflow + Baseflow Contributions)	Total abstracted for irrigation (million m3)	Total Usage (Irrigation + BHN + Town Supply)	Groundwater Balance (million m3)
G30A1	Papkuils	131.1	292	3.5%	1.34								
G30A2	Papkuils Lower	10.0	292	3.5%	0.10								
G30A_Groundwater		604.3	260	3.5%	5.50								
	G30A_Total				**6.94**	**0**	**0.124**	**0**	**0.128981875**	**0.252981875**	**6.79956**	**7.05255**	**-0.11070**
G30B1	Upper Kruismans	23.7	505	23.0%	2.75								
G30B1	Upper Kruismans	92.4	300	5.0%	1.39								
G30B2	Soutkloof	17.8	415	23.0%	1.69								
G30B2	Soutkloof	194.5	300	5.0%	2.92								
G30B3	Huis tributary	53.8	505	23.0%	6.25								
G30B3	Huis tributary	288.5	300	5.0%	4.33								
	G30B_Total				**19.32**	**1.58**	**1.88738**	**0.053676**	**0.0382885**	**3.5593445**	**2.1537**	**5.71304**	**13.61017**
G30C1	Kleinvlei	64.3	404	23.0%	5.98								
G30C2	Jansekraal	62.6	404	23.0%	5.81								

Sub-catchments used to calculate recharge	River System	Area (km2)	MAP (mm)	Estimated Recharge (% of total annual flow)	Calculated recharge (Mm3)	Total calculated baseflow (million m3)	Total calculated springflow from WARMS 2022 (million m3)	Total abstracted for Town supply (million m3)	Basic Human Need (2011)	Reserve (BHN + Springflow + Baseflow Contributions)	Total abstracted for irrigation (million m3)	Total Usage (Irrigation + BHN + Town Supply)	Groundwater Balance (million m3)
G30C3	Bergvallei	218.2	383	3.5%	2.92								
	G30C_Total				**14.72**	**1.14**	**0.398**	**0.074207**	**0.003531375**	**1.615738375**	**6.33080**	**7.94654**	**6.76926**
G30D1	KA upper	64.8	517	23.0%	7.71								
G30D1	KA lower	55.1	366	5.0%	1.01								
G30D2	Hol upper	51.7	517	23.0%	6.15								
G30D2	Hol lower	102.6	366	5.0%	1.88								
G30D3	Matroosfontein	128.2	347	3.5%	1.56								
G30D4	Verlorenvlei	151.8	347	3.5%	1.84								
	G30D_Total				**20.14**	**2.3**	**0.976462**	**0.03798867**		**3.32445067**	**10.53787**	**13.86232**	**6.27765**
G30E1	Kruisfontein	90.4	286	3.5%	0.91								
G30E2	Verlorenvlei	44.9	286	3.5%	0.45								
G30E3	Verlorenvlei	35.3	286	3.5%	0.35								
G30E4	Verlorenvlei	190.5	286	5.0%	2.72								
	G30E_Total				**4.43**	**0**	**0.7706**	**0.443172**	**0.020905375**	**1.234677375**	**2.9434064**	**4.17808**	**0.25440**
G30F1	Langvlei	194.2	352	3.5%	2.39								
G30F2	Lambertshoek	98.9	352	23.0%	8.01								
G30F3		397.8	236	3.5%	3.29								
G30F4		30.2	212	3.5%	0.22								

Sub-catchments used to calculate recharge	River System	Area (km2)	MAP (mm)	Estimated Recharge (% of total annual flow)	Calculated recharge (Mm3)	Total calculated baseflow (million m3)	Total calculated springflow from WARMS 2022 (million m3)	Total abstracted for Town supply (million m3)	Basic Human Need (2011)	Reserve (BHN + Springflow + Baseflow Contributions)	Total abstracted for irrigation (million m3)	Total Usage (Irrigation + BHN + Town Supply)	Groundwater Balance (million m3)
G30F_Groundwater_North		20.2	175	3.5%	0.12								
G30F_Groundwater_South		59.1	212	3.5%	0.44								
	G30F_Total				**14.47**	**1.56**	**0.1284**	**0.98592**	**0.024847375**	**2.699167375**	**18.43323**	**21.13240**	**-5.10282**
G30G1	Jakkals	134.4	268	xx	11.15								
G30G2	Peddies	49.4	268	23.0%	3.05								
G30G3		317.5	208	3.5%	2.31								
G30G4		21.7	138	3.5%	0.10								
G30G_Groundwater_West		89.8	138	3.5%	0.43								
G30G_Groundwater_East		44.2	208	3.5%	0.32								
	G30G_Total				**17.37**	**0**	**0.53949**	**0.203213**	**0.130752125**	**0.873455125**	**3.616832**	**4.49029**	**12.87576**
G30H1		580.8	204	3.5%	4.15								
G30H_Groundwater		495.4	138	3.5%	2.39								
	G30H_Total				**6.53**	**0**	**0**	**0**	**0.059102625**	**0.059102625**	**2.31426**	**2.37337**	**4.16041**

Sub-catchments used to calculate recharge	River System	Area (km2)	MAP (mm)	Estimated Recharge (% of total annual flow)	Calculated recharge (Mm3)	Total calculated baseflow (million m3)	Total calculated springflow from WARMS 2022 (million m3)	Total abstracted for Town supply (million m3)	Basic Human Need (2011)	Reserve (BHN + Springflow + Baseflow Contributions)	Total abstracted for irrigation (million m3)	Total Usage (Irrigation + BHN + Town Supply)	Groundwater Balance (million m3)
F60A	Brak	386	103	3.5%	**1.39**	**0**		**0**	**0.0010585**	**0.0010585**		**0.00106**	**1.39047**
F60B	Klein-Goerap	320	129	3.5%	**1.44**	**0**		**0.183146**	**0.008514**	**0.191660025**		**0.19166**	**1.25314**
F60C	Sout	622	114	3.5%	**2.48**	**0**		**0**	**0.00406975**	**0.00406975**		**0.00407**	**2.47771**
F60D	Groot-Goerap	481	120	3.5%	**2.02**	**0**		**0**		**0**		**0.00000**	**2.02020**
F60E		120	116	3.5%	**0.49**	**0**		**0**	**0.000556625**	**0.000556625**		**0.00056**	**0.48664**
G10K_Groundwater_North		201.5	505	23.0%	**23.40**	**unknown X**	**unknown Y**	**0**	**0.084068625**	**#VALUE!**	**unknown Z**	**#VALUE!**	**23.32-XYZ**

7.2 Scenarios run on Groundwater Balance for G30 and F60 catchments

Some scenarios were developed for the hydrology Pitman model and these were replicated were possible as groundwater scenarios. For Scenario 1, groundwater abstraction for irrigation was reduced by 50%, this is seen as a scenario that would facilitate sustainably functioning of aquatic ecosystems in the area. Scenario 2, a climate change scenario was modelled based on the results of the National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa (Schutte et al, WRC 2021). Annual Precipitation was re-calculated to simulate the effects of potential climate change. The expected change in rainfall is displayed in **Table 27**.

Table 27: Projected changes in mean annual rainfall (Schütte et al, WRC 2021), taken from hydrology report that forms part of this study

Quaternary Catchment	Mean annual rainfall – average GCMs present day (mm)	Mean annual rainfall – average GCMs near future (mm)	Mean annual rainfall – average GCMs distant future (mm)	Relative change – present to near future (%)
F60A	124.5	105.4	84.4	-15%
F60B	145.6	126.5	95.1	-13%
F60C	155.8	133.0	105.2	-15%
F60D	135.8	117.3	93.1	-14%
F60E	139.4	119.2	95.9	-14%
G30A	263.3	232.2	193.6	-12%
G30B	369.9	323.2	253.7	-13%
G30C	379.6	341.4	273.3	-10%
G30D	362.2	319.8	266.1	-12%
G30E	281.6	248.7	206.4	-12%
G30F	291.6	260.9	212.3	-11%
G30G	248.6	222.5	181.2	-11%
G30H	206.3	178.6	140.4	-13%

The scenarios were run in the Pitman model and the results are presented in **Table 28**. From the results, it can be seen that abstraction for irrigation is by far the biggest user of water for the G30 catchments, and thus reducing irrigation amounts by 50% does have a large impact on the water balance. For the second scenario, a small reduction in rainfall does not have a large impact, although it does change some areas that had a small positive water balance , into the negative. As noted, the current water balance does have some assumptions linked to the recharge, spring flow and irrigation volumes and thus any updates to the water balance would require that these water balance scenarios should also be updated. The detailed spreadsheets are available in **Annexure C** (Scenario 1_Irrigation Reduction and Scenario 2_Climate Change), to allow for easy updating of the various different scenarios and to the creation of more scenarios if required.

Table 28: Summarised results for the Scenarios run for the Groundwater Balances for G30 and F60

Quaternary Catchment	Water Balance (Mm^3/a) Current (2022)	Water Balance (Mm^3/a) Scenario 1: Irrigation Reduction	Water Balance (Mm^3/a) Scenario 2: Climate Change
G30A	-0.11	3.29	-0.943
G30B	13.61	14.68	11.098
G30C	6.77	9.93	5.297
G30D	6.27	11.55	3.86
G30E	0.25	1.73	-0.277
G30F	-5.10	4.11	-6.69
G30G	12.87	14.68	12.099
G30H	4.16	5.317	3.31
F60A	1.39	1.39	1.18
F60B	1.25	1.25	1.065
F60C	2.48	2.48	2.105
F60D	2.02	2.02	1.737
F60E	0.487	0.487	0.418

8. ASSUMPTIONS AND LIMITATIONS

During this study, certain assumptions limited the accuracy of the data acquired and the outcome of this report.

- A lack of data for the water resources in the study area resulted in lower confidence results than what would be the requirement of a Comprehensive Ecological Reserve determination study. Clear recommendations with regard to future monitoring of the water resources has been included in the outcomes of this study to rectify this shortcoming. The monitoring will in the assist with the management and curve unsustainable use as well as improving the analytical model that has been produced during this study.
- This report was written from the data that could be obtained during the course of this study. Although some areas were visited, the main source of data came from existing databases. Some assumptions had to be made on very little data and would need to be confirmed with additional studies and sampling.
- The groundwater quality data was obtained through landowners, mines, municipalities and DWS. However, it should be noted that these samples came from mostly production boreholes, targeted usually for the best yield and quality. So this analysis should not be seen to represent the average water quality for a specific area, but rather to give an indication of what is seen as usable water quality for a specific area. The samples usually also displayed only one set of results. It is known that seasonal changes may occur in the chemistry of groundwater and thus, this has not been accounted for.
- The coordinates of the NGA boreholes are sometimes found to be inaccurate. As these could not be confirmed during the course of this study, the coordinates had to be assumed to be accurate.
- All registered abstraction volumes that could be obtained from the WARMS dataset, are updated until July 2022. This database is updated continuously, so data points added after this time could not be considered.
- The NGA database for these areas was used to obtain groundwater-relevant information such as EC values, water levels and yield, downloaded in November 2022. This database is updated continuously, so data added after this time could not be considered.
- With regards to baseflow and recharge values, since the WRSM Pitman model is a rainfall-runoff model, it simulates surface water runoff and has limited groundwater modelling capabilities. Baseflow contributions were modelled explicitly by using a defined time series of inflows calculated outside of the model and with estimates obtained from Watson *et al*., 2019 and additional inputs made by the project team. This data was used for all of the G30 catchments, although the studies of Watson have mainly concentrated on the Verlorenvlei system and specifically the Krom-Antonies river. These values may not be proven to be relevant and accurate for the other G30 sub-catchments, but without any aquifer-specific recharge studies done in those areas, it was decided to use the values that have been specifically linked to a specific aquifer.

- The local geology information came mainly from the regional Council of Geoscience 1:250 000 scale maps and any borehole logs that could be obtained.
- Apart from the Matroozefontein seepage area monitoring, no spring flow monitoring data could be obtained. Registered WARMS sites linked to springs had to be used to provide some indication of spring flow. For springs and seepage areas like the Papkuil seepage area, the WARMS registered volume is seen as too low a volume to be representative of a wetland of that extent. Because no other data was available, the WARMS volume was used, but the actual spring flow is perceived to be much larger.
- Actual abstraction information could not be obtained and thus the 2017/2018 Crop Census (Western Cape Department of Agriculture, 2018) had to be used to provide an estimation of what amount of water is being used for irrigation purposes in these catchments. This dataset does not distinguish between areas irrigated by groundwater and areas irrigated by surface water. The split between groundwater and surface water use was taken from the latest V&V data obtained from DWS in 2022. Due to concerns regarding the accuracy of the initial V&V dataset, the data is currently being verified using Infrared imagery. However, at the time of this study, this dataset was found to be the most accurate depiction of the split between groundwater and surface water use for irrigation in the G30 catchment. The V&V data was thus only used in this study to determine the ratio of groundwater to surface water use. Interactive spreadsheets accompany this report to allow for ongoing updates, as more detailed information becomes available.
- To calculate an irrigation volume per catchment, in Mm^3/a, the average irrigation volume being used by DWS for the G30 catchments was used (7000 $m^3/ha/a$). It is assumed that some farmers would use more than this and some would use less. When more accurate actual water use volumes are available, this average irrigation volume per area can be updated. Interactive spreadsheets thus accompany this report to allow for ongoing updates, as more detailed information becomes available.

9. RECOMMENDATIONS

Some recommendations have been made to assist with the monitoring and ultimately the management of the G30 and F60 catchments:

- Firstly, the directive from the 2018 Government Gazette regarding the monitoring of groundwater abstraction volumes must be enforced and databases of abstraction data must be developed per catchment. This will vastly improve the accuracy of any future Reserve study and the management of water use for the area.
- G30F, G and H catchments : It is recommended that isotope and inorganic sampling commences to investigate the link between the E10 and the coastal G30 catchments of the northern Sandveld. It is hypothesized that the same system of lateral recharge from the mountainous areas towards the coastal areas occurs here as has been found for the Piketberg mountains and the adjacent coastal catchments, but due to the lack of isotope and inorganic analysis data for this portion of the Sandveld, it could not be proven during this study. Thus, it is recommended that the sampling be done and analysed to investigate whether the northern Sandveld does obtain its recharge from the Cederberg and Swartberg Mountains as is assumed.
- G30B, C, D and E catchments: More monitoring sites need to be included in the Piket-Bo-Berg area, as well as the Swartberge and Citrusdal Mountains that are the assumed peak recharge areas for these catchments. Monitoring sites are also vitally needed in the Bergvallei and Jansekraal valleys, as very monitoring data could be obtained for these areas. For the G30D (Moutonshoek) area, one company does monitor the water levels in their boreholes that have been installed with telemetry monitoring systems, and they have shown interest in sharing this dataset with DWS. Monitoring sites in the upper Krom-Antonies and Hol systems are still however needed. Important aquifers have been delineated to assist in guiding monitoring sites, as well as delineating areas where baseflow and spring flow could be affected by groundwater abstraction.

- It is understood that the Papkuils (G30A), Langvlei (G30F) and Jakkals (G30G) systems would each be unique in terms of the groundwater contribution to surface water flow, but due to a lack of baseflow separation and streamflow data, the relationship between the surface and groundwater for these systems could not be proven during this study. For systems where some observations could be interpreted to link the surface and groundwater systems, like for the Langvlei, the average breakdown between groundwater and surface water for the Verlorenvlei system was used. It is however recommended that each of these systems should have similar baseflow estimations as has been done for the Verlorenvlei systems. It is understood that these are costly and time-consuming studies and thus it is recommended that universities be contacted to assist with these proposed studies. It is also recommended to use a tracer aided rainfall-runoff model instead of standard models which are conceptual in terms of baseflow separation.

- G30A (Papkuils): Currently, the spring flow at Papkuils seepage area is not being monitored. This is a vital wetland and currently, the exact flow sustaining the wetland is unknown. The WARMS abstraction volume linked to the spring is also seen as very conservative as the volume registered is unlikely to maintain a wetland of this size. It is recommended that this seepage area be installed with spring flow measurement infrastructure just before the stream goes under the downstream road and that the water quality at this point is also monitored on a quarterly basis.

- G30B (Upper Kruismans): Currently, the spring flow at Eendekuil is not being monitored. It is recommended that a flow meter be installed on the 63 mm pipe between the spring collection box and the downstream dam.
- G30B (Upper Kruismans): It is important to note that NO groundwater monitoring is being done in this GRU by DWS. It is recommended that monitoring sites be identified in the delineated important aquifer area, near the Steenebrug area.
- G30E (Verlorenvlei river): Kruisfontein Springs, located towards the northeast of Redelinghuys, NEEDS to be monitored. The water from the various spring eyes flows into one channel that flows down and joins the Verlorenvlei river at Redelinghuys. It is recommended that a flow measuring and monitoring system be installed just before the streams from the springs join and where the Kruisfontein stream flows underneath the R366 road.
- G30E (Upper Verlorenvlei estuary): During the drought of 2016-2018, it was reported that when this area of the upper Verlorenvlei estuary dried up completely, a small pool of water in the centre of the vlei kept getting wet during the night and then dried during the day. This could not be investigated as that portion of the vlei did not completely dry up during 2021 and 2022. It is recommended that if this occurs again, the pool is sampled.
- G30E (Lower Verlorenvlei estuary): For the monitoring boreholes adjacent to the Verlorenvlei, more sampling and analysis are needed to link these changes with the specific activities and/or specific hydrogeological processes, thus increased water quality monitoring is recommended for these boreholes.
- G30F (Langvlei and Wadrift): Some boreholes in this GRU highlighted the localised nature of the elevated nitrate levels that has been monitored. It is thus recommended to not extrapolate the increase in nitrate that has been observed in certain boreholes across large areas until additional sampling of the wider area has been done. For areas where high nitrates have been observed, the surrounding boreholes should be sampled to measure the extent of the higher nitrate area.
- G30G (Jakkals): For the upper reaches of the Jakkals river system, no boreholes are being monitored. Multiple NGA boreholes have however been registered for this area. It is recommended that at least one of these boreholes be included in the monitoring of this system to monitor groundwater levels and quality in this area.
- F60E (Namaqualand): At Namaqua Sands Mine, the effect of mining activities has created a pollution plume. This is being closely monitored and modelled and the mine is working with DWS to minimise the impacts of the mining activities, but it does show that even in areas with a deep-water level and very high EC`s, the mining could still

impact the groundwater quality and levels. It is thus vital that any mining activity in these areas must if approved, continually monitor and model the groundwater and their effects on it. It is recommended that any proposed mining activity, or any other proposed activity that could impact on the groundwater in that, be closely evaluated, based on site specific conditions, before any decision is made to approve such and activity.

- F60C, D and E (Klein and Groot Goerap and Sout): Sampling of rivers and streams during flow events: At Namaqua Sands Mine, boreholes adjacent to the Groot Goerap do form part of their monitoring and sampling network and it is thus recommended that the river must be sampled when it next flows to compare the surface water to that of boreholes drilled in the riparian zone of the river. Initiating event related sampling will be the only way in which to samples these systems. It was also observed that some of the production boreholes at Bitterfontein seem to be drilled near drainage channels, and although these boreholes are located across the quaternary boundary in the E33D quaternary catchment, it would be recommended that isotope and inorganic sampling and analyses be done during surface water flow periods to investigate the relationship between these boreholes and the surface water systems in these areas. It is also recommended that the local community leaders be asked to sample any of the other rivers in the F60 catchments, when they flow. As these river systems are remote and far away from any DWS office, it is recommended that local residents be incorporated into a sampling network to gain information on these systems.

- F60B (Klein Goerap): The trends observed in the DWS monitoring boreholes could not clearly be linked to the Bitterfontein production boreholes for the municipality. It is recommended that the monitoring data from the actual production boreholes be obtained and incorporated into the DWS monitoring system. Because these boreholes and the desalination plant supply all the settlements and small towns in the area with their only source of water, it is vital that the sustainability of the system be monitored. Some form of telemetry system is installed, but the current system does not seem to store groundwater level data.

- F60B (Brak): Monitoring of the groundwater quality surrounding the Bitterfontein evaporation dams should linked to monitoring at the desalination plant. The municipality noted that this is currently not being done. It is thus recommended that sampling in a up to 1km radius around these dams is done to monitor the potential pollution these dams pose.

10. CONCLUSION

For the groundwater portion of the Reserve determination, available databases were used to obtain relevant groundwater data for the F60 and G30 catchments. Groundwater resource units (GRUs) were delineated and described. The available data was graphed and analysed for trends and changes. The relevant spreadsheets accompany this report and can be used in future to follow up on relevant monitoring sites or update the water balance equations.

For the G30 catchments, groundwater use is extensive in most areas. Groundwater forms the main source of water for town supply and irrigation. Groundwater quality and yield vary, with some areas displaying much better quality and groundwater availability than others.

Nine important aquifers have been delineated for the G30 catchments. It is recommended that groundwater monitoring should be focused in these areas, as well as an investigation of the current abstraction of groundwater and its impact on the baseflow of rivers in these systems. These important aquifers should be protected against over-abstraction as they are the most vulnerable groundwater resources in the area due to their good quality and high groundwater availability.

For the central G30 catchments, isotope dating has linked the groundwater found in the low-lying coastal regions with rainwater sampled in the higher-lying mountainous regions of the Piketberg and Citrusdal mountains (GEOSS, 2019), although most of the studies have been focused on the Piketberg Mountainous and the Verlorenvlei Catchment. Groundwater recharge in the Verlorenvlei catchments has been determined using rainfall/runoff modelling (Watson et al., 2018), a natural tracer technique using Chloride Mass Balance (CMB) (Watson et al., 2020 and GEOSS, 2019) and a GIS−based modelling approach (Conrad et al., 2004). Recharge dominantly occurs in areas of higher elevation, such as the Piketberg Mountains, and therefore into the TMG aquifer. Thus, it can be noted that aquifer-specific recharge values are available for the G30 catchments that make up the Krom-Antonies and Verlorenvlei system (G30D and G30E), but not for other G30 catchments. Although these values and assumptions were used for the other G30 catchments, recharge studies are needed for the other systems to correctly delineate recharge areas and thus assist with the management of these systems.

Baseflow and streamflow estimates were calculated for the four main tributaries (Bergvallei, Kruismans, Hol and Krom Antonies) that make up 81% of the streamflow into the Verlorenvlei. It was also found that of the water entering the Verlorenvlei, ~56% of the total flow is surface run-off, with groundwater baseflow and interflow contributing ~40% and ~4%, respectively (Watson et al., 2019). This percentage breakdown provided site-specific baseflow estimations that took into consideration the nature of the system. It was decided that these estimated baseflow percentages could be used to describe the flow systems of the other river systems in the G30 catchments. It is understood that the Papkuils, Langvlei and Jakkals systems would each be unique, but that due to a lack of baseflow separation and streamflow data, the average breakdown between groundwater and surface water for the Verlorenvlei system would be the most accurate to use at this time for catchments were surface-groundwater interaction has been identified. It is however recommended that each of these systems be monitored so that similar baseflow estimations can be done for each system in the future.

For the F60 catchments, it was observed that water users would target hillsides, against granite and other igneous rock hilly outcrops known locally as “koppies”. After rain events, the water in these shallow boreholes has been reported to experience a dramatic change in quality a day or two after the rain event occurred. The water quality would then slowly degrade over time, but would still represent the “freshest” water to be found in the area. It is thus hypothesized that these hill-side boreholes target the water found in the unconsolidated material, known as the regolith, thus abstracting water before it could enter deeper into the crystalline rock aquifer, where the flow slows down allowing for increased interacting with the surrounding minerals, creating more mineral rich, “salty” water. This aquifer comprised of weathered material has been used to describe groundwater systems in the northern Namaqualand (Titus, 2003, Friese et al., 2006 Pieterson et al., 2009) and seems to also describe the systems observed during this study in the southern Namaqualand (F60). Although this type of recharge is not generally seen as localised recharge, for the purpose of this study, these areas will be termed as “recent localised recharge”.

Groundwater abstraction in the F60 catchments is very low. Although the data was very limited, low-flowing springs are still present and locals noted that they have not observed a drop in water level. Although groundwater availability and quality are considered to be much lower and poorer than the G30 catchments, the local communities are still reliant on the groundwater for non-drinking domestic purposes and animal drinking water for most areas. Because abstraction and use are linked to very low-yield boreholes and springs, and drop in water level and change in quality could have a detrimental effect across the area. It is thus recommended that any proposed mining activity, or any other proposed activity that could impact the groundwater in that, be closely evaluated, based on site-specific conditions, before any decision is made to approve such an activity.

When looking at the monitoring data and speaking to local water users, some changes of note and concern should be noted:

For the entire G30 (Sandveld):

- Important springs and seepage areas have been identified. Apart from the Matroozefontein at Redelinghuys, none are being monitored and it is vital that these spring flows are equipped with flow monitoring devices and be incorporated into the DWS monitoring system.
- Recharge has been linked to the bordering mountain ranges, and although more studies are needed for the northern G30 catchments to delineate the extent of their recharge areas into the mountains of the E10 quaternary catchments, monitoring needs to be increased in these recharge areas, as historically it was focused on the coastal plains.
- Areas of deeper water levels have been reported in the area, pointing to localised decreased water levels creating long-lasting cones of influence due to high abstraction volumes being abstracted in wellfields.
- Nitrate and EC increases have been observed in some of the coastal G30 catchments. The nitrate increases are very localised and usually linked to boreholes adjacent to pivot circles. The extent of these increases should be investigated by sampling boreholes near where the high nitrate level has been picked up to investigate the size

of the potential pollution plume. EC increases are more gradual, it has been hypothesized that these are likely linked to poorer water quality interacting with the fresher water as the good quality water is targeted for abstraction.
- Groundwater abstraction is confined to specific areas, some being adjacent to river channels, springs and seepage areas. This is likely impacting the baseflow and thus the surface water systems. Even though water balance results might be positive, the impacts on surface water could be negative due to the potential targeting of surface water, interflow and baseflow.

For specific GRUs within G30 (Sandveld):

- G30C (Bergvallei): A reported drop in water level and drilling of deeper boreholes into the riparian zone, as well as multiple in-stream dams and the planting of orchards within the riparian zone and stream beds are potentially abstracting the large percentages of the baseflow contribution in the Bergvallei and Jansekraal valleys.
- G30F (Langvlei and Wadrift): Water levels for this area do show a significant drop and with the drying up of the lower Wadrift wetland having been linked to over-abstraction of groundwater, the negative water balance could be shown to be accurate for the area.
- G30E (Verlorenvlei): A smaller drop in water level was observed in the boreholes surrounding the Verlorenvlei wetland. The drop observed could be allowing water from the poorer quality sections of the primary aquifer to be drawn into the better quality water areas. Some groundwater inflow has been observed in the upper sections of the Verlorenvlei wetland and it is recommended that this be further studied as per the recommendations section of this report.

For the entire F60 (Namaqualand/Sout and Brak):

Groundwater abstraction is very low and current groundwater systems are observed as being very close to reference conditions. The rivers and streams need to be sampled during flow events to study the link between groundwater and surface water. A drop in water level in some of the DWS monitoring sites located near the Bitterfontein municipal production boreholes was observed. The trends observed in the DWS boreholes could not clearly be linked to the production boreholes for the municipality, although the municipality noted that they do have some issues with some of the boreholes. It is recommended that the monitoring data from the actual production boreholes be obtained and incorporated into the DWS monitoring system to investigate this further.

The information summarised in this report was compiled using materials, data and evidence derived from sources believed to be reliable and credible. While every endeavour has been made by the author (s) to ensure that the information provided is accurate and relevant, this report is, of necessity, based on information that could be reasonably sourced within the time period allocated to this project, and is dependent on information provided by other parties.

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