

Karoo Uranium Project Groundwater Investigation: Quaggasfontein Area: Open Pit Mining

Report Prepared for

Tasman Pacific Minerals Limited

Report Number 506857/3



Report Prepared by

The logo for srk consulting, featuring a stylized orange 's' symbol followed by the text 'srk consulting' in a grey sans-serif font.

April 2017

Karoo Uranium Project Groundwater Investigation: Quaggasfontein Area: Open Pit Mining

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Executive Summary

Introduction

The Karoo Uranium Project areas are located in the Beaufort West and Aberdeen districts in the Great Karoo, a semi-desert area geologically comprising interbedded shales, mudstones and sandstones, intruded by dolerite dykes and sills in the northern parts. Groundwater is a key resource in this arid environment and is used extensively by landowners for stock watering, domestic and irrigation purposes, and for municipal water supply. Uranium mineralisation is relatively common in the Great Karoo and, within the current study areas, it is mainly confined to channel sandstones from surface to relatively shallow depths. The mineralisation is regionally extensive, with the main zones referred to as Ryst Kuil, Haanekuul, De Pannen (Kareepoort) comprising the Ryst Kuil Study Area (RKSA) and Quaggasfontein the Quaggasfontein Study Area (QSA). This report covers groundwater characterisation of the latter study area but only assesses open pit mining, to support Tasman Pacific Minerals Limited's (the client) mining right application. The other mine areas are covered in separate reports.

A comprehensive groundwater investigation of the RKSA was carried out by SRK Consulting (South Africa) (Pty) Ltd (SRK) in 2007/2008. This involved, *inter alia*, a hydrocensus, surface geophysics, exploration drilling & yield testing and numerical flow & contaminant transport modelling. A groundwater monitoring network was also established. This was part of a study for UraMin/Areva into establishing uranium mining in the area but did not cover the QSA. Some background information from this investigation is included in the current report.

The client now intends to establish a series of relatively small and shallow open pits to exploit zones of uranium mineralisation, with a Central Processing Plant (CPP) in the south-west of the RKSA. The CPP will include a lined Tailings Storage Facility. The client appointed SRK in August 2016 to site and install four purpose-drilled geohydrological exploration boreholes, install dataloggers in two of these boreholes, carry out a hydrocensus and numerical flow & contaminant transport modelling. These are the main aspects covered in the current report and the reader is referred to the original SRK reports on groundwater and other references cited for further background information.

Background Geohydrology

The proposed mining areas fall within quaternary catchment J21A and a non-perennial stream runs through the area, from east to west.

The main regional aquifer is a channel sandstone, a fractured rock aquifer, which has a thickness of c.15 – 20 m in the proposed mine area. The uranium ore body is also hosted within this sandstone. There is a fairly strong east-west anisotropy with respect to transmissivity, which is caused by folding and fracturing related to the Cape Fold Belt to the south. Groundwater flow direction in the mining application area is generally to the north-west.

Catchment J21A is classified by the Department of Water and Sanitation as being 'stressed', especially in drought years. However, the 'scale' effect is of relevance here and they acknowledge that conditions could be different over smaller areas within the catchment, e.g. at the wellfield/borehole level and, by implication, mine level.

Farms were visited in August & September 2016 and positions of 37 boreholes recorded, with sparse information on depth, yield and use obtained from the owners, viz:

- Groundwater is mostly used for stock watering, domestic/municipal (Beaufort West) supply and some irrigation;
- Rest water levels ranged from 2.00 mbgl to 21.55 mbgl;
- Groundwater quality is variable, with electrical conductivity (EC) mostly (four boreholes) ranging from c.94 – 110 mS/m, with two 'highs' of 277 and 296 mS/m. The water is hard to very hard and of a mixed calcium/magnesium/sodium-bicarbonate/chloride/sulfate type, with relatively high fluoride and high nitrate content;
- Groundwater quality of the municipal boreholes is mostly poor, e.g. ECs of 170 – 305 mS/m, and of marginal quality for drinking water supplies; and
- Four groundwater samples were tested for radiological indicators and all exceed World Health Organisation screening levels for drinking water of 0.5 Bq/L for gross alpha activity, one only marginally.

Drilling and Test Pumping

Four purpose-drilled boreholes were drilled in the proposed mining area in October 2016, with the following results:

- Drilling depths were relatively shallow at 60 to 84 m due to the shallow nature of the proposed open pits;
- Only boreholes QFNW1 and QFNW2 had sufficient blow-yields, 7.2 and 0.3 L/s, respectively, to warrant test pumping being carried out;
- QFNW1 sustained a yield of 10.10 L/s over 48 h of pumping, with a recommended long-term yield of 1.90 L/s;
- Transmissivities derived from analysis of the test pumping results were low at 2 and 10 m²/day;
- Groundwater quality is relatively good, with electrical conductivities of c.95 mS/m (three boreholes), but the water is hard and has high nitrate levels (3.15 mg/L – 11.7 mg/L, as nitrogen);
- Significant differences in water quality between these purpose-drilled boreholes and those developed by Beaufort West Municipality add to the intuitive hypothesis of a lack of interconnectivity between the two areas based on distance; and
- Gross alpha activities are relatively high compared to hydrocensus sample results, at 1.04 to 2.99.

Leach Tests

- The 2016 acid-base accounting results show that the waste rock is classified as non-acid generating, i.e. acid rock drainage is unlikely; and
- The concentrations of uranium in the aqueous leachates (1:1 solid liquid ratio) of all waste rock samples are below the detection limit of 2 µg/L and the thorium concentrations range from <2 µg/L to 6 µg/L, i.e. mobilisation of significant concentrations of radionuclides such as uranium and thorium is highly unlikely.

Numerical Modelling

The predictive scenarios for mining at Quaggasfontein have been included in isolation from all other mining areas for this report. Due to the distance of Quaggasfontein from the other proposed mining areas, this is deemed reasonable, as interference between sites (interconnectivity/transmissivity) is highly unlikely beyond c.10 km separation distance. The CPP will also be located in a different quaternary catchment beyond any possible impact on groundwater in the QSA.

Four open pits are planned, designated OP1 – OP4 from west to east, with the largest being OP2. Pit depths range from 10 m – 23 m. The numerical modelling indicates the following:

Inflows

- Pits OP1 and OP4 are too shallow to intersect groundwater and no inflows are predicted;
- The highest estimated inflow rate of c.8.5 L/s occurs at OP3 in Month 1 of mining, with an inflow of c.7.4 L/s predicted for OP2, also in Month1, giving a cumulative total of c.16 L/s; However, much of this water will be lost to evaporation from pit surfaces and sumps, assuming 'passive' dewatering rather than active pumping from boreholes; and
- Total inflow reduces to c.7.4 L/s from OP2 only after Month 9 and then to zero, assuming all pits are backfilled.

Drawdowns

- The drawdown zone (-5 m) expands pseudo-radially to cover a maximum area of c.1 000 m x c.1 000 m after Month 9;
- Privately-owned borehole KWN2 (on the edge of pit OP3) and purpose-drilled groundwater exploration borehole QFNW2 could be temporarily affected by >5 m drawdowns caused by mining, possibly causing changes in yield and water quality. However, any such effects will be insignificant as these are low yielding boreholes (KWN2 could be destroyed by mining activities);
- The model reflects 'equivalent matrix hydraulic properties' and not fracture properties, and hence it is likely that the actual drawdown will not reach the extent shown, due to lack of actual interconnectivity between fractures;
- Recovery of the drawdown zone to <5 m across the area occurs rapidly and within one year following mine closure, with backfilling of all pits. This has been further confirmed by analytical calculations, taking into account that the hydraulic parameters of the mining areas are altered post-mining. The K values are increased to 10 m/d and the specific yield and porosity are assumed to be 0.3 (30%) due to the nature of the waste rock backfill in the pits. Only OP2 is still open during the last month of mining. The other pits will have already been in recovery; and
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes.

Groundwater Quality

- Potential contamination can arise from the open pits due to interaction of rainwater through waste rock, (increased exposed area for dissolution of salts from e.g. shales/mudstones), evaporation of inflow and surface runoff water concentrating salts and reaction with exposed areas of ore;

- After nine months of mining, there are small contaminant footprints around OP1 and OP4, due to ongoing recharge;
- After five years post-mining, and with backfilling in all pits, a potential contaminant plume has developed from OP2, extending down the groundwater flow path c.2 km towards, but not reaching, privately-owned borehole KWA3;
- After five years post-mining but with no backfilling of OP2, the potential contaminant plume is reduced in area and extent; and
- It should be noted that 'contamination' in this context refers to an increase in EC level - however small - above background; most such affected groundwater would still be 'fit-for-purpose'.

All drawdowns and 'plumes' are contained within the Quaggasfontein Application Area.

Recommendations

The following actions are recommended:

- Continue the existing groundwater monitoring programme, i.e. QFNW2 and 4, with continuous groundwater level measurements and bi-annual quality sampling and datalogger information download (May & November). Additional monitoring boreholes may be required to be installed;
- Carry out further assessment of specific pit groundwater management requirements, which will probably involve a combination of sub-horizontal drain holes and/or sumps, i.e. 'passive' dewatering. A water use licence application will be required;
- Confirm details on depths, yields, use, water levels and groundwater quality of potentially affected privately-owned boreholes, e.g. KWN2 and possibly KWN3 and 4, prior to commencement of mining;
- Do not backfill pits or, if backfilling is required, only partially backfill the 'downstream' open pit (OP2), so as to create a long-term but localised 'sink' to 'capture' any local groundwater contamination; and
- Carry out updating of the numerical modelling to refine scenario predictions as new data on mine planning and groundwater monitoring become available.

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Disclaimer

The opinions expressed in this Report have been based on the information supplied to SRK Consulting (South Africa) (Pty) Ltd (SRK) by Tasman Pacific Minerals Limited and data from local landowners and other sources, as indicated. SRK has exercised due care in reviewing the supplied/obtained information. Whilst SRK has compared the available data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the available data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

Statement of SRK Independence

Neither SRK nor any of the authors of this Report have any material present or contingent interest in the outcome of this Report, nor do they have any pecuniary or other interest that could be reasonably regarded as being capable of affecting their independence or that of SRK.

SRK has no beneficial interest in the outcome of the assessment which is capable of affecting its independence.

Glossary of Terms

Aquifer: A water-bearing geological formation capable of supplying useable quantities of groundwater to wells, boreholes and springs.

Anoxic: Water that is depleted in dissolved oxygen.

Becquerel: The SI unit of radioactivity, corresponding to one disintegration per second.

Contamination: The introduction of any substance into the environment by the action of man.

Dolerite: A medium-grained dark coloured intrusive, igneous rock comprising of mainly plagioclase feldspar and pyroxene.

Dyke: A vertical to sub-vertical linear intrusion of igneous rock.

Electrical Conductivity (EC): A measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in the water, mainly bicarbonate, chloride, sulfate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge.

Fractured-rock Aquifer: Aquifers where groundwater occurs within fractures and fissures in hard-rock formations.

Geohydrology: The study of the properties, distribution and circulation of groundwater. In South Africa it is used interchangeably with hydrogeology.

Gross Alpha (α) Activity: Total radioactivity due to alpha particle emissions.

Gross Beta (β) Activity: Total radioactivity due to beta particle emissions.

Groundwater: Refers to the water filling the pores and voids in geological formations below the water table.

Groundwater Flow: The movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone. Groundwater naturally drains from higher lying areas to low lying areas such as rivers, lakes and the oceans. The rate of flow depends on the slope of the water table and the transmissivity of the geological formations.

Groundwater Recharge: Refers to the portion of rainfall that actually infiltrates the soil, percolates under gravity through the unsaturated zone (also called the Vadose Zone) down to the saturated zone below the water table (also called the Phreatic Zone).

Groundwater Resource: All groundwater available for beneficial use, including by man, aquatic ecosystems and the greater environment.

Hydraulic Conductivity (K): Measure of the ease with which water will pass through porous material; defined as the rate of flow through a cross-section of one square meter under a unit hydraulic gradient at right angles to the direction of flow (in m/d).

Intergranular Aquifer: Aquifers where groundwater is contained in original intergranular interstices of sedimentary and weathered formations.

Oxic: Water that contains dissolved oxygen.

Pedepain: An extensive plain best developed in arid and semi-arid areas, terminated abruptly by uplands. The result of scarp recession, it consists of coalesced pediments.

Pollution: The introduction into the environment of any substance by the action of man that is, or results in, unacceptable harmful effects to man or the environment.

Ponded Water: The excessive accumulation of water in low-lying areas after sustained rainfall.

Recharge: The addition of water to the zone of saturation, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.

Redox: Reduction or oxidation is caused by an exchange of electrons between chemical species.

Saline Water: Water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids (>10 000 mg/L).

Saturated Zone: The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere

Specific Yield (S_y): Ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass.

Storativity (S): The volume of water released from storage per unit of aquifer storage area per unit change in head.

Transmissivity (T): the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.

Unconfined Aquifer: An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.

Unsaturated Zone: That part of the geological stratum above the water table where interstices and voids contain a combination of air and water; synonymous with *zone of aeration* or *vadose zone*.

Water Table: The upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

For a detailed dictionary of groundwater terms please refer to the following DWA website:

<http://www.dwa.gov.za/Groundwater/GroundwaterDictionary.aspx>

List of Abbreviations

Bq/L	Becquerel per litre
CDT	Constant Discharge Test
DWA	Department of Water Affairs (previously DWAF)
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation (previously DWAF and DWA)
EC	Electrical conductivity (measure of salinity of water)
EIA	Environmental Impact Assessment
GA	General Authorisation
GIS	Geographical Information System
ha	hectares
h/d	hours per day
L/s	Litres per second
m	metres
mamsl	metres above mean sea level
MAP	Mean Annual Precipitation
mbgl	metres below ground level
mg/L	milligrams per litre
mm	millimetres
mS/m	milli-Siemens per metre
m ³ /a	cubic metres per annum
NGA	National Groundwater Archive (previously NGDB)
SANAS	South African National Accreditation System
SDT	Step Drawdown Test
SRK	SRK Consulting (South Africa) (Pty) Ltd
TSF	Tailings Storage Facility
TDS	Total Dissolved Solids
WHO	World Health Organisation
WL	Water Level

1 Introduction

1.1 Background

At a workshop in Cape Town on 8 and 9 June 2016, Tasman Pacific Minerals Limited (the client) provided SRK Consulting (South Africa) (Pty) Ltd (SRK) with an overview of their proposed uranium mining activities in the Ryst Kuil and Quaggasfontein areas of the Great Karoo near Beaufort West in the Western Cape, and Aberdeen in the Eastern Cape. Based on SRK's previous groundwater work in the Ryst Kuil Area in 2007/2008 (SRK, 2008) and subsequent groundwater monitoring (SRK 2008, 2014), the client requested SRK to submit proposals to cover establishment of groundwater monitoring, siting and drilling of groundwater exploration/test boreholes, carry out a hydrocensus, numerical flow & contaminant modelling, and to compile a groundwater report for use in updating the previously submitted Environmental Impact Assessment (EIA) (Ferret, 2016), and attendance at water forum and other meetings in Beaufort West and surrounds.

The uranium mineralisation is regionally extensive, with the main zones referred to as Ryst Kuil, Haanekuil, De Pannen (Kareepoort) in the Ryst Kuil Study Area (RKSA) and Quaggasfontein in the Quaggasfontein Study Area (QSA). This report covers groundwater characterisation and mining (shallow open pits) in the QSA, to support the client's Mining Right Application. The other mine areas are covered in separate reports. A Central Processing Plant will be established in the south-west of the Ryst Kuil area, and will include a lined Tailings Storage Facility. These facilities will not impact on the QSA.

1.2 Purpose

The main thrust of this work is to assess the potential impacts of open pit uranium mining on the local aquifer and existing groundwater users and propose practicable mitigation measures to avoid and /or limit any identified impacts. This report will be used by Ferret to support the EIA in which the actual impact assessments will be covered. The study areas, mining right areas, quaternary catchments, drainage and main roads are shown in **Figure 1-1**.

1.3 Deliverables

The agreed project deliverables were as follows:

1. Provide a stand-alone groundwater report that can be used to support the EIA (by Ferret), in support of the Quaggasfontein mining application;
2. Establish a groundwater monitoring network;
3. Carry out a hydrocensus in the QSA to provide a baseline database of groundwater use and quality; and
4. Construct a calibrated numerical flow model of the area and then a contaminant transport model.

1.4 Work Programme

The total work programme comprised:

- Data collation and review, based mainly on the 2007/2008 investigation (SRK, 2008) and other relevant reports;

- Site visits, carried out on 21 and 22 July and 26 September 2016, the former with the client and regulatory authorities and to attend Water Forum and IAP meetings, and the latter with the client for numerical modelling team site orientation;
- Installation of two dataloggers in two new, purpose-drilled boreholes in the Quaggasfontein mining area, QFNW2 and QFNW4, on 22 December 2016;
- Detailed hydrocensus to collect background information on borehole locations, groundwater use and quality;
- Borehole siting and drilling to fill in gaps in the geohydrological database;
- Pump testing of two of these new boreholes (based on blow-yield) to determine long-term yields and hydraulic parameters such as transmissivity (T) and storage (S), which involved:
 - A step drawdown test (SDT) consisting of 4 x 60 min consecutive tests, each conducted at a higher pumping rate, followed by recovery of the water level for a similar time period;
 - A 48 h (QFNW2) and 72 h (QFNW1) constant discharge test (CDT), followed by water level recovery for the duration of the CDT; and
 - Measurement (at fixed intervals) of the water level, discharge rate, electrical conductivity (EC) and pH of the water abstracted during the tests.
- Water samples were taken during the hydrocensus and from three of the new boreholes and submitted for macro-chemical analyses & metals scan, and for background radiological analyses; and
- Data analysis, conceptual, flow and contaminant transport modelling, and compilation of this report.

Hydrocensus, test pumping and chemical analysis databases are available on request.

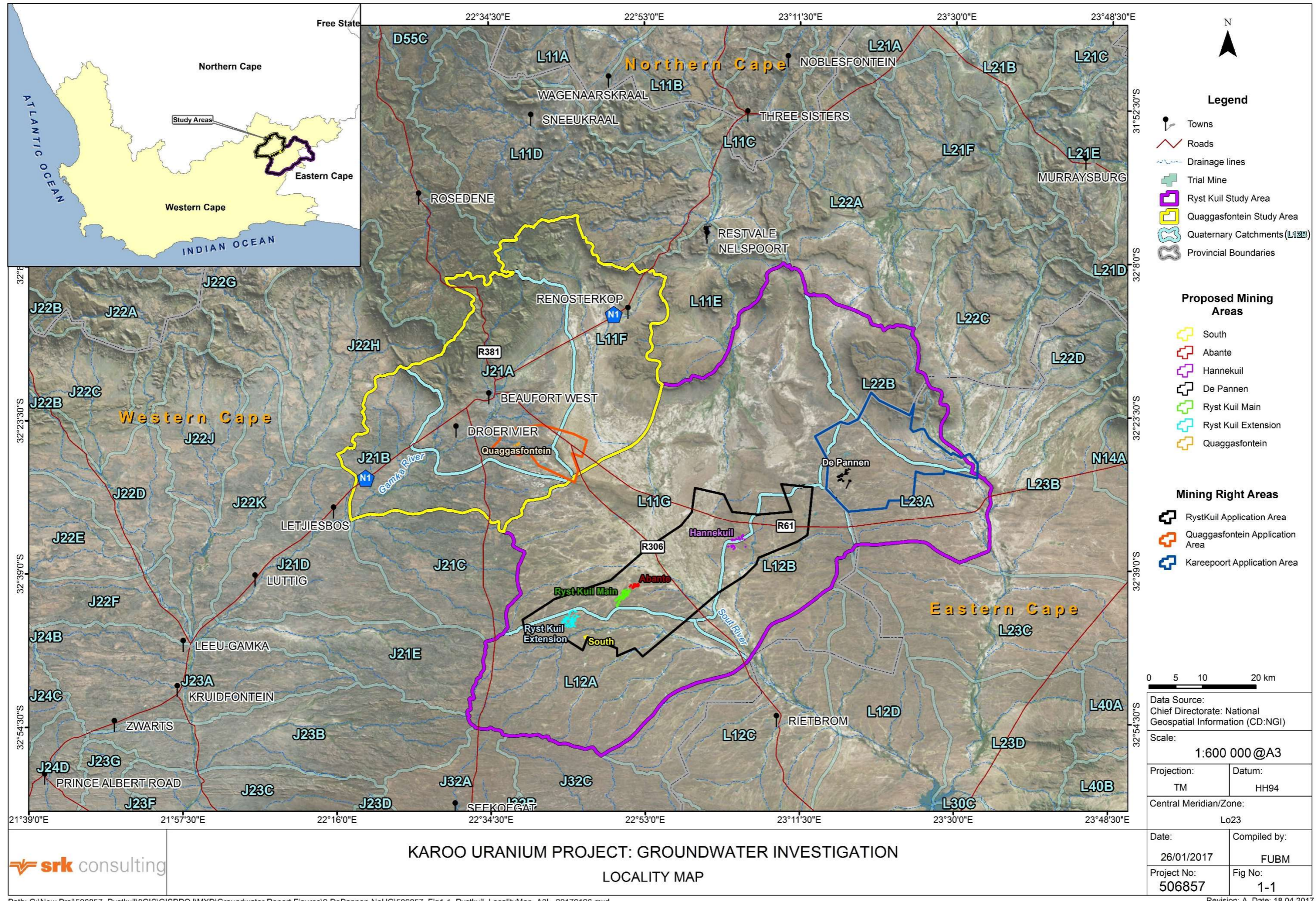


Figure 1-1: Locality Map

2 Background Information

This report covers the work programme set-out under **Subsection 1.2**. The reader is also referred to the following reports for further background details on groundwater in the similar and adjacent Ryst Kuil Study Area, which are not repeated herein:

- *SRK Consulting. Ryst Kuil Uranium Project Definitive Feasibility Study: Groundwater Investigation Phase 1. Report 379859. August 2007.*
- *SRK Consulting. Ryst Kuil Uranium Project Definitive Feasibility Study: Groundwater Investigation Phase 2. Report 379859/1. July 2008.*

A report by the Department of Water and Sanitation (DWS, 2015) on the Breede-Gouritz Water Management Area also contains relevant information related to Reserve determination for quaternary catchment J21A. At the catchment scale, and without site-specific drilling or yield testing to provide a more detailed assessment, catchment J21A is rated therein as 'stressed', especially in drought years.

The QSA mainly consists of fractured and fractured & intergranular aquifers. There are intergranular or primary aquifers in extensive pediment areas to the north-east (see **Figure 2-1**). These aquifers are composed of sand, silt and some gravel, pebbles and boulders. The proposed mining areas fall within quaternary catchment J21A and a non-perennial stream (the Quaggarivier) runs through the area, from east to west

The fractured aquifer is mainly developed in sandstones of the Beaufort Group, while fractured and intergranular aquifers are associated with Karoo dolerites. An inclined dolerite sill crosses the QSA with a northwest-southeast trending outcrop. The uranium (U) mineralisation is mainly within a narrow zone of 'channel' sandstone, which is also the main groundwater-bearing horizon. Groundwater occurrence and movement in these aquifers is controlled by fractures, joints and fissures, including the jointed transitional zone between the weathered and fresh rock components, and along bedding planes. Relatively good quality groundwater is found within the secondary aquifers.

The area has a unique physiography, with steep mountains of the Nuweveldberg to the north giving way rapidly southwards to extensive flat-lying areas or pedepain. These are characterised by shallow alluvial soils prone to flooding, sometimes very extensively and with strong overland flow, in times of heavy rainfall. This pedepain is postulated to be the result of headward erosion and retreat of the Great Escarpment to the north. Although some of this water will infiltrate into the alluvium and shallow, weathered fractured aquifer, large volumes of water are postulated to be removed from the catchment by evaporation, which is further discussed under numerical modelling in **Section 4**.

Groundwater flow in the fractured aquifer generally occurs along two main, well-defined conjugate joint sets that are in an east-west and north-northwest to south-southeast orientation. The continuity, spacing and aperture of these joints are controlled by sandstone thickness and the degree and type of folding. The Beaufort Group rocks are gently folded due to the proximity of the Cape Fold Belt (CFB) to the south, and the axes of both anticlinal and synclinal folds trend east-west.

On the quaternary catchment scale, the weathered aquifer is c.43 m thick and the fractured aquifer c.100 m thick (DWS, 2015). At the mine-site scale, the thickness of the main channel sandstone aquifer is c.15 to 20 m, often interbedded with mudstone/shale, according to the purpose-drilled borehole logs (see Appendix 1). Average groundwater levels are relatively shallow in the local aquifers, ranging between c.2 and c.21 m below ground level (mbgl).

Three paragraphs containing key insights to the DWS (2015) study, and of relevance to this report, are quoted below:

“Scale is an important aspect in the study. The objective of the study is to determine the amount of water required for the groundwater Reserve as well as the amount of groundwater that can safely be allocated to current/future groundwater developments. For the purpose of this study, the resolution that is used is the quaternary catchment scale, which is typically tens of kilometres in dimension. Should assessments be done on a smaller scale, such as the wellfield scale that ranges from hundreds of metres to kilometres or borehole scale that ranges between sub-metres to several hundreds of metres or a couple of kilometres, then different conclusions may be reached. It is important to note that the scale of the assessment will have an influence on the assessments – a complex challenge that is associated with hydrogeology, especially in fractured aquifers....”

*“It must be noted that due to the conservative nature of the Desktop-Rapid Reserve methodology (**Section 2.1.5**) catchments that flag as “stressed” may declassify during the Intermediate and higher level Reserve iterations. It is acknowledged that the average regional values above will not be applicable on a local quaternary catchment or wellfield scale, but do provide a primary catchment or regional perspective...”*

“A more detailed groundwater Reserve determination with groundwater dependent ecosystems (GDE) delineation was performed for the J21A catchment as part of the water use licence application (WULA) for groundwater development for Beaufort West. This document should also be used when classifying and setting resource quality objectives for J21A.”

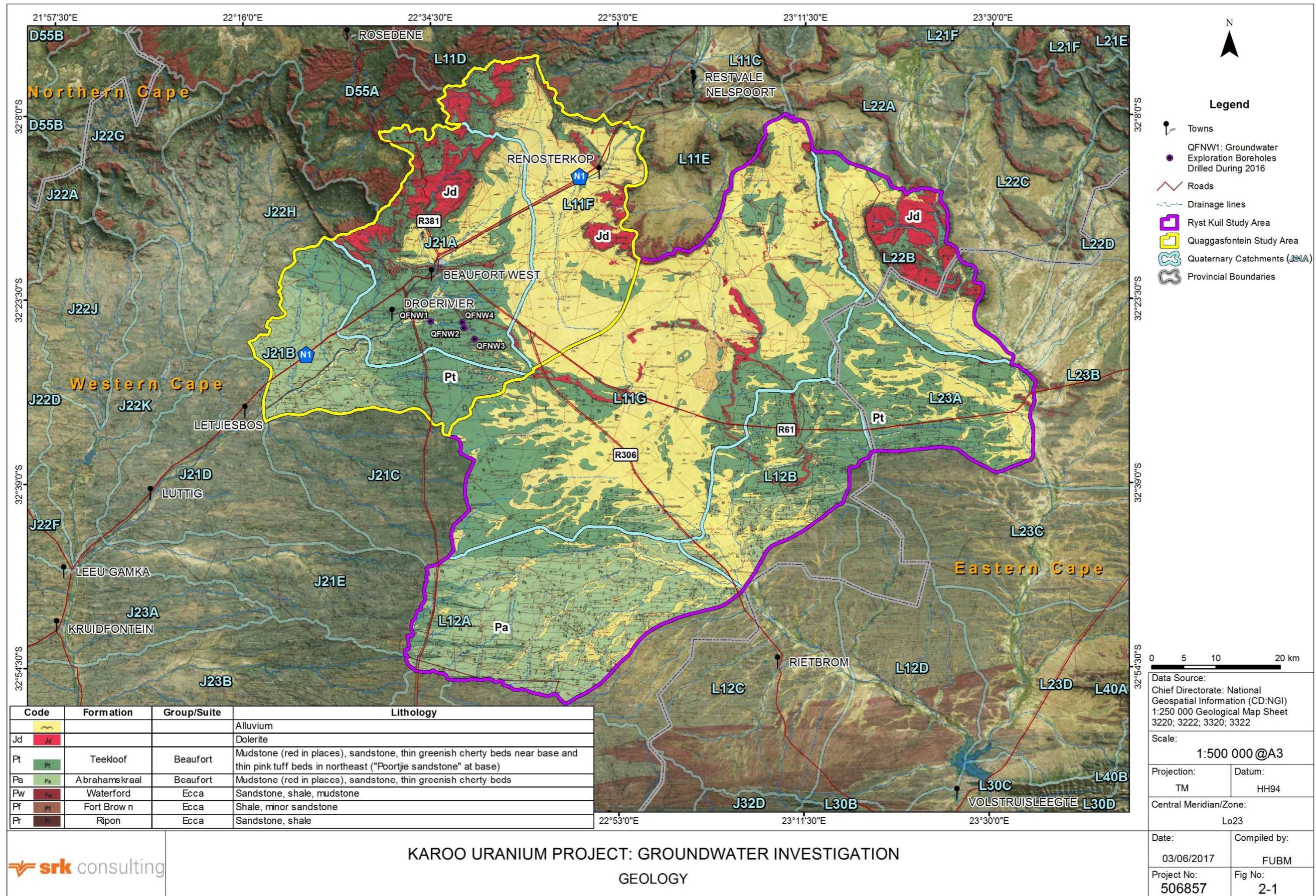


Figure 2-1: Geology

3 Discussion of Results

3.1 Hydrocensus

Farms were visited in August and September 2016 and details on 37 boreholes e.g. depth, yield and use obtained, where available (see **Figure 3-1**). The groundwater is mainly used for stock watering, domestic and irrigation purposes. Information provided by owners on borehole depths and yields was generally very sparse. Most boreholes are equipped with wind pumps and are estimated to yield relatively small volumes in the range 600 – 800 m³/a.

Water levels range from 2.00 mbgl (STR boreholes) to 21.55 (BBK boreholes), with specific ranges as follows:

- HR boreholes: 11.08 – 19.90 mbgl;
- BBK boreholes: 18.03 – 21.55 mbgl;
- KWN boreholes: 14.18 – 18.57 mbgl; and
- STR boreholes: 2.00 – 7.55 mbgl.

3.1.1 Municipal Boreholes

The municipality has a small wellfield comprising four boreholes on Hans Rivier 196 and Steenrotsfontein 168 in the QSA (see **Figure 3-1**). Very little information could be obtained on these boreholes apart from abstraction rates, which reportedly total c.550 000 m³/a. They are located c.10 km upstream of the proposed mining area. Chemical analyses were obtained from the DWS report (2015) and a Water Use Licence Application (WULA) has been submitted (GEOSS, 2012a).

3.2 Borehole Siting and Drilling

The QSA was not part of the earlier (2007/2008) SRK investigations and so new groundwater exploration boreholes were sited and drilled in this area in October 2016, viz:

- QFNW1: Syncline in sandstone with underlying mudstone (see **Figure 3-2**);
- QFNW2: Joint sets in sandstone, likely on or near a syncline (see **Figure 3-3**);
- QFNW3: Syncline in mudstone; and
- QFNW4: Anticline in mudstone (see **Figure 3-4**).

These boreholes were drilled to a maximum depth of 84 m because of the shallow (c.20 m) depth of the proposed mining in this area. Borehole sites are shown on **Figure 2-1** and lithological logs in **Appendix A**. Drilling results are summarised in **Table 3-1**.

Table 3-1: Summary of Quaggasfontein Groundwater Exploration Boreholes

Borehole No.	Depth (m)	Rest Water Level (mbgl)	Groundwater Intersections (mbgl)	Blow Yield (L/s)	Lab. EC (mS/m)
QFNW1	84	16.64	26-29, 38, 65	6.1, 6.6, 7.2	94.4
QFNW2	60	12.74	18, 36	0.3	94.8
QFNW3	64	-	59	0.2	95.4

QFNW4	64	-	52	Seep	-
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Only QFNW1 (in fractured mudstone) yielded significant groundwater, with test pumping undertaken at >10 L/s for 3 days resulting in a maximum drawdown of only c.8 m. Anomalously, yields from QFNW2 (in the channel sandstone) are far lower, with pumping at <0.5 L/s for 2 days resulting in a maximum drawdown of c.6 m. The relatively shallow depth of the other boreholes could have contributed to their low blow-yields. Dataloggers were installed in QFNW2 and QFNW4 on 22 December 2016.

3.3 Yield Testing

Only boreholes QFNW1 and QFNW2 had sufficient blow-yields to warrant yield testing. This was carried out by WellTek Services during the period 24 October to 3 November 2016. **Table 3-2** gives a summary of the testing programme.

Table 3-2: Quaggasfontein Yield Testing Results

Borehole No.	CDT Yield (L/s)	Maximum Drawdown (m)	Late* T (m ² /day)	S	Recommended Long-term Yield (L/s)
QFNW1	10.10	7.95 (72 hours)	c.10	4.4x10 ⁻³	1.90
QFNW2	0.45	6.20 (48 hours)	c.2	4.4x10 ⁻³	0.35

*T derived from later time data, which is usually taken to be more representative for use in long-term predictive modelling

The T and long-term yields obtained are much lower than those determined for the RKSA (which includes De Pannen/Kareepoort) in the 2007/2008 investigation (SRK, 2008). This may be due to the channel sandstone being less well developed and increased distance from the CFB and therefore less influence regarding folding and fracturing propagation. The QFNW boreholes were also drilled to relatively shallow depths because of the shallow depths of the proposed open pits. Discussion on T and S values is given under numerical modelling in **Subsection 4.6**.

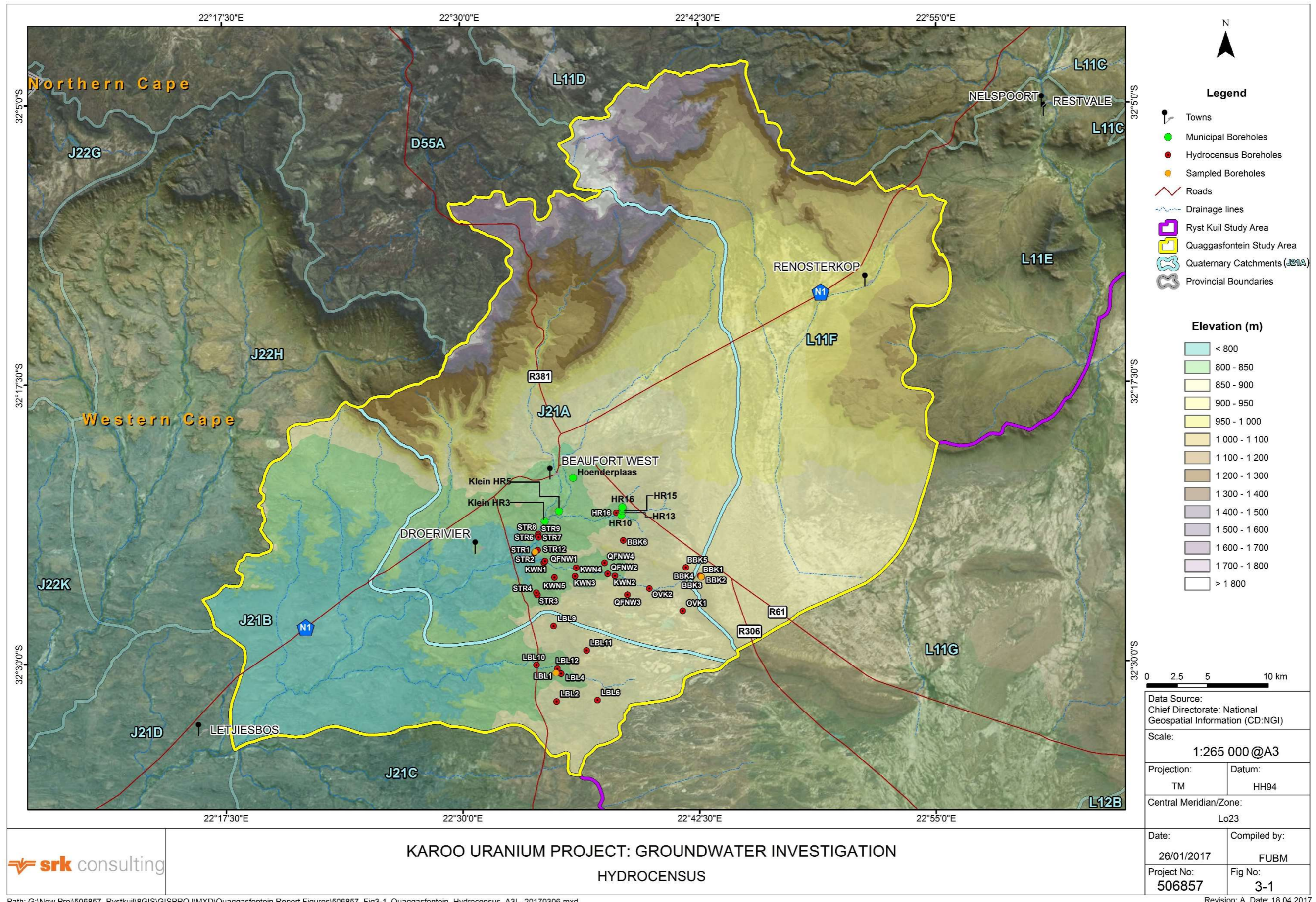


Figure 3-1: Hydrocensus



Figure 3-2: Quaggasfontein Drilling – QFNW1



Figure 3-3: Quaggasfontein Drilling – QFNW2

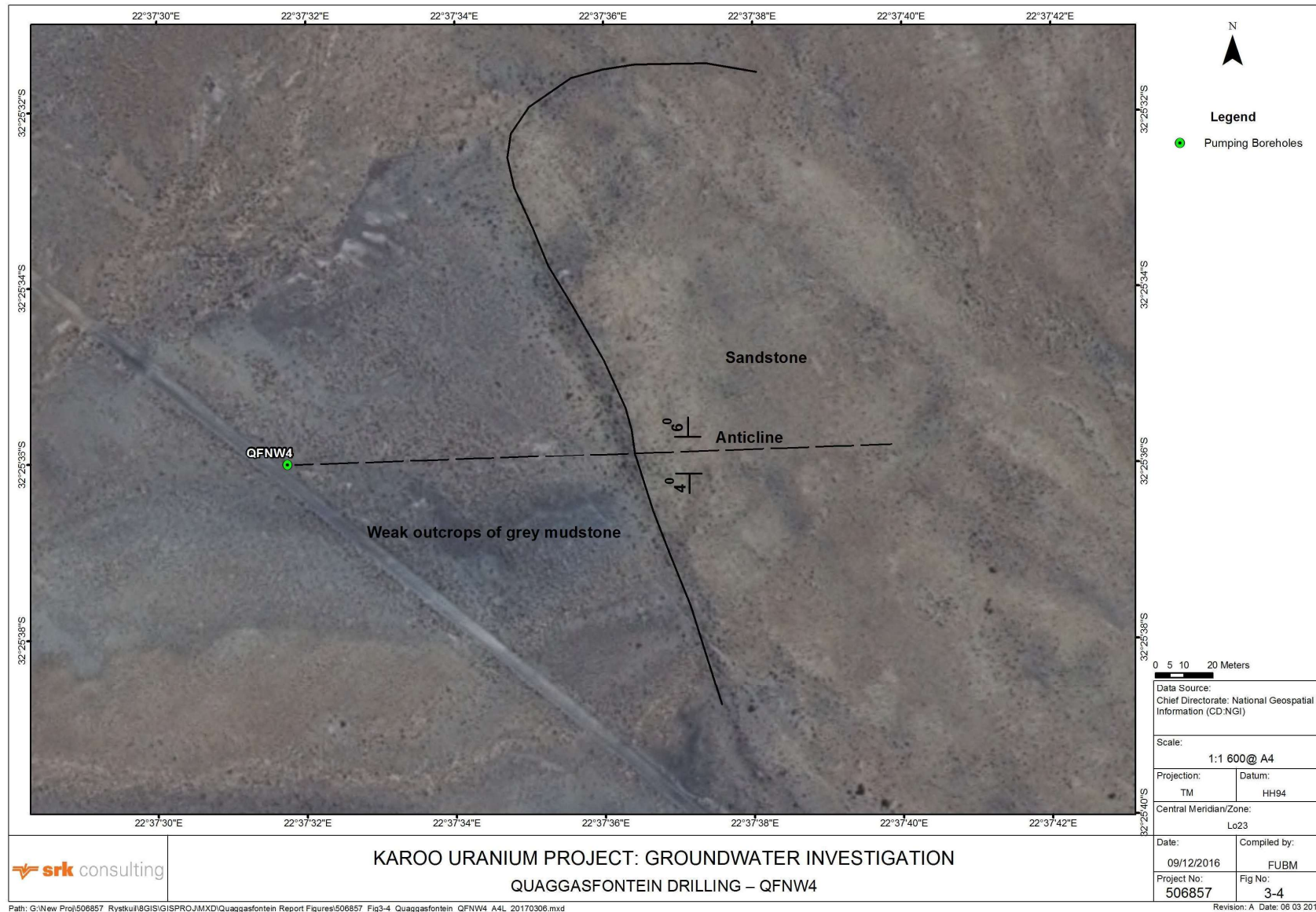


Figure 3-4: Quaggasfontein Drilling – QFNW4

3.4 Water Quality Analyses

3.4.1 Chemical Analyses

Water samples were collected during the hydrocensus and from the new purpose-drilled boreholes and submitted to UIS Laboratories in Centurion for metals scans and macro-chemical analyses. Results from the boreholes developed by Beaufort West Municipality (BWM) in the catchment are also included, taken from Table 2.13 of DWS (2015). A summary of the main ions is given in **Table 3-3**.

Table 3-3: Summary of Macro-Chemistry for 2016 Sampled Boreholes*

BH No.	pH	EC (mS/m)	Total Hardness (as CaCO ₃)	Na	K	Ca	Mg	Cl	SO ₄	NO ₃ (as N)	F
KWN1	7.68	277	773	212	6.32	223	52.5	356	421	<0.13	0.805
STR1	7.89	296	686	315	2.98	161	68.9	368	477	<0.13	0.852
BBK1	7.75	110	423	82.1	4.54	106	38.5	127	95.3	13.4	0.953
QFNW1	7.65	94.4	352	114	5.02	99.8	24.9	92.3	81.8	3.15	0.857
QFNW2	7.35	94.8	376	84.7	7.05	108	26	99.1	70.5	11.5	1.13
QFNW3	7.34	95.4	386	90.9	7.59	111	26.6	98.2	71.8	11.7	1.16
Flagship BH (BWM)	7.6	170.0	NA	198.0	0.0	118.0	39.0	195.0	195.0	NA	NA
HR15 (BWM)	7.2	305.0	NA	203.0	9.5	320.0	79.0	605.0	399.0	NA	NA
HR16 (BWM)	7.2	302.0	NA	204.0	6.3	321.0	79.0	619.0	409.0	NA	NA
SR9 (BWM)	8.0	284.0	NA	345.3	2.8	148.4	59.3	370.1	368.4	NA	NA

*values are reproduced from the certificates of analysis

NA Not analysed

The groundwater is alkaline and ECs are within the range 94 – 305 mS/m, with too few results to make generalisations on reasons for the differences. EC is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in the water, mainly bicarbonate, chloride, sulfate, nitrate, sodium (Na), potassium, calcium (Ca) and magnesium (Mg), all of which carry an electrical charge.

The EC of most groundwater falls well below the SANS 241-1:2015 limit for drinking water (<170 mS/m) except for KWN1 and STR1, and three of the municipal boreholes. The groundwater is hard to very hard and is mostly a mixed sodium-chloride (Cl)/calcium-magnesium-sulfate (SO₄)/Na₂Ca bicarbonate (HCO₃)₂ type. Nitrate levels (<11 mg/L as nitrogen - N - recommended by SANS 241) are relatively elevated in the boreholes with lower EC, probably as a result of agricultural activities, e.g. application of fertilizers and wastes from stock pens. However, the nitrate levels in the boreholes with the highest ECs are conversely low.

The BWM boreholes HR15, HR16 and SR9 have considerably poorer water quality than the new purpose-drilled boreholes, further suggesting that they are not connected hydraulically and that the latter may have better recharge sources. These boreholes provide water of marginal quality for

drinking purposes. Groundwater quality provides further evidence to back the 'scale' issue highlighted in **Section 2**.

3.4.2 Leach Testing

The 2016 acid-base accounting results show that the waste rock is classified as non-acid generating, i.e. acid rock drainage is unlikely to occur. The mobility of uranium in water is controlled by a number of factors, primarily pH, redox status and concentrations of coexisting dissolved ions, particularly carbonate/bicarbonate (high in QSA). Uranium is redox-sensitive and generally occurs in water principally under oxic conditions, i.e. dissolved oxygen is present. Under anoxic conditions, i.e. in the absence of oxygen, uranium is reduced to its tetravalent state and its concentration in water is usually low as a result of stabilisation of the sparingly soluble mineral, uraninite.

The concentrations of uranium in abundant silicate minerals such as quartz and feldspar and carbonate minerals are usually low. The concentrations of uranium in the aqueous leachates (1:1 solid liquid ratio) of all waste rock samples are below the detection limit of 2 µg/L and the thorium concentrations range from <2 µg/L to 6 µg/L, i.e. mobilisation of significant concentrations of uranium/thorium is highly unlikely.

3.4.3 Radiological Analyses

Four water samples from the 2016 hydrocensus and three from the purpose-drilled boreholes were submitted to the Necs laboratory in Pretoria for gross α and β activity analyses. A summary of gross α and β activities is given in **Table 3-4**. Two of these boreholes had also been sampled in 2011 as part of a separate one-off study (pers. comm. C Esterhuyse) and these results are included.

Table 3-4: Summary of Gross Alpha & Beta Activity and Uranium

Borehole No.	Alpha Activity (Bq/L*)		Beta Activity (Bq/L)		Uranium (metals scan, mg/L) 2016
	2011	2016	2011	2016	
KWN1	0,780	1.99	0.11	0.69	0.076
BBK1	NS	0.507	NS	-0,11	<0.01
STR1	NS	0.865	NS	-0.014	0.03
OVK1	0.570	0.872	0.290	0.32	-
QFNW1	NS	2.99	NS	1.82	0.037
QFNW2	NS	1.44	NS	1.15	0.024
QFNW3	NS	1.04	NS	0.822	0.023

*Becquerel per litre

NS: Not sampled

Target water quality for drinking purposes for gross α activity is <0.5 Bq/L, where uranium or radon are the main α emitters (World Health Organisation - WHO). All samples are above this limit, one only marginally so. The metals scans show U ranging from <0.01 – 0.076 mg/L. Comparison of the 2011 and 2016 gross α results suggests some natural variation, although the sample population is very small.

3.5 Monitoring

Groundwater level monitoring began in November 2007 in the Ryst Kuil area but only on 22 December 2016 in the QSA and so some background information from the former area is included here. Discussion is limited to the two areas nearest to (though some distance from) Quaggasfontein, i.e. Haanekuil and Ryst Kuil; the Quaggasfontein loggers are due for data download in the second quarter of 2017.

The localities of boreholes equipped with loggers are indicated in **Figure 3-1**.

3.5.1 Groundwater Levels

Haanekuil Sub-Area

The groundwater level behaviour of boreholes in this sub-area is illustrated in **Figure 3-5**. The logger installed in borehole HNKW26 malfunctioned less than three years after it was installed. During this period the groundwater level fluctuations in this borehole mimicked those of borehole HKLW1. Both boreholes have shallow groundwater levels of <10 mbgl. Prominent spikes in the groundwater level recorded in borehole HKLW1 are caused by recharge from the adjacent earth dam when it fills after intense thunderstorms.

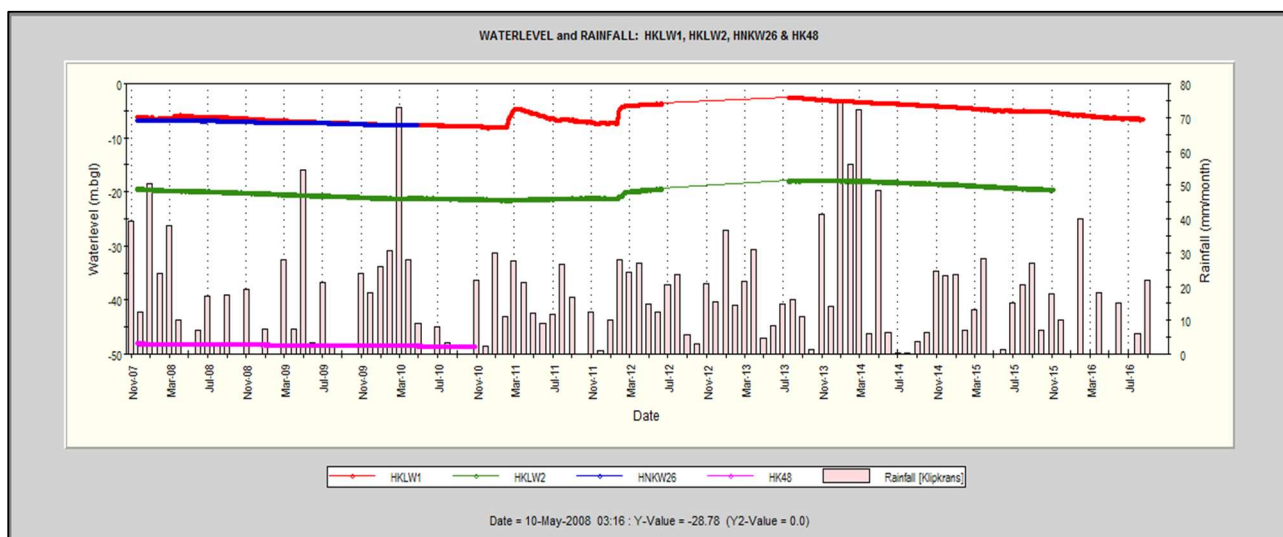


Figure 3-5: Groundwater Level Behaviour of Boreholes in the Haanekuil Sub-Area

Borehole HKLW2 has much less pronounced groundwater level fluctuations, and the water level remains fairly constant. Again, the water level in this borehole is relatively deep compared to that of boreholes HKLW1 and HNKW26. The groundwater level behaviour recorded in borehole HK48 is also very stable with a continuous gradual decline during the period November 2007 to November 2010. This decline correlates well with the declines recorded in the other three boreholes during this time. The logger malfunctioned after November 2010, and no more water levels were recorded.

Ryst Kuil Sub-Area

The groundwater level behaviour of boreholes in this sub-area is illustrated in **Figure 3-6**. The logger installed in borehole VKLM1 malfunctioned after the download of 2013, and therefore no recent groundwater records are available. The loggers installed in boreholes KDK820 and KKR333 have also malfunctioned since the last download in October 2015. However, with the data available, it is clear that borehole VKLM1 has a different groundwater level behaviour compared to boreholes KDK820H, KKRW2 and KKR333. This is due to the combined effect of recharge from a nearby earth

dam when filled after thunderstorms and abstraction from irrigation boreholes in the area. Also, the groundwater level in borehole VKLM1 is much shallower than the levels in the other boreholes in the area.

Groundwater levels in boreholes KKRW2 and KDK820H show a very similar long-term trend. A number of spikes, which are associated with local good rainfall events (which do not necessarily reflect in the rainfall recorded at Klipkrans rainfall station 10 km south-west and Beaufort West 45 km north), are visible in the groundwater level recorded in borehole KDK820H. This phenomenon is likely to be caused by direct recharge from the old mine decline in the vicinity of this borehole. During intense thunderstorms surface runoff enters the decline causing a substantial rise in the water level. Apparently, borehole KDK820H is linked to the shaft by fractures and/or joints which cause a similar rise in the groundwater level of this borehole. It is also clear that there is a time lag of about three years between good rainfall events and the peak of a gradual rise of the groundwater level in these boreholes. Therefore, the recharge caused by the good rains received during the 2013/2014 summer may only cause a rise of the groundwater levels in these boreholes by the end of 2016/early 2017.

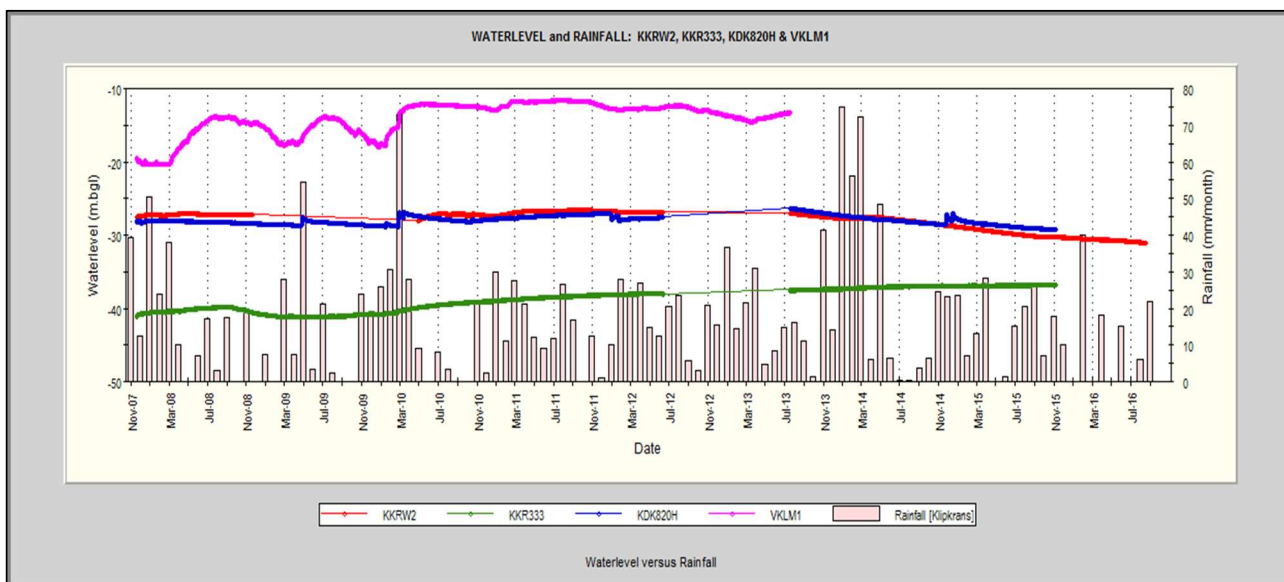


Figure 3-6: Groundwater Level Behaviour of Boreholes in the Ryst Kuil Sub-Area

Borehole KKR333 has a different long-term groundwater level behaviour to boreholes KDK820H and KKRW2. This borehole also has the deepest groundwater level. The reason for the decline evident during the period September 2008 to March 2009 and subsequent gradual rise of the groundwater level in this borehole is still uncertain. However, it is assumed to be linked to a deeper circulating groundwater system with longer time lapses between rainfall events (possibly regional rather than local) and rising water levels in the borehole. The gradual variations of groundwater level over extended periods of time are further supported by this theory.

3.5.2 Groundwater Quality

The macro-chemical results indicate that the fluoride content in groundwater from this area is relatively high and only borehole KDKW6 continuously yields groundwater suitable for prolonged human consumption. This borehole is drilled into a trial mine/decline from the 1978/1979 work by ESSO (SRK, 2007) and the EC values indicate that there is very good recharge from local rain events. The decline entrance was formerly open to surface water runoff (sealed by the client in 2016, although runoff could still enter) and there is evidence that rain water drained down the decline. Therefore, groundwater from this borehole is probably not yet representative of the area. The nitrate values of groundwater samples taken from boreholes KDKW1, KDKW4 and KDK0017 vary considerably over time. The high nitrate concentrations are likely linked to pollution from surface sources, e.g. livestock

wastes, via active recharge. (Note: These boreholes are only equipped with a short length of casing and surface water can easily infiltrate between the casing and borehole wall and reach the groundwater level. Water levels and water quality are shown on **Figure 3-7**.

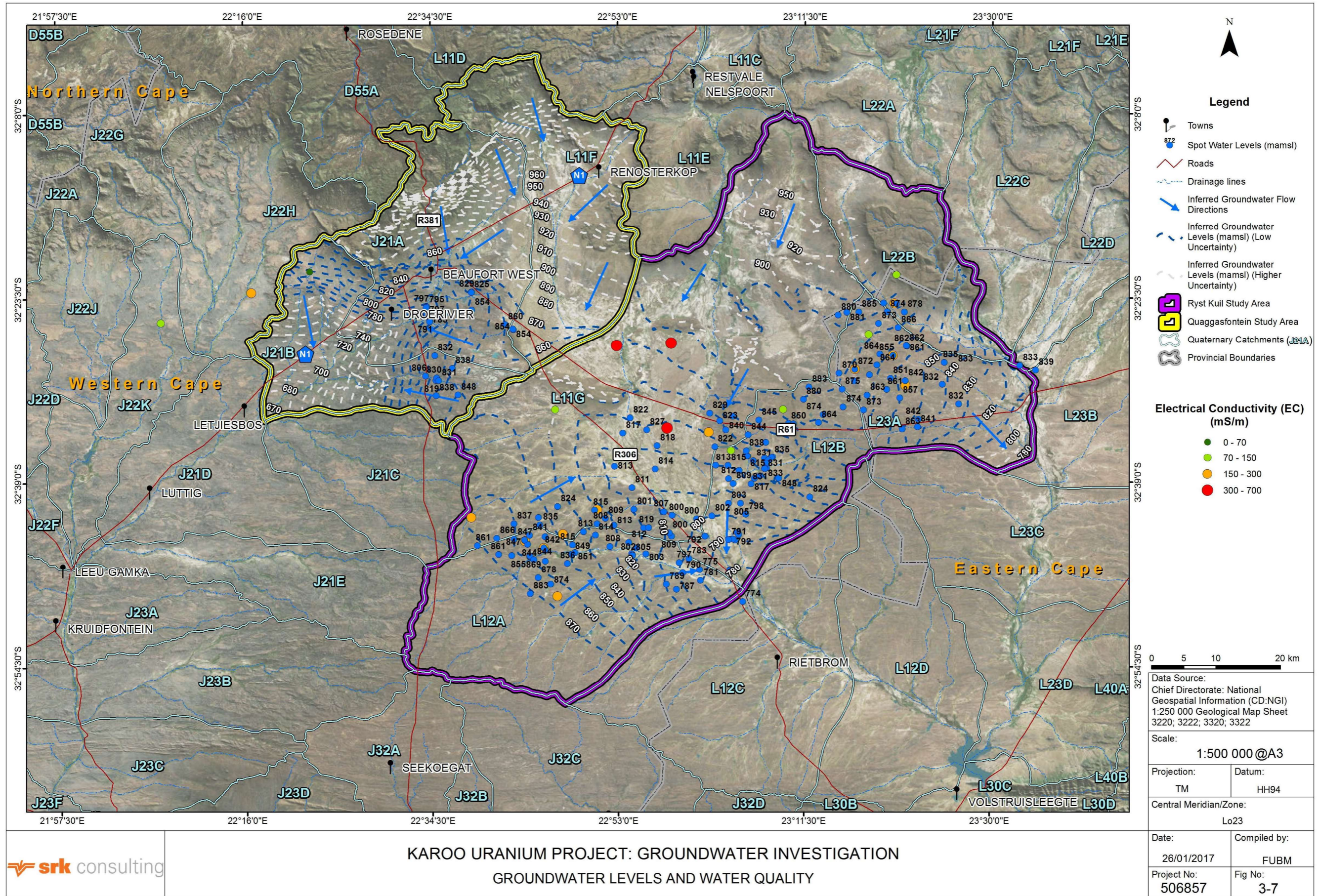


Figure 3-7: Groundwater Levels and Water Quality

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4 Numerical Model Set-up and Calibration

Key input to the scenario modelling was provided by separate studies on mine planning and design (pers. comm. G. Roets, DRA 2017) and geochemistry (pers. comm. R. O'Brien, SRK, 2016).

4.1 Approach

4.1.1 Groundwater Flow Equation

A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow where the effect of for example the contamination sites are taken into account.

The simulation model (*MODFLOW*) used in this modelling study is based on three-dimensional groundwater flow and may be described by the following equation:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) \pm W = S \frac{\partial h}{\partial t} \quad (1)$$

Where

h = hydraulic head [Length]

K_x, K_y, K_z = Hydraulic Conductivity [Length / Time]

S = storage coefficient

t = time [Time]

W = source (recharge) or sink (pumping) per unit area [Length / Time]

x, y, z = spatial co-ordinates [Length]

For steady state conditions the groundwater flow Equation (1) reduces to the following equation:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) \pm W = 0$$

4.1.2 Modelling Code

In order to investigate the behaviour of aquifer systems in time and space, and to predict their response to external stresses, it is standard industry practice to employ numerical flow modelling techniques. *MODFLOW88/96* (Harbaugh and McDonald, 1996a&b), a modular three-dimensional finite difference groundwater flow model, which was developed by the U.S. Geological Survey, was the software used during this investigation. It is an internationally accepted and benchmarked modelling package that calculates the solution of the groundwater flow equation using the finite difference approach. A professional graphical interface, *Groundwater Vistas*, developed by Environmental Simulations, Inc, (Rumbaugh and Rumbaugh, 1999), was used to create the model and to analyse and display the modelling results.

A few reasons why *MODFLOW* has been selected as the modelling package, and more specifically *Groundwater Vistas* as the graphical interface, are listed below:

- *MODFLOW* simulates steady and non-steady state flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination thereof;

- Flow from external stresses, such as flow to boreholes, aerial recharge, evapotranspiration, flow to drains and flow through river beds, can be simulated;
- Hydraulic conductivity or transmissivity for any layer may differ spatially and be anisotropic, as is the case in the fractured rock aquifer in the study areas;
- The storage coefficient may be heterogeneous;
- *MODFLOW* is currently internationally the most used numerical model for flow problems; and
- The *MT3D* mass transport package runs together with *MODFLOW*. This facilitates simulation of the transfer of solutes within the groundwater flow model.

It should be noted that, in the case of a secondary fractured-rock aquifer such as is present at the site, the finite difference model uses a representative elementary volume representation of groundwater flow by assuming very low flows through a representative matrix for the entire area, instead of modelling slightly higher flows through discrete fractures. Alternative software solutions for modelling fracture networks were considered, but were not deemed to be feasible for this study, due to the lack of data for the discrete fractures in the area (including density, orientation, extent, aperture, etc.). The representative volume matrix flow approach, provided by *MODFLOW*, was taken to be the most applicable platform for approximating the solution, with caveats noted where applicable.

MODFLOW is an internationally accepted and benchmarked modelling tool that is used for calculation of the solution of the groundwater flow equation using the finite difference approach. Post processing was completed using *ESRI ArcGIS* and *MS Excel* spreadsheets.

4.1.3 Calibration Process

Calibration is required to account for unmeasured, unknown, or unrepresented conditions or processes and uncertainty in measured input data. The model calibration step requires the greatest effort. Model calibration usually involves most of the following steps, in the order listed:

- Calibrate the flow model before calibrating the flow and transport model. Accept only convergent, stable and well balanced model calculations;
- Simulate natural background conditions to predict the water levels and concentrations corresponding to pre-existing conditions, and compare predictions with any available observations;
- Modify model assumptions and/or uncertain input data, within reasonable bounds, to obtain a realistic simulation. Specify model input data in ranges of values. Note the accuracy of these data so that changes made during the calibration procedure will concentrate on the most uncertain data while remaining within realistic bounds;
- Predict transient flow and transport conditions for the period of development up to the present. Ideally, the transient calibration period should be as long as, or longer than, the period of future predictions to which the calibrated model will be applied; and
- Evaluate the model predictions versus historical observations.

4.1.4 Assumptions and Limitations

The following assumptions were made during the development of the numerical groundwater model:

- The thicknesses of weathered, fractured and fresh rock layers are inferred based on available data when this report was compiled;

- Long-term modelled abstraction rates from boreholes have been estimated based on available information;
- The model domain extends to the quaternary catchment boundaries in order to ensure that the full recharge area is represented and that modelled drawdown and contaminant flow predictions are not influenced by model boundary effects. However, the model area is therefore very extensive and there are some areas where there are few or no observation data available for model calibration. These areas have modelled water levels based on similar parameterisation and methodologies to other areas of the site. Although the water levels cannot be corroborated in this area, they are assumed to be 'fit-for-purpose' in terms of the representation of the regional groundwater flows; and
- The predictive scenarios for Quaggasfontein have been included in isolation from all other mining activities for this report. Due to the distance of Quaggasfontein from the other proposed mining areas, this is deemed reasonable, as interference between sites (interconnectivity/transmissivity) is highly unlikely beyond c.10 km separation distance.

The following limitations of the model should be noted:

- Simulation of flow in specific fracture zones. Such zones exist within the study area, but on the scale of the regional and scenario modelling it is considered that *MODFLOW* will provide adequate representation of the system response; and
- Numerical groundwater models are very useful tools for assisting in the simulation and prediction of groundwater movement under proposed scenarios. They are always theoretical, however, and only based on available data, and therefore careful interpretation of the results and regular update of the model (e.g. with water level monitoring data), is required in order to draw the most informative conclusions.

4.2 Model Domain and Grid

The proposed Quaggasfontein mining area is located in the southern section of the Quaggasfontein numerical groundwater model domain, within quaternary catchment J21A. The full Quaggasfontein model boundary follows the quaternary catchment boundaries of L11F, J21A and J21B. The model grid did not require rotation as the axes of both anticlinal and synclinal folds (and thus hydraulic anisotropy) trend almost directly east-west (see **Section 2**).

The total area covered by the four layers of the finite difference grid is approximately 3 967 km² (comprising of 686 rows and 750 columns). Within the grid and four layers, there are 1 250 224 active modelling cells, resulting in an active model area of approximately 2 129 km².

The coordinates for the modelled area are -69 414, -3 608 141 (lower left corner). The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results. Once the network has been set up, all initial and boundary conditions, sources, sinks and aquifer parameters are entered. Model calibration is then conducted to ensure that the flow model shows similar behaviour to the actual system under investigation.

4.3 Boundary Conditions

One of the first and most important tasks in groundwater modelling is that of identifying the model area and its boundaries. A model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries, however, have to be specified. Boundaries occur at the edges of the model area and at locations in the model where external influences are represented, such as rivers, wells and mine voids.

Criteria for selecting hydraulic boundary conditions are primarily topography, hydrology and geology. The topography, geology, or both, may yield boundaries such as impermeable strata or potentiometric surfaces controlled by surface water, or recharge/discharge areas such as inflow boundaries along mountain ranges. The flow system allows the specification of boundaries in situations where natural boundaries are a considerable distance away.

Boundary conditions must be specified for the entire boundary and may vary with time. At a given boundary section, just one type of boundary condition can be assigned. Boundaries in groundwater models can be specified as:

- Constant head or constant concentration boundary conditions;
- Neuman (or specified flux) boundary conditions; and
- Cauchy (or a combination of Constant and Neuman) boundary conditions.

The following boundary conditions are included in the model:

- Drainage channels and pans are also represented by **drains**, which in this case allow one-way flow from ground to surface water. They are set at the local height of topography with a bed conductance of 0.1 m/d; and
- All other model boundaries are set as **no flow** boundaries as they coincide with boundaries of quaternary catchments.

4.4 Initial Conditions

The generation of a groundwater level contour map is useful for 'sense-checking' of the calibrated steady state (long-term equilibrium) model result to that of the conceptual model. As input to steady state simulations, however, initial water level heads do not influence the resulting modelled water levels. They simply affect the rapidity at which initial numerical convergence to a solution is achieved.

Following calibration of the steady state model, the long-term heads output from the steady state models were used as initial heads for all subsequent transient (time-dependent) models.

4.5 Sources and Sinks

Sources and sinks can be defined as recharge and abstraction sources in the aquifer, respectively. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, springs, evapotranspiration, outflow to surface water and, for Quaggasfontein, open pits.

The initial groundwater recharge values used in the model are taken from the Phase 1 Ryst Kuil report (SRK 2007) where the Maxey-Eakin (1949) empirical methodology was applied. Following model calibration, the mean annual effective recharge for the QSA is c.5.3 mm/a, which equates to an average recharge rate of c.2.1% of MAP (of c.245 mm/a). This is within the range accepted in the DWS (2015) report. The recharge factor is altered quarterly during all transient model runs, to account for seasonal variations. The factors are calculated from the long-term alterations in average rainfall per quarter.

Abstraction rates from both municipal and numerous local stock watering boreholes were included in the model, with abstraction volumes as described in **Subsection 3.1**.

4.6 Aquifer Parameters

4.6.1 Aquifer Dimensions

The model consists of four layers, representing the following:

1. 10 m thick upper weathered aquifer and alluvium (where applicable);
2. 10 m thick lower weathered aquifer;
3. 25 m thick fractured aquifer; and
4. c.150 m thick fresh rock formations.

The top elevation of the model was assigned to topography by importing the GIS shape file for the 20 m Digital Elevation Map of the area.

The approximate thicknesses of the formations were inferred from drill logs and local knowledge.

4.6.2 Hydraulic Properties

Two main parameters are used to describe the physical properties of the aquifer, namely T and S. Transmissivity is a measure of the ease with which groundwater flows in the subsurface and is related to K by: $T = Kb$, where b is the saturated thickness of the aquifer.

Storativity is the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, S is equal to the product of the specific storage and aquifer thickness of the saturated porous medium. For an unconfined aquifer, S is the ratio of the volume of water that drains by gravity to that of the total volume and is known as specific yield.

In the finite difference method, geohydrological parameters are assigned to model cells or blocks, while hydraulic head and flow are attributed to their centre points. Each cell in the model therefore has an individual geohydrological domain code. Geohydrological zones, per model layer / depth, were defined based on the conceptual model, pumping tests and calibration results, and are broadly grouped as follows (see **Figure 4-1**):

1. Alluvial deposits;
2. Dolerite;
3. Palaeochannels (sandstone);
4. Shale/Mudstone (remainder of area);
5. Geological structures, including:
 - a. Dolerite dykes;
 - b. Faults;
 - c. Anticlinal fold axes; and
 - d. Synclinal fold axes

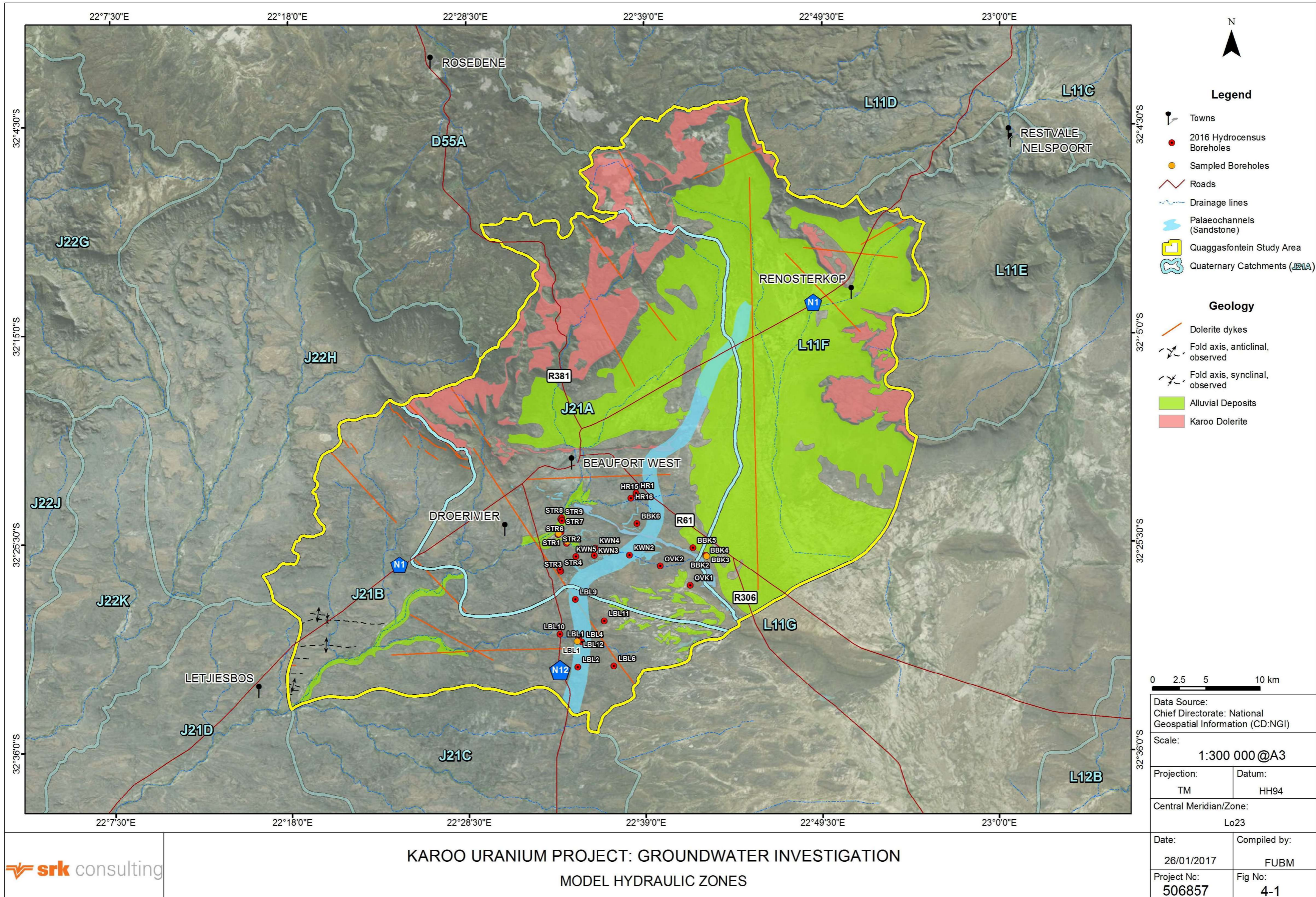
Each zone in the model has been parameterised (assigned horizontal K and S values), based on the results of pumping tests and model calibration. The finite difference model uses a representative elementary volume representation of groundwater flow by assuming very low flows through a representative matrix for the entire area, instead of modelling slightly higher flows through discrete fractures.

Hydraulic properties of each zone for the base-case scenario are tabulated below in **Table 4-1**.

The K values are within the range estimated in the conceptual model. There are varying levels of uncertainty associated with model parameters and sensitivity analyses were used to evaluate the implications of these uncertainties.

Table 4-1: Model Hydraulic Properties

Model Zone No.	Aquifer Type	Lateral (East-West) Hydraulic Conductivity (m/d)	Lateral (North-South) Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Storage (m ⁻¹)	Depth (m)	Storativity / Specific Yield (-)	Porosity (-)
Model Layer 1 & 2: Weathered (c. 2 x 10 m thick)								
1	Shale / Mudstone	0.6	0.3	0.03	0.0001	10	0.001	0.01
2	Dolerite	0.001	0.001	0.0001	0.0001	10	0.001	0.01
4	Stream Alluvium (L1 only)	4	4	0.4			0.1	0.1
5	Channel Sandstone	4	2	0.2	0.0001	10	0.001	0.01
8	Dolerite Dykes	0.001	0.001	0.0001	0.0001	10	0.001	0.01
9	Faults / Lineaments	10	10	1	0.0001	10	0.001	0.01
10	Anticlines in Shale	2	1	0.1	0.0001	10	0.001	0.01
11	Synclines in Shale	4	2	0.2	0.0001	10	0.001	0.01
12	Anticlines in Channel Sandstone	4	2	0.2	0.0001	10	0.001	0.01
13	Synclines in Channel Sandstone	8	4	0.4	0.0001	10	0.001	0.01
Model Layer 3: Fractured (c. 25 m thick)								
14	Shale / Mudstone	0.1	0.04	0.004	0.0001	10	0.001	0.01
15	Dolerite	0.001	0.001	0.001	0.0001	10	0.001	0.01
16	Channel Sandstone	2	1	0.1	0.0001	10	0.001	0.01
19	Dolerite Dykes	0.001	0.001	0.0001	0.0001	10	0.001	0.01
20	Faults / Lineaments	0.1	0.1	0.01	0.0001	10	0.001	0.01
21	Anticlines in Shale	2	1	0.1	0.0001	10	0.001	0.01
22	Synclines in Shale	1	0.5	0.05	0.0001	10	0.001	0.01
23	Anticlines in Channel Sandstone	2	1	0.1	0.0001	10	0.001	0.01
24	Synclines in Channel Sandstone	2	1	0.1	0.0001	10	0.001	0.01
Model Layer 4: Lower Hydraulic Conductivity Zone (c. 150 m thick)								
25	Shale / Mudstone	0.002	0.001	0.0001	0.000001	150	0.00015	0.01
26	Dolerite	0.001	0.0001	0.0001	0.000001	150	0.00015	0.01
27	Dolerite Dykes	0.001	0.0001	0.0001	0.000001	150	0.00015	0.01
28	Faults / Lineaments	0.1	0.1	0.001	0.000001	150	0.00015	0.01
29	Anticlines	0.2	0.1	0.001	0.000001	150	0.00015	0.01
30	Synclines	0.2	0.1	0.01	0.000001	150	0.00015	0.01



KAROO URANIUM PROJECT: GROUNDWATER INVESTIGATION
MODEL HYDRAULIC ZONES

Path: G:\New Proj\506857 Rystkuil\GIS\GISPROJ\MXD\Quaggasfontein Report Figures\506857 Fig4-1 Quaggasfontein ModelHydraulicZones A3L 20170306.mxd

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Figure 4-1: Model Hydraulic Zones

4.7 Calibration Results

The steady state head distribution (average long-term water levels) is dependent on recharge, T, sources, sinks and boundary conditions specified. For a given recharge component and set of boundary conditions, the head distribution across the aquifer under steady-state conditions can be obtained. The simulated head distribution can then be compared to the measured head distribution and the modelled values can be altered within realistic bounds until an acceptable correspondence between measured and simulated heads is obtained.

The 2016 hydrocensus water level data were used to calibrate the steady state groundwater flow model. Calibration of the boreholes closest to proposed mining areas was given priority. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated water levels and hydraulic gradient.

The target water levels versus simulated water levels are shown in **Figure 4-2**. The simulated water levels are mostly within 5 m of observed at the site. Some boreholes were actively pumping and therefore it is not unexpected that the simulated water level is higher than that observed during local pumping. The calibrated Pearson Product-Moment Correlation Coefficient between the observed and modelled water levels is 96%. The mass balance error is 0.11%, which is within the calibration criteria of 0.5%. The individual inputs and outputs are within keeping of the conceptual model.

Transient calibration was undertaken using long-term seasonal recharge as well as pumping test data at QFNW1 and QFNW2 to cover the study area, with calibrated hydraulic properties also correlated with those established during the Ryst Kuil model calibration, situated adjacent to this model and based in a similar geological setting. During the transient calibration, boundary condition properties were reviewed, and S values altered within defined ranges in order to find the 'best fit'. As the observations took place within the pumping boreholes themselves, and observation boreholes used were too far away to register impact, well-skin effects need to be taken into account in interpreting the model 'fit'. Modelled and observed drawdown and recovery curves for the pumping tests are shown in **Figure 4-2**. Calibration between model and observed values showed a good fit, except for that for QFNW2 where the model underestimates the actual drawdown observed when pumping at c.0.45 L/s. QFNW2 was expected to have a higher hydraulic conductivity (and therefore lower drawdown in pumping tests) as it is located in the channel sandstone. However, it is likely that the specific location drilled intersected a disproportionately low number of fractures compared to the rest of the channel sandstone, and the relatively shallow depth could also have been a contributing factor. This is not a concern regarding the reliability of the model. It is a common issue in the representation of point source data with local anomalies in a regional scale model. Regional model properties of the channel sandstone are based on averaging of data from various sources including test pumping regionally, literature and experience.

Following successful steady state and transient calibration of the numerical flow model for the project area, the model was found to be 'fit-for-purpose' for running predictive scenarios, as per the model objectives.

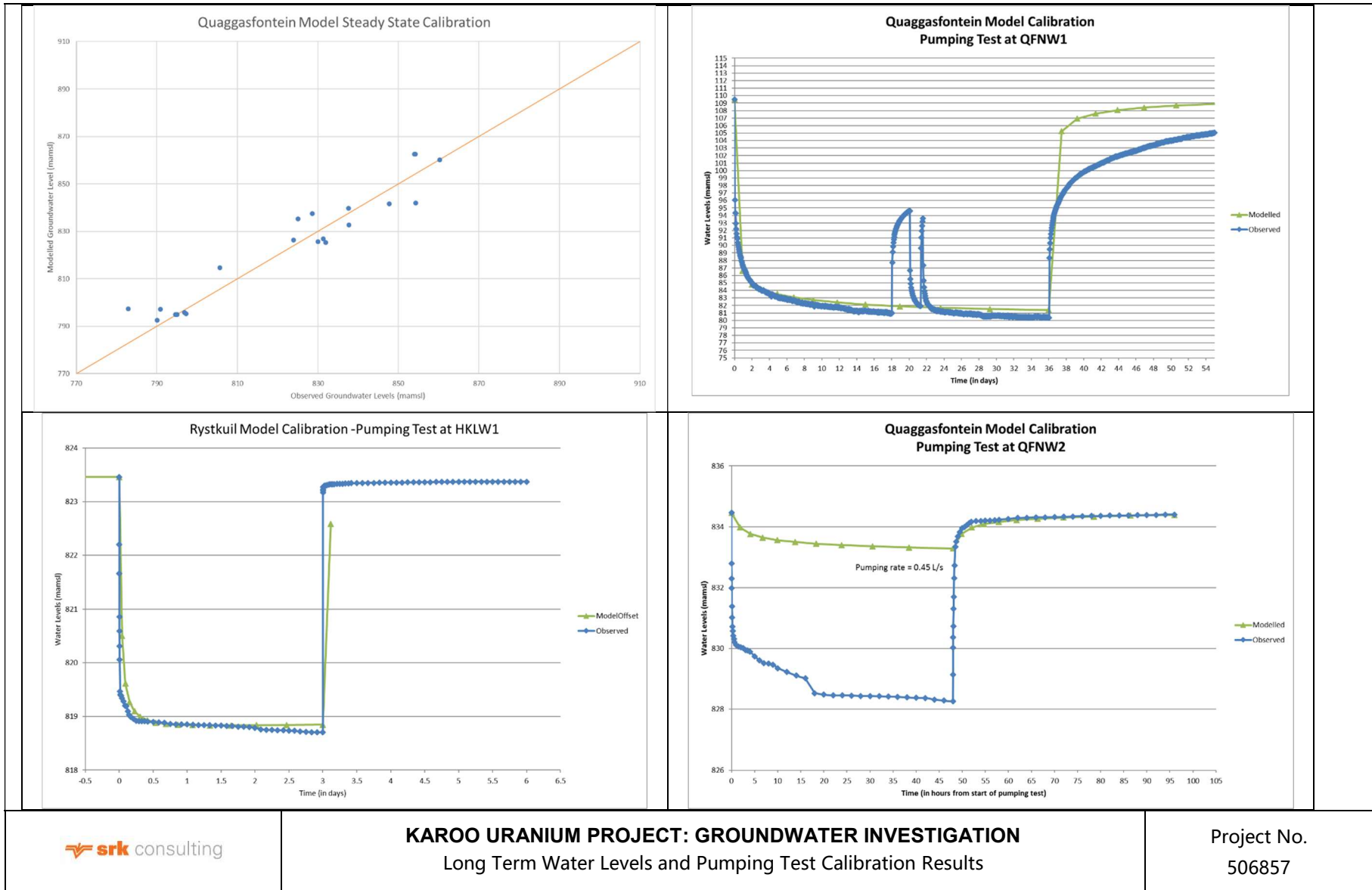


Figure 4-2: Model Long Term Water Levels and Pumping Test Calibration Results

5 Modelling of Predictive Scenarios

5.1 Model Scenario Objectives

The objectives of the numerical geohydrological model predictive scenarios are as follows (same model and parameters as previously described, used for these):

- To estimate mine pit passive inflow rates;
- To estimate the extent of the drawdown zone over time; and
- To estimate the maximum potential contaminant plume footprint.

5.2 Model Scenario Set-up

Scenarios undertaken included the following:

1. Simulation of the nine month mining period at Quaggasfontein ('most likely' S, based on experience and literature values for this geology on a regional scale);
2. Simulation of the 5-year post-mining recovery period at Quaggasfontein, with backfilling of all pits;
3. Simulation of the 5-year post-mining recovery period at Quaggasfontein, leaving OP2 pit open such that a pit lake is formed; and
4. Simulation of the 5-year post-mining recovery period at Quaggasfontein, leaving all pits open i.e. no backfilling, such that pit lakes are formed.

All scenarios include groundwater flow as well as contaminant transport. Contaminant transport parameterisation is as follows:

- Contaminant Plume Indicator Element: EC, as it is largely conservative and therefore represents the furthest reach of the plume;
- Background regional EC level: 150 mS/m, based on background monitoring data;
- Longitudinal Dispersivity: 100 m, an estimation from literature (Spitz and Moreno, 1996);
- Transverse Dispersivity: 10 m, one tenth of longitudinal dispersivity, an estimation from literature (Bear and Verruijt, 1992); and
- Diffusion Co-efficient: 10^{-9} m²/s, an estimation from literature (Appelo & Postma, 2005).

For the source concentration, it was initially planned to use the leachate laboratory results for the waste rock. However, the actual worst-case 'mud-dominated' leachate result indicated a long-term source concentration of c.60 mS/m. As it was not intended for the model to simulate the 'cleaning' of the aquifer from source, it was decided to use 300 mS/m (double the background concentration) to simulate the maximum possible plume footprint area, a 'worst-case' scenario.

5.3 Model Scenario Results

Table 5-1 shows the Quaggasfontein mine schedule and the predicted inflow rates to the mining areas. The model predictive scenarios were undertaken in periods of one month in duration such that there are nine model periods, covering nine months of mining. The particular 'Open Pit' (OP) area in operation (see **Figure 5-1** for locations) is highlighted in yellow. The number shown in each cell per pit area and time period is the average approximate inflow rate in units of L/s. Note that this inflow rate

is calculated from an 'integrated average volume'¹ over the period of active mining of the specified area. The final columns show the total inflows per time period, in units of L/s and m³/hr. The following key points are noted:

- The highest estimated inflow rate of c.8.5 L/s occurs at OP2. This is a result of it being the largest and deepest pit at 23 m depth, approximately 8 m below the water table; and
- The maximum total inflows at any one time are c.16 L/s during months one to eight from OP2 and OP3. However, much of this water will be lost to evaporation from pit surfaces and sumps.

Figure 5-1 shows the modelled drawdown zones near Quaggasfontein, for periods of 6 months, 9 months, and 1 year post-mining (two scenarios showing 'backfill' and 'no backfill' of pits). Drawdowns >5 m are considered significant in terms of potential effect on local private groundwater users and thus the contours commence at -5 m and continue in 2 m intervals. The outlines of the mining areas are shown in black and are labelled. All potential impacts are well within the Quaggasfontein Application Area, which is not visible on this figure as it falls outside the zoomed-in area shown. The following key points are noted:

- The drawdown zone expands pseudo-radially with time to a maximum of c.1 km after one year of mining when OP2 is still open;
- Should the mining rate be halved then similar drawdowns will occur but will take proportionately longer to propagate;
- Privately-owned borehole KWN2 (on the edge of OP3) and purpose-drilled groundwater exploration borehole QFNW2 could be temporarily affected by >5 m drawdowns caused by mining, possibly causing changes in yield and water quality. However, any such effects will be insignificant as these are low yielding boreholes (KWN2 could be destroyed by mining activities). Details on ownership, depths, yields, use, water levels, and groundwater quality of these potentially affected privately-owned boreholes should be updated/confirmed prior to commencement of mining;
- The model reflects 'equivalent matrix hydraulic properties' and not fracture properties, and hence it is likely that the actual drawdown will not reach the extent shown, due to lack of actual interconnectivity between fractures;
- Recovery of the drawdown zone to <5 m across the area occurs rapidly and within one year following mine closure, with backfilling of all pits. This has been further confirmed by analytical calculations, taking into account that the hydraulic parameters of the mining areas are altered post-mining. The K values are increased to 10 m/d and the specific yield and porosity are assumed to be 0.3 (30%) due to the nature of the waste rock backfill in the pits. Only OP2 is still open during the last month of mining. The other pits will have already been in recovery; and
- Should there be no backfilling, groundwater levels will remain depressed around OP2 and OP3 due to high evaporation from the pit lakes and local 'sinks' will be created; however, drawdown below previous natural water levels would be <5 m.

¹ As each individual open pit or underground area is entered in the model as a single event, the actual model results per time step show a decrease in inflows with time. However, this decrease is not 'real' as it is likely to be balanced by the fact that the pit depth will increase with time during mining. However, the total flow volume over the time period will be representative. Thus estimates can be assumed using averaged inflow rates that result in an equivalent total flow volume.

Figure 5-2 shows the potential contamination footprint² near Quaggasfontein, for the scenario of one year post-mining, and then five years of recovery post-mining for the scenarios (three alternatives) of backfilling all pits, allowing for pit lake formation in OP2 and allowing for pit lake formation in all pits. The purple dashed contours indicate the maximum estimated extent of the contaminant plume (see footnote 2). All potential impacts are well within the Quaggasfontein Application Area, which is not visible on this figure as it falls outside the zoomed-in area shown. The following key points are noted:

- Potential contamination can arise from the open pits due to water percolating through waste rock (greater surface area for dissolution of salts from shales/mudstones), evaporation of inflow and surface runoff water (concentration of salts) and reaction with exposed areas of ore;
- After nine months of mining and one year post-mining, there are small contaminant footprints starting around OP1 and OP4 (already in recovery) and expanding to include all pits by one year, due to ongoing recharge;
- After five years post-mining, and with backfilling in all pits, a potential contaminant plume has developed from OP2, extending down the groundwater flow path c.2 km towards, but not reaching, privately-owned borehole KWA3;
- After five years post-mining but with no backfilling of OP2, the potential contaminant plume is reduced in area and extent. The pits will never 'over-top'; and
- If a pit lake is allowed to form at OP2 and OP3, then the modelling shows an additional potential plume area around the pit areas due to the increase in salinity at the pit lake due to evaporation and the potential for plume movement via dispersion and diffusion mechanisms. However, the pit lakes show a continuous drawdown of c.3 m below natural groundwater level in the area (due to the effects of evaporation) and thus local groundwater advective flow is inward, which would therefore serve as a potential contaminant 'trap' or 'sinks' and pits would never 'overtop'.

² taken as the 151 mS/m model concentration contour, i.e. any change above background EC; such groundwater will still be 'fit-for-purpose'.

Table 5-1: Quaggasfontein Mine Schedule with Predicted Inflow Rates

Period No.	Period Name (Y = Years; M = Months)	Length (days)	Elapsed Length (years)	Mine Area in Operation / Being Dewatered via Sumps (L/s)				Mine Area Backfilled with Waste Rock	Approximate Total Mine Inflow Rate (L/s)	Approximate Total Mine Inflow Rate (m ³ /hr)
				OP1	OP2	OP3	OP4			
Topography (mamsl*):				851	852	850	850			
Depth of Pit (mamsl):				841	829	829	839			
Approximate Water Level (mamsl):				835	837	838	838			
1	Y1M1	30	30	0	7.4	8.5	0		15.9	57
2	Y1M2	30	60	0	7.4	8.5	0		15.9	57
3	Y1M3	30	90	0	7.4	8.5	0		15.9	57
4	Y1M4	30	120	0	7.4	8.5	0		15.9	57
5	Y1M5	30	150		7.4	8.5	0	OP1	15.9	57
6	Y1M6	30	180		7.4	8.5	0		15.9	57
7	Y1M7	30	210		7.4	8.5	0		15.9	57
8	Y1M8	30	240		7.4	8.5		OP4	15.9	57
9	Y1M9	30	270		7.4			OP3	7.4	27

*m above mean sea level

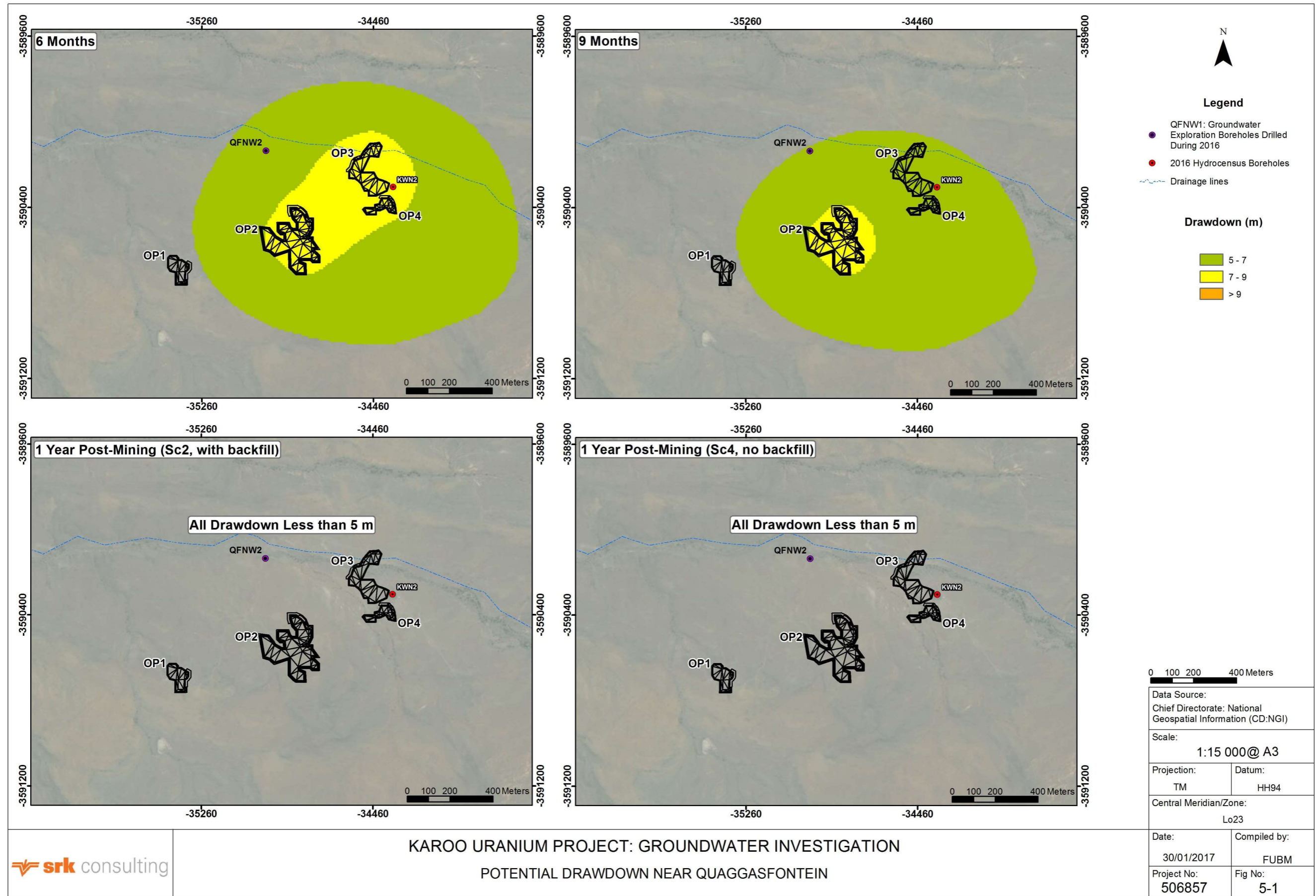


Figure 5-1: Potential Drawdown near Quaggasfontein

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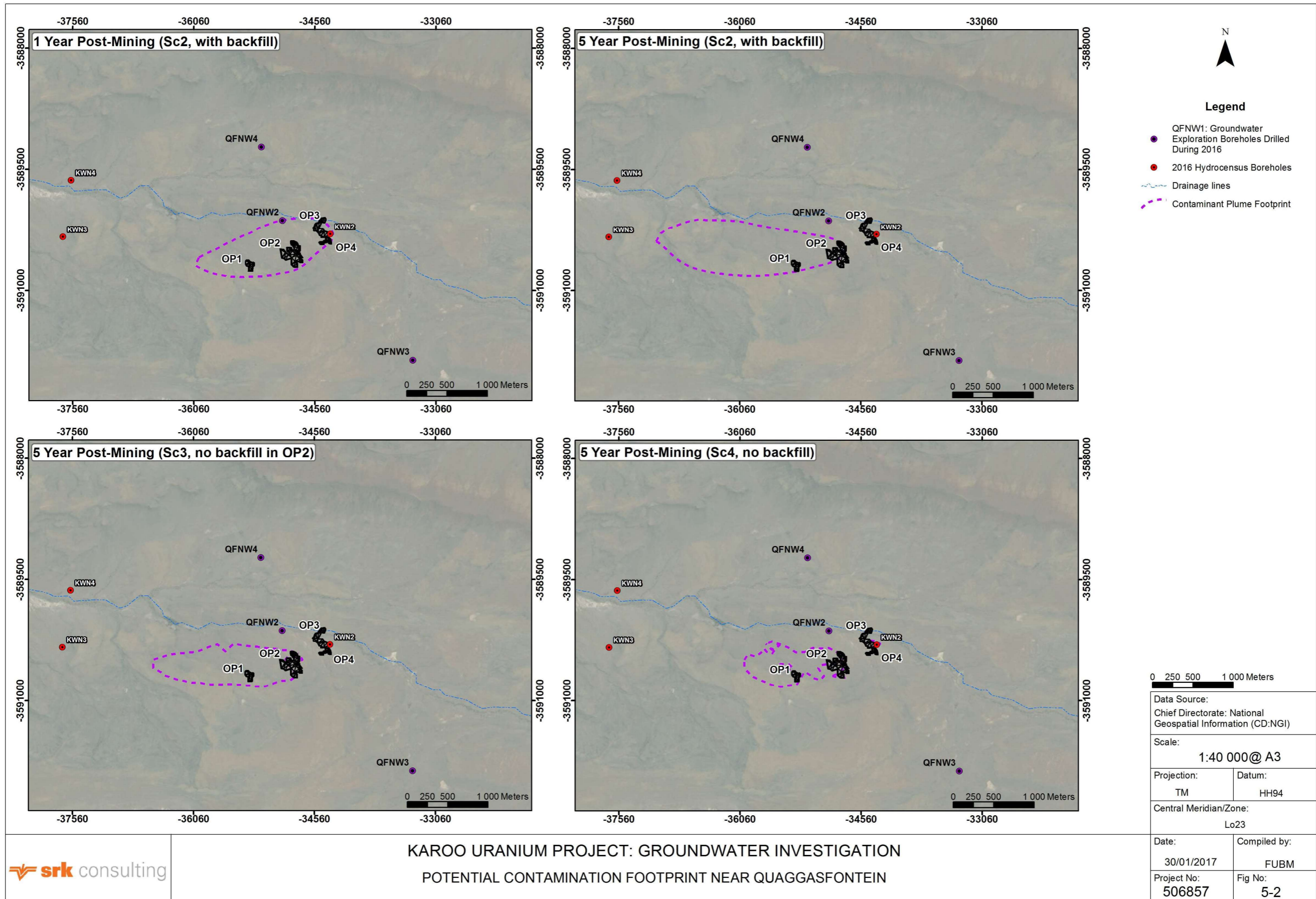


Figure 5-2: Potential Contamination Footprint near Quaggasfontein

6 Conclusions

Background

- The main regional aquifer is a channel sandstone, a fractured rock aquifer, which has a thickness of c.15 – 20 m in the proposed mining area. The uranium ore body is also hosted within this sandstone;
- There is a fairly strong east-west anisotropy with respect to transmissivity, which is caused by folding and fracturing related to the Cape Fold Belt to the south;
- Catchment J21A is classified by the Department of Water and Sanitation as being 'stressed', especially in drought years. However, the 'scale' effect is of relevance here and they acknowledge that conditions could be different over smaller areas within the catchment, e.g. at the wellfield/borehole level and, by implication, mine level.
- Farms were visited in August & September 2016 and positions of 37 boreholes recorded, with sparse information on depth, yield and use obtained from the owners, viz:
 - Groundwater is mostly used for stock watering, domestic/municipal (Beaufort West) supply and some irrigation;
 - Rest water levels ranged from 2.00 mbgl to 21.55 mbgl;
 - Groundwater quality is variable, with electrical conductivity mostly (four boreholes) ranging from c.94 – 110 mS/m, with two 'highs' of 277 and 296 mS/m. The water is hard to very hard and of a mixed calcium/magnesium/sodium-bicarbonate/chloride/sulfate type, with relatively high fluoride and high nitrate content;
 - Groundwater quality of the Beaufort West municipal boreholes is mostly poor, e.g. ECs of 170 – 305 mS/m, and of marginal quality for drinking water supplies; and
 - The four groundwater samples radiologically tested all exceed World Health Organisation screening levels for drinking water of 0.5 Bq/L for gross α activity, one only marginally.

Drilling and Test Pumping

Four purpose-drilled boreholes were sited and installed in October 2016, with test pumping of the two higher yielding boreholes, viz:

- Drilling depths were relatively shallow at 60 to 84 m due to the shallow nature of the proposed open pits;
- Only borehole QFNW1 and QFNW2 had sufficient blow-yields, 7.2 and 0.3 L/s, respectively, to warrant test pumping being carried out;
- QFNW1 sustained a yield of 10.10 L/s over 48 h of pumping, with a recommended long-term yield of 1.90 L/s;
- Transmissivities derived from analysis of the test pumping results were relatively low at 2 and 10 m²/day;
- Groundwater quality is relatively good, with electrical conductivities of c.95 mS/m (three boreholes), but the water is hard and has high nitrate levels (3.15 mg/L – 11.7 mg/L, as nitrogen);

- Significant differences in water quality between these purpose-drilled boreholes and those developed by Beaufort West Municipality add to the intuitive hypothesis of a lack of interconnectivity between the two areas based on distance; and
- Gross α activities are relatively high compared to hydrocensus sample results, at 1.04 to 2.99.

Leach Testing

- The 2016 acid-base accounting results show that the waste rock is classified as non-acid generating, i.e. acid rock drainage is unlikely; and
- The concentrations of uranium in the aqueous leachates (1:1 solid liquid ratio) of all waste rock samples are below the detection limit of 2 $\mu\text{g/L}$ and the thorium concentrations range from $<2 \mu\text{g/L}$ to 6 $\mu\text{g/L}$, i.e. mobilisation of significant concentrations of radionuclides such as uranium and thorium is highly unlikely.

Numerical Modelling

The predictive scenarios for mining at Quaggasfontein have been included in isolation from all other mining areas for this report. Due to the distance of Quaggasfontein from the other proposed mining areas, this is deemed reasonable, as interference between sites (interconnectivity/transmissivity) is highly unlikely beyond c.10 km separation distance. The CPP will also be located in a different quaternary catchment beyond any possible impact on groundwater in the QSA.

Four open pits are planned, designated OP1 – OP4 from west to east, with the largest being OP2. Pit depths range from 10 m – 23 m. The numerical modelling indicates the following:

Inflows

- Pits OP1 and OP4 are too shallow to intersect groundwater and no inflows are predicted;
- The highest estimated inflow rate of c.8.5 L/s occurs at OP3 in Month 1 of mining, with an inflow of c.7.4 L/s predicted for OP2, also in Month1, giving a cumulative total of c.16.0 L/s; However, much of this water will be lost to evaporation from pit surfaces and sumps, assuming 'passive' dewatering rather than active pumping from boreholes; and
- Total inflow reduces to c.7.4 L/s from OP2 only after Month 9 and then to zero, assuming all pits are backfilled.

Drawdowns

- The drawdown zone (>5 m) expands pseudo-radially to cover a maximum area of c.1 000 m x c.1 000 m after Month 9;
- Privately-owned borehole KWN2 (on the edge of pit OP3) and purpose-drilled groundwater exploration borehole QFNW2 could be temporarily affected by >5 m drawdowns caused by mining, possibly causing changes in yield and water quality. However, any such effects will be insignificant as these are low yielding boreholes (KWN2 could be destroyed by mining activities);
- The model reflects 'equivalent matrix hydraulic properties' and not fracture properties, and hence it is likely that the actual drawdown will not reach the extent shown, due to lack of actual interconnectivity between fractures;
- Recovery of the drawdown zone to <5 m across the area occurs rapidly and within one year following mine closure, with backfilling of all pits. This has been further confirmed by analytical calculations, taking into account that the hydraulic parameters of the mining areas are altered

post-mining. The K values are increased to 10 m/d and the specific yield and porosity are assumed to be 0.3 (30%) due to the nature of the waste rock backfill in the pits. Only OP2 is still open during the last month of mining. The other pits will have already been in recovery; and

- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes.

Groundwater Quality

- Potential contamination can arise from the open pits due to interaction of rainwater through waste rock, (increased exposed area for dissolution of salts from e.g. shales/mudstones), evaporation of inflow and surface runoff water concentrating salts and reaction with exposed areas of ore;
- After nine months of mining, there are small contaminant footprints around OP1 and OP4, due to ongoing recharge;
- After five years post-mining, and with backfilling in all pits, a potential contaminant plume has developed from OP2, extending down the groundwater flow path c.2 km towards, but not reaching, privately-owned borehole KWA3;
- After five years post-mining but with no backfilling of OP2, the potential contaminant plume is reduced in area and extent. The pits will never 'over-top'; and
- Contamination in this context is taken as any increase in EC above background and such groundwater will still be mostly 'fit-for-purpose.'

All drawdowns and 'plumes' are well within the Quaggasfontein Application Area.

7 Recommendations

Based on the information provided and conclusions of this report, the following is recommended:

- Continue the existing groundwater monitoring programme, i.e. QFNW2 and 4, with continuous groundwater level measurements and bi-annual quality sampling and datalogger information download (May & November). Additional monitoring boreholes may be required. The next monitoring run is planned for the second quarter of 2017;
- Carry out further work to determine specific pit groundwater management requirements, which will probably be a combination of sub-horizontal drain holes and sumps, i.e. 'passive' dewatering. A WULA will be required;
- Confirm details on ownership, depths, yields, use, water levels and groundwater quality of potentially affected privately-owned boreholes, e.g. KWN2 and possibly KWN3 and 4, prior to commencement of mining;
- Unless convincingly motivated for other reasons (e.g. potential visual or other impacts of waste rock dumps), do not fully backfill the 'downstream' open pit (OP2) or any pits, so as to retain a long-term but localised 'sink' to 'capture' any potential local groundwater contamination; and
- Update the numerical modelling to refine scenario predictions as new data become available on mine plans and from monitoring.

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted geohydrological and environmental practices.

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APPENDICES

Appendix A: Borehole Logs

Bh No		QFNW1		Lat	Long		
		Start: 18/10/16 Stop: 18/10/16		-32.42526	22.57306		
Depth (mbgl)	Geology	Water Strike (mbgl)	Blow Yield (ℓ/s)	EC (mS/m)	pH	Comments	
0 - 1.5	Yellow brwn clayey topsoil						
-13.5	Grey jointed sandstone						
32	Purple to grey mudstone, Fractured at 14 mbgl, Well fractured at 26-29 mbgl	26 - 29	6.10	255	7.45		
-34	Well jointed mudstone with sandstone inerbeds. Iron staining on jointing surfaces						
-41	Jointed grey to purple mudstone with chloride staining. Some interbedded grey siltstone with calcite	38	6.60	280	7.50		
-53	Weakly jointed mudstone with silstone interbeds						
-54	Jointed grey siltstone with calcite and iron staining						
-63	Weakly jointed mudstone with silstone interbeds						
-73	Mainly jointed light grey sandstone with minor mudstone interbeds	65	7.25	287	7.50		
-84	Jointed grey mudstone with interbedded grey siltstone. Joints filled with calcite WL = 18.08 mbgl 19/10/16 08h10						
CONSTRUCTION							
0 - 3 m	254mm Air Percussion Drilling						
3 - 84 m	177mm Air Percussion Drilling						
	3.1m x190mm ID x 6mm plain PVC casing						

Borehole Log – QFNW1

Bh No		QFNW2		Lat	Long		
		Start: 19/10/16 Stop: 19/10/16		-32.43489	22.62815		
Depth (mbgl)	Geology	Water Strike (mbgl)	Blow Yield (ℓ/s)	EC (mS/m)	pH	Comments	
0 - 3	Well weathered and jointed light grey sandstone						
-17	Light grey weakly jointed sandstone with minor purple mudstone interbeds						
-20	Well jointed and partially weathered sandstone	18				Seep	
-39	Light grey weakly jointed sandstone with minor purple mudstone interbeds	36	0.30	176	7.53		
-40	Mainly purple mudstone with minor light grey sandstone						
-60	Weakly jointed light grey sandstone WL = 12.76 mbgl 20/10/16 16h00						
CONSTRUCTION							
0 - 3 m	254mm Air Percussion Drilling						
-60	177mm Air Percussion Drilling						
	3.1m x190mm ID x 6mm plain PVC casing						

Borehole Log – QFNW2

Bh No		QFNW3		Lat	Long		
		Start: 20/10/16 Stop: 20/10/16		-32.45055	22.64537		
Depth (mbgl)	Geology	Water Strike (mbgl)	Blow Yield (ℓ/s)	EC (mS/m)	pH	Comments	
0 - 3	Well weathered and jointed mudstone						
-4	Jointed purple to grey mudstone						
-11	Weakly jointed grey mudstone with minor siltstone interbeds						
-13	Fractured grey mudstone						
-23	Jointed grey to purple mudstone						
-26	Jointed grey siltstone						
-29	Jointed purple to grey mudstone						
-30	Jointed grey siltstone						
-39	Jointed grey mudstone with siltstone interbeds						
-41	Jointed light grey siltstone						
-58	Jointed grey mudstone with siltstone interbeds						
-60	Well jointed grey mudstone with calcite	59	0.20	154	7.48		
-64	Jointed grey mudstone with siltstone interbeds						
	WL = 14.21 mbgl 21/10/16 07h50						
CONSTRUCTION							
0 - 3 m	254mm Air Percussion Drilling						
-64	177mm Air Percussion Drilling						
	3.1m x190mm ID x 6mm plain PVC casing						

Borehole Log – QFNW3

Bh No		QFNW4		Lat	Long		
		Start: 21/10/16 Stop: 21/10/16		-32.42667	22.62549		
Depth (mbgl)	Geology	Water Strike (mbgl)	Blow Yield (ℓ/s)	EC (mS/m)	pH	Comments	
0 - 3	Well weathered and fractured mudstone with siltstone interbeds						
-11	Jointed and partially weathered mudstone with siltstone interbeds						
-13	Well jointed and weathered mudstone with siltstone interbeds						
-18	Jointed and partially weathered mudstone with siltstone interbeds						
-26	Jointed grey siltstone						
-29	Jointed mudstone with siltstone interbeds						
-53	Mainly jointed fine grained grey sandstone	52				Seep	
-57	Grey siltstone with mudstone interbeds						
-58	Fine grained grey sandstone						
-59	Grey siltstone with mudstone interbeds						
-60	Fine grained grey sandstone						
-64	Grey siltstone with mudstone interbeds						
CONSTRUCTION							
0 - 3 m	254mm Air Percussion Drilling						
-64	177mm Air Percussion Drilling						
	3.1m x190mm ID x 6mm plain PVC casing						

Borehole Log – QFNW4

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