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GROUNDWATER INVESTIGATION:
RYST KUIL SUB-AREAS AND HAANEKUIL:
OPEN PIT AND UNDERGROUND URANIUM MINING

Prepared for

LUKISA INVEST 100 (PTY) LTD

Compiled by

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Areas of Expertise
Groundwater Supply, Dewatering, Mining, Subsurface Contamination, Shale Gas, Nuclear Sites and Landfills

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Groundwater Investigation:
Ryst Kuil Sub-Areas and Haanekuil:
Open Pit and Underground Uranium Mining

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Executive Summary

Introduction

The Karoo Uranium Project areas under consideration are located in the Beaufort West District in the Great Karoo, a semi-desert area of 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, irrigation and domestic purposes, and for municipal water supply for Beaufort West.

Uranium (U) mineralisation is relatively common in the Great Karoo and, within the study area, it is mainly confined to palaeochannel sandstones from surface to relatively shallow depths. The mineralisation is regionally extensive, with the main deposits referred to as Ryst Kuil (Main, Extension and Abante sub-areas) and Haanekuil, referred to hereinafter as the Ryst Kuil Study Area (RKSA).

A comprehensive groundwater investigation of the RKSA was initially 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. This study was updated in 2015-2017 for the Tasman-Lukisa partnership.

Lukisa Invest 100 (Pty) Ltd now intends to establish a series of small open pits and underground mines to exploit some zones of U mineralisation, with a Central Processing Plant (CPP) in the south-west of the Ryst Kuil area, between the Ryst Kuil Main and Abante areas. The CPP will include a lined Tailings Storage Facility (TSF). Groundwater will need to be sourced from production boreholes for project/CPP start-up, while specific mine water requirements will be met by predicted pit/underground mine inflows and/or purpose-drilled dewatering boreholes.

Aquatox Consulting Pty Ltd (Atox) is managing the Environmental Impact Assessment (EIA) for the mining rights application and appointed Peter Rosewarne, Groundwater Consultant, in April 2025 to update the hydrocensus and the 2017 report and to also include the groundwater monitoring carried out between 2018 and 2024.

Background on the Ryst Kuil Study Area

The RKSA is probably unique in terms of a mining rights application in South Africa in that the following work has been carried out on the area:

- Initial U mining investigation in the late 1970s, including excavation of a trial mining area, with dewatering and subsequent rewatering.
- Detailed investigations including hydrocensus, surface geophysics, drilling of 17 groundwater exploration boreholes, packer and aquifer testing to determine aquifer hydraulic parameters, chemical analysis of groundwater samples and numerical flow and contaminant transport modelling in 2007/2008.
- Update of the hydrocensus and numerical modelling in 2015-2017.
- Groundwater level (including level-loggers) and quality (cations/anions and radiological indicators) monitoring since 2007.

- Update of the hydrocensus and revision of the 2017 report in 2025.
- Monitoring of a backfilled open pit at Rietkuil by Atox between 2022 and 2024.
- Voluminous supporting research work on Karoo aquifers carried out *inter alia* for the Department of Water and Sanitation (DWS), the Water Research Commission and Shell International.

Important background geohydrological information includes:

- The main regional aquifer is a palaeochannel sandstone, a fractured rock aquifer, which extends in a northeast-southwest direction across the whole RKSA and has a width of c. 2.5 km, widening to the north-east and south-west. It has a variable thickness of 20 – 40 m to depths of *c*.100 m below surface but up to *c*.140 m in places. The U ore bodies are hosted within this sandstone, which is frequently interbedded with mudstones.
- Aquifer transmissivity (*c*.12 – *c*.380 m^2/day) and borehole yields (*c*.5 – *c*.25 L/s), according to test results from purpose-drilled groundwater exploration boreholes, are highest in the south-west and decrease to the north-east. This is a function of sandstone lithology, thickness and structure. There is also a fairly strong east-west anisotropy with respect to transmissivity/hydraulic conductivity, which is caused by folding and fracturing related to the Cape Fold Belt to the south.
- Based on the above information, this sandstone constitutes an important local aquifer.
- A groundwater monitoring network of 13 boreholes, established along the mineralised zone in November 2007, shows mostly very low amplitude (*c*.0.1 m) fluctuations in groundwater levels up to 2016, whereafter loggers were either removed or allowed to run down. Greater fluctuations (<1 m) occur in response to pumping from nearby (<500 m) farmer’s boreholes (and exploration rig supply boreholes in 2007) and filling of dams with surface water runoff.
- Generally, the shallower groundwater levels (<30 m below ground level - mbgl) respond fairly quickly to good local rainfall events, whilst boreholes with deeper (≥40 mbgl) groundwater levels appear to indicate a time lag of approximately three years between good rainfall events and rising groundwater levels. This is possibly due to a component of deep throughflow and/or a delay in release of groundwater from interbedded mudstones.
- Analysis of exploration borehole logs shows that groundwater levels are at least 40 m above the main water strike in all boreholes, the latter being the critical level below which a drop in water level will be accompanied by a drop in borehole yield.
- Groundwater level and quality monitoring was continued between 2017 and 2024.
- Farms were visited in August & September 2016 and positions of 248 boreholes recorded and information on depth, yield and use obtained from the owners where possible, and water samples taken for chemical and radiological analysis. Findings include:
    - Groundwater is mostly used for stock watering, domestic supply and irrigation.
    - Water levels range from near-surface (<10 mbgl) to shallow (<30 mbgl) to deep (>30 mbgl).
    - Groundwater quality is very variable, with electrical conductivity (EC) mostly ranging from c.90 – 300 mS/m but up to 516 mS/m in places. The water is hard to very hard and of a mixed calcium/magnesium/sodium-bicarbonate/chloride/sulfate type, with often high fluoride and nitrate content.

  - Most groundwater samples are below the South African National Standard 2015 target level of 0.03 mg/L and the Department of Water and Sanitation's (DWS) upper limit of 0.286 mg/L for uranium.

- A follow-up survey was carried out in late April 2025 and 46 boreholes were re-visited. Virtually all RWLs were higher than in 2016, mostly c.2 – 5 m but some 20 – 30 m higher, and ECs were mostly lower.
- There is little evidence (based on hydrocensus and monitoring data) of depletion of aquifer groundwater levels despite the periodic drought conditions and the area being classified on a regional scale as one with a water deficit.
- Acid-base accounting results show that the waste rock is classified as non-acid generating, i.e. acid rock drainage is unlikely.

Trial Mining Area

A trial underground mine was developed in 1978/1979 and the workings allowed to flood after temporary dewatering had allowed the taking of representative formation/ore samples. This trial mining and accompanying groundwater monitoring (2007 to present) has allowed some important general inferences to be drawn on the likely impacts of mining on groundwater and *vice versa*, viz:

- The trial mine was developed in one of the most transmissive parts of the channel sandstone aquifer but underground workings were able to be kept 'dry' by a combination of pumping from boreholes and a sump, initially at 32 L/s, reducing to 16 L/s long-term, and local grouting of some major water-bearing fractures.
- The drawdown from this dewatering was quite extensively propagated but was of relatively small magnitude, *c*.2 m; such a drawdown is unlikely to have deleterious effect on the performance of existing production boreholes given the >40 m between rest water levels and main water strikes in groundwater exploration boreholes.
- The quality of the water in these flooded workings meets drinking water standards for macro-chemistry, apart from fluoride (a common issue in the Karoo), after c.38 years, with no indication of acid rock drainage.

However, in 2022 the decline was rehabilitated by backfilling in a process approved by the National Nuclear Regulator. In addition, groundwater quality monitoring in a borehole adjacent to a backfilled open pit in the Rietkuil area between 2022 and 2024 showed gross α and β emissions and U-238 concentrations below the domestic water use limits of the DWS and closure was approved by the Department of Minerals and Energy.

Groundwater Supply

It has been estimated that natural recharge for the RKSA is *c*.64 Mm^3/a (2.4% of Mean Annual Precipitation). However, the volume of groundwater that may be practically/sustainably abstracted from the aquifers in the study area is limited by, *inter alia*, transmissivity and connectivity over the respective sub-catchments. Based on this consideration, the Utilisable Groundwater Resource Potential (UGRP) was determined (DWAF, 2005). When considering the sub-catchments containing the mine application areas, i.e. L11G, L11A and L11B, the UGRP under 'dry' conditions is *c*.7 Mm^3/a or *c*.220 L/s.

The central processing plant (CPP) requires *c*.43 L/s at full operating capacity, with the local groundwater quality meeting requirements for this purpose. The CPP will have three water storage dams, two of 2 000 m^3 capacity and one of 1 900 m^3 (this excludes provision for stormwater control). These will require to be full six months prior to full plant commissioning to enable water and leak testing to be carried out. It is proposed to meet this requirement by pumping from the trial mine area at 17 L/s for *c*.100 days. The balance of 26 L/s will be met from production boreholes, either those drilled in 2007/2008 or, if these are found to be unusable for any reason, then nearby replacement boreholes. These may have to be deepened as mining progresses and may also act as mine dewatering boreholes. A combination of 40% water recycling from the tailings storage facility (TSF), dewatering/supply boreholes and pit inflows will sustain the CPP water requirements thereafter. This supply is considered to be sustainable based on historical pumping from the trial mine area, test pumping of purpose-drilled groundwater explorations boreholes and numerical modelling.

Mining

Thirty-three open pits (OP) in five mining areas and seventeen underground sections (UG) in three mining areas are proposed to be established according to information supplied by DRA Global, at Haanekuil (OP1-7 and UG1&3), Ryst Kuil Abante (OP1-7), Ryst Kuil Main (OP1-3 and UG1&2), Ryst Kuil Extension (OP1-12 – possibly only nine - and UG1-12). Initial mining duration is planned to be 16 years with possible extension to 30 years. However, for predictive, numerical flow and contaminant transport modelling, an initial mining duration of c.10 years, as posited in 2017, has been assumed. This approach is supported by the trial mine and open pit backfilling monitoring data, RWL and groundwater quality and the wealth of research into Karoo aquifers. This modelling will be updated in the future as required.

Due to the complexity of the planned mining operations and uncertainties in assigning hydraulic parameters to the various formations, an 'envelope' approach was adopted for the numerical modelling, with upper envelope storativity of 0.01 and lower envelope storativity of 0.001. This gives likely upper and lower limits on predicted inflows, extent of drawdown and groundwater quality changes. The numerical modelling indicates the following:

Inflows

Upper Envelope (Storativity of 0.01)

- An estimated cumulative inflow rate of >100 L/s occurs during Year(Y)4 Quarter(4) to Y8Q3 at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3, peaking at *c*.140 L/s during Y5Q2 and Q3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

Lower Envelope (Storativity of 0.001)

- The highest estimated cumulative inflow rate of *c*.60 – 70 L/s occurs during Y6Q1 to Y8Q3, mainly at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

Drawdowns

Upper Envelope (Storativity of 0.01)

- The >5 m drawdown zone coalesces to a maximum of *c*.19 km (NE-SW) x *c*.6 km (NNW-SSE) in the Ryst Kuil sub-areas after 9.25 years of mining, largely confined to the palaeochannel sandstone/mining areas. Approximately twenty currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.

- At Haanekuil the >5 m drawdown zone expands pseudo-radially to a radius of c.2 km after 9.25 years of mining. Three currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.
- Recovery of the drawdown zone in the RKSA is significant in terms of depth and area (*c*.50%) 10 years after cessation of mining, with backfilling, and is complete at Haanekuil.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

Lower Envelope (Storativity of 0.001)

- The >5 m drawdown zone expands to an essentially similar extent as drawdown is more strongly affected by changes in T rather than $S/S_{y.}$
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.
- Recovery of the drawdown zone (>5 m) is essentially complete 10 years after cessation of mining, with backfilling.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

Groundwater Quality

- Potential contamination can arise from the open pits due to interaction of rainwater through waste rock, (increased exposed area for mineral dissolution), evaporation of inflow and surface runoff water concentrating salts and reaction with exposed areas of ore.
- After c.10 years of mining, there is a small potential impact area around Ryst Kuil Extension, Ryst Kuil Main and the TSF. Other potential impact areas, including Haanekuil, are still being captured by the drawdown zone of the dewatered pits and underground sections.
- Ten years post-mining, and with backfilling in all pits, the potential impacted areas can be seen to contract slightly, with the potential to slightly change water quality at a maximum of four existing privately-owned boreholes.
- Five years post mining, potential contaminant plumes near Haanekuil migrate southwards from the Haanekuil pits in an ellipsoid shape to a maximum distance of c.500 m. However, these plumes dilute to background levels by 10 years post-mining.
- If a pit lake is allowed to form at one down-gradient pit in all areas, then the modelling shows a slight decrease in plume area linked to the pit lakes showing a continuous drawdown of *c*.5 m below natural groundwater levels / recovery levels 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 ‘sink’ and pits would never ‘overtop’.
- Upper and lower envelopes of storativity result in very similar groundwater impact areas, thus showing a relatively low sensitivity of the contaminant transport model to storativity assigned to the channel sandstone.
- Water quality monitoring in and around the trial mine and a backfilled open pit at Rietkuil shows no indication of residual acid rock drainage or a contamination plume developing.

Impact Assessment

- The groundwater impact significance is rated as **Low** with a high degree of confidence in the predictions.

Overall, it can be summarised that groundwater RWLs and quality have been maintained or enhanced despite the periodic droughts that affect the area and that the channel sandstone aquifer is resilient to stress.

Mitigation

The following mitigation measures are recommended:

- Carry out further site-specific investigations before mining commences for geological structures, groundwater monitoring and to establish a groundwater supply and determine specific mine groundwater management requirements, e.g. dewatering boreholes, sub-horizontal drain holes and/or sumps. A water use licence application will be required.
- Install ‘early warning’ boreholes so that any negative effects of mining can be identified before they cause interference with privately-owned boreholes.
- Do not backfill the “downstream” open pit in each mining area so that it acts as a “sink” to capture any contaminated groundwater.
- Prepare contingency plans to maintain current water supply (volumes) and quality to potentially adversely affected landowners.

Recommendations

- Investigate the practicality, effectiveness and cost of groundwater control measures such as grouting of fractures and use of dewatering boreholes, and re-use options such as artificial recharge using excess water made from mining, and supply of excess water to affected and/or other groundwater users.
- Update the numerical modelling (possibly using a fracture-flow modelling code) to refine scenario predictions as new data become available on mine plans, geological structures and from monitoring, and to include the above groundwater control measures and extension of the mining period.

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Disclaimer

The opinions expressed in this Report have been based on the information supplied by Aquatox (Pty) Ltd, data from local landowners, previous investigations in the study area and other sources, as indicated. Due care has been exercised in reviewing the supplied/obtained information. Whilst the available data has been compared 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. Peter Rosewarne 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 the current 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 the author had no prior knowledge nor had the opportunity to evaluate.

Statement of Independence and Competence

Peter Rosewarne does not have any material present or contingent interest in the outcome of this Report, nor does he have any pecuniary or other interest that could be reasonably regarded as being capable of affecting his independence.

Peter holds a BSc Hons degree in Geology from London University (1974) and an MSc degree in hydrogeology (1984) from Rhodes University. He is a registered natural scientist (Reg. No. 1474/83) and has 50 years of experience. He started his career doing geological mapping in the Karoo in the Merwerville-Fraserburg area and has carried out groundwater supply investigations for Beaufort West Municipality. He was the project hydrogeologist on the 2007/2008 and 2015/2017 investigations of the Ryst Kuil uranium prospect. He chaired the Karoo Groundwater Expert Group, a group of hydrogeologists and hydrochemists with over 250 years of combined experience investigating the impacts of fracking on Karoo aquifers. He was the project leader on the Groundwater Resource Phase 2 Project for the Department of Water and Sanitation, doing the first quantification of South Africa’s groundwater resources. He has written specialist groundwater reports for numerous EIAs, including for Eskom’s proposed nuclear sites at Thyspunt, Bantamsklip and Duynefontyn. He has written 32 scientific papers and presented at numerous local and international symposia.

Glossary of Terms

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

Confined Aquifer: An aquifer bounded above by an impermeable layer.

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.

Gross alpha (α) activity: Total radioactivity due to alpha particle emissions (basically helium atoms).

Gross beta (β) activity: Total radioactivity due to beta particle emissions (basically electrons).

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.

Pedeplain: 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.

Piezometric Surface: A hypothetical surface defined by the level to which groundwater rises in a confined aquifer in observation boreholes.

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 (throughflow).

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 DWS website:
http://www.dwa.gov.za/Groundwater/GroundwaterDictionary.aspx

List of Abbreviations

Atox	Aquatox Consulting Pty Ltd
c.	Circa, approximately
CDT	Constant Discharge Test
CPP	Central Processing Plant
DRA	DRA Global Ltd
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation (previously DWAF then DWA)
EC	Electrical conductivity (measure of salinity of water)
EIA	Environmental Impact Assessment
GA	General Authorisation
GIS	Geographical Information System
GRA2	Groundwater Resource Assessment Phase 2
ha	hectares
h/d	hours per day
L/s	Litres per second
m	metres
Ma	Million years ago
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
mst	mudstone
NA	not analysed
NGA	National Groundwater Archive (previously NGDB)
RKH	Ryst Kuil sub-areas and Haanekuil
RKSA	Ryst Kuil Study Area
RWL	Rest water level
SANAS	South African National Accreditation System
SDT	Step Drawdown Test
slst	siltstone
SRK	SRK Consulting (South Africa) (Pty) Ltd
sst	sandstone
TSF	Tailings Storage Facility
TDS	Total Dissolved Solids
UGRP	Utilisable Groundwater Resource Potential
WHO	World Health Organisation
WL	Water Level

1 Introduction

1.1 Background

The Karoo Uranium Project areas covered by the mining right application of Lukisa Invest 100 (PTY) Ltd (the client) are located in the Beaufort West District of the Western Cape in the Great Karoo. This is 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, irrigation and domestic purposes, and for municipal water supply to Beaufort West (BW).

The uranium (U) mineralisation is regionally extensive, with the deposits of relevance to this study are referred to as Ryst Kuil (Main, Extension and Abante) and Haanekuil (Ryst Kuil Study Area, RKSA). These deposits have been studied extensively, starting in 1978, with further detailed investigations in 2007/2008 and 2016-2017, with ongoing groundwater level and quality monitoring from 2007 until 2024. These earlier groundwater studies were carried out by SRK Consulting (South Africa) Pty Ltd (SRK) and form the basis for the current report to support the Environmental Impact Assessment (EIA) for the Mining Right Application. Molybdenum (Mo) will be a secondary by-product of the mining.

Aquatox Consulting Pty Ltd (Atox) appointed Peter Rosewarne, groundwater consultant, to update the 2017 SRK report in April 2025. This report first covers groundwater characterisation of the broader RKSA and then assesses mining impacts (open pits and underground) and is structured as follows:

Section 1: Background, Purpose, Deliverables and Work Programme.

Section 2: Background Information (combining 1979, 2007/2008 and 2016/2017 data).

Section 3: Updates from 2018-2025.

Section 4: Numerical Model Set-up and Results.

Section 5: Modelling of Predictive Scenarios.

Section 6: Impact Assessment

Section 7: Conclusions.

Section 8: Mitigation and Recommendations.

Section 9: References.

1.2 Purpose

The main thrust of this work is to assess the potential impacts of open pit and underground U mining on the local aquifers and existing groundwater users and propose groundwater control measures to avoid and/or limit any identified impacts. Groundwater will need to be sourced from production boreholes for project/Central Processing Plant (CPP) start-up, while specific mine water requirements will be met by predicted pit/underground section inflows and/or purpose-drilled dewatering boreholes.

This report will be used by Atox to support the EIA. The study areas, mining right areas, quaternary catchments, drainage, trial mining area (see **Subsection 2.1.2**) and main roads are shown in **Figure** 1.

1.3 Deliverables

The project deliverables were as follows:

1. Provide a stand-alone groundwater report that can be used to support the EIA (by Atox), in support of the mining right application.
2. Update the hydrocensus of the RKSA previously surveyed in 2016 to provide a baseline database of groundwater use and quality.
3. Update the SRK report of 2017.

1.4 Work Programme

The total work programme comprised:

- Data collation, review and capture, based mainly on the 2016/2017 investigation (SRK, 2017) and groundwater monitoring programme (November 2007-2016 and 2022-2024);
- Site visits were previously carried out by P Rosewarne on five occasions in 2016, including with the then client, regulatory authorities and to attend Water Forum and I&AP meetings in BW and Aberdeen;
- Hydrocensus to collect background information from selected borehole locations to compare with the 2016 data. Mr C. Esterhuyse, who carried out the 2016 hydrocensus, carried out the update in late April 2025. Whilst every effort has been made to cover all boreholes in the study area, it is possible that some have been missed;
- Field electrical conductivity (EC) and pH were measured and eight water samples were taken during the 2025 hydrocensus and submitted for macro-chemical analyses for Na, K, Ca, Mg, Cl, SO_4, NO_3, Total Alkalinity and F. Metals scans and background radiological analyses were limited to As, Mo and U as the former have been the subject of ongoing groundwater monitoring between 2022 and 2024. Laboratory analyses were carried out by UIS Laboratories in Kimberley. Sampling concentrated on boreholes used for domestic water supply.
- Data analysis and update of the SRK report of 2017. Ms Sheila Imrie was responsible for the numerical flow and contaminant transport models at that time, the relevant process and results of which have been carried over to the current study.

The hydrocensus, chemical analyses and other databases are available on request.

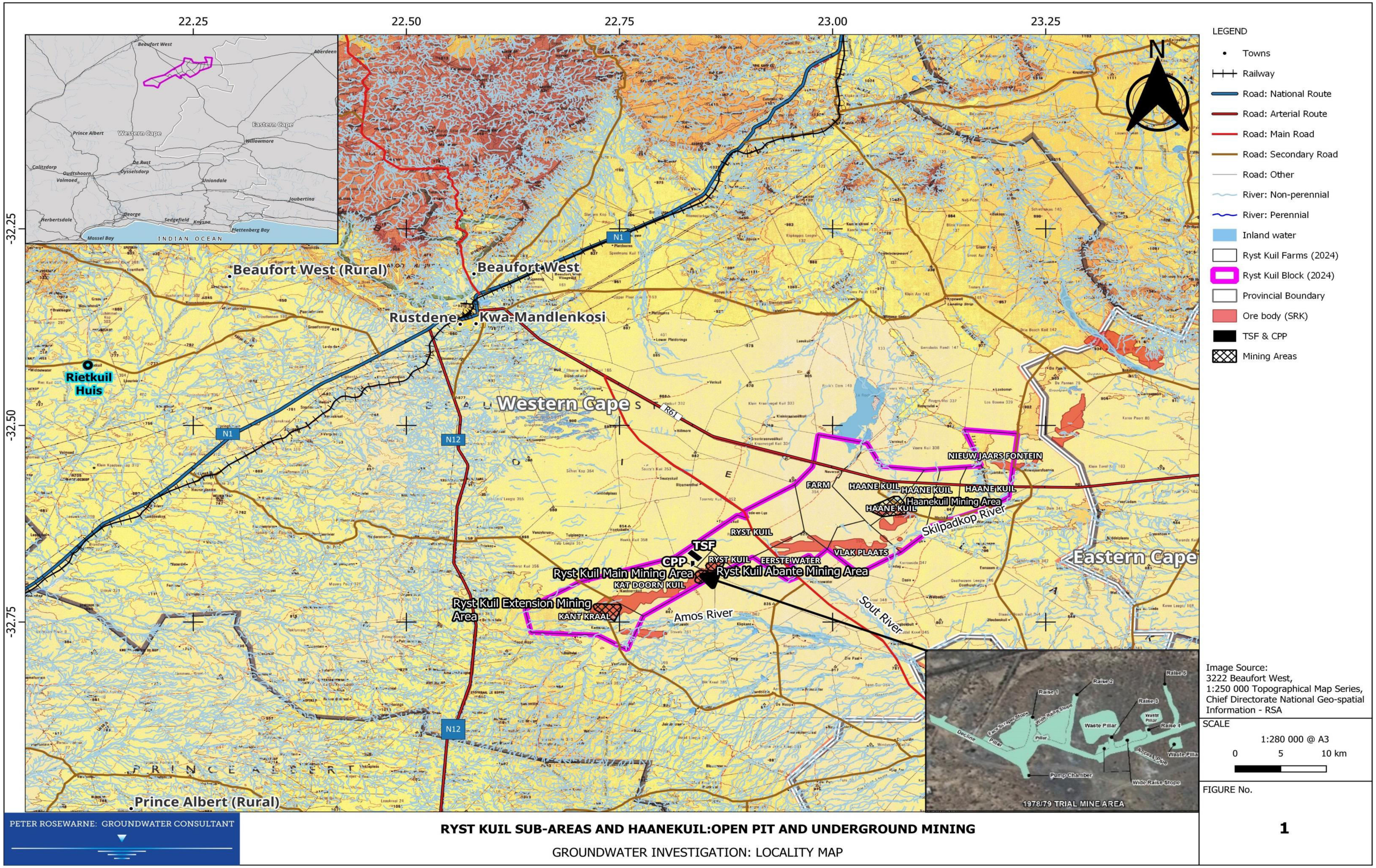

Figure 1: Locality Map

2 Background Information

This report covers the work programme set-out under **Subsection 1.24**. However, to put this work into context, a summary of some of the pertinent findings of the previous detailed investigations carried out in the RKSA is provided in **Subsection 2.1**. The reader is referred to the following studies (full titles in **Section 9**), which give an indication of the unique detail and timespan of hydrogeological investigation of the proposed mining area:

- Trial mining by ESSO in the late 1970s.
- Ryst Kuil Uranium Project Definitive Feasibility Study: Groundwater Investigation Phase 1, August 2007, and Phase 2, July 2008.
- Ryst Kuil and Quaggasfontein Groundwater Investigations, 2015=2017. Farms in the RKSA were visited in August and September 2016 and details on 248 boreholes e.g. depth, yield, rest water levels (RWLs) and use obtained, where available. However, relatively little information could be obtained from the owners.
- Groundwater monitoring (water levels and quality – cations/anions and radionuclides and indicators) in the RKSA from 2008 to 2016;
- Further water level and quality (cations/anions and radionuclides and indicators) monitoring from 2022 to 2024.

Apart from the 1970s work, Peter Rosewarne was the project manager and provided technical input on all of the above projects while Chris Esterhuyse carried out much of the site work, including geological mapping, hydrocensus, borehole siting, drilling and test pumping supervision. The numerical flow and contaminant transport modelling covered in 2008 was revised and updated in the 2017 report.

2.1 Ryst Kuil Catchment

The amount of information available for the assessment of the hydrogeology of this area and the effect of mining on groundwater/aquifers and *vice versa* is probably unique in South Africa. This information comprises:

- Groundwater level and quality monitoring from 2007 to 2016 (**Figure 5)**;
- Three sets of hydrocensus databases (2007, 2016 and 2025);
- Initial (2008) and subsequently updated (2017) and refined numerical and contaminant transport modelling; and
- Detailed assessment of Karoo aquifers and the potential impacts of fracking by independent researchers/organisations (e.g. CSIR, 2016).

In addition, Peter Rosewarne was project manager for the Karoo Groundwater Expert Group, convened by Shell South Africa, from 2012 to 2015. This was a group of hydrogeologists and hydrochemists with a cumulative c.250 years of experience of Karoo hydrogeology brought together to provide a collective, impartial overview of available information and provide hypotheses on deeper groundwater occurrence and interaction with shallower aquifers. Work carried out included review of all available information on Karoo aquifers and geology, conceptualisation of shallow and deep groundwater flow, vulnerability and attributes[1] mapping (Rosewarne *et al* 2012 & 2013), risk assessment approach and production of several technical papers and presentations at shale gas and groundwater workshops and symposia (Rosewarne *et al* 2012 & 2013, Rosewarne, 2014 & 2015).

A study was carried out on naturally occurring hazardous trace elements in the BW (and others) area (Water Research Commission, 2008). This found naturally elevated levels of e.g. U and arsenic (As) in groundwater, mostly from mine exploration boreholes, and wide variation over small distances. There was little correlation between rock geochemistry and groundwater chemistry, which has been provisionally attributed to complex flow regimes within fractures.

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 adjacent 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.

2.1.1 Climate

The climate is arid to semi-arid with long periods of insignificant amounts of rainfall. The desert-like environment is reflected in the sparse vegetal cover that comprises mostly varieties of woody shrubs and succulents. Drought conditions are common over the region and periods of up to nine months have recorded no rainfall (SRK, 2007).

Based on rainfall data for the period 1990 to 2020 obtained from “Weather and Climate,” the average mean annual precipitation (MAP) at Beaufort West is 359 mm, most of which occurs during January to March (see **Figure 2**). Precipitation occurs predominantly in the form of thunder storms and so can vary significantly across quaternary catchments. Annual rainfall during a ‘wet year’ (approximately every 15 to 30 years) ranges between 300 and 740 mm/a, while during a typical ‘dry year’ it is <100 mm/a (SRK, 1996). An abandoned weather station at Ryst Kuil (no. 70/698) had records from 1926 to 1944, with the MAP for that period being 178 mm/a. Greatest precipitation occurs along the northern parts of the study area where elevations are greater. The potential evaporation for the investigated area is about 2 100 mm/a (SRK, 1979b).

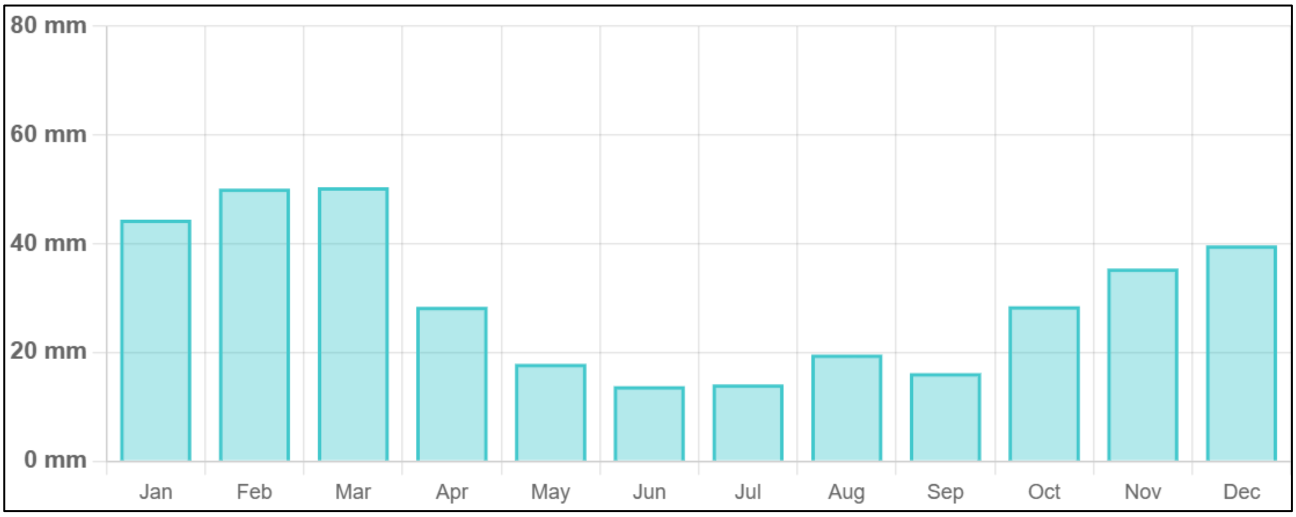

Figure 2: Mean Monthly Precipitation at Beaufort West

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[1] A combination of structure, lithology, depth to water level, yield and water quality, weighted and contoured to produce attribute maps.

2.1.2 Topography

The topography across the study area is composed of gently rolling landscape that is directly related to stratigraphy, with the surface being represented by a gently-eroded plain or pediment. Occasional low hills occur due to the outcrop of more resistant sandstones and dolerites.

Elevation across the RKSA varies from >1 000 m above mean sea level (mamsl) along both the western and eastern portions and 750 mamsl along the central parts (**Figure 1**). The higher lying parts north of the study area are composed of the Nuweveld Mountain Range, which is capped by sheets or sills of dolerite in places. It is expected that the flat topography will result in low hydraulic gradients in those areas.

2.1.3 Drainage

Drainage is partly superimposed, but is mostly controlled by geological structures. The major river channel is the Sout River (**Figure 1**), which drains in a southerly direction towards the Sout River Vlei. All rivers are ephemeral, i.e. rivers that are generally storm-event driven and flow occurs <20% of the time; these rivers have a limited (if any) baseflow component with no groundwater discharge (DWAF, 2006).

2.1.4 Geology

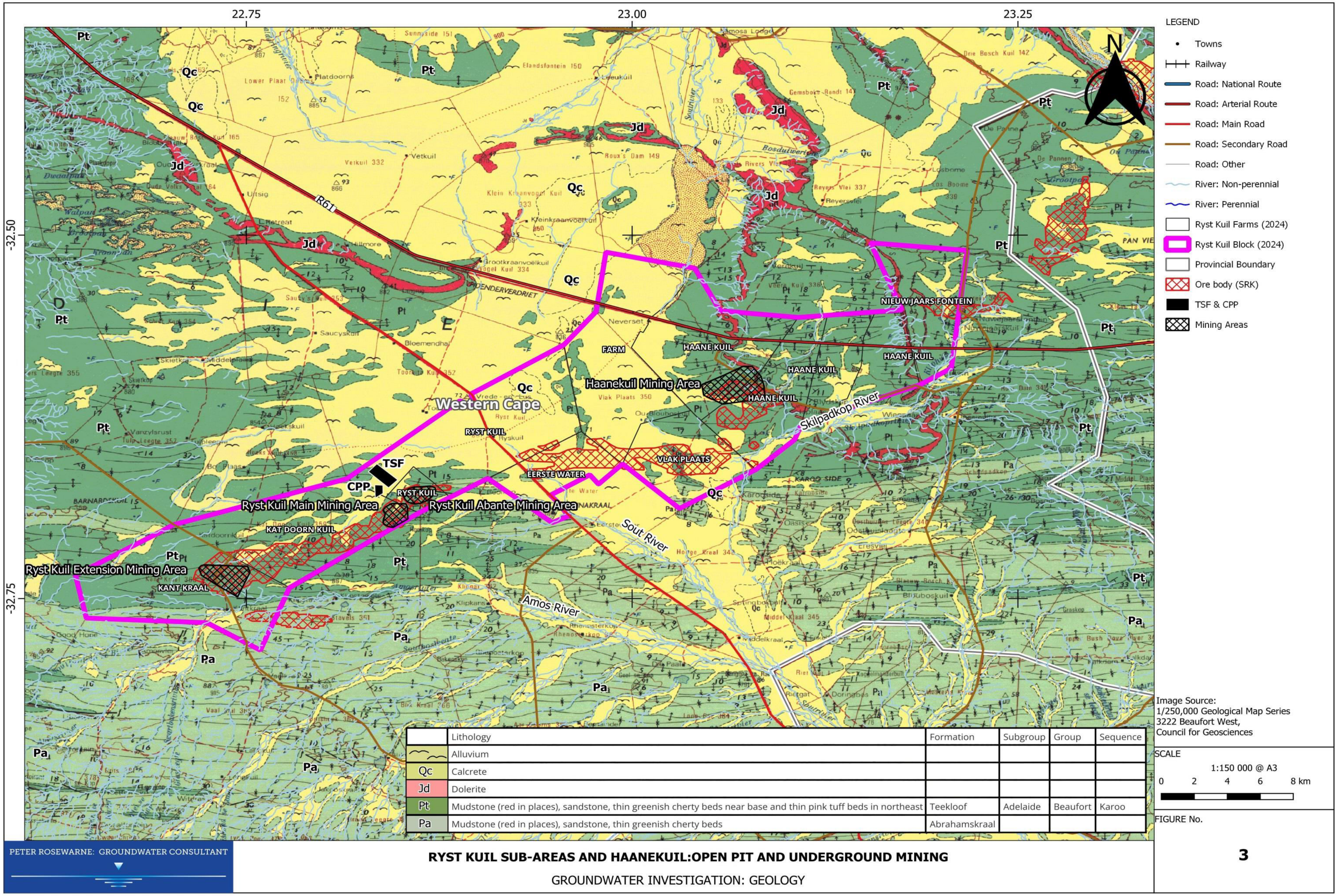
Based on the published 1:250 000 scale geological maps, sheets 3220 Sutherland and 3222 Beaufort West, four lithological units are found in the study area, namely the Teekloof Formation, the Abrahamskraal Formation, Karoo Dolerites and Quaternary-age deposits (**Figure 3**).

2.1.5 Unconsolidated Sediments

The principal alluvial deposits are concentrated along the valleys, stream courses and flood zones of the drainage systems in the study area. All superficial deposits are of Quaternary age.

The alluvium consists of silt at the top and gravels, pebbles and boulders towards the bottom. Thinner layers of alluvium elsewhere generally only consist of silt. The boulders are generally composed of dolerite and metamorphosed sedimentary rocks. The coarse gravel and sandy alluvium are features of flood deposits. Reddish-brown iron-rich sands have developed in the proximity of dolerite outcrops. Calcretes are also found in places.

The soil cover is generally thin over the investigated area. This allows for the stratigraphy and structures being fairly well-defined from the aerial photograph interpretation. Based on drilling results, BRGM (1977) indicated that the thickness of the alluvium along the Sout River is >10 m.



	Lithology	Formation	Subgroup	Group	Sequence
⌒⌒	Alluvium				
Qc	Calcrete				
Jd	Dolerite				
Pt	Mudstone (red in places), sandstone, thin greenish cherty beds near base and thin pink tuff beds in northeast	Teekloof	Adelaide	Beaufort	Karoo
Pa	Mudstone (red in places), sandstone, thin greenish cherty beds	Abrahamskraal			

Figure 3: Geology

2.1.6 Sedimentary Formations

The bedrock generally consists of alternating green to grey sandstone and reddish to brown mudstone / siltstone units of the Permo-Triassic age Poortjie Member of the Teekloof Formation that forms part of the Adelaide Subgroup of the Beaufort Group, which in turn forms part of the Karoo Supergroup. Occasional mudstone, chert and conglomerate beds are also found in places. Along the southern part of the study area, mudstone and sandstone of the Abrahamskraal Formation occurs. The lithological units are discontinuous and show rapid lateral and vertical facies changes. The sediments are upward fining, i.e. sandstones at the bottom and mudstones at the top. The bedrock is generally fresh, hard and indurated.

The ‘Main Sandstone’ was deposited in a meandering river environment, reflected by its thinning and thickening horizons along its c.18 km length and c.3 km width. The sandstones in the area occur as lenses, and thick layers or lenses >10 m thick were observed north of the Hannekuil East ore body in the Ryst Kuil study area (at the farm Sout Rivers Vlei). The dip of the sedimentary strata is rarely measurable and the strata can be considered as sub-horizontal.

2.1.7 Intrusive Rocks

During the Jurassic period (195 Ma to 135 Ma), the sedimentary formations were intruded by medium to coarse grained dolerites, forming interconnected dyke and sill structures in the investigated area. The dolerites are intrusive at all levels of the sedimentary sequence, but most prominently displayed as transgressive sheets or sills. However, there are no dolerite structures outcropping along the western RKSA.

2.1.8 Mineralisation

The U deposits are found in the alternating sandstone and mudstone / siltstone units and were deposited along permeable palaeoriver channels upon encountering predominately organic debris and associated H_2S reductants (SRK Consulting, 2007). Mineralisation is consistent with formation during metamorphic alteration of the deposit and U horizons coincide with green schist facies mineral assemblages (Bowell and Connelly, 2007). The deposits were deposited as thin, irregular shaped lenses that range in width from <200 m to several hundred metres, and are on average 1 m thick.

The major ore mineral is coffinite and the closely related U-silicates. Gangue minerals include calcite, minor sulfides and organic complexes (SRK Consulting, 2007). The occurrence of sulfide indicates reducing conditions during formation. It is understood that Mo occurs within organic complexes at a grade of approximately 700 ppm. Arsenic (As) is also a trace constituent.

The average depth of mineralization below current ground level is between 60 and 80 m, although it may be as deep as 150 m along the deposits towards the east.

2.1.9 Structural Geology

The Beaufort Group rocks are gently folded due to the proximity of the Cape Fold Belt to the south. The axes of both anticlinal and synclinal closed folding trend E-W and the intensity of folding decreases northwards away from the Cape Fold Belt (SRK Consulting, 1979b). At Ryst Kuil, the dips of these folds are generally <5° and not >10°. Towards BW, the sediments are flat, while south of the Amos River, dips increase to between 10 and 20°. The folds are often asymmetrical with steeper dips on the southern limbs (SRK Consulting, 1979b).

As the rocks underwent folding, the arenaceous sandstones retained their thickness but were subjected to brittle deformation resulting in significant fracturing. As a result of differential movement occurring between the sandstones and the argillaceous rocks (the siltstones and mudstones), a well-defined open bedding plane contact developed (SRK Consulting, 1979b). Major water strikes have been reported by drillers at the contact.

At Ryst Kuil, the majority of groundwater flow is along the two main, well defined conjugate joint sets that trend in an E-W and NNW-SSE direction. These joints developed during folding and resulted from a north-south principal stress direction (SRK Consulting, 1979b). These tensional joint sets strike at 340 to 350° (prominent direction) and 270 to 280° (secondary direction), and are perpendicular to and parallel to, the fold axes, respectively.

The continuity, spacing and aperture of these joints are controlled by sandstone thickness and the degree and type of folding. The jointing system identified in the sandstones is not continuous in the softer rocks (SRK Consulting, 1979b). The dimensions of joints, including length and aperture width, decreases with decreasing sandstone thickness.

Large groundwater inflows and air losses were encountered during drilling into the main synclinal axis along the northern boundary of Kat Doorn Kuil farm (SRK Consulting, 1979b), as a result of the jointing. Based on drilling records, the anticlinal areas in the investigated area did not result in increased inflows into the boreholes. Faulting has generally not been reported to occur in the study area and has also not been identified on the published geological maps.

2.2 Hydrocensus 2016

Boreholes covered by the 2016 hydrocensus are shown on **Figure 4**. Groundwater is used for stock watering, irrigation and domestic purposes. Information from the owners on borehole depths and yields was generally very sparse and estimates of abstraction have been made based on i) windpump size and use for stock watering and ii) hectares of irrigated land. Most boreholes are equipped with windpumps and are estimated to yield relatively small volumes in the range 600 – 800 m^3/a. Some are equipped with submersible or turbine pumps and the groundwater is used mainly for irrigation purposes, mostly during the period September to April.

2.3 Borehole Siting, Drilling and Testing

During the 2007/08 investigation, 17 groundwater exploration boreholes were drilled in the RKSA, to depths of between 50 and 143 m. Extensive yield testing was carried out with pumping rates ranging from 3 - 26 L/s and T and S values obtained. Packer testing was also carried out on three boreholes to determine zone-specific K values. It was therefore considered that sufficient data were available for this area and further drilling and testing was not carried out in the RKSA in 2016 or 2025. Selected details of these boreholes are given in **Table 1** and locations are shown on **Figure 5**. Test pumping information is used to assist with the numerical model calibration in **Section 4**.

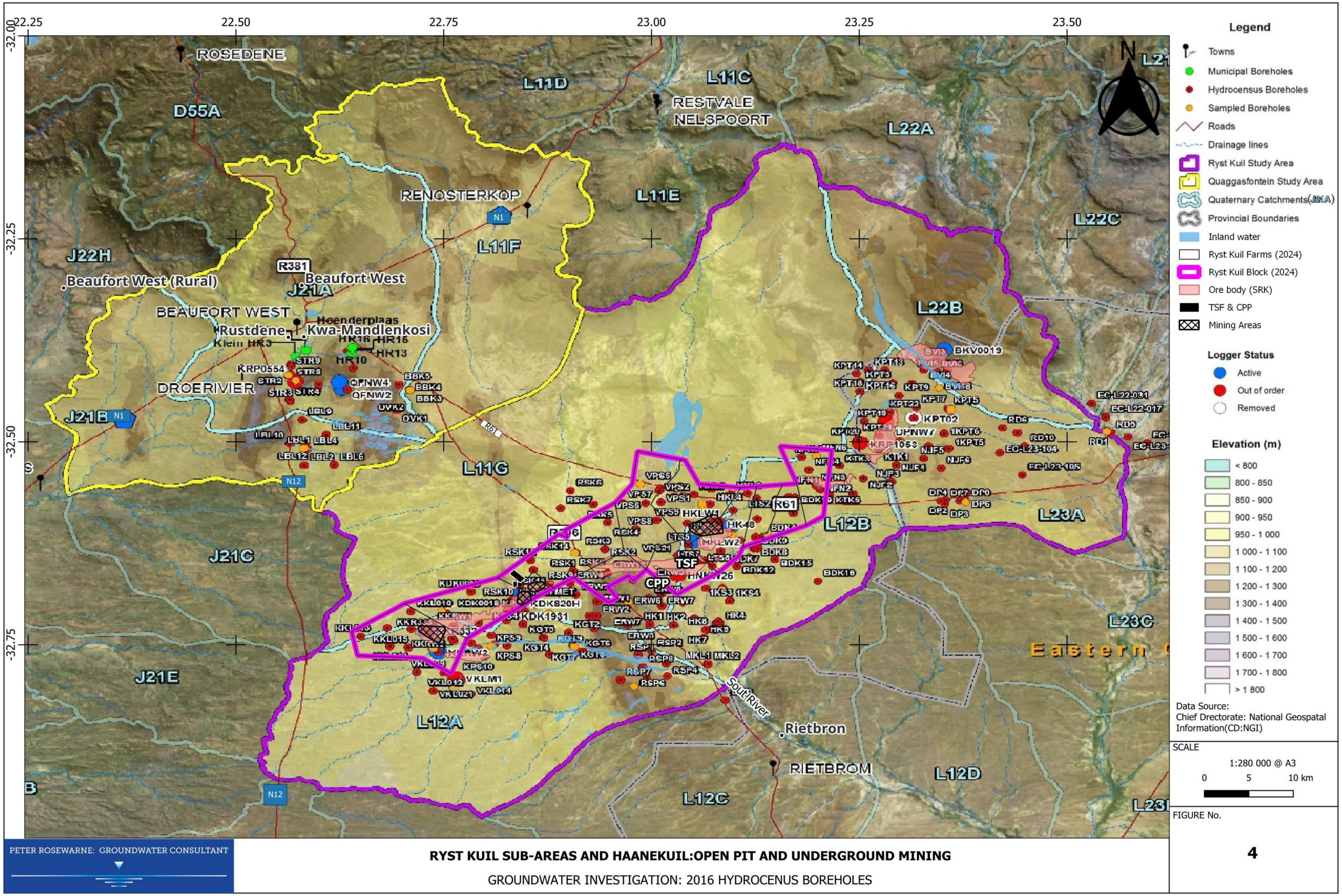


Figure 4: 2016 Hydrocensus Boreholes

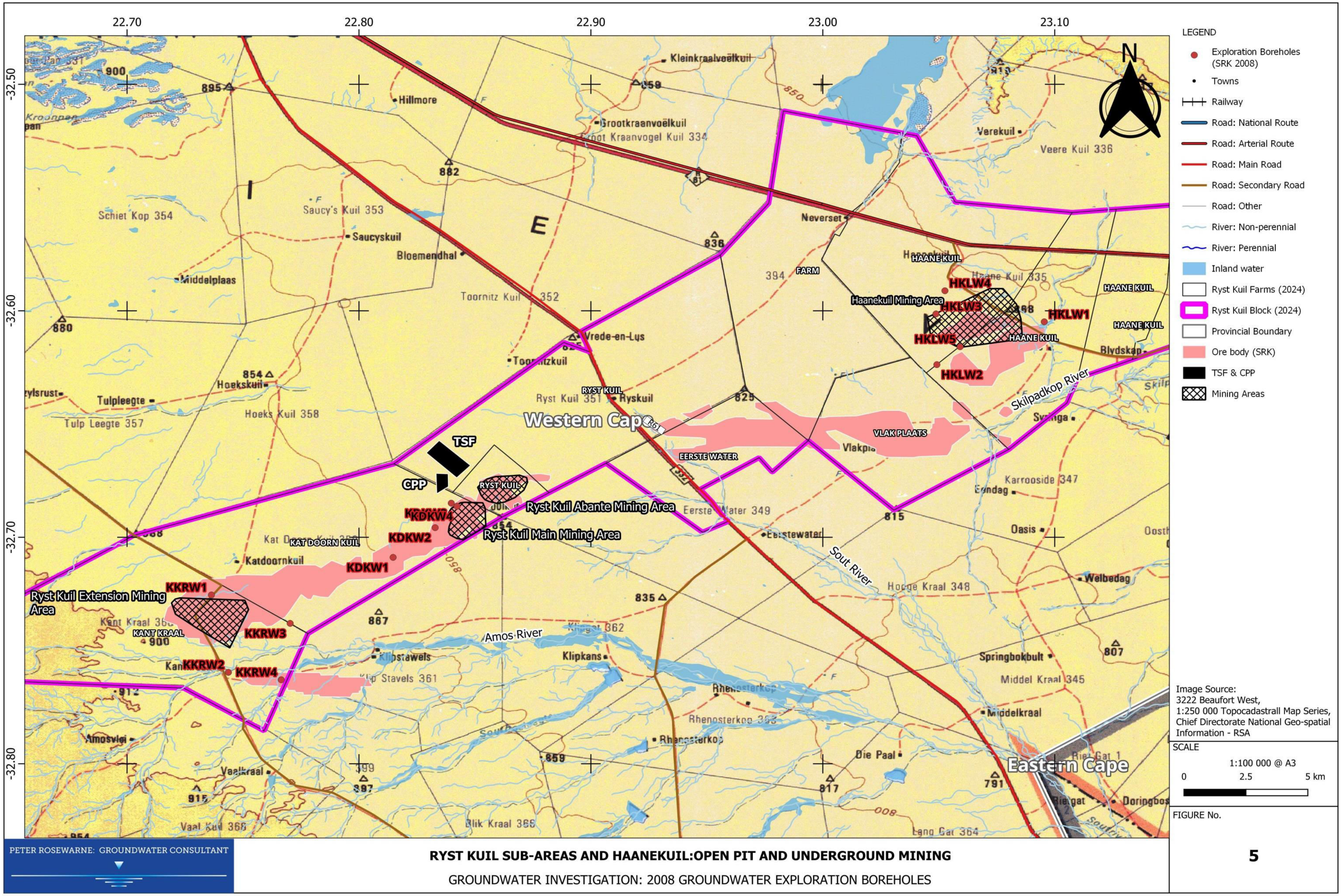


Figure 5: 2008 Groundwater Exploration Boreholes

Table 1: Results of Groundwater Exploration Drilling in the RKSA 2008

BH No.	Depth (m)	Tested Yield (L/s)	Long-term Sustainable Yield (L/s)	EC (mS/m)	Water Level (mbgl)	T (m^2/day)
KDKW1	120	26.7	24.0*	176	34.25	265-380
KDKW2	140	8.6	8.7	150	30.20	27-112
KDKW4	120	10.3	5.8	165	26.98	12-22
KKRW1	120	15.1	16.0*	165	34.73	90-110
KKRW2	120	10.0	5.1	160	26.25	14-33
HKLW1	49	3.5	4.5	138	5.87	42-70
HKLW4	125	7.1	8.3	165	24.50	37-70

*probably optimistic and 50% of this would be a more realistic starting yield

The results obtained from the nine yield tested boreholes, as well as three previously tested boreholes (BH758, BH725 and 636), were analysed by using the FC-Flow Characteristic method and some using the Cooper–Jacob method (SRK, 2008). The FC-method was specifically developed for determining sustainable yields of boreholes penetrating fractured-rock aquifers. In the calculations the following allowances were made:

1. Abstraction from all other known production boreholes in the area;
2. Effective recharge of 5 mm/annum (3.9 mm in calibrated model discussed in **Subsection 4.5**);
3. Data extrapolated for a nominal 5 years; and
4. Dewatering of a nominal 30 – 40 m (available drawdown) over this period.

The long-term sustainable yields listed in the above table appear to be on the high side (see also comment on effective recharge), although undoubtedly attainable in the short-term (weeks). The pumping of 16 L/s over a period of one year from the trial mine (SRK, 2007), despite grouting of some major water-bearing fractures, supports this assumption. However, for inclusion in numerical modelling scenarios of pumping of groundwater for supply to the CPP, much reduced yields have been assumed. Discussion on yield is continued in **Subsection 3.5** and on T and S values in **Subsection 4.6**.

2.4 Hydrogeology

The area has a unique physiography, with steep mountains of the Nuweveldberg to the north giving way rapidly southwards to extensive flat-lying areas, which form a pedeplain. These areas are characterised by shallow alluvial soils prone to flooding, sometimes very extensively and with strong overland flow, in times of heavy rainfall. This pedeplain is postulated to be the result of headward erosion and retreat of the Great Escarpment to the north. Although some of this flood 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**.

The RKSA area consists of intergranular, fractured and fractured & intergranular aquifers. The intergranular or primary aquifers are located along river channels and underlie the Sout River drainage area (see **Figure 3**) and extensive pediment areas. These aquifers are composed of sand, silt and some gravel, pebbles and boulders. Based on borehole logs, the primary aquifers are *c*.10 m thick on average and >10 m along in the main Sout River area. Within the primary aquifer, groundwater levels range between 10 and 25 m below ground level (mbgl). Yields of boreholes drilled in these aquifers can be high, i.e. >5 L/s. However, groundwater quality is generally poor, probably due to evaporation of shallow groundwater/ponded water and subsequent incorporation of surface evaporative salts into shallow rainfall recharge water.

The fractured aquifer is mainly developed in sandstones of the Beaufort Group, while fractured and intergranular aquifers are associated with Karoo dolerites. The U mineralisation (with associated Mo and As) is mainly contained within a narrow zone of palaeochannel 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, since the primary porosity of the sandstone is almost nil. Relatively good quality groundwater is found within the secondary aquifers, especially along the Ryst Kuil and Haanekuil ore bodies. Some information on aquifer lithology, water strikes and RWLs from the drilling in 2008 is given in **Table 2**.

Table 2: Summary of Selected 2008 Exploration Borehole Logs

Borehole No.	Depth (m)	Lithology	Water Strikes# (mbgl)	RWL (2008) (mbgl)
HKLW1	50	Sst*/dolerite	16, 24, 35, **44**	5.87
HKLW4	125	Sst	35, 38, 47, 60, **74**	24.50
KKDW1	140	Interbedded sst/mst**	48-49, 55, 66, 76-78, **87**, 91, 113, 124, 131, 133	34.25
KDKW2	140	Interbedded sst/mst	41, 52, 125, **133**	30.20
KDKW4	120	Interbedded sst/mst	28, 43, 54, **75**	26.98
KRKW1	120	Interbedded sst/mst	59-60, 64-65, 68, 73, 78, 96, **108**	34.73
KRKW2	120	Interbedded sst/mst	12, 35, 41-45, 52-53, 61-62, **66**, 95	26.25

*sandstone **mudstone #main water strike in **bold**

According to the above table, the channel sandstone contains interbedded mudstone and 83% of water strikes occurred at depths of <100 m. This information is used as a basis for selecting an aquifer thickness and lithologies for the numerical modelling

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-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 fold axes of both anticline and synclines trend east-west.

The thickness of the main palaeochannel sandstone aquifer is variable, commonly from *c*.20 – 40 m, and to depths of *c*.100 m and sometimes *c*.140 m below surface, with interbedded mudstones. Aquifer width is c.2.5 km in the central areas, widening to the north-east and south-west. Aquifer transmissivity (*c*.12 – *c*.380 m^2/day) and borehole yields (*c*.5 – *c*.25 L/s), according to test results from purpose-drilled groundwater exploration boreholes, are highest in the south-west and decrease to the north-east. This is a function of sandstone lithology, thickness and structure. There is also 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. Based on the above information, this sandstone is a major aquifer

Average groundwater RWLs are relatively deep in the secondary aquifers, ranging between 15 and 40 mbgl. Long-term monitoring (see **Subsection 2.6**) shows little or no drop in these deep water levels despite local groundwater use and periods of drought. However, it is possible to completely abstract groundwater from the more permeable sandstone layers of a multi-layered aquifer system without materially affecting the piezometric levels in the less permeable layers (Woodford and Chevallier, 2002).

The RWLs are all at least 40 m above the main water strikes in all the exploration boreholes. In the absence of such information for existing farmer’s boreholes, it is assumed that such a situation exists at all of these as well. This is of importance when assessing the impact of mining on RWLs, as is discussed in **Subsection 5.3**.

It is worth noting here that the extent of aquifer development in the RKH area was only discovered as a result of U prospecting and follow-up groundwater investigations in 1978/1979 and 2007/2008. An approach was made to Beaufort West Municipality by SRK/Areva in *c*.2005 to make the information available to them to assist development of an additional groundwater supply source but the offer was not taken up.

2.5 Water Quality Analyses

2.5.1 Macro-Chemistry

Water samples collected during the 2016 hydrocensus were submitted to UIS Laboratories in Centurion for metals scans and macro-chemical analyses. A summary of the main indicators and ions (in mg/L) is given in **Table 3**.

Table 3: Summary of Macro-Chemistry for 2016 Sampled Boreholes from the RKSA

BH No.	pH	EC (mS/m)	Total Hardness (as $CaCO_3$)	Na	K	Ca	Mg	Cl	SO_4	NO_3 (as N)	F	As
LKL1	7.75	416	1 360	264	14.7	389	95.2	637	508	0.167	1.85	0.011
RSK13	8	284	630	287	9.47	171	49.5	402	394	0.236	1.49	<0.01
KPS9	7.81	173	403	174	4.76	113	29.2	195	237	0.636	0.983	<0.01
RSP6	7.57	327	785	306	9.47	226	53.5	552	351	0.19	1.32	0.01
HKL13	7.68	112	357	112	7.72	92.7	30.6	125	70.4	10.8	1.69	<0.01
LTS11	7.73	119	344	136	5.73	85.5	31.8	136	80.9	9.18	1.92	<0.01
KGT9	8.1	298	570	339	10.7	133	57.6	444	358	21.7	1.99	<0.01
KGT3	8	207	433	242	13.9	116	34.7	242	243	19.6	2.67	<0.01
BDK1	8	188	449	171	6.91	110	42.5	228	163	0.614	2.02	<0.01
1KS2	7.6	306	683	295	8.98	172	61.3	509	347	0.201	1.68	0.011
VPS5	7.94	420	328	745	10.2	132	113	941	634	<0.13	2.09	<0.01
VKL01	7.9	88.3	191	116	3.31	76.7	21.1	88.8	123	4.55	1.41	<0.01
KD0002	7.95	99.5	240	115	6.67	96.1	26.8	134	119	4.03	0.962	<0.01
RSK14	7.99	200	298	301	9.74	119	53.8	374	305	0.634	1.79	0.021

*values are reproduced from the certificates of analysis

The groundwater is alkaline and most ECs are within the range *c*.90 – *c*.300 mS/m. The higher ECs may be associated with boreholes along river courses and in pediment areas, probably due to evaporative effects on shallow groundwater and incorporation of evaporite salts into local, direct recharge. 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 $(HCO_3)_2$, chloride (Cl), sulfate (SO_4), nitrate, sodium (Na), potassium, calcium (Ca) and magnesium (Mg), all of which carry an electrical charge (positive or negative).

The groundwater is hard to very hard and is mostly a mixed $NaCl/Ca\text{-}MgSO_4$, $Na_2Ca(HCO_3)_2$ type. Fluoride (F) is generally elevated compared to drinking water standards (<1.5 mg/L recommended by SANS 241), commonly 1 - 2 mg/L and up to 2.67 mg/L (KGT3). Elevated F is a common feature of Karoo groundwater and is usually attributed to dissolution of detrital apatite (a calcium phosphate mineral containing F) grains in sandstones. Nitrate levels (<11 mg/L as nitrogen - N - recommended by SANS 241) are also generally elevated-to-highly elevated, *c*.6 - 22 mg/L as N, e.g. in KGT3 and KGT9, probably as a result of agricultural activities, e.g. application of fertlizers and wastes from stock pens.

2.5.2 Radiological Analyses

Selected (mainly those used for domestic supply) water samples from the 2016 hydrocensus were submitted to the Necsa laboratory in Pretoria for gross α and β activity analyses. A summary of results is given in **Table 4**.

Table 4: Summary of Gross Alpha & Beta Activity and Uranium Concentration 2016

Borehole No.	Gross α Activity (Bq/L)	Gross β Activity (Bq/L)	U (metals scan, mg/L)
SANS target limit	**-**	**-**	**0.03**
DWS Ideal target	**0.5**	**1.28**	**<0.07**
DWS Upper limit	**-**	**-**	**0.284**
LKL1	1.25	0.44	0.066
RSK13	1.06	0.27	0.018
KPS9	0.397	0.0071	<0.01
RSP6	2.46	0.35	0.032
HKL13	0.778	0.402	0.014
LTS11	0.695	-0.0037	0.015
KGT9	1.42	0.24	0.025
KGT3	1.02	0.21	0.022
BDK1	0.997	0.16	0.017
1KS2	0.963	0.25	0.02
VV1	0.387	0.194	NA
GP1	0.244	0.12	NA

The metals scans show U generally <0.03 mg/L (SANS 241-1:2015 target limit 0.03 mg/L; DWS domestic water "Ideal" target limit is <0.07 mg/L and "Upper" limit is 0.284 mg/L), apart from LKL1.

2.5.3 Acid Base Accounting

The 2016 acid-base accounting (ABA) results (see **Table 5**) show that the waste rock is classified as non-acid generating and this is supported by the water quality within the 38-year-old underground trial mining area, i.e. acid rock drainage is unlikely to occur. Leach testing of waste rock also shows no mobilisation of U (results below laboratory detection limit).

Table 5: ABA Results for the Waste Rock Samples

Sample No	Pit	Lithology	Paste pH	Total S	TAP	+NP	NNP	TNPR
			S.U	%	($CaCO_3$) kg/t			
SRK8606	Ryst Kuil Abante	Sst	8.8	<0.01	<0.31	11.9	11.6	38.390
SRK8606		Sst	8.5	<0.01	<0.31	21.4	21.1	69.030
SRK8605		Slst	8.8	<0.01	<0.31	6.88	6.6	22.190
SRK8605		Slst	8.2	<0.01	<0.31	22.4	22.1	72.260
SRK8615		Sst	8.1	<0.01	<0.31	9.43	9.1	30.420
SRK8614		Slst	8.3	<0.01	<0.31	7.13	6.8	23.000
SRK8616	Haanekuil	Mst	7.7	<0.01	<0.31	12	11.7	38.710
SRK8618		Sst	8.7	<0.01	<0.31	13.2	12.9	42.580
SRK8617		Slst	8.4	<0.01	<0.31	23.9	23.6	77.100
SRK8620	Ryst Kuil Ext	Mst	8.1	<0.01	<0.31	15	14.7	48.390
SRK8607		Sst	8.7	<0.01	<0.31	0.26	-0.1	0.840
SRK8609		Slst	8.4	<0.01	<0.31	15.8	15.5	50.970
SRK8625	Ryst Kuil Main	Mst	8.6	<0.01	<0.31	13.8	13.5	44.520
SRK8627		Mst	8.5	<0.01	<0.31	16.8	16.5	54.190
SRK8603		Sst	9.0	<0.01	<0.31	3.82	3.5	12.320

Sample No	Pit	Lithology	Paste pH	Total S	TAP	+NP	NNP	TNPR
			S.U	%	(CaCO$_3$) kg/t			
SRK8604		Sst	9.2	<0.01	<0.31	6.36	6.1	20.520
SRK8630		Sst	8.7	<0.01	<0.31	11.7	11.4	37.740
SRK8603		Sst	8.6	<0.01	<0.31	4.08	3.8	13.160
SRK8604		Sst	8.2	<0.01	<0.31	13	12.7	41.940
SRK8626		Slst	8.9	<0.01	<0.31	33.1	32.8	106.770
SRK8628		Slst	8.4	<0.01	<0.31	13.8	13.5	44.520

Note:

1. Total acid potential (TAP) = acid potential based on total sulfur.
2. The measured NP (Sobek titration) is indicated by Bulk NP that is used to calculate TNPR.
3. Total Net Neutralisation Potential Ratio (TNNP) is the difference between Bulk NP and TAP.
4. Total Neutralisation Potential Ratio (TNPR) is the ratio of TAP and Bulk NP.
5. Slst siltstone

2.6 Monitoring

Groundwater level and quality monitoring began in November 2007 in the RKSA, the latter only in the trial mine area (based on a historical application to the regulators for dewatering of the workings to allow access for further sampling and resource evaluation). The localities of boreholes equipped with loggers are indicated on **Figure 5**. The area covered by the loggers has been divided into two sub-areas, i.e.:

1. The Haanekuil sub-area, with boreholes HKLW1, HKLW2, HK48 and HNKW26; and
2. The Ryst Kuil sub-area, with boreholes VKLM1, KKRW2, KKR333, KDK1931 and KDK820H.

Of the 13 originally installed loggers, only those installed in boreholes BKV0019, HKLW1, and KKRW2 were still operative when checked in August 2016. These boreholes are located on the farms Bok Vlei, Haane Kuil and Kant Kraal, respectively. The loggers installed in boreholes DPNW7, KRP1053, HK48, HNKW26 and VKLM1 had malfunctioned, whilst those installed in boreholes KDK1931 and KRP0554 had been removed by unknown persons. Boreholes HKLW1, HKLW2 and DPNW7 are groundwater exploration boreholes drilled during SRK’s 2008 investigation for Uramin. The other boreholes are mine exploration boreholes, except VKLM1, which is an exploration borehole drilled by the previous farm owner.

During an upgrade of the monitoring network in August 2016, new loggers were installed in boreholes HKLW2 (Haanekuil), KKR333 (Kant Kraal) and KDK1931 & KDK820 (Kat Doorn Kuil). This means that there were seven active loggers in the RKSA.

There was a general memory overflow in the loggers prior to the previous download in July 2013, with a resultant loss of data for the period June 2012 to July 2013. Only the loggers installed in boreholes VKLM1 and DPNW7 recorded groundwater levels during this period due to the fact that these loggers were reprogrammed during 2012. Rainfall data for the area were previously obtained from the South African Weather Service for the Klipkrans rainfall station. However, this station closed in January 2014 and subsequent rainfall data were obtained from the Beaufort West rainfall station. Although it is the closest rainfall station to the RKSA, it is a relatively long distance away, and rainfall in the RKSA may differ considerably from that recorded at Beaufort West. This is due to the dominance of erratic electrical storms in the generation of precipitation in the Karoo.

2.6.1 Groundwater Levels

Haanekuil

The groundwater level behaviour of boreholes in this sub-area is illustrated in **Figure 6**. 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.

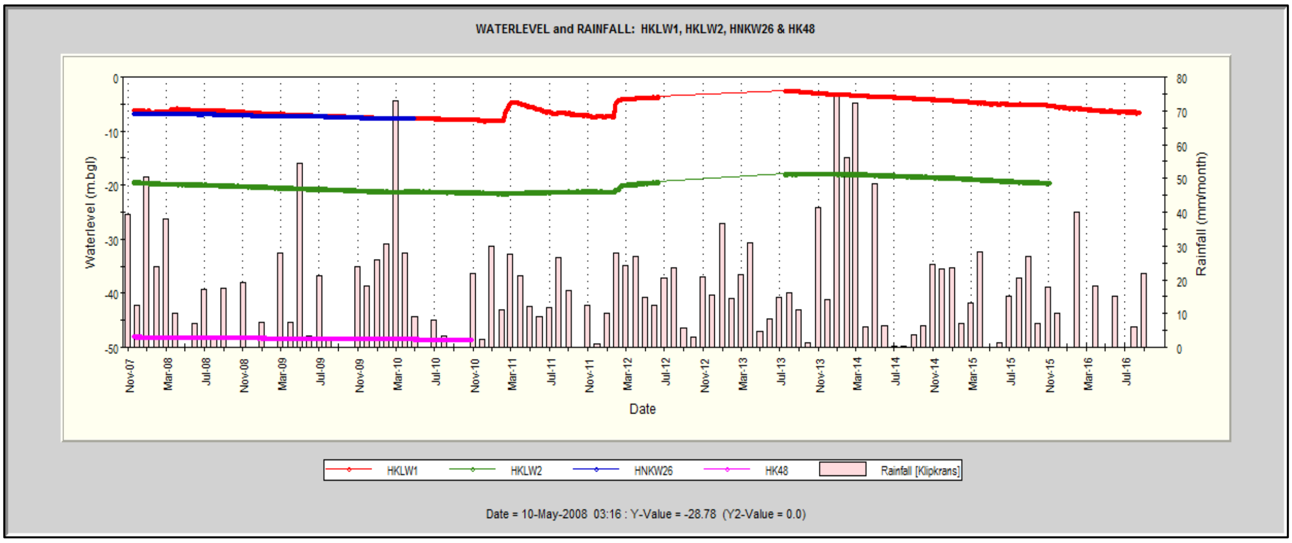


Figure 6: Groundwater Level Behaviour of Boreholes in the Haanekuil Sub Area

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

The groundwater level behaviour of boreholes in this sub-area is illustrated in **Figure 7**. 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.

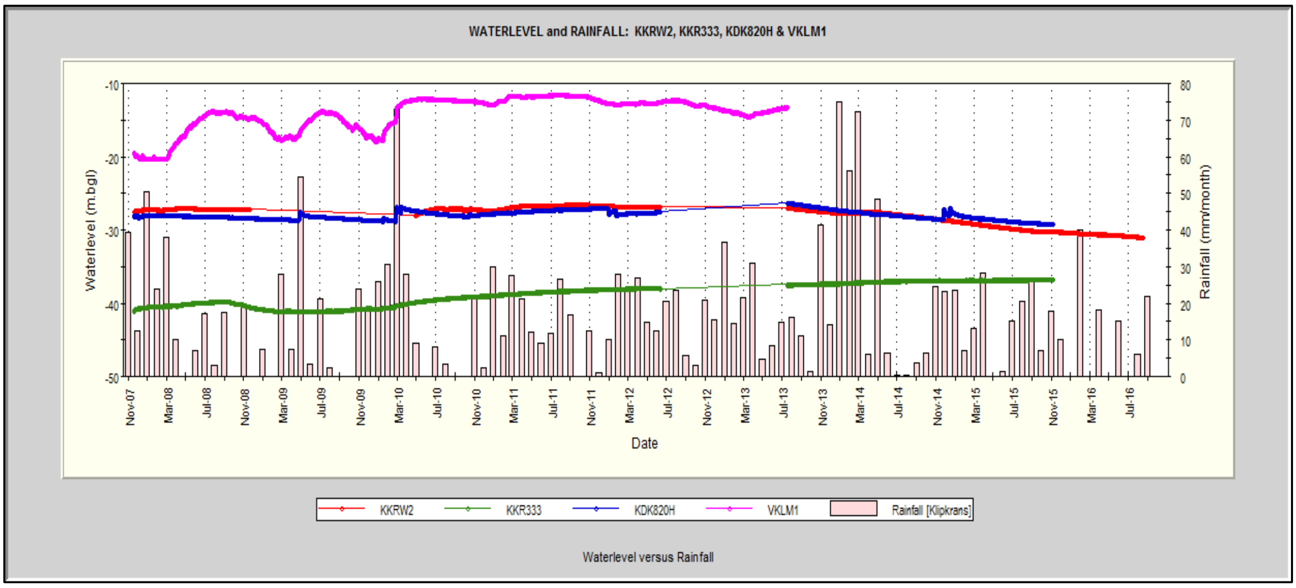


Figure 7: Groundwater Level Behaviour of Boreholes in the Ryst Kuil Sub-Area

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 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. A further mechanism that could be in operation here is the slow drainage of groundwater from matrix mudstones into fractures in the sandstone and the masking of depletion of groundwater in the latter by piezometric pressures in the former.

2.7 Groundwater Supply

It was estimated (DWAF 2005) that recharge for the RKSA is *c*.64 Mm^3/a (2.4% of Mean Annual Precipitation, MAP). However, the volume of groundwater that may be practically/sustainably abstracted from the aquifers in the study area is limited by, *inter alia*, transmissivity and connectivity over the respective sub-catchments. Based on this consideration, the Utilisable Groundwater Resource Potential (UGRP) was determined (DWAF, 2005). When considering the sub-catchments containing the mine application areas, i.e. L11G, L11A and L11B, the UGRP under ‘dry’ conditions is *c*.7 Mm^3/a or *c*.220 L/s.

Water feed and storage requirements for mining were verified by DRA Global Ltd (pers. comm. D. Dalrymple, May 2017). The CPP requires *c*.43 L/s at full operating capacity, with the groundwater quality indicated in **Subsection 3.3** meeting requirements for this purpose. The CPP will have three water storage dams, two of 2 000 m^3 capacity and one of 1 900 m^3 (this excludes provision for stormwater control). These need to be full six months prior to full plant commissioning to enable water and leak testing to be carried out. It is proposed to meet this requirement by pumping from the trial mine (dewatering) at 17 L/s for *c*.100 days. The balance of 26 L/s will be met from production boreholes, either those drilled in 2007/2008 or, if these are found to be unusable for any reason, then nearby replacement boreholes. These may have to be deepened as mining progresses and may also act as mine dewatering boreholes.

A combination of 40% recycling of TSF water, dewatering/supply boreholes and pit inflows will sustain the CPP water requirements thereafter. Pumping rates will be reduced by at least 50% compared to the long-term rates indicated in **Table 1**. This supply is considered to be sustainable based on historical pumping of the trial mine, test pumping of purpose-drilled groundwater exploration boreholes and numerical modelling.

Claims were made by farmers in 2016 of interference by mine exploration boreholes on privately-owned boreholes, with one of the latter apparently running dry allegedly due to exploration drilling *c*.9 km away. Such interference (from drilling/pumping of single boreholes) is considered to be highly unlikely in an essentially unconfined aquifer system. To illustrate this, a simple consideration of Darcy's Law (Q=KiA), where:

Q = flow (m^3/day);

K = hydraulic conductivity (m/day);

i = hydraulic gradient; and

A = area (m^2).

indicates that matrix flow into a fracture along a 9 km length would compensate for any likely impact of an additional borehole, *viz*:

0.1 (lowest K for mudstone in Table 4-1) x 0.5 (50 m drawdown extending 100 m laterally from fracture) x 9 000 (1 m effective fracture width) x 2 (flow from both sides of the fracture)

= *c*.900 m^3/day or 37.5 m^3/hour (10.4 L/s).

Some prominent hydrogeologists with many decades of Karoo groundwater experience were canvassed for their opinions on the likelihood of such interference and they were unanimous in rating it as highly unlikely (pers. comms. March 2017, Dr K Pietersen, A Woodford, D Visser and P Hobbs). It is considered most likely that the borehole was simply over-pumped and, with either no water level measurements to provide warning or fracture storage depletion being masked by piezometric pressures in less permeable layers, the borehole suddenly failed. Detailed site investigations would be required to shed further light on this matter.

2.8 Trial Mining Area

An exploration programme was initiated on the farm Ryst Kuil by ESSO during 1974. Following identification of outcropping mineralization and an exploration drilling programme on Ryst Kuil, the extent of an *c*.70 km strike-length subsurface fluvial sandstone palaeochannel and several large discontinuous U-Mo deposits were defined (SRK, 2007).

A decline and trial mine were established by ESSO in the Ryst Kuil ore body, in the current proposed Ryst Kuil Main mine area (see **Figure 1)**, whereby they constructed a sample preparation plant extracting about 4 500 t of ore between August 1978 and September 1979. Access to the ore body was via an approximately 500 m long, 6° tracked decline (SRK, 2007). Dewatering of the decline/trial mining area, which was *c*.50 m below ground surface, was by means of boreholes and a sump. Drawdown of up to 1 m was propagated for *c*.1.5 km in an east-west direction and *c*.<1 km in a north-south direction. This indicates anisotropy in terms of fracture/aquifer hydraulic conductivity (K) and T, paralleling the main fold trends in the area. This has been taken into account in the numerical modelling.

SRK (1979c) reported that certain areas of the trial mine were subjected to moderate to high groundwater inflows from fractures, which were subsequently grouted to reduce the long-term dewatering requirements. As a result of the grouting, steady inflow into the workings was approximately *c*.16 L/s. It was estimated that without the grouting, inflow may have amounted to between *c*.35 and *c*.52 L/s, with some areas in the decline containing large fractures yielding *c*.75 L/s. This grouting appears to have only had a local effect on groundwater flow, with high yielding boreholes being developed in the area in 2008 (SRK, 2008). Pumping at 16 L/s for one year resulted in the removal of c.505 000 m^3 from storage, which gives some idea of the amount of groundwater contained in the regional channel sandstone aquifer. This water was discharged to a settling area to the north and subsequent investigation of soil radioactivity in *c*.2008 revealed no measurable residual impact (pers. comm. J. Slabbert, 2017)

Chemical analyses of water samples obtained from one exploration borehole penetrating the flooded area, TM15, and two nearby show that the macro-chemistry is similar to that in surrounding farmer’s boreholes. A summary of the chemical analyses is given in **Table 6**. Samples were also sent to the Necsa laboratory in Pretoria for radioactivity analysis. Uranium, thorium and gross α and ß activity were analysed for and results are shown in **Table 7**.

Table 6: Summary of Chemical Analyses from Trial Mining Area Boreholes (2007)

Determinand*	Results		
	TM05	TM15	TM21
pH at 25 °C	7.6	7.5	7.6
Electrical conductivity (mS/m, 25 °C)	78.5	49.5	91.9
Calcium	39.8	48.6	55.3
Magnesium	10.3	7.1	12.3
Sodium	112	64	126
Potassium	6.4	7.6	4.6
Free and saline ammonia as N	< 0.3	< 0.3	< 0.3
Chloride	75	23	96
Sulfate	52	35	95
Total alkalinity as $CaCO_3$	217	172	210

*all determinands in milligrams per litre unless otherwise stated

The macro-chemical results indicate that the fluoride content in groundwater from the trial mine area is relatively high and only borehole KDKW6 continuously yields groundwater suitable for prolonged human consumption. This borehole is drilled into the 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 in *c*.2008, although run-off could still enter) and there is evidence that rainwater drained down the decline. 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.

Table 7: Radioactivity Analysis Results from Trial Mining Area Boreholes (2007)

Radionuclide (mBq/L)*	Sample ID		
	TM05	TM15	TM21
U-238	178	38.6	105
U-234	664	85.2	379
Th-230	1.29	NA	NA
U-235	7.52	1.78	4.84
Th-227	0.57	0.724	3.12
Th-232	0.427	0.0766	1.92
Th-228	0.926	0.604	1.67
Gross α activity (Bq/L)**	0.657	0.178	0.571
Gross ß activity (Bq/L)	0.388	0.226	0.241

NA - Not analysed *milli-Bequerels per litre **Bequerels per litre

3 Updates from 2018-2025

3.1 Hydrocensus

A “top-up” hydrocensus was carried out in late April 2025 to update the 2016 information, during which 46 boreholes were checked. Results are shown in **Table 8** and borehole positions are shown on **Figure 8**.

Table 8: April 2025 Hydrocensus Data

Bh No	Equipment	Use	RWL (mbgl)	EC* (mS/m)	2016 EC (mS/m)	pH	2016 RWL (mbgl)	RWL Change (m)	Comments
BDK1	WP	Stock	5.68				7.86	2.18	
BDK14	WP	Stock	3.65				5.72	2.07	
BDK2	Submersible	Domestic	5.09	147	188	7.59	7.28	2.19	
BDK22	WP	Stock	4.86				7.29	2.43	
BDK4	WP	Stock	4.54				6.83	2.29	
BDK5	WP	Stock	4.76				7.1	2.34	
BDK6	Submersible	Irrigation	4.22				6.56	2.34	
HK48	None	None	46.11				48.51	2.4	
HKL13	Submersible	Domestic	4.47	105	112	7.54	8.28	3.81	
HKL8	WP	Stock	21.59	170	209	7.48	7.98	-13.61	2025 pumping water level
HKLW1	None	None	3.62				6.51	2.89	
HKLW2	Solar pump	Stock	25.5	126	175	7.53	19.56	-5.94	2025 pumping water level
HKLW3	None	None	20.61				19.95	-0.66	2007 water level
HKLW4	Solar pump	Stock	25.29	136	160	7.5	24.5	-0.79	2025 pumping water level
HNKW26	None	None					7.56		Not visited, too wet
KDK0002	WP	None	7.54						WP out of order, no 2016 WL, roots in bh

Bh No	Equipment	Use	RWL (mbgl)	EC* (mS/m)	2016 EC (mS/m)	pH	2016 RWL (mbgl)	RWL Change (m)	Comments
KDK1931	None	None	36.09						No previous water level
KDK820H	None	None	25.89				29.22	3.33	
KDKW1	None	None	32.64				34.25	1.61	
KDKW2	None	None	28.13				30.2	2.07	2007 water level
KDKW4	None	None	25.07				26.98	1.91	2007 water level
KGT18	Submersible	Domestic	9.4	190		7.6			New bh
KGT3			14.94	91		7.65	21.56	6.62	
KGT9	WP	Stock	10.29	197	298	7.5	23.37	13.08	
KKL001	Submersible	None	7.08				37.25	30.17	Standby, pumps dry after 10 minutes
KKL002	None	None	4.74				6.23	1.49	
KKR333	None	None						0	Demolished
KKR333A	None	None	14.39				36.74	22.35	2016 WL measured in demolished bh KKR333 150m south
KKR333B	None	None	12.9						
KKRW1	None	None	29.53				34.73	5.2	2007 water level
KKRW2	Submersible	Domestic	25.21	158	160	7.6	31	5.79	
KPS10	Submersible	Irrigation	14.89				27	12.11	
KPS9	WP	Domestic	9.36	160	173	7.6	11.05	1.69	
LTS10	None	None	10.84				12.56	1.72	Ran "dry", no longer in use
LTS11	Submersible	Domestic	25.47	129	119	7.45	23.05	-2.42	2025 pumping water level
LTS12	Submersible	None	15.1				22.12	7.02	Not in use
LTS3	Submersible	Irrigation	3.1				5.89	2.79	
RKMA064U	None	None	24.45						No previous water level
RSK13	WP	Stock	6.13	226	284	7.6	8.53	2.4	
RSK14	WP	Domestic	5.95	248	200	7.65			No previous water level
RSK5	WP	Stock	5.12				7.25	2.13	
RSK7	WP	Stock	5.92	575		7.7	12.52	6.6	
VKL1	Submersible	Domestic	16.26	66	88	7.7			2025 pumping water level
VKLM1	None	None	6.57				13.24	6.67	
VPS17	WP	Stock	20.98	104	113	7.4	20.59	-0.39	
VPS2	Submersible	Stock	14.98	135	165	7.5	13.43	-1.55	2007 WL
VPS8								0	Not visited - too wet

*blue indicates a decrease in EC, red, an increase

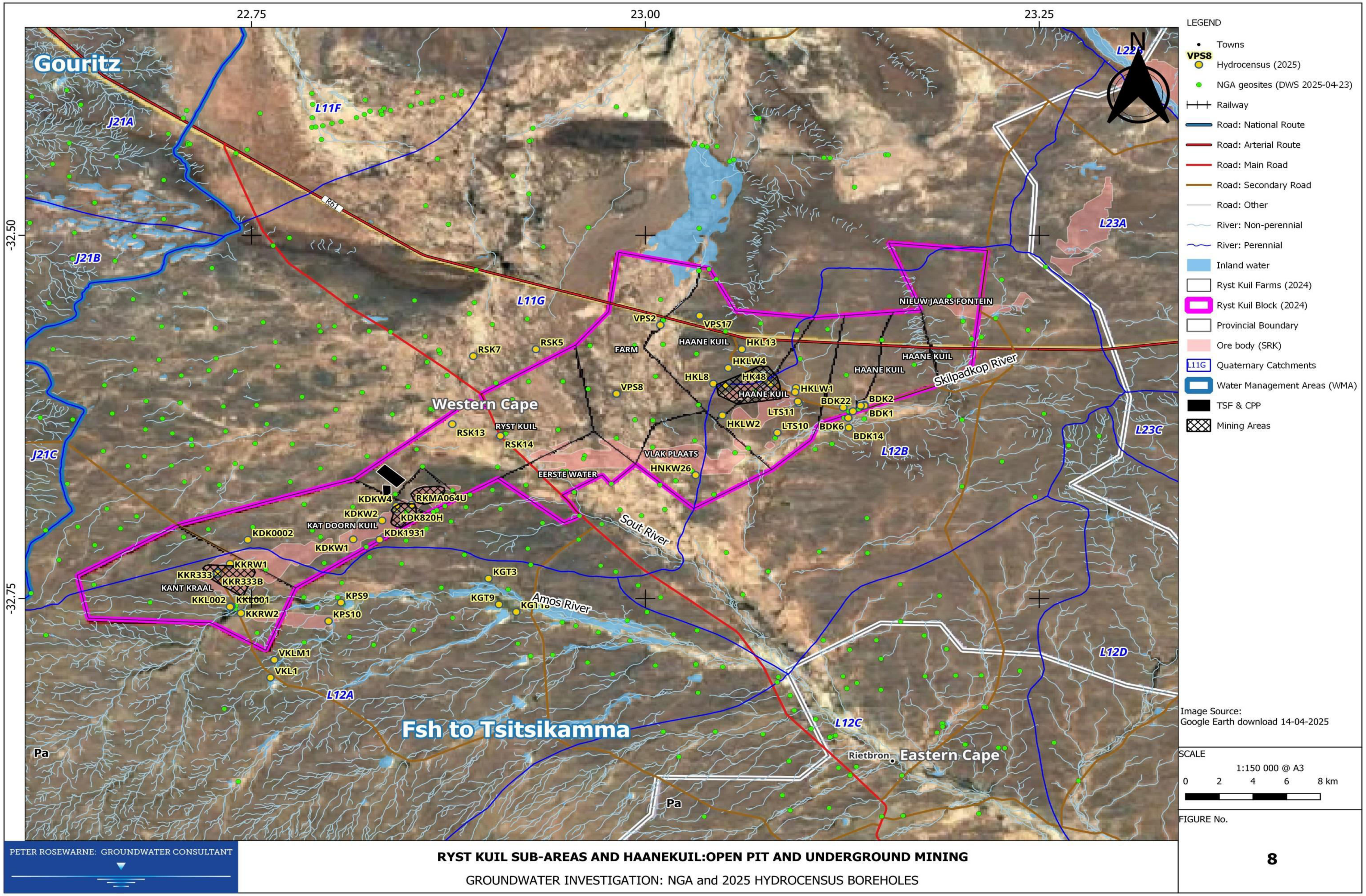


Figure 8: NGA and 2025 Hydrocensus Boreholes

Table 9 shows a comparison of groundwater RWLs measured in the May 2007 hydrocensus with those measured in August/September 2016 (RKH sub-areas only) and April 2025. According to SRK, 2007, the main rainfall in the area occurs from January to March. The 2007 hydrocensus was carried out in May, i.e. soon after the main rains should have fallen. Although the 2016 hydrocensus was apparently carried out prior to the main rains, there had been extensive rainfall in the area prior to the survey, making some gravel roads temporarily impassable. This was also the case in 2025. Those water levels showing a >10% change are indicated in red (drop) and blue (rise) whilst those in black show minimal change.

Table 9: Comparison of Groundwater Levels, 2007, 2016 and 2025

Borehole Number	2007 RWL (mbgl)	2016 RWL (mbgl)	2025 RWL (mbgl)
VPS17	20.59	21.71	20.08
KKRW1	34.73	37.15	29.33
KKRW2	26.25	31.44	25.21
KKL011	41.14	41.35	-
KKR333	40.98	33.21	14.30*
ERW5	9.22	9.88	-
ERW9	25.86	23.64	-
ERW10	3.04	7.18	-

*KKR333 demolished; water level measured in borehole 150 m away

Water levels range from ‘near-surface’ (<10 mbgl) to ‘shallow’ (<30 mbgl) to ‘deep’ (>30 mbgl), with the two shallowest water levels showing the largest fluctuation (drop), as might be expected. From the somewhat sparse record above it would appear that groundwater levels have mostly stayed at similar levels or risen in the past 18 years.

Groundwater levels obtained from the NGA database were used to compile an illustrative groundwater elevation contour map, as shown in **Figure 9**. This map shows groundwater flows from the west, north and east, centred on the Sout River drainage. Wider spacing of the contour lines in the central area indicates either a thickening of the aquifer or an increase in K/T in this area.

Some comparisons of ECs with 2007, 2016 and 2025 measurements are available and are listed in **Table 10**. Noteworthy changes are indicated in blue (>20% decrease), although this is a small sample population.

Table 10: Comparison of 2007, 2016 and 2025 EC Readings

Borehole No.	2007 EC (mS/m)	2016 EC (mS/m)	2025 EC (mS/m)
HKL13	118	112	105
VKL01	134	88.3	66
KDK0002	162	99.5	-
KKL001	192	121	-

Most readings show a decrease in 2016 compared to 2007 but this could be influenced by most of the duplicate ECs being on the low side for the area. However, the 2025 EC readings almost all show a decrease over 2016, as indicated in **Table 10**. Groundwater quality as EC from the 2025 hydrocensus is shown on **Figure 10**.

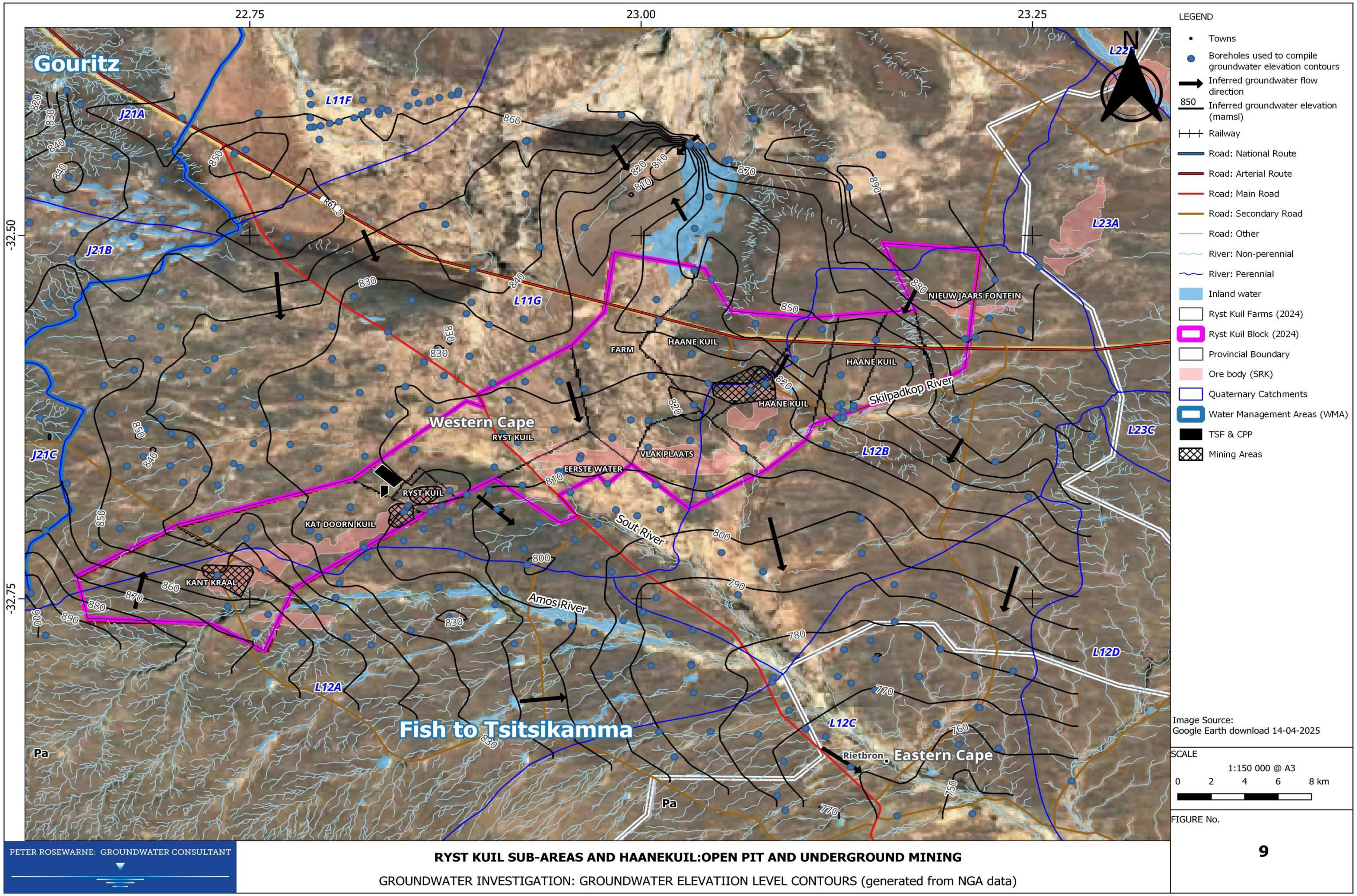


Figure 9: Groundwater Elevation Contours (mamsl) [generated from NGA borehole data]

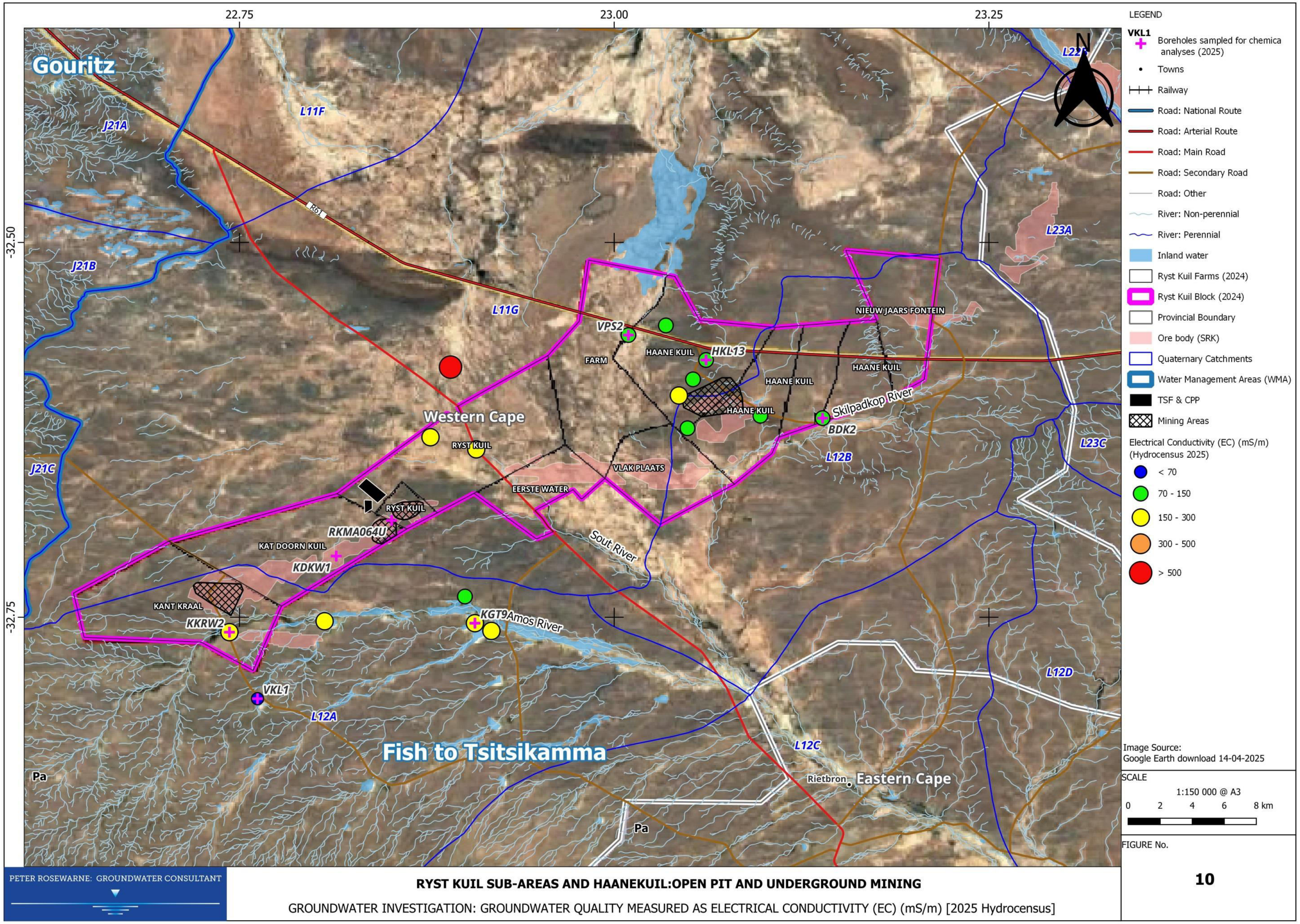


Figure 10: Groundwater Quality Measured as Electrical Conductivity (EC) (mS/m) [Hydrocensus 2025]

3.2 Groundwater Quality

The results of chemical analyses on water samples taken during the 2025 hydrocensus are shown in **Table 11**, with DWAF (1996) Target Limits for domestic water use indicated.

Table 11: Summary of Macro-Chemistry for 2025 Sampled Boreholes*

BH No.	pH 6-9#	EC (mS/m) 70	Total Alkalinity (as $CaCO_3$)	Na <100	K <50	Ca <32	Mg <30	Cl <100	SO_4 <200	NO_3 (as N) <6.0	F <1.0	As <0.1	Mo	U
Haanekuil														
VPS2	7.10	139	440	158	6.72	60.35	35.36	148	108	2.69	1.69	0.002	0.019	0.062
BDK2	7.21	169	337	171	7.31	59.22	37.40	215	183	10.2	1.71	0.002	0.019	0.053
HKL13	7.59	108	326	92.11	7.09	36.59	24.88	108	68.79	10.68	1.42	0.004	0.014	0.04
Ryst Kuil														
KDKW1	7.01	54.36	175	57.72	3.51	25.88	4.70	31.91	37.06	5.45	1.30	0.003	0.013	0.008
RKM064U	7.14	102	277	90.11	3.65	58.61	12.70	123	77.01	1.59	1.11	0.093	0.534	0.082
KKRW2	7.4	183	265	173	4.27	91.09	24.87	276	226	2.93	0.923	0.006	0.019	0.045
KGT9	7.41	265	356	335	16.71	97.92	55.36	398	379	13.86	1.61	0.005	0.024	0.060
VKL1	7.36	67.75	208	59.13	2.97	47.39	12.25	34.44	92.77	4.77	1.44	0.009	0.029	0.013

*values are reproduced from the original laboratory certificate of analysis, all in mg/L unless otherwise stated. #DWAF Target limits for domestic water use.

Although most constituents exceed the DWS Target values, apart from in KDKW1 and VKL1, all others with the exception of KGT9, are of potable standard, especially for residents used to this quality of water. The waters are hard to very hard. Borehole KGT9 is of poor quality with very high sodium, chloride, sulfate and nitrate. It is located close to the Amos River and is thus probably subject to influence from evaporated salts. The generally high nitrate values are attributed to animal wastes. Uranium levels are low.

3.3 Groundwater Monitoring 2018-2025

In December 2022, the trial mine adit was sealed with concrete, the radioactive material left on site from the trial mining was placed at the bottom of the access road/decline and covered with material stockpiled on site (see **Figure 11**). This was all approved by the National Nuclear Regulator.

Figure 11: Rehabilitated Decline Area (image Atox)

Of interest to the study is the backfilling of a trial open pit at the Rietkuil U prospect in 2022. Groundwater quality was monitored by Atox as part of the process to obtain a closure certificate from the Department of Mineral Resources and Energy. Groundwater samples from borehole RTKHuis (location shown on **Figure 1**) were taken in 2018, 2019, 2020, 2021 and 2022, on four occasions in 2023, and twice in 2024 and analysed for cations, anions, metals scans and the radiological indicators, gross α and β emissions and U-234, -235 and -238. The results are shown in **Table 12**.

Table 12: Radioactivity Analysis Results for the RTKHuis Borehole

Determinand	Gross Alpha (Bq/L)	Gross Beta (Bq/L)	U-238 (mg/L)
DWS recommended limits	**<0.5 Bq/L**	**<1.38 Bq/L**	**<0.284 mg/L**
10/10/2018	0,502	0,326	0.159
04/03/2020	0,277	0,257	0.011
23/11/2021	0,594	0,033	-
12/12/2022	0.382	<0.260	0.199
12/04/2023	0.452	0.631	0.196
27/07/2023	0.335	0.613	0.162
17/10/2023	0.494	<0.250	0.224
14/11/2023	0.313	0.372	0.151
27/4/2024	0.685	<0.250	0.219
11/06/2024	0.888	1.010	0.267

All results are below the DWS recommended limits apart from Gross α for April and June 2024. These results were accepted by the DWS and a closure certificate issued by the Department of Minerals and Energy in 2024.

RWLs were measured in seven of the monitoring boreholes established in 2007 during the 2025 hydrocensus. Hydrographs are shown in **Figures 12** and **13**. Rainfall as recorded by the Department of Agriculture at BW was obtained for the past five years to assist in explaining the 2025 hydrocensus RWLs and ECs and is shown in **Table 13**.

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Table 13: Monthly Rainfall at Beaufort West 2019-2025 (mm)

Month	2019	2020	2021	2022	2023	2024	2025
January	0	50	35	28	26	7	15
February	17	46	9	59	16.5	4	14.5
March	16	61	21	42	78.5	15	72
April	19	12	5	17	1	51	32.5
May	21	0	6	52	50	0	
June	0	0	0	32	36	32	
July	4	3	8	8	6	15	
August	0	17	18	2	4	0	
September	11	7	0	18	32	4	
October	0	45	23	3	38	20	
November	0	11	32	37	0	5	
December	2	9	100	121	33	0	
TOTAL	**90**	**261**	**257**	**419**	**321**	**153**	**134**

The table shows how erratic rainfall is in the Karoo, with 2019 being a very dry year while 2022 and 2023 could be described as being “wet” years. There was high rainfall in March 2025 which could account for the generally raised RWLs measured during the late April hydrocensus.

Brief explanations for the hydrographs[2] in **Figure 12** (Ryst Kuil) and **Figure 13** (Haanekuil) are:

Ryst Kuil

- In all four boreholes, the April 2025 RWL is the highest recorded.
- The water level in borehole VKLM1 is affected by abstraction for irrigation from borehole VKL04 approximately 800 m to the south and recharge from an earth dam 500 m south of the borehole. The logger stopped working during 2011.
- There is no significant abstraction within 5 km from KDK820H. Relatively quick water level changes could be a result of rainwater runoff entering the nearby old mine decline.
- The nearest significant groundwater abstraction to KKR333 is from borehole KKL005, 2100 m to the southeast. Latest groundwater level measured was taken in an open borehole KKR333A, 150 m north of KKR333.
- Borehole KKRW2 has been equipped with a submersible pump by the owner and is used for domestic and small-scale irrigation. Pump yield is approximately 3 L/s.

Haanekuil

- The logger in HK48 was removed by unknown person(s) during 2011.

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[2] Note that it is a quirk of the *Aquimon* graphing programme that data points are joined up even when there is a large time gap between measurements

- HKLW1 water level is affected by a nearby earth dam (recharge) and abstraction for irrigation from borehole LTS3, 320 m to the south.
- Borehole HKLW2 has been equipped with a solar pump by the farmer. The latest water level is a pumping water level.

Overall, it can be summarised that groundwater RWLs and quality have been maintained or enhanced despite the periodic droughts that afflict the area and that the channel sandstone aquifer is resilient to stress.

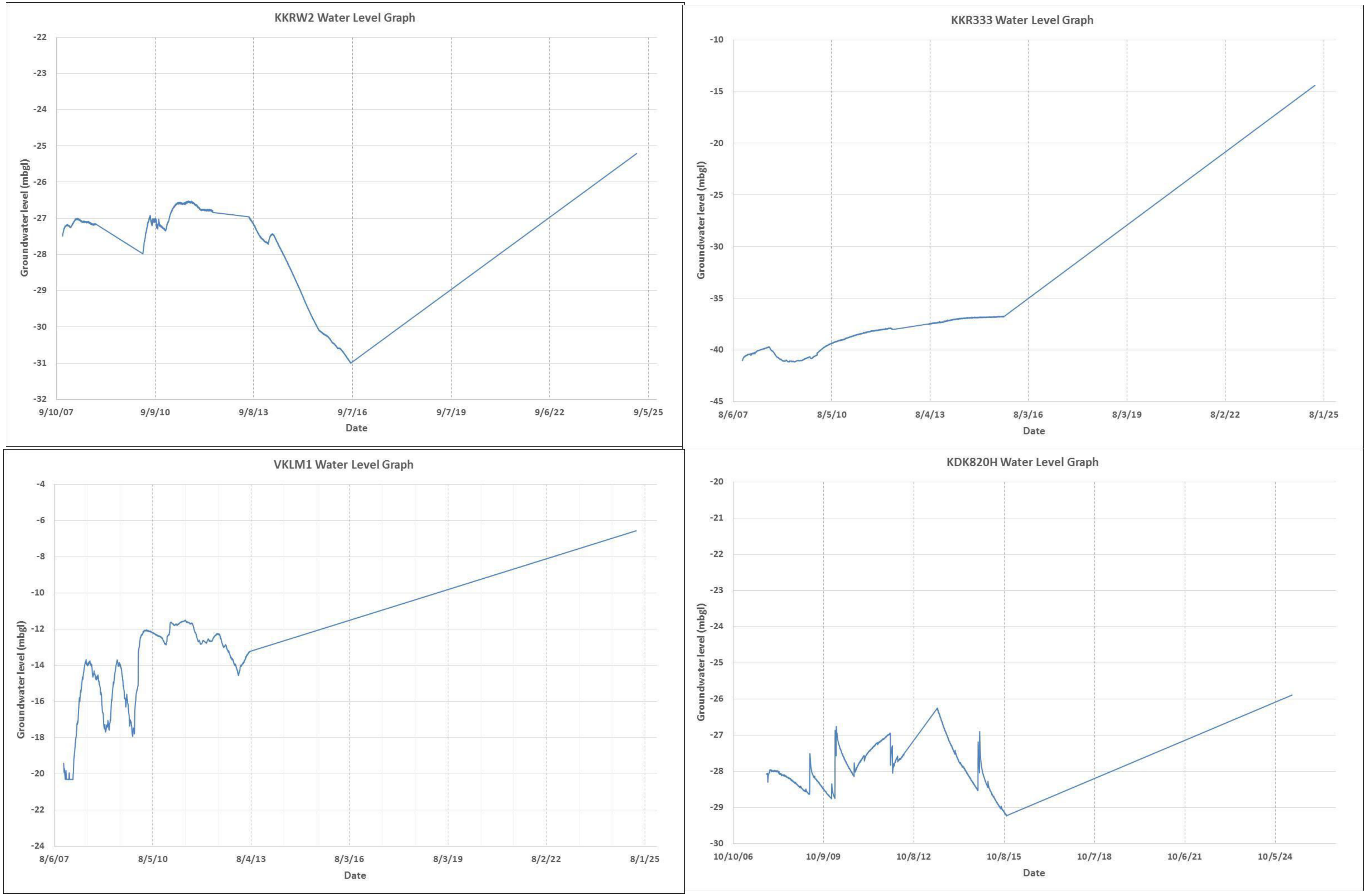


Figure 12: Hydrographs for the Ryst Kuil Sub-area

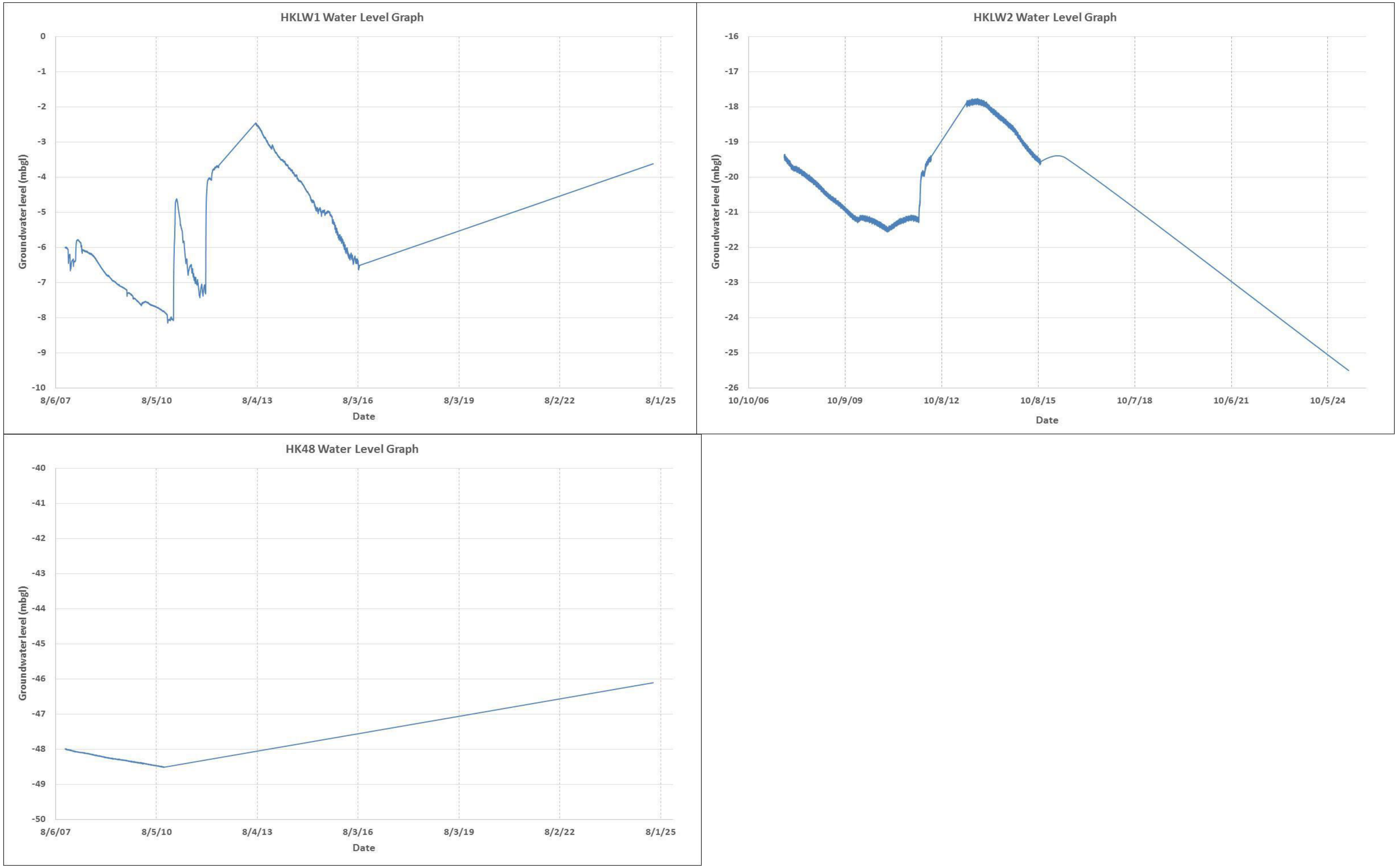


Figure 13: Hydrographs for the Haanekuil Sub-area

4 Numerical Flow 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), TSF (pers. comm. B. Engelsman, SRK, 2016) and geochemistry (pers. comm. R. O'Brien, SRK, 2016). The open pit and underground mine numbering system and schedule is as obtained from DRA and has been accepted as being an accurate reflection of the intended mining plans. Thirty-three open pits (OP) in five mining areas and seventeen underground sections (UG) in three mining areas are proposed to be established, at Haanekuil (OP1-7 and UG1&3), Ryst Kuil Abante (OP1-7), Ryst Kuil Main (OP1-3 and UG1&2) and Ryst Kuil Extension (OP1-12 and UG1-12). The simulated mining duration is 10 years, with 10 years of recovery.

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:

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

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:

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

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. *MODFLOW* (Harbaugh and McDonald, 1996a&b), a modular three-dimensional finite difference groundwater flow model, which was originally developed in the 1980s 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 area;
- The storage coefficient may be heterogeneous;
- Internationally, *MODFLOW* is currently the most used numerical model for groundwater flow problems;
- The software is regularly updated and is applicable to groundwater flow in most aquifer environments; 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, e.g. *FRACMAN* but were not deemed to be feasible for this study, mainly due to the lack of sufficient 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. Drilling, yield and packer testing support the hypothesis that the main sandstone aquifer is extensively fractured spatially and with depth rather than being dominated by single, discrete fractures, although these may be present.

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;
- Groundwater levels measured since 2017 do not show any anomalous trends and so it has not been considered necessary to update the 2017 numerical model;
- Long-term modelled abstraction rates from privately-owned boreholes have been estimated based on available information (such as size of irrigated area), as discussed in **Section 2**;
- 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 large areas, usually more than *c.*20 km distance from the mining site 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 following limitations of the model should be noted:

- The proposed mining operations comprise of a complex combination of 33 open pits and 17 underground sections;
- These are input into the model according to the schedule of mining provided by DRA but they ‘appear’ in the model instantaneously at an incremental depth calculated by dividing the total depth in the final mine plans by the number of model stress periods (of three months length) over which the pit/underground is active;
- 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. Further modelling may be carried out at individual mine area scale after additional information becomes available from purpose-drilled supply/dewatering boreholes and accompanying borehole siting techniques, such as remote sensing and surface geophysics; 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 and any new drilling information), is required in order to draw the most informative conclusions.

4.2 Model Domain and Grid

The RKH mining application area is located in the south-western section of the RKSA numerical groundwater model domain, within quaternary catchments L11G (Ryst Kuil) and L12B (Haanekuil), and falling within the Western Cape provincial boundary. The full Ryst Kuil model boundary follows the quaternary catchment boundaries of L22B, L11G, L12A and L12B. 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 **Subsection 2.1.4**).

The total area covered by the five layers of the finite difference grid is approximately 9 910 km^2 (comprising of 1 502 rows and 1 759 columns). The grid cell size is discretised to a minimum of 12.5 m x 12.5 m over the mining sites, and up to 100 m x 100 m at more distant locations within the model boundary. Within the grid and five layers, there are 7 833 182 active modelling cells, resulting in an active model area of approximately 4 439 km^2.

The coordinates for the modelled area are -46 172, -3 651 090 (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:

- Cross-model boundary flow through the south-eastern Sout River drainage area is simulated using **drains** (combination constant head boundary condition, where flux is only allowed out of the model domain and is controlled by a conductance value);
- 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;

- Model Layer 4 and 5, representing fresh rock, includes the use of a combination of **general heads** (constant head controlled by a conductance value) and **drains** on some boundaries, to allow for cross quaternary catchment flow at depth, where this flow fits with the conceptual model and monitoring results; and
- All other boundaries were set as **no flow** boundaries as they coincide with the boundary of the quaternary catchment.

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 and outflow to surface water.

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 RKSA is estimated at *c*.3.9 mm/a, which equates to an average recharge rate of *c*.1.6% of MAP (of *c*.245 mm/a). This is deemed to be an appropriate and conservative value. 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.

Evaporation is also applied to the top layer of the model, with potential evaporation of 2 100 mm/a (Phase 1 report, SRK 2007) and an extinction depth of 5 mbgl. The effect of evaporation is thus mainly applicable to alluvial areas and pans where there is a shallow groundwater table relative to the surface topography.

Abstraction rates from 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;
4. *c*.100 m thick fresh rock formations with good water strikes at fractures (divided into four sub-layers to improve representation of vertical conductivity and calculation of mine pit inflows); and
5. *c*.50 m thick competent 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 = Kd, where d 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 (S_y).

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 3**):

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 in **Table 14**.

The K values are within the range estimated in the conceptual model (**Section 3**). There are varying levels of uncertainty associated with model parameters and sensitivity analyses were used to evaluate the implications of these uncertainties.

Hydraulic property values allocated to the various lithologies are based on site-specific data such as test pumping, logs of deep core boreholes drilled by the Southern Oil Exploration Corporation (SOEKOR) in the 1960s and 1970s, literature and experience. Data sources include:

- Test pumping data analysis (SRK,2008);

- Woodford and Chevallier (2002), p40 – 45; and
- Prof. Steyl *et al* (2012).

Given the wide range in values, an ‘envelope’ approach was followed with upper and lower S_y values of 0.01 (1%) and 0.001 (0.1%), respectively.

Table 14: 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 10m thick)								
1	Shale / Mudstone	0.8	0.4	0.04	N/A	10	0.001	0.01
2	Dolerite	0.001	0.001	0.0001	N/A	10	0.001	0.01
3	Salt Pan Alluvial Aquifer (L1 only)	2	2	0.2	N/A	10	0.1	0.1
4	Stream Alluvium (L1 only)	4	4	0.4	N/A	10	0.1	0.1
5	Channel Sandstone (south-west)	8	4	0.4	N/A	10	0.001 - 0.01	0.01
6	Channel Sandstone (central)	4	2	0.2	N/A	10	0.001 - 0.01	0.01
7	Channel Sandstone (north-east)	2	1.0	0.10	N/A	10	0.001 - 0.01	0.01
8	Dolerite Dykes	0.001	0.001	0.0001	N/A	10	0.001	0.01
9	Faults / Lineaments	10	10	1	N/A	10	0.001	0.01
10	Anticlines in Shale	2	1	0.1	N/A	10	0.001	0.01
11	Synclines in Shale	4	2	0.2	N/A	10	0.001	0.01
12	Anticlines in Channel Sandstone	6	3	0.3	N/A	10	0.001 - 0.01	0.01
13	Synclines in Channel Sandstone	8	4	0.4	N/A	10	0.001 - 0.01	0.01
Model Layer 3: Fractured (*c.* 25m thick)								
14	Shale / Mudstone	0.1	0.04	0.004	N/A	10	0.00001	0.01
15	Dolerite	0.001	0.001	0.001	N/A	10	0.00001	0.01
16	Channel Sandstone (south-west)	1	0.4	0.04	N/A	100	0.001 - 0.01	0.01
17	Channel Sandstone (central)	0.4	0.2	0.02	N/A	100	0.001 - 0.01	0.01
18	Channel Sandstone (north-east)	0.2	0.1	0.01	N/A	100	0.001 - 0.01	0.01
19	Dolerite Dykes	0.001	0.001	0.0001	N/A	10	0.00001	0.01
20	Faults / Lineaments	0.1	0.1	0.01	N/A	10	0.00001	0.01
21	Anticlines in Shale	0.2	0.1	0.01	N/A	10	0.00001	0.01
22	Synclines in Shale	0.4	0.2	0.02	N/A	10	0.00001	0.01
23	Anticlines in Channel Sandstone	0.6	0.3	0.03	N/A	10	0.001 - 0.01	0.01
24	Synclines in Channel Sandstone	0.8	0.4	0.04	N/A	10	0.001 - 0.01	0.01
Model Layer 4 and 5: Lower Hydraulic Conductivity Zone (*c.* 150m thick)								

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 (-)
25	Shale / Mudstone	0.08	0.04	0.004	0.000001	150	0.00001	0.01
26	Dolerite	0.001	0.0001	0.0001	0.000001	150	0.00001	0.01
27	Dolerite Dykes	0.001	0.0001	0.0001	0.000001	150	0.00001	0.01
28	Faults / Lineaments	0.1	0.1	0.001	0.000001	150	0.00001	0.01
29	Anticlines	0.2	0.1	0.001	0.000001	150	0.00001	0.01
30	Synclines	0.4	0.2	0.002	0.000001	150	0.00001	0.01

4.7 Calibration Results

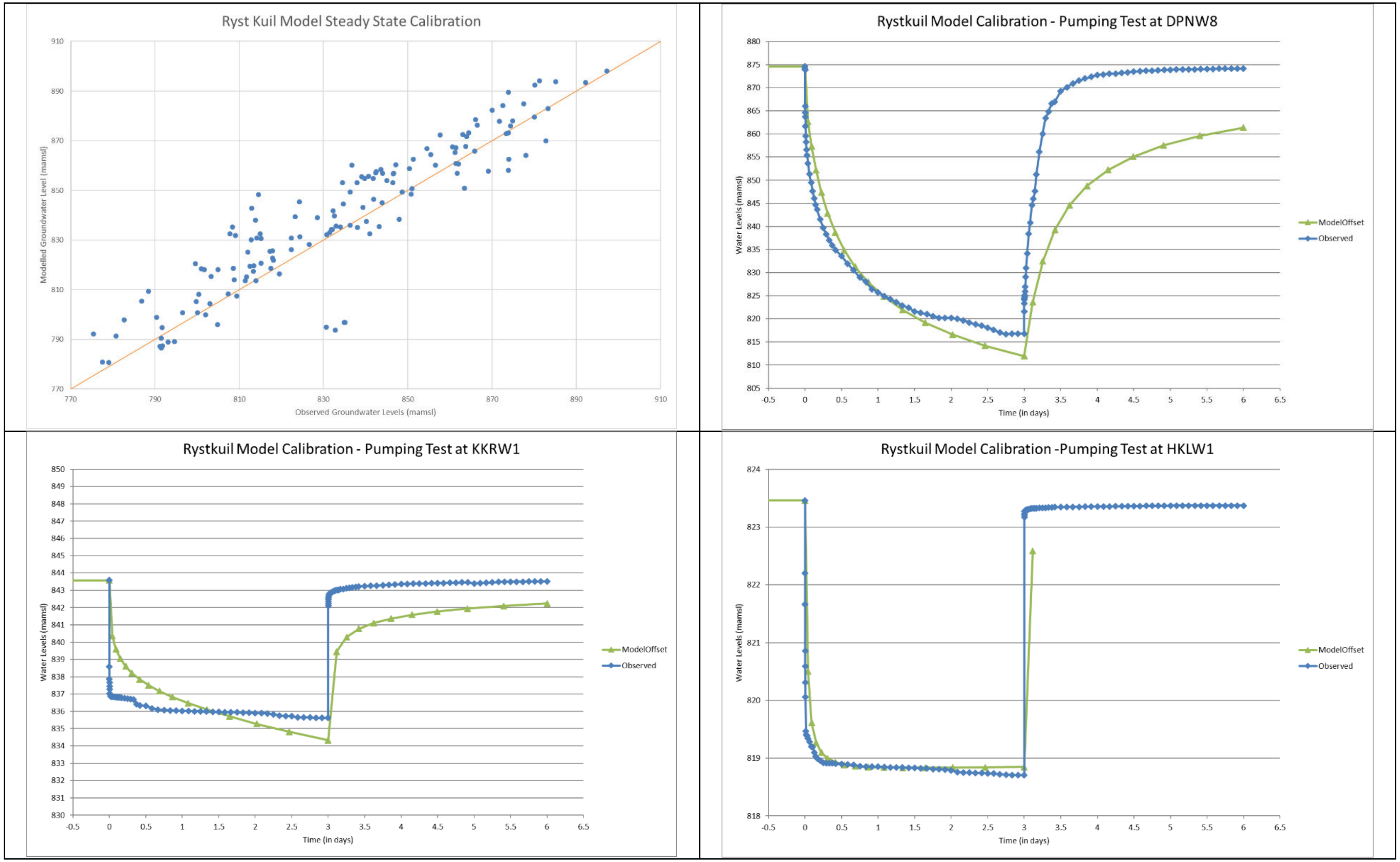
The steady state head distribution (average long-term water levels) is dependent on recharge, T, sources, sinks and boundary conditions specified. For a given recharge component and set of boundary conditions, the head distribution across the aquifer under steady state conditions can be obtained. The 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.

A combination of 2007 and 2016 hydrocensus and monitoring boreholes was 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 144**. The simulated water levels are mostly within 5 m of those measured 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 92%. 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 boreholes KKRW1, HKLW1, HKLW4, HKL04 and DPNW8 to cover the study area. The details of the pumping tests are discussed in the Ryst Kuil Phase 2 Report (SRK, 2008). 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 144**.

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.


Ryst Kuil Model Steady State Calibration

Rystkuil Model Calibration - Pumping Test at DPNW8

Rystkuil Model Calibration - Pumping Test at KKRW1

Rystkuil Model Calibration -Pumping Test at HKLW1

Figure 14: Model Long-Term Water Levels and Pumping Test Calibration Results (from SRK, 2017)

5 Modelling of Predictive Scenarios

5.1 Model Scenario Objectives

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

- To simulate groundwater abstraction from production boreholes to supply the CPP.
- To estimate open pit and underground mine passive inflow rates.
- To estimate the extent of the drawdown zone over time.
- To estimate the recovery of drawdown over time after cessation of mining, under Backfill and ‘No Backfill of One Pit Per Area‘ scenarios.
- To estimate the maximum potential contaminant plume footprint.

Note that due to the relatively short period of active mining, it has not been considered necessary to carry out long-term climate change predictions and incorporation of same into model scenarios.

5.2 Model Scenario Set-up

Scenarios undertaken included the following:

- Simulation of the 270 days pre-mining (includes CPP start-up), initial c.10-year mining and 10-year post-mine periods;
- Open pits and underground sections for the Ryst Kuil and Haanekuil areas simulated to elevations and schedule as provided by DRA (email, April 2017);
- Six predictive scenarios as follows:
    a. Groundwater flow scenarios 1 and 2 to represent the lower and upper envelopes of storativity values for the channel sandstone (0.001 and 0.01 for scenario 1 and 2, respectively).
    b. Contaminant transport scenarios 3 and 4, again differentiated by upper and lower envelopes of storativity values, with an increased number of vertical model layers (from 8 to 10) to simulate the tailings material and liner as individual layers acting as a retarded, but potential seepage source, above the current topography.
    c. Groundwater flow and transport scenarios 5 and 6, again differentiated by upper and lower envelopes of storativity values, with the assumption of ‘no backfill’ in one pit per area. These ‘no backfill’ pits were selected to be Ryst Kuil Main: OP3, Ryst Kuil Extension: OP6, Ryst Kuil Abante: OP7 and Haanekuil: OP3.In the ‘no backfill’ scenario, the elevation of the layers was altered over the pit areas and the ‘high-K lake method’ used to ensure that the effects of increased evaporation from a pit lake were effectively simulated;
- The pumping of production boreholes for groundwater supply was included in the model scenarios. Assumed pumping rates are as follows:
    - KDKW6 (near the trial mine) pumping at 17 L/s from 270 days prior to the commencement of mining / CPP commissioning, and continued throughout the initial 10 year mine period.

  - KDKW1 pumping at 7 L/s following plant commissioning for the first 3 months, following which pumping decreases to 5 L/s. This decrease after 3 months is associated with the timings for expected *c*.40% return of recycled water from the TSF.
  - KDKW7 pumping at 7 L/s following CPP commissioning for the first 3 months, following which pumping decreases to 5 L/s for the next 6 months and then no pumping thereafter (associated with the timings for expected maximum return from the TSF).
  - BH758 and BH725 each pumping at 6 L/s following plant commissioning for the first 3 months, following which pumping decreases to 3 L/s each for the next 6 months, with no pumping thereafter.
- An additional scenario 3 to model the potential groundwater impact footprint arising from leaching of backfill in the pits and through the lining of the TSF and the return water dam (RWD).

Contaminant transport assumptions and parameterisation are as follows:

- Potential Contamination Leaching from Backfill in Pits: Modelled as a specified high-contaminant recharge zone active in the period from planned pit backfill to 10 years post-mining.
- Potential Contamination Leaching through TSF (Phase 1 and Phase 2) and RWD: Modelled using two additional layers above the model and only active over the area of the TSF and RWD. Pressure head in TSF assumed to increase by *c*.5 m per year to a maximum head of *c*.25 m as per the TSF design criteria. Permeability of tailings material assumed to be 1 x 10^{-7} m/s and permeability of the double liner (high density polyethylene or HDPE) assumed to be 1 x 10^{-12} m/s, with a thickness of 3 mm per layer.
- Contaminant Plume Indicator Element: EC, as it is largely conservative and therefore represents the furthest reach of quality changes.
- 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).
- Diffusion Co-efficient: 10^{-9} m^2/s, an estimation from literature (Appelo & Postma, 2005).
- 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

5.3.1 Inflows

Table 15 and **Table 16** show the RKH mine schedule and the predicted inflow rates to the mining areas for the lower and upper envelope of storativity (and thus inflow rates), respectively. The first model stress period is 270 days in length during which the modelled production boreholes are active. Mining is assumed to commence in the second model stress period. The active mine periods are a ‘quarter of a year’ / ‘three months’ in length such that there are thirty-three model periods, covering c.10 years of initial mining. This is followed by four model stress periods representing the 10 years of recovery post-mining. The particular OP or UG in operation is highlighted in yellow and blue, respectively. 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’[3] 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 m^3/hr. The following key points are noted:

Upper Envelope (S of 0.01)

- An estimated cumulative inflow rate of >100 L/s occurs during Year(Y)4 Quarter(4) to Y8Q3 at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3, peaking at *c*.140 L/s during Y5Q2 and Q3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

Lower Envelope (S of 0.001)

- The highest estimated cumulative inflow rate of *c*.60 – 70 L/s occurs during Y6Q1 to Y8Q3, mainly at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

5.3.2 Drawdowns

Figure 15 through to Error! Reference source not found.**18** (as per SRK’s numerical modelling) show the modelled drawdown zones for periods of 1 year, 5 years, 10 years mining and 10 years post-mining for the upper and lower envelopes and zoomed in over the Ryst Kuil and Haanekuil areas, respectively. Drawdowns >5 m are conservatively considered to be potentially significant in terms of potential effect on local private groundwater users and thus the contours commence at -5 m and continue in 5 m intervals. The outlines of the mining areas are shown in colours and are labelled. The following key points are noted:

Upper Envelope (S of 0.01)

- The >5 m drawdown zone expands to a maximum of *c*.19 km (NE-SW) x *c*.6 km (NNW-SSE) in the Ryst Kuil sub-areas after c.10 years of mining, with a preferential expansion along the channel sandstone aquifer and mining areas. Approximately twenty currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.
- At Haanekuil the >5 m drawdown zone expands pseudo-radially to a radius of c.2 km after 9.25 years of mining. Three currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.

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[3] 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.

- Recovery of the drawdown zone in the Ryst Kuil sub-areas is significant in terms of depth and area (*c*.50%) 10 years after cessation of mining, with backfilling, and is complete at Haanekuil.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

Lower Envelope (S of 0.001)

- The >5 m drawdown zone expands to an essentially similar extent in the RKSA and Haanekuil, as drawdown is more strongly affected by changes in T rather than $S/S_{Y.}$
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.
- Recovery of the drawdown zone (>5 m) in the Ryst Kuil sub-areas and Haanekuil is essentially complete 10 years after cessation of mining, with backfilling.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

5.3.3 Groundwater Quality

Figure 19 and **Figure 20** show the potential groundwater quality impact area near Ryst Kuil, for the scenario of that which follows immediately after c.10 years of mining, and then a further 10 years of recovery post-mining for the scenarios of backfilling all pits versus allowing for pit lake formation in one defined pit per area, respectively. The yellow dashed contours indicate the maximum estimated extent of the affected area[4]. The following key points are noted:

- Potential contamination can arise from the open pits due to interaction of rainwater through waste rock, (increased exposed area for mineral dissolution), evaporation of inflow and surface runoff water concentrating salts and reaction with exposed areas of ore.
- At mining, there is a small potential impact area around Ryst Kuil Extension, Ryst Kuil Main and the TSF. Potential impacts from other areas are still being captured by the drawdown zone of the dewatered pits.
- Ten years post-mining, and with backfilling in all pits, the potential impact areas can be seen to contract slightly, with the potential to slightly change water quality at a maximum of four currently privately-owned boreholes.
- If a pit lake is allowed to form at one downgradient pit in all areas, then the modelling shows a slight decrease in impacted area linked to the pit lakes showing a continuous drawdown of *c*.5 m below natural groundwater levels / recovery levels 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 ‘sink’ and pits would never ‘overtop’.
- Upper and lower envelopes of storativity result in very similar groundwater impact areas, thus showing a relatively low sensitivity of the contaminant transport model to storativity assigned to the channel sandstone.

Water quality monitoring in and around the trial mine shows no indication of residual acid rock drainage or a contamination plume. Similarly, the open pit area at Rietkuil was backfilled in 2022 and

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[4] taken as the 155 mS/m model concentration contour

groundwater quality monitoring in an adjacent borehole and dam showed no change in water chemistry or radiological indicators.

Figure 21 shows the potential groundwater quality impact area near Haanekuil, for the scenario of that which follows immediately after c.10 years of mining, and then a further 5 years and 10 years of recovery post-mining for the worst-case quality scenario of backfilling all pits. The yellow dashed contours indicate the maximum estimated extent of the affected area[5]. The following key points are noted:

- During mining there is no modelled contamination plume near Haanekuil. This is due to Haanekuil having the only underground workings still in operation in the last quarter of mining, hence the active draining of the underground workings (and associated drawdown zone) is capturing any potential plume contaminants.
- By five years post-mining, the modelled contamination around Haanekuil is shown at both a 155 mS/m model concentration contour (quadrant 2) and a lower detection of 151 mS/m (quadrant 3). Potential contaminant plumes migrate southwards from the Haanekuil pits in an ellipsoid shape to a maximum distance of *c.*500 m.
- By ten years post-mining, the modelled contamination around Haanekuil shows contaminant dilution to background levels due to natural recharge and groundwater throughflow in the area.

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[5] taken as the 155 mS/m model concentration contour except for quadrant 3, as specified in the title

Table 15: Ryst Kuil Sub-Areas Mine Schedule with Predicted Inflow Rates in L/s (Lower Envelope)

Model Sc1	Reach:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	Total
Days	Mining Period	Ext_OP1	Ext_OP2	Ext_OP3	Ext_OP4	Ext_OP5	Ext_OP6	Ext_OP7	Ext_OP8	Ext_OP9	Ext_OP10	Ext_OP11	Ext_OP12	Ext_UG1	Ext_UG3	Ext_UG5	Ext_UG6	Ext_UG7	Ext_UG8	Ext_UG10	Ext_UG11	Ext_UG12	Aba_OP1	Aba_OP2	Aba_OP3	Aba_OP4	Aba_OP5	Aba_OP6	Aba_OP7	Sth_OP1	Sth_OP2	Sth_OP3	Sth_OP4	Main_OP1	Main_OP2	Main_OP3	Main_UG1	Main_UG2	Main_UG3	Han_OP1	Han_OP2	Han_OP3	Han_OP4	Han_OP5	Han_OP6	Han_OP7	Han_UG1	Han_UG3	
74																																																	0
163																																																	0
270																																																	0
361	Y1Q1	0		0		0	0	0	0		0	0	0																					7	0	0													7
453	Y1Q2	1		4		5	0	0	0		1	0	2	0	0	0			0															22	0	0													34
544	Y1Q3	0		3		3	0	0	0	0	6	0	9	0	0	0			0															15	6	0	0	0											41
635	Y1Q4	0	0	2		2	0	0	3	0	4	0	7	0	0	0			0	0		0												14	5	2	0	0											39
727	Y2Q1	0	0	1	0	1	0	1	3	0	4	0	6	0	0	0	0	0	0	0	0	0												13	3	5	0	0											37
818	Y2Q2	0	0	1	0	1	0	1	2	0	3	0	5	0	0	0	0	0	0	0	0	0												11	1	9	0	0											35
909	Y2Q3	0	0	1	0	1	0	1	2	0	3	0	5	0	0	0	0	0	0	0	0	0												10	0	10	0	0											32
1001	Y2Q4	0	0	1	0	1	0	0	2	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					8	0	11	0	0											31
1092	Y3Q1	0	0	1	0	1	0	0	2	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					6	0	14	0	0											31
1183	Y3Q2	0	1	0	0	0	0	0	2		3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					5	0	13	0	0											29
1274	Y3Q3	0		1		1	0	0	2		3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	3	0	13	0	0											28
1366	Y3Q4	0		1		1	0	0	2		3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	2	0	0	0	3	0	10	0	0	0										29
1457	Y4Q1	0		1		1	0	0	2		2	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	7	0	0		1	0	2	2	0	9	0	0	0										31
1548	Y4Q2	0	0	1		1	0	0	1		2	0	3	0	0	2	0	0	0	0	0	0	0	2	0	0		4	0		2	0	3	2	0	8	0	0	0										32
1640	Y4Q3	0		1		1	0	0	1		2	0	3	0	0	3	0	0	0	0	0	0			0	4			0			2	3	2	0	8	0	0	0										29
1731	Y4Q4	0		1		0	0	0	1		2	0	2	0	0	4	0	0	0	0	0	0				2			3			7		2	0	8	0	0	0		4	10		5					51
1822	Y5Q1	0		1		0	0	0	1		2	0	2	0	0	5	0	0	0	0	0	0							5					1	0	7	0	0	0		5	12		7	2				52
1914	Y5Q2	0		1		0	0	0	1		2	0	2	0	0	6	1	0	0	0	0	0							6					1	0	7	0	0	0		5	12		9	6				59
2005	Y5Q3	0		0		0	0	0	1		1	0	1	1	1	7	2	0	0	0	0	0							6					1	0	6	0	0	0	2	6	15		9	7	0			65
2096	Y5Q4	0		0		0	0	0	1		1	0	0	1	1	7	3	0	0	0	0	1												1	0	6	0	1	0	6	9	14				0			52
2188	Y6Q1	0		0		0	0	0	0		1	0	0	2	1	8	4	0	0	0	0	1												1	0	5	2	1	0	6	9	13				0			55
2279	Y6Q2	0		0		0	0	0	0		0	0	0	2	1	8	5	0	0	0	0	1												1	0	5	2	1	0	10	9	11				0			57
2370	Y6Q3	0		0		0	0	0	0		0	0	0	2	2	8	5	1	0	1	0	1												1	0	4	4	1	0	8	9	13				0			59
2462	Y6Q4	0		0		0	0	0	0			0		2	2	8	6	1	0		0													1	0	3	3	2	1	7		16				0			51
2553	Y7Q1	0				0	0	0	0			0		3		9	6	2	0		0													0	0	3	2	2	2	6		20	0			0			54
2644	Y7Q2	0				0	0							3		9	6																	0	0	2	3	2	2	5		21	0			0			55
2735	Y7Q3	0				0	0							3		10	6																	0	0	2	3	2	4	5		22	0				0	0	56
2827	Y7Q4	0				0	0							3		10	7																	0	0	1	2	2	5	4		20					0	2	57
2918	Y8Q1	0				0	0							3		10	8																	1		1	2		5	4		19					0	5	57
3009	Y8Q2	0				0	0							3		10	8																	1		1	2		5	4		17					0	9	59
3101	Y8Q3	0				0	0							4		9	8																	1		1	3		5	3		15					0	13	61
3192	Y8Q4																																	1			3			3		12					1	15	34
3283	Y9Q1																																							1		7					2	22	32
3384	Post: 0.27 yrs																																																0
3504	Post: 0.6 yrs																																																0
3649	Post: 1 yrs																																																0
3749	Post: 1.27 yrs																																																0
3869	Post: 1.6 yrs																																																0
4014	Post: 2 yrs																																																0
4315	Post: 2.82 yrs																																																0
4676	Post: 3.81 yrs																																																0
5110	Post: 5 yrs																																																0
5611	Post: 6.37 yrs																																																0
6213	Post: 8.02 yrs																																																0
6936	Post: 10 yrs																																																0
Total		**1**	**1**	**21**	**0**	**17**	**1**	**4**	**29**	**0**	**52**	**0**	**69**	**33**	**7**	**133**	**75**	**4**	**0**	**1**	**0**	**5**	**0**	**2**	**0**	**5**	**13**	**4**	**20**	**2**	**4**	**9**	**8**	**135**	**16**	**175**	**32**	**12**	**30**	**74**	**55**	**267**	**0**	**30**	**15**	**0**	**3**	**65**	**1431**

Table 16: Ryst Kuil Sub-Areas Mine Schedule with Predicted Inflow Rates in L/s (Upper Envelope)

Model Sc2	Reach:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	Total
Days	Mining Period	Ext_OP1	Ext_OP2	Ext_OP3	Ext_OP4	Ext_OP5	Ext_OP6	Ext_OP7	Ext_OP8	Ext_OP9	Ext_OP10	Ext_OP11	Ext_OP12	Ext_UG1	Ext_UG3	Ext_UG5	Ext_UG6	Ext_UG7	Ext_UG8	Ext_UG10	Ext_UG11	Ext_UG12	Aba_OP1	Aba_OP2	Aba_OP3	Aba_OP4	Aba_OP5	Aba_OP6	Aba_OP7	Sth_OP1	Sth_OP2	Sth_OP3	Sth_OP4	Main_OP1	Main_OP2	Main_OP3	Main_UG1	Main_UG2	Main_UG3	Han_OP1	Han_OP2	Han_OP3	Han_OP4	Han_OP5	Han_OP6	Han_OP7	Han_UG1	Han_UG3	
74																																																	0
163																																																	0
270																																																	0
361	Y1Q1	0		0		0	0	0	0		0	0	0																					14	0	0													14
453	Y1Q2	2		6		7	0	0	0		1	0	3	0	0	0			0															37	10	0													66
544	Y1Q3	1		4		5	0	0	2	0	8	0	13	0	0	0			0															24	20	6	0	0											82
635	Y1Q4	0	0	4		4	0	0	6	0	7	2	11	0	0	0			0	0		0												21	16	13	0	0											84
727	Y2Q1	0	0	3	0	2	5	3	4	0	6	1	9	0	0	0	0	0	0	0	0	0												19	13	18	0	0											85
818	Y2Q2	0	0	2	0	2	3	2	4	0	6	0	9	0	0	0	0	0	0	0	0	0												17	11	22	0	0											79
909	Y2Q3	0	0	2	0	2	3	2	4	0	6	0	8	0	0	0	0	0	0	0	0	0												16	9	24	0	0											74
1001	Y2Q4	0	0	2	0	1	2	2	3	0	5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					14	7	27	0	0											72
1092	Y3Q1	0	0	2	0	1	2	1	3	1	5	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					13	6	29	0	0											71
1183	Y3Q2	0	2	1	1	1	1	1	3		5	0	7	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0					12	4	30	0	0											71
1274	Y3Q3	0		1		1	1	1	3		5	0	7	0	0	2	0	0	0	0	0	0	0	3	0	3	0	3	0	0	0	0	0	11	3	26	0	0											69
1366	Y3Q4	0		1		1	1	1	3		5	0	7	0	0	4	0	0	0	0	0	0	2	4	0	4	1	3	0	4	0	0	0	10	1	23	0	0	0										76
1457	Y4Q1	0		1		1	1	1	3		4	0	6	0	0	6	0	0	0	0	0	0	4	4	0	4	1	4	1		3	0	3	9	0	22	0	0	0										78
1548	Y4Q2	0	0	1		1	1	1	3		4	0	6	0	0	8	0	0	0	0	0	0	6	7	0	7		11	2		4	2	5	8	0	21	0	0	0										98
1640	Y4Q3	0		1		1	1	1	3		4	0	5	0	0	10	0	0	0	0	0	0			0	0			5			4	5	7	0	20	0	0	0										67
1731	Y4Q4	0		1		1	1	1	3		4	0	5	0	0	12	1	0	0	0	0	0				0			10			8		6	0	19	1	1	0		8	14		7					102
1822	Y5Q1	0		1		1	0	1	3		4	0	5	1	0	14	3	0	0	0	0	0							14					4	0	17	2	2	0		11	19		11	7				119
1914	Y5Q2	0		1		1	0	0	2		3	0	4	3	1	15	5	1	0	0	0	0							18					3	0	16	3	3	0		12	19		14	13				138
2005	Y5Q3	0		1		1	0	0	2		3	0	3	3	1	15	6	1	0	0	0	1							17					2	0	15	4	4	2	3	11	21		13	11	0			144
2096	Y5Q4	0		0		0	0	0	2		3	0	2	4	2	16	8	2	0	1	0	2												2	0	13	5	5	3	9	15	22				0			118
2188	Y6Q1	0		0		0	0	0	2		2	0	1	5	3	18	8	2	0	2	0	3												2	0	12	7	4	7	8	14	20				0			119
2279	Y6Q2	0		0		0	0	0	1		2	0	0	6	3	19	10	3	0	3	0	3												1	0	10	7	4	9	12	13	18				0			126
2370	Y6Q3	0		0		0	0	0	1		1	0	0	6	4	19	10	4	0	4	0	4												1	0	8	7	5	12	10	13	20				0			130
2462	Y6Q4	0		0		0	0	0	1			0		6	4	18	10	5	0		0													1	0	6	6	6	17	9		22				0			112
2553	Y7Q1	0				0	0	0	0			0		5		18	10	7	0		0													1	0	5	5	7	19	8		26	0			0			111
2644	Y7Q2	0				0	0							5		19	10																	0	0	4	6	6	22	7		27	0			1			106
2735	Y7Q3	0				0	0							6		19	11																	0	0	3	5	4	24	6		27	0				0	0	105
2827	Y7Q4	0				0	0							6		19	11																	0	0	2	3	5	24	6		25					0	5	107
2918	Y8Q1	0				0	0							6		17	12																	1		2	3		26	5		23					0	10	105
3009	Y8Q2	0				0	0							6		16	13																	1		1	3		26	5		20					0	14	106
3101	Y8Q3	0				0	0							7		14	13																	1		1	3		26	5		19					0	18	106
3192	Y8Q4																																	1			9			4		14					1	21	49
3283	Y9Q1																																							2		10					3	30	45
3384	Post: 0.27 yrs																																																0
3504	Post: 0.6 yrs																																																0
3649	Post: 1 yrs																																																0
3749	Post: 1.27 yrs																																																0
3869	Post: 1.6 yrs																																																0
4014	Post: 2 yrs																																																0
4315	Post: 2.82 yrs																																																0
4676	Post: 3.81 yrs																																																0
5110	Post: 5 yrs																																																0
5611	Post: 6.37 yrs																																																0
6213	Post: 8.02 yrs																																																0
6936	Post: 10 yrs																																																0
Total		**3**	**2**	**38**	**1**	**33**	**22**	**19**	**60**	**1**	**92**	**5**	**128**	**75**	**19**	**298**	**142**	**25**	**0**	**10**	**0**	**14**	**12**	**19**	**0**	**19**	**2**	**23**	**67**	**4**	**7**	**15**	**13**	**259**	**100**	**414**	**80**	**57**	**217**	**101**	**97**	**366**	**0**	**45**	**31**	**1**	**4**	**97**	**3035**

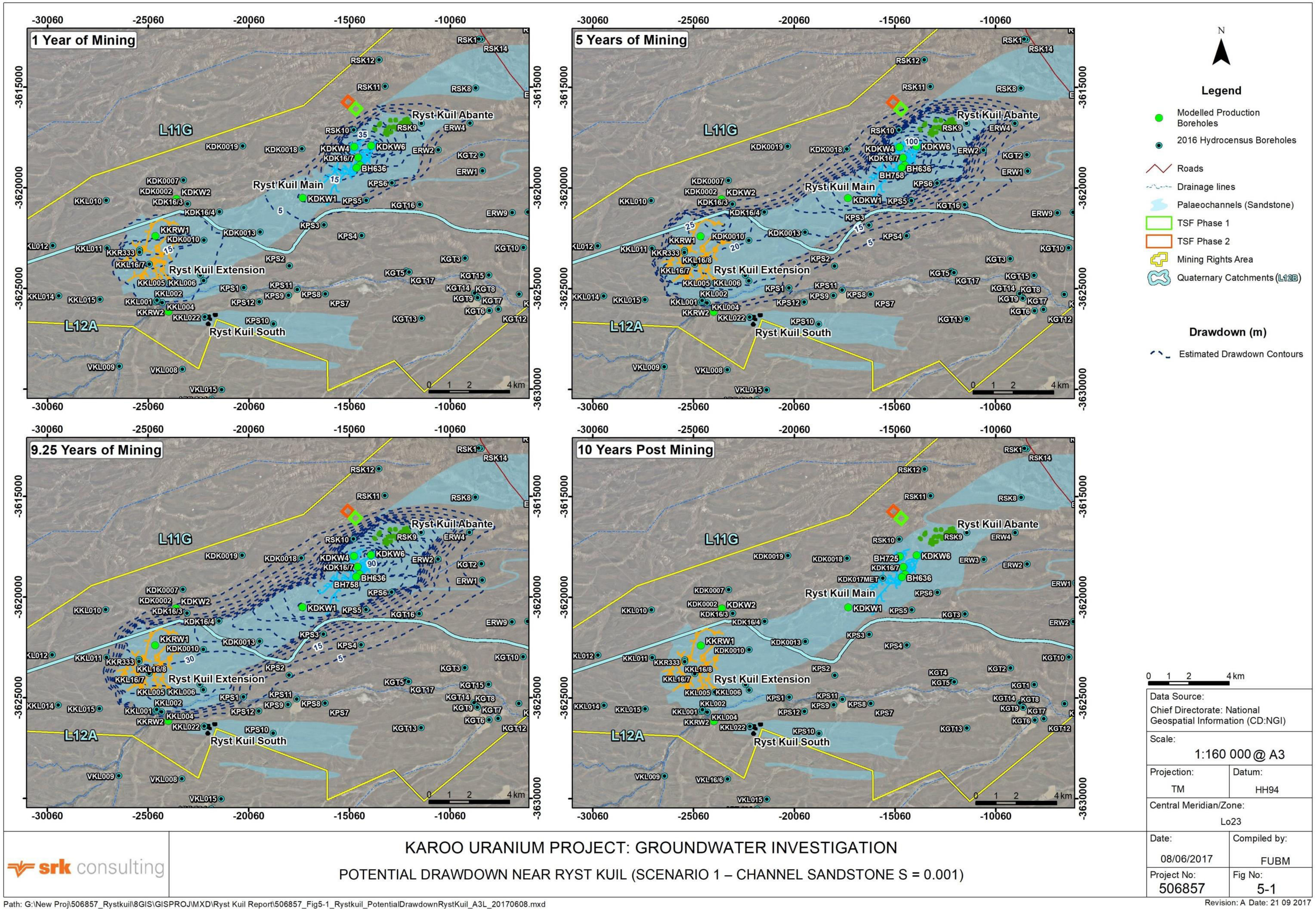
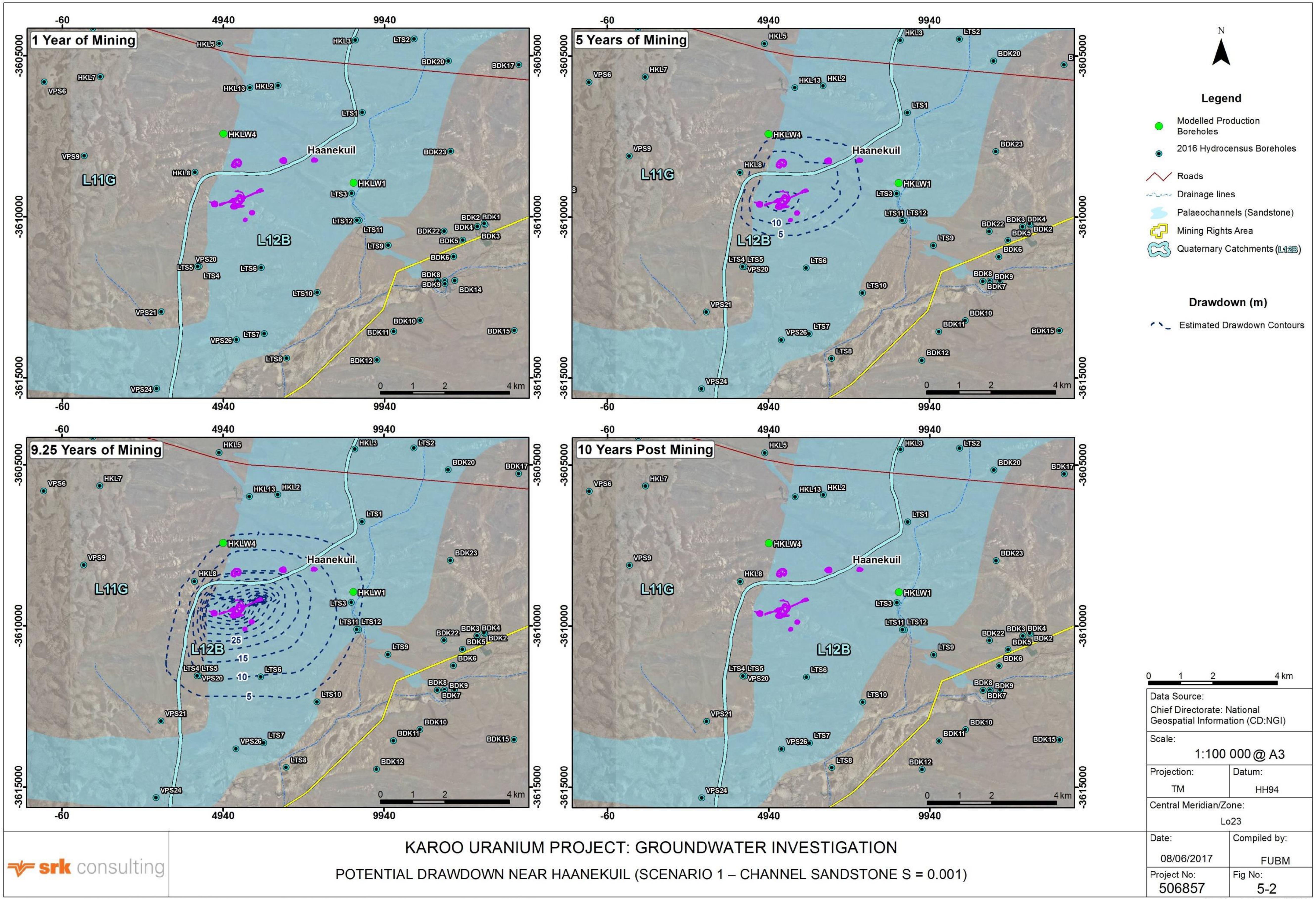


Figure 15: Potential Drawdown near Ryst Kuil (Scenario 1 – Channel Sandstone S = 0.001)



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Revision: A Date: 08 06 2017

Figure 16: Potential Drawdown near Haanekuil (Scenario 1 – Channel Sandstone S = 0.001)

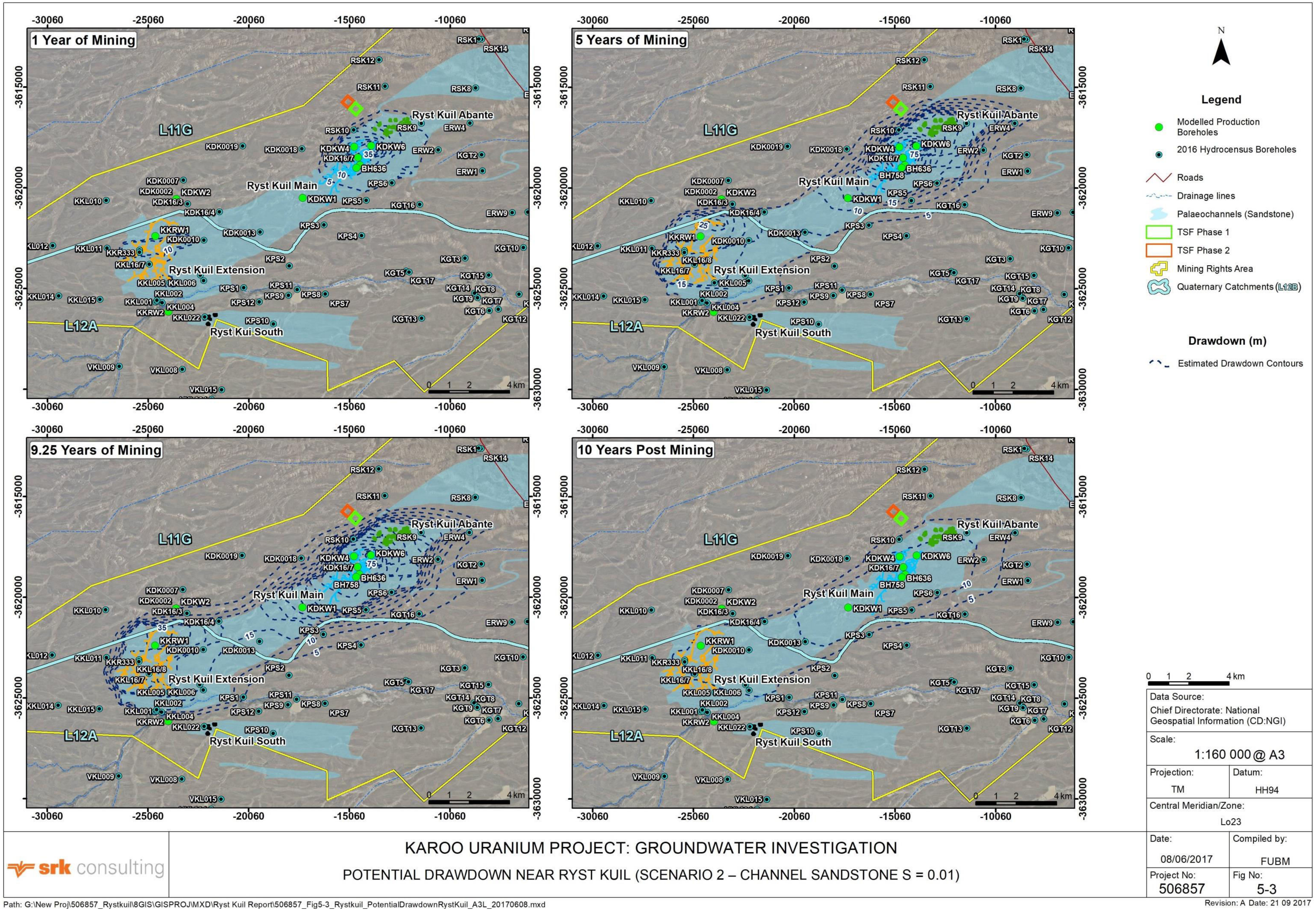
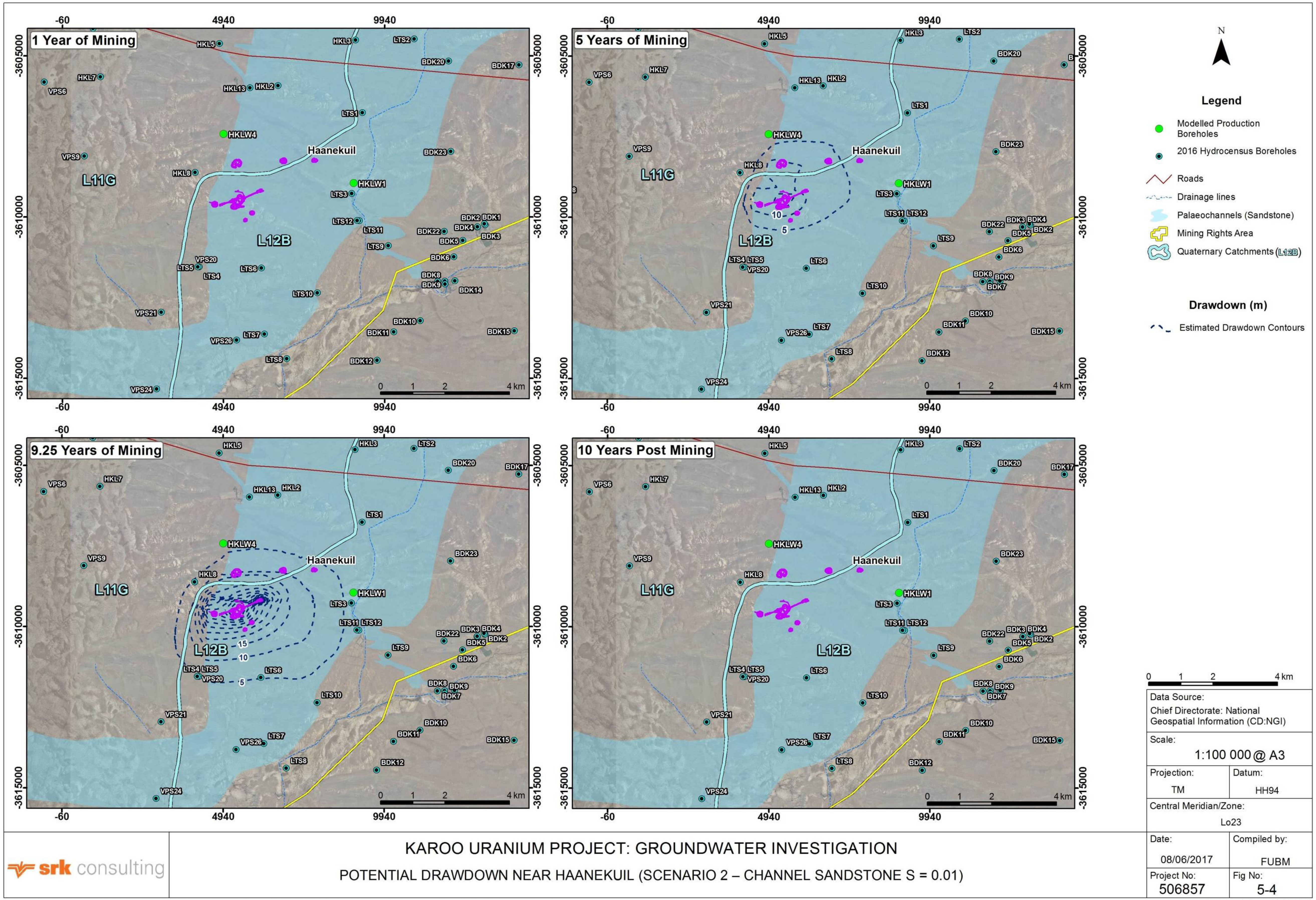


Figure 17: Potential Drawdown near Ryst Kuil (Scenario 2 – Channel Sandstone S = 0.01)



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Revision: A Date: 08 06 2017

Figure 18: Potential Drawdown near Haanekuil (Scenario 2 – Channel Sandstone S = 0.01)

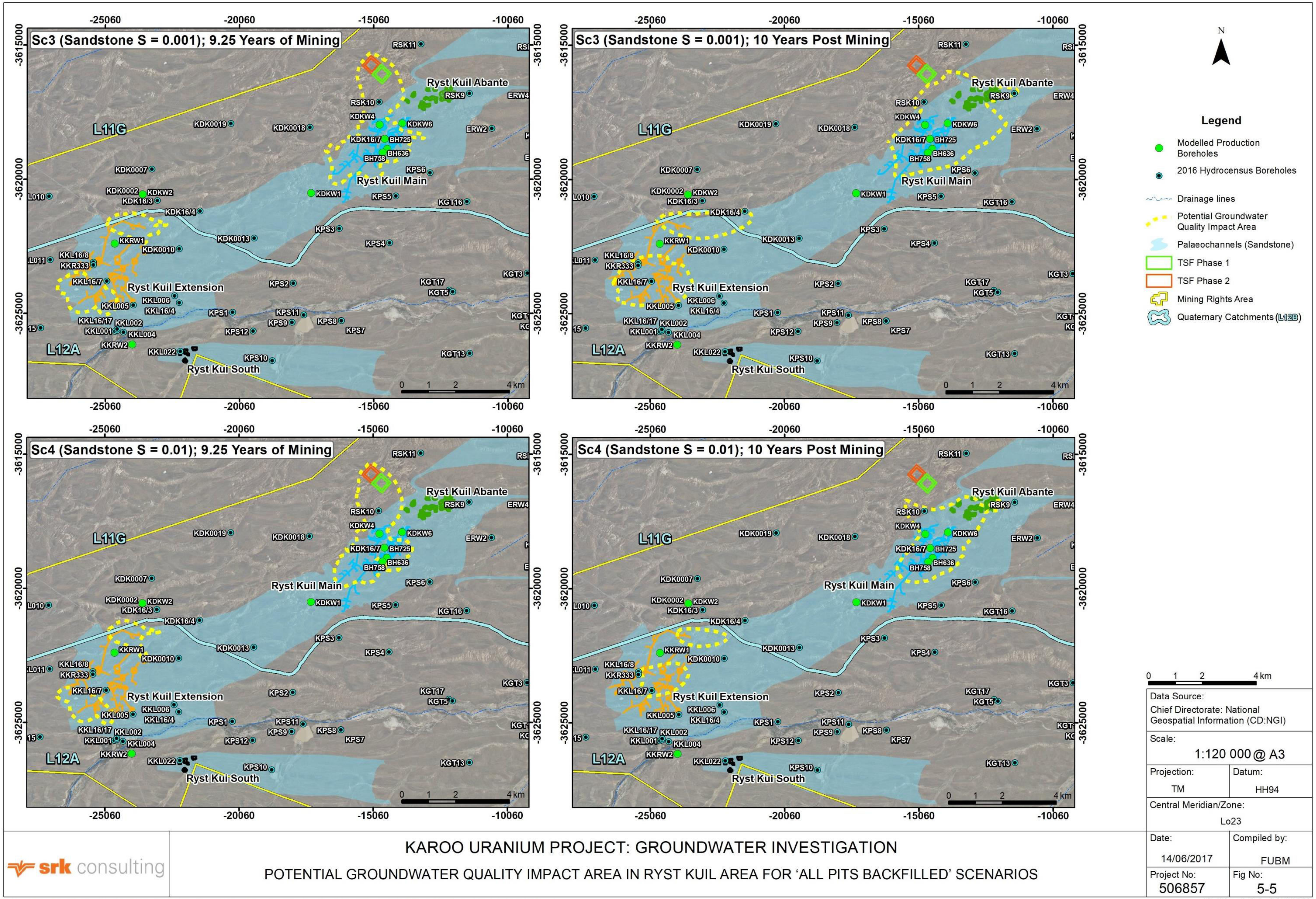

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Figure 19: Potential Groundwater Quality Impact Area in Ryst Kuil for 'All Pits Backfilled' Scenarios

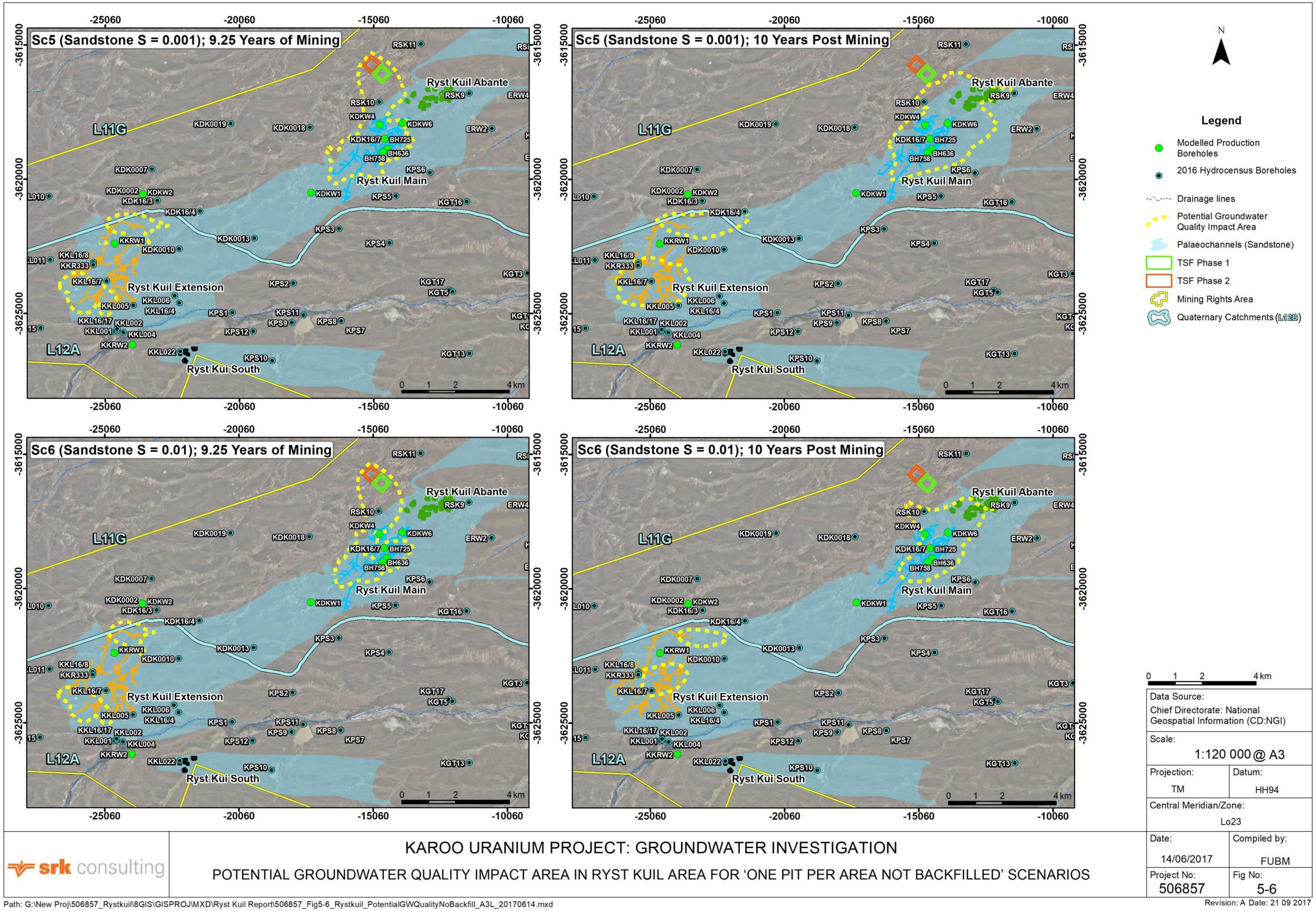
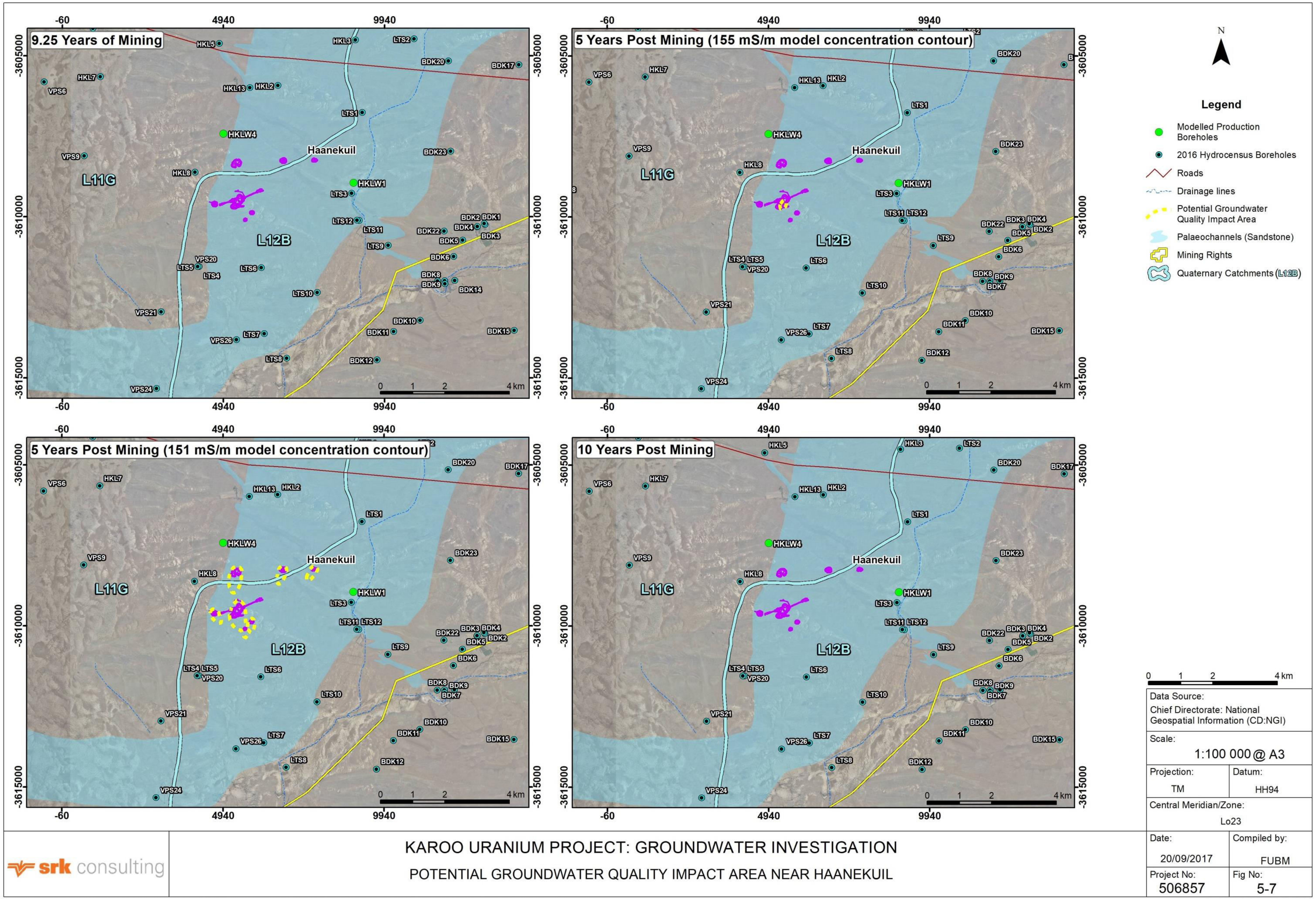


Figure 20: Potential Groundwater Quality Impact Area in Ryst Kuil for 'One Pit not Backfilled'Scenarios



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Revision: A Date: 20 09 2017

Figure 21: Potential Groundwater Quality Impact Area near Haanekuil

5.4 Groundwater Control and Re-Use

Groundwater Control

In the light of the significant inflows predicted for mines in the RKSA, some possible groundwater control measures and re-use options are discussed below.

- **Grouting of Fractures**

  This technique is widely used in the mining and construction industries where large inflows of groundwater are expected/encountered when excavating ground for civil engineering structures and mines. It involves the pumping of a suitable chemical slurry into e.g. fractures, under pressure which seals-off the local flow once it has set. It was used in the trial mining area to reduce some high fracture inflows of up to 75 L/s so that the decline and workings could be successfully dewatered. The requirements in the RKSA will be similar but on a larger scale and will require further feasibility studies to assess effectiveness and cost.

- **Dewatering**

  The inflow predictions indicate that passive dewatering methods such as sumps will not be sufficient in many cases to depressurise open pit faces and maintain sufficiently dry underground workings. Purpose-drilled dewatering boreholes will almost certainly be required, strategically sited both outside and possibly within the mines. These will be supplemented by sumps and sub-horizontal drain holes.

Groundwater Re-Use

There may be an excess of groundwater available after use during mining operations, supply to the CPP and recycling from the TSF. Some possible re-use options include:

- **Artificial Recharge**

  This is the introduction of water (often treated effluent but could be any suitable, quality-wise, excess groundwater or surface water) into an aquifer from surface, usually by means of recharge ponds or boreholes. It is being successfully applied to replenish the fractured rock aquifer supplying the city of Windhoek in Namibia. Here, *c*.8 Mm^3/a (254 L/s) of treated excess water is injected into the aquifer via boreholes (Murray, 2011). In South Africa it has been successfully carried out at Atlantis north of Cape Town for decades (treated effluent and stormwater runoff) via infiltration ponds into an unconfined sand aquifer. The feasibility of any such undertaking at Ryst Kuil will require investigation, testing, implementation, monitoring and management, with liaison and authorisation from the DWS.

- **Supply of Excess Water to Local Landowners**

  Excess water could be made available to landowners whose boreholes are adversely affected by dewatering drawdown or who can use such excess water, albeit on a potentially short-term basis. Groundwater quality from dewatering boreholes should be comparable to natural background.

6 Impact Assessment

The assessment of impacts was based on the specialists' expertise, professional judgement, field observations and desk-top analysis. The significance of potential impacts that may result from the proposed project was then determined. The **significance** of an impact is defined as a combination of the **consequence** of the impact occurring, including possible irreversibility of impacts and/or loss of irreplaceable resources, and the **probability** that the impact will occur. The criteria used to determine impact consequence are presented in **Table 17**, with the yellow-shaded scores/options indicating the site-specific impacts assessed for the groundwater investigation.

Table 17: Criteria Used to Determine the Consequence of the Impact

Rating	Definition of Rating	Score
A. *Extent* *– the area over which the impact will be experienced*		
Local	Confined to project or study area or part thereof (e.g. site)	1
Regional	The region, which may be defined in various ways, e.g. cadastral, catchment, topographic	2
(Inter) national	Nationally or beyond	3
B. ***Intensity*** *– the magnitude of the impact in relation to the sensitivity of the receiving environment, taking into account the degree to which the impact may cause irreplaceable loss of resources*		
Low	Site-specific and wider natural and/or social functions and processes are negligibly altered	1
Medium	Site-specific and wider natural and/or social functions and processes continue albeit in a modified way	2
High	Site-specific and wider natural and/or social functions or processes are severely altered and/or irreplaceable resources[6] are lost	3
C. ***Duration*** *– the timeframe over which the impact will be reversed*		
Short-term	Up to 2 years	1
Medium-term	2 to 15 years	2
Long-term	More than 15 years or irreversible	3

The combined score of these three criteria corresponds to a **Consequence Rating**, as shown in **Table 18**.

Table 18: Method used to determine the Consequence Score

***Combined Score* (A+B+C)**	3 – 4	5	6	7	8 – 9
Consequence Rating	Very low	Low	Medium	High	Very high

Once the consequence was derived, the probability of the impact occurring was considered, using the probability classifications presented in **Figure 19.**

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[6] Defined as important cultural or biological resource which occur nowhere else, and for which there are no substitutes.

Table 19: Probability Classification

***Probability**– the likelihood of the impact occurring*	
Improbable	< 40% chance of occurring
Possible	40% - 70% chance of occurring
Probable	> 70% - 90% chance of occurring
Definite	> 90% chance of occurring

The overall **significance** of impacts was determined by considering consequence and probability using the rating system prescribed in **Table 20**.

Table 20: Impact significance ratings

		Probability			
		Improbable	Possible	Probable	Definite
Consequence	Very Low	**INSIGNIFICANT**	**INSIGNIFICANT**	**VERY LOW**	**VERY LOW**
	Low	**VERY LOW**	**VERY LOW**	**LOW**	**LOW**
	Medium	**LOW**	**LOW**	**MEDIUM**	**MEDIUM**
	High	**MEDIUM**	**MEDIUM**	**HIGH**	**HIGH**
	Very High	**HIGH**	**HIGH**	**VERY HIGH**	**VERY HIGH**

Finally the impacts were also considered in terms of their status (positive or negative impact) and the confidence in the ascribed impact significance rating. The prescribed system for considering impacts status and confidence (in assessment) is laid out in **Table 21**.

Table 21: Impact status and confidence classification

Status of impact	
Indication whether the impact is adverse (negative) or beneficial (positive).	+ ve (positive – a 'benefit')
	– ve (negative – a 'cost')
Confidence of assessment	
The degree of confidence in predictions based on available information, SRK's judgment and/or specialist knowledge.	Low
	Medium
	High

The impact significance rating should be considered by authorities in their decision-making process based on the implications of ratings ascribed below:

- **INSIGNIFICANT**: the potential impact is negligible and **will not** have an influence on the decision regarding the proposed activity/development.
- **VERY LOW**: the potential impact is very small and **should not** have any meaningful influence on the decision regarding the proposed activity/development.
- **LOW**: the potential impact **may not** have any meaningful influence on the decision regarding the proposed activity/development.
- **MEDIUM**: the potential impact **should** influence the decision regarding the proposed activity/development.
- **HIGH**: the potential impact **will** affect the decision regarding the proposed activity/development.
- **VERY HIGH**: The proposed activity should only be approved under special circumstances.

Practicable mitigation and optimisation measures are recommended in **Section 8**.

7 Conclusions

Background

- The main regional aquifer is a palaeochannel sandstone, a fractured rock aquifer, which extends in a northeast-southwest direction across the whole RKSA and has a width of c. 2.5 km, widening to the north-east and south-west. It has a variable thickness of 20 – 40 m to depths of *c*.100 m below surface but up to *c*.140 m in places. The U deposits are hosted within this sandstone, which is frequently interbedded with mudstones.
- Aquifer transmissivity (*c*.12 – *c*.380 m^2/day) and borehole yields (*c*.5 – *c*.25 L/s), according to test results from purpose-drilled groundwater exploration boreholes, are highest in the south-west and decrease to the north-east. This is a function of sandstone lithology, thickness and structure. There is also a fairly strong east-west anisotropy with respect to T and K, which is caused by folding and fracturing related to the CFB to the south.
- Based on the above information, this sandstone is an important aquifer.
- Generally, the shallower groundwater levels (<30 mbgl) respond fairly quickly to good local rainfall events, whilst boreholes with deeper (≥40 mbgl) groundwater levels appear to indicate a time lag of approximately three years between good rainfall events and rising groundwater levels. This is possibly due to a component of deep throughflow and/or possibly a delay in release of groundwater from interbedded mudstones.
- Farms were visited in August & September 2016 and positions of 248 boreholes recorded, and information on depth, yield and use obtained from the owners where possible, and water samples taken for chemical and radiological analysis. Findings include:
    - Groundwater is mostly used for stock watering, domestic supply and irrigation;
    - Water levels range from near-surface (<10 mbgl) to shallow (<30 mbgl) to deep (>30 mbgl);
    - Groundwater quality is very variable, with electrical conductivity mostly ranging from c.90 – 300 mS/m but up to 516 mS/m in places. The water is hard to very hard and of a mixed calcium/magnesium/sodium-bicarbonate/chloride/sulfate type, with often high fluoride and nitrate content; and
    - Most groundwater samples are below the DWS guideline level of 0.03 mg/L for uranium.
- In the 2025 hydrocensus update, 47 boreholes were revisited. Groundwater levels were mostly 2 – 5 m higher than in 2016 and ECs were mostly lower.
- The 2016 acid-base accounting results show that the waste rock is classified as non-acid generating, i.e. acid rock drainage is unlikely.

Trial Mine Area

The RKSA is probably unique in terms of a proposed mining area in that a trial underground mining area was developed in 1978/1979 and the workings allowed to flood after temporary dewatering had allowed the taking of representative formation/ore samples. This trial mining and accompanying groundwater monitoring (2007 to present) has allowed some important general inferences to be drawn on the likely impacts of mining on groundwater and *vice versa*, viz:

- The trial mine was developed in one of the most transmissive parts of the channel sandstone aquifer but underground workings were able to be kept ‘dry’ by a combination of pumping from boreholes and a sump, initially at 32 L/s, reducing to 16 L/s long-term, and local grouting of some major water-bearing fractures.
- The drawdown from this dewatering was quite extensively propagated but was of relatively small magnitude, *c*.2 m; such a drawdown is unlikely to have deleterious effect on the performance of existing production boreholes. and
- The quality of the water in these flooded workings meets drinking water standards for macro-chemistry, apart from fluoride (common issue in the Karoo area) after c.38 years, with no indication of acid mine drainage.

The decline was rehabilitated in 2020 by backfilling, as approved by the National Nuclear Regulator and an open pit at Rietkuil was backfilled and groundwater monitoring carried out to obtain closure from the Department of Minerals and Energy in 2024.

Groundwater Supply

It was estimated that recharge for the RKSA is *c*.64 Mm^3/a (2.4% of MAP). However, the volume of groundwater that may be practically/sustainably abstracted from the aquifers in the study area is limited by, *inter alia*, transmissivity and connectivity over the respective sub-catchments. Based on this consideration, the Utilisable Groundwater Resource Potential (UGRP) was determined. When considering the sub-catchments containing the mine application areas, i.e. L11G, L11A and L11B, the UGRP under ‘dry’ conditions is *c*.7 Mm^3/a or *c*.220 L/s.

The CPP requires *c*.43 L/s at full operating capacity, with the groundwater quality meeting requirements for this purpose. The CPP will have three water storage dams, two of 2 000 m^3 capacity and one of 1 900 m^3 (excludes provision for stormwater control). These will require to be full six months prior to full plant commissioning to enable water and leak testing to be carried out. It is proposed to meet this requirement by pumping from the trial mine at 17 L/s for *c*.100 days. The balance of 26 L/s will be met from production boreholes, either those drilled in 2007/2008 or, if these are found to be unusable for any reason, then nearby replacement boreholes. These may have to be deepened as mining progresses and may also act as mine dewatering boreholes. A combination of 40% recycling of water from the TSF, dewatering/supply boreholes and pit inflows will sustain the CPP water requirements thereafter. This supply is considered to be sustainable based on historical pumping of the trial mine, test pumping of purpose-drilled groundwater exploration boreholes and numerical modelling.

Mining

Thirty-three open pits (OP) in five mining areas and seventeen underground sections (UG) in three mining areas are proposed to be established, at Haanekuil (OP1-7 and UG1&3), Ryst Kuil Abante (OP1-7), Ryst Kuil Main (OP1-3 and UG1&2) and Ryst Kuil Extension (OP1-12 and UG1-12). The initial mining simulation period is c.10 years. Due to the complexity of the planned mining operations and uncertainties in assigning hydraulic parameters to the various formations, an ‘envelope’ approach was adopted for the numerical modelling. Upper and lower envelope storativity of 0.01 and 0.001 was assigned. This gives likely upper and lower limits on predicted inflows, extent of drawdown and groundwater quality changes. The numerical modelling indicates the following:

Inflows

Upper Envelope (S of 0.01))

- An estimated cumulative inflow rate of >100 L/s occurs during Year(Y)4 Quarter(4) to Y8Q3 at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3, peaking at *c*.140 L/s during Y5Q2 and Q3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

Lower Envelope (S of 0.001)

- The highest estimated cumulative inflow rate of *c*.60 – 70 L/s occurs during Y6Q1 to Y8Q3, mainly at Ryst Kuil Main OP1, 2 and 3 and Haanekuil OP3 and UG3. This is mainly a result of the depth of mining, i.e. *c*.130 m below the natural groundwater level.

Drawdowns

Upper Envelope (S of 0.01)

- The >5 m drawdown zone coalesces to a maximum of *c*.19 km (NE-SW) x *c*.6 km (NNW-SSE) in the Ryst Kuil sub-areas after c.10 years of mining, largely confined to the palaeochannel sandstone/mining areas. Approximately twenty currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.
- At Haanekuil the >5 m drawdown zone expands pseudo-radially to a radius of c.2 km after c.10 years of mining. Three currently privately-owned boreholes could be temporarily affected by >5 m drawdowns, which might impact on yields and possibly water quality.
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.
- Recovery of the drawdown zone in the Ryst Kuil sub-areas is significant in terms of depth and area (*c*.50%) 10 years after cessation of mining, with backfilling, and is complete at Haanekuil.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

Lower Envelope (S of 0.001)

- The >5 m drawdown zone expands to an essentially similar extent in the RKSA, as drawdown is influenced more strongly by changes in T rather than S/S_{Y}.
- It is likely that the actual drawdown will not reach the extent shown, due to lack of interconnectivity between individual fractures.
- Recovery of the drawdown zone (>5 m) in the RKSA is essentially complete 10 years after cessation of mining, with backfilling.
- With no backfilling, the drawdowns will recover more slowly and to a lesser extent because of high evaporation from the exposed pit lakes, which is taken into account in the modelling.

Groundwater Quality

- Potential contamination can arise from the open pits due to interaction of rainwater with waste rock, (increased exposed area for mineral dissolution), evaporation of inflow and surface runoff water concentrating salts and reaction with exposed areas of ore.
- After c.10 years of mining, there is a small potential impact area around Ryst Kuil Extension, Ryst Kuil Main and the TSF. Other potential impact areas, including Haanekuil, are still being captured by the drawdown zone of the dewatered pits and underground sections.

- Ten years post-mining, and with backfilling in all pits, the potential impacted areas can be seen to contract slightly, with the potential to slightly change water quality at a maximum of four currently privately-owned boreholes.
- Five years post-mining, potential contaminant plumes near Haanekuil migrate southwards from the Haanekuil pits in an ellipsoid shape to a maximum distance of c.500 m. However, these plumes dilute to background levels by 10 years post-mining.
- If a pit lake is allowed to form at one down-gradient pit in all areas, then the modelling shows a slight decrease in impact area linked to the pit lakes showing a continuous drawdown of *c*.5 m below natural groundwater levels / recovery levels 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 ‘sink’ and pits would never ‘overtop’.
- Upper and lower envelopes of storativity result in very similar groundwater impact areas, thus showing a relatively low sensitivity of the contaminant transport model to storativity assigned to the channel sandstone.
- Water quality monitoring in and around the trial mine shows no indication of residual acid rock drainage or a contamination plume.

Impact

- The groundwater impact significance is rated as **Low** with a high degree of confidence in the predictions.

Overall, it can be summarised that groundwater RWLs and quality have been maintained or enhanced despite the periodic droughts that afflict the area and that the channel sandstone aquifer is resilient to stress.

8 Mitigation and Recommendations

The following mitigatory measures are proposed:

- Carry out further site-specific investigations before mining commences for pit/underground mine geological structures, groundwater monitoring and to establish a groundwater supply and determine specific mine groundwater management requirements, e.g. dewatering boreholes, sub-horizontal drain holes and sumps. A Water Use Licence Application will be required.
- Install ‘early warning’ boreholes so that any negative effects of mining can be identified before they cause interference with privately-owned boreholes.
- Do not backfill the “downstream” open pit in each mining area so that it acts as a “sink” to capture any contaminated groundwater.
- Prepare contingency plans to maintain current water supply (volumes) and quality to potentially adversely affected landowners.

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

- Investigate the practicality, effectiveness and cost of groundwater control measures such as grouting of fractures, dewatering boreholes, and re-use options such as artificial recharge using excess water made from mining and supply of excess water to affected and/or other existing/potential groundwater users.
- Update the numerical modelling (possibly using a fracture-flow modelling code) to refine scenario predictions if new data become available on mine plans, geological structures and from monitoring and to include the above groundwater control measures and extension of the mining duration.

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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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