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DOORNHOEK FLUORSPAR: HYDROGEOLOGICAL SPECIALIST INVESTIGATION

Groundwater Impact Assessment

Innovation in Sustainability

Technical Report: **ES16/068**

Prepared for: **Southern Palace (Pty) Ltd &SA Fluorite (Pty) Ltd**

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31 January 2017

Conducted for:
Southern Palace (Pty) Ltd &
SA Fluorite (Pty) Ltd

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List of Abbreviations

Avg	=	Average
BH	=	Borehole
DEM	=	Digital Elevation Model
DWS	=	Department of Water Affairs and Sanitation
DWAF	=	Former Department of Water Affairs and Forestry
EC	=	Electric Conductivity
E.N.	=	Electro Neutrality
HC	=	Hydrocensus
K	=	Hydraulic Conductivity (m/d)
L/s	=	Litres per second
mamsl	=	Metres Above Mean Sea Level
MAP	=	Mean Average Precipitation
MAE	=	Mean Average Evaporation
mbgl	=	Metres Below Ground Level
m3/d	=	Cubic meters per day
m3/a	=	Cubic meters per annum
PFS	=	Pre-feasibility Study
SoW	=	Scope of Work
T	=	Transmissivity (m^2/d)
TDS	=	Total Dissolved Solids
WL	=	Water Level
WGS	=	World Geodetic System
WMA	=	Water Management Area

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

Exigo Sustainability (Pty) Ltd (hereafter referred to as Exigo) was appointed by Southern Palace (Pty) Ltd and SA Fluorite (Pty) Ltd to conduct a hydrogeological specialist investigation for the proposed Doornhoek Fluorspar Project.

1.1 Project background

A hydrogeological baseline assessment, fatal flaw analysis and development of a monitoring network for baseline characteristics prior to mine initiation were conducted in 2013. This was followed by a pre-feasibility study (PFS) level assessment during 2015. Based on the outcomes of the baseline assessment as well as PFS study, an updated hydrogeological specialist investigation scope of work was formulated and carried out.

1.2 Objectives

The objectives of this study include:

1. Conduct a hydrogeological specialist investigation to update the site baseline conditions as well as evaluating potential environmental impacts associated with the new proposed mining activities and infrastructure as well as relevant mitigation measures.
2. Extend the hydrocensus to evaluate the groundwater regime regionally, with potential groundwater users as well as include the mining right areas.
3. Conduct aquifer testing to delineate contact weathered zones and evaluate structure behaviour for update of the numerical groundwater flow model.
4. Conduct an Environmental Impact Assessment.

1.3 Terms of reference

The terms of reference was undertaken in accordance with the proposal HG-P-15-174-V1 submitted in December 2015. The study comprises four phases and the scope of work (SoW) for each phase is detailed below:

1.3.1 Phase A: Hydrocensus survey update and hydrochemical evaluation

Phase A includes the following actions:

i. Hydrocensus survey update to evaluate the existing surface and groundwater users, community borehole locations and depths, regional water levels, abstraction volumes, local springs as well as environmental receptors in the vicinity of the new mining right areas and proposed operations.

ii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of ten (10) water samples to evaluate potential trends of the macro and micro chemistry composition (analyses at SANAS accredited laboratory).

iii. Data interpretation aiding in aquifer classification and vulnerability ratings. Development of a scientifically defendable hydrochemical baseline.

1.3.2 Phase B: Aquifer characterization – Aquifer testing

Phase B includes the following actions:

i. Aquifer testing on existing boreholes if the boreholes are accessible and approved by owners to be tested. Constant discharge tests should not be longer than 12 hours and observation borehole will be implemented for measurements to evaluate local aquifer behaviour aiding in structure characterisation.

ii. Data preparation and interpretation of drawdown curves.

1.3.3 Phase C: Numerical groundwater flow and mass transport model update

Phase C includes the following actions:

i. Update the existing conceptual hydrogeological model using interpreted geology data and historical site characterisation information as well as new updated ground water information as model input.

ii. Update of a regional three-dimensional numerical groundwater flow model by applying the Finite Element FLOW (FEFLOW) modelling software developed by WASY. Model domain to include new proposed infrastructure and layouts of existing/proposed infrastructure and mining footprint.

iii. Calibration of groundwater flow model using site specific updated groundwater levels and information.

iv. Development of a numerical mass transport model utilizing the calibrated groundwater flow model as basis.

v. The calibrated model will be used to simulate management scenario's as follows:

   a. Steady state groundwater flow directions, hydraulic gradient and flow velocities.

   b. Groundwater abstraction zone of influence and dewatering volumes.

   c. Interactions between surface water and groundwater.

   d. Seepage potential from product stockpiles and storage facilities.

   e. Mass transport plume migration with time.

   f. Management and mitigation measures.

1.3.4 Phase D: Hydrogeological impact assessment and reporting

Phase D includes the following actions:

i. Compilation of a detailed hydrogeological specialist report with conclusions and recommendations on the following aspects:

a. Fatal flaw and gap analyses.

b. Site baseline characterisation.

c. Aquifer characterisation and interpretation.

d. Field work summary and interpretation.

e. Numerical groundwater flow model.

f. Updated environmental impact assessment and risk matrix.

g. Mitigation and management measures.

h. Integrated surface water and groundwater management.

ii. Compilation of a water monitoring protocol.

1.4 Information sources

The following information sources were considered and evaluated as part of the desktop review of this investigation:

- Council of Geoscience, 1996. Geological map sheet (2524 Mafikeng; 2526 Rustenburg; 2624 Vryburg; 2626 Wes-Rand) 1:250 000.
- GIS shape files and spatial data (Datum: WGS_1984; Projection: Transverse Mercator, LO25, LO27).
- Google Earth, 2016. 6.0.12032 Beta.
- Hill, M and Vivier, JJP, 2015. Doornhoek Fluorspar Mine: Groundwater Baseline Report. G 14/143 15-07-15.

1.5 Declaration of independence

Exigo is an independent company and does not have any financial interest in the proposed project other than the remuneration for work performed in terms of this SoW.

2 SITE DESCRIPTION

2.1 Project area location

The project area and mining right is situated on farms Strydfontein 326, Witrand 325, Rhenosterfontein 304, Doornhoek 305, Kafferskraal 306, Knoflookfontein 310, Bronkhorstfontein 911, Paardeplaats 296, Saamgevoeg 320, and Kwaggafontein 297. Zeerust is the closest town situated some 18 km northwest of the study area. The site locality is depicted in Figure 2-1 with general site coordinates listed in Table 2-1.

Table 2-1 General site coordinates (Datum: D_WGS_1984)

Latitude	-25.75
Longitude	26.21

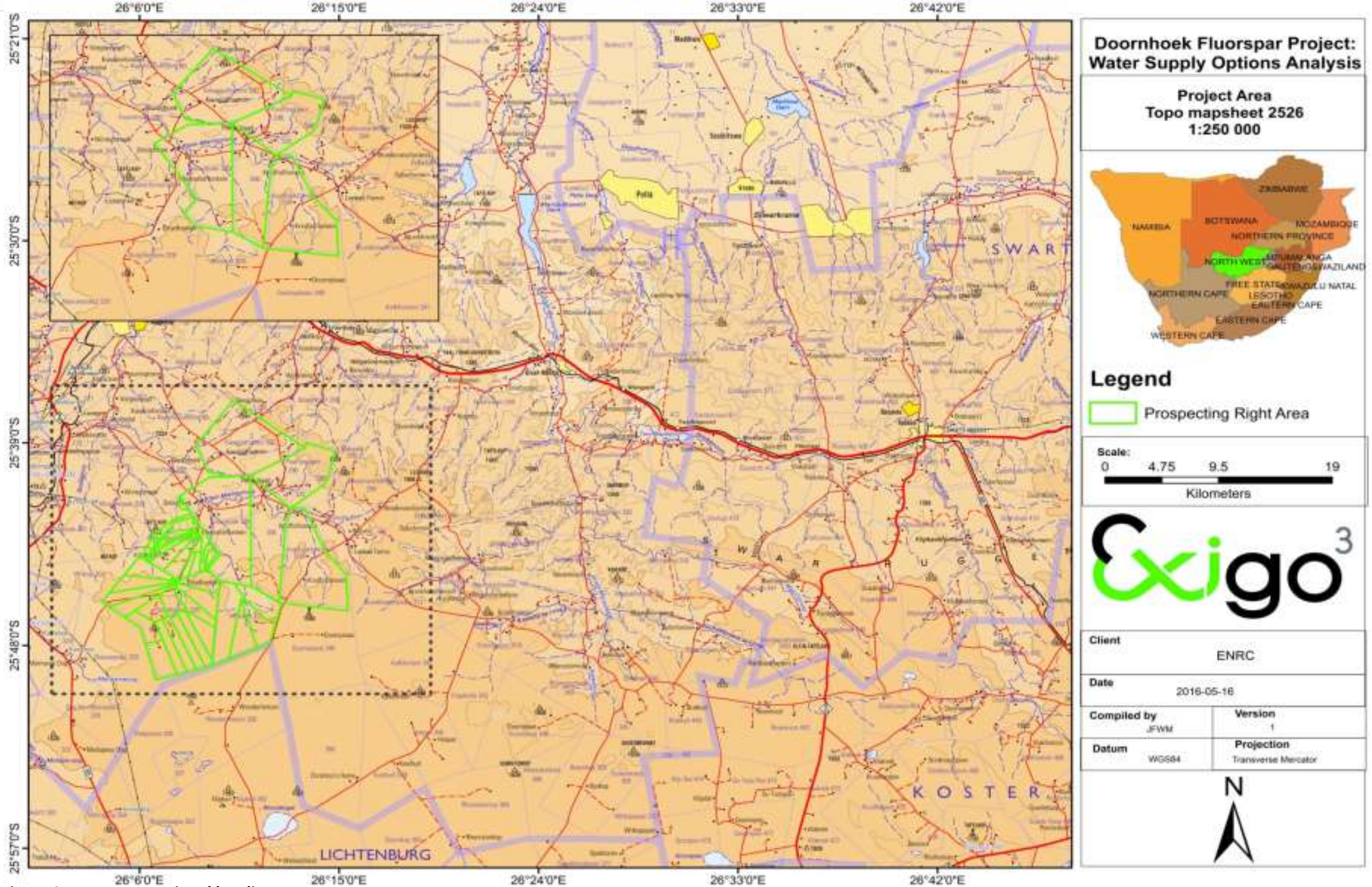

Figure 2-1 Regional locality map

2.2 Site layout

The site layout will consist of the following mining and associated infrastructure:

- Overburden and Topsoil stockpiles;
- Minerals processing plant and associated infrastructure;
- Tailings storage facility (TSF);
- Haul roads and access road;
- Mine offices;
- Water supply pipelines;
- Electrical reticulation and sub-stations; and
- Water Treatment Plant.

2.3 Surface water, topography and drainage

The study area is situated within quaternary catchment A31D which falls within the Crocodile (West) and Marico water management area. The quaternary catchment is drained by the perennial Klein Marico River, a tributary of the Groot Marico River, which in turn is a tributary of the Marico River which flows into the Limpopo River north of the project site. The Klein Marico River flows North-westerly along the boundary of the focus area before diverting in a northerly direction and again in an easterly direction to flow into the Klein Maricopoort dam east of the town of Zeerust. A smaller unnamed tributary of the Klein Marico River drains the western lobe of the focus area. The mean annual runoff (MAR) determined from quaternary catchment A31D is 9.04 Mm3/a (WR 2005) (Figure 2-3). A mine surface water balance was conducted with the delineated catchment indicated in Figure 2-4. The surface water catchment area was calculated at approximately 15 500 ha with a mean annual runoff volume estimated at 1.75 Mm^3 (~55.5 L/s).

The focus area is at an elevation of approximately 1450 mamsl. The topography of the catchment gently slopes in a northerly-westerly direction.

2.4 Climate and rainfall

The study area is characterised by warm summer months and cool dry winters. The average maximum temperatures for the region occur between November and January with temperatures peaking at 31°C. The average minimum temperatures are experienced through June and July.

Two rainfall stations were identified in the study area. A rainfall analysis was conducted on station 0509283, the data was sourced from the WRIMS rainfall database. The raw dataset spans 84 years from 1928 to 2012 and required little data patching. The calculated mean annual precipitation is 573.4 mm/a. Figure 2-2 depicts the rainfall distribution graphs with Table 2-2 summarising the dataset statistics. The lower 5th percentile of data is 326.3 mm/a and the upper 95th percentile 823.8 mm/a. The lower 5th and upper 95th percentiles equate to the one in twenty year flood and drought conditions respectively. Approximately 60% of rain occurs over only four months between November and February. Very little rainfall thus occurs over the winter months resulting in non-perennial streams in the study region. The mean annual evaporation for quaternary catchment A31D is 1901 mm/a (WR2005).

Table 2-2 Table showing historical rainfall data statistics from 1928 – 2012

	1928 – 2012												
	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
AVERAGE	200.10	169.18	104.14	34.70	12.40	7.40	1.70	1.30	1.30	24.20	78.80	181.90	817.30
MINIMUM	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.50	0.00	291.00
MAXIMUM	301.20	277.00	234.90	206.50	90.30	140.90	72.90	62.20	88.50	193.00	214.80	249.60	1040.40
ST DEV	56.31	60.04	51.70	41.25	20.48	19.29	9.40	11.16	22.91	35.24	43.52	52.73	159.39
1:20 year flood (95th percentile)	207.70	220.06	175.60	129.44	57.32	35.74	15.42	30.89	71.70	119.16	162.52	194.00	821.00
1:20 year drought (5th percentile)	28.78	25.74	12.98	0.00	0.00	0.00	0.00	0.00	0.00	5.00	10.52	17.84	327.29

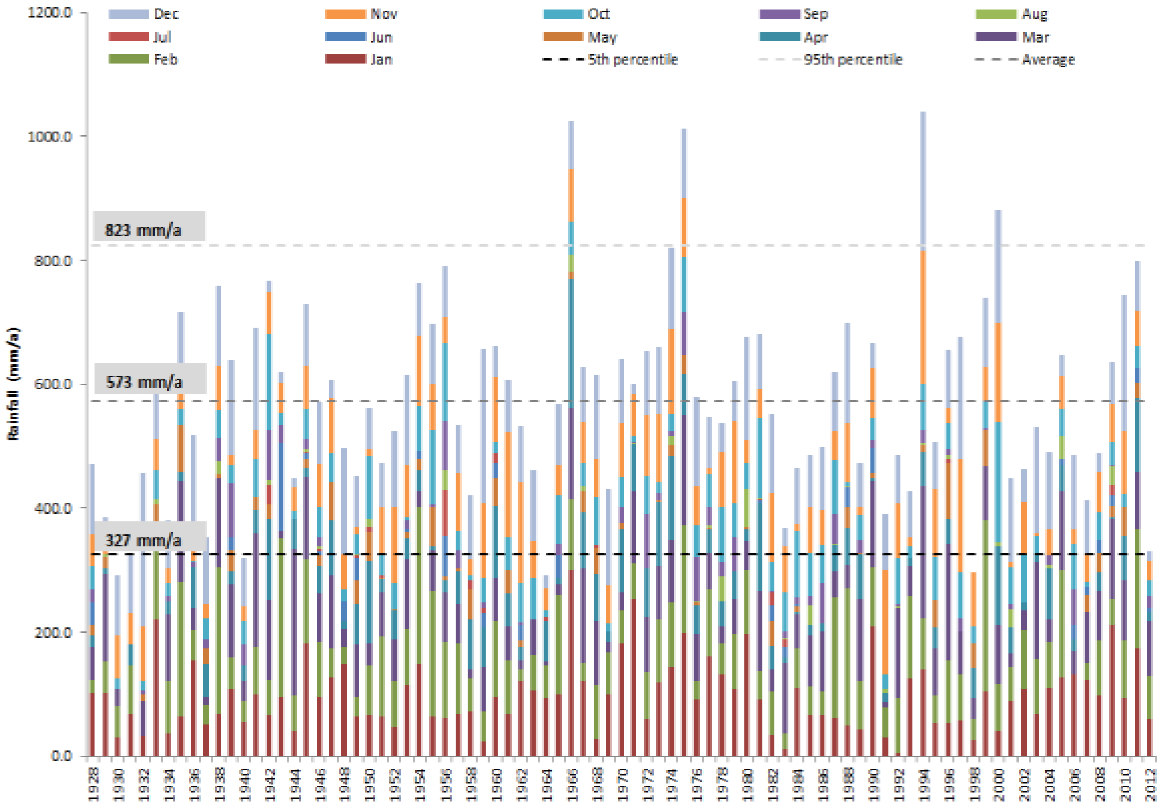

Figure 2-2 Monthly rainfall distribution (1928 – 2012)

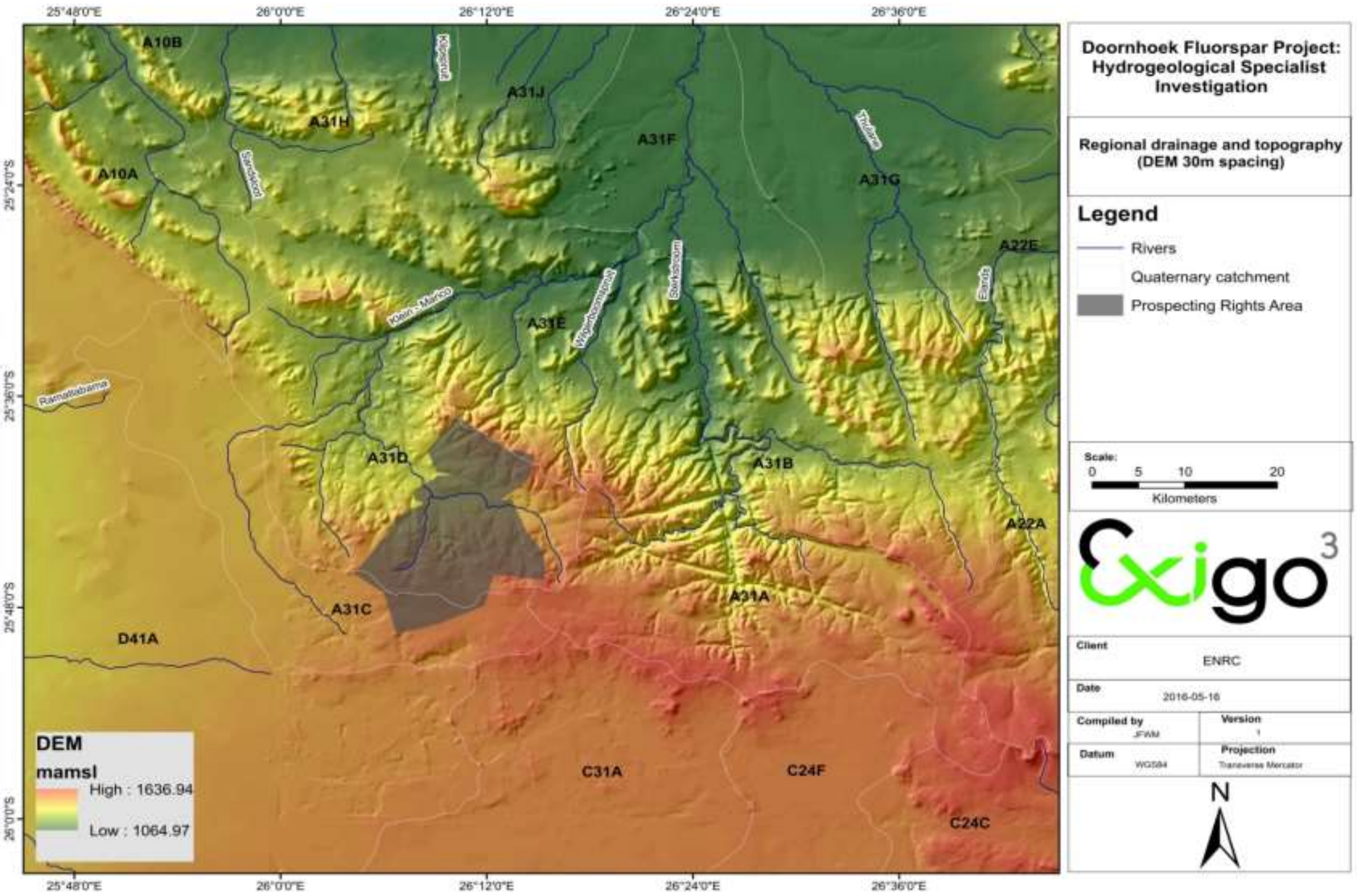

Figure 2-3 Regional drainage, quaternary catchments and DEM

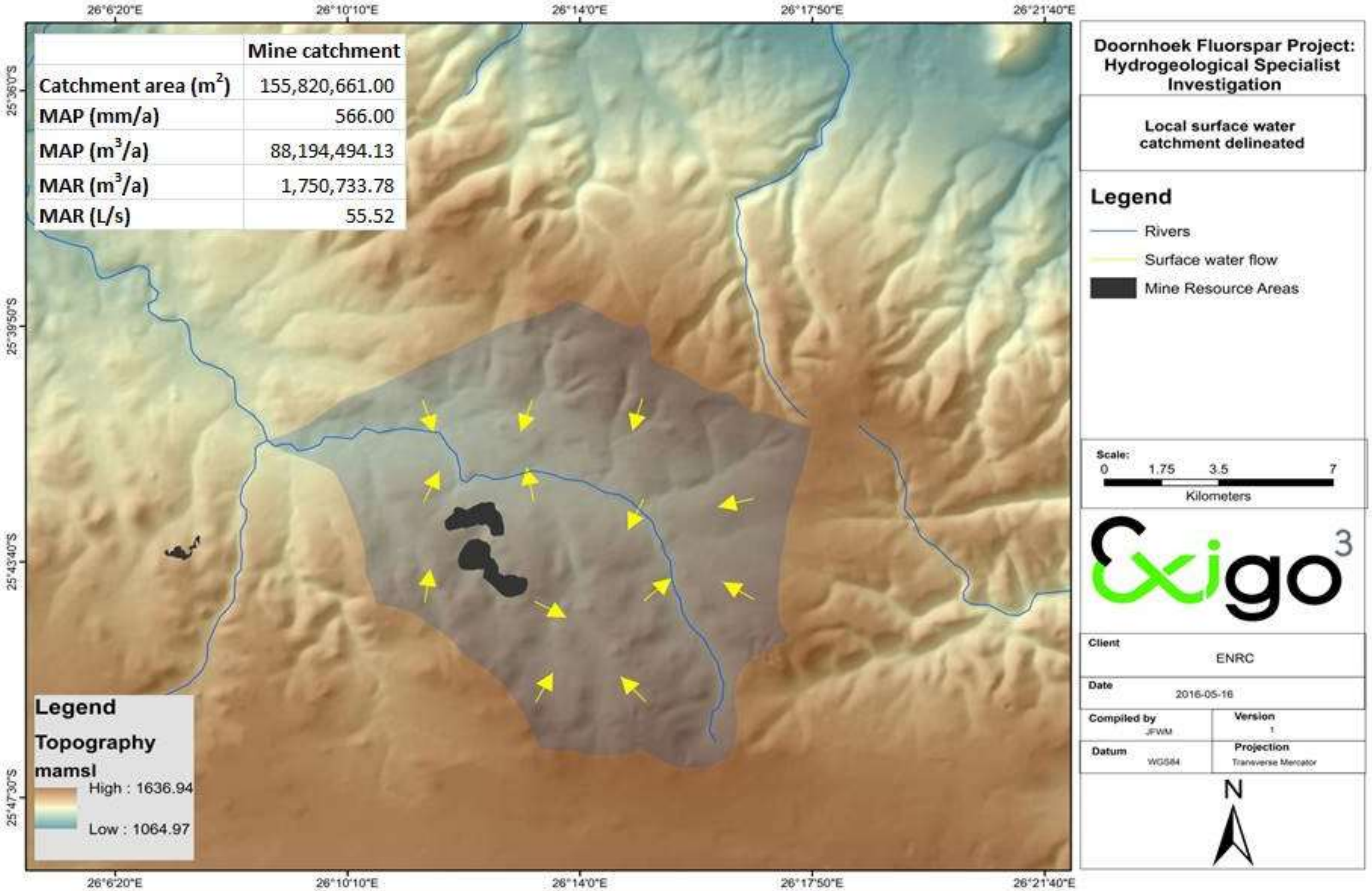

Figure 2-4 Mine surface water catchment

2.5 Geology

The following section describes the regional geology as depicted in the 1:250 000 geological maps sheets of Rustenburg (2526) and Mafikeng (2426)(Figure 2-5). Geological cross sections and slice positions are indicated in Figure 2-6.

The project site is located on Vaalian age Chunniespoort group sediments (Transvaal Super Group). The Chunniespoort group is largely represented by dolomite, dolomitic limestone, chert and shale and is intruded by numerous dolerite dykes.

The fluorspar deposits are large bedded replacement deposits of the classical Mississippi Valley type. Fluorspar mineralisation occurs mainly associated with stromalites in the Middle Frisco Zone and appears to have been introduced post deposition by hydrothermal brines. The fluorite occurs as a filling in permeable beds; within small gas cavities in the stromalites.

The stratigraphic sequence of interest to this study thus consists of the upper formations of the Malmani sub-group and the overlying Pretoria group shales and clastics. The upper formations of the Malmani sub group include the Eccles and the Frisco formations.

The Eccles formation outcrops south of the project area and is characterised as a chert rich formation. The Frisco Formation overlies the Eccles formation. This unit hosts fluorite deposits and comprises stromalitic dolomites. The Frisco formation is overlain by the clastic and iron-rich sediments of the Penge Formation which in turn is unconformably overlain by Pretoria Group shales and clastic sediment of the Rooiberg formation. Shales, Bevets conglomerates and the Polo Ground Member of the Timeball Hill formation overlies the Rooiberg formation and is found outcropping in the northern portion of the study area. A dolerite dyke has intruded this formation and outcrops on the northern portion of the Doornhoek farm. Both east-west trending and north south trending dolerite dykes are abundant in the project area.

Extensive geological mapping has been conducted on the farms Strydfontein 326, Witrand 325, Rhenosterfontein 304, Doornhoek 305, Farm 306, Knoflookfontein 310. Much of the study area consists of the dolomite package overlain by cherts of the Penge formation. In the northern sections of the study area the Pretoria group shales, conglomerates and quartzites are extensive.

Based on the geological cores and cross sectional mapping (Sa Flourite (Pty) Ltd), the Frisco formation is subdivided into three units, the lower, middle and upper Frisco. The mineralisation zone is predominantly associated with the Middle Frisco unit and although of variable thickness the main mineralisation zone appears to be between 10-35 m thick

Cross sectional maps were available for the Rhenosterfontein 304, Doornhoek 305, Farm 306 and Knoflookfontein 310. The cross sections indicate that the sedimentary units dip gently. Numerous east-west trending and north-south trending normal faults transect the stratigraphic sequence.

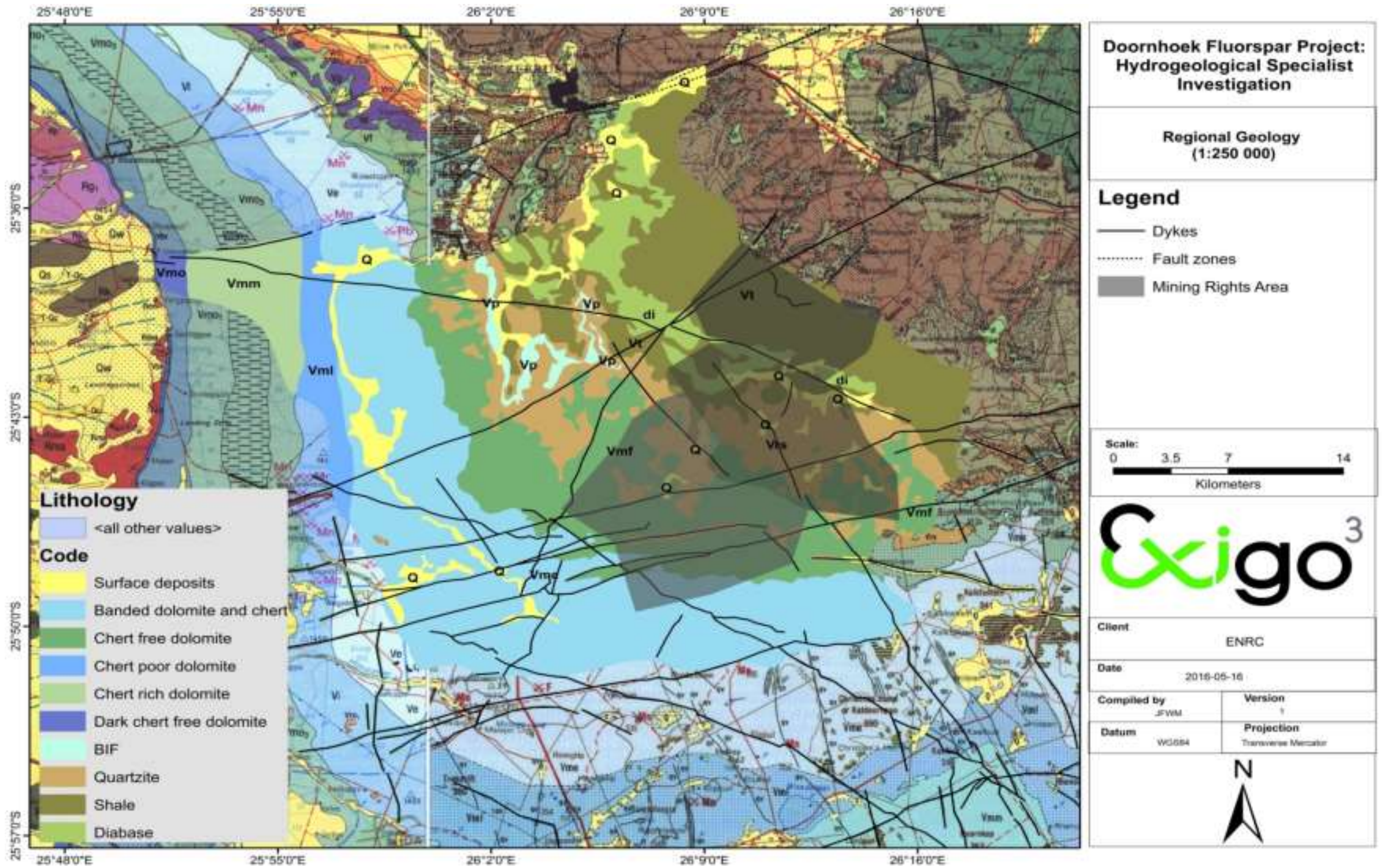

Figure 2-5 Regional geology map Rustenburg (2526 and Mafikeng 2426)

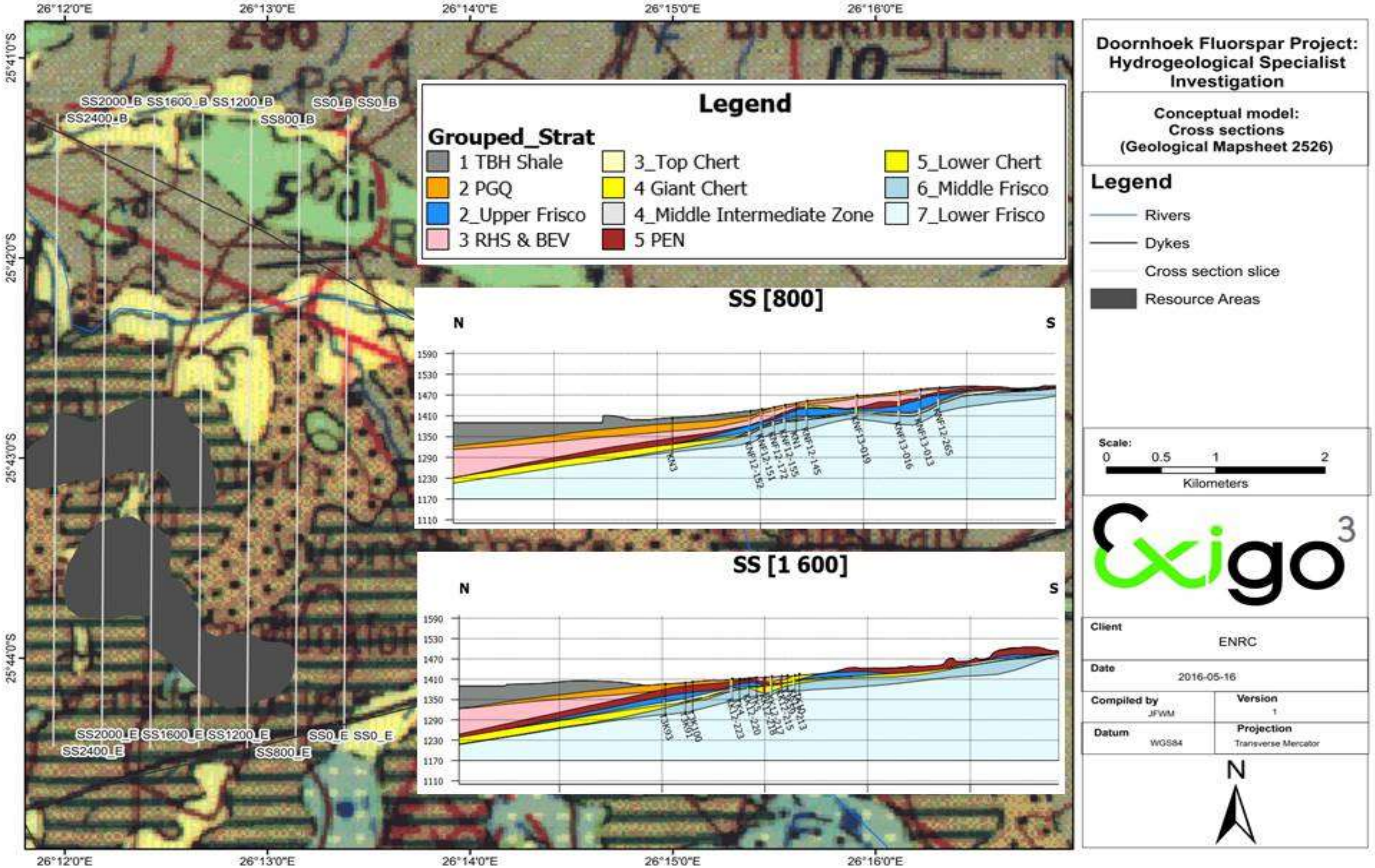

Figure 2-6 Geological cross sections of resource areas C and D

2.6 Hydrogeology

2.6.1 Aquifer geometry and boundaries

The predominant geological units consist of dolomites, cherts and shales. Weathering of the Pretoria Group shales and quartzites, the upper most lithological units in the study area, creates a good medium for groundwater storage and likely permit significant flow where bounded by a dolerite dyke which commonly intersects the strata. The underlying dolomitic package likely has variable permeability largely governed by the presence and absence of chert layers. As depicted in the stratigraphic sequence and observed from the geological cores viewed during the site visit, the upper sequence of the dolomites is largely laminar. These units likely have poor permeability and secondary structures such as faults and joints are important to groundwater flow.

A band of chert underlies the laminar dolomites and overlies the main mineralisation zone. The cherts are likely to exhibit appreciable groundwater flow. Below the mineralisation zone the dolomites are characterised as massive and again secondary structures form preferential flow paths for groundwater flow. As no hydrogeologically significant unit defines the aquifer base, the thickness of the aquifer is considered as ± 100 m. Sub-vertical dolerite dykes cross cut the sedimentary units of the region. These dykes are inferred to have low permeability relative to the country rock and thus act as barriers to groundwater flow and essentially compartmentalise the aquifer. This inference was based largely on the occurrence and location of springs within the study area as indicated in Figure 3-7.

2.6.2 Aquifer parameters

Aquifer parameters, hydraulic conductivity and storativity are necessary parameters for the characterisation of an aquifer. Common to fractured aquifers, the hydraulic conductivity was found to be largely controlled by the proximity of the tested borehole to geological structures. Table 3-1 summarises aquifer parameters derived from tests in various hydrostratigraphic units. Country dolomite rock units display low median hydraulic conductivities in the order of 0.05 m^2/d, while boreholes located on the dyke margins show median hydraulic conductivity values in the order of 4.3 m^2/d. Tests carried out in the shale and quartzite units indicate hydraulic conductivity values of 0.01 to 0.23 m^2/d respectively which is also representative of literature values (Spitz and Moreno, 1996). Alluvial units targeted indicate relatively higher hydraulic conductivity values of 0.37 to 4.36 m^2/d as expected. While hydraulic conductivity can be effectively estimated from field tests, storativity can only be estimated with a level of confidence from a numerical model calibrated against transient water levels.

2.6.3 Recharge

The water chemistry in the study area typically has a Ca-Mg-HCO_3 signature which is indicative of freshly recharged groundwater. The low chloride concentrations observed in groundwater coupled with moderate rainfall conditions is further evidence of high recharge on the dolomite aquifers. Due to the low chloride concentrations (harmonic mean <2 mg/ℓ), the chloride mass balance method for determining recharge is not accurate.

- According to the Vegter recharge map, recharge in the area is on the order of 65 mm/a in the southern portion of the catchment, decreasing to approximately 45 mm/a in the northern portion of the catchment.
- According to the Harvest Potential Map, recharge within the catchment is in the order of 25 -50 mm/a.
- Based on the Acru map, recharge to the vadose zone is in the order of 10 mm/a.

2.6.4 Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). The assessment found the aquifer to be sole-source as described in Table 2-3.

Table 2-3 Aquifer classification (After Parsons, 1995)

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Minimum Requirements (1998)
Sole Source Aquifer	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (<150 mS/m).	High yielding aquifer (5-20 ℓ/s) of acceptable water quality.
Minor Aquifer	These can be fractured or potentially fractured rocks, which do not have a high primary permeability or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.	Moderately yielding aquifer (1-5 ℓ/s) of acceptable quality or high yielding aquifer (5-20 ℓ/s) of poor quality water.

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Minimum Requirements (1998)
Non-Aquifer	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 ℓ/s) of good quality water or moderately yielding aquifer (1-5 ℓ/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

3 SITE INVESTIGATION

3.1 Hydrocensus user survey

In May 2016, a regional hydrocensus user survey was conducted within a 30km radius from the project area to establish a hydrogeological and hydrochemical baseline going forward. A hydrocensus was previously also conducted in 2013 focussing more on the central parts of the project area. A spatial distribution map is indicated in Figure 3-1 with a detailed description of all geo-sites surveyed summarised in Appendix A.

3.1.1 Site type

A total of 119 geo-sites were surveyed and recorded which include 92% (110 sites) boreholes, 1% (1 site) defunct shaft, 1% (1 site) shallow water well, 4% (5 sites) springs and 2% (2 sites) as surface water bodies (Figure 3-3).

3.1.2 Site status and application

Of the 119 surveyed sites, 80 % (97 sites) are in use and 20% (22 sites) are not in use. Of the 97 sites in use, the majority were utilised for domestic and livestock purposes, 38% (37 sites) and 30% (29 sites) ;respectively, 22% (21 sites) for irrigation purposes, 8% (8 sites) for wildlife stock and 2% (2 sites) for monitoring purposes (Figure 3-4).

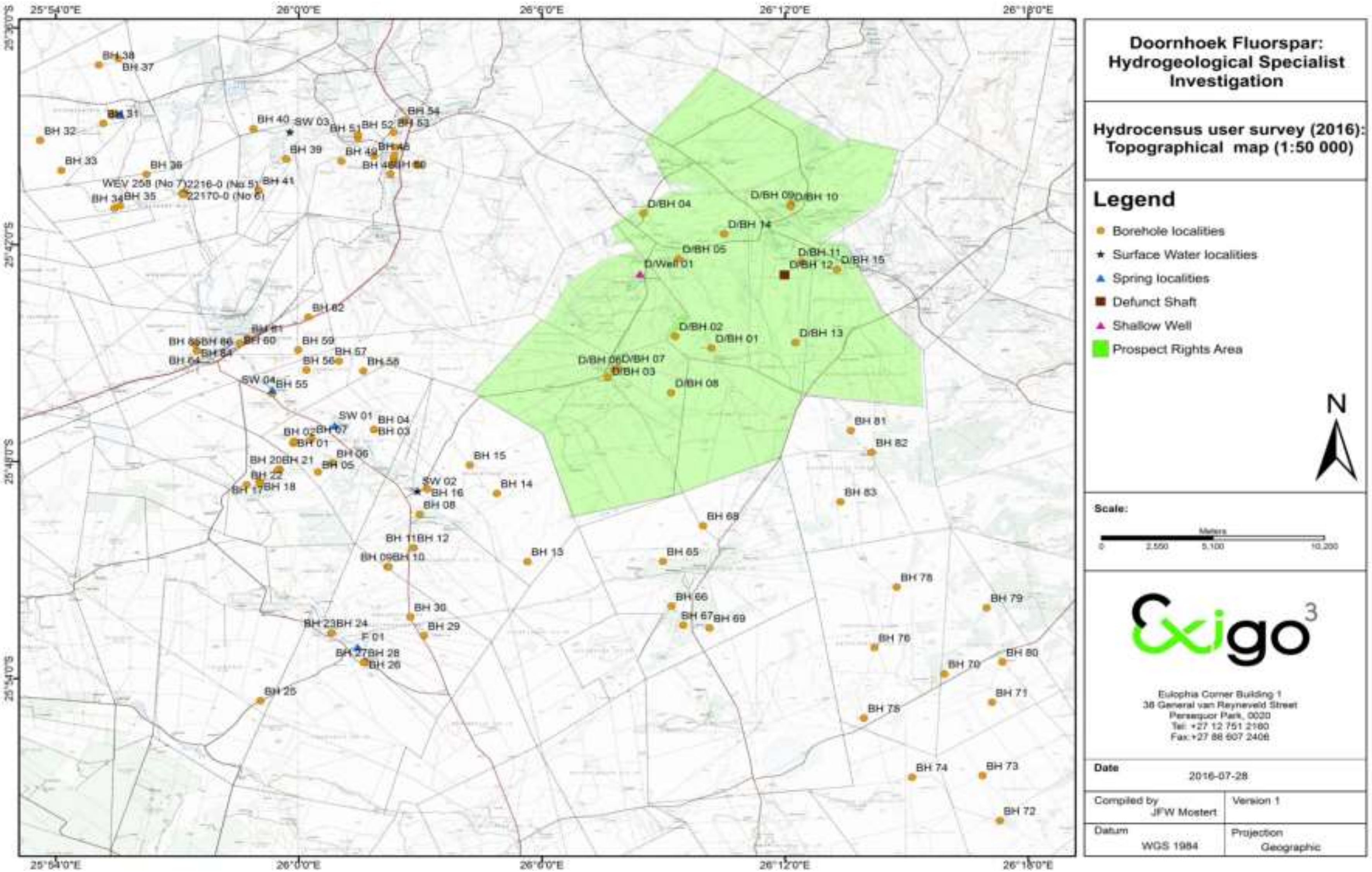

Figure 3-1 **Hydrocensus user survey spatial distribution map**

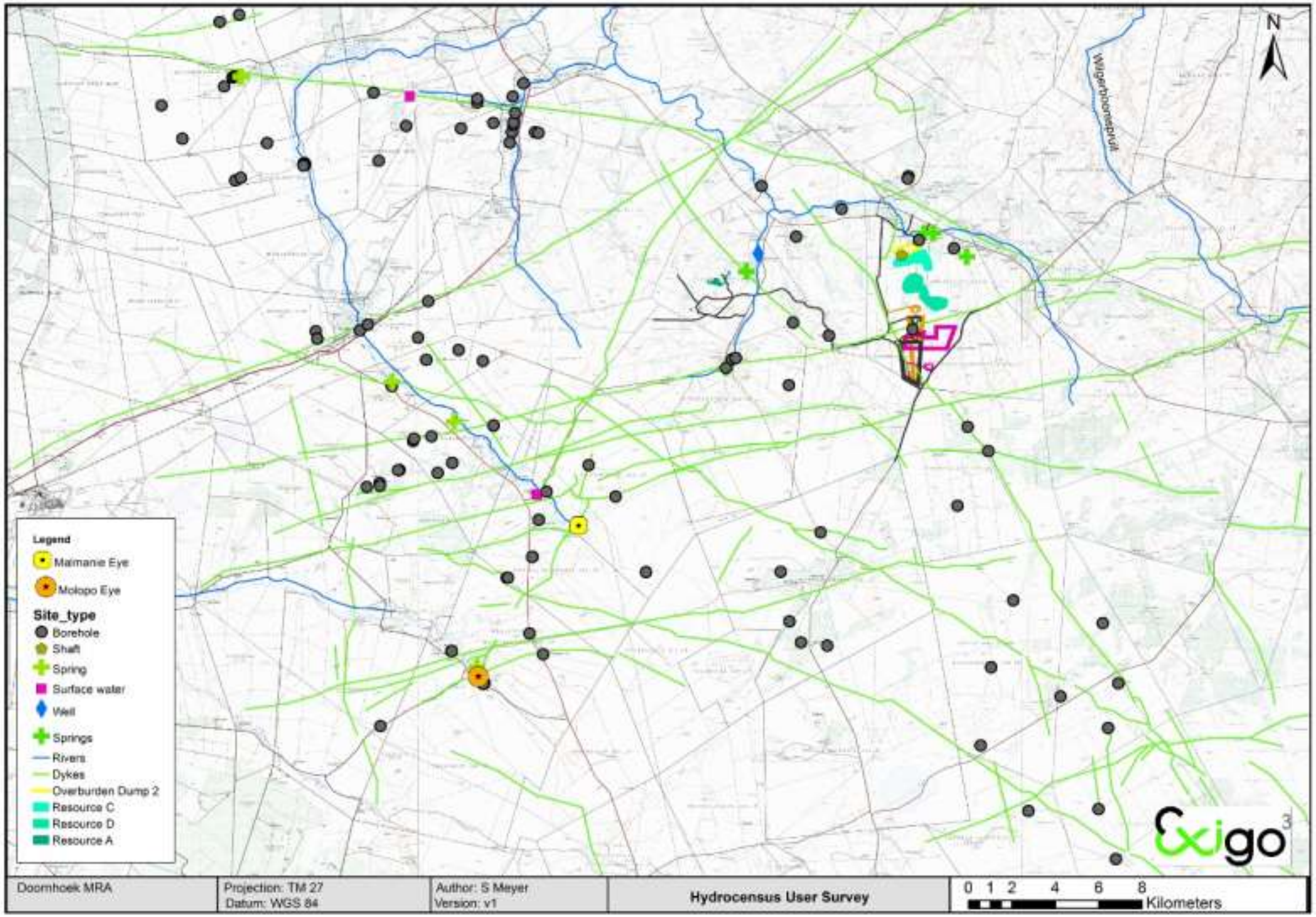

Figure 3-2 **Hydrocensus user survey with Malmani and Molopo Eye**

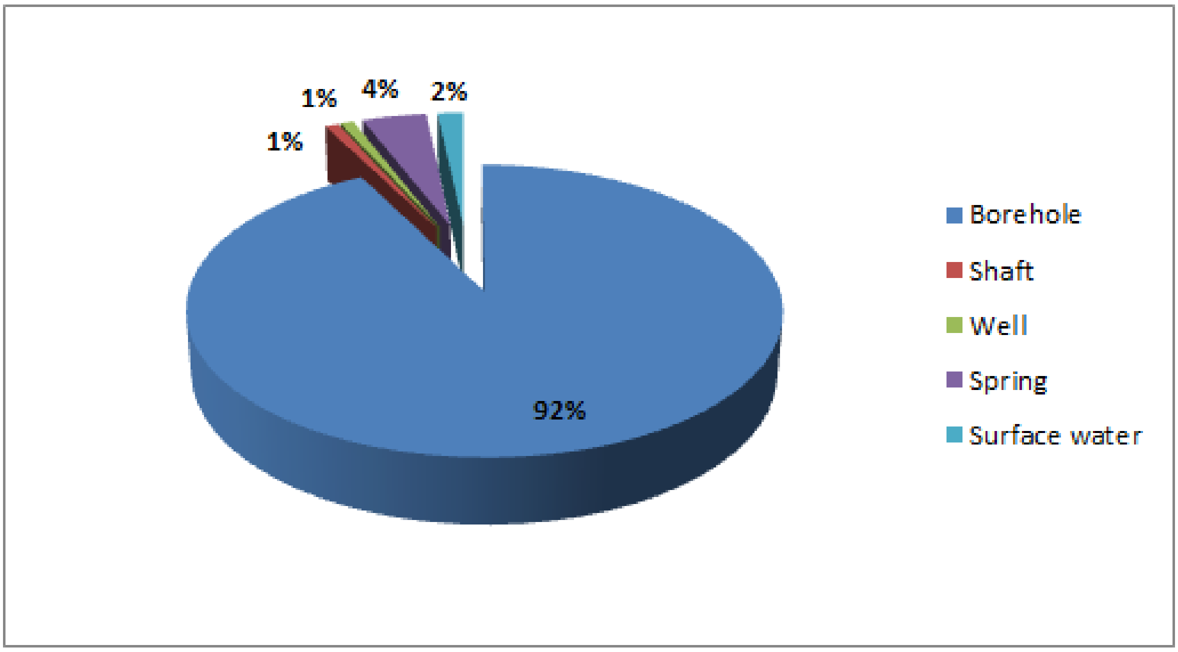

Figure 3-3 Hydrocensus site type

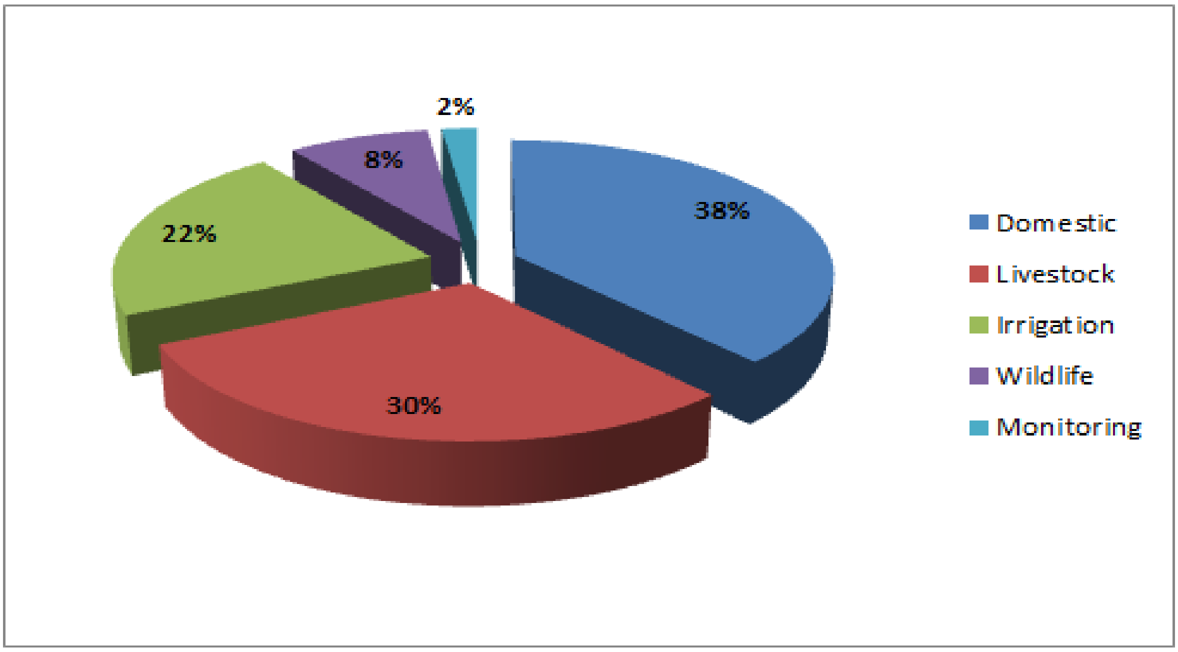

Figure 3-4 Hydrocensus water application

3.1.3 Water levels and depth to groundwater

Water level data and hydraulic head elevation is relevant for determining the flow regime of the regional and local groundwater system and movement within the substrata. Water levels recorded were used to compile a regional groundwater flow map and, as indicated in Figure 3-5, the regional groundwater flow is in a general northerly direction, following the surface water drainage system of the catchment. Figure 3-6 provides an indication of the depth to groundwater map, with possible over-abstraction noticeable to the south and southwest of the project area. Water levels measured during the 2016 hydrocensus survey display the following statistics: average water level = 16.5 mbgl, maximum = 59.61 mbgl, minimum = 0 mbgl (artesian) with a standard deviation of ~12 m, indicative of a pumped and dynamic aquifer system (Figure 3-8). Water levels recorded during the initial hydrocensus user survey (2013) were compared with newly obtained data and, as depicted in Figure 3-9, indicate an escalation in deeper water levels which can be ascribed to prevailing draught conditions and possible over-abstraction at isolated areas.

3.2 Aquifer tests and calculated parameters

Aquifer tests were conducted on earmarked boreholes to evaluate the hydraulic parameters of the identified aquifer zones (Figure 3-15). In order to estimate hydraulic conductivity of the aquifer units, falling head tests (2015) as well as constant discharge tests (2016) were carried out at localities in the vicinity of the proposed mining area. Refer to Table 3-1 for a statistical summary of hydraulic conductivity values calculated per lithology. An average hydraulic conductivity (K) value of 1.20 m/d was calculated with the minimum value of 0.01 m/d measured within the shale units and a maximum value of 4.50 m/d measured in the alluvial material within the weathered perimeters of the traversing dyke structures. The 5th percentile was presented by a value of 0.02 m/d with the 95th percentile 4.39 m/d. Drawdown and recovery curve per tested borehole is indicated in Figure 3-10 to Figure 3-14 with potential boundaries reached indicated (Table 3-2). From this data it is inferred that there is a possible direct hydraulic link between the local groundwater system and the surface water feature i.e. Klein Marico River, as inflow boundaries reached during late pumping, are indicative of a constant head hydraulic gradient as would be expected.

Table 3-1 Statistical summary: aquifer testing

Borehole	Formation targeted	Hydraulic Conductivity(m/d)
DH117	Dolomite	0.05
1T1	Dolomite	0.51
1T2	Dolerite Dyke & Alluvial material	0.90
DH125	Dolerite Dyke & Alluvial material	4.50
RH12-045	Dolerite Dyke & Alluvial material	4.31
RHRC12-066D	Chert/dolomite	0.02
RHRC12-022D	Chert/dolomite	0.03
KKPQ12-229	Chert/dolomite	0.37
DBH04	Dolerite	0.30
DBH05	Shale/Quartzite& Fault zone	0.23
DBH09	Shale	0.01
DBH14	Alluvial material	4.06
DBH16	Alluvial material	0.37
MIN		**0.01**
MAX		**4.50**
AVERAGE		**1.20**
STANDARD DEVIATION		**1.78**
5th PPERCENTILE		**0.02**

95th PERCENTILE	**4.39**

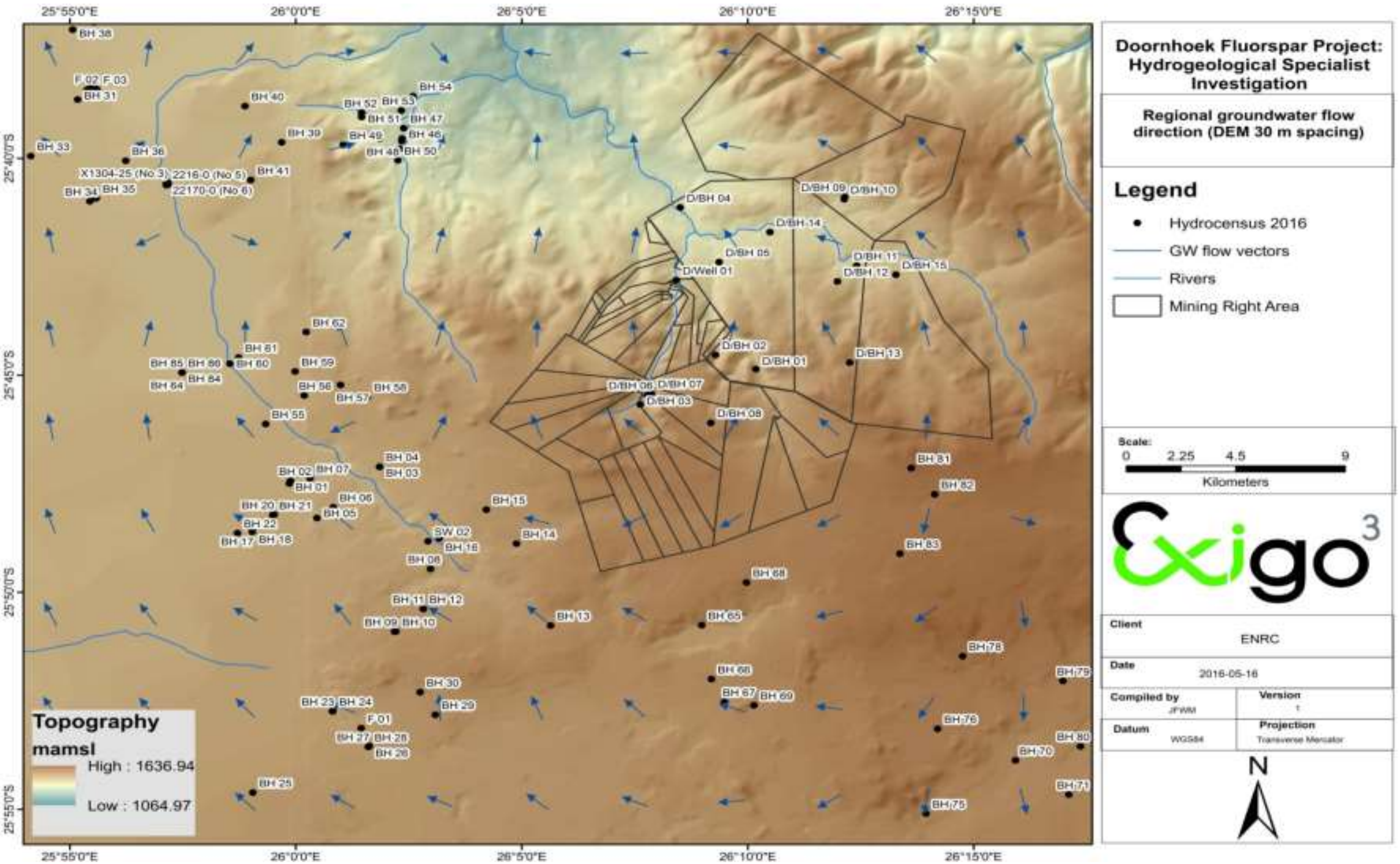

Figure 3-5 Regional groundwater flow direction

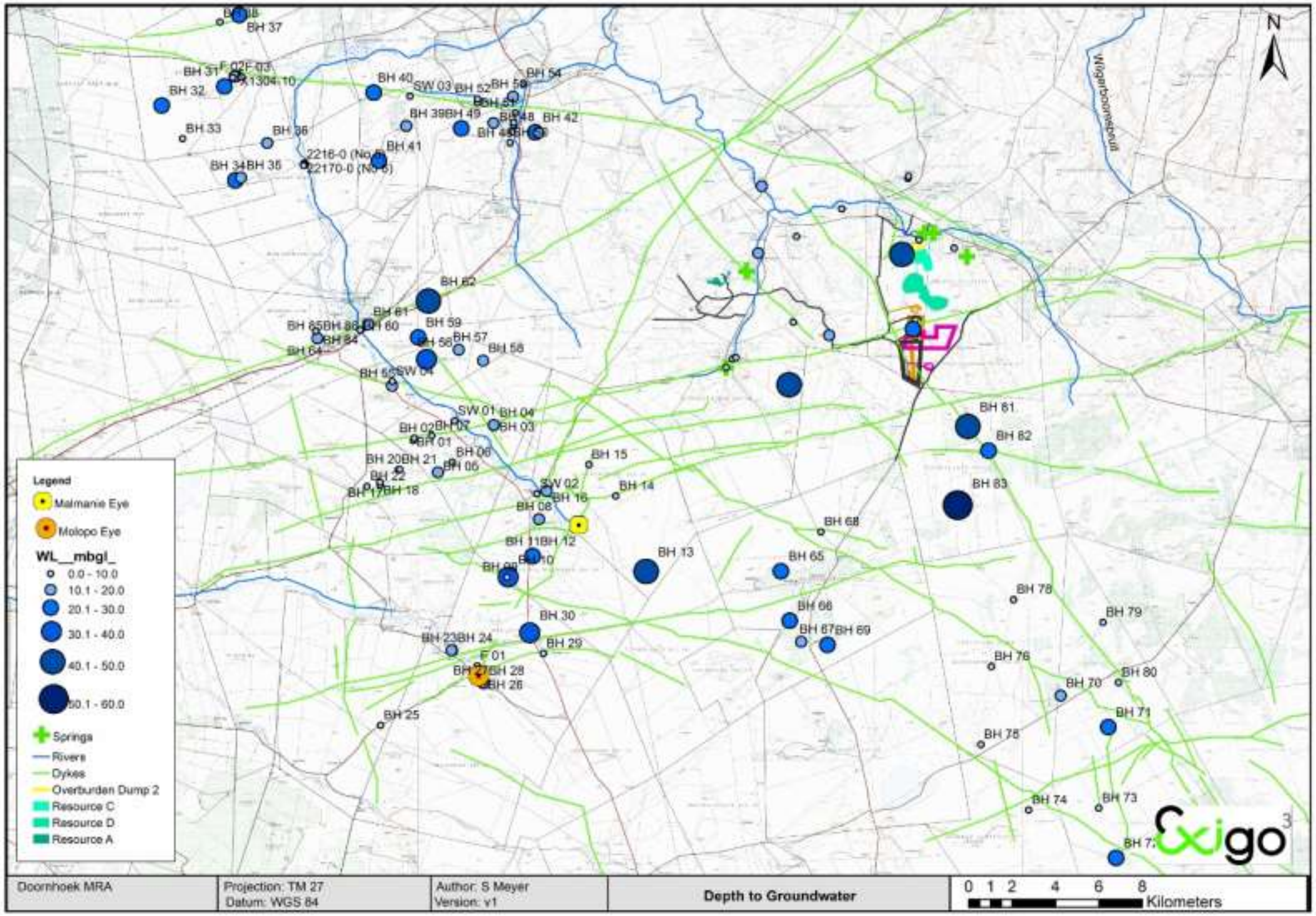

Figure 3-6 **Depth to groundwater map**

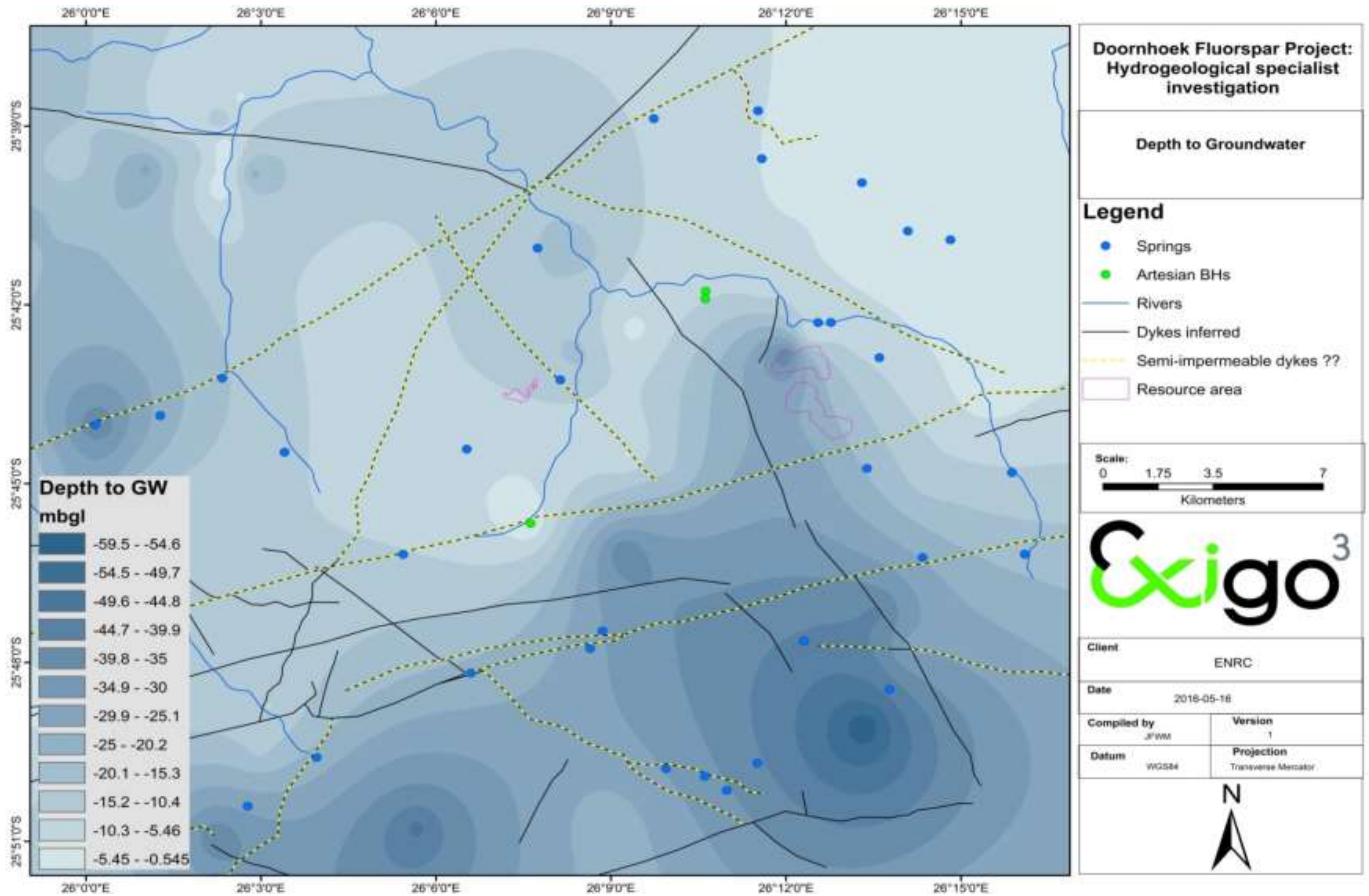

Figure 3-7 Depth to groundwater map in correlation to spring localities, artesian borehole localities and regional structures

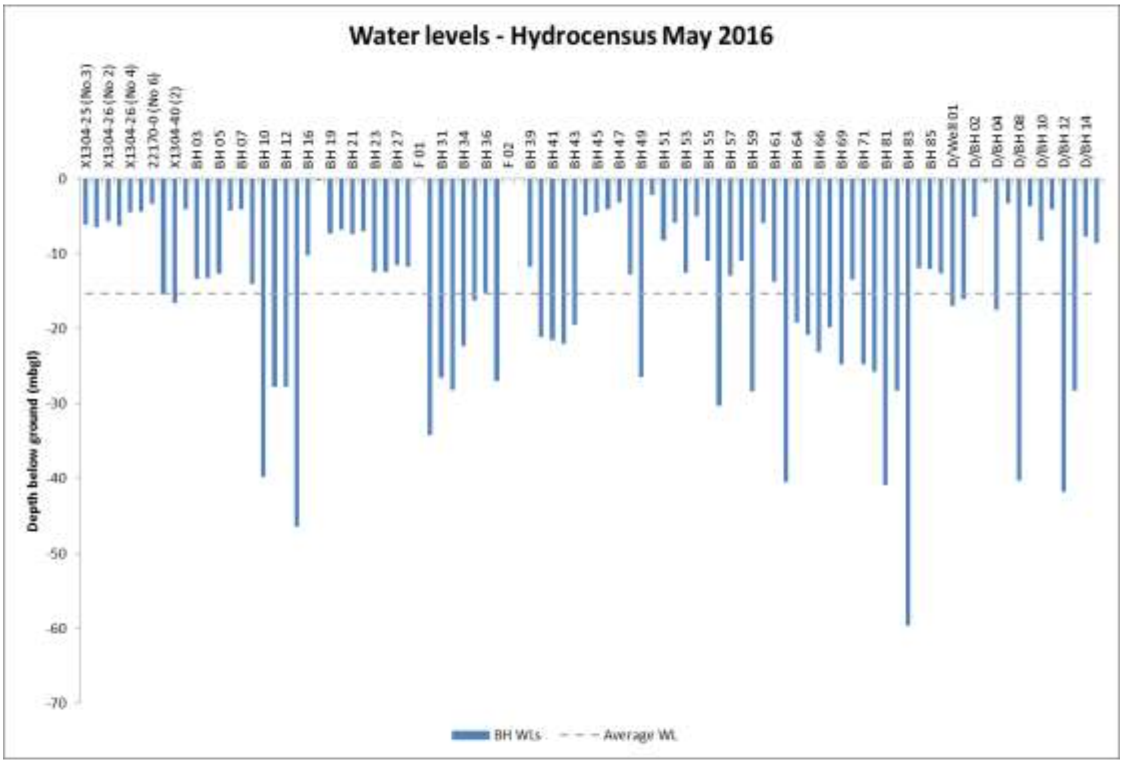

Figure 3-8 Hydrocensus water levels (2016)

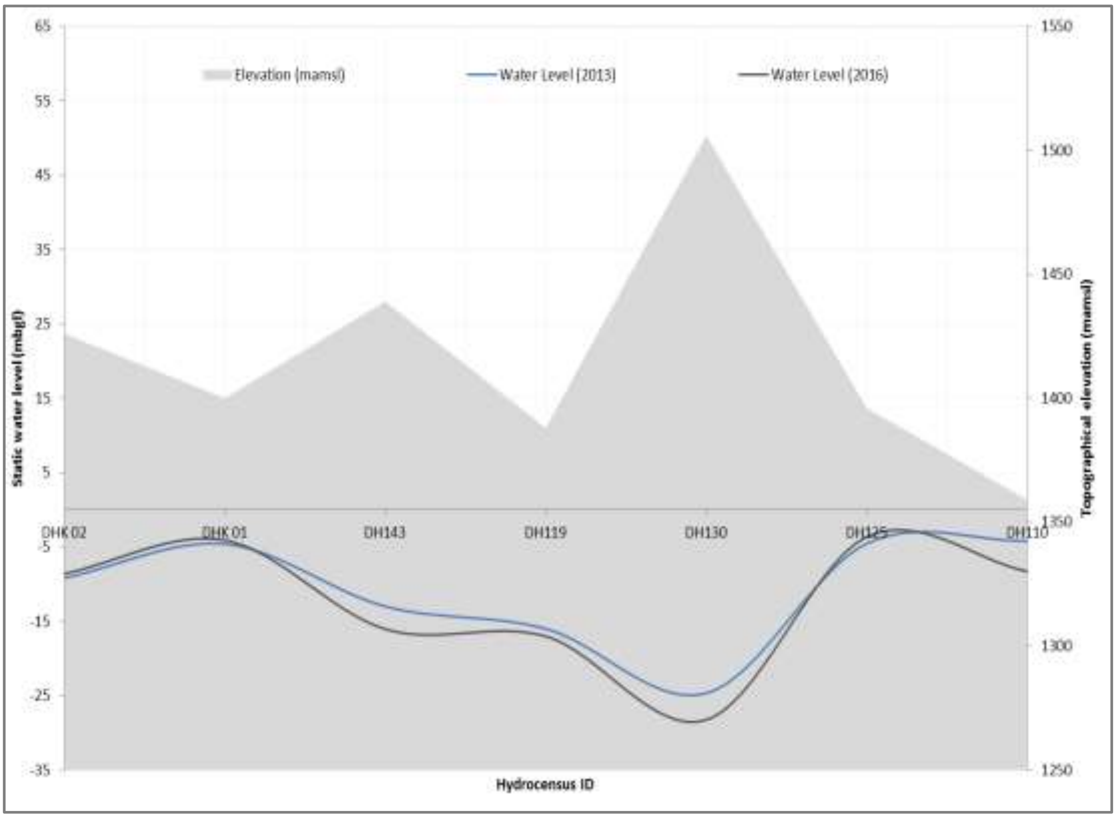

Figure 3-9 Hydrocensus water levels comparison

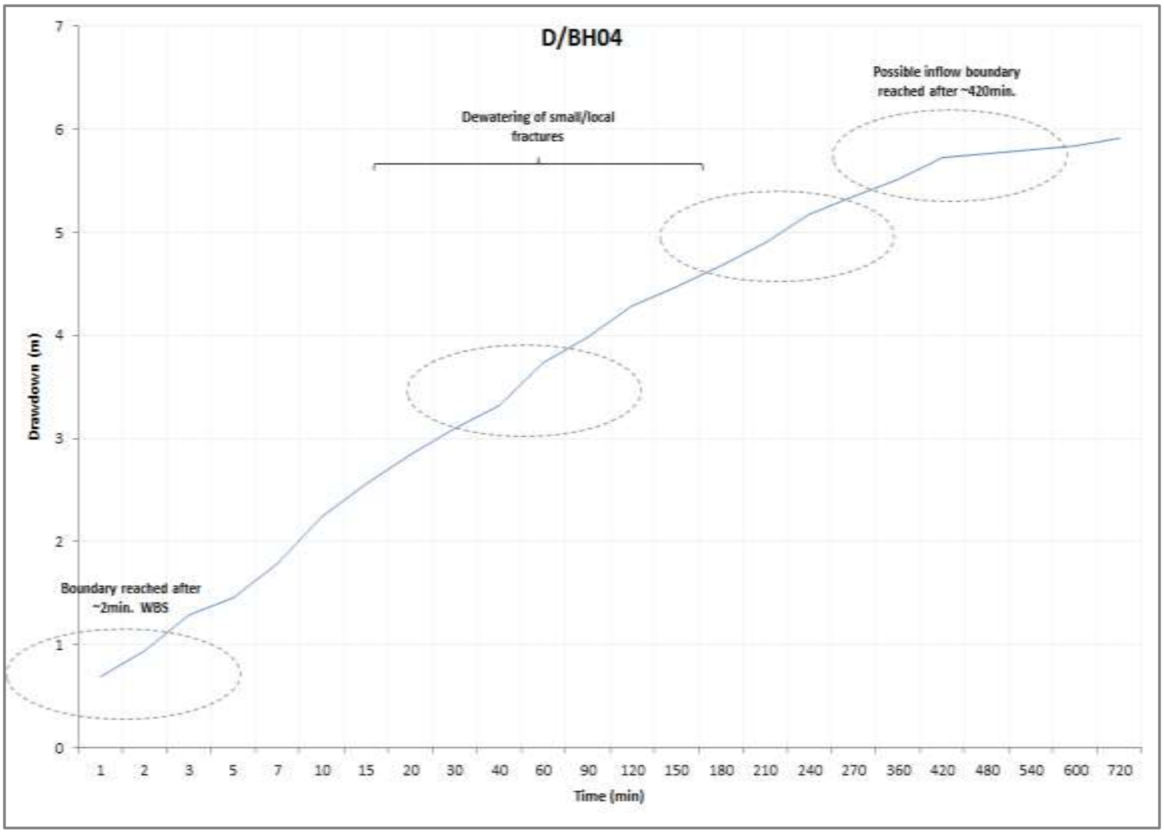

Figure 3-10 Pump tests drawdown curve and identified boundaries – D/BH04

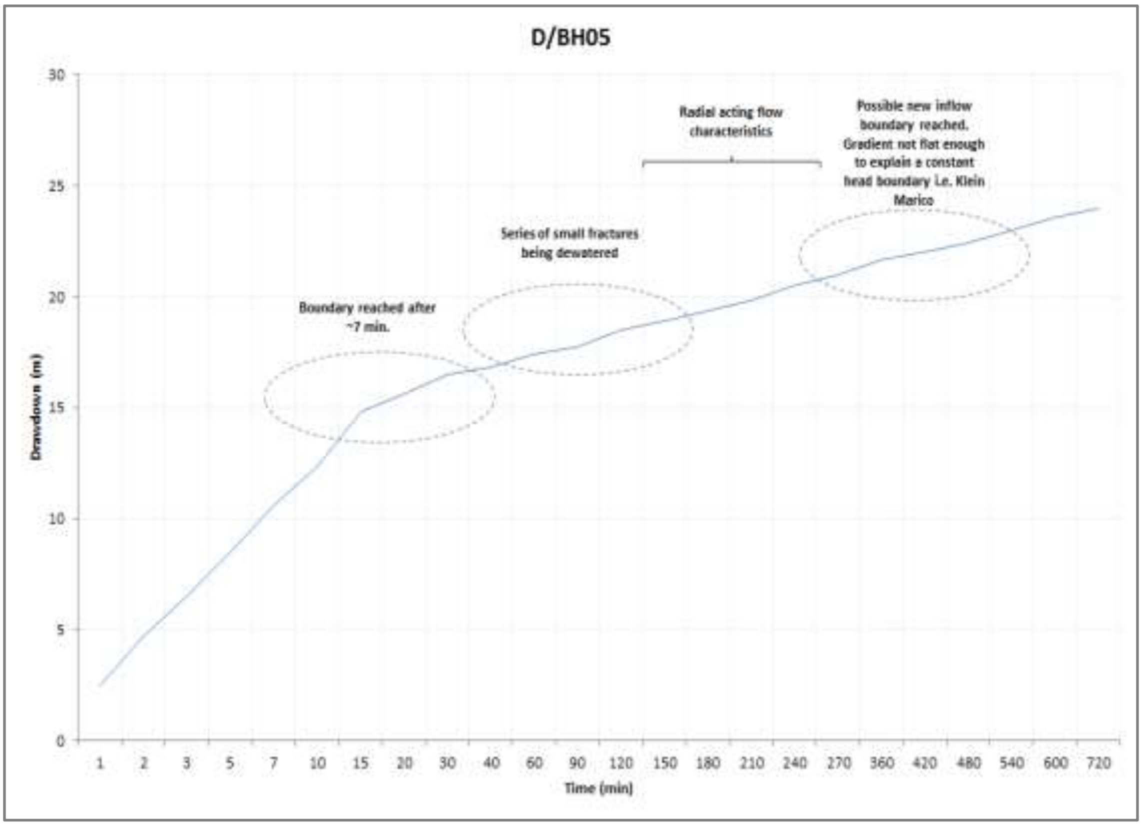

Figure 3-11 Pump tests drawdown curve and identified boundaries – D/BH05

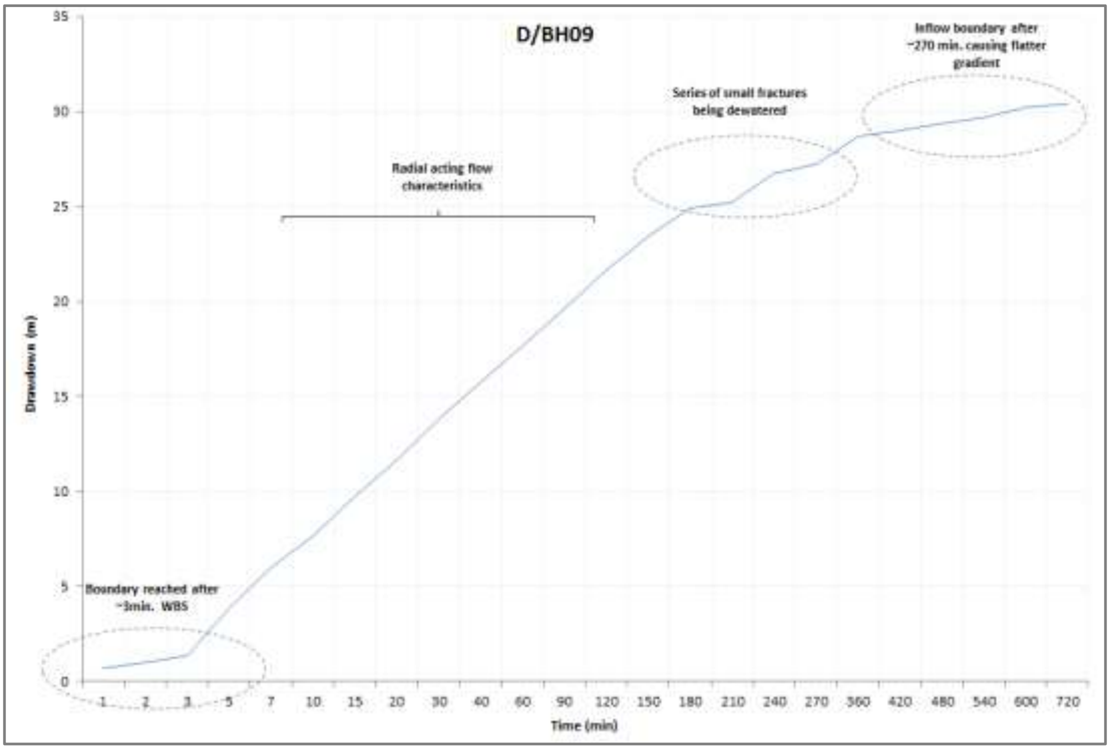

Figure 3-12 Pump tests drawdown curve and identified boundaries – D/BH09

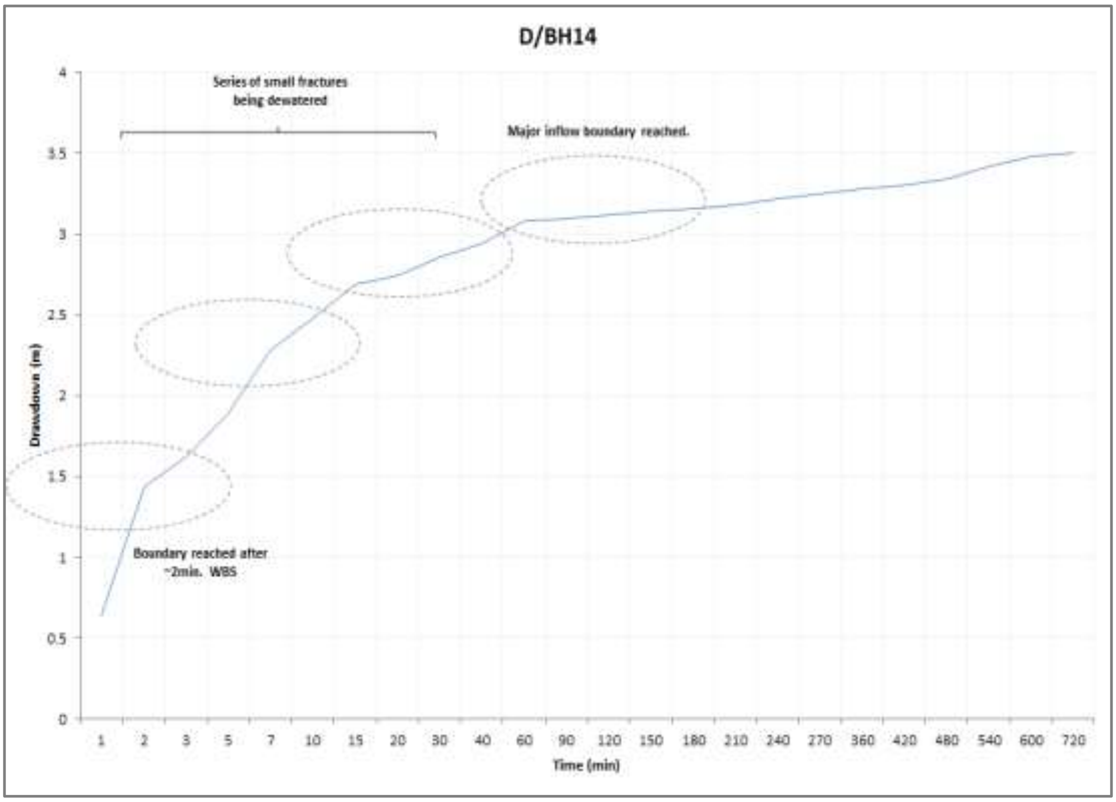

Figure 3-13 Pump tests drawdown curve and identified boundaries – D/BH14

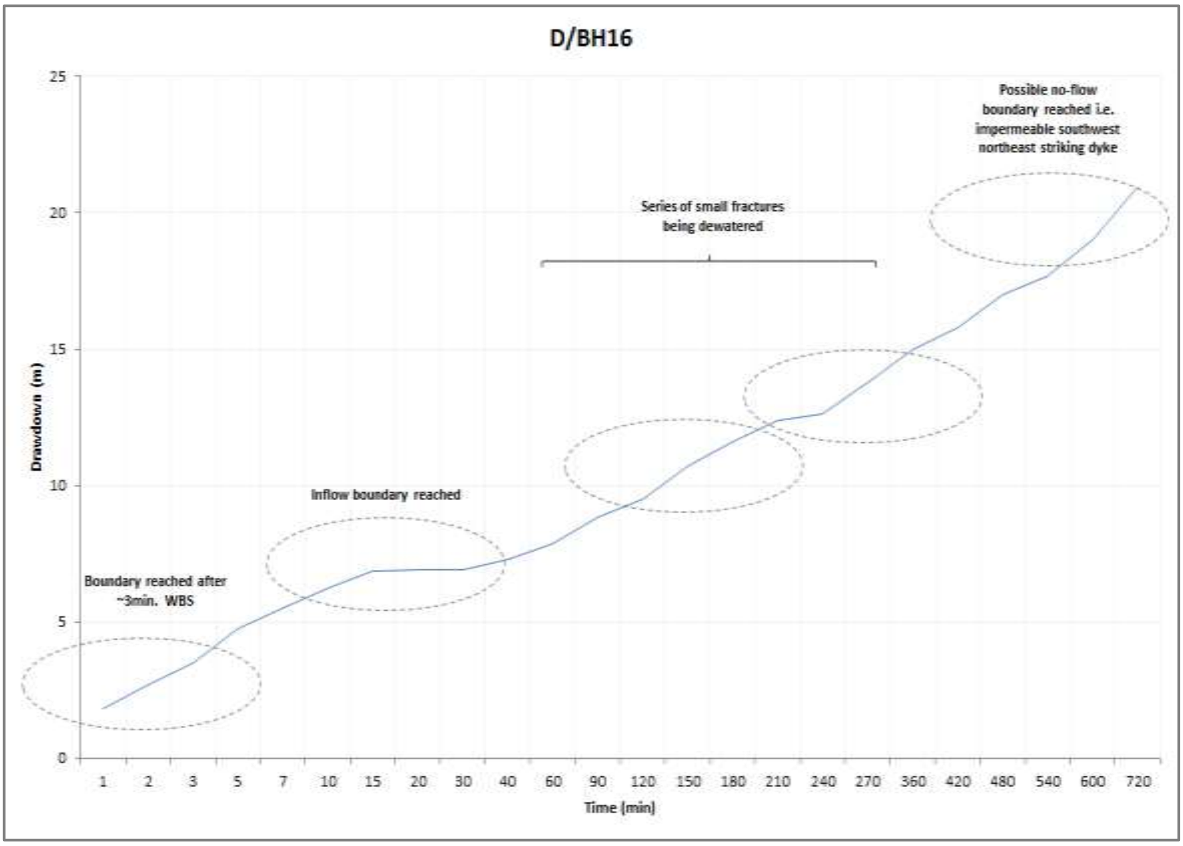

Figure 3-14 **Pump tests drawdown curve and identified boundaries – D/BH16**

Table 3-2 Aquifer test.drawdown and recovery interpretation and sustainable yield calculations.

Basic Information											
Label	Longitude	Latitude	Borehole depth (mbgl)	Water level (mbgl)	Estimated Aquifer thickness	Tested yield (ℓ/s)	Constant discharge duration (hr)	Available Drawdown (m)	Drawdown reached (m)	% Drawdown used	Pump depth inlet
DBH04	-25.685690	26.141840	30.12	13.10	17.02	0.56	12.00	16.30	5.22	32.02	29.40
DBH05	-25.706600	26.156070	49.50	4.18	45.32	5.40	12.00	44.60	23.99	53.79	48.78
DBH09	-25.681480	26.202460	69.10	5.90	63.20	0.20	12.00	57.10	30.40	53.24	63.00
DBH14	-25.695000	26.174880	18.00	7.74	10.26	2.05	12.00	9.56	3.50	36.61	17.30
DBH16	-25.760780	26.129220	40.15	7.16	32.99	7.65	12.00	28.84	20.92	72.54	36.00
		Maximum	**69.10**	**13.10**	**63.20**	**7.65**	**12.00**	**57.10**	**30.40**	**72.54**	**63.00**
		Minimum	**18.00**	**4.18**	**10.26**	**0.20**	**12.00**	**9.56**	**3.50**	**32.02**	**17.30**
		Average	**41.37**	**7.62**	**33.76**	**3.17**	**12.00**	**31.28**	**16.81**	**49.64**	**38.90**
		Total	**206.87**	**38.08**	**168.79**	**15.86**	**60.00**	**156.40**	**84.03**	**248.20**	**194.48**

Basic Information		Transmissivity (m²/d)					
Label	Latitude	AQTESOLV Analysis CD Early T (m²/d)	AQTESOLV Analysis CD Late T (m²/d)	AQTESOLV Analysis Recovery T (m²/d)	FC Analysis CD Transmissivity (m²/d)	FC Analysis Recovery Transmissivity (m²/d)	Average Transmissivity (m²/d)
DBH04	26.141840	4.50	6.50	4.35	4.65	4.40	4.88
DBH05	26.156070	6.90	11.33	12.23	10.40	9.70	10.11
DBH09	26.202460	0.26	0.47	0.24	0.28	0.27	0.30
DBH14	26.174880	31.24	40.26	42.20	40.39	40.05	38.83
DBH16	26.129220	14.45	9.73	9.48	9.62	9.89	10.63
	Maximum	**31.24**	**40.26**	**42.20**	**40.39**	**40.05**	**38.83**
	Minimum	**0.26**	**0.47**	**0.24**	**0.28**	**0.27**	**0.30**
	Average	**11.47**	**13.66**	**13.70**	**13.07**	**12.86**	**12.95**
	Total	**57.35**	**68.29**	**68.50**	**65.34**	**64.31**	**64.76**

Basic Information		Sustainable yield (ℓ/s)					
Label	Latitude	FC Analysis Sustainable yield (ℓ/s)	Sustainability Check - Cooper Jacob (ℓ/s)	Average Sustainable yield (ℓ/s)	Radius of Recharge zone (m)	Abstraction duty cycle (h)	Abstraction per annum (m³/a)
DBH04	26.141840	0.72	0.65	0.69	480.11	12.00	21602.16
DBH05	26.156070	3.66	3.50	3.58	1242.37	12.00	112898.88
DBH09	26.202460	0.14	0.17	0.16	241.57	12.00	4888.08
DBH14	26.174880	2.60	2.75	2.68	914.30	12.00	84358.80
DBH16	26.129220	3.07	2.44	2.76	1322.57	12.00	86881.68
	Maximum	**3.66**	**3.50**	**3.58**	**1322.57**	**12.00**	**112898.88**
	Minimum	**0.14**	**0.17**	**0.16**	**241.57**	**12.00**	**4888.08**
	Average	**2.04**	**1.90**	**1.97**	**840.18**	**12.00**	**62125.92**
	Total	**10.19**	**9.51**	**9.85**			**310629.60**

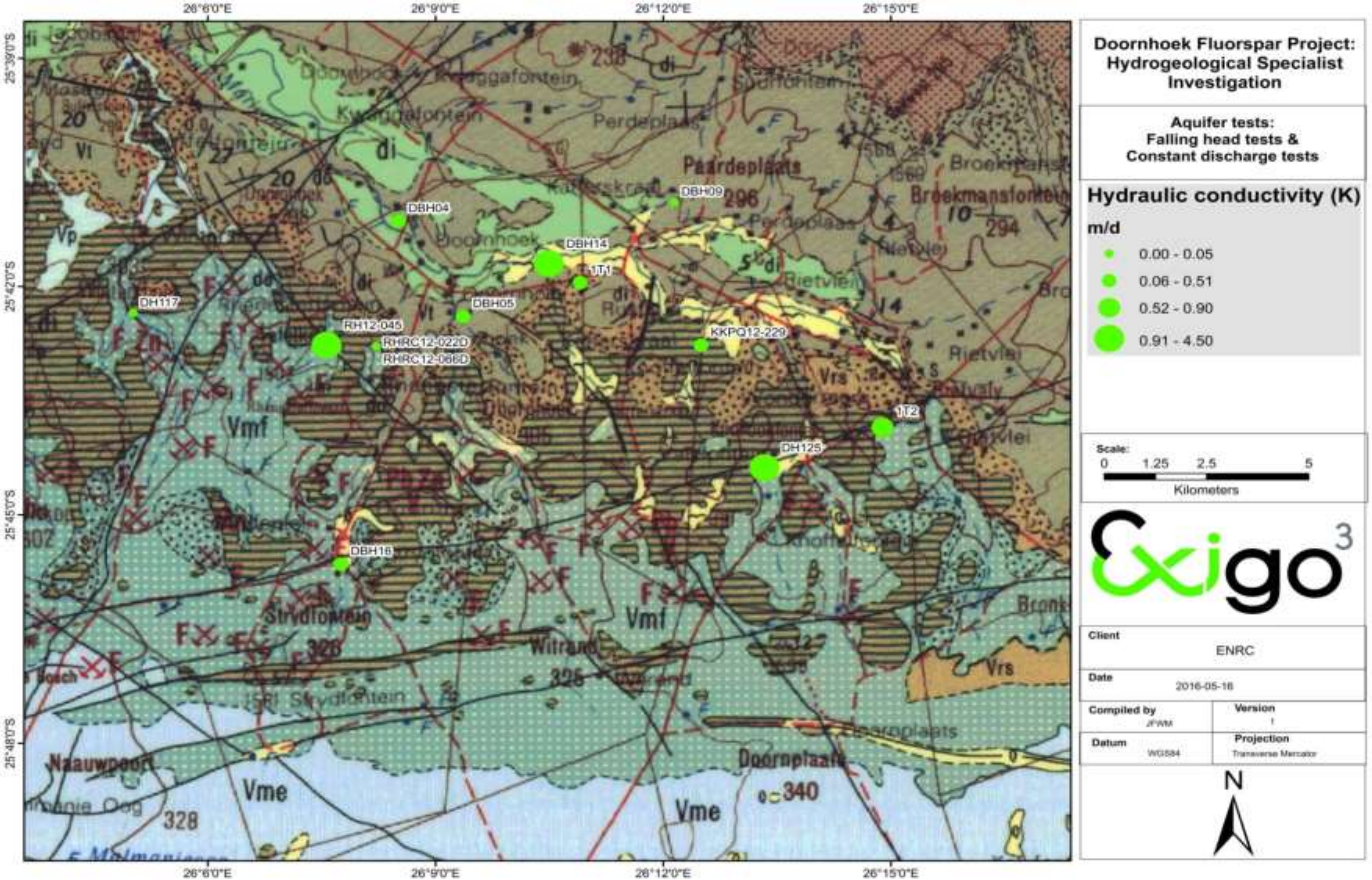

Figure 3-15 Aquifer testing: Spatial distribution of hydraulic conductivity

3.3 Hydrochemistry

Baseline hydrochemical data was obtained through the pre-feasibility sampling run performed in 2013. Sixteen of the surveyed 2016 hydrocensus sites, including borehole sites subjected to pump tests, were selected for chemical analyses and the development of a water quality baseline (Figure 3-21). The sample points were selected to represent the spatial extent of the site and incorporate all water application areas (mining, agricultural as well as domestic application). Of the sites selected, fourteen are representative of groundwater, one surface water sample and one spring sample. Samples were submitted at a SANAS (South African National Accreditation System) accredited laboratory for macro- and micro chemical analysis. The following sections outlines the water quality evaluated against the relevant standards and describes the hydrochemical characteristics of the groundwater and surface water quality evaluated.

3.3.1 Data validation

The laboratory precision was validated by employing the plausibility of the chemical analysis i.e. electro neutrality (E.N.). The E.N. is determined according to Equation 3-1, below. An error of less than 5% is an indication that the analysis results are of suitable precision for further evaluation.

Equation 3-1 Electro-neutrality

$$\text{E.N.}[\%] = \frac{\sum cations[\text{meq/L}] + \sum anions[\text{meq/L}]}{\sum cations[\text{meq/L}] - \sum anions[\text{meq/L}]} \cdot 100\% < 5\%!$$

The plausibility of the EC is determined through Equation 3-1. An analysis where an error of less than 10% between the EC and sum of cation or sum of anions is obtained is deemed to have suitable precision for further analysis.

Table 3-3 Laboratory precision and data validity

Sample Localities	Σ Cations (meq/l)	Σ Anions (meq/l)	Electro-Neutrality [E.N.] % > 5%: Poor lab precision
D/BH01	11.62	-12.16	-2%
D/BH03	5.21	-5.24	0%
D/BH04	8.42	-9.14	-4%
D/BH05	3.95	-4.16	-3%
D/BH09	0.99	-0.98	0%
D/BH12	5.28	-5.44	-1%
D/Well01	6.44	-7.58	-8%
BH10	3.24	-3.41	-2%
BH14	3.70	-3.95	-3%
BH16	4.00	-4.12	-2%
BH65	3.68	-3.74	-1%
BH82	2.87	-3.17	-5%
SW02	3.63	-3.77	-2%
F01	5.01	-4.88	1%
22170-0	6.85	-7.42	-4%
BH23	7.51	-7.89	-2%

3.3.2 Hydrochemical evaluation

In the majority of samples evaluated, the laboratory precision is suitable according to the determined plausibility, except for sample D/Well01. However the error is small and for the purpose of hydrochemical characterisation, the analysis is deemed to be of suitable precision. Major findings from the 2013 baseline study are listed below (refer to Figure 3-16):

- Groundwater quality of the selected sampling sites is in accordance with most constituent concentration limits specified in SANS 241:2011. Exceptions include elevated fluoride which is a consequence of the fluorspar deposits in the study area, manganese which is commonly associated with dolomite aquifers and elevated selenium which was only observed in the May 2013 monitoring data, this trend should be evaluated in future monitoring.
- Boreholes sampled in Compartment 9 indicate water qualities associated with external impacts if compared to sites showing a typical rock water interaction fingerprint.
- The current land uses do not negatively impact on groundwater quality in the study area.
- The water chemistry in the study area typically has a Ca-Mg-HCO_3 signature which is indicative of freshly recharged groundwater. The low chloride concentrations observed in groundwater coupled with moderate rainfall conditions is further evidence of high recharge on the dolomite aquifers.

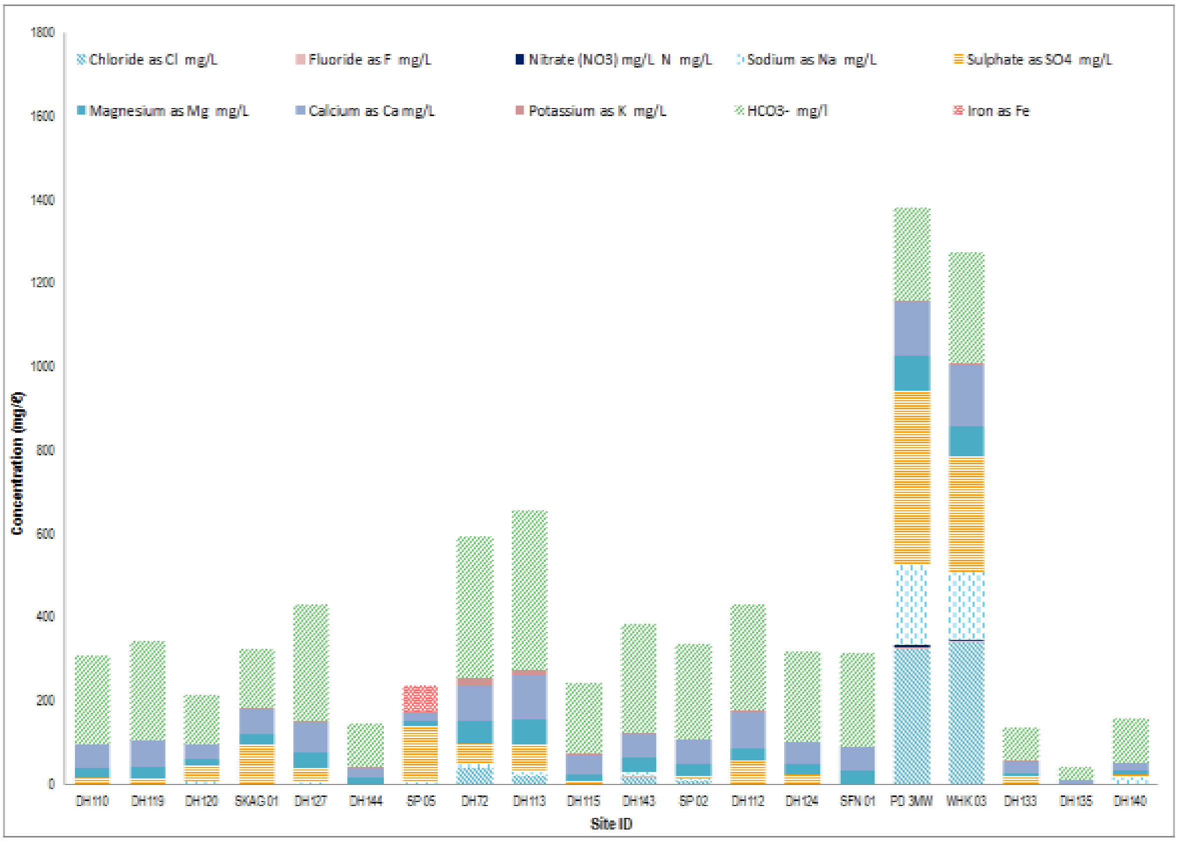

Figure 3-16 **Composite bar chart baseline hydrochemistry (2013)**

Major findings from the 2016 sample analysis are listed below (refer to Figure 3-17, Figure 3-21):

- Groundwater quality of the selected sampling sites is in accordance with most constituent concentration limits specified in SANS 241:2011. As reflected in the baseline water quality data (2013) fluoride (D/BH01, D/BH12) and manganese (BH10, BH14) are still elevated (Figure 3-22).
- Sampling localities D/BH01, D/BH04 and D/Well01 indicate elevated nitrate levels.
- Dominant ions of water sampled still reflect a Ca-Mg-HCO3 signature which is indicative of freshly recharged groundwater (Figure 3-18).

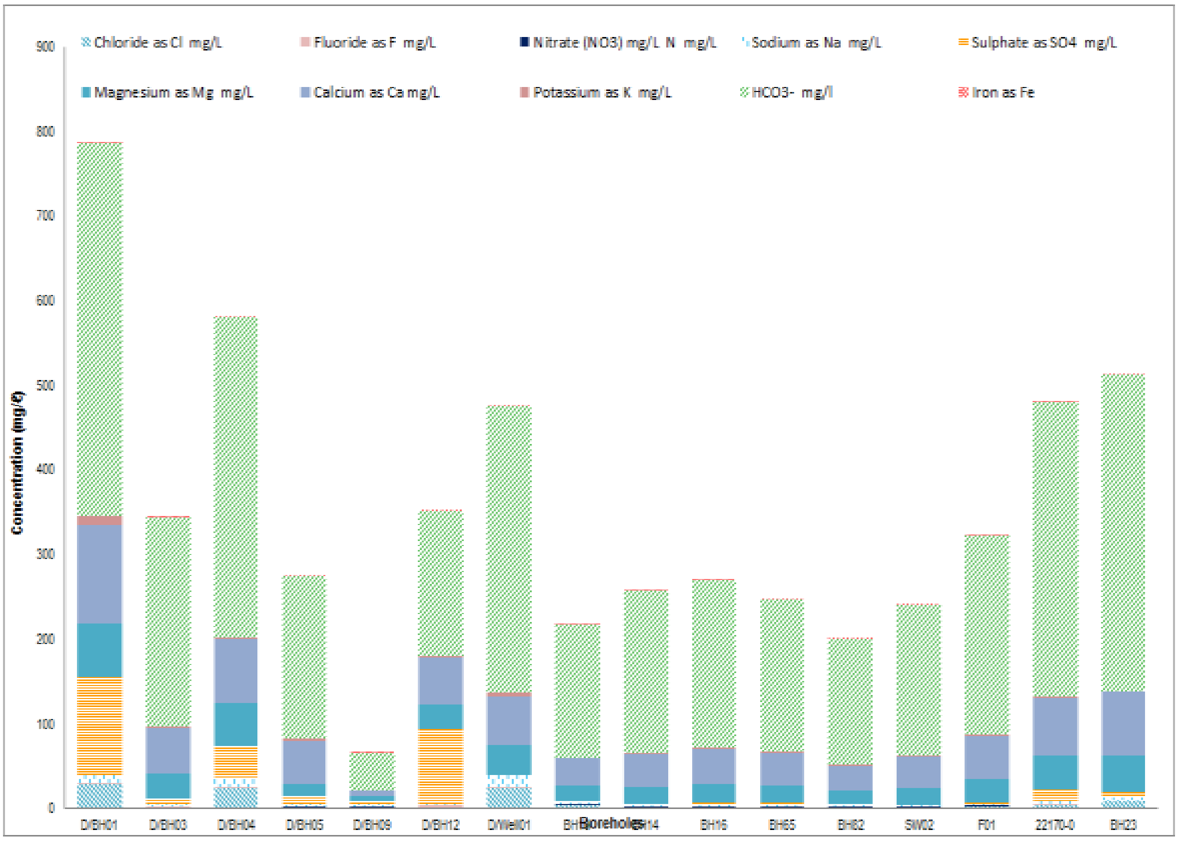

Figure 3-17 **Composite bar chart hydrocensus 2016 hydrochemistry**

3.3.3 Hydraulic connectivity

Figure 3-19 represents a piper diagram comparing groundwater sampling localities (pre-and post-pump testing) surface water sampling localities as well as spring localities. Figure 3-20 depicts the hydrochemical composition of sample locality D/BH04 (in close proximity to surface water body), compared to surface water locality, SW02 i.e. upstream sample of the Klein Marico River. Should there be a direct hydraulic link between the river and the local aquifer, one would expect that the chemical composition of D/BH04, after the duration of the pump test conducted, would more closely reflect the hydrochemical composition of SW02. This is not the case and no direct link between the aquifers and surface water features could be clearly verified. It should however be noted that the river system is assumed to be a gaining river, with groundwater base flow discharging and feeding regional drainages.

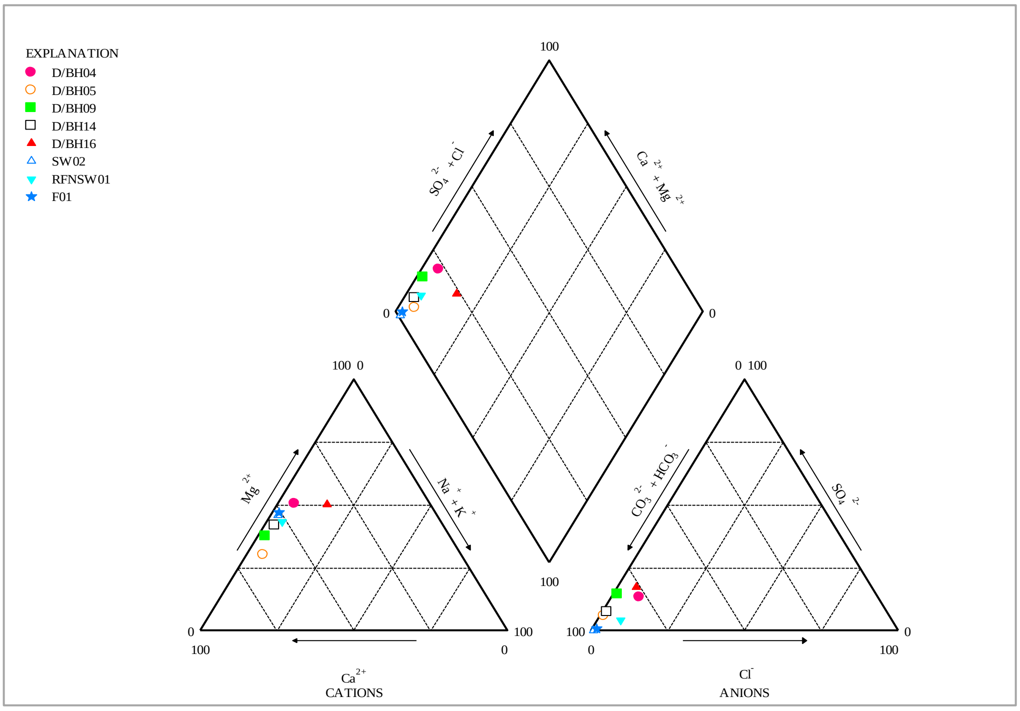

Figure 3-18 Piper diagram depicting hydrocensus 2016 surface water and groundwater dominant ions

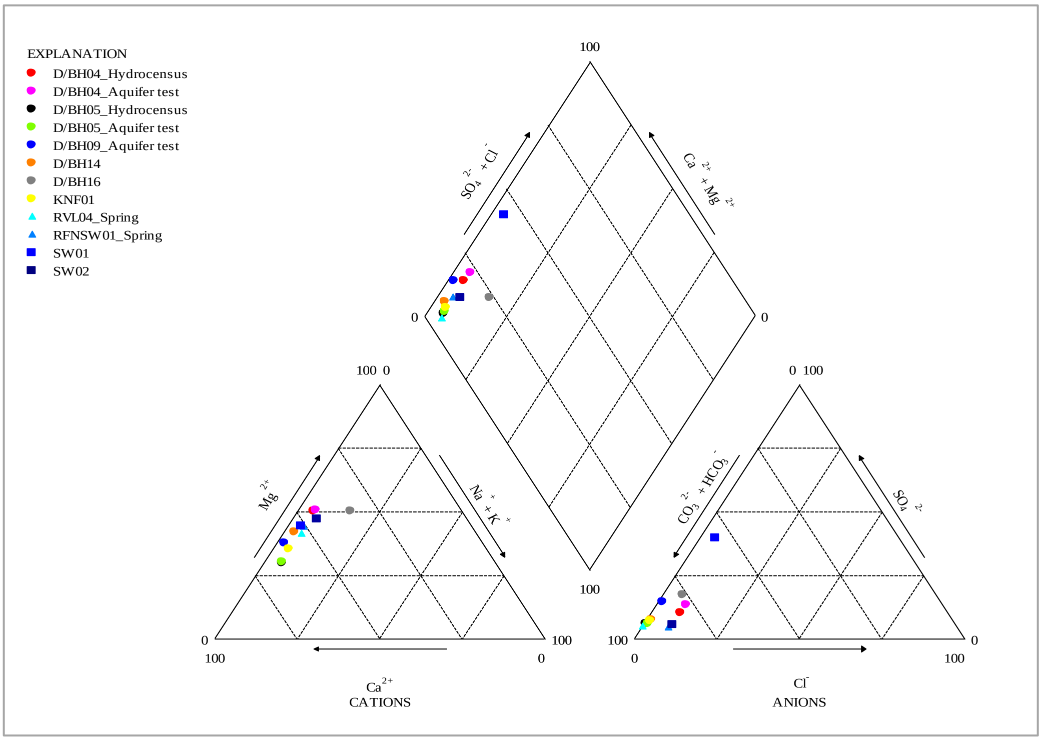

Figure 3-19 Piper diagram depicting a comparison of dominant ions between pump tested boreholes, surface water localities and sampled springs

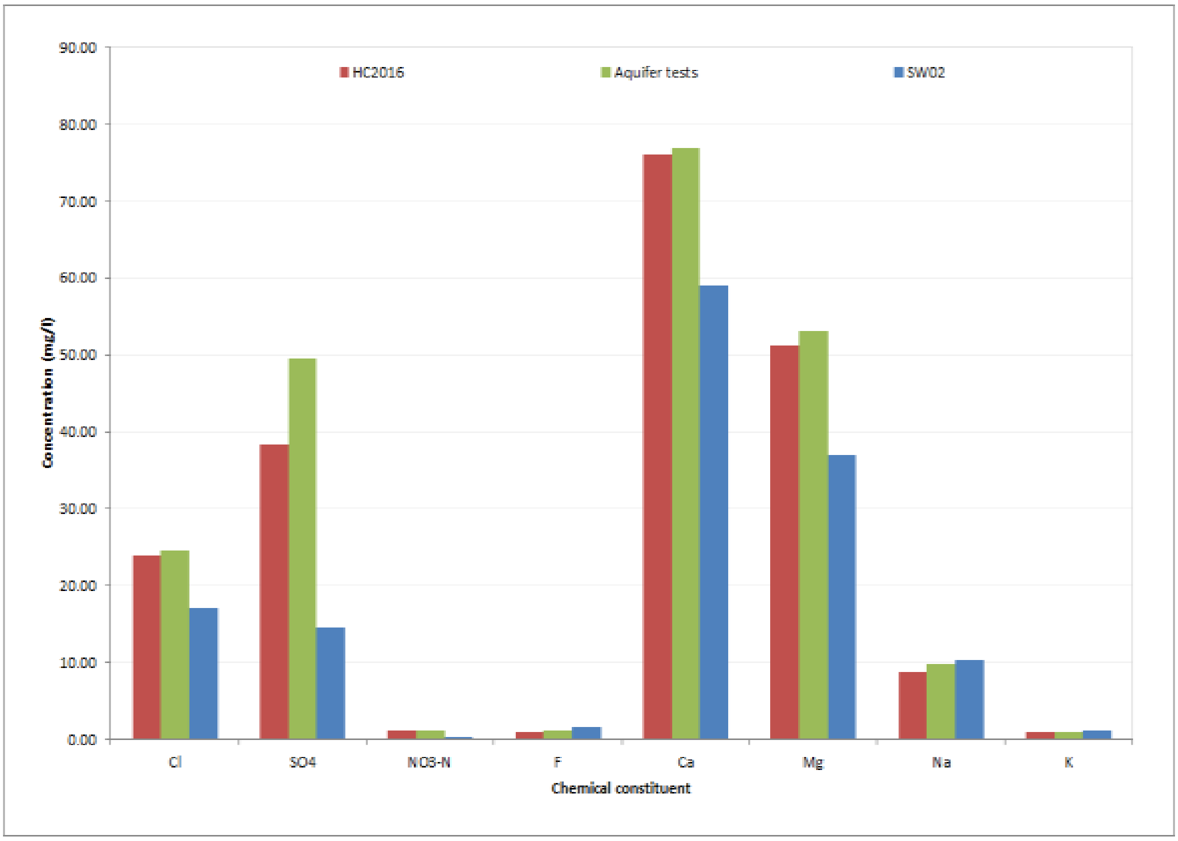

Figure 3-20 **Bar chart hydrochemical comparison**

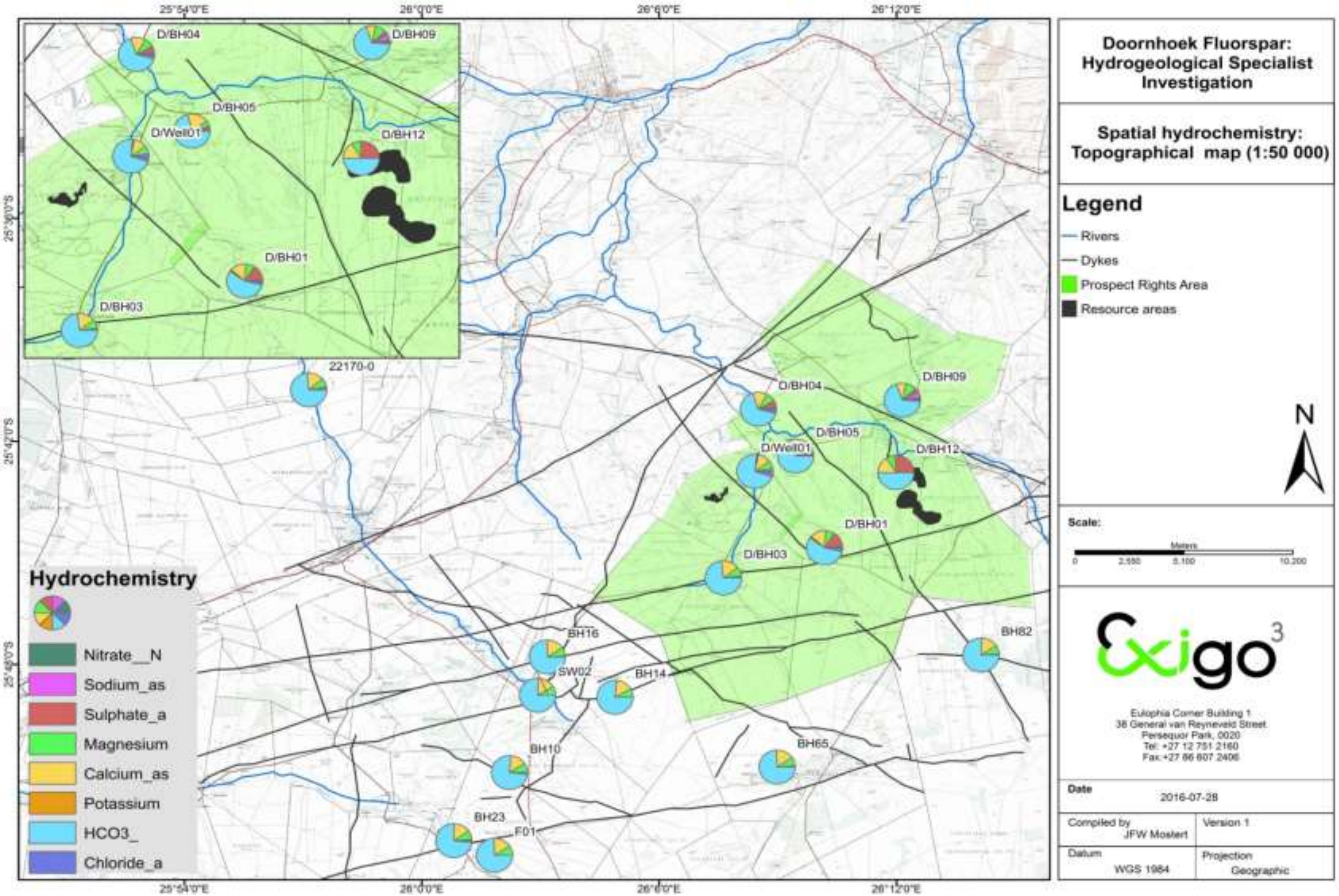

Figure 3-21 **Spatial distribution hydrochemistry**

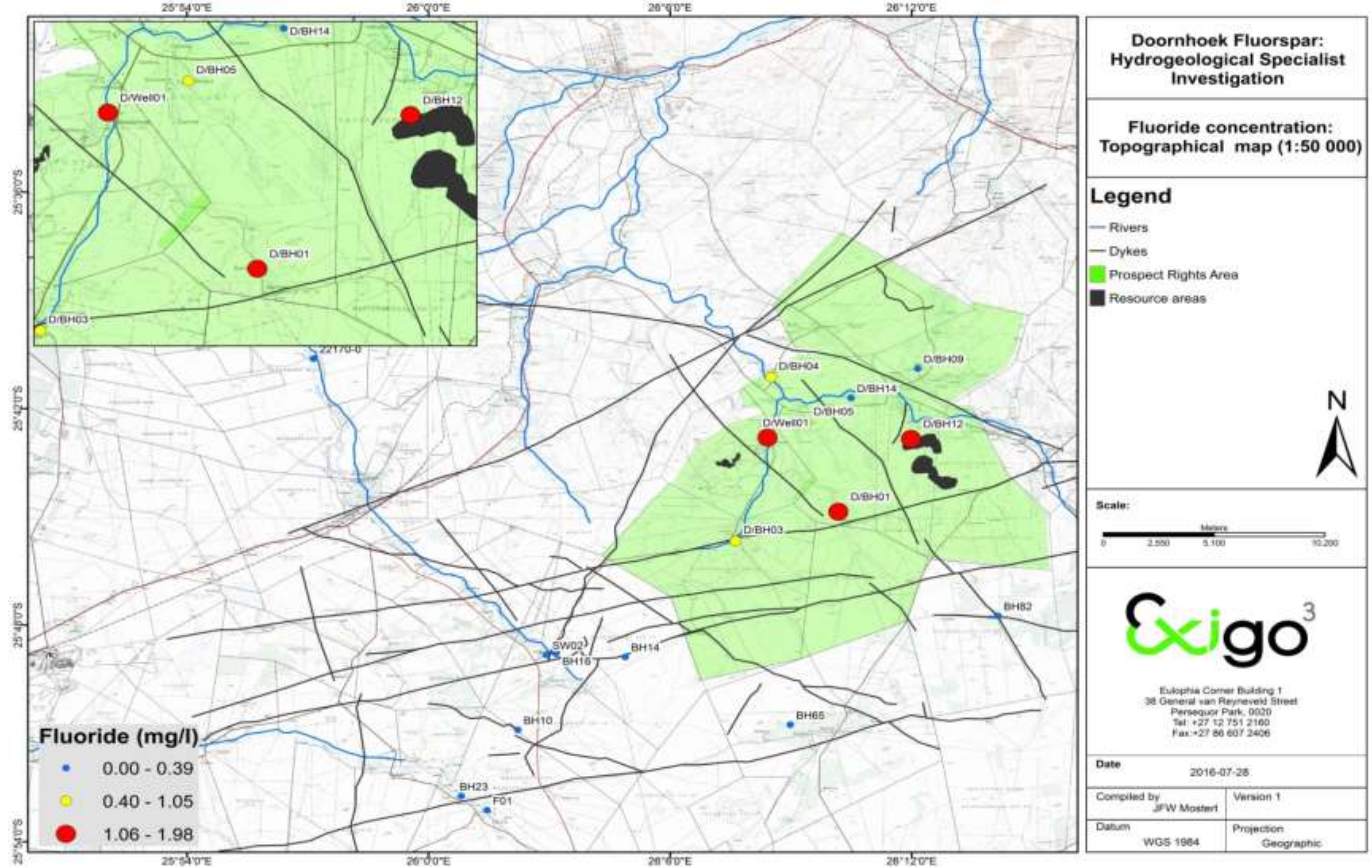

Figure 3-22 Spatial distribution fluoride concentration

4 NUMERICAL GROUNDWATER FLOW MODEL

4.1 Introduction

A numerical groundwater flow model has been utilised to aid in decision making, understanding the sensitivity of the system and provide focus to the field work to be conducted in ensuing phases of this project. Previously, limited field work has been conducted and the historical model was viewed as high level and has been qualified rather than calibrated. The fieldwork component was updated as detailed in Section 3 Site investigation and this data was used in the model reconstruction, recalibration and additional simulations.

In addition, the client supplied updated mining schedules and mine site layouts. This data was used in the update of the numerical model as well as the detailed simulations.

4.2 Objectives

The key objectives of this study are listed below:

1. Determine whether the existing spatial distribution of measured heads adequately describe the heterogeneity within the model domain.
2. Simulate the proposed mining activities and ascertain the potential impacts on the local groundwater regime.
3. Assess the possible impact on the local groundwater regime i.e. water levels, availability and quality. Also assess impact on local drainages/rivers with regards to possible surface water flow reduction and water quality impact.

4.3 Project description

The following information was used in the setup and simulations of the groundwater flow and mass transport model:

The project has the potential to contain a large fluorspar resource which could sustain a mining operation well into the future. The deposit hosts both surface and underground resources sufficient to justify an initial life of mine of 30 years. At full production the resource is proposed to be mined at 1.5 million tonnes per annum as follows:

- Resource Area A: Opencast mining up to a maximum depth of approximately 60 m from year 5 to 10. The average depth would be 30 m in the basin, however, 60 m depth were simulated as a conservative approach.
- Resource Area C: Opencast mining up to a depth of approximately 90 m from year 20 to 30.
- Resource Area D: Opencast mining up to a depth of approximately 90 m from year 10 to 20 with the possible mining of the areas to the side of the resource taking place from year 20 to 30.

4.4 Assumptions and limitations

As described above, this model is viewed as high level and has been qualified rather than calibrated. Identified data limitations include:

1. Falling head tests as well as aquifer tests were conducted to determine hydraulic conductivity.
    a. The spatial extent of the aquifer tests were enlarged as to obtain more aquifer parameters to use in the model setup and recalibration. Hydraulic conductivity values are available for the dolomite and dolerite dykes. No hydraulic conductivity values are available for the shale and conglomerate units north of the focus area. As such the hydraulic conductivities of the latter units has been assumed from literature and qualified through development of the model.
2. The concept of representative elementary volumes have been applied i.e. a scale has been assumed so that heterogeneity within a system becomes negligible and thus can then be treated as a homogeneous body i.e. the mapped dolomite are treated as a uniform unit.
3. Recharge to the aquifer units is unknown and has been assumed from data collected in similar hydrogeological settings.
4. Groundwater abstraction rates are based on the WARMS database. Additional abstraction rates were assigned based on the aquifer tests concluded (Table 3-2).
5. The aquifer is assumed to be compartmentalized by semi-impermeable dyke structures.
6. As the proposed mining depth is expected to terminate at 90 mbgl, the aquifer thickness is assumed at 150 m. This assumption was made as there is no hydrogeological significant unit delineating the aquifer bottom.
7. The rivers in the area have been treated as gaining type streams. As such groundwater is lost from the system via base flow to streams. The aquifer is not however being replenished by losing stream conditions. As the area is characterised by non-perennial rivers this assumption is viewed to be valid.
8. Groundwater divides have been assumed to align with surface water divides. It is assumed that groundwater cannot flow across this type of boundaries.
9. It is assumed that recharge does not vary seasonally with changes in rainfall.

4.5 Model set-up

The following sub sections describe the conceptual model and input parameters of the numerical model.

4.5.1 Software and mesh

The proposed mine and surrounding groundwater catchment has been described by developing a three dimensional numerical model on the finite element simulation system for subsurface flow and transport process, Feflow®.

The model domain has an aerial extent of 906 km^2 and has been described by a two layer model consisting of triangular mesh comprising 1 171 197 nodes and a corresponding 1 558 478 elements. The mesh was developed to explicitly incorporate hydrogeological boundaries, rivers and known boreholes. Within the focus area the element density has been increased, while a coarser mesh was applied to the elements on the periphery of the model where little data was available. The mesh quality is described below:

- Delaunay violating triangles 2.2%
- Interior holes: 0
- Obtuse angles: 1%> 120^0, $21.2^{\%}$ > 90^0.

4.5.2 Boundary conditions

The external boundaries of the model were delineated to coincide with topographical features such as surface water divides, rivers and drainage lines, cognisance of the underlying geology was however also considered in development.

- Hydraulic head boundaries (Blue): The rivers are defined as hydraulic head boundaries where the fixed head is assumed to be equal to topographical elevation. A maximum flow constraint of zero has been applied to the boundary condition in order to simulate gaining type rivers systems i.e. the rivers remove groundwater from the system but do not recharge the aquifer zones. Sensitivity scenarios i.e. possible influence of the Klein Marico River on mine dewatering volumes was simulated.

- No Flow type boundaries (Green): As mentioned, groundwater divides have been assumed to correlate with surface water divides. Thus all water sheds have been defined as no flow type boundaries i.e. boundaries where flow lines are parallel with boundary.

4.6 Sources

Recharge is the primary source of inflow to the model domain. Due to a lack of suitable field data for estimating recharge, initial values for model development were derived from literature. The probable recharge values were determined through model qualification; these values are provided in Table 4-1 below.

4.7 Sinks

Since the closure of the Witkop mine the primary sink in the catchment is groundwater abstraction for livestock watering and domestic purposes. The volume of water abstracted and the distribution of abstraction boreholes was sourced from the WARMS data base. The distribution of abstraction wells simulated within the flow model is depicted in Figure 4-6.

4.7.1 Aquifer parameters

Hydraulic conductivity for model development was obtained from falling head tests, aquifer tests and literature. Through model qualification process hydraulic conductivity values describing the aquifer zones were determined. The hydraulic conductivity values of the calibrated model are provided in Table 4-4.

Storativity values were assumed from literature as no suitable tests have yet been conducted to calibrate the model to obtain storage parameters.

4.7.2 Schematic Conceptual model

The components of the conceptual model described in the previous subsections are displayed schematically in Figure 4-1.

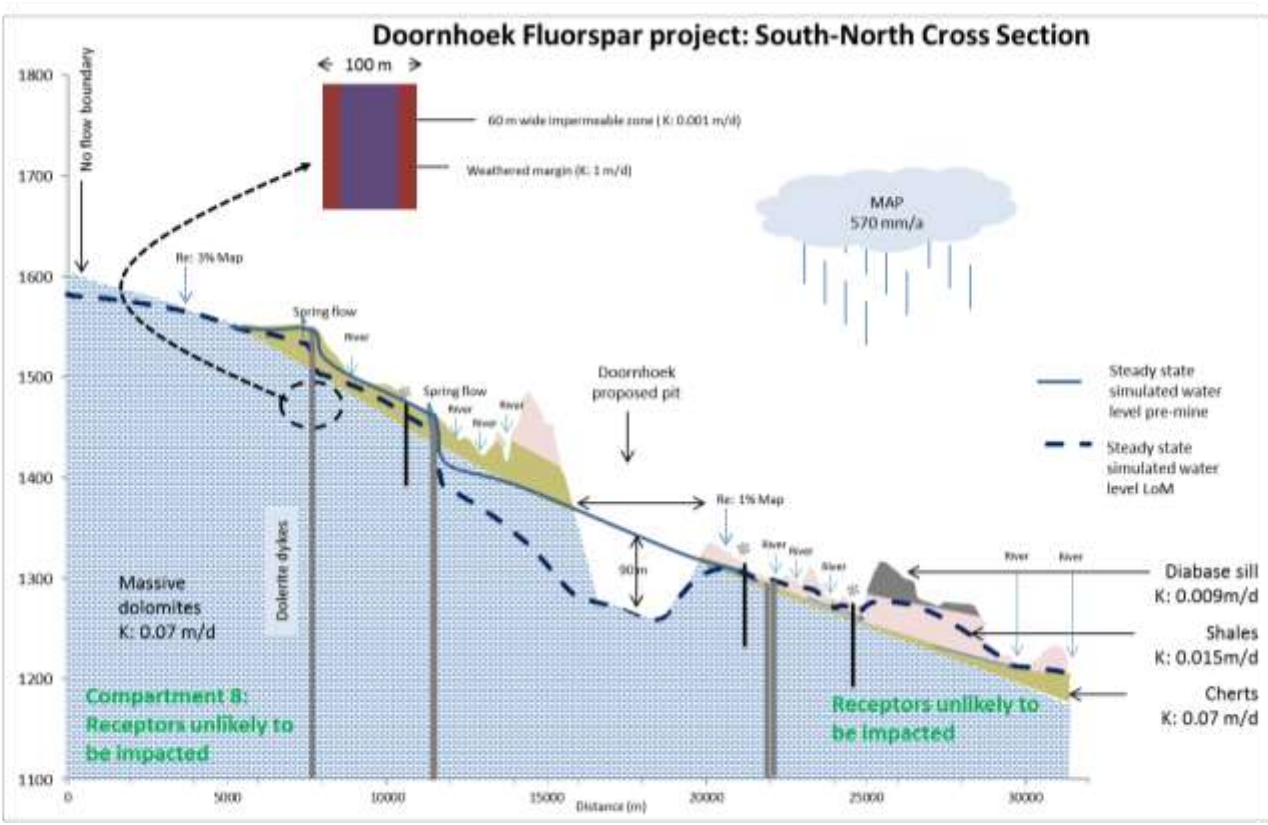

Figure 4-1 Conceptual model

4.7.3 Summary of model inputs, data sources and uncertainty

Model input parameters, data sources and data uncertainty are provide in Table 4-1, below

Table 4-1 Model input parameters, data sources and uncertainty

Input parameter	Scale	Source, parameter or assumption description	Data uncertainty
Topography (DEM)		The topographic elevations were interpolated from the 1:50 000 scale 20 m contour intervals as well as the Lidar survey.	Low
Rivers, streams, drainages	1:50 000	Digitised from topographical maps and aerial imagery.	Low
Lithology	1:250 000	GCS geological map sheets - Rustenburg (2526)and Mafikeng (2426) and ENRC detailed mapping	Moderate
Geological structures		High resolution aerial magnetic surveys. While the positions and extent are known the hydraulic characteristics are associated with uncertainty.	Moderate
Mine Layout		A mine layout was supplied by the client	Low
Boreholes and pumping rates		AGES hydrocensus 2013, Exigo Monitoring 2013 -2015, WARMS and aquifer tests conducted during 2016.	Moderate
Rainfall		Collected from rainfall stations within the catchment.	Low-moderate
Steady State Modelling Parameters – Flow Model			
Boundary conditions		Northern model boundary – Fixed hydraulic head boundary with a max flow constraint = 0 m^3/d	Low-moderate
		Eastern, western and southern boundaries are no flow boundaries correlating with surface water divides.	Low-Moderate
		Rivers and drainages within the model domain are described by fixed head boundary conditions and maximum flow constraints of 0 m^3/d. Similarly the dyke structures are assigned as seepage faces so as to simulate spring flows within the model domain.	Low-moderate
Recharge		Recharge could not be estimated from the existing data and was assumed from literature and refined through model qualification.	Moderate
Hydraulic Conductivity		The hydraulic conductivity was estimated from falling head tests literature and aquifer test.	Low
Aquifer thickness		The aquifer thickness is 150 m – the aquifer likely extends deeper than 150 m however no data exists to validate the exact depth.	Moderate
Transient State Modelling Parameters & Mass transport model			
Initial Hydraulic Heads		Simulated heads obtained from simulated steady state conditions as calibrated.	Moderate
Specific Storage		The volume of water that a unit volume of aquifer releases from or takes into storage per unit change in head. $S = S_s \times D$. S_s, refer to Section 4.4.4	High
Effective Porosity		Porosity is the ratio of the volume of void space to the total volume of the rock of earth material. Assumed conservative porosity of 3% was used in the transient simulations.	High
Longitudinal dispersion coefficient		No field work has been conducted to determine the dispersivity. An approximation of 20 m was used.	High
Transverse dispersion coefficient		Transverse dispersivity was assumed to be 10 x smaller than the longitudinal dispersivity (2 m)	High

4.8 Simulation 1: Model qualification and calibration

Based on the conceptual model described above, a numerical model was developed. Under steady state conditions the groundwater flow equation is reduced to exclude storativity and only transmissivity (or hydraulic conductivity) and recharge are considered in the model qualification[1] process. Qualification is the process of adjusting model parameters (hydraulic conductivity and recharge) until a suitable error between simulated and measured hydraulic heads is achieved[2].

Two sets of data points were used in the recalibration of the three dimensional groundwater flow model. A regional set of groundwater data points gathered during the 2016 updated hydrocensus and consists of 78 points, the summary is provided in Table 4-2.

Table 4-2 Summary of regional calibration points

Detail	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
Average	**14.35**	**-8.59**	**330.19**
Minimum	**0.49**	**-61.57**	**0.24**
Maximum	**61.57**	**20.23**	**3791.27**
Correlation	Σ = 1061.56	Σ = -635.43	Σ = 24434.37
	1/n = 14.35	1/n = -8.58	1/n = 330.19
			SQRT = 18.17
			RMS% of water level range = 7.08%

The second is focussed group of data points gathered around the proposed site. This set of points consists of 48 points and the summary of the calibration is provided in Table 4-3.

Table 4-3 Summary of focussed calibration points

Detail	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
Average	**10.03**	**-9.14**	**233.06**
Minimum	**0.34**	**-70.26**	**0.12**
Maximum	**70.26**	**8.27**	**4937.10**
Correlation	Σ = 481.60	Σ = -438.87	Σ = 11186.84
	1/n = 10.03	1/n = -9.14	1/n = 233.06
			SQRT = 15.27
			RMS% of water level range = 6.08%

1The terminology qualification has been used over model calibration due to limited data used for development of this model. Additional field work will be required in or to decrease uncertainty and produce a calibrated model over a qualified model.

2 Spitz and Moreno (1996) specify a normalized root mean square error of less than 5% is deemed suitable for model qualifications

The steady state model was deemed calibrated based on the acceptable percentages of Root Mean Square Errors obtained for both datasets i.e. <10%.

The calibrated hydraulic parameters are provided in Table 4-4.

Table 4-4 Calibrated aquifer parameters

	Lithology	Layer	Thickness	Transmissivity	Kx,y	Kz	Storage Coefficient
1	Chert Poor Dolomite	1	10	7	0.7000	7.00E-01	5.60E-04
2	Chert rich Dolomite		10	7	0.7000	7.00E-01	5.60E-04
3	BIF		10	7	0.7000	7.00E-01	5.60E-04
4	Banded Dolomite and Chert		10	14	1.4000	1.40E+00	5.60E-04
5	Chert Free Dolomite		10	7	0.7000	7.00E-01	5.60E-04
6	Dark Chert Free Dolomite		10	7	0.7000	7.00E-01	5.60E-04
7	Dolerite		10	7	0.7000	7.00E-01	5.60E-04
8	Quartzite		10	1.5	0.1500	1.50E-01	5.60E-04
9	Shale		10	1.49	0.1490	1.49E-01	2.00E-05
10	Surface Deposits		10	50	5.0000	5.00E+00	4.00E-03
11	Dyke		10	0.1	0.0100	1.00E-02	5.60E-04
12	Dyke Contact		10	100	10.0000	1.00E+01	5.60E-04
13	Chert Poor Dolomite	2	140	21	0.1500	0.15	5.60E-04
14	Chert Rich Dolomite		140	21	0.1500	0.15	5.60E-04
15	BIF		140	21	0.1500	0.15	5.60E-04
16	Banded Dolomite and Chert		140	28	0.2000	0.20	5.60E-04
17	Chert Free Dolomite		140	21	0.1500	0.15	5.60E-04
18	Dark Chert Free Dolomite		140	21	0.1500	0.15	5.60E-04
19	Dolerite		140	21	0.1500	0.15	5.60E-04
20	Dyke		140	0.1	0.0007	0.00	5.60E-04
21	Dyke Contact		140	100	0.7143	0.71	5.60E-04

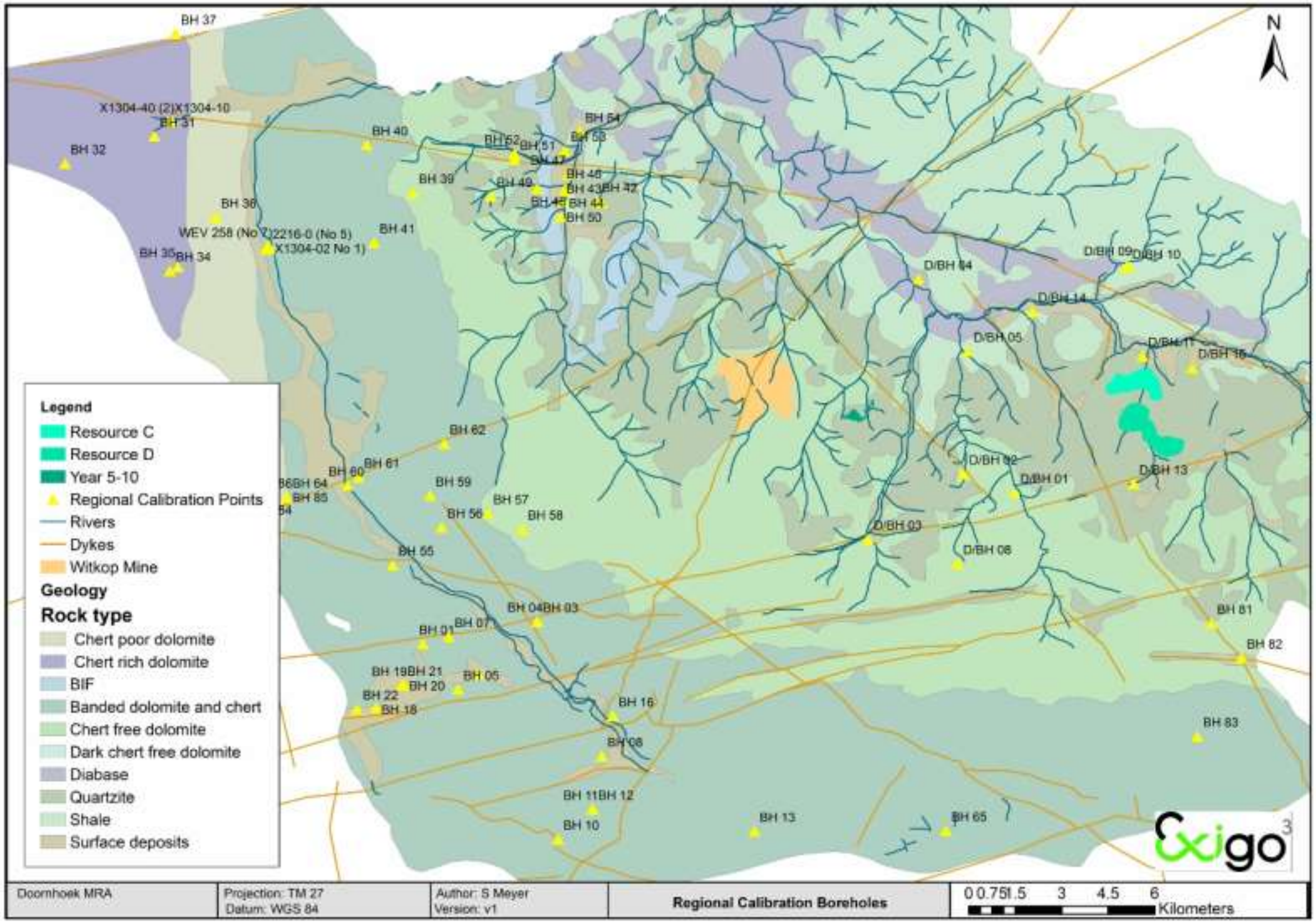

Figure 4-2 **Regional calibration boreholes**

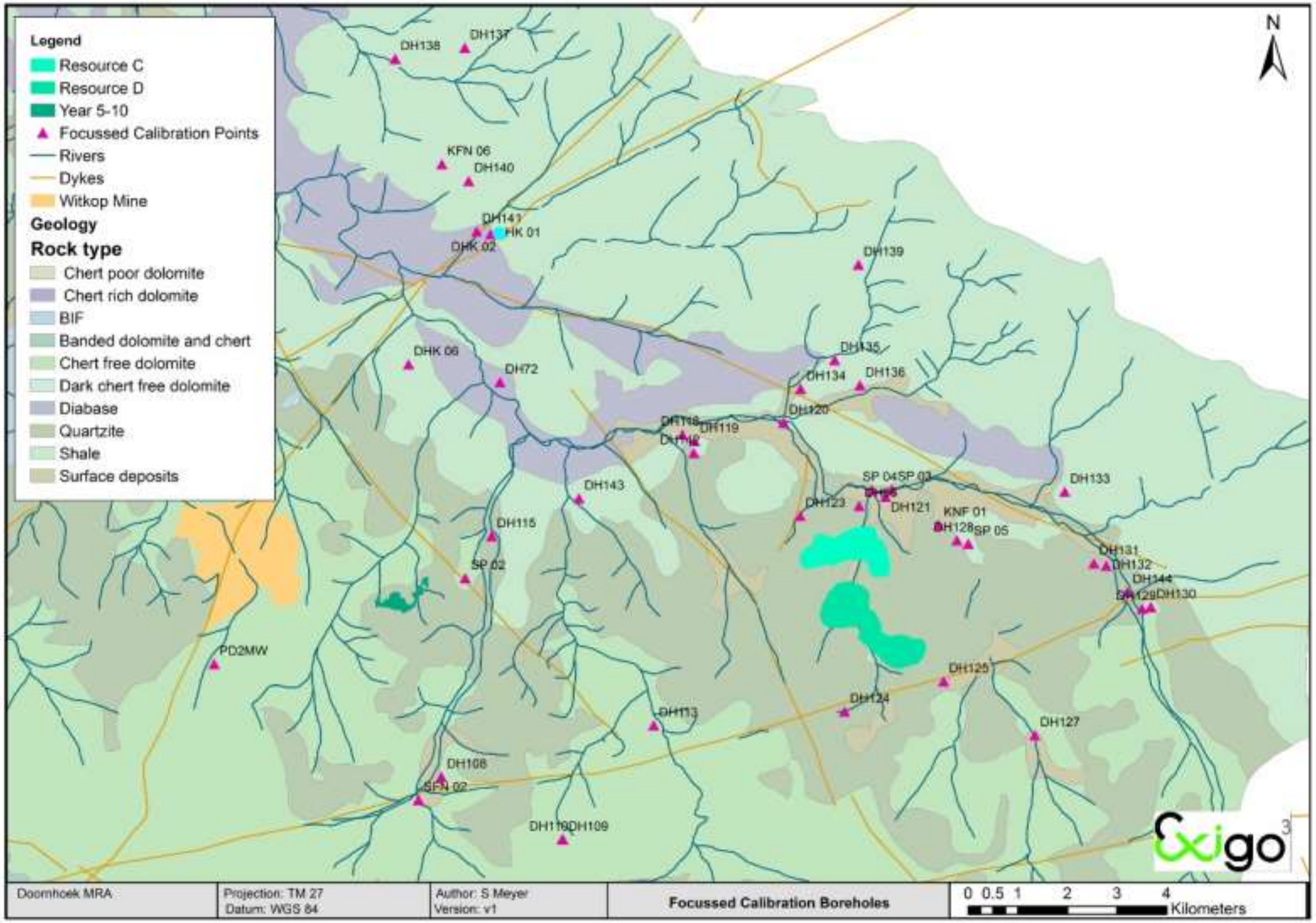

Figure 4-3 **Focussed calibration boreholes**

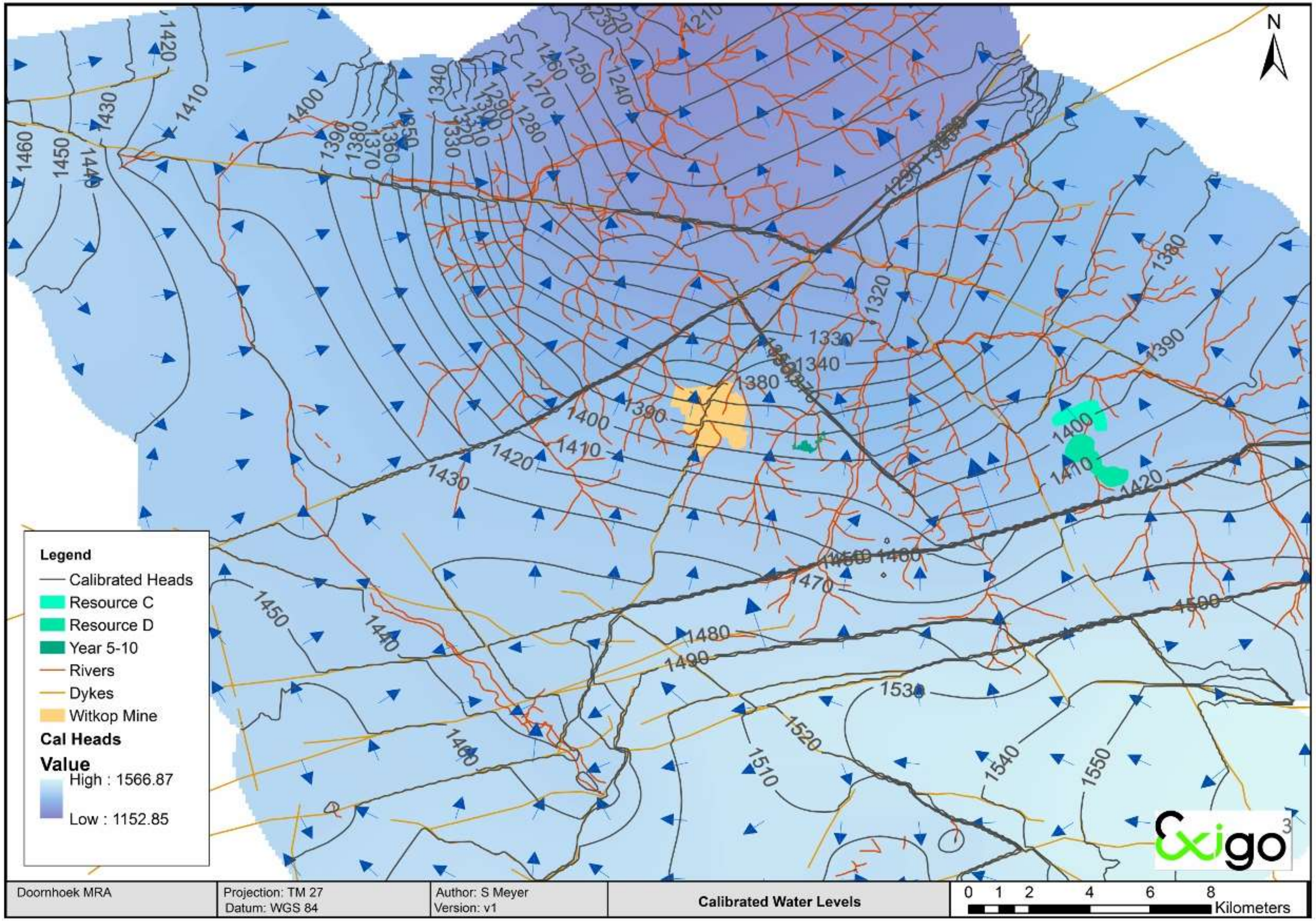

Figure 4-4 **Steady state calibrated heads and flow contours**

4.8.1 Management scenarios

In order to reach the model objectives the following scenarios will be simulated:

1. Review of sensitivity analysis and uncertainty analysis:
2. Determine the area of impact associated with the mine development under steady state conditions
3. Determine area of impact associated with transient dewatering of mine.
4. Determine suitable areas for placement of mine residue facilities so as to reduce the possible impact associated with the facilities.

4.8.2 Summary of model sensitivity

- The model shows negligible sensitivity to transmissivity in a range ±10% of the base case. Thus limited additional data will be required to constrain the transmissivity of the country rock.
- The model shows negligible sensitivity to a reduced recharge of 10% relative to base case and marginal sensitivity to increased recharge of 10% relative to base case.

4.9 Simulation 2: Transient mine dewatering and water supply simulation

4.9.1 Setting the scene on resource management

Impacts are associated with development and the management and mitigation of the possible impacts correlates with sustainable development. The area under investigation needs to be understood before any impacts can be qualified and/or quantified and then only proper management scenarios be implemented.

Registered Water Users

The registered water users located in quaternary catchments A31D and A31C were sourced from the Department of water affairs (DWA) Water use authorisation and registration management system (WARMS). Water users that do not receive their water from a service provider, local authority, water board, irrigation board, government water scheme or other bulk supplier and who are using water for irrigation, mining purposes, industrial use, feedlots, or in terms of a General Authorisation must register on this database.

The registered water users per compartment are provided in **Table 4-5**. There are 50 registrations in the vicinity of the proposed mine. Twelve of these registered users occur within compartment 1 are thus likely to be effected by mine dewatering at the proposed operations. Three recorded springs are also in compartment 1. The largest number of registered users occurs in compartment 19 east of the focus area and across the Klein Marico River.

The compartment with the highest registered water use is compartment 9. These allocations are registered to the Witkop Mine operation. This operation is however no longer active and this allocation is unlikely to be utilised annually.

The number of registered water users indicates that the area under investigation and possible influence by the proposed mining activities are very sensitive and proper management scenarios are required.

Table 4-5 Registered Water Users- Warms database

Compartment	No of registrations	Total of all registered volumes (m^3/a)
Compartment 1	12	194517
Compartment 19	20	234977
Compartment 2	4	59757
Compartment 20	6	257710
Compartment 3	2	96606
Compartment 4	2	86880
Compartment 5	2	116741
Compartment 9	2	2324000
Total	50	3371188

Crocodile (West) Marico Water Management Area Internal Strategic Perspective (ISP)

The National Water Act (NWA, 1998) requires that for each Water Management Area (WMA) a Catchment Management Agency (CMA) be established. The CMA will guide the management of the water resources of the WMA. The Marico, Upper Molopo and Upper Ngotwane catchments are part of the Crocodile (West) and Marico WMA.

Commercial irrigation, urban water use and rural domestic water use forms the three major water user sectors. Irrigation is the major water user in the greater Marico area along the Groot Marico River and the Klein Marico. The major source of supply to the water users and uses are the dolomitic aquifers of the Grootfontein compartments and the Molopo Springs.

The ISP found that the available water resources of the Marico catchments do not meet the water requirements at the appropriate levels of assurance of supply i.e. the catchments are in deficit. The ISP also found that the available water resources of the catchments are not well understood, especially the long term sustainable yield from groundwater resources abstracted from dolomites. Groundwater is widely available in chert horizons and karst zones with borehole yields between 5 and 20 L/s common and feasible. The aquifers in the catchments are important sources of stream base flow for the Groot Marico and the tributaries (DWAF, 2004).

In essence, the ISP concludes that groundwater management in the catchments are of utmost importance. The current water balance indicates a deficit in supply versus demand and little to no possibility of surface water resources being established. Groundwater resources is the only viable option, provided the development is accompanied by a detailed analyses and license application process.

Additionally, certain strategies such as alien vegetation eradication along the Klein Marico riparian zones will increase the water balance and possibly off set negative impacts.

4.9.2 Mine sequence and detail

A detailed mine plan and site layout with alternatives was provided by the client. The mine schedule and alternatives was evaluated as part of this study and incorporated into the numerical groundwater flow model (Figure 4-5, Figure 4-6).

The mining sequence was incorporated into the groundwater flow model as shown in Figure 4-5.

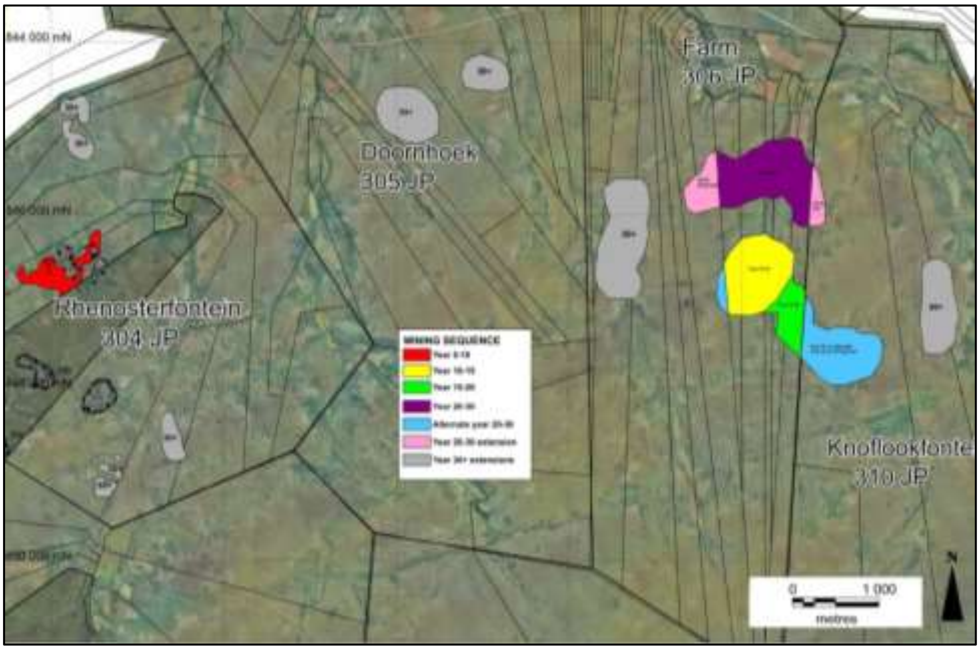

Figure 4-5 **Planned mining sequence (Client)**

4.9.3 Constrained versus Unconstrained flow from the Klein Marico River

Two scenarios for potential mine dewatering rates were simulated, i.e. all rivers constrained, i.e. the Klein Marico River contributes zero volumes to mine dewatering. Secondly, the Klein Marico River was constrained such that the potential inflows do not exceed the Mean Annual Run-off from the mine area catchment (Figure 4-7). As discussed in section 3.2, a possible link does exist between the surface water (Klein Marico River) and the groundwater i.e. currently under pristine conditions the river is classified as a gaining river – groundwater reports as base flow and contributes to the surface water flow.

Should the hydraulic gradients be reversed due to mine dewatering, possible leaking from the Klein Marico River to the groundwater might be induced. Thus the need to simulate constrained versus unconstrained flow in the Klein Marico River to obtain a sense of possible volumes. The river basin and possible flow is constrained by the lithological type and associated parameters.

Also, flow will occur through discrete fractures. The characteristics and presence of these potential fracture zones / hydraulic links between the proposed open pits and Klein Marico River should be investigated in the next phase with the following:

1. Detailed geophysical traverses to map the subsurface geological scene between the Klein Marico River and Recourse C.
2. Drilling of aquifer characterization boreholes on discrete fractures zone and/or zones of preferential flow.
3. Long term aquifer tests of the boreholes (96 hours+). The hydraulic regime should be stressed maximal and samples taken every 4 hours for isotopic analyses and fingerprinting. Samples of the Klein Marico should also be taken and analysed for leakage. The tests will confirm a possible link and mixing ratios between groundwater and surface water.

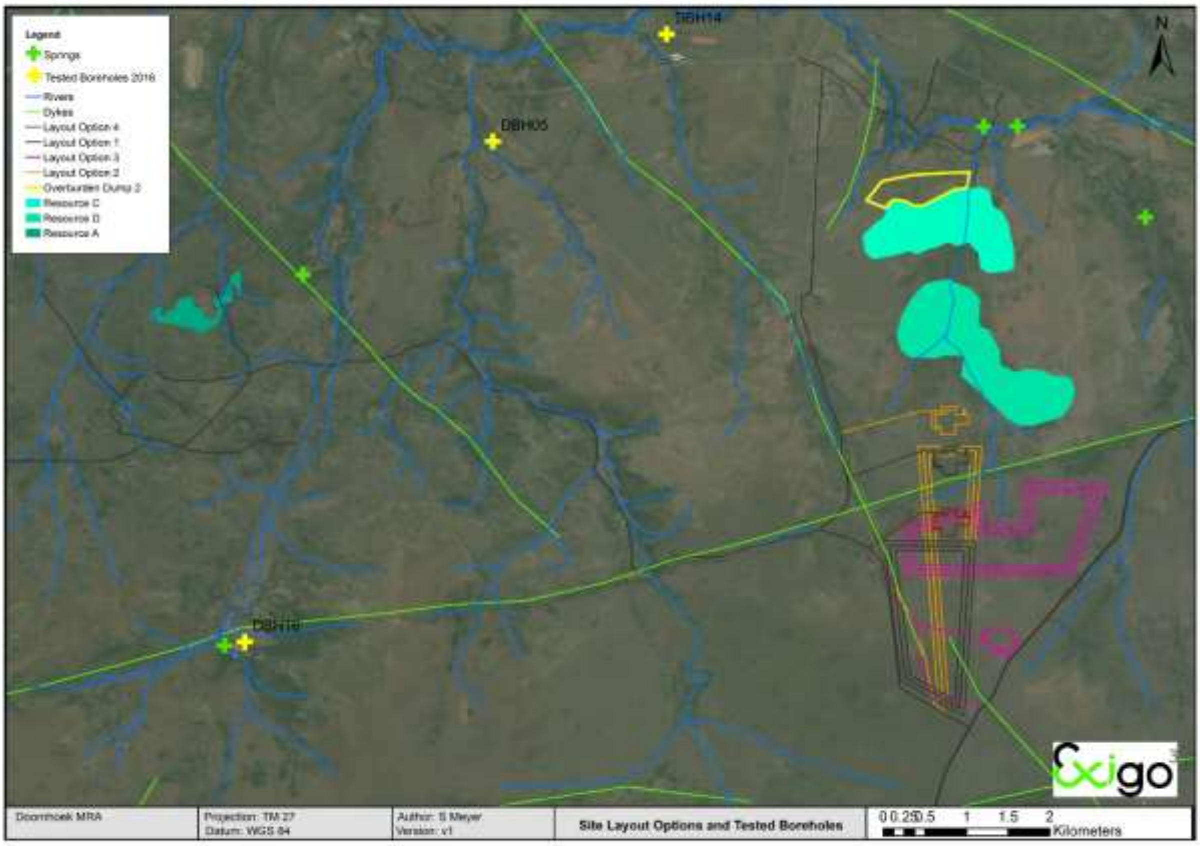

Figure 4-6 **Site layout options and alternartives with water supply boreholes**

As shown in Table 4-6 and Figure 4-7 the MAR for the mine catchment is approximately 55 L/s (4800 m^3/d) correlating to a runoff coefficient of 2% compared to the 250 L/s for the quaternary catchment A31D. The maximum influence i.e. reduction of flow could be approximately 20% of the runoff in the A31D quaternary catchment.

The constraints on the Klein Marico River north of the proposed open pits were assigned such that a maximum of 4800 m^3/d would be able to potentially flow into the modelled open pit. The actual volume reporting to the open pit is a function of the hydraulic conductivity of the underlying layers i.e. quartzites and shales and the gradient induced by the mine advancement.

In the follow up phase additional analyses should be done to investigate the influence of droughts and floods on the potential inflow volumes and vice versa.

Table 4-6 Mean Annual Runoff (MAR) from mine catchment

	Quad A31D	Mine catchment
Catchment area (m^2)	704,014,193.00	155,820,661.00
MAP (mm/a)	566.00	566.00
MAP (m^3/a)	398,472,033.24	88,194,494.13
MAR (m^3/a)	7,910,000.00	1,750,733.78
MAR (L/s)	250.82	**55.52**
MAR % of MAP	1.99	

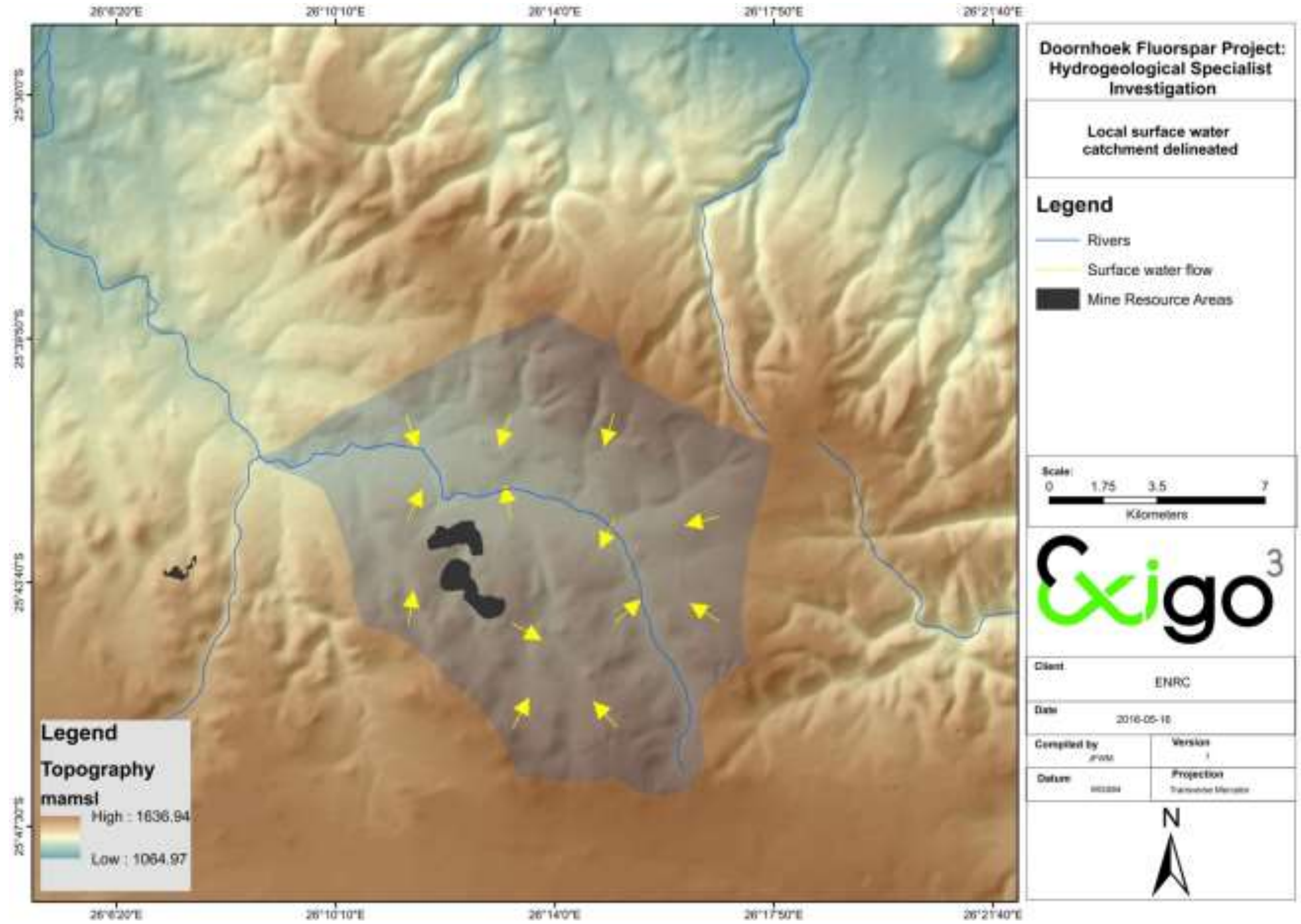

Figure 4-7 Mine area cathcment for MAR assessment

The influences of droughts and floods should be included in the updated modelling scenarios for planning purposes. The influence should be studied in the next phases and impacts simulated on the potential dewatering rates.

The mine dewatering model was simulated for a total of 30 years Life of Mine (LoM). Each open pit was simulated discretely and individual dewatering volumes were calculated for each pit.

- The estimated inflows during LoM are expected to initiate between year 9 and year 10 at the Year 5 – 10 open pit (Resource A). This pit was simulated to only reach a maximum depth of 60 mbgl. The maximum depth of 60 m was taken from the highest peak to the lowest part of mineralization and is only a small percentage of the pit. The majority of the pit is not more than 30 m deep. The pit was included in the groundwater flow model as 60 m deep across the entire pit area to simulate maximum impact for the conservative scenario according to the precautionary principle; however, analogue sites indicate no dewatering volumes. Peak dewatering rates at this pit reach approximately 1000 m^3/d at the end of year 10. Once mining stops, the steady state dewatering rate potentially associated with this open pit stabilizes at 320 m^3/d. This could be regarded as a potential water supply source. However, analogue sites (existing open pits in the area) indicated dry conditions and no dewatering rates – however, the existing pits are shallower than the proposed pits.

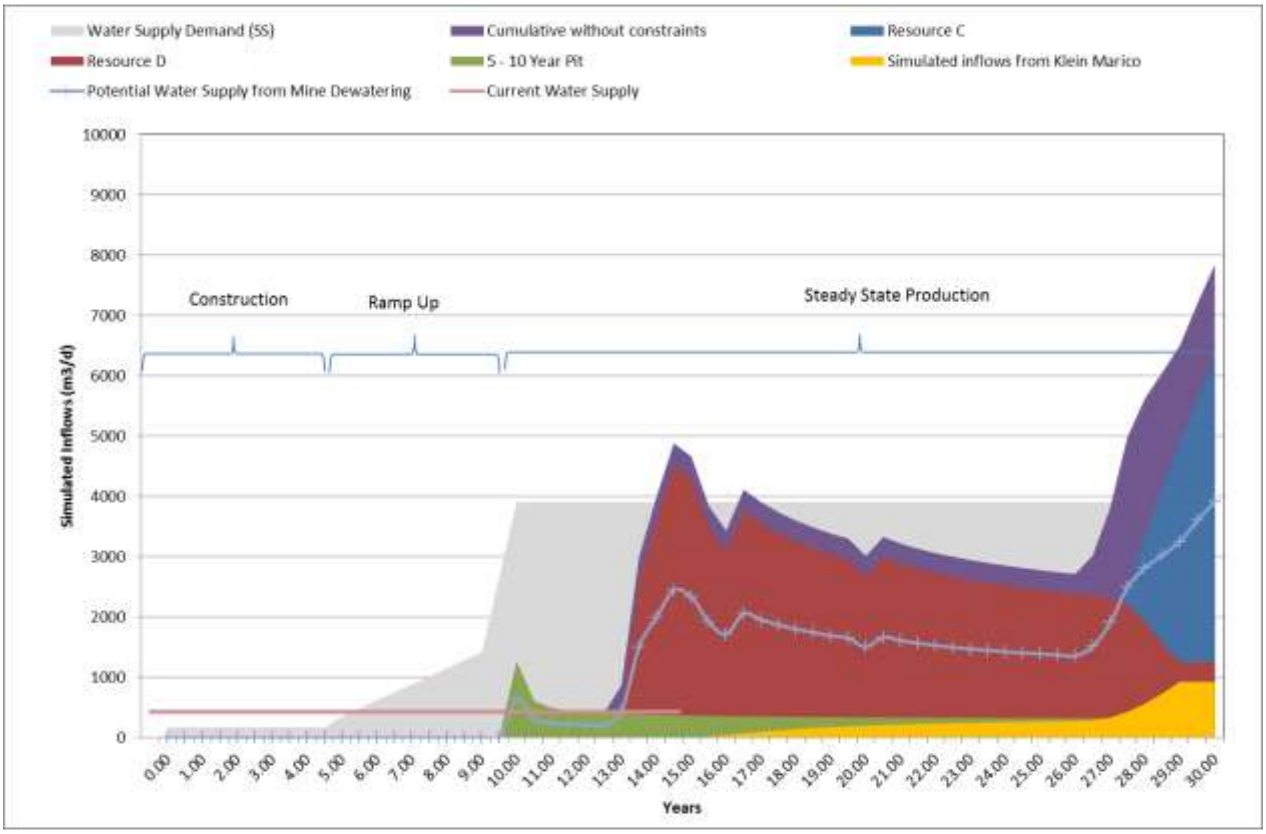

Figure 4-8 **Simulated volumes associated with mine dewatering**

- Resource D is mined from year 10 to year 30 and reaches a maximum depth of 90 mbgl. A pit depth of 90 m was applied on the entire model area to simulate maximum impact i.e. the conservative case according to the precautionary principle. Potential dewatering rates peak at 5000 m^3/d at year 14 and steadily declines to a dewatering rate varying between 2000 m^3/d and 3000 m^3/d. The peak in dewatering rates indicates the volume of storage removed from the aquifer (Compartment 1) and the decline in dewatering rates suggest the steady state rates expected. The effect of evaporation on dewatering rates should be accounted for, and up to 50% of reported dewatering volumes (collected in the open pit) could be lost to evaporation. Should pre-dewatering by means of a curtain of dewatering wells around the open pit be the preferred option, then the dewatering volumes should be closer to the total simulated volumes i.e. not evaporation exposed volumes.

- Resource C is mined between year 20 and year 30 and reaches a maximum depth of 90 mbgl. This resource is also located the closest to the Klein Marico River, and should any influence of potential inflow from the river be expected, it will be seen at this resource. Pre-dewatering of the area (and compartment) during mining of Resource D, influence the dewatering rates at Resource C. A steep increase in dewatering rates was simulated between year 26 and year 27 of mining and peak at 8000 m^3/d. This peak in simulated dewatering volumes is only an indication. Once long term monitoring and abstraction data becomes available, then the model should be re-calibrated and the scenarios re-simulated to refine the envelope of uncertainty with regards to dewatering volumes.
- The increase in possible inflow from the Klein Marico River was also simulated and shown in Figure 4-8. The inflows from the Klein Marico River increases as the Zone of Influence (ZOI) increase with time and hence the hydraulic gradient. The volume of flow is a function of the hydraulic parameters of the river base as well as the gradient. With an increase in these parameters an increase in potential flow would occur i.e. open discrete fractures linking the surface water feature with groundwater and/or deeper open pits, closer to the river etc. Maximum simulated inflows reach approximately 900 m^3/d resulting in less than 4% impact on the simulated surface water runoff in the A31D quaternary catchment. Once the possible link between the Klein Marico River and the groundwater has been established, then the simulated inflows should be updated with a detailed assessment on the surface water runoff of the Klein Marico River catchment area as well as the Groot Marico river catchment area.
- Alien vegetation eradication in the riparian zone of the Klein Marico River plays an important role in offsetting the potential impact of seepage from the river towards the open pits. The nett change in flow should be studied and determined based on the volumes of alien vegetation available. The positive offset on the local water balance should be determined and the resultant difference in flow in the river could offset the seepage volumes. A detailed surface water flow model, coupled with a biodiversity study and mapping of the alien

vegetation should be conducted in the follow up phase. It is also suggested that local labour should be used for the alien vegetation eradication program.

- Water supply was included in the simulation. As detailed in section 3.2 and Table 3-2 five boreholes were subjected to aquifer tests for the purpose of sustainable water supply to the mine. The boreholes and proposed yields (average sustainable yields) were included in the simulation (Table 4-7, Figure 4-6)

Table 4-7 Water Supply Boreholes (Figure 4-6)

Basic Information			Sustainable yield (ℓ/s)					
Label	Longitude	Latitude	FC Analysis Sustainable yield (ℓ/s)	Sustainability Check -Cooper Jacob (ℓ/s)	Average Sustainable yield (ℓ/s)	Radius of Recharge zone (m)	Abstraction duty cycle (h)	Abstraction per annum (m³/a)
DBH04	-25.685690	26.141840	0.72	0.65	0.69	480.11	12.00	21602.16
DBH05	-25.706600	26.156070	3.66	3.50	3.58	1242.37	12.00	112898.88
DBH09	-25.681480	26.202460	0.14	0.17	0.16	241.57	12.00	4888.08
DBH14	-25.695000	26.174880	2.60	2.75	2.68	914.30	12.00	84358.80
DBH16	-25.760780	26.129220	3.07	2.44	2.76	1322.57	12.00	86881.68
Maximum			**3.66**	**3.50**	**3.58**	**1322.57**	**12.00**	**112898.88**
Minimum			**0.14**	**0.17**	**0.16**	**241.57**	**12.00**	**4888.08**
Average			**2.04**	**1.90**	**1.97**	**840.18**	**12.00**	**62125.92**
Total			**10.19**	**9.51**	**9.85**			**310629.60**

- However subsequent to the hydrogeological assessment and supporting regional water balance it is proposed that water supply be conducted from groundwater resources. Groundwater resources will be developed in Compartment 1 and 2 with the possibility of compartment 8 should sufficient resources not be available in the first two mentioned. The applicant understands that groundwater development may have a negative impact with regards to water supply in terms of water quantity and quality due to mining activities and water supply to the mine, and will implement mitigation measures supported by monitoring to mitigate and limit any impacts in this regard. Any landowners who may be verified to be affected will be subject to compensation and/or purchase agreements.

- From the detailed environmental site water balance the average calculated make-up water from the external water source (wellfields) at full production is 116 654 m^3/month (3830 m^3/day). The average tonnes of ore processed at full production 123 750 tonnes per month. The average water use per tonne of ore processed was calculated at 0.94 m^3/tonnes of ore which is within the expected range of between 0.7 m^3/t to 1.2m^3/t for similar mining developments.

- The sensitivity and influence of the constraints and possible inflows from the Klein Marico River were simulated as well. The aquifer tests described in Section 3.2 (Aquifer tests and calculated parameters) indicate a potential connection between the surface water runoff in the Klein Marico River and the groundwater. The difference in simulated inflows due to potential inflows from the Klein Marico River increases to a maximum of 900 m^3/d.

- The proposed development and simulated influence are located a substantial distance away from the Marico eye and no influence is envisaged on the quality and quantity of flow according to the current mine layout, depth and schedule.

The mine numerical groundwater flow modelling follows the precautionary principle. In such a case where assumptions were made due to a gap in data, a conservative approach is taken. The simulated impacts are provided and reported on, however, should the follow up studies be completed and the gaps addressed, the resultant impact on the receiving environment should be less.

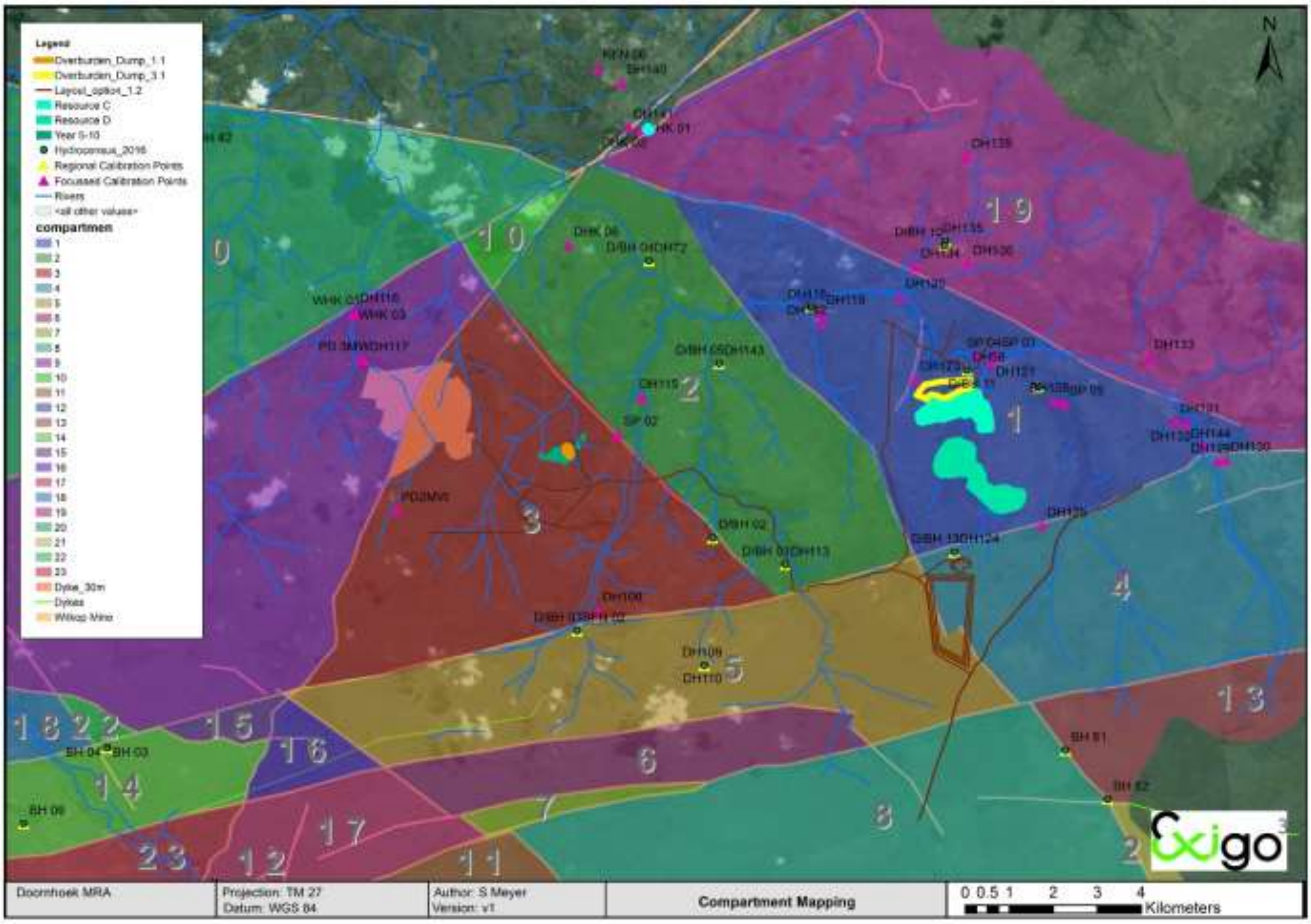

Figure 4-9 **Compartment mapping for influence assessment**

Through evaluation of the data sources the dyke structures in vicinity of the proposed mine were mapped. The identified dykes were then overlain across a simplified geological map and compartments were mapped according to the intersecting dyke structures (Figure 4-9).

Twenty-three compartments were identified. The focus area of the proposed mine is situated over three compartments demarcated as compartments 1, 3 and 4. The identification of springs along the dyke separating compartments 1, 2 and from 4 and 5 indicates that the dyke is likely semi-impermeable to impermeable. Therefore, water table drawdown associated with a mining operation in compartments 1, 2 and 3 are likely not to extend southerly into compartments 4 and 5 (Figure 4-9).

The peak zone of influence due to mine dewatering is shown in Figure 4-10. Compartmental dewatering is observed and the simulated impact is limited to compartments 1 and 2 for Resource C and Resource D and Compartment 3 for the 5 – 10 Year pit (Resource A). The dykes, assumed to be semi-impermeable/leaky, acts as natural mitigation measures and contain the zone of influence. However, cross compartmental leaking is possible and should form part of the follow up phase of investigations, which are recommended below:

1. Detailed geophysics on the dykes separating compartment 1 and 2 as well as compartments 1 and 4. The geophysics should be perpendicular to the dykes as well as along the dykes to site suitable drilling targets. Drilling should take place both sides of the dykes as well as in the most permeable section of the dyke.
2. Drilling and testing to confirm dyke integrity. The dykes could act as natural mitigation measures i.e. to limit and secure possible impacts to certain compartments. The cross-dyke testing in paired boreholes (opposite the dyke from each other) will confirm possible leakage and influence. Testing within the dyke, if possible, will confirm upper permeability value of the dyke material for model update and management scenario measures.

The simulated zone of influence for the Resource A open pit is contained within compartment 3 and the steady state drawdown contours indicated a maximum drawdown potential up to 5 m. The simulation was conducted to formulate management strategies, little to no impact is foreseen and no dewatering influences due to the mining depth being 30 m across the open pit area rather than the maximum depth of 60 m used in the modelling scenarios. Monitoring should be conducted in compartment 3 and across the dyke in compartment 2. The spring SP02 could possibly be influenced by the dewatering and should be part of the monitoring program.

The monitoring program should include boreholes located on both sides of the dykes i.e. west (compartment 1 and 2) and southern compartment boundaries (compartment 1 and 4), to accurately monitor the influence. Discreet fractures might exist which could contribute to influences beyond the compartments. A maximum drawdown of 52 m i.e. change in current calibrated water levels, were simulated within compartment 1. The zone of influence (ZOI) would possibly reach the Klein Marico River, and hence the inflow from the river simulated as part of these scenarios.

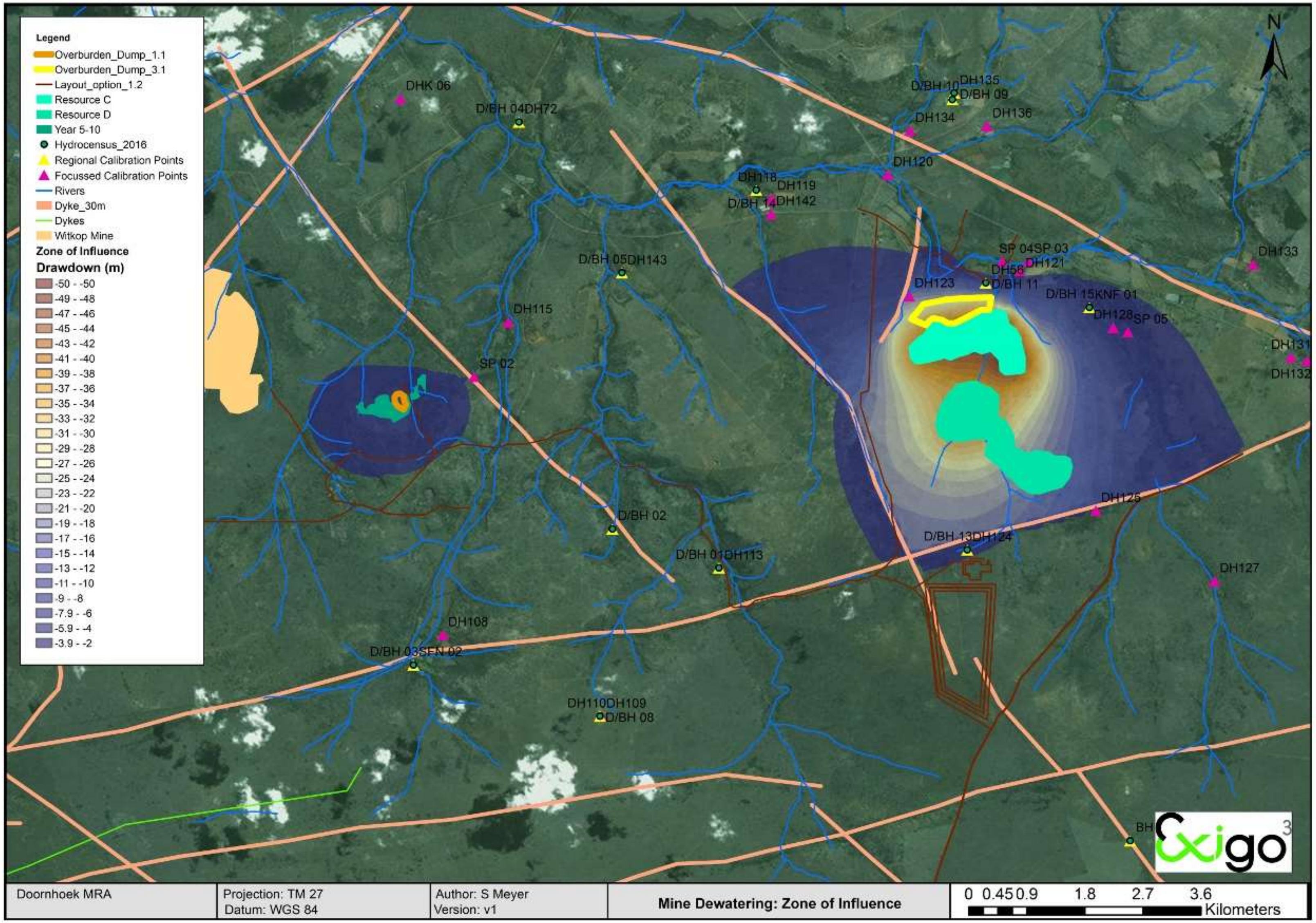

Figure 4-10 Zone of Influence (ZOI) associated with transient mine dewatering

4.10 Simulation 3: Mass transport associated with the TSF and overburden dumps

This scenario details the possible contaminant plume which could originate from the TSF and the overburden dumps for the initial 30 years of the LoM. This scenario is only a simulation for management purposes i.e. advective transport was simulated on possible leaching concentrations of sulphates, TDS and fluoride to show in which direction a possible plume could migrate. This will enable the client to install adequate monitoring points and mitigation measures to address this possibility.

4.10.1 Geochemical background

The detailed geochemical model compiled by Dr. Hansen from Geochemical Dynamic Systems i.e. *Doornhoek Fluorspar Geochemical Risk Assessment – Waste classification and geochemical modelling* was used as reference to obtain the baseline and possible leachate parameters associated with the mining infrastructure, especially the overburden dump and TSF position and alternatives.

For the operational phase, the model results indicated that sulphate values in the tailings pore water exceed regulatory values and groundwater baseline values. Additionally, fluoride values in the tailings will range from 0.9 mg/L to 2.7 mg/L, with the latter value the maximum (Hansen, RN 2016). The waste rock results associated with the overburden dumps indicated sulphide to be below detection limits and fluoride similar to the baseline values. For the purposes of the mass transport model during the operational phase, TDS was used as a scalar value to indicate potential impacts and propose suitable management measures.

4.10.2 Mass transport model input

TDS was used as a parameter associated with the overburden dumps and sulphates and fluoride with the TSF. The background and possible leachate values used were obtained from the detailed geochemical analyses conducted on the waste material (Hansen, RN 2016).

Analysing the background values of sulphates in the groundwater shows the average concentration for sulphates in the groundwater is 95 mg/ℓ, 1.8 mg/ℓ for F and 501 mg/ℓ for TDS. As detailed in the geochemical assessment a possible 880 mg/ℓ of sulphates and 2.7 mg/ℓ of F could leach from the TSF during the operational phase. For the overburden dumps, a possible 994 mg/ℓ could leach associated with TDS.

A porosity of 5% was assigned for to the dolomitic lithologies and 3% for the remaining units. The scenarios of sulphate leaching from the TSF and overburden dumps were simulated with a linearly increasing trend over the initial 30 years, thus starting at the background values and ending at the simulated leachate concentrations i.e. sourced from the geochemical model results. Fluxes were assigned to the TSF and overburden dumps to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned to the overburden dumps and a 0.001 m/d flux to the waste material deposited on the TSF. This could influence the water balance and possible dewatering rates due to the close proximity of especially the overburden dump to the open pit. However, due to the small extent of the overburden dumps, this is not foreseen as a major impact.

The TSF positons for site layouts 1 and 4 are the same i.e. only the position of the proposed plant area changes. Hence, for the next simulation reference is made to TSF Option 1 which includes both 1 and 4 (Figure 4-6).

The TSF Option 1 (4) was simulated first. Both sulphate and fluoride was used as sources to simulate the possible migration of salts originating from this facility. The placement of the facility spans over two compartments i.e. 4 and 5. We would suggest that the dyke separating compartment 4 and 5 be used as a natural mitigating measure i.e. the entire TSF position should be located within compartment 4.

The resultant simulated flow associated with the TSF 1 (4) is shown in Figure 4-11 and Figure 4-12. The simulation indicated that a potential larger impact zone is created by the SO_4 simulation if compared to the F simulation due to the difference in potential source and baseline values. Thus, for the TSF alternative simulations (Options 2 and 3) SO_4 was used as potential contaminant source.

Both scenarios indicated that the potential contaminant impacts compartment 4, compartment 5 to the west, compartment 1 and 2 to the north. To mitigate this impact, monitoring should be implemented to assist in the management of the impact in all four compartments i.e. monitoring boreholes drilled on either side of the dykes, both shallow and deep paired boreholes to monitor deeper fractured flow and shallower perched groundwater flow. As mentioned, moving the TSF position closer to the open pits and within one compartment (4) or two compartments maximum (1 and 4) would be ideal. The open pits and zone of influence due to mine dewatering will act as a mitigation measure capturing the plume and containing it. The placement of the TSF south of the open pits is ideal with regards to possible impacts on the Klein Marico River – the open pits will intercept any possible contaminant and contain this from a groundwater perspective. Surface water runoff, should be mitigated accordingly. The post operational plan should be optimised such that the open pits creates a sink and contain any salts originating from the TSF and overburden dumps.

The TDS simulation associated with the overburden dumps are shown in Figure 4-13. The dumps are substantially smaller than the TSF. The placement of the overburden dumps is ideal i.e. close to the open pits. The hydraulic gradient induced by the mine dewatering contains the possible plume originating from the dumps and act as a mitigation measures. A possible change in position of the overburden dump associated with Resource C would be to shift this dump south i.e. away from the Klein Marico River. An optimization exercise should be performed on the position in the follow up phases.

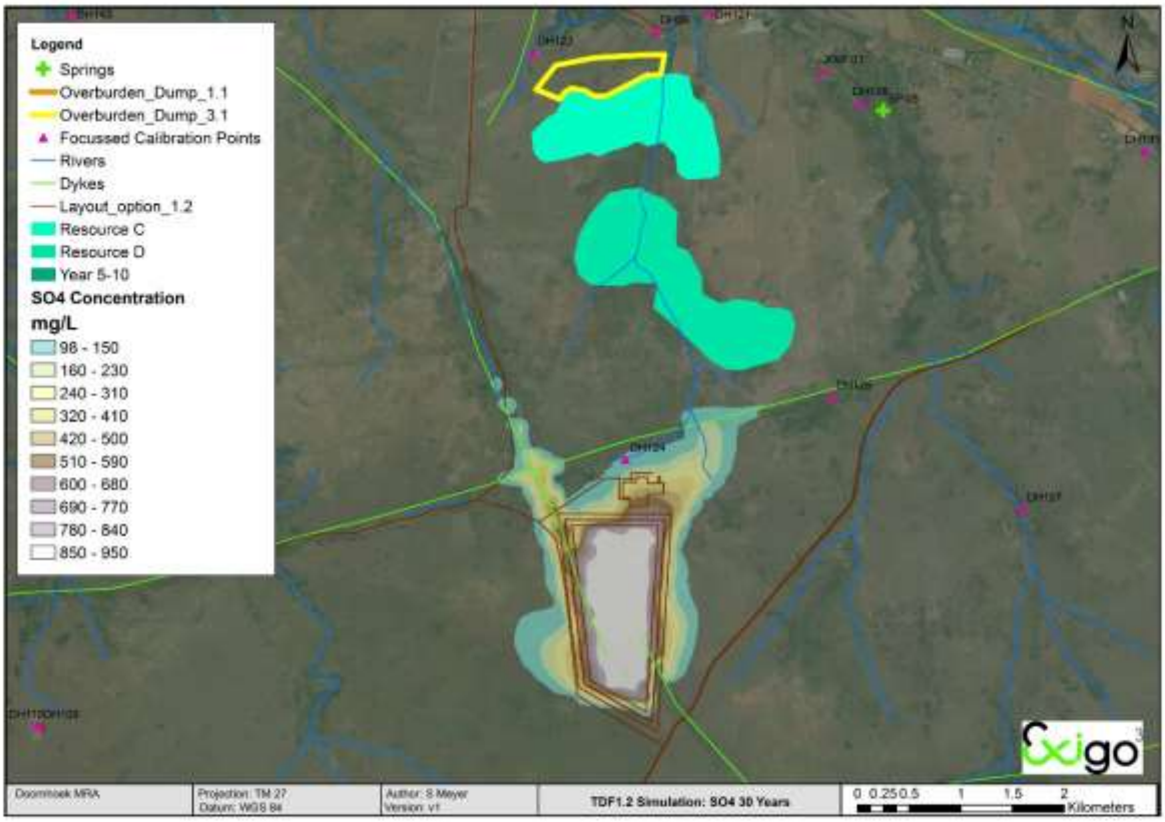

Figure 4-11 SO4 simulated transport for TSF Option 1 (4)

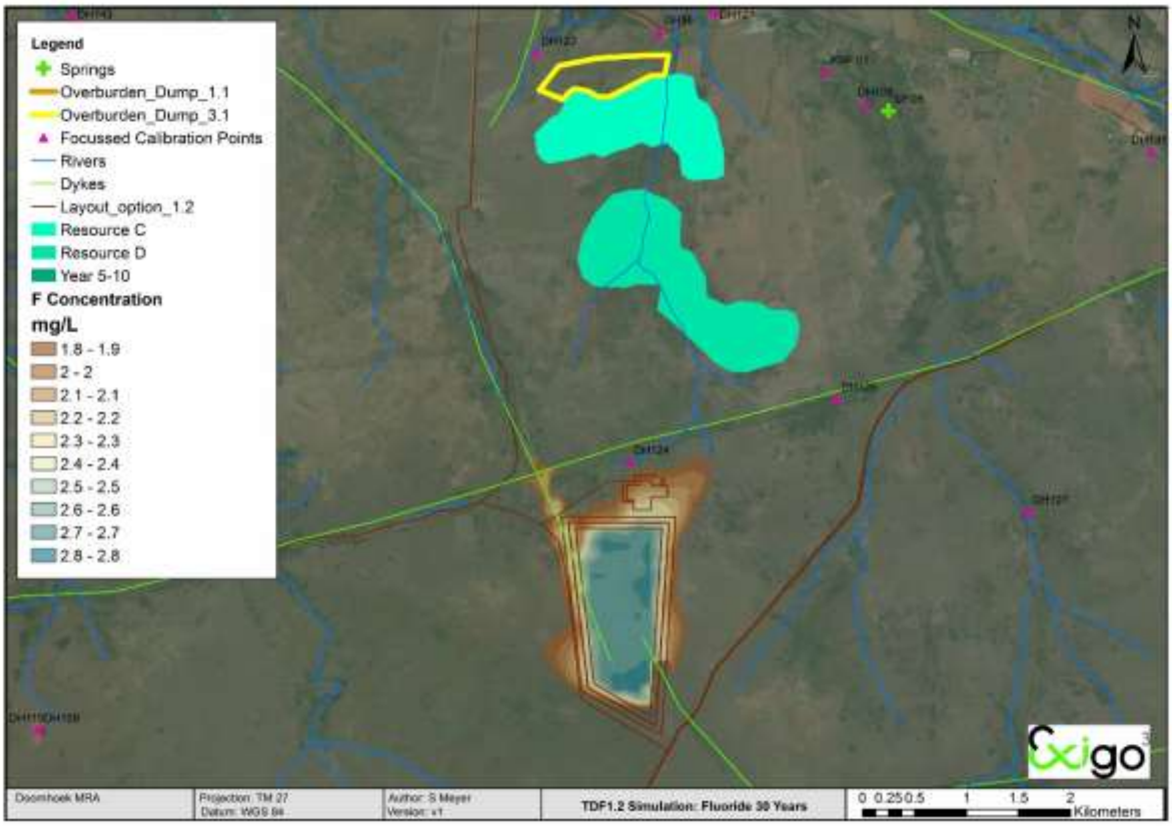

Figure 4-12 F simulated transport for TSF Option 1 (4)

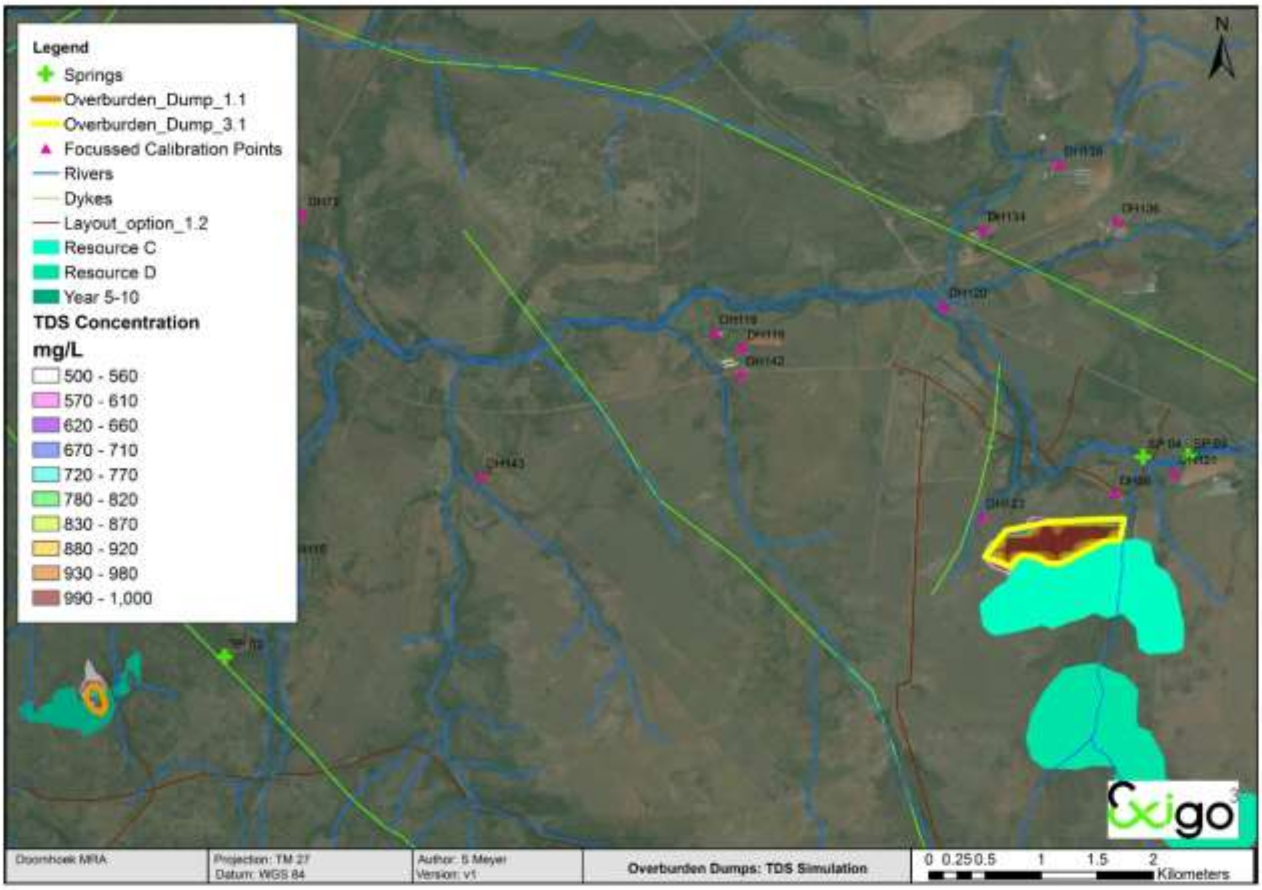

Figure 4-13 **TDS simulated transport the overburden dumps**

Monitoring points should be installed between the overburden dumps and the closest receptor i.e. the Klein Marico River. Again paired boreholes, both shallow and deep, should be drilled to monitor the perched and fractured aquifer flow.

4.10.3 Infrastructure alternatives

As part of the study, various alternatives for the placement of the TSF were supplied as shown in Figure 4-6. The preferred mine site layout and associated TSF position as shown in Layout Option 1 and 4 were analysed in the previous section. The mass transport associated with Option 2 and 3 are shown in Figure 4-14 and Figure 4-15. The migration of Option 2 shows that the ZOI associated with the open pits acts as mitigation to possible flow which is positive. The flow associated with Option 3 migrates to the east along the dyke contact (semi-impermeable) and along the surface water drainage. This is not preferable. A combination of Option 1 (4) and 2 would be preferred without any extension of the TSF into compartment 5.

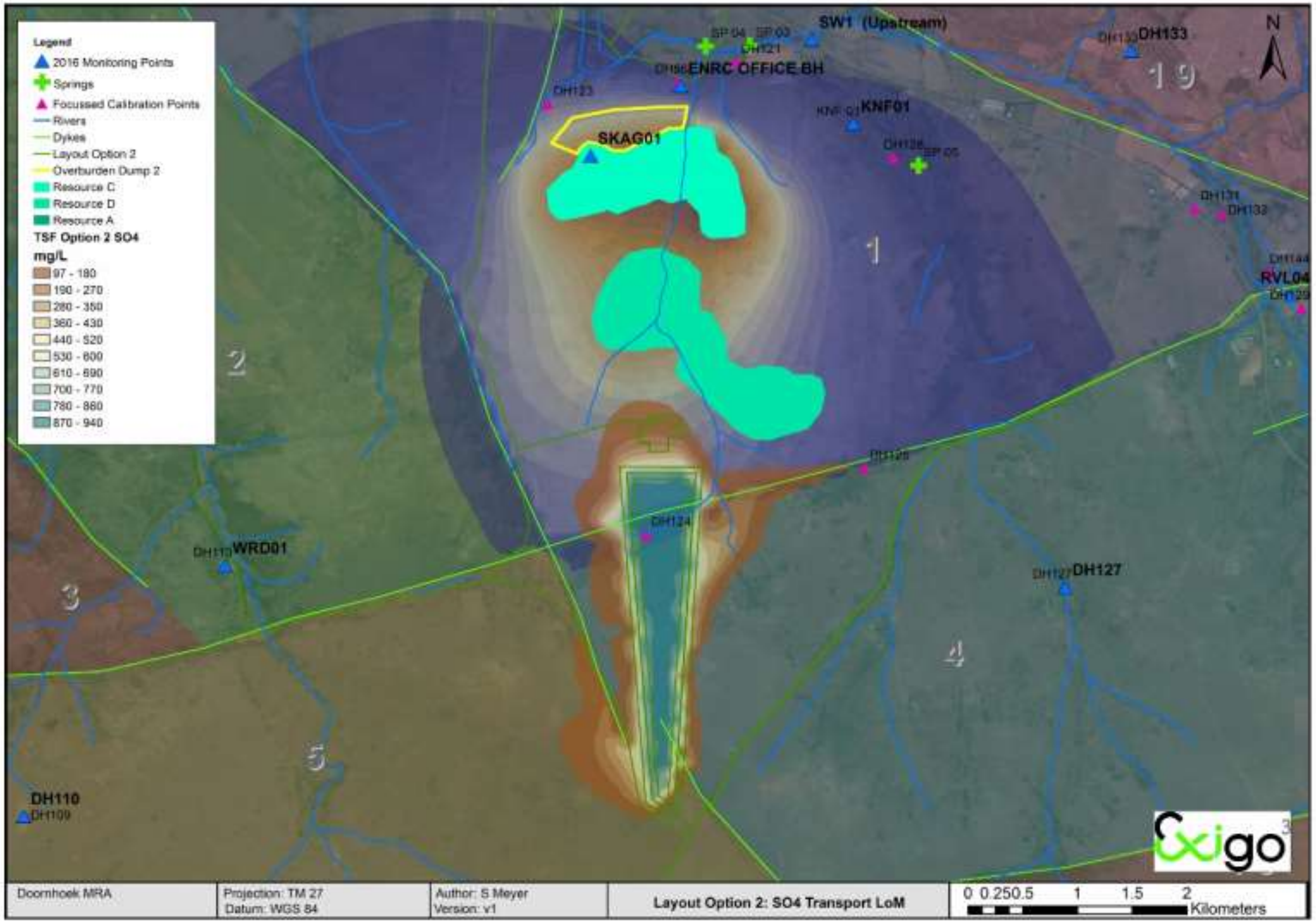

Figure 4-14 **SO4 simulated transport for TSF Option 2**

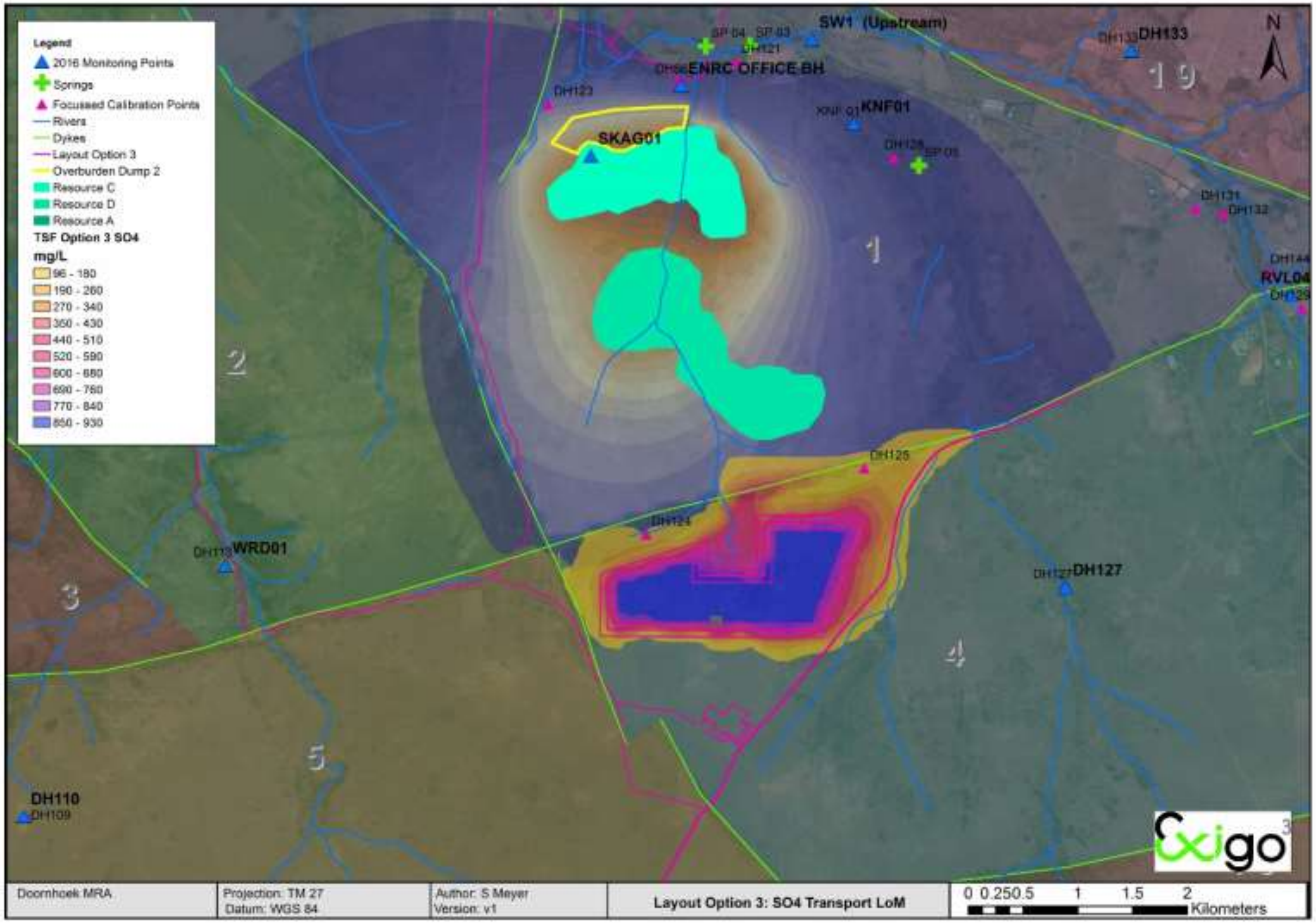

Figure 4-15 **SO4 simulated transport for TSF Option 3**

4.11 Surface water and groundwater balance: Summary and impacts

The steady state calibrated model indicated that 33 856 m^3/d of recharge water flows into the groundwater catchment area due to infiltrating from precipitation. This annual recharge is averaged per day. This resultant flow is produced from a combination of recharge inflow; outflow as groundwater base flow, and from losses, such as evapotranspiration. The groundwater balance shown in Table 4-8 is derived from the total inflows (recharge) and the total outflows (base flow and losses).

Additionally, for Compartment 1 and 2 combined, the total volume of groundwater reporting as base flow to the Klein Marico River is approximately 527 m^3/d and the recharge is on these compartment correlate to 920 m^3/d.

For the steady state calibration, community abstraction from boreholes was included. The volumes are assumptions based on the application and should be verified, especially any water users in compartment 1 and 2.

The transients simulations indicated that mine dewatering, flow from the TSF and overburden dumps contribute -4190 m^3/d, 770 m^3/d and 150 m^3/d to the water balance respectively. Additional water supply removes 432 m^3/d from the water balance.

For compartment 1 and 2, the base flow to the Klein Marico River during the operational phase of the mining activities decreased to 327 m^3/d i.e. a difference of 200 m^3/d. Maximum simulated losses or leakage from the river to the proposed open pit equated to 877 m^3/d.

It is important to understand the possible link between the Klein Marico River and the local aquifer, the extent and the characteristics. Follow up studies should be conducted to refine the volumes possibly leaked from the Klein Marico River and quantify the loss in base flow from compartment 1 to the Klein Marico River.

Table 4-8 **Water balance evaluation for steady state calibration**

Scenario 1: Pre-development steady state calibrated model				
	Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
1	Recharge from precipitation:	33856	0	**33856**
2	Mine Dewatering	0	0	**0**
3	Abstraction: Community Boreholes	0	-2355	**-2355**
4	Abstraction: Possible Mine Supply	0	0	**0**
5	Recharge from TSF	0	0	**0**
6	Recharge from Overburden Dumps	0	0	**0**
7	Base flow and losses	0	-31502	**-31502**
8	Storage	0	0	**0**
	Total	**33856**	**-33857**	**-1**

Scenario 1: Pre-development steady state calibrated model				
	Component	Inflow (m^3/d)	Outflow (m^3/d)	Balance (m^3/d)
Balance Error (%)				**0.00%**

Table 4-9 Water balance evaluation for mine dewatering, water supply and mass transport

Scenario 2: Transient state mine dewatering, water supply and mass transport				
	Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
1	Recharge from precipitation:	33856	0	**33856**
2	Mine Dewatering	0	-4190	**-4190**
3	Abstraction: Community Boreholes	0	-2355	**-2355**
4	Abstraction: Possible Mine Supply	0	-432	**-432**
5	Recharge from TDF	770	0	**770**
6	Recharge from Overburden Dumps	150	0	**150**
7	Base flow and losses	0	-30556	**-30556**
8	Storage	2450	0	**2450**
	Total	**37226**	**-37533**	**-307**
Balance Error (%)				**-0.82%**

4.12 Additional simulations required in follow up phases for impact assessment and mitigation measures

The closure impacts associated with the mine dewatering and infrastructure rehabilitation should be updated with detailed modelling once the closure plan has been finalised. The detailed modelling is dependent on the following:

1. Will the TSF and overburden dumps be reworked and/or rehabilitated to minimise the water balance?
2. The open pits will be partially backfilled. The closure plan should be optimised such that the open pits minimise the potential impact on the Klein Marico River (decreased ZOI) while still capturing and containing any possible migration of salts from the TSF and overburden dumps. Post closure pit flooding simulations should be conducted and included in the closure plan.
3. A dynamic integrated environmental water balance and salt balance to determine the impacts of the mine on the groundwater and surface water during the operational and post operational phases.
4. Detailed sustainability modelling, both analytical and numerical should be conducted once the water supply resources have been identified and developed.
5. The impact of alien vegetation eradication on the riparian zone along the Klein Marico River

should be investigated. Detailed offset volumes should be determined and included in the Integrated Water Use License Application process.

6. Mine dewatering optimisation. Compartment 1 will be affected by mine dewatering caused by mining of the Recourse C and D open pits. Collecting the groundwater within the open pits with traditional sumps will expose the resource to evaporation losses and ultimately decrease the water available for affected IAPs and possible surplus water supply to the mining operations. Also, any water in contact with mining operations is classified as dirty or grey water and should be treated before discharging can take place. Installing a curtain of dewatering boreholes around the open pits would be the preferred option. The compartment will be pre-dewatered and the mining conditions will be dry i.e. a safer working environment. The water is classified as non-contact water and could be directly discharged back in the Klein Marico River (offset of possible impact by mine dewatering ZOI), supplied to IAPs or used in the mining process. These scenarios of sump collection and pre-dewatering should be assessed in detail in the follow-up phase of the hydrogeological study.
7. The possibility of sinkhole formation due to mine dewatering and reduction in pressure head in the dolomitic aquifer should be addressed. The hydrogeological investigation will form part of a detailed geotechnical investigation addressing this risk.

5 PROPOSED MONITORING POINTS

The client has been conducting ongoing groundwater and surface water monitoring at several points since 2013 (Figure 5-1). In addition to this, to expand the baseline before construction commences, the points as proposed in Table 5-1 are proposed to gather and record sensitive baselines data. Once the complete baselines have been identified, a monitoring program optimisation should be completed to maximise value from information recorded at various points. A cost benefit analysis should be completed with statistical analysis on data recorded and possible duplication of point sets and value.

The location of the proposed points and the monitoring aim of the points are provided in Table 5-1 and Figure 5-1 respectively.

Table 5-1 Proposed additional monitoring points

Id	Lat	Long	Description
1	26.1992	-25.709	Monitor between Resource C & Klein Marico River
2	26.2159	-25.7098	Monitor between Resource C & Klein Marico River
3	26.2234	-25.7165	Monitor influence to east of open pits
4	26.1741	-25.7095	Monitor influence between Comp 1 and 2
5	26.1723	-25.7115	Monitor influence between Comp 1 and 2

Id	Lat	Long	Description
6	26.1854	-25.7197	Monitor influence between Comp 1 and 2
8	26.1837	-25.7222	Monitor influence between Comp 1 and 2
9	26.1938	-25.7359	Monitor influence between Comp 1 and 2
10	26.1904	-25.7373	Monitor influence between Comp 1 and 2
11	26.1991	-25.7483	Monitor influence between Comp 4 and 5
12	26.1958	-25.7494	Monitor influence between Comp 4 and 5
13	26.1993	-25.7592	Monitor influence between Comp 4 and 5
14	26.2023	-25.7678	Monitor influence between Comp 4 and 5
15	26.1316	-25.7222	Monitor Resource A dewatering
16	26.1211	-25.7291	Upstream Resource A
17	26.1223	-25.7197	Downstream Resource A
18	26.2127	-25.775	Upstream TSF
19	26.2325	-25.7277	Compartment 1 East
20	26.238	-25.7085	Upstream Klein Marico
21	26.215	-25.7049	Influence Klein Marico
22	26.203	-25.7049	Influence Klein Marico
23	26.1963	-25.6963	Influence Klein Marico
24	26.179	-25.6931	Downstream Klein Marico

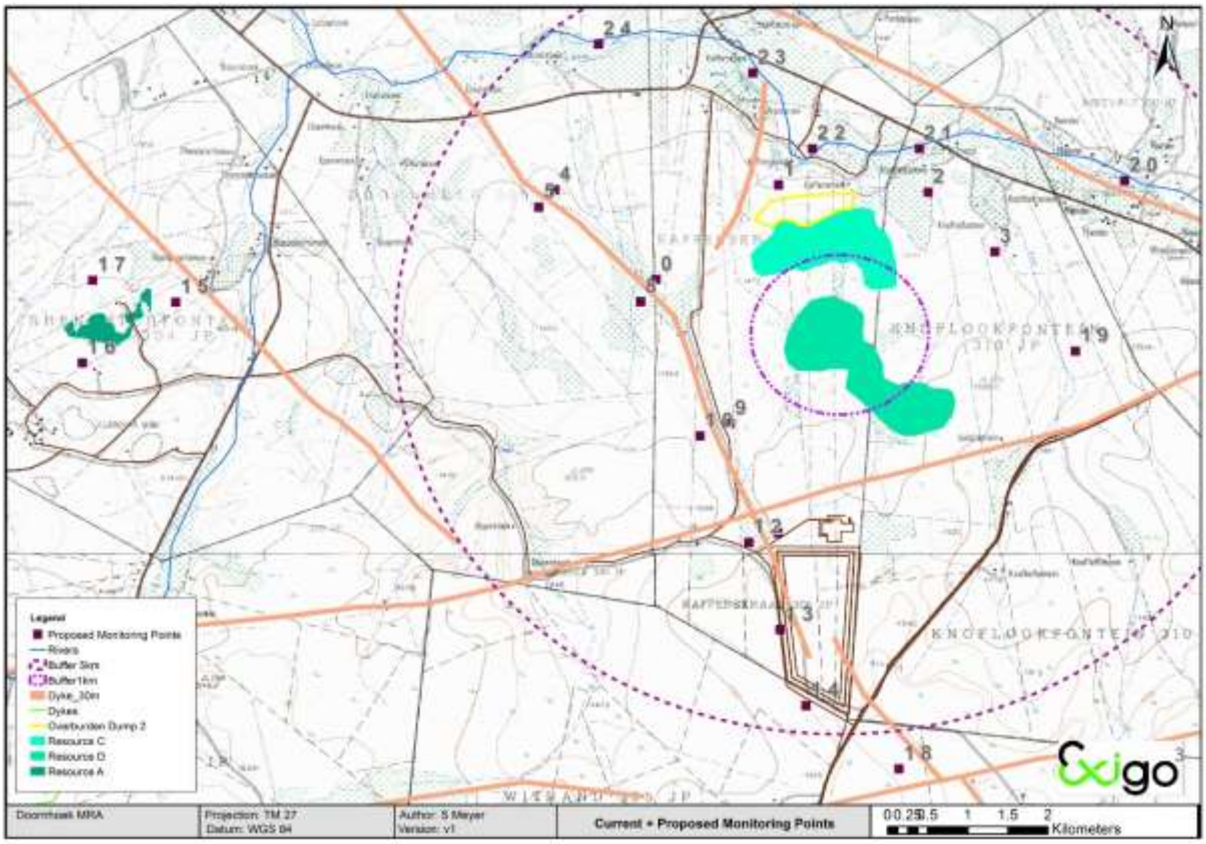

Figure 5-1 **Current and proposed monitoring points**

6 IMPACT ASSESSMENT

6.1 Assessment Methodology

An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human activities related to alternatives under study for meeting a project need.

The significances of the potential groundwater impacts were determined through a synthesis of the criteria below:

Probability: This describes the likelihood of the impact actually occurring.

Improbable: The possibility of the impact occurring is very low, due to the circumstances, design or experience.

Probable: There is a probability that the impact will occur to the extent that provision must be made therefore.

Highly Probable: It is most likely that the impact will occur at some stage of the development.

Definite: The impact will take place regardless of any prevention plans, and there can only be relied on mitigatory actions or contingency plans to contain the effect.

Duration: The lifetime of the impact

Short term: The impact will either disappear with mitigation or will be mitigated through natural processes in a time span shorter than any of the phases.

Medium term: The impact will last up to the end of the phases, where after it will be negated.

Long term: The impact will last for the entire operational phase of the project but will be mitigated by direct human action or by natural processes thereafter.

Permanent: Impact that will be non-transitory. Mitigation either by man or natural processes will not occur in such a way or in such a time span that the impact can be considered transient.

Scale: The physical and spatial size of the impact

Local: The impacted area extends only as far as the activity, e.g. footprint

Site: The impact could affect the whole, or a measurable portion of the above mentioned properties.

Regional: The impact could affect the area including the neighbouring residential areas.

Magnitude/ Severity: Does the impact destroy the environment, or alter its function.

Low: The impact alters the affected environment in such a way that natural processes are not affected.

Medium: The affected environment is altered, but functions and processes continue in a modified way.

High: Function or process of the affected environment is disturbed to the extent where it temporarily or permanently ceases.

Significance: This is an indication of the importance of the impact in terms of both physical extent and time scale, and therefore indicates the level of mitigation required.

Negligible: The impact is non-existent or unsubstantial and is of no or little importance to any stakeholder and can be ignored.

Low: The impact is limited in extent, has low to medium intensity; whatever its probability of occurrence is, the impact will not have a material effect on the decision and is likely to require management intervention with increased costs.

Moderate: The impact is of importance to one or more stakeholders, and its intensity will be medium or high; therefore, the impact may materially affect the decision, and management intervention will be required.

High: The impact could render development options controversial or the project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor in mitigation.

The following weights were assigned to each attribute:

Table 6-1 Risk scoring table

Aspect	Description	Weight
Probability	Improbable	1
	Probable	2
	Highly Probable	4
	Definite	5
Duration	Short term	1
	Medium term	3
	Long term	4
	Permanent	5
Scale	Local	1
	Site	2
	Regional	3

Aspect	Description	Weight
Magnitude/Severity	Low	2
	Medium	6
	High	8
Significance	**Sum (Duration, Scale, Magnitude) x Probability**	
	Negligible	<20
	Low	<40
	Moderate	<60
	High	>60

The significance of each activity is rated without mitigation (WOM) measures and with mitigation measures (WM) for both construction, operational and closure phases of the open pit development. The mitigation effect of each impact will be indicated without and with mitigation measures as follows:

- Can be reversed
- Can be avoided, managed or mitigated
- May cause irreplaceable loss of resources

Construction is associated with the Construction Phase as well as the Operational Phase:

1. Construction Phase: All activities on site up to the start of operation, including initial site preparations.
2. Operational Phase: All activities including the operational and maintenance of the proposed development.

6.2 Planning Phase

6.2.1 Planning Phase Activities

1. Stakeholder engagement: aquifer testing arrangements.
2. Establishment and operation of construction camp.
3. Anthropogenic activities on site.
4. Fuelling and movement of construction vehicles.

6.2.2 Mitigation Measures

1. Monitor borehole yield and water level during pump test to prevent over-abstraction.
2. Chemical sanitary facilities to be used and situated down gradient from local drainage systems.
3. Best practise camp management and house-keeping principles to be implemented.

4. Fuelling of vehicles at earmarked concrete-lined areas. Fuel storage in bunded areas. Spill trays to be utilized where necessary. Include spectrum of hydrocarbon elements in monitoring program.

6.3 Construction Phase

The infrastructure proposed for the planned Doornhoek Fluorspar Mine during construction is:

- Access roads
- Processing Plant
- Supporting buildings
- Temporary construction camp
- Ablution facilities

6.3.1 Construction Phase Activities

1. Inadequate sanitary facilities and ablutions facilities can result in health risks and groundwater / surface water contamination.
2. Explosives will be used in the open pit clearing and development; this may contribute nitrates to the groundwater. Monitoring will confirm and quantify concentration and should be included in the monitoring protocol.
3. Activities during the construction phase can significantly increase the risk of surface water pollution. The areas cleared of vegetation and impacted on by excavation must be managed to prevent sedimentation of storm water channels. The location of stockpiled or excavated soil material must be done in such a way as to prevent siltation of drainage systems.
4. The construction camp must be adequately managed to avoid surface water contamination, which could result from littering or inadequate sanitation facilities.

Without mitigation measures the impact of construction related activities can be moderate to low without mitigation measures and negligible to low with mitigation measures.

6.3.2 Mitigation Measures

The following mitigation measures are recommended:

1. Construction should preferably take place during the dry season.
2. Adequate fuel containment facilities to be used during construction phase.
3. The use of all materials, fuels and chemicals which could potentially leach into underground water must be controlled.
4. All materials, fuels and chemicals must be stored in a specific and secured area to prevent pollution from spillages and leakages.
5. Construction vehicles and machines must be maintained properly to ensure that oil spillages

are kept at a minimum.

6. Spill trays must be provided if refuelling of construction vehicles are done on site.
7. Chemical sanitary facilities must be provided for construction workers. Construction workers should only be allowed to use temporary chemical/ permanent toilets on the site. Chemical toilets shall not be within close proximity of the drainage system. Frequent maintenance should include removal without spillages.
8. No uncontrolled discharges from the construction camp shall be permitted.
9. Chemical storage areas should be sufficiently contained, and the use of chemical should be controlled.
10. The removed soil and vegetation should be replaced once construction is complete and the pipeline cavities filled in and re-vegetated where possible.
11. Real time monitoring should be installed in equipped boreholes and monthly monitoring should be conducted on water levels measurements, groundwater quality and isotope and hydro chemical fingerprinting to establish origin of groundwater if abstracted close to Klein Marico River.

6.4 Operational Phase

6.4.1 Mine dewatering, water supply and mass transport

The simulated drawdown due to mine dewatering is shown in Figure 4-10 and the potential migration of salts associated with the TSF and overburden dumps are shown in Figure 4-11, Figure 4-12 and Figure 4-13.

1. A radius of influence is associated with the mine dewatering during LoM which could impact neighbouring groundwater users and sensitive receptors i.e. springs and the Klein Marico River. Mine dewatering is a function of time and hydraulic parameters, and thus the numerical flow modelling is a management tool that should be used for decision making.
2. The simulation showed that the average dewatering rates are approximately 4000 m^3/d with possible peak inflows to the end of the 30 year Life of Mine of above 7000 m^3/d. Depending on the method of abstraction i.e. sumps versus pre-dewatering, the mine dewatering volumes could be as much as 50% less due to evaporation losses.
3. The overburden dumps plumes shows little migration due to the position of these facilities with regards to the zone of influence and position relative to the open pits i.e. the facility is located within the ZOI and hence shows little migration. Adequate monitoring should be conducted around the overburden dumps to assess possible flow in the unsaturated zone beneath the dumps.

4. The migration of salts form the TSF should be monitored. Plume migration might flow across compartment boundaries and adequate monitoring should be installed to detect and manage.
5. Depletion of the groundwater in the aquifer and related compartment due to the proposed open pit mining dewatering.
6. Possible inflow from the Klein Marico River into the open pit mine. Water collected in the open pit mine (or dewatering wells) should be sampled and tested with hydrochemical and isotope finger printing monthly to verify the origin. If the origin is established to be from the Klein Marico River, the water should be treated to an acceptable quality and discharged back into the Klein Marico River. If it is confirmed that the water seepage into the open pit mine is a diluted combination between surface water from the Klein Marico River and groundwater, then the dilution ratios should be calculated and the surface water quantities should be released back into the river. The groundwater component should be licensed and could be used in the mine circuit if the license is granted.
7. Contamination of surface and groundwater quality due to contaminated storm water run-off which originates from the proposed TSF and overburden dumps as well as the process plant site.
8. Increased erosion and silt loading of surface water bodies
9. Contamination of groundwater sources due to dewatering by the open pit mines.
10. Change in local drainage patterns and hence flow regimes.
11. Possible groundwater seepage from the TSF and overburden dumps along the hydraulic head gradient of the groundwater regime below this facility.
12. Depletion of groundwater levels due to over abstraction from water supply boreholes identified as sustainable water supply boreholes.
13. In-adequate groundwater and water supply management i.e. failure to comply with monitoring protocol and not adhering to sustainable abstraction from water supply boreholes.
14. Additional water supply boreholes should be drilled to supplement the current wellfield to supply in the majority of mines water demand. Additional sources of groundwater should be identified and explored in the future to supply the required make up water demand.
15. Vandalism of water supply infrastructure due to inadequate protection.

6.4.2 Mitigation Measures

1. The radius of influence should be monitored with local and regional water level

measurements monthly. Substitute water should be supplied if it's found and proven that neighbouring water levels and yields are affected.

2. Detailed geophysics between the open pits and the Klein Marico River should be conducted to map possible preferential flow paths connecting the open pit and the river. Drilling and long term aquifer testing should be conducted as well as ongoing monitoring with isotope analyses and finger printing to establish the source of the dewatered volumes.
3. Inclined packer testing could be conducted below the Klein Marico River to assess the possible inflows into the open pit mine associated with a possible structure along the Klein Marico River. The groundwater flow model should be updated accordingly.
4. Long duration aquifer tests should be conducted on any newly drilled water supply, monitoring and/or seepage capturing boreholes drilled during the LoM.
5. On-going isotope analyses should be conducted (at least quarterly samples) on the water supply boreholes as well as the water captured in the open pit mine to confirm the origin of the water in comparison to the surface water from the Klein Marico River.
6. The groundwater flow model should be updated every two years or as soon as additional groundwater exploration and/or monitoring data becomes available.
7. Water seeping into the open pit mine should be directed into a sump and pumped to surface. Real time monitoring should be implemented to record the volumes pumped from the open pit mine.
8. Water pumped from the open pit mine should be pumped into a dirty water system and should not be allowed to enter any clean water system, natural drainage line, or the aquifer.
9. Storm water from the TSF and overburden dumps should be contained in a process water dam and included in a closed dirty water system
10. The pipeline should be properly maintained and inspected at regular intervals for the early detection of leakages, malfunctioning and acts of vandalism.
11. Pipeline construction at river crossings and in flood lines should be adequate to withstand flood conditions.
12. The pipeline should be visible and/ or marked to prevent damage to pipeline.
13. The pipeline and related infrastructure should be designed to minimise evaporation and transmission losses.
14. Pressure gauges should be installed at the pipeline for the early detection of pressure loss that may indicate leakages.
15. Monthly visual checks for damp areas around borehole equipment and pipeline.

16. Communities and IAPs should be consulted before construction of the pipeline. Significant issues would be permission to build the pipeline and education about the pipeline.
17. Boreholes and related equipment should be in a fenced in area in a locked pump house for protection against theft and vandalism.
18. Communities should be consulted in advance about the potential lowering of water levels in their boreholes.
19. Groundwater levels should be monitored in all pumping wells throughout.
20. Groundwater levels should be monitored at all monitoring boreholes.
21. A monitoring program must be implemented and honoured.
22. All water retention structures, including process water dams; pollution control dam, etc. should be constructed to have adequate freeboard to be able to contain water from 1:50 year rain events.
23. Monitoring points of surface water features should be identified and monitored.
24. Groundwater and surface water quality information should be determined by sampling the surface water containment water (from the GN704 storm water management system) and monitoring boreholes located upstream and downstream of the mining and infrastructure.
25. Flow measurements in the Klein Marico River should be taken upstream and downstream of the mine site. The flow measures should be recorded on ongoing basis to monitor possible impacts and flow reductions caused by the mine dewatering. Alien vegetation eradication should be implemented to off-set the possible flow reduction and increase the water balance of the local catchment.

6.5 Post Operational Phase

6.5.1 Mine re-watering, radius of influence and seepage from the TSF

1. Increased groundwater ingress at disturbed/rehabilitated areas.
2. Migration of contamination plume from mine contamination sources.
3. Post-closure pit flooding and acidification.
4. Permanent radius of influence due to mine dewatering
5. Sulphate and Fluoride leaching from the TDF
6. Increased TDS / Nitrate leaching from the overburden dumps

The groundwater levels could take a substantial time to recover post operations and this should be confirmed with monitoring for at least 12 months post closure.

6.5.2 Mitigation Measures

1. Rehabilitate the TSF to limit ingress and recharge to these facilities and minimise potential leaching into the groundwater
2. Monitoring of water quality in the neighbouring boreholes and monitoring boreholes drilled for that purpose should continue quarterly post closure for at least 12 months.
3. The radius of influence due to mining will decrease; however, a permanent radius of influence could exist. Affected groundwater users should be compensated.
4. Simulate post closure geochemical leaching and use results to update and optimise post closure rehabilitation plan.
5. Monitoring of groundwater upstream and downstream of the mine overburden dump facilities should be continued. Provision for this should be made in the rehabilitation budget.
6. Monitoring of surface water features upstream and downstream of the mine should be continued. Provision for this should be made in the rehabilitation budget.

6.6 General Mitigation measures

A management plan should be compiled and implemented at the mine. A monitoring protocol is included in section 10 Appendix B: Monitoring Protocol

Table 6-2 Impact assessment ratings

Nr	Activity	Impact	Without or With Mitigation	Nature (Negative or Positive Impact)	Probability		Duration		Scale		Magnitude/ Severity		Significance		Mitigation Measures	Mitigation Effect
					Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude		
Planning Phase																
1	Stakeholder engagement: aquifer testing arrangements.	Lowering of local water levels caused by pump testing.	**WOM**	**Negative**	Highly Probable	4	Short term	1	Local	1	Medium	6	32	Low	Monitor borehole yield and water level during pump test to prevent over-abstraction.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Short term	1	Local	1	Low	2	8	Negligible		
2	Establishment and operation of construction camp.	Groundwater and surface water contamination.	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Chemical sanitary facilities to be used and situated down gradient from local drainage systems.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Short term	1	Site	2	Low	2	10	Negligible		
3	Anthropogenic activities on site.	Contamination risk.	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Short term	1	Site	2	Low	2	10	Negligible		
4	Fuelling and movement of construction vehicles.	Risk of hydrocarbon spillage and contamination.	**WOM**	**Negative**	Highly Probable	4	Long term	4	Site	2	High	8	56	Moderate	Fuelling of vehicles at earmarked concrete-lined areas. Fuel storage in bunded areas. Spill trays to be utilized where necessary. Include spectrum of hydrocarbon elements in monitoring program.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Medium term	3	Site	2	Medium	6	22	Low		
Construction Phase																
5	Oil, grease and diesel spillages from construction vehicles	Contamination risk.	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Short term	1	Local	1	Low	2	8	Negligible		
6	Pollution of groundwater due to sanitation facilities	Deterioration of groundwater quality	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Short term	1	Local	1	Low	2	8	Negligible		
7	Ground and surface water pollution due to storage of chemicals and building materials	Deterioration of groundwater and surface quality	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Local	1	Medium	6	8	Negligible		
8	Spillages from diesel (fuel storage) facilities	Deterioration of groundwater and surface quality	**WOM**	**Negative**	Highly Probable	4	Short term	1	Site	2	Medium	6	36	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		
Operational Phase																
9	Dewatering zone of influence.	Lowering of regional groundwater levels.	**WOM**	**Negative**	Definite	5	Long term	4	Regional	3	High	8	75	High	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate the potential zone of influence. Mining operation to provide alternative water should lowering of regional water levels cause a decrease in borehole yields.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Long term	4	Regional	3	High	8	30	Low		
10	Contaminant leaching from mine waste facilities.	Groundwater and surface water contamination.	**WOM**	**Negative**	Definite	5	Long term	4	Regional	3	High	8	75	High	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution plume migration.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Medium term	3	Regional	3	Medium	6	24	Low		
11	Use of explosives for mine pit development.	Contribution to nitrate over-load in groundwater and surface water resources.	**WOM**	**Negative**	Highly Probable	4	Medium term	3	Site	2	Medium	6	44	Moderate	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution plume migration.	Can be avoided, managed or mitigated
			WM	**Positive**	Highly Probable	4	Medium term	3	Site	2	Low	2	28	Low		
12	Hydrocarbon spillages from fuel storage facilities, fuelling and wash-bays.	Hydrocarbon contamination of groundwater and surface water resources.	**WOM**	**Negative**	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate	Fuelling of vehicles at earmarked concrete-lined areas. Fuel storage in bunded areas. Spill trays to be utilized where necessary. Include spectrum of hydrocarbon elements in monitoring program.	Can be avoided, managed or mitigated
			WM	**Positive**	Probable	2	Long term	4	Site	2	Medium	6	24	Low		
13	Flooding of the open pit	Unsafe working conditions	**WOM**	**Negative**	Improbable	1	Long term	4	Site	2	Medium	6	12	Negligible	Implement dewatering strategy and keep water levels below pit advance.	Can be avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Site	2	Low	2	5	Negligible		
14	Pollution of groundwater due to sanitation facilities	Deterioration of groundwater quality	**WOM**	**Negative**	Highly Probable	4	Long term	4	Site	2	Medium	6	48	Moderate	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	**Positive**	Improbable	1	Short term	1	Site	2	Low	2	5	Negligible		
15	Seepage from overburden dumps	Deterioration of groundwater quality	**WOM**	**Negative**	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution	Can be avoided, managed or

Nr	Activity	Impact	Without or With Mitigation	Nature (Negative or Positive Impact)	Probability		Duration		Scale		Magnitude/ Severity		Significance		Mitigation Measures	Mitigation Effect
					Magnitude	Score	Magnitude	Score	Magnitude	Score	Magnitude	Score	Score	Magnitude		
			WM	Positive	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible	plume migration.	mitigated
16	Sulphate and Fluoride leaching from the TDF	Deterioration of groundwater quality	WOM	Negative	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution plume migration.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible		
17	Increased TDS / Nitrate leaching from the overburden dumps	Deterioration of groundwater quality	WOM	Negative	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution plume migration.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible		
18	Dewatering: Water from the Klein Marico into the open pit	Depletion of surface water resource	WOM	Negative	Highly Probable	4	Long term	4	Regional	3	High	8	60	Moderate	Long duration tests completed on boreholes between the pit and river to confirm water volumes to be discharged back into the river.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Medium term	3	Regional	3	Medium	6	24	Low		
19	Dewatering: Spring flow affected	Deterioration of spring flow quantity	WOM	Negative	Definite	5	Long term	4	Regional	3	High	8	75	High	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate the potential zone of influence. Mining operation to provide alternative water should lowering of regional water levels cause a decrease in borehole yields.	May cause irreplaceable loss of resources
			WM	Positive	Probable	2	Long term	4	Regional	3	High	8	30	Low		
20	Water losses: leaking pipes	Insufficient maintenance and increase in water use	WOM	Negative	Probable	2	Medium term	3	Site	2	High	8	26	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	Positive	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		
21	Water Losses: Transmission losses and evaporation	Insufficient maintenance and increase in water use	WOM	Negative	Probable	2	Medium term	3	Site	2	Medium	6	22	Low	Best practise camp management and house-keeping principles to be implemented.	Can be avoided, managed or mitigated
			WM	Positive	Improbable	1	Short term	1	Local	1	Low	2	4	Negligible		
22	Dewatering: Depletion of water levels in boreholes due to over pumping - Higher than recommended yield	Depletion of groundwater resource, impact on neighbouring users	WOM	Negative	Probable	2	Long term	4	Regional	3	High	8	30	Low	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate the potential zone of influence. Mining operation to provide alternative water should lowering of regional water levels cause a decrease in borehole yields.	Can be reversed
			WM	Positive	Highly Probable	4	Medium term	3	Site	2	Medium	6	44	Moderate		
23	Dewatering: Depletion of water levels in boreholes due to over pumping - Longer than recommended pumping time	Depletion of groundwater resource, impact on neighbouring users	WOM	Negative	Probable	2	Long term	4	Regional	3	High	8	30	Low	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate the potential zone of influence. Mining operation to provide alternative water should lowering of regional water levels cause a decrease in borehole yields.	Can be reversed
			WM	Positive	Improbable	1	Medium term	3	Site	2	Medium	6	11	Negligible		
24	Dewatering: Depletion of community water supply boreholes due to dewatering	Depletion of groundwater resource, impact on neighbouring users	WOM	Negative	Definite	5	Long term	4	Regional	3	High	8	75	High	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate the potential zone of influence. Mining operation to provide alternative water should lowering of regional water levels cause a decrease in borehole yields.	Can be reversed
			WM	Positive	Highly Probable	4	Medium term	3	Regional	3	Medium	6	48	Moderate		
Post-Closure Phase																
25	Increased groundwater ingress at disturbed/rehabilitated areas.	Potential decanting of groundwater at low elevation areas.	WOM	Negative	Highly Probable	4	Long term	4	Site	2	Medium	6	48	Moderate	Implement rehabilitation management plan for re-vegetation and decrease in water ingress.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Long term	4	Site	2	Low	2	16	Negligible		
26	Migration of contamination plume from mine contamination sources.	Contamination of regional groundwater and surface water resources.	WOM	Negative	Definite	5	Long term	4	Regional	3	High	8	75	High	Monitoring protocol to be implemented at strategically placed monitoring locations to evaluate pollution plume migration.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Long term	4	Regional	3	Low	2	18	Negligible		
27	Post-closure pit flooding	Negative impact on regional groundwater resources.	WOM	Negative	Probable	2	Long term	4	Local	1	Medium	6	22	Low	Monitor pit water quality as part of post-closure phase.	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Long term	4	Local	1	Low	2	14	Negligible		
28	Permanent radius of influence due to mine dewatering	Depletion of groundwater resource, impact on neighbouring users	WOM	Negative	Definite	5	Permanent	5	Regional	3	High	8	80	High	Backfill optimisation strategies to optimise water level rebound post closure	May cause irreplaceable loss of resources
			WM	Positive	Probable	2	Medium term	3	Regional	3	Medium	6	24	Low		
29	Sulphate and Fluoride leaching from the TDF	Deterioration of groundwater quality	WOM	Negative	Definite	5	Permanent	5	Regional	3	High	8	80	High	Rehabilitate as part of the closure plan to minimise post closure impact	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible		
30	Increased TDS / Nitrate leaching from the overburden dumps	Deterioration of groundwater quality	WOM	Negative	Definite	5	Permanent	5	Regional	3	High	8	80	High	Rehabilitate as part of the closure plan to minimise post closure impact	Can be avoided, managed or mitigated
			WM	Positive	Probable	2	Medium term	3	Site	2	Low	2	14	Negligible		

7 CONCLUSIONS AND RECOMMENDATIONS

To follow are conclusions and recommendations based on the outcomes of this investigation:

7.1 Conclusions

The following conclusions were drawn from this study:

1. The study area is situated in the A31D quaternary catchment within the Crocodile West and Marico Water Management Areas.
2. Mining will be conducted in the Malmani dolomites, which is an inferred major aquifer.
3. Groundwater quality of the selected sampling sites during 2016 is in accordance with most constituent concentration limits specified in SANS 241:2011. As reflected in the baseline water quality data (2013) fluoride (D/BH01, D/BH12) and manganese (BH10, BH14) are still elevated (Figure 3 21). Sampling localities D/BH01, D/BH04 and D/Well01 indicate elevated nitrate levels.
4. Cumulative dewatering volumes were simulated for the separate open pits. Dewatering volumes after 10 years of mining will reach an average of 4000 m^3/d and peak after 26 years of mining at above 7000 m^3/d. Once detailed drilling and long term aquifer testing was conducted within compartment 1, then the model and dewatering simulations should be updated.
5. Water supply from 5 boreholes for sustainable water supply was included in the simulation. In addition, community abstraction was also included to asses' cumulative impacts.
6. Detailed geochemical assessments were completed and the results were used in the mass transport simulations. SO_4 and F were used for the TSF and TDS for the overburden dumps.
7. The preferred TSF position (1 and 4) traverses 2 compartments i.e. 4 and 5. This complicates monitoring and management and it is suggested that the position be revised to only fall in one compartment i.e. 4 or alternatively 1 and 4. The open pits will act as a natural mitigation measure.
8. Existing springs recorded in compartment 1 was simulated to be affected and should be included in the monitoring protocol. Flow changes should be monitored before construction commences.
9. The possibility for sinkhole formation due to groundwater level depletion should be investigated in conjunction with a detail geotechnical investigation.

7.2 Recommendations

1. Due to the sensitivity of the model to the characteristics/integrity of the dyke structures it is necessary to conduct geophysics surveys, drill and test sets of boreholes to evaluate the hydraulic connectivity of compartments, the material properties of the dykes and obtain the necessary spatial head distribution for model calibration. Boreholes should be drilled to assess the following compartments:
    - Compartment 1 and 2 – Resource C and D and mine dewatering impact
    - Compartment 3 and 2 – Resource A open pit influence
    - Compartment 4 and 5 – TSF position and possible migration of salts across the dykes
2. Geophysical surveys and drilling of deep (+- 150 - 200m) groundwater exploration and characterisation boreholes (x10) should be drilled within compartment 1. These boreholes should be subjected to long duration aquifer tests. The data should be used to update the mine dewatering model and possible water supply. Detailed assessments should be conducted on the influence on current groundwater users and water abstracted from storage and mining of the water resource. An analysis should be done to verify suitability of the volumes of groundwater in compartment 1 for bulk water supply to the mine.
3. Detailed geophysical mapping should be completed between the open pits and the Klein Marico River. Boreholes should be drilled on preferential flow paths and long duration testing should commence (96hours+). Isotope sampling and testing should be conducted to verify the origin of the abstracted water and possible mixing ratios between surface water (Klein Marico River) and groundwater.
4. Flow gauges should be installed in the Klein Marico River upstream and downstream of the proposed mine site to record surface water flow.
5. Detailed alien vegetation mapping in the riparian zone of the Klein Marico River should be conducted. The possible positive offset of alien vegetation eradication should be investigated and used as input in the water balance updated in the follow up phases. Possible net saving and influences on the water balance for the mine catchment should be validated and possibly included in the IWUL application.
6. Detailed aquifer characteristics should be obtained for the areas associated with TSF and overburden dumps to assess the inflow rates and possible migration of salts. Shallow core boreholes and packer tests should be completed to obtain hydraulic values for the upper weathered zone.
7. A trade-off study should be completed on the dewatering method i.e. in-pit dewatering collection in a sump versus pre-dewatering by means of deep wells placed around the open

pits.

8. Subsequent to the hydrogeological assessment and supporting regional water balance it is proposed that water supply be conducted from groundwater resources. Groundwater resources will be developed in Compartment 1 and 2 with the possibility of compartment 8 should sufficient resources not be available in the first two mentioned

9. Groundwater exploration to supplement the mine make up water demand should be undertaken in the follow up phase.

10. Moving the TSF position closer to the open pits and within one compartment (4) or two compartments maximum (1 and 4) would be ideal. The open pits and zone of influence due to mine dewatering will act as a mitigation measure capturing the plume and containing it.

11. A possible change in position of the overburden dump associated with Resource C would be to shift this dump south i.e. away from the Klein Marico River.

12. Maximum simulated inflows from the Klein Marico River reached approximately 900 m^3/d resulting in less than 4% impact on the simulated surface water runoff in the A31D quaternary catchment. Once the possible link between the Klein Marico River and the groundwater has been established, then the possible inflows should be updated with a detailed assessment on the surface water runoff of the Klein Marico River catchment area as well as the Groot Marico river catchment area.

13. The applicant understands that groundwater development may have a negative impact with regards to water supply in terms of water quantity and quality due to mining activities and water supply to the mine, and will implement mitigation measures such as monitoring to mitigate and limit any impacts in this regard. Any landowners who may be verified to be affected will be subject to compensation or purchase agreements.

14. Detailed post operational groundwater flow modelling should be conducted. Details such as partially pit backfilling optimisation should be included.

15. Simulations of post operational impacts of pit flooding, mass transport and pit lake geochemistry should be conducted.

16. Current monitoring is ongoing and should be supplemented in the follow up phase with cross compartmental drilling of paired boreholes as well as boreholes between the Klein Marico River and the open pits.

17. The closure plan should be optimised such that the open pits minimise the potential impact on the Klein Marico River (decreased ZOI) while still capturing and containing any possible migration of salts from the TSF and overburden dumps.

18. A dynamic integrated environmental water balance and salt balance to determine the

impacts of the mine on the groundwater and surface water during the operational and post operational phases should be compiled.

19. Detailed sustainability modelling, both analytical and numerical should be conducted once the water supply resources have been identified and developed.
20. The impact of alien vegetation eradication on the riparian zone along the Klein Marico River should be investigated. Detailed offset volumes should be determined and included in the Integrated Water Use License Application process.
21. The possibility of sink hole formation due to mine dewatering and reduction in pressure head in the dolomitic aquifer should be addressed. The hydrogeological investigation should form part of a detailed geotechnical investigation addressing this risk.

8 REFERENCES

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9 APPENDIX A: WATER MANAGEMENT

9.1 Legislation and water licensing

The following legislation should be adhered to:

- National water act Water Act, 1998 (Act No. 36 of 1998)
- GN 704; Regulations on use of water for mining and related activities aimed at the protection of water resources (Kriek, 2009)

9.2 Integrated Water Use Licensing Application (IWULA) according to the NWA, Act No. 36 of 1998

Before any water usages can commence all the water uses should be licensed as part of an Integrated Water Use Licensing Application (IWULA). Water uses are defined in section 21 of the National Water Act, Act No. 36 of 1998 and are included in Information Box A in this document

Information Box A

21. For the purposes of this Act, water use includes -
(a) taking water from a water resource;
(b) storing water;
(c) impeding or diverting the flow of water in a watercourse;
(d) engaging in a stream flow reduction activity contemplated in section 36;
(e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
(g) disposing of waste in a manner which may detrimentally impact on a water resource;
(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
(i) altering the bed, banks, course or characteristics of a watercourse;
(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
(k) using water for recreational purposes.

(Kriek, 2009), NWA, 1998

9.3 Section 21: National Water Act, Act No. 36 of 1998

The applicable section 21 water uses that should be licensed is summarised in Table 9-1.

Table 9-1 Applicable Section 21 Water Use Licenses

Section	Description	Definition
21 (a)	Taking water from a resource. (This will include pumping water out from underground)	A water resource includes a river, stream, dam, spring, aquifer, wetland, lake and a pan. Abstracting water from an off-channel dam having no catchments (for example a balancing dam), a canal, or a pipeline is not taking of water from a resource. The Minister may, however, require a person to have a license to take water from a government water work.
21 (b)	Storing of water	Storing Water (NOTE: Every dam with a wall more than 5m high or which is capable of storing more than 50000 m³ needs to be classified and may need dam safety licenses to construct).
21 (c)	Impeding or diverting the flow of water	Causing an obstruction to the flow of water in a watercourse, or diverting some or all of the flow in or from a watercourse.
21 (e)	Engaging in a controlled activity	Irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterworks. An activity aimed at the modification of atmospheric precipitation. A power generation activity which alters the flow regime of a water resource. Intentional recharging of an aquifer with any waste or water containing waste.
21 (g)	Disposing of waste in a manner which may detrimentally impact on a water resource. This includes the, sludge ponds, process water dams, overburden dump and Pollution Control Dam etc.	Disposal of waste that takes place in on site facilities, such as slurry dams, return water dams, storm water containment dams, oxidation ponds and disposal into evaporation ponds.
21 (i)	Altering the bed, banks, course or characteristics of a watercourse	Altering of the watercourse including: The energy of the watercourse; The morphology of the watercourse; The physical characteristics of the watercourse; The chemical characteristics; Changes that affect flood dynamics; The biotic component
21 (j)	Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people	Removing, discharging or disposing of water found underground in the continuation of an activity or for the safety of persons. If part of the water removed for this reason is not disposed of or discharged into a water resource, but used for some purpose, this water use will be considered to be the taking of water in terms of section 21(a).

9.4 Section 25: National Water Act, Act No. 36 of 1998

If the option is taken to abstract water from a water scheme or transfer from an existing user to an applicant, it might be necessary to include a section 25 application together with the section 21 (a) applications. The applicable section 25 uses are listed in Table 9-2.

Table 9-2 Possible Section 25 Applications

No	Water use
25 (1)	A water management institution may, at the request of a person authorised to use water for irrigation under this Act, allow that person on a temporary basis and on such conditions as the water management institution may determine, to use some or all of that water for a different purpose, or to allow the use of some or all of that water on another property in the same vicinity for the same or a similar purpose.
25 (2)	A person holding an entitlement to use water from a water resource in respect of any land may surrender that entitlement or part of that entitlement:
	a. In order to facilitate a particular licence application under section 41 for the use of water from the same resource in respect of other land; and
	b. On condition that the surrender only becomes effective if and when such application is granted.

9.5 Section 27: National Water Act, Act No. 36 of 1998

Additional requirements from DWS would be a section 27 motivation. In a section 27 motivation the applicant must provide the following assessment information in addition to the application forms and technical information, in order for the DWS official to be able to assess the application in terms of Departmental policies regarding equity, redress, and the economic empowerment of historically disadvantaged individuals (HDIs):

- The applicant’s current water use entitlements
- A description of the race and gender ownership and control of the water use licence applied for
- An explanation of the efficient and beneficial use of water in the public interest
- A description of the socio-economic impact of the issuing or refusal of the licence
- The strategic importance of the water use to be authorised
- A description of the investments related to the water use already made or to be made
- An explanation of the duration of the undertaking for which the licence is required.
- Adherence to the Broad-based Black Economic Empowerment (BBBEE) Guideline for section 27 evaluation

The following factors will also be considered, and the Department may request additional information:

- Any catchment management strategy applicable to the water resource

- Other water users of the resource
- The Class and the resource quality objectives of the water resource
- The quality of the water in the resource required for the Reserve and international obligations

9.6 GN 704 Regulations on the use of water for mining and related activities aimed at the protection of water resources

Although all regulations as stipulated in GN 704 and included in section 9.2 of this document should be adhered to, the following regulations are of special importance in the feasibility report, and were referenced from the GN 704 document.

9.6.1 Section 4: Restriction of Locality

"No person in control of a mine or activity may-

a) Locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year floodline or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on waterlogged ground, or on the ground likely to become waterlogged, undermined, unstable or cracked;

b) Except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year floodline or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest;

c) Place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or open cast mine excavation, prospecting diggings, pit or any other excavation; or

d) Use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year floodline of any watercourse or estuary."

9.6.2 Section 6: Capacity requirements of clean and dirty water systems

"Every person in control of a mine or activity must-

a) Confine any unpolluted water to a clean water system, away from any dirty area;

b) Design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;

c) Collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity, into a dirty water system;

d) Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and

e) Design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act.

f) Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years."

9.6.3 Section 7: Protection of water resources

Every person in control of a mine or activity must take reasonable measures-

a) Prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act;

b) Design, modify, locate, construct and maintain all water systems, including residue deposits, in any area so as to prevent the pollution of any water resource through the operation or use thereof and to restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or the disturbance of vegetation, or the alteration of flow characteristics;

c) Cause effective measures to be taken to minimise the flow of any surface water or floodwater into mine workings, opencast workings, other workings or subterranean caverns, through cracked or fissured formations, subsided ground, sinkholes, outcrop excavations, adits, entrances or any other openings;

d) Design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;

e) Prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources;

f) ensure that water used in any process at a mine or activity is recycled as far as practicable, and any facility, sump, pumping installation, catchment dam or other impoundment used for recycling water, is of adequate design and capacity to prevent the spillage, seepage or release of water containing waste at any time;

g) At all times keep any water system free from any matter or obstruction which may affect the efficiency thereof; and

h) Cause all domestic waste, including wash-water, which cannot be disposed of in a municipal sewage system, to be disposed of in terms of an authorisation under the Act.

(Kriek, 2009)

10 APPENDIX B: MONITORING PROTOCOL

Ongoing monitoring at groundwater and surface water points were conducted since 2013 and still ongoing. The current monitoring points are provided in Table 10-1 and shown in

Detailed annual reports for 2014 and 2015 have been compiled and are available.

Table 10-1 Monitoring points as from 2013 to current

Nr.	Location	Monitoring Frequency	Sampling method	Type	Latitude	Longitude
Surface Water Monitoring Locations						
1	SW1 (Upstream)	Jul	Grab	River	-25.70445	26.21790
2	SW2 (Downstream)	Jul	Grab	River	-25.68795	26.14149
3	RFNSW01	Jul	Grab	Spring	-25.72098	26.13553
Groundwater Monitoring Locations						
1	SKAG01	Jul	Bail	Old Mine Shaft	-25.71399	26.19972
2	DH140	Jul	Pump	Borehole	-25.64910	26.13616
3	DHK04	Jul	Pump	Borehole	-25.65853	26.13748
4	DH120	Jul	Pump	Borehole	-25.69286	26.19320
5	DH135	Jul	Bail	Borehole	-25.68150	26.20246
6	KNF01	Jul	Pump	Borehole	-25.71137	26.22130
7	DH133	Jul	Pump	Borehole	-25.70537	26.24415
8	DH127	Jul	Pump	Borehole	-25.74945	26.23874
9	DH143	Jul	Pump	Borehole	-25.70655	26.15612
10	DH72	Jul	Pump	Borehole	-25.68553	26.14182
11	WHK03	Jul	Bail	Borehole	-25.69650	26.08121
12	DH112	Jul	Pump	Borehole	-25.74763	26.09565
13	DH109	Jul	Bail	Borehole	-25.76879	26.15323
14	DH110	Jul	WL only	Borehole	-25.76829	26.15309
15	SFN02	Jul	Pump	Borehole	-25.76120	26.12705
16	RVL04	Jul	Pump	Borehole	-25.72544	26.25730
17	ZDP01	Jul	Pump	Borehole	-25.67960	26.04014
18	WRD01	Jul	Pump	Borehole	-25.74766	26.16966
19	DHK04B	Jul	WL only	Borehole	-25.65821	26.13761
Previous Digby Wells Monitoring Locations						
1	BHF01	N/A	Pump	Borehole	-25.77849	26.30166
2	KFN02	N/A	Pump	Borehole	-25.62694	26.12280
3	KPL03	N/A	Pump	Borehole	-25.78284	26.01685
4	MMO01	N/A	Pump	Borehole	-25.82440	26.04970
5	WFT01	N/A	Pump	Borehole	-25.84834	26.16643
6	WKL01	N/A	Pump	Borehole	-25.60671	26.23422
7	ENRC OFFICE BH	N/A	Pump	Borehole	-25.70823	26.20712

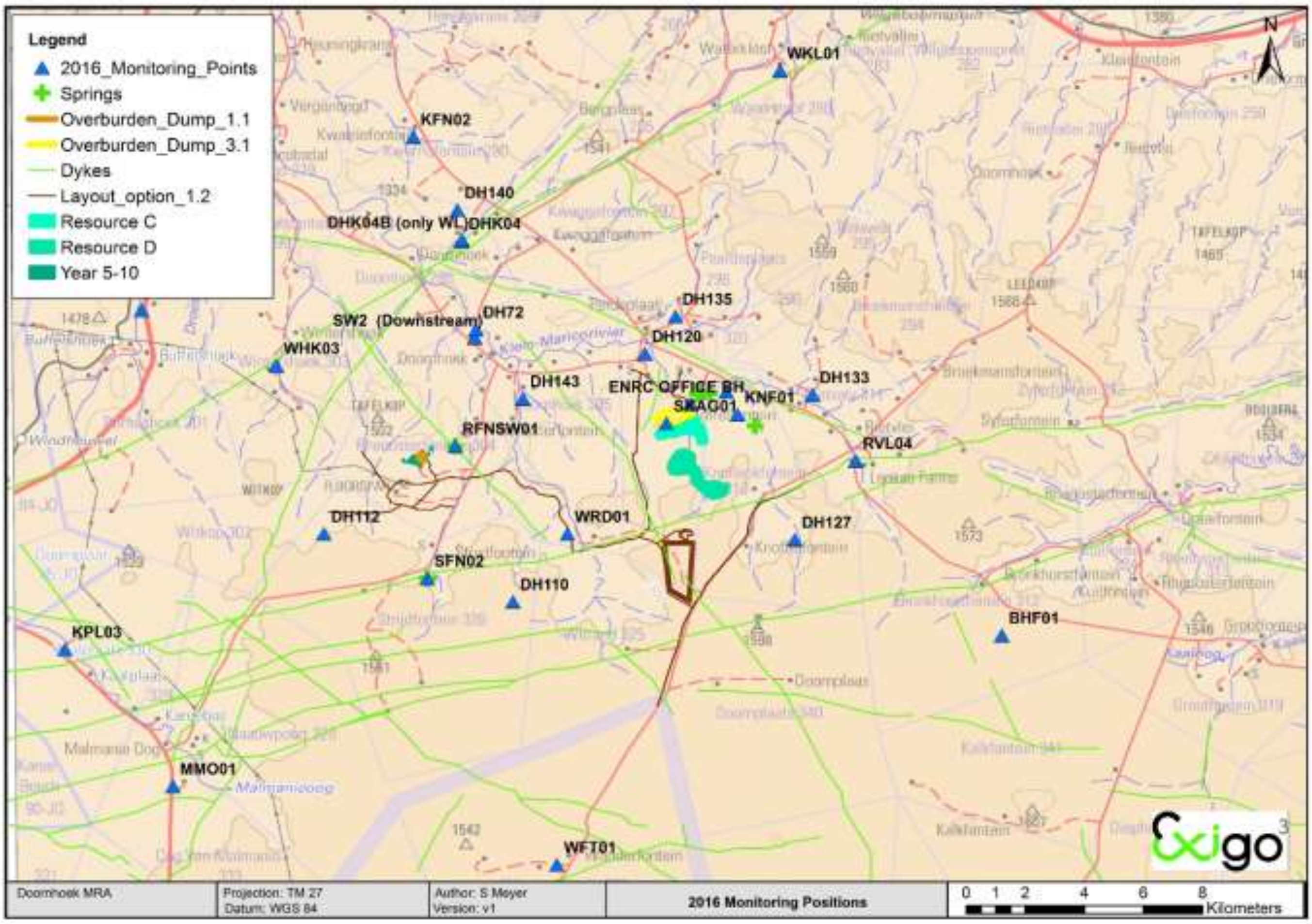

Figure 10-1 Current monitoring positions (2016)

10.1 Monitoring objectives

The monitoring objectives are to detect and manage the possible impacts of the project and related infrastructure on the hydrological environment.

The main objective of the monitoring is to:

- Obtain accurate information of the chemical, micro biological and physical characteristics of the receiving environment
- The timely detection of any changes in the chemical, micro biological and physical characteristics of the receiving environment
- The timely detection of any changes in the chemical, micro biological and physical characteristics of waste released into the environment.
- To detect any spills at or malfunctions at the project or related infrastructure.

- To obtain information that can be used to update the environmental management plan.
- To determine if applicable environmental laws and standards are adhered to.
- Refine and update the conceptual and numerical (management) models.
- Provide an on-going performance record for effectively controlling possible pollution.

This will ensure that management is aware of problems and unexpected impacts that arise, and are in a position to implement additional mitigation measures at an early stage.

10.2 Possible pollution sources

Potential pollution sources include the following:

1. Offices, Change House etc.
2. Diesel storage tanks
3. Sewage tanks and drain networks
4. Overburden dumps and stock piles
5. TSF

10.3 Receiving environment

The following hydrological units may be impacted by the Doornhoek Fluorspar Mine and related activities:

- The weathered overburden
- Klein Marico River
- Springs
- The recharge zone
- Fractured rock aquifer
- Several drainage lines in the project area
- Community abstraction points

Additional monitoring points should be established in the follow up phase:

1. Detailed monitoring points between the open pits and the Klein Marico river, both shallow and deep paired boreholes.
2. Monitoring points on both sides of the dykes separating the following compartments:
    a. Compartment 3 and 2 – monitoring of impact of Resource A open pit.
    b. Compartment 4 and 5 – monitoring of impact of preferred TSF position

c. Compartment 1 and 2 – monitoring of potential ZOI created by the open pit dewatering.

10.4 Additional Monitoring Points

Additional monitoring points should be included in the monitoring protocol once these points have been established. These points include:

- Monitoring points to be drilled around the proposed TSF and overburden dumps. These points should consist of shallow and deep boreholes to effectively monitor shallow and deep migration of salts both in the perched and deeper fractured rock aquifer.
- Any additional water supply boreholes to be drilled in the future should be included in the monitoring protocol.

Constant isotope sampling and analyses should be conducted to ensure that water abstracted at the water supply boreholes as well as water pumped from the open pit mine workings does not originate from the Klein Marico River. This sampling should be done monthly.

10.5 Monitoring frequency

10.5.1 Construction phase monitoring

During the construction phase of the project both water level and water quality monitoring should take place on a monthly basis. Sampling runs and water level measurements should thus be conducted once a month until construction is done on site.

10.5.2 Post construction phase monitoring

After the construction phase of the project is done, water level and water quality monitoring should continue for LoM and for 5 years post-closure of the mine. This monitoring should take place on a quarterly basis.

10.6 Sampling parameters

Additional water quality monitoring should be done through sampling of groundwater and surface water at the points listed in Table 5-1 **Error! Reference source not found.**and sent to an accredited laboratory for analysis in addition to the current water monitoring sites. The parameters listed in Table 10-2 should be analysed for and reported on in the monitoring reports.

Table 10-2 Sampling parameters

Sample Type	Field measurements	Laboratory analysis: Chemical
Ground water	pH, EC, temperature (measured with instrument during sampling)	NO2 - N; NO3 - N; Cl; SO4; PO4-P; CO3; HCO3; Na; K; Ca; Mg; T Alk; TDS; NH4; Zn; F; Cr; Fe; Mn; Cu; Cd; Co; Pb; Ni; Al; pH; EC; TDS; T Hard; LSI; Total Anion; Total Cation

10.7 Sampling procedures

(EH Venter; TT Mokalapa 2008) The sampling procedure for groundwater should be done according to the protocol by Weaver, 1992. The actions can be summarised as follows:

1. Calibrate the field instruments before every sampling run. Read the manufacturers manual and instructions carefully before calibrating and using the instrument.
2. Purging a borehole can be done in the following ways:
    a. With a portable pump
    b. With an already installed submersible pump
    c. By lowering a bailer into the hole
3. Prior to sampling, measure the water level and record.
4. Install the pump (If not equipped) with the inlet close to the static water level.
5. Set up the EC, pH and temperature meter.

6. Start pumping and record the pumping rate in ℓ/s.
7. Continuously measure the pH and EC values.
8. If the field chemistry stabilizes the borehole is purged. Note that approximately three columns of water should be removed. The volume of water to be removed is calculated using the following formula:

   Volume of standing water = $\pi r^2 \times h \times 1000$, where

   R = radius of borehole in meter

   H = height of water column in meter
9. Some boreholes are low yielding and go dry when purging. Leave the borehole to recover for a few hours. When returning, install the pump with the inlet close to the static water level and continue with the next step. Alternatively, bail the borehole.
10. Sample for microbiological constituents – using a sterilised glass bottle. Avoid contact with the inner surface of the bottle or cap. Fill the sample bottle without rising.
11. Sample for chemical constituents – remove the cap of the plastic 1 litre sample bottle, but do not contaminate inner surface of cap and neck of sample bottle with hands. Fill the sample bottle without rising.
12. Leave sample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
13. Replace the cap immediately.
14. Complete the sample label with a water resistant marker and tie the label to the neck of the sample bottle with a string or rubber band. The following information should be written on the label
    a. An unique sample number and description
    b. The date and time of sampling
    c. The name of the sampler
15. Place sample in a cooled container (e.g. cool box) directly after collection. Try and keep the container dust-free and out of any direct sunlight. Do not freeze samples.
16. Complete the data sheet for the borehole
17. See to it that the sample gets to the appropriate laboratory as soon as possible. The microbiological sample should be kept by $4^{o}C$ and reach the laboratory within 24 hours, the micro biological sample should be taken in a bottle provided by the laboratory specifically for micro biological samples. Samples for chemical analysis should reach the laboratory

preferably within seven days.