Groundwater Complete

Makganyane Proposed Iron Ore Mine

Report on geohydrological investigation as specialist Risk Assessment

July 2025

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MAKGANYANE PROPOSED IRON ORE MINE: REPORT ON GEOHYDROLOGICAL INVESTIGATION AS SPECIALIST RISK ASSESSMENT, JULY 2025

EXECUTIVE SUMMARY:

Groundwater Complete was contracted by Assmang (PTY) LTD to conduct a geohydrological risk assessment and report on findings as specialist input on the groundwater environment in the Makganyane proposed mining area. This report is the deliverable of that study and apart from the main purpose of supporting the mining right application the content will be sufficient to inform future Environmental Impact Assessment (EIA) and Environmental Management Programme (EMPr) for the Makganyane Iron Ore Project (hereinafter referred to as Makganyane). A locality map of the project area is provided in **Figure 1-1**.

The project is located on the farm of Makganyene 667, which covers an area of approximately 1 544 hectares. It is located approximately 23 km north-west of Postmasburg in the Northern Cape Province. Assmang's Beeshoek Iron Ore Mine is located ± 16 km south-east of the Makganyane area.

Iron ore is the target mineral and mining is, will occur from opencast pits. Only the actual mining of ore will take place on Makganyane, ore processing and beneficiation will be hauled to Assmang's Beeshoek Mine where a processing plant and discard facilities already exist. Thus, the only mining infrastructure that will be situated on site will be the waste dump- and product stockpile facilities.

The following is a summary of important information contained throughout the report:

- The lowest surface elevation of approximately 1 250 meters above mean sea level (mamsl) occurs near a tributary to the south/south-west, while the highest elevations are found in the hills in the centre of the farm at approximately 1 360 mamsl.
- The Soutloop River and its numerous tributaries that cut through the project area are non-perennial and only experience any flow during and directly after a significant rainfall event.
- The project area is located within the D73A quaternary catchment, which covers an area of just over 3 200 km^2.
- The mean annual precipitation for the project area is in the region of 320 mm.
- Evapotranspiration is very high in excess of 2 200 mm/year.
- The project area has a net environmental moisture deficit for the entire year.
- Numerous faults and/or igneous intrusions (dykes) occur throughout the project area and are of significant importance to the geohydrology. Few of the structures seemed to act as either prominent barriers for horizontal groundwater flow, or as preferred flow paths for extended distances.
- Exploration boreholes drilled in the Makganyane area intersected highly brecciated areas (mainly banded iron formation, shale and quartzite) at depths of between ± 30 and 300 meters below surface. From a geohydrological perspective, these areas are

of significant importance as they have the potential to yield significant volumes of groundwater.

- A total of 98 boreholes were located during the hydrocensus.
- Agriculture and livestock watering are the main water uses in the area.
- The Makganyane area is underlain by two distinct and very different aquifers.
- The first of the aquifers exists in the eastern and western flatter areas of the Makganyane property. The host rock of the aquifer is the andesitic lavas of the Ongeluk Formation.
- The second aquifer present in the Makganyane area is the aquifer that exists mainly in the planned mining area. This aquifer exists mainly in a specific layer, namely the chert-breccia layer.
- Topographical highs and lows were used to approximate no-flow boundaries for the model.
- The relationship in the Makganyane does not have a linear relationship between the surface topography and groundwater elevation.
- Groundwater levels in the flatter areas to the west of the hills varied between 7 and 22 meters below surface (mbs), while the water levels to the east of the hills varied between 18 and 28 mbs.
- The groundwater levels in the hilled area were markedly deeper, ranging between 30 and 100mbs.
- The lowest measured static groundwater elevation of approximately 1 237 meters above mean sea level (mamsl) occurs in the down gradient groundwater flow direction towards the south/south-west, while the highest elevation of ± 1 289 mamsl is found to the hills in the centre of the mining rights area.
- By substituting the hydraulic head difference over lateral distance, average hydraulic gradients were calculated to be in the order of 0.0042 or 0.42% and was then used to calculate the rate of groundwater movement (the so-called 'Darcy flux') in the project area.
- By making use of these values, the average rate of flux in the project area was calculated to be in the order of 4.8 meters per year.
- Due the highly varying nature of aquifers that are present in the Makganyane area, the groundwater flow calculated for this report only represents a regional average flow velocity and direction. Flow velocity and direction both vary significantly if tested more specifically on a smaller scale.
- The project area achieved a score of 6 and the underlying aquifer can therefore be regarded as having a medium vulnerability.
- The GQM rating for Makganyane is 8, which indicates a high level of protection.
- After consideration of all the data collected by conducting the slug tests and constant rate tests, the following summary of conclusions was drawn:
  - Two different aquifers exist in the Makganyane area.
  - The aquifer where mining activities will be concentrated is a highly heterogeneous aquifer with hydraulic parameters varying significantly over short distances.
  - The aquifer to the east and west of the hills have shallower water levels and is expected to have a higher groundwater yield, however, very few of them were pump tested.

  - The two aquifers are poorly connected to each other.
  - The matrix transmissivities of the aquifer in the hills range from 0.08 to 57 m2/d.
  - The aquifer provides little to middling volumes of water.
- An average recharge of 2% was calculated with the Chloride Method, which is in line with the 1.8 - 2.4% range of Vegter.
- Based on all the gathered information and experience from previous studies in similar areas, the mean annual recharge to the aquifer regime in the Makganyane was assumed to be in the order of 2% or 6.5 mm/a.
- Groundwater is considered to be of good quality and also suitable for human consumption according to the South African National Standards for drinking water (SANS 241:2015).
- Groundwater samples were collected from a total of 20 boreholes located on and around the Makganyane property.
- Groundwater samples were taken from 10 of the pump testing boreholes.
- Among the hydrocensus boreholes, samples were taken from 10 user boreholes in use for specifically domestic or livestock watering purposes and located closer to mining operations.
- Two samples were taken from the old Kimberlite shaft at different depths.
- Groundwater TDS concentrations measured in the site specific groundwater user boreholes vary between 330 mg/l and 590 mg/l and is considered a normal range for this arid region.
- The highest nitrate concentrations measured during this study is around 7 mg/l.
- Groundwater magnesium concentrations are relatively low and vary between ± 27 mg/l and 64 mg/l.
- Boreholes display groundwater chloride concentrations of between approximately 8 mg/l and 68 mg/l.
- Since no mining occurs within the immediate vicinity of any of the hydrocensus boreholes, the elevated nitrate concentrations are believed to originate from areas where animals congregate in significant numbers (feedlot, kraal, etc.).
- Groundwater within the Makganyane area is dominated by calcium and magnesium cations, while bicarbonate alkalinity dominates the anion content.
- The concentrations of groundwater parameters measured in the old Kimberlite pit were largely similar the qualities measured in the other Makganyane boreholes.
- None of the concentrations exceeded the SANS 241:2015 guidelines for drinking water purposes.
- The only difference between the concentrations measured in the Kimberlite pit versus the surrounding area is slightly higher concentrations of sodium, magnesium and potassium likely due to higher evaporation.
- For a negative groundwater quality impact to be registered the following three components should be present:
  - A source to generate and release the contamination,
  - A pathway along which the contamination may migrate, and
  - A receptor to receive the contamination.

Summary of the numerical model

- Steady state simulation – Model runs until groundwater levels reach a state of equilibrium, i.e. total groundwater inflow from natural sources is equal to the total volume of groundwater outflow through natural sinks.
- Transient state simulation – Model runtime is predetermined according to desired scenario and groundwater levels are now affected by sinks and sources other than natural.
- Due to the heterogeneity of the aquifer many of the boreholes had greatly varying groundwater elevation in spite of being located close together.
- An acceptable correlation was achieved considering the heterogeneity of the aquifer.

Summary of flow model simulation:

- A maximum groundwater level drawdown of ± 110 m was simulated for the planned Makganyane Pit.
- An area of approximately 5.9 km2 of the water table was simulated to be affected by the opencast mining of the two pits (i.e. area simulated to experience >5m lowering of water levels).
- The flow model assumed a rapid deepening of the pits in the first few years of mining. This will cause a high volume of inflow during the first years of mining since a significant amount of water needs to be pump from storage in the saturated mine material.
- Due to the relatively short life of mine, the rate of inflow will not have stabilized to reach an equilibrium by the time mining ends and water levels will have started to recover.
- As the mining progresses average influx volumes of between 20 and 40 m3/h may be expected.
- The shape and extent of the depression cone are largely determined by the hydraulic properties of the surrounding aquifer/s and geological structures. Impacts on groundwater levels will be exacerbated along certain transmissive geological structures (i.e. open fractures and discontinuities).
- No hydrocensus boreholes are located within this affected area, however, the “KR”-boreholes to the north will still be affected in terms of groundwater quantity due to the proximity to the cone of influence, for which some form of compensation will have to be planned.
- After mining has ceased, the pits will fill with water, allowing the surrounding groundwater levels to slowly recover.
- The radius of the cone of depression may increase slightly after mining has ceased, but it will start becoming shallower immediately.
- The water level recovers to between 20 and 30 meters below normal.

Summary of pit dewatering

- The most important function of the flow modelling is in estimating approximate dewatering volumes.
- The Inflow into the opencast pits have been calculated for each stress period and is displayed below:

Stress Period	Period Length	South Pit		North Pit	
		Daily Volume	Pump Rate	Daily Volume	Pump Rate
	Year	m^3/d	L/H	m^3/d	L/H
1	10	0	0	0	0
2	0.25	0	0	0	0
3	0.25	0	0	0	0
4	0.25	0	0	0	0
5	0.25	0	0	0	0
6	0.25	0	0	460	19174
7	0.25	0	0	734	30577
8	0.25	0	0	810	33736
9	0.25	28	1155	814	33923
10	0.25	78	3269	875	36449
11	0.25	187	7806	991	41293
12	0.25	156	6500	668	27814
13	100	0	0	0	0

Summary of the contamination transport model simulation

- Any potential contamination is expected to slowly migrate down from the surface towards the groundwater level, transported by rainwater during recharge.
- The concentration of the contamination, 100% at the source, will slowly dilute as it moves away from the source.
- By the end of modelling, the contamination had moved between 120m and 150m down-gradient.
- Potential contamination may eventually reach the position of the pit and seep into the pit void.

Summary of the risk assessment

- The main activities of the proposed mine that may have an effect on groundwater quality or quantity availability are listed below:
    - Generation of stockpile and WRD;
    - Excavation of the pits;
    - Waste water generation and management.
- Mitigation measures were recommended for each of the potential risk areas in section 5.

	Generation of stockpile and WRD		Excavation of the pits		Waste water generation and management	
	No mitigation	With mitigation	No mitigation	With mitigation	No mitigation	With mitigation
Significance/Risk	6.4	4.8	32	22.4	6.4	3.2
Risk Class	Low risk	Low risk	Medium risk	Low risk	Low risk	Low risk

Summary of the monitoring recommendations

- Groundwater monitoring should be conducted to assess the impacts of the proposed new mining activities on groundwater quality and quantity
- Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals.
- There are five areas that need to be monitored to focus on different aspects of monitoring. Existing exploration boreholes located in advantageous positions should be used for monitoring purposes.
- the mine should also consider including some active user boreholes located within at least a 1 km radius (but preferably 2 km) of the planned mining activities
- Groundwater samples should be analysed at a SANAS accredited laboratory for chemical and physical constituents normally associated with iron ore mining and related activities

Monitoring Area	Boreholes	Monitoring Focus
North Pit	MK0102 MK0089 MK0445 KR02	Water level monitoring
South Pit	MK0254 MK0134 MK0090 MK0326 MEX1	Water level monitoring
WRD	MEX27 MK0123 MK0124 MK0046	Inorganic compounds
Stockpile	MK0416 MK0417A MK0171 MK0058/275	Inorganic compounds
Office latrine	Additional borehole necessary	Bacteriological monitoring

Based on the groundwater characteristics of the project area and the proposed activities, the project can be supported from a groundwater perspective. It will present very low risk to the groundwater environment, provided that all management and monitoring actions as provided in this report be implemented and maintained throughout the life of the project.

1 INTRODUCTION

1.1 BACKGROUND INFORMATION AND PROJECT SUMMARY

Groundwater Complete was contracted by Assmang (PTY) LTD to conduct a geohydrological risk assessment and report on findings for the proposed Makganyane mining area. This report is the deliverable of that study and apart from the main purpose of supporting the mining right application, the content will be sufficient to inform future Environmental Impact Assessment (EIA) and Environmental Management Programme (EMPr) for the Makganyane Iron Ore Project (hereinafter referred to as Makganyane). A locality map of the project area is provided in **Figure 1-1**.

The project is located on the farm of Makganyene 667, which covers an area of approximately 1 544 hectares. It is located approximately 23 km north-west of Postmasburg in the Northern Cape Province. Assmang's Beeshoek Iron Ore Mine is located ±16 km south-east of the Makganyane area.

Iron ore is the target mineral and mining will occur from opencast pits. Only mining will take place on Makganyane, as the ore will be hauled to Assmang's Beeshoek Mine where a processing plant and discard facilities already exist. Thus, the only mining infrastructure that will be situated on site will be the waste dump- and product stockpiles.

Please note that an old diamond mine was located on the property, of which the pit is still open and flooded with water to near-surface. Another small defunct diamond mining operation is also present on the neighbouring farm to the north on the border of the Makganyane property.

The main objectives of this study were:

- To determine the potential impacts of the proposed mining and related activities on groundwater quantity (depression cone), groundwater quality (contamination plumes) and estimate approximate groundwater dewatering volumes;
- To discuss the current (baseline) groundwater environment and characteristics before the commencement of any mining activities; and
- To propose a groundwater monitoring protocol to ensure a continued improvement of the understanding of the groundwater baseline conditions.

1.2 METHODOLOGY

The main objective of this study was to determine the potential impacts of the proposed new mining and related activities on local groundwater quality conditions and water levels. In order to successfully achieve this objective, the following methodology was followed:

- Topographic maps were consulted and used in the general description of the surface topography and water courses located within the immediate vicinity of the project area *(Section 2.1)*.
- Climatic conditions namely the mean annual rainfall, temperatures and evaporation were obtained from DWA weather station data and discussed *(Section 2.2)*.
- Relevant reports from other related studies and the 1:250 000 scale geological map of the project area were consulted in the assessment and discussion of the local geology *(Section 2.3)*.
- The findings of hydrocensus/user survey were assessed to determine the number and distribution of groundwater users in the project area and their groundwater uses. Groundwater quality and water level information collected during these surveys were also applied in this investigation as explained in the following paragraphs *(Section 3.1)*.
- Topographic and geological maps were used in the delineation of the aquifer underlying the project area *(Section 3.2)*.
- Groundwater level information collected during the hydrocensus/user survey as well as exploration boreholes was used in the assessment of the groundwater level depth *(Section 3.3)*.
- Groundwater level information was also used to calculate groundwater flow directions, gradients and velocities as accurate as possible *(Section 3.4)*.
- Geological information together with the findings of previous groundwater related studies were used to identify and characterise the aquifers underlying the project area *(Section 3.5)*.
- The results of aquifer tests (i.e. slug tests and constant rate pumping tests) that were performed for the study were assessed to determine representative aquifer parameters such as transmissivity and storativity *(Section 3.6)*.
- Various sources *(Vegter, 1995)* and methods were consulted in the assessment of the aquifer recharge rate for the project area *(Section 3.7)*.
- Groundwater samples were analysed at a SANAS accredited laboratory. The results of the analyses were used in the assessment of the groundwater quality conditions *(Section 3.8)*.
- The summary of the waste classification report by IQS Holdings (2025) was used to determine source terms for the various potential contamination sources on the property *(Section 3.9)*.
- Possible groundwater contamination sources were discussed based on the outcome of the waste classification report *(Section 3.10)*.
- All possible receptors were identified within the project area with the help of information gathered during the hydrocensus/user survey and topographic maps *(Section 3.12)*.
- A conceptual model was formed and summarised on the basis of all the information that was collected and available during the time of this study (Section 3.13)
- With the numerical groundwater flow model only being simplified representations of the very complex and highly heterogeneous aquifer system/s underlying the project

area, certain model restrictions and limitations inevitably do exist and were discussed briefly *(Section 4.1)*.

- Aquifer parameters and model boundaries that were used in the construction of the model and delineation of the modelled area respectively were based on information from the conceptual model and discussed in detail *(Section 4.2)*.
- Groundwater level information collected during the hydrocensus/user survey and pump test phase was used extensively in the steady state calibration of the groundwater flow model *(Section 4.3)*.
- The main aim or objective of the flow model was to simulate/predict the groundwater influx into the pits during the mining process *(Section 4.4.1)*.
- Water level impacts from the planned opencast mining were displayed and discussed, i.e. estimation of groundwater depression cone as a result of the opencast mining *(Section 4.4.2)*.
- In an attempt to quantify the effect of the most important parameters (Transmissivity, storativity and recharge) on the modelling results, a sensitivity analysis was performed *(Section 4.4.1)*.
- Contour maps of the model simulated groundwater depression cone were generated and discussed in detail *(Section 5.1).*
- The dewatering design was discussed in detail *(Section 5.2).*
- Contour maps of the model simulated potential contamination plumes were generated and discussed *(Section 5.3).*
- Groundwater risk assessments were conducted for each of the hazardous activities *(Section 5.4).*
- Comments were made on the possibility of cumulative impacts from surrounding mining and related activities *(Section 5.5)*.
- A comprehensive groundwater monitoring plan/protocol was proposed and discussed in detail, which is recommended for the construction, operational and post closure phases of mining *(Section 6)*.

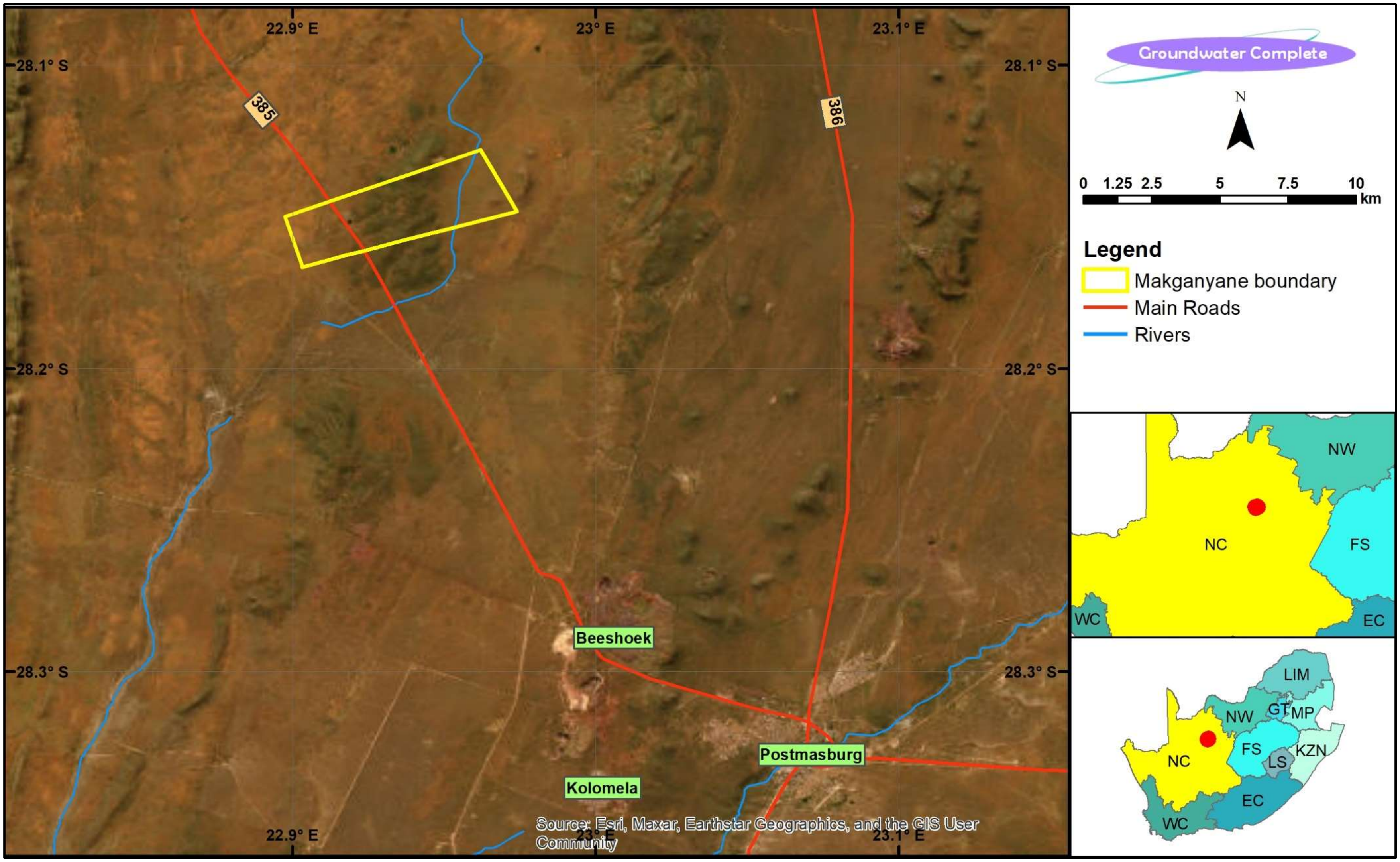

Figure 1-1: Locality map of the project and surrounding area with property boundary.

2 SITE SETTING

2.1 SURFACE TOPOGRAPHY AND WATER COURSES

The surface topography of the project area consists of relatively flat areas to the eastern and western regions of the property with a hilly area in the middle. The lowest surface elevation of approximately 1 250 meters above mean sea level (mamsl) occurs near a tributary streambed which eventually becomes part of the Soutloop River to the south/south-west, while the highest elevations are found in the hills in the centre of the farm at approximately 1 360 mamsl.

The project area is drained by tributaries of the Soutloop watercourse, which is mostly dry apart from run-off during and directly after significant rainfall events. The watercourse and tributaries occur as flat, open valley-bottom areas that are often up to 1 km wide.

The project area is located within the D73A quaternary catchment, which covers an area of just over 3 200 km^2. Surface elevations and water courses for the project area are indicated in **Figure 2-1**.

Summary:

- *The lowest surface elevation of approximately 1 250 meters above mean sea level (mamsl) occurs near a tributary to the south/south-west, while the highest elevations are found in the hills in the centre of the farm at approximately 1 360 mamsl.*
- *The Soutloop River and its numerous tributaries that cut through the project area are strictly non-perennial and only experience flow during and directly after a significant rainfall event.*
- *The project area is located within the D73A quaternary catchment, which covers an area of just over 3 200 km^2.*

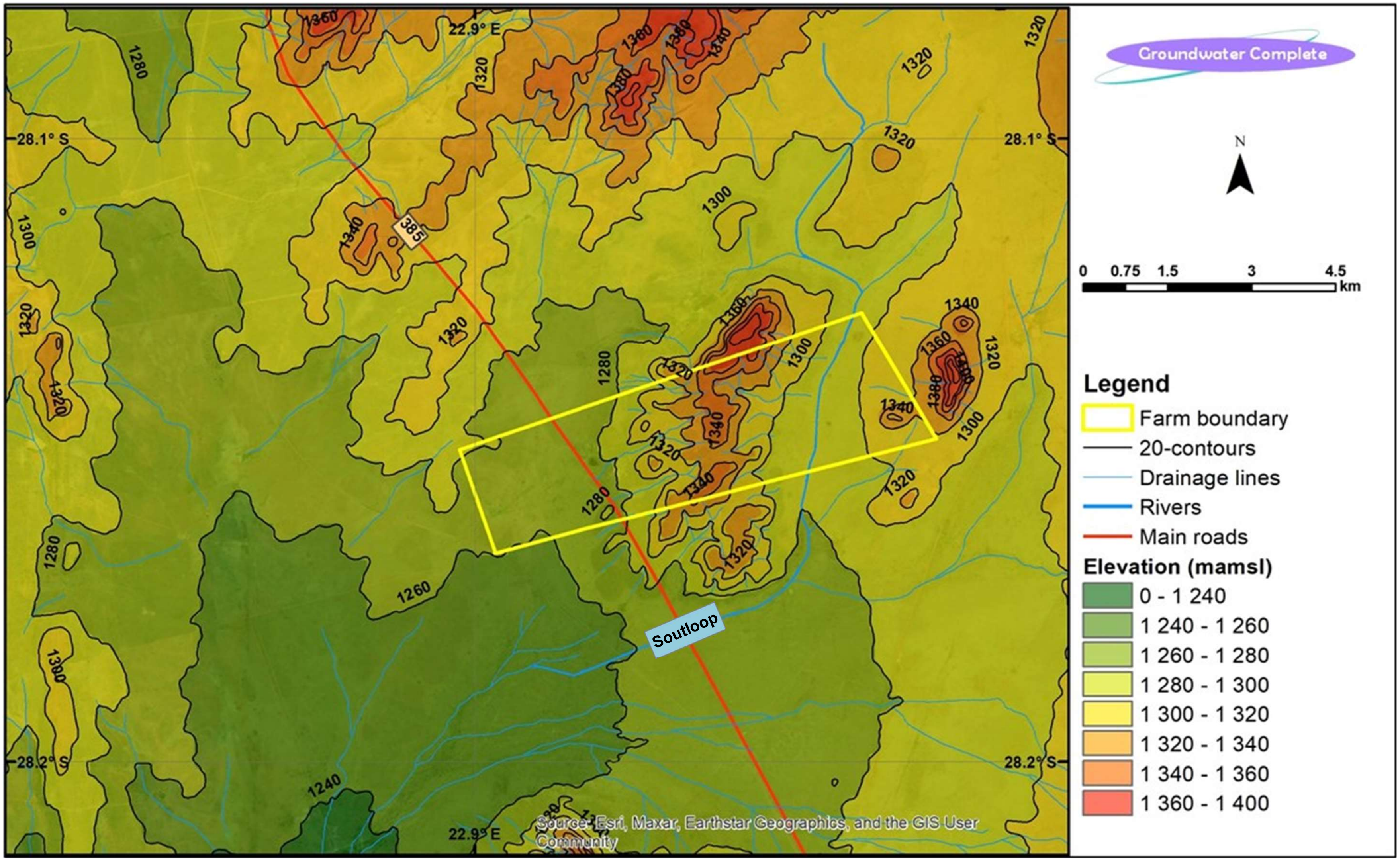

Figure 2-1: Surface elevations for the project area (mamsl)

2.2 CLIMATIC CONDITIONS

The project area has a semi-desert climate with hot summers and mild to cold winter temperatures. Average temperatures vary from approximately 25 ºC in the summer month of January to nearly 20 ºC in the July **(Figure 2-2)**.

The mean annual precipitation (MAP) for the project area is in the region of 320 mm. Rainfall and evaporation data was gathered from the Department of Water and Sanitation (DWS) meteorological station D4E002. Rainfall is at its highest during the warm summer months and decreases to nearly zero during the cold winter months. Evapotranspiration is very high (in excess of 2 200 mm/year), resulting in a significant environmental moisture deficit throughout the year **(Figure 2-3)**.

Summary:

- *The mean annual precipitation for the project area is in the region of 320 mm.*
- *Evapotranspiration is very high and in excess of 2 200 mm/year.*
- *The project area has a net environmental moisture deficit for the entire year.*

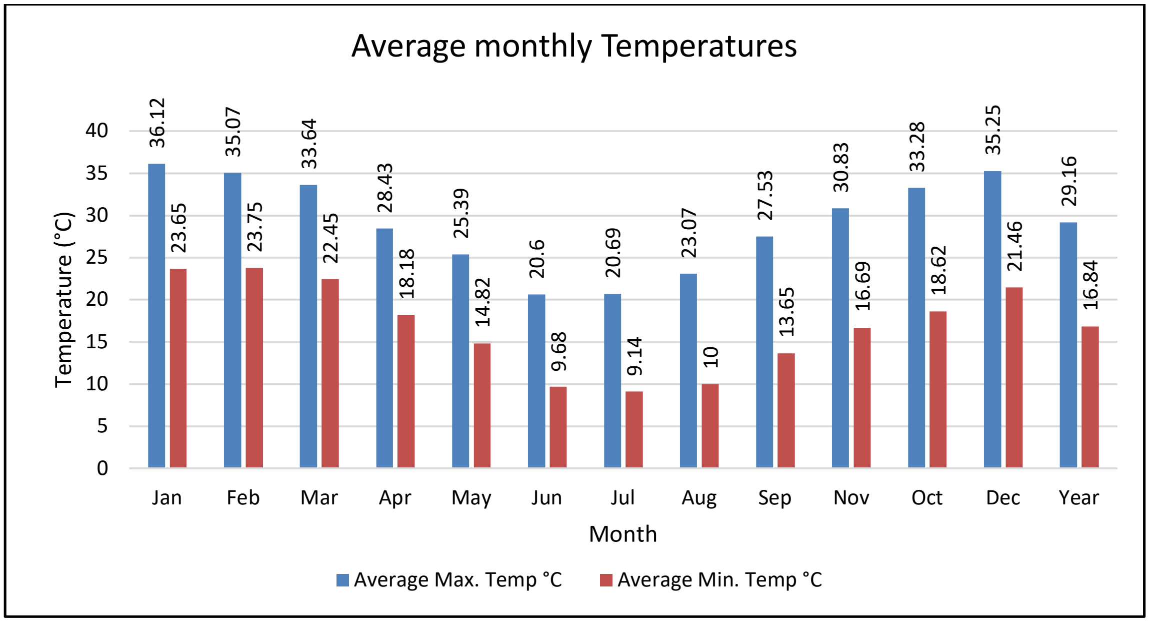

Figure 2-2: Average monthly temperatures for the Postmasburg area (weatherandclimate.com/)

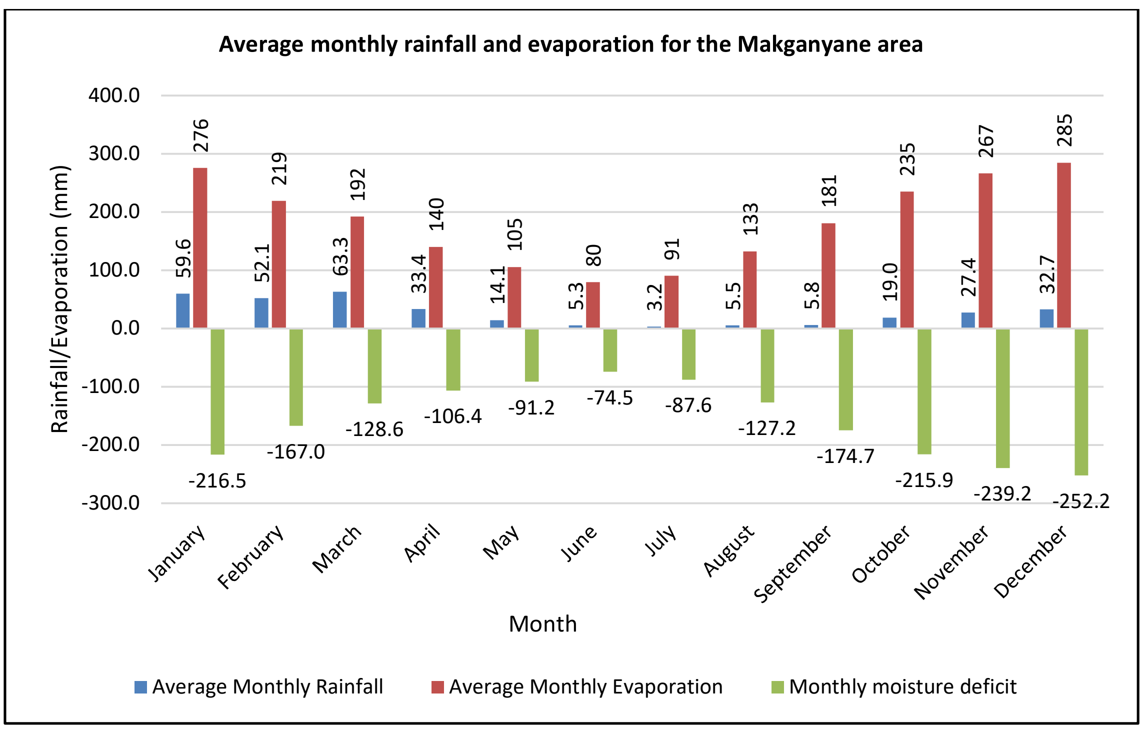

Figure 2-3: Mean annual rainfall and evaporation for the project area *(DWS, 2024)*

2.3 GEOLOGY

All geological information provided in this report was interpreted from the 1:250 000 scale geological map of the project area provided in **Figure 2-4** as well as an internal geological report on the Makganyane resource conducted by Assmang *(Makganyene: Phase 1 Geological Exploration, 2021)*.

A simplified stratigraphic column is provided in **Figure 2-5** to indicate the layers as they appear in the Makganyane area. A clear picture of the regional geological layout is formed if the abovementioned column is viewed in conjunction with **Figure 2-6** in vertical cross-section format.

The Maremane dome is the main geological feature in the area between Postmasburg in the south and Sishen in the north. It forms a large anticline structure stretching over tens of kilometers consisting mainly of dolomite. The top of the dome ends in an unconformity, in which the banded iron formation (BIF) and Wolhaarkop formations were formed. The chert units (Wolhaarkop Formation), comprising angular to sub-rounded chert fragments in a grey-brown chert matrix, unconformably overlies the carbonates. The breccia is thought to be the result of solution collapse and cavity formation within the underlying dolomites. With the collapse of the underlying dolomite, the overlying chert broke-up and accumulated in the cavity. These zones of brecciated cherts are most likely the source (transmissive fracture zones) of water in the boreholes where the highest yields were recorded.

The BIF within the area belongs to the Kuruman Iron Formation and have locally been named the Manganore Iron Formation (Beukes, 1983). The Makganyane iron-ore deposits were formed by the reformation of BIF's during the end of the formation of the Pretoria/Postmasburg groups.

A clastic succession of sedimentary rocks (conglomerates, shales, flagstones and quartzites) of the Gamagara Formation were deposited above an unconformity surface formed on the upper parts of the Asbestos Hills Subgroup. The Gamagara sequence is well developed in the Sishen area. The Koegas Group rocks fill synclinal basins around the Wolhaarkop Dome, having been thrust onto the Gamagara Formation.

The Koegas Subgroup is, in turn, conformably overlain by diamictite of the Makganyene Formation, upon which lavas of the Ongeluk Formation have been subaqueously extruded. The Makganyane area is mainly covered by a dome of Koegas Group Nelani and Rooinekke formations with some outcrops of diamictite of the Makganyene Formation. Surrounding the dome is a region of Ongeluk Formation andesitic lavas, almost entirely blanketed by sand, dolocrete and calcrete of the Kalahari Group.

In a hard rock environment, geological structures such as faults and intrusive dykes often play a major role in groundwater flow and mass transport. Such structures may form linear zones of very high yield or the opposite – they may also form barriers for horizontal groundwater flow and compartments when they are impermeable. Several of these geological structures (dykes and faults) have been mapped throughout the Makganyane area as indicated in **Figure 2-7**.

There are two regional dykes occurring in the Makganyane area, which are also indicated in the abovementioned figure in black. Please note that aquifer tests were conducted on observation boreholes located near and around these indicated structures, However, the test results yielded low aquifer transmissivities, which suggests that these structures act as barriers to groundwater flow rather than preferred pathways. While aquifer tests with the associated observation boreholes were planned to be near and around several of the indicated structures, very few of these proved to have significant effects on the transmissivity and permeability of the aquifer. In other words, few of the structures seemed to act as either prominent barriers for horizontal groundwater flow, or as preferred flow paths for extended distances.

Summary:

- *Numerous faults and/or igneous intrusions (dykes) occur throughout the project area and are of significant importance to the geohydrology. Few of the structures seemed to act as either prominent barriers for horizontal groundwater flow, or as preferred flow paths for extended distances.*
- *Exploration boreholes drilled in the Makganyane area intersected highly brecciated areas (mainly banded iron formation, shale and quartzite) at depths of between ±30 and 300 meters below surface. From a geohydrological perspective, these areas are of significant importance as they have the potential to yield significant volumes of groundwater.*

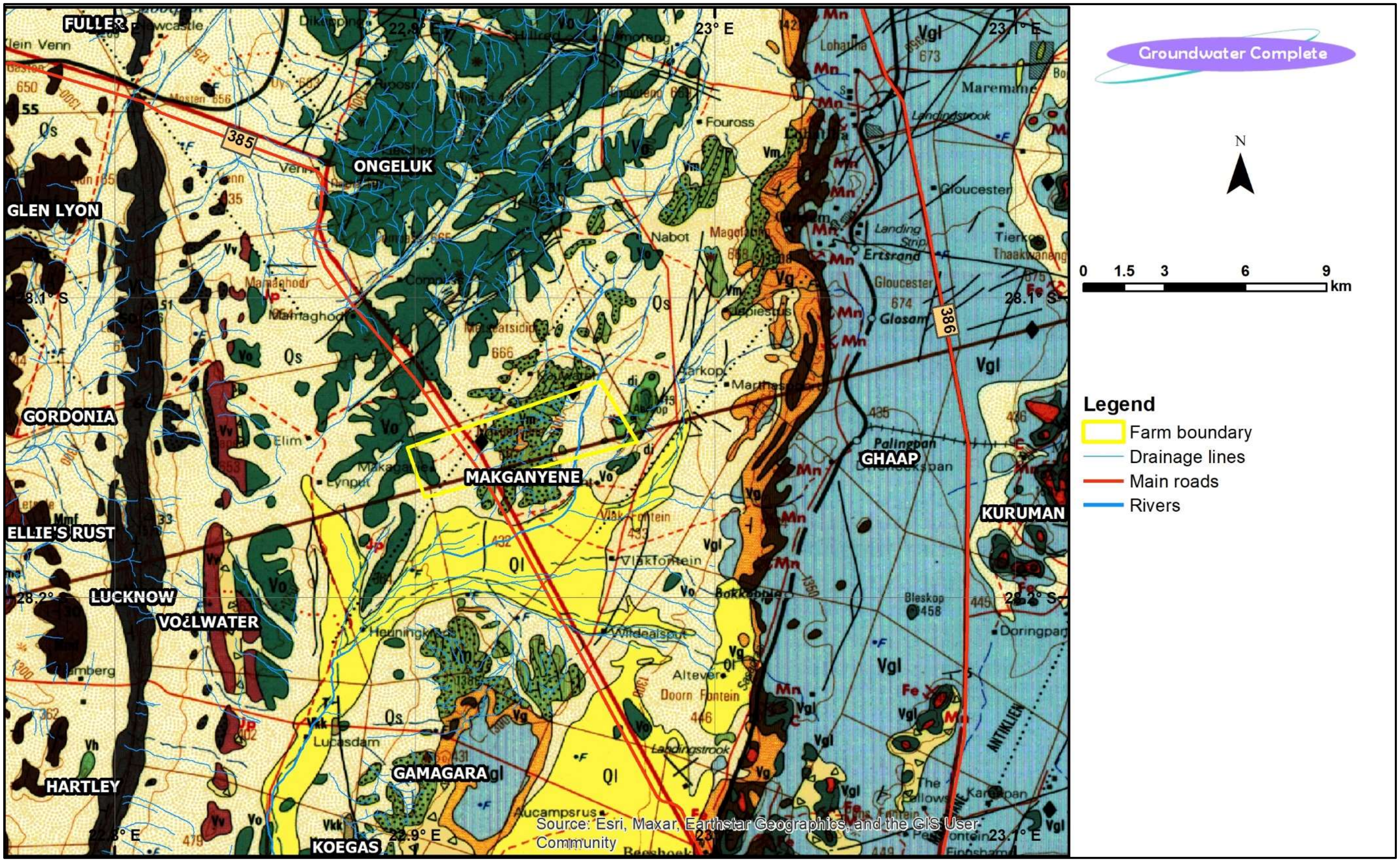

Figure 2-4: 1:250 000 scale geological map of the project area

Supergroup	Group	Subgroup	Formation	Member	Major lithology	Thickness (m)
Traansvaal	Posmasburg		Ongeluk		Andesite lava	> 180
			Makganyene		Diamictite, cherty carbonate	< 10
		Major Unconformity				
	Ghaap	Koegas	Nelani		Silicate lutite, grainstone	< 40
			Rooinekke		Iron-formation, 'upper dolomite'	0 - 130
		Major thrust				
Keis	Elim		Gamagara	Paling	Shale	20-80
				Marthaspoort	Quartzite with intermittent conglomerates	
				Sishen	Shale	
				Doornfontein	Basal iron rich conglomerate	
		Major Unconformity				
			Manganore	Blinkklip	Iron/chert breccia	0 - 100
					Iron-fomation and iron ore	
			Wolhaarkop		Siliceous chert breccia	0 - 30
	Ghaap	Campbellrand			Dolomite	

Figure 2-5: Postulated Simplified Makganyene stratigraphic column (modified after Beukes, pers. comm., 2019).

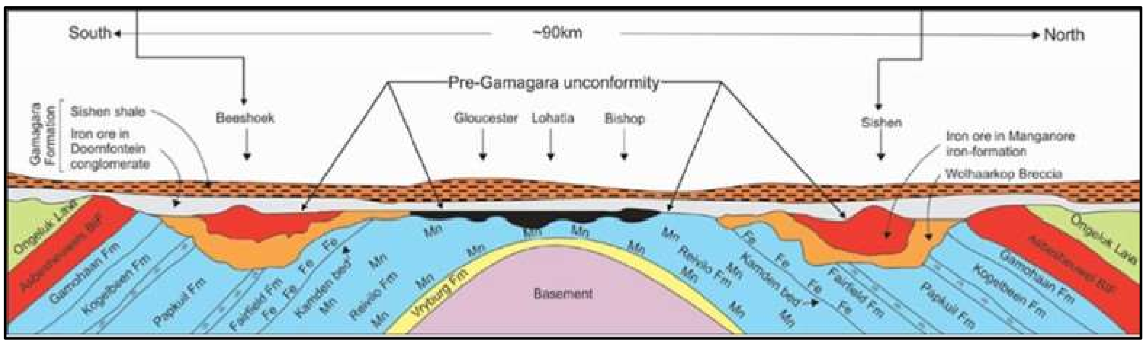

Figure 2-6: Schematic north-south sections across the Maremane Dome (Smith and Beukes, 2016).

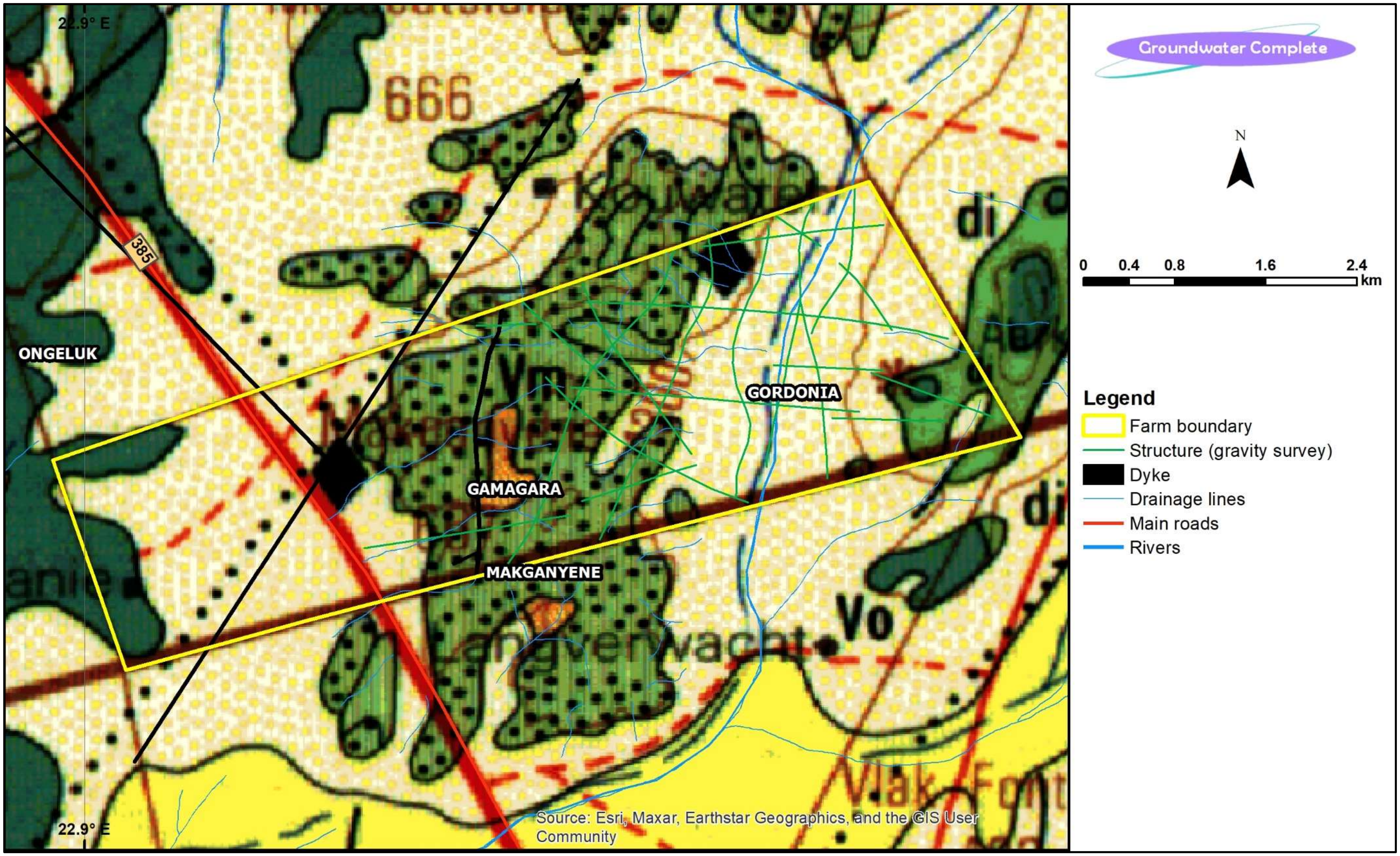

Figure 2-7: Structural geology of the Makganyane area determined using gravity *(Mouton, 2019)*

3 CONCEPTUAL MODEL OF GEOHYDROLOGY

A conceptual model is in reality a holistic understanding of the workings and characteristics of the aquifer regime underlying the project area. A good understanding of the geohydrological environment is fundamental to the accurate assessment of potential groundwater impacts associated with the proposed mining activities. The conceptual model is formed through holistic interpretation of baseline conditions (from hydrocensus and groundwater level measurements to mine borehole database), geology and geological structures, aquifer parameter distribution (gained from pump tests), water quality, aquifer recharge and external stresses from sources and sinks that may be caused by the mining operation. The conceptual model for this project area is discussed in all its different components in as much detail as possible in the remainder of this section of the report.

3.1 RESULTS OF HYDROCENSUS/USER SURVEY

A hydrocensus/user survey was conducted on farms surrounding Makganyane by Aquatico Scientific, who has extensive experience in the sampling and impact monitoring in the surrounding area. The survey was conducted in January 2024 during the previous study conducted on Makganyane. There was one area where access could not be gained during the previous hydrocensus and was surveyed in April 2025. The data collected during these surveys are summarised in **Figure 3-1** and in **Table 3-1**.

The main aims and objectives of a hydrocensus field survey can be summarised as follow:

- To locate all interested and affected persons (I&APs) with respect to groundwater – mostly groundwater users,
- To collect all relevant information from the I&APs (i.e. name, telephone number, address, etc.),
- Accurately log representative boreholes on the I&APs properties, and
- To collect all relevant information regarding the logged boreholes (i.e. yield, age, depth, water level etc.) but especially the application (use) of groundwater abstracted from the boreholes.

All the information and knowledge gained from the hydrocensus data provides a snapshot of current groundwater conditions – the so-called baseline. The main value of this picture is to use as baseline comparison for future reference, i.e. to compare future groundwater conditions (water levels and quality) in a mining scenario where impacts may occur with the baseline before any mining with its related stresses on the groundwater system took place. It therefore assists greatly to consider the validity of potential future claims from surrounding groundwater users of water quality and level (availability) impacts as a result of the mining operation.

A total of 98 boreholes were located, and their positions are indicated in **Figure 3-1**. The various uses of the boreholes are indicated in **Figure 3-2** in the form of a pie chart. From the abovementioned it is clear that agriculture and livestock watering are the main water uses in the area. The complete information collected on all boreholes during the hydrocensus is provided in **Table 3-1**.

Summary:

- *A total of 98 boreholes were located during the hydrocensus.*
- *Agriculture and livestock watering are the main water uses in the area.*

Table 3-1: User- and borehole information collected during the hydrocensus.

Locality Name	X coordinate	Y coordinate	Water level	Measure borehole depth	Property	Owner	Contact	Cell	Locality type	Current use	Type of pump
HK01	22.9317	-28.1968		29.1	Heuningkranz	Kumba Iron Ore	Izak Gous	0836979037	Borehole	na	
HK02	22.9161	-28.2034		5.38					Borehole	na	
HK03	22.9126	-28.2144	67.3						Borehole	Animal Drinking	Solar Pump
HK04	22.8939	-28.2224	17.68	30.45					Borehole	na	Open Borehole
HK05	22.8796	-28.2140	8.97	90.45					Borehole	na	Open Borehole
HK06	22.8802	-28.2144	8.54	14.55					Borehole	na	Open Borehole
HK07	22.8802	-28.2144							Borehole	na	Open Borehole
HK08	22.8803	-28.2146	8.5	12.05					Borehole	na	Open Borehole
HK09	22.8814	-28.2140	8.3	11.75					Borehole	Domestic	Monopump
HK10	22.8816	-28.2140	8.1	10					Borehole	na	Open Borehole
HK11	22.8820	-28.2116							Borehole	na	Open Borehole
HK12	22.8804	-28.2046		9.65					Borehole	na	Open Borehole
HK13	22.8912	-28.1875	16.88	24.74					Borehole	na	Open Borehole
HK14	22.8975	-28.1947	12.78	16.1					Borehole	na	Open Borehole
HK15	22.9061	-28.1876	15.03	30.45					Borehole	Animal Drinking water	Solar Pump
HK16	22.8814	-28.2134	7.99	49.48					Borehole	na	Open Borehole

LT01	22.8952	-28.1492	21.71	55.45	Lynput	Gerhard Claassens	Gerhard Claassens	0825618391	Borehole	agriculture and animal drinking	Solar Pump
LT02	22.8778	-28.1555	21.07	39.85					Borehole	Agriculture and animal drinking	Windpump
LT03	22.8734	-28.1711	8.01	11					Borehole	na	Open Borehole
LT04	22.8734	-28.1711	8.28	38.5					Borehole	Agriculture Animal drinking	Solar Pump
LT05	22.8723	-28.1728	7.83	14.85					Borehole	Agriculture	Windpump
LT06	0.0000	0.0000	8.05	27.95					Borehole	na	Open Borehole
LT07	22.8633	-28.1651							Borehole	Agriculture,Animal drinking	Monopump
LT08	22.8591	-28.1625	9.55	50.55					Borehole	Animal Drinking water	Windpump
LT09	22.8264	-28.1693	48.51						Borehole	Agriculture and animal drinking	Windpump
LT10	22.8331	-28.1503	40.95	76.01					Borehole	na	Open Borehole
LT11	22.8011	-28.1673	54.8						Borehole	Agriculture and animals	Windpump
LT12									Borehole		
LT13									Borehole		
LT14	22.83466	-28.1707	29.74	118.2					Borehole	na	Open Borehole
LT15	22.83134	-28.1698	32.48						Borehole	Agriculture and animals	Windpump
LT16	22.85658	-28.1599							Borehole	na	Open Borehole
LT17	22.86316	-28.1648	9.16	14.4		Chris Claassens	Chris Claassens	078 936 7919	Borehole	Domestic and agriculture	Solar Pump
LT18	22.86376	-28.1664							Borehole	Not in use	Monopump
LT19	22.87219	-28.1735	7.44	10.25					Borehole	na	Open Borehole
LT20									Borehole		

LT21	22.79044	-28.1581	80.12	150					Borehole	agriculture and animal drinking	Windpump
LT22	22.81885	-28.1452	55.99	150					Borehole	na	Open Borehole
LT23	22.80598	-28.1457	45.22						Borehole	Currently not being used, used for agriculture and animal drinking	Solar Pump
LT24	22.83458	-28.1556	42.16	47.12					Borehole	na	Open Borehole
LT25	22.83335	-28.1498	50.15						Borehole	Domestic, and agriculture	Windpump
LT26	22.83485	-28.1555	47.61	75.95					Borehole	Animal Drinking water	Solar Pump
LT29									Borehole		
AP01	22.98709	-28.1317	11.89	30					Borehole	Agriculture and animal drinking	Solar Pump
AP02	22.98724	-28.1315	11.42	33					Borehole	na	Open Borehole
AP03	22.98741	-28.1315	10.71	18					Well	na	Windpump
AP04	22.98832	-28.1314	25.97	200					Borehole	Agriculture and animal drinking	Solar Pump
AP05	22.98912	-28.1301	9.65	16.05					Well	na	Open Borehole
AP06	22.98728	-28.131	10.53	30.44					Borehole	na	Open Borehole
AP07	22.98719	-28.1309	11.3	36.4					Borehole	Domestic,	Open Borehole
AP08	22.99008	-28.1245	17.76	59.65	Aarkop	Chris Claassens	Chris Claassens	na	Borehole	agriculture and animal drinking	Solar Pump
AP09	22.99041	-28.1242							Borehole	na	Open Borehole
AP10	22.99103	-28.1285	11.43	42.85					Borehole	Agriculture and animal drinking	Solar Pump
AP11	22.99035	-28.1295	12.52	18.3					Borehole	na	Open Borehole
AP12	22.99033	-28.1295							Well	na	Open Borehole
AP13	22.97112	-28.1183	12.66	26.1					Borehole	Agriculture and animal drinking	Solar Pump
AP14	22.98383	-28.1309							Borehole	na	Open Borehole
AP15	22.98461	-28.1314	18.91	200					Borehole	na	Open Borehole

AP16	22.98237	-28.1331	20.4						Borehole	na	Open Borehole
EM01	22.86074	-28.1522	10.97	15.06	Elim	Izak Gous	Izak Gous	0836979037	Borehole	na	Open Borehole
EM02	22.85574	-28.1474	12.3	18.84					Well	Drinking water and agriculture	Solar Pump
EM03	22.83935	-28.1343	32.4	42.59					Borehole	Agriculture and animal drinking	Solar Pump
EM04	22.85939	-28.1347	82.4						Borehole	agriculture and animal drinki	Solar Pump
EM05	22.88092	-28.1345	9.75	40.19					Borehole	Agriculture and animal	Solar Pump
EM06	22.86216	-28.1507	-	-					Borehole	Domestic	Monopump
EM07	22.86379	-28.1522	11.4	26.55					Borehole	Irrigation and Animal Drinking	Monopump
KR12	22.93588	-28.1258	10.23	21.76	Kouwater	Koos Venter	Koos Venter	0835264979	Borehole	Domestic, and Agriculture animal drinking	Submersible pump
KR13	22.9087	-28.1124	13.48	21.95					Borehole	Agriculture and Animal drinking	Windpump
KR14	22.90853	-28.1125	13.5	31.6					Borehole	Agriculture and animal drinking	Solar Pump
KR15	22.88936	-28.1267	13.09	41.05					Borehole	Agriculture and animal drinking	Windpump
KR16	22.90394	-28.1362							Borehole	Agriculture and animal drinking	Windpump
KR17	22.90377	-28.1362	12.42	13.8					Borehole	na	Open Borehole
KR01	22.93607	-28.1282		10.4	Kouwater 2	Chris Claassens	Chris Claassens	0833040849	Well	na	Windpump
KR02	22.936	-28.1282	11.4	60.35					Borehole	Agriculture and domestic	Submersible pump
KR03	22.93585	-28.1282		8.8					Well	na	Open Borehole
KR04	22.93603	-28.1283		10.1					Well	na	Windpump
KR05	22.93599	-28.1283							Borehole	na	Submersible pump
KR06	22.93703	-28.1275							Well	na	Open Borehole
KR07	22.94588	-28.1205	13.46	22.45					Borehole	agriculture animal drinking	Solar Pump

KR08	22.95989	-28.1271								Borehole	Agriculture and mining	Windpump
KR09	22.95708	-28.129	20.44	150.9						Borehole	na	Open Borehole
KR10	22.93378	-28.0951	17.31	26.51						Borehole	na	Open Borehole
KR11	22.93398	-28.095	25.33	47.5						Borehole	Agriculture and animal drinking	Solar Pump
ME01	22.92375	-28.1516	27.38	115.46	Makganyane	Bok Wessels	Bok wessels	082855		Borehole	na	Open Borehole
ME03	22.91127	-28.1549	7.4	26.5						Borehole	na	Open Borehole
ME04	22.90307	-28.1574	11.72	45.75						Borehole	Not used, Was used for mining water	Submersible pump
ME05	22.90295	-28.1572	12.75	41.35						Borehole	Not used, was used for mining water	Monopump
ME06	22.90364	-28.1602	8.55	60.65						Borehole	Domestic, and agriculture	Solar Pump
ME07	22.92016	-28.1518								Dam	na	Open Borehole
ME08	22.90314	-28.1603	8.58	14.95						Borehole	na	Open Borehole
VN01	22.97425	-28.1545			Vlakfontein					Borehole	Unknown	Wind Pump
VN02	22.97453	-28.154								Borehole	Unknown	Solar Pump
VN03	22.98354	-28.1494								Borehole	na	Covered With Concrete
VN04	23.00454	-28.1505								Borehole	Unknown	Solar Pump
VN06	22.97502	-28.1633								Borehole	na	Covered With Concrete
VN07	22.96436	-28.1665								Borehole	Unknown	Solar Pump
VN08	22.96762	-28.1889								Borehole	Unknown	Solar Pump

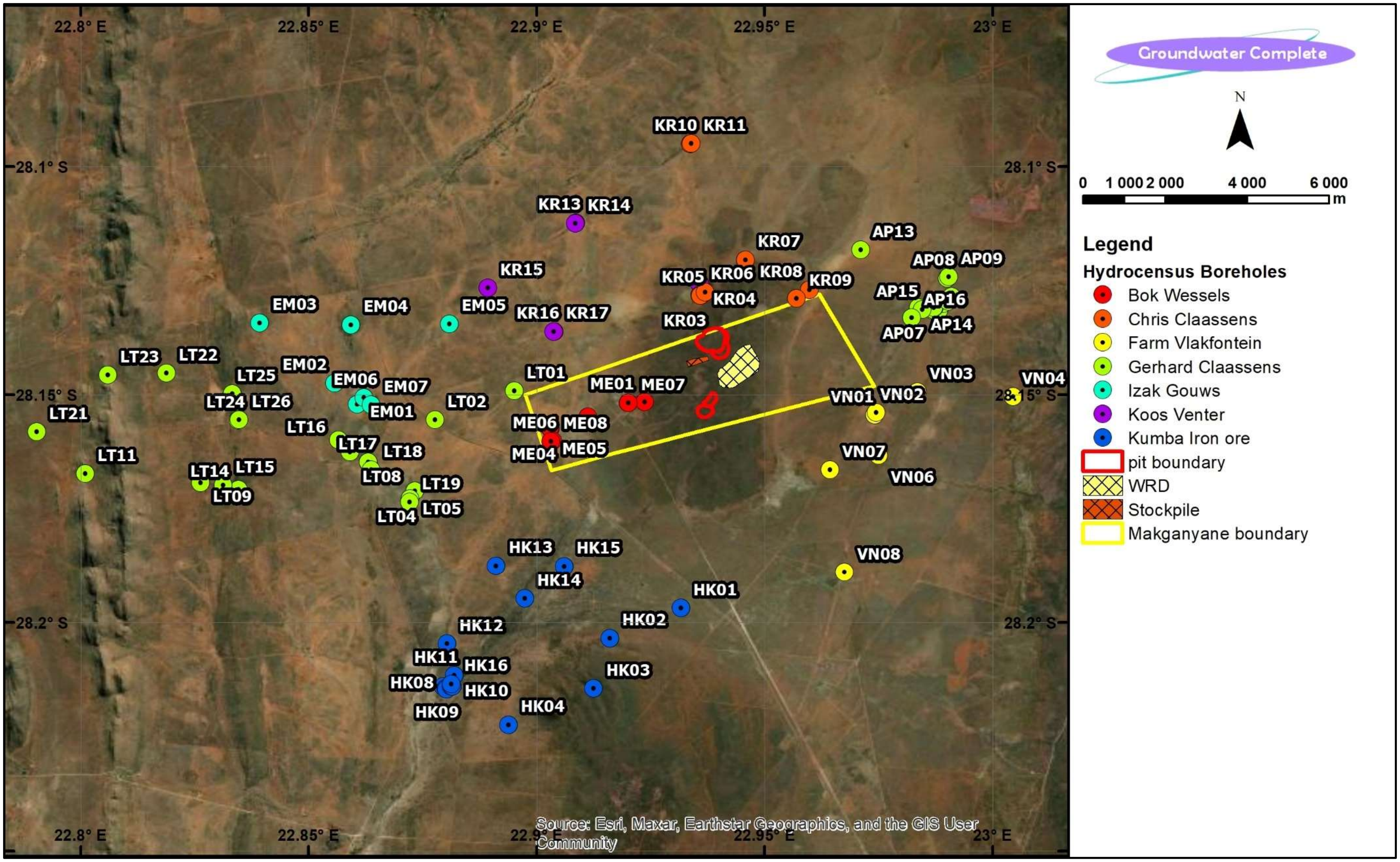

Figure 3-1: Map of user boreholes found during the hydrocensus.

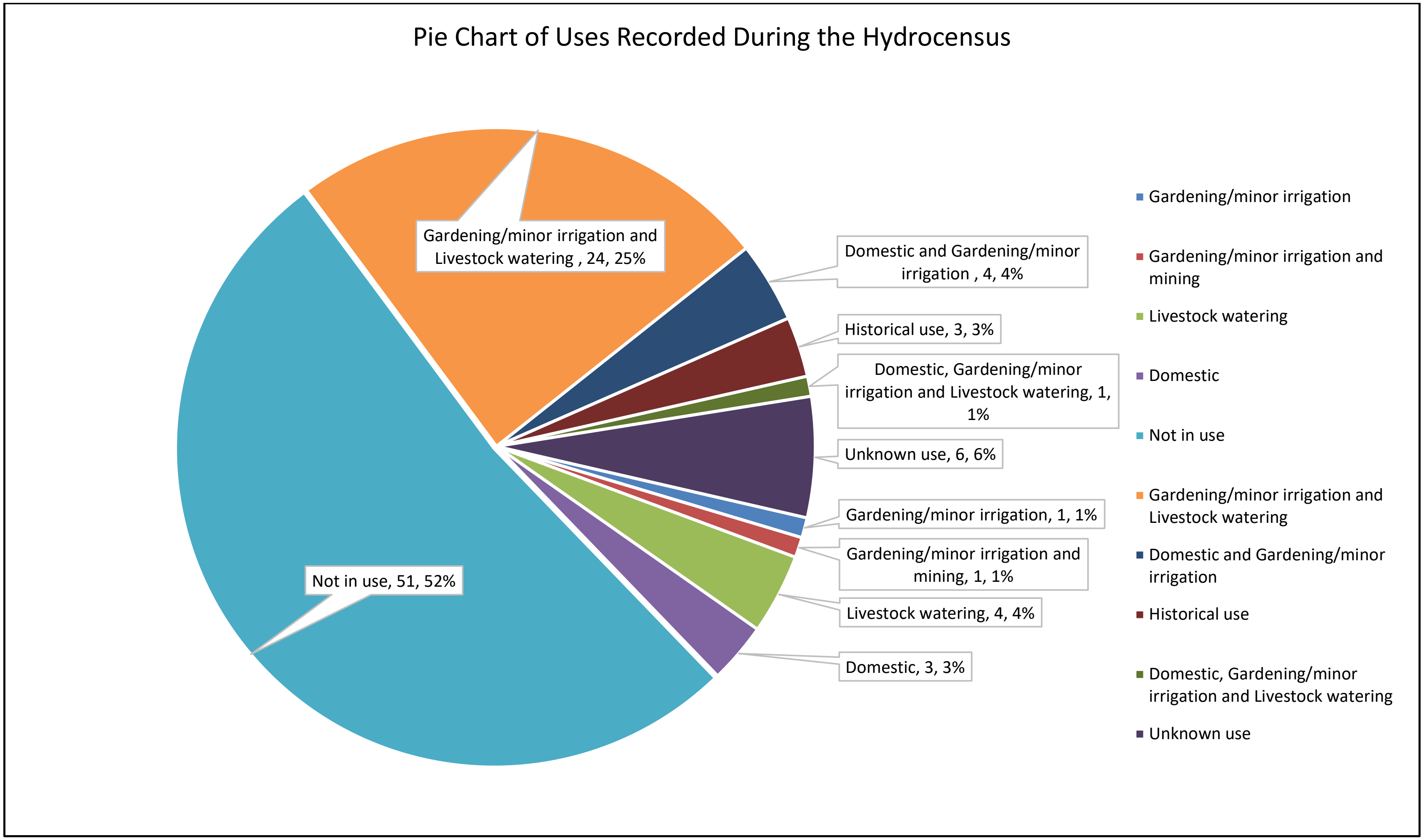

Figure 3-2: Pie chart of groundwater uses recorded during the hydrocensus.

3.2 AQUIFER DELINEATION

The interpretation of aquifer types and their distribution presented here is based on the analysis of water level patterns, geological data, water strike depths from exploration boreholes, and most notably, aquifer test results. While the initial phase of aquifer testing yielded critical insights into the aquifer's structure and hydraulic behaviour, it is important to recognize the significant degree of hydraulic variability – both vertically and laterally. As such, this interpretation should be regarded as a preliminary iteration for the project area, serving as a foundation for future refinement through ongoing monitoring and further testing to enhance confidence in system understanding and, by extension, the reliability of model outputs and forecasts.

The Makganyane area is underlain by two distinct and very different aquifers, though they are of the same type. The first of the aquifers exists below the flatter topography in the eastern and western areas of the Makganyane property. The host rock of the aquifer is the andesitic lavas of the Ongeluk Formation. The un-weathered lavas are largely of a lower permeability. In the weathered zone and also at deeper elevations major networks of fractures can exist (between different lava flow events during formation etc.) that can act as conduits for groundwater movement. When these conduits are intersected by boreholes, they provide a relatively abundant flow of groundwater. The static groundwater levels in this aquifer are generally shallow. Water levels to the west of the central hilly topography vary between 7 and 22 meters below surface (mbs), while the water levels to the east of the hills vary between 18 and 28 mbs.

The second aquifer present in the Makganyane area is the aquifer that exists mainly in the planned mining area. This aquifer exists mainly in a specific layer, namely the chert-breccia layer of the Wolhaarkop and Blinkklip formation. This aquifer is highly variable in thickness, fracture size, orientation, extent and hydraulic fracture interconnectivity. Water levels were generally deep with often low (but also highly varying) transmissivities. Groundwater levels in the boreholes from this aquifer vary between 30 and 100 mbs.

Because both aquifers are of a secondary fractured rock type and fractures could assume any geometry and orientation, the physical boundary or 'end' of the aquifers is very difficult to specify or quantify. The second aquifer (located in the hills) is of course confined to the hilled area and likely does not extend outside the boundary of the hills, however, even its exact extent is difficult to define. Aquifer boundary conditions that are generally considered during the delineation process are described below:

- No-flow boundaries are groundwater divides (topographic high or low areas/lines) across which no groundwater flow is possible.
- Constant head boundaries are positions or areas where the groundwater level is fixed at a certain elevation and does not change (perennial rivers/streams or dams/pans).
- Groundwater flow barriers such as fully impervious dykes or other geological structures that can cause compartmentalisation of the aquifer.

A combination of topographic highs and lows (which coincides with riverbeds and watercourses) were used to roughly delineate the aquifer system used in the project for the purpose of modelling **(Figure 3-3)**. The aquifer was estimated to cover an area of approximately 90 km^2.

Summary:

- *The Makganyane area is underlain by two distinct and very different aquifers.*
- *The first of the aquifers exists in the eastern and western flatter areas of the Makganyane property. The host rock of the aquifer is the andesitic lavas of the Ongeluk Formation.*
- *The second aquifer present in the Makganyane area is the aquifer that exists mainly in the planned mining area. This aquifer exists mainly in a specific layer, namely the chert-breccia layer.*
- *Topographical highs and lows were used to approximate no-flow boundaries for the model.*

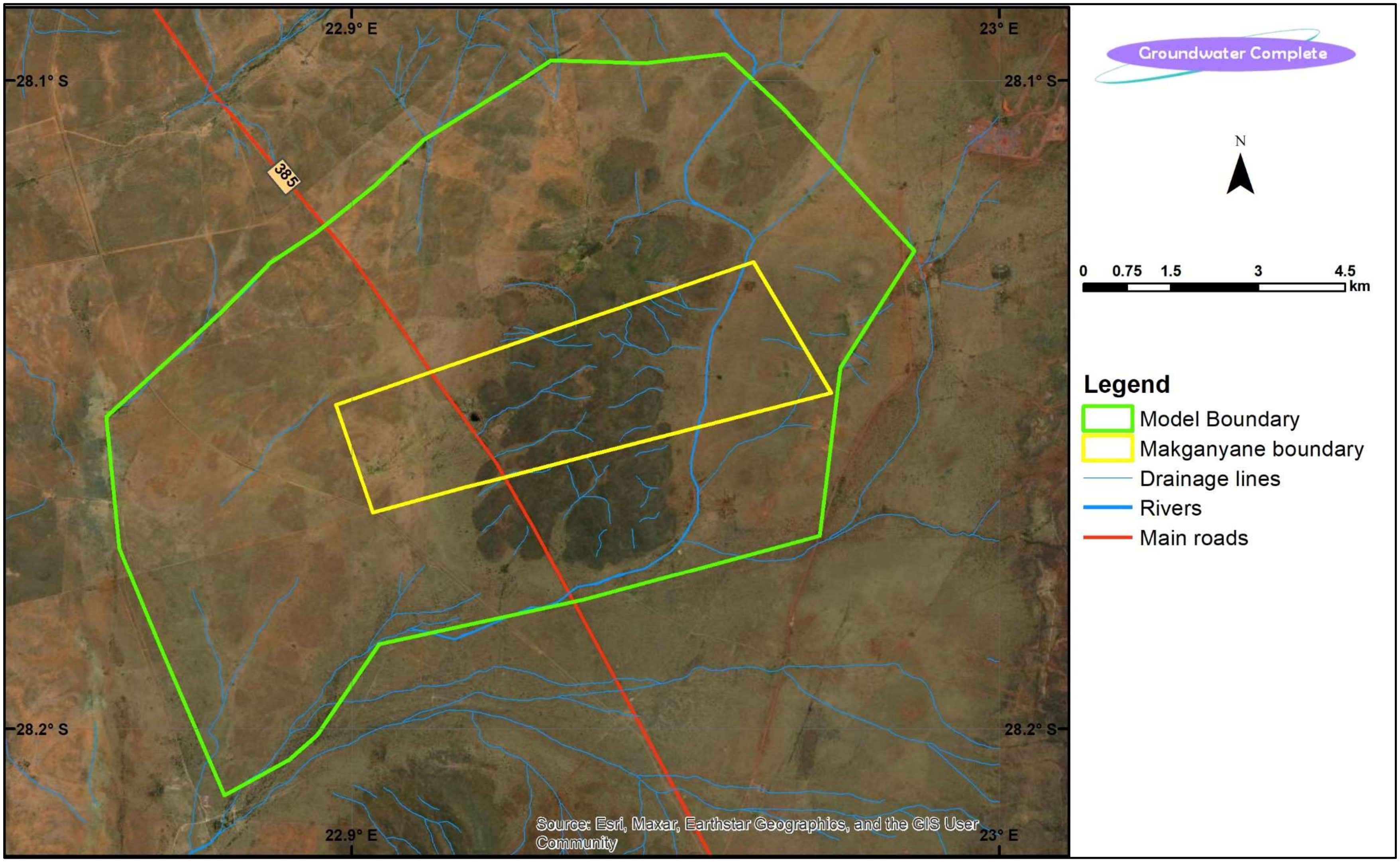

Figure 3-3: Aquifer delineation for project area.

3.3 GROUNDWATER LEVEL DEPTH

Groundwater level information was collected during the original hydrocensus/user survey in 2023, during the pump testing (in pumping as well as observation boreholes), during the drilling of the numerous exploration boreholes as well as the remeasurement of various boreholes during the 2025 hydrocensus update. A graph comparing the water levels measured in 2023 to the water levels measured in 2025 is displayed in **Figure 3-4** to indicate the continued validity of the available data. It is clear from the above-mentioned figure that the groundwater levels remained the same as during the previous study.

A thematic groundwater level map is provided in **Figures 3-6** and an expanded view of the same information over the planned mining area is provided in **Figure 3-7**. This water level information played an integral role in the understanding of the groundwater environment, forming of the conceptual model and the eventual calibration of the numerical groundwater flow model **(Section 4.3)**.

A linear relationship normally exists between the surface topography and groundwater elevation under natural conditions (i.e. the groundwater ‘table' mimics the surface topography on a regional scale). This relationship does not hold for large parts of the Makganyane area, especially in the central hilly area that is the current focus of planned iron ore mining. This is likely due to a combination of the highly varying nature of the fractured aquifer and the presence of two completely different aquifers. A graph of borehole collar elevation versus groundwater level elevation is presented in **Figure 3-5**. Two different somewhat linear correlations are clearly evident. This indicated that the groundwater levels measured in some of the boreholes mimicked the topography to some extent while the groundwater levels in other boreholes did not do so at all.

Groundwater levels in the flatter areas to the west of the hills varied between 7 and 22 meters below surface (mbs), while the water levels to the east of the hills varied between 18 and 28 mbs. The groundwater levels in the hilled area were markedly deeper, ranging between 30 and 100 mbs.

A static groundwater elevation contour map stretching over the modelled area is provided in **Figure 3-8**. The lowest measured static groundwater elevation of approximately 1 237 meters above mean sea level (mamsl) occurs in the down gradient groundwater flow direction towards the south/south-west, while the highest elevation of ± 1 289 mamsl is found in the hills in the centre of the mining rights area **(Figure 3-8)**.

Summary:

- *Not all groundwater levels have a linear relationship with regards to the surface topography.*
- *Groundwater levels in the flatter areas to the west of the hills varied between* 7 and 22 *meters below surface (mbs), while the water levels to the east of the hills varied between 18 and 28 mbs.*

- *The groundwater levels in the hilled area were markedly deeper, ranging between 30 and 100mbs.*
- *The lowest measured static groundwater elevation of approximately 1 237 meters above mean sea level (mamsl) occurs in the down gradient groundwater flow direction towards the south/south-west, while the highest elevation of ± 1 289 mamsl is found in the hills in the centre of the mining rights area.*

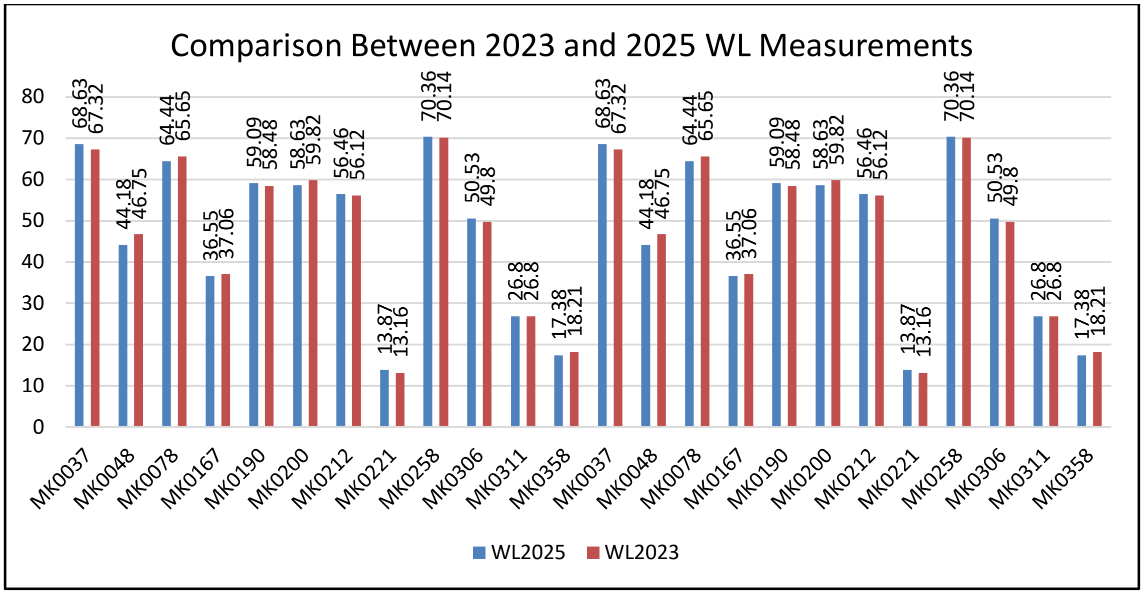

Figure 3-4: Comparison between 2023 and 2025 groundwater level measurements

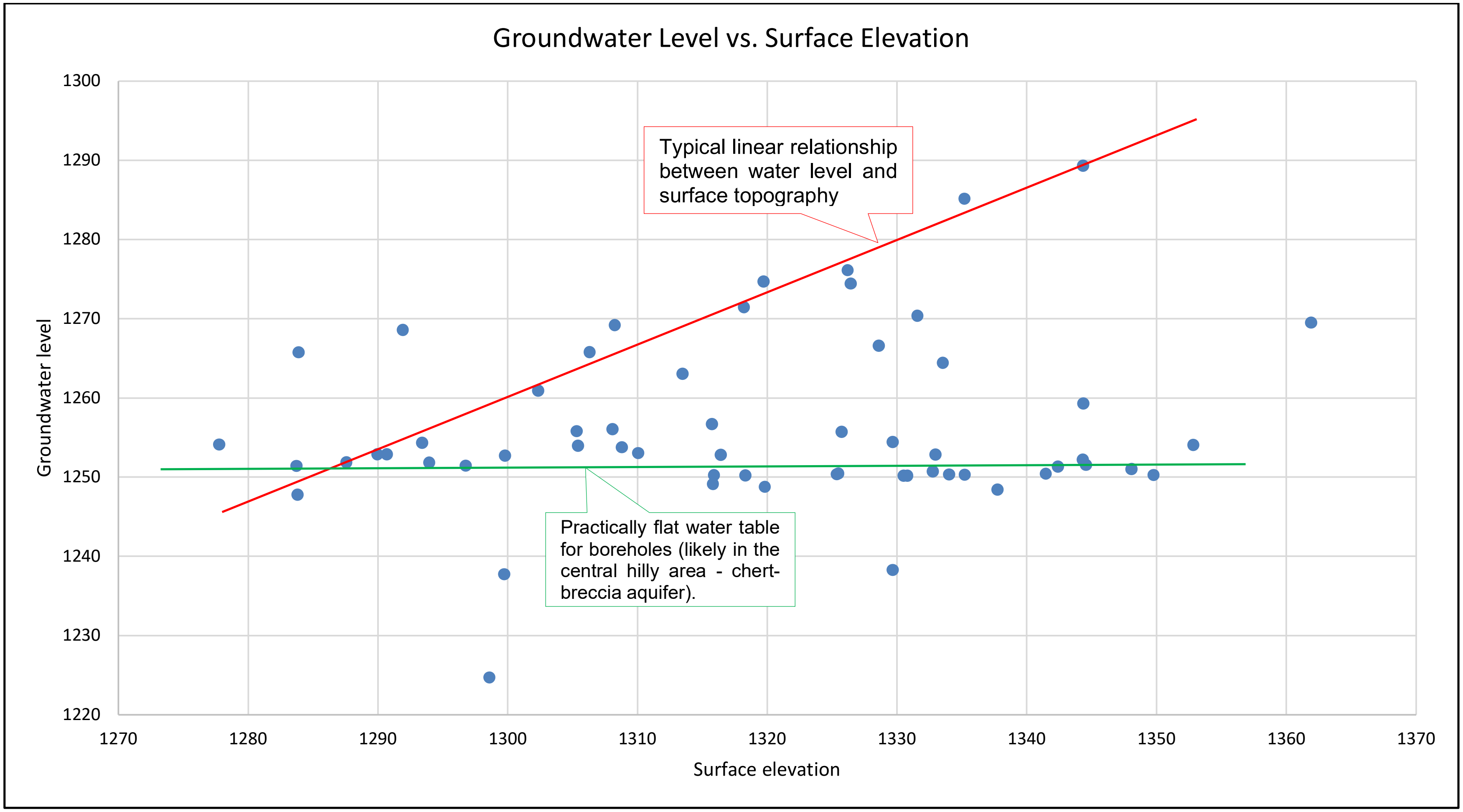

Figure 3-5: Relationship between surface and groundwater elevation.

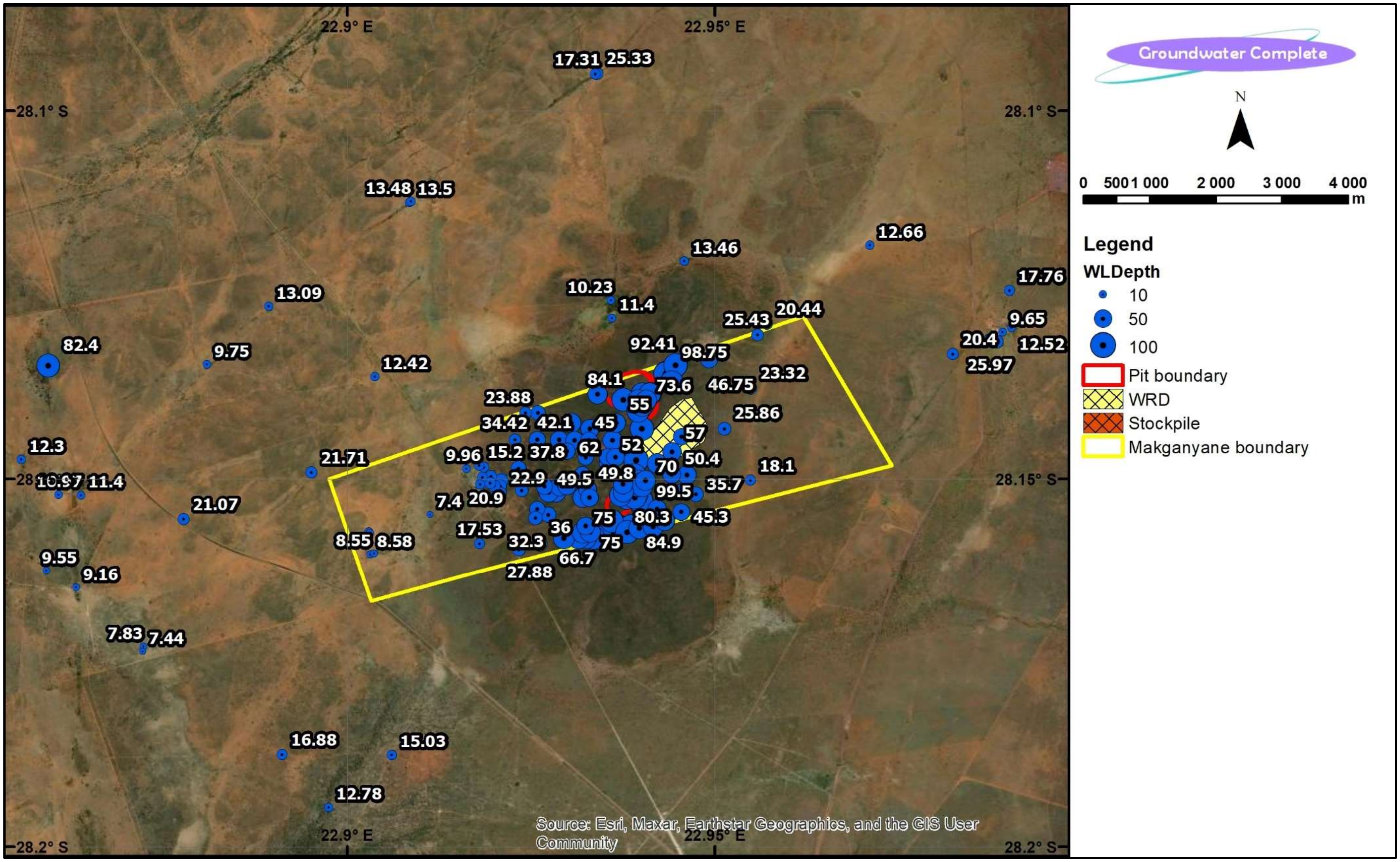

Figure 3-6: Thematic map of groundwater depths (mbs)

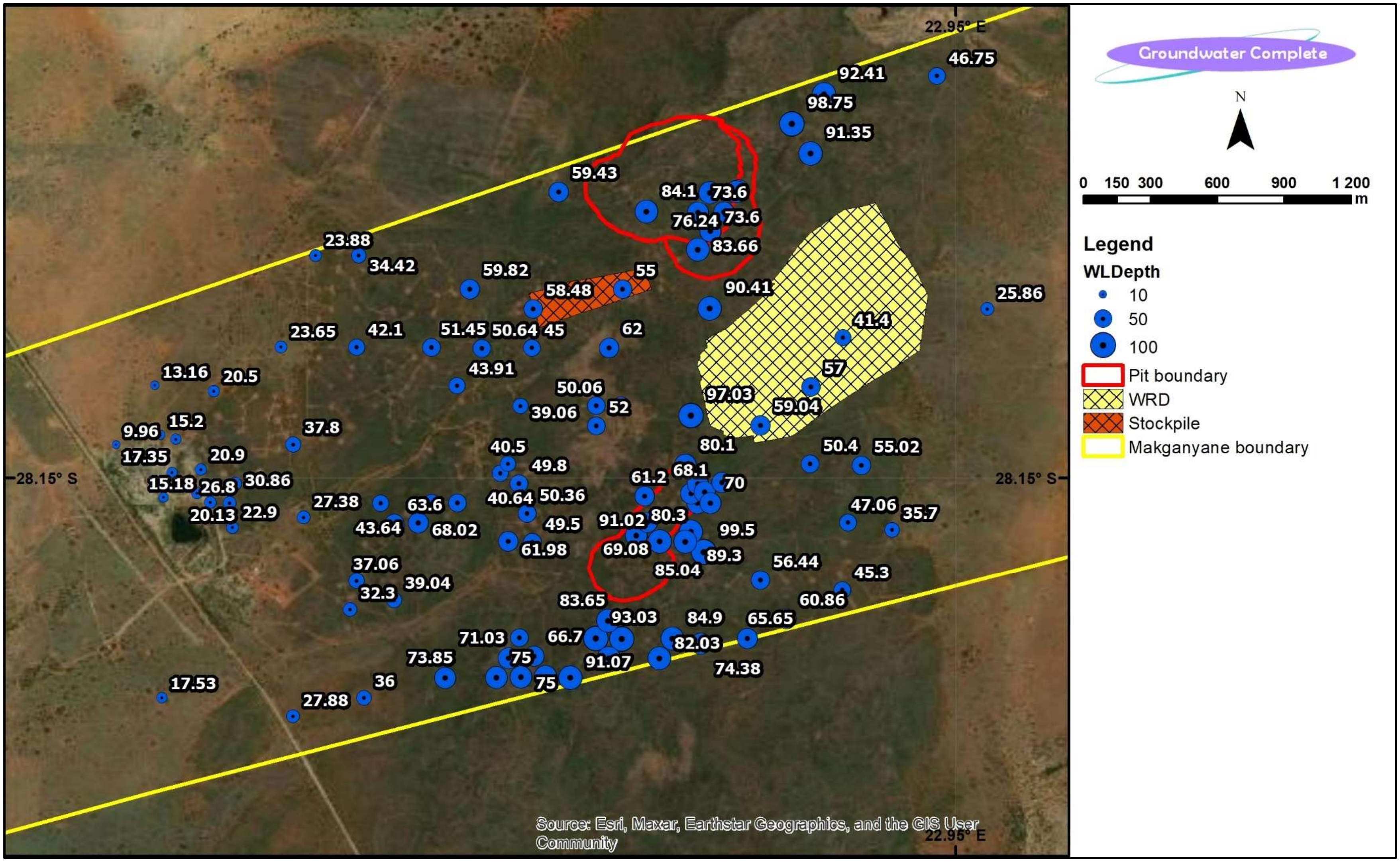

Figure 3-7: Close up thematic map of groundwater depths (mbs) in proposed mining area.

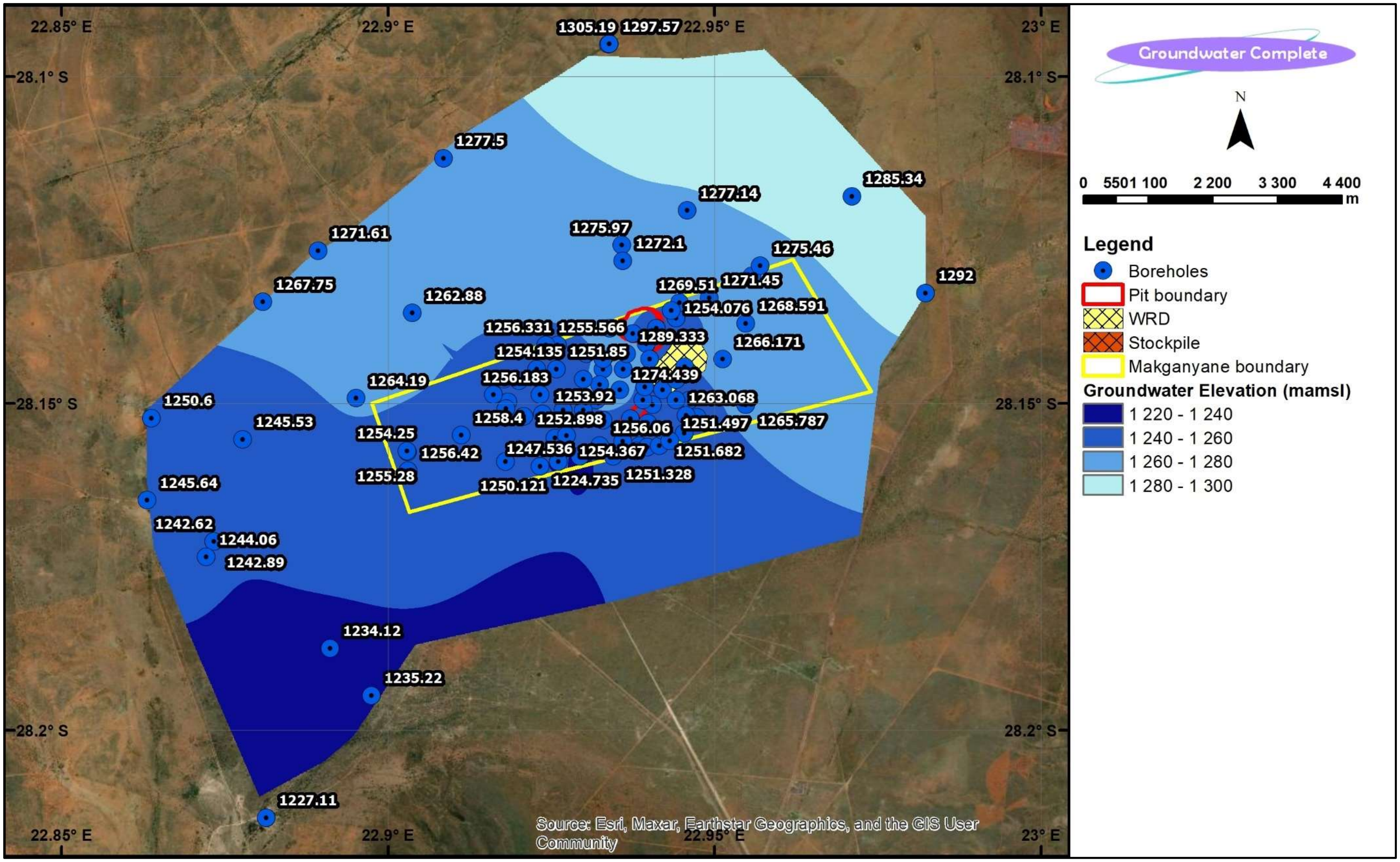

Figure 3-8: Contour map of measured groundwater elevations (mamsl)

3.4 GROUNDWATER FLOW EVALUATION (DIRECTIONS, GRADIENTS AND VELOCITIES)

The groundwater level information collected during the hydrocensus/user surveys was used to generate a contour map of the groundwater elevations in the project area, which is provided in **Figure 3-8**. This information was used in turn to determine the direction of groundwater flow, which as a result of gravity is from higher to lower hydraulic elevations (i.e. from north to south and north-east to south-west).

Please note that due the high variability of aquifer hydraulics in the Makganyane area, the groundwater flow calculated for this report only represents a regional average flow velocity and direction. Flow velocity and direction both vary significantly if tested more specifically on a smaller scale.

It was also used to calculate the groundwater gradient within the project area with the following equation:

$$i = dH / dL$$

Where:

i	=	*Hydraulic gradient*
dH	=	*Head difference*
dL	=	*Lateral distance over which gradient is measured*

By substituting the hydraulic head difference over lateral distance, the average hydraulic gradient was calculated to be in the order of 0.0042 or 0.42% and was then used to calculate the rate of groundwater movement (the so-called 'Darcy flux') in the project area. The following equation was used in the calculation *(after Fetter, 1994)*:

$$v = \frac{KI}{\phi}$$

Where:

v = flow velocity (m/day)		
K = hydraulic conductivity (m/day)	=	*0.25*
I = average hydraulic gradient	=	*0.0042*
ϕ = probable average porosity	=	*0.08*

The hydraulic conductivity (K) and average porosity were chosen so as to provide a liberal estimation of seepage velocity. The actual seepage through the aquifer matrix should be lower than calculated, but highly transmissive fracture zones or areas of steeper gradient might cause higher transport rates. Under stressed conditions, such as at groundwater abstraction areas, the seepage velocities could increase another order of magnitude.

By making use of these values, the average flow velocity (or more aptly referred to as the Darcy flux) in the project area was calculated to be in the order of 4.8 meters per year.

Summary:

- *By substituting the hydraulic head difference over lateral distance, the average hydraulic gradient was calculated to be in the order of 0.0042 or 0.42% and was then used to calculate the rate of groundwater movement (the so-called 'Darcy flux') in the project area.*
- *By making use of these values, the average rate of flux in the project area was calculated to be in the order of 4.8 meters per year.*
- *Due the highly varying nature of aquifers that are present in the Makganyane area, the groundwater flow calculated for this report only represents a regional average flow velocity and direction. Flow velocity and direction both vary significantly if tested more specifically on a smaller scale.*

3.5 AQUIFER CHARACTERISATION

3.5.1 GROUNDWATER VULNERABILITY

The *Groundwater Vulnerability Classification System* used in this investigation was developed as a first order assessment tool to aid in the determination of an aquifer's vulnerability/susceptibility to groundwater contamination. This system incorporates the well-known and widely used *Parsons Aquifer Classification System (1993)* as well as drinking water quality guidelines as stated by the *Department of Water Affairs and Forestry*. This system is especially useful in situations where limited groundwater related information is available and is explained in **Table 3-3** and **Table 3-4**. The project area achieved a score of **7 (Table 3-2)** and the underlying aquifer can therefore be regarded as having a medium vulnerability.

Table 3-2: Groundwater vulnerability rating for project area.

	Rating
Depth to groundwater level	1
Groundwater quality	3
Aquifer type	3
Total score:	**7**

Table 3-3: Groundwater vulnerability classification system.

Rating	***4***	***3***	***2***	***1***
Depth to groundwater level	0 – 3 m	3 – 6 m	6 – 10 m	>10 m
Groundwater quality *(Domestic WQG*)*	Excellent (TDS < 450 mg/l)	Good (TDS > 450 < 1 000 mg/l)	Marginal (TDS > 1 000 < 2 400 mg/l)	Poor (TDS > 2 400 mg/l)
Aquifer type *(Parsons Aquifer Classification)*	Sole aquifer system	Major aquifer system	Minor aquifer system	Non-aquifer system

** WQG = Water Quality Guideline.*

Table 3-4: Groundwater vulnerability rating.

Vulnerability	Rating
Low vulnerability	≤ 4
Medium vulnerability	> 4 ≤ 8
High vulnerability	≥ 9

3.5.2 AQUIFER CLASSIFICATION

Information from geological maps and experience gained from numerous groundwater related studies conducted in similar geohydrological environments suggest that two aquifers are present in the project area, however they are by definition of the same type. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. Aquifer classification according to the Parsons Classification system is summarised in **Table 3-5**.

The two aquifers are discussed in **Section 3.2**. The **first aquifer** (in the flat areas to the east and west of the Makganyane boundary) is a relatively shallow, **semi-confined fractured aquifer**. Due to the shallow water level and high permeability of the host rock, the boreholes drilled into this aquifer have high yields of good quality water. Farmers in the region use this aquifer widely for domestic purposes and livestock water supply with limited irrigation of gardens and fodder. **According to the Parsons Classification system the aquifer is usually regarded as a major aquifer system.**

The **second aquifer** (in the hills where proposed mining is to take place) is the deeper, **secondary porosity (fractured) aquifer** that occurs at depths usually exceeding 30 meters below surface and will be the major aquifer system in the affected groundwater zone. Fracturing in the aquifer usually occurs in the brecciated banded iron formation and to a lesser extent shale and quartzite at depths of between ±88 and 230 m below surface. Fracturing is usually concentrated near the banded iron formation ore bodies where mineralization and preservation of ore bodies occurred through folding, thrusting, fracturing and sinkhole formation/slumping.

This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often occurring higher than the water-bearing fracture position. The fractures may occur in any of the co-existing host rocks due to different tectonic, structural and depositional processes. **According to the Parsons Classification system the aquifer could also be regarded as a major aquifer system.**

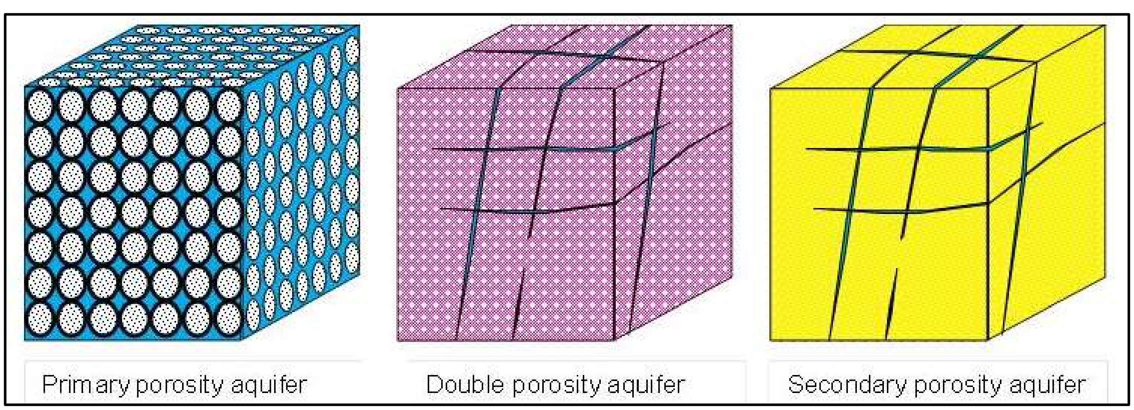

Figure 3-9: Types of aquifers based on porosity.

Table 3-5: Parsons Aquifer Classification *(Parsons, 1995).*

Sole Aquifer System	An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formation, 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 (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers.
Non-Aquifer System	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 unusable. However, groundwater flow through such rocks, although impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

3.5.3 Aquifer Protection Classification

The combination of Aquifer Vulnerability Classification rating and Aquifer System management Classification provides a protection level referred to as Groundwater Quality Management Classification (GQM).

Table 3-6: GQM = Aquifer System Management (ASM) x Aquifer Vulnerability (AV).

ASM Classification		**AV Classification**		**GQM**		**Makgan-yane GQM**
Class	**Points**	**Class**	**Points**	**Index**	**Level of protection**	
Sole Source Aquifer System	6	High	3	<1	Limited	
Major Aquifer System	4			1 - 3	Low	
Minor Aquifer System	2	Medium	2	3 – 6	Medium	8
Non-aquifer System	0			6 – 10	High	
Special Aquifer System	0 - 6	Low	1	>10	Strictly non-degradation	

The GQM rating for Makganyane is 8, which indicates a high level of protection. Therefore, it is recommended that the monitoring system outlined in **Section 6** be in place for the proposed development.

3.6 Aquifer Testing

3.6.1 Slug Tests

Slug tests are conducted by the increasing and decreasing of a known level of water in a borehole and the simultaneous monitoring of the water levels until equilibrium is reached. A slug is submerged in the water of the test borehole causing the water level to rise due to the volumetric displacement. Conversely, when the volume of the slug is removed from the borehole the water level decreases. When the slug alters the water level of the borehole, the water level starts to return to its start/static level. This ‘recovery’ is then measured and used to calculate a hydraulic conductivity. The time it takes for the water level to recover to 70% of the original level is also recorded.

This information is then used to estimate the approximate groundwater yield of the borehole. The more quickly the displaced water level returns to the static position, the higher the potential yield of the borehole will be. Although low in cost and quick, the slug test results remain only a high-level estimation of the yield, mainly since the limited water level replacement by the slug only affects a very limited area around the borehole.

A round of slug-testing was conducted by Mr. Andre Gerber of Waterpoint Groundwater Exploration in 2022 and the results are displayed in **Table 3-7**.

At the start of the pump testing that was conducted at Makganyane, Groundwater Complete also conducted a number of slug tests. These slug tests were thus used as a precursor to the pumping to help determine the best boreholes and region for conducting the pumping tests. The resulting K-Values and 70% recovery times are indicated in **Table 3-8**. Please note that, where no 70% recovery time is recorded, the recovery time was longer than 300 seconds.

The results indicated that the aquifers in the Makganyane area were highly heterogeneous, especially in the hills in the centre of the property. The boreholes in the flat areas had faster recovery times (i.e. higher K-values), indicating higher yielding aquifers.

Table 3-7: Borehole rankings based on 70% recovery regression times (Gerber, 2022).

Site Name	70% Slug Recovery Time (s)	K-Value
MK0188	2	>10
MK0048	3	7.76
MK0078	5	8.6
MK0020	16	0.85
MK0111	17	0.96
MK0212	21	0.71
MK0161	23	0.44
MEX22	32	1.01
MK0221	42	0.51
MK0251	42	0.92
MK0250	47	0.35
MK0019	110	0.16
MK0035	132	0.09
MK0112A	185	0.13
MK0126A	220	0.13
MK0248	390	0.04
MK0174	30%	<0.05
MK0178	65%	0.09

Table 3-8: Results of Slug tests conducted by groundwater Complete in 2023.

Boreholes	Time to 70% (sec)	K-value
MK36	30	11.1
MK37	> 300 seconds	0.013
MK48	55	0.91
MK171	> 300 seconds	0.005
MK172	> 300 seconds	0.0025
MK200	> 300 seconds	0.037
MK212	14	6.6
MK311	47	0.75
MK358	130	0.39

3.6.2 CONSTANT RATE TESTS

Before the constant rate test is conducted, a step drawdown test is conducted. This test serves to evaluate borehole performance, in order to check the hydraulic efficiency of the borehole and to determine the optimal discharge rate needed for the constant rate test. When conducting a step test, water is pumped from the borehole at different (increasing) discharge rates for a set period of time, ensuring that, during each step, the discharge is kept constant, all the while measuring the decrease in water level. Afterwards, the data is evaluated to determine a pumping rate that will stress the aquifer but not pump dry the borehole before the end of the test.

A constant rate pumping test is then performed to determine aquifer parameters, such as transmissivity and hydraulic conductivity. The test basically involves the abstraction of groundwater from a borehole by means of a pump (submersible- or mono pump) at a known rate. Measurements of the decreasing water level within the borehole are taken at predetermined intervals, which are generally short at the start of the test and increase as the test progresses. After the test has been completed and the pump has been shut down, measurements are again taken of the water level as it starts to recover or rise in the borehole. The recovery data is also analysed with recovery test algorithms to aid in aquifer parameter estimation.

This water level versus time data is then analysed with software developed specifically for pumping test interpretation, and aquifer parameters are calculated for the tested borehole. Aquifer parameters play an important role in the conceptualisation of the project area (i.e. conceptual model), which ultimately forms the foundation for the numerical groundwater flow and mass transport models.

Aquifer transmissivity is defined as a measure of the amount of water that could be transmitted horizontally through a unit width of aquifer by the fully saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is the product of the aquifer thickness and the hydraulic conductivity of the aquifer, usually expressed as m^2/day (Length^2/Time).

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely, and a value of 0.002 to 0.01 is taken as representative for the proposed mining area. The storage coefficient values calculated from the pump tests proved to be in this order of magnitude.

The pump testing was conducted by AB Pumps who are leaders in pump testing in southern Africa. A total of 13 boreholes were tested, however, four of the boreholes had yields that were poor enough to be pumped dry during the step-testing phase. The data collected from these boreholes during this short pumping time was nonetheless used in the assessment. The remaining boreholes were pumped for a period of 48 hours and recovery was measured for

24 hours, or until the geohydrologist on call judged that the testing was sufficient to determine the aquifer parameters.

The drawdown vs. time plot using the Cooper-Jacob formula for borehole MK0200 is displayed as an example in **Figure 3-9**. A straight line was fitted to different sections of the plot, the function of which can be used to determine transmissivity (T) and storativity (S). Borehole MK0200 is displayed as it represents a very typical (textbook) example of a fractured aquifer's drawdown plot. The drawdown is steep until the position of a fracture is reached, the fracture causes the drawdown to level out until the transmissive fracture system has been largely dewatered, after which it becomes steep once again, meaning the water is sourced from the lower permeability aquifer matrix. Each section is used to calculate the transmissivity of the fractured aquifer and matrix of the borehole.

The data collected from these tests were used to calculate aquifer parameters (such as transmissivity [T] and Storativity [S]) by various methods, the results of which may be viewed in **Table 3-9**. A map of the tested boreholes, displaying the resulting aquifer parameters, is available in **Figure 3-10**. All raw pumping test, slug test and drawdown plots can be viewed in **Appendices A**, **B** and **C**, respectively.

Table 3-9: Aquifer parameters resulting from pumping tests.

Site Name	FC Sust Q			FC CJ				AQTSLV CJ			
	Tm	Tf	S_{late}	Tm	Tf	Sm	Sf	Tm	Tf	Sm	Sf
MK37	0.08	0.95	0.001	0.1	0.6	0.007	0.001	0.08	0.68	0.002	2.7E-04
MK48	1.1	12.8	0.001	1.6	28	0.002	1.1E-25		25.6		2.6E-22
MK78	6	25.6	0.001	30.9	136.2	0.000	9.2E-22	29.4	435	0.001	9.7E-70
MK167		1.6	0.001	0.1	1.1	0.006	0.001	0.1	1.4	0.001	5.6E-05
MK190		1.6	0.001	0.1	0.6	0.004	0.002	0.1	0.7	0.001	2.3E-04
MK200	0.2	0.95	0.001	0.1	2.1	0.006	1.4E-07	0.1	2.7	0.001	3.9E-10
MK212	4.1	24.7	0.001	2.0	25.7	0.04	4.5E-07	2.1	25.2	0.008	6.9E-13
MK221	0.3	4.4	0.001	0.5	4.2	2.7	0.018	0.3	0.4	0.55	3.4E-02
MK252	3.4	23.7	0.001	3.9	78.2	7.2	3.5E-08	4.50	126	0.85	6.0E-14
MK258	56.9	67.2	0.001	45	100.3	0.7	0.029	40	110	0.19	2.7E-03
MK306		0.95	0.001	0.1	2.8	0.006	1.6E-06	0.1	0.2	0.001	5.8E-04
MK311	2.5	24.7	0.001	2.2	13.6	0.6	5.2E-05	1.8	11	0.2	1.0E-04
MK358	0.5	5.5	0.001	0.4	1.8	0.6	0.001	0.8	1.9	0.007	1.4E-04
Harmonic Mean	0.4	2.6	0.001	0.2	2.1	0.001	1.4E-24	0.2	1.0	0.002	1.3E-68

Please note:

FC Sust Q	-	Values calculated using FC program's Sustainable Q method
FC CJ	-	Values calculated using FC program's Cooper-Jacob Equation
AQTSLV CJ	-	Values calculated using AQTESOLVE's Cooper-Jacob Equation
Tm	-	Transmissivity of the aquifer matrix
Tf	-	Transmissivity of the fractures
Sm	-	Storativity of the aquifer matrix
Sf	-	Storativity of the fractures

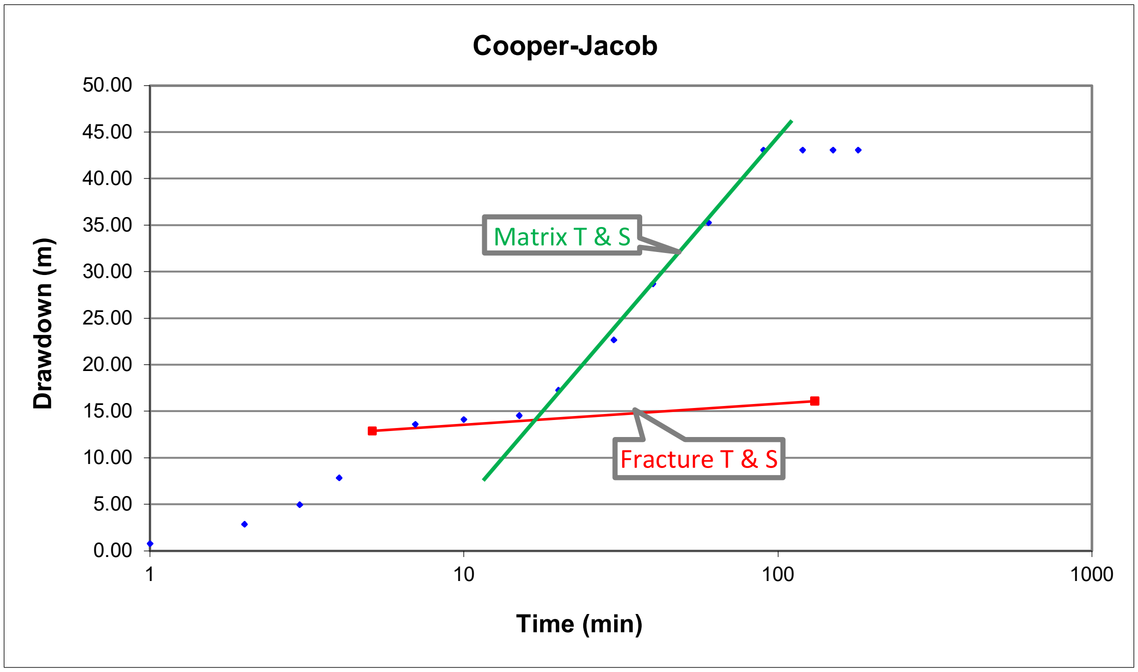

Figure 3-10: Cooper-Jacob plot for the pumping test of borehole MK0200.

3.6.3 AQUIFER TEST CONCLUSIONS

After consideration of all the data collected by conducting the slug tests and constant rate tests, the following summary of conclusions was drawn:

- Two different aquifers exist in the Makganyane area.
- The aquifer where mining activities will be concentrated is a highly heterogeneous aquifer with hydraulic parameters varying significantly over short distances.
- The aquifer to the east and west of the hills have shallower water levels and is expected to have a higher groundwater yield, however, very few of them were pump tested.
- The two aquifers are poorly connected to each other.
- The matrix transmissivities of the aquifer in the hills range from 0.08 to 57 m^2/d.
- The aquifer provides little to middling volumes of water.

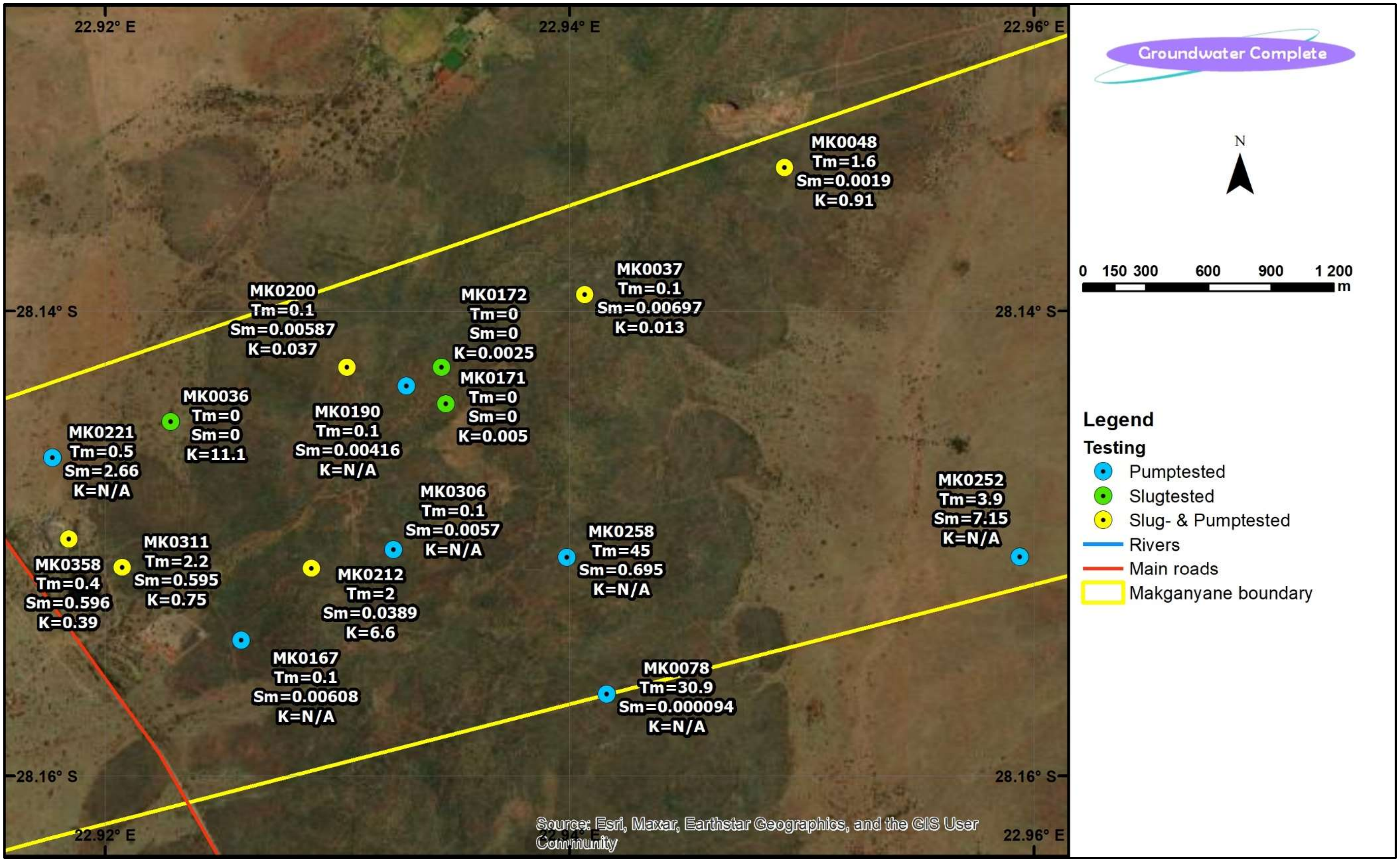

Figure 3-11: Map of pump-tested boreholes with resulting aquifer parameters – matrix T, matrix S and K (where the boreholes were slug-tested).

3.7 AQUIFER RECHARGE RATE

According to the Vegter groundwater recharge map of South Africa provided in **Figure 3-12**, the mean annual recharge to the aquifer underlying the project area should be in the order of 6 - 8 mm, which, based on an average rainfall of approximately 320 mm/a **(Figure 2-3)**, calculates to an effective recharge of between 1.8 and 2.5% of rainfall. Where rock outcrop occurs or in areas where the soil cover is thin, the effective recharge percentage may be slightly higher. Conversely, the effective recharge is expected to be lower or even zero in low-lying topographies where discharge generally occurs and where thicker layers of sediment have been deposited.

The recharge was also calculated with the chloride method, using groundwater chloride values measured for the hydrocensus and pump testing boreholes **(Figure 3-7)**. According to the chloride method, recharge for the Makganyane area is in the order of 2.1%, putting it in the same range as the Vegter estimates.

Another recharge estimation was proposed by Van Tonder and Xu (2001), based on the geology of the aquifer host rock **(Table 3-10)**. The above-mentioned method also estimates the recharge at Makganyane at around 5 - 9% of the annual rainfall, which translates to between 16 and 28.8 mm/a.

Based on all the gathered information and experience from previous studies in similar areas, the mean annual recharge to the aquifer regime in the Makganyane area was estimated to be in the order of 2% or 6.5 mm/a.

Summary:

- *An average recharge of 2% was calculated with the Chloride Method, which is in line with the 1.8 - 2.4% range of Vegter.*
- *Based on all the gathered information and experience from previous studies in similar areas, the mean annual recharge to the aquifer regime in the Makganyane was estimated to be in the order of 2% or 6.5 mm/a.*

Table 3-10: Typical recharge to different aquifer host rocks (Van Tonder & Xu, 2001).

Geology	% Recharge (soil cover <5m)	% Recharge (soil cover >5 m)
Sandstone, mudstone, siltstone	5	2
Hard Rock (granite, gneiss etc.)	7	4
Dolomite	12	8
Calcrete	9	5
Alluvial sand	20	15
Coastal sand	30	20
Alluvium	12	8

Table 3-11: Recharge in the Makganyane area as calculated using the chloride-method.

Name	Value	Unit
Cl-rain	0.4	mg/l
Rain per Annum	320	mm/a
MK0078	17	mg/l
MK0252	15	mg/l
MK0212	20	mg/l
MK0258	12	mg/l
MK0358	40	mg/l
MK0037	23	mg/l
MK0311	43	mg/l
MK0048	13	mg/l
MK0167	28	mg/l
MK0221	24	mg/l
LT17	21	mg/l
LT25	42	mg/l
ME01	68	mg/l
ME06	13	mg/l
EM06	10	mg/l
HK09	50	mg/l
HK15	50	mg/l
AP13	17	mg/l
KR12	23	mg/l
KR15	8	mg/l
Harmonic mean	19.5	mg/l
Recharge	6.6	(mm/a)
Percentage of MAP	**2.1**	**%**

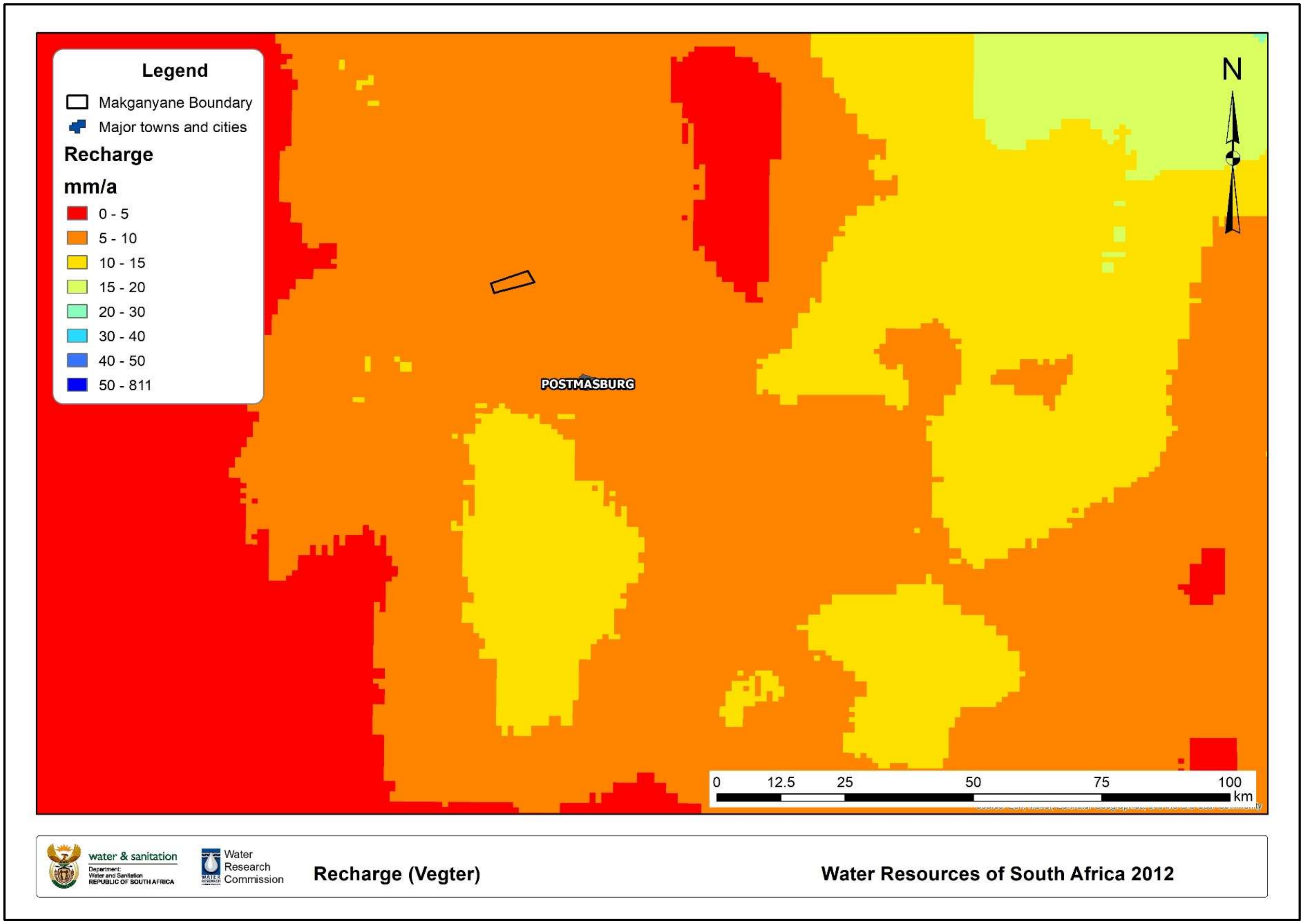

Figure 3-12: Mean annual aquifer recharge for South Africa ***(Vegter, 1995).***

3.8 GROUNDWATER QUALITY CONDITIONS

Groundwater quality data is available for a total of 20 boreholes, 10 pumping test boreholes and 10 that were sampled during the previous study for the Makganyane project in 2023. Two additional groundwater samples were taken from the Kimberlite Shaft (old diamond mine shaft) and analysed, one deep and one shallow. The positions of the sampled boreholes are indicated in **Figure 3-14**. The collected data was evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations with the South African National Standards for drinking water **(Table 3-11)**.

The four main factors usually influencing groundwater quality are:

- **Annual recharge** to the groundwater system,
- **Type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **Flow dynamics** within the aquifer(s), determining the water age and
- **Source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific source of groundwater pollution is present up gradient from the borehole, only the other three factors play a role.

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, Expanded Durov and Stiff diagrams. Of these three types, the Expanded Durov diagram probably gives the most holistic water quality signature. The layout of the fields of the Expanded Durov diagram (EDD) is shown in **Figure 3-13**. Although never clear-cut, the general characteristics of the different fields of the diagram could be summarized as follows:

<u>Field 1:</u>
Fresh, very clean recently recharged groundwater with HCO_3 and CO_3 dominated ions.

<u>Field 2:</u>
Field 2 represents fresh, clean, relatively young groundwater that has started to undergo mineralization with especially Mg ion exchange.

<u>Field 3:</u>
This field indicates fresh, clean, relatively young groundwater that has undergone Na ion exchange (sometimes in Na - enriched granites or felsic rocks) or because of contamination effects from a source rich in Na.

<u>Field 4:</u>
Fresh, recently recharged groundwater with HCO_3 and CO_3 dominated ions that has been in contact with a source of SO_4 contamination or that has moved through SO_4 enriched bedrock.

<u>Field 5:</u>
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing / contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 6:

Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 7:

Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 8:

Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing/contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.

Field 9:

Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.) or water that has moved a long time and / or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

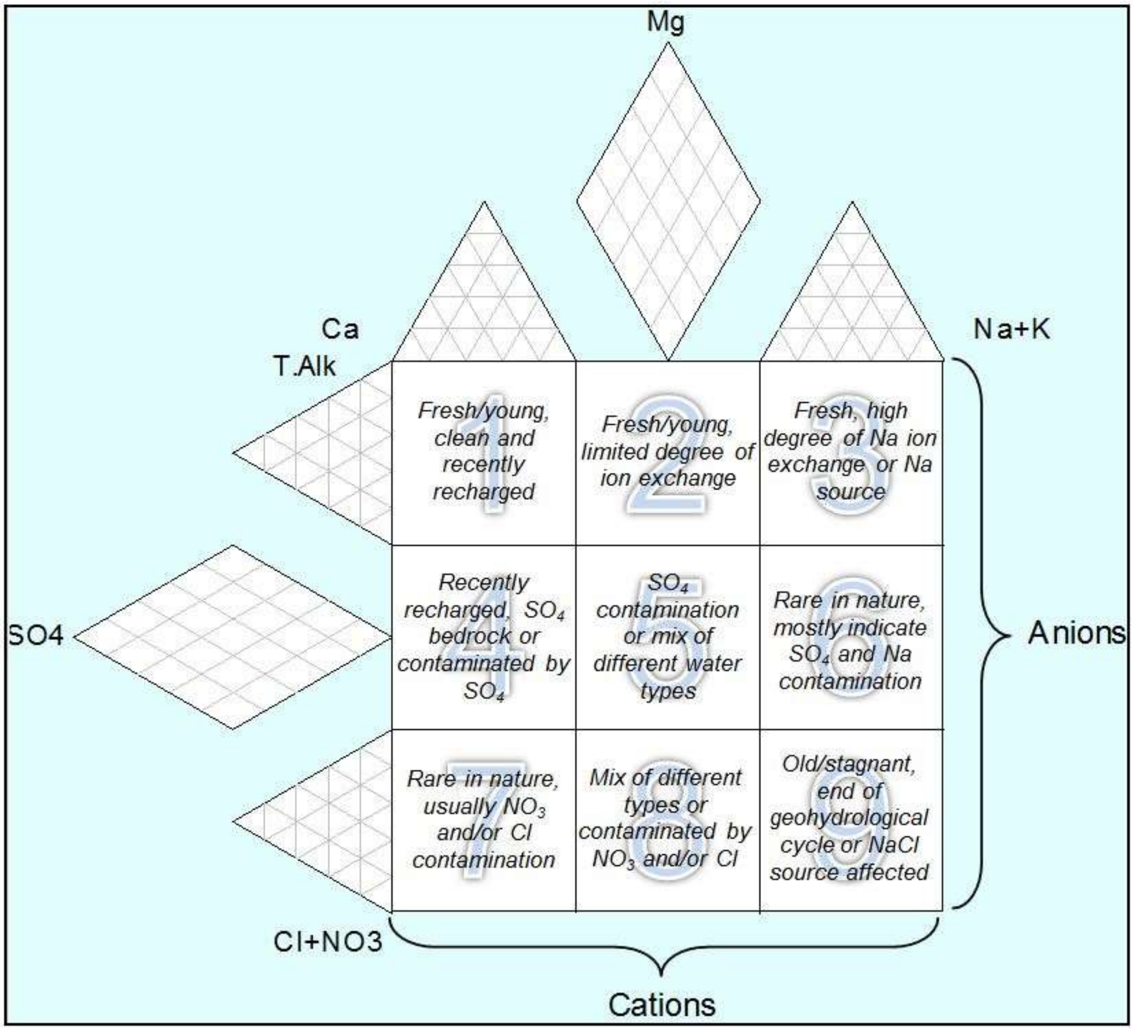

Figure 3-13: Layout of fields of the Expanded Durov diagram.

Another way of presenting the signature or water type distribution in an area is by means of Stiff diagrams. These diagrams plot the equivalent concentrations of the major cations and anions on a horizontal scale on opposite sides of a vertical axis. The plot point on each parameter is linked to the adjacent one resulting in a polygon around the cation and anion axes. The result is a small figure/diagram of which the geometry typifies the groundwater composition at the point. Groundwater with similar major ion ratios will show the same geometry. Ambient groundwater qualities in the same aquifer type and water polluted by the same source will for example display similar geometries.

Table 3-12: South African National Standards for drinking water *(SANS 241:2015)*

Determinant	Risk	Unit	Standard limits
Physical and aesthetic determinants			
Free chlorine	Chronic health	mg/l	≤ 5
Monochloramine	Chronic health	mg/l	≤ 3
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Total dissolved solids	Aesthetic	mg/l	≤ 1 200
Turbidity	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 °C	Operational	pH units	≥ 5 to ≤ 9.7
Chemical determinants - macro-determinants			
Nitrate as N	Acute health – 1	mg/l	≤ 11
Nitrite as N	Acute health – 1	mg/l	≤ 0.9
Sulfate as SO_4^{2-}	Acute health – 1	mg/l	≤ 500
	Aesthetic	mg/l	≤ 250
Fluoride as F^-	Chronic health	mg/l	≤ 1.5
Ammonia as N	Aesthetic	mg/l	≤ 1.5
Chloride as Cl^-	Aesthetic	mg/l	≤ 300
Sodium as Na	Aesthetic	mg/l	≤ 200
Zinc as Zn	Aesthetic	mg/l	≤ 5
Chemical determinants - micro-determinants			
Aluminium as Al	Operational	µg/l	≤ 300
Antimony as Sb	Chronic health	µg/l	≤ 20
Arsenic as As	Chronic health	µg/l	≤ 10
Barium Ba	Chronic health	µg/l	≤ 700
Boron B	Chronic health	µg/l	≤ 2 400
Cadmium as Cd	Chronic health	µg/l	≤ 3
Total chromium as Cr	Chronic health	µg/l	≤ 50
Cobalt as Co	Chronic health	µg/l	≤ 500
Copper as Cu	Chronic health	µg/l	≤ 2 000
Cyanide (recoverable) as CN^-	Acute health – 1	µg/l	≤ 70
Iron as Fe	Chronic health	µg/l	≤ 2 000
	Aesthetic	µg/l	≤ 300
Lead as Pb	Chronic health	µg/l	≤ 10
Manganese as Mn	Chronic health	µg/l	≤ 400
	Aesthetic	µg/l	≤ 100
Mercury as Hg	Chronic health	µg/l	≤ 6
Nickel as Ni	Chronic health	µg/l	≤ 70
Selenium as Se	Chronic health	µg/l	≤ 40
Uranium as U	Chronic health	µg/l	≤ 15
Vanadium as V	Chronic health	µg/l	≤ 200
Organic determinants			
Total organic carbon	Acute health – 1	mg/l	≤ 10

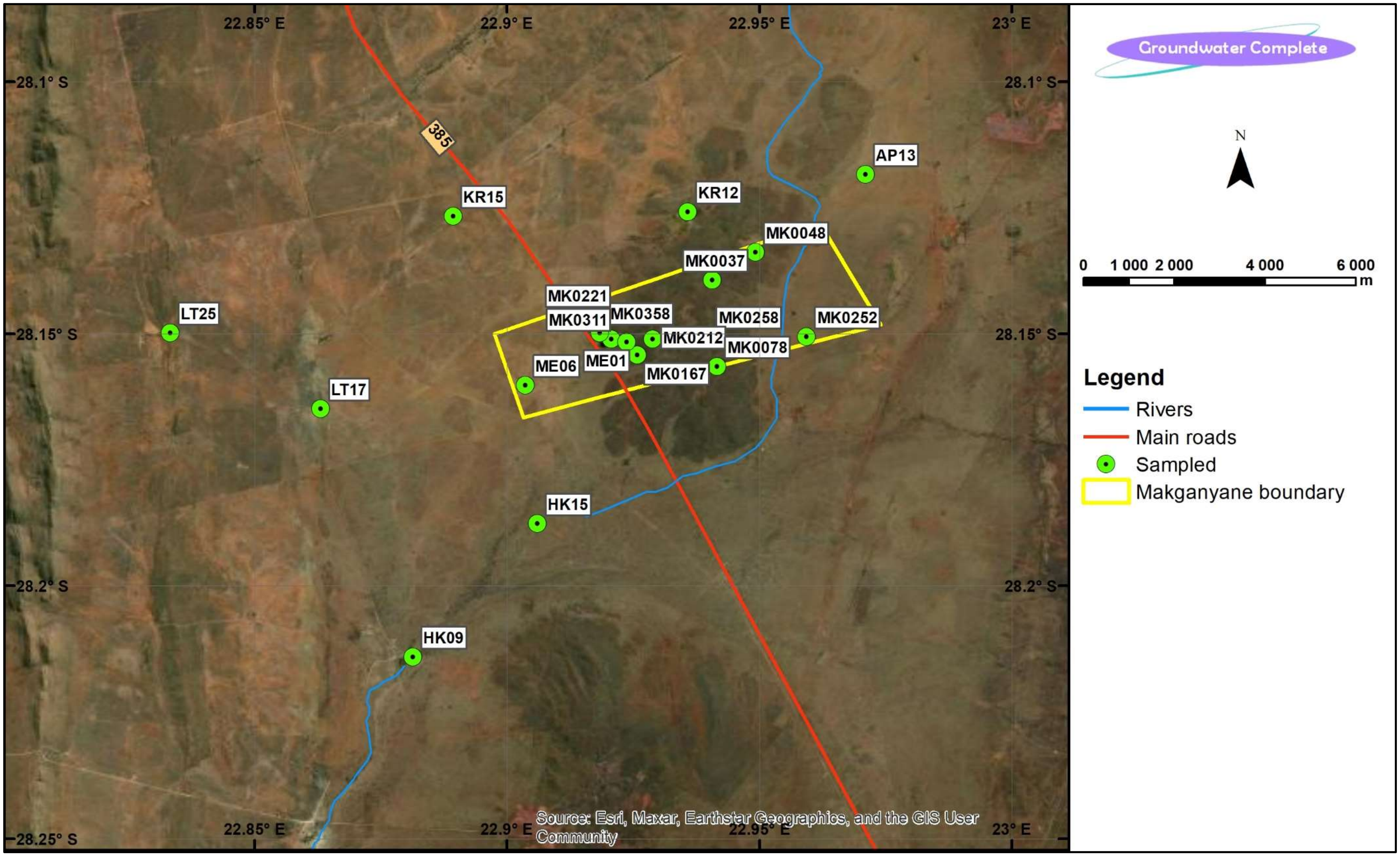

Figure 3-14: Positions of sampled pumping and groundwater user boreholes.

Groundwater samples were collected from a total of 21 localities on and around the Makganyane property and their positions are indicated in **Figure 3-14.** The groundwater samples were analysed at a SANAS accredited laboratory *(Aquatico Laboratories)* for a wide range of chemical and physical indicator parameters.

Only those parameters most likely to be affected by iron ore mining activities will be discussed in detail (TDS, pH, NO_3, Mg and Cl), however, all parameters will be assessed and anomalies will be pointed out and discussed if necessary.

Groundwater samples were taken from 10 of the pump testing boreholes. Among the hydrocensus boreholes, samples were taken from 10 user boreholes in use specifically for domestic or livestock watering purposes and located closer to mining operations. Two samples were taken from the old Kimberlite shaft at different depths. A comprehensive list of concentrations of the chemical and physical indicator parameters is provided in **Table 3-13**.

Total dissolved solids (TDS) is a good indicator of the overall quality of groundwater, as it provides a measure of the total amount or weight of salts that are present in solution. An increase in TDS will therefore indicate an increase in the total inorganic content of the groundwater. Groundwater TDS concentrations measured in the site-specific groundwater user boreholes vary between 330 mg/l and 590 mg/l **(Table 3-13)**, which are well below the maximum permissible SANS value of 1 200 mg/l and is considered a normal range for an arid region.

Groundwater **pH** under natural conditions is affected by the chemical composition of the aquifer host rock(s). At very low pH levels dissolved toxic metal ions are present, which can lead to severe health problems if consumed. At low pH levels (less than ± 4.5) the water will have a sour taste. At high pH levels there is a health hazard due to the de-protonated species, and water will have a soapy taste. Groundwater pH values vary from 7.7 to 8.8, which are within recommended SANS ranges for drinking water purposes.

Groundwater **nitrate** contamination in the iron ore mining environment is generally caused by the extensive usage of nitrate-based explosives and will therefore mainly be concentrated around pit areas. Rock material that has been exposed to the explosives will more often than not contain remnants of nitrate, which dissolve readily in water. Discard dumps and ROM stockpiles are therefore also regarded as potential sources of nitrate contamination. The highest nitrate concentrations measured during this study are around 7 mg/l, which do not exceed the maximum permissible SANS value of 11 mg/l **(Table 3-13)**. Since no mining occurs within the immediate vicinity of these three boreholes(KR12, LT17 and LT25), the nitrate contamination is believed to originate from other sources. The most common sources of nitrate in groundwater are municipal and industrial wastewaters, refuse dumps, animal feed lots and septic systems. Other sources are runoff or leachate from manured or fertilized agricultural lands and urban drainage. In addition, nitrogen compounds are emitted into the air by power plants and automobiles and are then carried from the atmosphere to the earth's surface through rainfall (Nugent and Kamrin, 2014).

Magnesium is an alkali metal that occurs naturally in groundwater. Except for diarrhoea when consumed at very high concentrations (>200 mg/l), no significant health risks are associated with the intake of magnesium. No guideline concentration is therefore specified for magnesium in the South African National Standards *(SANS 241:2015)* for drinking water purposes. Groundwater magnesium concentrations are relatively low and vary between ±27 mg/l and 64 mg/l **(Table 3-13)**.

Chloride usually has no health effects when consumed at concentrations generally found in fresh groundwater. Sensitive groundwater users may experience nausea and vomiting at chloride concentrations in excess of 1 200 mg/l. Boreholes display groundwater chloride concentrations of between approximately 8 mg/l and 68 mg/l, which are well below the maximum permissible SANS value of 300 mg/l.

The concentrations of groundwater parameters measured in the old Kimberlite pit were largely similar the qualities measured in the other Makganyane boreholes. None of the concentrations exceed the SANS *241:2015* guidelines for drinking water purposes. The only differences between the concentrations measured in the Kimberlite pit versus the surrounding area are slightly higher concentrations of sodium, magnesium and potassium.

According to the Expanded Durov diagram **(Figure 3-15)**, groundwater in the Makganyane area is dominated by **calcium** and **magnesium** cations, while **bicarbonate alkalinity** dominates the anion content. The plot positions in fields one and two of the EDD are representative of fresh, very clean and recently recharged groundwater. Both the plot positions in the EDD and the geometries of the Stiff diagrams also confirm that groundwater in the area generally has very similar macro-element composition.

Summary:

- *Groundwater is considered to be of good quality and also suitable for human consumption according to the South African National Standards for drinking water (SANS 241:2015).*
- *Groundwater samples were collected from a total of 20 boreholes located on and around the Makganyane property.*
- *Groundwater samples were taken from 10 of the pump testing boreholes.*
- *Among the hydrocensus boreholes, samples were taken from 10 user boreholes in use for specifically domestic or livestock watering purposes and located closer to mining operations.*
- *Two samples were taken from the old Kimberlite shaft at different depths.*
- *Groundwater TDS concentrations measured in the site specific groundwater user boreholes vary between 330 mg/l and 590 mg/l and is considered a normal range for this arid region.*
- *The highest nitrate concentrations measured during this study are around 7 mg/l.*
- *Groundwater magnesium concentrations are relatively low and vary between ±27 mg/l and 64 mg/l.*
- *Boreholes display groundwater chloride concentrations of between approximately 8 mg/l and 68 mg/l.*

- *Since no mining occurs within the immediate vicinity of any of the hydrocensus boreholes, the elevated nitrate concentrations are believed to originate from areas where animals congregate in significant numbers (feedlot, kraal, etc.).*
- *Groundwater within the Makganyane area is dominated by* ***calcium*** *and* ***magnesium*** *cations, while* ***bicarbonate alkalinity*** *dominates the anion content.*
- *The concentrations of groundwater parameters measured in the old Kimberlite pit were largely similar to the qualities measured in the other Makganyane boreholes.*
- *None of the parameters' concentrations exceeded the SANS 241:2015 guidelines for drinking water purposes.*
- *The only differences between the concentrations measured in the Kimberlite pit versus the surrounding area are slightly higher concentrations of sodium, magnesium and potassium – likely due to higher evaporation.*

Table 3-13: Concentrations of chemical and physical indicator parameters for site specific groundwater user boreholes.

Locality	Sampled date	pH	EC	TDS	Alk	Cl	SO_4	NO_3	TON	NO_2	NH_4	PO_4	F
			mS/m	mg/l	mg $CaCO_3$/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
MK 0078	01-Nov-2023	7.8	57	428	304	17	21	4.1	4.1		0.1	0.0	-0.3
MK 0252	01-Dec-2023	8.4	48	361	231	15	59	0.7	0.7		0.2	0.0	0.3
MK 0212	12-Nov-2023	8.1	54	405	238	20	88	0.6	0.6		0.1	0.0	-0.3
MK 0258	13-Nov-2023	7.7	55	411	316	12	25	2.0	2.0		0.1	0.0	-0.3
MK 0358	27-Nov-2023	8.0	74	545	300	40	109	1.6	1.6		0.1	0.0	-0.3
MK 0037	08-Nov-2023	7.8	70	525	406	23	42	0.7	0.7		0.1	0.0	-0.3
MK 0311	23-Nov-2023	7.9	75	558	339	43	85	1.1	1.1		0.2	0.0	-0.3
MK 0048	07-Nov-2023	8.0	55	408	328	13	28	0.9	0.9		0.2	0.0	-0.3
MK 0167	19-Nov-2023	8.1	67	485	295	28	99	0.7	0.7		0.2	0.0	0.4
MK 0221	17-Nov-2023	7.9	63	461	303	24	32	5.6	5.6		0.2	0.0	-0.3
LT17	23-Jan-2024	8.6	53	418	277	21	16	6.8	6.9	-0.1	0.0	0.0	-0.3
LT25	23-Jan-2024	8.8	62	466	344	42	15	6.6	6.6	-0.1	0.0	0.1	-0.3
ME01	24-Jan-2024	8.6	72	516	360	68	27	-0.2	-0.2	-0.1	0.5	0.1	-0.3
ME06	25-Jan-2024	8.6	45	338	231	13	16	3.4	3.5	-0.1	0.0	0.1	-0.3
EM06	24-Jan-2024	8.6	46	346	240	10	13	3.6	3.6	-0.1	0.0	0.1	-0.3
HK09	22-Jan-2024	8.6	81	589	406	50	55	5.0	5.0	-0.1	0.0	0.0	-0.3
HK15	22-Jan-2024	8.3	69	545	365	50	30	5.0	5.1	-0.1	0.0	0.0	-0.3
AP13	25-Jan-2024	8.5	49	389	256	17	25	3.5	3.5	-0.1	0.0	0.0	-0.3
KR12	25-Jan-2024	8.5	59	435	304	23	18	7.2	7.2	-0.1	0.0	0.1	-0.3
KR15	25-Jan-2024	8.6	41	346	231	8	12	4.4	4.4	-0.1	0.0	0.1	-0.3
Kimberlite shaft Shallow	06-Jun-2025	8.6	85	575	286	131	26	0.4			0.1	-0.0	-0.3
Kimberlite shaft Deep	06-Jun-2025	8.5	85	569	287	135	16	0.4			0.08	-0.0	-0.3

Table 3-13: Concentrations of chemical and physical indicator parameters for site specific groundwater user boreholes (continued).

Locality	Sampled date	Ca	Mg	Na	K	Al	Fe	Mn	Cr	Cu	Ni	Thard
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg $CaCO_3$/l
MK 0078	01-Nov-2023	74	41	19	2.7	-0	-0	-0				353
MK 0252	01-Dec-2023	44	28	45	1.9	-0	-0	0.05				223
MK 0212	12-Nov-2023	69	38	19	4.4	-0	-0	0.21				329
MK 0258	13-Nov-2023	73	43	16	3.4	-0	-0	-0				357
MK 0358	27-Nov-2023	106	48	27	3.8	-0	-0	0.04				462
MK 0037	08-Nov-2023	88	61	21	4.4	-0	-0	0.46				472
MK 0311	23-Nov-2023	87	60	32	4.5	-0	-0	0.15				462
MK 0048	07-Nov-2023	74	43	17	2.1	-0	-0	0.19				362
MK 0167	19-Nov-2023	58	57	37	4.0	-0	-0	0.14				379
MK 0221	17-Nov-2023	79	42	27	1.8	-0	-0	-0				368
LT17	23-Jan-2024	55	36	27	1.5	0.25	-0	-0	-0	-0	-0	285
LT25	23-Jan-2024	35	58	36	2.0	0.18	-0	-0	-0	-0	-0	323
ME01	24-Jan-2024	72	56	30	4.3	0.27	-0	1.47	-0	-0	-0	408
ME06	25-Jan-2024	46	27	17	1.0	0.2	-0	-0	-0	-0	-0	226
EM06	24-Jan-2024	48	31	19	1.6	0.22	-0	-0	-0	-0	-0	248
HK09	22-Jan-2024	69	64	27	2.4	0.33	-0	-0	-0	-0	-0	437
HK15	22-Jan-2024	82	49	30	2.6	0.3	-0	-0	-0	0	-0	405
AP13	25-Jan-2024	65	32	17	0.9	0.28	-0	-0	-0	0	-0	293
KR12	25-Jan-2024	64	36	25	2.2	0.27	-0	-0	-0	-0	-0	308
KR15	25-Jan-2024	42	27	18	1.4	0.2	-0	-0	-0	0	-0	217
Kimberlite shaft Shallow	06-Jun-2025	29	72	76	11.5	-0	-0	0.07	-0	0.03	-0	370
Kimberlite shaft Deep	06-Jun-2025	29	70	73	11.2	-0	-0	0.06	-0	0.03	-0	362

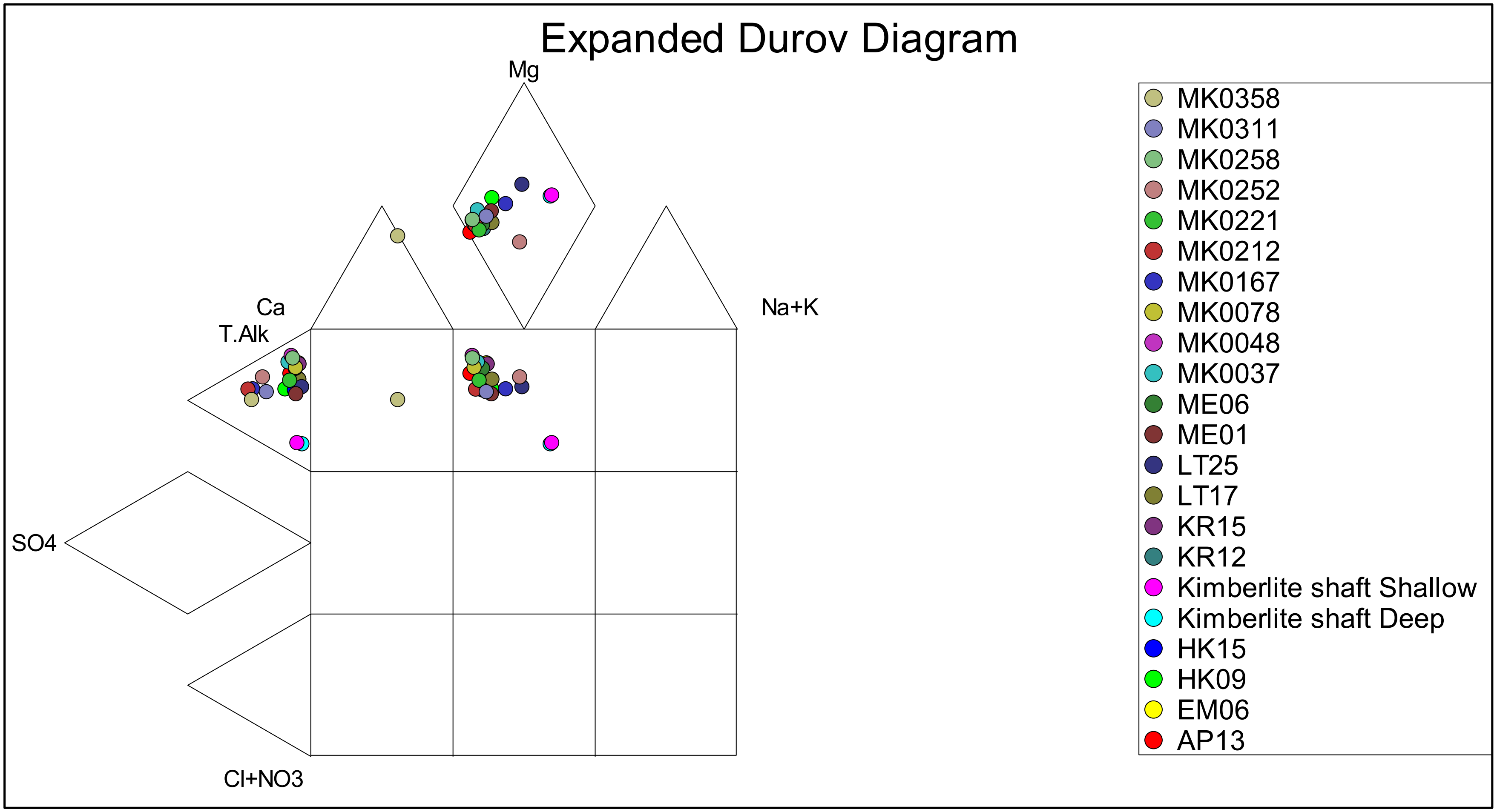

Figure 3-15: Expanded Durov diagram of groundwater chemistry for sampled boreholes.

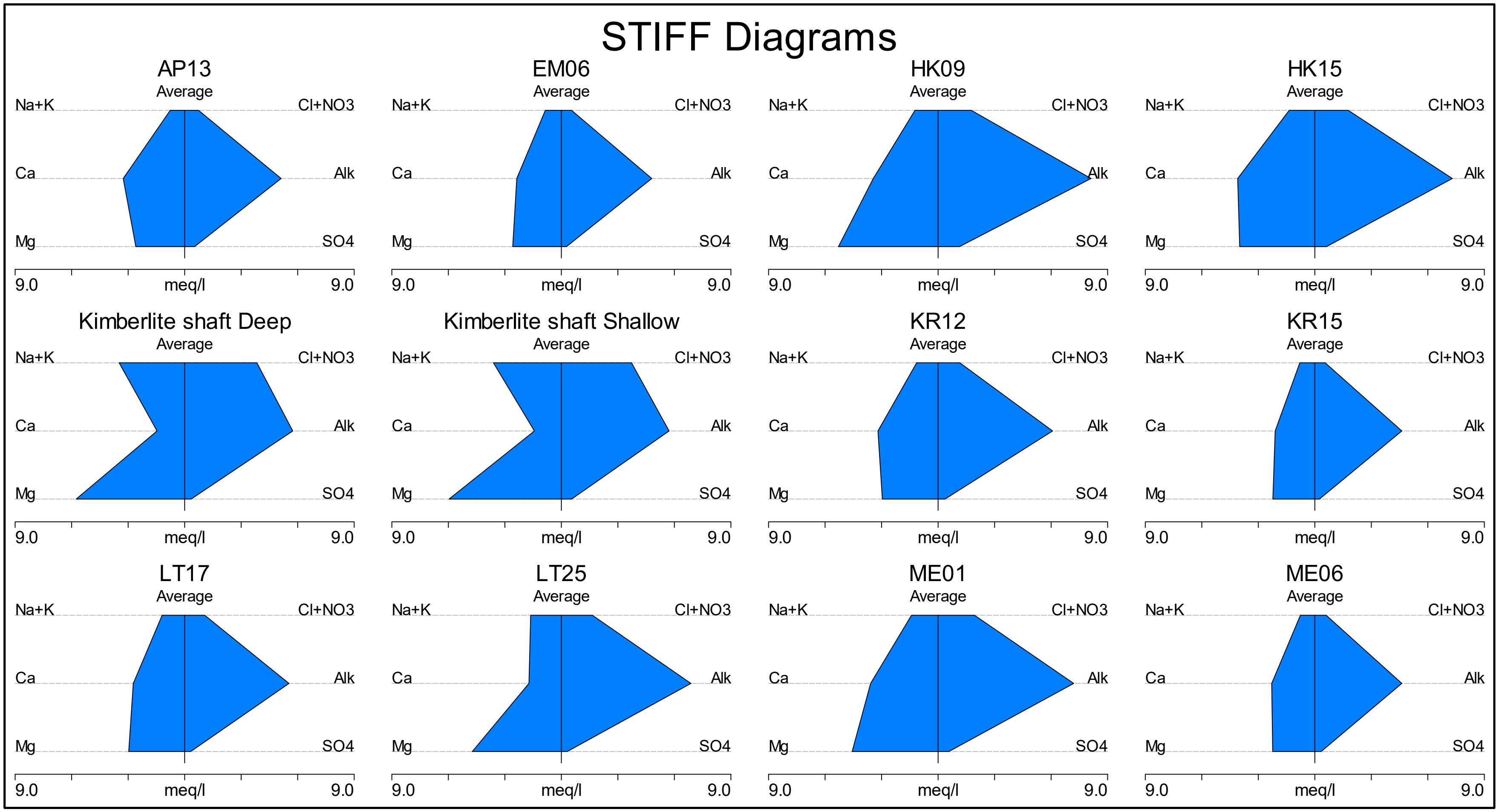

Figure 3-16: Stiff diagram of groundwater chemistry for sampled boreholes.

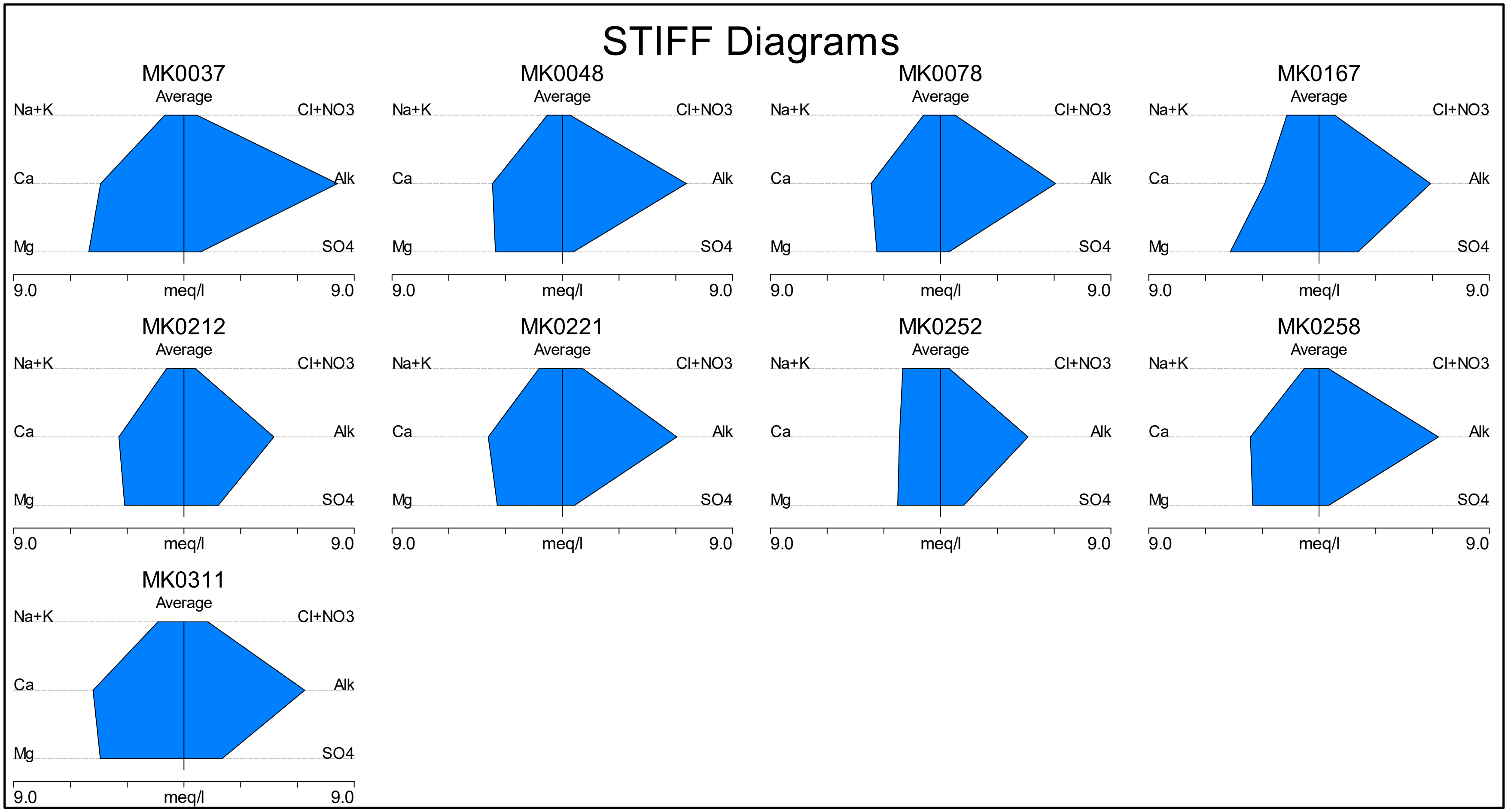

Figure 3-16: Stiff diagram of groundwater chemistry for sampled boreholes (continued).

3.9 Waste Classification

The following is a summary of the waste classification report conducted by IQS Holdings (2025):

The outcome of the risk assessment is summarised in **Table 3-14**. The XRF results show that the geological material (waste rock) contains mainly silica (quartz), iron oxide, aluminium oxide and potassium oxide while sample MK0240 also contains 5% manganese oxide. The mineralogical information also shows that the samples exist mainly of quartz and hematite with lesser amounts of other iron-bearing minerals.

The ABA and NAG results show that the waste rock will not be acid forming and the total sulphur concentration of all samples were lower than the 0.3% threshold to be considered acid generating. Under complete oxidation, the water quality interacting with the rock material will have a pH of 6.3 – 6.5.

The core samples contain elevated total Ba, Ni, Co, Mn and Ni concentrations, exceeding the GN R. 635 initial total concentration threshold (TCT0) and TCT1 in sample MK0240. Due to the low leachable concentrations of all constituents (<LCT0), the waste rock is assessed as a Type 4 waste and non-hazardous according to GHS. The short-term leach test shows that the constituents are insoluble at the current pH of the material (pH 6.9 – 7.4) and the impact on the receiving environment is expected to be insignificant. The short-term leachate and run-off quality will be compliant with the water quality guidelines for domestic use, agricultural use and for aquatic ecosystems.

No material impacts on the local aquifers and ecosystems are anticipated due to the proposed disposal of the waste rock.

Table 3-14: Waste Rock Risk Assessment summary

Aspect		Waste Rock
Chemical	Acid-base accounting	Not acid-generating
	Paste pH	Neutral (6.9-7.4)
	Chemical composition of leachate (short- term)	No exceedances of water quality guidelines, except Mn in sample MK0240
	Propensity to oxidise and decompose, stability and reactivity	Not containing minerals that will react with oxygen and water to produce ARD
	Concentration of volatile organics	Not applicable
Waste classification	Physical hazards	Not hazardous
	Health hazards	Not hazardous
	Environmental hazard	Not hazardous
	Classification	Not hazardous in terms of GHS
	Total concentrations	TC > TCT0 (Ba, Ni, Co, Mn and Ni)
	Total concentrations	TC > TCT1 (Mn) in sample MK0240
	Leachable concentrations	LC < LCT0 for all constituents

	Assessment	Type 4 waste, due to low leachable concentrations (LC< LCT0)
Toxicity	Ecotoxicology	Not ecotoxic (low leachability)
Presence of vulnerable ecosystems		Artificial channelled valley bottom wetland, located in the eastern portion of the focus area, associated with the unnamed river
Mitigation measures to manage the impact on receiving environment		Continuous surface- and groundwater monitoring. Regular updates of numerical and geochemical model

3.10 POTENTIAL SOURCES OF CONTAMINATION

A source area is defined as an area from which groundwater contamination is generated or released in the form of seepage or leachate. Source areas are subdivided into two main groups:

- Point sources
  Contamination can be easily traced back to a single origin.
- Diffuse sources
  Diffuse sources of groundwater contamination are typically associated with poor quality leachate formation through numerous surface sources.

There are a number of possible areas in any mining operation that may act as sources of groundwater contamination. These include, but are not limited to, waste rock dumps (WRD), ROM pads, paste dams, tailings dams, pollution control dams (PCD), processing plants and sewage facilities. Potential contamination sources associated with the proposed Makganyane mining and related activities are as follows **(Figure 3-17)**:

- Stockpile; and
- Waste rock dump.

According to the waste classification (IQS Holdings, 2025), the sources at Makganyane will have a very low potential of producing poor quality leachate to groundwater.

Summary:

- *Potential contamination sources associated with the proposed Makganyane mining and related activities are the planned Stockpile and WRD.*
- *According to the waste classification (IQS Holdings, 2025), the sources at Makganyane will have a very low potential of producing poor quality leachate to groundwater.*

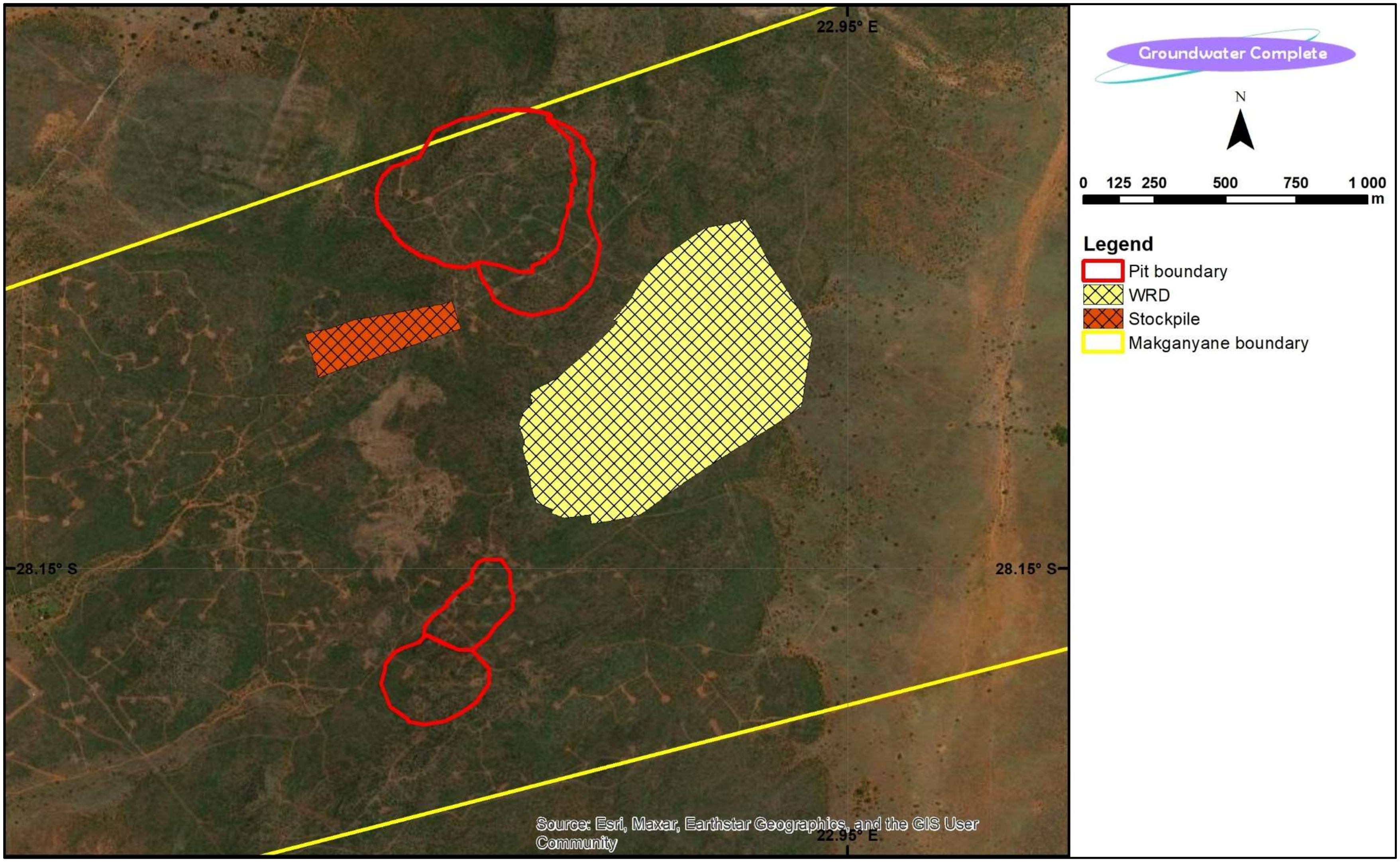

Figure 3-17: Positions of potential sources of contaminations

3.11 POTENTIAL PATHWAYS FOR CONTAMINATION

In order for contamination to reach and eventually affect a receptor(s), it must travel along a preferred pathway. The effectiveness of a pathway in conducting contamination is determined by three main factors, namely:

- Hydraulic conductivity of pathway;
- Groundwater hydraulic gradient; and
- The cross-sectional area through which flow occurs.

All three above-mentioned factors have a linear relationship with the flow of contamination through a preferred pathway. This means that an increase in any one of the three will lead to an increase in flow.

Two potential pathways were identified in the project area and are discussed shortly:

- **Structures such as dykes and faults** have the potential to serve as sufficient pathways for contamination. Many structures occur in the Makganyane area, any of which may act to some extent as preferred pathways.
- The crystalline nature of an igneous dyke is characteristic of an aquiclude, however, none of the structures mapped by previous studies appeared to act notably as aquicludes during the aquifer testing. Rapid cooling during intrusion usually causes highly transmissive fracture zones to form along the contact between the intrusive and surrounding rock.
- Flow rates may increase by several orders of magnitude if a transmissive geological structure is located in the down gradient groundwater flow direction and when orientated parallel to the local flow direction.
- If any of the source infrastructures mentioned in Section 3.10 induce groundwater mounding through artificial recharge (in the form of seepage), the groundwater gradient will increase, thereby increasing groundwater flow velocity away from the source.

3.12 POTENTIAL RECEPTORS OF CONTAMINATION

A receptor of groundwater contamination is typically a groundwater user who relies on it for domestic, irrigation, or livestock watering purposes. Surface water features (stream, river, dam, etc.) that rely on groundwater base flow for sustaining the aquatic environment are also considered to be important receptors.

The groundwater users are discussed fully in **Section 3.1**. A total of 90 boreholes were located during the hydrocensus. The various uses were mainly a combination of domestic use, agriculture and livestock watering – agriculture and livestock watering are the most common water uses. Please note that 38 of the boreholes that were found were in use at the time of the surveys. Only 14 of these are located within a two-kilometre radius of the mining rights area. Depending on the outcome of the numerical model simulations **(Section 5)**, some of these boreholes will be regarded as possible receptors.

The numerous tributaries of the Soutloop River that cut through the mining rights area are not perennial and only experience significant flow during and directly after a major rainfall event.

These (mostly dry) riverbeds are not believed to receive any significant groundwater baseflow and are therefore not regarded as potential receptors of contamination that may originate from the mining rights area.

Summary:

- *For a negative groundwater quality impact to be registered the following three components should be present:*
    - *A source to generate and release the contamination,*
    - *A pathway along which the contamination may migrate, and*
    - *A receptor to receive the contamination.*
- *All three these components will be present within the project area.*
- *The source has a low risk of contamination as determined by the waste classification report.*
- *The pathway is relatively poor, resulting in slow transportation of contamination.*
- *Possible receptors are relatively far away from the potential sources.*
- *It stresses the importance of a comprehensive early detection groundwater monitoring program.*

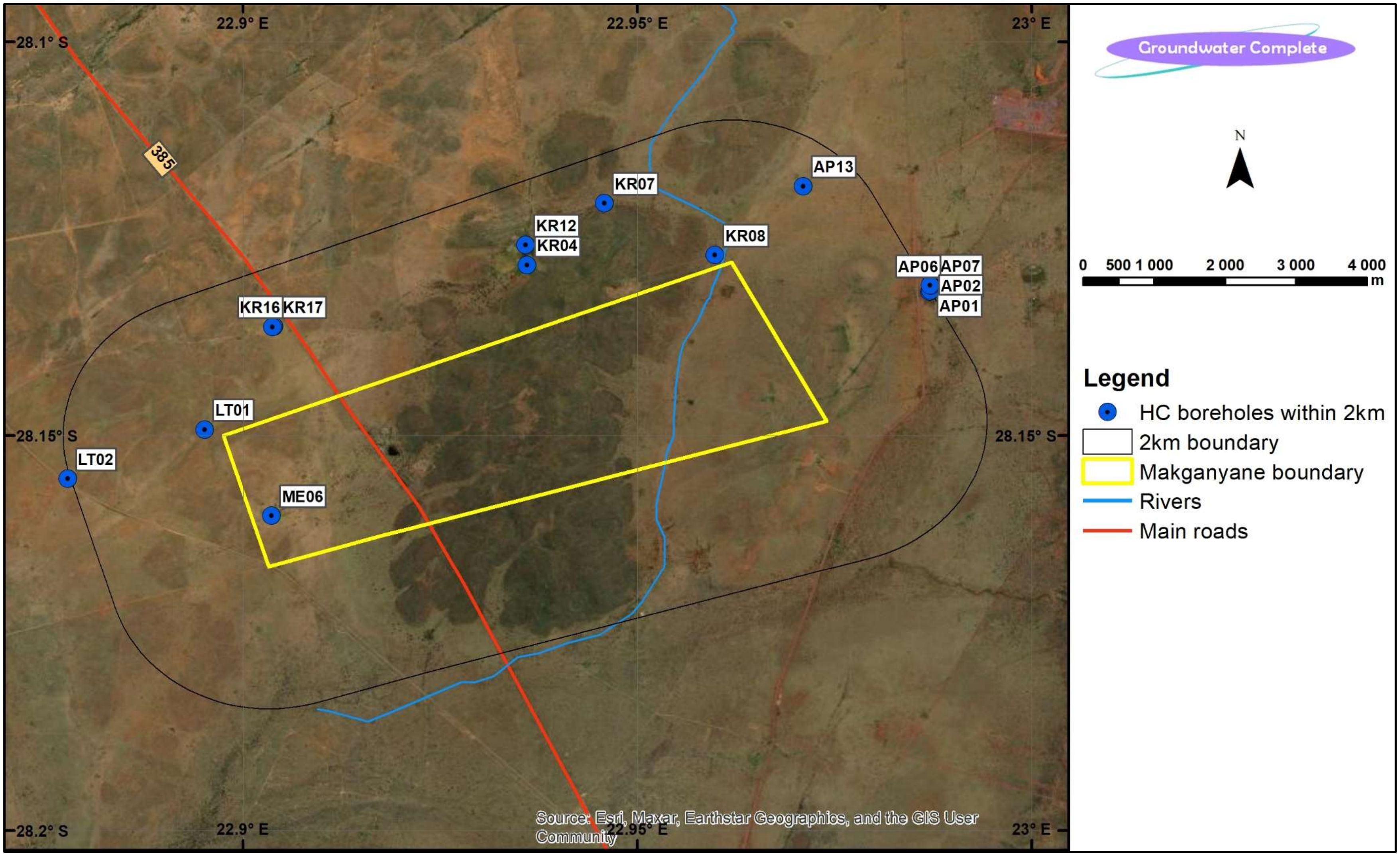

Figure 3-18: Hydrocensus boreholes that are in use and located within a two-kilometre radius of the mining rights area.

3.13 Summary of Conceptual Model

A vertical cross-section through the project area from west to east is provided in **Figure 3-19**. Please note that a south-to-north section is expected to be mostly the same since the Makganyane area is situated on a geological dome. Based on the assessment of all groundwater-related aspects and other relevant studies, we conceptualize the geohydrological system underlying the Makganyane area as follows:

- Some surface water drainage features, including tributaries of the Soutloop River, are present in the project area. However, none of these are perennial and only carry significant flow during or immediately after major rainfall events.
- The project area has a semi-desert climate, with hot summers and cold winters. It lies within a summer rainfall region, with a mean annual precipitation (MAP) of approximately 320 mm.
- The geology underlying the project area consists of various formations. The planned mining area is primarily underlain by the Nelani and Rooinekke Formations, with local occurrences of diamictite from the Makganyene Formation. These are underlain by the Gamagara Formation, which hosts localized iron ore deposits at its base. Beneath the iron ore lies the Manganore and Wolhaarkop Formations, which are especially significant for groundwater, as they host the most significant aquifers. The final formation of importance is the Campbell Rand Dolomite. On the eastern and western margins of the area, lava flows of the Ongeluk Formation overlie all these units. The practical hydrogeological implications of this stratigraphy are illustrated in **Figure 3-19**.
- Geological structures, including dolerite dykes and localised faults, are widespread across the project area. These may influence groundwater flow by acting as preferred pathways for groundwater and potential contaminants. However, aquifer testing did not indicate that these features significantly affect groundwater flow behaviour. The dyke structures were therefore not found to be fully impervious to groundwater flow.
- Groundwater levels in the flatter areas to the west of the hills varied between 7 and 20 meters below surface (mbs), while the water levels to the east of the hills varied between 18 and 28 mbs. The groundwater levels in the hilled area were markedly deeper, ranging between 30 and 100 mbs.
- Due to the highly varying nature of aquifers that are present in the Makganyane area, the groundwater flow calculated for this report only represents a regional average flow velocity and direction. Flow velocity and direction may both vary significantly if tested more specifically on a smaller scale. By making use of these values, the average flow velocity in the project area was calculated to be in the order of 4.8 meters per year.
- The Makganyane area is underlain by two distinct and very different aquifers:
  - The first of the aquifers exists in the eastern and western flatter areas of the Makganyane property. The host rock of the aquifer is the andesitic lavas of the Ongeluk Formation.
  - The second aquifer present in the Makganyane area is the aquifer that exists mainly in the planned mining area. This aquifer exists mainly in a specific layer, namely the chert-breccia layer.
- Based on all the gathered information, the mean annual recharge to the aquifer regime in the Makganyane area should be in the order of 2% of MAP or 6.5 mm/a.

- Groundwater is considered to be of good quality and generally suitable for human consumption according to **SANS 241:2015** (South African National Standard for drinking water).
- There are two (2) potential sources of groundwater contamination that will be part of the Makganyane operations. The waste classification study conducted by IQS Holdings (2025) indicated that both these potential sources have extremely low risks of causing contamination.
- A total of 90 boreholes were identified during the hydrocensus. Most were used for a combination of domestic supply, agriculture, and livestock watering – with the latter two being the most common uses. Of these, 38 boreholes were in use at the time of the survey, and only 14 are located within a two-kilometre radius of the mining rights area. Depending on the outcomes of the numerical mass transport model simulations, some of these boreholes may be identified as receptors **(Figure 3-18)**.
- No major or perennial (baseflow receiving) rivers/streams are located within close proximity to the proposed mining activities. Therefore, surface water features are not expected to act as receptors of potential contamination.
- Pit dewatering will be necessary to maintain a dry and safe mining environment. This is expected to cause a local lowering of the groundwater table, resulting in the formation of a groundwater depression cone.
- Groundwater levels are expected to increase slightly below the waste rock dump and stockpile as a result of increased aquifer recharge. This process is better known as groundwater mounding.
- It needs to be considered that even the relatively low average volume of rainfall will amount to a considerable total volume which should be considered in the dewatering of the pit.

Two sectional sketches are included in **Figures 3-19** and **3-20.** The first was developed to illustrate the subsurface environment as it pertains to groundwater. To simplify a geologically complex and heterogeneous system into a more quantifiable conceptual model, many geological layers were grouped together. The second was received from Practara and was helpful to understand the local geological stratigraphy as it is relevant to the planned Makganyane operations.

An additional cross-section was developed specifically to illustrate the likely behaviour and migration pathways of any potential contamination plumes originating from the mining infrastructure. **Figure 3-21** presents a schematic, not-to-scale cross-section through the stockpile and WRD, including key hydrogeological features such as the groundwater table, recharge zones, and the conceptual pit geometry. The representation includes both identified source areas and their respective plumes, overlaid with generalised flow directions.

The North pit, located north of the cross-section plane, is expected to act as a significant hydraulic sink due to ongoing dewatering activities. This artificial lowering of the groundwater table in the vicinity of the pit is anticipated to draw contaminated groundwater in that direction, resulting in a distortion or elongation of any contamination plumes migrating from the WRD and stockpile. Although the original direction of plume movement would typically follow the regional hydraulic gradient, the influence of the pit may override this in localised areas, pulling the plumes toward the pit over time.

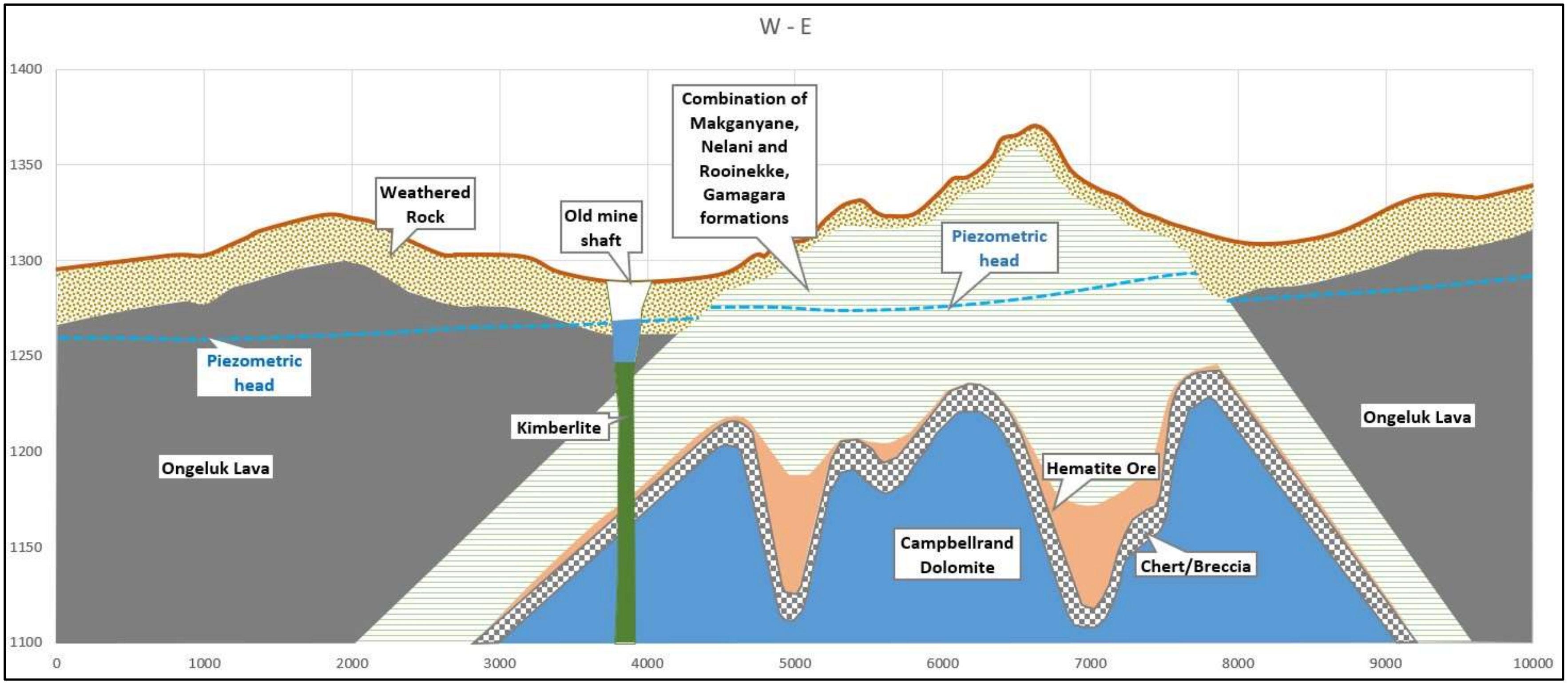

Figure 3-19: Vertical cross-section from west to east through the project area, showing the layers important to the geohydrology.

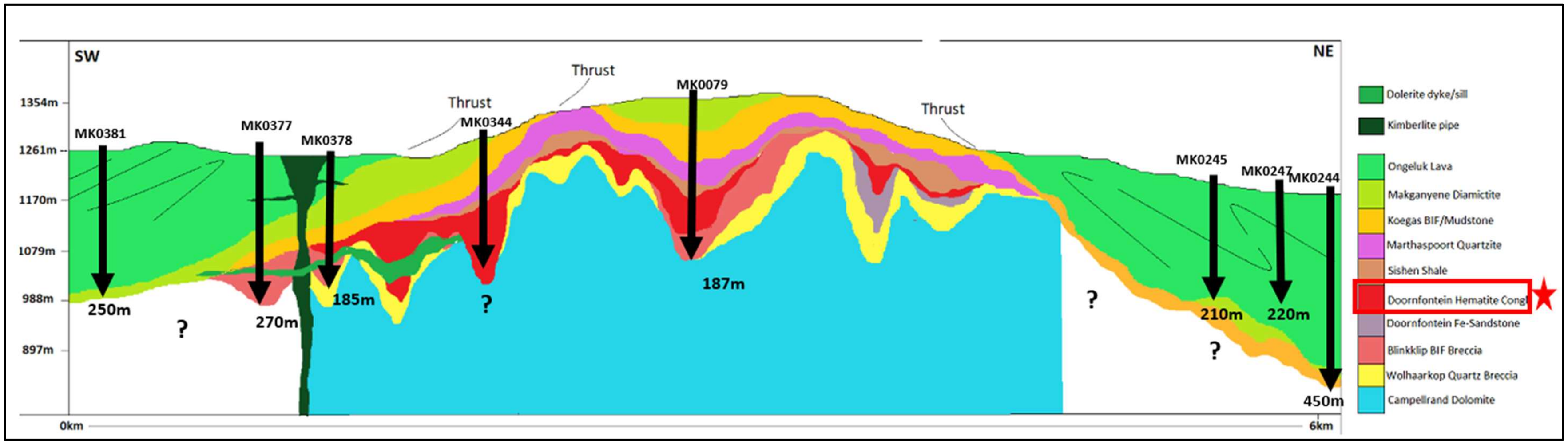

Figure 3-20: Geological cross-section as interpreted by Practara.

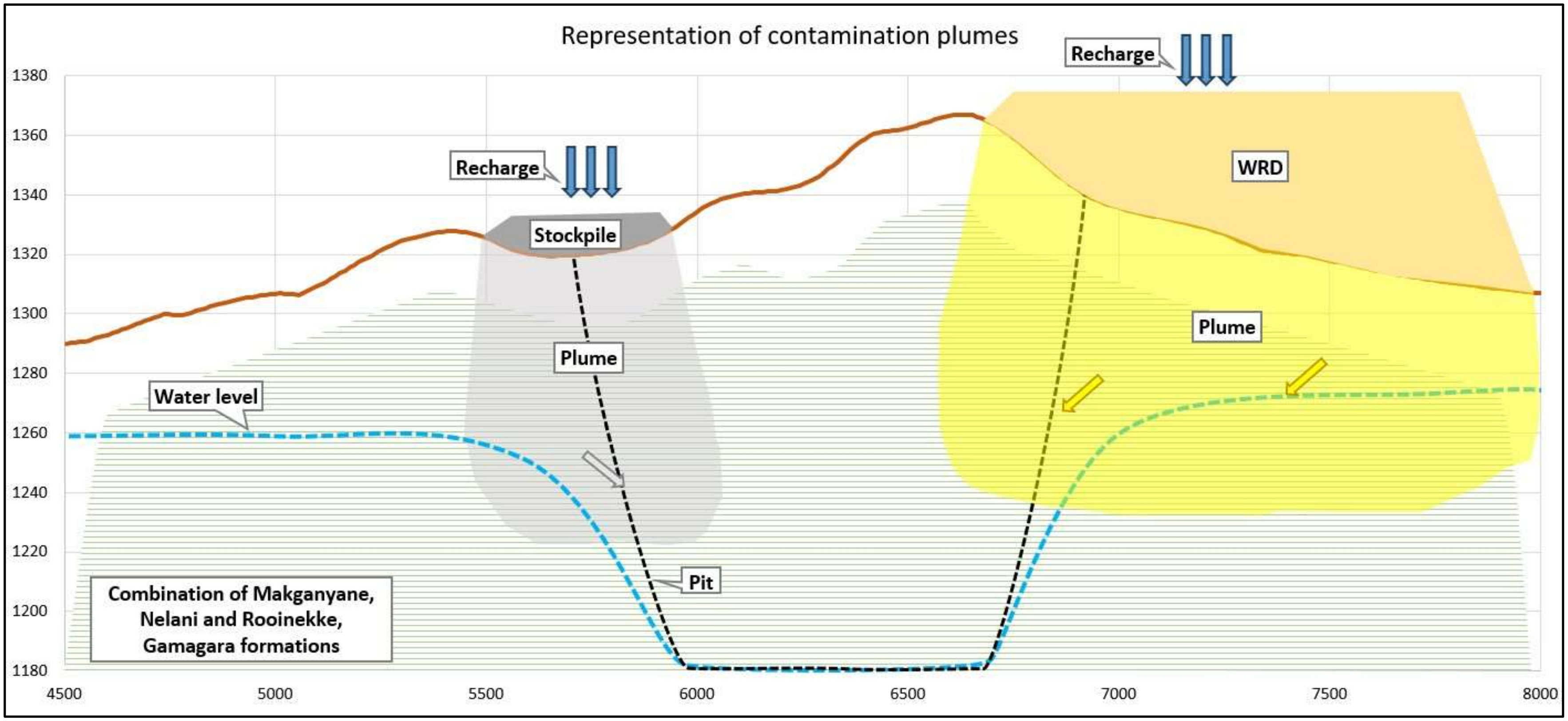

Figure 3-21: Cross-section to display the expected movement of contamination conceptually.

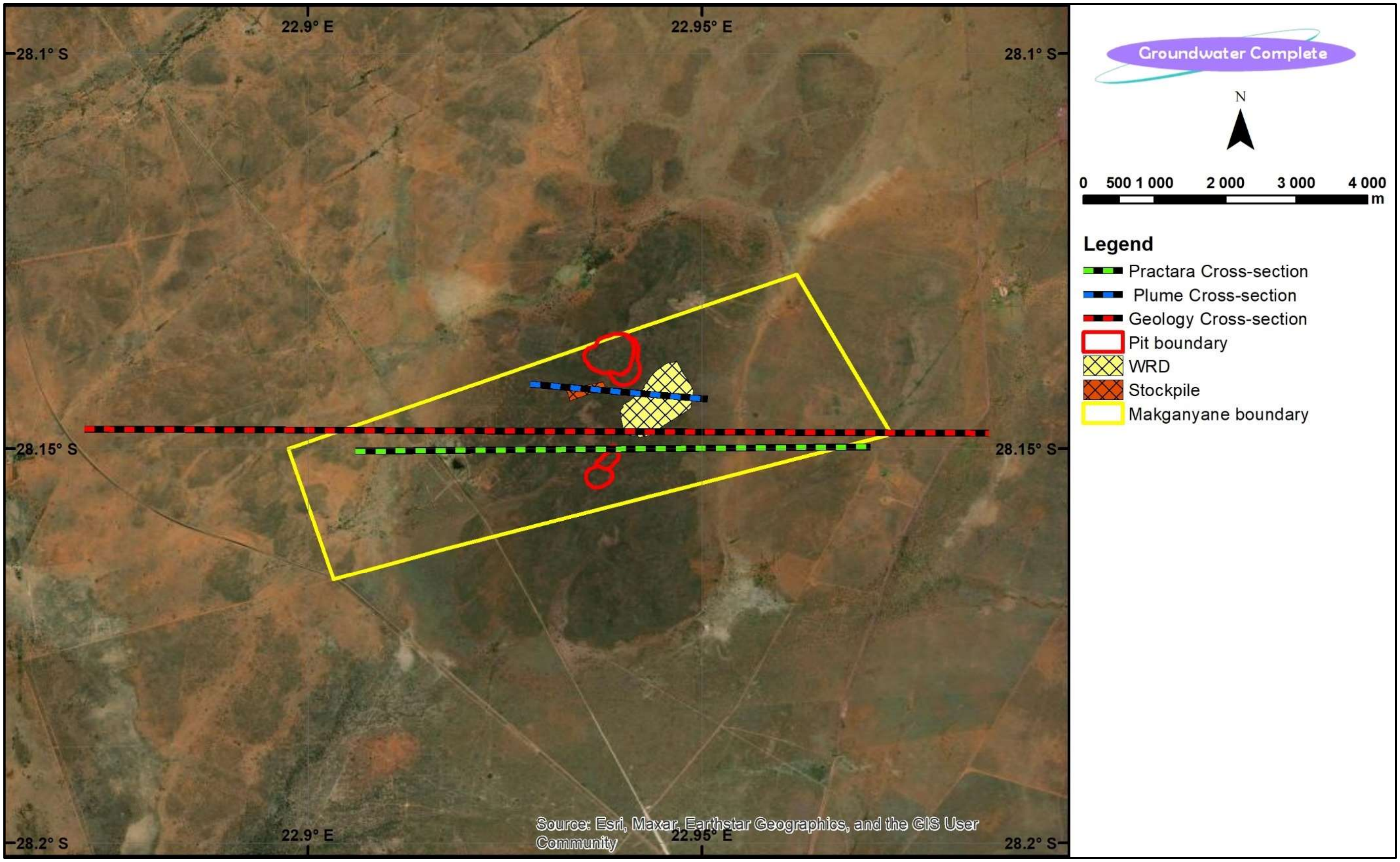

Figure 3-22: Position of cross-section over the project area.

4 NUMERICAL GROUNDWATER MODEL

4.1 MODEL RESTRICTIONS AND LIMITATIONS

The numerical groundwater model, despite all efforts and advances in software and algorithms, remains a very simplified representation of the very complex and heterogeneous interacting aquifer systems underlying the project area. The integrity of a numerical model depends strongly on the formulation of a sound conceptual model and the quality and quantity (distribution, length of records, etc.) of input data. Nonetheless, a numerical model can still be used quite successfully to assess the effectiveness of various management and remediation options/techniques, especially if the shortcomings in information and assumptions made in the construction and calibration of the model are clearly listed and kept in mind during modelling.

The main purpose is thus not to try to predict what the exact groundwater level or concentration of a certain element will be at a certain position at a specific moment in the future. The heterogeneity of the natural groundwater system, especially the secondary fractured rock aquifer environment underlying the project area, is simply too great to accurately incorporate and simulate accurately in the model. The purpose is therefore to evaluate what the relative magnitude or contribution of certain impacts or different pollution sources will be on the larger groundwater regime and then to determine which remediation options would have the most beneficial effects.

Although relatively good borehole coverage occurs in many parts of the modelled area, the significant heterogeneity of the aquifer still makes assigning representative geohydrological flow or mass transport parameters to the entire model grid problematic.

Numerous faults and dykes have been mapped in the project area, however, direct aquifer parameter estimation data is not available for these structures. Aquifer test conducted near some of the dykes and faults indicated no increased or decrease in flow due to the structures. It is however still possible that some of the structures can aid or restrict groundwater flow. Because the aquifer underlying the project area is of a secondary fractured rock type, groundwater flow and contaminant migration is fully restricted to open fractures and discontinuities associated with geological structures. These structures therefore have the ability to significantly affect the outcome of a model. The type and extent of the effect they each may have will entail a much more detailed and in-depth study to the point where it becomes too complicated to feasibly implement within the current modelling framework.

4.2 MODEL DOMAIN AND BOUNDARY CONDITIONS

The Processing MODFLOW 11 modelling package was used for the model simulations. It is a finite difference type model capable of performing multi-layered (i.e. 3-dimensional) flow and contaminant transport simulations. It uses the MODFLOW algorithm for the flow modelling, while the MT3DMS algorithm was used for contaminant transport modelling. MODFLOW possesses a graphics user interface (GUI) that allows users to set up the model, define layers, input parameters, and view results using a graphical layout, rather than writing the input files by hand or coding them directly.

The finite difference model grid is indicated in **Figure 4-1**. Model dimensions and aquifer parameters used in the construction and calibration of the model are provided in **Table 4-1**.

No-flow boundaries were used to define the model area. In a model, as in nature, they represent groundwater divides (topographic highs or lows) and geological structures (dykes) across which no groundwater flow is possible. These boundaries were based on topographical data available from the Surveyor General.

The first model layer ranges in thickness between 14 m (mostly in the flats) and 200 m (in the hills) in thickness throughout the modelled area and represents the shallow weathered zone aquifer to the east and west and the succession of relatively low-permeability layers located above the chert and breccia aquifer in the hilled area.

In the flat area to the east and west of the Makganyane area, the second and third layer are identical and represent the fractured-rock type aquifer hosted within the andesitic Ongeluk Lava Formation.

In the hilled area in the centre of the Makganyane boundary, the second layer also represents the thin, highly heterogeneous layer of chert and breccia in which most of the water is available. The third layer represents the underlying dolomites from the Maremane Dome, which have been found to generally yield very low groundwater volumes.

Table 4-1: Model dimensions and aquifer parameters

Grid size	Easting = 12 705 m Northing = 12 375 m
Rows and Columns	Rows = 847, Columns = 825
Cell size	15 m by 15 m
Total nr. of Cells	2 096 325
Layers	Layer 1: Confined Layer 2: Confined Layer 3: Confined
Transmissivity layer 1	1.5 m^2/day
Transmissivity layer 2	Hills: 2.2 m^2/day Flats: 8 m^2/day
Transmissivity layer 3	Hills: 0.6 m^2/day Flats: 8 m^2/day
Specific yield layer 1	0.1
Storage coefficient layer 2	0.005
Storage coefficient layer 3	0.005
Effective porosity layer 1	8%
Effective porosity layer 2	5%
Effective porosity layer 3	5%

Recharge	2% of MAP

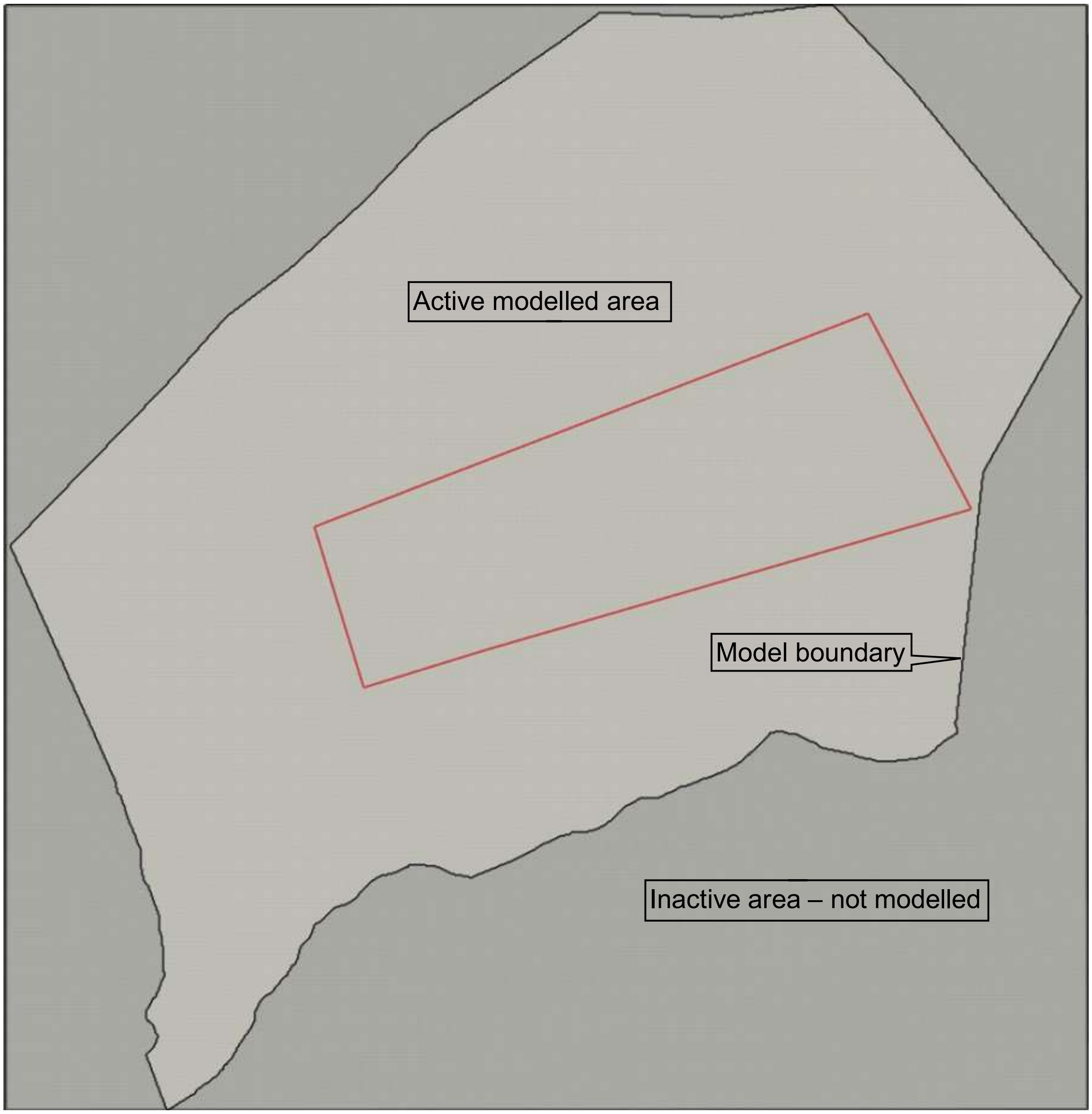

Figure 4-1: Numerical model grid.

4.3 MODEL CALIBRATION RESULTS

During the steady-state calibration of a flow model, adjustments are made to mainly the hydraulic properties (transmissivity), vertical hydraulic conductivity of the aquifer host rock and effective recharge values **(Table 4-1)** until an acceptable correlation is achieved between the measured/observed groundwater elevations and those simulated by the model. These model-simulated groundwater elevations are then specified as initial groundwater levels and form the basis for the transient state model simulations to follow.

Groundwater level information was collected during the hydrocensus/user surveys, during the pump testing (in pumping as well as observation boreholes), as well as during the drilling of the numerous exploration boreholes **(discussed in Section 3.3)**. Due to the high heterogeneity of the aquifer, groundwater levels vary significantly, despite boreholes being located close together. Therefore, filtering and averaging of the water level information were necessary and anomalous water levels were identified and excluded from the model calibration process. An acceptable correlation was achieved, considering the heterogeneous nature of the aquifer **(Figure 4-2)**.

The calibrated groundwater elevations were exported from the flow model and used to construct a contour map of the steady-state groundwater elevations **(Figure 4-3)**.

Summary:

- *Steady state simulation – the model runs until groundwater levels reach a state of equilibrium, i.e. total groundwater inflow from natural sources is equal to the total volume of groundwater outflow through natural sinks.*
- *Transient state simulation – the model runtime is predetermined according to desired scenario and groundwater levels are now affected by sinks and sources other than natural.*
- *Due to the heterogeneity of the aquifer many of the boreholes have greatly varying groundwater elevations in spite of being located close together.*
- *An acceptable correlation was achieved considering the high heterogeneity of the aquifer.*

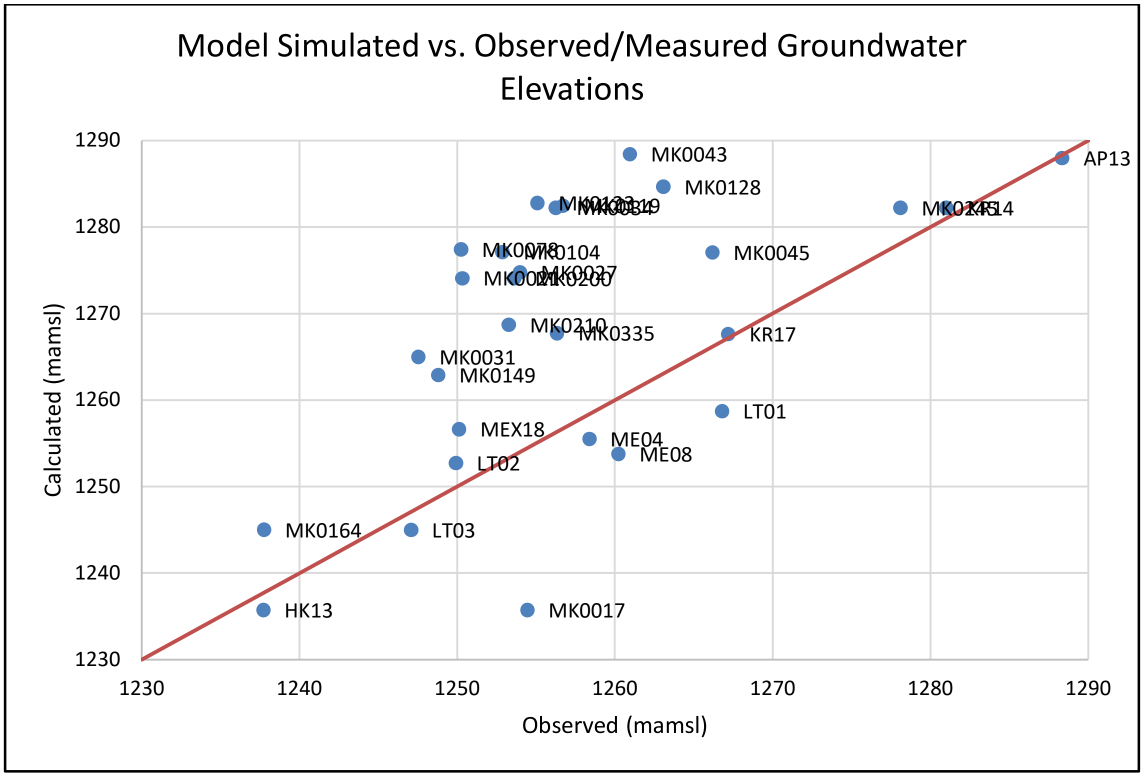

Figure 4-2: Numerical flow model calibration results.

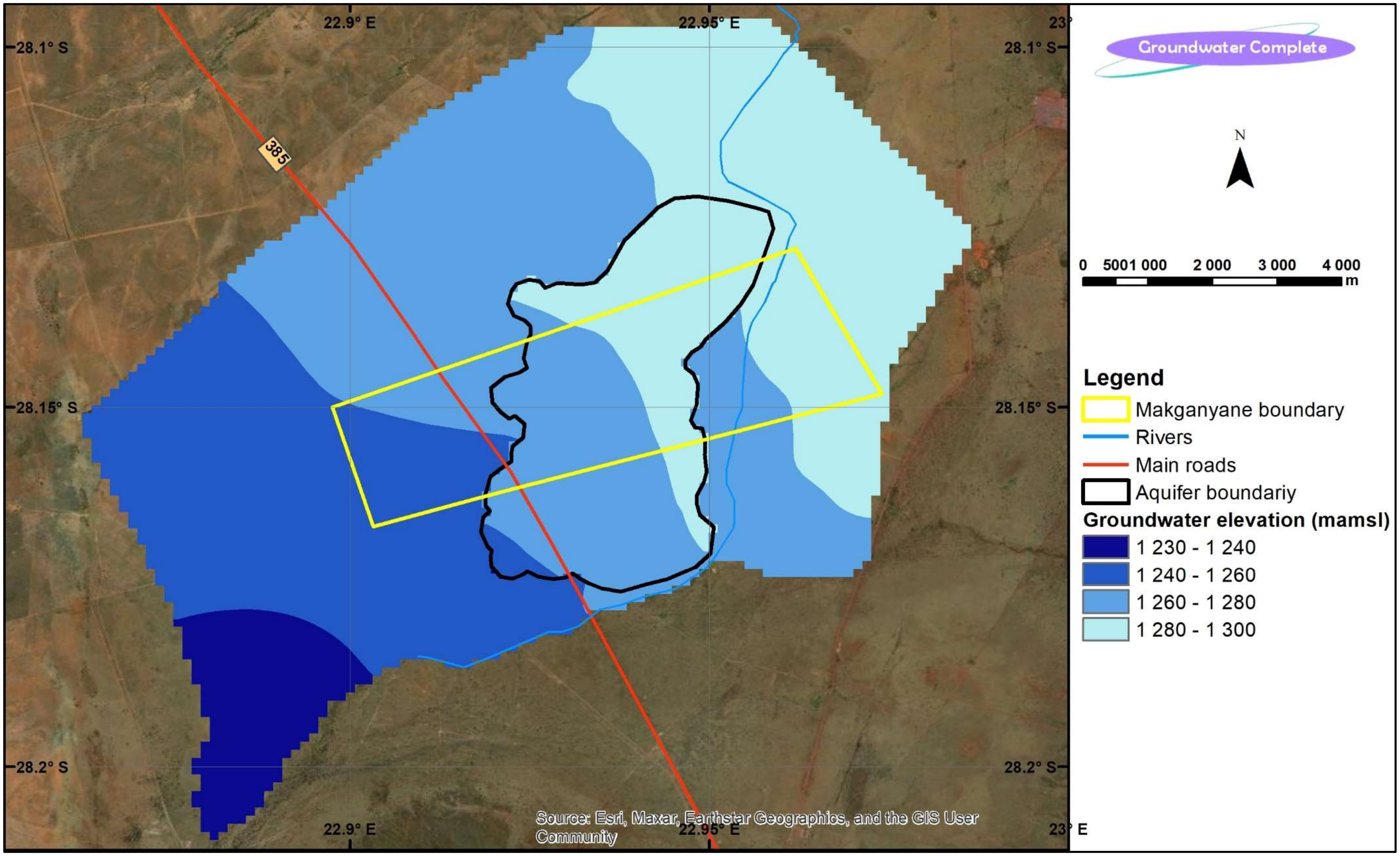

Figure 4-3: Model simulated steady state (ambient/unaffected) groundwater elevations (mamsl).

4.4 FLOW MODEL

4.4.1 ESTIMATION OF PIT DEWATERING VOLUMES

The most important function of the flow modelling for this project was the estimation of approximate dewatering volumes that would be required during the operational mining phase. By using the aquifer parameters collected from aquifer tests and refined in the model calibration, the numerical model can be used to calculate a ‘water budget’ for the opencast pits.

In order to simulate the mining process, a schedule for the progress of the pits is needed. Each time step at which the pit is mined will be simulated by the model. The planned contours of the pits are used in conjunction with the life of mine (LOM) schedule. The mine schedule and progress information was obtained from the Practara MS PowerPoint presentation from December 2022. The pit floor contours are indicated in **Figure 4-4**.

The conceptual mining area has been split into two separate pits, a North pit and South pit (each split into two different planning phases). The planned North pit ranges between 1160 mamsl and 1370 mamsl, deepening very steeply. This abrupt deepening is also the reason for the large dewatering volumes in the first stress periods of the North pit. The elevations of the South pit range from 1230 mamsl to 1350 mamsl.

It is important to note once again that the pit geometries at the time of this study are only conceptual and will be refined. The dewatering values provided in this report can also be refined further as more detailed information about the year-to-year progress of the pits becomes available.

To obtain the pit inflows, drain nodes are added to the model at the elevations of the pit floors. These drain nodes ‘drain’ all water from the model above them, removing it from the model. A water budget or zone budget function can be used to calculate the volume of water that is removed by the drain nodes.

The inflow into the opencast pits calculated according to the above-mentioned methodology has been calculated for each stress period and is displayed in **Table 4-2**.

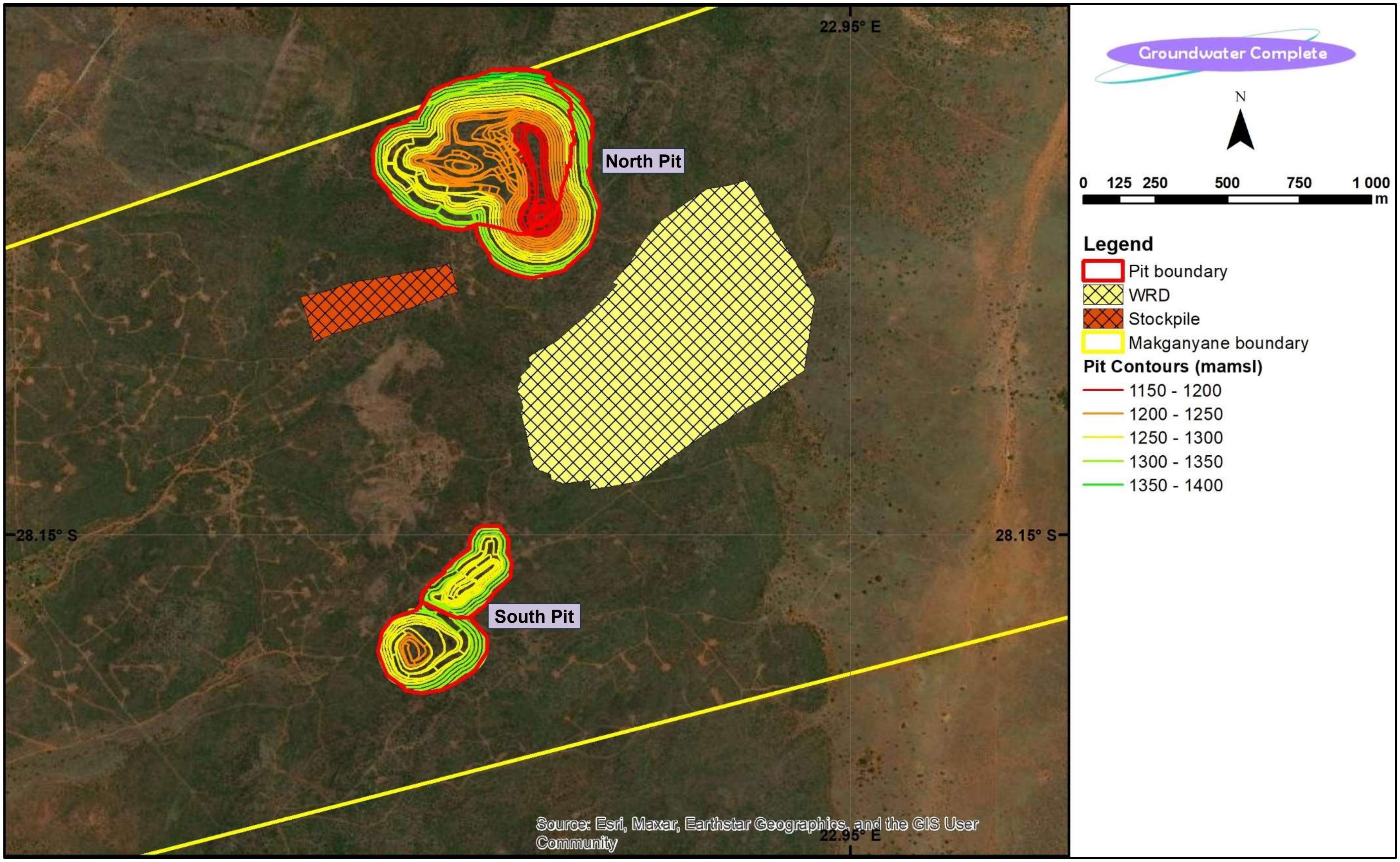

Figure 4-4: Mine contours used during dewatering calculations.

Table 4-2: Model simulated groundwater influx from year one through to mine closure.

<table>
<tr><th rowspan="2">Stress Period</th><th>Period Length</th><th>South pit</th><th>North pit</th><th>Total</th><th>Total</th><th>Approximate annual volume</th></tr>
<tr><th>Year</th><th>m^3/d</th><th>m^3/d</th><th>m^3/d</th><th>m^3/h</th><th>m^3</th></tr>
<tr><td>1</td><td>10</td><td>0</td><td>0</td><td>0</td><td>0</td><td></td></tr>
<tr><td>2</td><td>0.25</td><td>0</td><td>0</td><td>0</td><td>0</td><td rowspan="4">0</td></tr>
<tr><td>3</td><td>0.25</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>4</td><td>0.25</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>5</td><td>0.25</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>6</td><td>0.25</td><td>0</td><td>460</td><td>460</td><td>19</td><td rowspan="4">1 039 000</td></tr>
<tr><td>7</td><td>0.25</td><td>0</td><td>730</td><td>730</td><td>31</td></tr>
<tr><td>8</td><td>0.25</td><td>0</td><td>810</td><td>810</td><td>34</td></tr>
<tr><td>9</td><td>0.25</td><td>28</td><td>810</td><td>840</td><td>35</td></tr>
<tr><td>10</td><td>0.25</td><td>80</td><td>875</td><td>950</td><td>40</td><td rowspan="3">1 079 000</td></tr>
<tr><td>11</td><td>0.25</td><td>190</td><td>990</td><td>1180</td><td>49</td></tr>
<tr><td>12</td><td>0.25</td><td>160</td><td>670</td><td>820</td><td>34</td></tr>
<tr><td>13</td><td>100</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

Due to the fact that the model is a simple representation of a complex and highly varied environment, it is good to keep in mind that some of the modelled parameters may be incorrect. The water budget presented in this report is the result of the interplay between various parameters, each of which has a different effect on the resulting volume estimations. In an attempt to quantify the effect of the most important parameters (transmissivity, storativity and recharge), a sensitivity analysis was performed. This entails taking each of the aforementioned parameters, one at a time, and halving or doubling them and comparing the resulting flow volumes with the initial flow volumes.

The other unknown in the modelling environment is the geological structures encountered during the geophysics study. No notable effects were detected from the structures during aquifer tests; however, not all structures were tested and some structures may indeed have effects on the permeability and transmissivity of the aquifer. All structures intersecting the conceptual pits **(Figure 2-7)** were added to the model to analyse the resulting groundwater inflow into the pit if structures had a higher transmissivity than the surrounding host rock. A transmissivity of 5 m^2/d was ascribed to all potential structures.

The sensitivity analysis for the Makganyane model is presented in **Table 4-3**. From the resulting modelled increases and decreases in pit inflow it is clear that the only parameter that has a significant influence on the pit inflows is the transmissivity. This is a positive result, as aquifer tests were conducted from which transmissivity values were calculated, providing reliability to the transmissivity values used in the numerical model.

Table 4-3: Result of sensitivity analysis on modelled pit flow volumes.

Basic			Structures		Transmissivity/2		Transmissivity x 2		Recharge/2		Recharge x 1.5		Storativity/2		Storativity x 2	
Transmis-sivity L2	2.2	m^2/d	2.2	m^2/d	1.1	m^2/d	4.4	m^2/d	2.2	m^2/d	2.2	m^2/d	2.2	m^2/d	2.2	m^2/d
Recharge	2	%	2	%	2	%	2	%	1	%	3	%	2	%	2	%
Storativity	0.005	N/A	0.005	N/A	0.005	N/A	0.005	N/A	0.005	N/A	0.005	N/A	0.0025	N/A	0.01	N/A
Period	Volume (m^3/d)		Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease	Volume (m^3/d)	In/Decrease
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	520		550	30	335	-185	740	220	510	-10	520	0	490	-30	610	90
7	980		1020	40	730	-250	1250	270	970	-10	970	-10	830	-150	1210	230
8	980		940	-40	700	-280	1270	290	840	-140	980	0	795	-185	1110	130
9	1210		1280	70	920	-290	1730	520	1155	-55	1250	40	1000	-210	1570	360
10	1300		1300	0	920	-380	1690	390	1160	-140	1225	-75	1080	-220	1410	110
11	1330		1655	325	1100	-230	2300	970	1520	190	1580	250	1360	30	1850	520
12	740		970	230	645	-95	1400	660	900	160	950	210	910	170	1000	260

4.4.2 ESTIMATION OF THE RADIUS OF INFLUENCE

Impacts on groundwater levels are expected to occur as a result of pit dewatering. The flow model was therefore used to simulate this potential impact (i.e. groundwater depression cone). The extent of the groundwater level impacts is governed by the hydraulic properties (transmissivity) of the aquifer host rock, storativity and time. The influence of transmissivity on the radius/extent of water level impacts is explained by means of the following equation *(Bear, 1979)*:

$$R(t) = 1.5(Tt/S)^{1/2}$$

Where R = Radius (m),
T = Aquifer transmissivity (m^2/d),
t = Time (days),
S = Storativity.

From the equation it is clear that an increase in transmissivity will lead to an increase in the radius of influence (extent of depression cone). Impacts on groundwater levels are therefore expected to extend radially along fracture systems accept where there are influences from highly transmissive geological structures, which is why structural geological information plays such an important role in the construction of an accurate flow model. Furthermore, such structures may also greatly increase groundwater discharge into the mine voids (refer to the simulation and discussion **Section 4.4.1**). During the aquifer tests, none of the structures were found to have any notable effects on the groundwater.

A stress period in the model is a period where groundwater flow conditions are constant. All time dependent parameters in the model, such as drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period. The total model simulation runtime of 2 and $^3/_4$ years for active mining followed by 100 years for post-closure:

Stress period	Simulation time	Comments
1	10 Years	Simulate ambient pre-mining conditions.
2 – 12	2 and $^3/_4$ Years	Simulate active opencast mining. Mining ceases after 2 and $^3/_4$ years at the end of stress period 12.
13	100 Years	Simulate the effects of open pits after mining into which water seeps and evaporates to cause a continued slight effect on groundwater surrounding levels.

In order to better indicate the impact of the planned opencast mining and related activities on the surrounding groundwater levels, initial groundwater elevations were subtracted from the simulated groundwater elevations at the end of mining. The difference between these two data sets therefore represents the total decrease in water level (drawdown) experienced over the simulation time. This data was used to construct a contour map of the model simulated groundwater depression cone, which is indicated in **Figure 5-2**. Groundwater user boreholes are also indicated in the abovementioned figure.

4.5 MASS TRANSPORT MODEL

The calibrated flow model served as the foundation for the construction of the mass transport model. This enabled the simulation of potential contaminant migration through the groundwater system over time. Two components of the proposed mining infrastructure were identified as possible sources of contamination: the ore stockpile and the waste rock dump. Although waste classification studies indicated a low risk of contamination from these facilities, they were conservatively included as source zones in the transport model to evaluate potential long-term impacts under worst-case scenarios.

Each source was assigned a concentration boundary condition simulating the recharge containing 100% of a hypothetical contaminant load. This approach ensures that the model can still provide valuable insight into the risk of downstream groundwater quality impacts. The positions of the source areas were mapped according to the conceptual layout of the mining operation, and their dimensions were applied as input to the MT3DMS transport package linked to the MODFLOW flow simulation.

By coupling the mass transport model to the existing flow framework, contamination movement through the aquifer system could be simulated under transient conditions. The results help to delineate the extent of potential plume migration from each source and determine whether downgradient receptors such as boreholes or surface water bodies may be impacted over the life of the mine and beyond.

The results of the MT3DMS modelling are indicated in the form of concentration contours over time in **Figure 5-5 to 5-8**.

5 DISCUSSION OF GROUNDWATER IMPACTS AND RISK ASSESSMENT

5.1 IMPACTS ON GROUNDWATER LEVELS

As previously mentioned, the conceptual model formed the basis for the numerical groundwater flow model. According to the conceptual model **(Section 3.13)**, impacts on groundwater levels are expected to occur as a result of pit dewatering (groundwater depression cone). These effects will continue after mining has ceased because the pits will remain open, the voids will fill with water which will be vulnerable to evaporation throughout the year. The numerical groundwater flow model was consequently used to simulate/predict the extent of the impacts as accurately as possible. Furthermore, the flow model was also used to simulate/predict groundwater inflow volumes from start of mining through to 100 years after mine closure **(Table 4-2)**.

It was also emphasized that a secondary fractured rock aquifer (such as the one underlying the project area) is a highly complex and heterogeneous system. Coupled with model restrictions one is expected to come across either over- or under-estimations of the predicted groundwater impacts. The model results are therefore regarded as being qualitative rather than quantitative for use in planning of management and mitigation measures. The model results/predictions also need to be verified and updated regularly by means of a comprehensive groundwater monitoring program as outlined in **Section 6** of the report.

A contour map of the model simulated groundwater depression cones is provided in **Figures 5-1 to 5-4**. The colour scale provided in the abovementioned figures represents water level drawdown in meters below surface. In other words, the contours represent **the vertical depth of decline of the static piezometric water level as a result of development of the open pit voids** if assumed that the void is kept dry **through pumping out all groundwater ingress down to the deepest pit floor**.

Summary of flow model simulation (Figures 5-1 to 5-4):

- A maximum groundwater level drawdown of ±110 m was simulated for the planned Makganyane North pit.
- An area of approximately 5.9 km^2 of the water table was simulated to be affected by the opencast mining of the two pits (i.e. area simulated to experience >5 m lowering of water levels).
- The flow model assumed a rapid deepening of the pits in the first few years of mining. This will cause a high volume of inflow during the first years of mining since a significant amount of water needs to be pumped from storage in the saturated mine material.
- Due to the relatively short life of mine, the rate of inflow will not have stabilized to reach an equilibrium by the time mining ends and water levels will have started to recover.
- As the mining progresses, average influx volumes of between 20 and 40 m^3/h may be expected **(Table 4-2)**.

- The shape and extent of the depression cone are largely determined by the hydraulic properties of the surrounding aquifer/s and geological structures. Impacts on groundwater levels will be exacerbated along certain transmissive geological structures (i.e. open fractures and discontinuities).
- No hydrocensus boreholes are located within this affected area **(Figure 5-2), however,** the “KR”-boreholes to the north will still be affected in terms of groundwater quantity due to the proximity to the cone of depression, for which some form of compensation will have to be planned.
- After mining has ceased, the pits will fill with water, allowing the surrounding groundwater levels to slowly recover.
- The radius of the cone of depression may increase slightly after mining has ceased, but it will start becoming shallower immediately.
- The water level recovers to between 20 and 30 meters below the static or pre-mining level at around 25 years post closure.

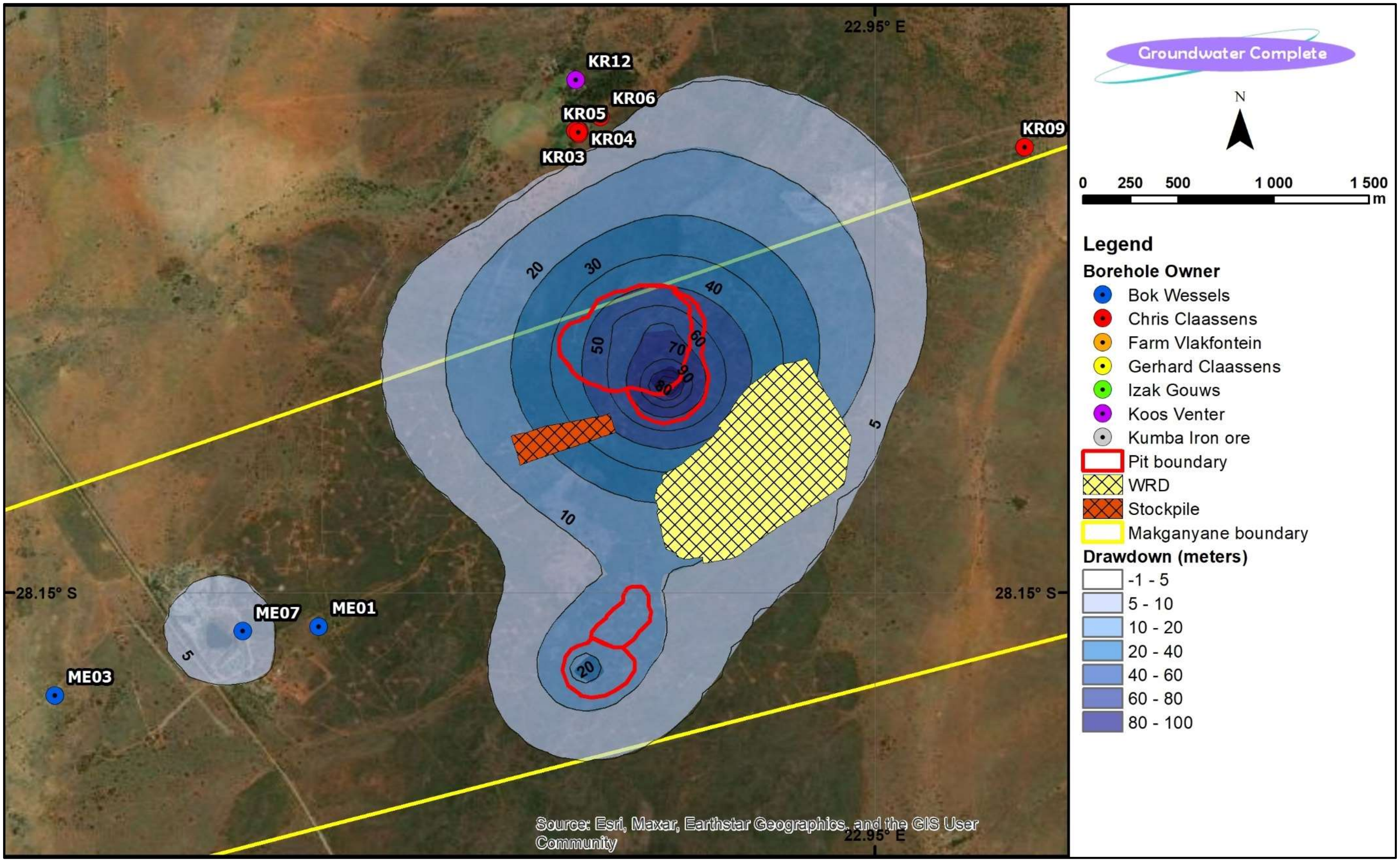

Figure 5-1: Model simulated groundwater depression cone at mine closure

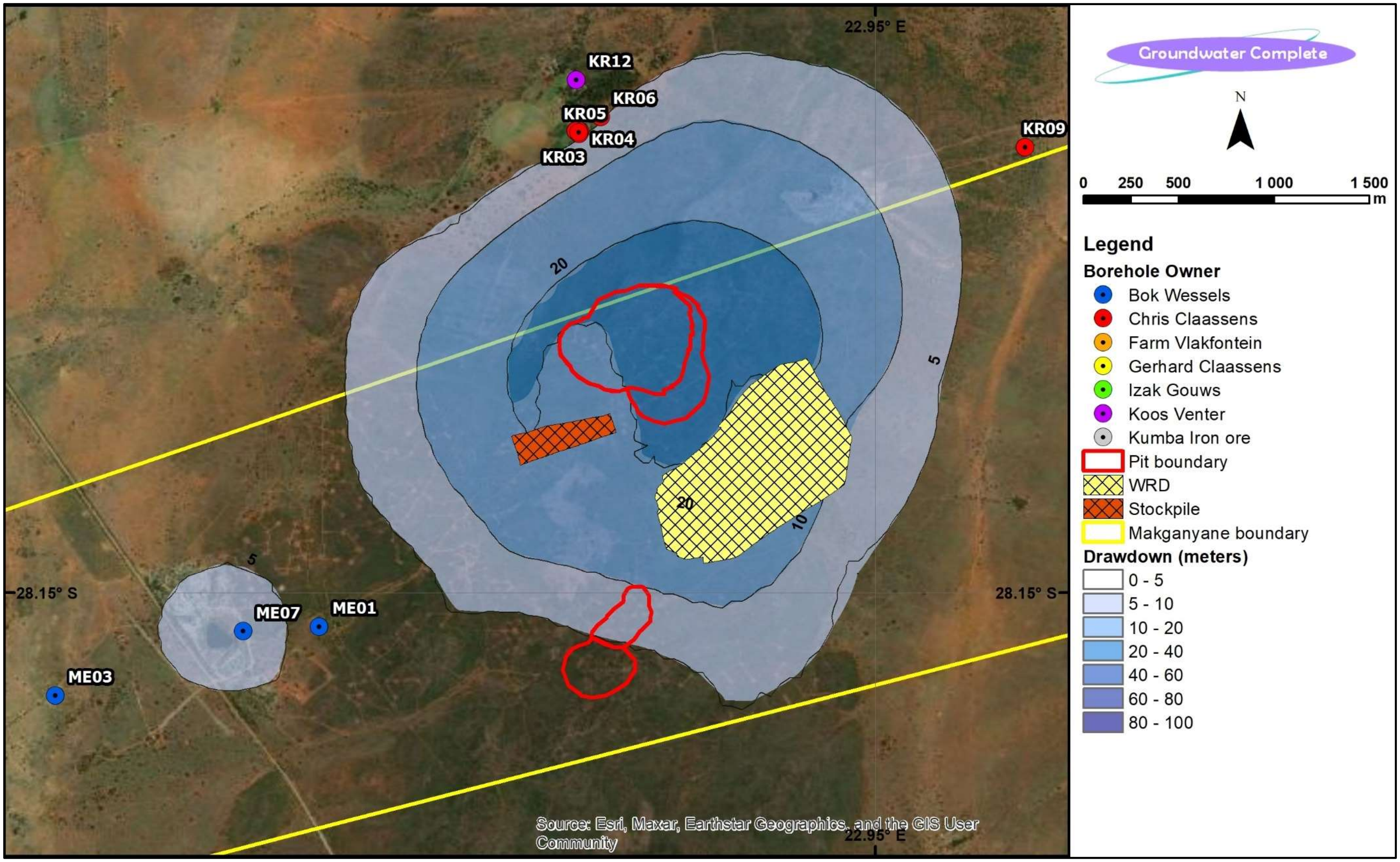

Figure 5-2: Model simulated groundwater depression cone at 25 years past closure

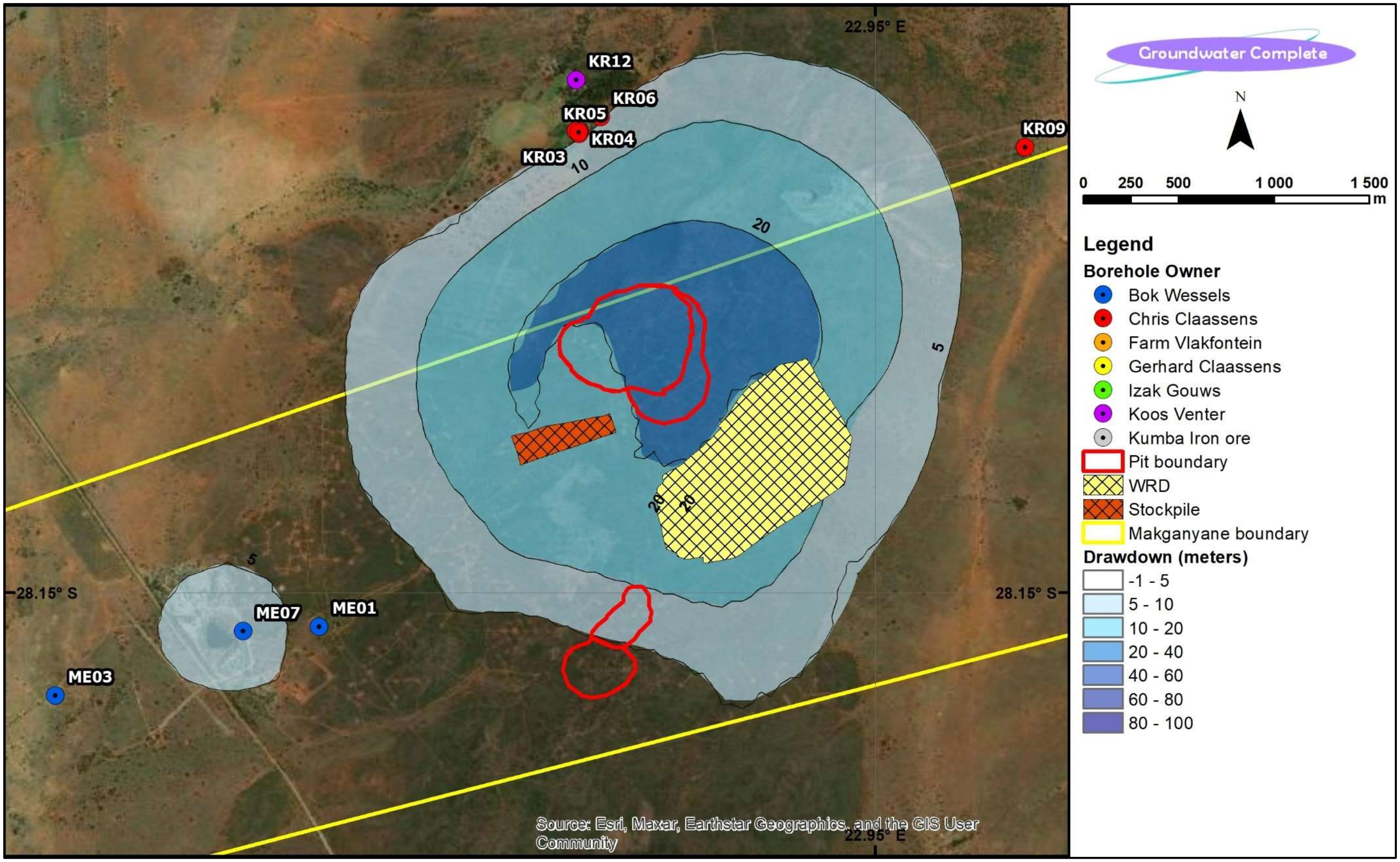

Figure 5-3: Model simulated groundwater depression cone at 50 years past closure

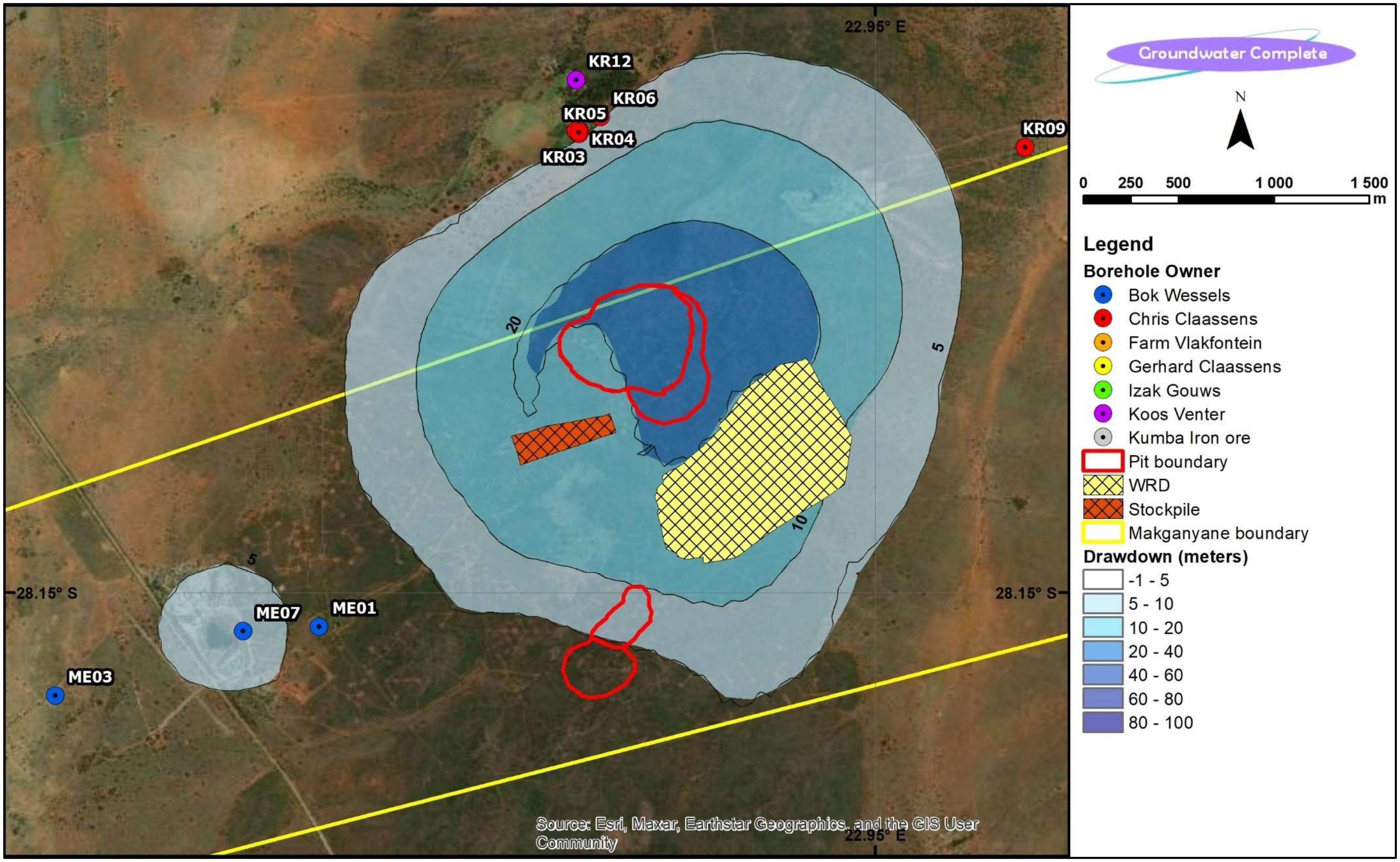

Figure 5-4: Model simulated groundwater depression cone at 100 years past closure

5.2 DEWATERING DESIGN

Understanding the approximate dewatering requirements is essential for effective planning and design of the dewatering system. The selected dewatering method has significant implications for both safety and overall project cost.

The most commonly employed dewatering technique involves blasting a sump in the deepest part of the pit to collect and remove groundwater. This method is effective as it allows large pumps to access the water and be pumped out efficiently. The disadvantage of this method, however, is that the walls of the pit are often wetted in sections due to groundwater seepage through the pit faces. From a geotechnical and rock engineering perspective, saturated rock in the pit walls mean reduced sheer strength which results in flatter slope design to enable safe and stable slopes. The cost of even a few degrees of flatter pit slope can significantly affect the economic viability of the mining project.

An alternative or complementary solution to sump dewatering is the use of strategically placed dewatering boreholes. These boreholes are pumped at controlled rates to lower groundwater levels in advance of mining. For such a system to be viable, a well-distributed network of high-yielding boreholes must be developed within transmissive fracture zones. The findings of this report and the pump test program indicate that the majority of boreholes drilled within the Makganyane mining area are effectively ‘dry’, having failed to intersect transmissive fractures below the water table.

It is also very important to keep in mind the impact of rainfall run-off. The annual rainfall runoff calculations into the pits are displayed in **Table 5-1**. The daily abstraction volume that would be required to remove the rainfall runoff is also included in the abovementioned table. The runoff was calculated using a runoff coefficient of 100% of rainfall. It is likely unrealistically high, but was presented in this way in order to provide the worst case scenario. The most important factor to note when considering the rainfall is that the rainfall is highest during the summer months of January, February and March **(Figure 2-3)**.

In the earlier study (conducted in 2023), when the conceptual designs for the opencast pits were considerably larger, a dual dewatering strategy was proposed. This included both sump pumping and the installation of scavenger boreholes to intercept groundwater before it could seep into the pit. At the time, this approach was justified by the anticipated high volumes of groundwater inflow. However, following the recent refinement and downsizing of the pit geometry, the predicted inflows have been significantly reduced. As a result, the practicality and cost-effectiveness of deploying multiple boreholes are now being reconsidered. Current model results indicate that the expected groundwater inflow volumes per quarter, as presented in **Table 5-2**, are sufficiently low to be managed entirely by strategically placed sump pumps within the pits. This makes the exclusive use of sump pumping a more viable and economical solution, eliminating the need for costly borehole development and maintenance while still ensuring effective dewatering.

Table 5-1: Dewatering calculations for direct rainfall on pit surfaces.

Parameter	North Pit	South Pit	Unit
Pit area	350 600	125 800	m^2
Rainfall	320	320	mm
Runoff at 100%	112 190	40 250	m^3
Daily pump rate to extract	307	110	m^3/d

Table 5-2: Dewatering design volumes.

Stress Period	Period Length	South Pit		North Pit	
		Daily Volume	Pump Rate	Daily Volume	Pump Rate
	Year	m^3/d	L/H	m^3/d	L/H
1	10	0	0	0	0
2	0.25	0	0	0	0
3	0.25	0	0	0	0
4	0.25	0	0	0	0
5	0.25	0	0	0	0
6	0.25	0	0	460	19174
7	0.25	0	0	734	30577
8	0.25	0	0	810	33736
9	0.25	28	1155	814	33923
10	0.25	78	3269	875	36449
11	0.25	187	7806	991	41293
12	0.25	156	6500	668	27814
13	100	0	0	0	0

5.3 IMPACTS ON GROUNDWATER QUALITY

Contamination contours were exported from the contaminant transport model for the end of mining, 20 years, 40 years and 100 years post closure **(Figures 5-5 to 5-8)**. The plumes are displayed as a percentage of the original contaminant released into the groundwater (the contaminant being released at the source at 100%).

Any potential contamination is expected to slowly migrate down from the surface towards the groundwater table, transported by rainwater during recharge. The contamination will then start to migrate from directly beneath the source in the down-gradient direction at more-or-less the movement rate specified in Section 3.10.2. The concentration of the contamination, 100% at the source, will slowly dilute as it moves away from the source.

The main movement of contaminants is downgradient, towards the north pit which forms a groundwater sink. Contamination is therefore largely contained by the depression cone formed by the north pit, while the migration rate is restricted by the poor transmissivity of the aquifer host rock. By the end of modelling, the contamination had moved between 120 m and 150 m down-gradient. Potential contamination may eventually reach the position of the pit and seep into the pit void.

Summary of the contamination transport model simulation

- Any potential contamination is expected to slowly migrate down from the surface towards the groundwater level, transported by rainwater during recharge.
- The concentration of the contamination, 100% at the source, will slowly dilute as it moves away from the source.
- By end of mining, no contamination is simulated to have reached the groundwater.
- By the end of modelling, the contamination had moved between 120m and 150m down-gradient.
- Potential contamination may eventually reach the position of the pit and seep into the pit void.

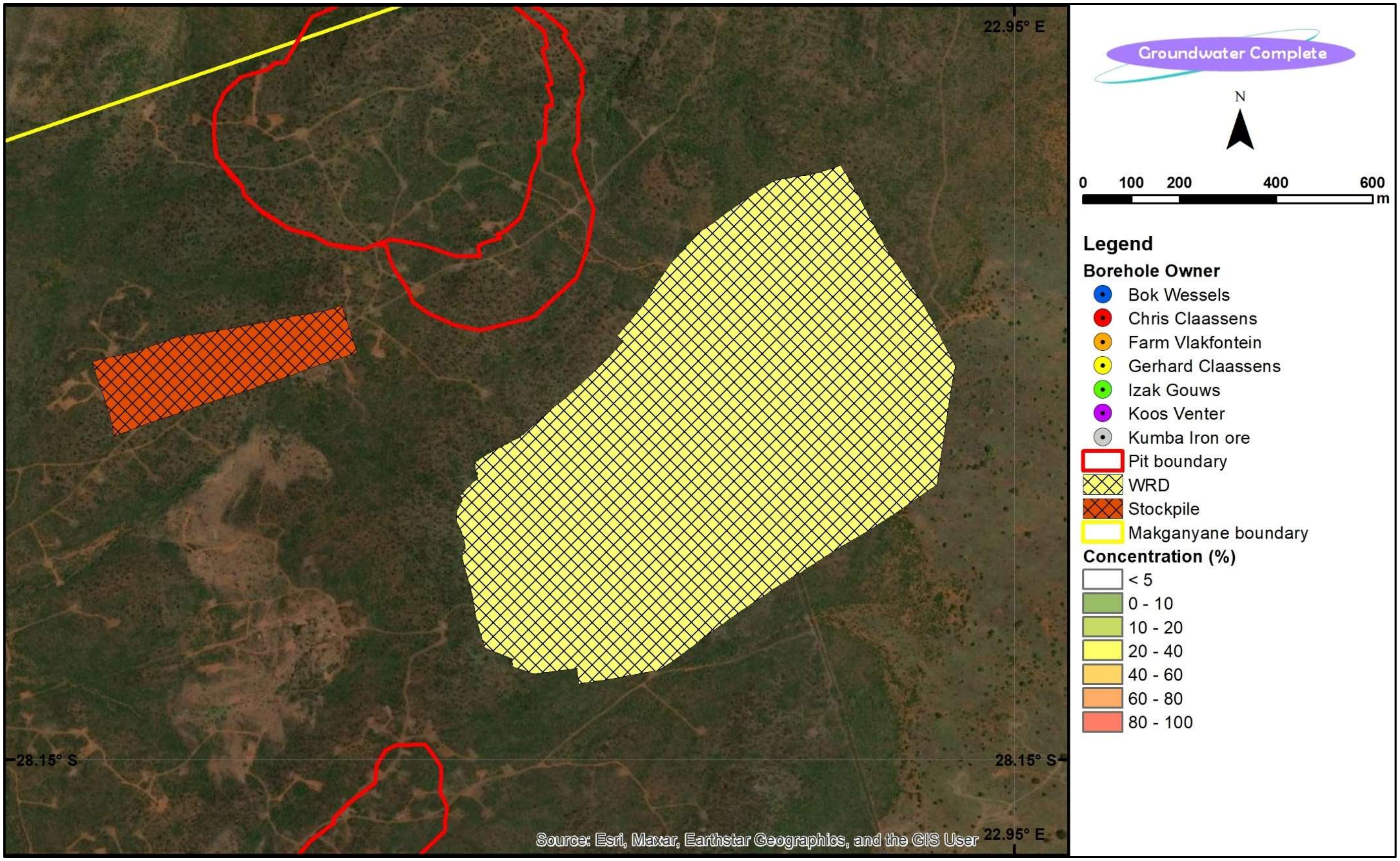

Figure 5-5: Model simulated contamination plume at mine closure

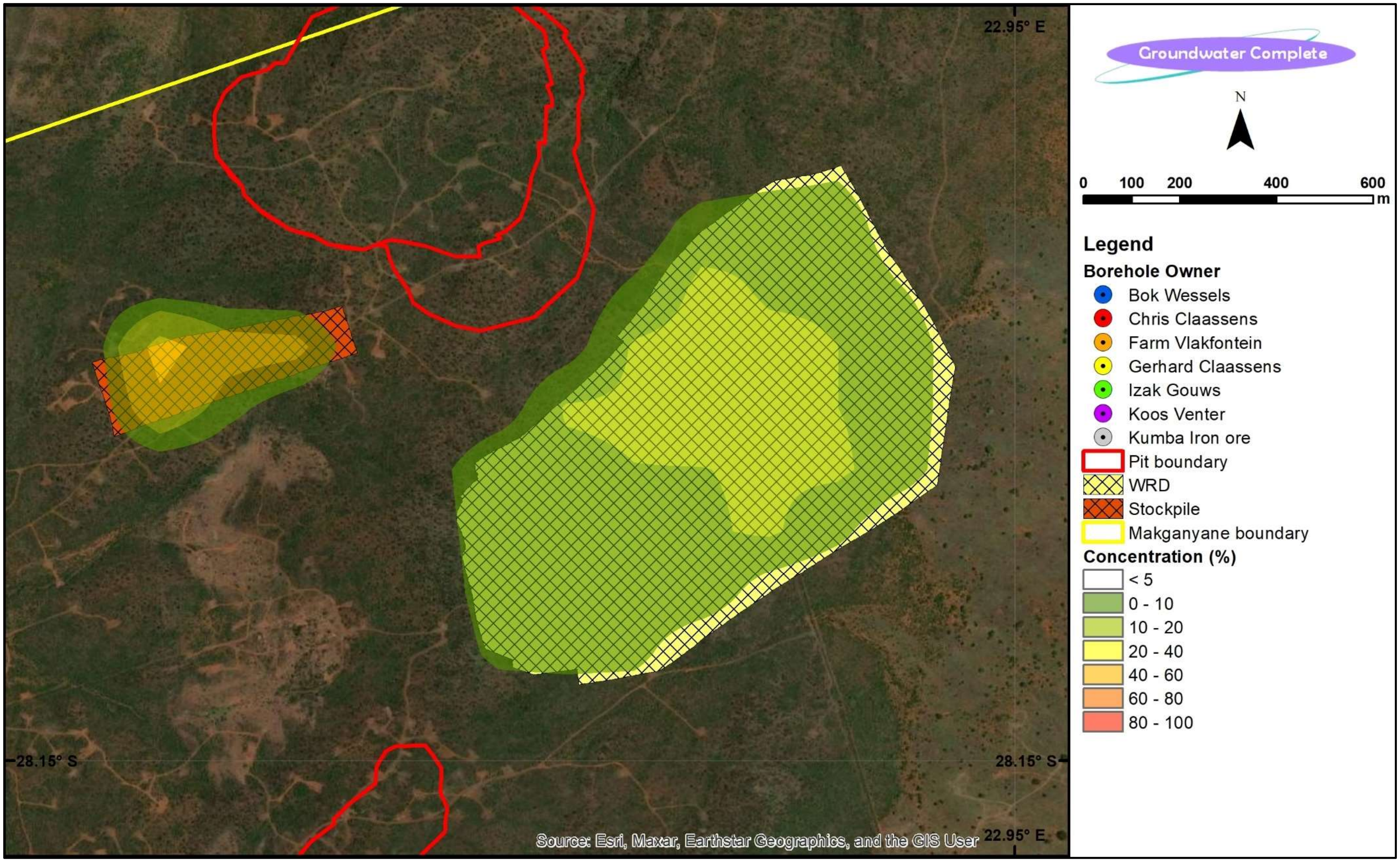

Figure 5-6: Model simulated contamination plume at 20 years past closure

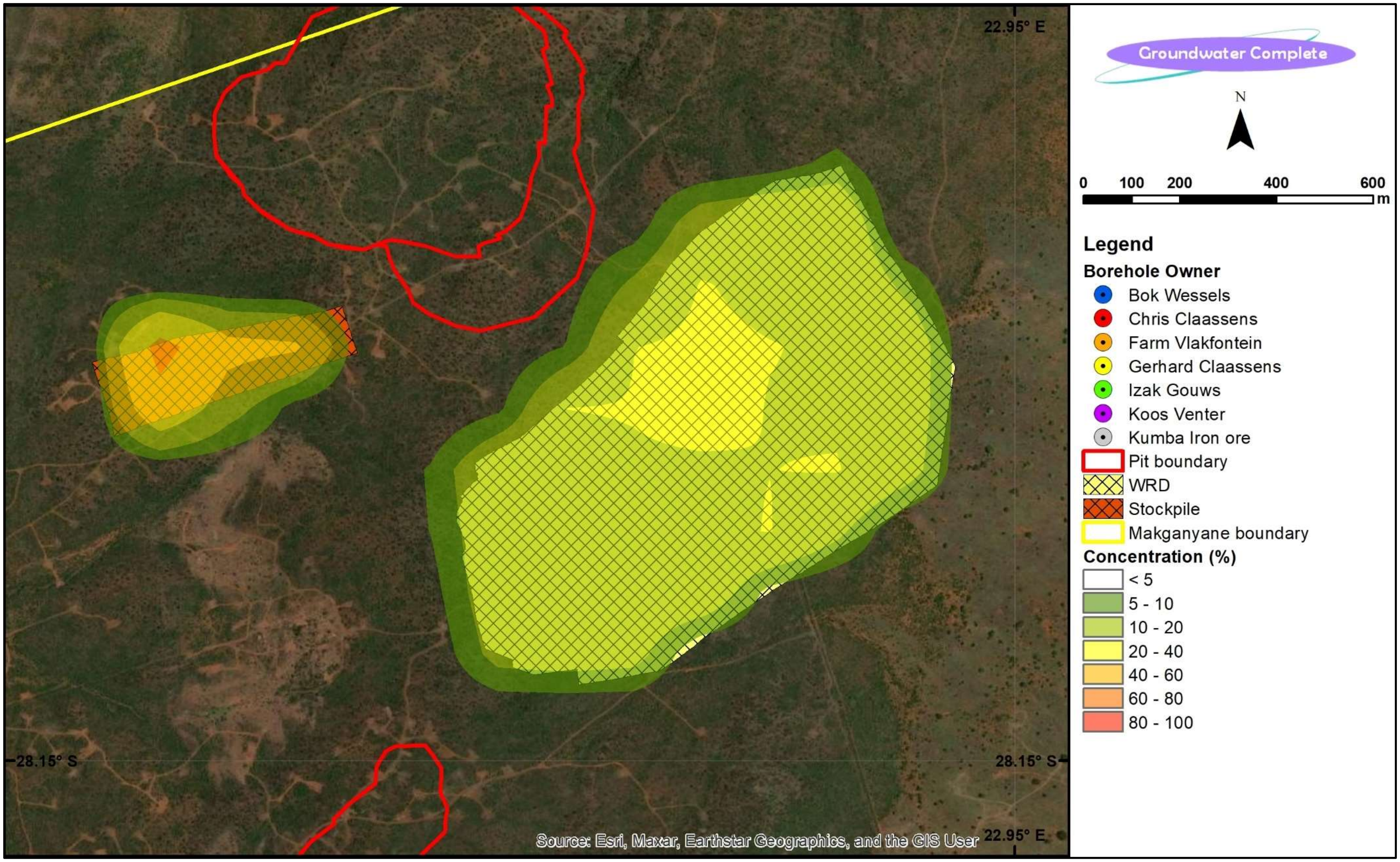

Figure 5-7: Model simulated contamination plume at 40 years past closure

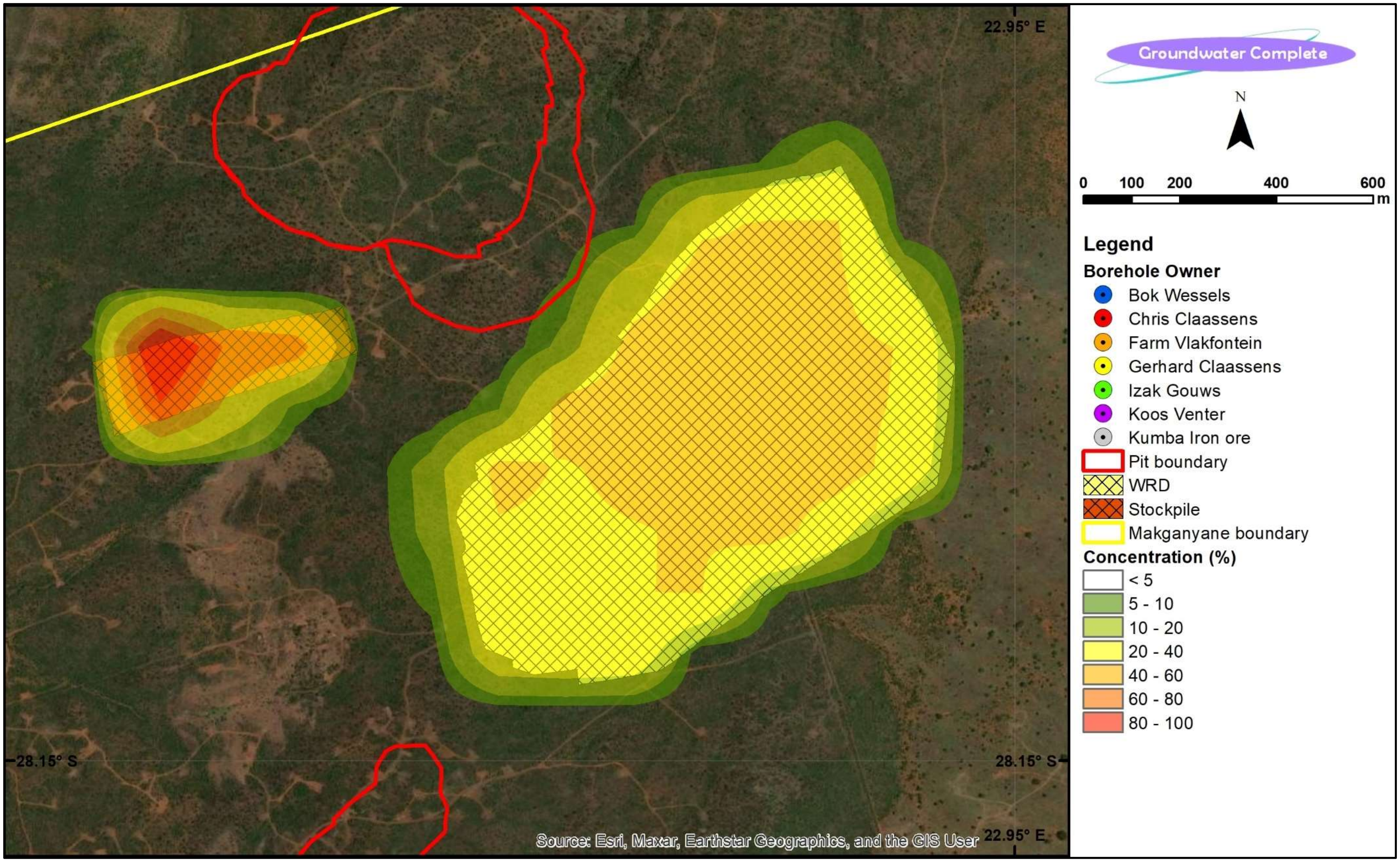

Figure 5-8: Model simulated contamination plume at 100 years past closure

5.4 GROUNDWATER RISK ASSESSMENT

Before a meaningful groundwater risk assessment can be conducted, the proposed activities applied for in the mining right must first be assessed and understood. Where activities are not intrusive (to the groundwater system) and involve no risk of generating a poor-quality leachate or seep on surface that could reach the groundwater system, it means there is an insignificant risk to assess or describe. The more intrusive the activity becomes, or the more hazardous materials are used to conduct the activity, the higher the potential risk.

Understanding of the exact activities forms the basis of identifying, rating and managing the potential groundwater risks that may be associated with the mining project. The main activities of the proposed mine that may have an effect on groundwater quality and/or quantity are listed below:

- Generation of stockpile and WRD;
- Excavation of the pits; and
- Waste water generation and management.

These risks associated with, and management actions proposed for, the mining operations are discussed and quantified according to a risk matrix described in the rest of this section. The risk assessment matrix according to which potential risk and impact related to groundwater are rated is provided in **Table 5-3**.

Table 5-3: Risk rating tables

Rating Type	Description of rating type	Rating
Intensity	**Negative Impacts**	
	Negligible / non-harmful; no change in aquifer	0
	Very low / potentially harmful; negligible deterioration in aquifer (<5% change)	+1
	Low / slightly harmful; minor deterioration in aquifer (<10% change)	+2
	Medium / moderately harmful; moderate deterioration in aquifer (>10% change)	+3
	High / severely harmful; large deterioration in aquifer	+4
	Very high / critically harmful; critical deterioration in aquifer	+5
	Positive Impacts	
	Negligible; no change in aquifer	0
	Very low / potentially beneficial; negligible improvement in aquifer (<5% change)	-1
	Low / slightly beneficial; minor improvement in aquifer (<10% change)	-2
	Medium / moderately beneficial; moderate improvement in aquifer (>10% change)	-3
	Highly beneficial; large improvement in aquifer and/or increase in protection status	-4
	Very highly beneficial; improvement to near-natural state and/or major increase in protection status	-5
extent	Footprint	1
	On site or within 100 m of the site	2
	Within a 20 km radius of the centre of the site	3
	Beyond a 20 km radius of the site	4
	Crossing provincial boundaries or on a national / land wide scale	5
Duration	Transient (One day to one month)	1
	Short-term (a few months to 5 years) OR repeated infrequently (e.g. annually) for one day to one month	2
	Medium-term (5 – 15 years)	3
	Long-term (ceases with operational life)	4
	Permanent	5

Probability	Improbable / Unlikely	20%
	Low probability	40%
	Medium probability	60%
	Highly probable	80%
	Definite / Unknown	100%

Table 5-4: Aquifer importance rating (Parson's rating was used [Section 3.5.2])

Low or Very Low Aquifer Importance rating; (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 unusable. However, groundwater flow through such rocks, although impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants	**Low / Very low** = 2
Medium Aquifer Importance rating; (minor aquifer) These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers.	**Moderate** = 3
High Aquifer Importance rating; (major aquifer) Highly permeable formation, 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 (less than 150 mS/m).	**High** = 4
Very High Aquifer Importance rating; (Sole aquifer) An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	**Very high** = 5

Table 5-5: Description of rating results

RATING	CLASS	MANAGEMENT DESCRIPTION
1 – 29	**(L) Low Risk** **OR** **(+) Positive** **(+ +) Highly positive**	Acceptable as is or with proposed mitigation measures. Impact to watercourses and resource quality small and easily mitigated, or positive.
30 – 60	**(M) Moderate Risk**	Risk and impact on watercourses are notable and require mitigation measures on a higher level, which costs more and require specialist input. Licence required.
61 – 100	**(H) High Risk**	Watercourse(s) impacts by the activity are such that they impose a long-term threat on a large scale and lowering of the Reserve. Licence required.

5.4.1 GENERATION OF STOCKPILE AND WRD

Nature of impact:		
Deposition of potential leachate forming material.		
Discussion:		
Any rock removed from the ground that is not target ore will be placed on the WRD. The ore will be placed on the stockpile to await removal to the plant at another location. These will then be exposed to the oxidising environment and leaching rainfall. The placement of porous material may cause minor changes in the effective groundwater recharge for the footprint areas of the stockpile and WRD. The effect will be slightly positive in that effective groundwater recharge may increase slightly. Normally, this will also affect the groundwater quality due to poor quality leachate. However, as the waste classification declared the materials relatively inert, the likelihood of poor-quality leachate is very low.		
Cumulative impacts:		
No active operations occur near enough that any cumulative impacts will apply in this regard.		
Mitigation:		
A sealing layer can be constructed beneath the dumps in order to seal it off from groundwater, however, due to the expected inertness of the materials, this is not deemed necessary.		
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	**+1**	**+1**
Extent	2	1
Duration	5	5
Probability	20%	20%
Severity	8	6
Consequence	32	24
Significance/Risk	6.4	4.8
Risk Class	Low risk	Low risk

5.4.2 EXCAVATION OF THE PITS

Nature of impact:		
Creation of a void for groundwater to flow into.		
Discussion:		
An Opencast pit will be excavated in order to reach the ore at depth. The void will reach below the water table, which will cause groundwater to flow into the pit. During the active phase, water will seep to the deepest part of the pit and be removed by pumps to keep the pit dry. After decommissioning, the void will fill with groundwater to a few meters below the water table. constant evaporation will cause the pit to remain a groundwater sink. The effect is considered positive and negative. Negative as it may impact the water availability in some of the user boreholes to the north. Positive in that the gradient of groundwater towards the pit will contain any potential contamination from the Stockpile or WRD.		
Cumulative impacts:		
No active operations occur near enough that any cumulative impacts will apply in this regard.		
Mitigation:		
Due to the nature of the activity and impacts, not much can be done to prevent or mitigate the impact.		
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	**+2-2**	**+1-2**
Extent	3	3
Duration	5	5
Probability	100%	80%
Severity	8	7
Consequence	32	28
Significance/Risk	32	22.4
Risk Class	Medium risk	Low risk

5.4.3 WASTE WATER GENERATION AND MANAGEMENT

Nature of impact:		
Production of waste in the form of sewage.		
Discussion:		
The site office building will require a number of ablution facilities. These facilities will make use of sealed septic system which will be serviced and extracted by professionals. The system will only pose a risk to the groundwater environment if a spill/leakage should take place.		
Cumulative impacts:		
No active operations occur near enough that any cumulative impacts will apply in this regard.		
Mitigation:		
Routine maintenance of the sewage system may decrease the risk of failure and spillage.		
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	**+1**	**+1**
Extent	1	1
Duration	2	2
Probability	40%	20%
Severity	4	4
Consequence	16	16
Significance/Risk	6.4	3.2
Risk Class	Low risk	Low risk

5.5 CUMULATIVE IMPACTS

The proposed mining operation at Makganyane is not expected to contribute to any cumulative adverse groundwater quality and/or quantity impacts because of the following main reasons:

- The hydraulic groundwater flow parameters are too low; and
- The short life-of-mine proposed for Makganyane will cause flow or mass transport impacts to reach a steady state well before they reach the surrounding mining operations such as Assmang's Beeshoek to the east, Anglo American's Kolomela to the south-east, Glosam to the north-east and Khumani and Sishen to the north.

6 GROUNDWATER MONITORING PROGRAM

Groundwater monitoring should be conducted to assess the impacts of the proposed new mining activities on groundwater quality and quantity (water levels), the latter being the most important at this stage.

Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals. It must be mentioned that this monitoring schedule should be re-assessed at a later stage in terms of stability of water levels and quality.

There are five areas that need to be monitored to focus on different aspects of monitoring. Existing exploration boreholes located in advantageous positions should be used for monitoring purposes. **Table 6-1** indicates the focus areas as well as the names of the existing boreholes that may be used for monitoring and what their focus should be.

Table 6-1: Monitoring areas

Monitoring Area	Boreholes	Monitoring Focus
North Pit	MK0102 MK0089 MK0445 KR02	Water level monitoring
South Pit	MK0254 MK0134 MK0090 MK0326 MEX1	Water level monitoring
WRD	MEX27 MK0123 MK0124 MK0046	Inorganic compounds
Stockpile	MK0416 MK0417A MK0171 MK0058/275	Inorganic compounds
Office latrine	Additional borehole necessary	Bacteriological monitoring

Together with the recommended boreholes listed above, the mine should also consider including some active user boreholes located within at least a 1 km radius (but preferably 2 km) of the planned mining activities **(Figure 3-18)**. Monitoring of abstraction rates (flow meters), water levels (at least quarterly) and groundwater quality (at least 6-monthly) in these boreholes should commence at least a year before commencement of the construction phase.

Groundwater samples should be analysed at a SANAS accredited laboratory for chemical and physical constituents normally associated with iron ore mining and related activities **(Table 6-2)**.

Table 6-2: Groundwater constituents for routine analysis

Monitoring	Variable
6-monthly	EC, pH, TDS, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, iron, manganese, aluminium and turbidity.

The main complaint from neighbouring farmers causing the most conflict with iron ore mines in the Makganyane region is of boreholes drying up as a result of mining. If the bankable feasibility study confirms the Makganyane project as feasible, it is strongly recommended that a round of aquifer testing is conducted on the boreholes of nearby farmers that are in active use. This should happen before any mining commences. Combined with the hydrocensus and water level monitoring program, this should provide sufficient information to address such claims based on facts and prevent emotional conflicts.

The following maintenance principles should be adhered to:

- Monitoring boreholes should be capped and locked at all times;
- Borehole depths should be measured quarterly and the boreholes blown out with compressed air (if required); and
- Vegetation around the boreholes should be removed on a regular basis and the borehole casings painted, when necessary, to prevent excessive rust and degradation.

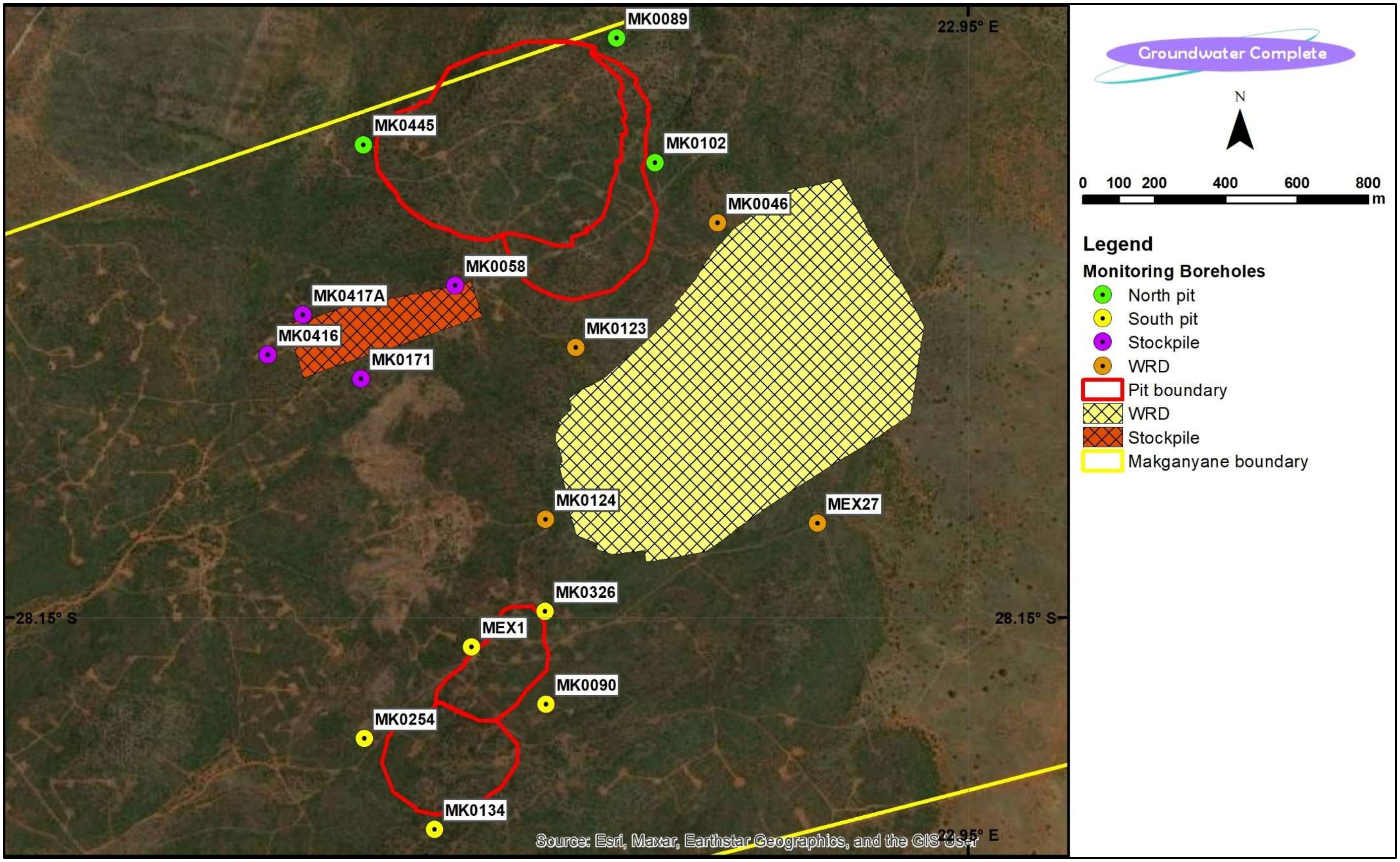

Figure 6-1: Monitoring borehole suggestion.

7 CONCLUSIONS AND RECOMMENDATIONS

The following is a summary of important information contained throughout the report:

- The lowest surface elevation of approximately 1 250 meters above mean sea level (mamsl) occurs near a tributary to the south/south-west, while the highest elevations are found in the hills in the centre of the farm at approximately 1 360 mamsl.
- The Soutloop River and its numerous tributaries that cut through the project area are strictly non-perennial and only experience flow during and directly after a significant rainfall event.
- The project area is located within the D73A quaternary catchment, which covers an area of just over 3 200 km^2.
- The mean annual precipitation for the project area is in the region of 320 mm.
- Evapotranspiration is very high and in excess of 2 200 mm/year.
- The project area has a net environmental moisture deficit for the entire year.
- Numerous faults and/or igneous intrusions (dykes) occur throughout the project area and are of significant importance to the geohydrology. Few of the structures seemed to act as either prominent barriers for horizontal groundwater flow, or as preferred flow paths for extended distances.
- Exploration boreholes drilled in the Makganyane area intersected highly brecciated areas (mainly banded iron formation, shale and quartzite) at depths of between ±30 and 300 meters below surface. From a geohydrological perspective, these areas are of significant importance as they have the potential to yield significant volumes of groundwater.
- A total of 98 boreholes were located during the hydrocensus.
- Agriculture and livestock watering are the main water uses in the area.
- The Makganyane area is underlain by two distinct and very different aquifers.
- The first of the aquifers exists in the eastern and western flatter areas of the Makganyane property. The host rock of the aquifer is the andesitic lavas of the Ongeluk Formation.
- The second aquifer present in the Makganyane area is the aquifer that exists mainly in the planned mining area. This aquifer exists mainly in a specific layer, namely the chert-breccia layer.
- Topographical highs and lows were used to approximate no-flow boundaries for the model.
- Not all groundwater levels have a linear relationship with regards to the surface topography.
- Groundwater levels in the flatter areas to the west of the hills varied between 7 and 22 meters below surface (mbs), while the water levels to the east of the hills varied between 18 and 28 mbs.
- The groundwater levels in the hilled area were markedly deeper, ranging between 30 and 100mbs.
- The lowest measured static groundwater elevation of approximately 1 237 meters above mean sea level (mamsl) occurs in the down gradient groundwater flow direction towards the south/south-west, while the highest elevation of ± 1 289 mamsl is found in the hills in the centre of the mining rights area.
- By substituting the hydraulic head difference over lateral distance, the average hydraulic gradient was calculated to be in the order of 0.0042 or 0.42% and was then used to

calculate the rate of groundwater movement (the so-called 'Darcy flux') in the project area.

- By making use of these values, the average rate of flux in the project area was calculated to be in the order of 4.8 meters per year.
- Due the highly varying nature of aquifers that are present in the Makganyane area, the groundwater flow calculated for this report only represents a regional average flow velocity and direction. Flow velocity and direction both vary significantly if tested more specifically on a smaller scale.
- The project area achieved a score of 6 and the underlying aquifer can therefore be regarded as having a medium vulnerability.
- The GQM rating for Makganyane is 8, which indicates a high level of protection.
- After consideration of all the data collected by conducting the slug tests and constant rate tests, the following summary of conclusions was drawn:
    - Two different aquifers exist in the Makganyane area.
    - The aquifer where mining activities will be concentrated is a highly heterogeneous aquifer with hydraulic parameters varying significantly over short distances.
    - The aquifer to the east and west of the hills have shallower water levels and is expected to have a higher groundwater yield, however, very few of them were pump tested.
    - The two aquifers are poorly connected to each other.
    - The matrix transmissivities of the aquifer in the hills range from 0.08 to 57 m2/d.
    - The aquifer provides little to middling volumes of water.
- An average recharge of 2% was calculated with the Chloride Method, which is in line with the 1.8 - 2.4% range of Vegter**.**
- Based on all the gathered information and experience from previous studies in similar areas, the mean annual recharge to the aquifer regime in the Makganyane was estimated to be in the order of 2% or 6.5 mm/a.
- Groundwater is considered to be of good quality and also suitable for human consumption according to the South African National Standards for drinking water (SANS 241:2015).
- Groundwater samples were collected from a total of 20 boreholes located on and around the Makganyane property.
- Groundwater samples were taken from 10 of the pump testing boreholes.
- Among the hydrocensus boreholes, samples were taken from 10 user boreholes in use for specifically domestic or livestock watering purposes and located closer to mining operations.
- Two samples were taken from the old Kimberlite shaft at different depths.
- Groundwater TDS concentrations measured in the site specific groundwater user boreholes vary between 330 mg/l and 590 mg/l and is considered a normal range for this arid region.
- The highest nitrate concentrations measured during this study are around 7 mg/l.
- Groundwater magnesium concentrations are relatively low and vary between ±27 mg/l and 64 mg/l.
- Boreholes display groundwater chloride concentrations of between approximately 8 mg/l and 68 mg/l.

- Since no mining occurs within the immediate vicinity of any of the hydrocensus boreholes, the elevated nitrate concentrations are believed to originate from areas where animals congregate in significant numbers (feedlot, kraal, etc.).
- Groundwater within the Makganyane area is dominated by calcium and magnesium cations, while bicarbonate alkalinity dominates the anion content.
- The concentrations of groundwater parameters measured in the old Kimberlite pit were largely similar to the qualities measured in the other Makganyane boreholes.
- None of the parameters' concentrations exceeded the SANS 241:2015 guidelines for drinking water purposes.
- The only differences between the concentrations measured in the Kimberlite pit versus the surrounding area are slightly higher concentrations of sodium, magnesium and potassium – likely due to higher evaporation.
- For a negative groundwater quality impact to be registered the following three components should be present:
    - A source to generate and release the contamination,
    - A pathway along which the contamination may migrate, and
    - A receptor to receive the contamination.

Summary of the numerical model

- Steady state simulation – Model runs until groundwater levels reach a state of equilibrium, i.e. total groundwater inflow from natural sources is equal to the total volume of groundwater outflow through natural sinks.
- Transient state simulation – Model runtime is predetermined according to desired scenario and groundwater levels are now affected by sinks and sources other than natural.
- Due to the heterogeneity of the aquifer many of the boreholes had greatly varying groundwater elevation in spite of being located close together.
- An acceptable correlation was achieved considering the heterogeneity of the aquifer.

Summary of flow model simulation:

- A maximum groundwater level drawdown of ±110 m was simulated for the planned Makganyane North pit.
- An area of approximately 5.9 km^2 of the water table was simulated to be affected by the opencast mining of the two pits (i.e. area simulated to experience >5 m lowering of water levels).
- The flow model assumed a rapid deepening of the pits in the first few years of mining. This will cause a high volume of inflow during the first years of mining since a significant amount of water needs to be pumped from storage in the saturated mine material.
- Due to the relatively short life of mine, the rate of inflow will not have stabilized to reach an equilibrium by the time mining ends and water levels will have started to recover.
- As the mining progresses, average influx volumes of between 20 and 40 m^3/h may be expected.
- The shape and extent of the depression cone are largely determined by the hydraulic properties of the surrounding aquifer/s and geological structures. Impacts on

groundwater levels will be exacerbated along certain transmissive geological structures (i.e. open fractures and discontinuities).

- No hydrocensus boreholes are located within this affected area, however, the "KR"-boreholes to the north will still be affected in terms of groundwater quantity due to the proximity to the cone of depression, for which some form of compensation will have to be planned.
- After mining has ceased, the pits will fill with water, allowing the surrounding groundwater levels to slowly recover.
- The radius of the cone of depression may increase slightly after mining has ceased, but it will start becoming shallower immediately.
- The water level recovers to between 20 and 30 meters below the static or pre-mining level at around 25 years post closure.

Summary of pit dewatering

- The most important function of the flow modelling is in estimating approximate dewatering volumes.
- The Inflow into the opencast pits have been calculated for each stress period and is displayed below:

Stress Period	Period Length	South Pit		North Pit	
		Daily Volume	Pump Rate	Daily Volume	Pump Rate
	Year	m³/d	L/H	m³/d	L/H
1	10	0	0	0	0
2	0.25	0	0	0	0
3	0.25	0	0	0	0
4	0.25	0	0	0	0
5	0.25	0	0	0	0
6	0.25	0	0	460	19174
7	0.25	0	0	734	30577
8	0.25	0	0	810	33736
9	0.25	28	1155	814	33923
10	0.25	78	3269	875	36449
11	0.25	187	7806	991	41293
12	0.25	156	6500	668	27814
13	100	0	0	0	0

Summary of the contamination transport model simulation

- Any potential contamination is expected to slowly migrate down from the surface towards the groundwater level, transported by rainwater during recharge.
- The concentration of the contamination, 100% at the source, will slowly dilute as it moves away from the source.
- By end of mining, no contamination is simulated to have reached the groundwater.
- By the end of modelling, the contamination had moved between 120m and 150m down-gradient.

- Potential contamination may eventually reach the position of the pit and seep into the pit void.

Summary of the risk assessment

- The main activities of the proposed mine that may have an effect on groundwater quality or quantity availability are listed below:
    - Generation of stockpile and WRD;
    - Excavation of the pits;
    - Waste water generation and management.
- Mitigation measures were recommended for each of the potential risk areas in section 5.

	Generation of stockpile and WRD		Excavation of the pits		Waste water generation and management	
	No mitigation	With mitigation	No mitigation	With mitigation	No mitigation	With mitigation
Significance/Risk	6.4	4.8	32	22.4	6.4	3.2
Risk Class	Low risk	Low risk	Medium risk	Low risk	Low risk	Low risk

Summary of the monitoring recommendations

- Groundwater monitoring should be conducted to assess the impacts of the proposed new mining activities on groundwater quality and quantity
- Groundwater monitoring (i.e. sampling and water level measurements) should be conducted at quarterly intervals.
- There are five areas that need to be monitored to focus on different aspects of monitoring. Existing exploration boreholes located in advantageous positions should be used for monitoring purposes.
- the mine should also consider including some active user boreholes located within at least a 1 km radius (but preferably 2 km) of the planned mining activities
- Groundwater samples should be analysed at a SANAS accredited laboratory for chemical and physical constituents normally associated with iron ore mining and related activities

Monitoring Area	Boreholes	Monitoring Focus
North Pit	MK0102 MK0089 MK0445 KR02	Water level monitoring
South Pit	MK0254 MK0134 MK0090 MK0326 MEX1	Water level monitoring

WRD	MEX27 MK0123 MK0124 MK0046	Inorganic compounds
Stockpile	MK0416 MK0417A MK0171 MK0058/275	Inorganic compounds
Office latrine	Additional borehole necessary	Bacteriological monitoring

Based on the groundwater characteristics of the project area and the proposed activities, the Section 21 (g) WUL application can be supported from a groundwater perspective. It will present very low risk to the groundwater environment, provided that all management and monitoring actions as provided in this report be implemented and maintained throughout the life of the project.

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9 APPENDIX A: PUMPING TEST DATA

Borehole Depth	204			MK0037				
Water level	81.6							
Pump inlet depth	151.4							
Datum above case	0.4							
Casing height	0.3							
pump inlet diam.	170							
Average Yield	0.3							
Available Drawdown	70			Obs. BH	MK0024	MK0083	MK0108	MK0081
				Distance	106	103	99.3	14
				WL	73.6	73.61	76.24	79.13
Time (min)	Drawdown (m)		Time (min)	Recovery (m)				
1	3.92		1	64.60				
2	4.90		2	56.29				
3	6.01		3	51.92				
4	6.99		4	46.78				
7	8.48		7	41.66				
10	10.93		10	34.49				
15	11.89		15	29.60				
20	13.06		20	22.41				
30	20.90		30	19.56				
40	26.86		40	17.61				
60	37.69		60	15.92				
90	43.90		90	13.22				
120	52.04		120	11.77				
150	61.39		150	9.48				
180	70.04		180	7.85				

Borehole Depth	234.6	**MK0048**				
Water level	52.4					
Pump inlet depth	151.5					
Datum above case	0.6					
Casing height	0.1					
pump inlet diam.	170					
Average Yield	4.6					
Available Drawdown	106.6	**Obs. BH**	MK51	MK375	MK20	
		Distance	699	742	449	
		WL	21.13	25.43	92.68	

Time (min)	Drawdown (m)		Time (min)	Recovery (m)			
1	11.95		1	52.51			
2	18.33		2	36.46			
3	23.88		3	24.67			
4	36.49		4	14.5			
7	48.25		7	11.21			
10	54.55		10	9.62			
15	60.55		15	8.66			
20	63.1		20	8.39			
30	64.8		30	8.11			
40	65.57		40	7.98			
60	66.24		60	7.74			
90	66.72		90	7.51			
120	66.9		120	7.31			
150	67.05		150	7.13			
180	67.3		180	6.97			
210	67.41		210	6.78			
240	67.59		240	6.67			
300	68.01		300	6.41			
360	68.28		360	6.17			
420	68.38		420	5.98			
480	68.49		480	5.75			
540	68.62		540	5.57			
600	68.89		600	5.38			
720	69.03		720	4.97	0	0	0
840	69.26		840	4.69			
960	69.64		960	4.48			
1080	70.16		1080	4.09			
1200	70.22		1200	3.94			
1320	70.37		1320				
1440	70.54		1440		0	0	0

Borehole Depth	120.5			**MK0078**			
Water level	65.19						
Pump inlet depth	115.45						
Datum above case	0.64						
Casing height	0.14						
pump inlet diam.	170				99	99	99
Average Yield	3.8			**Obs. BH**	MK50	MK161	MK115
Available Drawdown	50.45			**Distance**	189	174	261
				WL	74.38	60.8	56.44
Time (min)	Drawdown (m)		Time (min)	Recovery (m)			
1	4.84		1	7.88			
2	5.67		2	3.91			
3	6.49		3	1.74			
4	7.57		4	1.26			
7	7.94		7	1.11			
10	8.39		10	0.92			
15	9.65		15	0.85			
20	9.89		20	0.79			
30	9.94		30	0.73			
40	9.99		40	0.67			
60	10.04		60	0.56			
90	10.27		90	0.47			
120	10.47		120	0.39			
150	10.62		150	0.34			
180	10.73		180	0.29			
210	10.83		210	0.25			
240	10.95		240	0.21			
300	11.23		300	0.16			
360	11.27		360	0.15			
420	11.31		420	0.14			
480	11.34		480	0.12			
540	11.41		540	0.11			
600	11.44		600	0.1			
720	11.55		720	0.06			
840	11.69		840	0.03			
960	11.8		960	0			
1080	11.92		1080				
1200	12.01		1200				
1320	12.1		1320				
1440	12.2		1440		0	0	0
1560	12.28		1560				
1680	12.37		1680				
1800	12.39		1800				
1920	12.42		1920				
2040	12.37		2040				
2160	12.38		2160		0	0	0
2280	12.38		2280				
2400	12.43		2400				
2520	12.4		2520				
2640	12.45		2640				

2760	12.47		2760				
2880	12.5		2880		0	0	0

Borehole Depth	238.9	**MK0167**	
Water level	60.4		
Pump inlet depth	151.4		
Datum above case	0.0		
Casing height	0.2		
pump inlet diam.	170.0		
Average Yield	0.5		Obs. BH
Available Drawdown	91.0		Distance
			WL

Time (min)	Drawdown (m)		Time (min)	Recovery (m)	
1	7.00		1	60.02	
2	9.29		2	52.25	
3	10.23		3	52.18	
4	11.19		4	53.9	
7	12.92		7	53.69	
10	14.34		10	53.47	
15	18.90		15	53.2	
20	23.31		20	52.69	
30	40.90		30	52.27	
40	52.45		40	51.8	
60	67.11		60	51.04	
90	79.80		90	50.27	
120			120	49.81	
150			150	49.39	
180			180	48	
210			210	48.58	
240			240	48.06	
300			300	47.63	

Borehole Depth	178	**MK0190**
Water level	59	
Pump inlet depth	154	
Datum above case	0.53	
Casing height	0.13	
pump inlet diam.	170	
Average Yield	0.5	Obs. BH
Available Drawdown	95	Distance
		WL

Time (min)	Drawdown (m)		Time (min)	Recovery (m)	
1	2.95		1	84.7	
2	6.23		2	80.54	
3	9.08		3	75.52	
4	12.36		4	69.75	
7	15.12		7	63.51	
10	17.33		10	59.56	
15	26.80		15	56.75	
20	33.02		20	55.3	
30	48.40		30	52.81	
40	53.81		40	50.3	
60	61.76		60	47.9	
90	72.78		90	45.73	
120			120	43.43	
150			150	41.6	

Borehole Depth	113.4	**MK0200**
Water level	60.3	
Pump inlet depth	103.4	
Datum above case	0.5	
Casing height	0.2	
pump inlet diam.	170	
Average Yield	0.3	Obs. BH
Available Drawdown	43.1	Distance
		WL

Time (min)	Drawdown (m)		Time (min)	Recovery (m)	
1	0.79		1	39.48	
2	2.87		2	31.84	
3	4.96		3	24.85	
4	7.84		4	17.8	
7	13.62		7	14.69	
10	14.12		10	12.93	
15	14.54		15	12.06	
20	17.27		20	11.37	
30	22.69		30	10.03	
40	28.7		40	8.82	
60	35.28		60	7.9	
90	43.1		90	7.04	
120	43.1		120		
150	43.1		150		
180	43.1		180		

Borehole Depth	173.4	**MK0212**						
Water level	57.58							
Pump inlet depth	151.45							
Datum above case	0.63							
Casing height	0							
pump inlet diam.	170							
Average Yield	7.8	Obs. BH	MK0213	MK0025	MK0026	MK0294	MK0210
Available Drawdown	95.33	Distance	94	111	233	310	194
		WL	68.02	51.75	63.02	40.64	43.64

Time (min)	Drawdown (m)		Time (min)	Recovery (m)					
1	6.87		1	39.02					
2	13.57		2	21.20					
3	28.87		3	14.55					
4	29.19		4	13.98					
7	30.74		7	13.82					
10	31.85		10	13.51					
15	43.02		15	13.24					
20	46.76		20	12.83					
30	48.95		30	12.45					
40	49.77		40	12.01					
60	50.52		60	11.34					
90	51.00		90	10.68					
120	62.33		120	10.12					
150	63.37		150	9.71					
180	63.70		180	9.37					
210	64.01		210	9.06					
240	64.25		240	8.80					
300	64.77		300	8.25					
360	65.25		360	7.81					
420	65.88		420	7.43					
480	66.99		480	7.08					
540	67.50		540	6.85					
600	68.46		600	6.54					
720	70.11		720	6.15	0.11	1.21	0	0	0
840	71.19		840	5.95					
960	72.01		960	5.25					
1080	69.02		1080	4.84					
1200	69.21		1200	4.54					
1320	70.44		1320	4.29					
1440	71.98		1440	4.12		3.47	0	0	0
1560	72.46		1560						
1680	72.90		1680						
1800	73.36		1800						
1920	73.79		1920						
2040	73.91		2040						
2160	74.02		2160		0.13	5.76	0	0	0
2280	74.15		2280						

2400	74.25		2400						
2520	74.44		2520						
2640	72.31		2640						
2760	73.00		2760						
2880	73.42		2880		0.12	8.12	0	0	0

Borehole Depth	77.84	**MK0221**				
Water level	13.75					
Pump inlet depth	73.4					
Datum above case	0.68					
Casing height	0.1					
pump inlet diam.	170					
Average Yield	1.15	Obs. BH	MK0385	MK0395	MK0355	MK0331
Available Drawdown	59.65	Distance	303	219	253	235
		WL	9.96	15.2	17.35	20.5

Time (min)	Drawdown (m)		Time (min)	Recovery (m)				
1	0.55		1	18.47				
2	0.85		2	17.69				
3	1.14		3	17.04				
4	1.57		4	15.59				
7	2.05		7	15.45				
10	2.75		10	13.30				
15	3.04		15	11.19				
20	3.35		20	9.27				
30	3.64		30	6.07				
40	3.81		40	5.74				
60	4.02		60	5.41				
90	4.25		90	4.30				
120	4.48		120	3.27				
150	4.61		150	2.84				
180	4.77		180	2.15				
210	4.85		210	1.94				
240	4.90		240	1.86				
300	5.17		300	1.67				
360	5.26		360	1.37				
420	5.31		420	1.26				
480	5.49		480	1.15				
540	5.72		540	1.09				
600	5.93		600	1.07				
720	5.99		720	0.98	0.45	0	0	0
840	6.10		840	0.87				
960	6.17		960	0.81				
1080	6.36		1080	0.73				
1200	6.49		1200	0.68				
1320	6.58		1320	0.64				
1440	6.66		1440		0.68	0	0	0
1560	10.81		1560					
1680	13.69		1680					

1800	14.59		1800					
1920	15.67		1920					
2040	16.87		2040					
2160	17.43		2160		0.82	0	0	0
2280	18.10		2280					
2400	18.46		2400					
2520	18.56		2520					
2640	18.67		2640					
2760	18.75		2760					
2880	18.97		2880		0.94	0	0	0

Borehole Depth	195	**MK252**					
Water level	23.8						
Pump inlet depth	151.5						
Datum above case	0.7						
Casing height	0.0						
pump inlet diam.	170						
Average Yield	7.5	Obs. BH	MK060	MK0253	MK0251	MK0245	
Available Drawdown	127.6	Distance	459	225	226	510	
		WL	16.73	19.9	24.99	28.46	

Time (min)	Drawdown (m)		Time (min)	Recovery (m)				
1	1.68		1	18.74				
2	4.3		2	12.86				
3	7.19		3	12.81				
4	9.05		4	12.74				
7	11.2		7	12.7				
10	12.2		10	12.68				
15	12.6		15	12.65				
20	12.74		20	12.61				
30	12.92		30	12.56				
40	13.23		40	12.51				
60	13.42		60	12.43				
90	13.5		90	12.33				
120	13.72		120	12.24				
150	13.95		150	12.16				
180	14.15		180	12.08				
210	14.31		210	12.01				
240	14.42		240	11.95				
300	14.54		300	11.82				
360	14.87		360	11.71				
420	15.17		420	11.63				
480	15.33		480	11.53				
540	15.48		540	11.4				
600	15.75		600	11.38				
720	16.16		720	11.23	0	4.74	0	0
840	16.55		840	11.08				
960	16.9		960	10.92				
1080	17.31		1080	10.79				

1200	19.54		1200	10.67				
1320	20.32		1320	10.56				
1440	21.27		1440	10.46	0	8.12	0	0
1560	22.45		1560					
1680	23.28		1680					
1800	23.88		1800					
1920	24.56		1920					
2040	25.18		2040					
2160	26.05		2160		0	8.25	0	0
2280	27		2280					
2400	27.79		2400					
2520	28.27		2520					
2640	29.11		2640					
2760	29.99		2760					
2880	30.66		2880		0	8.39	0	0

Borehole Depth	161.3	**MK0258**						
Water level	70.9							
Pump inlet depth	151.4							
Datum above case	0.7							
Casing height	0.0							
pump inlet diam.	170							
Average Yield	18	Obs. BH	MK263	MK2	MK257	MK260	MK105	
Available Drawdown	80.6	Distance	42	46	55	54.5	60	
		WL	0.19	70.6	72.92	74.65	73.95	

Time (min)	Drawdown (m)		Time (min)	Recovery (m)					
1	0.46		1	10.46					
2	0.68		2	7.82					
3	0.92		3	5.37					
4	1.47		4	4.34					
7	2.82		7	4.3					
10	3.94		10	4.2					
15	4.78		15	4.07					
20	5.97		20	3.95					
30	6.88		30	3.83					
40	7.5		40	3.6					
60	8.89		60	3.35					
90	9.58		90	3.03					
120	9.93		120	2.68					
150	10.22		150	2.43					
180	10.44		180	2.22					
210	10.63		210	2.02					
240	10.79		240	1.85					
300	11.04		300	1.56					
360	11.29		360	1.34					
420	11.47		420	1.13					

480	11.64		480	1.02					
540	11.8		540	0.91					
600	11.93		600	0.81					
720	12.14		720	0.69	0.03	4.89	5.28	4.32	4.4
840	12.34		840	0.59					
960	12.48		960	0.48					
1080	12.6		1080	0.46					
1200	12.7		1200	0.44					
1320	12.81		1320	0.42					
1440	12.9		1440	0.4	0.05	0.05	5.89	5.79	6.1
1560	12.99		1560						
1680	13.05		1680						
1800	13.11		1800						
1920	13.12		1920						
2040	13.22		2040						
2160	13.26		2160		0.05	5.45	6.11	6.06	6.34
2280	13.31		2280						
2400	13.37		2400						
2520	13.42		2520						
2640	13.46		2640						
2760	13.51		2760						
2880	13.57		2880		0.06	6.48	6.13	6.08	6.37

Borehole Depth	137.2	**MK0306**
Water level	49.9	
Pump inlet depth	121.4	
Datum above case	0.6	
Casing height	0.03	
pump inlet diam.	170	
Average Yield	0.3	Obs. BH
Available Drawdown	71.5	Distance
		WL

Time (min)	Drawdown (m)		Time (min)	Recovery (m)	
1	6.64		1	44.37	
2	6.92		2	42.54	
3	7.1		3	42.31	
4	7.22		4	42.13	
7	7.39		7	41.32	
10	8.54		10	40.19	
15	10.34		15	37.80	
20	15.08		20	35.61	
30	24.35		30	32.10	
40	30.31		40	27.53	
60	39.36		60	23.56	
90	44.64		90	20.46	
120			120	16.14	
150			150	13.25	
180			180	10.20	
210			210	7.81	
240			240	5.47	
300			300	4.03	

Borehole Depth	274.8	**MK0311**				
Water level	27.7					
Pump inlet depth	151.5					
Datum above case	0.7					
Casing height	0.2					
pump inlet diam.	170					
Average Yield	7.8		Obs. BH	MK404	MK356	MK378
Available Drawdown	123.8		Distance	88.9	88.9	120
			WL	30.86	22.54	22.9

Time (min)	Drawdown (m)		Time (min)	Recovery (m)			
1	4.41		1	51			
2	7.92		2	45.86			
3	10.59		3	40.47			
4	15.77		4	32.71			
7	23.65		7	26.86			
10	31.36		10	21.34			
15	38.28		15	18.02			
20	40.06		20	16.22			
30	42.1		30	13.66			
40	43.04		40	12.36			
60	44.92		60	10.5			
90	46.35		90	8.58			
120	47.92		120	7.18			
150	49.42		150	6.2			
180	50.62		180	5.38			
210	51.51		210	4.72			
240	52.21		240	4.16			
300	53.16		300	3.36			
360	56.67		360	2.67			
420	58.2		420	2.2			
480	59.12		480	1.84			
540	60.3		540	1.57			
600	64.07		600	1.35			
720	68.12		720	1.05	4.48	1.64	6.42
840	70.9		840	0.81			
960	73.05		960	0.64			
1080	75.29		1080	0.52			
1200	76.97		1200	0.43			
1320	77.34		1320	0.37			
1440	78.49		1440	0.33	5.14	2.34	7.74
1560	79.86		1560				
1680	80.67		1680				
1800	81.72		1800				
1920	82.84		1920				
2040	83.29		2040				
2160	83.96		2160		5.19	2.39	7.8
2280	84.4		2280				
2400	84.87		2400				
2520	85.32		2520				
2640	85.79		2640				

2760	86.01		2760				
2880	87.29		2880		5.24	2.44	7.87

Borehole Depth 246.3
Water level 18.2
Pump inlet depth 151.5
Datum above case 0.4
Casing height 0.3
pump inlet diam. 170
Average Yield 1.8
Available Drawdown 133.2

MK0358

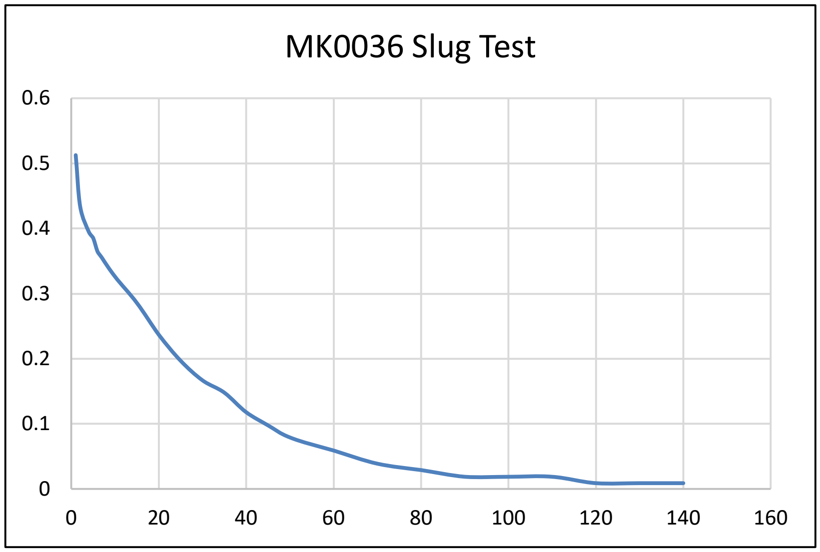
Obs. BH	MK377	MK312	MK355	MK357
Distance	110	114	154	130
WL	15.18	20.9	17.48	20.13

Time (min)	Drawdown (m)		Time (min)	Recovery (m)				
1	2.21		1	58.74				
2	3.52		2	42.51				
3	4.9		3	31.3				
5	9.51		5	24.62				
7	16.58		7	20.43				
10	20		10	14.02				
15	26.18		15	9.05				
20	29.15		20	6.53				
30	31.06		30	3.82				
40	39.49		40	2.65				
60	41.73		60	2.07				
90	44.16		90	1.62				
120	47.92		120	1.35				
150	50.96		150	1.19				
180	52.01		180	1.07				
210	53.64		210	0.97				
240	54.29		240	0.88				
300	55.89		300	0.76				
360	56.62		360	0.67				
420	57.45		420	0.6				
480	58.38		480	0.55				
540	59.17		540	0.5				
600	60.09		600	0.45				
720	62.03		720	0.4	0.09	0.12	1.28	0.1
840	63.15		840	0.35				
960	64.72		960	0.35				
1080	65.08		1080					
1200	66		1200					
1320	66.89		1320					
1440	67.5		1440		0.14	0.19	1.49	0.16
1560	68.24		1560					
1680	69.08		1680					
1800	69.94		1800					
1920	70.8		1920					
2040	71.78		2040					
2160	72.67		2160		0.25	0.33	1.68	0.2

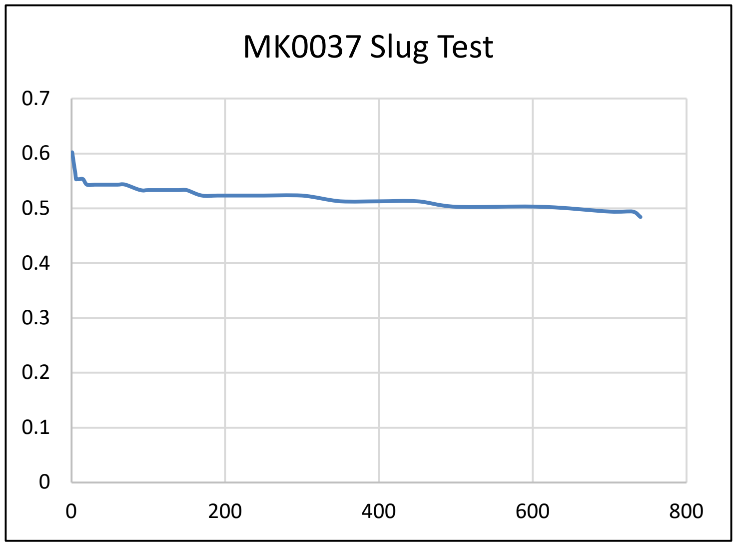
2280	73.49		2280					
2400	74.91		2400					
2520	75.62		2520					
2640	76.84		2640					
2760	78.81		2760					
2880	79.97		2880		0.33	0.5	2.83	0.27

10 APPENDIX B: SLUG TEST DATA

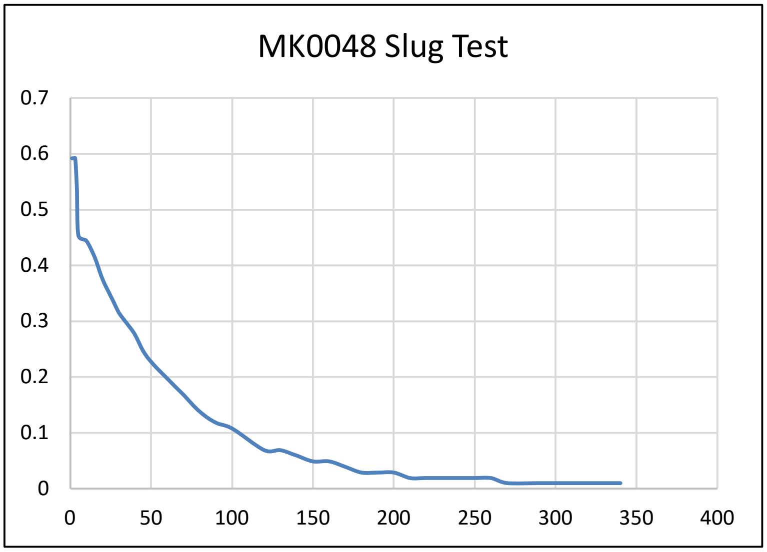
Time (min)	Drawdown (m)
0	0.513
1	0.434
2	0.395
4	0.385
5	0.365
6	0.355
7	0.326
10	0.286
15	0.237
20	0.197
25	0.167
30	0.148
35	0.118
40	0.098
45	0.079
50	0.059
60	0.039
70	0.029
80	0.019
90	0.019
100	0.019
110	0.009
120	0.009
130	0.009
140	0.009



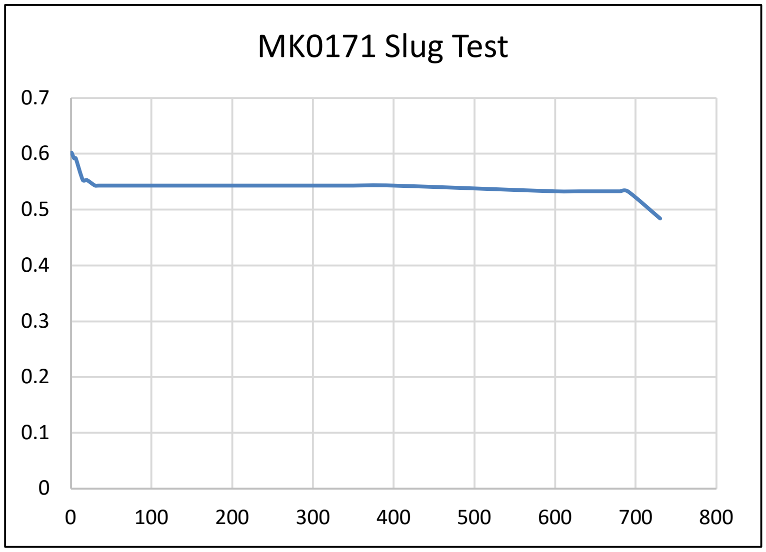
Time (min)	Drawdown (m)
0	0.602
1	0.563
5	0.553
6	0.553
7	0.553
8	0.553
9	0.553
10	0.553
15	0.543
20	0.543
30	0.543
40	0.543
50	0.543
60	0.543
70	0.533
90	0.533
100	0.533
120	0.533
130	0.533
140	0.533
150	0.523
170	0.523
190	0.523
220	0.523
230	0.523
240	0.523
250	0.523
300	0.513
350	0.513
400	0.513
450	0.503
500	0.503
610	0.494
700	0.494
730	0.484



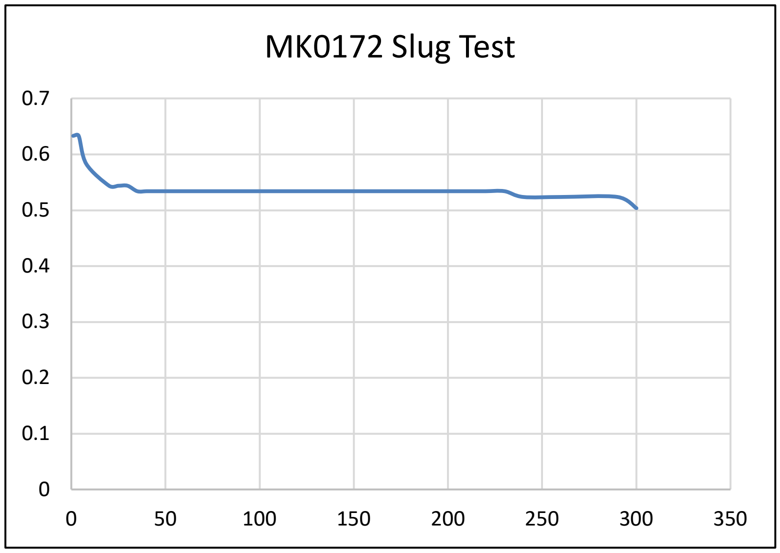
Time (min)	Drawdown (m)
0	0.592
1	0.592
2	0.592
3	0.543
4	0.454
5	0.444
10	0.415
15	0.375
20	0.345
25	0.316
30	0.296
35	0.276
40	0.247
45	0.227
50	0.197
60	0.168
70	0.138
80	0.118
90	0.108
100	0.069
120	0.069
130	0.059
140	0.049
150	0.049
160	0.039
170	0.029
180	0.029
190	0.029
200	0.019
210	0.019
220	0.019
240	0.019
250	0.019
260	0.01
270	0.01
290	0.01
300	0.01
310	0.01
320	0.01
330	0.01



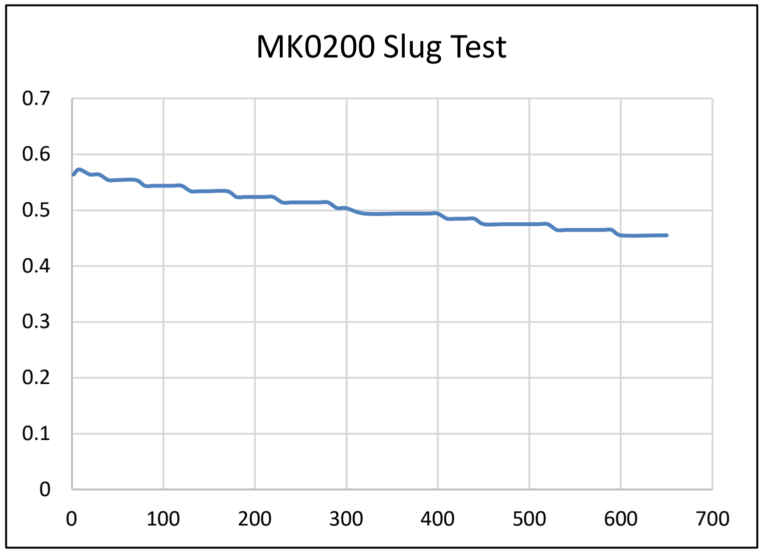
Time (min)	Drawdown (m)
0	0.602
1	0.592
4	0.592
6	0.553
15	0.553
20	0.543
30	0.543
35	0.543
70	0.543
80	0.543
100	0.543
110	0.543
120	0.543
130	0.543
140	0.543
150	0.543
220	0.543
230	0.543
240	0.543
250	0.543
260	0.543
280	0.543
290	0.543
310	0.543
320	0.543
330	0.543
340	0.543
350	0.543
400	0.533
600	0.533
630	0.533
660	0.533
670	0.533
680	0.533
690	0.484



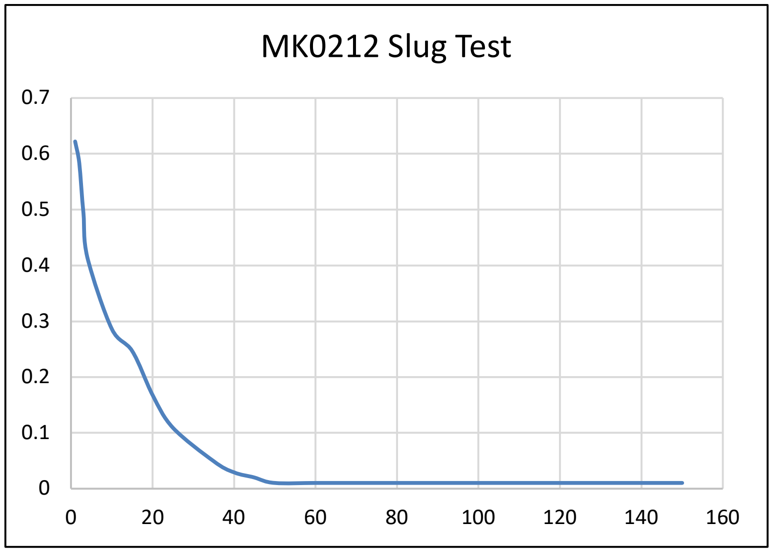
Time (min)	Drawdown (m)
0	0.633
1	0.633
4	0.583
8	0.544
20	0.544
25	0.544
30	0.534
35	0.534
40	0.534
45	0.534
70	0.534
80	0.534
90	0.534
100	0.534
110	0.534
120	0.534
130	0.534
140	0.534
150	0.534
160	0.534
170	0.534
180	0.534
190	0.534
200	0.534
210	0.534
220	0.534
230	0.524
240	0.524
260	0.524
290	0.504



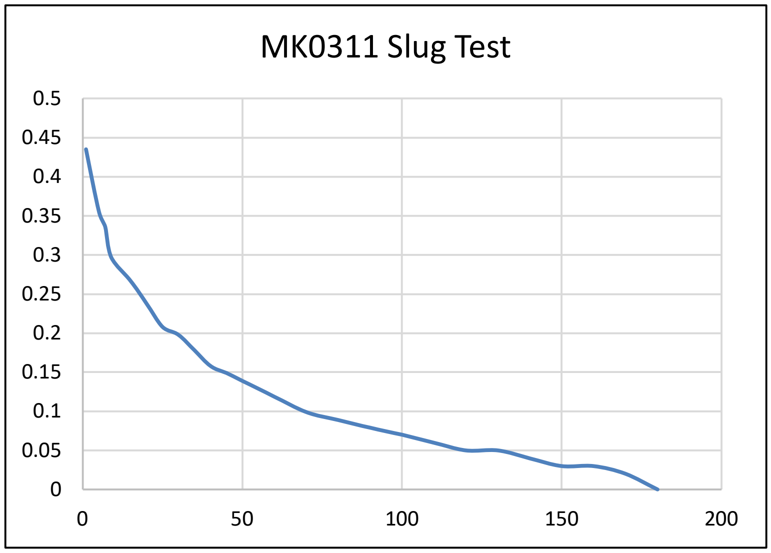
Time (min)	Drawdown (m)
0	0.564
2	0.573
8	0.564
20	0.564
30	0.554
40	0.554
50	0.554
70	0.544
80	0.544
90	0.544
100	0.544
110	0.544
120	0.534
130	0.534
140	0.534
150	0.534
170	0.524
180	0.524
190	0.524
200	0.524
210	0.524
220	0.514
230	0.514
240	0.514
250	0.514
260	0.514
270	0.514
280	0.504
290	0.504
300	0.494
320	0.494
360	0.494
370	0.494
380	0.494
390	0.494
400	0.485
410	0.485
420	0.485
430	0.485
440	0.475
450	0.475
500	0.475
550	0.465
600	0.455
640	0.455



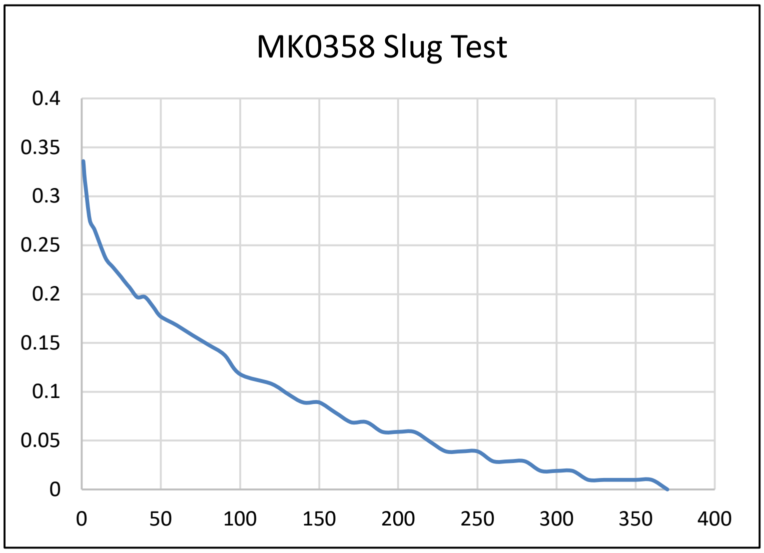
Time (min)	Drawdown (m)
0	0.622
1	0.583
2	0.494
3	0.415
4	0.286
10	0.247
15	0.168
20	0.109
25	0.049
35	0.029
40	0.02
45	0.01
50	0.01
60	0.01
70	0.01
80	0.01
90	0.01
100	0.01
110	0.01
120	0.01
130	0.01
140	0.01



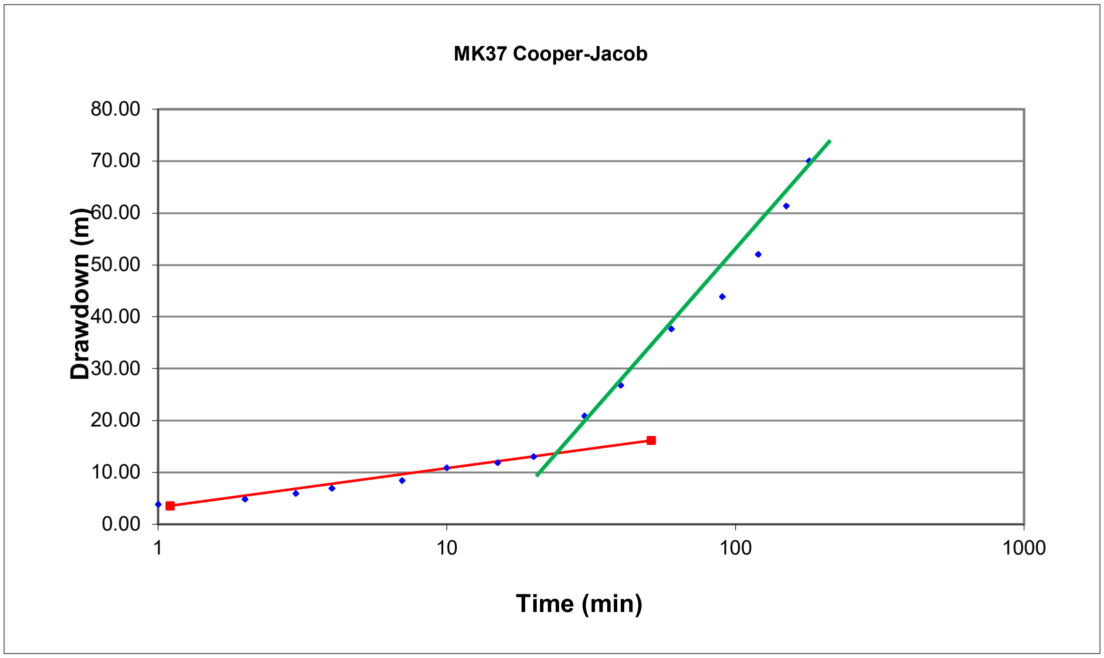
Time (min)	Drawdown (m)
0	0.435
1	0.356
5	0.336
7	0.297
9	0.267
15	0.238
20	0.208
25	0.198
30	0.178
35	0.158
40	0.149
45	0.139
50	0.119
60	0.099
70	0.089
80	0.079
90	0.07
100	0.06
110	0.05
120	0.05
130	0.04
140	0.03
150	0.03
160	0.02
170	0

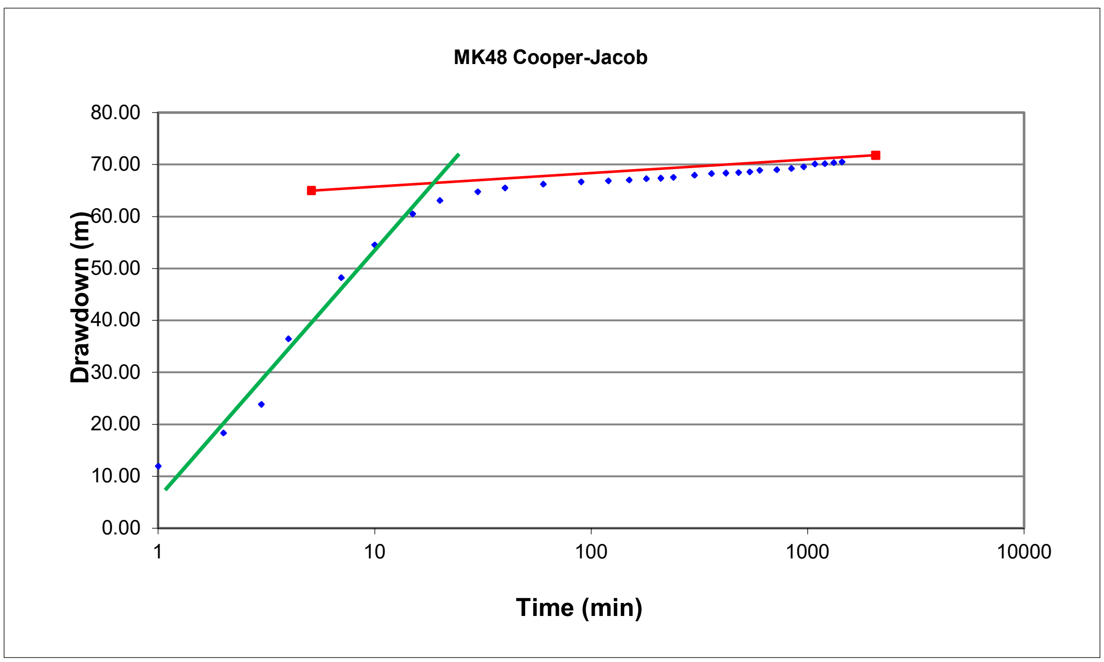


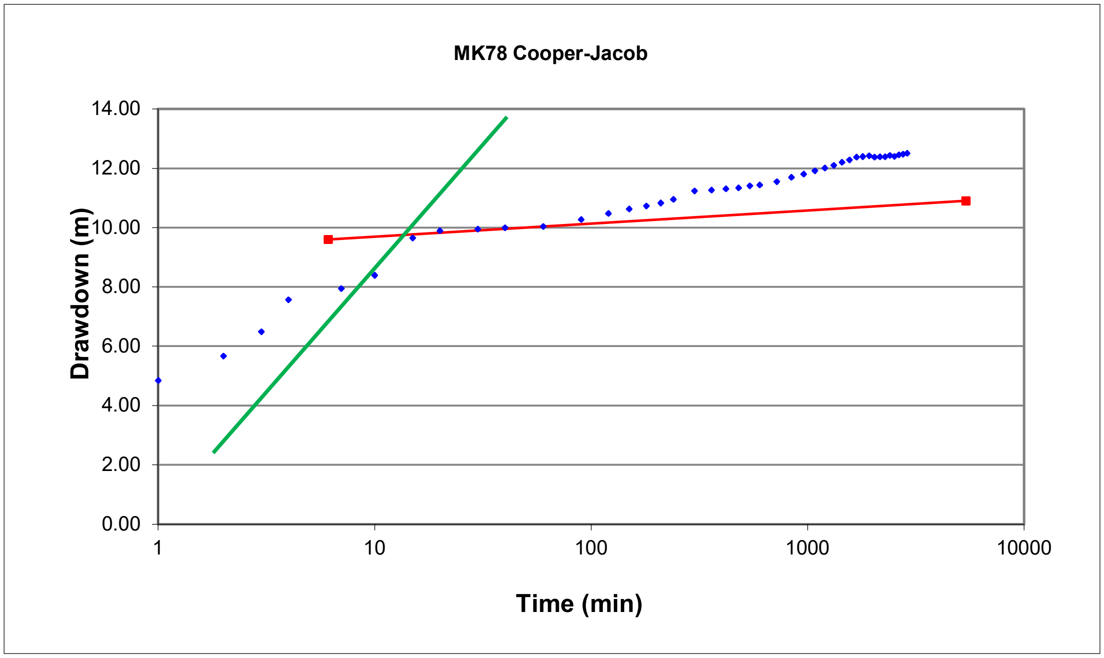
Time (min)	Drawdown (m)
0	0.336
1	0.316
2	0.276
5	0.266
8	0.237
15	0.227
20	0.217
25	0.207
30	0.197
35	0.197
40	0.187
45	0.177
50	0.168
60	0.158
70	0.148
80	0.138
90	0.118
100	0.108
120	0.098
130	0.089
140	0.089
150	0.079
160	0.069
170	0.069
180	0.059
190	0.059
200	0.059
210	0.049
220	0.039
230	0.039
240	0.039
250	0.029
260	0.029
270	0.029
280	0.019
290	0.019
300	0.019
310	0.01
320	0.01
330	0.01
340	0.01
350	0.01
360	0

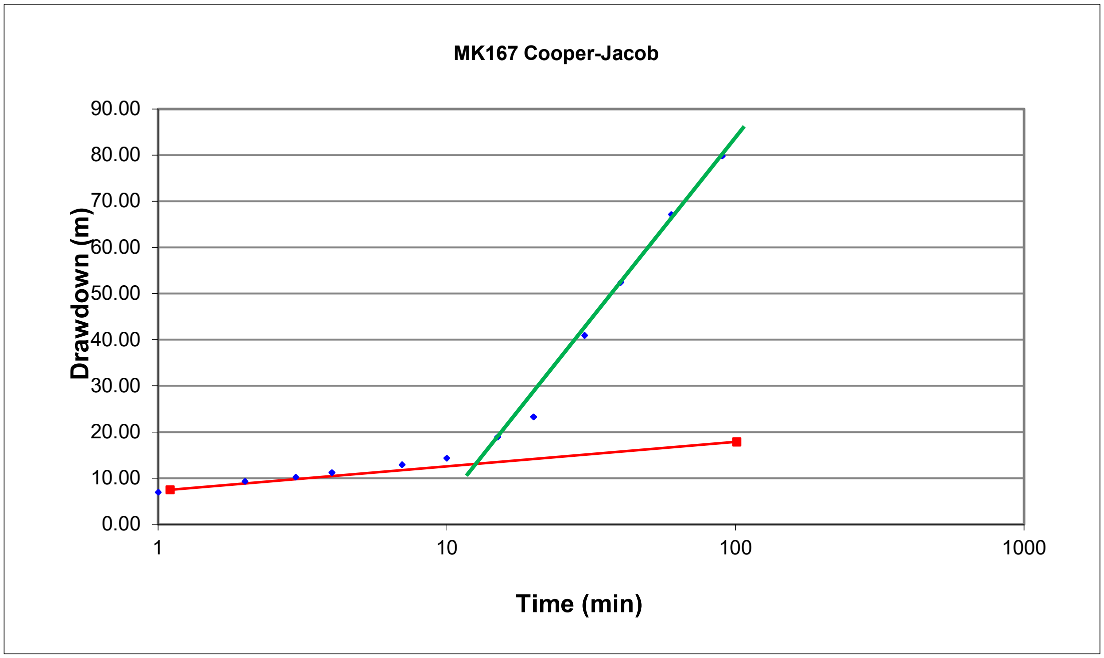


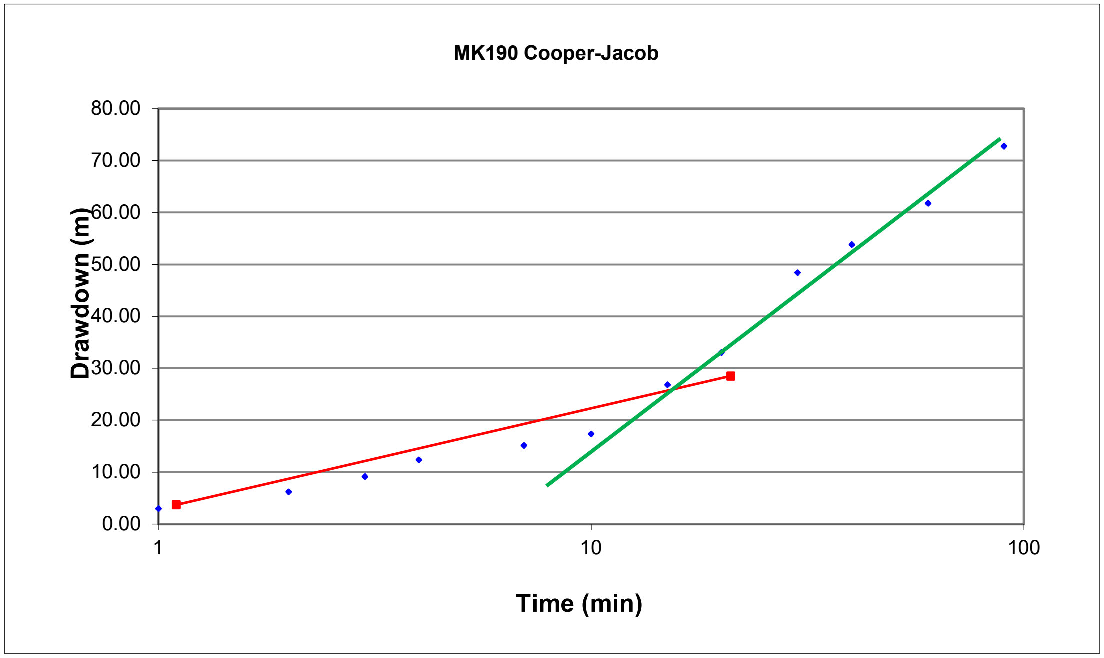
11 APPENDIX C: PUMPING TEST DRAW DOWN PLOTS

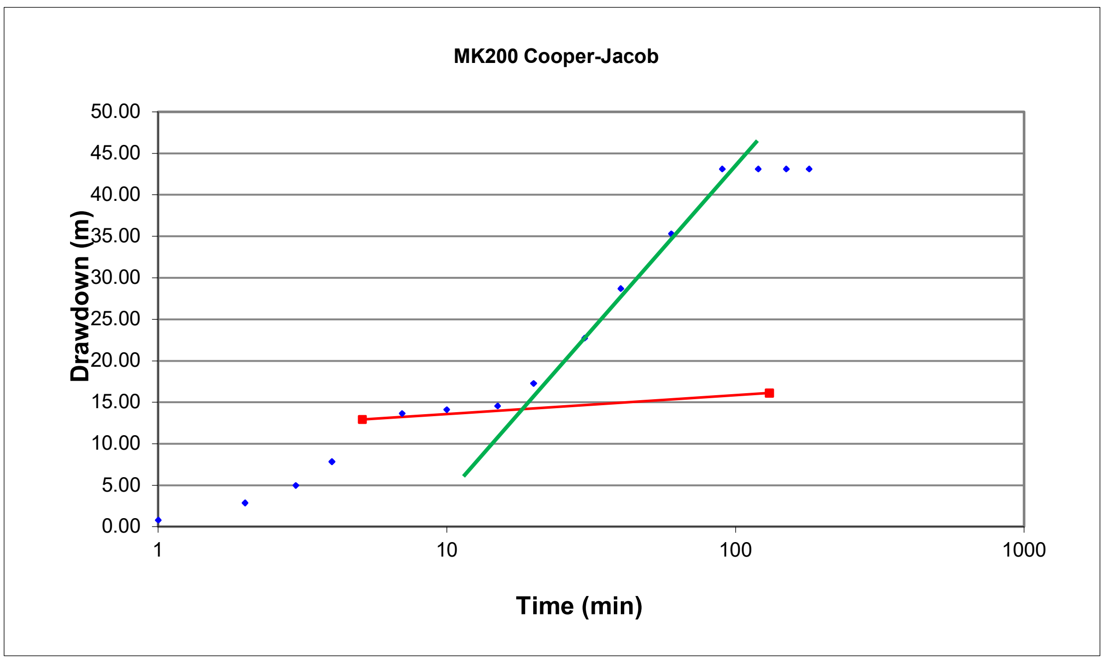


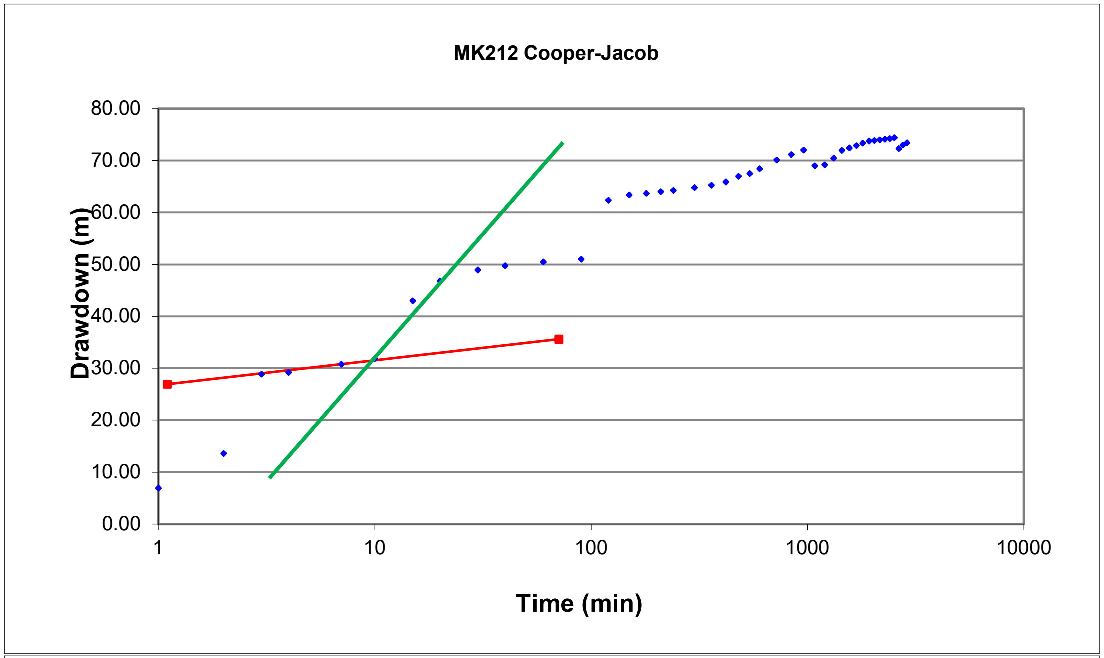


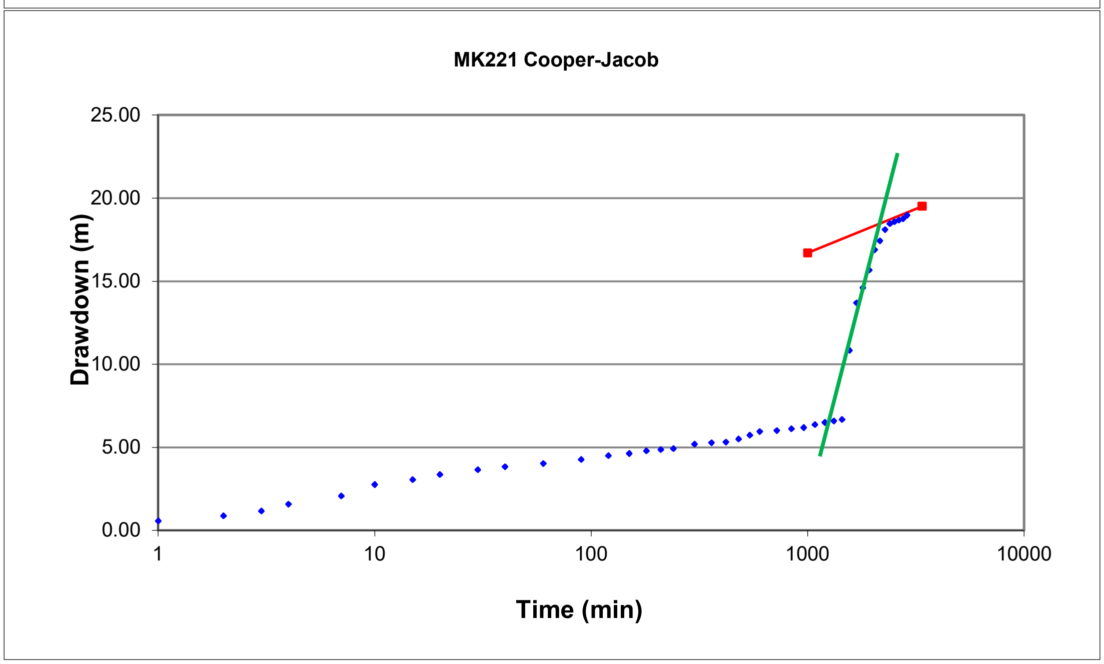

MK78 Cooper-Jacob
Drawdown (m)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
Time (min)

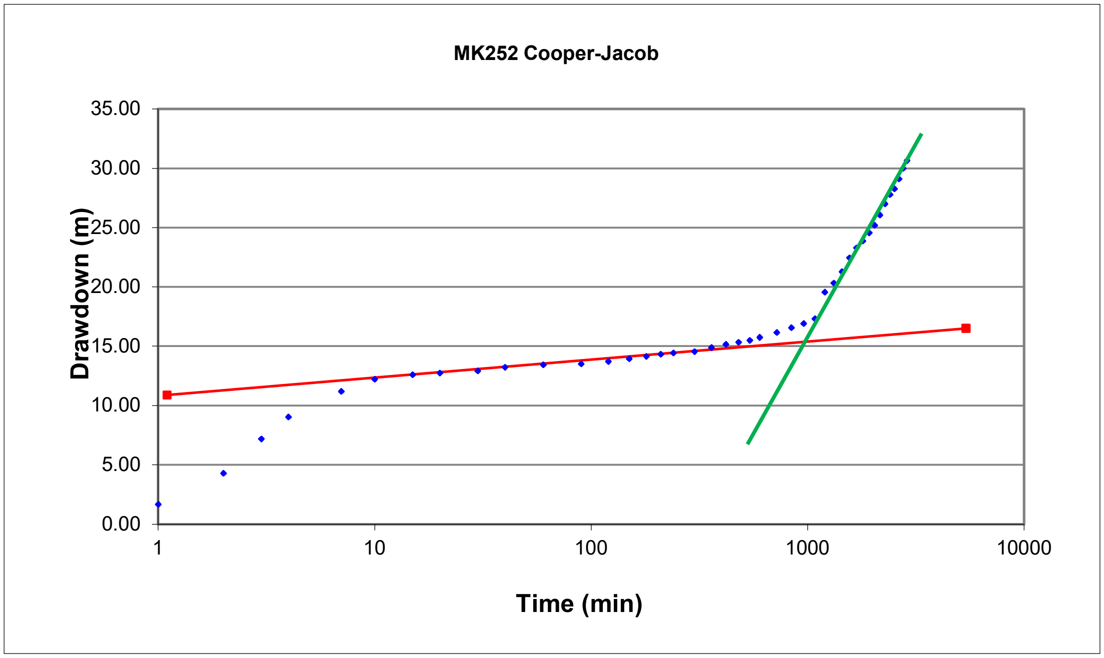

MK167 Cooper-Jacob
Drawdown (m)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
10
100
1000
Time (min)

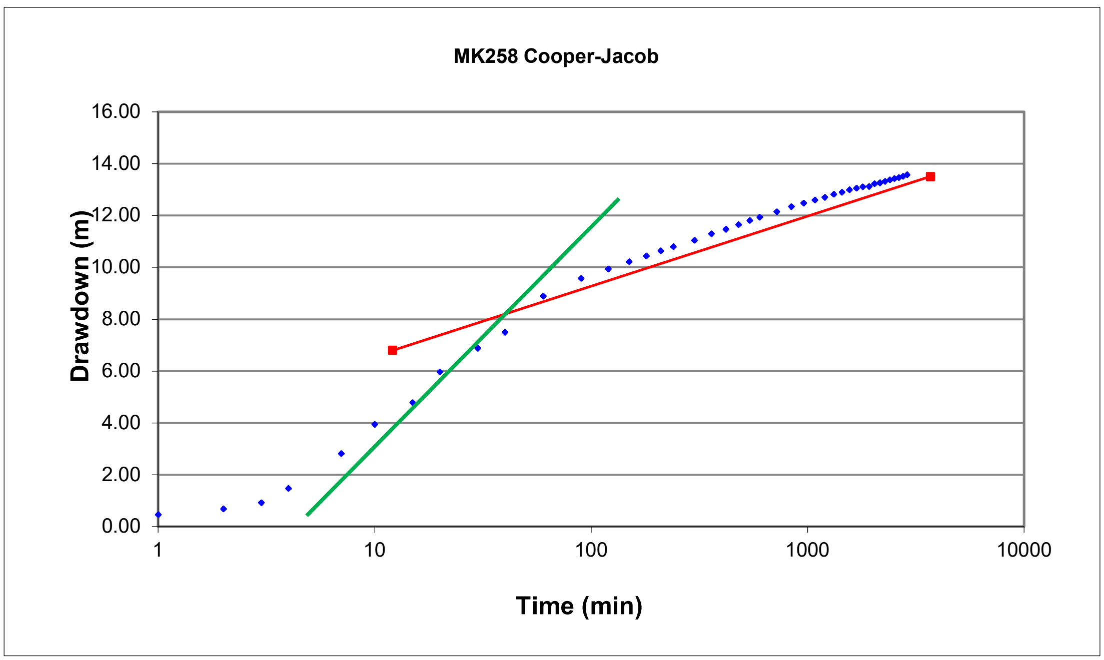

MK190 Cooper-Jacob
Drawdown (m)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
10
100
Time (min)

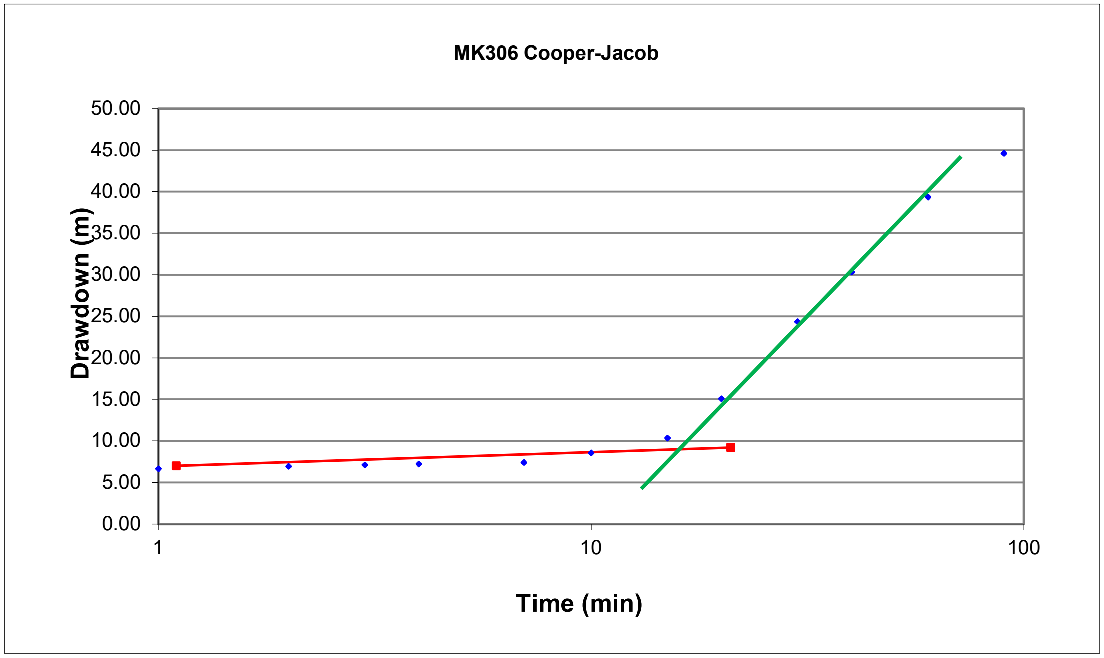

MK200 Cooper-Jacob
Drawdown (m)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
10
100
1000
Time (min)

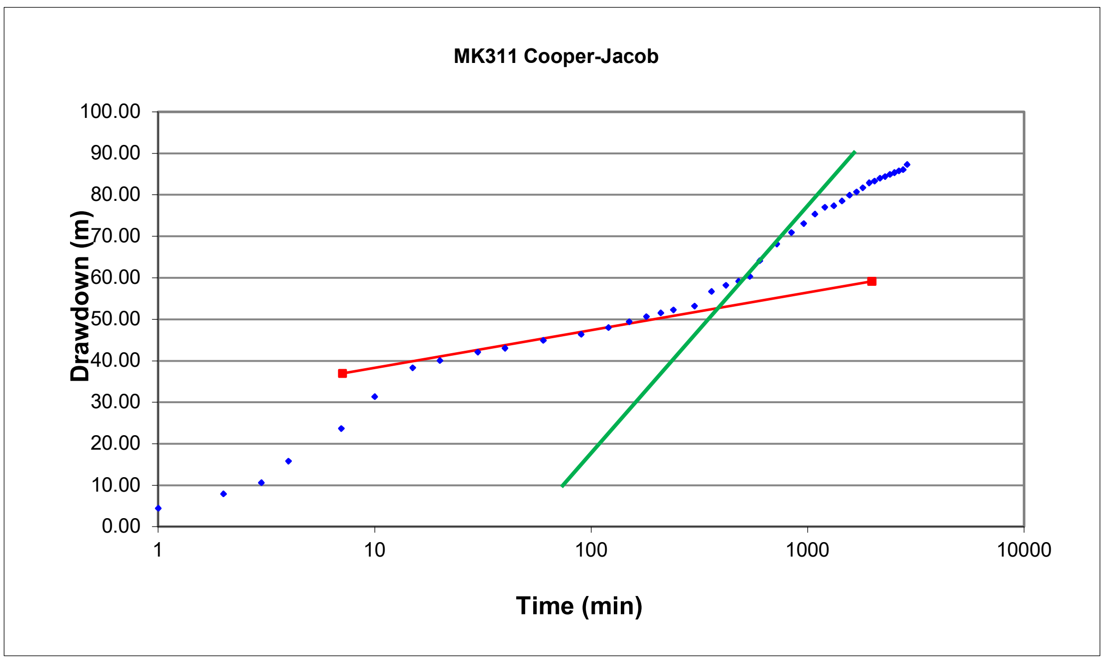

MK212 Cooper-Jacob
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Drawdown (m)
1
10
100
1000
10000
Time (min)

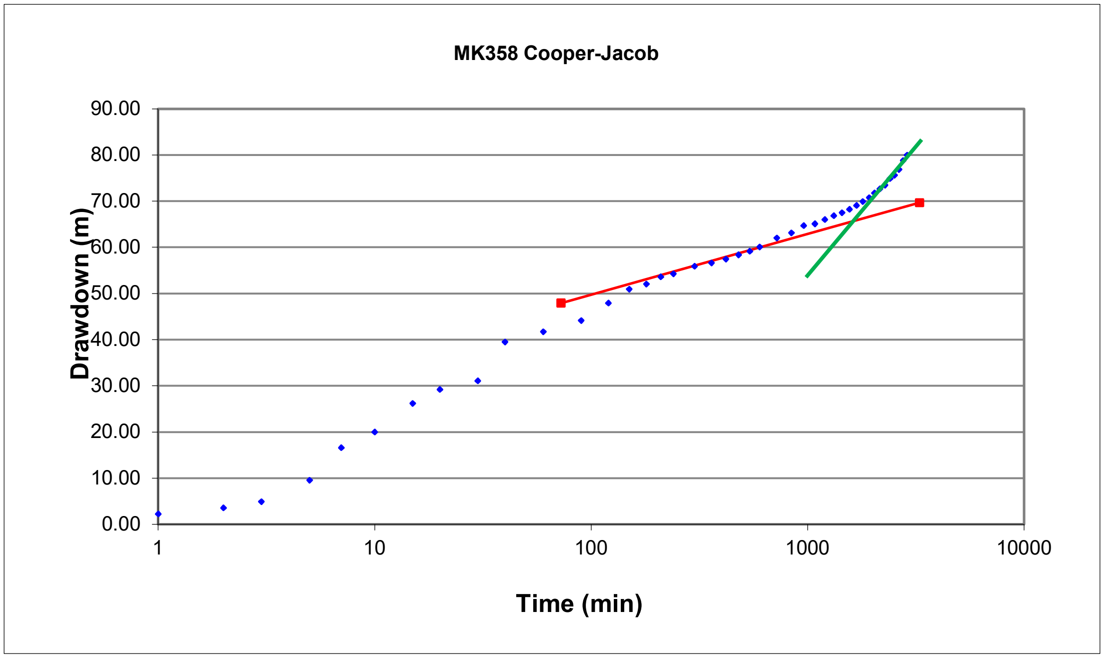

MK221 Cooper-Jacob
25.00
20.00
15.00
10.00
5.00
0.00
Drawdown (m)
1
10
100
1000
10000
Time (min)


MK252 Cooper-Jacob
Drawdown (m)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
10
100
1000
10000
Time (min)


MK258 Cooper-Jacob
Drawdown (m)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
10
100
1000
10000
Time (min)


MK306 Cooper-Jacob
Drawdown (m)
Time (min)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
10
100


MK311 Cooper-Jacob
Drawdown (m)
Time (min)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
10
100
1000
10000



MK358 Cooper-Jacob
Drawdown (m)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
10
100
1000
10000
Time (min)