HARMONY GOLD MINING LIMITED

ASSESSMENT OF THE POTENTIAL GEOHYDROLOGICAL IMPACT ASSOCIATED WITH THE BACKFILLING OF THE KUSASALETHU MAIN SHAFT WITH GOLD TAILINGS

FINAL REPORT

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MvB Consulting

PO Box 2166, Rant en Dal, 1751

Cell:079 741 9595

E-mail: marius@mvbconsult.co.za

Marius van Biljon
(PhD, Pr. Sci. Nat.)
Geohydrologist

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MvB Consulting

PO Box 2166, Rant en Dal, 1751
Cell:079 741 9595
E-mail: marius@mvbconsult.co.za

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1. INTRODUCTION

Environmental Impact Management Services (EIMS) appointed MVB Consulting to conduct a geohydrological study to assess the potential groundwater impacts if the Kusasalethu Main Shaft is filled with gold tailings.

In 2022 MVB Consulting developed a numerical groundwater flow and contaminant transport model to assess the potential impact from the Deelkraal and Kusasalethu tailings storage facilities (TSF's) and their associated infrastructure on the groundwater quality in the region.

The Kusasalethu Main Shaft (Main Shaft) was added as a point source to this model and the potential contamination plume migration over time was simulated. The contaminant source concentration was based on a study conducted by Golder Associates in 2015 named *"ANGLOGOLD ASHANTI - Classification and Assessment of Five Tailings Storage Facilities"*.

2. STUDY PURPOSE AND TERMS OF REFERENCE

The purpose of the geohydrological study is to assess the following:

- Assessment of the geohydrological environment in terms of aquifer development, aquifer hydraulics, groundwater flow and groundwater chemistry.
- Assessment of the potential impacts of backfilling the shaft with tailings material.
- Recommended management measures to mitigate potential impacts.

The study includes the following:

- Desktop study of existing information.
- Conceptual model of the groundwater system.
- Numerical groundwater flow and mass transport model.
- Risk assessment and reporting.

3. SITE LOCALITY AND DESCRIPTION

3.1 Locality of the Study Area

The mines are collectively referred to as Kusasalethu Mine as the Deelkraal operations have been decommissioned. The study focussed on Harmony's Kusasalethu Operations, specifically the shaft area. The area is characterised by mining with several mining companies operating in the region. Current land use in the area is mining related, residential areas and agricultural activities.

The Kusasalethu Mine is situated approximately 10km south-west of the town of Carletonville in the Northwest Province (**Figure 3.1**). The shaft is located on a quartzite ridge, which has a gentle gradient of approximately 4° to the south.

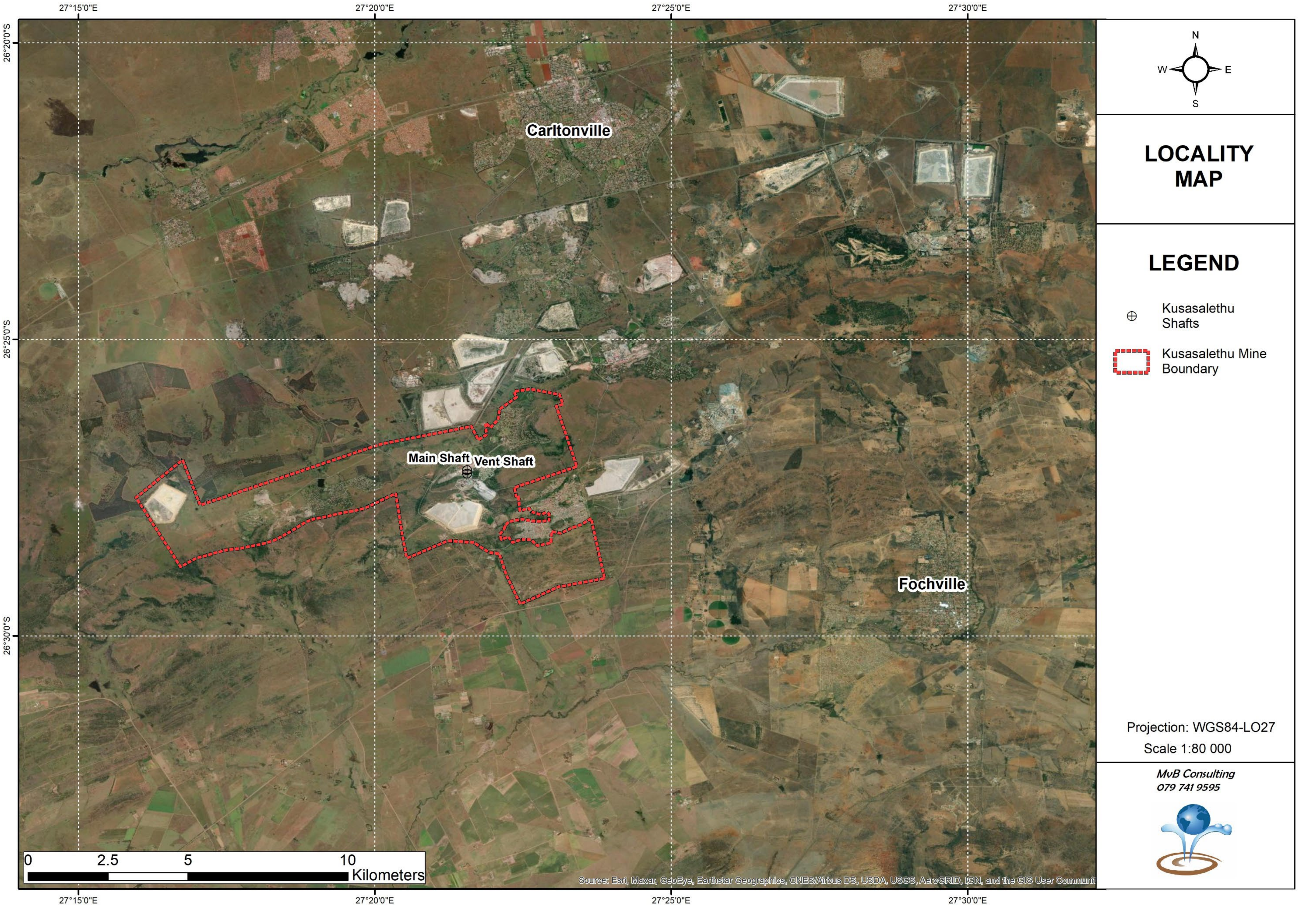

Figure 3.1: Project Locality

4. GEOGRAPHICAL SETTING

4.1 Topography and Drainage

Regional drainage in the study area is towards both towards the north and south (**Figure 4.1**). Drainage from the decommissioned Deelkraal residue deposits is mainly north (Quaternary catchment C23E). Varkenslaagte Spruit, a tributary of the Wonderfontein Spruit, flows westward along the northern boundary of the Harmony property. The Wonderfontein Spruit flows into the Mooi River and eventually into the Vaal River.

Drainage from the operational Kusasalethu residue deposits and shaft area is mainly south (Quaternary catchment C23J), into the Loop Spruit. The Loop Spruit flows in a westerly direction and joins the Mooi River at Potchefstroom from where it flows to the Vaal River.

The topography changes rapidly over short distances from 1 600 metres above sea level (mamsl) at the top of the ridge to 1 560 mamsl at the Varkenslaagte Spruit and 1 420 mamsl in the Loopspruit (**Figure 4.1**)

4.1.1 Water Management Area

The Kusasalethu Operations stretch over two quaternary catchments (C23E and C23J) which forms part of the Lower Vaal Water Management Area. The Vaal Water Management Area (WMA) is the result of the consolidation of the Upper, Middle and Lower Vaal catchments (**Figure 4.1**).

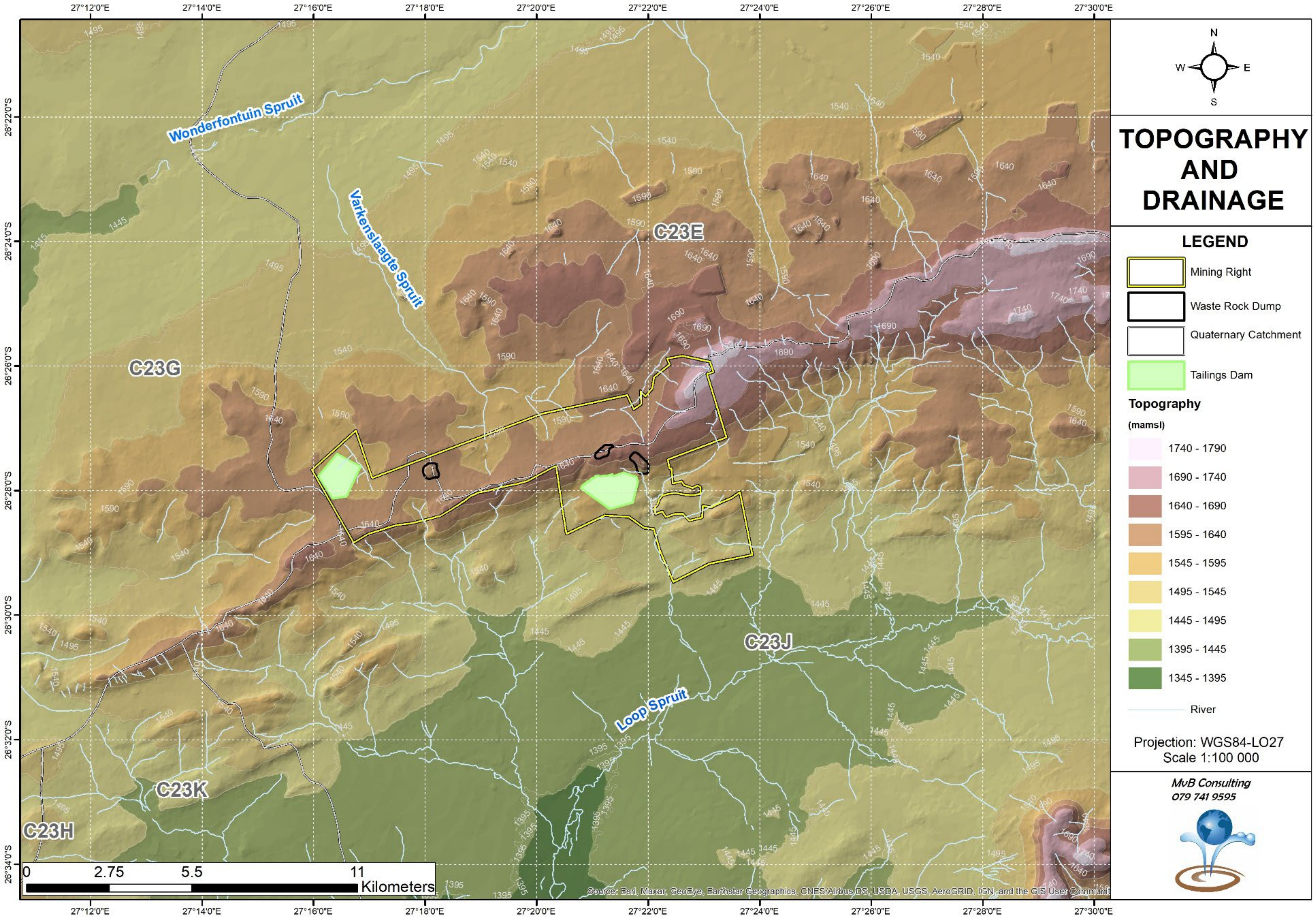

Figure 4.1: **Regional topography and drainage**

4.2 Climate and Rainfall

The climate near the Carletonville area is warm to hot summers with mostly clear skies, and cold winter days and frosty nights. Rainfall occurs mainly during the summer months as a result of thunderstorm activity. The mean annual precipitation is between 500mm to 600mm per annum depending on the location of the weather station (**Table 4.1** and **Figure 4.2)**. Accurate rainfall data for four weather stations located within proximity to the site is obtained from a Groundwater Monitoring Assessment Report compiled by Jones and Wagener, dated 2017.

Table 4.1: Annual Rainfall

Station	Fochville	Carletonville	Westonaria	Average
January	115	113	103	110
February	90	83	82	85
March	80	87	77	81
April	37	37	37	37
May	10	9	9	9
June	0	0	0	0
July	0	0	0	0
August	1	1	0	1
September	11	9	11	10
October	57	52	51	53
November	78	81	85	81
December	91	94	104	96

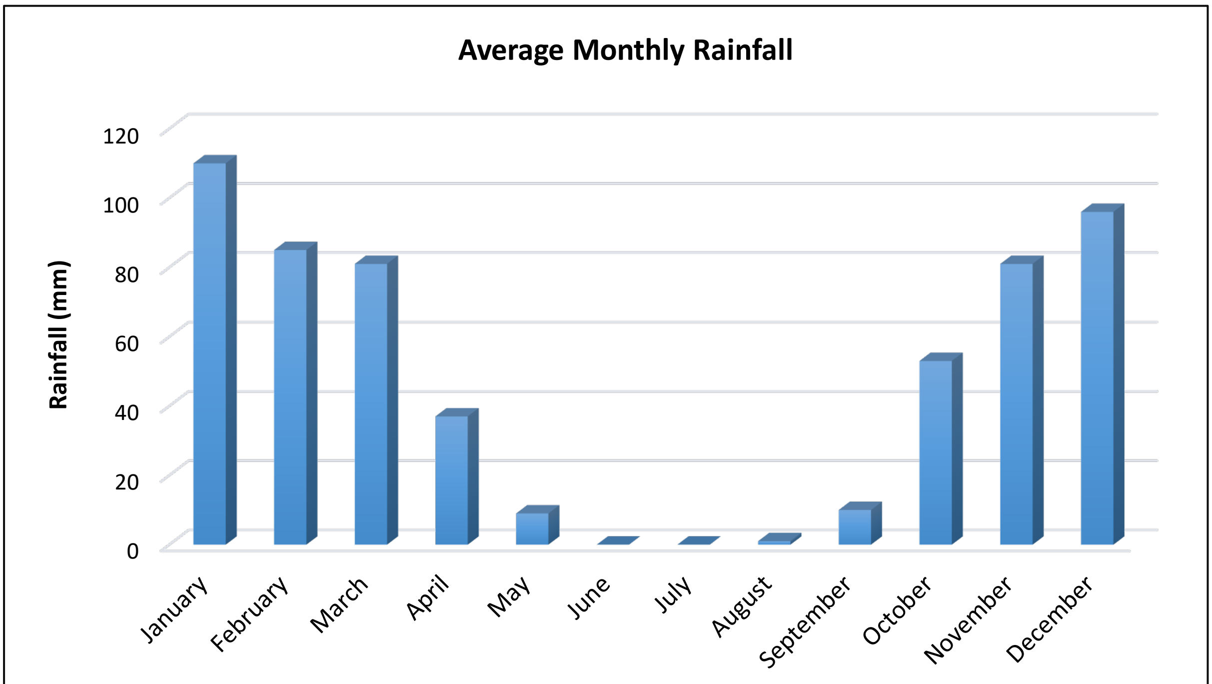

Figure 4.2: Average monthly rainfall for the region (Jones & Wagener, 2017)

5. SCOPE OF WORK

5.1 Introduction

The following sections describes the methodology and findings of the geohydrological assessment.

5.2 Regional Resource Determination

A key aspect of any groundwater assessment is a thorough understanding of the groundwater resource. The groundwater resource is described according to the following criteria:

- Aquifer boundaries.
- Aquifer type.
- Groundwater usage.
- Hydrochemistry.
- Drainage and baseflow.
- Aquifer recharge.
- Aquifer classification.

6. METHODOLOGY

6.1 Desk study

The following data sources were consulted to complete the study:

- Groundwater Monitoring Assessment Report for Kusasalethu and Deelkraal Operations compiled by Jones and Wagener, 2017.
- Kusasalethu Borehole Drillling Technical Note, compiled by MVB Consulting (2021) Report No: A079_TN01_r1_Kusasalethu_Drilling_Nov2021.
- Kusasalethu and Deelkraal Tailings Facilities Feasibility Study for Cut-off Drains to Collect Groundwater Seepage compiled by M van Biljon for Jones & Wagener (2014) Report No: JW038/14/E137-Rev1.
- Geohydrological Modelling for The Kusasalethu and Deelkraal Waste Facilities, Northwest Province (2022). MVB Consulting Report No. MvB090/22/A079.
- Anglogold Ashanti. Classification and Assessment of Five Tailings Storage Facilities (2015). Golder Associates Report No. 15536706-298511-1.
- National Groundwater Archive (NGA) Groundwater Level Data (2429CA).
- South African Water Quality Guidelines Volume 4: Agricultural Use: Irrigation and Volume 5: Agricultural Use: Livestock Watering (DWAF, 1996).
- The Groundwater Assessment Project II (GRA II) (DWAF, 2006).
- Vegter Maps (Groundwater Baseflow and Recharge).
- 1: 500 000 Geohydrological Map Series of South Africa.
- 1:250 000 Geological Map Series of South Africa

6.2 Hydro-census and Borehole Information

A hydro census was not included in the scope of the study. Groundwater data from newly drilled boreholes were collected in November 2021. Other groundwater information was obtained from the quarterly groundwater monitoring reports (2021) which was provided by the Kusasalethu Environmental Department.

6.3 Drilling and siting of boreholes

Routine surface and groundwater sampling takes place at Kusasalethu and (now decommissioned) Deelkraal TSF. In January 2017, J&W drilled a total of five (5) boreholes (which included 2 borehole pairs) as per recommendation from previous reports.

In November 2021, MVB Consulting drilled seven (7) additional groundwater monitoring boreholes, to fulfil the requirements of the Water Use License (WUL) as instructed by the Department of Water and Sanitation (DWS). The new boreholes were pump tested and sampled to include in the update of the numerical groundwater model. Information collected during the borehole drilling include borehole locality, borehole construction details and groundwater level.

The boreholes near the shaft area are shown on **Figure 6.1**. The borehole information for these boreholes is summarised in **Table 6.1**.

Table 6.1: Borehole Information (MVB Consulting, 2021)

ID	Coordinates			Groundwater Level		Date drilled	Depth (m)
	S	E	Topo Height (mamsl)	Water Level (mbgl)	Water Level (mamsl)		
BH4	27.27662	-26.4552	1565.36	47.88	1517.48	16/11/2021	60
BH6	27.35982	-26.4599	1614.10	17.53	1596.57	16/11/2021	56
BH7	27.36519	-26.4625	1544.82	2.78	1542.04	16/11/2021	25
BH8 (Shallow)	27.3664	-26.4756	1483.58	47.20	1436.38	16/11/2021	25
BH8 (Deep)	27.3664	-26.4765	1483.27	4.80	1478.47	16/11/2021	38
BH9	27.348	-26.467	1553.26	2.87	1550.39	16/11/2021	38
MBH14	27.36578	-26.4653	1522.95	1.21	1521.74	16/11/2021	27

6.4 Geophysical survey and results

As part of WUL instructions, a geophysical survey was conducted to site ideal locations for monitoring boreholes. The geophysical assessment comprised of both magnetic and electrical resistivity survey. In addition to the geophysical survey, desktop surveying was done by studying the available existing geological and hydrogeological data of the local area. The information assisted in the selection of the preferred field techniques.

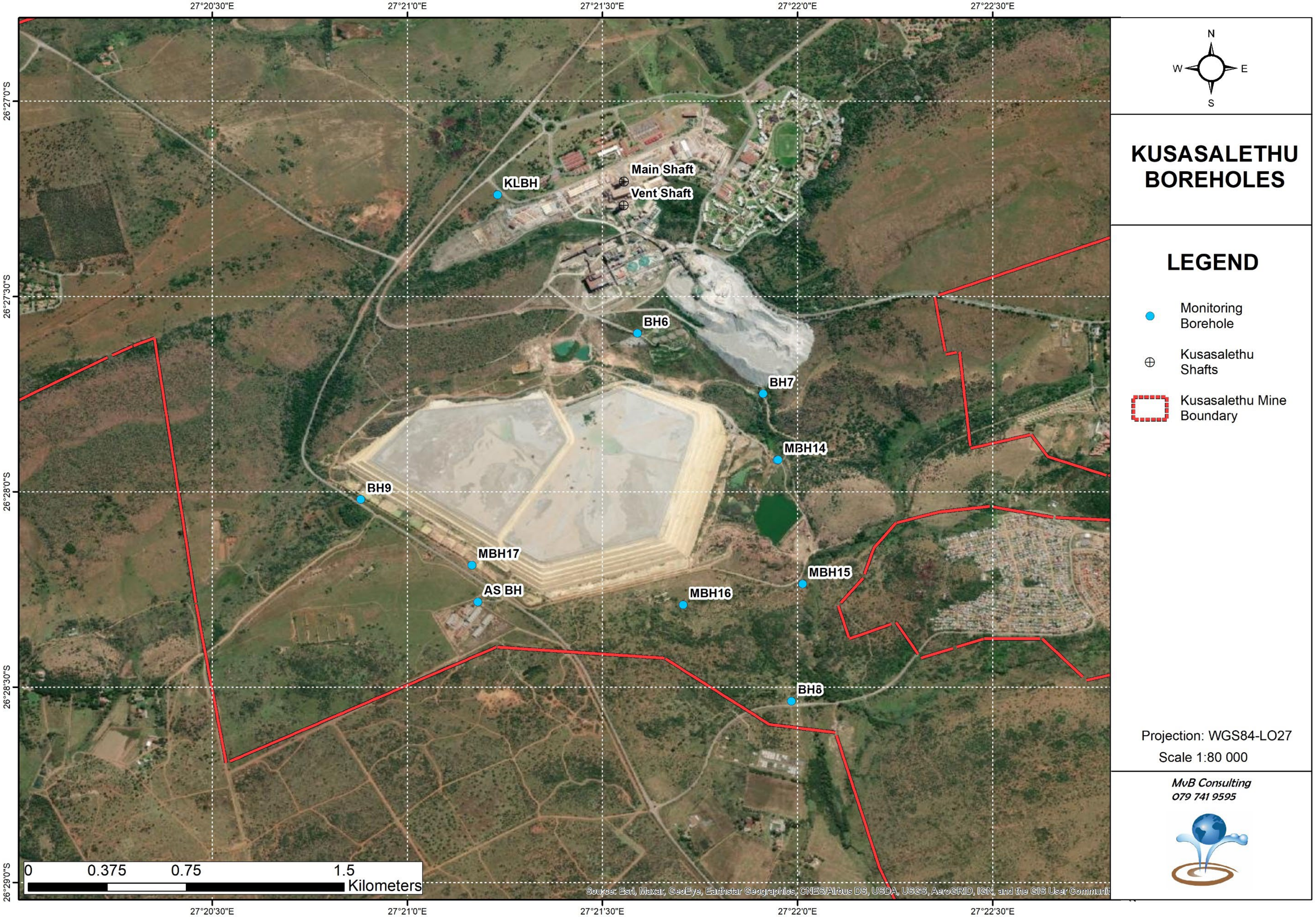

Figure 6.1: **Kusasalethu Boreholes**

6.5 Aquifer Testing

Aquifer testing was completed on the newly drilled boreholes (MVB Consulting, 2021). Constant rate and recovery tests were conducted, and transmissivity and hydraulic conductivity values were estimated for the weathered and fractured aquifer.

6.6 Sampling and Chemical Analysis

Seven (7) groundwater samples were collected from the newly drilled boreholes on the 28th of November 2021. The samples were submitted to DD Science, a SANAS accredited laboratory.

6.7 Groundwater Recharge Calculations

Recharge is defined as the process by which water is added from outside to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation. Groundwater recharge (R) for the study area was calculated using the chloride method (Bredenkamp et al., 1995) and is expressed as a percentage of the Mean Annual Precipitation (MAP). The method is based on the following equation:

$$\mathrm{R} = \frac{\text{Chloride concentration in rainfall}}{\text{Harmonic mean of Cl concentration in ground water}} \times 100$$

The average chloride in rainfall for areas inland is approximately 0.5 mg/ℓ and the harmonic mean of the chloride concentration values in (uncontaminated) groundwater samples obtained from the mining area is 13.384 mg/ℓ.

$$R = \frac{0.5}{13.4} \times 100 = 3.7\%$$

6.8 Numerical Groundwater Model

The available data was interpreted and used to prepare a conceptual model. The conceptual model will be converted to a numerical groundwater model using FEFLOW, a modular three-dimensional finite element groundwater flow model. The initial purpose of the model was to simulate the following:

- Impact on the groundwater quality on down-gradient receptors and surface streams during the operational and post-closure phase of the mine.

The backfilling of Main Shaft and the potential contamination impact to down-gradient receptors has now also been included into the model.

The basic steps involved in modelling can be summarised as:

- Collecting and interpreting field data: Field data are essential to understand the natural system and to specify the investigated groundwater problem. The numerical model develops into a site-specific groundwater model when real field parameters are assigned. The quality of the simulations depends largely on the quality of the input data.
- Calibration & validation: Model calibration and validation are required to overcome the lack of input data, but they also accommodate the simplification of the natural system in the model. In model calibration, simulated values like potentiometric surface or concentrations are compared with field measurements. The model input data are altered within ranges, until the simulated and observed values are fitted within a chosen tolerance. Input data

and comparison of simulated and measured values can be altered either manually or automatically.

- Model validation is required to demonstrate that the model can be reliably used to make predictions. A common practice in validation is the comparison of the model with a data set not used in model calibration. Calibration and validation are accomplished if all known and available groundwater scenarios are reproduced by the model without varying the material properties or aquifer characteristics supplied to the model.
- Modelling scenarios: Alternative scenarios for a given area may be assessed efficiently. When applying numerical models in a predictive sense, limits exist in model application. Predictions of a relative nature are often more useful than those of an absolute nature.

7. PREVAILING GROUNDWATER CONDITIONS

7.1 Regional Geology

The geology of the region is the controlling agent for aquifer development. The regional surface geology over the study area is presented as **Figure 7.1** and the general stratigraphy as described in the Jones & Wagener Report (2014) is as follows:

- Witwatersrand Supergroup.
- Ventersdorp Supergroup.
- Transvaal Supergroup; and
- Karoo Supergroup

7.1.1 Witwatersrand Supergroup

The geology of the Witwatersrand Supergroup is well understood and documented as a result of extensive mining and exploratory drilling. Truswell, 1977 describes the geology in the region of the mine aquifer.

The development and preservation of the Witwatersrand basin is structurally controlled. The structural patterns control the influx of groundwater into the underground workings and as a result it is important to understand which features act as conduits and which features act as flow barriers. Dykes and sills of at least four different ages have also intruded the Witwatersrand strata. The intrusion of the dykes has often taken place along fault planes. The oldest dykes are usually diabase, representing feeder dykes to the overlying Ventersdorp lavas. There are intrusions of pyroxenite, gabbro and dolerite probably of Bushveld age. A third group belongs to the basic or alkaline dyke swarm related to the Pilanesberg alkaline complex. Finally, the youngest intrusions are of Karoo dolerite.

The Witwatersrand basin is a thick sequence of shale, quartzite and conglomerate. The average dip of the strata is 30° south. There are two main divisions, a lower predominantly argillaceous unit, known as the West Rand Group and an upper unit, composed almost entirely of quartzite and conglomerates, known as the Central Rand Group.

The West Rand Group is divided into three subgroups namely the Hospital Hill, Government Reef and Jeppestown. These rocks comprise mainly shale, but quartzite, banded ironstones, tillite and intercalated lava flows are also present. The rocks were subjected to low - grade metamorphism causing the shale to become more indurated and slaty. The original sandstone was recrystallised to quartzite.

The Central Rand Group is divided into the Johannesburg and Turffontein Subgroups and is composed largely of quartzites, within which there are numerous conglomerate zones. The conglomerate zones may contain any number of conglomerate bands, with individual bands interbedded with quartzite. The upper conglomerates are usually thicker with coarser fragments. An argillaceous zone known as the Booysens Shale (also known as the Kimberley Shale) separates the Johannesburg and Turffontein Subgroups. The economic gold deposits (reefs) are contained within the Central Rand Group.

7.1.2 Ventersdorp Supergroup

The younger Ventersdorp Supergroup overlies the Witwatersrand rocks. Although acid lavas and sedimentary intercalations occur, the Ventersdorp is composed largely of andesitic lavas and related pyroclastics. The Ventersdorp Supergroup consists of the

Platberg Group and the Klipriviersberg Group. The Klipriviersberg Group consists of the Alberton and Westonaria Formations.

The Alberton Formation is composed of green – grey amygdaloidal andesitic lavas, agglomerates and tuffs. The thickness amounts to 1500m. The lack of sediments in this sequence indicates a rapid succession of lava flows, which probably came from fissure eruptions. Material of similar composition forms the oldest dykes that have intruded the Witwatersrand rocks. The abundant agglomerates provide indications of periodic explosive activity. The removal of huge volumes of volcanic material from an underlying magma chamber gave rise to tensional conditions and as a result a number of faulted structures, horst and grabens, were formed.

7.1.3 Transvaal Supergroup

Overlying the Ventersdorp Lavas are the Black Reef quartzite and dolomite of the Transvaal Supergroup. The Black Reef quartzite comprises coarse to gritty quartzite with occasional economically exploitable conglomerates (reefs). The entire area was peneplained in post-Ventersdorp time and it was on this surface that the Transvaal Supergroup was deposited, some 2200 million years ago. The deposition commenced with the Kromdraai Member with the Black Reef at its base. The occurrence of the gold is not as widespread as in the Witwatersrand and mainly restricted to north-south trending channels. The Black Reef is overlain by a dark, siliceous quartzite with occasional grits or small pebble bands. The quartzite grades into black carbonaceous shale. The shale then grades into the overlying dolomite through a transition zone of approximately 10m thick.

Overlying the Kromdraai Member is the dolomite of the Malmani Subgroup of the Chuniespoort Group. The dolomites are present on surface just 500m north of the Deelkraal TSF. About 1300 Ma ago the region was subjected to tension resulting in the formation of a number of large north to north-easterly striking faults. Many of the faults penetrated the full Transvaal sequence as well as the underlying Ventersdorp and Witwatersrand Supergroups. Some of the faults were filled by Pilansberg age dykes, which subdivided the dolomite into watertight groundwater compartments. The Wonderfonteinspruit tributary flows across the non-dewatered Bosbok – Turffontein dolomitic groundwater compartment. This is a sensitive aquifer that needs to be protected against impacts from the mines and other contaminant sources.

The dolomites are overlain in the south by the Pretoria Group rocks. The Rooihoogte Formation forms the basal member of the Pretoria Group, consisting of the Bevets conglomerate, shale and quartzite. The Bevets conglomerate varies in thickness between 3m and 60m (Parsons and Killick, 1985). Overlying the Bevets conglomerate is shale and sporadically developed quartzite, referred to as the Pologround quartzite. Where developed the Pologround quartzite is overlain by 150m – 200m of pink to purple shales, forming the basis of the Timeball Hill Formation. The shale is overlain by quartzite, which forms the linear north-easterly trending ridges in the south of the study area.

7.1.4 Local Geology

Based on the geological logs BH4, BH6 and BH9 are generally characterized as layers of unweathered quartzites overlain by shales, and diabase at the base.

The contact between the Hekpoort Andesite Lavas and the Timeball Hill shale is evident from log MBH14. In some areas shales have undergone low to medium grade metamorphism causing them to become slaty. Hekpoort Andesite lavas are also evident in in logs from BH8s and BH8d.

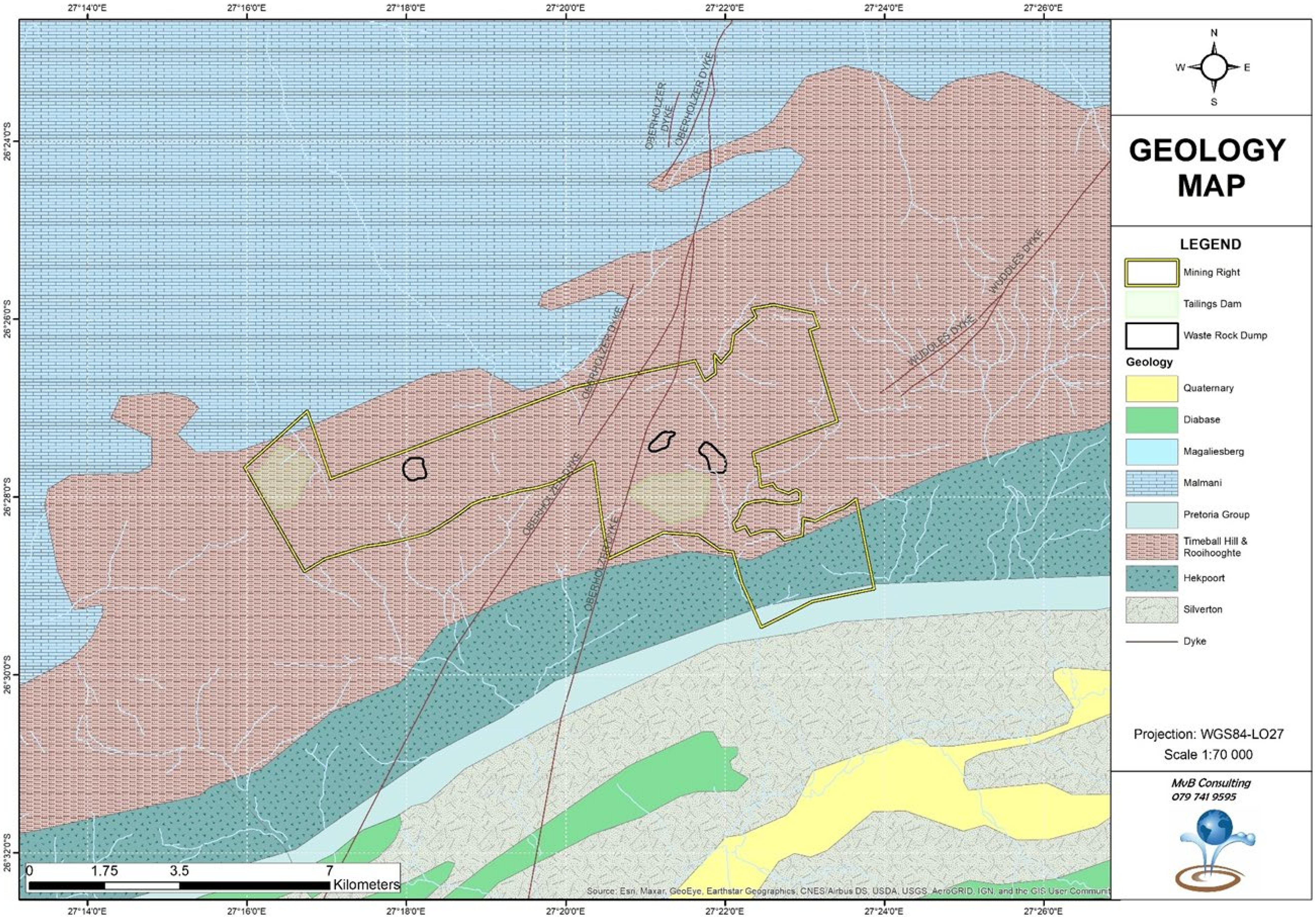

Figure 7.1: Regional Surface Geology

7.2 Geohydrological Setting

7.2.1 Introduction

The geohydrology of the study area was assessed based on available mine monitoring data, previous studies (Jones & Wagener, 2014, MVB Groundwater Consulting, 2012; JMA Consulting, 2007) and additional field work. The geohydrological setting and conceptual model of the study area is described according to the following criteria:

- Hydro census and borehole information (**Section 6.3)**
- Regional Hydrogeology.
- Aquifer type.
- Aquifer parameters.
- Groundwater gradients and flow.
- Water Balance.
- Aquifer classification.

7.2.2 Aquifer Type

With reference to **Section 7.1** none of the rock types, apart from the Transvaal dolomite, described earlier is known to contain significant aquifers. Most groundwater occurrences are restricted to the upper weathered formations and fractures. These formations are not considered to contain economic and sustainable aquifers, but localised high yielding boreholes may, however, exist where significant fractures are intersected. Malmani dolomite is located north of the Kusasalethu mining area, these dolomites are known to contain significant groundwater. There are two distinct aquifers in the study area. The geohydrological report compiled by J&W (2014) was used to supplement the following section:

- **Weathered Aquifer**: The first is a shallow weathered aquifer, mainly restricted to the weathered shale and quartzite of the Witwatersrand rocks. The base of the aquifer is the impermeable quartzite and shale formations, whereas the top of the aquifer would be the surface topography. The groundwater table is affected by seasonal and atmospheric variations and generally mimics the topography. These aquifers are classified as semi-confined. The most consistent water strike is located at the fresh bedrock / weathering interface. Groundwater elevations vary between 0.5m and 14m below surface.
- **Fractured Aquifer:** The second is the deeper fractured rock aquifer. The deeper, fresh shale/quartzite aquifer where fracture flow dominates. Groundwater migration within the upper portion of the aquifer appears to be governed by jointing while major faults and intrusions form the significant conduits at depth. The depth to groundwater in this aquifer ranges from artesian to 38m below the surface. The two aquifers (weathered and fractured) are mostly hydraulically connected but confining layers such as clay and shale often separate the two. In the latter instance the fractured aquifer is classified as confined.
- **Dolomitic Karst Aquifer**: Carbonate rocks are practically impermeable and therefore devoid of any effective primary porosity. During its geological history, however, the dolomite is subjected to karstification and erosion. During this dissolution processes, the carbonate is removed from the dolomite and residual products such as silica, iron and manganese oxides and hydroxides (wad) are left behind. The residual mass spongy, compressible, of low density and has a high void volume. Fissures and caves also develop. Fault zones are preferential

zones of weathering and are transformed into ground water conduits. The potential for large-scale ground water exploitation depends solely on the extent to which the dolomite has been leached by percolating rainfall and groundwater drainage, as well as the degree to which it has been transformed into aquifers capable of yielding significant quantities of water and sustaining high abstraction capacities.

The dolomite aquifer is unlikely to be impacted on by the activities at Kusasalethu, but it is near the Deelkraal TSF. The weathered and fractured aquifers are present beneath the entire Kusasalethu infrastructure, although the weathered aquifer may not always be well developed.

7.2.3 Groundwater Gradients and Flow

The available groundwater levels as measured from the most recent water level data is shown in **Table 7.1**.

Table 7.1: Groundwater levels

Borehole ID	Coordinates		Collar elevation (mamsl)	Water Level (mbs)	Water Level (mamsl)
	Longitude	Latitude			
BH4	127321	-2927904	1565.36	47.88	1517.48
BH6	135615	-2928510	1614.1	17.53	1596.57
BH7	136147	-2928799	1544.82	2.78	1542.04
BH8 (Shallow)	136268	-2930236	1483.58	47.2	1436.38
BH8 (Deep)	136268	-2930236	1483.27	4.8	1478.47
BH9	134426	-2929282	1553.26	2.87	1550.39
MBH14	136187	-2929109	1522.95	1.21	1521.74

Note: mbs = metres below surface; mamsl = metres above mean sea level

Based on the limited data available, the depth to groundwater in the area varies between 1.21 metres below surface level to 47 metres below surface level.

In most geological terrains, the groundwater mimics the topography and to test if this is the case within the study area the available groundwater levels were plotted against the topography (represented by the borehole Z values). In the Kusasalethu area, a good correlation (83%) exists.

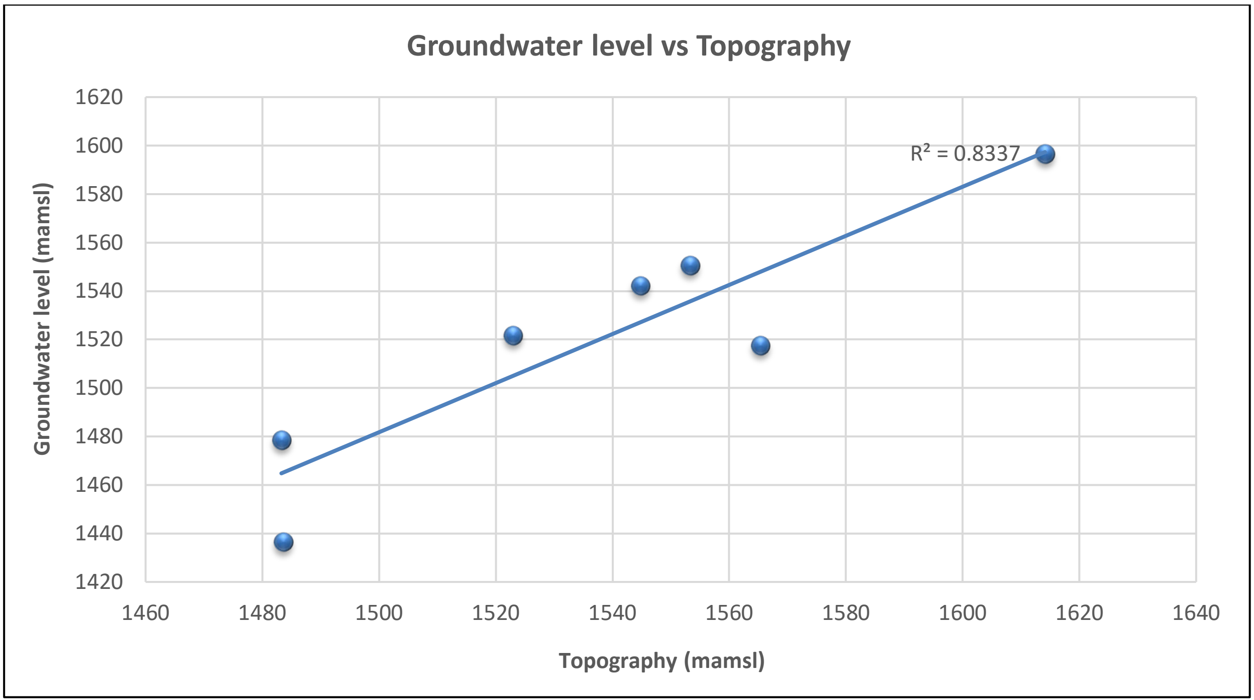

Figure 7.2: Relationship between groundwater table and topography

If a good linear relationship is proven, the regional groundwater level van be interpolated. The interpolation, known as Bayesian Interpolation, uses both the measured groundwater levels and the topography to generate a regional groundwater gradient map. Groundwater generally mimics topography and flows from topographic highs to valley lows. In some cases, the groundwater may contribute to baseflow depending on the properties of both the streambed and the aquifer properties. Since in some cases there are artesian wells, it is most likely that there some rivers are sustained by groundwater flow.

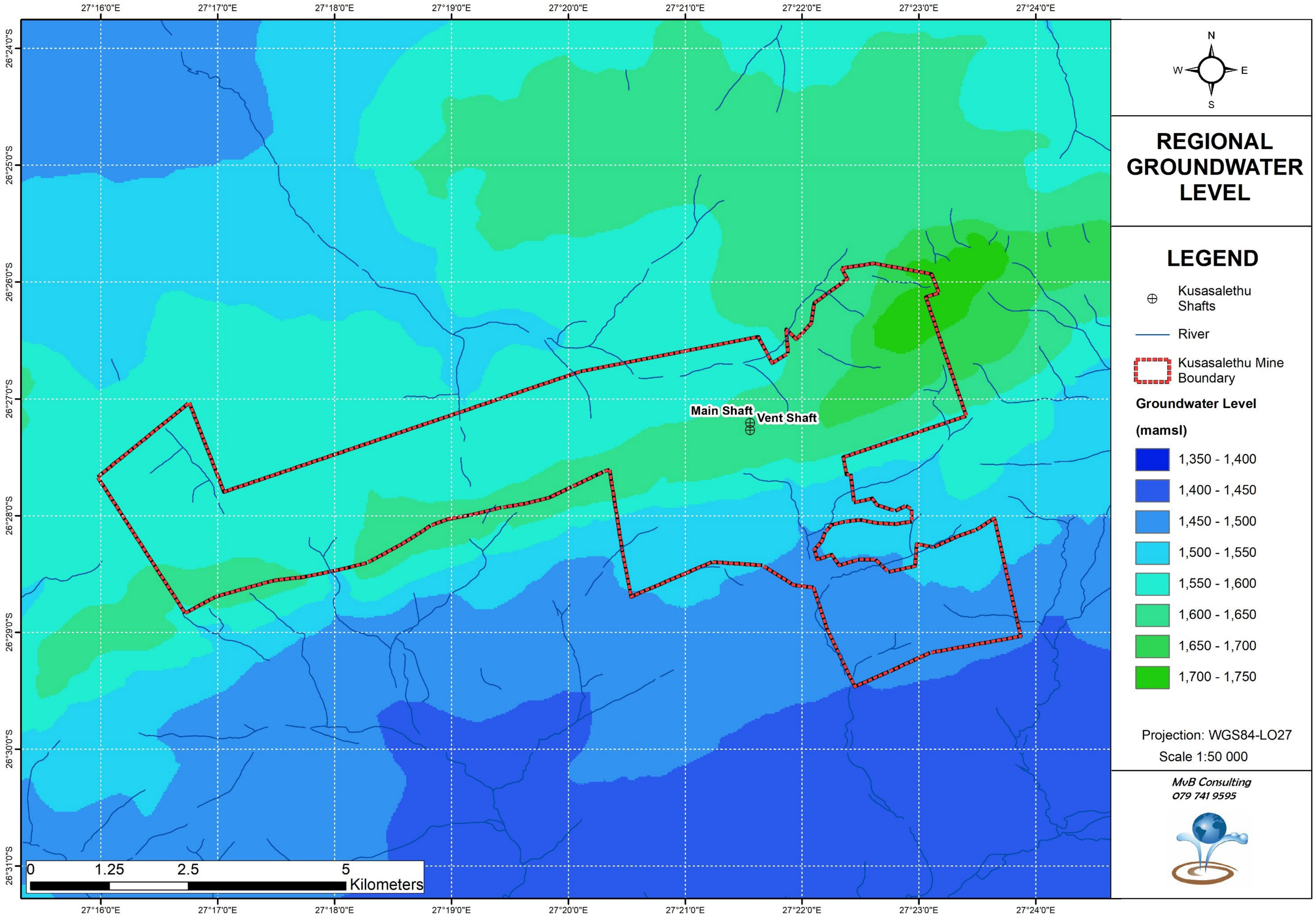

Figure 7.3: **Regional groundwater gradient**

7.2.4 Aquifer Parameters

Important aquifer parameters are obtained from borehole or test pumping and include Hydraulic Conductivity (K), Transmissivity (T) and Storativity (S). These parameters are defined as follows (Krusemann and De Ridder, 1991):

- *Hydraulic Conductivity (K):* This is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. It is normally expressed in metres per day (m/day).
- *Transmissivity (T):* This is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the full, saturated thickness of the aquifer. Transmissivity is the product of the average hydraulic conductivity and the saturated thickness of the aquifer. Transmissivity is expressed in metres squared per day (m^2/day).
- *Storativity (S):* The storativity of a saturated confined aquifer is the volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface. Storativity is a dimensionless quantity.

The recently drilled boreholes were pump tested in November 2021. The calculated aquifer parameters for all the tested boreholes are presented in **Table 7.2.**

Boreholes BH8s and BH7 have most likely intersected a fracture which allows for the preferential flow of water. The remaining pump test results indicate that the groundwater movement (and contamination) is slow.

Table 7.2: Summarised aquifer parameters obtained from pump tests (Van Biljon, 2022)

Borehole	Transmissivity (m^2/d)			Hydraulic Conductivity (m/d)		
	Constant Rate	Recovery	Average	Constant Rate	Recovery	Average
BH6	7.94×10^{-1}	3.46×10^{-1}	0.57	2.83×10^{-2}	1.24×10^{-2}	0.02
BH7	$9.93 \text{ X } 10^{-1}$	1.99	1.49	$4.15 \text{ X } 10^{-2}$	8.35×10^{-2}	0.06
BH8d	4.32×10^{-1}	1.33×10^{-1}	0.28	1.56×10^{-2}	4.78×10^{-3}	0.01
BH8s	1.77	5.63×10^{-1}	1.17	1.15×10^{-1}	3.67×10^{-2}	0.09
BH9	7.18×10^{-1}	5.02×10^{-1}	0.61	2.42×10^{-2}	1.69×10^{-2}	0.02
MBH14	9.93×10^{-1}	1.01×10^{-1}	0.55	5.02×10^{-2}	5.12×10^{-3}	0.03

7.3 Water Chemistry

7.3.1 Potential Contaminant Sources

Historically, unregulated impoundment on land was the preferred option for waste disposal. Gold mining waste was estimated to account for 221 million tons or 47% of all mineral waste produced in South Africa, making it the largest, single source of waste and pollution (Viljoen, 2009).

Formerly unregulated disposal of waste in the form of waste rock dumps, slimes dams and sand sumps have resulted in geochemically unstable structures which have been exposed to varying degrees of wind and water erosion (Viljoen, 2009). Where sulphide-containing tailings are exposed to oxygen (air or water) the material is oxidized to produce acidic leachate in the form of ferrous and ferric sulphates as well as iron hydroxides. Groundwater surrounding gold dumps are potentially associated with sulphate, chloride, calcium, magnesium, manganese and aluminum if the management of contaminated water is not effective and seepage is not confined to an allocated area (Groundwater Abstract Pty Ltd, 2019). Metals such as cobalt, copper, zinc, nickel may also be elevated (Groundwater Abstract Pty Ltd, 2019).

Similarly in underground operations where mine-water pumping is constant and mine water level is stable, little pyrite oxidation occurs below the water level, and few metals are leached resulting in a relatively non-environmentally aggressive mine water. Active pyrite oxidation will, however, continue to occur in the unsaturated zone and, if pumps are turned off, the rising water level will leach out heavy metals, resulting in highly acid and contaminating solution (Banks et al., 1996)

Where Nitrate-based explosives have been extensively used for mining and quarrying, residues of explosives may be oxidized to nitrates and mobilized in groundwater (Banks et al.,1996). Other possible contamination sources could originate from sewage effluent resulting from poor sewage management in informal settlements. Contaminants related to the mismanagement of sewerage effluent systems include coliforms (eg. E.coli) bacteria viruses, ammonia, phosphate and nitrate as well as sulphate secondary salt leaching from sewage effluent.

7.3.2 Acid Generation Capacity

Sulphide minerals are formed and stable under reducing conditions (Dold, 2017). Acid mine drainage commonly occurs when sulphide minerals (pyrite, chalcopyrite, galena, covellite and sphalerite) are exposed to oxidizing conditions. The oxidizing conditions are created by exposure to moisture and oxygen. The oxidation process results in the release of dissolved Fe^{2+}, SO_4^{2-} and H^+ (ABA, 2001). The oxidation of sulphide-minerals containing iron produce net acidity via its oxidation, except for common sulphides such as molybdenite, enargite and stibnite (Dold, 2017). The process of acid rock drainage is generated by a series of the following chemical reactions:

$$\mathrm{FeS}_{2(s)} + \frac{7}{2}\mathrm{O}_{2(aq)} + \mathrm{H_2O} \rightarrow \mathrm{Fe}^{2+} + 2\mathrm{SO}_4^{2-} + 2\mathrm{H}^+$$ *Equation 1*

The liberated Fe^{2+} can oxidize automatically at pH>4 or when catalyzed by bacterial activity <4 (*Acidithiobacillus* spp. or *Leptosprillum* spp,) (Equation 2) (Dold, 2017). Iron-oxidizing bacteria greatly accelerate iron oxidation which, in turn, speeds up the acid generation.

$$Fe^{2+} + \frac{1}{4}O_{2(aq)} + H^+ \rightarrow Fe^{3+} + H_2O$$ *Equation 2*

Ferric iron is not soluble above pH values of ~3. The produced ferric iron can hydrolyse and produce Fe (III) Hydroxides which liberates 3 mol protons per mole of iron according to Equation 3:

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3(s)} + 3H^+ \qquad \textit{Equation 3}$$

The overall reaction liberates 16 mole of protons per mole of pyrite oxidized:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad \textit{Equation 4}$$

The rate of pyrite oxidation depends on a majority of factors, the main factors being reactive surface area of pyrite, oxygen concentration and solution pH, presence of bacteria and catalytic agents (Skousen J., Sextone A. and Ziemkiewics, 2000).

Where mine-water pumping is constant and mine water level is stable, little pyrite oxidation occurs below the water level, and few metals are leached resulting in a relatively non-environmentally aggressive mine water. Active pyrite oxidation will, however, continue to occur in the unsaturated zone and, if pumps are turned off, the rising water level will leach out heavy metals, resulting in highly acid and contaminating solution (Banks et al., 1996)

In some geological settings the alkaline content of surrounding lithologies could act as buffering systems, countering the acid produced from pyrite oxidation. Carbonates and Clays have proven to sufficiently neutralize acid rock drainage (Skousen J., Sextone A. and Ziemkiewics, 2000). The balance between acid-producing potential and neutralizing capacity should provide reasonable indication of the potential acidity or alkalinity that may occur from the weathering of mined material.

7.3.3 Groundwater Quality

Seven (7) groundwater samples were collected from the recently drilled boreholes on the 28th of November 2021. The localities of the representative boreholes are indicated in **Figure 7.4** and the results are summarised in **Table 7.3**.

Furthermore, the most recent groundwater monitoring results were made available by Harmony Gold and is also included in this section of the report (**Table 7.4**).

The groundwater chemistry is compared to the SANS 241 (2015) specifications for drinking water. The SANS 241 Drinking Water Specification is the definitive reference on acceptable limits for drinking water quality parameters (for a lifetime consumption) in South Africa and provides guideline levels for a range of water quality characteristics. In The absence of SANS 241 limits the DWAF (1996)[1] limits are used.

The borehole samples are also compared to the South African Water Quality Guidelines Volume 4: Agricultural Use: Irrigation and Volume 5: Agricultural Use: Livestock Watering (DWAF, 1996). Concentrations that exceed the SANS 241 guideline limits are highlighted in **red**, and the livestock watering guidelines are in **green**.

[1] Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use, Volume 4: Irrigation Guidelines and Volume 5: Livestock Watering

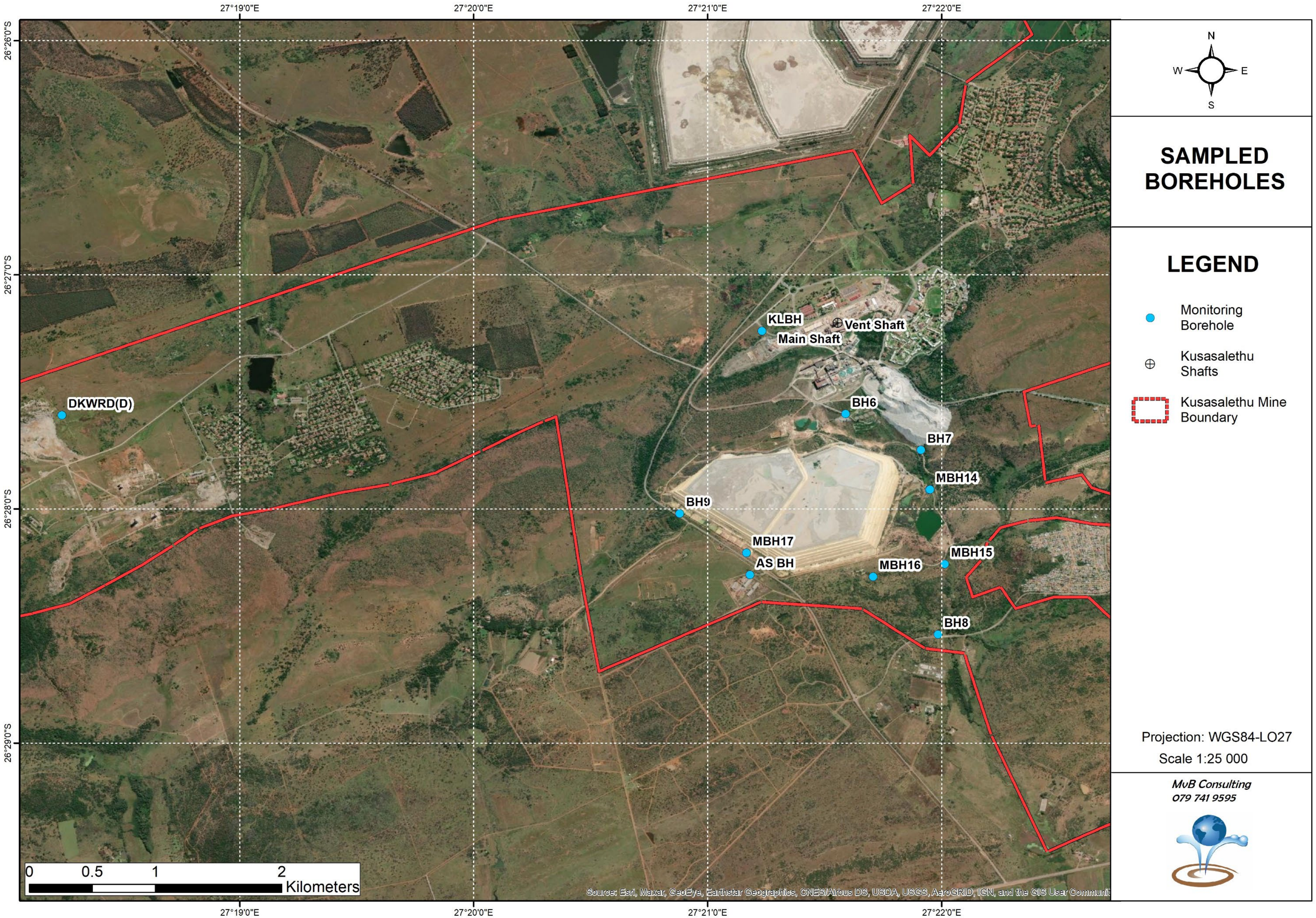

Figure 7.4: **Localities of the samples boreholes**

Table 7.3: Groundwater quality (November 2021)

Parameter	Unit	SANS 241	DWAF Livestock 1996	BH4 28 November 2021	BH6 28 November 2021	BH7 28 November 2021	BH8 28 November 2021	BH8S 28 November 2021	BH9 28 November 2021	MBH14 28 November 2021
pH	pH	≤5 - ≥9.7	NG	6.6	5.5	5.2	6.9	6.9	5.5	5.5
EC	mS/m	≤170	NG	130	109	147	241	213	226	132
TDS	mg/ℓ	≤1 200	<1000	1090	109	1250	2340	2100	1670	1030
Ca	mg/ℓ Ca	32*	<1000	136	72	194	293	217	104	127
Mg	mg/ℓ Mg	30*	<500	36	9.8	18	158	127	52	24
Na	mg/ℓ Na	<200	<2000	87	120	94	44	37	219	105
K	mg/ℓ K	<50*	NG	10	17	15	3.2	3.4	7.4	12
F	mg/ℓ F	<1.5	NG	0.1	0.2	0.4	0.6	0.5	0.4	0.2
T.Alk	mg $CaCO_3$/L	NG	NG	141	11	4.1	128	118	16	51
Cl	mg/ℓ Cl	<300	<1500	120	152	118	114	115	114	68
SO_4	mg/ℓ SO_4	<500	<1000	403	260	619	1040	875	792	478
NO_3-N	mg/ℓ N	<11	<100	8.2	18	18	2.7	4.0	1.8	13
Al	mg/ℓ Al	<0.3	<5	0.003	0.005	0.018	0.005	0.002	0.014	0.002
Fe	mg/ℓ Fe	<2	<10	0.007	0.007	0.004	0.004	0.002	7e-4	0.011
Mn	mg/ℓ Mn	<0.4	<10	1.434	0.5	0.58	10.3	7.6	31.4	1.37
Cu	mg/ℓ Cu	<2	<0.5	0.003	0.003	0.004	0.001	0.005	0.005	0.003
Zn	mg/ℓ Zn	<5	<20	0.02	0.2	0.08	0.001	0.016	0.16	0.073
Cr	mg/ℓ Cr	<0.05	<1	2e-5	2e-5	2e-4	2e-5	9e-5	6e-5	1e-4
Ni	mg/ℓ Ni	<0.07	<1	0.01	0.01	0.06	0.06	0.05	0.06	0.02
Co	mg/ℓ Co	NG	<1	0.04	0.06	0.08	0.18	0.15	0.42	0.04
Cd	mg/ℓ Cd	<0.003	<0.01	4e-5	3e-4	3e-4	2e-4	9e-5	6e-5	2e-4
U	mg/ℓ U	<0.07	NG	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Table 7.4: Groundwater monitoring results for catchment C23J (Loopspruit), December 2021

Parameter	Unit	SANS 241	DWAF Livestock 1996	Anglo BH	MBH14	MBH15	MBH16	MBH17	KLBH4	HYD
				December 2021		December 2021	December 2021	December 2021	Dec 2021	December 2021
pH	pH	≤5 - ≥9.7	NG			7.14	7.95	4.88	7.9	
EC	mS/m	≤170	NG			103	215	19.7	78.8	
TDS	mg/ℓ	≤1 200	<1000			722	1768	162	578	
Ca	mg/ℓ Ca	32*	<1000			142	226	12.8	70.9	
Mg	mg/ℓ Mg	30*	<500			34.6	120	7.54	33.0	
Na	mg/ℓ Na	<200	<2000			21.4	94.0	11.6	33.3	
K	mg/ℓ K	<50*	NG			14.1	23.9	0.170	4.82	
F	mg/ℓ F	<1.5	NG			<0.263	0.284	0.266	<0.263	
T.Alk	mg $CaCO_3$/L	NG	NG			50.8	753	13.7	42.1	
Cl	mg/ℓ Cl	<300	<1500			83.1	168	8.00	68.7	
SO_4	mg/ℓ SO_4	<500	<1000			340	484	65.2	139	
NO_3-N	mg/ℓ N	<11	<100			2.99	0.299	1.30	21.8	
Al	mg/ℓ Al	<0.3	<5			0.007	0.016	0.401	<0.002	
Fe	mg/ℓ Fe	<2	<10			<0.004	0.046	0.048	0.005	
Mn	mg/ℓ Mn	<0.4	<10			0.507	0.731	0.360	<0.001	
Cu	mg/ℓ Cu	<2	<0.5			<0.002	<0.002	0.003	<0.002	
Zn	mg/ℓ Zn	<5	<20			<0.002	<0.002	0.180	<0.002	
Cr	mg/ℓ Cr	<0.05	<1			<0.003	<0.003	<0.003	<0.003	
Ni	mg/ℓ Ni	<0.07	<1			<0.002	<0.002	0.094	<0.002	
Co	mg/ℓ Co	NG	<1			<0.003	0.044	0.048	<0.004	
Cd	mg/ℓ Cd	<0.003	<0.01			<0.002	<0.002	<0.002	0.002	
U	mg/ℓ U	<0.07	NG			<0.015	<0.015	<0.015	<0.015	

The following conclusions can be derived from **Table 7.3**:

- The groundwater samples obtained from the newly drilled boreholes are characteristic of mining impacted water. It is important to note that these boreholes are drilled close to potential contamination sources to monitor seepage.
- Groundwater contaminants commonly associated with gold tailings include sulphate, chloride, calcium, magnesium, manganese, and aluminium.
- Most of the samples are below neutral to slightly acidic, with elevated TDS, elevated salts and metals.
- Calcium exceeds the SANS 241 drinking water guidelines for all boreholes, and magnesium, sulphate and manganese exceed for some boreholes
- Where pH values are elevated above 6, the total alkalinity is elevated to around 120 mg/ℓ $CaCO_3$. The alkaline pH and presence of alkalinity could be indicative of either lime dosing or the presence of a body of calcium carbonate rock acting as a buffer to counter the acidity of the water. Despite the more alkaline pH, numerous parameters exceeding the SANS 241 Drinking water guidelines.
- Borehole BH8-shallow and deep was drilled to monitor the seepage towards the Wedela agricultural project (receptor). The borehole pair indicates mining impact. This borehole pair is some distance from the TSF and it is more likely that this impact is as a result with interaction from the nearby stream, which has also been affected by seepage from the mine infrastructure.
- Along the western side of the Kusasalethu TSF is borehole BH9 showing signatures of mining impacted water with elevated sulphate, calcium, magnesium, sodium which contributes to the elevated TDS value. In addition, the manganese concentration is also well above the guideline concentration. This borehole was drilled to monitor seepage from the south-western side of the TSF into a small stream.
- Borehole BH6 and BH7 are located near the plant and WWTW facility, respectively. The nitrate concentrations are elevated above the SANS 241 drinking water guidelines.

The following conclusions can be derived from the boreholes located in the Loopspruit catchment (**Table 7.4**):

- Boreholes Anglo Borehole. MBH14 and HYD1 could not be sampled during both sampling runs. MBH14 has been re-drilled since, as part of the MVB borehole drilling.
- Borehole MBH16 and MBH15 are down-gradient to the south, of the Kusasalethu TSF. These two boreholes show similar exceedances of calcium, magnesium, and manganese. Borehole MBH16, which is closer to the TSF also has elevated TDS and EC.
- It is important to note that the November 2021 results indicate that boreholes BH8s and BH8d appear to be more impacted than the downgradient MBH15 and MBH16 in December 2021, the chemistry fluctuates significantly and the spike in concentration could be attributed to an isolated event.
- Borehole KLBH appear to be largely unaffected. The borehole was drilled to monitor potential impact from an up-gradient waste rock terrace. The water quality is good.

8. AQUIFER CHARACTERISATION

8.1 Aquifer Classification and Vulnerability

An aquifer classification system provides a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection. This would facilitate the adoption of a policy of differentiated groundwater protection.

Other uses could include:

- Defining levels of investigation required for decision making.
- Setting of monitoring requirements.
- Allocation of manpower resources for contamination control functions.

The aquifer classification system used to classify the aquifers is the proposed National Aquifer Classification System of Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification. Parsons suggests that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues. He also suggests that some level of flexibility should be incorporated when using such a classification system.

The South African Aquifer System Management Classification is presented by five major classes:

- Sole Source Aquifer System.
- Major Aquifer System.
- Minor Aquifer System.
- Non-Aquifer System.
- Special Aquifer System.

The following definitions apply to the aquifer classification system:

- Sole source aquifer system: “An aquifer that is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonable alternative sources should the aquifer become depleted or impacted upon. Aquifer yields and natural water quality are immaterial”.
- Major aquifer system: “Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good”.
- Minor aquifer system: “These can be fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although this aquifer seldom produces large quantities of water, they are both important for local supplies 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 does occur, although imperceptible, and needs to be considered when assessing risk associated with persistent pollutants”.
- Special aquifer system: “An aquifer designated as such by the Minister of Water Affairs, after due process”.

A second variable classification is needed for sound decision making, as the ability of an aquifer to yield water to a particular user is not adequately stated. In this case it was decided to use the vulnerability of the aquifer to contamination as a second parameter (**Table 8.1**). A weighting and rating approach is then used to decide on the appropriate level of groundwater protection (**Table 8.2**).

Table 8.1: Ratings for the aquifer quality management classification system

Class	Points	Vulnerability	Points
Sole Source Aquifer System	6	**High**	3
Major Aquifer System	4	**Medium**	2
Minor Aquifer System	2	**Low**	1
Non-Aquifer System	0		
Special Aquifer System	0-6		

Table 8.2: Appropriate level of groundwater protection required

GQM Index	Level of Protection
<1	Limited Protection
1 – 3	Low Level Protection
3 – 6	Medium Level Protection
6 – 10	High Level Protection
>10	Strictly Non-degradation

After rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a Groundwater Quality Management (GQM) index.

Based on the above, the aquifer in the study area is classified as follows:

Description	Aquifer	Vulnerability	Rating	Protection
Weathered	Minor Aquifer (2)	2	4	Medium Level Protection
Fractured	Minor Aquifer (2)	2	4	Medium Level Protection
Dolomite	Major Aquifer (4)	2	8	High Level Protection

The weathered and fractured aquifer are not known to contain significant groundwater resources but could potentially be important for baseflow therefore these rivers deserve a rating of four and consequently require medium protection. North of the Deelkraal and Kusasalethu operations are dolomitic compartments which are known to contain large amounts of exploitable groundwater. These aquifers require high level protection against contamination and over-abstraction.

9. NUMERICAL MODEL

9.1 Introduction

The conceptual geohydrological model described in the previous section was translated to a calibrated numerical groundwater flow and mass transport model. The purpose of the model is mainly to use as a tool to simulate the following:

- Contaminant plume migration from the backfilled Kusasalethu Main Shaft over a period of 50 and 100 years.

The basic steps involved in modelling can be summarised as:

- *Collecting and interpreting field data:* Field data are essential to understand the natural system and to specify the investigated groundwater problem. The numerical model develops into a site-specific groundwater model when real field parameters are assigned. The quality of the simulations depends largely on the quality of the input data.
- *Calibration & validation:* Model calibration and validation are required to overcome the lack of input data, but they also accommodate the simplification of the natural system in the model. In model calibration, simulated values like potentiometric surface or concentrations are compared with field measurements. The model input data are altered within ranges, until the simulated and observed values are fitted within a chosen tolerance. Input data and comparison of simulated and measured values can be altered either manually or automatically.
- *Model validation:* Model validation is required to demonstrate that the model can be reliably used to make predictions. A common practice in validation is the comparison of the model with a data set not used in model calibration. Calibration and validation are accomplished if all known and available groundwater scenarios are reproduced by the model without varying the material properties or aquifer characteristics supplied to the model.
- *Modelling scenarios:* Alternative scenarios for a given area may be assessed efficiently. When applying numerical models in a predictive sense, limits exist in model application. Predictions of a relative nature are often more useful than those of an absolute nature.

9.2 Assumptions and Limitations

The following conditions typically need to be described in a model:

- Geological and geohydrological features.
- Boundary conditions of the study area (based on the geology and geohydrology).
- Initial groundwater levels of the study area.
- The processes governing groundwater flow.
- Assumptions for the selection of the most appropriate numerical code.

Field data is essential in solving the conditions listed above and developing the numerical model into a site-specific groundwater model. Specific assumptions related to the available field data include:

- The top of the aquifer is represented by the generated groundwater heads.
- The available geological / geohydrological information was used to describe the different aquifers. The available information on the geology and field tests is considered as correct.

To develop a model of an aquifer system, certain assumptions must be made. The following assumptions were made:

- The system is initially in equilibrium and therefore in steady state, even though natural conditions have been disturbed.
- No abstraction boreholes were included in the initial model.
- The boundary conditions assigned to the model are considered correct.
- The impacts of other activities (e.g., agriculture) have not been considered.

It is important to note that a numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that is available. This implies that there are always errors associated with groundwater models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes.

9.3 Model Set-up

To investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. FEFLOW, a modular three-dimensional finite element groundwater flow model was the software used during this investigation. It is an internationally accepted modelling package, which calculates the solution of the groundwater flow equation using the finite element approach.

The modelling area was selected based on a combination of topographical and drainage control and covers an area of approximately 1 577 km^2. The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulation results.

Network constructed for the site consists of 977 060 elements. It must be noted that the network was refined in the vicinity of sources of potential contamination.

The model consists of two layers and their associated hydraulic conductivities:

- A shallow weathered aquifer, subdivided into 11 sub-layers with various hydraulic conductivity, with a thickness of 25.00 metres
- A fractured aquifer, subdivided into 11 sub-layers with various hydraulic conductivity, and a thickness of 150.00 metres.

The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results. Once the network has been set up, all initial and boundary conditions, sources, sinks, and aquifer parameters are entered.

9.4 Model Boundary Conditions

One of the first and most demanding tasks in groundwater modelling is that of identifying the model area and its boundaries. Consequently, a model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries, however, must be specified. Boundaries occur at the edges of the model area and at locations in the model area where external influences are represented, such as rivers, boreholes, and leaky impoundments.

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

Boundary conditions must be specified for the entire boundary and may vary with time. At a given boundary section just one type of boundary condition can be assigned. As a simple example, it is not possible to specify groundwater flux and groundwater head at an identical boundary section. Boundaries in groundwater models can be specified as:

- Dirichlet (also known as constant head or constant concentration) boundary conditions.
- Neuman (or specified flux) boundary conditions.
- Cauchy (or a combination of Dirichlet and Neuman) boundary conditions.

The tributaries were set as constant head boundaries that were limited by a maximum hydraulic head set as a constraint. This is commonly used where small streams or non-perennial drainages occur within a model domain. Natural groundwater divides were set as no-flow boundaries.

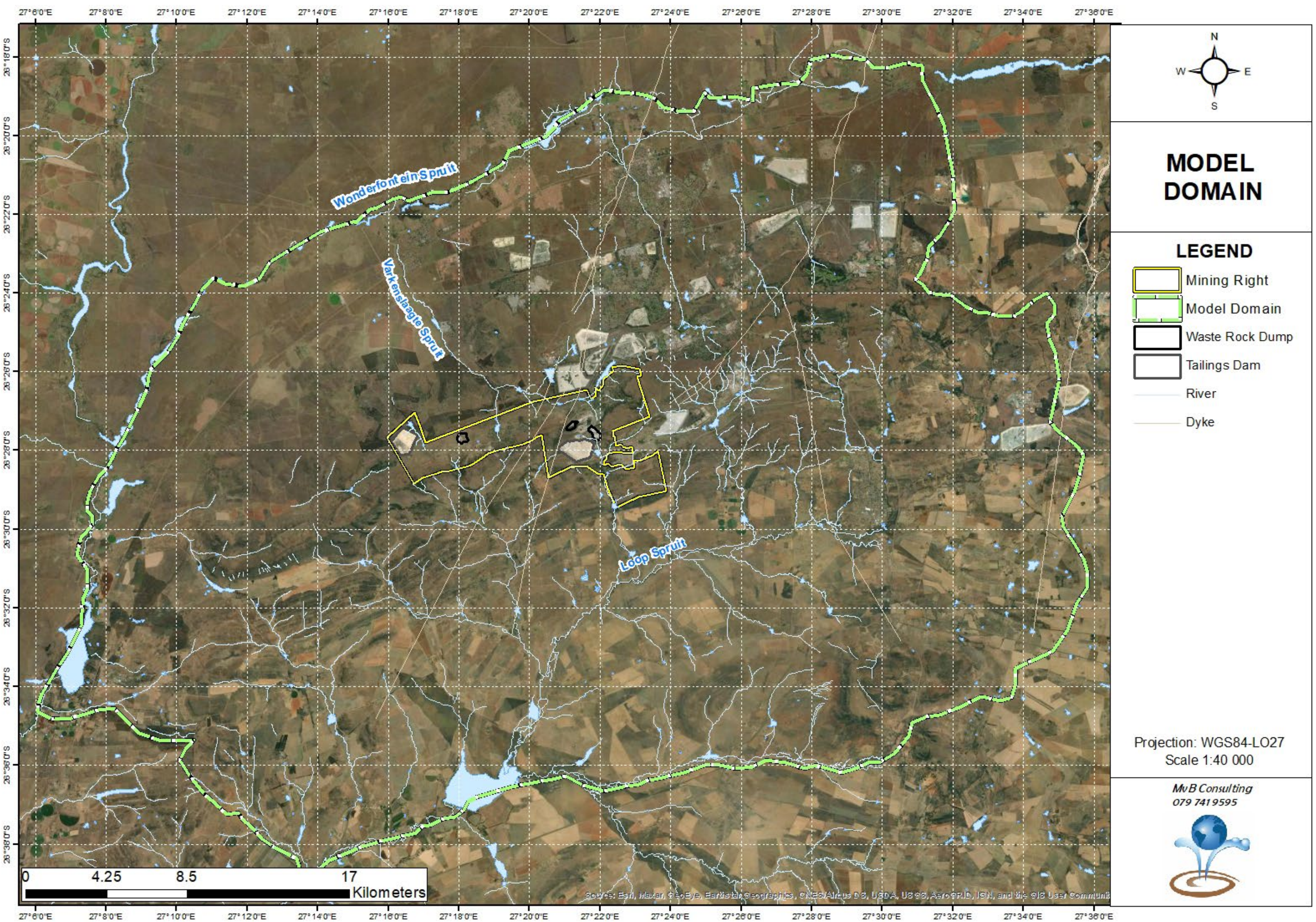

Figure 9.1: Model Domain

9.5 Initial Conditions

Initial conditions are vital for modelling flow problems. Initial conditions must be specified for the entire area. Generally, the initial water level/head distribution acts as the starting distribution for the numerical calculation. The water levels shown in **Table 7.3** were used as initial conditions for the model.

9.6 Sources and Sinks

Sources and sinks can be defined as recharge and abstraction sources in the aquifer. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, springs, evapotranspiration, and outflow to surface water. Initially only recharge due to precipitation was included in the model. The average mean annual precipitation (MAP) is approximately 569 mm/a. The effective recharge for the model was set to approximately 28 mm/a.

9.7 Aquifer Parameters

The aquifer parameters discussed in **Section 7.2.4** were initially used in the numerical model. The model is calibrated using the groundwater level elevations which are a function of the product of the saturated aquifer thickness, the hydraulic conductivity and effective aquifer recharge. Should the average aquifer thickness therefore be under/overestimated, this can be compensated for by adjustment of the hydraulic conductivity values during model calibration.

The simulated groundwater level distribution is compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correlation between measured and simulated heads is obtained. The calibration process was done by adjusting the model parameters for hydraulic conductivity (K) and recharge within a narrow range compatible with the historic data and geohydrological situation.

The calibrated hydraulic conductivities of the mining area are shown in **Table 9.1**.

Table 9.1: Modelled aquifer parameters

Model Layer	Hydrostratigraphic unit	Layer thickness (m)	Hydraulic Conductivity (K)		Recharge (Re)	Specific storage (Sc)
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)	In/Outflow on top/bottom (mm/a)	Sc (1/m)
Layer 1	Chuniespoort Group	25.00	1.000	0.100	28.0	1.0E-03
	Ecca Group		0.100	0.010	28.0	
	Pretoria Group (Siliciclastic rocks)		0.020	0.002	15.0	
	Pretoria Group (Mafic and Ultramafic volcanic rocks)		0.250	0.025	15.0	
	Pretoria Group (Silverton Formation)		0.400	0.040	15.0	
	Pretoria Group (Magaliesberg Formation)		0.050	0.005	28.0	
	Felsic rocks		0.060	0.006	28.0	
	Losberg Complex		0.050	0.005	28.0	
	Alluvial deposits		1.500	1.500	28.0	
	Dyke weathered perimeter		0.750	0.075	28.0	
	Dyke matrix		0.010	0.001	28.0	
	Chuniespoort Group		0.500	0.050		
	Ecca Group		0.050	0.005		

Layer 2	Pretoria Group (Siliciclastic rocks)	150.00	0.010	0.001	0.0	1.0E-05
	Pretoria Group (Mafic and Ultramafic volcanic rocks)		0.125	0.013		
	Pretoria Group (Silverton Formation)		0.200	0.020		
	Pretoria Group (Magaliesberg Formation)		0.025	0.003		
	Felsic rocks		0.030	0.003		
	Losberg Complex		0.025	0.003		
	Dyke weathered perimeter		0.375	0.038		
	Dyke matrix		0.005	0.001		

9.8 Calibration of the Model

A groundwater flow model for the study area was constructed to simulate disturbed groundwater flow conditions. The calibrated conditions serve as starting heads for the transient simulations of groundwater flow.

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

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

Where:

h	= hydraulic head [L].
K_x, K_y, K_z	= Hydraulic Conductivity [L/T].
S	= storage coefficient.
t	= time [T].
W	= source (recharge) or sink (pumping) per unit area [L/T].
x, y, z	= spatial co-ordinates [L].

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

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)\pm W = 0 \qquad (2)$$

The head distribution is dependent upon the recharge, hydraulic conductivity, sources, sinks and boundary conditions specified. For a given recharge component and set of boundary conditions, the head distribution across the aquifer can be obtained for a specific hydraulic conductivity value. The simulated head distribution can then be compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

The calibration process was done by changing the model parameters for hydraulic conductivity and recharge. Information obtained from the recently drilled boreholes were used to calibrate the groundwater flow. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads (**Table 9.2** and **Figure 9.2**).

Table 9.2: Flow calibration results

Calibration BH	Topographical Elevation (mamsl)	Water Level (mbgl)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)
BH02D	1587.19	48.45	1538.74	1568.60	-29.86	29.86	891.44
BH03D	1599.20	7.05	1592.15	1596.51	-4.36	4.36	19.00
BH4	1560.00	47.88	1512.12	1507.97	4.15	4.15	17.24
BH6	1610.59	17.53	1593.06	1594.81	-1.75	1.75	3.06
BH7	1587.42	2.78	1584.64	1586.93	-2.29	2.29	5.25
BH8D	1480.55	4.80	1475.75	1470.26	5.49	5.49	30.10
BH9	1553.91	2.87	1551.04	1557.30	-6.26	6.26	39.23
MBH14	1517.96	1.82	1516.14	1520.38	-4.24	4.24	17.96
MBH15	1500.01	2.17	1497.84	1480.61	17.23	17.23	297.05
MBH16	1517.12	5.72	1511.40	1492.51	18.89	18.89	356.87
MBH17	1544.82	17.03	1527.79	1540.66	-12.87	12.87	165.71
HYD1	1453.36	0.00	1453.36	1450.32	3.04	3.04	9.26
HYD2	1461.16	5.46	1455.70	1461.26	-5.56	5.56	30.86
HYD3	1468.53	3.92	1464.61	1464.78	-0.17	0.17	0.03
HYD4	1472.73	9.92	1462.81	1464.84	-2.03	2.03	4.10
HYD5	1461.07	5.21	1455.86	1460.20	-4.34	4.34	18.84
HYD6	1480.82	19.69	1461.13	1465.48	-4.35	4.35	18.91
HYD7	1481.55	18.85	1462.70	1466.16	-3.45	3.45	11.94
HYD8	1482.04	11.57	1470.47	1468.66	1.81	1.81	3.29
HYD9	1475.25	17.29	1457.96	1464.48	-6.52	6.52	42.51
HYD10	1476.53	18.62	1457.91	1464.15	-6.24	6.24	38.91
HYD11	1502.10	0.00	1502.10	1496.09	6.01	6.01	36.18
HYD12	1499.58	1.68	1497.90	1502.82	-4.92	4.92	24.23
HYD13	1503.41	17.28	1486.13	1508.20	-22.06	22.06	486.86
HYD14	1515.82	9.97	1505.85	1509.18	-3.33	3.33	11.12
Average	**1511.71**	**11.90**	**1499.81**	**1502.52**	**-2.72**	**7.25**	**103.20**
Minimum	**1453.36**	**0.00**	**1453.36**	**1450.32**	**-29.86**	**0.17**	**0.03**
Maximum	**1610.59**	**48.45**	**1593.06**	**1596.51**	**18.89**	**29.86**	**891.44**
Correlation			**0.98**				
∑					**-67.96**	**181.23**	**2579.93**
1/n					**-2.72**	**7.25**	**103.20**
Root Mean Square Deviation (RMSD)					**1.65**	**2.69**	**10.16**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)							**7.27**

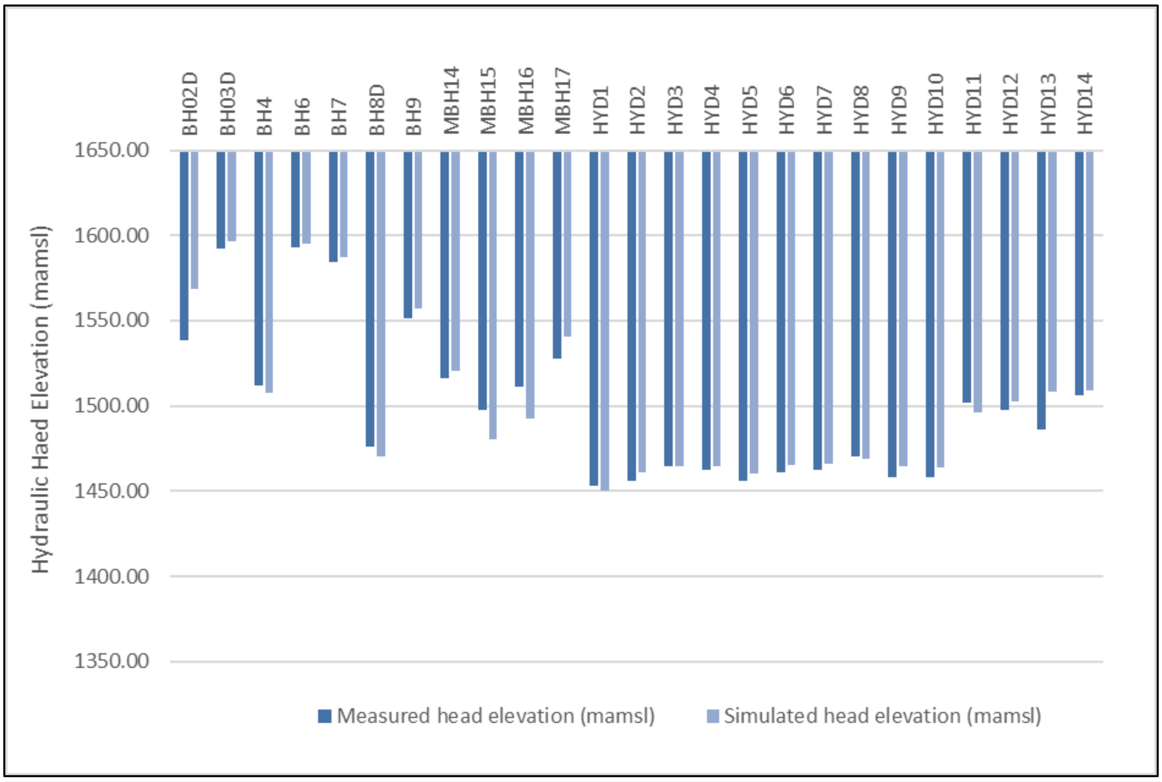

Figure 9.2: Model calibration – Groundwater levels

9.9 Numerical Groundwater Mass Transport Model

9.9.1 Waste Classification and Source Chemistry

The Kusasalethu Main Shaft was added as a point source to the existing mass transport model. The contaminant source concentration was based on a study conducted by Golder Associates in 2015 named *"ANGLOGOLD ASHANTI - Classification and Assessment of Five Tailings Storage Facilities"*. The following is a summary from the Golder Report.

AngloGold Ashani appointed Golder Associates Africa (Golder) to classify and assess tailings waste from five (5) Tailings Storage Facilities (TSF's), three in Vaal River and two in West Wits as well as water from the Return Water Dams (RWD's).

In terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R.635 of 23 August 2013), the potential level of risk associated with disposal of wastes can be determined by following the prescribed and appropriate leach test protocols. The results must be assessed against the four levels of thresholds for leachable and total concentrations, which in combination, determines the waste type and associated barrier design / liner requirements. The relevant terminology is as follows:

- LC = means the leachable concentration of a particular contaminant in a waste, expressed as mg/l.
- TC = means the total concentration of a particular contaminant in a waste, expressed as mg/kg.
- LCT= means the leachable concentration thresholds for particular contaminants in a waste (LCT0, LCT1, LCT2, LCT3).
- TCT= means the total concentration thresholds for particular contaminants in a waste (TCT0, TCT1, TCT2).

According to the Waste Classification Process, the waste needs to be analysed to determine total and leachable concentrations of potential Constituents of Concern (CoCs). The results are then compared to the threshold values to determine the waste type. In the case of containment facilities (PCDs, settling ponds, RWD's etc.), the composition of the water in the facility is assessed as the LC of CoC's. The type of waste is classified as follows (**Table 9.3**):

Table 9.3: NEMWA R 635 stipulation of criteria to evaluate waste for landfill disposal

Stipulated by NEMWA R 635	Criteria	Type Waste
Compare TC and LC of the waste sample to the TCT and LCT limits	LC > LCT3, or TC > TCT2	0
	LCT2 < LC ≤ LCT3 or TCT1< TC ≤ TCT2	1
	LCT1 < LC ≤ LCT2 or TC ≤ TCT1	2
	LCT0 < LC ≤ LCT1 and TC ≤ TCT1	3
	LC≤ LCT0 and TC < TCT0	4

Waste classification according to SANS 10234 (based on the Global Harmonised System) indicates physical, health and environmental hazards. The SANS 10234 covers the harmonised criteria for classification of potentially hazardous substances and mixtures, including wastes, in terms of its intrinsic properties/hazards.

The chemical test results and based here on the intrinsic properties of the waste streams were used for the SANS 10234 classification. Constituents present in concentrations exceeding 1% are used for classification in terms of health hazards, except when the constituent is known to be toxic at lower concentrations (carcinogens etc.) (**Table 9.4**).

Environmental hazard is based on toxicity to the aquatic ecosystem and distinguish between acute and chronic toxicity, bioaccumulation and biodegradation.

Table 9.4: Cut-off values/concentration limits for hazard classes (Golder, 2015)

Hazard class	Cut-off value (concentration limit) %
Acute toxicity	> 1.0
Skin corrosion	> 1.0
Skin irritation	> 1.0
Serious damage to eyes	> 1.0
Eye irritation	> 1.0
Respiratory sensitisation	> 1.0
Skin sensitisation	> 1.0
Mutagenicity: Category 1 Category 2	 > 0.1 > 1.0
Carcinogenicity	> 0.1
Reproductive toxicity	> 0.1
Target organ systemic toxicity	> 1.0
Hazardous to the aquatic environment	> 1.0

There are 5 TSFs at the Vaal River and West Wits plant area, namely Mponeng and Savuka within West Wits complex, and Kareerand, West complex and Mispah within the Vaal River complex. Tailings samples were collected from the abovementioned TSFs by using a soil auger and a spade. Due to the heterogeneous nature of the tailings facility, one composite sample per TSF were collected. A duplicate sample (Kareerand2) was taken for quality control purposes.

The sample names and numbers are indicated in **Table 9.5**.

Table 9.5: Sample names and numbers (Golder, 2015)

Water samples from RWD's		Tailings samples	
MPSW1	Mponeng TSF, West Wits	MPONENG	TSF, West Wits
MIDWAY1	Kareerand TSF, Vaal River	KAREERAND	TSF, Vaal River
MIDWAY2	Kareerand TSF, Vaal River	KAREERAND2	TSF, Vaal River
BOKAMP DAM	West Complex, Vaal River	WEST COMPLEX	TSF, Vaal River
MISPAH-RWD	Mispah TSF, Vaal River	MISPAH	TSF, Vaal River
SVK-SW1	Savuka TSF, West Wits	SAVUKA	TSF, West Wits

The water and tailings samples were submitted to an accredited laboratory, for the following analyses as prescribed by GN R. 635 of 2013

- Total digestion (aqua regia) of tailings samples followed by:
    - Semi-quantitative 33 element ICP scan, which covers the heavy metals of concern such as lead, copper, manganese, arsenic, uranium, etc.
- ASLP deionised water extract (1:20) of tailings samples followed by:
    - Semi-quantitative 33 element ICP scan, which covers the heavy metals of concern such as lead, copper, manganese, arsenic, uranium, etc.
    - Cations and anions including Ca, Na, K, Mg, SO_4, Cl_2, F_2, NH_4, NO_3, and pH.
- Water samples:
    - Semi-quantitative 33 element ICP scan, which covers the heavy metals of concern such as lead, copper, manganese, arsenic, uranium, etc.
    - Cations and anions including Ca, Na, K, Mg, SO_4, Cl_2, F_2, NH_4, NO_3, and pH.

Table 9.6 presents the analytical results (inorganic CoCs) of the aqua regia digestion of the tailings samples collected from the TSFs, compared to TCT levels. These results show the following:

- West Wits Area: Total Cu, As, Ni and Pb concentrations of the tailings samples were ≥ TCT0 level while the concentration of all other CoCs were below TCT0 levels.
- Vaal River Area: Total Cu, As and Pb concentrations of the tailings samples were ≥ TCT0 level while the concentration of all other CoCs were below TCT0 levels.

Table 9.6: Analytical results of aqua regia digestion of TSF sediment samples (Golder, 2015)

CoCs	TCT0	TCT1	TCT2	MPONENG	SAVUKA	KAREERAND	KAREERAND2	WEST COMPLEX	MISPAH
	mg/kg concentration of element								
Al	Ng			13 820	16 710	3 780	3 804	5 563	4 605
As	5.8	500	2 000	52.7	19.6	96.6	105.8	73.5	121.1
Ba	62.5	6 250	25 000	23	21	29	34	15	27
Ca	Ng			8 557	6 074	5 529	4 848	3 428	4 209
Cd	7.5	260	1 040	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Co	50	5 000	20 000	32.5	25.5	28.7	30.1	42	14.1
Cr	46 000	800 000	N/A	118.4	123.4	55	29.2	35.7	61.9
Cu	16	19 500	78 000	61	60	23	25	41	22
Fe	Ng			31 790	33 870	16 130	16 490	15 500	14 000
Hg	0.93	160	640	0.2	<0.1	0.1	0.2	<0.1	0.2
K	Ng			330	89	238	278	335	134
Mg	Ng			7 897	5 069	1 882	2 060	3 526	930
Mn	1 000	25 000	100 000	382	411	616	631	609	289
Mo	40	1 000	4 000	1.3	1.4	2.9	0.8	1	2.3
Na	Ng			424	67	323	402	169	81
Ni	91	10 600	42 400	132.1	96.5	53	53.7	83.8	41.3
Pb	20	1 900	7 600	67	34	52	56	42	110
Sb	10	75	300	3	3	2	2	2	2
Se	10	50	200	<1	<1	1	<1	<1	<1
Ti	Ng			954	813	53	56	94	30
U	Ng			<5	<5	10	12	47	<5
V	150	2 680	10 720	31	40	8	7	9	8
Zn	240	160 000	640 000	125	61	86	97	109	43
Grey: TC >TCT0 but < TCT1; Yellow: TC >TCT1 but <TCT2; Red: TC >TCT2									

The analytical results of the 1:20 deionised water extract of the tailings samples, compared to LCT levels, are shown in **Table 9.7**. These results show the following:

- All the tailings samples have acidic pH.
- Slightly elevated As concentrations in Kareerand 1 and 2 as well as Savuka samples, exceeding LCT0 levels.
- Elevated Mn and Ni concentrations in West Complex and Mispah tailings, exceeding the LCT0 level, while the leachable Mn and Ni in the rest of the tailings samples were < LCT0 levels.
- Elevated SO_4 concentrations in all tailings except Savuka, exceeding LCT0 but still lower than LCT1 levels.

The analytical results of the water samples collected from the RWDs are presented in and **Table 9.8**. The following CoC were present in elevated concentrations:

- As concentration in Midway1 exceeded the LCT0 level.
- Co concentrations in Midway1, Midway2 and Mispah RWDs exceeded the LCT0 level.
- Cu concentrations in SVK-SW1 and Midway1 exceeded the LCT0 level.
- Mn, Ni and SO_4 concentrations in all the RWDs exceeded the LCT0 levels.
- Se concentrations in MPSW1, Midway1, Midway2 and Mispah RWDs exceeded the LCT0 level.
- Cl concentration in MPSW1 and Mispah RWD exceeded the LCT0 level.
- NO_3 concentrations in MPSW1, Mispah RWD and Bokamp Dam exceed the LCT0 level.

Table 9.7: Analytical results of Tailings leachate (Golder, 2015)

CoCs	LCT0	LCT1	LCT2	LCT3	MPONENG	KAREERAND1	KAREERAND2	WEST COMPLEX	MISPAH	SAVUKA
	mg/l concentration of element in 1:20 extract									
Al	Ng				0.115	0.079	0.075	<0.020	3.004	0.228
As	0.01	0.5	1	4	<0.0025	0.0115	0.0109	<0.0025	0.0058	0.0243
Ba	0.7	35	70	280	0.011	0.025	0.025	0.006	0.013	<0.003
Ca	Ng				134	164.1	169.4	90.5	265.7	31.7
Cd	0.003	0.15	0.3	1.2	<0.0005	<0.0005	<0.0005	0.0018	0.0024	<0.0005
Co	0.5	25	50	200	0.006	0.079	0.087	0.487	0.281	0.01
Cr	0.1	5	10	40	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Cr(VI)	0.05	2.5	5	20						
Cu	2	100	200	800	<0.007	<0.007	<0.007	<0.007	0.015	<0.007
Fe	Ng				0.049	<0.020	<0.020	<0.020	0.917	0.119
Hg	0.006	0.3	0.6	2.4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
K	Ng				4.6	2.1	2.3	1.2	1.7	2.3
Mg	Ng				8.4	5.2	5.9	11.4	11.8	1.1
Mn	0.5	25	50	200	0.013	0.252	0.254	9.106	7.044	<0.002
Mo	0.07	3.5	7	28	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Na	Ng				32.3	12.2	13.9	2.5	9.1	7.1
Ni	0.07	3.5	7	28	0.002	<0.002	<0.002	0.754	0.433	<0.002
P	Ng				<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb	0.01	0.5	1	4	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sb	0.02	1	2	8	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Se	0.01	0.5	1	4	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
U	Ng				0.025	<0.01	<0.01	0.036	0.278	0.012
V	0.2	10	20	80	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	0.0017
Zn	5	250	500	2 000	0.004	0.004	0.004	0.377	0.418	0.003
pH	Ng				5.01	4.16	4.12	4.08	3.3	3.73
Cl	300	15 000	30 000	120 000	37.1	5.5	6.4	0.9	8.7	2.8
SO_4	250	12 500	25 000	100 000	350.63	418.61	424.67	270.04	583.25	75.64
NO_3	11	550	1 100	4 400	1.3	1.9	2.3	0.6	6.1	0.3
F	1.5	75	150	600	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Grey: TC >LCT0 but <LCT1; Yellow: TC >LCT1 but <LCT2; Orange: TC >LCT2 but <LCT3; Red: >LCT3										

Table 9.8: Analytical results of RWD water samples (Golder, 2015)

CoCs	LCT0	LCT1	LCT2	LCT3	MPSW1	SVK-SW1	MIDWAY1	MIDWAY2	MISPAH RWD	BOKAMP DAM
	mg/l concentration of element in 1:20 extract									
Al	Ng				<0.02	<0.02	<0.02	<0.02	0.035	<0.02
As	0.01	0.5	1	4	<0.0025	<0.0025	0.0131	0.0088	0.0083	0.0063
B	0.5	25	50	200	0.139	0.165	0.049	0.05	0.127	0.068
Ba	0.7	35	70	280	0.054	0.04	0.017	0.02	0.044	0.034
Ca	Ng				395.3	337.1	605.7	554.5	545.1	297.7
Cd	0.003	0.15	0.3	1.2	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Co	0.5	25	50	200	0.205	0.307	2.493	2.495	1.026	0.207
Cr	0.1	5	10	40	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Cr(VI)	0.05	2.5	5	20						
Cu	2	100	200	800	0.536	9.651	2.699	2.698	0.482	1.954
Fe	Ng				0.092	0.701	<0.02	<0.02	0.033	0.227
Hg	0.006	0.3	0.6	2.4	<0.001	<0.001	0.002	0.002	<0.001	<0.001
K	Ng				81	50.4	35.4	34.8	80.7	50.2
Mg	Ng				42.7	24.7	80.6	81.3	90.6	45.8
Mn	0.5	25	50	200	3.387	0.871	0.581	0.584	24.34	6.95
Mo	0.07	3.5	7	28	0.041	0.05	0.04	0.04	0.029	0.027
Na	Ng				1279	370	602.8	549	752	341.5
Ni	0.07	3.5	7	28	1.76	0.67	2.187	2.184	1.404	0.241
Pb	0.01	0.5	1	4	<0.005	0.008	0.005	<0.005	0.006	<0.005

CoCs	LCT0	LCT1	LCT2	LCT3	MPSW1	SVK-SW1	MIDWAY1	MIDWAY2	MISPAH RWD	BOKAMP DAM
	mg/l concentration of element in 1:20 extract									
Sb	0.02	1	2	8	0.012	0.011	<0.002	<0.002	<0.002	0.003
Se	0.01	0.5	1	4	0.013	<0.003	0.021	0.019	0.013	<0.003
Sr	Ng				1.699	1.212	0.593	0.6	0.971	0.495
U	Ng				<0.005	<0.005	0.236	0.236	0.111	0.01
V	0.2	10	20	80	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Zn	5	250	500	2 000	0.03	0.05	0.088	0.09	0.108	0.022
pH	Ng				7.99	8.38	8.28	8.29	7.81	8.01
Cl	300	15 000	30 000	120 000	1 142.4	272.4	253.1	255.3	388	166.6
SO_4	250	12 500	25 000	100 000	1 407.3	1 181.44	2 305.43	2 276.59	2 516.49	1 216.56
NO_3	11	550	1 100	4 400	55	4.3	9.9	9.7	29.2	18
F	1.5	75	150	600	0.4	0.3	-	-	-	-
Grey: TC >LCT0 but <LCT1; Yellow: TC >LCT1 but <LCT2; Orange: TC >LCT2 but <LCT3; Red: >LCT3										

The tailings is classified as follows in terms of SANS 10234:

- Physical hazards - Tailings is not explosive, flammable or oxidising and does not release toxic gases when in contact with water or acid. Therefore, it is not hazardous in terms of physical characteristics.
- Health hazards – Constituents present in the Tailings concentrations > 1% include Al (1.3 – 1.6 %) and Fe (1.4 – 3.4 %) (**Table 9.6**), but these constituents do not constitute a health risk.

  Other CoC's present in the tailings in elevated concentrations include As, Cu, Ni (Mponeng and Savuka) and Pb, but the total concentrations of these CoC's were lower than 0.1% (cut-off limit for carcinogens) and the soluble concentrations were below detection in the majority of samples. Although As, Ni and Pb are considered to be carcinogenic and hazardous to human health at these low concentrations it will not pose an unacceptable risk to human health.

  The total U concentrations in all the tailings samples were < 0.005% and will not pose unacceptable risk to human health.

  Based on this assessment, the total and soluble concentrations of CoCs in the tailings and RWD samples are too low to pose an unacceptable risk to human health and the tailings is not hazardous.
- Environmental hazard – The total concentration of the Al and Fe in the Tailings exceed the cut-off limit of 1%. The leachable concentrations of As, Mn, Ni and SO_4 in the tailings samples were elevated (**Table 9.7**) and the Co, Cu, Mn, Ni, Se, Cl, NO_3 and SO_4 concentrations in the RWD were elevated (**Table 9.8**).

  Due to these elevated concentrations of CoCs, the Tailings are considered to pose an environmental risk (harmful to aquatic life) and are hazardous in terms of SANS 10234. The sediment from the RWD will also be hazardous based on the elevated soluble concentrations of CoC's represented by the RWD water samples.

9.9.2 Numerical Model Input

Mass transport modelling in this situation refers to the simulation of water contamination or pollution due to deteriorating water quality in response to man's disturbance of the natural environment (for example residue deposits). Transport through a medium is mainly controlled by the following two processes:

- Advection is the component of contaminant movement described by Darcy's Law. If uniform flow at a velocity V takes place in the aquifer, Darcy's law calculates the distance (x) over which a labelled water particle migrates over a time period t as x = Vt.
- Hydrodynamic dispersion comprises two processes:
  - Mechanical dispersion is the process whereby the initially close group of labelled particles are spread in a longitudinal as well as in a transverse direction because of the velocity distribution (as a result of varying microscopic streamlines) that develops at the microscopic level of flow around the grain particles of the porous medium. Although this spreading is both in the longitudinal and transversal direction of flow, it is primarily in the former direction. Very little spreading can be caused in the transversal direction by velocity variations alone.

- Molecular diffusion mainly causes transversal spreading, by the random movement of the molecules in the fluid from higher contaminant concentrations to lower ones. It is thus clear that if V = 0, the contaminant is transported by molecular diffusion, only or in other words the higher the velocity of the groundwater, the less the relative effect of molecular diffusion on the transportation of a labelled particle.

In addition to advection, mechanical dispersion and molecular diffusion, several other phenomena may affect the concentration distribution of a contaminant as it moves through a medium. The contaminant may interact with the solid surface of the porous matrix in the form of adsorption of contaminant particles on the solid surface, deposition, solution of the solid matrix and ion exchange. All these phenomena cause changes in the concentration of a contaminant in a flowing fluid.

The FEFLOW software was used to provide numerical solutions for the concentration values in the aquifer in time and space. The required input into the model includes:

- Input concentrations of contaminants.
- Hydraulic conductivity values.
- Porosity values.
- Longitudinal dispersivities.
- Transversal dispersivities.
- Hydraulic heads/water levels in the aquifer over time.

Input concentrations in the model were specified at nodes over the areas where contamination is expected. Transmissivities for the aquifer were specified according to the values obtained during the steady state water level calibration. A longitudinal dispersivity value of 100 m was selected for the simulations (see Spitz and Morene, 1996; and Bear and Verruijt, 1992) estimated the average transversal dispersivity to be 10 to 20 times smaller than the longitudinal dispersivity. An average value of 10 m was selected for this parameter during the simulations.

Sulphate (SO_4) is considered a conservative tracer that is representative of the impacts from the mining waste on the groundwater. However, based on the geochemical assessment the sulphate concentrations in the tailings material was found to be relatively low (<500 mg/L). The manganese (Mn) concentrations are, however, elevated (up to 8 mg/L) and it was therefore decided to model both parameters to obtain a fair assessment of the possible impacts.

The source concentrations that were included in the numerical model are as follows:

- Sulphate (SO_4) 500 mg/L.
- Manganese (Mn) 8 mg/L.

10. GEOHYDROLOGICAL IMPACTS

10.1 Introduction

To address the objectives of this study, a mass transport model was used to simulate the potential impacts of backfilling the shaft with tailings material. There are two possible scenarios when backfilling the shaft with tailings (**Figure 10.1**):

- **Scenario A**: The shaft liner is intact and there is no interaction between the material in the shaft and the surrounding aquifer. Groundwater will flow around the backfilled shaft.
- **Scenario B**: The shaft liner has been compromised and groundwater can flow into and through the tailings material in the shaft.

In Scenario A there is no possible contaminant impact, and this option was therefore not modelled. The model simulations assumed the worst-case scenario, which is Scenario B.

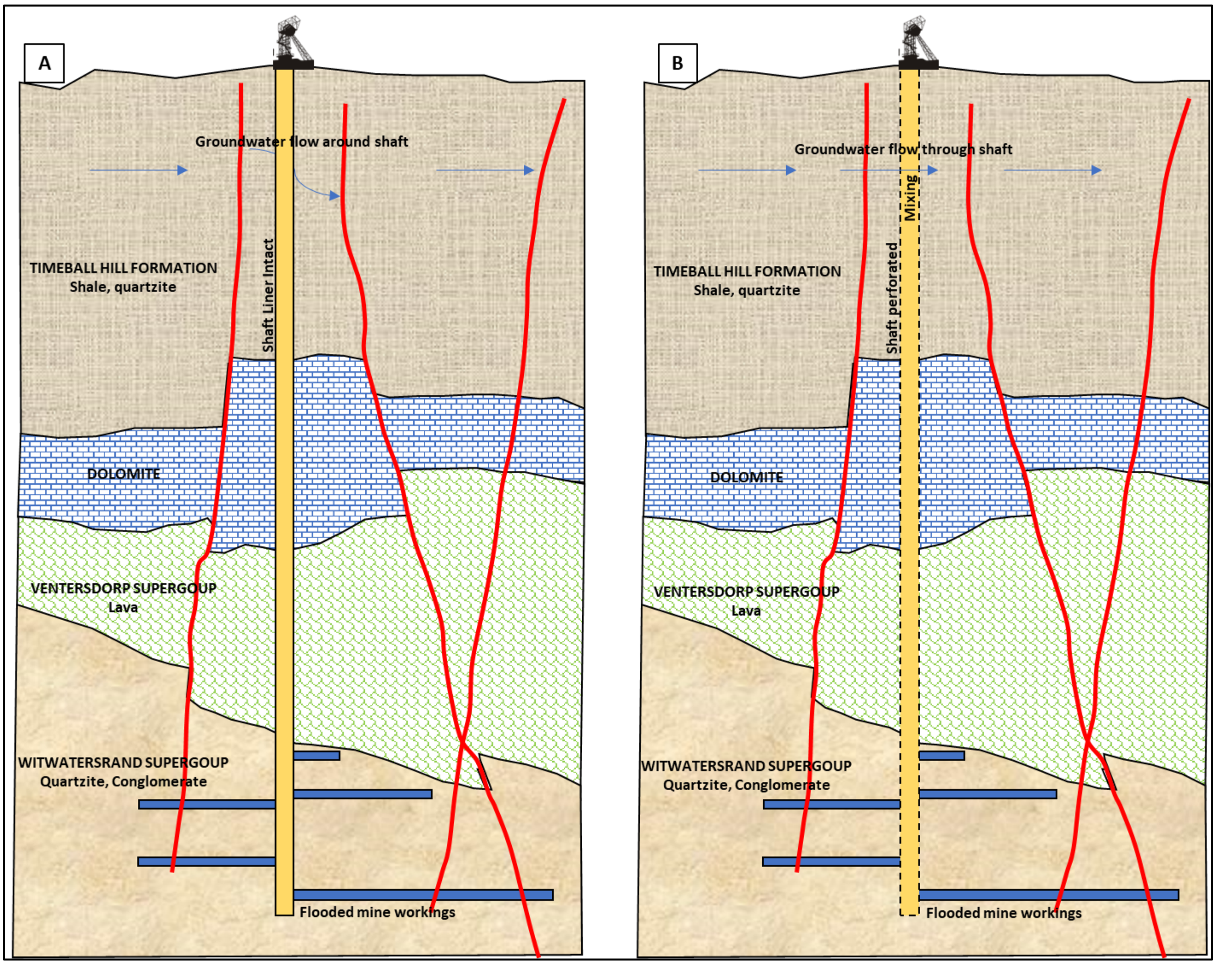

Figure 10.1: Bacfilling scenarios

The numerical model was used to simulate the following scenarios:

- Sulphate contaminant plume migration after 50 and 100 years.
- Manganese contaminant plume migration after 50 and 100 years.

Simulations were conducted for both the weathered and fractured aquifers. The modelling results are summarised in the chapters below. Only the potential impact from backfilling the Kusasalethu Main Shaft is presented below. Current and future impacts from the Waste Rock Dumps and Tailings Facilities are excluded from this assessment.

10.2 Simulated Sulphate Contaminant Plumes

The simulated sulphate plumes that may potentially emanate from the backfilled Main Shaft are presented in **Figure 10.2** to **Figure 10.5**. The contour intervals are loosely based on the national drinking water guidelines.

- According to the South African Water Quality Guidelines (second edition). Volume 1: Domestic Use (DWAF, 1996) the target water quality for sulphate is 200 mg/L (Orange contour interval).
- According to SANS 241 (2015) guideline limits the concentrations should be ≤500 mg/L (Red contour interval).

The expected impacts are as follows:

- Based on the SANS 241 guideline the non-compliant plume (<500 mg/L), which is also the source plume, in the weathered aquifer would migrate in a southerly direction over a distance of 60m in 50 years (**Figure 10.2**) and 70m after 100 years (**Figure 10.3**).
- Based on the SANS 241 guideline the non-compliant plume (<500 mg/L) in the fractured aquifer would migrate in a southerly direction over a distance of 120m in 50 years (**Figure 10.4**) and 130m after 100 years (**Figure 10.5**).
- Based on the DWAF 1996 guideline the non-compliant plume (<200 mg/L) in the weathered aquifer would migrate in a southerly direction over a distance of 115m in 50 years (**Figure 10.2**) and 125m after 100 years (**Figure 10.3**).
- Based on the DWAF 1996 guideline the non-compliant plume (<200 mg/L) in the fractured aquifer would migrate in a southerly direction over a distance of 255m in 50 years (**Figure 10.4**) and 260m after 100 years (**Figure 10.5**).
- Plume migration is generally quicker in the fractured aquifer due to lower porosity values than those in the weathered aquifer.
- Due to the low sulphate source concentration (500 mg/L) the sulphate impact is very low.
- In all instances the plume (represented by the worst-case scenario of 200 mg/L) remains within the mine property and does not impact on any down-gradient receptors.

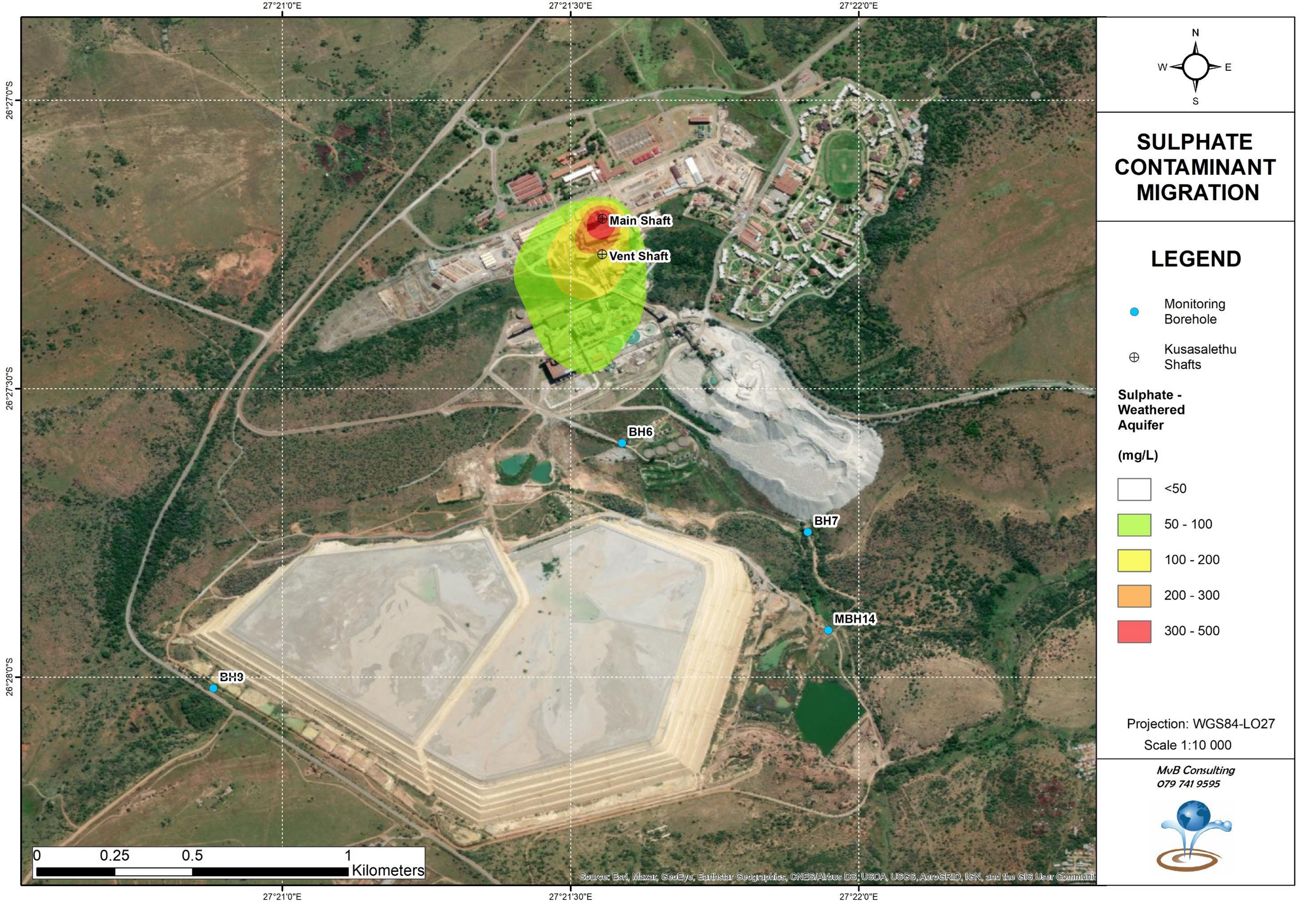

Figure 10.2: Simulated sulphate plume in the weathered aquifer after 50 years

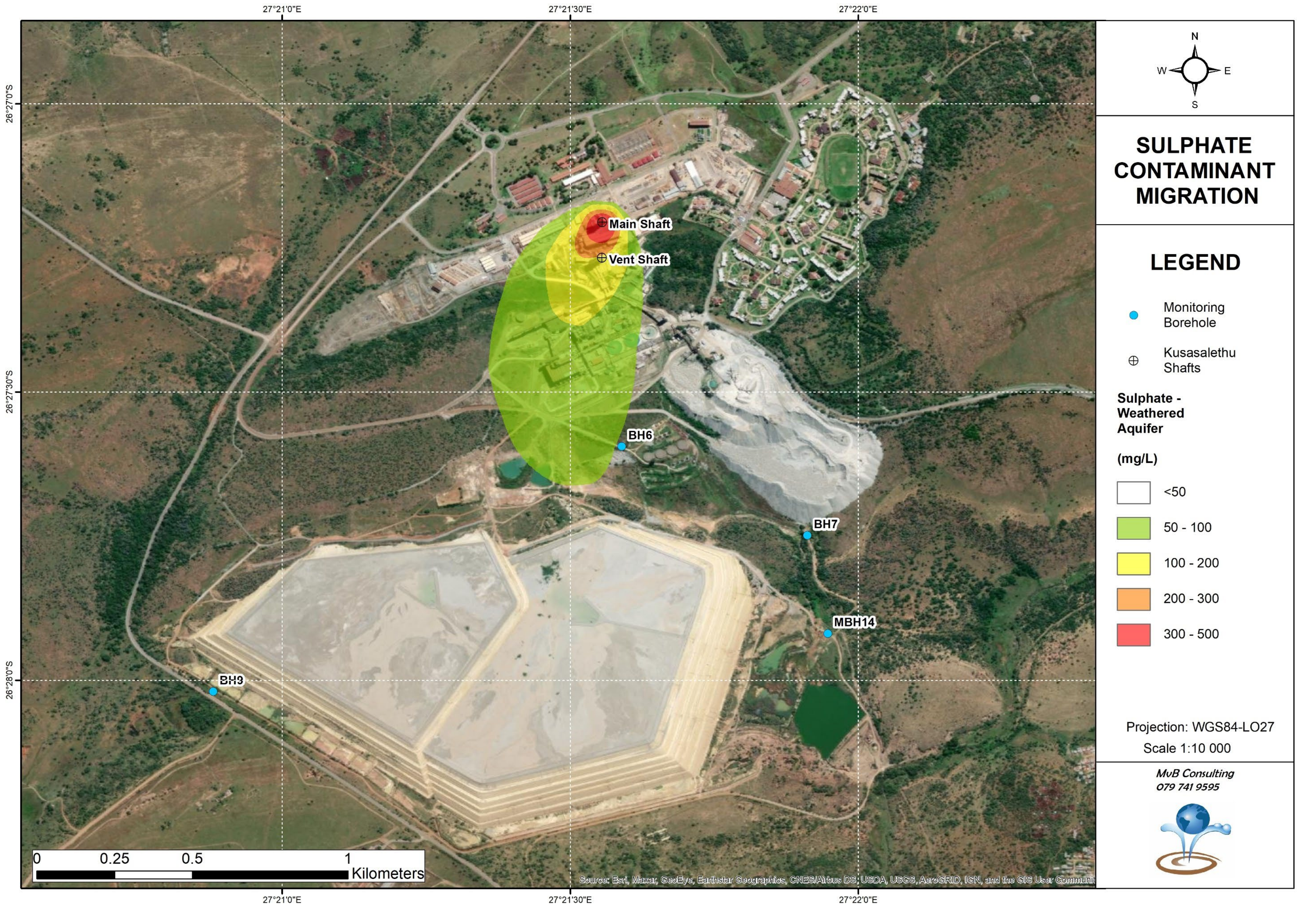

Figure 10.3: Simulated sulphate plume in the weathered aquifer after 100 years

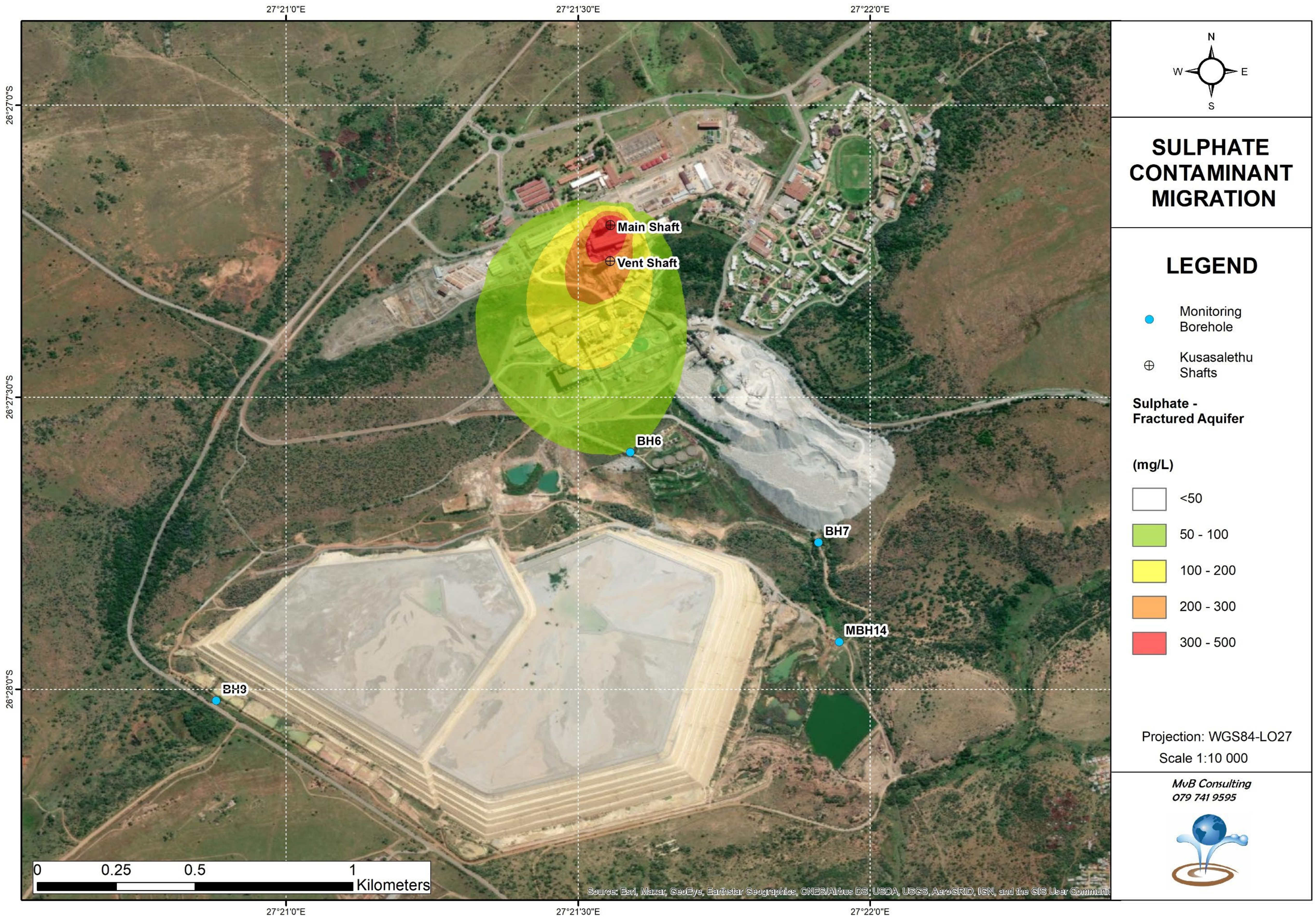

Figure 10.4: **Simulated sulphate plume in the fractured aquifer after 50 years**

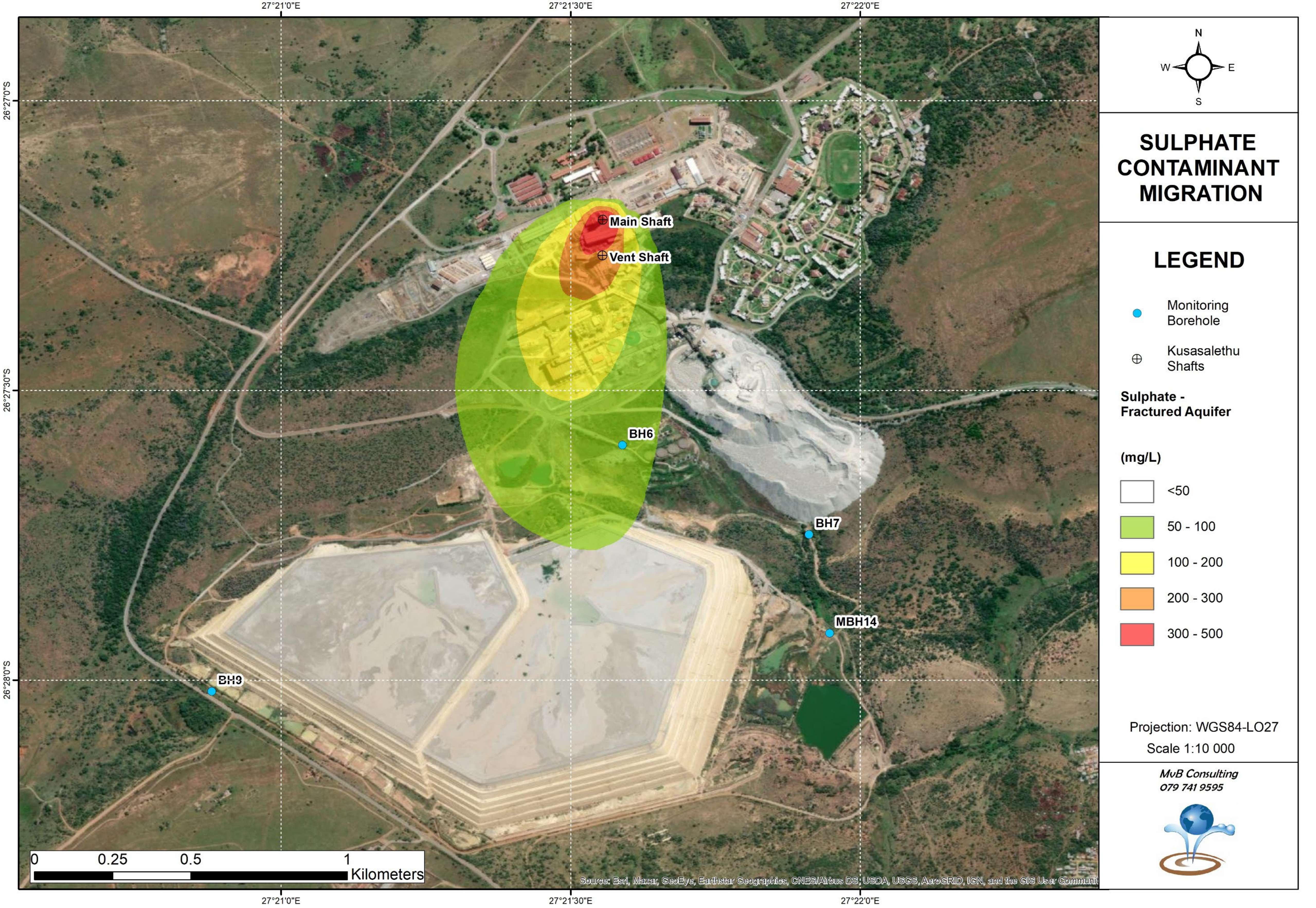

Figure 10.5: **Simulated sulphate plume in the fractured aquifer after 100 years**

Monitoring boreholes BH6 and BH7 were included in the model as observation points and the sulphate load increase over time to these boreholes are shown in **Figure 10.6**. The sulphate concentrations in these boreholes all remain below the SANS 241 guidelines for drinking water and only BH7 exceed the DWAF 1996 drinking water guidelines after six years.

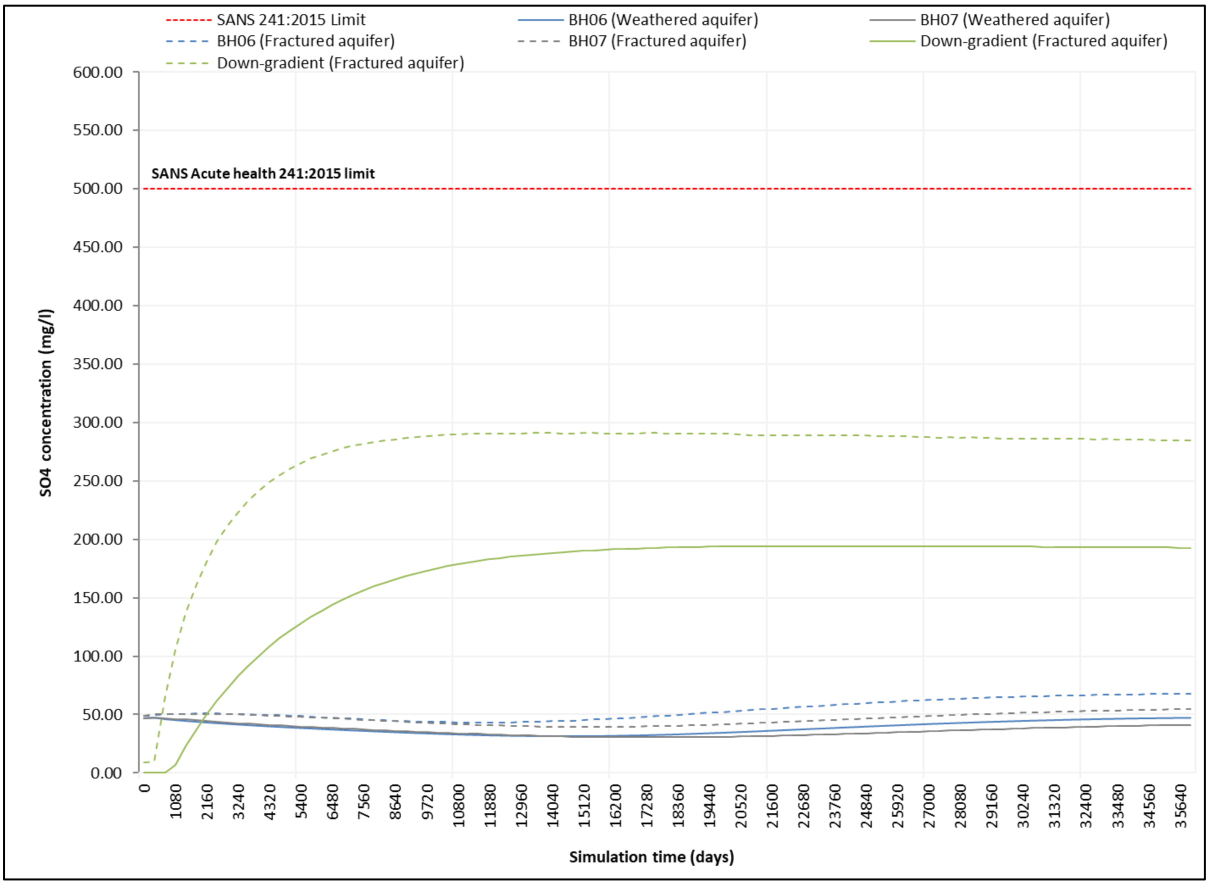

Figure 10.6: Sulphate load to boreholes BH6 and BH7 over time

10.3 Simulated Manganese Contaminant Plumes

The simulated manganese plumes that may potentially emanate from the backfilled Main Shaft are presented in **Figure 10.7** to **Figure 10.10**. The contour intervals are also based on the national drinking water guidelines.

- According to the South African Water Quality Guidelines (second edition). Volume 1: Domestic Use (DWAF, 1996) the target water quality for manganese is 0.1 mg/L. Health effects are only likely to occur at concentrations >14 mg/L based on these guidelines.
- According to SANS 241 (2015) aesthetic guideline limits the concentrations should be ≤0.1 mg/L and ≤0.4 mg/L Green contour interval) for the chronic health guideline limits.

The expected impacts are as follows:

- Based on the SANS 241 guideline the non-compliant plume (<0.4 mg/L) in the weathered aquifer would migrate in a southerly direction over a distance of 880m in 50 years (**Figure 10.7**) and 1 800m after 100 years (**Figure 10.8**).
- Based on the SANS 241 guideline the non-compliant plume (<0.4 mg/L) in the fractured aquifer would migrate in a southerly direction over a distance of 1 060m in 50 years (**Figure 10.9**) and 1 900m after 100 years (**Figure 10.10**).

- The source plume (8 mg/L) in the weathered aquifer would migrate in a southerly direction over a distance of 110m in 50 years (**Figure 10.7**) and 130m after 100 years (**Figure 10.8**).
- The source plume (8 mg/L) in the fractured aquifer would migrate in a southerly direction over a distance of 225m in 50 years (**Figure 10.9**) and 250m after 100 years (**Figure 10.10**).
- Plume migration is generally quicker in the fractured aquifer due to lower porosity values than those in the weathered aquifer.
- The manganese plume also remains within the mine property over the 100-year simulation period. The source concentration impact of 8 mg/L only migrates a maximum distance of 250m from the shaft, which classifies this impact as minor.

Figure 10.7: **Simulated manganese plume in the weathered aquifer after 50 years**

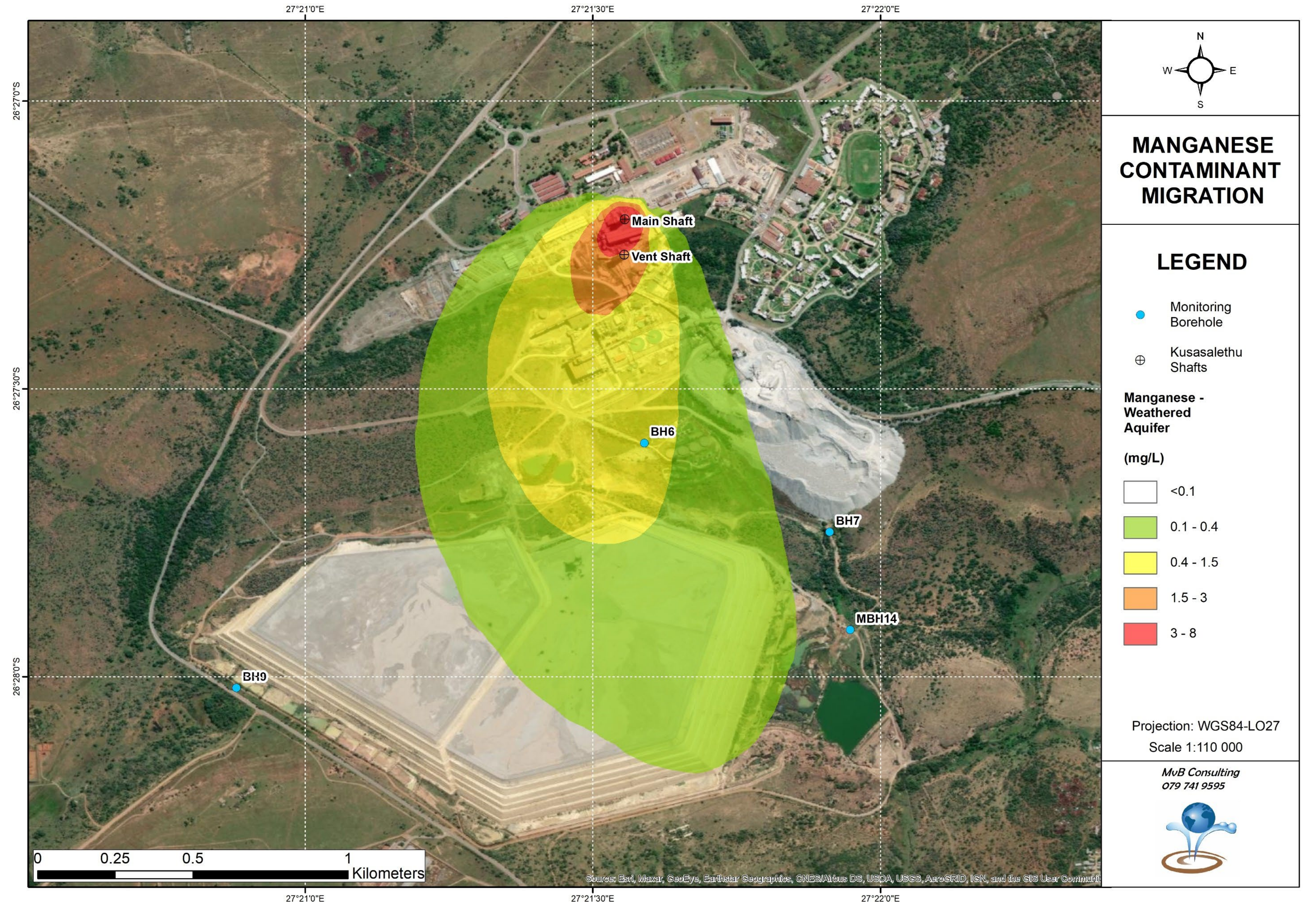

Figure 10.8: Simulated manganese plume in the weathered aquifer after 100 years

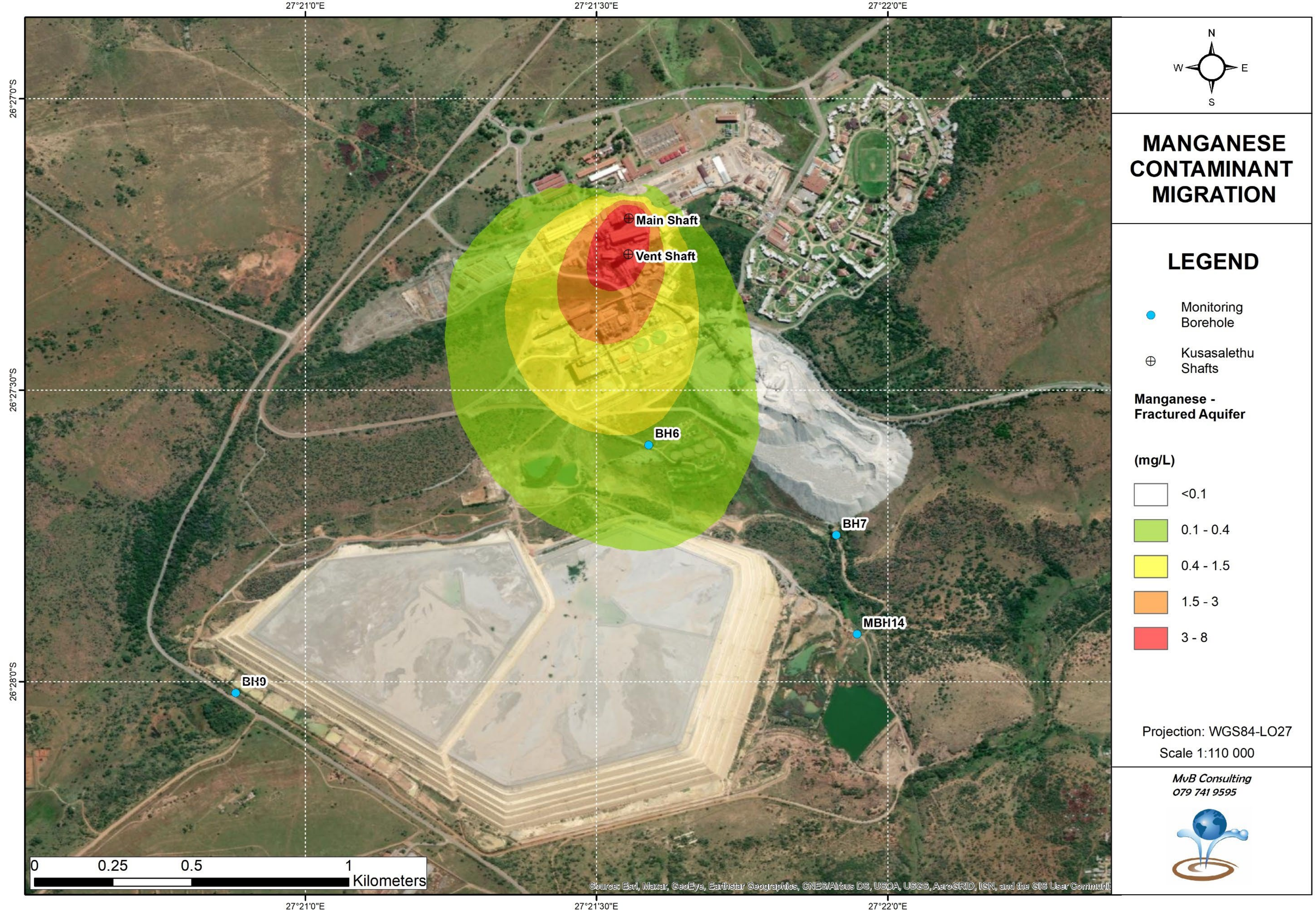

Figure 10.9: Simulated manganese plume in the fractured aquifer after 50 years

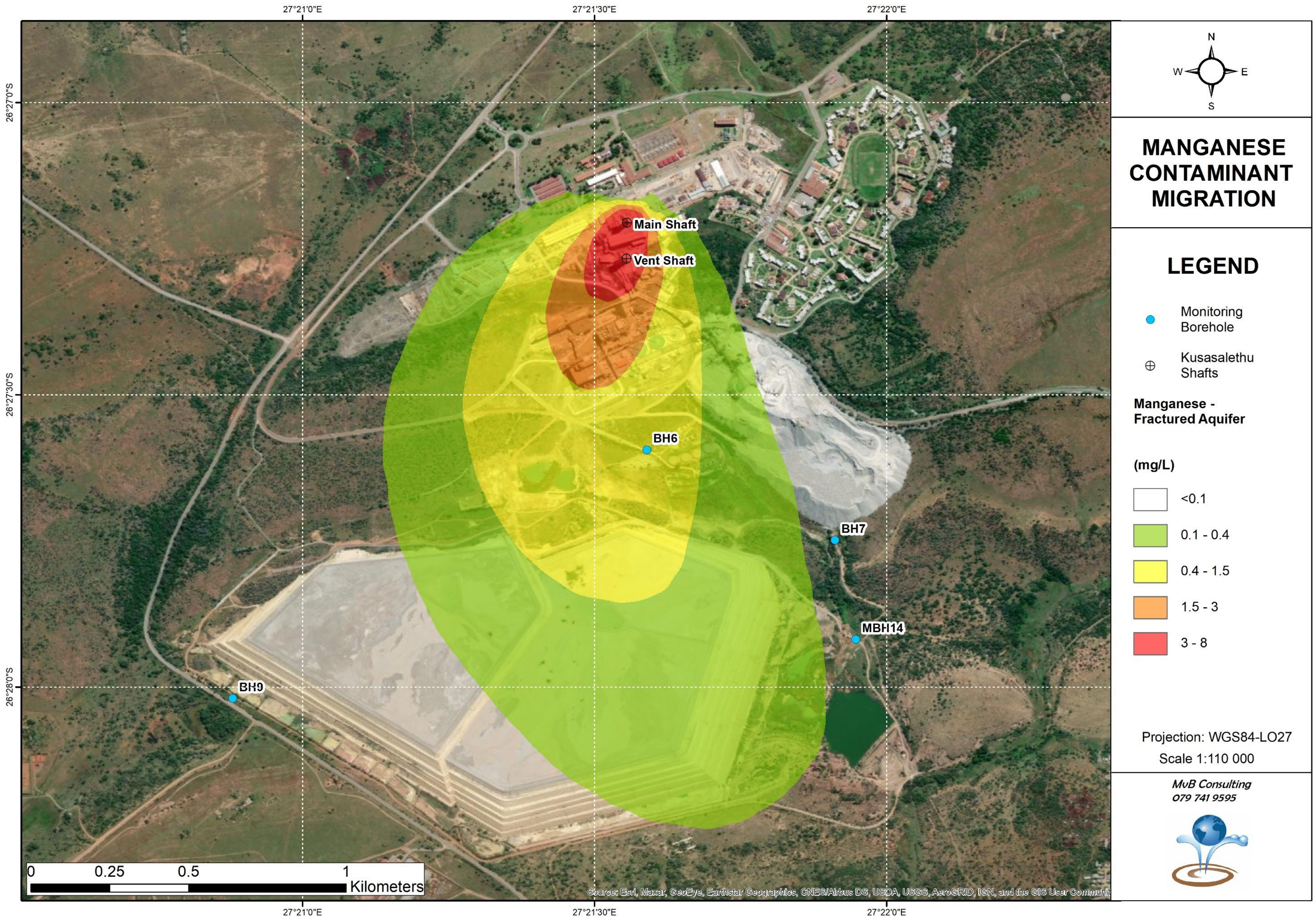

Figure 10.10: Simulated manganese plume in the fractured aquifer after 100 years

Monitoring boreholes BH6 and BH7 were included in the model as observation points and the manganese load increase over time to these boreholes are shown in **Figure 10.11**. The manganese concentration in borehole BH7 is expected to exceed the SANS 241 guidelines for drinking water and BH6 will exceed the limits after 54 years.

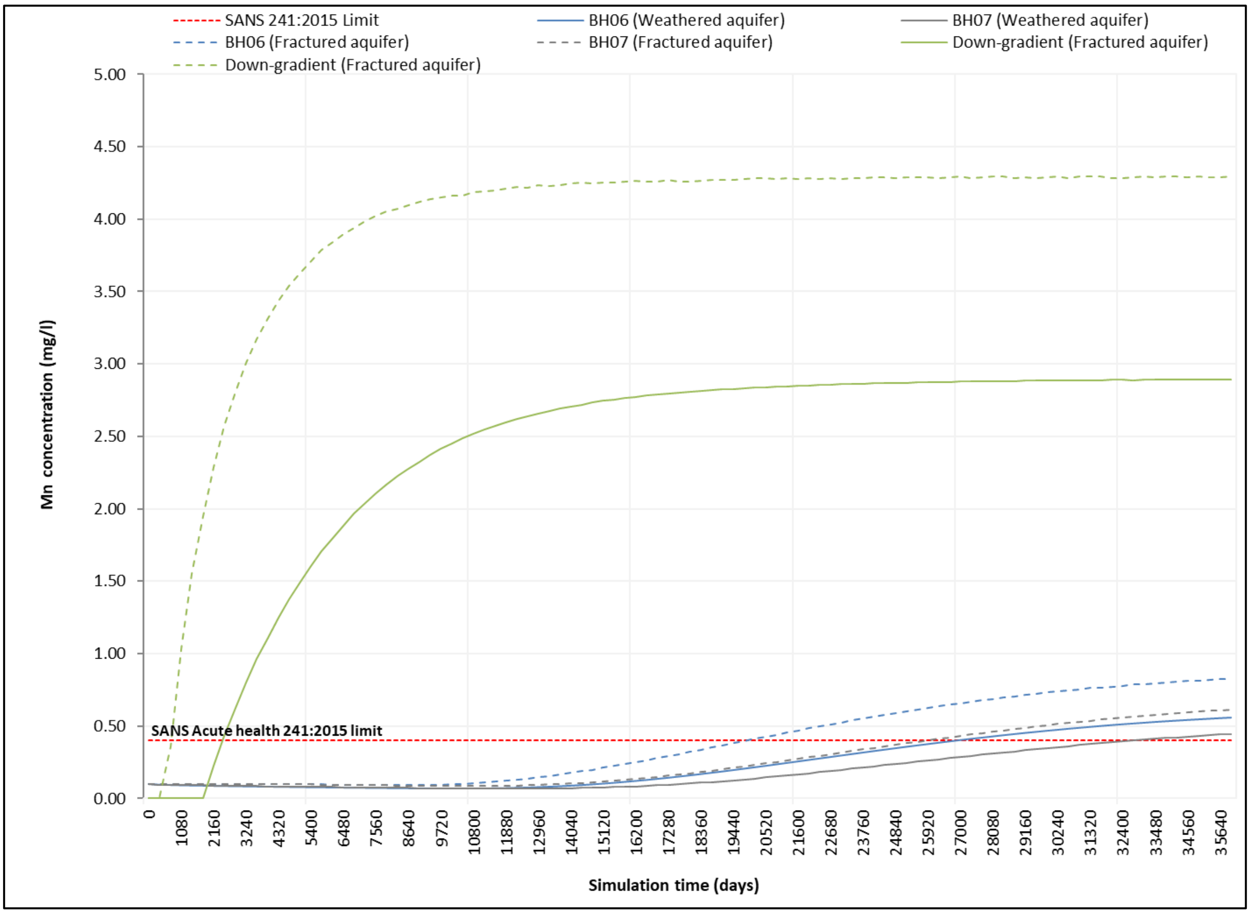

Figure 10.11: Manganese load to boreholes BH6 and BH7 over time

10.4 Impact Summary and Discussion

Contamination migrating from the backfilled shaft will combine with the impact from the downgradient Kusasalethu TSF, in the unlikely event that Scenario B (shaft liner compromised) occurs. It therefore makes it unnecessary to implement any further remedial options to intercept or contain this potential plume from the shaft.

Extensive rehabilitation is planned for the TSF, and this will also deal with any contamination that may migrate from the backfilled shaft. Possible remedial options that were considered to contain the TSF plume and ensure that down-gradient receptors are not impacted on included the following (Van Biljon, 2022):

- **Cut-off trenches.** In this type of geological terrain, the construction of a cut-off drain is considered a potential remedial option. The installation of seepage capturing trenches is very effective where the weathering (shallow weathered aquifer) is less than 8 – 10m. Experience has shown that in this geological terrain most of the contamination occurs in the weathered aquifer, which will be captured by a cut-off trench.

The effectiveness of cut-off trenches was previously simulated by the model, and the estimated groundwater inflow volume into the cut-off trench is illustrated in **Figure 10.12**.

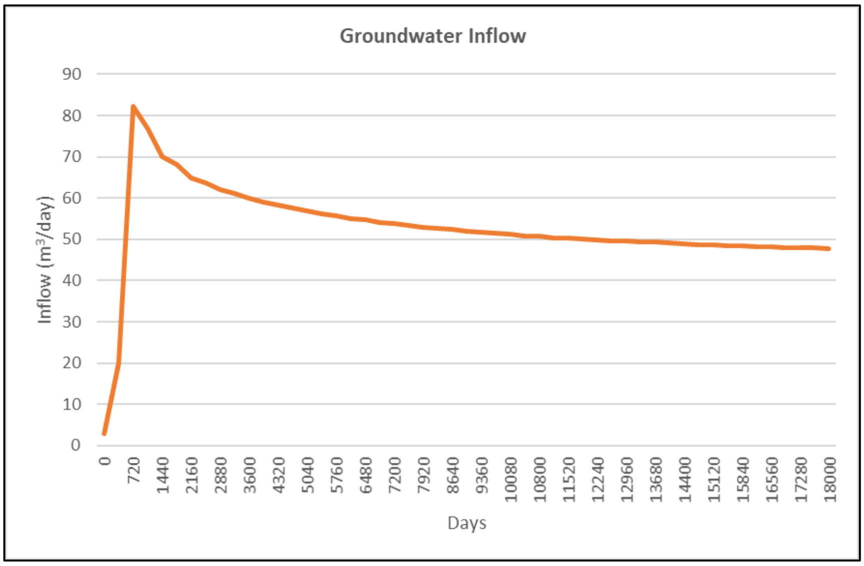

Figure 10.12: Estimated groundwater inflow into the Kusasalethu cut-off trench

- **Horizontal wells.** A horizontal or a series of horizontal wells may also be considered as an alternative for a cut-off drain. This may be a more cost-effective solution, although this method is not yet widely used. In theory it has the same influence as a cut-off drain and is therefore not modelled separately.

The principle of horizontal wells is illustrated in **Figure 10.13** below.

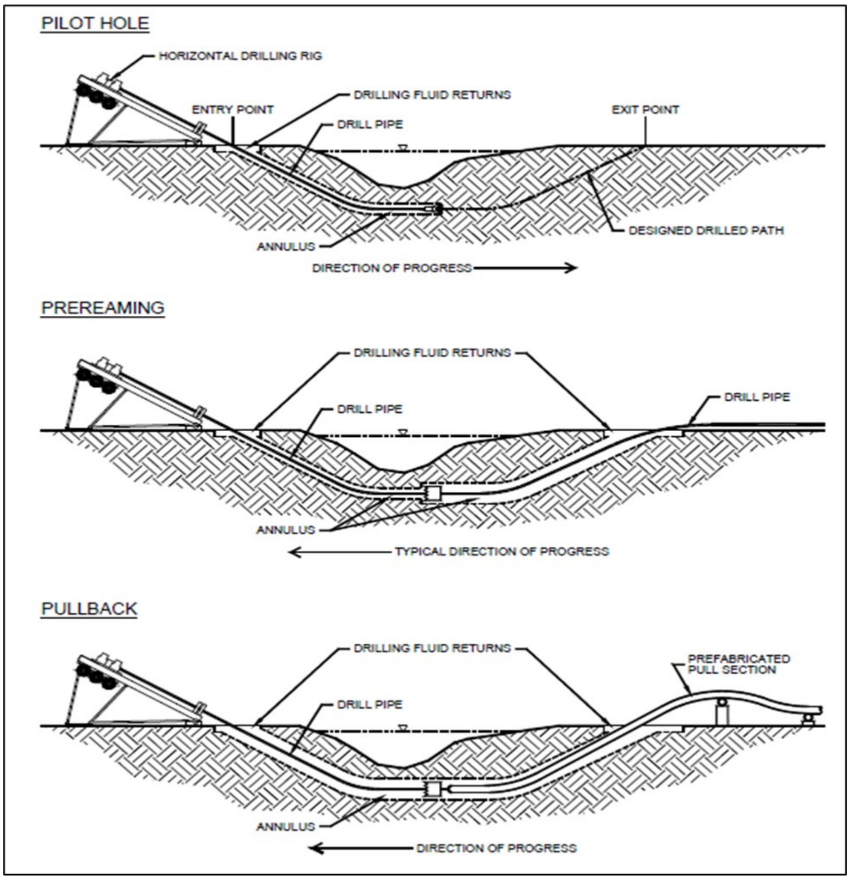

Figure 10.13: Horizontal drilling process

- **Source removal and capping.** The tailings facilities may be re-mined or used for backfill, but some material is likely to remain. This can be capped to reduce rainwater infiltration through the waste material. The following measures can be considered to reduce rainwater seepage through the tailings facility, post closure.
    - Placing bentonite (attapulgite in acidic environments) onto the surface of the TSF to reduce recharge and/or placing a topsoil/clay layer. The latter will require additional vegetation establishment.
    - Planting eucalyptus species or Rhus species to increase heavy metal entrapment and evapotranspiration (phytoremediation).
- **Phytoremediation** ('phyto' means plant) is a generic term for the group of technologies that use plants for remediating soils, sludges, sediments and water contaminated with organic and inorganic contaminants. Phytoremediation can be defined as "the efficient use of plants to remove, detoxify or immobilise environmental contaminants in a growth matrix (soil, water or sediments) through the natural biological, chemical or physical activities and processes of the plants" (https://bohatala.com/application-and-techniques-for-phytoremediation/).

The effectiveness of the above options, as well as the capital costs involved were considered in recommending the most practical and suitable option. The advantages and disadvantages of the various options are summarised in **Table 10.1**.

Table 10.1: Ranking of the potential groundwater remedial options

Rank	Option	Advantages	Disadvantages

1	Phyto-remediation	• Cost effective • Low maintenance • Effective remedial option if correctly applied • Low chance of vandalism • Can be a community involvement project	• Several years before fully operational • Require maintenance during establishment • Mainly restricted to the shallow groundwater
2	Scavenger boreholes and treatment	• Cost effective • Can remove contaminants from the fractured aquifer	• High maintenance • High chance of vandalism and theft • Abstracted water must be treated
3	Horizontal wells	• More cost effective than cut-off trench • Low chance of vandalism if free draining	• Require maintenance • Not commonly used as remedial option • Mainly restricted to the weathered aquifer • Abstracted water may have to be treated
4	Cut-off trench	• Effective option to intercept contamination in the weathered aquifer • Low chance of vandalism if free draining	• Very expensive • Require maintenance • Mainly restricted to the weathered aquifer • Abstracted water may have to be treated

The preferred remedial option is source removal and/or capping with phytoremediation. Studies have shown that phytoremediation is a cost-effective method to contain and abstract contamination from the shallow groundwater. This is especially effective in a geological area such as this where the aquifer parameters are low and groundwater movement is slow. Due to the slow movement, sufficient time will be available for the trees to grow to their maximum absorption rate, without compromising further groundwater quality deterioration.

It is recommended that this option be implemented with immediate effect. Approval of this concept is, however, subject to studies to select the most suitable trees and relevant approvals from the authorities.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

MVB Consulting was appointed to conduct a geohydrological study to assess the potential groundwater impacts if the Kusasalethu Main Shaft is filled with gold tailings. In 2022 MVB Consulting developed a numerical groundwater flow and contaminant transport model to assess the potential impact from the Deelkraal and Kusasalethu tailings storage facilities (TSF's) and their associated infrastructure on the groundwater quality in the region. The Kusasalethu Main Shaft (Main Shaft) was added as a point source to this model and the potential contamination plume migration over time was simulated. The contaminant source concentration was based on a study conducted by Golder Associates in 2015.

The purpose of the geohydrological study is to assess the following:

- Assessment of the geohydrological environment in terms of aquifer development, aquifer hydraulics, groundwater flow and groundwater chemistry.
- Assessment of the potential impacts of backfilling the shaft with tailings material.
- Recommended management measures to mitigate potential impacts.

Most groundwater occurrences are restricted to the upper weathered formations and fractures. These formations are not considered to contain economic and sustainable aquifers, but localised high yielding boreholes may, however, exist where significant fractures are intersected. There are two distinct aquifers in the study area:

- **Weathered Aquifer**: The first is a shallow weathered aquifer, mainly restricted to the weathered shale and quartzite of the Witwatersrand rocks. The base of the aquifer is the impermeable quartzite and shale formations, whereas the top of the aquifer would be the surface topography. The groundwater table is affected by seasonal and atmospheric variations and generally mimics the topography. These aquifers are classified as semi-confined. The most consistent water strike is located at the fresh bedrock / weathering interface. Groundwater elevations vary between 0.5m and 14m below surface.
- **Fractured Aquifer:** The second is the deeper fractured rock aquifer. The deeper, fresh shale/quartzite aquifer where fracture flow dominates. Groundwater migration within the upper portion of the aquifer appears to be governed by jointing while major faults and intrusions form the significant conduits at depth. The depth to groundwater in this aquifer ranges from artesian to 38m below the surface. The two aquifers (weathered and fractured) are mostly hydraulically connected but confining layers such as clay and shale often separate the two. In the latter instance the fractured aquifer is classified as confined.

Groundwater generally mimics topography and flows from topographic highs to valley lows. In some cases, the groundwater may contribute to baseflow depending on the properties of both the streambed and the aquifer properties.

The conceptual geohydrological model was translated to a calibrated numerical groundwater flow and mass transport model. The purpose of the model is mainly to use as a tool to simulate the following:

- Contaminant plume migration from the backfilled Kusasalethu Main Shaft over a period of 50 and 100 years.

FEFLOW, a modular three-dimensional finite element groundwater flow model was the software used during this investigation. It is an internationally accepted modelling package, which calculates the solution of the groundwater flow equation using the finite element approach.

The modelling area was selected based on a combination of topographical and drainage control and covers an area of approximately 1 577 km^2. The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulation results.

Network constructed for the site consists of 977 060 elements. It must be noted that the network was refined in the vicinity of sources of potential contamination.

The model consists of two layers and their associated hydraulic conductivities:

- A shallow weathered aquifer, subdivided into 11 sub-layers with various hydraulic conductivity, with a thickness of 25m
- A fractured aquifer, subdivided into 11 sub-layers with various hydraulic conductivity, and a thickness of 150m.

The model network extends over a larger area than the area under investigation to ensure that the model boundaries will not affect simulated results. Once the network has been set up, all initial and boundary conditions, sources, sinks, and aquifer parameters were entered.

The Kusasalethu Main Shaft was added as a point source to the existing mass transport model. The contaminant source concentration was based on a study conducted by Golder Associates in 2015 named *"ANGLOGOLD ASHANTI - Classification and Assessment of Five Tailings Storage Facilities"*. The following is a summary from the Golder Report.

Sulphate is considered a conservative tracer that is representative of the impacts from the mining waste on the groundwater. However, based on the geochemical assessment the sulphate concentrations in the tailings material was found to be relatively low (<500 mg/L). The manganese concentrations are, however, elevated (up to 8 mg/L) and it was therefore decided to model both parameters to obtain a fair assessment of the possible impacts.

The source concentrations that were included in the numerical model are as follows:

- Sulphate (SO_4) 500 mg/L.
- Manganese (Mn) 8 mg/L.

To address the objectives of this study, a mass transport model was used to simulate the potential impacts of backfilling the shaft with tailings material. There are two possible scenarios when backfilling the shaft with tailings:

- **Scenario A**: The shaft liner is intact and there is no interaction between the material in the shaft and the surrounding aquifer. Groundwater will flow around the backfilled shaft.
- **Scenario B**: The shaft liner has been compromised and groundwater can flow into and through the tailings material in the shaft.

In Scenario A there is no possible contaminant impact, and this option was therefore not modelled. The model simulations assumed the worst-case scenario, which is Scenario B.

The numerical model was used to simulate the following scenarios:

- Sulphate contaminant plume migration after 50 and 100 years.

- Manganese contaminant plume migration after 50 and 100 years.

Simulations were conducted for both the weathered and fractured aquifers. Only the potential impact from backfilling the Kusasalethu Main Shaft is presented in this report. Current and future impacts from the Waste Rock Dumps and Tailings Facilities are excluded from this assessment.

The results from the modelling exercise are summarised in **Table 11.1**.

Table 11.1: Contaminant plume migration summary

Aquifer	Sulphate	Manganese
	Source Plume Migration (500 mg/L)	Source Plume Migration (8 mg/L)
Weathered Aquifer		
50 Years	60m	110m
100 Years	70m	130m
Fractured Aquifer		
50 Years	120m	225m
100 Years	125m	250m

- Plume migration is generally quicker in the fractured aquifer due to lower porosity values than those in the weathered aquifer.
- Due to the low sulphate source concentration (500 mg/L) the sulphate impact is very low.
- The source concentration impact of 8 mg/L only migrates a maximum distance of 250m from the shaft, which classifies this impact as minor.
- In all instances the plume remains within the mine property and does not impact on any down-gradient receptors.

11.2 Recommendations

Contamination migrating from the backfilled shaft will combine with the impact from the downgradient Kusasalethu TSF. It therefore makes it unnecessary to implement any further remedial options to intercept or contain this potential plume from the shaft.

Extensive rehabilitation is planned for the TSF, and this will also deal with any contamination that may migrate from the backfilled shaft. Possible remedial options that were considered to contain the TSF plume and ensure that down-gradient receptors are not impacted on included the following (Van Biljon, 2022):

- **Cut-off trenches.** In this type of geological terrain, the construction of a cut-off drain is considered a potential remedial option. The installation of seepage capturing trenches is very effective where the weathering (shallow weathered aquifer) is less than 8 – 10m. Experience has shown that in this geological terrain most of the contamination occurs in the weathered aquifer, which will be captured by a cut-off trench. The effectiveness of cut-off trenches was previously simulated by the model and shown to collect a maximum of 80 m^3 of contaminated water per day.

- **Horizontal wells.** A horizontal or a series of horizontal wells may also be considered as an alternative for a cut-off drain. This may be a more cost-effective solution, although this method is not yet widely used. In theory it has the same influence as a cut-off drain and is therefore not modelled separately.
- **Source removal and capping.** The tailings facilities may be re-mined or used for backfill, but some material is likely to remain. This can be capped to reduce rainwater infiltration through the waste material. The following measures can be considered to reduce rainwater seepage through the tailings facility, post closure.
    - Placing bentonite (attapulgite in acidic environments) onto the surface of the TSF to reduce recharge and/or placing a topsoil/clay layer. The latter will require additional vegetation establishment.
    - Planting eucalyptus species or Rhus species to increase heavy metal entrapment and evapotranspiration (phytoremediation).
- **Phytoremediation** ('phyto' means plant) is a generic term for the group of technologies that use plants for remediating soils, sludges, sediments and water contaminated with organic and inorganic contaminants. Phytoremediation can be defined as "the efficient use of plants to remove, detoxify or immobilise environmental contaminants in a growth matrix (soil, water or sediments) through the natural biological, chemical or physical activities and processes of the plants" (https://bohatala.com/application-and-techniques-for-phytoremediation/).

The effectiveness of the above options, as well as the capital costs involved were considered in recommending the most practical and suitable option. The advantages and disadvantages of the various options are summarised below.

Rank	Option	Advantages	Disadvantages
1	Phyto-remediation	• Cost effective • Low maintenance • Effective remedial option if correctly applied • Low chance of vandalism • Can be a community involvement project	• Several years before fully operational • Require maintenance during establishment • Mainly restricted to the shallow groundwater
2	Scavenger boreholes and treatment	• Cost effective • Can remove contaminants from the fractured aquifer	• High maintenance • High chance of vandalism and theft • Abstracted water must be treated
3	Horizontal wells	• More cost effective than cut-off trench • Low chance of vandalism if free draining	• Require maintenance • Not commonly used as remedial option • Mainly restricted to the weathered aquifer • Abstracted water may have to be treated
4	Cut-off trench	• Effective option to intercept contamination in the weathered aquifer • Low chance of vandalism if free draining	• Very expensive • Require maintenance • Mainly restricted to the weathered aquifer • Abstracted water may have to be treated

The preferred remedial option is source removal and/or capping with phytoremediation. Studies have shown that phytoremediation is a cost-effective method to contain and abstract contamination from the shallow groundwater. This is especially effective in a geological area such as this where the aquifer parameters are low and groundwater movement is slow. Due to the slow movement, sufficient time will be available for the trees to grow to their maximum absorption rate, without compromising further groundwater quality deterioration.

It is recommended that this option be implemented as soon as possible. Approval of this concept is, however, subject to studies to select the most suitable trees and relevant approvals from the authorities.

12. SPECIALIST REASONED OPINION

This report has been drafted as per the latest requirements for specialist reports as set by the Department of Environmental Affairs and listed in Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07 April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA).

I, Marius van Biljon, hereby declare that:

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, Regulations and all other applicable legislation;
- I have not, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- All the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of regulation 48 and is punishable in terms of section 24F of the Act.

It is my opinion that the proposed backfilling of the Kusasalethu shaft will have a negligible impact on the quality of the groundwater in the vicinity of the shaft. The primary reasons for this conclusion are as follows:

- The geochemical assessment indicated that the leachable concentrations of As, Mn, Ni and SO_4 in the tailings samples were elevated. The concentrations are, however, low and the highest sulphate (SO_4) concentrations are only 500 mg/L, which is still within the SANS 241 drinking water guidelines.
- The shafts are likely to fill with water after mine closure, up to an elevation that equates to the regional groundwater table. If the tailings are deposited below the groundwater level in the region, i.e., the shaft is not backfilled to surface, reducing conditions will be present and the typical AMD reactions will not occur.
- The shafts are concrete lined, which are expected to remain intact during backfilling. This prevents interaction between the groundwater and the tailings material and any contamination that may leach from the tailings will remain in the shaft barrel.

- In the unlikely event that contaminant seepage does occur the plume from the shaft will combine with the impact from the downgradient Kusasalethu TSF. The mine proposes rehabilitation of this TSF and the underlying groundwater and the low seepage volumes from the shaft will be captured by this rehabilitation.

It is recommended that the project be approved. An additional monitoring borehole at the shaft should be considered to confirm the findings of this report and to act as an early warning device.

13. REFERENCES

Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use.

Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Irrigation.

Krusemann, G.P.; De Ridder, N.A. (1991): Analysis and evaluation of pumping test data - ILRI Publications, No. 47, 2. Ed., 377 pages, Wageningen.

Jones & Wagener. 2014. Kusasalethu and Deelkraal Tailings Facilities Feasibillty Study for Cut Off Drains to Colect Groundwater Seepage Report no. JW038/14/E137

Parsons R, (1995). A South African Aquifer System Management Classification. WRC Report No KV 77/95, Pretoria.

Peeters L., Fasbender D, Batelaan O and Dassargues A (2009) Bayesian data fusion for water table interpolation: Incorporating a geohydrological conceptual model in kriging. Water Resources Research Vol 46 W08532 DOI:1029/2009WR008353

SANS 241-2. (2011). South African National Standard. Drinking Water – Part 2: Application of SANS 241-1.

Skousen J.G, Sexstone A and Ziemkiewics (2000) Acid Mine Drainage Control and Treatment. American Society of Agronomy and American Society for Surface Mining and Reclamation. Agronomy No. 41

Usher B.H, Cruywagen L-M., Necker E and Hodgson F.D.I (2001) Acid-Base Accounting, Techniques and Evaluation (ABATE) Report to the Water Research Commission

Van Biljon M (2022). Geohydrological Modelling for the Kusasalethu and Deelkraal Waste Facilities, Northwest Province. MVB Consulting Report No. MvB090/22/A079.