ENVIRONMENTAL IMPACT MANAGEMENT SERVICES

GEOHYDROLOGICAL IMPACT ASSESSMENT OF THE PROPOSED KALGOLD GOLD MINE EXPANSION, NORTHWEST PROVINCE

FINAL REPORT

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Executive Summary

The purpose of the study is primarily to assess the potential impacts from the proposed mining extension and associated waste facilities on the groundwater regime. The proposed new gold processing plant and explosives magazine are not considered potential contaminant sources as these are lined (concreted) and within a closed water circuit (plant).

The deliverables from the study include the following:

- Conceptual geohydrological model.
- Numerical groundwater flow and mass transport model that was utilised to assess the following:
  - Contaminant migration from the recommissioned tailings facility (TSF).
  - Contaminant migration for the current and proposed waste rock dumps (WRD).
  - Contaminant migration from D-zone tailings disposal.
- A geohydrological risk assessment of the impacts on the groundwater and recommendations on the way forward.

Geological Setting

The Kalgold operation is located within the Kraaipan Greenstone Belt, which forms part of the larger Amalia-Kraaipan Greenstone terrain (Wilson and Anhaeusser, 1998). The Kraaipan Greenstone Belt consists of north trending linear belts of Archaean meta-volcanic and metasedimentary rocks, separated by granitoid units. Mineralisation occurs in shallow dipping quartz veins, which occur in clusters or swarms, within the steeply dipping magnetite-chert banded iron formation. Disseminated sulphide mineralisation, dominated mostly by pyrite, occurs around and between the shallow dipping quartz vein swarms. The following rocks are associated with the ore body (Pers. Comm. Hilton Chirambadare, 2011):

- The footwall consists of mafic schist and the hanging wall of greywacke, shale, sandstone, conglomerate and siltstone.
- The host rock is Banded Iron Formation (BIF) intercalated with shale.

Conceptual Groundwater Model

The following aquifers are present in the vicinity of Kalgold mine (Auctus, 2011):

- The quaternary Kalahari sand, which covers the project area, forms an intergranular, unconfined aquifer in the upper 30m of the geological succession. The deposit consists typically of sand and silt. In intergranular porous deposits, like the Kalahari sands, aquifer parameters are reasonably homogeneous. There is currently no aquifer parameter information available for this aquifer in the study area and literature-based values have therefore been used to quantify this aquifer. It is unclear whether this aquifer is laterally extensive over the project area, but the aquifer is probably recharged seasonally with rainwater and therefore could contribute to water make in the pits. If boreholes are used regionally to abstract groundwater from this aquifer, the yield per borehole is expected to be 0.10 – 0.50 litres per second (ℓ/s), which is low.
- A deeper fractured rock aquifer is formed by bedding planes, fractures and faults in the weathered and competent meta-sediments of the Kraaipan Greenstone Belt. In fractured rocks, the interconnected discontinuities are the main passage for groundwater flow and the solid rock blocks considered to be of very low permeability or impermeable. Despite the absence of geological logs, the aquifer characteristics

obtained from the recently pumped boreholes are thought to represent this aquifer. Inherently, these types of aquifers are heterogeneous, as is evident from the pump test information. The fractured rock aquifer will be recharged through rainwater infiltrating from the overlying intergranular aquifer or through direct recharge where the Banded Iron Formation (BIF) outcrops. The depth to groundwater in this aquifer is on average 25m, based on measurements in the monitoring boreholes thought not to be affected by mining or groundwater abstraction. Aquifer test information suggests that the aquifer could yield 0.50 – 3.0 ℓ/s, which is higher than that recorded for the intergranular Kalahari sand aquifer.

Since the fractured aquifer is the sole water supply to the farms in the region it is regarded as a sensitive and important aquifer that needs high level protection.

Groundwater samples are routinely collected and analysed by DD Science, a SANAS accredited laboratory. The quality of the groundwater on the mine can be summarised as follows:

- Boreholes BH93 and BH97 have high salinity with elevated TDS concentrations. These boreholes are located up-gradient from the mining activities and the high salinity can only be attributed to the borehole's proximity to the easterly dams where evaporation is high. The fact that the sulphate concentration in borehole Bh93 is also elevated may, however, suggest that there is some mining impact as well.
- The boreholes in close proximity to the tailings facility (BH103 and BH106) show mining impact with elevated sulphate concentrations. There is no recent analysis for borehole BH15, which is located immediately down-gradient from the tailings facility. Borehole BH4, which is located further down-gradient shows that the contamination migrates slowly, and this borehole is still within the drinking water limits.
- The water quality in D-Zone pit, into which tailings is currently deposited shows high concentrations of EC, TDS, sulphate, nitrate, ammonia, calcium, sodium and potassium.

Numerical Groundwater Model

To investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. The modelling area was selected based on a combination of topographical, geological and structural control and covers an area of approximately 414 km^2.

A two-layered aquifer model was constructed and calibrated for the Kalgold site using the finite element 3D-modelling package FEFLOW 7.1.

The model comprises 2 layers, 719 098 elements and 542 691 nodes. The total depth of the model is 280m deep. The 2 layers build into the model are:

- Layer 1 – Shallow weathered aquifer (Kalahari Sand). This aquifer has an estimated average depth of 30m.
- Layer 2 – Deeper fractured aquifer. This aquifer has an estimated depth of 250m.

The groundwater flow model was calibrated, and an acceptable correlation was obtained between the observed and simulated piezometric heads.

A mass transport model was developed to simulate contaminant transport through the aquifer. Input concentrations in the model were specified at cells over the areas where contamination is expected. Total Dissolved Solids (TDS) was selected as a conservative tracer that represents the migration of contaminants through the aquifer. The input concentrations were specified as average concentrations (mg/ℓ). Based on the waste assessment and groundwater monitoring the following TDS concentrations were assigned to the various waste bodies:

Tailings facility:	1 750 mg/ℓ.
Waste rock:	1 033 mg/ℓ.
ROM pad:	1 690 mg/ℓ.
D-Zone:	4 500 mg/ℓ.

Geohydrological Impact Assessment

Mining Schedule and Water Requirements

The mining schedule estimated a Life of Mine (LOM) of approximately 10 years after July 2024. The ore tonnages peak at approximately 300 000 tons per month. Monthly tailings deposition from July 2024 will be 260 000 tons into D-Zone and 40 000 tons on the existing TSF. Based on the 2020 water usage the required water volume is in the region of 1.50 m^3/ton milled (Van Biljon, 2021). This equates to 14 988 m3/day or ~15 Mℓ/day for the increased production rate of 300 000 tons per month.

Impacts on Groundwater Levels

The unavoidable inflow of groundwater into the opencast pits and the pumping of this water will have an impact on the groundwater levels near the mining operations. There are four (4) private boreholes that may potentially be impacted by this dewatering. These include:

KFBH1:	Potential 21m drop in the groundwater level expected.
KFBH2:	Potential 57m drop in the groundwater level expected, which may cause this borehole to dry up.
KFBH3:	Potential 17m drop in the groundwater level expected.
KFBH20:	Potential 28m drop in the groundwater level expected.

It is recommended that these boreholes be included in the mine monitoring programme to verify the findings of this simulation. Borehole KFBH2 may need to be replaced if the simulations prove to be correct. It is further recommended that the groundwater levels in the “High and Medium Risk” categories are measured quarterly to verify model predictions and to act if necessary. The depths of these boreholes should also be confirmed.

During the operational phase of the mine the water will be pumped from the opencast operations. Post-closure this pumping will cease, and the groundwater level will recover. It is estimated that it will take approximately 25 years to recover to the average pre-mining groundwater level. Due to the high evaporation rates in the region the pits will always, if left open, act as a sink and groundwater flow will be towards the pits.

Impacts on Groundwater Quality

Waste assessment and waste classification studies were recently undertaken. Distilled water shake flask tests were performed on the waste rock and the tailings samples to determine which soluble constituents are present in the material. There are no elements exceeding the Leachable Concentration Threshold (LCT0) for any of the samples, indicating a low contaminant seepage risk.

The contaminant plume migration from the Kalgold waste bodies were simulated with the numerical model. The waste assessment as well as the groundwater monitoring data was utilised in determining the source concentrations that were included in the mass transport model. Total Dissolved Solids (TDS) was selected as a conservative tracer that represents the migration of contaminants through the aquifer.

The following post-closure alternatives were simulated:

- Alternative 1: In the first scenario the Watertank and A-Zone pits will be left open or backfilled with tailings material if required. If backfilled the groundwater levels will revert to pre-mining water levels. The WRD will be removed (sold as aggregate), and it is assumed that the TSF will be capped and vegetated. This option is currently the preferred option according to which the mining feasibility is planned.
- Alternative 2: In the second scenario the Watertank and A-Zone pits remain open. In this instance the pit will fill with water, which will remain below the regional groundwater level due to evaporation. The pit will act as a sink and will continue to draw groundwater towards it. The WRD's will remain, and it is assumed that the TSF will be capped and vegetated.

In each instance the two alternatives are compared to the do-nothing scenario in which the pits remain open, the WRD's will remain and the TSF will be uncapped. In other words, no rehabilitation measures will be implemented.

Please note that capping and vegetating of the waste facilities were simulated as a potential remedial option. This has, however, not been verified as the only option and has not been approved by the environmental management team as the most viable option.

There are potentially two (2) significant risks that may impact the groundwater regime. These are as follows:

- **Reduction in the groundwater levels.** During opencast mining groundwater will flow into the workings, which will then be pumped out. This will result in the lowering of the groundwater levels in the vicinity of the open pits during the operational phase of the mining operation. The extent of this dewatering cone is important as it can potentially impact on private groundwater users and in extreme situations may cause boreholes to dry up. After mining ceases the groundwater levels are expected to recover and this risk will no longer be applicable.
- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** The waste bodies at Kalgold includes the tailings facility (TSF) and the waste rock dumps (WRD). Rainwater seepage through the waste material may become contaminated and when entering the groundwater system, the contaminants will migrate from these facilities. Due to this contaminant migration down-gradient receptors may be impacted on. Receptors include surface streams and private groundwater users.

Mitigation of the risks above may include the following:

- **Reduction in the groundwater levels.** This risk is essentially a short-term risk. Continuous monitoring of the groundwater levels in the monitoring boreholes as well as in selected private boreholes is recommended. This will provide early warning if private users are to be impacted on, in which case the mine should supply these farmers with an alternative source until the groundwater levels recover. Alternative sources can include a new borehole or a water supply pipeline from the mine.

  The surface streams in the area are classified as losing streams. In other words, the groundwater does not contribute to the baseflow in the streams. Lowering of the groundwater level will therefore not impact on any of the streams.
- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** This risk is regarded as a longer-term risk and two alternatives, as described above, were evaluated to mitigate this risk. The primary receptors that may be impacted are the private groundwater users. Due to the streams being losings streams any groundwater contamination is also not expected to impact on the streams.

The numerical modelling and risk assessment concluded the following:

- The potential lowering of the groundwater level is regarded as a low risk and if the recommended mitigation is implemented the risk reduces even further.
- The recommissioning of the TSF will contribute marginally to the contaminant load. The capping and vegetating of the TSF will largely terminate additional load to the groundwater system after mine closure. The contaminants that entered the system during the operational phase will continue to migrate after closure.
- D-Zone pit will be filled with tailings to just below the original groundwater level of 1 210 mamsl. A pool of water will remain within the pit and the pit will act as a sink. Groundwater flow would therefore be towards D-Zone pit and any contamination will be contained within the immediate vicinity of the pit. If, however, the Watertank and A-Zone pits are also left open the groundwater level in these pits is expected to be lower than that in D-Zone, due to a larger surface area and higher evaporation. In this instance water from D-Zone will be pulled towards Watertank and A-Zone pits.
- Removal of the WRD's and its associated impacts is considered slightly more advantageous, if it is an economical viable option.
- Both alternatives are acceptable in terms of groundwater contamination as the potential pollution will largely be restricted to the mining footprint.
- Mitigation to minimize the groundwater impacts post-closure includes the rehabilitation of the TSF. The rehabilitation is assumed to include the capping and vegetation of the tailings facility. If the TSF is capped the recharge rate reduces significantly, but the contamination currently in the groundwater continues to migrate down-gradient. It will, however, clean up quicker than when it is not capped and is expected to clean up 25 – 30 years after rehabilitation.

The geohydrological assessment indicated that in all instances the contaminant plumes are contained and irrespective of the rehabilitation option, the private groundwater users will not be impacted during mining or after closure.

Recommendations

Monitoring will be especially important to verify the model simulations and to adjust should that be necessary. The following is recommended in terms of monitoring:

- Water volumes pumped from the various opencast pits should be measured with flow meters and recorded daily.
- Rainfall should be measured daily to distinguish between rainfall and groundwater inflow into the opencast pits.
- The quality of the in-pit water should be monitored regularly.
- Groundwater quality monitoring in the mine monitoring boreholes should continue as per the WUL requirements.
- It is recommended that the private boreholes are also sampled and analysed annually. The previous sampling was conducted in 2011 as part of the hydro census.
- The borehole and pump installation depths of these private boreholes should also be measured if possible, to allow for a more accurate risk assessment in terms of the available drawdown and risk of drying up.
- Groundwater levels in the mine monitoring boreholes, as well as the "High Risk" private boreholes should be monitored quarterly.

This rigorous monitoring programme is recommended due to the sensitivity of this "Sole Supply Aquifer" and to provide the mine with sufficient and defendable information should claims against the mine arise.

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CONTENTS PAGE

List of Figures

List of Tables

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1. INTRODUCTION

Kalgold Gold Mine, Harmony Gold Ltd (Kalgold) first started operation during the mid-1990s as an opencast gold mining operation situated in the Kraaipan Greenstone Belt. The initial operation focussed on mining of the D-Zone ore body. The economic ore body was mined out by a single open pit operation, along a strike length of 1 300m and to a depth of approximately 290m below surface. The mining operation at D-Zone open pit ceased in March 2009. Mining at Kalgold Mine has continued despite the operation cessation at D-Zone. The A-Zone, Windmill and Watertank open pits are relatively new opencast operations.

The potential geohydrological impacts from the mine on the groundwater, based on the revised mine plan and associated waste infrastructure, were investigated. This report summarises the methodology and findings of the geohydrological investigation.

2. STUDY PURPOSE AND TERMS OF REFERENCE

The purpose of the study is primarily to assess the potential impacts from the proposed mining extension and associated waste facilities on the groundwater regime. The proposed new gold processing plant and explosives magazine are not considered potential contaminant sources as these are lined (concreted) and within a closed water circuit (plant).

The deliverables from the study include the following:

- Conceptual geohydrological model.
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    - Contaminant migration from D-zone tailings disposal.
- A geohydrological risk assessment of the impacts on the groundwater and recommendations on the way forward.

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CK2010/140005/23)

3. SITE LOCALITY AND DESCRIPTION

3.1 Locality of the Study Area

Kalgold is an open pit mining operation, which accesses gold-bearing ore in a banded iron formation in a shear zone within the Kraaipan Greenstone Belt (Harmony, 2009). Kalgold Mine is located some 50km to the south-west of Mafikeng, Northwest Province (**Figure 3.1**). The Kalgold operation consists of the following mining areas:

- D-Zone, the largest ore body, which was mined as a single opencast operation along a strike length of 1 300m from 1996 to 2009.
- A-Zone is an opencast section that was commissioned in 2005.
- Watertank is an opencast section commissioned in 2008.

Mining activities within the project area include a heap leach pad (not in use), a Tailings Storage Facility (TSF) (to be recommissioned in July 2024), waste rock dumps, a gold processing plant and the opencast pits, as shown in **Figure 3.2**. Kalgold proposes to recommission the current tailings facility and expand the Spanover waste rock dump. A new metallurgical plant and ROM pad is also proposed.

3.2 Topography and Regional Drainage

The topography in the vicinity of the mining area is flat but undulating and ranges from 1 245 metres above mean sea level (mamsl) in the south-east to 1 220 mamsl in the north-west. The regional catchment in which the mine is located is characterised by generally north-westerly flowing drainages leading to the Molopo River (GCS, 2008). The catchment is drained by a few small tributaries including the Mareetsane River, Morokwa River and Koedoe Spruit drainages. These convert and flow into the Setlagole River which drains north-west into the Molopo River (**Figure 3.3**).

The Morokwa River flows along the southern boundary of the mine and has been diverted around D-Zone pit. This river is generally dry and only flows for short periods after rainfall events. There is generally no flow in the Morokwa drainage and there are therefore no riparian water users in the area (GCS, 2008). However, certain landowners have constructed dams along the drainage which impound stormwater runoff after high rainfall. This surplus water is not normal and is available only for short periods.

Baseflow contribution to river and stream features represents one of the primary natural groundwater discharge processes. There is currently limited information available on the depth of groundwater levels in the vicinity of the Morokwa River. The Morokwa is an ephemeral or non-perennial stream, which means that the baseflow is insufficient to maintain permanent flow. The average depth to groundwater boreholes not affected by mining is 25m below surface. In areas where mining has affected groundwater levels, the depth to groundwater is as much as 50m. Since the groundwater levels are naturally deep, as well as due to the impact of mine dewatering, it is assumed that the Morokwa River is a losing stream. This means that the stream loses water by seepage to the adjacent or underlying aquifers. The stream is therefore expected to recharge the aquifer at least periodically during the rainy season.

The other streams in the larger catchment, although not affected by mine dewatering, are also expected to be losing streams. Groundwater levels in boreholes close to the Mareetsane River are on average 30m below surface and those near the Koedoe Spruit have an average depth of 7m below surface (Auctus, 2012).

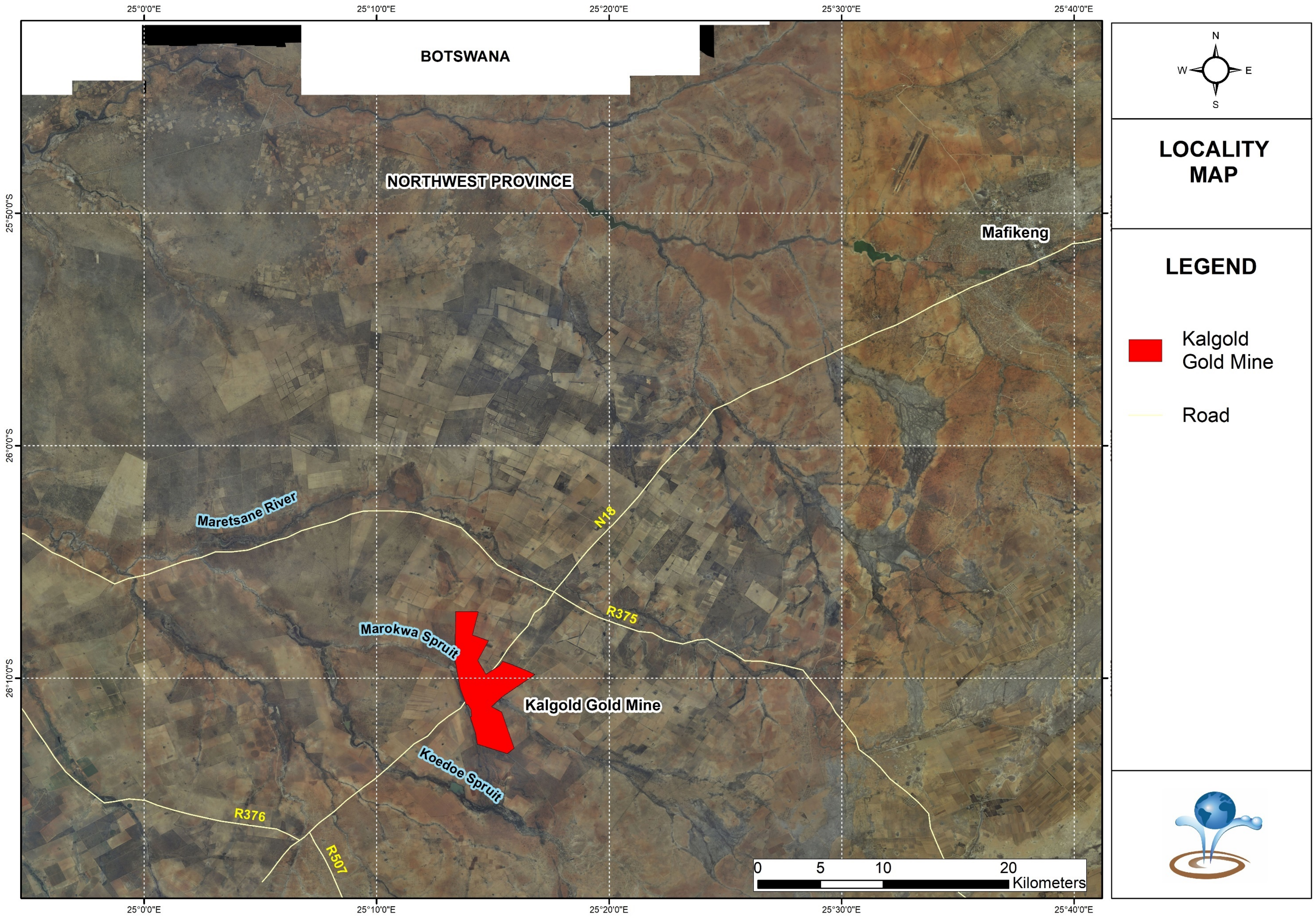

Figure 3.1: **Locality of Kalgold mine**

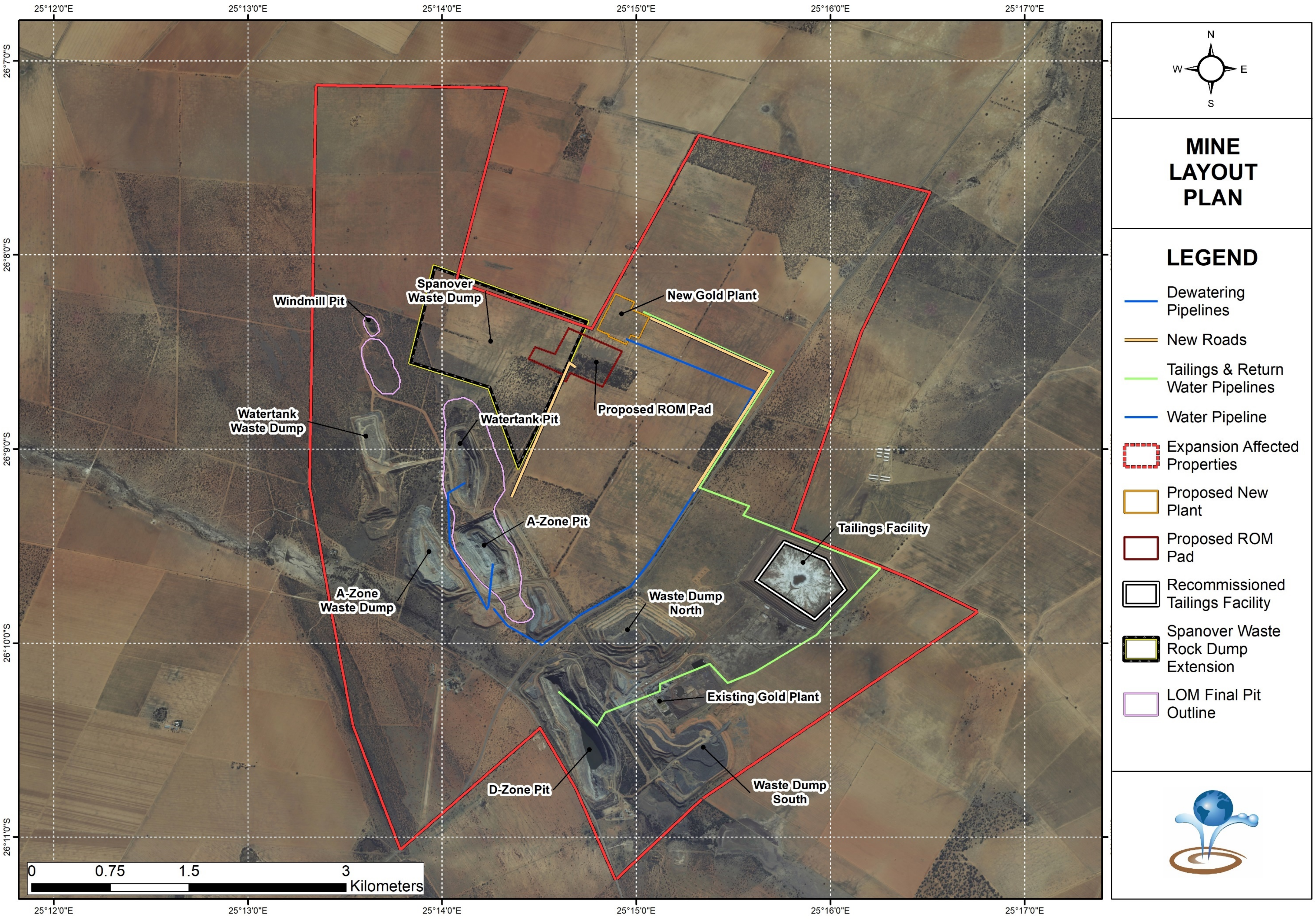

Figure 3.2: **Kalgold mine layout**

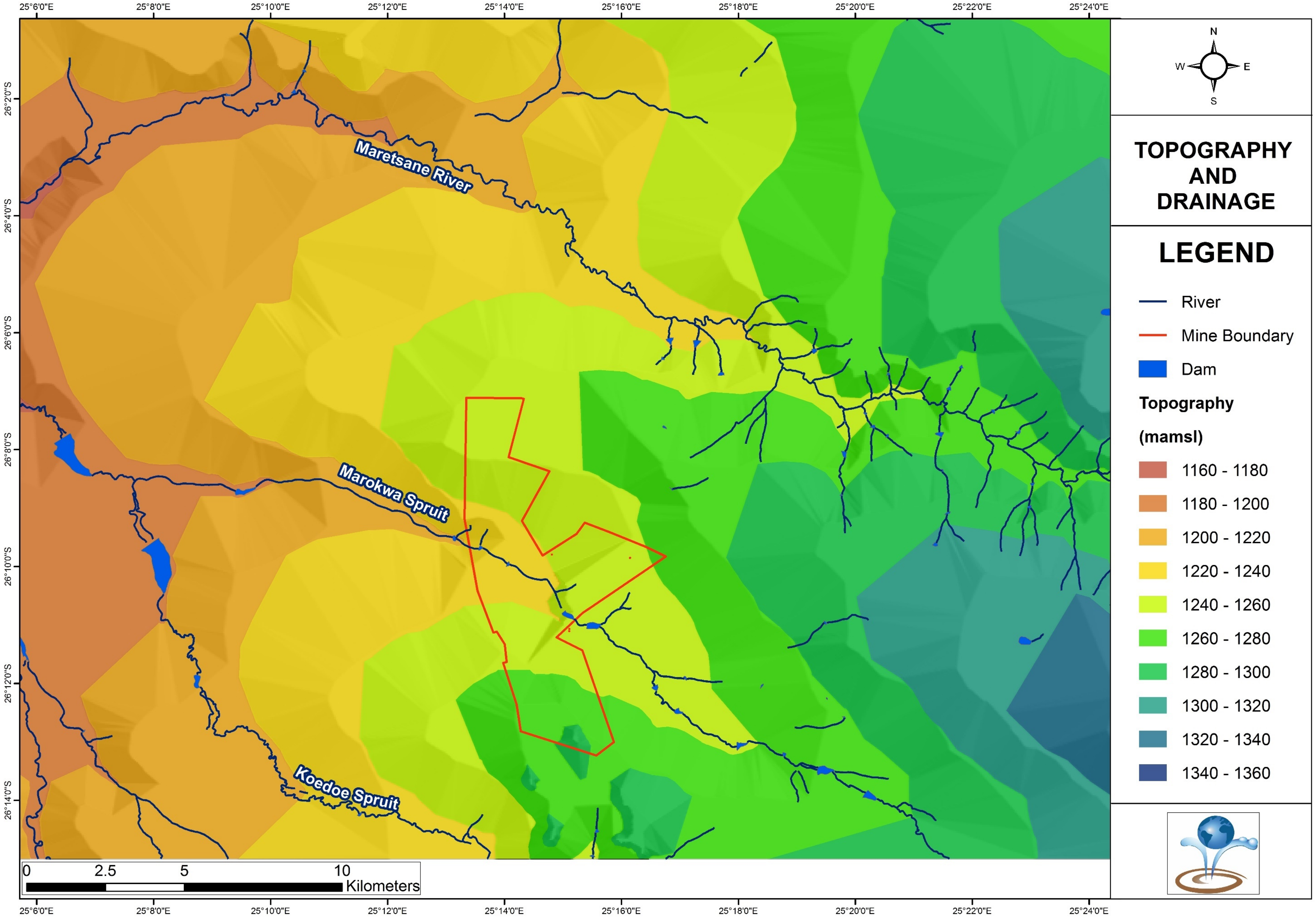

Figure 3.3: Regional topography and drainage

3.3 Rainfall

The average rainfall data between January 2012 – December 2019, as measured at Kalgold mine, is presented in **Table 3.1**. Higher rainfall figures of 489 mm/annum were recorded at Neverset, the closest weather station (Jones & Wagener, 2017).

Table 3.1: Average rainfall at Kalgold mine (2012 – 2019)

Month	Average
October	13.33
November	10.17
December	36.67
January	49.13
February	63.00
March	30.31
April	24.71
May	1.50
June	4.17
July	1.33
August	0.00
September	7.33
Mean Annual Precipitation (MAP)	**241.65**

The contribution of rainfall to the mine's current water balance is only direct rainfall (based on Kalgold rainfall data), on the opencast pits (**Table 3.2**).

Table 3.2: Rainfall contribution to the water balance

Month	Rainfall	Windmill	A-zone	Watertank	D-zone	Total
	(mm)	(m^3/month)	(m^3/month)	(m^3/month)	(m^3/month)	(m^3/month)
January	56.14	1 082	18 417	9 671	25 986	**55 155**
February	59.86	1 153	19 637	10 312	27 708	**58 810**
March	34.64	667	11 364	5 967	16 034	**34 032**
April	25.33	488	8 310	4 363	11 725	**24 886**
May	1.50	29	492	258	694	**1 474**
June	4.17	80	1 368	718	1 930	**4 097**
July	1.33	26	436	229	616	**1 307**
August	0.00	0	0	0	0	**0**
September	7.33	141	2 405	1 263	3 393	**7 201**
October	13.33	257	4 373	2 296	6 170	**13 096**
November	10.17	196	3 336	1 752	4 707	**9 992**
December	36.67	706	12 030	6 317	16 974	**36 027**
Total	**250.47**	**4 826**	**82 167**	**43 146**	**115 937**	**246 076**

Note: Windmill area – 19 266 m^2; A – zone area: 328 051 m^2
Watertank area: 172,261 m^2; D – zone area: 462,878 m^2

4. CONCEPTUAL GEOHYDROLOGICAL MODEL

4.1 Geological Setting

The Kalgold operation is located within the Kraaipan Greenstone Belt, which forms part of the larger Amalia-Kraaipan Greenstone terrain (Wilson and Anhaeusser, 1998). The Kraaipan Greenstone Belt consists of north trending linear belts of Archaean meta-volcanic and metasedimentary rocks, separated by granitoid units. Mineralisation occurs in shallow dipping quartz veins, which occur in clusters or swarms, within the steeply dipping magnetite-chert banded iron formation. Disseminated sulphide mineralisation, dominated mostly by pyrite, occurs around and between the shallow dipping quartz vein swarms. The following rocks are associated with the ore body (Pers. Comm. Hilton Chirambadare, 2011):

- The footwall consists of mafic schist and the hanging wall of greywacke, shale, sandstone, conglomerate and siltstone.
- The host rock is Banded Iron Formation (BIF) intercalated with shale.

The greenstone formations are exposed in discontinuous outcrops of steeply dipping rocks which define three narrow, sub-parallel belts that strike approximately north-south (GCS, 2008). The ore body mined at Kalgold occur within the central belt which comprises banded iron formation (BIF), magnetite quartzite, chert, greywacke, shale and schist. The gold mineralization is hosted by steeply dipping BIF that are interbedded with schist, shale and greywacke. The greenstones are hosted within intrusive granite and gneiss.

The Kraaipan greenstone is intruded by numerous east-west trending dykes. One such dyke cuts across the southern boundary of the mining lease area. The area is further characterised by abundant faults with displacement from a few metres to hundreds of metres. Groundwater movement in the area takes place in a northerly direction mainly along strike on the contacts of the cherty banded iron units and is affected by cross-cutting dykes and faults (GCS, 2008).

Figure 4.1 shows the regional surface geology in the study area.

4.2 Geohydrological Setting

4.2.1 Introduction

The geohydrology of the study area was assessed based on available mine monitoring data, previous studies and limited 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.
- Aquifer type.
- Aquifer parameters.
- Groundwater gradients and flow.
- Groundwater and mine water chemistry.
- Aquifer classification.

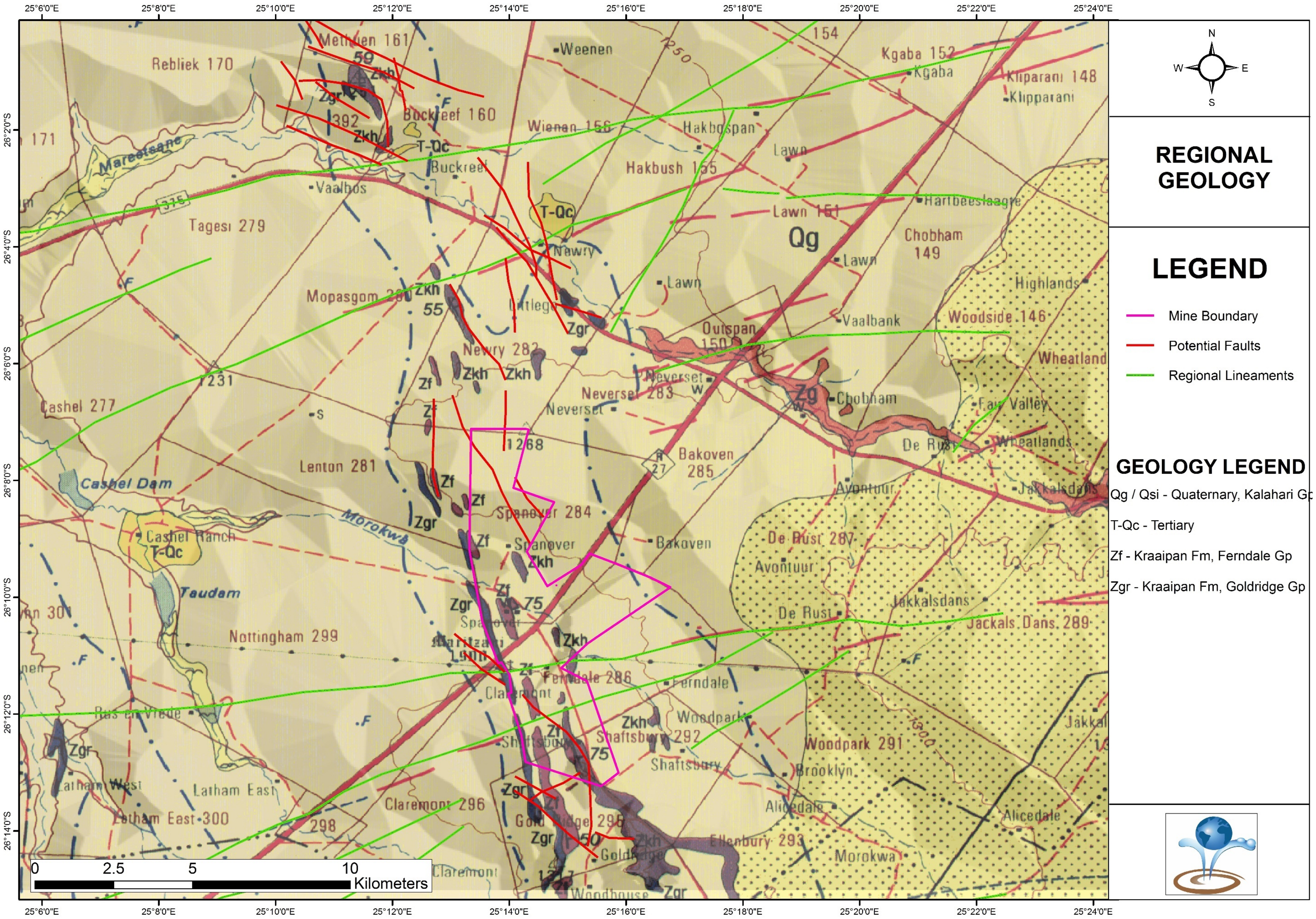

Figure 4.1: Regional geology

4.2.2 Hydro Census and Borehole Information

Auctus (2011) conducted a hydro census on all the neighbouring farms. The hydro census was conducted within an approximate radius of 5km around the mine. Twenty-nine boreholes were identified within this radius and included private as well as selected mine boreholes. The hydro census information is summarised in **Table 4.1.**

It is important that the hydro census boreholes are shown in this assessment as some of them may be impacted on when dewatering of the pits takes place.

Over the years Kalgold also drilled additional boreholes including several water supply and dewatering boreholes. Information from all available boreholes were utilised in understanding the geohydrological regime.

The localities of the hydro census as well as the current mine boreholes are shown in **Figure 4.2.**

Table 4.1: Hydro census information

ID	Coordinates		Farm	Owner	Tel nr.	Waterlevel (mbcl)		Collar height	Date drilled	Depth
	S	E				Static	Pumped			
KFBH1	26.17375	25.20916	Nottingham	Mr T N Meyer	0823882909		12.55	0.1	+25 Years ago	Not Known
KFBH2	26.15494	25.2212	Nottingham	Mr T N Meyer	0823882909	--	--	0.15	+25 Years ago	65m
KFBH3	26.14994	25.27291	Bakoven	Mr W de Chavonnes Vrugt	0829462303	25.3		0.2	Not Known	Not Known
KFBH4	26.19087	25.22564	Koedoesrand	Mr W de Chavonnes Vrugt	0829462303	24.4		0.25	Not Known	Not Known
KFBH5	26.18855	25.22763	Koedoesrand	Mr W de Chavonnes Vrugt	0829462303		47.2	0.2	Not Known	Not Known
KFBH6	26.18979	25.22993	Koedoesrand	Mr W de Chavonnes Vrugt	0829462303	38.1		0.07	Not Known	Not Known
KFBH7	26.22145	25.2594	Goldridge	Mr F J Du Preez	0823899336		58	0.35	Not Known	Not Known
KFBH8	26.17079	25.13834	Nottingham	Mr G Grobler	0825543232	10.7		0.08	+12 Years	Not known
KFBH9	26.14799	25.1588	Nottingham	Mr G Grobler	0825543232	--	--	0.25	Not Known	Not Known
KFBH10	26.24162	25.20737	Claremont	Mr W Labuschagne	0823875445	--	--	0.5	+11 Years	50
KFBH11	26.24199	25.20831	Claremont	Mr W Labuschagne	0823875445	--	--		Not Known	Not Known
KFBH12	26.24389	25.20639	Claremont	Mr W Labuschagne	0823875445	--	--		Not Known	Not Known
KFBH13	26.15539	25.31127	Avontuur	Mr N Meyer	0823208790	--	--	0.1	Not Known	Not Known
KFBH14	26.16626	25.2848	De Rust	Mr N Meyer	0823208790	--	--	0.1	Not Known	Not Known
KFBH15	26.19172	25.2781	Ferndale	Mr N Meyer	0823208790	10.75		0.15	Not Known	Not Known
KFBH16	26.18999	25.27571	Ferndale	Mr N Meyer	0823208790	--	--	0	Not Known	Not Known
KFBH17	26.18466	25.31164	De Rust	Mr N Meyer	0823208790	--	--	0.2	Not Known	Not Known
KFBH18	26.11152	25.26715	Neverset	Mr D Bothma	0823882800		31.53	0.3	Not Known	100
KFBH19	26.11332	25.26231	Neverset	Mr D Bothma	0823882801	30.06		0.1	Not Known	100
KFBH20	26.14301	25.2086	Lenton	Mr D Bothma	0823882801	52.22		0.15	Not Known	Not Known
KFBH21	26.20223	25.25225	Ferndale	Mr Norman Meyer	0823880744	35.36		0.2	1960	60
KFBH22	26.20232	25.25216	Ferndale	Mr Norman Meyer	0823880744	--	--	0.2	1970	60
KFBH23	26.2002	25.25191	Ferndale	Mr Norman Meyer	0823880744		37.84	0.2	Not Known	60
KFBH24	26.22153	25.2594	Goldridge	Mr F J Du Preez	0823899336	55.3		0.3	Not Known	Not Known
KFBH25	26.24114	25.25563	Goldridge	Mr F J Du Preez	0823899336	31.8		0.15	Not Known	Not Known
KFBH26	26.16193	25.27531	Avontuur	Mr N Meyer	0823208790	--	--	0.15	Not Known	Not Known
KFBH27	26.17351	25.27861	De Rust	Mr N Meyer	0823208790	--	--	0.15	Not Known	Not Known
KFBH28	26.19466	25.27615	De Rust	Mr N Meyer	0823208790			0.15	Not Known	Not Known
KFBH29	26.19338	25.2702	Ferndale	Mr N Meyer	0823208790	--	--	0.15	Not Known	Not Known

ID	Type of pump	Yield	Pump To	Size of reservoir	Pumping hours/day	Water use	Comments
		ℓ/s		(liters)			
KFBH1	Submersible	Not known	To Tank	5000l	5	Domestic, Cattle	
KFBH2	Submersible	Not known	To Tank	5000l	3	Domestic, Cattle	Unable to measure, hole closed, Analyses of 2000 and 2002 given
KFBH3	Submersible	3600	To Tank	4 x 5000l	6	Domestic, Cattle and Piggery	
KFBH4	Submersible	Not known	To Tank	1 x 2500l	6	Domestic	Pumps into same Tank as KFBH5, one sample taken while both were pumping into Tank
			To Dam	1 x 20000l			
			To Dam	1 x 50000l			
KFBH5	Submersible	Not known	To Tank then Dam		6	Domestic, Cattle	Pumps into same Tank as KFBH4, one sample taken while both were pumping into Tank
KFBH6	Submersible	Not known	To Tank then Dam			Domestic, Cattle	Pumps into same Tank as KFBH4 & 5, no Sample of this one, pump in for repairs
KFBH7	Submersible	Not known	To Tank then Dam	1 x 5000l	7	Domestic, Cattle, Sheep and Pigs	
				1 x 20000l			
KFBH8	Submersible	Not known	To Tank	5000l	5	Domestic, irrigation	Busy building Chalets, going to use water
KFBH9	Submersible	Not known	To Lodge, to Tank	1 x 2000l	8	Domestic, irrigation	
				1 x 10000l			
KFBH10	Mono pump	Not known	To tanks	2 x 5000l	6	Domestic, Sheep and Cattle	Pumps into same Tank as KFBH11, one sample taken while both were pumping into Tank
KFBH11	Mono pump	Not known	To tanks	2 x 5000l	6	Domestic, Sheep and Cattle	Pumps into same Tank as KFBH10, one sample taken while both were pumping into Tank
KFBH12	Submersible	Not known	N/A	N/A		Hole closed	Hole closed, no water level
KFBH13	Wind pump	Not known	To Tank and Dam	1 x 5000l		Domestic and Cattle	
KFBH14	Wind pump	Not known	To Dam	20000l		Cattle	
KFBH15	Submersible	Not known	To Dam	20000l	4	Cattle	
KFBH16	Submersible	Not known	To Tank	5000l	5	Domestic and Irrigation	
KFBH17	Mono pump	Not known	To Tank	5000l	5	Domestic and Irrigation	
KFBH18	Submersible	Not known	To Tank	5000l	8	Domestic and Cattle	
KFBH19	Submersible	Not known	To Tanks	3 x 10000l	8	Domestic	Pumped from Tanks to Farmhouse 10km away
KFBH20	Mono pump	Not known	To Tank and crips	5000l	5	Domestic and Cattle	
KFBH21	Submersible	14000	To Tank	10000l	6	Domestic and Cattle	This hole and KFBH22 pumps into same Tank, both busy running, one sample taken
KFBH22	Submersible	9000	To Tank	10000l	6	Domestic and Cattle	This hole and KFBH21 pumps into same Tank, both busy running, one sample taken
KFBH23	Submersible	4000	To Dam	20000l	6	Domestic and Cattle	
KFBH24	No pump	Not known	N/A	N/A	N/A	Not in use	
KFBH25	No pump	Not known	N/A	N/A	N/A	Not in use	
KFBH24	No pump	Not known	N/A	N/A	N/A	Not in use	
KFBH25	No pump	Not known	N/A	N/A	N/A	Not in use	
KFBH26	Wind pump	Not known	To Dam	20000l	N/A	Cattle	
KFBH27	Wind pump	Not known	To Dam	20000l	N/A	Cattle	
KFBH28	Wind pump	Not known			N/A	Cattle	
KFBH29	Wind pump	Not known			N/A	Domestic	

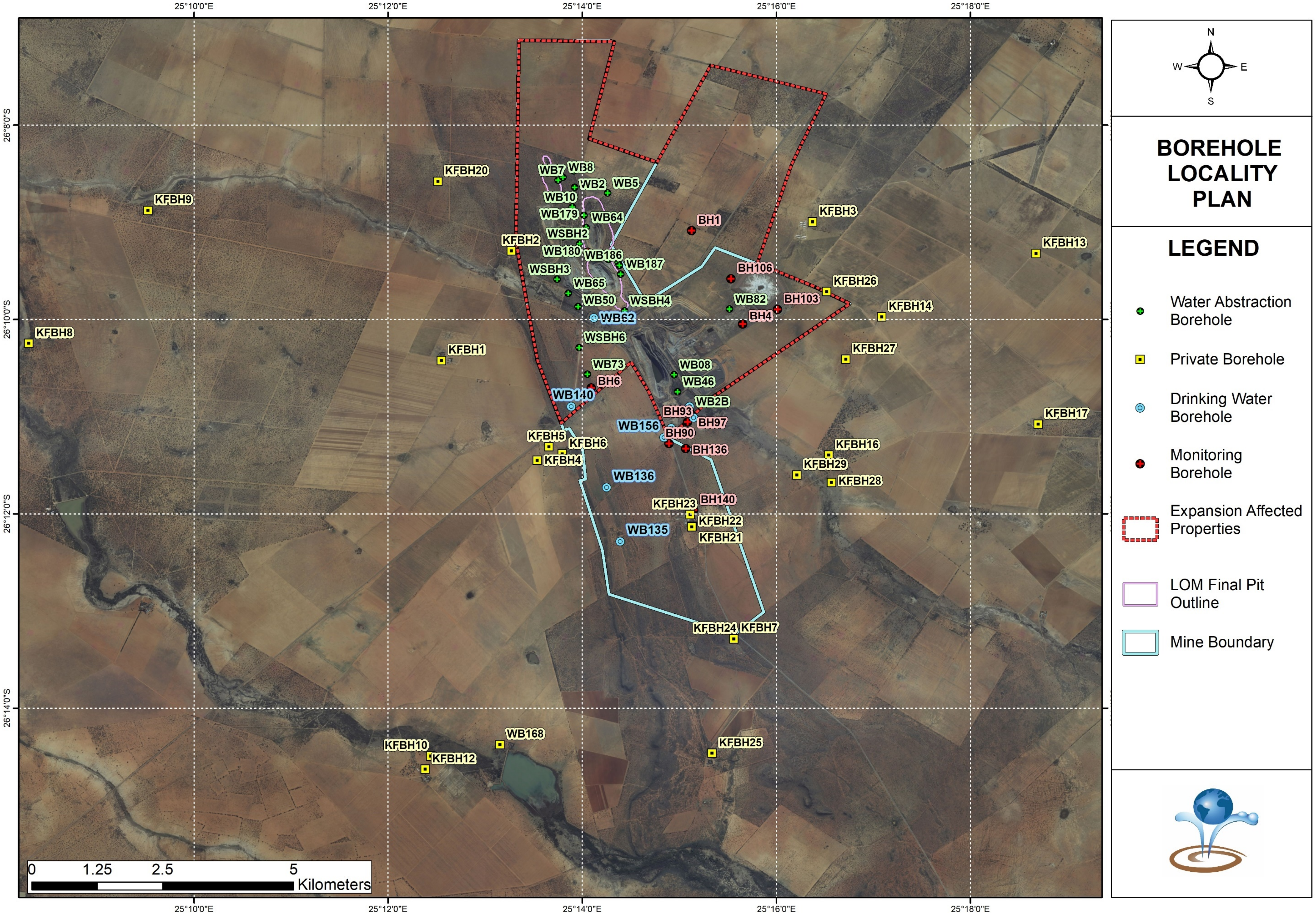

Figure 4.2: **Borehole locality plan**

4.2.3 Aquifer Type

The available information suggests the presence of the following aquifers in the modelled area, as illustrated in the schematic cross section in **Figure 4.3**.

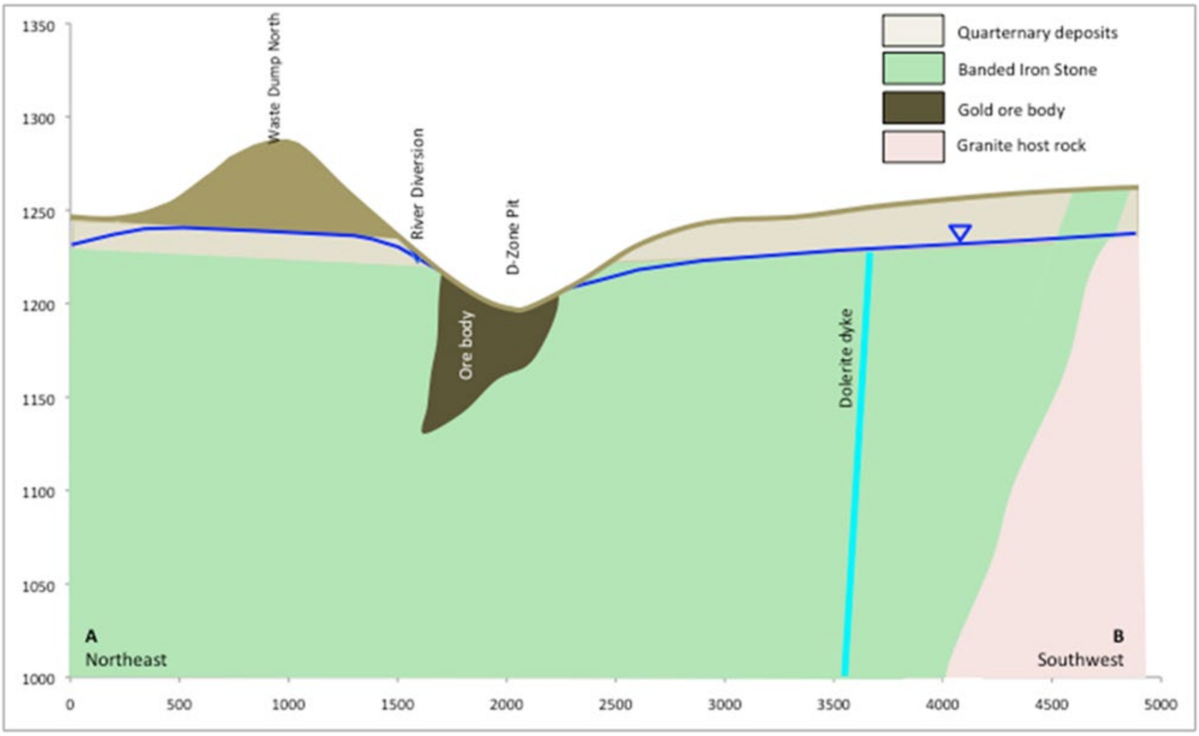

Figure 4.3: Schematic cross-section showing different aquifers (Auctus, 2011)

The following aquifers are present in the vicinity of Kalgold mine (Auctus, 2011):

- The quaternary Kalahari sand, which covers the project area, forms an intergranular, unconfined aquifer in the upper 30m of the geological succession. The deposit consists typically of sand and silt. The rate of recharge to the aquifer is normally below 1% of the Mean Annual Precipitation (MAP). It is however assumed, based on groundwater level information that the three boreholes with shallow groundwater levels of ±10m (WB168, WB114 and KFBH15) are possibly drilled into this aquifer. A groundwater mound has potentially formed underneath the waste rock dump at the D-Zone Pit, which may result in a slightly elevated groundwater level in that area. In intergranular porous deposits, like the Kalahari sands, aquifer parameters are reasonably homogeneous. There is currently no aquifer parameter information available for this aquifer in the study area and literature-based values have therefore been used to quantify this aquifer. It is unclear whether this aquifer is laterally extensive over the project area, but the aquifer is probably recharged seasonally with rainwater and therefore could contribute to water make in the pits. If boreholes are used regionally to abstract groundwater from this aquifer, the yield per borehole is expected to be 0.10 – 0.50 litres per second (ℓ/s), which is low.
- A deeper fractured rock aquifer is formed by bedding planes, fractures and faults in the weathered and competent meta-sediments of the Kraaipan Greenstone Belt. In fractured rocks, the interconnected discontinuities are considered to be the main passage for groundwater flow and the solid rock blocks considered to be of very low permeability or impermeable. Despite the absence of geological logs, the aquifer characteristics obtained from the

recently pumped boreholes are thought to represent this aquifer. Inherently, these types of aquifers are heterogeneous, as is evident from the pump test information, which indicates that the transmissivity in this aquifer varies between 0.90 and 346 m^2/day. The fractured rock aquifer will be recharged through rainwater infiltrating from the overlying intergranular aquifer or through direct recharge where the Banded Iron Formation (BIF) outcrops. The depth to groundwater in this aquifer is on average 25m, based on measurements in the monitoring boreholes thought not to be affected by mining or groundwater abstraction. Aquifer test information suggests that the aquifer could yield 0.50 – 3.0 ℓ/s, which is higher than that recorded for the intergranular Kalahari sand aquifer.

4.2.4 Groundwater Gradients and Flow

Groundwater levels were measured as a first step to determine the regional groundwater gradients and flow directions. The available groundwater levels are shown in **Table 4.2**.

Table 4.2: Groundwater levels

Borehole	X - Coordinate	Y - Coordinate	Collar Elevation (mamsl)	Water Level (mbs)	Water Level (mamsl)
WB 62	23 479.88	-2 895 563.15	1238.00	23.80	1214.20
WB 168	21 851.36	-2 903 443.10	1240.00	4.43	1235.57
WB 135	25 187.20	-2 897 769.54	1245.00	33.50	1211.50
WB 136	25 423.60	-2 897 900.87	1245.00	23.80	1221.20
WB 93	25 108.40	-2 897 244.21	1238.00	26.75	1211.25
WB 99	24 819.47	-2 896 823.94	1230.00	31.44	1198.56
WB 82	25 922.66	-2 894 827.69	1247.00	23.35	1223.65
WB 114	24 504.27	-2 895 169.15	1240.00	11.74	1228.26
WB 64	23 401.08	-2 893 619.43	1240.00	52.55	1187.45
KFBH 3	27 288.52	-2 893 514.36	1260.00	25.30	1234.70
KFBH 4	22 560.55	-2 897 979.67	1250.00	24.40	1225.60
KFBH 6	23 007.08	-2 897 874.60	1250.00	38.10	1211.90
KFBH 8	13 840.08	-2 895 747.02	1200.00	10.70	1189.30
KFBH 15	27 761.32	-2 898 111.00	1252.00	10.75	1241.25
KFBH 19	26 237.86	-2 889 416.79	1259.00	30.06	1228.94
KFBH 20	20 879.50	-2 892 700.10	1239.00	52.22	1186.78
KFBH 21	25 213.47	-2 899 266.73	1270.00	35.36	1234.64
KFBH 24	25 796.40	-2 901 394.31	1280.00	55.30	1224.70
KFBH 25	25 528.66	-2 903 600.70	1275.00	31.80	1243.20
WB 66	23 429.49	-2 894 045.47	1240.50	44.70	1195.80
WB 82	25 890.47	-2 894 830.26	1250.60	3.20	1247.40
WB 179	23 358.30	-2 893 310.29	1243.50	34.96	1208.54
WB 180	23 002.95	-2 893 727.00	1240.00	38.41	1201.59
WBH182	23 478.46	-2 893 241.26	1244.70	73.43	1171.27
WBH183	23 631.85	-2 893 376.76	1243.50	42.03	1201.47
WBH184	23 775.02	-2 894 192.29	1240.00	36.96	1203.04
WBH185	23 907.96	-2 894 302.22	1240.00	32.26	1207.74

Borehole	X - Coordinate	Y - Coordinate	Collar Elevation (mamsl)	Water Level (mbs)	Water Level (mamsl)
WBH186	23 925.85	-2 894 355.91	1240.00	32.12	1207.88
WBH187	23 977.36	-2 894 463.03	1240.00	32.42	1207.58
WB08	24 943.86	-2 896 082.05	1232.71	20.08	1212.63
WB46	24 996.78	-2 896 408.82	1231.76	15.20	1216.56
WB73	23 448.17	-2 896 069.77	1239.11	42.03	1197.08
WB30	24 175.04	-2 895 195.20	1228.26	37.98	1190.28
WB2B	25 223.17	-2 896 783.30	1233.96	13.17	1220.79
WB50	23 292.28	-2 894 786.48	1223.48	29.66	1193.82
WB64	23 438.54	-2 893 275.13	1238.12	40.50	1197.62

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

Typically, a linear relationship exists between the depth to groundwater and the topography, since groundwater normally drains under gravity towards streams and rivers. At Kalgold, however, a poor correlation (36%) exists, and it cannot be assumed that groundwater flow mimics the topography (**Figure 4.4**). The disturbance in this relationship is caused by the dewatering around Watertank and A-Zone pits, as well as the cone of depression around D-zone pit.

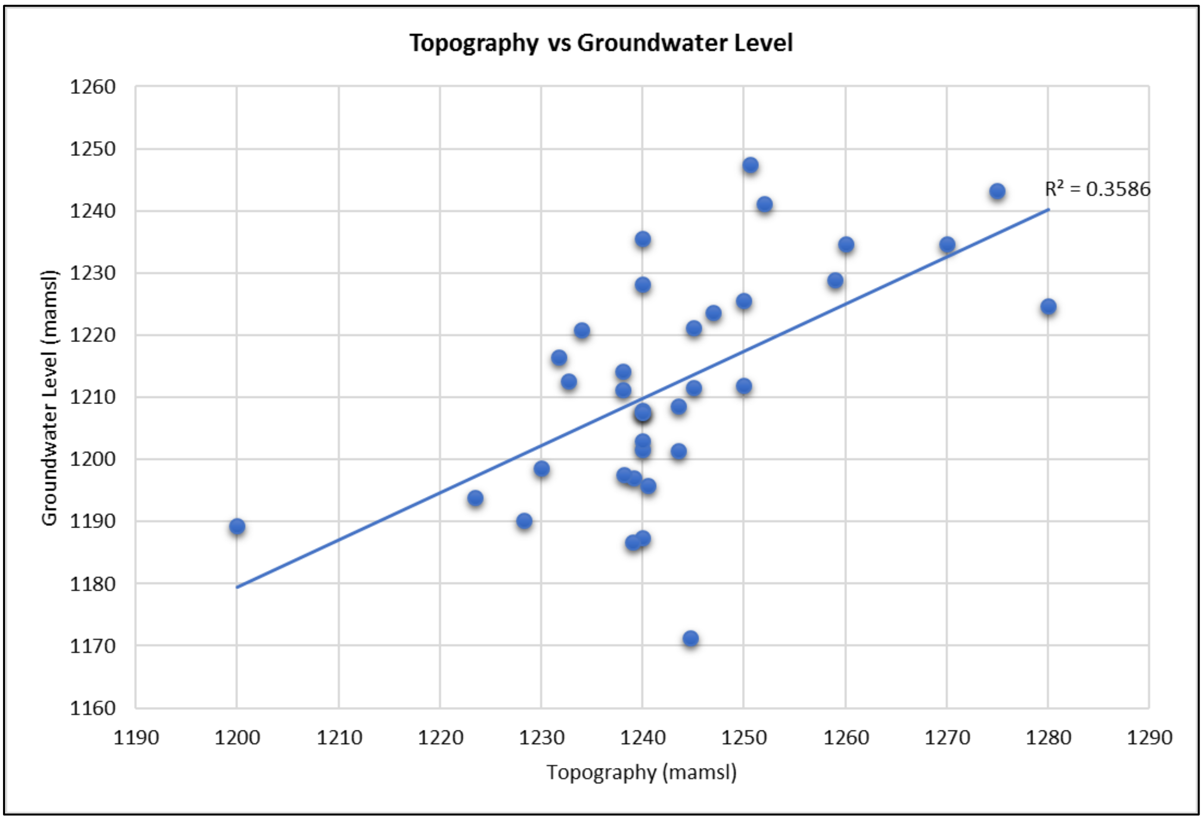

Figure 4.4: Relationship between topography and groundwater table

Contouring of the measured groundwater levels indicate that the regional groundwater flow is primarily towards the dewatering cone in the vicinity of the various mining pits (**Figure 4.5**).

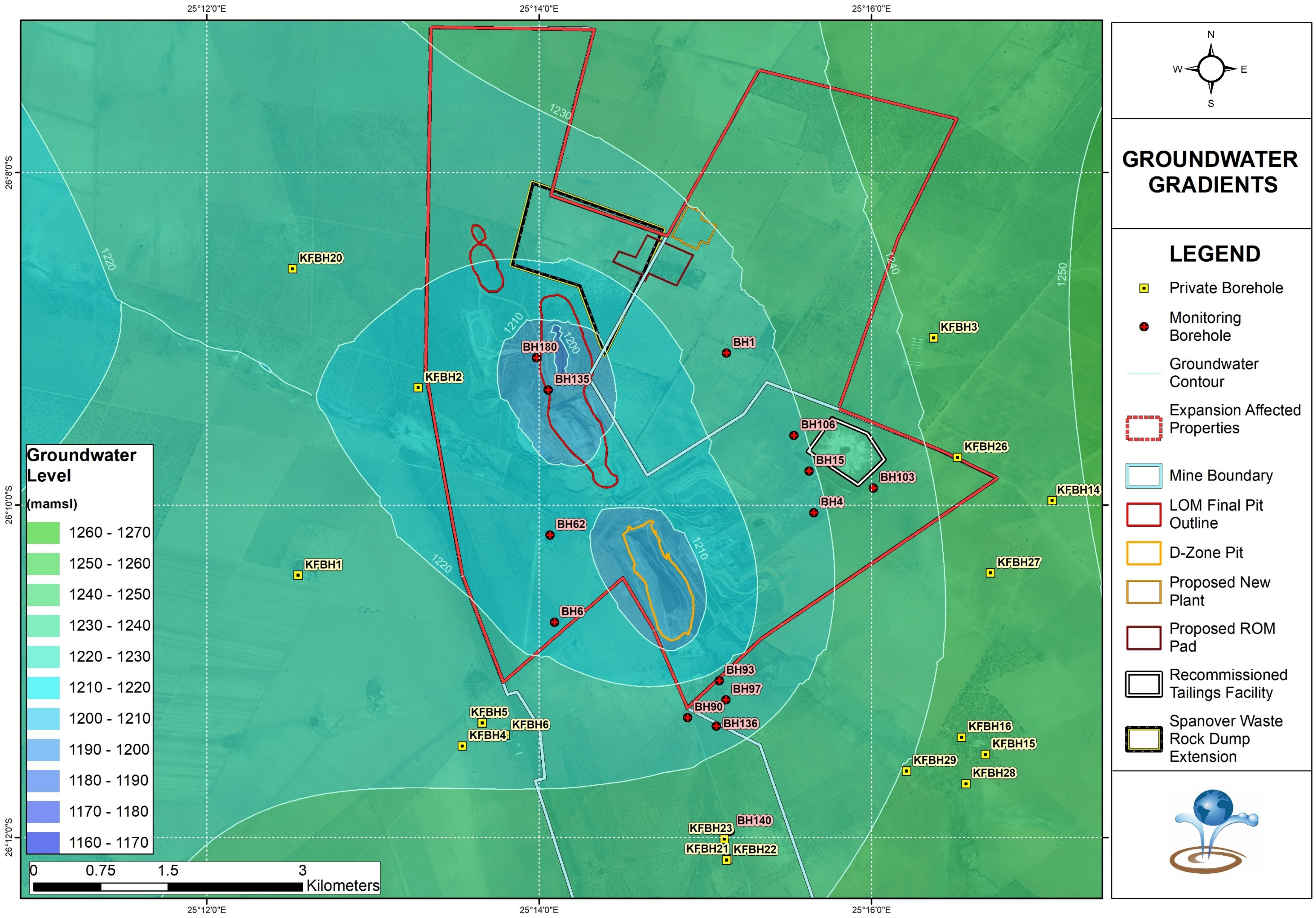

Figure 4.5: **Regional groundwater gradient**

4.2.5 Aquifer Parameters

Aquifer parameters are obtained from the test pumping of boreholes. Important parameters that can be obtained from borehole or test pumping 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.

Several dewatering and water supply boreholes have been tested previously at Kalgold, not only to calculate the aquifer parameters, but also to estimate the safe and maximum yield of each of the boreholes. The pump testing consisted of step tests, constant discharge (CD) and recovery tests.

The calculated aquifer parameters for all the tested boreholes are presented in **Table 4.3**. The large variation in the aquifer parameter values is an indication of the variability of the aquifer.

Table 4.3: Summarised aquifer parameters

Borehole	Pumping Rate	Test Duration	Transmissivity	Hydraulic Conductivity
	(lit/sec)	(Hours)	(m^2/day)	(m/day)
WB 66	0.61	12	33.50	0.059
WB 82	0.49	12	0.73	0.014
WB 179	0.54	10	3.34	0.050
WB 180	0.98	12	3.80	0.066
WB 182	1.25	4	2.57	0.092
WB 183	0.92	12	0.99	0.013
WB 184	0.81	12	4.17	0.037
WB 185	0.45	7	0.35	0.003
WB 186	2.50	12	2.83	0.024
WB 187	0.54	12	0.65	0.006
WB 08	3.35	13	36.18	0.699
WB 46	4.98	2	70.40	1.283
WB 73	3.36	45	100.25	14.235
WB 30	3.65	47	51.33	1.390
WB 65	3.29	13	14.62	0.470
WB 64	5.00	28	58.50	12.930
WB 2B	3.09	45	21.74	2.650
WB 50	2.07	4	26.47	1.320

Borehole	Pumping Rate	Test Duration	Transmissivity	Hydraulic Conductivity
	(lit/sec)	(Hours)	(m^2/day)	(m/day)
KG127 (WSBH1)	3.50	37	144.00	4.130
KG129 (WSBH4)	3.30	10	2.00	0.035
KG137 (WSBH6)	3.30	40 min	2.16	0.037
KG128 (WSBH2)	3.30	20 min	1.98	0.029
KG130 (WSBH3)	3.30	25 min	1.72	0.024
KG219 (WB2)	7.97	24	37.05	0.650
KG220 (WB10)	3.08	24	13.25	0.288
KG222 (WB5)	1.52	24	5.7	0.122
KG223 (WB7)	3.96	12	7.52	0.167
KG224 (WB8)	3.30	24	17.35	0.526
KG225 (WB11)	3.41	24	46.85	0.820

4.2.6 Groundwater and Mine Water Chemistry

Groundwater samples are routinely collected and analysed by DD Science, a SANAS accredited laboratory. The localities of the groundwater monitoring boreholes are shown in **Figure 4.6** and the February 2020 results are shown in **Table 4.4**.

The groundwater chemistry is compared to the SANS 241 (2015) specifications for drinking water. Concentrations that exceed the SANS 241 guideline limits are highlighted in red. In the absence of SANS 241 limits the DWAF[1] (1996) limits are used.

The SANS 241 Drinking Water Specification is the definitive reference on acceptable limits for drinking water quality parameters in South Africa and provides guideline levels for a range of water quality characteristics. The SANS 241 (2015) Drinking-Water Specification effectively summarises the suitability of water for drinking water purposes for lifetime consumption.

With reference to **Table 4.4** the following observations are made:

- Boreholes BH93 and BH97 have high salinity with elevated TDS concentrations. These boreholes are located up-gradient from the mining activities and the high salinity can only be attributed to the borehole's proximity to the easterly dams where evaporation is high. The fact that the sulphate concentration in borehole Bh93 is also elevated may, however, suggest that there is some mining impact as well.
- The boreholes in close proximity to the tailings facility (BH103 and BH106) show mining impact with elevated sulphate concentrations. There is no recent analysis for borehole BH15, which is located immediately down-gradient from the tailings facility. Borehole BH4, which is located further down-gradient shows that the contamination migrates slowly, and this borehole is still within the drinking water limits.
- The water quality in D-Zone pit, into which tailings is currently deposited shows high concentrations of EC, TDS, sulphate, nitrate, ammonia, calcium, sodium and potassium.

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

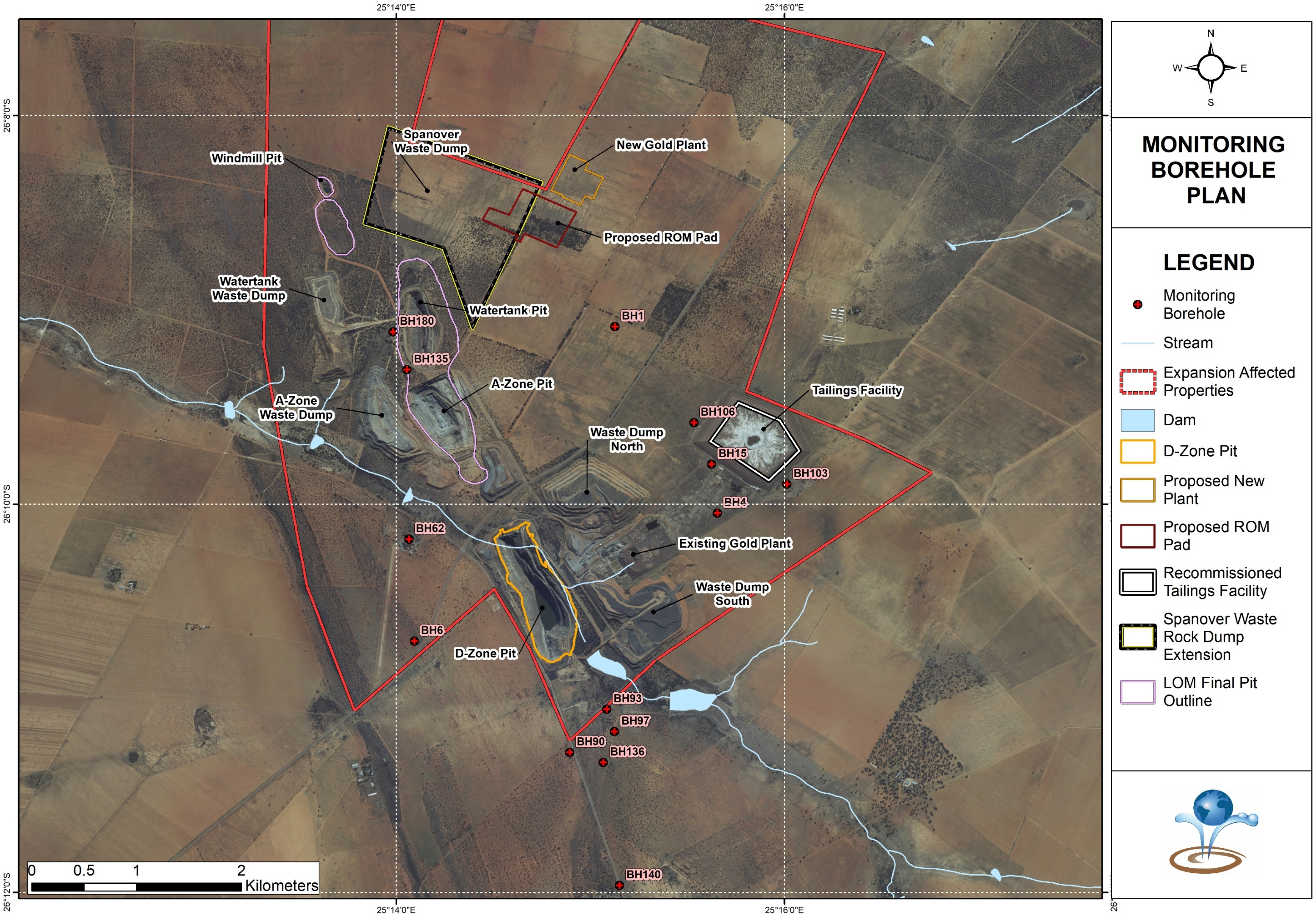


Figure 4.6: **Kalgold waste sites and groundwater monitoring boreholes**

Table 4.4: Groundwater chemistry

Determinant	Unit	SANS 241	WB 90	WB 93	WB 97	BH1	BH4	BH6	WB 103	WB 106	BH62	WB 140	BH180	D-Zone
pH	pH Units	≤5 - ≥9.7	7.8	7.0	7.2	7.7	6.9	7.5	8.1	7.4	6.3	7.5	7.4	8.9
Total Alkalinity	mg $CaCO_3$/ℓ	-	-	-	-	-	-	-	-	-	22	-	133	402
Total hardness	mg $CaCO_3$/ℓ	-	561	816	659	440	405	282	842	658	32	292	840	193
Conductivity	mS/m	≤170	134	436	214	115	140	63	240	220	15	120	174	584
Total Dissolved Solids	mg/ℓ	≤1 200	803	3 600	1 500	691	939	344	2 030	1 740	105	708	1 520	4 220
Suspended Solids	mg/ℓ	-	<10	12	<10	160	54	79	10	117	<10	<10	<10	12
Chloride	mg/ℓ	≤300	124	347	377	181	177	188	350	143	25	147	371	208
Sulphate	mg/ℓ	≤500	147	504	200	72	245	<40	295	724	<40	69	193	2 330
Nitrate	mg/ℓ	≤11	-	-	-	-	-	-	-	-	2.3	-	16.1	17.8
Fluoride	mg/ℓ	≤1.5	0.3	0.2	0.2	0.1	0.4	0.4	0.7	0.4	<0.08	0.1	0.5	1.5
Ammonia	mg/ℓ	≤1.5	-	-	-	-	-	-	-	-	2.4	-	2.3	17.3
Calcium	mg/ℓ	32*	116	187	165	89	80	49	191	173	10	63	239	33
Magnesium	mg/ℓ	30*	66	85	60	53	50	39	89	55	1.8	33	59	27
Sodium	mg/ℓ	≤200	65	122	77	47	57	35	29	99	14	49	36	867
Potassium	mg/ℓ	50*	2.2	2.3	2.0	2.7	1.9	2.8	2.1	9.0	0.6	2.4	2.0	876
Iron	mg/ℓ	≤2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Manganese	mg/ℓ	≤0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Aluminium	mg/ℓ	≤0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Arsenic	mg/ℓ	≤0.01	-	-	-	-	-	-	-	-	<0.1	-	<0.1	<0.1

Determinant	Unit	SANS 241	WB 90	WB 93	WB 97	BH1	BH4	BH6	WB 103	WB 106	BH62	WB 140	BH180	D-Zone
Cadmium	mg/ℓ	≤0.003	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cobalt	mg/ℓ	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lead	mg/ℓ	≤0.01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	mg/ℓ	≤0.07	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Zinc	mg/ℓ	≤5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper	mg/ℓ	≤2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	-
Boron	mg/ℓ	≤2.4	0.08	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	-
Turbidity	mg/ℓ	≤5	-	-	-	-	-	-	-	-	0.3	-	7.6	3.9
COD	mg/ℓ	-	-	-	-	-	-	-	-	-	<20	-	<20	52
Free CN	mg/ℓ CN	≤0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
WAD Cyanide	mg/ℓ CN	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.5
Oil	mg/ℓ	-	0.4	0.8	0.8	0.6	0.8	0.8	1.2	1.6	-	0.8	-	-

Note: *****DWAF Guideline

A waste assessment was recently undertaken at Kalgold (Hansen, 2020) during which the waste material from the following sites were evaluated (see **Figure 4.6** for localities):

- D-Zone pit (gold tailings).
- Spanover WRD (waste rock).
- Watertank WRD (waste rock).
- Low-grade Stockpile (low-grade ore).

The report is attached as **Appendix A** and can be summarised as follows.

Distilled water shake flask tests were performed on the waste rock and the tailings samples to determine which soluble constituents are present in the material. The results are presented in **Table 4.5**. There are no elements exceeding the Leachable Concentration Threshold (LCT0) for any of the samples indicating a low contamination seepage risk.

Table 4.6 indicates that all the total analysis concentrations of the waste rock material fall below the lowest regulatory threshold value (TCT1), with the exception of boron, which exceeds the regulatory value of TCT1, but is below the regulatory value of TCT2.

According to the criteria set out in R635 the Kalgold waste rock classifies as Type 3. The waste assessment as well as the groundwater monitoring data was utilised in determining the source concentrations that were included in the mass transport model.

Table 4.5: Comparison of leach test data to R635 Leach Concentration Threshold (LCT) regulatory values

Inorganic Waste constituents	Abbreviation	R635 Leach Concentration Threshold Values				Water Tank WRD	Spanover WRD	Spanover low-grade ore	Tailings
		LCT0	LCT1	LCT2	LCT3	mg/L			
		mg/L	*mg/L*	*mg/L*	*mg/L*				
Metal Ions									
Arsenic	**As**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Boron	**B**	0.5	25	50	200	0.0	<0.025	<0.025	<0.025
Barium	**Ba**	0.7	35	70	280	0.0	<0.025	<0.025	<0.025
Cadmium	**Cd**	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001	<0.001
Cobalt	**Co**	0.5	25	50	200	0.0	<0.025	<0.025	<0.025
Chromium (Total)	**Cr(Total)**	0.1	5	10	40	<0.001	<0.025	<0.025	<0.025
Chromium (VI)	**Cr(VI)**	0.05	2.5	5	20	<0.010	<0.010	<0.010	<0.010
Copper	**Cu**	2.0	100	200	800	<0.001	<0.010	<0.010	<0.010
Mercury	**Hg**	0.006	0.3	0.6	2.4	<0.001	<0.001	<0.001	<0.001
Manganese	**Mn**	0.5	25	50	200	0.1	<0.025	0.068	0.025
Molybdenum	**Mo**	0.07	3.5	7	28	<0.001	<0.025	<0.025	<0.025
Nickel	**Ni**	0.07	3.5	7	28	0.00	<0.025	<0.025	<0.025
Lead	**Pb**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Antimony	**Sb**	0.02	1.0	2	8	<0.001	<0.001	<0.001	<0.001
Selenium	**Se**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Vanadium	**V**	0.2	10	20	80	<0.001	<0.025	<0.025	<0.025
Zinc	**Zn**	5.0	250	500	2 000	0.0	<0.025	<0.025	<0.025
Inorganic Anions									
Total Dissolved Solids	**TDS**	1 000	12 500	25 000	100 000	40	34	128	226
Chloride	**Cl**	300	15 000	30 000	120 000	<2	2	7	18
Sulphate	**SO_4**	250	12 500	25 000	100 000	12	3	49	87
Nitrate as Nitrogen	**NO_3-N**	11	550	1 100	4 400	<0.1	<0.1	<0.1	<0.1
Fluoride	**F**	2	75	150	600	<0.2	<0.2	<0.2	<0.2
Cyanide (Total)	**CN^-(Total)**	0	4	7	28	<0.02	<0.02	<0.02	0.12

Table 4.6: Comparison of the total analysis data to R635 Total Concentration Threshold (TCT) regulatory values

Waste constituents	Abbreviation	R635 Total Concentration Threshold Values			Water Tank WRD	Spanover WRD	Spanover low-grade ore	Tailings
		TCT0	TCT1	TCT2	*mg/kg*			
		mg/kg	*mg/kg*	*mg/kg*				
Metal Ions								
Arsenic	**As**	5.8	500	2 000	1.2	1.6	6.0	0.8
Boron	**B**	150	15 000	60 000	227	90	33	90
Barium	**Ba**	62.5	6 250	25 000	60	195	79	74
Cadmium	**Cd**	7.5	260	1 040	<0.4	<0.4	<0.4	<0.4
Cobalt	**Co**	50	5 000	20 000	1.2	<10	<10	<10
Chromium (Total)	**Cr(Total)**	46 000	800 000	n.a	156	290	306	188
Chromium (VI)	**Cr(VI)**	6.5	500	2 000	<2	<5	<5	<5
Copper	**Cu**	16.0	19 500	78 000	<0.4	84	126	55
Mercury	**Hg**	0.93	160	640	0.4	<0.4	<0.4	<0.4
Manganese	**Mn**	1 000	25 000	100 000	60	1 680	1 828	2 300
Molybdenum	**Mo**	40	1 000	4 000	2.8	<10	<10	<10
Nickel	**Ni**	91	10 600	42 400	4	121	113	93
Lead	**Pb**	20	1 900	7 600	15	7.6	8	8.8
Antimony	**Sb**	10	75	300	<0.4	<0.4	<0.4	<0.4
Selenium	**Se**	10	50	200	<0.4	<0.4	<0.4	<0.4
Vanadium	**V**	150	2 680	10 720	43	244	85	72
Zinc	**Zn**	240.0	160 000	640 000	<0.400	103	101	115
Inorganic Anions								
Fluoride	**F**	100	10 000	40 000	<0.5	239	174	183
Cyanide (Total)	**CN^-(Total)**	14	10 500	42 000	<0.5	<0.5	<0.5	54

4.2.7 Aquifer Classification

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 4.7**). A weighting and rating approach is then used to decide on the appropriate level of groundwater protection (**Table 4.8**).

Table 4.7: Ratings for the aquifer quality management classification system

Class	Points	Class	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 4.8: 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 added to obtain a Groundwater Quality Management (GQM) index.

Based on the above, the aquifers in the study area are classified as follows:

Description	Aquifer	Vulnerability	Rating	Protection
Weathered Aquifer	Minor (2)	2	4	Medium
Fractured Aquifer	Sole Source (6)	2	8	High

Since the fractured aquifer is the sole water supply to the farms in the region it is regarded as a sensitive and important aquifer that needs high level protection.

5. NUMERICAL GROUNDWATER MODEL

5.1 Introduction

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

- Estimated pit groundwater inflow volumes during the mining process;
- Dewatering requirements to keep the pit dry during mining; and
- Groundwater level changes during the mining process and potential impacts on the yields of neighbouring farm boreholes.

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.

5.2 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; and
- 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; and
- Many aquifer parameters have not been determined in the field and therefore must be estimated.

In order 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;
- The boundary conditions assigned to the model are considered correct; and
- 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.

5.3 Model Set-up

In order to investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. The modelling area was selected based on a combination of topographical, geological and structural control and covers an area of approximately 414 km^2 (**Figure 5.1**).

A two-layered aquifer model was constructed and calibrated for the Kalgold site using the finite element 3D-modelling package FEFLOW 7.1.

The model comprises 2 layers, 719 098 elements and 542 691 nodes. The total depth of the model is 280m deep. The 2 layers build into the model are:

- Layer 1 – Shallow weathered aquifer (Kalahari Sand). This aquifer has an estimated average depth of 30m; and
- Layer 2 – Deeper fractured aquifer. This aquifer has an estimated depth of 220m.

The model construction is presented in **Figure 5.2**.

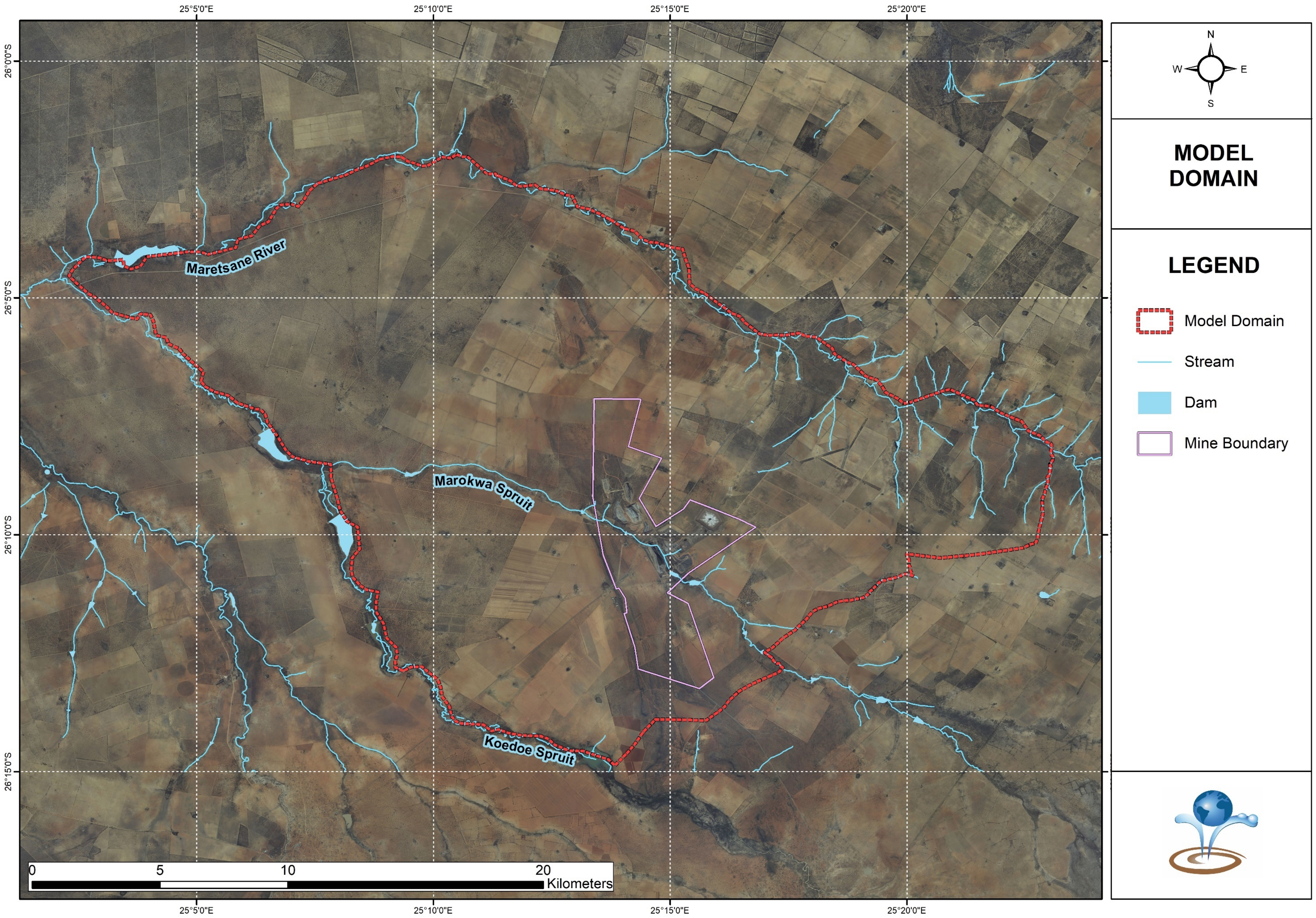


Figure 5.1: **Model boundary**

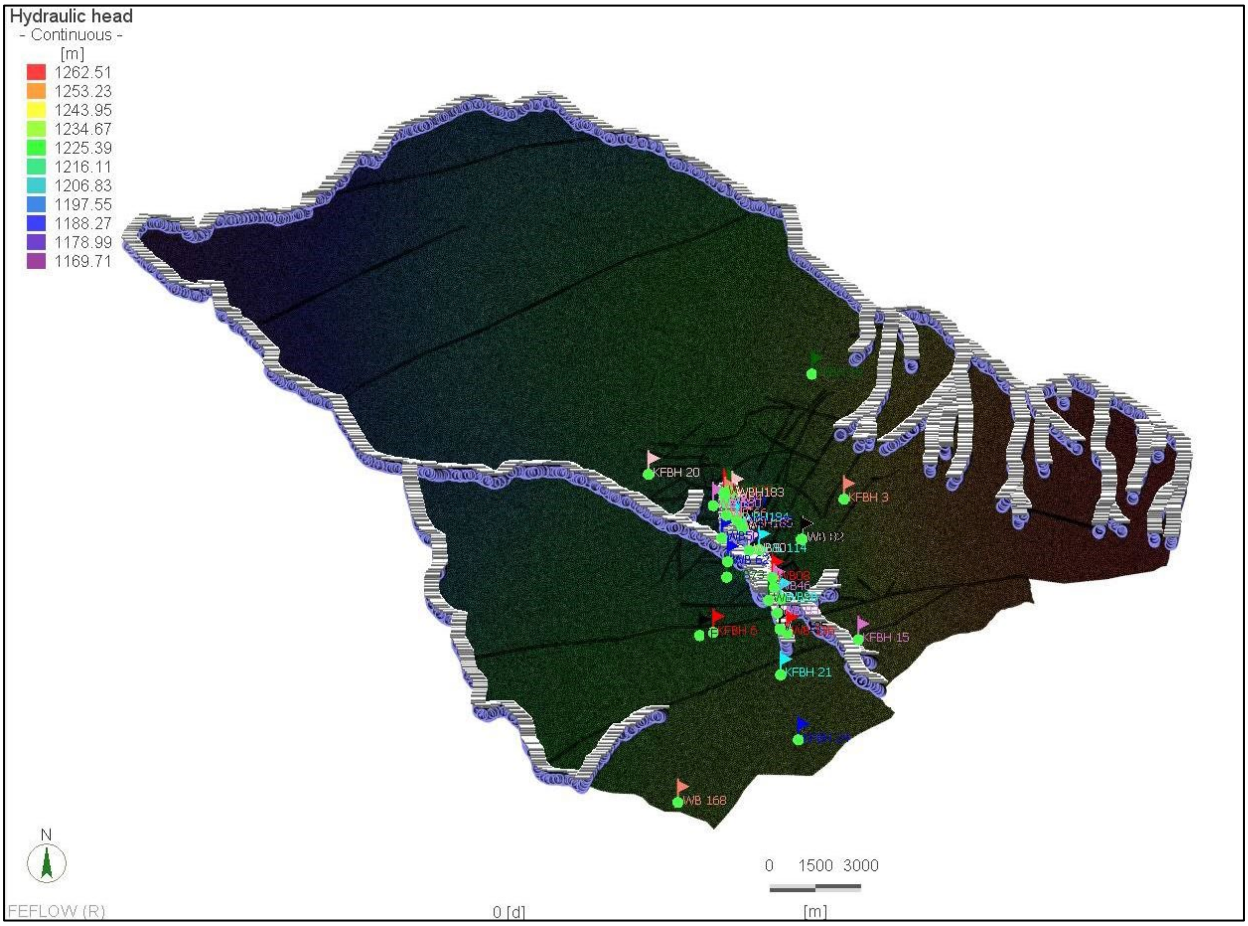


Figure 5.2: **Model construction**

5.4 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, have to 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, wells, 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 should 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.

Boundaries of the numerical model were chosen to reflect the geometry of the groundwater system. The surface streams were incorporated as drains into the modelling domain.

5.5 Initial Conditions

Initial conditions are vital for modelling flow problems. Initial conditions should be specified for the entire area. Generally, the initial groundwater level / head distribution acts as the starting distribution for the numerical calculation. The groundwater levels shown in **Figure 4.5** were used as initial conditions for the model.

5.6 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 steady state calibration simulations were conducted using recharge values of approximately 10mm per annum, which corresponds to 2% of the estimated annual regional precipitation (MAP) of 489 mm. The rainfall figures used to calculate the recharge are the Neverset rainfall figures, which is higher than those recorded on the mine. This was done to represent the worst-case scenario in terms of potential contaminant seepage. Due to higher infiltration rates the recharge on the waste rock dumps and TSF was estimated at a slightly higher percentage of 5%.

Current abstraction from the system (from boreholes and the pits) was included in the model calibration.

5.7 Aquifer Parameters

The aquifer parameters discussed in **Section 4.2.5** 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 test results and hydrogeological situation.

The calibrated hydraulic conductivities of the mining area are shown in **Table 5.1** and illustrated in **Figure 5.3**.

Table 5.1: Modelled aquifer parameters

Model Layer	Hydrostratigraphic unit	Layer thickness (m)	Hydraulic Conductivity (K)		Anisotropy (Kz)	Recharge (Re)	Specific storage (Sc)	Porosity (n)
			Kx,y 1:1 (m/d)	Kz 1:10 (m/d)		In/Outflow on top/bottom (mm/a)	Sc (1/m)	
Layer 1	Quaternary deposits (Qw)	30.00	0.900	0.900	1.000	9.78	1.0E-04	3.0E-02
	Qg		0.300	0.150	0.500			
	Zgr		0.200	0.100	0.500			
	Zf		0.200	0.100	0.500			
	Zkh		1.000	0.500	0.500			
	Dykes		0.050	0.003	0.050			
	Dykes (weathered perimeter)		0.750	0.375	0.500			
	Thrusts		0.750	0.375	0.500			
Layer 2	Qg	220.00	0.150	0.075	0.500	0.00	1.0E-05	1.0E-02
	Zgr		0.100	0.050	0.500			
	Zf		0.100	0.050	0.500			
	Zkh		0.500	0.250	0.500			
	Dykes		0.500	0.003	0.006			
	Dykes (weathered perimeter)		0.375	0.013	0.033			
	Thrusts		0.375	0.013	0.033			

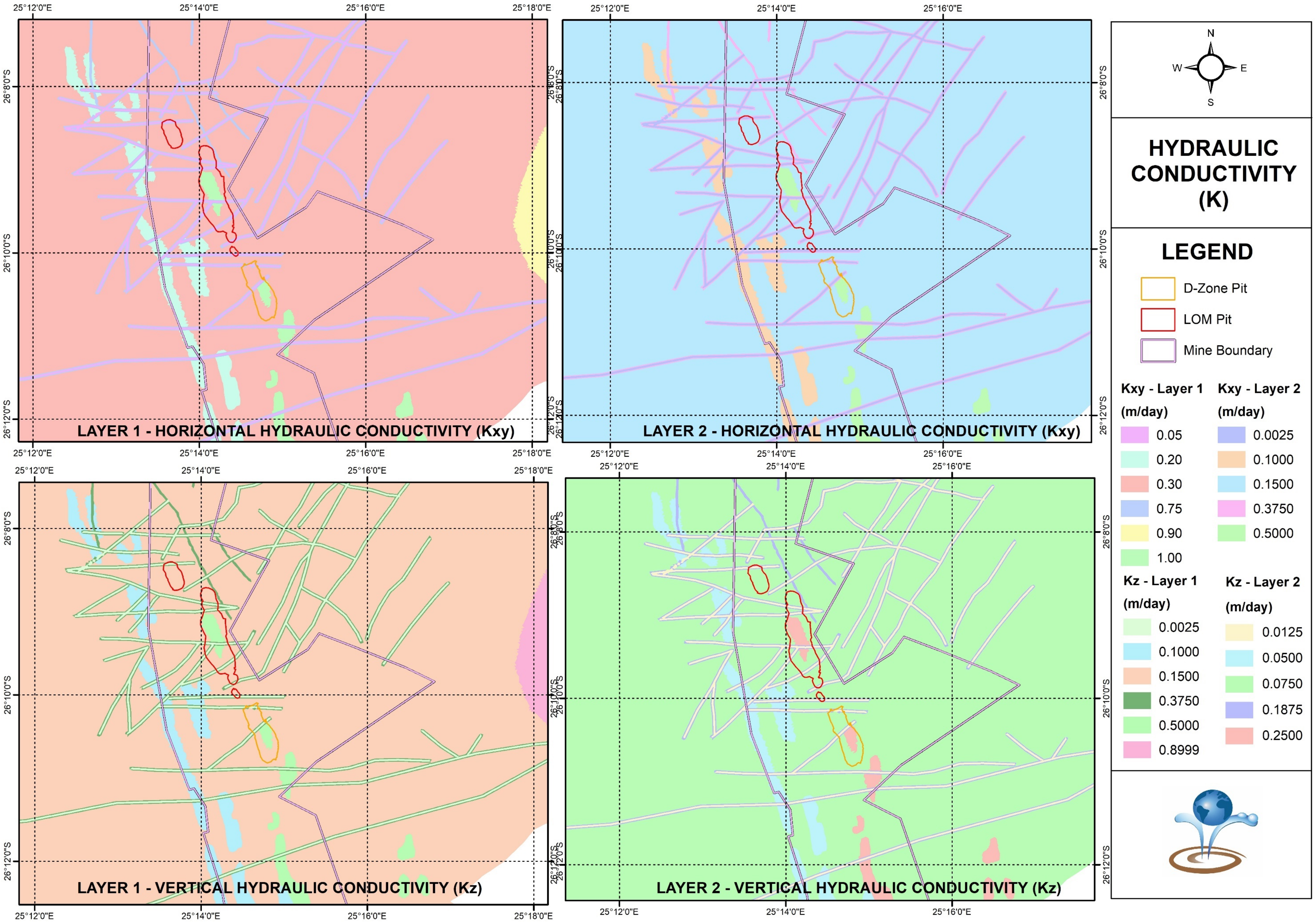


Figure 5.3: **Hydraulic Conductivity distribution**

5.8 Mathematical Flow Model

A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow where the effect of for example the waste body is considered.

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

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

where

h = hydraulic head [L]

Kx,Ky,Kz = 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:

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

5.8.1 Calibration of the Steady State Model

According to the conceptual model for the system the calculated head distribution ($h_{x,y,z}$) is dependent upon the recharge from rainfall, hydraulic conductivity and boundary conditions. For a given hydraulic conductivity value (or transmissivity value) and set of boundary conditions specified, the head distribution across the aquifer can be obtained for a specific recharge value. This simulated head distribution can then be compared to the measured head distribution and the recharge and evaporation values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

Steady state calibration was accomplished by varying the hydraulic conductivity values within a realistic range based upon the field data and the recharge rate until a reasonable match between the measured groundwater elevations and the simulated groundwater elevations was obtained. The model was calibrated against measured groundwater levels.

The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads. The steady state calibration results are presented in **Table 5.2** and **Figure 5.4**.

Table 5.2: Flow calibration results

Calibration Site	Topographical Elevation (mamsl)	Water Level (mbs)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)
KFBH1	1234.34	12.55	1221.79	1223.47	-1.68	1.68
KFBH3	1261.59	25.30	1236.29	1242.04	-5.75	5.75
KFBH4	1253.19	24.40	1228.79	1228.06	0.73	0.73
KFBH6	1256.99	38.10	1218.89	1227.13	-8.24	8.24
KFBH15	1254.80	10.75	1244.05	1243.51	0.54	0.54
KFBH18	1261.12	31.53	1229.59	1241.40	-11.81	11.81
KFBH19	1263.55	30.06	1233.49	1240.33	-6.84	6.84
KFBH20	1234.79	12.56	1222.23	1222.22	0.01	0.01
KFBH22	1261.92	25.40	1236.52	1236.66	-0.14	0.14
KFBH23	1261.16	24.50	1236.66	1235.77	0.89	0.89
KFBH27	1259.52	10.80	1248.72	1243.45	5.27	5.27
WB 62	1238.00	23.80	1214.20	1212.22	1.98	1.98
WB 168	1240.00	4.43	1235.57	1238.39	-2.82	2.82
WB 136	1249.18	23.80	1225.38	1229.97	-4.59	4.59
WB 93	1240.65	26.75	1213.90	1220.47	-6.56	6.56
WB 99	1240.00	31.44	1208.56	1208.77	-0.21	0.21
WB 82	1250.45	23.35	1227.10	1228.46	-1.36	1.36
KFBH 21	1270.00	35.36	1234.64	1236.64	-2.00	2.00
WB 66	1240.50	44.70	1195.80	1203.29	-7.49	7.49
WB 179	1243.54	34.96	1208.58	1206.47	2.11	2.11
WB 180	1240.00	38.41	1201.59	1208.88	-7.29	7.29
WBH183	1243.74	42.03	1201.71	1205.01	-3.30	3.30
WBH184	1242.41	36.96	1205.45	1206.15	-0.70	0.70
WBH185	1240.94	32.26	1208.68	1208.17	0.51	0.51
WBH186	1240.89	32.12	1208.77	1208.47	0.31	0.31
WBH187	1240.69	32.42	1208.27	1209.09	-0.82	0.82
WB08	1232.71	20.08	1212.63	1209.73	2.90	2.90
WB2B	1233.96	13.17	1220.79	1219.86	0.93	0.93
WB50	1235.92	29.66	1206.26	1210.36	-4.10	4.10
WB64	1240.59	40.50	1200.09	1201.33	-1.24	1.24
WB30	1240.00	37.98	1202.02	1211.06	-9.04	9.04
WB46	1231.76	15.20	1216.56	1209.90	6.66	6.66
WSBH1	1247.14	32.97	1214.17	1215.51	-1.34	1.34
WSBH2	1240.00	32.15	1207.85	1204.15	3.70	3.70
WSBH3	1238.20	29.48	1208.72	1212.26	-3.54	3.54
WB 2	1249.52	33.30	1216.22	1218.18	-1.96	1.96
WB 5	1249.19	25.54	1223.65	1216.92	6.73	6.73
WB 7	1250.36	33.50	1216.86	1219.43	-2.57	2.57
WB 8	1251.26	33.00	1218.26	1219.76	-1.50	1.50
WB 10	1244.43	36.10	1208.33	1213.11	-4.78	4.78
WB 11	1253.51	32.80	1220.71	1220.84	-0.13	0.13

Calibration Site	Topographical Elevation (mamsl)	Water Level (mbs)	Measured head elevation (mamsl)	Simulated head elevation (mamsl)	Mean Error (m)	Mean Absolute Error (m)
WB 1	1247.97	33.90	1214.07	1215.93	-1.86	1.86
WB 4	1245.00	25.10	1219.90	1217.33	2.57	2.57
Average	**1246.41**	**28.21**	**1218.19**	**1218.57**	**-1.58**	**3.24**
Minimum	**1231.76**	**4.43**	**1195.80**	**1201.33**	**-11.81**	**0.01**
Maximum	**1270.00**	**44.70**	**1248.72**	**1243.51**	**6.73**	**11.81**
Correlation			**0.95**			
∑					**-67.82**	**139.49**
1/n						**3.24**
Root Mean Square Deviation (RMSD)						**1.80**
Normalised Root Mean Square Deviation (NRMSD) (% of water level range)						

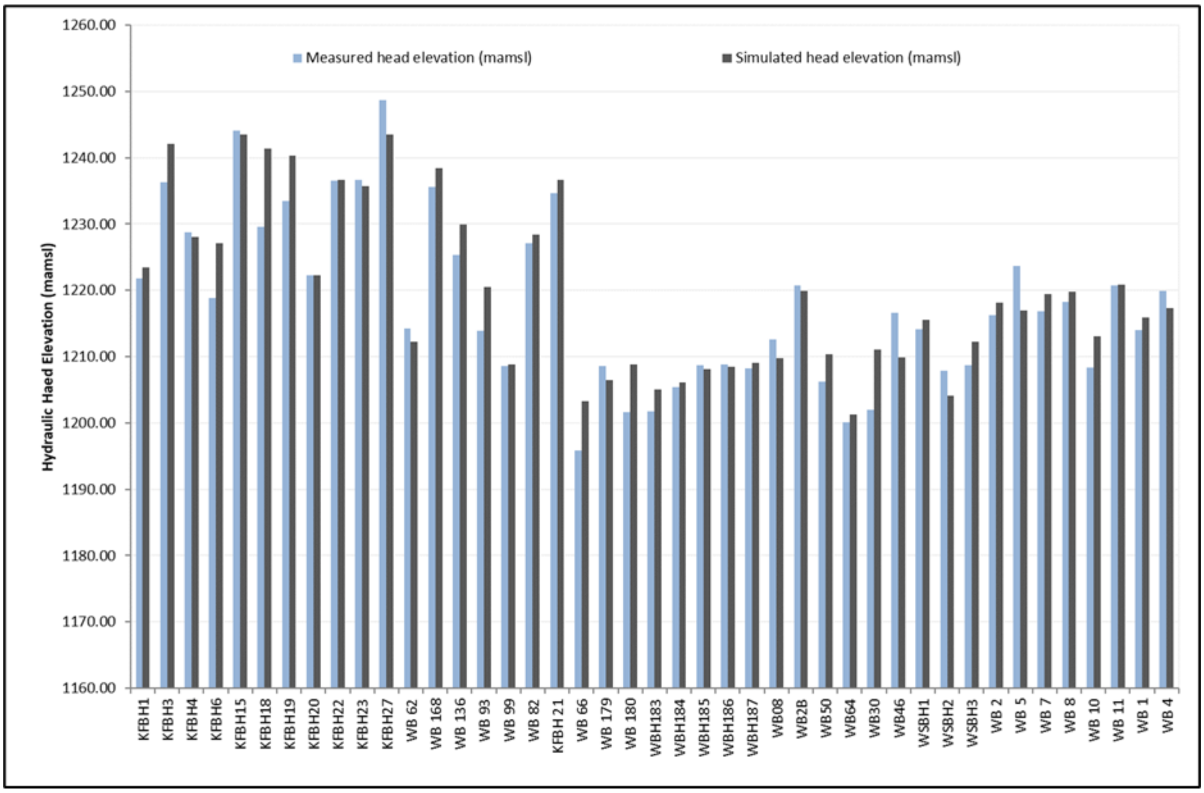


Figure 5.4: Model calibration – Groundwater level

5.9 Numerical Groundwater Mass Transport Model

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 MT3D 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.
- Transmissivity values.
- Porosity values.
- Longitudinal dispersivities.
- transversal dispersivities.
- Hydraulic heads/water levels in the aquifer over time.

Transmissivities for the aquifer were specified according to the values obtained during the scenario of the steady state water level calibration.

A longitudinal dispersivity value of 100 m was selected for the simulations (see Table D.3 – Field-Scale Dispersivities in Spitz and Moreno, 1996). Bear and Verruijt (1992) estimated the average transversal dispersivity to be 10 to 20 times smaller than the longitudinal dispersivity. An average value of 10m was selected for this parameter during the simulations. The hydraulic head values as calculated during the steady state simulations were specified in the model.

Input concentrations in the model were specified at cells over the areas where contamination is expected. Total Dissolved Solids (TDS) was selected as a conservative tracer that represents the migration of contaminants through the aquifer. The input concentrations were specified as average concentrations (mg/ℓ). Based on the waste assessment and groundwater monitoring the following TDS concentrations were assigned to the various waste bodies:

Tailings facility:	1 750 mg/ℓ.
Waste rock:	1 033 mg/ℓ.
ROM Pad:	1 690 mg/ℓ.
D-Zone:	4 500 mg/ℓ.

6. GEOHYDROLOGICAL IMPACT ASSESSMENT

6.1 Mining Schedule

The mining schedule estimated a Life of Mine (LOM) of approximately 10 years after July 2024. The ore tonnages peak at approximately 300 000 tons per month. Monthly tailings deposition from July 2024 will be 260 000 tons into D-Zone and 40 000 tons on the existing TSF.

6.2 Mine Water Balance and Water Requirements

6.2.1 Current Mine Water Usage

Based on the 2020 water usage the required water volume is in the region of 1.50 m^3/ton milled (Van Biljon, 2021). This equates to 14 988 m^3/day or ~15 Mℓ/day of process water (excluding dust suppression and drinking water) for the increased production rate of 300 000 tons per month.

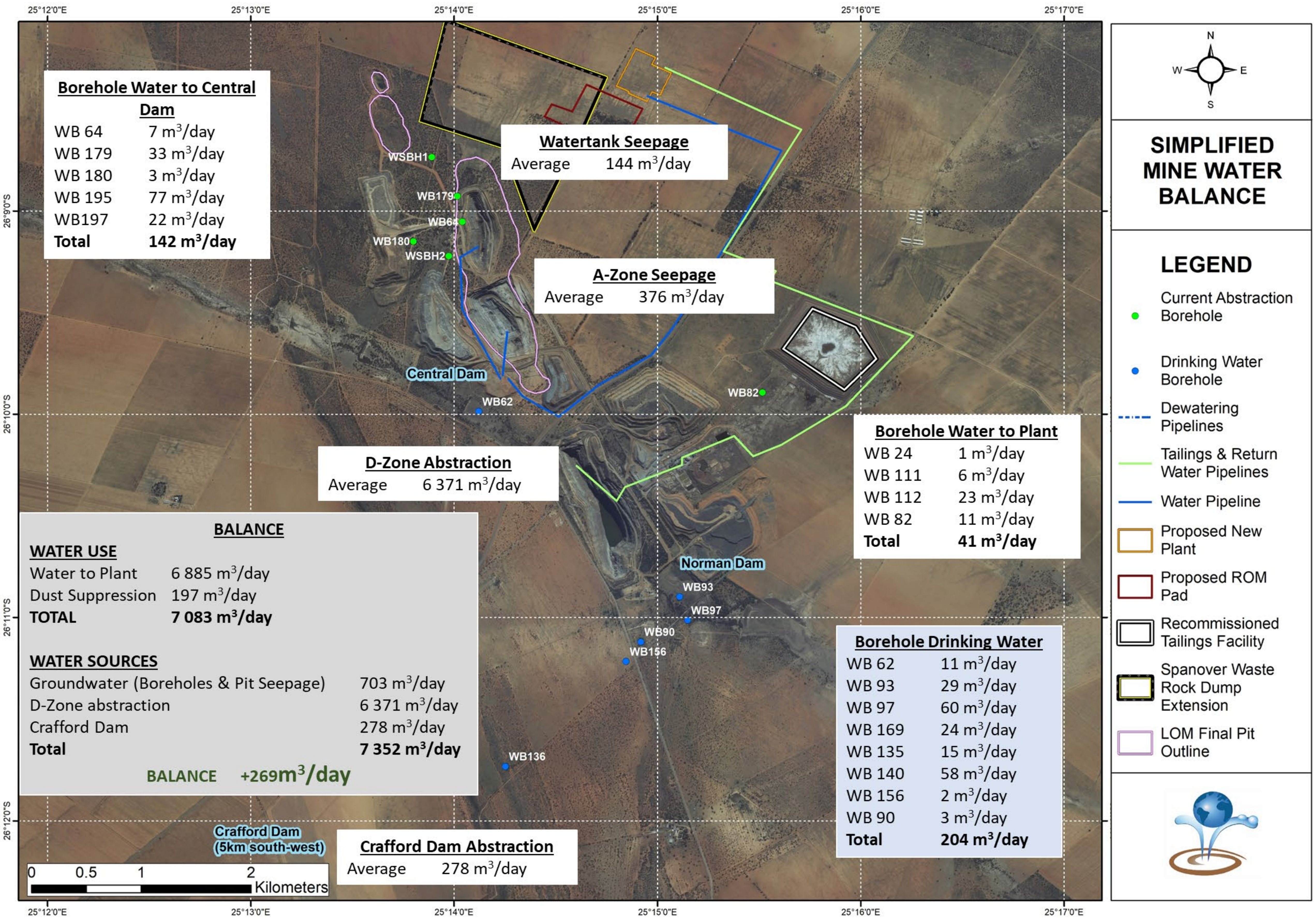
6.2.2 Mine Water Balance

The mine water balance is made up from the following sources:

- Borehole water.
- Groundwater seepage / rainfall from the various pits.
- Return water from D-Zone pit.
- Crafford dam.

Rainfall may contribute to the water balance, but other than rainfall directly into the pits, the rainfall is not accounted for. It is assumed that the water volumes abstracted from the pits include the rainfall.

The current water supply can meet the demand of 5.4 Mℓ/day. A simplified mine water balance is presented in **Figure 6.1**.



Borehole Water to Central Dam

WB 64	7 m³/day
WB 179	33 m³/day
WB 180	3 m³/day
WB 195	77 m³/day
WB197	22 m³/day
Total	**142 m³/day**

Watertank Seepage

Average	144 m³/day

A-Zone Seepage

Average	376 m³/day

D-Zone Abstraction

Average	6 371 m³/day

Borehole Water to Plant

WB 24	1 m³/day
WB 111	6 m³/day
WB 112	23 m³/day
WB 82	11 m³/day
Total	**41 m³/day**

BALANCE

WATER USE

Water to Plant	6 885 m³/day
Dust Suppression	197 m³/day
TOTAL	**7 083 m³/day**

WATER SOURCES

Groundwater (Boreholes & Pit Seepage)	703 m³/day
D-Zone abstraction	6 371 m³/day
Crafford Dam	278 m³/day
Total	**7 352 m³/day**

BALANCE +269m³/day

Borehole Drinking Water

WB 62	11 m³/day
WB 93	29 m³/day
WB 97	60 m³/day
WB 169	24 m³/day
WB 135	15 m³/day
WB 140	58 m³/day
WB 156	2 m³/day
WB 90	3 m³/day
Total	**204 m³/day**

Crafford Dam Abstraction

Average	278 m³/day

Figure 6.1: Simplified mine water balance (Van Biljon, 2019)

6.3 Dewatering Impacts

The unavoidable inflow of groundwater into the opencast pits and the pumping of this water will have an impact on the groundwater levels near the mining operations. The estimated groundwater inflow volumes over the LOM are shown in **Table 6.1** and illustrated in **Figure 6.2**.

Table 6.1: Simulated groundwater inflow volumes

Year	A-Zone	Watertank	Combined	Combined (Including rainfall & evaporation)
	(m^3/day)	(m^3/day)	(m^3/day)	(m^3/day)
2021	410	250	660	0
2022	4 411	2 404	6 814	998
2023	4 225	2 134	6 359	543
2024	3 935	1 980	5 915	99
2025	4 574	2 470	7 044	1 228
2026	4 284	2 272	6 556	740
2027	4 166	2 182	6 348	532
2028	5 549	4 350	9 899	4 083
2029	5 882	4 284	10 166	4 350
2030	5 661	4 184	9 845	4 029
2031	5 625	3 712	9 337	3 521
2032	5 737	2 801	8 538	2 722
2033	5 664	7 900	13 565	7 749
2034	5 176	8 116	13 292	7 476

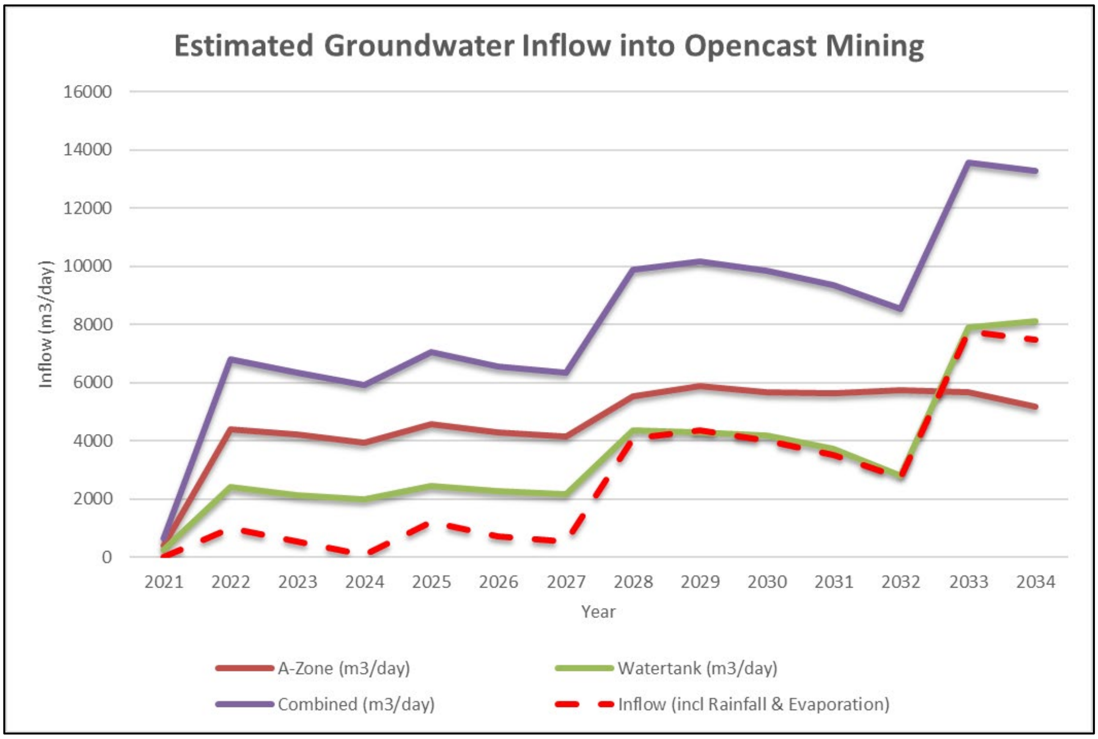


Figure 6.2: Simulated total groundwater inflow volumes

The dewatering impact is illustrated in **Figure 6.3**, which shows the expected groundwater drawdown cone at the end of mining (FY34).

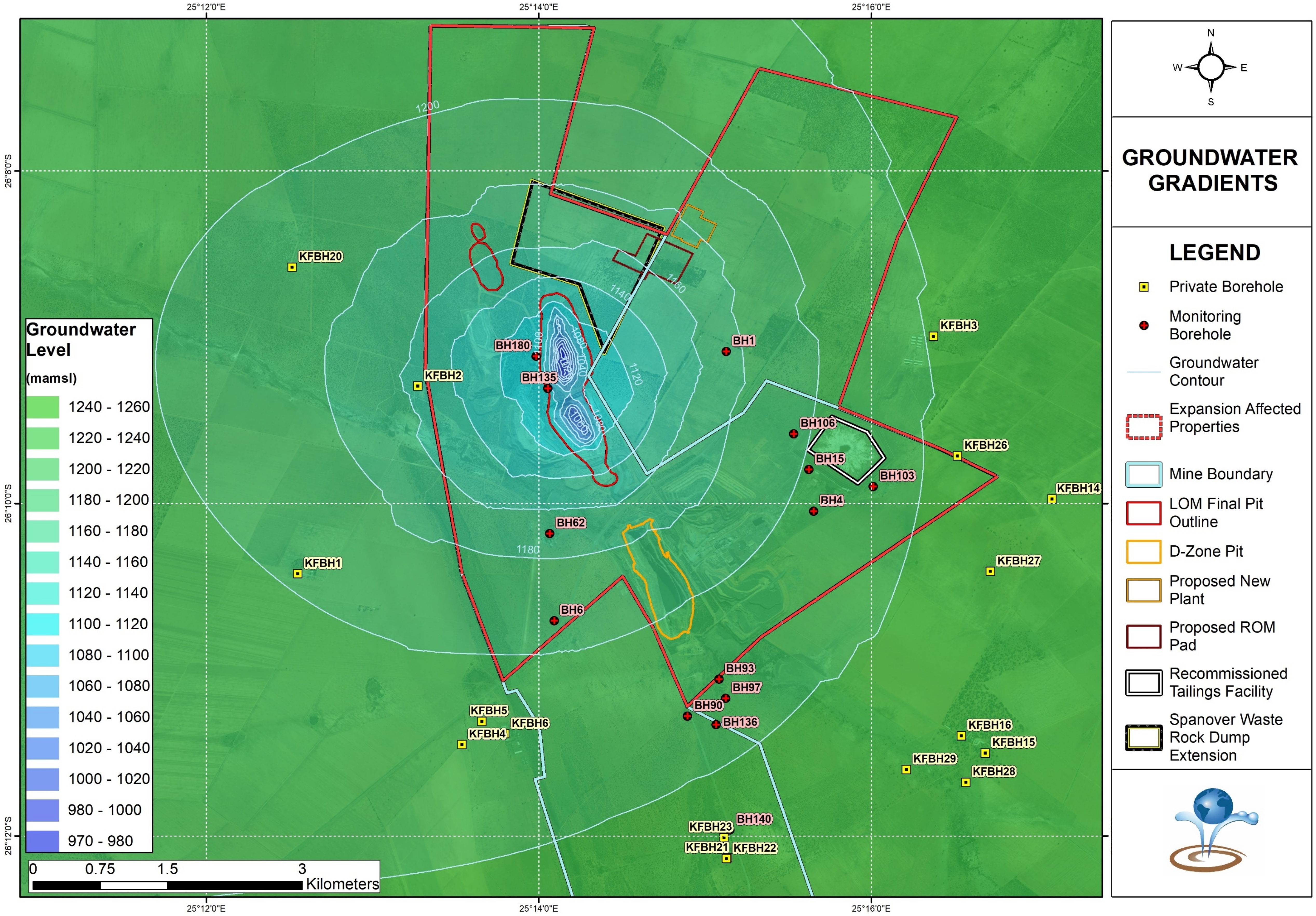


Figure 6.3: **Simulated groundwater drawdown at the end of mining (2034)**

An assessment of the potential impacts to private boreholes was undertaken as shown in **Table 6.2**. The available drawdown in each borehole cannot be accurately assessed as all the borehole depths could not be measured during the hydro census (see **Table 4.1**). Were these depths could not be measured a depth of 80m was assumed. The depth of borehole KFBH2 was, however, measured and the simulations indicate that this borehole may dry up.

Table 6.2: Groundwater levels in private boreholes

BH ID	Current Water Level	Current Available Drawdown	Water Level at end of Mining	End of Mining Available Drawdown	Difference in Water Level	Risk
	(mamsl)	(m)	(mamsl)	(m)	(m)	
KFBH1	1219.51	65.87	1198.37	44.73	-21	High Risk
KFBH2	1212.50	59.78	1155.21	Dry	-57	High Risk
KFBH3	1238.25	56.75	1220.76	39.26	-17	Medium Risk
KFBH4	1226.36	52.52	1212.21	38.37	-14	Medium Risk
KFBH5	1225.44	51.45	1210.23	36.25	-15	Medium Risk
KFBH6	1226.13	49.14	1211.62	34.63	-15	Medium Risk
KFBH7	1238.07	38.07	1229.81	29.81	-8	Low Risk
KFBH8	1201.04	81.04	1201.11	81.11	0	Low Risk
KFBH9	1203.73	82.54	1202.24	81.05	-1	Low Risk
KFBH10	1230.81	70.81	1231.91	71.91	1	Low Risk
KFBH11	1230.81	70.81	1231.91	71.91	1	Low Risk
KFBH12	1230.81	70.81	1231.91	71.91	1	Low Risk
KFBH13	1252.70	42.97	1247.72	37.98	-5	Low Risk
KFBH14	1242.32	53.09	1233.62	44.39	-9	Low Risk
KFBH15	1240.10	60.10	1231.66	51.66	-8	Low Risk
KFBH16	1238.22	58.22	1229.96	49.96	-8	Low Risk
KFBH17	1250.35	50.67	1246.06	46.38	-4	Low Risk
KFBH18	1237.68	56.56	1226.89	45.77	-11	Medium Risk
KFBH19	1236.30	52.75	1223.98	40.42	-12	Medium Risk
KFBH20	1218.68	64.20	1190.56	36.08	-28	High Risk
KFBH21	1235.52	45.98	1225.28	35.73	-10	Low Risk
KFBH22	1235.54	46.00	1225.29	35.74	-10	Low Risk
KFBH23	1235.08	49.65	1224.46	39.03	-11	Low Risk
KFBH24	1238.09	38.09	1229.81	29.81	-8	Low Risk
KFBH25	1237.38	47.91	1231.27	41.80	-6	Low Risk
KFBH26	1237.75	56.14	1224.07	42.46	-14	Medium Risk
KFBH27	1238.23	58.23	1228.89	48.89	-9	Low Risk
KFBH28	1239.65	59.65	1231.06	51.06	-9	Low Risk
KFBH29	1238.01	58.01	1228.64	48.64	-9	Low Risk

There are four (4) private boreholes that may potentially be impacted by this dewatering. These include:

- KFBH1: Potential 21m drop in the groundwater level expected.
- KFBH2: Potential 57m drop in the groundwater level expected, which may cause this borehole to dry up.
- KFBH3: Potential 17m drop in the groundwater level expected.
- KFBH20: Potential 28m drop in the groundwater level expected.

It is recommended that these boreholes be included in the mine monitoring programme to verify the findings of this simulation. Borehole KFBH2 may need to be replaced if the simulations prove to be correct. It is further recommended that the groundwater levels in the "High and Medium Risk" categories are measured quarterly to verify model predictions and to act if necessary. The depths of these boreholes should also be confirmed.

During the operational phase of the mine the water will be pumped from the opencast operations. Post-closure this pumping will cease, and the groundwater level will recover. It is estimated that it will take approximately 25 years to recover to the average pre-mining groundwater level (**Figure 6.3**). Due to the high evaporation rates in the region the pits will always, if left open, act as a sink and groundwater flow will be towards the pits.

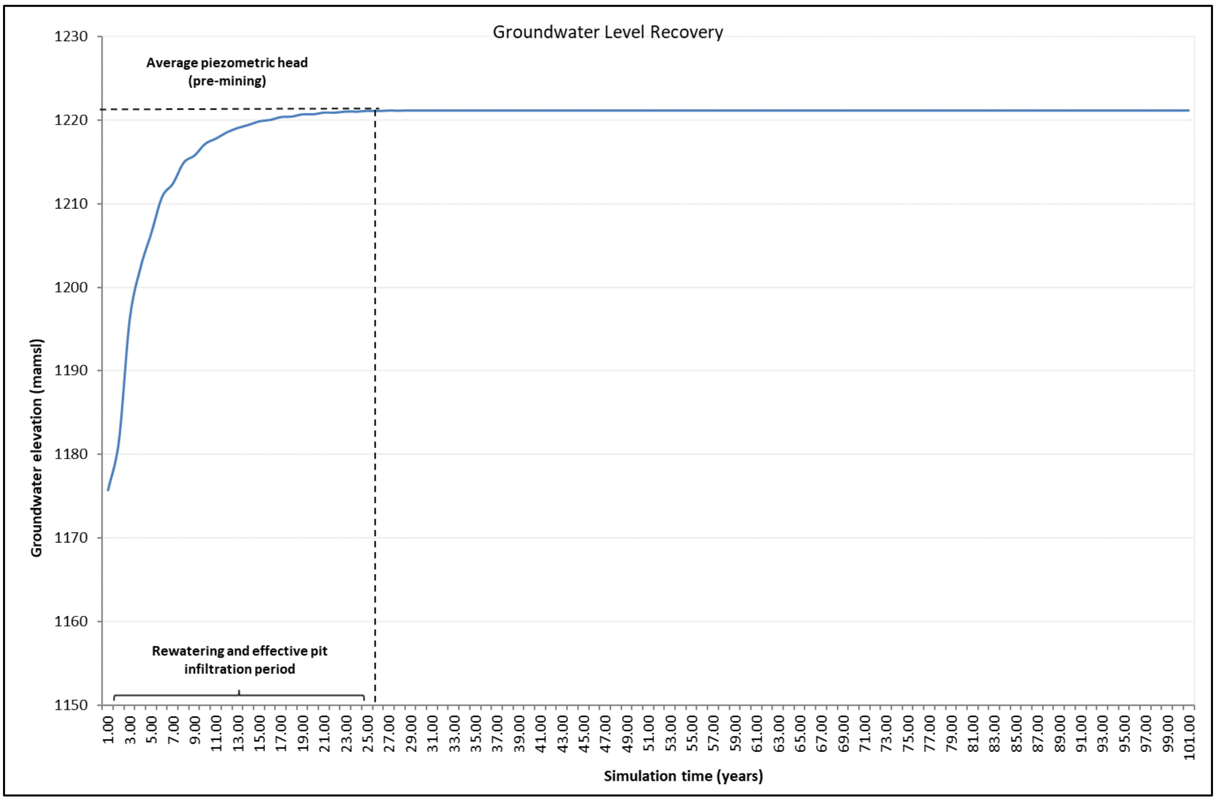


Figure 6.4: Simulated groundwater level recovery post-closure

6.4 Groundwater Quality Impacts

The contaminant plume migration from the Kalgold waste bodies were simulated with the numerical model. Total Dissolved Solids (TDS) was selected as a conservative tracer that represents the migration of contaminants through the aquifer. Based on the waste assessment and groundwater monitoring the following TDS concentrations were assigned to the various waste bodies:

- Tailings facility: 1 750 mg/ℓ.
- Waste rock: 1 033 mg/ℓ.
- ROM pad: 1 690 mg/ℓ.
- D-Zone: 4 500 mg/ℓ.

The simulated contaminant plume at the end of mining is shown in **Figure 6.5**.

The TDS contour intervals in the figures are based on the following guidelines:

- 500 mg/ℓ TDS: Current concentrations near waste rock dumps.
- 1 000 mg/ℓ TDS: Target water quality for Livestock Watering[2].
- 1 200 mg/ℓ TDS: SANS 241 Drinking Water Guidelines.

The following post-closure alternatives were simulated:

- Alternative 1: In the first scenario the Watertank and A-Zone pits will be left open or backfilled with tailings material if required. If backfilled the groundwater levels will revert to pre-mining water levels. The WRD will be removed (sold as aggregate), and it is assumed that the TSF will be capped and vegetated. This option is currently the preferred option according to which the mining feasibility is planned.
- Alternative 2: In the second scenario the Watertank and A-Zone pits remain open. In this instance the pit will fill with water, which will remain below the regional groundwater level due to evaporation. The pit will act as a sink and will continue to draw groundwater towards it. The WRD's will remain, and it is assumed that the TSF will be capped and vegetated.

In each instance the two alternatives are compared to the do-nothing scenario in which the pits remain open, the WRD's will remain and the TSF will be uncapped. In other words, no rehabilitation measures will be implemented. The results of these simulations are presented in **Figure 6.6** (Alternative 1) and **Figure 6.7** (Alternative 2).

Please note that capping and vegetating of the waste facilities were simulated as a potential remedial option. This has, however, not been verified as the only option and has not been approved by the environmental management team as the most viable option.

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

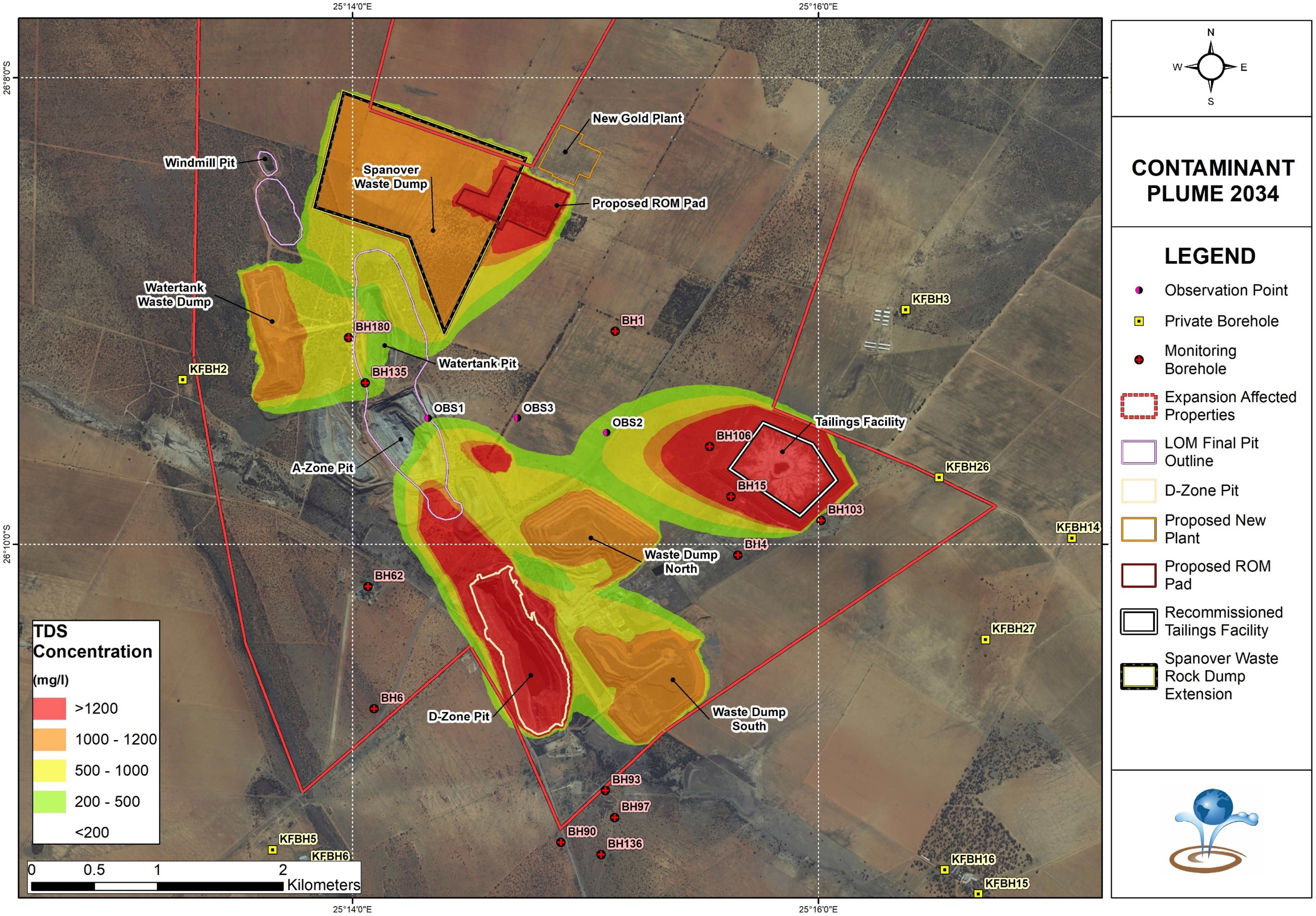

Figure 6.5: **Simulated TDS plume at the end of mining (2034)**

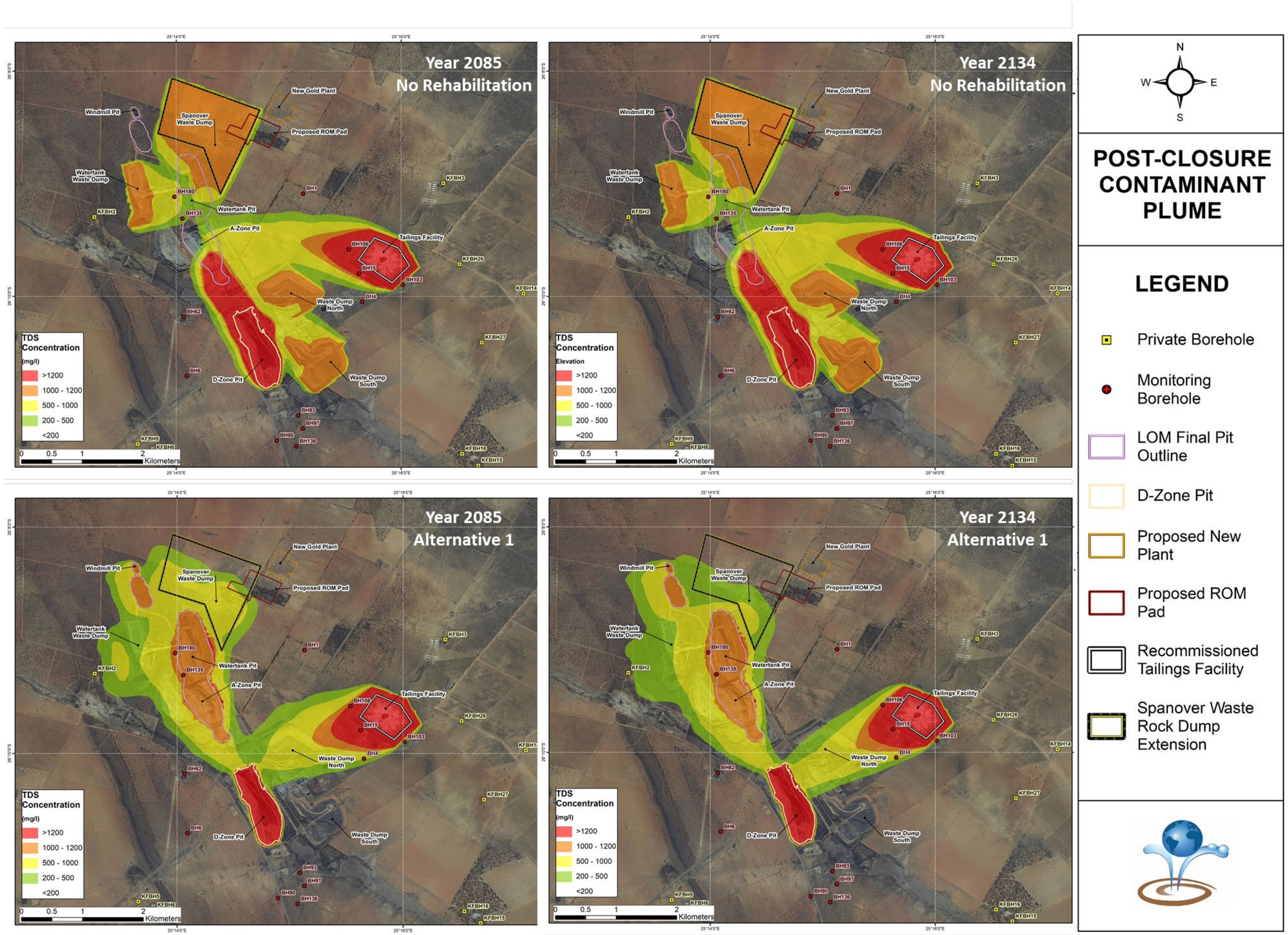

Figure 6.6: **Comparison between contaminant plumes after 50 and 100 years – Post-closure alternative 1 (pits backfilled with waste rock and TSF capped)**

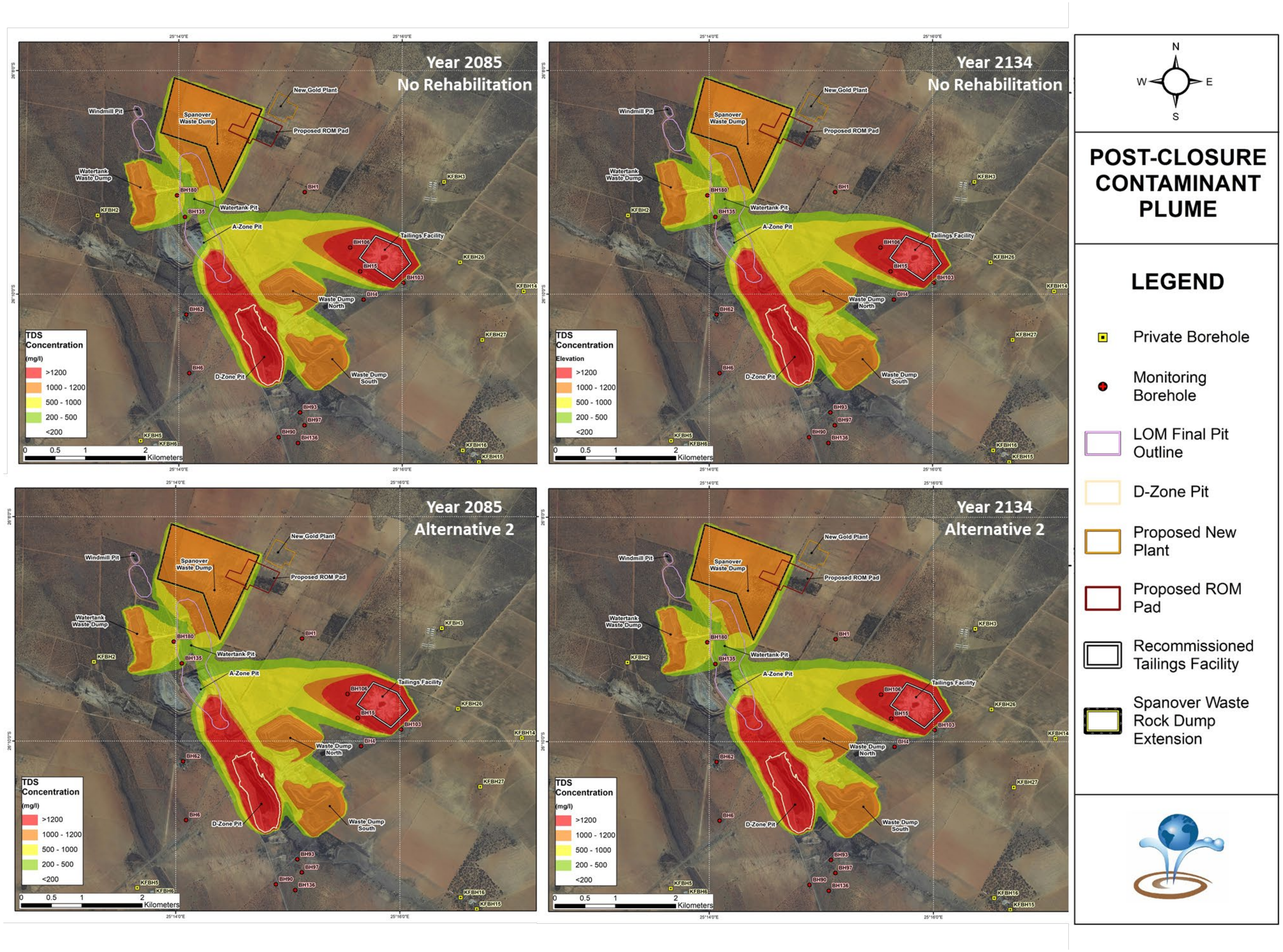

Figure 6.7: **Comparison between contaminant plumes after 50 and 100 years – Post-closure alternative 2 (pits open, WRD's remain and TSF capped)**

It is evident from the figures above that while the pits remain open after closure they continue to act as sinks, drawing water towards them and therefore containing any contamination within the pits. With the backfilling of the pits and the removal of the WRD, the impacted footprint areas clean-up after some time. In this scenario the contaminant plume from the TSF migrates towards D-zone as opposed to towards A-Zone if the pits remain open. If the TSF is capped the recharge rate reduces significantly, but the contamination currently in the groundwater continues to migrate down-gradient. It will, however, clean-up quicker than when it is not capped.

The simulations have indicated that in all instances the contaminant plumes are contained and irrespective of the rehabilitation option, the private groundwater users will not be impacted during mining or after closure.

Shown on **Figure 6.5** are three observation points (OBS1, OBS2 and OBS3) that shows the changes in TDS concentration, down-gradient from the TSF, over time. In this assessment the pits remain open and the TSF is uncapped.

It is evident from **Figure 6.8** that the contamination, in terms of TDS, remains below the SANS guideline limits for drinking water. The closest observation point is 900m down-gradient from the TSF and closer to the TSF the concentrations do exceed the SANS guidelines limits.

OBS2, which is closest to the TSF, stabilises approximately 25 years after closure and rehabilitation. The other observation points show a similar trend.

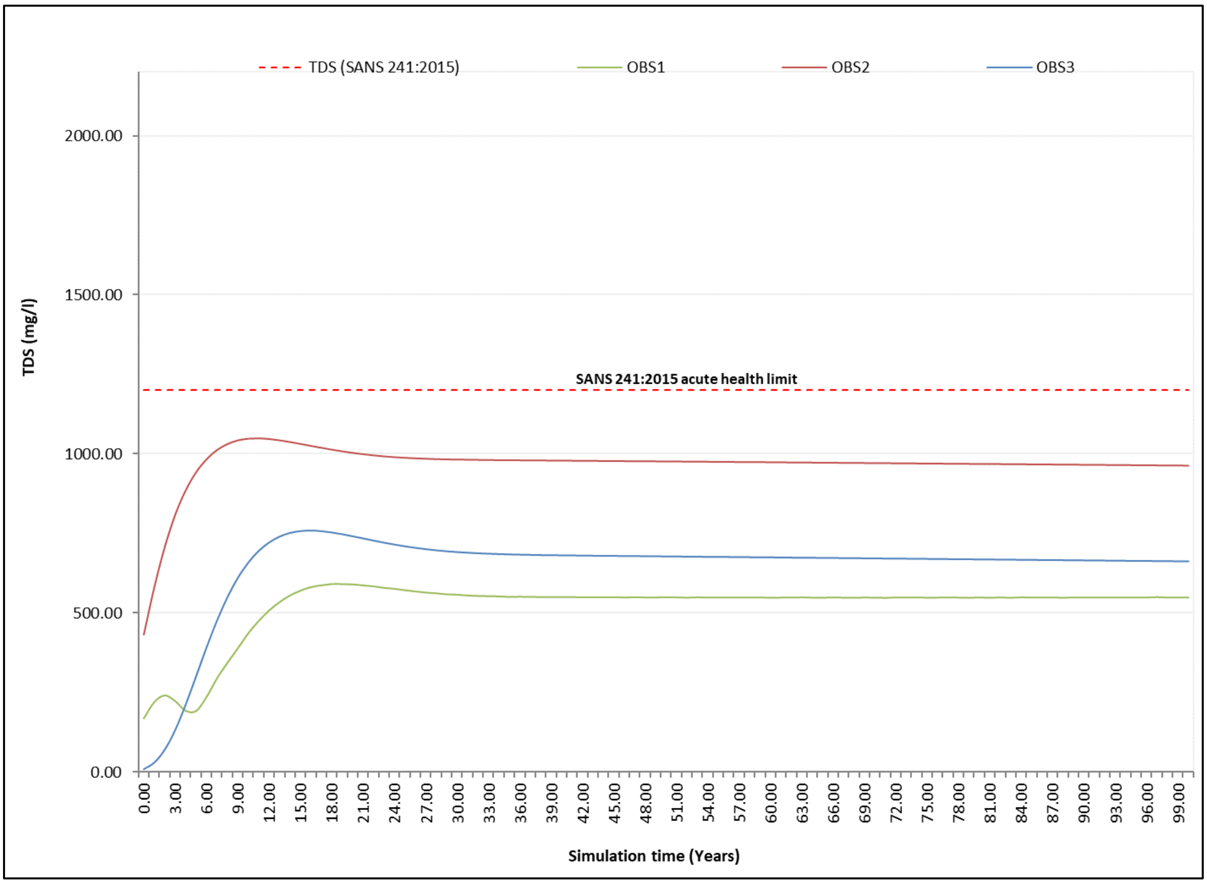

Figure 6.8: **Change in TDS concentration at observation points over time**

6.5 Risk Assessment

The impact significance rating methodology, as presented herein and utilised for all EIMS Impact Assessment Projects, is guided by the requirements of the NEMA EIA Regulations 2014 (as amended). The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/ likelihood (P) of the impact occurring. The ER is determined for the pre- and post-mitigation scenario. In addition, other factors, including cumulative impacts and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S). The impact assessment will be applied to all identified alternatives.

6.5.1 Determination of the Environmental Risk

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER). The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and Reversibility (R) applicable to the specific impact.

For the purpose of this methodology the consequence of the impact is represented by:

$$\boldsymbol{C} = \frac{(\boldsymbol{E}+\boldsymbol{D}+\boldsymbol{M}+\boldsymbol{R})*\boldsymbol{N}}{\boldsymbol{4}}$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in **Table 6.3** below.

Table 6.3: Criteria for determining Impact Consequence

Nature	-1	Likely to result in a negative/ detrimental impact
	+1	Likely to result in a positive/ beneficial impact
Extent	1	Activity (i.e. limited to the area applicable to the specific activity)
	2	Site (i.e. within the development property boundary)
	3	Local (i.e. the area within 5 km of the site)
	4	Regional (i.e. extends between 5 and 50 km from the site)
	5	Provincial / National (i.e. extends beyond 50 km from the site)
Duration	1	Immediate (<1 year)
	2	Short term (1-5 years)
	3	Medium term (6-15 years)
	4	Long term (15-65 years, the impact will cease after the operational life span of the project)
	5	Permanent (>65 years, no mitigation measure of natural process will reduce the impact after construction)
Intensity	1	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected)
	2	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected)
	3	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way, moderate improvement for +ve impacts)
	4	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease, high improvement for +ve impacts)
	5	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease, substantial improvement for +ve impacts)
Reversibility	1	Impact is reversible without any time and cost.
	2	Impact is reversible without incurring significant time and cost.
	3	Impact is reversible only by incurring significant time and cost.
	4	Impact is reversible only by incurring prohibitively high time and cost.
	5	Irreversible Impact.

Once the C has been determined, the ER is determined in accordance with the standard risk assessment relationship by multiplying the C and the P. Probability is rated/ scored as per **Table 6.4**.

Table 6.4: Probability scoring

Probability	1	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%),
	2	Low probability (there is a possibility that the impact will occur; >25% and <50%),
	3	Medium probability (the impact may occur; >50% and <75%),
	4	High probability (it is most likely that the impact will occur- > 75% probability), or
	5	Definite (the impact will occur),

The result is a qualitative representation of relative ER associated with the impact. ER is therefore calculated as follows:

$$ER = C \times P$$

Table 6.5: Determination of Environmental Risk

Consequence	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Probability					

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in **Table 6.6**.

Table 6.6: Environmental Risk Scores

ER Score	Description
<9	Low (i.e. where this impact is unlikely to be a significant environmental risk/ reward).
≥9 ≤17	Medium (i.e. where the impact could have a significant environmental risk/ reward),
>17	High (i.e. where the impact will have a significant environmental risk/ reward).

The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post implementation of relevant management and mitigation measures (post-mitigation). This allows for a prediction in the degree to which the impact can be managed/mitigated.

6.5.2 Impact Prioritisation

Further to the assessment criteria presented in the section above, it is necessary to assess each potentially significant impact in terms of:

- Cumulative impacts; and
- The degree to which the impact may cause irreplaceable loss of resources.

To ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented.

Table 6.7: Criteria for Determining Prioritisation

Cumulative Impact (CI)	Low (1)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.
	Medium (2)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.
	High (3)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/ definite that the impact will result in spatial and temporal cumulative change.
Irreplaceable Loss of Resources (LR)	Low (1)	Where the impact is unlikely to result in irreplaceable loss of resources.
	Medium (2)	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources but the value (services and/or functions) of these resources is limited.
	High (3)	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions).

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in Table 5. The impact priority is therefore determined as follows:

$$Priority = CI + LR$$

The result is a priority score which ranges from 2 to 6 and a consequent PF ranging from 1 to 2 (Refer to **Table 6.8**).

Table 6.8: Determination of Prioritisation Factor

Priority	Prioritisation Factor
2	1
3	1.125
4	1.25
5	1.375
6	1.5

In order to determine the final impact significance, the PF is multiplied by the ER of the post mitigation scoring. The ultimate aim of the PF is an attempt to increase the post mitigation environmental risk rating by a factor of 0.5, if all the priority attributes are high (i.e. if an impact comes out with a high medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

Table 6.9: Final Environmental Significance Rating

Significance Rating	Description
<-17	High negative (i.e. where the impact must have an influence on the decision process to develop in the area).
≥-17, ≤-9	Medium negative (i.e. where the impact could influence the decision to develop in the area).
>-9, < 0	Low negative (i.e. where this impact would not have a direct influence on the decision to develop in the area).
0	No impact
>0, <9	Low positive (i.e. where this impact would not have a direct influence on the decision to develop in the area).
≥9, ≤17	Medium positive (i.e. where the impact could influence the decision to develop in the area).
>17	High positive (i.e. where the impact must have an influence on the decision process to develop in the area).

The significance ratings and additional considerations applied to each impact provide a quantitative comparative assessment of the alternatives being considered.

6.5.3 Impact Assessment Result

The mine is already in the production phase and the potential impacts during production, decommissioning and post-closure were assessed. The following post-closure alternatives were assessed:

- Alternative 1: In the first scenario the Watertank and A-Zone pits will be left open or backfilled with tailings material if required. If backfilled the groundwater levels will revert to pre-mining water levels. The WRD will be removed (sold as aggregate), and it is assumed that the TSF will be capped and vegetated. This option is currently the preferred option according to which the mining feasibility is planned.
- Alternative 2: In the second scenario the Watertank and A-Zone pits remain open. In this instance the pit will fill with water, which will remain below the regional groundwater level due to evaporation. The pit will act as a sink and will continue to draw groundwater towards it. The WRD's will remain, and it is assumed that the TSF will be capped and vegetated.

Please note that capping and vegetating of the waste facilities were simulated as a potential remedial option. This has, however, not been verified as the only option and has not been approved by the environmental management team as the most viable option.

There are potentially two (2) significant risks that may impact the groundwater regime. These are as follows:

- **Reduction in the groundwater levels.** During opencast mining groundwater will flow into the workings, which will then be pumped out. This will result in the lowering of the groundwater levels in the vicinity of the open pits during the operational phase of the mining operation. The extent of this dewatering cone is important as it can potentially impact on private groundwater users and in extreme situations may cause boreholes to dry up. After mining ceases the groundwater levels are expected to recover and this risk will no longer be applicable.

- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** The waste bodies at Kalgold includes the tailings facility (TSF) and the waste rock dumps (WRD). Rainwater seepage through the waste material may become contaminated and when entering the groundwater system, the contaminants will migrate from these facilities. Due to this contaminant migration down-gradient receptors may be impacted on. Receptors include surface streams and private groundwater users.

Mitigation of the risks above may include the following:

- **Reduction in the groundwater levels.** This risk is essentially a short-term risk. Continuous monitoring of the groundwater levels in the monitoring boreholes as well as in selected private boreholes is recommended. This will provide early warning if private users are to be impacted on, in which case the mine should supply these farmers with an alternative source until the groundwater levels recover. Alternative sources can include a new borehole or a water supply pipeline from the mine.

  The surface streams in the area are classified as losing streams. In other words, the groundwater does not contribute to the baseflow in the streams. Lowering of the groundwater level will therefore not impact on any of the streams.

- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** This risk is regarded as a longer-term risk and two alternatives, as described above, were evaluated to mitigate this risk. The primary receptors that may be impacted are the private groundwater users. Due to the streams being losings streams any groundwater contamination is also not expected to impact on the streams.

The geohydrological impact assessment for the Kalgold Expansion Project is presented in **Table 6.10**. With reference to **Table 6.10** the following is concluded:

- The potential lowering of the groundwater level is regarded as a low risk and if the recommended mitigation is implemented the risk reduces even further.
- The recommissioning of the TSF will contribute marginally to the contaminant load. The capping and vegetating of the TSF will largely terminate additional load to the groundwater system after mine closure. The contaminants that entered the system during the operational phase will continue to migrate after closure.
- D-Zone pit will be filled with tailings to just below the original groundwater level of 1 210 mamsl. A pool of water will remain within the pit and the pit will act as a sink. Groundwater flow would therefore be towards D-Zone pit and any contamination will be contained within the immediate vicinity of the pit. If, however, the Watertank and A-Zone pits are also left open the groundwater level in these pits is expected to be lower than that in D-Zone, due to a larger surface area and higher evaporation. In this instance water from D-Zone will be pulled towards Watertank and A-Zone pits.
- Both alternatives are acceptable in terms of groundwater contamination as the potential pollution will largely be restricted to the mining footprint.

Table 6.10: Kalgold groundwater impact assessment table

IMPACT DESCRIPTION				Pre-Mitigation							Post Mitigation								Priority Factor Criteria			
Identifier	Impact	Alternative	Phase	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Pre-mitigation ER	Nature	Extent	Duration	Magnitude	Reversibility	Probability	Post-mitigation ER	Confidence	Cumulative Impact	Irreplaceable loss	Priority Factor	Final score
1	Reduction in groundwater levels	Alternative 2	Operation	-1	3	3	2	2	3	-7.5	-1	2	2	1	2	3	-5.25	Medium	2	2	1.25	-6.5625
2	Contaminant seepage from TSF	Alternative 2	Operation	-1	2	4	3	3	4	-12	-1	2	3	3	3	3	-8.25	Medium	2	2	1.25	-10.3125
3	Contaminant seepage from WRD	Alternative 2	Operation	-1	2	4	3	3	3	-9	-1	2	3	2	2	2	-4.5	Medium	2	2	1.25	-5.625
1	Reduction in groundwater levels	Alternative 1	Decommissioning	-1	3	3	2	2	3	-7.5	-1	2	2	1	2	2	-3.5	Medium	2	2	1.25	-4.375
2	Contaminant seepage from TSF	Alternative 1	Decommissioning	-1	2	4	3	3	4	-12	-1	2	3	3	3	3	-8.25	Medium	2	2	1.25	-10.3125
3	Contaminant seepage from WRD	Alternative 1	Decommissioning	-1	2	4	3	3	3	-9	-1	2	3	2	2	2	-4.5	Medium	2	2	1.25	-5.625
4	Reduction in groundwater levels	Alternative 2	Decommissioning	-1	3	3	2	2	3	-7.5	-1	2	2	1	2	3	-5.25	Medium	2	2	1.25	-6.5625
5	Contaminant seepage from TSF	Alternative 2	Decommissioning	-1	2	4	3	3	4	-12	-1	1	2	1	2	1	-1.5	Medium	2	2	1.25	-1.875
6	Contaminant seepage from WRD	Alternative 2	Decommissioning	-1	2	4	3	3	3	-9	-1	2	3	1	3	2	-4.5	Medium	2	2	1.25	-5.625
1	Reduction in groundwater levels	Alternative 1	Rehab and closure	-1	3	3	2	2	3	-7.5	-1	1	2	1	1	1	-1.25	Medium	2	2	1.25	-1.5625
2	Contaminant seepage from TSF	Alternative 1	Rehab and closure	-1	2	4	3	3	4	-12	-1	2	3	2	2	2	-4.5	Medium	2	2	1.25	-5.625
3	Contaminant seepage from WRD	Alternative 1	Rehab and closure	-1	2	4	3	3	3	-9	-1	1	3	1	4	2	-4.5	Medium	2	2	1.25	-5.625
4	Reduction in groundwater levels	Alternative 2	Rehab and closure	-1	3	3	2	2	3	-7.5	-1	1	2	1	1	2	-2.5	Medium	2	2	1.25	-3.125
5	Contaminant seepage from TSF	Alternative 2	Rehab and closure	-1	2	4	3	3	4	-12	-1	2	3	2	2	2	-4.5	Medium	2	2	1.25	-5.625
6	Contaminant seepage from WRD	Alternative 2	Rehab and closure	-1	2	4	3	3	3	-9	-1	2	3	1	3	2	-4.5	Medium	2	2	1.25	-5.625

7. CONCLUSIONS

The purpose of the study is primarily to assess the potential impacts from the proposed mining extension and associated waste facilities on the groundwater regime. The existing numerical groundwater flow and mass transport model was upgraded to reflect the impacts on the groundwater quality and regional groundwater levels.

The deliverables from the study include the following:

- Conceptual geohydrological model.
- Numerical groundwater flow and mass transport model that was utilised to assess the following:
    - Contaminant migration from the recommissioned tailings facility.
    - Contaminant migration for the current and proposed waste rock dumps.
    - Contaminant migration from D-zone tailings disposal.
- A geohydrological risk assessment of the impacts on the groundwater and recommendations on the way forward.

The main conclusions of this study are summarised below.

The following aquifers are present in the vicinity of Kalgold mine (Auctus, 2011):

- The quaternary Kalahari sand, which covers the project area, forms an intergranular, unconfined aquifer in the upper 30m of the geological succession.
- A deeper fractured rock aquifer is formed by bedding planes, fractures and faults in the weathered and competent meta-sediments of the Kraaipan Greenstone Belt.

The aquifer in the region is classified as a “Sole Source Aquifer” meaning that it is the only source of water for the local community. Since the fractured aquifer is the sole water supply to the farms in the region it is regarded as a sensitive and important aquifer that needs high level protection.

The mining schedule estimated a Life of Mine (LOM) of approximately 10 years after July 2024. The ore tonnages peak at approximately 300 000 tons per month. Monthly tailings deposition from July 2024 will be 260 000 tons into D-Zone and 40 000 tons on the existing TSF. Based on the 2020 water usage the required water volume is in the region of 1.50 m3/ton milled (Van Biljon, 2021). This equates to 14 988 m3/day or ~15 Mℓ/day for the increased production rate of 300 000 tons per month.

The unavoidable inflow of groundwater into the opencast pits and the pumping of this water will have an impact on the groundwater levels near the mining operations. There are four (4) private boreholes that may potentially be impacted by this dewatering. These include:

- KFBH1: Potential 21m drop in the groundwater level expected.
- KFBH2: Potential 57m drop in the groundwater level expected, which may cause this borehole to dry up.
- KFBH3: Potential 17m drop in the groundwater level expected.
- KFBH20: Potential 28m drop in the groundwater level expected.

It is recommended that these boreholes be included in the mine monitoring programme to verify the findings of this simulation. Borehole KFBH2 may need to be replaced if the simulations prove to be correct. It is further recommended that the groundwater levels in the “High and Medium Risk” categories are measured quarterly to verify model predictions and to act if necessary. The depths of these boreholes should also be confirmed.

During the operational phase of the mine the water will be pumped from the opencast operations. Post-closure this pumping will cease, and the groundwater level will recover. It is estimated that it will take approximately 25 years to recover to the average pre-mining groundwater level. Due to the high evaporation rates in the region the pits will always, if left open, act as a sink and groundwater flow will be towards the pits.

Waste assessment and waste classification studies were recently undertaken. Distilled water shake flask tests were performed on the waste rock and the tailings samples to determine which soluble constituents are present in the material. There are no elements exceeding the Leachable Concentration Threshold (LCT0) for any of the samples, indicating a low contaminant seepage risk.

The contaminant plume migration from the Kalgold waste bodies were simulated with the numerical model. The waste assessment as well as the groundwater monitoring data was utilised in determining the source concentrations that were included in the mass transport model. Total Dissolved Solids (TDS) was selected as a conservative tracer that represents the migration of contaminants through the aquifer. Based on the waste assessment and groundwater monitoring the following TDS concentrations were assigned to the various waste bodies:

Tailings facility:	1 750 mg/ℓ.
Waste rock:	1 033 mg/ℓ.
ROM pad:	1 690 mg/ℓ.
D-Zone:	4 500 mg/ℓ.

The following post-closure alternatives were simulated:

- Alternative 1: In the first scenario the Watertank and A-Zone pits will be left open or backfilled with tailings material if required. If backfilled the groundwater levels will revert to pre-mining water levels. The WRD will be removed (sold as aggregate), and it is assumed that the TSF will be capped and vegetated. This option is currently the preferred option according to which the mining feasibility is planned.
- Alternative 2: In the second scenario the Watertank and A-Zone pits remain open. In this instance the pit will fill with water, which will remain below the regional groundwater level due to evaporation. The pit will act as a sink and will continue to draw groundwater towards it. The WRD’s will remain, and it is assumed that the TSF will be capped and vegetated.

In each instance the two alternatives were compared to the do-nothing scenario in which the pits remain open, the WRD’s will remain and the TSF will be uncapped. In other words, no rehabilitation measures will be implemented.

Please note that capping and vegetating of the waste facilities were simulated as a potential remedial option. This has, however, not been verified as the only option and has not been approved by the environmental management team as the most viable option.

There are potentially two (2) significant risks that may impact the groundwater regime. These are as follows:

- **Reduction in the groundwater levels.** During opencast mining groundwater will flow into the workings, which will then be pumped out. This will result in the lowering of the groundwater levels in the vicinity of the open pits during the operational phase of the mining operation. The extent of this dewatering cone is important as it can potentially impact on private groundwater users and in extreme situations may cause boreholes to dry up. After mining ceases the groundwater levels are expected to recover and this risk will no longer be applicable.
- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** The waste bodies at Kalgold includes the tailings facility (TSF) and the waste rock dumps (WRD). Rainwater seepage through the waste material may become contaminated and when entering the groundwater system, the contaminants will migrate from these facilities. Due to this contaminant migration down-gradient receptors may be impacted on. Receptors include surface streams and private groundwater users.

Mitigation of the risks above may include the following:

- **Reduction in the groundwater levels.** This risk is essentially a short-term risk. Continuous monitoring of the groundwater levels in the monitoring boreholes as well as in selected private boreholes is recommended. This will provide early warning if private users are to be impacted on, in which case the mine should supply these farmers with an alternative source until the groundwater levels recover. Alternative sources can include a new borehole or a water supply pipeline from the mine.

  The surface streams in the area are classified as losing streams. In other words, the groundwater does not contribute to the baseflow in the streams. Lowering of the groundwater level will therefore not impact on any of the streams.

- **Deterioration of the groundwater quality due to contaminant seepage from the waste bodies.** This risk is regarded as a longer-term risk and two alternatives, as described above, were evaluated to mitigate this risk. The primary receptors that may be impacted are the private groundwater users. Due to the streams being losings streams any groundwater contamination is also not expected to impact on the streams.

The numerical modelling and risk assessment concluded the following:

- The potential lowering of the groundwater level is regarded as a low risk and if the recommended mitigation is implemented the risk reduces even further.
- The recommissioning of the TSF will contribute marginally to the contaminant load. The capping and vegetating of the TSF will largely terminate additional load to the groundwater system after mine closure. The contaminants that entered the system during the operational phase will continue to migrate after closure.
- D-Zone pit will be filled with tailings to just below the original groundwater level of 1 210 mamsl. A pool of water will remain within the pit and the pit will act as a sink. Groundwater flow would therefore be towards D-Zone pit and any contamination will be contained within the immediate vicinity of the pit. If, however, the Watertank and A-Zone pits are also left open the groundwater level in these pits is expected to be lower than that in D-Zone, due to a larger surface area and higher evaporation. In this instance water from D-Zone will be pulled towards Watertank and A-Zone pits.

- Removal of the WRD's and its associated impacts is considered slightly more advantageous, if it is an economical viable option.
- Both alternatives are acceptable in terms of groundwater contamination as the potential pollution will largely be restricted to the mining footprint.
- Mitigation to minimize the groundwater impacts post-closure includes the rehabilitation of the TSF. The rehabilitation is assumed to include the capping and vegetation of the tailings facility. If the TSF is capped the recharge rate reduces significantly, but the contamination currently in the groundwater continues to migrate down-gradient. It will, however, clean up quicker than when it is not capped and is expected to clean up 25 – 30 years after rehabilitation.

The geohydrological assessment indicated that in all instances the contaminant plumes are contained and irrespective of the rehabilitation option, the private groundwater users will not be impacted during mining or after closure.

8. RECOMMENDATIONS

Monitoring will be especially important to verify the model simulations and to adjust should that be necessary. The following is recommended in terms of monitoring:

- Water volumes pumped from the various opencast pits should be measured with flow meters and recorded daily.
- Rainfall should be measured daily to distinguish between rainfall and groundwater inflow into the opencast pits.
- The quality of the in-pit water should be monitored regularly. If it is necessary to discharge surplus water into the surface streams this activity will have to be licenced. The licence will specify monitoring requirements in terms of frequency and parameters to be analysed.
- Groundwater quality monitoring in the mine monitoring boreholes (see **Figure 4.6**) should continue as per the WUL requirements.
- It is recommended that the private boreholes are also sampled and analysed annually. The previous sampling was conducted in 2011 as part of the hydro census.
- The borehole and pump installation depths of these private boreholes should also be measured if possible, to allow for a more accurate risk assessment in terms of the available drawdown and risk of drying up.
- Groundwater levels in the mine monitoring boreholes, as well as the "High Risk" private boreholes should be monitored quarterly.

This rigorous monitoring programme is recommended due to the sensitivity of this "Sole Supply Aquifer" and to provide the mine with sufficient and defendable information should claims against the mine arise.

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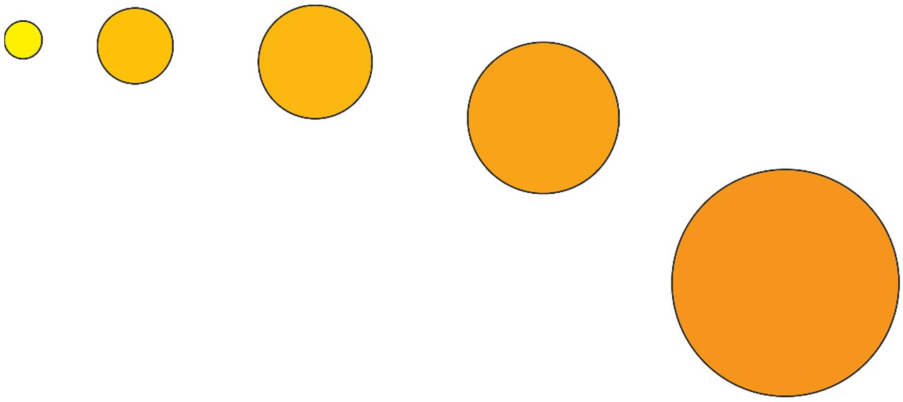
APPENDIX A

GEOCHEMISTRY AND WASTE ASSESSMENT



Kalgold

Geochemical mineral waste characterisation & assessment

GeoDyn Systems

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Kalgold

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AMD	Acid Mine Drainage
LCT	Leach Concentration Threshold
NEMWA	National Environmental Management Waste Act
R635	Regulation 635
TCT	Total Concentration Threshold
XRD	X-Ray Diffraction

1 INTRODUCTION

Geochemical Dynamic Systems (GeoDyn) was requested by MvB Consulting (MvB) to conduct a waste classification and acid mine drainage (AMD) assessment for mineral waste material, i.e, low-grade ore, tailings and two types of waste rock from the Kalgold mining operations, Water Tank waste rock, Spanover Waste Rock, Spanover low-grade ore and the Kalgold tailings material (Figure 1).

1.1 Project objectives

The project has the following main objectives:

- Classification of the mineral waste material from the Kalgold mining operations.
- Assessment of the likelihood of the development of AMD conditions from the mineral waste material.
- Pollution source term identification and potential contaminant concentrations.
- Environmental geochemical risk assessment of the waste rock material

2 METHODOLOGY

2.1 Classification of mineral waste

The mineral waste classification was conducted according to the National Environmental Waste Management Act[1] Regulation 635 (R635). This classification has two components. The first is to compare the total chemical composition of the waste with the Total Concentration Threshold (TCT) values of R635. The second is to conduct a leach test and compare the results with the Leach Concentration Threshold (LCT) values in R635. The results of the combination of the two components mentioned above is used to derive an overall waste type according to the R635 criteria, as outlined in Table 1. The laboratory data, which was used for the classification, is shown in Appendix B.

Table 1 Waste classification criteria (R635) and corresponding required engineered barrier system (R636)

Waste class	Criteria (R635)	Description	Engineered Barrier System Requirement (R636)
Type 4	LC ≤ LCT0 and LC ≤ TCT 0	Inert	None (soil compaction)
Type 3	LCT0 < LC ≤ LCT1 **and** TC ≤ TCT 1 Wastes with all element or chemical substance leachable concentration levels for metal ions and inorganic anions ≤ LCT0, provided all chemical substance concentration levels below R635 concentration limits for organics and pesticides, the inherent physical and chemical character of the waste is stable and will not change over time and the waste is disposed of to landfill without any other waste	Low risk	Class C
Type 2	LCT1 <LC ≤ LCT2 **and** TC ≤ TCT1	High risk	Class B
Type 1	LCT2 < LC ≤ LCT3 **or** TCT1 < TC ≤ TCT2 If the TC of an element or chemical substance is > TCT2 and the concentration cannot be reduced below the TCT 2 limit but the LC for a particular element or chemical If a particular chemical substance in a waste is not listed with corresponding LCT and TCT limits Wastes that have not been assessed and to be determined to be otherwise		Class A
Type 0	LC > LCT3 **or** TC > TCT2	Hazardous	Hazardous waste disposal site

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[1] Act 59 of 2008

Figure 1 Sample locality map

2.2 Assessment of AMD potential and source term characterisation

A laboratory Acid-Base Accounting (ABA) analysis and numeric geochemical modelling, which is rooted in equilibrium thermodynamics and chemical kinetics, was used to assess the processes in the mineral waste, which could potentially cause pollution and contamination of the surrounding environment. These processes include those which could potentially cause AMD, which are outlined in Section 4**.**

The USGS geochemical modelling software package, PHREEQC, was used to develop the geochemical models. The model setup, uncertainties, assumptions and limitations are shown in Appendix A. Total chemical analyses (ICP-MS) as well as mineralogy (XRD) data were used as input to the geochemical models. The geochemical models were also used to determine the sources of potential pollutants and to calculate likely concentrations at which these pollutants leach into the environment.

3 WASTE CLASSIFICATION

The results of the comparison between the LCT and TCT class values of R635 is shown in Table 2 and Table 3.

3.1 Leach Concentration Threshold assessment

Table 2 indicates that the leach concentrations of all the LCT parameters fall below LCT0 values of R635.

3.2 Total Concentration Threshold assessment

Table 3 indicates that all the total analysis concentrations of the waste rock material fall below the lowest regulatory threshold value (TCT1), with the exception of boron, which exceeds the regulatory value of TCT1, but is below the regulatory value of TCT2.

3.3 Classification of waste rock material

According to the criteria set out in R635 (Table 1) the Kalgold Water Tank waste rock as well as the Spanover low-grade ore classifies as Type 3. This classification depends on the mobility of boron in the natural environment, i.e. the ability of boron to leach from the waste rock material under natural conditions. This leachability is assessed in the numeric geochemical modelling phase (Section 4 and Section 5).

4 CONCEPTUAL GEOCHEMICAL FRAMEWORK

The conceptual framework forms the basis of the geochemical modelling and is therefore discussed in this section for the Kalgold mineral waste material (Figure 2).

Table 2 Comparison of leach test data to R635 Leach Concentration Threshold (LCT) regulatory values

Inorganic Waste constituents	Abbreviation	R635 Leach Concentration Threshold Values				Water Tank Waste Rock Dump	Spanover Waste Rock dump	Spanover low-grade ore	Tailing
		LCT0	LCT1	LCT2	LCT3				
		mg/L	*mg/L*	*mg/L*	*mg/L*	mg/L			
					Metal Ions				
Arsenic	**As**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Boron	**B**	0.5	25	50	200	0.0	<0.025	<0.025	<0.025
Barium	**Ba**	0.7	35	70	280	0.0	<0.025	<0.025	<0.025
Cadmium	**Cd**	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001	<0.001
Cobalt	**Co**	0.5	25	50	200	0.0	<0.025	<0.025	<0.025
Chromium (Total)	**Cr(Total)**	0.1	5	10	40	<0.001	<0.025	<0.025	<0.025
Chromium (VI)	**Cr(VI)**	0.05	2.5	5	20	<0.010	<0.010	<0.010	<0.010
Copper	**Cu**	2.0	100	200	800	<0.001	<0.010	<0.010	<0.010
Mercury	**Hg**	0.006	0.3	0.6	2.4	<0.001	<0.001	<0.001	<0.001
Manganese	**Mn**	0.5	25	50	200	0.1	<0.025	0.068	0.025
Molybdenum	**Mo**	0.07	3.5	7	28	<0.001	<0.025	<0.025	<0.025
Nickel	**Ni**	0.07	3.5	7	28	0.00	<0.025	<0.025	<0.025
Lead	**Pb**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Antimony	**Sb**	0.02	1.0	2	8	<0.001	<0.001	<0.001	<0.001
Selenium	**Se**	0.01	0.5	1	4	<0.001	<0.001	<0.001	<0.001
Vanadium	**V**	0.2	10	20	80	<0.001	<0.025	<0.025	<0.025
Zinc	**Zn**	5.0	250	500	2 000	0.0	<0.025	<0.025	<0.025
					Inorganic Anions				
Total Dissolved Solids	**TDS**	1 000	12 500	25 000	100 000	40	34	128	226
Chloride	**Cl**	300	15 000	30 000	120 000	<2	2	7	18
Sulphate	**SO_4**	250	12 500	25 000	100 000	12	3	49	87
Nitrate as Nitrogen	**NO_3-N**	11	550	1 100	4 400	<0.1	<0.1	<0.1	<0.1
Fluoride	**F**	2	75	150	600	<0.2	<0.2	<0.2	<0.2
Cyanide (Total)	**CN^-(Total)**	0	4	7	28	<0.02	<0.02	<0.02	0.12

Table 3 Comparison of the total analysis data to R635 Total Concentration Threshold (TCT) regulatory values

Waste constituents	Abbreviation	R635 Total Concentration Threshold Values			Water Tank Waste Rock Dump	Spanover Waste Rock dump	Spanover low-grade ore	Tailings
		TCT0 mg/kg	TCT1 mg/kg	TCT2 mg/kg	mg/kg			
Metal Ions								
Arsenic	**As**	5.8	500	2 000	1.2	1.6	6.0	0.8
Boron	**B**	150	15 000	60 000	227	90	33	90
Barium	**Ba**	62.5	6 250	25 000	60	195	79	74
Cadmium	**Cd**	7.5	260	1 040	<0.4	<0.4	<0.4	<0.4
Cobalt	**Co**	50	5 000	20 000	1.2	<10	<10	<10
Chromium (Total)	**Cr(Total)**	46 000	800 000	n.a	156	290	306	188
Chromium (VI)	**Cr(VI)**	6.5	500	2 000	<2	<5	<5	<5
Copper	**Cu**	16.0	19 500	78 000	<0.4	84	126	55
Mercury	**Hg**	0.93	160	640	0.4	<0.4	<0.4	<0.4
Manganese	**Mn**	1 000	25 000	100 000	60	1 680	1 828	2 300
Molybdenum	**Mo**	40	1 000	4 000	2.8	<10	<10	<10
Nickel	**Ni**	91	10 600	42 400	4	121	113	93
Lead	**Pb**	20	1 900	7 600	15	7.6	8	8.8
Antimony	**Sb**	10	75	300	<0.4	<0.4	<0.4	<0.4
Selenium	**Se**	10	50	200	<0.4	<0.4	<0.4	<0.4
Vanadium	**V**	150	2 680	10 720	43	244	85	72
Zinc	**Zn**	240.0	160 000	640 000	<0.400	103	101	115
Inorganic Anions								
Fluoride	**F**	100	10 000	40 000	<0.5	239	174	183
Cyanide (Total)	**CN^-(Total)**	14	10 500	42 000	<0.5	<0.5	<0.5	54

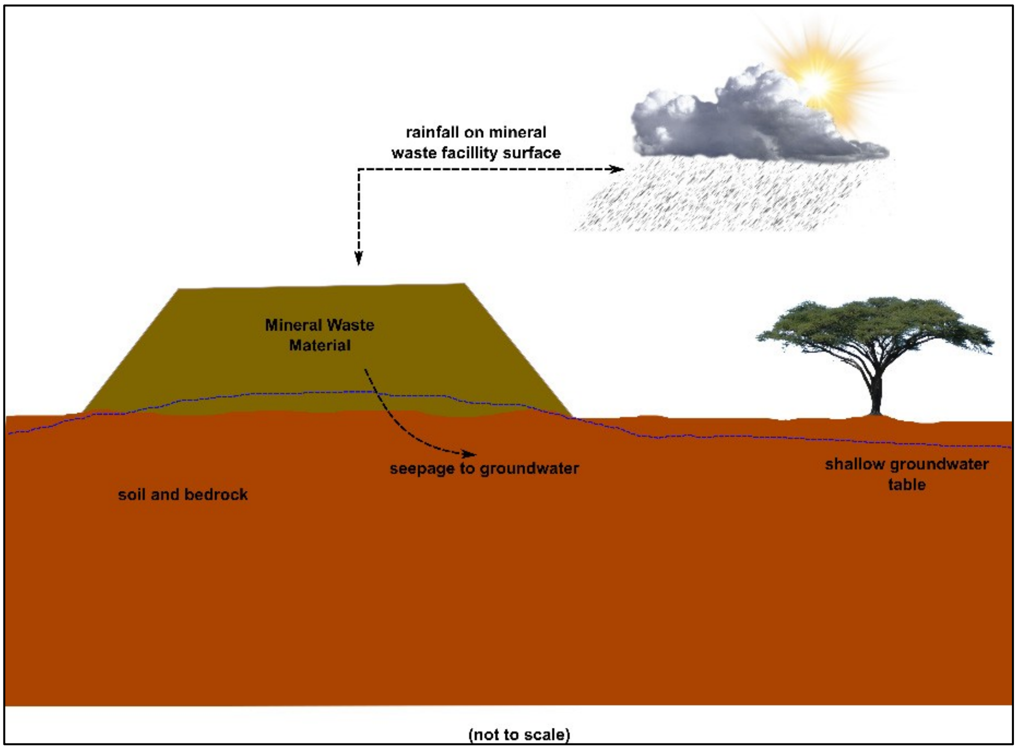

Figure 2 Conceptual model of the Kalgold waste rock material

4.1 Water tank waste rock material

The water tank waste rock dump (WTWRD) can be visualised as a dump or facility, open to the Earth's atmosphere in terms of oxygen, rainfall; and evaporation, from which contaminants can potentially leach into the soil groundwater systems (Figure 2). The WTWRD particles are coarse. Water and oxygen infiltration into the facility thus occurs more readily. However, due to the coarse particle size, the reactive surface area of this material is relatively low and geochemical processes, such as the breakdown of pyrite and other minerals of which the waste rock is composed, are relatively slow. However, if pollutants can escape the waste rock material, they will tend to leach vertically into the substrate below the waste rock facility and eventually into the groundwater. This will occur over a period of 2 - 5 years. It will be difficult to prevent the ingress of water, but after mining the waste rock dump can be rehabilitated by shaping it to enhance water runoff and possibly covering it with topsoil. The groundwater modelling has, however, showed that contaminant migration will be towards the pit, where it will settle as long as the pit remains open. Down-gradient receptors are not expected to be impacted.

The waste rock consists of the following minerals:

Quartz	[SiO_2]
Plagioclase	[$NaAlSi_3O_8$]
Muscovite	[$KAl_2(AlSi_3)O_{10}(OH)_2$]
Chlorite	[$Fe_2Al_2SiO_5(OH)_4$]

The waste rock in the Witwatersrand generally contains small amounts of pyrite [FeS_2], which was thus added to the Kalgold waste rock model. The minerals listed above, including pyrite, release silica, sodium, aluminium, iron and sulphate into the waste rock pore solutions. Boron is associated with muscovite and chlorite.

4.2 Waste rock, low-grade ore and tailings material

This material is analogous to the WTWRD material in terms of mineralogy. The major differences between these waste materials and the WTWRD material are the mineral compositions and the particle sizes of the material. The mineralogical compositions of the various materials, which were used in the numeric geochemical models, are shown in Table 4.

Table 4 Kalgold mineral waste material mineral composition

Mineral	Ideal formula	Waste Rock (Water Tank and Spanover)	Spanover low-grade ore	Tailings
		wt%	*wt%*	*wt%*
Quartz	SiO_2	56.2	67.7	67.7
Gypsum	$CaSO_4.2H_2O$	0.1	0.5	0.6
Chlorite	$Mg_5Al_2Si_3O_{10}(OH)_8$	18.4	10.7	6
Dolomite	$CaMg(CO_3)_2$	1.6	8.2	4.9
Pyrite	FeS_2	1.9	2.2	2.9
Sepiolite	$Mg_4Si_6O_{15}(OH)_2.6H_2O$	10.8	4.9	5.8
Calcite	$CaCO_3$	6.3	0.1	0.8
Siderite	$FeCO_3$	2	3.9	9.2
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O$	1.2	0.2	0.5
Bassanite	$CaSO_4.0.5H_2O$	0	0.6	0.9
Chloritoid	$FeAl_2(SiO_4)O(OH)_2$	1.3	1	0.6

Table 4 indicates that all three mineral waste types contain the mineral pyrite. Pyrite is unstable in the presence of oxygen in the Earth's atmosphere and breaks down to form acidity. This acidity can be balanced by the minerals calcite and dolomite, which also occur in the Kalgold mineral waste types, if it occurs in sufficient concentrations.

5 GEOCHEMICAL MODELLING

This section outlines the results of the numeric geochemical model for the mineral waste material. The potential contaminants flagged in the Waste Classification section are included in the numerical models to determine whether they are able to leach from the various materials in the long term. Appendix A contains a more detailed account of the setup of the numeric geochemical models.

5.1 Water Tank Waste Rock Material

A summary of the geochemical model results of the mineral waste rock is shown inTable 5. The values in Table 5 are compared to the LCT0 values in R635, not for the purposes of classification, as this regulatory process has been followed and is reported in Section 3, but only for comparative purposes. The SANS (2015) drinking water guideline values are used as comparative values for pH, TDS, sodium, potassium, aluminium and iron, as R635 does not contain values for these parameters. This is also done for comparative risk assessment purposes and should not be used out of this context.

Table 5 Numeric geochemical model results of the long-term WTWRD material leachate

Parameter	Abbreviation	*Units*	LCT0	SANS	Water Tank Waste Rock
pH	**pH**	*pH units*	n.g.v.	5 - 9.7	6.4
Total dissolved solids	**TDS**	*mg/L*	1 000	1 200	6.0
Sodium	**Na^+**	*mg/L*	n.g.v.	200	0
Potassium	**K^+**	*mg/L*	n.g.v.	300	2
Sulphate	**SO_4^{2-}**	*mg/L*	250	250	3
Bicarbonate	**HCO_3^-**	*mg/L*	n.g.v.	n.g.v.	1
Aluminium	**Al^{3+}**	*mg/L*	n.g.v.	0.3	<0.001
Iron (Total)	**Fe_{total}**	*mg/L*	n.g.v.	0.3	<0.001
Boron (total)	**B_{total}**	*mg/L*	0.7	2.4	0.003

The comparison between the numeric geochemical model results and the regulatory guideline values (Table 5) indicates that boron is not likely to leach from the waste rock material in concentrations, which are significantly lower than the regulatory values. This is because boron occurs in the silicate minerals muscovite and chlorite, which is stable at earth surface conditions. Boron is therefore not likely to leach from the waste rock in concentrations that may pose an environmental risk to any water source. Thus the WTWRD material can be classified as Type 4 waste.

5.2 Spanover Waste Rock Material

A summary of the geochemical model results of the mineral waste rock is shown in Table 5. The values in Table 5 are compared to the LCT0 values in R635, not for the purposes of classification, as this regulatory process has been followed and is reported in Section 3, but only for comparative purposes. The SANS (2015) drinking water guideline values are used as comparative values for pH, TDS, sodium, potassium, aluminium and iron, as R635 does not contain values for these parameters. This is also done for comparative risk assessment purposes and should not be used out of this context.

The comparison between the numeric geochemical model results and the regulatory guideline values (Table 6) indicates that the Spanover waste rock material has the potential to leach sulphate in concentrations exceeding the regulatory guideline values. None of the metals nor metalloid contaminants are shown to exceed regulatory guideline values. This is due to the fact that these constituents are locked up within the mineral structure of the mineral waste material. The rate of breakdown of these minerals is too slow for these constituents to leach in amounts exceeding regulatory guideline values.

Table 6 Numeric geochemical model results of the long-term Kalgold waste rock material leachate

Parameter	Abbreviation	*Units*	LCT0	SANS	Spanover Waste Rock
pH	**pH**	*pH units*	n.g.v.	5 - 9.7	5.0
Total dissolved solids	**TDS**	*mg/L*	1 000	1 200	1 033
Sulphate	**SO_4^{2-}**	*mg/L*	250	250	836
Bicarbonate	**HCO_3^-**	*mg/L*	n.g.v.	n.g.v.	197
Aluminium	**Al^{3+}**	*mg/L*	n.g.v.	0.3	<0.001
Barium	**Ba^{2+}**	*mg/L*	0.7	0.7	0.006
Boron (total)	**B_{total}**	*mg/L*	0.7	2.4	0.003
Copper (total)	**Cu_{total}**	*mg/L*	2.00	2.00	0.016
Fluoride	**F^-**	*mg/L*	1.5	1.5	0.001
Iron (total)	**Fe_{total}**	*mg/L*	n.g.v.	0.3	<0.001
Manganese (total)	**Mn_{total}**	*mg/L*	0.5	0.4	0.014
Nickel	**Ni^{2+}**	*mg/L*	0.07	0.07	0.015
Uranium (total)	**U_{total}**	*mg/L*	n.g.v.	0.03	0.010
Vanadium (total)	**V_{total}**	*mg/L*	0.2	0.2	0.013

5.3 Spanover Low-Grade Ore Material

A summary of the geochemical model results of the low-grade ore material is shown in Table 7. The values in Table 7 are compared to the LCT0 values in R635, not for the purposes of classification, as this regulatory process has been followed and is reported in Section 3, but only for comparative purposes. The SANS (2015) drinking water guideline values are used as comparative values for pH, TDS, sodium, potassium, aluminium and iron, as R635 does not contain values for these parameters. This is also done for comparative risk assessment purposes and should not be used out of this context.

The comparison between the numeric geochemical model results and the regulatory guideline values (Table 7) indicates that the low-grade ore material has the potential to leach sulphate in concentrations exceeding the regulatory guideline values. It also has the potential for a TDS load exceeding regulatory guideline values, but this is due to the presence of bicarbonate with the sulphate. Bicarbonate is not considered a pollutant. None of the metals nor metalloid contaminants are shown to exceed regulatory guideline values. This is due to the fact that these constituents are locked up within the mineral structure of the mineral waste material. The rate of breakdown of these minerals is too slow for these constituents to leach in amounts exceeding regulatory guideline values.

5.4 Kalgold Tailings Material

A summary of the geochemical model results of the low-grade ore material is shown in Table 8. The values in Table 8 are compared to the LCT0 values in R635, not for the purposes of classification, as this regulatory process has been followed and is reported in Section 3, but only for comparative purposes. The SANS (2015) drinking water guideline values are used as comparative values for pH, TDS, sodium, potassium, aluminium and iron, as R635 does not contain values for these parameters. This is also done for comparative risk assessment purposes and should not be used out of this context.

Table 7 Numeric geochemical model results of the long-term Kalgold low-grade ore material leachate

Parameter	Abbreviation	Units	LCT0	SANS	Low-Grade Ore
pH	**pH**	*pH units*	n.g.v.	5 - 9.7	5.5
Total dissolved solids	**TDS**	*mg/L*	1 000	1 200	1 690
Sulphate	SO_4^{2-}	*mg/L*	250	250	1 414
Bicarbonate	HCO_3^-	*mg/L*	n.g.v.	n.g.v.	276
Aluminium	Al^{3+}	*mg/L*	n.g.v.	0.3	0.002
Barium	Ba^{2+}	*mg/L*	0.7	0.7	0.007
Boron (total)	B_{total}	*mg/L*	0.7	2.4	0.003
Copper (total)	Cu_{total}	*mg/L*	2.00	2.00	0.009
Fluoride	F^-	*mg/L*	1.5	1.5	0.001
Iron (total)	Fe_{total}	*mg/L*	n.g.v.	0.3	<0.001
Manganese (total)	Mn_{total}	*mg/L*	0.5	0.4	0.007
Nickel	Ni^{2+}	*mg/L*	0.07	0.07	0.008
Uranium (total)	U_{total}	*mg/L*	n.g.v.	0.03	0.010
Vanadium (total)	V_{total}	*mg/L*	0.2	0.2	0.007

The comparison between the numeric geochemical model results and the regulatory guideline values (Table 8) indicates that the low-grade ore material has the potential to leach sulphate in concentrations exceeding the regulatory guideline values. It also has the potential for a TDS load exceeding regulatory guideline values, but this is due to the presence of bicarbonate with the sulphate. Bicarbonate is not considered a pollutant. None of the metals nor metalloid contaminants are shown to exceed regulatory guideline values.

Table 8 Numeric geochemical model results of the long-term Kalgold tailings material leachate

Parameter	Abbreviation	Units	LCT0	SANS	Tailings
pH	**pH**	*pH units*	n.g.v.	5 - 9.7	4.5
Total dissolved solids	**TDS**	*mg/L*	1 000	1 200	1 750
Sulphate	SO_4^{2-}	*mg/L*	250	250	1 550
Bicarbonate	HCO_3^-	*mg/L*	n.g.v.	n.g.v.	199
Aluminium	Al^{3+}	*mg/L*	n.g.v.	0.3	1.02
Barium	Ba^{2+}	*mg/L*	0.7	0.7	0.007
Boron (total)	B_{total}	*mg/L*	0.7	2.4	0.003
Copper (total)	Cu_{total}	*mg/L*	2.00	2.00	0.023
Fluoride	F^-	*mg/L*	1.5	1.5	0.001
Iron (total)	Fe_{total}	*mg/L*	n.g.v.	0.3	<0.001
Manganese (total)	Mn_{total}	*mg/L*	0.5	0.4	0.02
Nickel	Ni^{2+}	*mg/L*	0.07	0.07	0.02
Uranium (total)	U_{total}	*mg/L*	n.g.v.	0.03	0.020
Vanadium (total)	V_{total}	*mg/L*	0.2	0.2	0.018

This is due to the fact that these constituents are locked up within the mineral structure of the mineral waste material. The rate of breakdown of these minerals is too slow for these constituents to leach in amounts exceeding regulatory guideline values.

The pH of the tailings material is shown to by 4.5, which is below the regulatory drinking water guidelines. This shows that some acidity can be expected to leach from the tailings material, however, the amount of acidity projected to leach does not constitute acid mine drainage conditions, which typically has pH values of < 4.

6 ENVIRONMENTAL GEOCHEMICAL RISK ASSESSMENT

The environmental assessment methodology of Malan Scholes was used to assess the potential impact environmental impacts from the waste rock material assessed and discussed in this report. The methodology uses the following concepts in the assessment:

- **Nature of the impact**: A *brief description of the impact being assessed, in terms of the proposed activity or project, including the socio-economic or environmental aspect affected by this impact.*
- **Status of the impact:** *Whether the impact is of benefit or detriment to the environment or whether it is neutral.*
- **Magnitude of the impact: A** *brief description of the intensity or amplitude of the impact on socio-economic or environmental aspects.*
- **Extent of the project:** A *brief description of the spatial influence of the impact or the area that will be affected by the impact*.
- **Duration of the impact: A** *short description of the period of time the impact will have an effect on aspects*.
- **Probability of the impact occurring: T**he *estimated chance of the impact happening*.
- **Degree to which the impact can be reversed:** *The ability of an impact to be changed from a state of affecting aspects to a state of not affecting aspects*.
- **Degree to which impact may cause irreplaceable loss of resources: T***he amount of resources that can/can't be replaced.*
- **Degree to which the impact can be mitigated:** *The effect of mitigation measures on the impact and its degree of effectiveness.*
- **Confidence rating:** *Level of certainty of the impact occurring*.
- **Significance of the impacts:** *The combination of the duration and importance of the impact, in terms of physical and socio-economic extent, resulting in an indicative level of mitigation required*.
- **Cumulative impacts:** *The effect the combination of past, present and "reasonably foreseeable" future actions have on aspects.*

The potential environmental impacts assessed during this study for the operational and post-operational phases are:

1. The potential of the mineral waste material types to generate ***acid mine drainage*** conditions;
2. The potential of the mineral waste material types to ***leach metals and metalloids*** to the mineral waste substrate and groundwater;
3. The potential of the mineral waste material types to ***leach sulfate*** to the mineral waste substrate and groundwater;
4. The potential of the mineral waste material types to ***leach boron*** to the mineral waste substrate and groundwater;
5. The potential of the mineral waste material types to ***leach nitrate*** to the mineral waste substrate and groundwater;

The risk matrix is shown in Table 9 and discussed in the sections below.

6.1 Operational Phase

6.1.1 Acid mine drainage

The environmental risk matrix (Table 9) indicates that the risk of the development of acid mine drainage (AMD) conditions without implementing mitigation measures in the Water Tank waste rock, Spanover waste rock and low-grade ore material is "Very Low". In the tailings, the risk rating is "Low". Although the AMD risk of the tailings material can be decreased to "Very Low" by the implementation of mitigation measures, this is not required in the operational phase, as the pH, derived from numeric geochemical modelling, is ~4.5, which is higher than is typically regarded as AMD, i.e pH < ~3.

6.1.2 Leaching of metals and metalloids

The environmental risk matrix (Table 9) indicates that the risk of leaching of metals and metalloids from all waste types, i.e. Water Tank waste rock, Spanover waste rock, low-grade ore and tailings material is "Very Low", without implementation of mitigation measures. The geochemical modelling has indicated that the risk of the leaching of metals and metalloids from all waste material types is negligible.

6.1.3 Leaching of sulfate

The environmental risk matrix (Table 9) indicates that the risk of leaching sulfate from the Water Tank waste rock material is "Very Low". The geochemical modelling has shown that the amount of sulfate expected to leach from this material is negligible.

The environmental risk of leaching sulfate from the Spanover waste rock and low-grade ore material is "Low" without any mitigation measures. This is mostly due to the of sulfate leaching from these waste material types. The Low-grade ore material will be removed before the post-operational phase and will thus not be at risk of leaching sulfate in the long-term post-closure. The waste rock material will not be removed due to the "Low" risk rating for this activity.

The environmental risk of leaching sulfate from the tailings material is "Medium".

Table 9 Environmental geochemical risk assessment impact matrix for the Kalgold waste rock

ENVIRONMENTAL ASPECT	NATURE OF THE IMPACT	IMPACT STATUS	MAGNITUDE	EXTENT	DURATION	REVERSIBILITY	IRREPLACEABILITY	PROBABILITY	SIGNIFICANCE	MITIGATION POTENTIAL	SIGNIFICANCE	CONFIDENCE RATING	CUMULATIVE IMPACTS
									PRE-MITIGATION		POST-MITIGATION		
Operational Phase													
GEOCHEMISTRY	Disposal of **Water Tank waste rock** onto the waste rock facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **low-grade ore** onto the low-grade ore stockpile facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and the resultant formation of ***acid mine drainage*** conditions	negative	5	3	5	2	15	2	30	High	15	Sure	Low
	Disposal of waste rock onto the **Water Tank waste rock** facility and resultant environmental pollution of Water Tank waste rock substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **low-grade ore** onto the low-frade ore facility and resultant environmental pollution of low-grade ore substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of waste rock onto the **Water Tank waste rock** facility and resultant environmental pollution of Water Tank waste rock substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	1	13	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	3	39	High	15	Sure	Low
	Disposal of **low-grade ore** onto the low-frade ore facility and resultant environmental pollution of low-grade ore substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	3	39	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	4	52	High	15	Sure	Low
	Disposal of **Water tank waste rock** onto the Water Tanks waste rock facility and resultant environmental pollution of Water Tanks waste rock substrate and groundwater from the ***leaching of boron*** from the Water Tank waste rock material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of boron*** from the waste rock material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **low-grade ore** onto the low-grade ore facility and resultant environmental pollution of low-grade ore substrate and groundwater from the ***leaching of boron*** from the low-grade ore material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of boron*** from the tailings material	neutral	2	3	5	1	11	2	22	High	11	Sure	Low
	Disposal of **Water tank waste rock** onto the Water Tanks waste rock facility and resultant environmental pollution of Water Tanks waste rock substrate and groundwater from the ***leaching of nitrate*** from the Water Tank waste rock material	negative	5	3	3	2	13	4	52	High	11	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of nitrate*** from the waste rock material	negative	5	3	3	2	13	4	52	High	11	Sure	Low
	Disposal of **low-grade ore** onto the low-grade ore facility and resultant environmental pollution of low-grade ore substrate and groundwater from the ***leaching of nitrate*** from the low-grade ore material	negative	5	3	3	2	13	4	52	High	11	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of nitrate*** from the tailings material	negative	5	3	3	2	13	4	52	High	11	Sure	Low
Post-Operational Phase													
GEOCHEMISTRY	Disposal of **Water Tank waste rock** onto the waste rock facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and the resultant formation of ***acid mine drainage conditions***	negative	5	3	5	2	15	2	30	High	15	Sure	Low
	Disposal of waste rock onto the **Water Tank waste rock** facility and resultant environmental pollution of Water Tank waste rock substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of metal(loid)s***	negative	5	3	5	2	15	1	15	High	15	Sure	Low
	Disposal of waste rock onto the **Water Tank waste rock** facility and resultant environmental pollution of Water Tank waste rock substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	3	39	High	15	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	3	39	High	15	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of sulfate***	negative	3	3	5	2	13	4	52	High	15	Sure	Low
	Disposal of **Water tank waste rock** onto the Water Tanks waste rock facility and resultant environmental pollution of Water Tanks waste rock substrate and groundwater from the ***leaching of boron*** from the Water Tank waste rock material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of boron*** from the waste rock material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of boron*** from the tailings material	neutral	2	3	5	1	11	1	11	High	11	Sure	Low
	Disposal of **Water tank waste rock** onto the Water Tanks waste rock facility and resultant environmental pollution of Water Tanks waste rock substrate and groundwater from the ***leaching of nitrate*** from the Water Tank waste rock material	negative	5	3	3	2	13	1	13	High	11	Sure	Low
	Disposal of **waste rock** onto the waste rock facility and resultant environmental pollution of waste rock substrate and groundwater from the ***leaching of nitrate*** from the waste rock material	negative	5	3	3	2	13	1	13	High	11	Sure	Low
	Disposal of **tailings** onto the tailings facility and resultant environmental pollution of tailings substrate and groundwater from the ***leaching of nitrate*** from the tailings material	negative	5	3	3	2	13	1	13	High	11	Sure	Low

6.1.4 *Leaching of boron*

The environmental risk matrix (Table 9) indicates that the risk of boron leaching from the Water Tank waste rock, Spanover waste rock and low-grade ore material is "Very Low', without the implementation of any mitigation measures. This is predominantly due to the low risk of the release of boron in concentrations exceeding any regulatory leaching guideline values. This is due to the fact that boron is contained in silicate minerals, which break down very slowly over time by the process of chemical weathering.

The environmental risk of boron leaching from the tailings material is "Low", which is slightly higher than for the other waste materials. This is due to the lower pH in the tailings material and the slightly elevated probability of the leaching of boron from the silicate minerals. The severity of the eventuality of boron leaching from the tailings material is negligible and therefore mitigation measures are not required.

6.1.5 *Leaching of nitrate*

The environmental risk matrix (Table 9) indicates that the risk of nitrate is "Medium" for all mineral waste types without the implementation of mitigation measures. This is due to the co-deposition of the mineral waste material and process water. The process water contains the nitrate and not the mineral waste material. Therefore, this environmental risk is only likely in the operational phase and the nitrate leaching will cease completely when mining operations cease.

6.2 Post-Operational Phase

6.2.1 *Acid mine drainage*

The environmental risk matrix (Table 9) indicates that the risk of the development of acid mine drainage (AMD) conditions without implementing mitigation measures in the Water Tank waste rock, Spanover waste rock and low-grade ore material is "Very Low". In the tailings, the risk rating is "Low". The AMD risk of the tailings material can be decreased to "Very Low" by the implementation of mitigation measures, such as capping the tailings in the post-operational phase. This will also have beneficial effects for other environmental risks, as described in the sections below.

6.2.2 *Leaching of metals and metalloids*

The environmental risk matrix (Table 9) indicates that the risk of leaching of metals and metalloids from all waste types, i.e. Water Tank waste rock, Spanover waste rock, low-grade ore and tailings material is "Very Low", without implementation of mitigation measures. The geochemical modelling has indicated that the risk of the leaching of metals and metalloids from all waste material types is negligible.

6.2.3 *Leaching of sulfate*

The environmental risk matrix (Table 9) indicates that the risk of leaching sulfate from the Water Tank waste rock material is "Very Low". The geochemical modelling has shown that the amount of sulfate expected to leach from this material is negligible.

The environmental risk of leaching sulfate from the waste rock and low-grade ore material is "Low" without any mitigation measures. This is mostly due to the of sulfate leaching from these waste material types. The Low-grade ore material will be removed before the post-operational phase and will thus not be at risk of leaching sulfate in the long-term post-closure. The waste rock and tailings material will not be removed, but due to the “Low” risk rating for this activity, mitigation measures can be applied, such as capping of the waste rock material.

The environmental risk of leaching sulfate from the tailings material is “Medium”. This risk rating can be decreased by applying simple mitigation measures, such as capping of the tailings facility.

6.2.4 Leaching of nitrate

The environmental risk matrix (Table 9) indicates that the risk of nitrate is “Medium” for all mineral waste types without the implementation of mitigation measures. This is due to the co-deposition of the mineral waste material and process water. The process water contains the nitrate and not the mineral waste material. Therefore, this environmental risk is only likely in the operational phase and the nitrate leaching will cease completely when mining operations cease. Mitigation in the post-operational phase is therefore not required.

7 CONCLUSIONS

The following conclusions follow from this study:

7.1 Kalgold Water Tank waste rock

- The Kalgold Water Tank waste rock material classifies as Type 3 according to the criteria set out in R635. However, the Type 3 class is reached by the exceedance of only boron and only in the total analysis (TCT). Long-term, numeric geochemical modelling confirms the leach test that the boron is located within the silicate mineral structures and are thus unlikely to leach from the waste rock in concentrations excluding any regulatory guideline values. The waste should therefore classify as Type 4 based on the geochemical assessment.
- The Kalgold Water Tank waste rock material is unlikely to produce acid mine drainage conditions.
- The risk rating of the cumulative impacts from the Kalgold Water Tank waste rock is “Low”.

7.2 Spanover waste rock

- The Kalgold Spanover waste rock material classifies as Type 3 according to the criteria set out in R635. However, the Type 3 class is reached by the exceedance of only boron and only in the total analysis (TCT). Long-term, numeric geochemical modelling confirms the leach test that the boron is located within the silicate mineral structures and are thus unlikely to leach from the waste rock in concentrations excluding any regulatory guideline values. The waste should therefore classify as Type 4 based on the geochemical assessment.
- The Kalgold waste rock material is unlikely to produce acid mine drainage conditions.
- The risk rating of the cumulative impacts from the Kalgold waste rock material is “Low”.

7.3 Kalgold Spanover low-grade ore material

- The geochemical assessment indicates that only sulfate is likely to exceed regulatory guidelines in the Operational Phase of the project. The low-grade ore material will be removed before closure of the mine, implying no long-term post-closure impacts. This material should therefore be classified as Type 4 as defined in R635.
- The low-grade ore material is unlikely to develop acid mine drainage conditions.
- The risk rating of the cumulative impacts from the Kalgold low-grade ore material is “Low”.

7.4 Kalgold tailings material

- The geochemical assessment indicates that only sulfate is likely to exceed regulatory guidelines in the Operational Phase of the project. In the post-operational phase a cap can be placed on the tailings facility to reduce oxygen infiltration into the facility and reduce sulfate leaching to acceptable levels in the Post-Operational phase. Therefore this material should be classified as Type 4 as defined in R635.
- Although the leachate from the tailings is expected to be slightly acidic (pH ~4.5), it is unlikely to develop acid mine drainage conditions, which generally has pH values of less than 3.

  The risk rating of the cumulative impacts from the Kalgold tailings material is “Low”

8 RECOMMENDATIONS

The following recommendations follow from the study:

1. Based on the geochemical assessment all the mineral waste types, i.e. the Water Tank waste rock, the Spanover waste rock, the low-grade ore material and the tailings material can be classified as Type 4.

9 REFERENCES

OMI Solutions (2020) Kalgold waste classification. *Technical Report*

APPENDIX A: MODEL SENSITIVITY, UNCERTAINTY AND LIMITATIONS

The sensitivities, uncertainties and limitations of the various geochemical models are presented in this section.

The Kalgold waste material is exposed to the Earth's atmosphere, which is aerobic and contains 21% oxygen. The minerals from the XRD analysis (Section 4) were used as kinetic inputs to the model to account for time in the geochemical processes. The WRD material consists of relatively large particle sizes, which imply low reaction rates of the geochemical processes The rates at which reactions, e.g. breakdown of pyrite, occurs, is correlated to the reactive surface area of the particles. The finer the particles, the larger the reactive surface area of the material as a whole and the more rapid reactions occur. The reactions for the mineral waste material therefore occur significantly slower than for the tailings material. Slower reaction rates and larger pore spaces between particles prevent the mineral waste facility to develop well-developed geochemical zones. Therefore the whole mineral waste facility can be treated as a single entity in the geochemical modelling. The permeability of Witwatersrand gold mineral waste is relatively large, due to the coarse particles. The contact-time between the waste-rock and the percolating water solution is therefore also significantly less in the mineral waste material. This an important consideration in modelling water quality from of these facilities. A conservative approach was followed in that the same ratio of water to rock of 1:1 is used in the mineral waste, thereby allowing geochemical reactions to take place, even though the exact ratio is uncertain.

The limitation of this model is that it simulates the geochemical processes, e.g. the breakdown of minerals, and cannot be used to calculate the rate at which water percolates through the tailings system.

APPENDIX B: LABORATORY CERTIFICATES

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2020-07-03
Project number: 1000
Report number: 92749
Date completed: 2020-07-24
Order number: MVB_20_02

Client name: MvB Consulting
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Telephone: ---
Facsimile: ---
Contact person: Marius van Biljon
Email: marius@mvbconsult.co.za
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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification	
	Water Tank Waste Rock Dump	Water Tank Waste Rock Dump
Sample Number	**98538**	**98538 D**
Paste pH	6.8	6.8
Total Sulphur (%) (LECO)	0.02	0.02
Acid Potential (AP) (kg/t)	0.763	0.778
Neutralization Potential (NP)	-1.48	-1.74
Nett Neutralization Potential (NNP)	-2.24	-2.52
Neutralising Potential Ratio (NPR) (NP : AP)	1.94	2.24
Rock Type	III	III

*** Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.**

Please refer to Appendix (p.2) for a Terminology of terms and guidelines for rock classification

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APPENDIX: TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms*: Maximum Potential Acidity (MPA)
  Method: Total S(%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn*: Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
  Method: Fizz Test ; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
  Calculation: NNP = NP – AP ; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
  Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

If NNP (NP – AP) < 0, the sample has the potential to generate acid
If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

Any sample with NNP < 20 is potentiall acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al*., 2003)

ROCK CLASSIFICATION

TYPE I	Potentially Acid Forming	Total S(%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate	Total S(%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-Acid Forming	Total S(%) < 0.25% and NP:AP ratio 1:3 or greater

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CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al*., 1997; Usher *et al*., 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	**< 1:1**	Likely AMD generating
Possibly	**1:1 – 2:1**	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	**2:1 – 4:1**	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	**>4:1**	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
3) NPR ratios of 3:1 to 1:1 are consider inconclusive.
4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al*., 2003)

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REFERENCES

LAWRENCE, R.W & WANG, Y. 1997**. Determination of Neutralization Potential in the Prediction of Acid Rock Drainage**. Proc. 4th International Conference on Acid Rock Drainage. Vancouver. BC. pp. 449 – 464.

PRICE, W.A., MORIN, K. & HUTT, N. 1997. **Guidelines for the prediction of Acid Rock Drainage and Metal leaching for mines in British Columbia**: Part 11. Recommended procedures for static and kinetic testing. In: Proceedings of the Fourth International Conference on Acid Rock Drainage. Vol 1. May 31 – June 6. Vancouver, BC., pp. 15 –30.

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SOREGAROLI, B.A. & LAWRENCE, R.W. 1998. Update on waste Characterisation Studies. Proc. Mine Design, Operations and Closure Conference. Polson, Montana.

USHER, B.H., CRUYWAGEN, L-M., DE NECKER, E. & HODGSON, F.D.I. 2003. **Acid-Base : Accounting, Techniques and Evaluation (ABATE): Recommended Methods for Conducting and Interpreting Analytical Geochemical Assessments at Opencast Collieries in South Africa.** Water Research Commission Report No 1055/2/03. Pretoria.

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CERTIFICATE OF ANALYSES

EXTRACTIONS AS 4439.3

Date received: 2020/07/03
Project number: 1000
Report number: 92749
Date completed: 2020/07/24
Order number: MVB_20_02

Client name: MvB Consulting
Address: P.O. Box 2166, Rant en Dal, 1751
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Analyses	Sample Identification Water Tank Waste Rock Dump				
Sample Number	98538				
TCLP / Borax / Distilled Water	Distilled Water				
Ratio*	1:20				
Units	mg/ℓ	LCT0 mg/l	LCT1 mg/l	LCT2 mg/l	LCT3 mg/l
As, Arsenic	<0.001	0.01	0.5	1	4
B, Boron	0.004	0.5	25	50	200
Ba, Barium	0.013	0.7	35	70	280
Cd, Cadmium	<0.001	0.003	0.15	0.3	1.2
Co, Cobalt	0.001	0.5	25	50	200
Cr$_{Total}$, Chromium Total	<0.001	0.1	5	10	40
Cr(VI), Chromium (VI)	<0.010	0.05	2.5	5	20
Cu, Copper	<0.001	2.0	100	200	800
Hg, Mercury	<0.001	0.006	0.3	0.6	2.4
Mn, Manganese	0.139	0.5	25	50	200
Mo, Molybdenum	<0.001	0.07	3.5	7	28
Ni, Nickel	0.001	0.07	3.5	7	28
Pb, Lead	<0.001	0.01	0.5	1	4
Sb, Antimony	<0.001	0.02	1.0	2	8
Se, Selenium	<0.001	0.01	0.5	1	4
U, Uranium	<0.001				
V, Vanadium	<0.001	0.2	10	20	80
Zn, Zinc	0.002	5.0	250	500	2000
Inorganic Anions	mg/ℓ				
Total Dissolved Solids*	40	1000	12 500	25 000	100 000
Chloride as Cl	<2	300	15 000	30 000	120 000
Sulphate as SO4	12	250	12 500	25 000	100 000
Nitrate as N	<0.1	11	550	1100	4400
Fluoride as F	<0.2	1.5	75	150	600
Total Cyanide as CN [o]	<0.02	0.07	3.5	7	28
Paste pH	6.8				
Acid Base Accounting	See attached report 92749 ABA				
X-ray Diffraction [o]	See attached report 92749 XRD				

[o] = Outsourced

***Please note:** 1. The samples were used as received.
2. A moisture content were determined for wet or moist samples.
3. In cases where the sample were a slurry, a solid to liquid ratio were done (reported). Moisture content were determined after filtration
4. The results are reported as received. The moisture content were not taken into account.

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CERTIFICATE OF ANALYSES

Digestion AS 4439.3

Date received:	**2020/07/03**			**Date completed:**	**2020/07/24**
Project number:	**1000**	**Report number:**	**92749**	**Order number:**	**MVB_20_02**

Client name:	**MvB Consulting**	**Contact person:**	**Marius van Biljon**
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Analyses	Sample Identification				
	Water Tank Waste Rock Dump				
Sample Number	98538		TCT0 mg/kg	TCT1 mg/kg	TCT2 mg/kg
Digestion	HNO3 : HF				
Dry Mass Used (g)	0.25				
Volume Used (mℓ)	100				
Units	mg/ℓ	mg/kg			
As, Arsenic	0.003	1.20	5.8	500	2000
B, Boron	0.567	227	150	15000	6000
Ba, Barium	0.150	60	62.5	6250	25000
Cd, Cadmium	<0.001	<0.400	7.5	260	1040
Co, Cobalt	0.003	1.20	50	5000	20000
$\mathrm{Cr}_{\mathrm{Total,}}$ Chromium Total	0.391	156	46000	800000	N/A
Cu, Copper	<0.001	<0.400	16	19500	78000
Hg, Mercury	0.001	0.400	0.93	160	640
Mn, Manganese	0.151	60	1000	25000	100000
Mo, Molybdenum	0.007	2.80	40	1000	4000
Ni, Nickel	0.010	4.00	91	10600	42400
Pb, Lead	0.037	15	20	1900	7600
Sb, Antimony	<0.001	<0.400	10	75	300
Se, Selenium	<0.001	<0.400	10	50	200
U, Uranium	0.003	1.20			
V, Vanadium	0.108	43	150	2680	10720
Zn, Zinc	<0.001	<0.400	240	160000	640000
Inorganic Anions	mg/ℓ	mg/kg			
Cr(VI), Chromium (VI) Total [o]	---	<2	6.5	500	2000
Total Fluoride [o]	---	<0.5	100	10000	40000
Total Cyanide as CN [o]	---	<0.5	14	10500	42000

[o] = Outsourced

UTD = Unable to determine

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CERTIFICATE OF ANALYSES
X-RAY DIFFRACTION

Date received: 2020-07-03
Project number: 1000

Report number: 92749

Date completed: 2020-07-14
Order number: MVB_20_02

Client name: MvB Consulting
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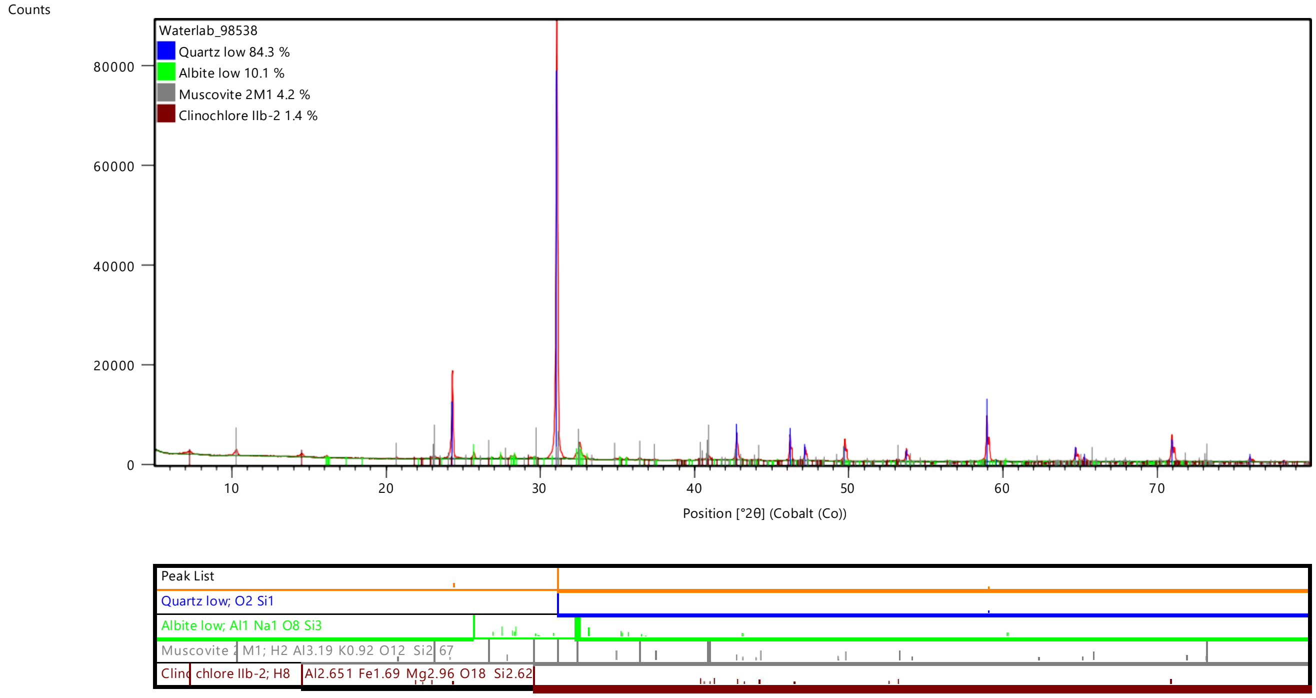
<table>
<tr><th colspan="2">Composition (%) [o]</th></tr>
<tr><th colspan="2">Water Tank Waste Rock Dump</th></tr>
<tr><th colspan="2">98538</th></tr>
<tr><th>Mineral</th><th>Amount
(weight %)</th></tr>
<tr><td>Quartz</td><td>84.3</td></tr>
<tr><td>Plagioclase</td><td>10.1</td></tr>
<tr><td>Muscovite</td><td>4.2</td></tr>
<tr><td>Chlorite</td><td>1.4</td></tr>
</table>

[o] = Outsourced



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Note:

The material was prepared for XRD analysis using a back loading preparation method.
Diffractograms were obtained using a Malvern Panalytical Aeris diffractometer with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation. The phases were identified using X'Pert Highscore plus software.
The relative phase amounts (weight %) were estimated using the Rietveld method.

Comment:

- In case the results do not correspond to results of other analytical techniques, please let me know for further fine tuning of XRD results.
- Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group. Smectite, lizardite (serpentine), vermiculite, chlorite and kaolinite peaks overlap, and further test would be necessary to distinguish. Identification is largely based on peak shapes and positions.
- Due to preferred orientation and crystallite size effects, results may not be as accurate as shown.
- Traces of additional phases such as kaolinite and smectite may be present.
- Amorphous phases, if present, were not taken into consideration during quantification.

Ideal Mineral compositions:

Compound Name	Ideal Chemical Formula
Quartz	SiO_2
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$
Chlorite	$(Mg,Fe)_5Al(AlSi_3O_{10})(OH)_8$
Muscovite/Mica	$K Al_2 ((OH)_2 Al Si_3 O_{10})$

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