ENVIRONMENTAL IMPACT MANAGEMENT SERVICES

HYDROGEOLOGICAL ASSESSMENT FOR THE PROPOSED TAILINGS REDEPOSITION ON THE HARMONY MPONENG LOWER COMPARTMENT TAILINGS STORAGE FACILITY

BASELINE REPORT

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1. INTRODUCTION AND TERMS OF REFERENCE

1.1 Project Description

Harmony Gold Mining Limited (Harmony) owns and operates a number of Gold Mines and Plants in the West Wits region in the Gauteng Province. The Savuka Plant currently deposits tailings onto the Savuka 5a, 5b, 7a & 7b Tailings Storage Facilities (TSFs). However, these facilities are approaching their final and approved height, and the current planned Life of Mine (LOM) for the West Wits region exceeds the available deposition capacity of these TSFs. Accordingly, Harmony is undertaking a feasibility assessment to recommence deposition on the Mponeng Lower Compartment Tailings Storage Facility.

Harmony is proposing to recommence deposition on the Mponeng Lower Compartment Tailings Storage Facility (hereafter referred to as Mponeng Lower Compartment TSF). The Mponeng Lower Compartment TSF is located at 26°27'11.18"S; 27°24'43.88"E (Figure 1.1 and Figure 1.2).

Mponeng Lower Compartment TSF is an existing TSF, however, the Mponeng Lower Compartment TSF is no longer in operation and is currently utilised as a Holding Dam, and a portion of it is used as an authorised Landfill Facility. In order to redeposit on the Mponeng TSF, from the Savuka Plant, slurry pipelines will need to be constructed from the Savuka Plant to the TSF. The proposed slurry and return water pipes extend from the south of Savuka Plant at starting point 26°25'24.95"S; 27°23'58.94"E, extending southwards, parallel to each other until reaching the northern extent of Mponeng TSF where they split. Thereafter, the slurry pipeline extends to west before connecting to Mponeng TSF while the return water pipeline extends east then south around the TSF to the return water dam. There is an alternative slurry and return water pipeline route which extends to the east through Western Deep Levels then south along Mponeng Gold Mine before heading to the west where it connects to Mponeng TSF.

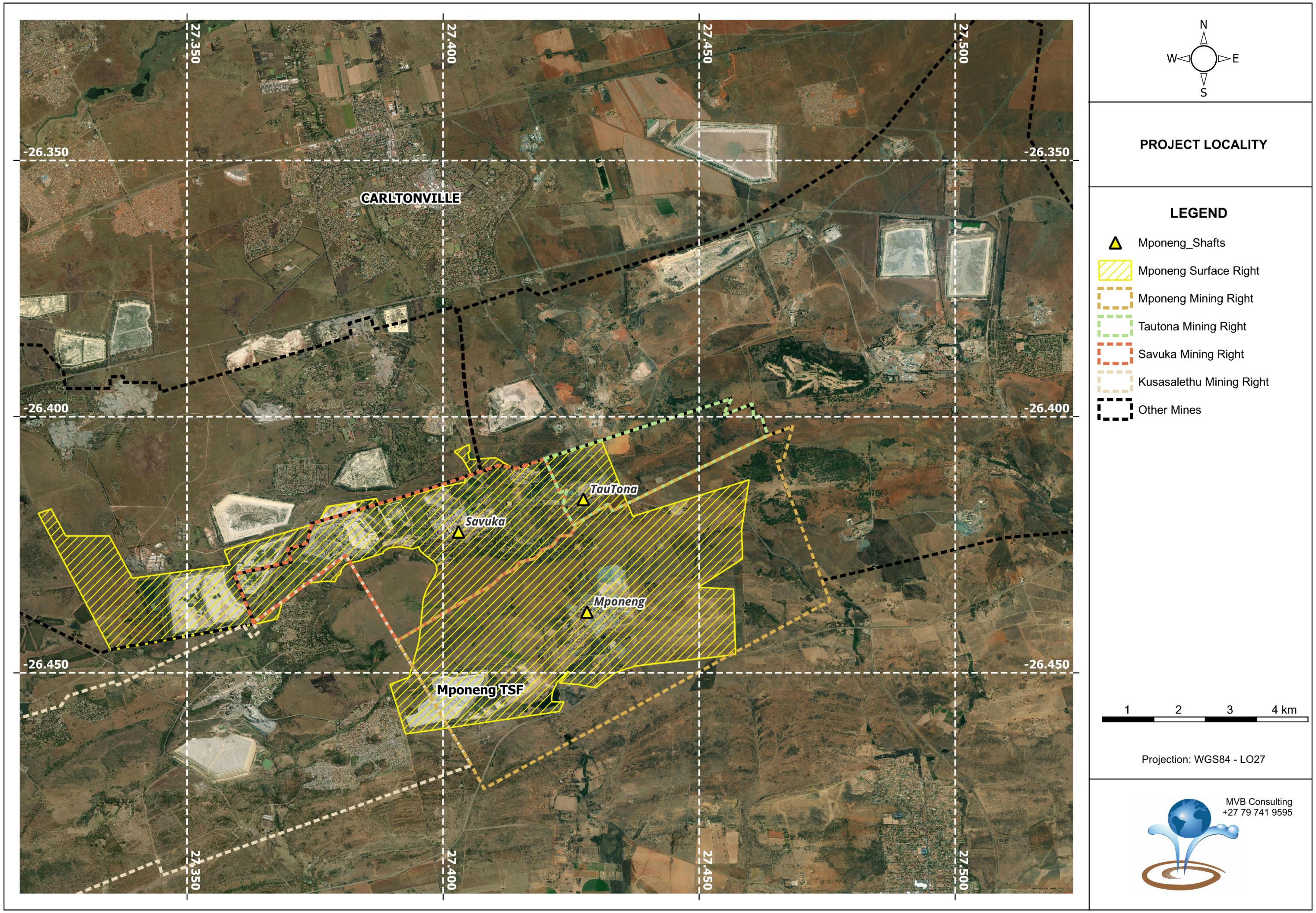

Figure 1.1: Locality of the study area

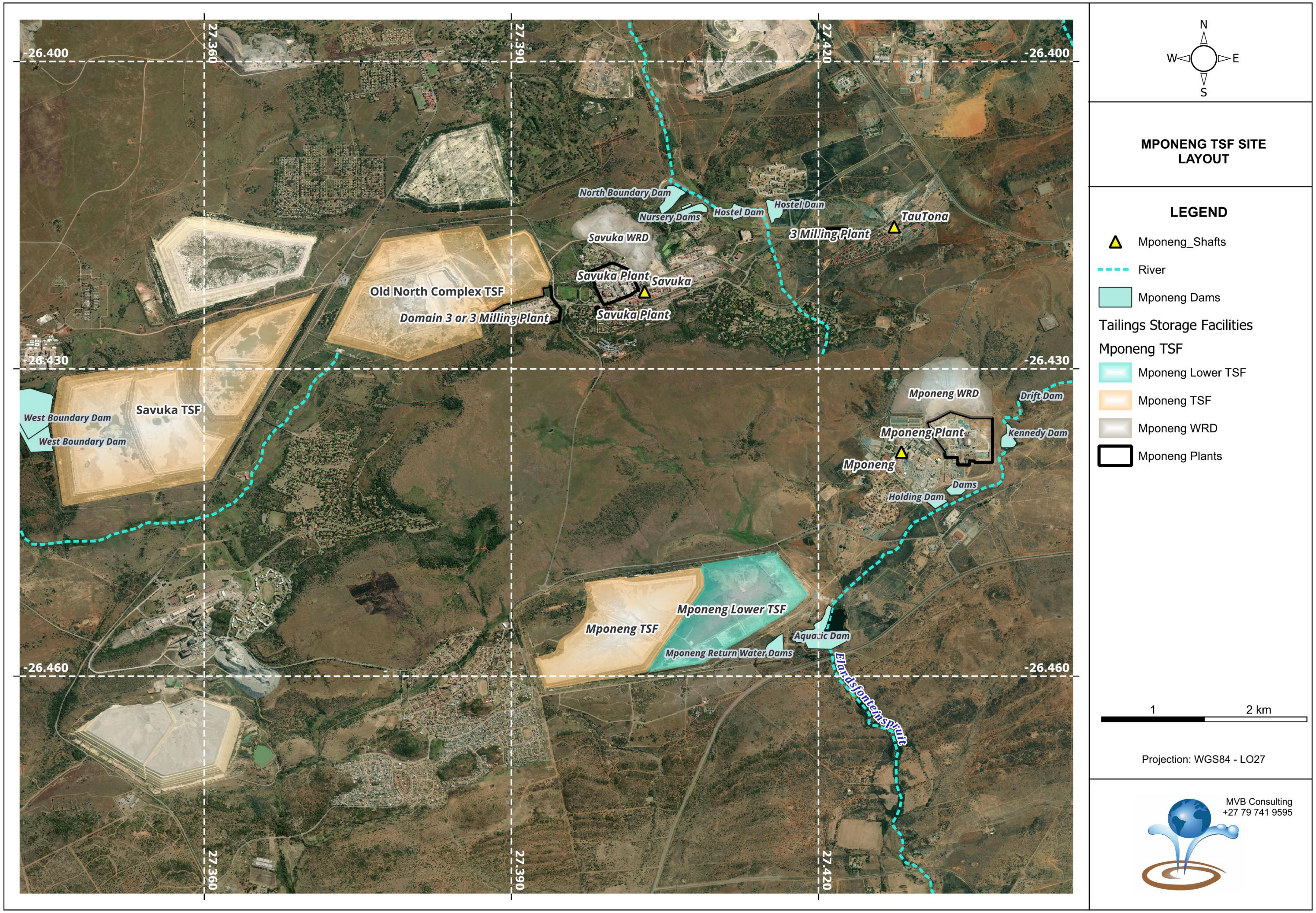

Figure 1.2: **Mponeng TSF site layout**

1.2 Scope of Work

Harmony has appointed Environmental Impact Management Services (Pty) Ltd (EIMS) as the Environmental Assessment Practitioner (EAP) to undertake the necessary environmental authorisation and associated consultation processes. MVB Consulting was requested to undertake a hydrogeological assessment for the proposed recommencing of tailings deposition on the Mponeng TSF. The hydrogeological study forms part of the environmental authorisation process.

The aim of the hydrogeological study is to assess the following:

- Assessment of the hydrogeological environment in terms of aquifer development, aquifer hydraulics, groundwater flow and groundwater chemistry.
- Assessment of the potential short and long-term impact from the Mponeng TSF on the groundwater environment.
- Recommended management measures to mitigate potential impacts.

The study includes the following:

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

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1.3 Data Review

This section details the data provided by the client and reports used in the study.

The datasets and reports listed in Table 1.1 was provided by the client for the study.

Table 1.1: Client datasets

Type	Description
Rainfall	Long-term site-specific data (South African Weather Services)
Monitoring Data	Annual Water Quality Monitoring Report for Harmony Gold Mine – WW & CWC: July 2022 to June 2023 (GCS, 2023)
Hydrogeological Reports	Groundwater Flow & Plume Model Update for the West Wits Operations (GCS, 2024).
	Groundwater Assessment for the Mponeng TSF Complex (GCS, 2019)
	Harmony Mponeng- TSF Spring Hydrogeological Investigation (PHASE 1) (GCS, 2025)

2. GEOGRAPHICAL SETTING

2.1 Climate and Rainfall

The climate is a typical Southern African Highveld climate with warm to hot summers and warm sunny winter days with frosty nights. Rainfall occurs predominantly during the summer months because of thunderstorm activity. The mean annual precipitation ranges from 565 mm to 697 mm per annum depending on the location of the weather station. Rainfall data was obtained from several sources, including mine data and data from the South African Weather Service. The rainfall for the region is summarised in Table 2.1.

Table 2.1: Rainfall Summary

Period	1927-2000	1962-2008	1983-2004	1966-2012	1900-2000	1958-2011	Regional Average
Station Name	Fochville	Carltonville	Wes Driefontein	Westonaria	Zuurbekom (RWB)	Randfontein	
Station Number	474899	4746809	04747421	04751744	475528	0475338 9	
Month	Average Monthly Rainfall (mm)						
January	104	118	98	130	113	126	**115**
February	81	86	74	85	98	92	**86**
March	80	77	70	81	78	83	**78**
April	45	52	33	48	46	52	**46**
May	18	14	14	13	17	12	**15**
June	9	7	8	6	6	7	**7**
July	5	3	2	3	5	2	**3**
August	7	7	8	10	7	6	**7**
September	23	19	18	21	19	20	**20**
October	56	70	69	72	68	69	**67**
November	95	87	80	100	100	99	**94**
December	97	111	92	129	111	104	**107**
Total	**620**	**651**	**565**	**697**	**668**	**672**	**646**

2.2 Topography and Drainage

The area north of the Mponeng TSF is characterized by a series of parallel hills that form the Gatsrand and have an elevation of approximately 1 770 metres above mean sea level (mamsl). Drainage from the Mponeng TSF deposits is mainly south (Quaternary catchment C23J and C23E), into the Loop Spruit. The Loop Spruit flows in a westerly direction and joins the Mooi River at Potchefstroom from where it flows to the Vaal River.

The study area forms part of the Lower Vaal Water Management Area. The Vaal Water Management Area (WMA) is the result of the consolidation of the Upper, Middle and Lower Vaal catchments.

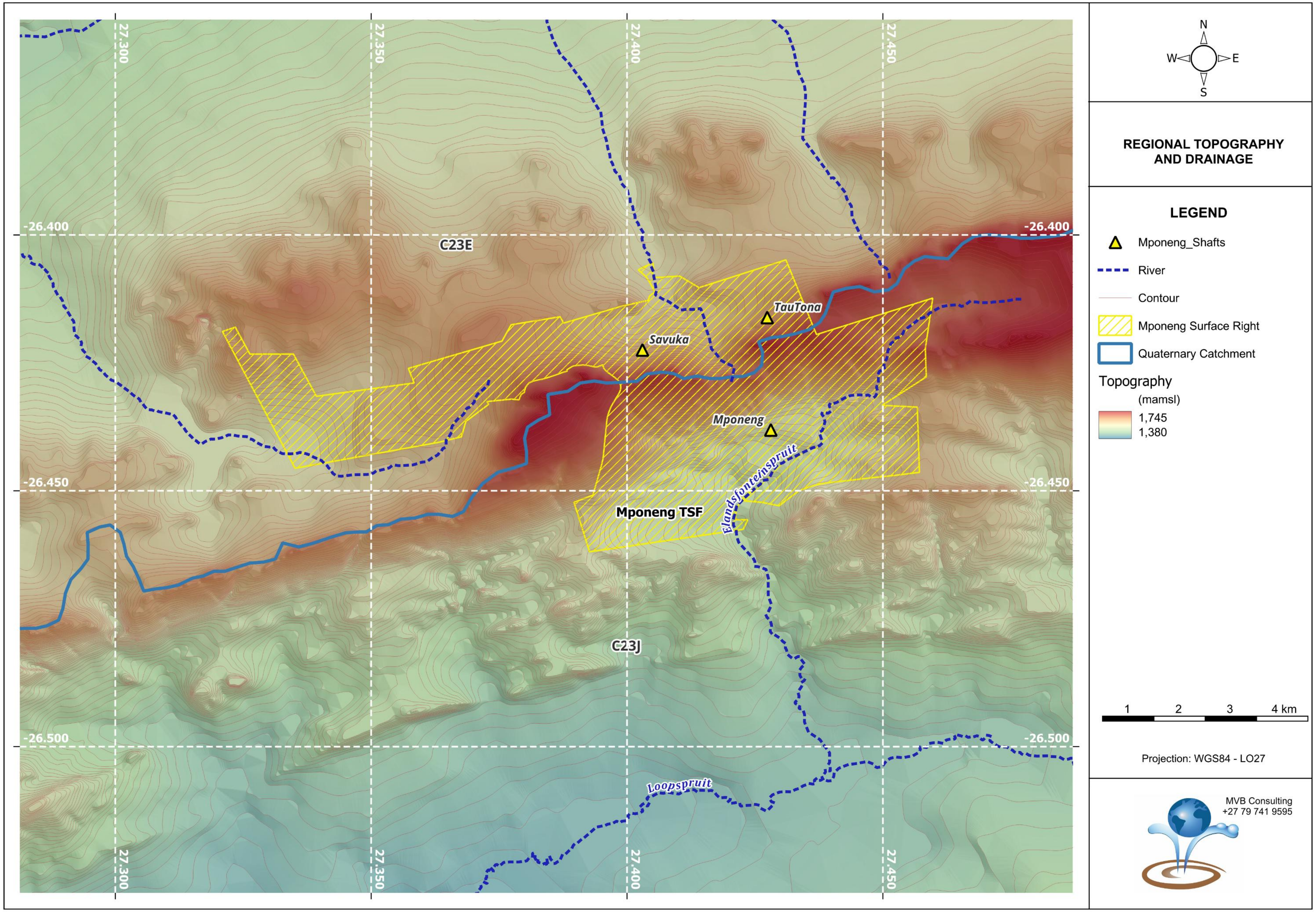

Figure 2.1: **Study area topography and drainage**

3. CONCEPTUAL HYDROGEOLOGICAL MODEL

A description of the conceptual hydrogeological model is important to provide an understanding of the regional geology, which is the governing factor in both the aquifer formation and the movement of groundwater, as well as the hydrogeological setting and groundwater occurrence in the mining area.

3.1 Geological Setting

The geology of the study area has been described in detail by several authors and mine geologists. The following section describes the regional and local geology.

The regional surface geology includes, in chronological order:

- Witwatersrand Supergroup.
- Ventersdorp Supergroup.
- Transvaal Supergroup.
- Karoo Supergroup.

The stratigraphy is shown in Figure 3.1 regional surface geology is presented in Figure 3.2.

3.1.1 Witwatersrand Supergroup

Truswell (1977) describes the geology of the Witwatersrand Basin as follows:

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

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

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

The economic gold placers (reefs) are restricted to the Central Rand Group of the Witwatersrand Supergroup. A primary economic horizon that is mined in all the mines in the region is the Ventersdorp Contact Reef (VCR), at the base of the Ventersdorp lava. The Carbon Leader is also mined extensively in the region. Mponeng exploits the Ventersdorp Contact Reef (VCR) via a twin-shaft system to depths of between 2 800m and 3 400m below surface (AngloGold Ashanti, 2018).

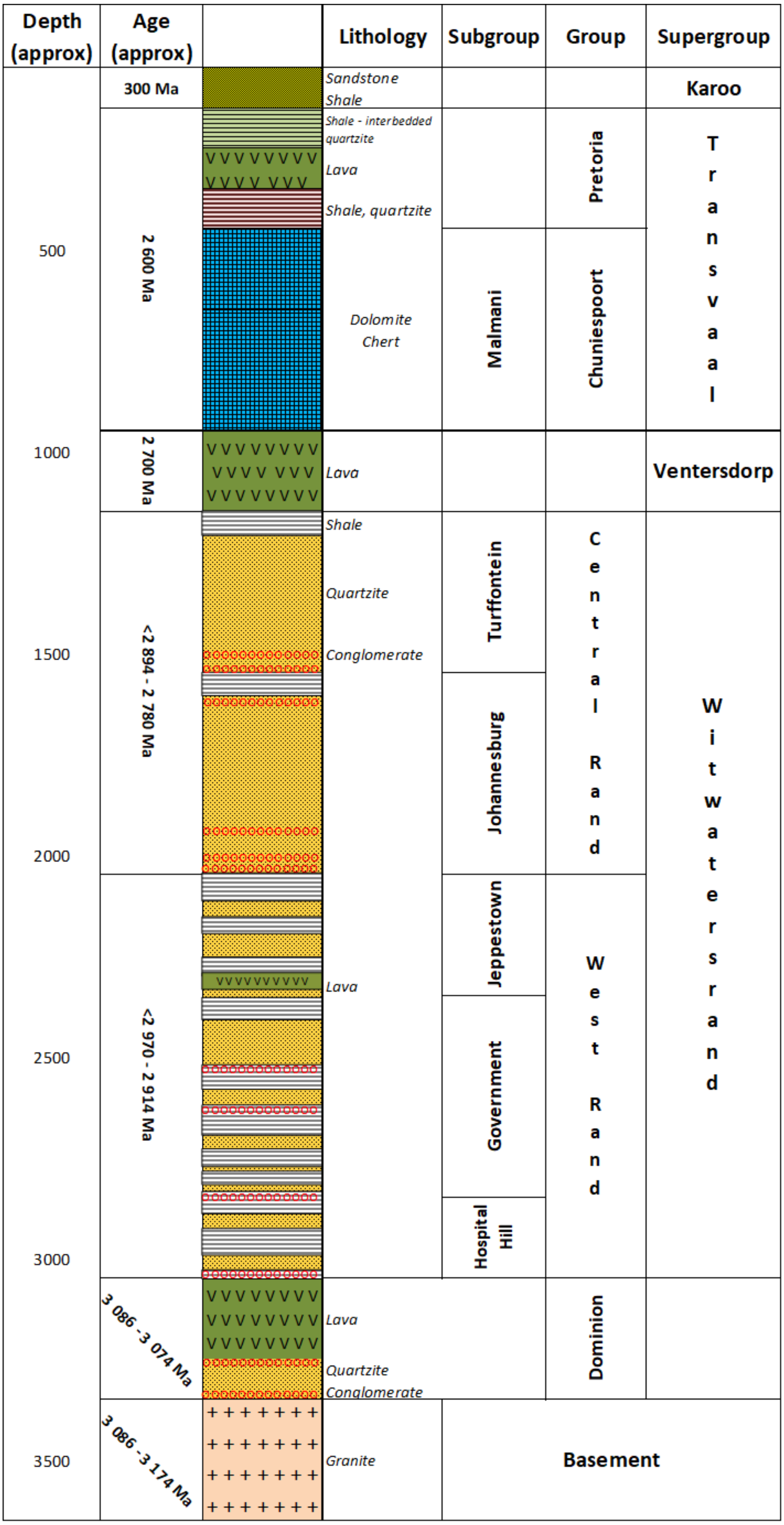

Figure 3.1: Stratigraphy of the study area (after Robb and Robb, 1998)

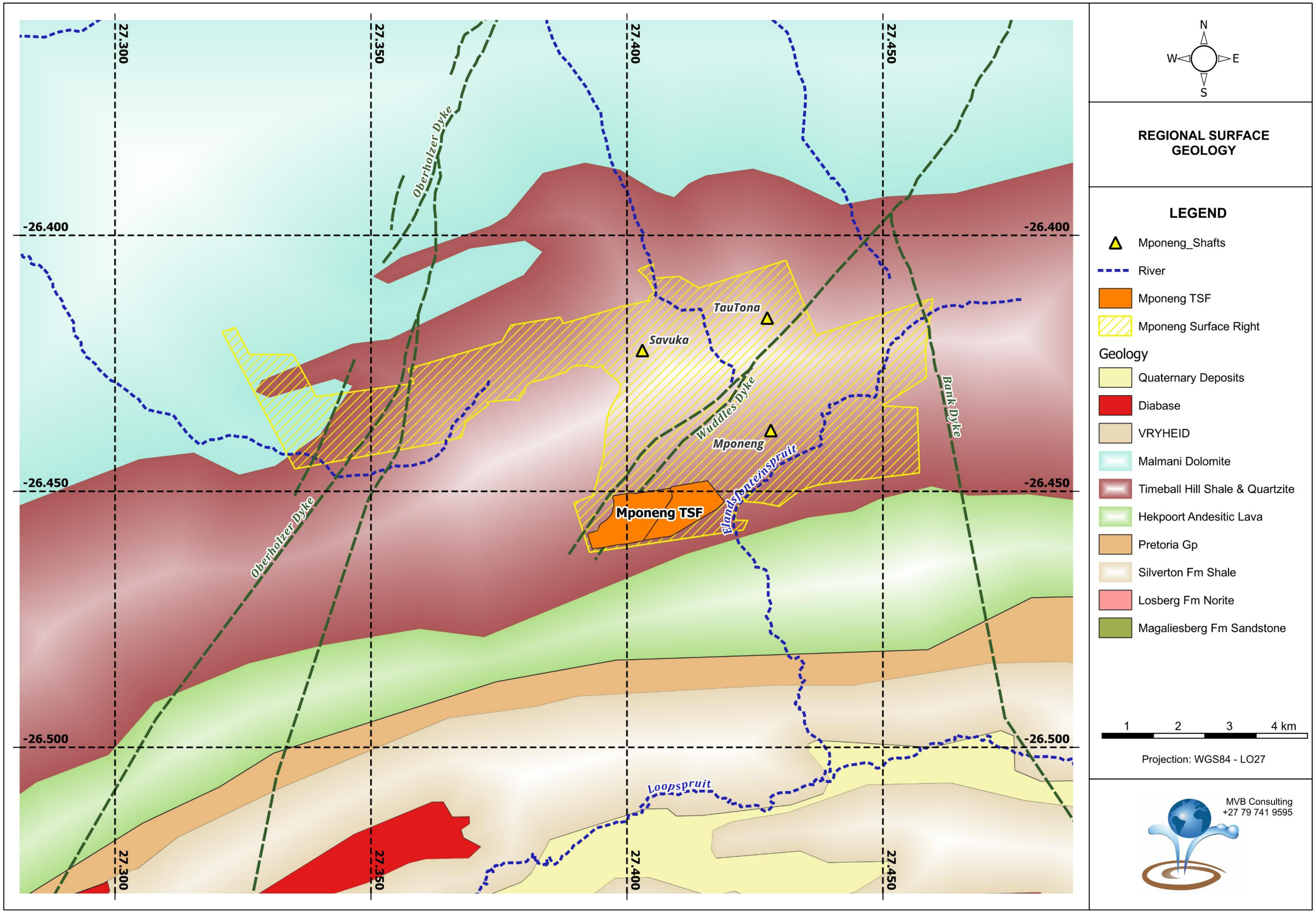

Figure 3.2: **Regional surface geology**

3.1.2 Ventersdorp Supergroup

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

The Ventersdorp lava plays an important role in terms of groundwater ingress into the underground workings. As a rule of thumb, areas that have less than 50 m of lava have a greater risk of water ingress. This is especially the case were mining takes place above the Witwatersrand strata, such as mining of the VCR at the base of the Ventersdorp succession. The lava acts as an impermeable barrier, largely preventing water from the overlying dolomite aquifer entering the mine.

3.1.3 Transvaal Supergroup

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

Overlying the Kromdraai Member is the dolomite of the Malmani Subgroup of the Chuniespoort Group. The dolomites vary between 200 m and 1 500 m in thickness. According to Parsons (1991) only the two lower formations of the Malmani Subgroup are present in the study area. The lowermost is the Oaktree Formation, which is succeeded southward by the Monte Christo Formation.

The Oaktree Formation consists of chert-poor homogenous dark-grey dolomite containing interbeds of carbonaceous shale, which decrease in frequency and thickness from the base of the formation upwards. Columnar stromatolytes are numerous within this sequence and the formation follows conformably on the Black Reef Formation with a transitional mixed zone consisting of carbonaceous and calcareous argillaceous and arenaceous sediments (Parsons, 1991).

The Monte Christo Formation follows conformably on the Oaktree Formation. The Monte Christo Formation consists of alternating chert-rich and chert-poor, dark to light-grey dolomite and has an estimated thickness of 700 m (Brink, 1979). A 1.5 m thick chert layer, consisting of 10 cm to 15 cm thick layers of chert separated by manganese-rich bands, is present towards the base of the formation. Layers of crystalline, coarse-grained dark dolomite, laminated calcareous shale, shaley dolomite and fine-grained white dolomite occur in the sequence, parts of which are chert-rich, containing numerous chert layers, 10 cm to 20 cm in thickness (Parsons 1991).

The Pretoria Group rocks overlie the dolomite aquifer and is also the surface geology at Mponeng mine. The Rooihoogte Formation forms the basal member of the Pretoria Group, consisting of the Bevets conglomerate, shale and quartzite. The Bevets conglomerate varies in thickness between 3 m and 60 m (Parsons and Killick, 1985). Overlying the Bevets conglomerate is shale and sporadically developed quartzite, referred to as the Pologround quartzite. Where developed the Pologround quartzite is overlain by 150 m – 200 m of pink to purple shales, forming the basis of the Timeball Hill Formation. The shale is overlain by quartzite, which forms the linear north-westerly trending ridges in the central portion of the study area.

Further south is the Hekpoort and Strubenkop Formations. These formations consist predominantly of andesite lava (Hekpoort Formation) and ferruginous shale (Strubenskop Formation). The weathering of the shale and the lava results in grey to dark grey silty sand and clay.

The Hekpoort Andesite Formation is visible through a number of scattered lava outcrops, giving it an uneven landscape. The quicker erosion of the softer tuffaceous sediments, interbedded between the amygdaloidal lava flows is believed to be the cause of the topographical features. The weathering of the Hekpoort Andesite results in dark to reddish – brown silty sand. These can contain fragments of lava and quartz ranging between pebble to cobble size.

The Strubenkop Formation achieves a maximum thickness of 130 m and consists predominantly of ferruginous shale. The contact between the Hekpoort and Strubenkop Formations is difficult to identify in the field, especially in view of the fact that localised intrusions of younger dolerite occur.

Most of these rocks, especially in the lower lying areas, are concealed beneath a cover of younger sedimentary rocks, residual soils and alluvium. There is also a significant accumulation of hillwash and transported sediments. The floodplains of the Loopspruit and its tributaries contain grey, silty to clayey soils.

3.1.4 Karoo Supergroup

The Karoo Supergroup was deposited approximately 345 million years ago. It commenced with glacial period during which most of South Africa was covered by a thick sheet of ice. This ice cap slowly moved towards the south, causing extensive erosion as a result of accumulated debris at the base. This debris was eventually deposited as the Dwyka tillite. The Dwyka, which generally form an impermeable barrier to the downward percolation of groundwater, is absent in most parts of the study area. Younger superficial deposits cover the Karoo in places. The Karoo strata filled the extremely rugged paleo-topography of the underlying karst dolomite to form a relatively even topography that is visible today.

3.2 Hydrogeological Setting

The hydrogeological setting and conceptual model of the study area is described according to the following criteria:

- Borehole information.
- Aquifer type.
- Groundwater use.
- Aquifer parameters.
- Aquifer recharge.
- Groundwater gradients and flow.
- Groundwater quality.
- Aquifer classification.

3.2.1 Borehole Information

There are several groundwater monitoring boreholes in the vicinity of the Mponeng Lower Compartment TSF. No private boreholes could be located within a 2km radius of the TSF. The localities of the available boreholes are shown on Figure 3.3 and summarised in Table 3.1.

Table 3.1: Mine monitoring boreholes (GCS, 2023)

BH ID	Longitude	Latitude	Z	Description	Borehole Depth (m)	Geology
MB10	27.43712	-26.43405	1569.26	SE of Mponeng RD; N of Mponeng GP	29.66	Timeball Hill Shale and Quartzite
MB11	27.42259	-26.45659	1499.16	SE of Mponeng TSF and Below aquatic Dam	30.00	Shales
MB13	27.40448	-26.44829	1560.05	N of Mponeng TSF, N road,	33.50	Timeball Hill Shale and Quartzite
MB20	27.40925	-26.44950	1541.87	Next to the eye (fountain)	30.00	Shales (weathered /fractured)
MB21	27.42008	-26.45717	1498.45	SE of Mponeng TSF, SE Mponeng RWD	30.00	Shales
MB22	27.42121	-26.45666	1497.81	SE of Mponeng TSF, SE Mponeng RWD	30.00	Shales and andesite lava
MB25	27.40665	-26.44800	1556.15	N of Mponeng TSF	100.00	Timeball Hill Shale and Quartzite
MB29	27.43672	-26.43869	1555.53	South of anti pollution dams at Mponeng Plant		-
MB32	27.41795	-26.45659	1507.50	S of S Mponeng RWD		-
MB33	27.41029	-26.45851	1524.70	South of South TSF below van Eeden dam		Borehole dry / blocked
MB34	27.40383	-26.45961	1535.43	South of South TSF below partition of 2 dams		Borehole dry / blocked
MB35	27.42000	-26.45030	1512.43	E of S s/dam next to soccer field	30.00	Timeball Hill Shale and Hekpoort andesite
MB39	27.39796	-26.43289	1705.33	On Gatsrand up from Wadela circle to Savuka	114.00	Timeball Hill Shale
MB50	27.43093	-26.43560	1563.83	South-west (down gradient) of Mponeng waste dump	35.00	Timeball Hill Shale and Quartzite
MB58	27.42236	-26.44803	1516.85	Downstream of Mponeng (south) sewage works		Borehole locked
MB62	27.41227	-26.45065	1534.33	Downstream Mponeng Solid Waste Site at TSF Compartment		-

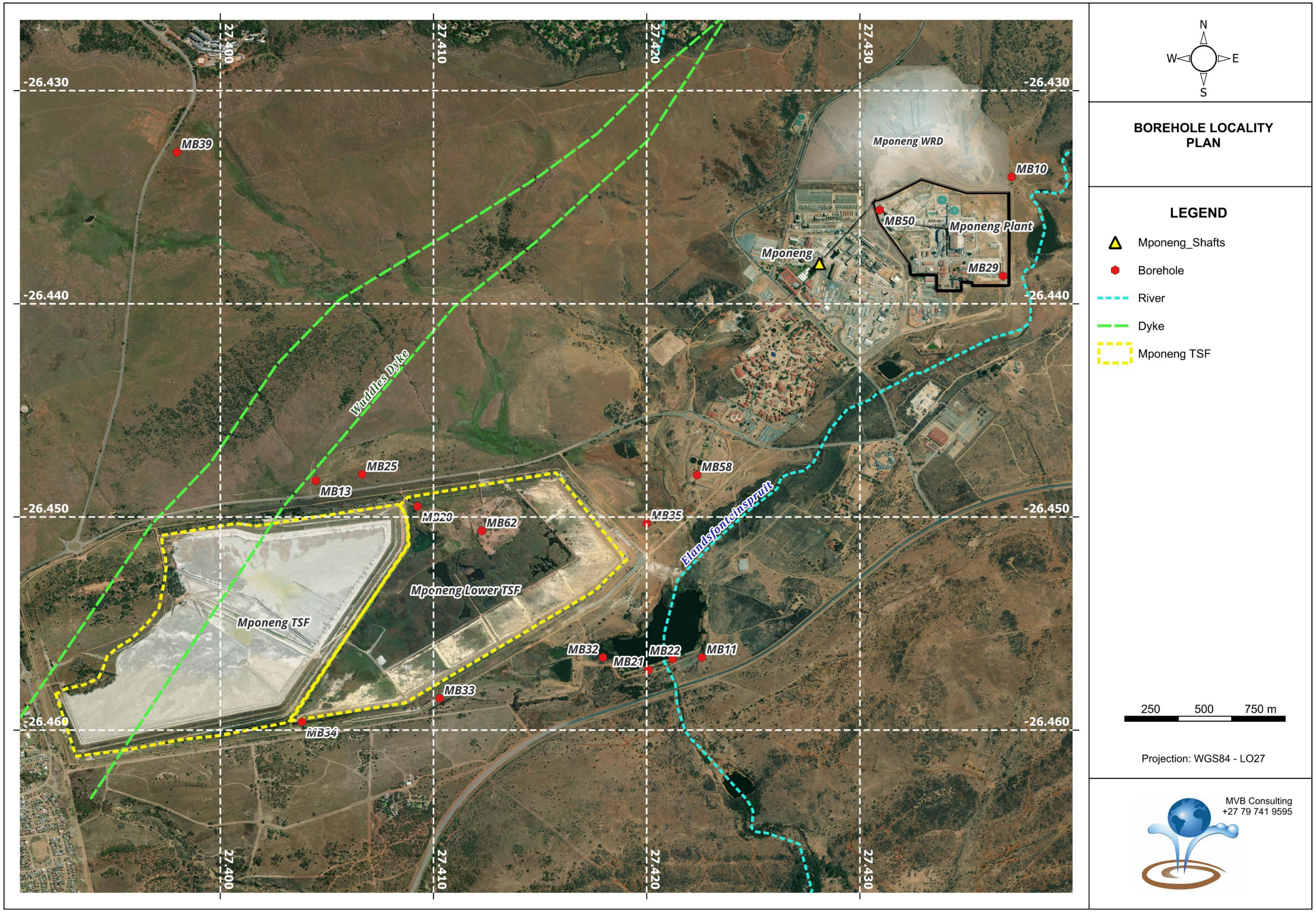

Figure 3.3: Available boreholes in the vicinity of the Mponeng TSF

3.2.2 Aquifer Type

Groundwater occurrences in the study area are predominantly restricted to the following types of terrains.

- Weathered and fractured rock aquifer in the Transvaal Formations.
- Dolomitic and Karst Aquifers.

Although the dolomite aquifer is the most prominent aquifer in the region, it does not play any role in the activities at the Mponeng Lower Compartment TSF. The Mponeng Lower Compartment TSF is predominantly located on the shale of the Timeball Hill formation. The dolomite is ±400m below surface at the Mponeng TSF site. Evidence has shown that there is no connectivity between the weathered / fractured aquifer and the underlying dolomite aquifer. Even in compartments where the dolomite aquifer is dewatered the groundwater levels in the weathered / fractured aquifer remains unaffected.

3.2.2.1. Weathered and Fractured Aquifer

Groundwater occurs in the near-surface geology in the weathered and fractured sedimentary deposits (quartzite and shale) of the Transvaal strata. The lava of the Hekpoort Formation has similar weathering characteristics to that of the shale and is therefore deemed as the same aquifer. These formations are not considered to contain economic and sustainable aquifers, but localised high yielding boreholes may, however, exist where significant fractures are intersected.

Groundwater occurrences are mainly restricted to the weathered formations, although fracturing in the underlying “fresh” bedrock may also contain water. Experience has shown that these open fractures seldom occur deeper than 60m. The base of the aquifer is the impermeable quartzite, shale and lava formations, whereas the top of the aquifer would be the surface topography. The groundwater table is affected by seasonal and atmospheric variations and generally mimics the topography. These aquifers are classified as semi-confined. The two aquifers (weathered and fractured) are mostly hydraulically connected, but confining layers such as clay and shale often separate the two. In the latter instance the fractured aquifer is classified as confined. The aquifer parameters, which includes transmissivity and storativity is generally low and groundwater movement through this aquifer is therefore also slow.

3.2.2.2. Dolomite Aquifer

Dolomite aquifers in the region are known to contain large quantities of groundwater and are commonly associated with sustainable groundwater abstraction. The water that plaques the underground mining is primarily derived from the dolomite aquifer overlying the workings.

The depth to groundwater in the region ranges from 4 m to 41 m below surface in the non-dewatered groundwater compartments (Zuurbekom and Boskop/Turffontein). This is in contrast to the groundwater levels in excess of 200 m in the dewatered compartments (Gemsbokfontein West, Venterspost, Bank and Oberholzer). The unsaturated zone in the dolomite aquifer ranges from weathered wad material and Karoo sediments within deep solution cavities or grykes (deeply weathered paleo-valley within the dolomite) to relatively fresh fractured dolomite between major solution cavities and at depth.

The shallow weathered dolomite aquifer has been formed because of the karstification which has taken place prior to the deposition of the Karoo sediments on top of the dolomites. There is general agreement that this aquifer is the significant source of water within the dolomite. The base of the weathered dolomite (aquifer) is irregular in nature and there are zones of deep weathering (grykes). The maximum depth to the base of this aquifer is in the order of 200 m below surface.

The non-weathered dolomite approximates a traditional fractured rock aquifer at depth where dissolution has been less pronounced. It is extremely unlikely that any significant groundwater flow occurs below these depths except along intersecting structural conduits to the underlying mine workings.

3.2.2.3. Relationship between the Weathered / Fractured Aquifer and the Dolomite Aquifer

Evidence has shown that there is no connectivity between the weathered / fractured aquifer and the underlying dolomite aquifer. Even in compartments where the dolomite aquifer is dewatered the groundwater levels in the weathered / fractured aquifer remains unaffected.

Figure 3.4 illustrates the relationship between the fractured and dolomite aquifers and also shows that the degree of karstification. Based on the exploration borehole information, it appears that the dolomite that that is covered by Transvaal strata is less karstified and the dolomite aquifer is therefore not as well developed. The mines situated south of the “Gatsrant” are generally dry mines with limited groundwater inflow, whereas the mines north of the “Gatsrant” is plagued by high groundwater inflow volumes. This is, in part, attributed to the well-defined karstification in the northern dolomites.

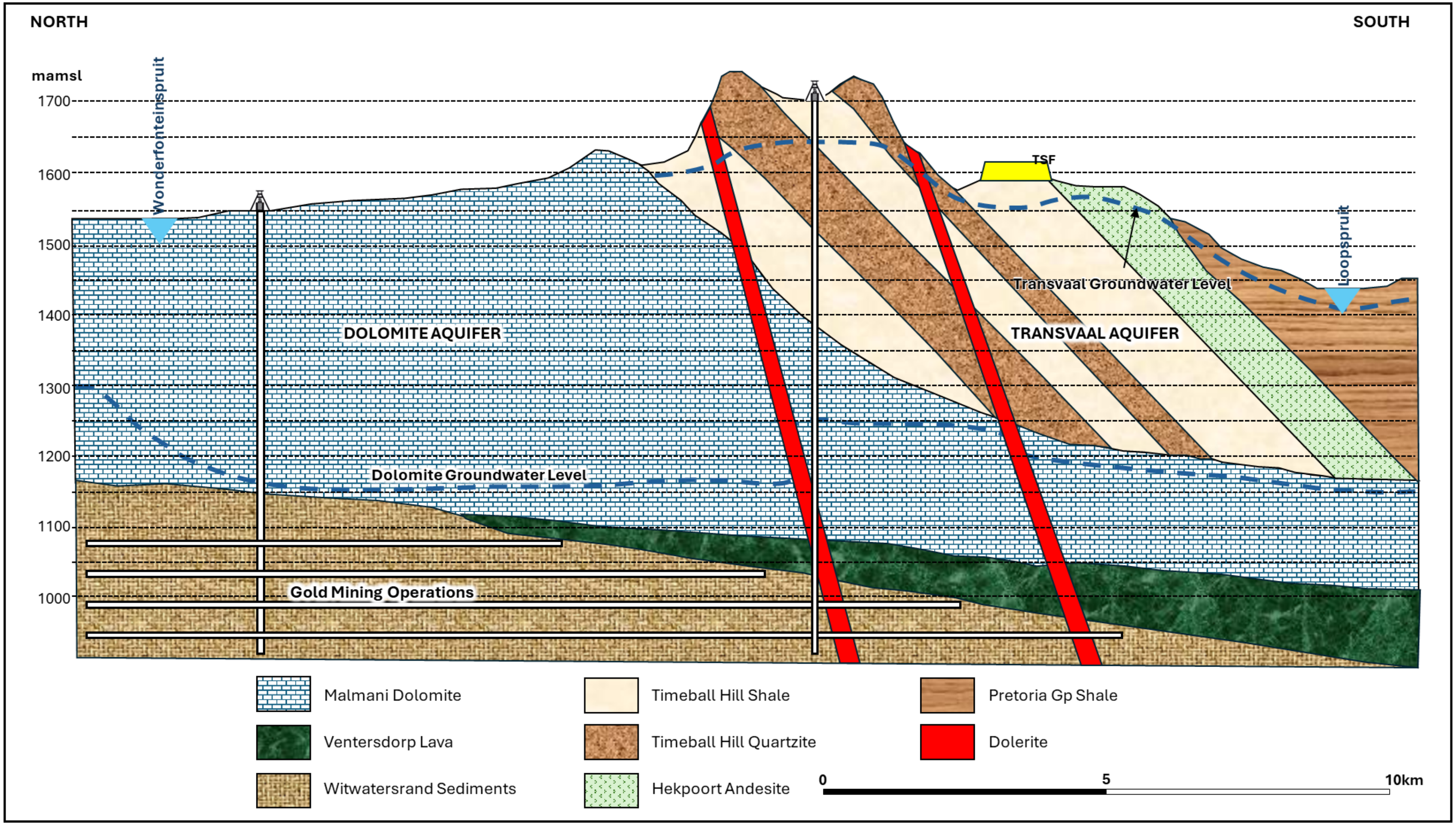

Figure 3.4: **Schematic geological section showing the relationship between the aquifers in the study area (Van Biljon, 2018)**

3.2.3 Aquifer Parameters

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.

Pump testing that was undertaken by GCS (2019) estimated the aquifer parameters in the weathered and fractured aquifer to be as follows (Table 3.2):

Table 3.2: Transmissivity and hydraulic conductivity values in the weathered and fractured aquifers (GCS, 2019)

ID	Blow Yield (litre/hour)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)		Aquifer
			Constant Discharge Test	Recovery Test	
MB10	23 000	-	12.9	6.08	Timeball Hill Shale and Quartzite
MB11	150	0.07	-	-	Shale
MB12	400	0.01	0.052	0.0303	Shale
MB13	1 190	0.7	0.1194	0.0363	Timeball Hill Shale and Quartzite
MB19	100	-	-	-	Shale
MB20	100 000	337	11.6	14.38	Shale (weathered / fractured)
MB21	1 600	2	-	-	Shale
MB22	3 600	13	0.5573	0.4645	Shale and andesitic lava
MB35	-	-	0.47	1.86	Timeball Hill Shale and Hekpoort Andesite
MB39	-	-	0.04	-	Timeball Hill Shale
MB50	Seepage	-	-	-	Timeball Hill Shale and Quartzite
MB51	Seepage	-	-	-	Timeball Hill Shale and Quartzite
MB58	3 000	-	-	-	Timeball Hill Shale and Quartzite

3.2.4 Aquifer Recharge

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

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

According to Vegter (1995) the recharge in the fractured aquifer is 31 mm / annum with water occurring in the shallow weathered zone and water bearing fractures only. This is equal to approximately 4% of mean annual precipitation. The average rainfall in the area is approximately 646 mm / annum. The average chloride in rainfall for areas inland is approximately 1.0 mg/L and the harmonic mean of the chloride concentration values in groundwater samples obtained from the mining area is 25.88 mg/L.

$$R = \frac{1}{25.88} \times 100 = 3.9\%$$

This value corresponds with Vegter's value.

3.2.5 Groundwater Gradients and Flow

The first important aspect when evaluating the geohydrological regime and groundwater flow mechanisms is the groundwater gradients. Groundwater gradients, taking into consideration fluid pressure, are used to determine the hydraulic head which is the driving force behind groundwater flow. The flow governs the migration of contaminants, and a detailed assessment of the flow was required to determine sub-surface flow directions from the TSF or any other potential contaminant source.

In most geological terrains, the groundwater mimics the topography and to test if this is the case within the study area the available groundwater levels were plotted against the topography (represented by the borehole collar elevations). The result of this assessment is presented in Figure 3.5. This graph indicates a very good correlation (99%) between the topography and the groundwater level, which suggests that groundwater flow will follow the topographical gradient.

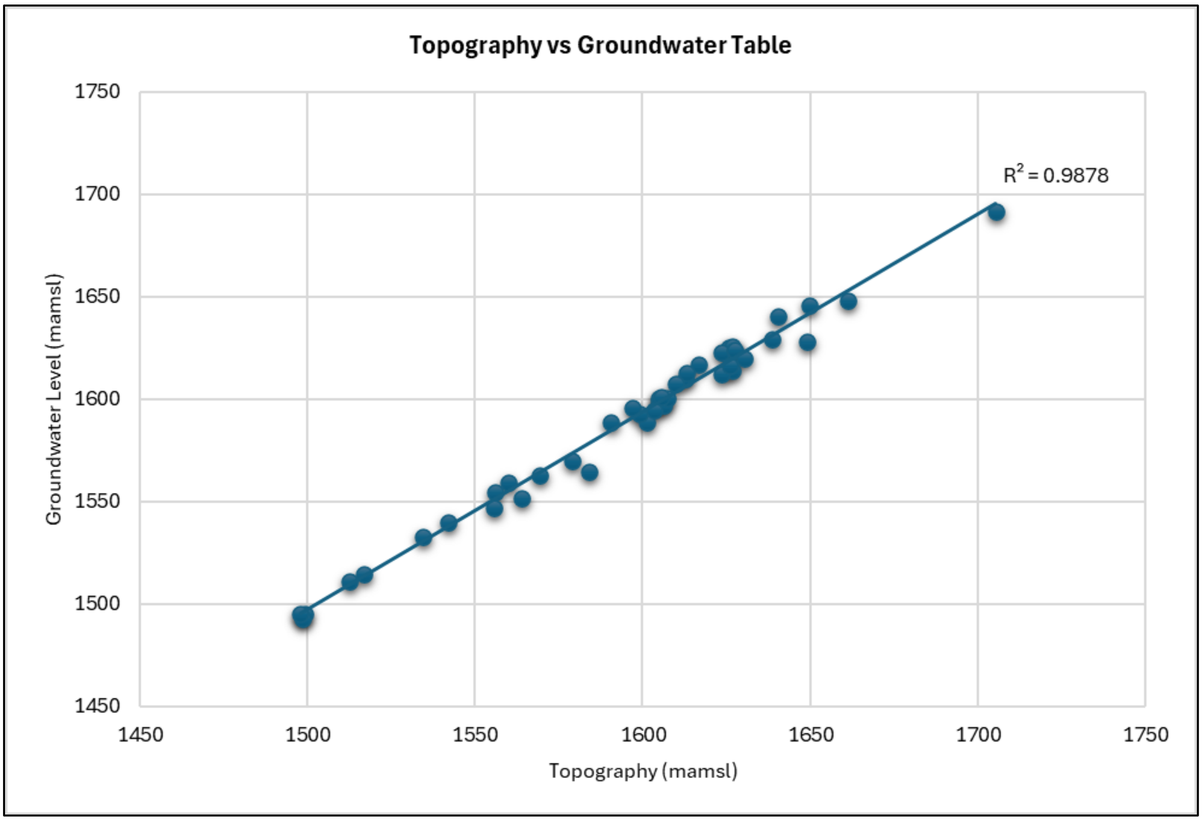

Figure 3.5: Correlation between topography and groundwater level

This relationship is known as the Bayesian relationship, and where this exists, the regional topography can be used to interpolate (Bayesian interpolation) a regional groundwater gradient map. Figure 3.6 depicts the groundwater level elevations, which as expected mimic the surface contours. Groundwater flow is perpendicular to the groundwater contours and flows predominantly towards the south-west.

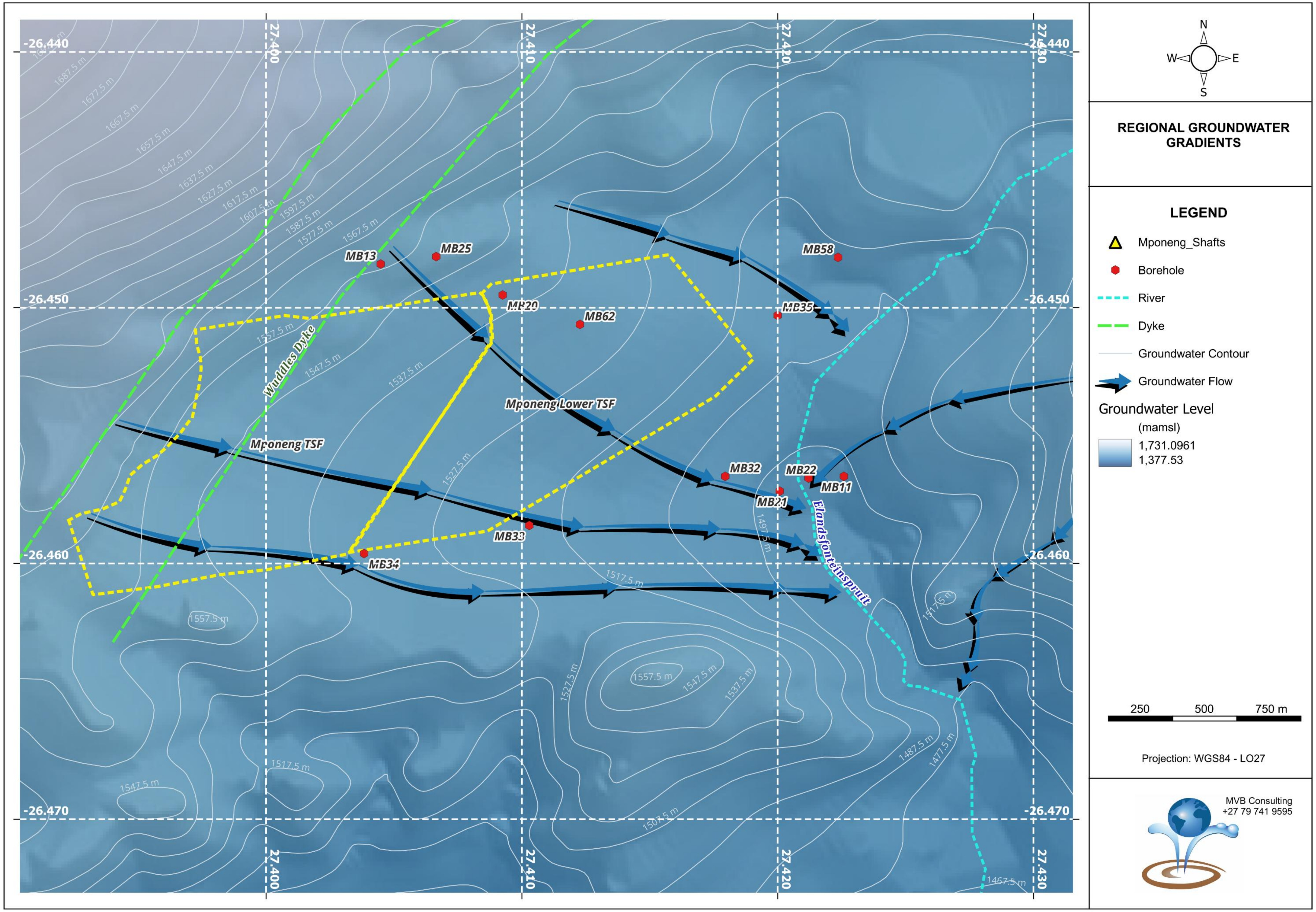

Figure 3.6: **Regional groundwater gradient**

3.2.6 Groundwater Quality

The mine routinely monitors the groundwater quality in the vicinity of the Mponeng Lower Compartment TSF. This data was made available and is used to assess the current impacts from the TSF.

Since there are no groundwater users within a 1km radius from the Mponeng Lower Compartment TSF, the groundwater chemistry is compared to the South African Water Quality Guidelines (second edition) Volume 5: Agricultural Use: Livestock Watering (Department of Water Affairs and Forestry, 1996), as well as the SANS 241 (2015). 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.

The guideline for livestock watering represents the target water quality specified in the guidelines. The target water quality guidelines were obtained from the *Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 5: Agricultural Use: Livestock Watering.* According to the guidelines (DWAF, 1996), the following constituents are of concern for livestock watering (Table 3.3).

Table 3.3: Livestock watering – chemicals of concern (DWAF, 1996)

Category A			
Water quality constituents that are potentially hazardous, with a high incidence of occurrence			
Constituent	**Target water quality (TWQR)**	**Constituent**	**Target water quality (TWQR)**
Salinity (TDS)	1000 mg/l	Calcium	1000 mg/l
Chloride	3000 mg/l	Fluoride	2 mg/l
Sulphate	1000 mg/l	Molybdenum	0.01 mg/l
Arsenic	1 mg/l	Magnesium	500 mg/l
Copper	5 mg/l	Nitrate and Nitrite	100 mg/l NO_3
Sodium	2000 mg/l	Toxic algae	-
Category B			
Water quality constituents that are potentially hazardous, with a low incidence of occurrence			
Constituent	**Target water quality (TWQR)**	**Constituent**	**Target water quality (TWQR)**
Cadmium	0.01 mg/l	Cobalt	1 mg/l
Chromium	-	Iron	10 mg/l
Mercury	1 µg/l	Nickel	5 mg/l
Lead	0.5 mg/l	Vanadium	1 mg/l
Zinc	20 mg/l	Manganese	10 mg/l
Selenium	50 µg/l	Pesticides	-
Boron	5 mg/l	Pathogens	200 counts/100ml Faecal Coliform
Aluminium	5 mg/l		

The chemistry of the groundwater is presented in Table 3.4. Where either of the guidelines are exceeded, the values are highlighted in pink.

With reference to Table 3.4, the following is observed:

- Monitoring boreholes MB29 and MB50 in the plant area show an impact. This is, however, not applicable to the current investigation.
- Monitoring boreholes MB32 and MB35 show an impact from the up-gradient Mponeng TSF. This is in line with the expected groundwater flow paths.
- The groundwater flow is towards the Return Water Dams (RWD), but borehole BH35 shows that the impacted water passes underneath the RWD. The impact is therefore expected to flow into the Aquatic Dam, or it will form part of the baseflow of the Elandsfonteinspruit. The relatively good water quality in the Aquatic Dam suggests that the impacted groundwater forms part of the baseflow of the stream.

The distribution of the sulphate (SO_4) concentrations provides an aerial view of the impact areas, which is as expected along the eastern and south-eastern boundary of the TSF (Figure 3.7).

Table 3.4: Groundwater chemistry

Analysis in mg/L (unless specified otherwise)	SANS 241	DWAF	MB39	MB10	MB29	MB32	MB50	MB11	MB13	MB62	MB20	MB21	MB22	MB25	MB35
Electrical Conductivity (mS/m)	170	-	2.4	4	219	313	228	118	2.2	7.7	1.5	109	98.5	2.1	435
Hardness Total			7	10	391	837	500	466	7	18	7	399	363	9.5	1434
pH	<5 - >9.7	-	6.5	6.6	5.7	6.6	5.7	7.7	6.3	6.8	6	7.2	6.9	5.8	4.8
Suspended Solids at 105°C	-	-	26	<25	94	<25	257	236	<25	408	358	260	220	1455	59
Total Dissolved Solids at 180°C	1 200	1 000	<100	<100	1 476	2 176	1 499	814	<100	<100	<100	760	682	165	2 971
Alkalinity Total	-	-	<30	<30	<30	57	<30	232	<30	<30	<30	190	156	<30	<30
Ammonia	1.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Calcium	-	1 000	<2.0	2.4	99	201	118	96	<2.0	2.6	<2.0	92	78	2.1	409
Chloride	300	1 500	<5	5	366	571	402	187	<5	12	<5	206	191	<5	814
Fluoride	1.5	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	<0.5
Magnesium	-	500	<2.0	<2.0	35	80	50	54	<2.0	2.7	<2.0	41	41	<2.0	99.6
Nitrate & Nitrite	11	100	0.8	1.6	11	7.6	54	1.7	1.1	1.7	<0.5	1.2	<0.5	0.9	<0.5
Orthophosphate	-	-	<0.05	<0.05	<0.05	0.1	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sodium	200	2 000	2.1	3.9	267	351	250	34	2.1	6.8	<2.0	37	32	2.2	396
Sulphate	500	1 000	<5.0	<5.0	468	775	334	94	<5.0	<5.0	<5.0	41	33	<5.0	1 261
Zinc	5	0.02	<0.10	<0.10	0.12	<0.10	0.19	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	1.1
Aluminium	0.3	5	<0.03	<0.03	0.04	<0.03	0.03	<0.03	<0.03	0.07	<0.03	<0.03	<0.03	<0.03	<0.03
Boron	2.4	5	<0.02	<0.02	0.08	0.05	0.04	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cadmium	0.003	0.01	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Copper	2	0.5	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cyanide Dissolved - CFA	0.2	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cyanide WAD - CFA	-	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Iron	2	10	0.05	<0.03	<0.03	0.03	<0.03	0.04	<0.03	0.09	3.5	0.7	4.5	<0.03	4.8
Lead	0.01	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese	0.4	10	<0.03	<0.03	1	0.22	0.2	0.23	0.18	0.04	0.26	1.6	2.4	0.091	4.2
Nickel	0.07	1	<0.03	<0.03	0.07	0.05	0.04	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	<0.03	0.14
Uranium	0.03	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

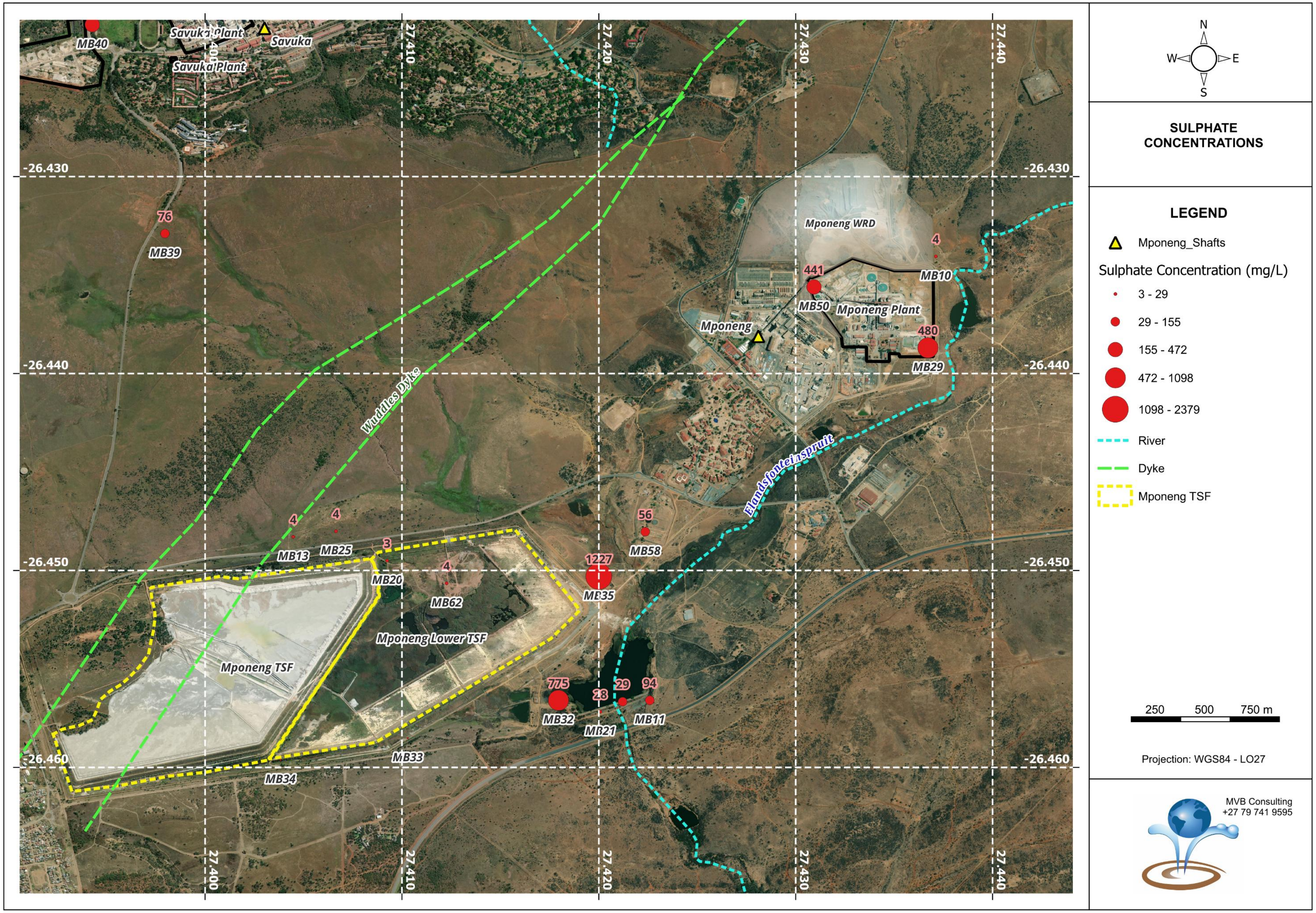

Figure 3.7: Sulphate concentrations in monitoring boreholes

3.2.7 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 3.5). A weighting and rating approach is then used to decide on the appropriate level of groundwater protection (Table 3.6).

Table 3.5: 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 3.6: Appropriate level of groundwater protection required

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

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

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

Description	Aquifer	Vulnerability	Rating	Protection
Weathered Aquifer	Minor (2)	1	2	Low
Fractured Aquifer	Minor (2)	1	2	Low

4. SUMMARY

Harmony currently deposits tailings onto the Savuka 5a, 5b, 7a & 7b TSFs, but these facilities are approaching their final and approved height, and the current planned LOM for the West Wits region exceeds the available deposition capacity of these TSFs., Harmony is therefore undertaking a feasibility assessment to recommence deposition on the Mponeng Lower Compartment TSF.

MVB Consulting was requested to undertake a hydrogeological assessment for the proposed recommencing of tailings deposition on the Mponeng Lower Compartment TSF.

The aim of the hydrogeological study is to assess the following:

- Assessment of the hydrogeological environment in terms of aquifer development, aquifer hydraulics, groundwater flow and groundwater chemistry.
- Assessment of the potential short and long-term impact from the Mponeng TSF on the groundwater environment.
- Recommended management measures to mitigate potential impacts.

This baseline report summarises the hydrogeological conceptual model, which is briefly described as follows:

4.1 Site Geology

The Mponeng TSF is predominantly located on the shale of the Timeball Hill formation. The Timeball Hill formation consist of 150 m – 200 m of pink to purple shale. The shale is overlain by quartzite, which forms the linear north-westerly trending ridges to the north of the TSF.

Further south is the Hekpoort and Strubenkop Formations. These formations consist predominantly of andesite lava (Hekpoort Formation) and ferruginous shale (Strubenskop Formation). The weathering of the shale and the lava results in grey to dark grey silty sand and clay.

The Malmani dolomite outcrops on surface to the north of the study area and dips underneath the Timeball Hill and Hekpoort Formations. The dolomite is an estimated depth of 400m below surface underneath the Mponeng Lower Compartment TSF.

4.2 Site Hydrogeology

Groundwater occurrences in the study area are predominantly restricted to the following types of terrains.

- Weathered and fractured rock aquifer in the Transvaal Formations.
- Dolomitic and Karst Aquifers.

Although the dolomite aquifer is the most prominent aquifer in the region, it does not play any role in the activities at the Mponeng Lower Compartment TSF. The dolomite is ±400m below surface at the Mponeng Lower Compartment TSF site. Evidence has shown that there is no connectivity between the weathered / fractured aquifer and the underlying dolomite aquifer. Even in compartments where the dolomite aquifer is dewatered the groundwater levels in the weathered / fractured aquifer remains unaffected.

Groundwater occurs in the near-surface geology in the weathered and fractured sedimentary deposits (quartzite and shale) of the Transvaal strata. The lava of the Hekpoort Formation has similar weathering characteristics to that of the shale and is therefore deemed as the same aquifer. These formations are not considered to contain economic and sustainable aquifers, but localised high yielding boreholes may, however, exist where significant fractures are intersected.

Groundwater recharge in the fractured aquifer is estimated at 31 mm / annum with water occurring in the shallow weathered zone and water bearing fractures only. This is equal to approximately 4% of mean annual precipitation. The average rainfall in the area is approximately 646 mm / annum.

In most geological terrains, the groundwater mimics the topography and at the Mponeng Lower Compartment TSF there is a good correlation between the topography and the groundwater level, which suggests that groundwater flow will follow the topographical gradient. The groundwater flow from the Mponeng Lower Compartment TSF is to the south-east, towards the Elandsfonteinspruit.

There are no private groundwater users in the vicinity of the Mponeng Lower Compartment TSF, but the mine routinely monitors the groundwater quality in the vicinity of the TSF. This data was made available and is used to assess the current impacts from the TSF.

The groundwater quality at the TSF can be summarised as follows:

- Monitoring boreholes MB32 and MB35 show an impact from the up-gradient Mponeng TSF. This is in line with the expected groundwater flow paths.
- The groundwater flow is towards the Return Water Dams (RWD), but borehole BH35 shows that the impacted water passes underneath the RWD. The impact is therefore expected to flow into the Aquatic Dam, or it will form part of the baseflow of the Elandsfonteinspruit. The relatively good water quality in the Aquatic Dam suggests that the impacted groundwater forms part of the baseflow of the stream.

4.3 Impact Assessment

As indicated above, the TSF is possibly impacting on the baseflow of the Elandsfonteinspruit. This stream is the only down-gradient receptor that may be directly impacted on by the current and proposed tailings deposition. The hydrogeological study aims to quantify that impact and to assess suitable management and remedial options. The following phase of the investigation will be the development of a numerical groundwater flow and mass transport model. The groundwater model, once calibrated, will be used to simulate contaminant migration and the effectiveness of recommended management options. The latter includes, but not restricted to, the following:

- Lining of the proposed tailings facility.
- Cut-off trench on the down-gradient side of the TSF.
- Scavenger boreholes to intercept and contain the contaminant plume.
- Phyto-remediation.

The most suitable remedial option may be one, or a combination of the above options. It is expected that a liner such as the inverted barrier system will be suitable to prevent contaminant impact the groundwater. There is, however, a cumulative impact from the existing TSF and the aim of the numerical modelling is to quantify the benefit of installing a liner.

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