WSM LESHIKA
CONSULTING (PTY) LTD

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Specialist Groundwater Report

For Phalaborwa Filling Station extention,

Limpopo Province

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HYDROGEOLOGY REPORT

04

GROUNDWATER SPECIALIST REPORT FOR PHALABORWA FILLING STATION EXTENTION, LIMPOPO PROVINCE

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ABSTRACT

WSM Leshika Consulting (Pty) Ltd, a firm of independent consulting engineers, engineering geologists and hydrogeologists was appointed by Ms Louise Agenbag of Polygon Environmental Planning (Pty) Ltd., a firm of environmental practitioners. The investigation is related to a Basic Environmental Assessment for the proposed expansion of an existing filling station in Coster Street Phalaborwa. The project is to prepare a basic assessment of the geohydrological components of an Environmental Authorisation.

The property owners are proposing to extend the proposed filling station on currently vacant land. The filling station currently stores 35 000 of fuel, which will be increased to 150 000 litres.

The filling station is situated on erf 1861 Phalaborwa a portion of the farm Laaste 24 LU. The filling station property is 0.23 ha in extent and is located at 23.9499 S, 31.1290 E in Ba-Phalaborwa Local Municipality.

The site is under lain by rocks of the **Makhutswi Gneiss (Zm)** (3268 Ma). The aquifer is fractured and weathered. The median yield is below 0.1 l/s and only 21% yield more than 1 l/s. The depth of weathering is less than 40 m in 90% of boreholes. Weathering and fracturing extend deeper than 55 m in only 6% of boreholes. 61% of boreholes have weathered zones of less than 20 m thickness. 81% have a combined weathered and fractured thickness of less than 40 m. In 68% of the cases water will be intercepted within the first 30m. Water occurs also in fault zones and to a lesser extent along dyke contacts. Few boreholes strike water below 40 m. Recharge is given as 9 mm/a in GRAII. Groundwater baseflow is 0 mm/a, and recharge is largely lost by evapotranspiration from shallow groundwater.

A hydrocensus within 1 km of the site found 4 boreholes. All the boreholes are across the catchment watershed. None of the boreholes are currently in use. One borehole has a yield of <0.05 l/s. Water levels at the catchment divide appear to be 0.7-1.2 mbgl. Water levels are expected to mirror the topography and groundwater flow is expected to be to the SW. Water quality is of Class 2, or Marginal due to sodium and chloride according to The Water Affairs Guidelines for Domestic Water Quality.

The site lies in the Lowveld Groundwater Region. The low yield results in the aquifer being classified as a Poor aquifer, or a **minor aquifer system.** The vulnerability of the aquifer can be considered moderate according to the DRASTIC system.

The USGS MODFLOW2000 Finite Difference groundwater model was utilised to simulate and plot groundwater flow. Groundwater flow is oriented to the SW. Water levels at the site are approximately 434-435 mamsl and flow is oriented to the SW. Groundwater levels are about 1-2 m below surface.

The extent of the contamination plume emanating from the upgraded filling station assuming a continuous spill of 1000 l/d with natural attenuation was simulated with RT3D.

Within 20 years the plume migrates 167 m, just beyond the industrial area but does not reach water courses or residential areas.

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LIST OF ABBREVIATIONS

Abbreviation or Acronym	Definition
EIA	Environmental impact assessment
DNAPL	Dense Non-Aqueous Phase Liquid (solvents, greases etc
DWS	Department of Water and Sanitation
GRAII	Groundwater resources assessment phase II
IWUL	Integrated Water Use Licence
LNAPL	Light Non-Aqueous Phase Liquid (petrol, diesel etc)
mamsl	Metres above mean sea level
mbgl	Metres below ground level
MODFLOW	Modular groundwater flow numerical model
MAP	Mean annual rainfall
NEMA	National Environmental Management Act
NGA	National groundwater archive
TPH	Total Petroleum Hydrocarbons
UST	Underground storage tanks
WR2012	Water resources south Africa 2012

LIST OF DEFINITIONS

Aquifer hydraulic properties	The properties of permeability and specific yield, or transmissivity and storativity that determine the rate at which an aquifer transmits water, and the volume of water it releases from storage
Baseflow	The contribution of subsurface water to surface water channels to maintain dry season flows
Blow Yield	The maximum rate at which water is blown from a borehole by an air compressor after drilling. Commonly assumed to be the maximum inflow rate into that borehole
Groundwater baseflow	The contribution to baseflow from the regional aquifer
Interflow	The contribution of subsurface water to surface water courses as baseflow before entering the regional aquifer
Cone of depression	The area affected by the abstraction of groundwater in terms of a drop in water level from the rest water level
Drawdown	The depth to which the groundwater level is drawn down below the original water level in response to abstraction
Harvest Potential	the maximum volume of ground water that may be abstracted per area without depleting the aquifers. It is based on estimated mean annual recharge and a rainfall reliability factor, which gives an indication of the possible drought length.
Permeability	The rate at which a permeable material transmits a fluid, expressed as a length per unit time
Recharge	Rate of ingress or replenishment of water into an aquifer expressed as a volume or depth per unit of time
Residual drawdown	Drawdown remaining after abstraction stops relative to a static or natural water level

GROUNDWATER SPECIALIST REPORT FOR PHALABORWA FILLING STATION AND FUEL DEPOT LIMPOPO PROVINCE

1. INTRODUCTION AND TERMS OF REFERENCE

1.1. Terms of Reference

WSM Leshika Consulting (Pty) Ltd, a firm of independent consulting engineers, engineering geologists and hydrogeologists was appointed by Ms Louise Agenbag of Polygon Environmental Planning (Pty) Ltd., a firm of environmental practitioners. The investigation is related to a Basic Environmental Assessment for the proposed expansion of an existing filling station in Coster Street Phalaborwa.

1.2. Objective

The project is to prepare a basic assessment of the geohydrological components of an Environmental Authorisation including:

- Description of the geohydrological environment.
- Prediction of the environmental impacts of the proposed activity on the geohydrological regime of the area.
- Mitigation measures based on physical, hydraulic, and hydro-geochemical information as gathered and predicted in the preceding phase.

1.3. Scope of Work

The geohydrological assessment is to consist of:

- Site inspection for the mapping of relevant geohydrological features,
- Data collection of existing information from topographical maps, ortho-photos, geological maps, hydrological information, meteorological information,
- Borehole/spring census of the property to assess groundwater utilisation,
- Evaluation of groundwater harvest potential (quality & quantity) relative to groundwater demand and property size,
- Groundwater flow modelling to predict the long-term impacts on the receiving environment,
- Assessment of the possible environmental impacts and to conceptualise mitigation measures,
- Recommendation for groundwater monitoring.

1.4. Background

The property owners are proposing to extend the proposed filling station on currently vacant land. The filling station currently stores 35 000 of fuel, which will be increased to 150 000 litres.

The property for the filling station is 0.23 ha in extent. The property is located on erf 1861 Phalaborwa, a portion of the farm Laaste 24 LU.

As a requirement for the environmental authorizations for the project, a Geohydrological Specialist Report is required to undertake an assessment of the baseline geohydrology of the proposed development site and the surrounding region. The aim of the assessment is to ascertain and characterise the geohydrological setting of the site and the geohydrological risk posed by the proposed filling station development on the receiving environment. These provisos fall under the National Environmental Management Act (Act No. 107 of 1998, NEMA).

1.5. Description of the development

The filling station is a currently operating small station (figure 1-1).

The site is shown in figure 1-2.

The surrounding properties are industrial (figure 1-4).

1.6. Applicable Legislation

This investigation is to address issues related to a Basic Assessment Report in terms of the Environmental Impact Assessment Regulations, 2014, promulgated in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), as amended.

Environmental authorisation of the development is required prior to commencement, since the development proposal triggers an activity listed in the EIA Regulations.

The activity that will be triggered is Listing Notice Number 1, Activity No. 14 of Government Notice No. R983 of 2014:

The development of facilities or infrastructure for the storage, or storage and handling, of a dangerous good, where such storage occurs in containers with a combined capacity of 80 but not exceeding 500 cubic meters.

1.7. Water Use

The site is serviced by municipal water

Figure 1-1 Existing filling station.

Figure 1-2 Entrance to filling station

Figure 1-3 Surrounding land use around the proposed development

2. INVESTIGSTION METHODOLOGY

The following key steps make up the phased approach of the investigation:

i. Desktop Investigation;

ii. Site and data assessment;

iii. Groundwater modelling;

iv. Preliminary Risk Assessment;

The methodology employed included a desktop review and assessment of the geology and geohydrology of the site and surrounding region, a review of existing water uses in the area, an assessment of the water quality status quo and a determination of the vulnerability and strategic value of the local aquifer.

The methodology followed consisted of:

- A site inspection for the mapping of relevant geohydrological features such as water users and receiving water bodies;
- The collection of existing information from: topographical maps, satellite imagery and geological maps;
- The collection of: Harvest Potential, recharge and baseflow data from the GRAII data base (Groundwater Resources Assessment II), meteorological information from WR2012 (Water Resources of South Africa 2012), borehole data from the NGA;
- A borehole/spring hydrocensus of the property area to assess groundwater utilisation and borehole water levels;
- The evaluation of groundwater potential (quality & quantity);
- Borehole drilling to establish depth to groundwater at the site
- Groundwater quality sampling for water quality analysis of major inorganics and Total petroleum hydrocarbons
- Groundwater flow and transport modelling utilising the MODFLOW and MODPATH groundwater models to determine the groundwater balance, the piezometric surface and flow orientation, and to predict the potential area of impact;
- An assessment of the possible environmental impacts;
- A conceptualisation of mitigation measures for the identified impacts;
- Formulating recommendations for a groundwater monitoring network.

3. SITE DESCRIPTION

3.1. Locality

The filling station is situated on erf 1861 Phalaborwa, a portion of the farm Laaste 24 LU. The filling station property is 0.23 ha in extent. The site co-ordinates are -23.9499 S, 31.1290 E (figure 3-1) in Ba-Phalaborwa. Local Municipality. It is accessed from Coster Street, in the Industrial southwestern part of Phalaborwa.

3.2. Topography

The site is located on a watershed between SW, NW and Easterly drainage. The regional gradient is to the southeast, which is the is the flow direction of the Ga-Selati river. The site sits on level ground sloping very gently to the WSW towards a tributary of the Ga-Selati river.

The site has a slight slope of 3 degrees, and lies between 438-439 mamsl, with the lowest point being the SW corner (figure 3-2).

Figure 3-3 shows a view from the SW towards the NE, with the ground surface falling away to the SW.

3.3. Climate

The climate is classified as Dry (B) under the Koeppen-Geiger classification. It falls under class Bsh, which is a Hot semiarid climate.

The mean annual rainfall for Phalaborwa is 530 mm/a. The Mean Annual S-pan evaporation is 1650 mm/a. December and January are the wettest months (figure 3-4).

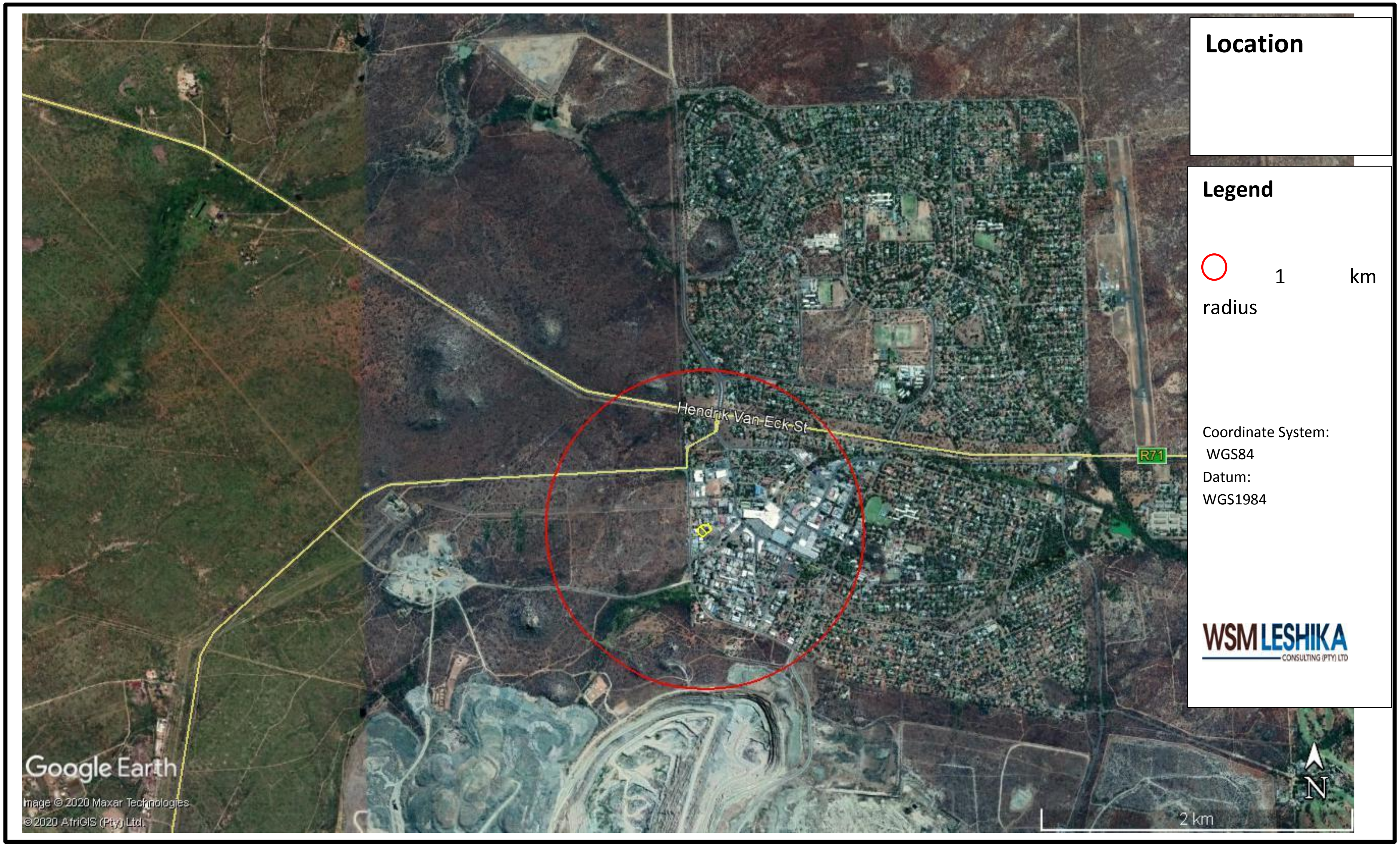

Figure 3-1 Locality

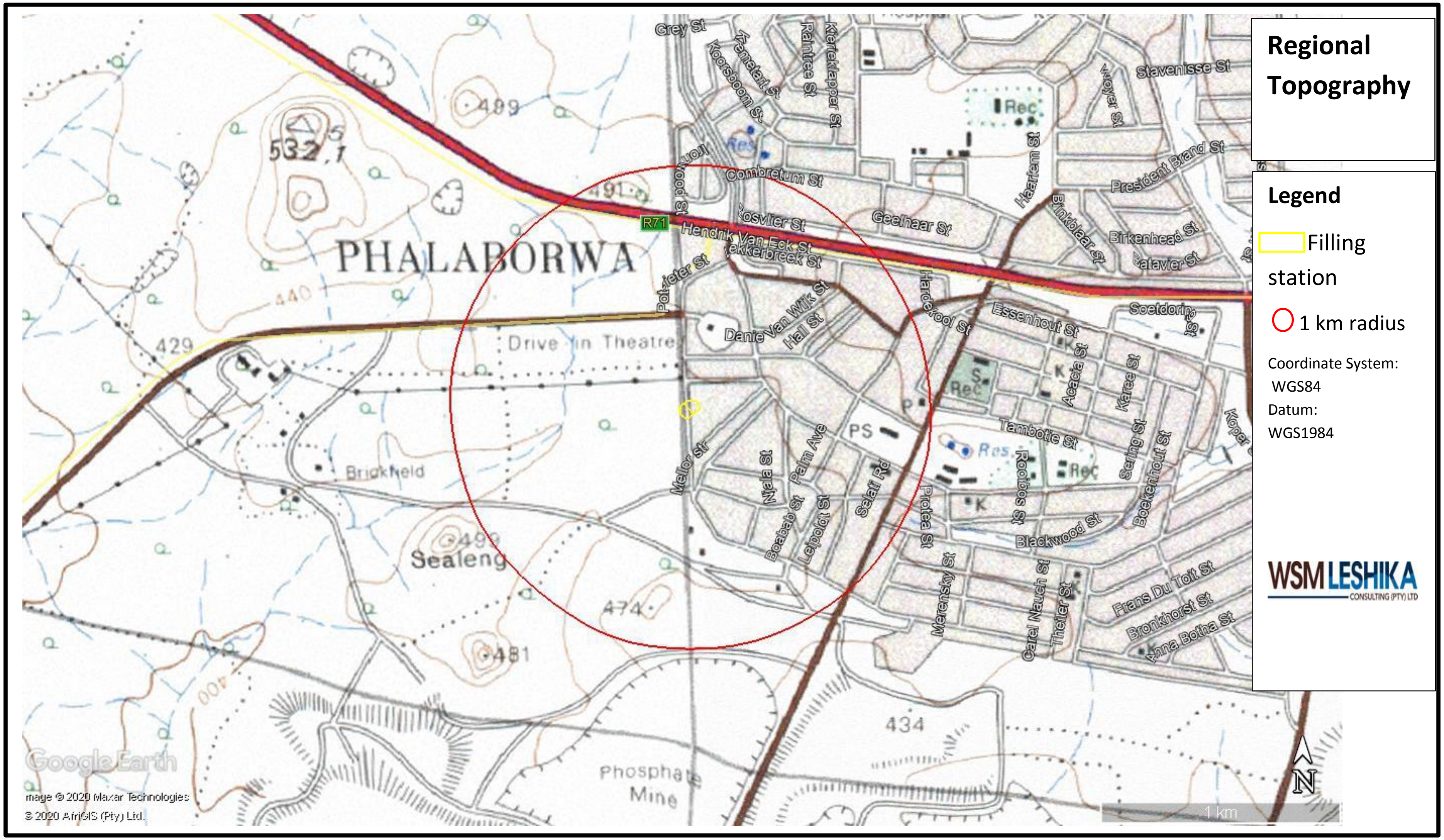

Figure 3-2 Site locality and topography

Figure 3-3 View from the SW to NE (x3 Vertical exaggeration)

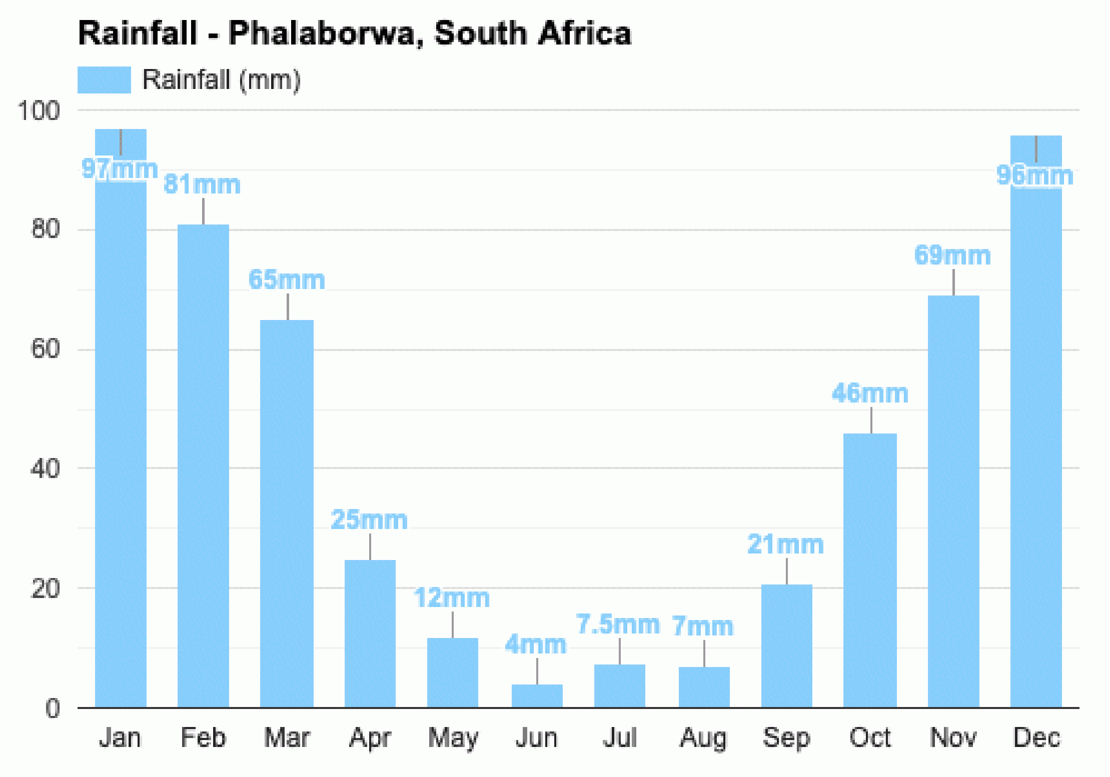

Figure 3-4 Mean monthly rainfall and evaporation

Average temperatures are warm throughout the year (figure 3-5).

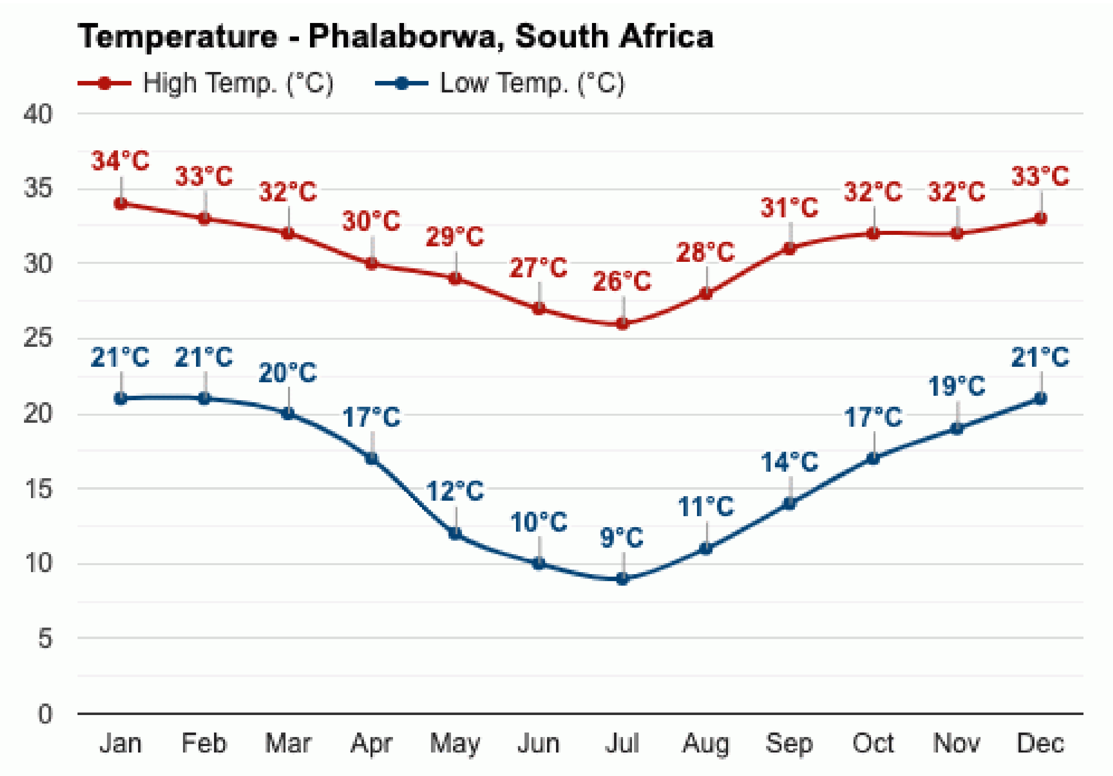

Figure 3-5 Average temperature

3.4. Drainage

The development lies in the SE corner of Quaternary catchment B72K (figure 3-6), which is 967 km^2 in size and drains south-eastwards. The catchment forms part of the Ga-Selati River System catchment, which is part of the Olifants River system.

The natural Mean Annual Runoff of the catchment is 7.9 million m^3/a (8.1 mm/a).

3.5. Soils and Vegetation

The site is classified as Phalaborwa-Timbavati Mopaneveld of the Mopane Bioregion according to the SANBI 2014 Landcover map.

The soils are classified as Loamy ands to sandy loams with a depth of over 450-850 mm.

3.6. Geology

3.6.1. *Lithology*

The geology is shown in figure 3-7.

The site is under lain by rocks of the **Makhutswi Gneiss (Zm)** (3268 Ma). The lithology consists of Biotite Gneiss and is characterized by its homogeneity although xenoliths of schist, amphibolite and banded ironstone do occur in the gneiss. (Schutte, 1986).

The **Phalaborwa Complex (Mps, Mpp and Mpa)** comprises syenite (Mps), pyroxenite, glimmerite, fenite (Mpp), and pegmatoid (Mps). The outcrop south of Phalaborwa expresses itself on the surface primarily as Loole Kop. In 1934 the first modern mining started with the extraction of apatite from this deposit. The very large low-grade copper sulphide ore body is now one of the largest open pit copper mines of the world. The open pit is 450 m deep and measures nearly 2 km in diameter.

3.7. Structure

Faults, and dykes are depicted in Figure 3-7. The structural history is extremely complex as they covered a time span of almost 1 000 Ma and is reflected by the variety of trends of these features. Visible in the vicinity is a NE-SW trend.

The prominent northeast-southwest oriented faults are considered to have played an important role in the intrusion history of the Phalaborwa Complex. It acted as channels for the movement of magma as well as terminators of moving blocks of crust and overlying strata.

A NE trending fault exists within 1 km north of the site.

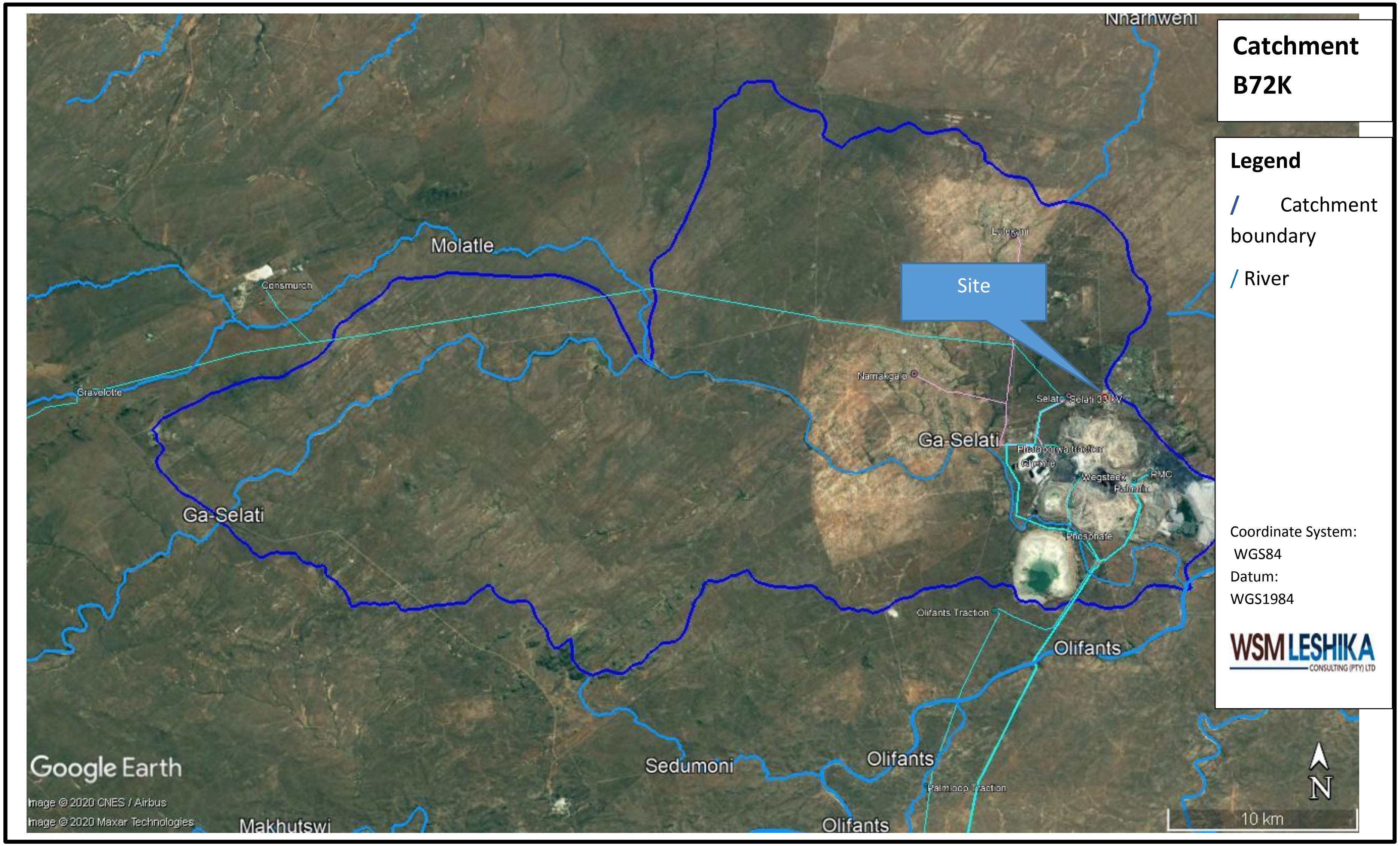

Figure 3-6 Drainage and Quaternary catchment

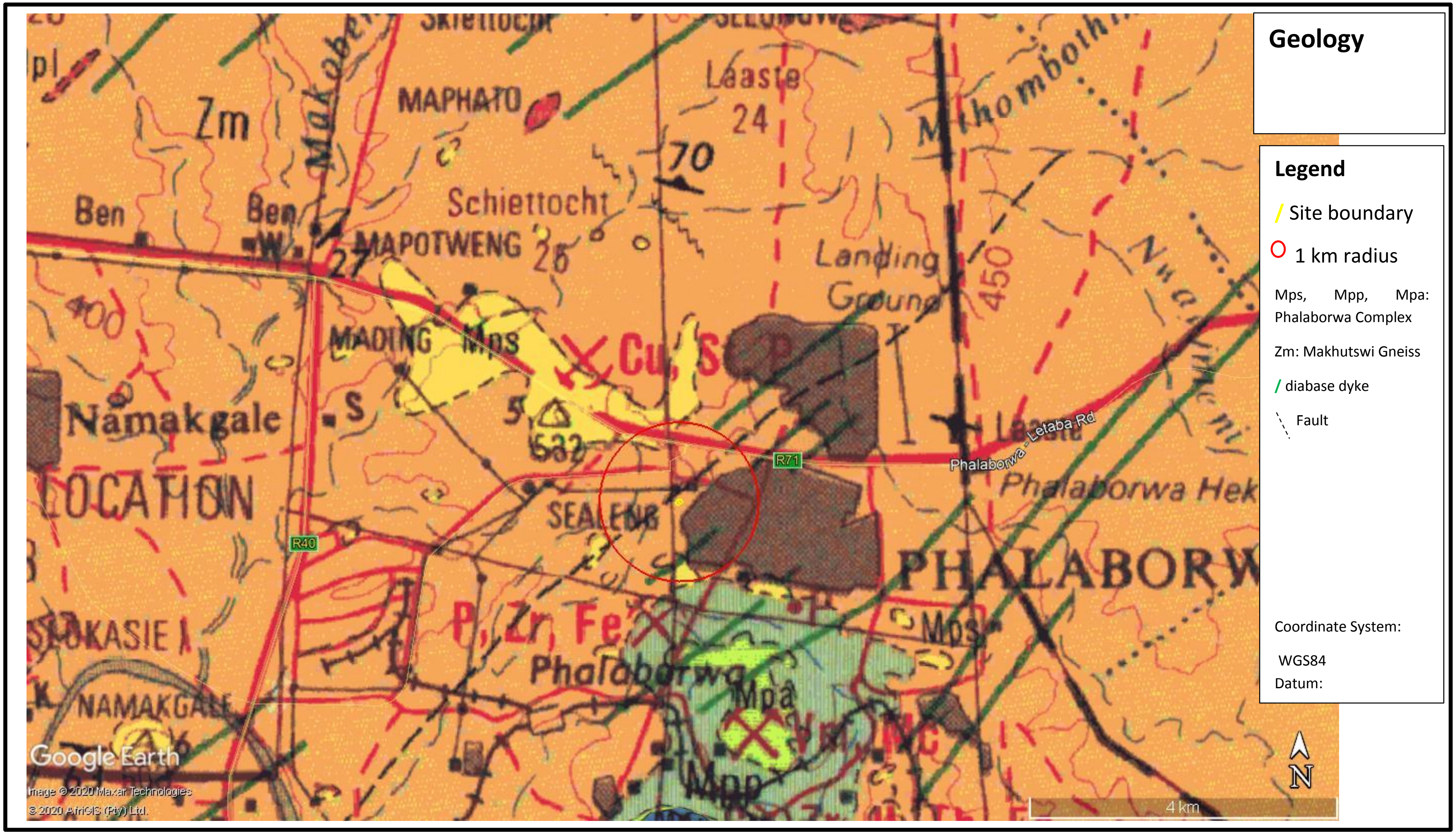

Figure 3-7 Geological map

4. THE HYDROGEOLOGY

4.1. Regional Hydrogeology

The area lies in the Lowveld Groundwater region. The aquifer is fractured and weathered. In terms of groundwater occurrence, basins of weathering and fractured zones at depth yield the best results.

Vegter (2003), lists the following yield statistics for gneisses and granites of the Lowveld Groundwater region (table 4-1).

Table 4-1 Yield distribution

Yield $\ell\,s^{-1}$	Number of holes	Percentage of holes	Percentage of successful holes
0 – 0.099	1631	53.0	
0.1 – 0.99	793	25.8	54.8
1.0 – 4.99	548	17.8	37.9
5.0 – 9.99	73	2.4	5.0
≥ 10	32	1.0	2.2
Total	3077	100	100

The median yield is below 0.1 l/s and only 21% yield more than 1 l/s.

Some of the high yielding boreholes in the Makhutswi Gneiss appear to be related to the occurrence of pegmatites in the area.

The depth of weathering is less than 40 m in 90% of boreholes. Weathering and fracturing extend deeper than 55 m in only 6% of boreholes. 61% of boreholes have weathered zones of less than 20 m thickness. 81% have a combined weathered and fractured thickness of less than 40 m.

In 68% of the cases water will be intercepted within the first 30m. Water occurs also in fault zones and to a lesser extent along dyke contacts. Current stress fields play an important role in the success rate of boreholes drilled along these structures.

Few boreholes strike water below 40 m (able 4-2). The yield distribution is independent of depth, suggesting a similar permeability for the weathered and fracture zones (figure 4-1).

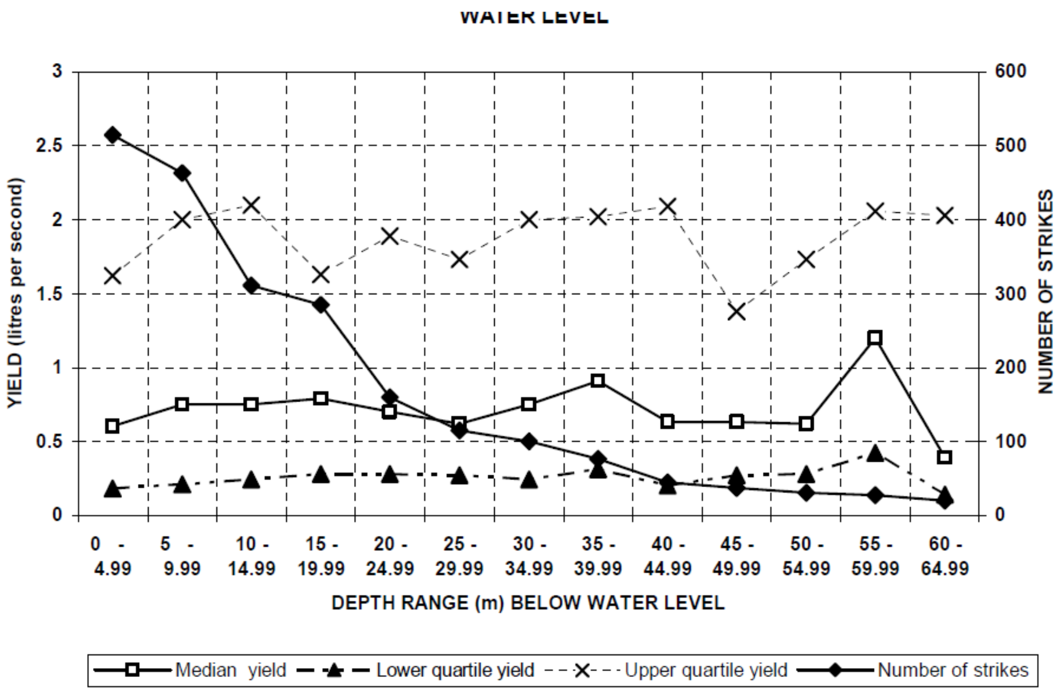

Figure 4-1 Yield vs depth of water strike

Groundwater in the Makhutswi Gneiss is of sodium–magnesium–bicarbonate–chloride character. The average nitrate and sodium values exceed the maximum allowable limit for domestic use.

Groundwater levels in this area almost invariably mimic the surface topography, with groundwater divides commonly coinciding with surface water divides.

The stagnant groundwater chemistry type, and the broadly flat terrain suggests that very little lateral groundwater movement occurs in these flat-lying areas. Structural features are usually the preferential pathways for water movement where they act as conduits rather than to contribute to storage.

Storage in the rock matrix is in micro pores and fractures.

4.2. Recharge and baseflow

Recharge for the catchment B72K is given as 9 mm/a in GRAII. Due to sandy soils and flat topography, most of this recharge percolates to the aquifer and only 0.06 mm/a is lost as interflow that emerges as seeps from saturated soil.

Groundwater baseflow is 0 mm/a, and recharge is largely lost by evapotranspiration from shallow groundwater.

4.3. Harvest Potential

Harvest Potential is defined as the maximum volume of ground water that may be abstracted per area without depleting the aquifers. It is based on estimated mean annual recharge and a rainfall reliability factor, which gives an indication of the possible drought length. The Harvest

Potential represents a synthesis of the amount of groundwater in storage in an aquifer system, the recharge, and the time span between these recharge events.

Exploitation Potential represents the portion of the Harvest Potential than can be economically exploited based on the limitations of borehole yield.

The harvest potential of the catchment is 12 mm/a, and 2760 for the filling station property. This is 8 m^3/d. The exploitation potential is 5 a m^3/a for the property. (table 4-2).

Table 4-2 Harvest and Exploitation Potential in m^3

	Filling station	
	Daily	Annual
Recharge	6	2047
Harvest Potential	8	2760
Exploitation Potential	5	1932
General Authorisation	3	1035

The volume of water that can be abstracted under the General Authorisation is 1035 m^3/a for the filling station, hence all abstraction above this volume must be licenced if it does not fall under a Schedule 1 domestic water use.

GRAII lists <1 mm/a of groundwater use, including livestock water use and rural water use. Groundwater use is well below harvest potential and recharge, with only 10% of recharge being abstracted (stress index =0.1).

4.4. Hydrocensus

A hydrocensus within 1 km of the site found the boreholes listed in table 4-3. The location of the boreholes is shown in figure 4-2. All the boreholes are across the catchment watershed.

None of the boreholes are currently in use.

Borehole H13-0756 has a yield of <0.05 l/s.

4.5. Groundwater levels and flow direction

Water levels at the catchment divide appear to be 0.7-1.2 mbgl.

No water level data exists to draw a piezometric map, however, given the relatively flat terrain, water levels are expected to mirror the topography and groundwater flow is expected to be to the SW.

4.6. Water Quality

Ground water quality was collected from borehole H13-0732. Table 4-4 shows the water quality results for macro constituents. Water quality is of Class 2, or Marginal due to sodium and chloride according to The Water Affairs Guidelines for Domestic Water Quality.

Table 4-3 Hydrocensus

BH No	COORDINATES		BH DEPTH (mbgl)	WATER LEVEL SWL (mbgl) 08/05/2020	EQUIPMENT	SAMPLED	ABSTRACTION/USE/NOTES	ELEVATION (m) Google Earth	CONTACT PERSON
	Latitude	Longitude							
H13-0495	-23.947030	31.134430	150	11.9	None	No	Not in use, not equipped, CLASS III from GRIP data	442	Bus Stop Clinic GRIP Borehole
H13-0496	-23.946810	31.134220	117.83	0.7	None	No	Not in use, not equipped, CLASS II from GRIP data	442	Bus Stop Clinic GRIP Borehole
H13-0732	-23.947110	31.134340	100.76	1.7	None	Yes	Not in use, not equipped, CLASS II from GRIP data, Sampled as background reference	442	Bus Stop Clinic GRIP Borehole
H13-0756	-23.946880	31.134210	100.52	Sealed	None	No	Not in use, not equipped, Tested 0.04 l/s yield, CLASS II from GRIP data	442	Bus Stop Clinic GRIP Borehole

Figure 4-2 Hydrocensus boreholes

Table 4-4 Water quality

ANALYSES	UNIT	H13-0732 08/05/2020	CLASSIFICATION				
			Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
PHYSICAL AND AGGREGATE PROPERTIES							
pH		8.7	5.0 - 9.5	4.5-5 or 9.5-10	4-4.5 or 10-10.5	3-4 or 10.5-11	< 3 or > 11
Conductivity	mS/m	165.9	< 70	70 - 150	150 - 370	370 - 520	> 520
TDS	mg/l	1078	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
ALKALINITY							
Bicarbonate alkalinity	CaCO3	302.5					
Carbonate alkalinity	CaCO3	31.70					
HARDNESS							
Total Hardness	CaCO3	157.87	< 200	200 - 300	300 - 600	> 600	
Ca - Hardness	CaCO3	14.70					
Mg - Hardness	CaCO3	14.17					
METALS							
Aluminium as Al	mg/l	<0.01					
Arsenic as As	mg/l	<0.03	< 0.01	0.01 - 0.05	0.05 - 0.2	0.2 - 2	> 2
Calcium as Ca	mg/l	5.88	< 80	80 - 150	150 - 300	> 300	
Copper as Cu	mg/l	<0.01	< 1	1 - 1.3	1.3 - 2	2 - 15	> 15
Iron as Fe	mg/l	0.02	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10
Magnesium as Mg	mg/l	34.92	< 70	70 - 100	100 - 200	200 - 400	> 400

Manganese as Mn	mg/l	0.04	< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Potassium as K	mg/l	4.52	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium as Na	mg/l	307.28	< 100	100 - 200	200 - 400	400 - 1000	> 1000
INORGANIC NON-METALLIC CONSTITUENTS							
Chloride as Cl	mg/l	356.6	< 100	100 - 200	200 - 600	600 - 1200	> 1200
Fluoride as F	mg/l	0.55	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	> 3.5
Ammonium as NH_4 - N	mg/l	<0.20					
Nitrate as NO_3 - N	mg/l	0.110	< 6	6 - 10	10 - 20	20 - 40	> 40
Nitrite as NO_2 - N	mg/l	<0.01	< 6	6 - 10	10 - 20	20 - 40	> 40
Orthophosphate as PO_4-P	mg/l	<0.05	< 0.1	0.1 - 0.25	0.25 - 1	> 1	
Sulphate as SO_4	mg/l	2.14	< 200	200 - 400	400 - 600	600 - 1000	> 1000
Silica as Si	mg/l	2.44					
WATER CLASS (CHEMISTRY)		CLASS II					
Sum Cations	meq/l	16.6493					
Sum Anions	meq/l	16.819878					

4.7. Aquifer classification

The site lies in the Lowveld Groundwater Region. The low yield results in the aquifer is classified as a Poor aquifer (table 4-5).

Table 4-5 Aquifer classification

Yield Index	Yield (l/s)	Aquifer Classification	Potential use
Low	<1	Poor	Domestic, stock water, garden
Medium	2-5	Medium	Limited development
High	6-20	Major	Small community
Very High	>20	Major	Large scale water supply

Classification can also be done in accordance with the following definitions for Aquifer System Management Classification (table 4-6):

<u>Sole Aquifer System:</u>

An aquifer which is used to supply 50 per cent or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.

<u>Major Aquifer System:</u>

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 (less than 150 mS/m Electrical Conductivity). The aquifer is a high-yield system of good quality water with a Harvest Potential greater than 50 000 $m^3/km^2/a$ or average borehole yield greater than 2 l/s.

<u>Minor Aquifer System:</u>

These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers. The aquifer is a moderate-yielding system of variable water quality with a Harvest Potential between 10 000 and 50 000 $m^3/km^2/a$ or average borehole yield between 1 and 2 l/s.

<u>Non-Aquifer System:</u>

These are formations with negligible permeability that are regarded as not containing ground water in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, ground water flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

A low- to negligible-yielding aquifer system of moderate to poor water quality with a Harvest Potential less than 10 000 $m^3/km^2/a$ or average borehole yield less than 1 l/s.

Table 4-6 Aquifer system and quality management classification

Aquifer System Management Classification			
Class	**Points**	**Site**	**Water Quality**
Sole Source Aquifer System:	6		
Major Aquifer System:	4		
Minor Aquifer System:	2	2	2
Non-Aquifer System:	0		
Special Aquifer System:	0 - 6		
Second Variable Classification Weathering/Fracturing			
Class	**Points**		
High:	3		
Medium:	2	2	2
Low:	1		
Aquifer Vulnerability Classification			
Class	**Points**		
High:	3		
Medium:	2	2	2
Low:	1		

The aquifer, in terms of the above definitions, is classified as a **minor aquifer system.**

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. The gneisses weather to clay rich material of low permeability, which reduces the recharge to the underlying aquifer, however, the water table is shallow, and the upper soils are shallow in nature, rendering the aquifer vulnerable. In terms of the above, the aquifer vulnerability is classified as Medium due to the sandy nature of the unsaturated zone and the shallow water table.

The Level of ground water protection required is based on the Ground Water Quality Management Classification (GQM Index = Aquifer System Management x Aquifer Vulnerability) (table 4-7). The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Ground Water Quality Management Index of 4 for the subject area, indicating that a Medium level of ground water protection is required.

Table 4-7 Level of groundwater protection

GQM Index	Level of Protection	Site
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	4
6 - 10	High Level	
>10	Strictly Non-Degradation	

4.8. Aquifer vulnerability

Aquifer vulnerability is the likelihood of an aquifer being affected by a contaminant load imposed by human activities at the ground surface. The assessment of the vulnerability is based on the estimated travel time for water to move from the ground surface to the water table. As the water moves through the ground, natural processes reduce the concentration of many contaminants.

The vulnerability of aquifers to contamination from sanitation systems and other pollution sources is high in areas of high rainfall and shallow water tables. The vulnerability is also high for fractured aquifers and other permeable environments such as sandy or gravel soils. This is mainly because of high flow rates and less time and distances available for filtration, die-off and adsorption processes to take place. Proper management of groundwater and control of hazardous activities on vulnerable aquifers is essential for the protection and the sustainability of the groundwater resource. A proactive approach to protect the groundwater resources from pollution is encouraged, as it may be very difficult and costly to treat the groundwater once it has been contaminated, particularly in terms of inorganic contaminants

Vulnerability is determined based on geohydrological factors and contaminant load. The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.

There are various methods for assessing groundwater vulnerability and the main one utilised in South Africa is DRASTIC.

DRASTIC is based on indices of:

- Depth to water table
- Recharge (net)
- Aquifer media
- Soil media
- Topography
- Impact of the vadose zone
- Conductivity

The depth to water is the distance the contaminant must travel before reaching the aquifer and indicates the contact time with the surrounding media.

Recharge indicates the amount of water per unit area of land penetrating the ground surface and reaching the water table. The quantity of water available for dispersion and dilution in the aquifer is controlled by this recharge.

An aquifer is a rock formation which will yield sufficient water quantities for use. Rocks which produce water from pore spaces have primary porosity and those where water is held in fractures, for example, have secondary porosity. The aquifer media describes the characteristics of the aquifer and is vital in groundwater vulnerability assessment in addition to determining the flow of water.

The soil media affects the recharge and the contaminant movement. Fine textured materials such as silts and clays restrict contaminant migration and decrease soil permeability. These areas have lower vulnerability when compared to gravels and sands for example which are highly permeable.

The topography, referring to the slope and slope variability of the land surface, affects groundwater vulnerability. It controls the movement of water by concentrating flows in topographic depressions. Topography controls the likelihood that the pollutants will either runoff or remains on the surface long enough to infiltrate.

The vadose zone, also termed the unsaturated zone is the portion of the subsurface in which soil pores contain either air or water. This zone contains natural organisms with the ability to break down contaminants into secondary products. The characteristics of the vadose zone therefore determine the contact time with these organisms since the path length and route will be influenced by vadose zone characteristics.

Hydraulic conductivity is the measure of an aquifer’s ability to transmit water when submitted to a hydraulic gradient. It controls the velocity of groundwater flow which controls the velocity of pollutant flow through the aquifer.

The equation used for the pollution potential (DRASTIC Index) is:

DRASTIC Index (DI) = DrDw + RrRW + ArAw + SrSw + TrTw + Ir Iw + CrCw

Where, r is the rating for the area evaluated and w is the importance weight of the parameter (normally from 1 to 5). The C conductivity term is excluded in the South African rating system. The ratings utilised are shown in table 4-8.

Table 4-8 DRASTIC Ratings

Depth to groundwater (D_R)

Range (m)	Rating
0 – 5	10
5 – 15	7
15 – 30	3
> 30	1

Net Recharge (R_R)

Range (mm)	Rating
0 – 5	1
5 – 10	3
10 – 50	6
50 – 100	8
> 100	9

Aquifer Media (A_R)

Range	Rating
Dolomite	10
Intergranular	8
Fractured	6
Fractured and weathered	3

Soil Media (S_R)

Range	Rating
Sand	8 – 10
Shrinking and/or aggregated clay	7 - 8
Loamy sand	6 - 7
Sandy loam	5 - 6
Sandy clay loam and loam	4 - 5
Silty clay loam, sandy clay and silty loam	3 - 4
Clay loam and silty clay	2 – 3

Topography (T_R)

Range (% slope)	Rating
0 – 2	10
2 – 6	9
6 – 12	5
12 – 18	3
> 18	1

Impact of the vadose zone (I_R)

Range	Rating
Gneiss,Namaqua metamorphic rocks	3
Ventersdorp, Pretoria, Griqualand West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutspansberg, Karoo (northern), Bushveld, Olifantshoek	4
Karoo (southern)	5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6
Dolomite	9
Beach sands and Kalahari	10

The corresponding weights to these parameters were as follows:

- Depth to groundwater (D_w) 5
- Recharge (R_w) 4
- Aquifer media (A_w) 3
- Soil Media (S_w) 2
- Topography (T_w) 1
- Impact of vadose zone (I_w) 5

The vulnerability classification according to the DRASTIC index is shown in table4-9. The assessment of the site is shown in table 4-10.

Table 4-9 DRASTIC Vulnerability classification

DRASTIC Index	Vulnerability
<70	Insignificant
70-80	Very Low
80-100	Low
100-120	Moderate
120-130	High
130-150	Very High
150-200	Extreme

Table 4-10 DRASTIC index

	value	Rating	DRASTIC Score (r*w)
Depth to Groundwater	2	10	50
Recharge	9	3	12
Aquifer media	Fractured and weathered	3	9
Soil Media	Loamy sand	7	14
Topography	3	9	9
Impact of Vadose zone	Gneiss	3	15
INDEX			109

The vulnerability of the aquifer can be considered moderate.

5. GROUNDWATER FLOW MODEL

The establishment of a numerical groundwater model was considered necessary to derive a water balance, to determine flow direction and to identify water users at risk from the proposed filling station.

5.1. Description of the Model

The USGS MODFLOW2000 Finite Difference groundwater model was utilised in the US Department of Defence GMS 10.0.11 (Groundwater Modelling System) interface to simulate and plot groundwater flow. MODFLOW numerically solves the three-dimensional partial differential equation which defines groundwater flow in a porous medium by using a finite-difference mathematical solution method. MODFLOW allows definition of the environment using parameter values, each of which can be applied to each specific grid cell and is assumed to be uniform over that cell.

MODFLOW in the GMS package has the relevant capabilities to simulate flow and contaminant transport in a heterogeneous environment. MODFLOW simulates steady and non-steady state flow in an irregularly shaped flow system in which aquifer layers can be set as confined, unconfined, or a combination of confined and unconfined. It allows flow to and from external stresses such as boreholes, recharge, evapotranspiration, discharge to springs/drains, seepage to and from riverbeds, and the effect of barrier dykes to be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (be different in one direction than the other). The storage coefficient/specific yield may be heterogeneous.

MODFLOW is currently the most internationally used numerical model for groundwater flow problems and can simulate a wide variety of systems. It is used to simulate systems for water supply, containment remediation and mine dewatering. MODFLOW has extensive publicly available documentation, and it is reviewed by the United States Geological Survey. When properly applied, MODFLOW is the recognised standard model accepted by courts, regulatory agencies, universities, consultants, and industry in the United States and elsewhere.

MODFLOW solves the equations for the three-dimensional movement of groundwater in a network of defined cells for defined time steps. Using defined parameters of transmissivity and storativity, together with specifications of flow and/or head conditions at the boundaries of an aquifer system (such as recharge, abstraction, evapotranspiration flow to and from rivers and drains etc.), MODFLOW solves for the value of head (water level) for each grid cell at each defined moment in time.

5.2. Conceptual Model

In every modelling study, the natural system is represented by a conceptual model representing the best understanding of how the natural system operates, the inputs, outputs, and stresses on the groundwater environment. The development of a conceptual model includes identifying hydrogeological layers, boundary conditions, and zones of similar or differing properties that need to be differentiated.

Based on the conceptual model, a numerical model is designed and constructed with equivalent but simplified conditions of the real world, in sufficient detail to meet the objectives of the modelling study and reproduce observed conditions. Transferring the real-world situation into an equivalent conceptual model system, which can then be solved using existing program mathematical codes, is a crucial step in groundwater modelling. The following are considered in the development of a conceptual model:

- The known geological and hydrogeological features and characteristics of the area and their vertical and horizontal variations;
- The presence of dykes or structures that restrict or enhance permeability
- The variations of permeabilities and storativities of the geological formations;
- The recharge to the aquifers and its variability;

- The static water levels/piezometric heads of the study area;
- The history of groundwater abstraction which modifies water levels and the water balance;
- The spatial and vertical extent to which intended activities will interact with the geology and hydrogeology on the region so that the lateral and vertical boundaries of concern can be identified;
- The identification of the processes and interactions taking place within the study area that will influence the movement of groundwater, such as evapotranspiration from riverine zones or shallow water table areas, abstraction from boreholes, dykes and faults and permeability boundaries, springs and baseflow to streams and rivers.

The conceptual model of the aquifer is shown in figure 5-1. It consists of a weathered and fractured rocks of Makhutswi Gneiss. The weathered zone is approximately 20 m thick. The aquifer drains by evapotranspiration from shallow water table regions.

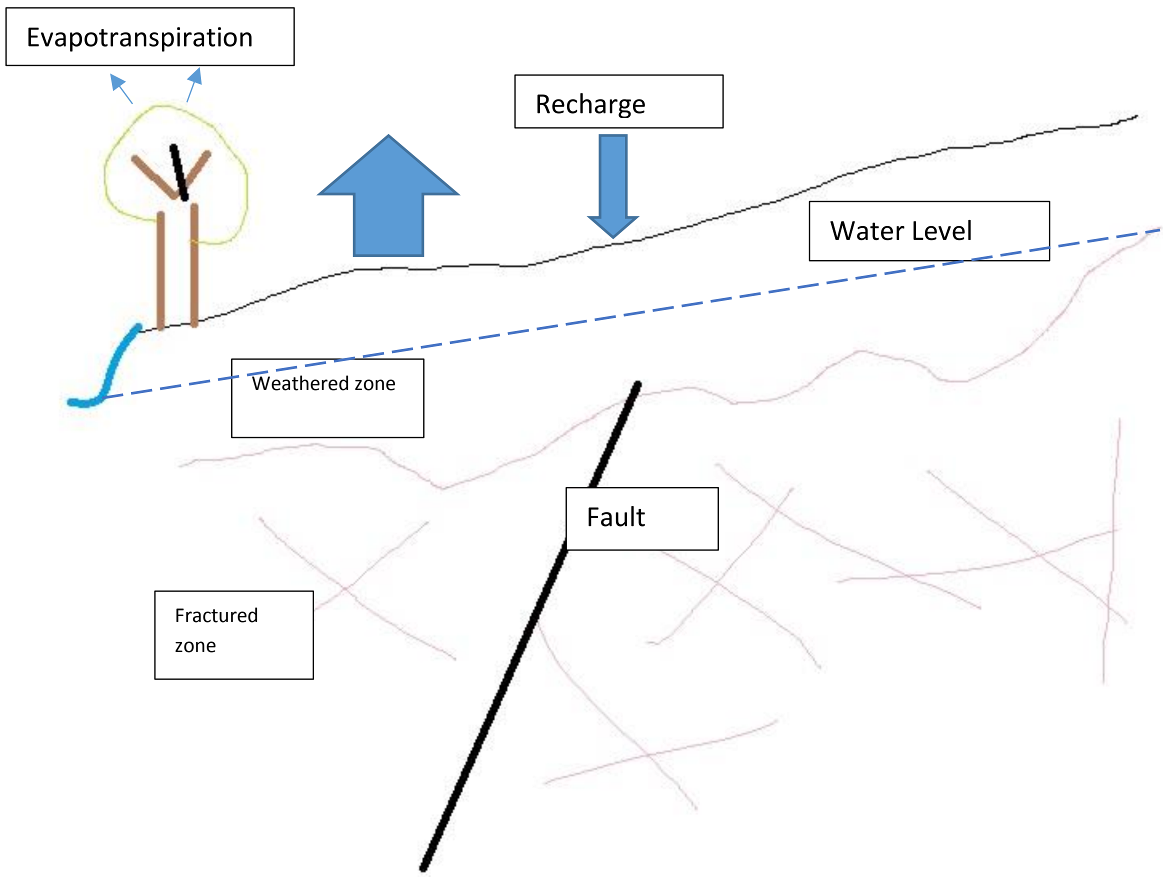

Figure 5-1 Conceptual model

5.2.1. *Model Layers*

The model was set up with 2 layers to accommodate the 2 conceptual layers described in 4.1.

Layer 1 is the weathered zone. It extends to 20 m in depth. This depth was selected according to the most frequent depth of weathering in Lowveld basement rock.

Layer 2 is the fractured zone from 20-40 mbgl. The base of the layer was taken as the depth of the lowest recorded water strike.

5.2.2. *Recharge*

Recharge was initially considered to be 9 mm/a, which is the recharge values from GRAII.

5.2.3. *Discharge*

The aquifer was considered to discharge naturally towards channels as baseflow. To simulate interactions between surface and groundwater, these rivers were modelled as head dependent boundaries. This implies that when aquifer water levels are above the level of the stream baseflow occurs.

Since GRAII shows that no baseflow occurs, it was considered necessary to include evapotranspiration due to the shallow groundwater conditions. Evaporation was applied to green zones identified on Google earth and calibrated so that no baseflow occurs.

5.2.4. *Boundary Conditions*

Modelling results are generally strongly influenced by boundary conditions. Boundaries control the flow direction and strongly influence the water balance of a numerical model; hence boundary conceptualisation is of critical importance. Generally, internal boundaries are fixed where known interchanges of water take place, and lateral boundaries should be sufficiently extended to zones where it is known no interchange takes place. For this reason, it is generally best to extend a model to no-flow boundaries, such as watersheds, or impermeable dykes, or perennial rivers across which no groundwater flow takes place, except into the river.

To avoid boundary condition problems, the model domain used topographic divides as boundaries (figure 5-2).

The model domain was envisaged as being a discrete interconnected unit bounded by various hydraulic boundaries. These include:

- Local watersheds were treated as no flow boundaries across which groundwater flow was assumed to be non-existent. The rationale behind this discretisation was that the interchange of water across flows lines is negligible.
- Ephemeral channels were simulated using a drain boundary (figure 5-2), which is a type of boundary that allows water to flow out of the aquifer when the water table is above the set elevation of the boundary. The rate of drainage is dependent on the head difference between the elevation of the drain and the water table in that cell times the drain conductivity. If the water table in adjacent model cells falls below the elevation of the drain, no drainage takes place.
- The entire model domain was assumed to drain by evaporation, where groundwater could be lost to vegetation if water levels were less than 6 m below surface. A higher evaporation rate was given to the green zones along drainage channels.
- The NE trending dykes and fault are oriented parallel to the direction of groundwater flow, hence do not serve as a barrier to flow. The fault underlies the main drainage

channel and therefore functions as a discharge zone. They therefore do not alter groundwater flow lines.

- The elevation of linear and areal boundaries, such as ephemeral drainages and evaporation surface depth were assumed to be equal to surface elevation, as determined from the topographic maps and a DTM.

Figure 5-2 Model Boundary domain

5.3. Horizontal and Vertical Spatial Definition

To define the horizontal extent, the model domain considered was the surface area between the identified watersheds (figure 5-3). The watershed and surface topography were defined by a DTM (figure 5-3).

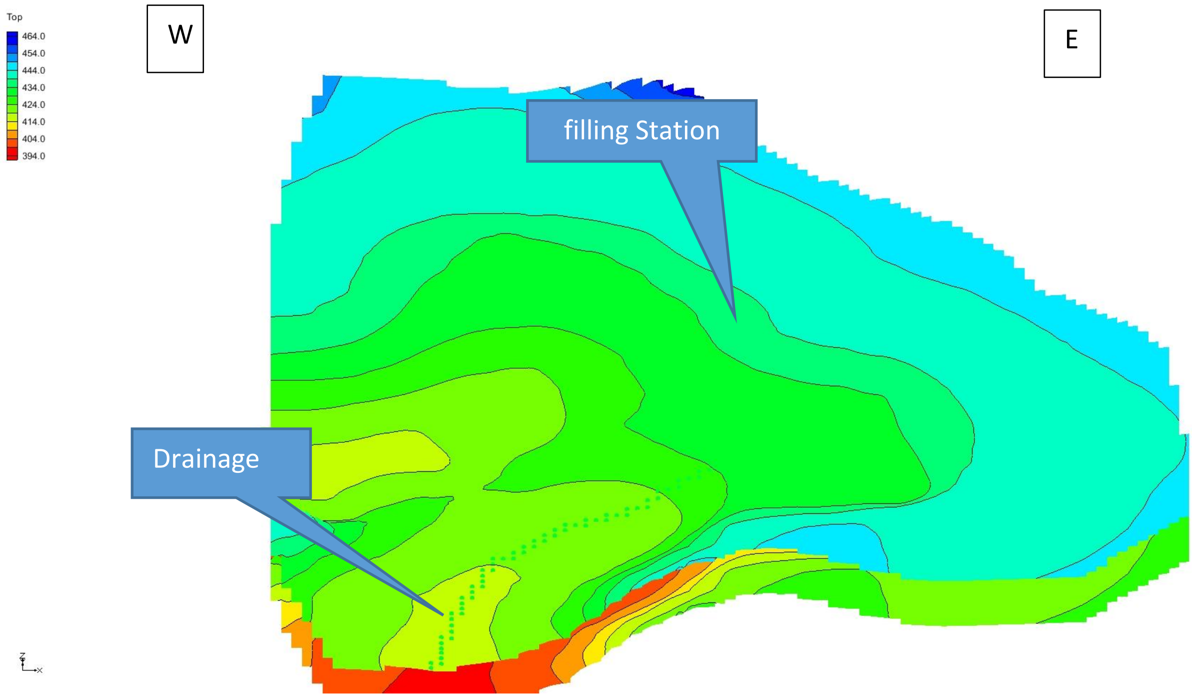

Figure 5-3 DTM of ground surface

In a finite difference model, the aquifer is represented by rectangular cell blocks in each model layer. Each cell is assigned a permeability, specific yield, specific storage, thickness, and recharge parameter. Hydraulic head in each cell of each layer and the exchange of water between cells and across boundaries are calculated simultaneously using finite difference mathematics until a finite solution is found within set convergence parameters. The model can be used to solve for heads under steady-state conditions, which are conditions that will occur when stability in water level and flow rates are reached, or for transient state conditions, which are flow rates and hydraulic heads that will exist after specific time intervals from an initial starting condition.

The model grid was set to 10 m x 10 m cells. The fine modelling interval allows the hydraulic gradients near the site to be represented.

The resulting grid was 213 x197 cells, oriented to the north.

5.4. Rivers and streams

The ephemeral tributary was considered to be a drain boundary. This can potentially drain the aquifer but not recharge it. The levels of these drains were obtained from the DTM. Drain conductance was set as 0.05 $m^2/d/m$, slightly higher than aquifer permeability.

The total baseflow to the ephemeral channel was calibrated to be zero, to match observed volumes in GRAII.

5.5. Evaporation

The generally shallow groundwater levels suggest that evaporation from groundwater can occur over a large area, hence groundwater evaporation was allowed across the entire domain. Evapotranspiration was set at a maximum rate of 0.0004 m/d for the green zones (146 mm/a). This was calibrated to evaporate the entire recharge. For the remainder of the catchment it was set to 0.00001 m/d, or a minimal 3.65 mm/a. Evaporation at the maximum rate occurs when groundwater is at surface, declining to 0 m/d when groundwater is 6 m below surface. Evaporation was also calibrated to keep groundwater levels below surface.

5.6. Permeability

Permeabilities in m/day were initially assigned to the gneiss by multiplying the median blow yield of 0.1 l/s by 6 to derive an average Transmissivity of 0.6 m^2/d. The transmissivity was then allocated as a permeability of 0.015 m/d for each of the two layers. This permeability was found to be slightly too low as water levels would rise to surface at the watershed. A final permeability of 0.018 m/d was calibrated to maintain water levels at 2 mbgl.

5.7. Rainfall Recharge

Recharge was set to 9 mm/d according to the GRAII value for the catchment.

5.8. Model Calibration

Calibration is the process whereby model parameters and boundary conditions are systematically altered in numerous consecutive simulations until simulated groundwater levels and flows across boundaries match observed field measurements to within an acceptable error margin. Calibration under known conditions against observed data is critical if the model is to be used to forecast scenarios for which no observed data is available.

Since no water levels are available in the model areas, calibration was restricted to the calibration of evaporation to remove all the recharge, and the calibration of permeability to keep water levels approximately 2 mbgl at the watershed, as found during the hydrocensus.

6. MODEL RESULTS

Modelling results are expressed as water level maps, drawdown maps from a pre-existing condition, or as a water balance, which is a calculation whereby the inflows and outflows of a groundwater system are determined. This is done by considering all the external and internal groundwater gains and losses in the aquifer such as:

Inflow: - groundwater flow into a specific area because of difference in gradients, groundwater recharge as a result of rainfall infiltration and losses from rivers.

Outflow: - groundwater leaving the system through the defined flow boundaries of the model due to the hydraulic gradient, borehole abstractions, baseflow to rivers and springs, and evapotranspiration.

6.1. Water Balance

The water balance of the model domain is shown in Table 7-1.

Table 6-1 Water balance under present and current conditions

Flow Component	Inflow (m^3/d)	Outflow (m^3/d)
Evapotranspiration		65.05
Ephemeral drains		0
Recharge	65.05	
Total	65.05	65.05

6.2. Water Level

The regional water level is shown in figure 6-1. Groundwater flow is oriented to the SW. The localised water level in figure 6-2. Water levels at the site are approximately 434-435 mamsl and flow is oriented to the SW.

Groundwater levels are about 1-2 m below surface.

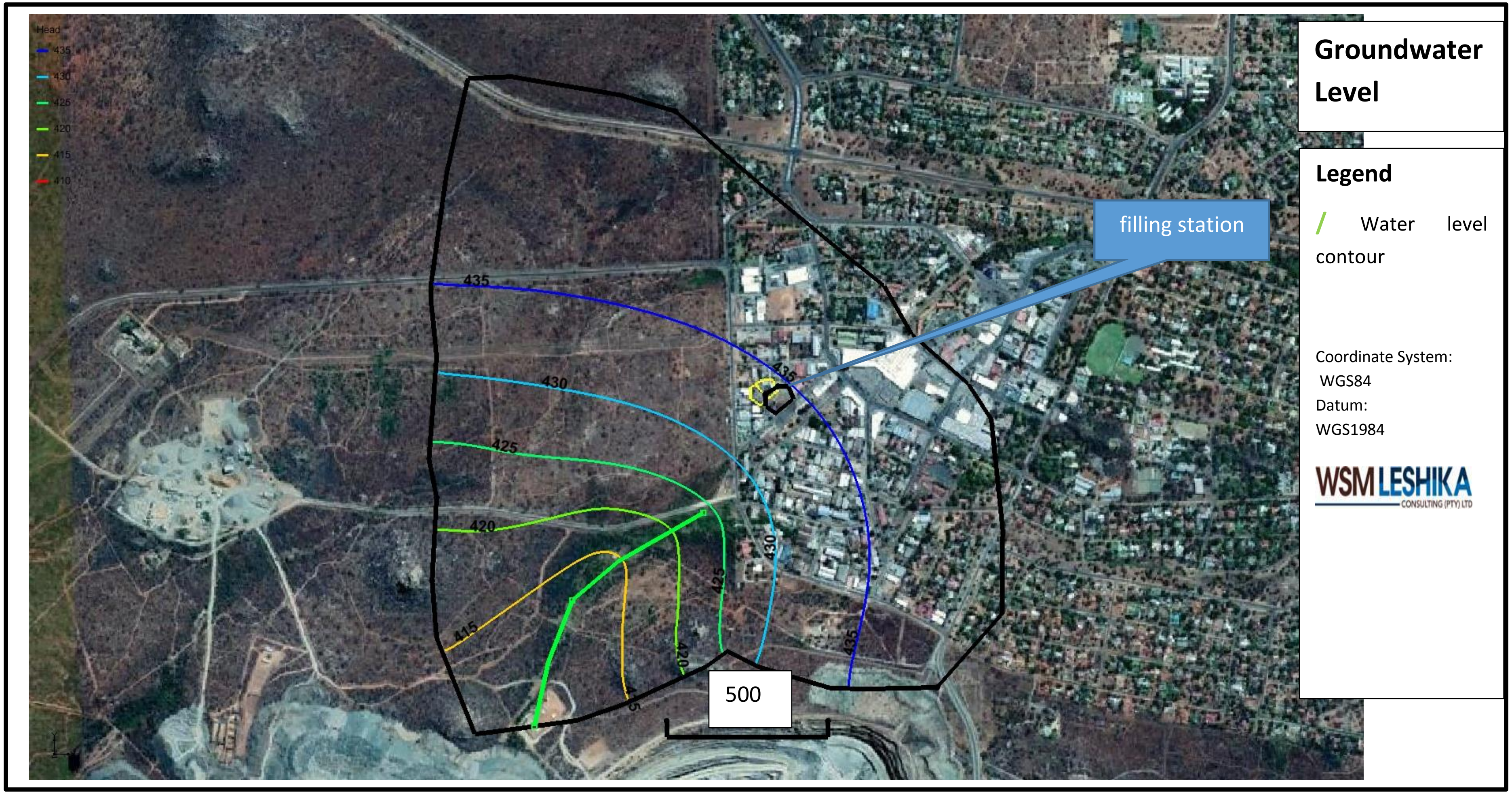

Figure 6-1 Regional water level

Figure 6-2 Local water level

7. POTENTIAL CONTAMINATION OF GROUNDWATER

7.1. Sources of contamination

Groundwater contamination from a filling station can occur from:

- Leaking underground petrol and diesel tanks (USTs).
- Leakage and spills of diesel and spills from above ground storage tanks.
- Accidental spills and overfills from filler areas.
- Leaks from the pumps.
- Leakage and spills in the forecourt areas.
- Leakage of oils and grease.

7.2. Types of contamination

Groundwater contamination can occur in several distinct phases:

- Light non-aqueous phase liquids (LNAPLs).
- Dense non-aqueous phase liquids (DNAPLs).
- Dissolved constituents from LNAPLs and DNAPLs.
- Vapours emanating from LNAPLs.

7.2.1. *LNAPLs*

LNAPLS are Light non-aqueous phase liquids (LNAPLs) such as diesel and petrol that are less dense than water. LNAPLs are hydrocarbons that do not mix with water and exist as a separate phase.

Upon release to the environment, LNAPLs will migrate downward to the water table. If a small volume of LNAPL is released to the subsurface, it will move through the unsaturated zone where a fraction of the hydrocarbon will be retained in soil pores. If sufficient LNAPL is released, it will migrate until it encounters a physical barrier (e.g., low permeability strata) or is affected by buoyancy forces near the water table. Once the saturated zone is reached, the LNAPL may move laterally along the upper boundary of the water-saturated zone. Although principal migration may be in the direction of the maximum decrease in water-table elevation, some migration may occur initially in other directions.

Infiltrating precipitation and passing ground water in contact with residual or mobile LNAPL will dissolve soluble components and form an aqueous-phase contaminant plume dissolved in groundwater. The solubles are largely the BTEX component (Benzene, Toluene, Ethylbenzene, Xylene), which are a risk to health and the environment as they have harmful effects on the central nervous system. The BTEX component typically makes up 18% of petrol. Because they are the most volatile and most soluble, and less easily attached to organics in the soil, the BTEX component is the most mobile component of hydrocarbon spills.

In addition, volatilization may result in further spreading of contamination into the unsaturated zone above.

LNAPL constituents may exist in any of four phases within the subsurface (figure 7-1):

- The LNAPL in its original state.
- Dissolved phase in groundwater.
- Gaseous phase in the unsaturated zone.
- Trapped in pore spaces in the saturated and unsaturated zone.

Since they migrate predominantly down gradient, the direction of groundwater flow is an indicator of zones at risk from spills and leaks of LNAPLs.

A contaminant plume will eventually reach equilibrium and will not continue to grow in space. This occurs once the rate of natural degradation by dilution, adsorption, dispersion, and chemical and biological degradation equals the input rate.

The length a plume will reach will depend on numerous factors, such as the magnitude and duration of the spill, the oxidation potential of the aquifer to attenuate the spill, and the permeability of the aquifer. Plume lengths are generally less than 100 m and generally do not exceed 300 m, Shih et al. (2004).

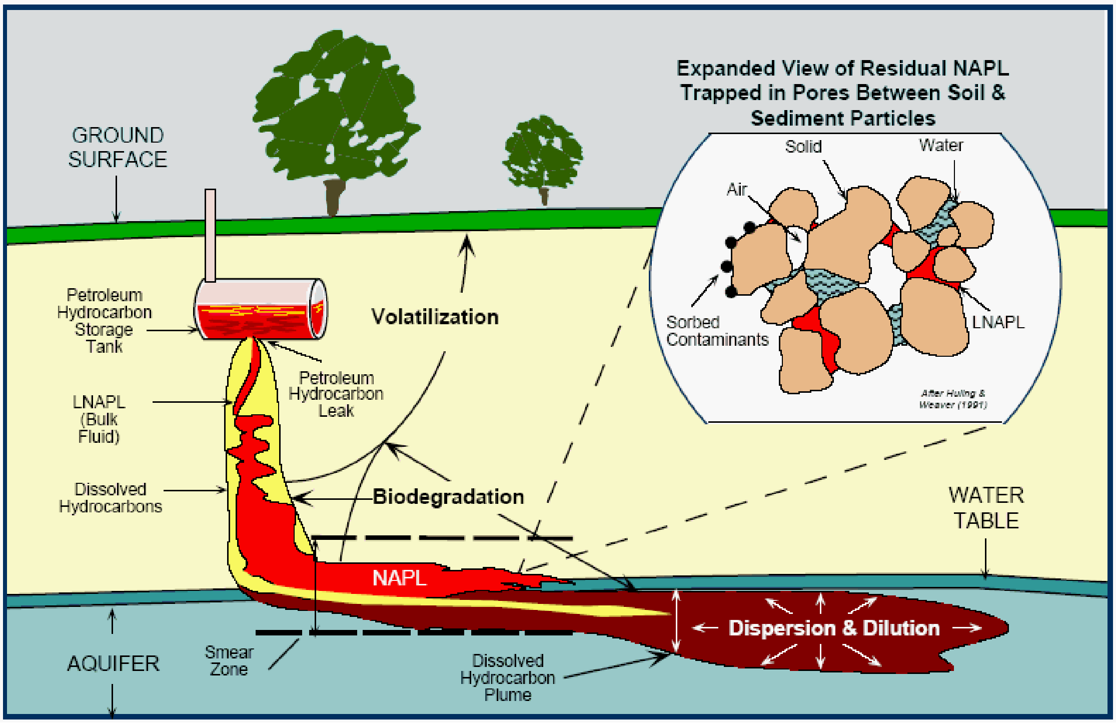

Figure 7-1 Occurrence of LNAPL from a leak

7.2.2. *DNAPLS*

Dense non-aqueous phase liquids (DNAPLs) are denser than water. They include solvents found in oils and grease.

When a DNAPL spill occurs, it migrates vertically through the unsaturated zone, with some of it retained in the soil. Infiltration of water can subsequently leach this volume, resulting in groundwater contamination along the direction of groundwater flow.

Volatilization of vapours from a DNAPL may also contaminate the ground water and soil.

If the DNAPL spill is large enough, the spill will migrate until it reaches the water table and contaminates the ground water directly. Since its density is greater than water, it continues to migrate downwards until it is intercepted by a low permeability formation where it begins to migrate laterally. Transport of the DNAPL will be largely dependent on the gradient of the stratigraphy. Consequently, flow may be in a different direction than groundwater flow.

Groundwater flowing through this plume will spread contamination down gradient.

DNAPL contamination may exist as four possible phases (figure 7-2):

- Gaseous phase in the unsaturated zone.
- Trapped in pore spaces in the saturated and unsaturated zone.
- Dissolved phase in groundwater.
- The DNAPL in its original state.

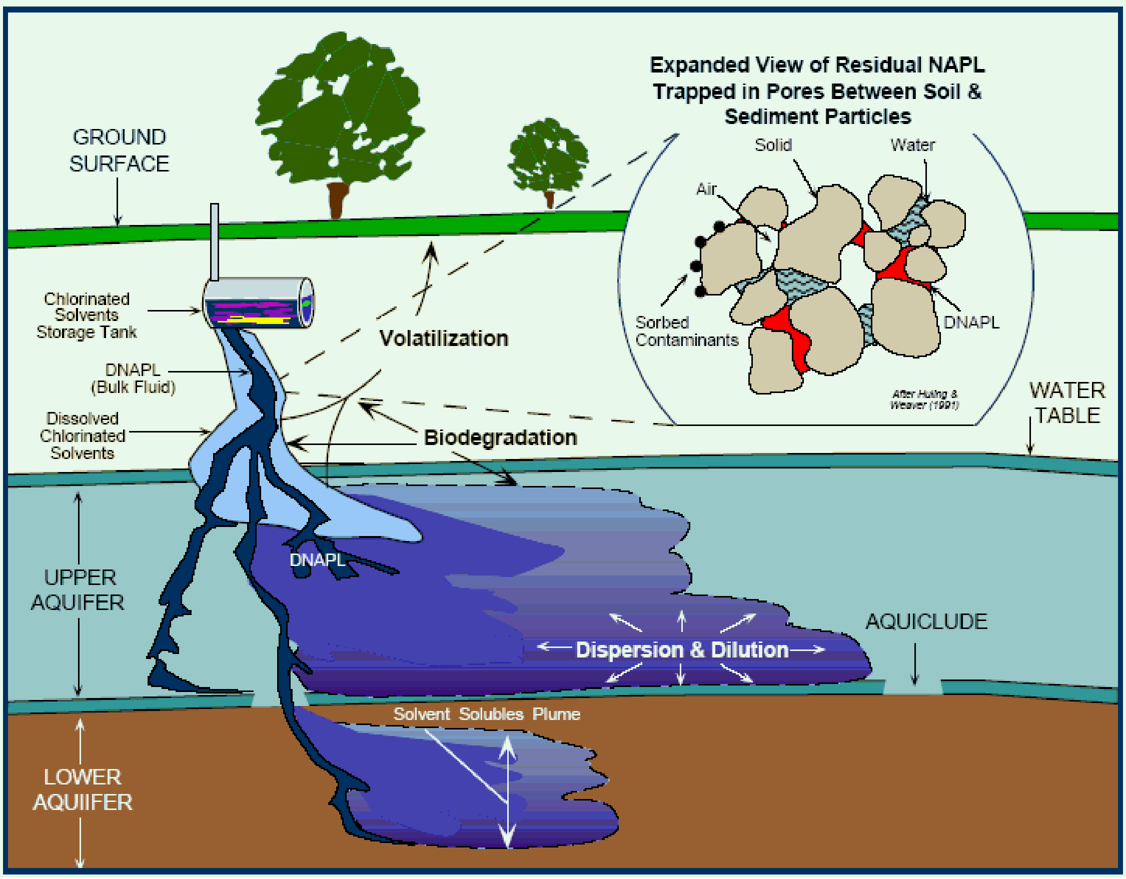

Figure 7-2 Occurrence of DNAPLs from a leak

7.3. Contamination Migration

The fate of any contamination emanating from the filling station is of concern as a potential source of groundwater contamination and seepage to surface water. The extent of any contaminant plume will depend on the volume of the spill and its duration, the rate at which natural attenuation takes place to degrade the spill by natural processes, and aquifer hydraulic properties. The extent of the contamination plume emanating from the proposed filling station assuming a continuous spill of 1000 l/d with natural attenuation was simulated with RT3D.

RT3D is a software package compatible with MODFLOW for simulating three-dimensional, multi-species, reactive transport of chemical compounds (solutes) in groundwater. It also allows for the simulation of the dispersion of contaminants through preferential pathways.

The extent of a potential contamination plume emanating from the filling station was also simulated using MODPATH, part of the MODFLOW suite of models, which traces the path lines of water particles as derived from the groundwater flow calculated by MODFLOW. MODPATH allows no attenuation, so is a very conservative approach. MODPATH allows both the fate of water through a contaminated zone to be traced by forward modelling, or the origin of water particles entering a borehole or stream to be traced by reverse modelling. This represents a worst-case scenario.

The models were run for a period of 20 years, assuming no action to mitigate the leak, with an assumed porosity of 0.5%, which is considered to be conservative for the weathered zone.

7.3.1. *Contaminant migration plume from MODPATH*

The 20-year contamination plumes of a petrol spill are shown in figure 7-3. In 20 years, the plume migrates to the edge of the industrial area. The slow rate of migration can be attributed to the low permeabilities and lack of abstraction in the immediate vicinity.

7.3.2. *BTEX plume from RT3D*

The migration of the contaminant plume, assuming natural attenuation of BTEX in the aquifer, is shown in figure 7-3. Within 20 years the plume migrates 167 m, just beyond the industrial area but does not reach water courses or residential areas.

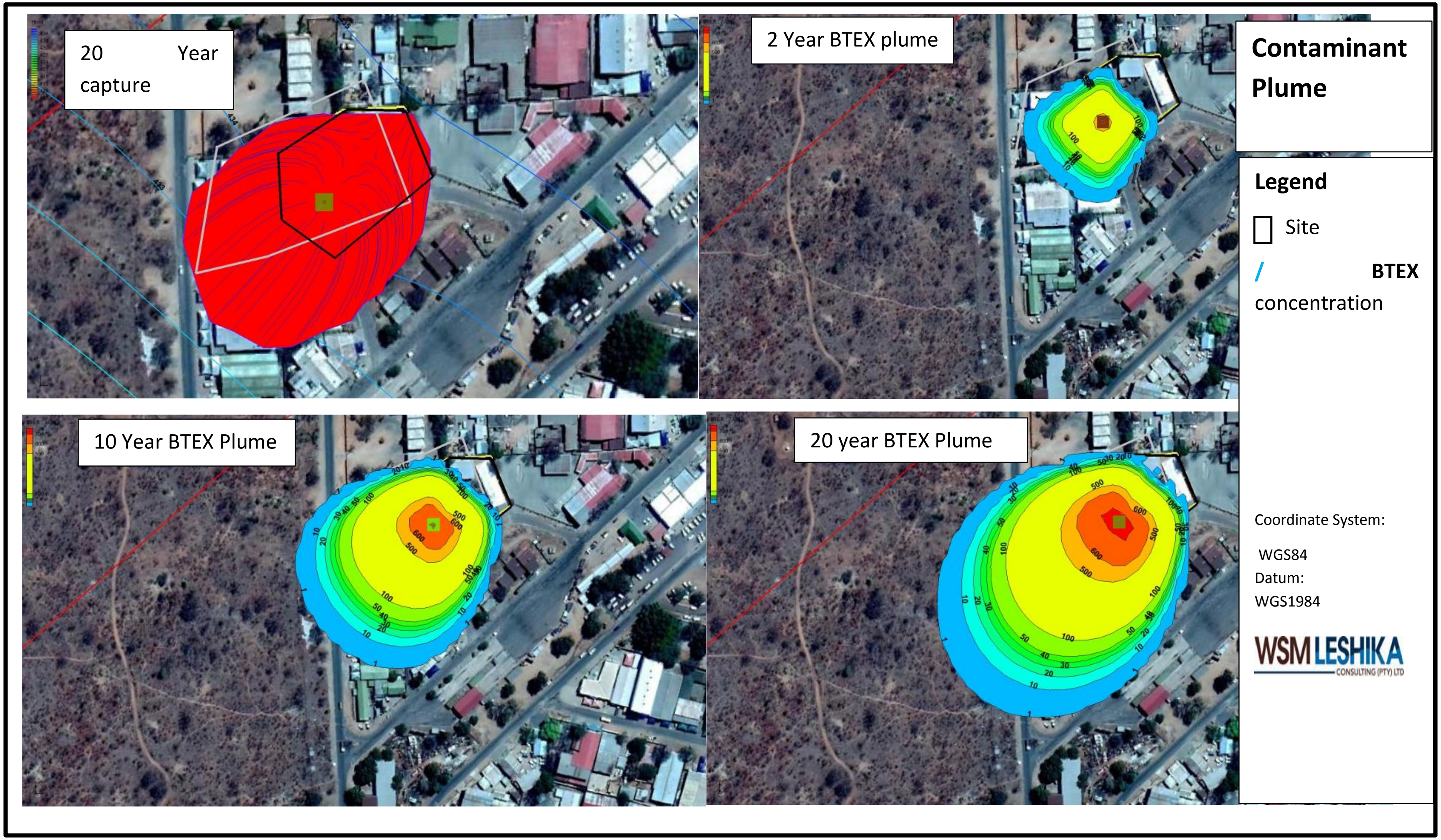

Figure 7-3 Potential contaminant plume and borehole capture zones

8. GROUNDWATER IMPACT ASSESSMENT

8.1. Impacts of the Proposed Filling Station Development

Two different types of activities are associated with the development: Firstly, the installation and construction must take place (construction phase) before the upgrades to the filling station can be put into operation (operational phase).

The proposed activity may detrimentally impact on water resources, including the underlying aquifer and downstream surface waters. These impacts may be associated with leakage from underground pipe fittings and underground storage tanks due to damage or poor maintenance, as well as surface spills and leaks from the forecourt area and the tanker filling area, because of poor operation and management of these areas. Contaminants of concern which would arise from these sources would include petroleum hydrocarbons and dissolved BTEX compounds.

Additional concerns include leakage from the sanitation system, uncontrolled surface runoff and leakage from the waste storage and handling areas. Contaminants arising from these sources would include microbial indicators, soap, oils, grease and limited hydrocarbons.

8.1.1. *Construction phase*

- Sources of water and soil pollution on construction sites include diesel and oil; paint, solvents, cleaners and other harmful chemicals; and construction debris and dirt.
- Spillages of oil, lubricants and fuel from construction vehicles, plant and machinery has the potential to contaminate the soil and surface and groundwater.
- Spillages and deposition of chemicals onsite can soak into ground water.
- When portions of the site are cleared, combined with the failure to implement erosion control measures effectively, silt-bearing run-off and sedimentation pollution will result.
- Ground disturbing activities such as blasting, and foundation construction can lead to increased erosion.
- Stormwater runoff has the potential to erode the topsoil.
- Soil compaction due to construction activities will reduce aeration, permeability, and water holding capacity of the soils and cause an increase in surface runoff, potentially causing increased sheet or gully erosion.

8.1.2. *Operational phase*

- Sources of soil and water pollution stem from leakage of the underground storage tanks, pipe works, equipment, and dispensers which are not immediately contained.
- The construction of parking areas and roofing structures will increase the impermeable surface area on the site leading to reduced ground absorption of stormwater and increased surface water runoff. This will further result in an increase in the quantity and velocity of stormwater leaving the site which, in turn, has the potential to transport contaminants away from the site into the natural environments and create soil erosion in vulnerable areas.

8.2. Activity Impact Assessment

Issues and potential impacts were identified that may arise as a result of the proposed development. The classification of each environmental impact was assessed in terms of its:

- duration (time scale)
- extent (spatial scale)
- probability (likelihood of occurring)
- severity (size or degree scale)

The above factors were used to determine the significance of each impact without any mitigation, as well as with mitigation measures. The classification of extent, duration, probability, and severity of impact was undertaken according to the criteria in table 8-1.

Table 8-1 Environmental risk and impact assessment criteria

DURATION		Score
Short term	6 months	1
Construction	36 months	2
Life of project		3
Post rehabilitation	Time for re-establishment of natural systems	4
Residual	Beyond the project life	5
EXTENT		
Site specific	Site of the proposed development	1
Local	Surrounding properties	2
District	Municipal district	3
Regional	Region	4
Provincial	Northwest	5
National	Republic of South Africa	6
International	Beyond RSA borders	7

PROBABILITY		
Almost Certain	100% probability of occurrence – is expected to occur	5
Likely	99% - 60% probability of occurrence – will probably occur in most circumstances	4
Possible	59% - 16% chance of occurrence – might occur at some time	3
Unlikely	15% - 6% probability of occurrence – could occur at some time	2

Rare	<5% probability of occurrence – may occur in exceptional circumstances	1
SEVERITY		
Catastrophic (critical)	Total change in area of direct impact, relocation not an option, death, toxic release off-site with detrimental effects, huge financial loss	5
Major (High)	> 50% change in area of direct impact, relocation required and possible, extensive injuries, long term loss in capabilities, off-site release with no detrimental effects, major financial implications	4
Moderate (medium)	20 – 49% change, medium term loss in capabilities, rehabilitation / restoration / treatment required, on-site release with outside assistance, high financial impact	3
Minor	10 – 19% change, short term impact that can be absorbed, on-site release, immediate contained, medium financial implications	2
Insignificant (low)	< 10 % change in the area of impact, low financial implications, localised impact, a small percentage of population	1

Risk is a combination of the probability, or frequency of occurrence of a hazard and the magnitude of the consequence of the occurrence (Nel 2002). Risk estimation (RE) is concerned with the outcome, or consequences of an intention, taking account of the probability of occurrence and can be expressed as P (probability) x S (severity) = RE. Risk evaluation is concerned with determining significance of the estimated risks and also includes the element of risk perception. Risk assessment combines risk estimation and risk evaluation (Nel 2002).

Potential impacts were identified and assessed by considering the criteria as outlined in table 8--2.

Table 8-2 Risk estimation

RISK ESTIMATION (Nel 2002)					
	SEVERITY				
PROBABILITY	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)
Almost certain (5)	H	H	E	E	E
Likely (4)	M	H	H	E	E
Possible (3)	L	M	H	E	E
Unlikely (2)	L	L	M	H	E

Rare (1)	L	L	M	H	H

E	Extreme risk – immediate action required, detail considerations required in planning by specialists – alternatives to be considered	4
H	High risk – specific management plans required by specialists in planning process to determine if risk can be reduced by design and management and auditing plans in planning process, taking into consideration capacity, capabilities and desirability – if cannot, alternatives to be considered, senior management responsibility	3
M	Moderate risk – management and monitoring plans required with responsibilities outlined for implementation, middle management responsibility	2
L	Low risk – management as part of routine requirements	1

IMPACT SIGNIFICANCE	
Negligible	The impact is non-existent or insubstantial, is of no or little importance to any stakeholder and can be ignored.
Low	The impact is limited in extent, even if the intensity is major; whatever its probability of occurrence, the impact will not have a significant impact considered in relation to the bigger picture; no major material effect on decisions and is unlikely to require management intervention bearing significant costs.
Moderate	The impact is significant to one or more stakeholders, and its intensity will be medium or high; therefore, the impact may materially affect the decision, and management intervention will be required.
High	The impact could render development options controversial or the entire project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor in project decision-making.
Very high	Usually applies to potential benefits arising from projects.

The significance of each impact was determined "without mitigation" and "with mitigation", taking into consideration alternatives, preventative and mitigation measures.

The groundwater risk and impact assessment are provided in table 8-3.

Table 8-3 Impacts on groundwater

Impact	E	D	S	P	RE	Without mitigation	Mitigation
Impact on water balance and water levels	1	3	1	1	1	The impact is negligible as no abstraction is planned.	No mitigation necessary
Contamination by wastewater during construction	2	2	2	4	3	Containment of dirty water during construction may infiltrate into the ground. This water could include salts and oils, as well as bacteriological contaminants	Containment of dirty water
Accidental spillage	1	3	3	3	3	On hard surfaces like the forecourt, the product can be covered and adsorbed with biodegradable absorbent materials. Spills on soils would require determining the vertical and lateral extent of contamination and an assessment of the risk of migration to determine if remedial action is required	Containment of spills
Overfills	1	2	2	3	2	On hard surfaces like the forecourt, the product can be covered and adsorbed with biodegradable absorbent materials. Spills on soils would require determining the vertical and lateral extent of contamination and an assessment of the risk of migration to determine if remedial action is required	Secondary containment around filler points and on top of tanks
Leaking tanks	2	3	2	3	2	Leaking USTs allow the LNAPL quick access to the water table, bypassing the bulk of the upper soil zone. Free product could accumulate at the water table and contribute dissolved BTEX constituents to groundwater flow through the site	Reconciliation of delivery and sales, monitoring wells for early detection, in line leak detection
Migration of pollution plume to surface water bodies and groundwater users	2	3	1	1	1	If a dissolved phase of LNAPL or DNAPL occurs, the plume could migrate to the SW. No groundwater users are in the area. Migration is slow due to the low permeability and low hydraulic gradient.	Rapid assessment of leaks and implementation of pump and treat or oxidation remediation technologies.

9. SUMMARY AND CONCLUSIONS

9.1. Summary

The site is under lain by rocks of the **Makhutswi Gneiss (Zm)** (3268 Ma). The aquifer is fractured and weathered. The median yield is below 0.1 l/s and only 21% yield more than 1 l/s. The depth of weathering is less than 40 m in 90% of boreholes. Weathering and fracturing extend deeper than 55 m in only 6% of boreholes. 61% of boreholes have weathered zones of less than 20 m thickness. 81% have a combined weathered and fractured thickness of less than 40 m. In 68% of the cases water will be intercepted within the first 30m. Water occurs also in fault zones and to a lesser extent along dyke contacts. Few boreholes strike water below 40 m. Recharge is given as 9 mm/a in GRAII. Groundwater baseflow is 0 mm/a, and recharge is largely lost bey evapotranspiration from shallow groundwater.

A hydrocensus within 1 km of the site found 4 boreholes. All the boreholes are across the catchment watershed. None of the boreholes are currently in use. One borehole has a yield of <0.05 l/s. Water levels at the catchment divide appear to be 0.7-1.2 mbgl. Water levels are expected to mirror the topography and groundwater flow is expected to be to the SW. Water quality is of Class 2, or Marginal due to sodium and chloride according to The Water Affairs Guidelines for Domestic Water Quality.

The site lies in the Lowveld Groundwater Region. The low yield results in the aquifer is classified as a Poor aquifer, or a **minor aquifer system.** The vulnerability of the aquifer can be considered moderate according to the DRASTIC system.

The USGS MODFLOW2000 Finite Difference groundwater model was utilised to simulate and plot groundwater flow. Groundwater flow is oriented to the SW. Water levels at the site are approximately 434-435 mamsl and flow is oriented to the SW. Groundwater levels are about 1-2 m below surface.

The extent of the contamination plume emanating from the upgraded filling station and depot assuming a continuous spill of 1000 l/d with natural attenuation was simulated with RT3D. Within 20 years the plume migrates 167 m, just beyond the industrial area but does not reach water courses or residential areas.

9.2. Monitoring and Management

The installation of USTs is covered by SANS 10089-3:2010. Above ground fuel storage tanks are covered by SANS 10131:2004.

Spills and leaks may occur, and minimising impacts requires rapid detection and response. To minimise the risk of a spill or leak the following are required:

- Spill and leak prevention.
- Spill and leak response procedures.
- Spill and leak monitoring.

9.2.1. *Spill and leak prevention*

Spill and leak prevention are part of the environmental plan and employee training.

The following minimum precautionary measures are recommended:

- Sealing of the forecourt area and other areas where fuel products are handled to prevent infiltration of petroleum products into the soil/rock underlying the site;
- Storm water draining from the surfaced areas should be collected in a sealed sump to be treated and/or removed;
- Preventative measures should be installed to prevent the storm water or other liquids draining into the natural soil.

Due to the shallow groundwater level, the underlying aquifer is very vulnerable to spillages.

The following will be recommended:

- Subsurface fuel tanks should be placed in concrete or PVC encasements with a sump system to prevent spilled fuel from entering the bedrock or aquifer;
- Fuel lines and dispensers should be rendered leak-proof and are recommended to be placed in encasements;
- Leak detectors are a preferred design alternative. In best practice tank and infrastructure design, leak detectors are installed which immediately switch off the submersible pump contained within the tank should a leak be detected.
- Overfill protection in the tank filling pipe work to prevent tank overfills during filling operations, preventing surface spillage.
- Above ground tanks require a berm and collection system

9.2.2. *Spill and leak response*

Spill response includes procedure to limit the spill, contain the spill, remove as much as possible of the spilled product, and a clean-up and soil and groundwater rehabilitation. Containing the spill localises the problem and minimises the extent of pollution. The clean-up process is determined by the volume of spill, whether it occurs on surface over paving, over soil, or is a leak from USTs.

Minor spills of less than 200 litres can be soaked up with fibres and a spill soaked into soil can be ploughed up to allow aeration to remediate the pollution.

Major spills can be contained by stopping the flow of product through control valves, turning off pumps, containing the spill with absorbing fibres, sandbags, sand or soil, preventing a spill from entering drains and storm water systems and creating a barrier to migration to water courses and flowing over permeable surfaces. Spills over soil require ploughing up of soil and the application of oxidising chemicals to increase oxidation.

9.2.3. *Groundwater monitoring*

To detect any changes in the aquifer system, as well as potential pollution derived directly or indirectly from the proposed development, monitoring of water levels and flow rates, water quality and trends, is imperative.

Early detection and identification of leaks requires a groundwater monitoring plan. Monitoring boreholes should be located up and down gradient of the USTs, which means to the NE and SW of the tanks. They should be constructed with continuous screens above and below the water table to accommodate rising and falling water table and capable of sampling an LNAPL floating on the water table, and dissolved phase constituents below the water table. Monitoring wells must be of uPVC or HDPE material and have an internal diameter of at least 50mm. It is recommended that a minimum of one up gradient and two down gradient wells be installed. The depth of the well must be at least 2m below the depth of the storage tank, or to the water level. Wellheads on boreholes down gradient of the proposed facility must be constructed to prevent any ingress of surface water either from a spill or flooding.

Early detection monitoring wells are to be sunk in the sand back fill adjacent to tanks for the monitoring of groundwater and identification of possible leaking tanks. In the past, oil companies did not install monitoring wells, which resulted in significant delays in detecting any subsurface product losses, with an associated high level of environmental risk. These can be established before back filling takes place, using high density polyethylene slotted / perforated pipes of 160 mm outside diameter, wrapped in a porous geotextile, or ABS (acrylonitrile-butadeine-styrene) single-walled wedge-slot tubular screens installed in each corner of the excavation to act as future observation wells. The bottom ends need to be plugged and the top ends finished off with a suitable plumber plug. The wells need to extend down to 500 mm below the floor of the excavation.

A proper groundwater quality monitoring program must be implemented as soon as possible, where initial sampling and analysis should allow for all major chemical, physical and bacteriological constituents as per (SANS 241). Follow-up sampling could monitor elements in excess only, as well as for traces of hydrocarbon contamination.

Teflon bailers can be used to sample the surface and just below surface of the water table. External user boreholes down gradient of the USTs should also be sampled. Accredited laboratories have set standards for sample preservation, holding times and sampling bottles and these specifications should be followed.

The monitoring programme should be audited for compliance to the stated objectives and adapted when and where required.

The network should be maintained and protected from vandalism and damage by vehicles. Table 9-1 lists a proposed monitoring schedule.

Table 9-1 Monitoring schedule recommended

	Weekly	Monthly	Quarterly	Annually
Potential Domestic use borehole	pH Electrical conductivity Faecal coliforms[1]	pH Electrical conductivity Faecal coliforms Nitrates Chemical oxygen demand		pH Electrical conductivity Faecal coliforms Nitrates Chemical oxygen demand Ca, Mg, Na, K, T-Alk, Cl, SO_4, F, Al, Fe, Mn TPH/BTEX
Monitoring boreholes		Water level Presence of LNAPL on surface of water table	pH Electrical conductivity Faecal coliforms Nitrates Chemical oxygen demand	pH Electrical conductivity Faecal coliforms Nitrates Chemical oxygen demand Ca, Mg, Na, K, T-Alk, Cl, SO_4, F, Al, Fe, Mn TPH/BTEX

9.3. Knowledge Gaps and Recommendations

Although, all available data was collected and utilised in the groundwater model, to ensure that the model presents the actual situation as accurately as possible, some limitations can be noted:

- No data is available on the depth of weathering and water level on site
- No permeability data is available from the site
- No background groundwater quality is available on site

It is recommended that a borehole be drilled to 40 m in the SW corner of the fuel depot site. This hole should be logged by a qualified person, tested for permeability via a falling test, and sampled for water macro constituents. This borehole would confirm the assumptions made in this report owing to lack of data. The hole should also be equipped as a monitoring borehole.

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10. APPENDIX 1 – WATER QUALITY

V0014

4. Sample and condition :

4.1 Date of sampling: 2020/05/08
4.2 Date sample submitted: 2020/05/11
4.3 Temp. upon sample reception: 10.9 °C
4.4 Sample defects noted: None

5. Sub contractor:

5.1 None

6. Results:

Table 1:
Refer to 2.1

Determinand	Test Method Reference	Unit	1-20/1396 WH20019 BH4 8/5/20 California	2-20/1396 WH20019 H13-0732 8/5/20 Phalaborwa	3-20/1396 California BH1 WH20019 8/5/20	4-20/1396 8/5/20 BH2 WH20019 California
Physical and aggregate properties						
pH @ 25 °C	CH-METH-001	pH units	7.7	8.7	7.0	7.5
Conductivity @25 °C	CH-METH-002	mS/m	81.4	165.9	95.5	62.3
*Total dissolved solids (calculated)	CH-METH-038	mg/l	529	1078	621	405
Alkalinity						
*Bicarbonate alkalinity as $CaCO_3$	CH-METH-054	mg/l	398.8	302.5	358.3	260.8
*Carbonate alkalinity as $CaCO_3$	CH-METH-054	mg/l	0.0	31.7	0.0	0.0
Hardness:						
*Total hardness as $CaCO_3$	CH-METH-039	mg/l	288.15	157.87	255.92	217.30
*Ca hardness as $CaCO_3$	CH-METH-039	mg/l	126.45	14.70	141.45	121.85
*Mg hardness as $CaCO_3$	CH-METH-039	mg/l	161.70	143.17	114.47	95.45
Metals						
Aluminium as Al	CH-METH-020	mg/l	0.03	<0.01	0.05	0.03
Arsenic as As	CH-METH-020	mg/l	<0.03	<0.03	<0.03	<0.03
Calcium as Ca	CH-METH-020	mg/l	50.58	5.88	56.58	48.74
Copper as Cu	CH-METH-020	mg/l	0.05	<0.01	0.04	0.01
Iron as Fe	CH-METH-020	mg/l	0.01	0.02	<0.01	<0.01
Magnesium as Mg	CH-METH-020	mg/l	39.44	34.92	27.92	23.28
Manganese as Mn	CH-METH-020	mg/l	0.01	0.04	0.02	<0.01
Potassium as K	CH-METH-020	mg/l	1.79	4.52	8.74	4.70
Sodium as Na	CH-METH-020	mg/l	82.77	307.28	116.88	58.53
Inorganic non-metallic constituents						
Chloride as Cl	CH-METH-050	mg/l	17.7	356.6	78.1	31.0
Fluoride as F	CH-METH-013	mg/l	0.64	0.55	0.57	0.65
Nitrogen						
*Ammonium as NH_4-N	CH-METH-031	mg/l	<0.20	<0.20	<0.20	<0.20
Nitrate as NO_3-N	CH-METH-050	mg/l	1.87	0.10	1.06	0.39
*Nitrite as NO_2-N	CH-METH-011	mg/l	<0.01	<0.01	0.04	<0.01
Phosphorus						
Ortophosphate as PO_4-P	CH-METH-032	mg/l	<0.05	<0.05	<0.05	<0.05
Sulphur						
Sulphate as SO_4	CH-METH-050	mg/l	30.60	2.14	37.83	16.86
Silica						
*Silica as Si	CH-METH-020	mg/l	26.66	2.44	21.20	24.69