MN48 MR CONSOLIDATION & EMP AMENDMENT SPECIALIST STUDY: UPDATED GROUNDWATER ASSESSMENT - KHWARA MINE

Mn48

Prepared for: Mn48 (Pty) Ltd

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1. INTRODUCTION

Mn48 (Pty) Ltd (Mn48) is developing a new underground manganese mining operation near Black Rock in the John Taolo Gaetsewe District Municipality, Northern Cape Province.

A groundwater assessment that included groundwater flow modelling was conducted by SLR in 2017 in order to provide specialist groundwater input into the Environmental Impact Assessment (EIA) and Environmental Management Programme (EMP) for the development of the proposed mine within the then named Khwara Mine site (SLR, 2017).

Subsequent to this report, Khwara Manganese (Pty) Ltd, who holds an approved EMPr for underground mining of manganese immediately adjacent and to the south of Lehating Mine and Mn48, entered into an agreement to combine the two adjacent mineral resources and surface rights comprising the Khwara and Lehating Mines into a single, high-grade manganese mining company that will be known as Mn48 (Pty) Ltd. Khwara Manganese (Pty) Ltd (Khwara) holds an approved EMPr for underground mining of manganese on Portion 2 of the farm Wessels 227 and the Remaining Extent and Portions 3 and 4 of the farm Dibiaghomo 226, while Mn48 has approval for a mine located on a portion of Portion 1 of the farm Lehating 741. The Khwara underground resource will be accessed via the Lehating mine, using Mn48's approved surface infrastructure. In this regard, no surface infrastructure will be established as part of the Khwara Mine.

Since this new agreement is proposing the consolidation of Mn48 and Khwara mining right areas, the groundwater assessment conducted in 2017 is required to be updated to reflect the change in name of the site. The results of the SLR (2017) groundwater assessment will remain unchanged, but recommendation will be made in order to address any potential gaps due to the change in Mn48's approved surface infrastructure and mine layout.

The proposed mining area is located approximately 15 km northwest of Hotazel in the Northern Cape. The site location is presented in Figure 1.

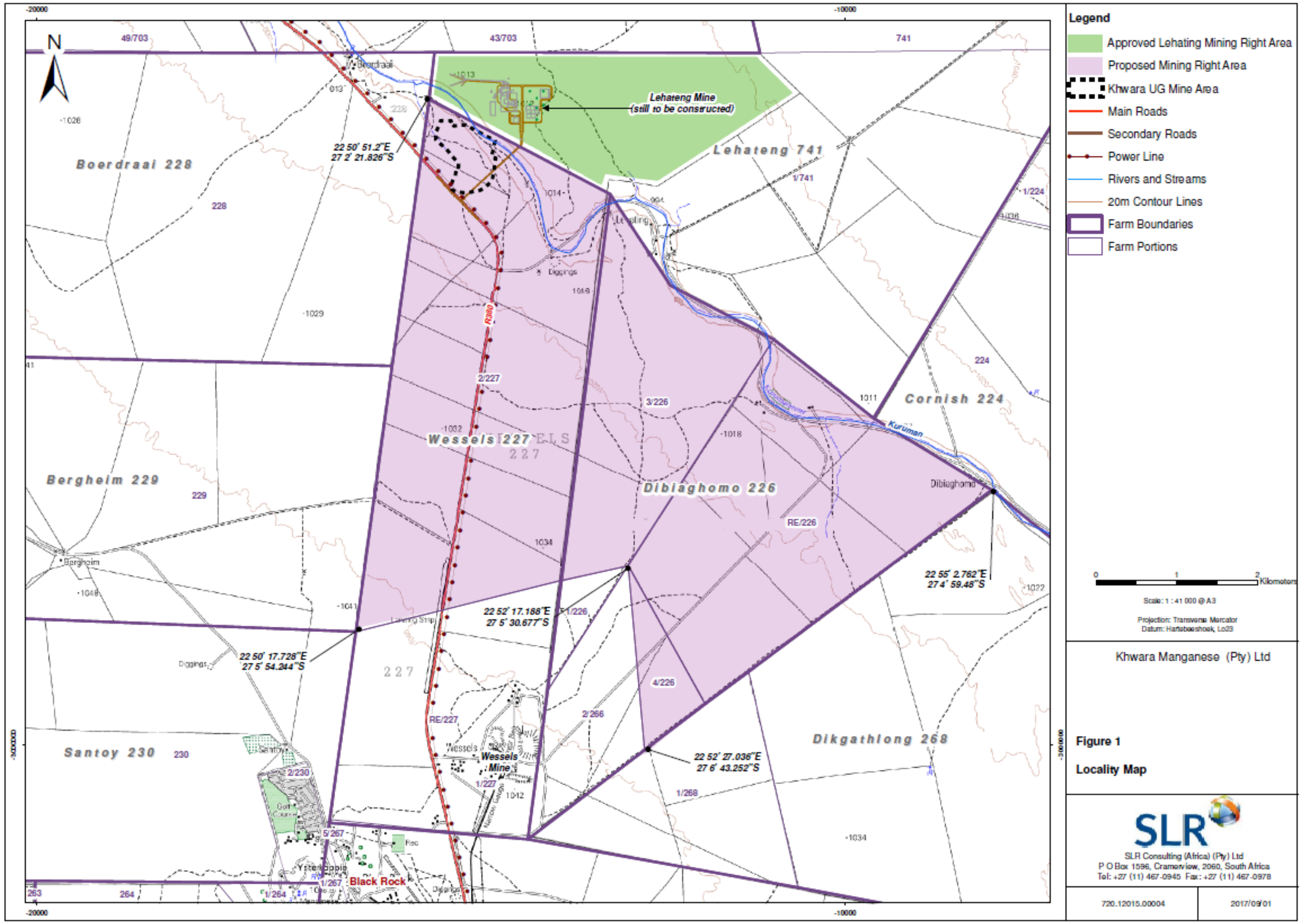

Figure 1: Locality map.

2. DETAILS OF SPECIALIST

Geohydrologist Mihai Muresan prepared this groundwater report, with assistance from Linda Munro, an environmental assessment practitioner. The details of the report authors are provided in Table 1 below.

Table 1: Details of original report authors.

Details	Project manager, author and reviewer	Co-author
Name	Mihai Muresan	Linda Munro
Tel No.:	011 467 0945	011 467 0945
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Key qualifications	M.Sc. in Hydrogeology and Engineering Geology	M.Sc. in Environmental Science
Experience	Over 25 years	Over 15 years
Professional registration	South African Council for Natural Scientific Professions: registration number	South African Council for Natural Scientific Professions: registration number

3. DECLARATION

I, Mihai Muresan hereby declare that I am an independent consultant, who has no interest or personal gains in this proposed project whatsoever, except receiving fair payment for rendering an independent professional service.

I am a hydrogeologist with over 25 years' experience conducting hydrogeological assessments for the mining industry. I am a registered professional scientist with the South African Council for Natural Scientific Professions.

My curriculum Vitae is provided in Appendix A.

4. GEOGRAPHICAL SETTING

4.1 TOPOGRAPHY AND DRAINAGE

The proposed project area is located in a relatively flat area with gentle slopes to the North East. The elevation on site varies from 990 m to 1107 m above mean sea level (mamsl). The Kuruman River is located on the north-eastern boundary of the proposed project site (Figure 2). The Kuruman River is ephemeral in nature and as such will only flow during heavy rain events and can be associated with a perched water table.

The general area surrounding the proposed project area is characterised with relatively flat with gentle slopes with the Koranna Berg mountain range located to the south west of the proposed project area respectively (Figure 1).

4.2 CLIMATE

4.2.1 Regional Climate

The proposed project area falls within the Northern Steppe Climatic Zone, as defined by the South African Weather Bureau. This is a semi-arid region characterised by seasonal rainfall, hot temperatures in summer, and colder temperatures in winter.

4.2.2 Rainfall

The mean annual precipitation (MAP) for the site is more than 300 mm/year. The mean annual rainfall measured at the nearby Winton (40 km away) and Milner (17 km away) weather stations ranges between 330 mm and 362 mm respectively. Rainfall is typically in the form of thunderstorms during the summer months of October to March. The peak rainy period occurs between the months of January to March. Rainfall is erratic and may vary significantly from year to year. Monthly average rainfall for each month is presented in Summary of monthly rainfall for the proposed project site (SLR, February 2013). below (SLR, September 2013).

Table 2: Summary of monthly rainfall for the proposed project site (SLR, February 2013).

Month	Rainfall (mm)	
	Winton - 392148 w	Milner - 393083 w
January	62.1	66.1
February	61.2	61.4
March	58.0	66.4
April	31.8	35.5
May	13.9	16.1
June	4.2	6.0
July	2.5	1.9
August	4.9	4.2
September	6.2	6.2
October	16.2	19.0
November	25.7	32.0
December	43.3	46.8
Annual	330.1	361.6

4.2.3 Evaporation

The WR2005 (2009) shows a range in annual evaporation for the site of greater than 2118 mm (A-Pan estimate). A correction factor of approximately 0.65 (based upon the annual average for monthly correction factors) allows for the translation of the A-Pan estimate to the evaporation estimate for a very shallow body of water (Lake), equivalent to 1375 mm. A summary of the adopted evaporation data for the proposed project area is provided in Table 3 below which indicates that the proposed project area is characterised by high evaporation rates (SLR, September 2013).

Table 3: Summary of evaporation data (SLR, February 2013).

Months	Mean monthly a-pan evaporation (mm)	Mean monthly lake evaporation (mm)
January	259.0	169.7
February	208.4	144.9
March	161.3	112.1
April	122.3	83.9
May	113.2	76.8
June	82.5	56.1
July	99.1	63.3
August	131.2	81.8
September	188.5	109.9

Months	Mean monthly a-pan evaporation (mm)	Mean monthly lake evaporation (mm)
October	236.3	135.9
November	243.6	157.8
December	272.7	183.3
Total	**2118.1**	**1375.7**

5. SCOPE OF WORK

The objective of the study was to construct and run a numerical groundwater model to simulate the proposed Mn48 mine and to determine the extent and magnitude of a possible cone of drawdown developed during and post-mining. The study was required to cumulatively assess the dewatering impacts from the Mn48 mining operations.

6. METHODOLOGY

6.1 DESK STUDY

A desk study was undertaken to collate all pertinent data:

- Geological
- Hydrogeological
- Mining

The available information examined which was applicable to the groundwater study is listed in Table 4.

Table 4: Sources of data.

Project	Document Title	Author and Reference	Document Date
Ntsimbintle Groundwater Assessment	Groundwater investigation for Ntsimbintle mine	Water Geosciences Consulting Ntsimbintle 27/02/09	February 2009
Groundwater Report – Lehating 741	Groundwater Report – Lehating 741	Metago Water Geosciences	April 2011
Numerical Modelling	Lehating Contaminant Transport Model Report	SLR Consulting	August 2013
Khwara Monitoring	Khwara Manganese Hydrocensus	SLR Consulting (Africa) (Pty) Ltd	September 2016

The reports and documents pertinent to the hydrogeological study are briefly overviewed below:

- A regional groundwater flow model was developed based on the available and determined (i.e. site specific) aquifer parameters to evaluate the potential impacts of mining activities on groundwater flow and quality. The numerical model is used to predict the development of the cone of drawdown as underground mining is progressing.
- The mining information was transmitted by the Mn48 Mine and consisted of future underground mining plans for the Mn48 Mine.

6.2 HYDROCENSUS

A hydrocensus was undertaken in September 2016. The objective of the hydrocensus was to re-visit groundwater boreholes identified during the 2013 hydrocensus conducted for the Lehating EIA, identify new groundwater boreholes, and measure and sample all possible groundwater point within a 7 km radius from the mine.

During the course of the hydrocensus, thirty (30) boreholes were identified and inspected. Details of the boreholes inspected are presented in Table 5 and Figure 2 illustrates the locations of identified boreholes in relation to the Project Area. An additional borehole is located on the farm Boerdraai and is used for domestic purposes. This borehole was equipped and could not be sampled.

For each borehole identified, parameters including the location, groundwater level, water quality, and groundwater usage including extraction volumes and application observations were recorded. In addition, groundwater sampling was conducted at selected sites in order to gather water quality information for the area.

The hydrocensus shows that the majority of boreholes identified are not used and are prospecting boreholes, however some boreholes were identified that are utilised for domestic purposes or livestock watering.

Table 5: Summary of hydrocensus boreholes.

Sample ID	Farm	Owner	Coordinates			Sampled	Water Use	Equipment	Condition
			Lat	Long	Z				
BD 1	Boerdraai 228	Gert Stander	-27.03589	22.8462	1011	Yes	Not in use	Not Equipped	Good
BOER 04	Boerdraai 228	Gert Stander	-27.03573	22.8477	1009	Yes	Not in use	Not Equipped	Good
BOER 06	Boerdraai 228	Gert Stander	-27.05772	22.7968	1038	Yes	Not in use	Not Equipped	Good
BOER 06 ALT	Boerdraai 228	Gert Stander	-27.05798	22.79683	1029	No			
BOER 07	Boerdraai 228	Gert Stander	-27.05126	22.79364	1030	No	Not in use	Not Equipped	Good
CORN 01	Cornish 224	Joseph Van Der Walt	-27.08263	22.91569	1011	Yes	Livestock watering	Windpump	Good
DIBIA 01	Dibiakgomo 226	Joseph Van Der Walt	-27.07283	22.88887	998	Yes	Livestock watering	Windpump	Good
DW 10	Dibiakgomo 226	Joseph Van Der Walt	-27.08142	22.74059	1057	Yes	Not in use	Not Equipped	Good
ELIZ 01	Dibiakgomo 226	Joseph Van Der Walt	-27.11189	22.77296	1056	Yes	Livestock and Domestic	Mono Pump	Good
VDM 01	Dibiakgomo 226	Joseph Van Der Walt	-27.08033	22.75013	1054	Yes	Domestic - All purposes	Submersible	Good
20LEXUK01	Lehating 741	ER Van Schalkwyke	-27.03599	22.835329	1008	No	Not in use	Not Equipped	Good
LEH 04	Lehating 741	ER Van Schalkwyke	-27.0537	22.87367	1005	Yes	Not in use	Not Equipped	Bad
LEH 05	Lehating 741	ER Van Schalkwyke	-27.05658	22.87487	1003	Yes	Domestic - All purposes	Submersible	Good
LEX	Lehating 741	ER Van Schalkwyke	-27.03728	22.84897	1010	Yes	Not in use	Not Equipped	Good
LEX 02	Lehating 741	ER Van Schalkwyke	-27.03708	22.85147	1012	Yes	Not in use	Not Equipped	Good
LEX 03	Lehating 741	ER Van Schalkwyke	-27.04034	22.85353	1005	Yes	Not in use	Not Equipped	Good
LEX 13	Lehating 741	ER Van Schalkwyke	-27.03986	22.85169	1009	No	No in use	Not Equipped	Good
LEX 14	Lehating 741	ER Van Schalkwyke	-27.03865	22.85645	1007	Yes	Not in use	Not Equipped	Good
LEX 15	Lehating 741	ER Van Schalkwyke	-27.03733	22.85312	1008	Yes	Not in use	Not Equipped	Good
LEX 17	Lehating 741	ER Van Schalkwyke	-27.03652	22.85015	1013	Yes	Not in use	Not Equipped	Good
LEX 18	Lehating 741	ER Van Schalkwyke	-27.03515	22.85042	1012	No	No in use	Not Equipped	Good
LEX 19	Lehating 741	ER Van Schalkwyke	-27.03978	22.85486	1006	Yes	Not in use	Not Equipped	Good
LEX 1A	Lehating 741	ER Van Schalkwyke	-27.03495	22.84873	1012	No	Not in use	Not Equipped	Good
LEX 20	Lehating 741	ER Van Schalkwyke	-27.04116	22.85587	1008	No	Not in use	Not Equipped	
LEX 21	Lehating 741	ER Van Schalkwyke	-27.0411	22.84551	1110	Yes	Not in use	Not Equipped	Good
LEX 24	Lehating 741	ER Van Schalkwyke	-27.04127	22.85354	1000	No	No in use	Not Equipped	Good
LEX 28	Lehating 741	ER Van Schalkwyke	-27.0391	22.86098	1005	Yes	Not in use	Not Equipped	Good

Sample ID	Farm	Owner	Coordinates			Sampled	Water Use	Equipment	Condition
			Lat	Long	Z				
LISAM	Lehating 741	ER Van Schalkwyke	-27.03598	22.88484	1014	No	No in use	Not Equipped	Good
MOLLO 01	Moller Ville 703	Johan Mollert	-27.01727	22.81568	991	Yes	Domestic - All purposes	Submersible	Good
WESSELS	Wessel Portion 2	Mine	-27.04588	22.84911	1007	No	Not in use	Not Equipped	Good
WESSELS 2	Wessel Portion 2	Mine	-27.04787	22.84975	1009	Yes	Domestic - All purposes	Submersible	Good

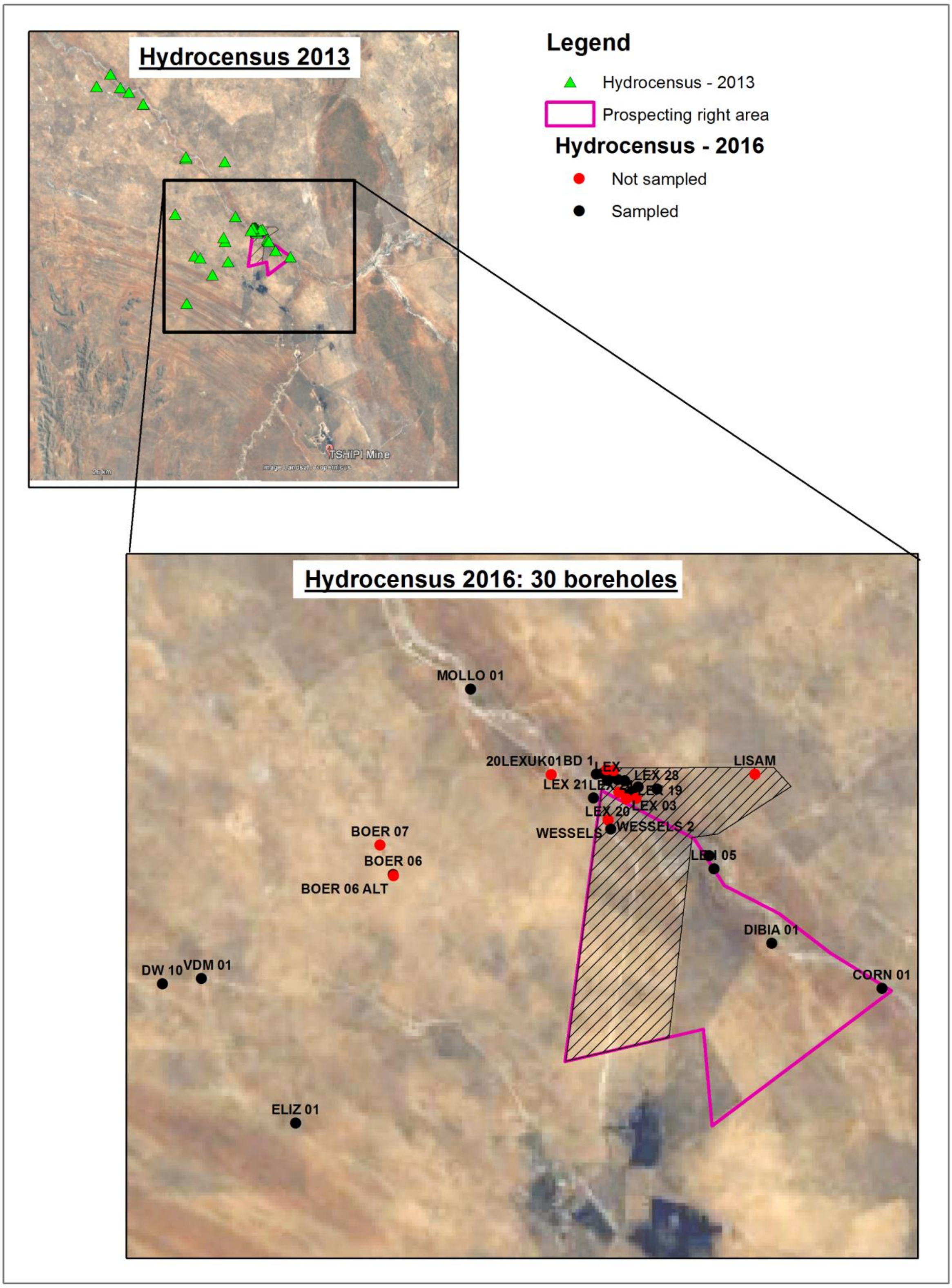

Figure 2: Hydrocensus points.

Where possible, the depth to groundwater and the depth to the base of each well were measured, using a Solinst dip meter. Depths were measured against the top of casing and ground level (Table 6).

Table 6: Mn48 Hydrocensus – Water level and field parameters.

Type	Sample ID	Water level					Field Parameters		
		mbcl	mbgl	mamsl	Casing Height (m)	Water Level Status	pH	EC	TEMP
Prospecting	BD 1	35.47	35.4	975.6	0.07	Static	8.24	283.00	22.40
Prospecting	BOER 04	37.1	37.05	971.95	0.1	Static	7.95	574.00	23.10
Prospecting	BOER 06	68.87	68.83	969.17	0.04	Static	7.64	402.00	22.40
Prospecting	BOER 06 ALT	-	-	1029					
Prospecting	BOER 07	84.24	83.84	946.16	0.4	Static			
Farm Borehole	CORN 01	-	-	-			8.30	319.00	26.90
Farm Borehole	DIBIA 01	-	-	-			7.85	304.00	26.10
Prospecting	DW 10	74.26	74.26	982.74	0	Static	7.82	362.00	24.80
Farm Borehole	ELIZ 01	62.34	62.06	993.94	0.28	Static	7.98	191.00	21.20
Farm Borehole	VDM 01	70.56	70.22	983.78	0.34	Pumping	7.67	392.00	24.20
Prospecting	20LEXUK01	-	-	-					
Prospecting	LEH 04	20.94	20.56	984.44	0.38	Static	9.06	599.00	24.50
Farm Borehole	LEH 05	-	-	-			7.53	917.00	22.40
Prospecting	LEX	59.34	59.26	950.74	0.08	Static	8.81	1073.00	26.50
Prospecting	LEX 02	57.6	57.57	954.43	0.03	Static	9.63	353.00	28.10
Prospecting	LEX 03	28.9	28.56	976.44	0.34	Static	7.68	303.00	25.10
Prospecting	LEX 13	34.77	34.57	974.43	0.2	Static			
Prospecting	LEX 14	64.81	64.73	942.27	0.08	Static	8.69	503.00	336.00
Prospecting	LEX 15	62.69	62.55	945.45	0.14	Static	8.34	781.00	27.50
Prospecting	LEX 17	57.98	57.82	955.18	0.16	Static	7.84	396.00	23.40
Prospecting	LEX 18	31.16	30.97	981.03	0.19	Static			
Prospecting	LEX 19	46.62	46.52	959.48	0.1	Static	6.82	431.00	22.60
Prospecting	LEX 1A	53.41	53.27	958.73	0.14	Static			
Prospecting	LEX 20	-	-	-					
Prospecting	LEX 21	45.16	45.03	1064.97	0.13	Static	7.67	386.00	28.30
Prospecting	LEX 24	20.83	20.63	979.37	0.2	Static			
Prospecting	LEX 28	40.25	40.14	964.86	0.11	Static	8.79	345.00	25.70
Prospecting	LISAM	54.63	54.63	959.37	0	Static			
Farm Borehole	MOLLO 01	46.06	44.49	946.51	1.57	Static	8.11	459.00	20.20
Farm Borehole	WESSELS	54.98	54.8	952.2	0.18	Static			
Farm Borehole	WESSELS 2	58.58	58.28	950.72	0.3	Recovering	6.98	291.00	22.40

6.2.1 Groundwater Quality

Sample Locations and Methodology

Groundwater samples were collected at twenty-three (23) of the boreholes visited by SLR. Sampled boreholes were selected based on location, in order to gather a spread of data across the area, and also based on operational status. Boreholes with installed and frequently operational pumps were selected as preferred sampling points to ensure water within the boreholes was representative of the intersected aquifer.

A number of samples were collected directly from the boreholes using disposable bailers and with a few groundwater samples collected from storage dams in which the borehole pumped to. Field parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature (°C) were measured using a calibrated multi-meter.

Groundwater quality results are presented in Table 7 and show elevated concentrations of electrical conductivity, total dissolved solids, chloride, fluoride, nitrate, manganese and selenium when compared to the South African National Standards 241 of 2015.

Table 7: Mn48 – Groundwater quality results.

Determinant	pH – Value at 25°C*	Electrical Conductivity in mS/m at 25°C*	Total Dissolved Solids at 180°C	Total Alkalinity as $CaCO_3$	Chloride as Cl	Sulphate as SO_4		Fluoride as F	Nitrate as N	Calcium as Ca
Unit	pH units	mS/m	mg/L	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l
SANS 241 (2015) DWS	5 - 9.7	<170	<1200		<300	<250	<500	<1.5	<11	
Risk	Operational	Aesthetic	Aesthetic		Aesthetic	Aesthetics	Acute	Chronic health	Chronic health	
Lex 04	8.3	65.5	340	172	137	2		0.3	0.2	3
Lex 02	8.7	57.1	308	100	109	42		0.2	0.1	11
Lex 05	7.8	111	648	424	114	61		0.2	6.8	70
Alex 03 ALT	7.8	53.8	258	120	115	2		0.2	0.2	33
Alex 19	7.8	43.5	208	185	159	2		0.2	0.2	19
Mollo 01	7.4	158	940	324	264	155		0.7	3.5	63
Lex 28	7.9	79.6	376	148	192	2		0.2	0.4	11
Lex 21	8.3	66.6	378	240	87	17		0.02	0.6	7
VDW 01	7.9	103	662	296	108	48		2	24	83
Lex 14	7.9	73.1	364	100	192	2		0.3	0.2	14
Wessels 2	7.8	193	1204	444	338	146		0.4	2.5	97
Corn 01	8.1	106	614	304	150	84		0.2	9.9	35
Boer 01	8	85.2	478	372	97	8		0.2	0.2	20
Boer 04	7.7	176	478	816	111	2		0.2	0.2	7
Lex 24	7.8	95.7	534	436	104	18		2	0.4	40
Elize 01	7.9	83.4	550	288	66	38		0.2	15	70
Lex 17	8.7	55.6	294	188	88	2		0.2	0.2	6
Lex 15	8.6	59.8	278	48	170	2		0.4	0.2	8
Lea 4	8.1	143	712	112	403	2		0.3	0.3	21
Boer 04 Alt	8.1	77.4	400	296	98	2		0.2	0.5	33
DW 10	7.8	90.4	528	408	76	12		0.3	0.5	74
Bib 19 01	7.7	128	770	424	166	95		0.2	8.2	76
Lex 13	8.4	53.7	238	140	106	2		2	0.2	9

Determinant	Magnesium as Mg	Potassium as K	Sodium as Na	Zinc as Zn	Aluminium as Al	Antimony as Sb	Arsenic as As	Cadmium as Cd	Total Chromium as Cr	Cobalt as Co
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241 (2015) DWS			<200	<5	<0.3	<0.02	<0.01	<0.003	<0.05	
Risk			Aesthetic	Aesthetic	Operational	Chronic health	Chronic health	Chronic health	Chronic health	
Lex 04	36	5.1	68	0.02	0.1	0.01	0.01	0.01	0.01	0.01
Lex 02	14	6.9	78	0.035	0.1	0.01	0.01	0.01	0.01	0.01
Lex 05	78	3.6	41	0.118	0.1	0.01	0.01	0.01	0.01	0.01
Alex 03 ALT	25	2.3	23	0.026	0.1	0.01	0.01	0.01	0.01	0.01
Alex 19	16	3.6	40	0.034	0.1	0.01	0.01	0.01	0.01	0.01
Mollo 01	55	6.7	184	0.22	0.1	0.01	0.01	0.01	0.01	0.01
Lex 28	52	6.3	53	0.028	0.1	0.01	0.01	0.01	0.01	0.01
Lex 21	49	5.1	46	0.063	0.1	0.01	0.01	0.01	0.01	0.01
VDW 01	40	10.2	58	0.049	0.1	0.01	0.01	0.01	0.004	0.01
Lex 14	21	6.1	89	0.031	0.1	0.01	0.01	0.01	0	0.01
Wessels 2	92	10.2	157	0.231	0.1	0.01	0.01	0.01	0	0.01
Corn 01	79	3.5	47	0.042	0.1	0.01	0.01	0.01	0.002	0.01
Boer 01	71	4.5	41	0.018	0.1	0.01	0.01	0.01	0	0.01
Boer 04	63	17.5	52	0.037	0.1	0.01	0.01	0.01	0	0.01
Lex 24	64	3.7	58	0.021	0.1	0.01	0.01	0.01	0	0.01
Elize 01	27	8	48	0.16	0.1	0.01	0.01	0.01	0	0.01
Lex 17	36	3.6	52	0.038	0.1	0.01	0.01	0.01	0	0.01
Lex 15	3	3.9	92	0.03	0.1	0.01	0.01	0.01	0	0.01
Lea 4	41	7.5	183	0.028	0.1	0.01	0.01	0.01	0	0.01
Boer 04 Alt	41	16	46	0.026	0.1	0.01	0.01	0.01	0	0.01
DW 10	39	9.3	44	0.032	0.1	0.01	0.01	0.01	0	0.01
Bib 19 01	81	3.4	66	2.079	0.1	0.01	0.01	0.01	0	0.01
Lex 13	25	3.9	42	0.034	0.1	0.01	0.01	0.01	0	0.01

Determinant	Copper as Cu	Iron as Fe		Lead as Pb	Manganese as Mn		Nickel as Ni	Selenium as Se	Vanadium as V
Unit	mg/l	mg/l		mg/l	mg/l		mg/l	mg/l	mg/l
SANS 241 (2015) DWS	<2	<0.3	<2	<0.01	<0.1	<0.4	<0.07	<0.04	
Risk	Chronic health	Aesthetics	Chronic health	Chronic health	Aesthetics	Chronic health	Chronic health	Chronic health	
Lex 04	0.01	0.025		0.01	0.025		0.01	0.016	0.01
Lex 02	0.01	0.025		0.01	0.215		0.01	0.024	0.01
Lex 05	0.01	0.025		0.01	0.025		0.01	0.02	0.01
Alex 03 ALT	0.01	0.025		0.01	**0.57**		0.01	0.039	0.01
Alex 19	0.01	0.025		0.01	0.033		0.01	0.017	0.01
Mollo 01	0.01	0.025		0.01	0.025		0.01	0.049	0.01
Lex 28	0.01	0.025		0.01	0.033		0.01	0.029	0.01
Lex 21	0.01	0.025		0.01	0.034		0.01	0.019	0.01
VDW 01	0.003	0.025		0.01	0.025		0.01	0.025	0.014
Lex 14	0.001	0.025		0.01	0.115		0.01	0.032	0.01
Wessels 2	0.002	0.025		0.01	0.184		0.01	0.075	0.01
Corn 01	0.002	0.025		0.01	0.025		0.01	0.043	0.01
Boer 01	0.001	0.025		0.01	0.055		0.01	0.032	0.01
Boer 04	0	0.192		0.01	0.074		0.01	0.03	0.01
Lex 24	0	0.025		0.01	0.052		0.01	0.022	0.01
Elize 01	0.001	0.025		0.01	0.025		0.01	0.013	0.01
Lex 17	0	0.025		0.01	0.025		0.01	0.024	0.01
Lex 15	0	0.025		0.01	0.025		0.01	0.028	0.01
Lea 4	0.001	0.025		0.01	**0.468**		0.01	0.075	0.01
Boer 04 Alt	0.001	0.025		0.01	0.025		0.01	0.027	0.01
DW 10	0.001	0.025		0.01	0.025		0.01	0.012	0.01
Bib 19 01	0.001	0.025		0.01	0.253		0.01	0.051	0.01
Lex 13	0.001	0.025		0.01	0.025		0.01	0.026	0.01

6.3 GROUNDWATER MODELLING

A three-dimensional groundwater numerical model was constructed using FEFLOW (finite elements) to simulate flow during and post mining. The results of the numerical model have been used for groundwater impact assessment.

7. PREVAILING GROUNDWATER CONDITIONS

7.1 GEOLOGY

7.1.1 Regional Geology

The proposed project is located on the south western outer rim of the Kalahari Manganese Field (KMF). The general stratigraphic column of the Kalahari Manganese Field is presented in Table 8.

Table 8: General stratigraphic column for the Kalahari Manganese Field.

<table>
<tr><th colspan="4">Supergroup / Group / Subgroup / Formation</th><th>Geological Description</th></tr>
<tr><td colspan="4">Kalahari Group</td><td>Kalahari sands, calcrete, clays & gravel beds</td></tr>
<tr><td colspan="5">Kalahari unconformity</td></tr>
<tr><td colspan="4">Karoo Supergroup</td><td>Dwyka tillite</td></tr>
<tr><td colspan="5">Dwyka unconformity</td></tr>
<tr><td colspan="3" rowspan="2">Olifantshoek Supergroup</td><td>Lucknow Formation</td><td>White ortho-quartzite</td></tr>
<tr><td>Mapedi Formation</td><td>Green, maroon and black shales and quartzites</td></tr>
<tr><td colspan="5">Olifantshoek unconformity</td></tr>
<tr><td rowspan="9">Transvaal Supergroup</td><td rowspan="9">Postmansburg Group</td><td rowspan="8">Voelwater Subgroup</td><td>Mooidraai Formation</td><td>Dolomite, chert</td></tr>
<tr><td rowspan="7">Hotazel Formation</td><td>Banded ironstone (upper)</td></tr>
<tr><td>Upper Mn Ore Body</td></tr>
<tr><td>Banded ironstone (middle)</td></tr>
<tr><td>Middle manganese body</td></tr>
<tr><td>Banded ironstone (middle)</td></tr>
<tr><td>Lower manganese body</td></tr>
<tr><td>Banded ironstone (lower)</td></tr>
<tr><td colspan="2">Ongeluk Formation</td><td>Andesitic Lava</td></tr>
</table>

Three beds of manganese ore are interbedded with the Banded Iron Formation (BIF) of the Hotazel Formation (Transvaal Supergroup).

The BIF of the Hotazel Formation typically consists of repeated thin layers of black iron oxides (magnetite or hematite) alternating with bands of iron-poor shales and cherts.

7.1.2 Local Geology

The Mn48 Mine is located on the south western outer rim of the Kalahari Manganese Field (KMF). Mn48 plans to exploit the manganese from the Hotazel Formation. The general stratigraphic column for the KMF is shown in Figure 3.

The Hotazel Formation is underlain by basaltic lava of the Ongeluk Formation (Transvaal Supergroup) and directly overlain by dolomite of the Mooidraai Formation (Transvaal Supergroup). The Transvaal Supergroup is overlain unconformably by the Olifantshoek Supergroup which consists of arenaceous sediments, typically interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The different formations present in the project area include the Mapedi and Lucknow units. The whole Supergroup has been deformed into a succession with an east-verging dip (SLR, 2014).

The Olifantshoek Supergroup is overlain by Dwyka Formation which forms the basal part of the Karoo Supergroup. At the mine this consists of tillite (diamictite) which is covered by sands, claystone and calcrete of the Kalahari Group (SLR, 2014)

The Hotazel Formation consists of Banded Iron Formation (BIF) and is made up of three manganese rich zones:

- Upper Manganese Ore Body (UMO)
- Middle Manganese Ore Body (MMO)
- Lower Manganese Ore Body (LMO)

The UMO is 10 cm to 15 cm thick and comprises moderate deposits of manganese. The poorly mineralised MMO is approximately 1 m thick and not economically efficient. The LMO is a highly mineralised unit consisting of six important mineralised zones (X, Y, Z, M. C and N).

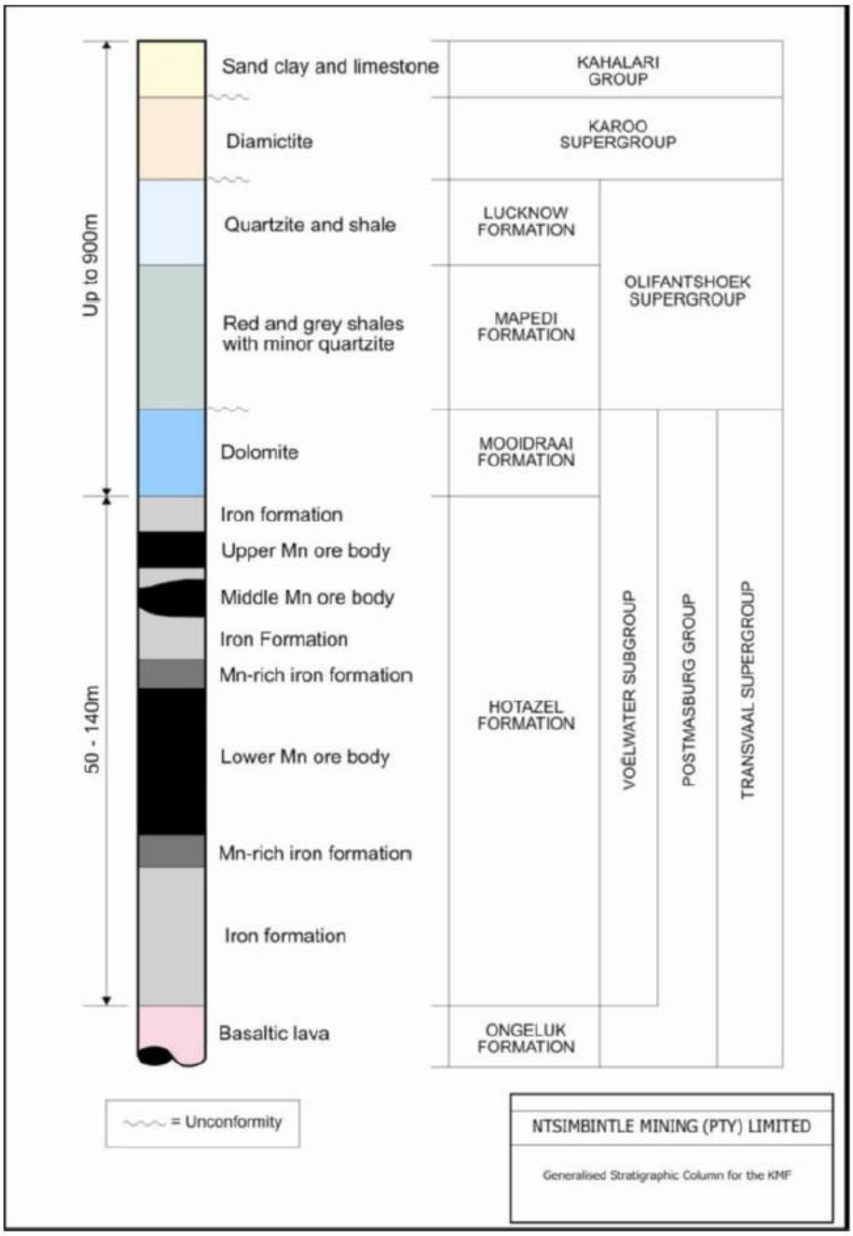

Figure 3: Generalised stratigraphic column for the KMF.

7.2 ACID-GENERATION CAPACITY

Geochemical analysis was conducted for the SLR (2013) study at the Lehating Mine, and this information is relevant to Mn48 (Khwara portion) because the geology is the same.

Laboratory tests to determine the potential of samples to produce Acid Rock Drainage (ARD) are generally grouped into two categories; static and kinetic tests. Static tests are relatively simple and undertaken as a preliminary assessment whereas kinetic tests are typically carried out if the results of the static tests are not conclusive or the samples are flagged as potentially acid generating

Static tests include Acid Base Accounting, sulphur speciation, inorganic carbon content, Net Acid Generation Tests and Synthetic Precipitation Leaching Procedure leach tests.

Acid Base Accounting (ABA) is an internationally accepted analytical procedure that screens the acid-producing and acid-neutralizing potential of a sample. The ABA tests assumes conservatively that all sulphur in the sample will react to form sulphuric acid, while some of the sulphur may also be present in non-acid producing sulphates, organic or elemental sulphur. An assessment of sulphur speciation is therefore undertaken to allow a better characterisation of the acid generating potential, which is related to the type of sulphur minerals present. Acid generation of samples with sulphide sulphur content below 0.3 % is considered short term.

The acid neutralising potential of a rock sample, predominantly from carbonates and exchangeable alkali and alkali earth cations is further characterised by the inorganic carbon content (as an estimate of carbonate contents in the tailing material) of the sample.

Net Acid Generation (NAG) tests directly determine the acid generating potential of sulphur minerals in a rock sample by oxidation with hydrogen peroxide (H2O2). The final NAG pH after complete oxidation of the sample is used as a screening criterion for the acid generation potential.

Four samples of various materials likely to be mined at Mn48 Mine (Lehating portion) were collected by a project geologist during exploratory drilling in December 2011 and sent to an accredited laboratory in Pretoria for static geochemical analysis. The sample consisted of the Kalahari Sands, Dwyka Formation and Ongeluk Lava which are considered to be representative of waste rock material.

The results of the ABA analysis are provided in Table 9 (SLR, Feb 2012).

Table 9: Summary of ABA and sulphur speciation results for the Mn48 Mine (Lehating portion) samples (SLR, February 2013).

Parameter	Kalahari Formation	Dwyka	Ongeluk Lava	Manganese Ore
NAG pH	6.72	6.8	4.18	6.45
NAG (kg H2So4/t)	<0.01	<0.01	1.176	<0.01
Paste pH	7.2	7.7	8	6.9
Total sulphur (%)	<0.01	Repeat Analysis	<0.01	0.05
Sulphate (SO_4^{2-}) Sulphur (%)	<0.01	Repeat Analysis	<0.01	0.04
Sulphate (S^{2-}) Sulphur (%)	0.01	Repeat Analysis	<0.01	<0.01
Acid potential (AP) (kg $CaCO_3$/t)	0.31	8.46	0.31	1.44
Total Carbon (%)	1.94	1.55	0.03	0.12
Organic Carbon (%)	0.05	0.46	0.01	<0.01
Inorganic Carbon (%)	1.89	1.09	0.02	0.11
Neutralising Potential (NP) (kg $CaCO_3$/t)	85.82	39.2	5.59	23.5
Net Neutralising Potential (NNP = NP + NA) - open	85.51	30.73	5.28	22.06
Net Neutralising Potential Ratio (NPR = NP/AP)	274.62	4.63	17.88	16.32
Assessment	Non-Acid Forming	Non-Acid Forming	Non-Acid Forming	Non-Acid Forming

The results suggest that all four samples are non-acid forming due to the limited sulphide sulphur content which is the primary source of acid. The total sulphur content of the manganese ore sample predominantly occurs as sulphate sulphur. This along with the paste pH of near neutral (6.9) suggests that the majority of sulphide minerals have been oxidised and the possibility of generating acid is low. The Kalahari sample demonstrates significant neutralising potential.

No residue material will however be disposed of on surface as part of the Mn48 Project.

7.3 HYDROGEOLOGY

7.3.1 Unsaturated Zone

From the groundwater risk assessment conducted by SLR (2013) it was established that the depth of the unsaturated zone is approximately 45 m. The unsaturated zone falls within the Kalahari Formation and consists of sand, clay and limestone.

7.3.2 Saturated Zone

A groundwater assessment was carried out by SLR in September 2013 for the Mn48 Mine (Lehating portion). From the investigations conducted two aquifers were distinguished to lie below the unsaturated zone within the Mn48 project area:

- Aquifer I: Shallow aquifer made of the Kalahari Beds, sand and calcrete
- Aquifer II: Deep fractured aquifer made of the Dwyka clay and the Mooidraai dolomite Formation.

The Kalahari sand and the sediment beds with its associated underlying calcrete layer overlie the low permeability Dwyka clay bed. The deeper fractured bedrock aquifer is formed from the Mooidraai dolomite Formation and Dwyka clay contact which acts as a confining layer (WGC, 2009).

7.3.3 Hydraulic Conductivity

A groundwater model was constructed in MODFLOW by SLR in 2013 to establish the groundwater regime with groundwater inflows into Mn48 Mine as well as to evaluate the potential future impacts on the groundwater flow regime with mine dewatering and possible contamination.

The summary of the initial hydraulic parameters, derived from the previous work is detailed in Table 10.

Table 10: Horizontal and vertical K of geological units used in previous modelling assessments in meters per day.

Aquifer	Hydraulic conductivity [m/d] Model Setup
Kalahari Deposits	0.975
Dwyka/Diamictites	0.03 – 0.975
Olifantshoek/Granite	0.006 – 0.178
Hotazel/BIF	0.01 – 0.975
Ongeluk/Basalt	0.013 – 0.23

7.4 GROUNDWATER LEVELS

Hydrocensus results and groundwater levels on site indicated that shallow groundwater levels correlated with surface topography. However, a similar correlation for deeper groundwater levels is not applicable. The groundwater level depths are provided in Table 6.

Of major importance for regional groundwater flow in the Mn48 Mine area is the continuous presence of an impermeable or semi-permeable interface between the upper, unconfined Kalahari aquifer and the deeper, confined Dwyka aquifer. This interface (i.e. a permeability contrast) prevents rapid vertical drainage of the Kalahari aquifer on a regional scale, thus permitting lateral groundwater flow in the Kalahari aquifer driven by topographic gradients. Vertical infiltration across this interface is controlled by the existence of major permeable zones such as regional fault systems, etc. Furthermore, there is no evidence of hydraulic connectivity between the river and groundwater.

7.5 GROUNDWATER QUALITY

Groundwater quality is discussed in section 6.2.1.

8. AQUIFER CHARACTERISATION

8.1 GROUNDWATER VULNERABILITY

The Aquifer Vulnerability Map of South Africa (Conrad et al. 1999c) indicates the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. Based on the map, the project area is classified as least to moderately vulnerable which implies the following:

- Least vulnerable: only vulnerable to conservative pollutants in the long term when continuously discharged or leached; and
- Moderately vulnerable: vulnerable to some pollutants, but only when continuously discharged or leached.

8.2 AQUIFER CLASSIFICATION

The classification scheme outlined in Table 11, (WRC Parsons, 1995) was created for strategic purposes as it allows the grouping of aquifer areas into types according to their associated supply potential, water quality and local importance as a resource.

Based on the aquifer classification map (Parsons and Conrad, 1998) the majority of study area is regarded a “poor aquifer” while the aquifer adjacent (west) to the proposed Mn48 portion is regarded as “minor” (Figure 4). A summary of the classification scheme is provided in Table 11. In this classification system, it is important to note that the concepts of Minor and Poor Aquifers are relative and that yield is not quantified. Within any specific area, all classes of aquifers should therefore, in theory, be present.

Therefore, Based on the 1:500 000 hydrogeological map sheet, Mn48 is located on an aquifer classed as a poor aquifer with potential groundwater yields between 0.1L/s and 2L/s.

Table 11: Aquifer classification (RSA).

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Min Requirements (1998)
Sole Source Aquifer	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High 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 (<150 mS/m).	High yielding aquifer (5-20 L/s) of acceptable water quality.
Minor Aquifer	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 both for local supplies and in supplying baseflow for rivers.	Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor quality water.
Non-Aquifer	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 L/s) of good quality water or moderately yielding aquifer (1-5 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

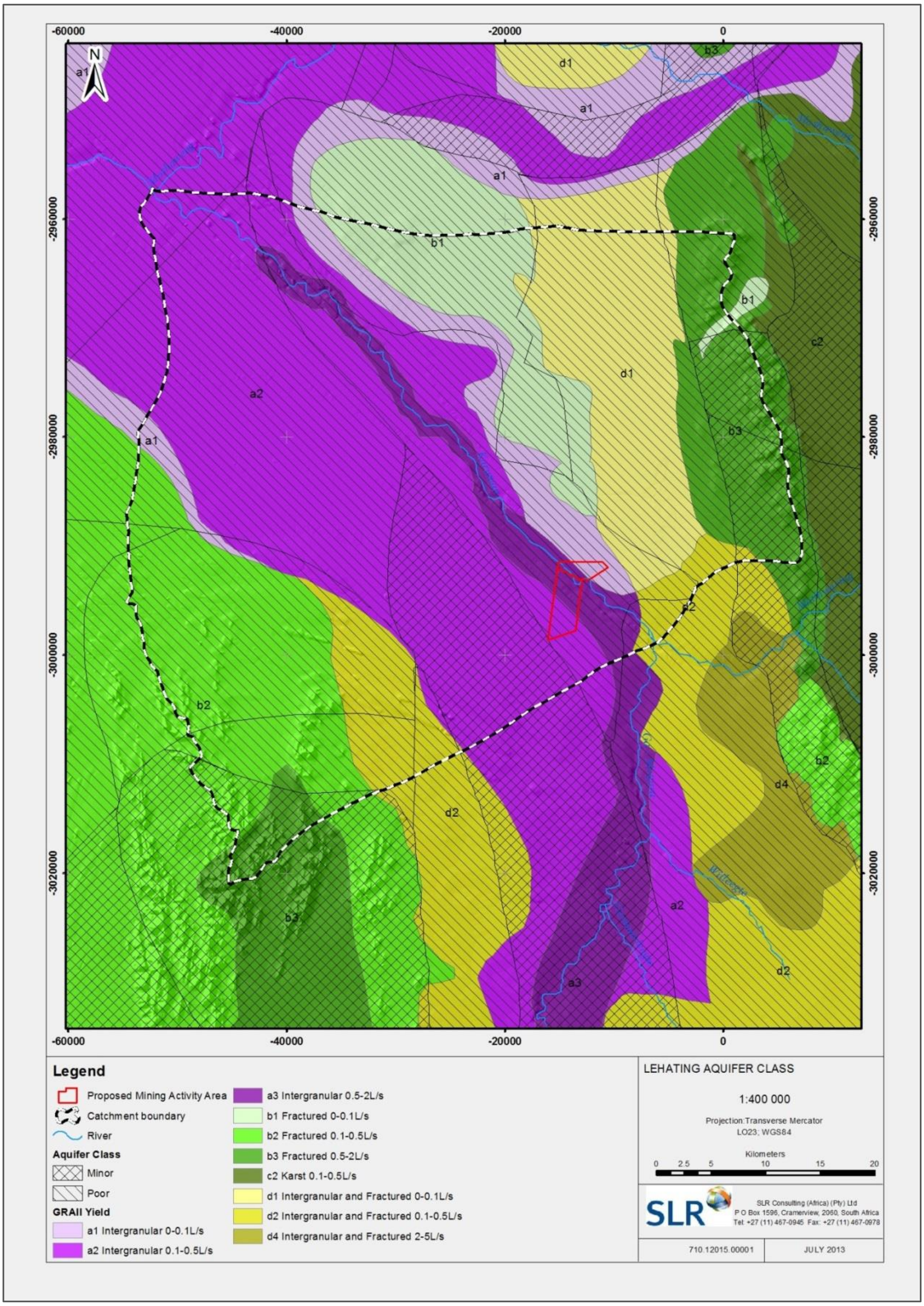

Figure 4: Aquifer classification map.

9. GROUNDWATER MODELLING

9.1 SOFTWARE MODEL CHOICE

For successful assessment of the mining and mining related activities impacts on the groundwater environment, FEFLOW (DHI-WASY) was selected to simulate groundwater flow and contaminant transport. FEFLOW is a finite elements groundwater flow and contaminant transport code appropriate for mining simulations.

9.2 MODEL SET-UP AND BOUNDARIES

The groundwater model domain for Mn48 Mine is shown in Figure 5. The model domain was selected based mainly on topography and the sub-catchments identified on the topographic data (RSA topography 50.000 series).

The northern model boundary and partially the southern boundary were selected as Specified head boundary, where groundwater flow in- and out- the model domain is allowed during predictive simulations.

The remaining boundaries are declared “no-flow” boundaries and generally represent watershed lines along the higher elevation in the area. The North-Eastern boundary was also included as a “no-flow” boundary as it delineates two sub-catchments, to the north and south, where the mine is situated.

From a groundwater flow point of view, all boundaries are sufficiently far from Mn48 mine, in such a way that they do not influence groundwater flow in the mine area.

9.3 GROUNDWATER ELEVATION AND GRADIENT

The groundwater elevation over the whole model domain was interpolated from the existing boreholes groundwater measurements, and compared with groundwater elevations from previous work (SLR, 2013). The initial (pre-mining) groundwater elevations computed for the model domain is shown in Figure 6.

The groundwater flow is from East-South-East towards North-West with a calculated gradient of 0.001 towards North-West.

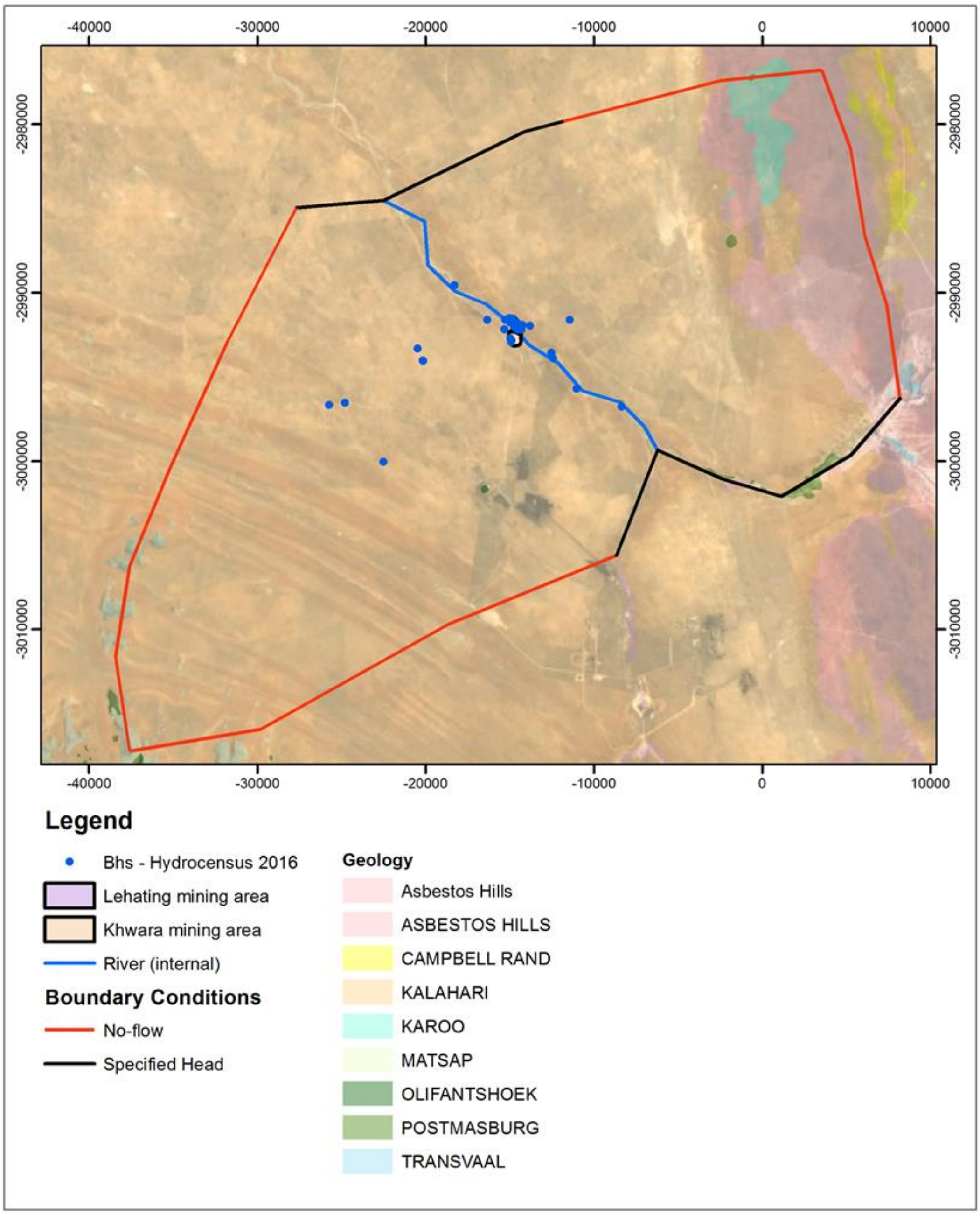

Figure 5: Mn48 model domain.

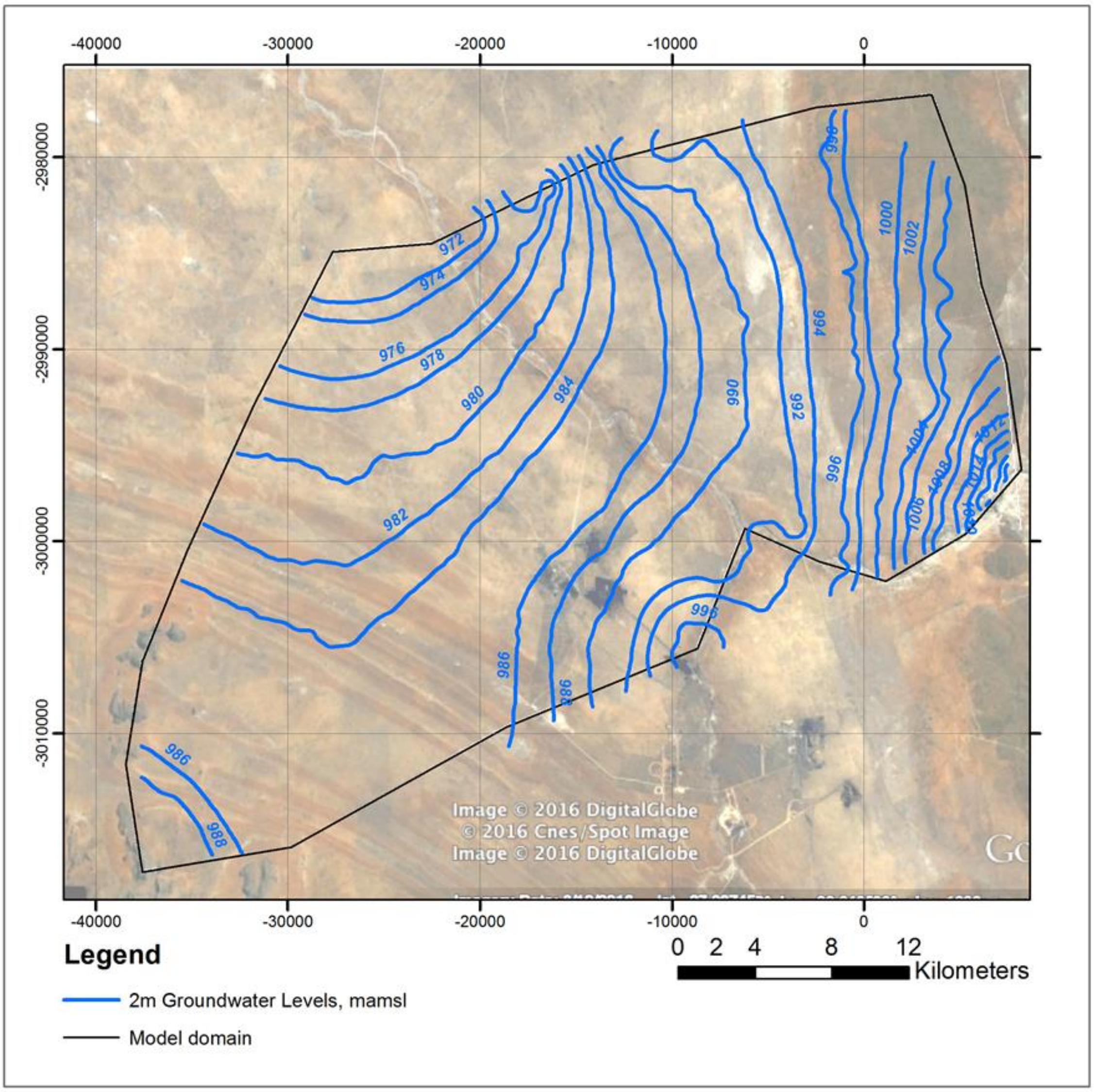

Figure 6: Pre-mining water levels.

9.4 GROUNDWATER SOURCES AND SINKS

Groundwater sources for the Khwara numerical model are represented mainly by rainfall recharge to the model. The annual recharge considered initially for the numerical model calibration is 2 x 10^{-4} m/d, calculated at 2% of M.A.P. The groundwater sinks are represented by the Lehating and Khwara underground mine voids (Figure 7).

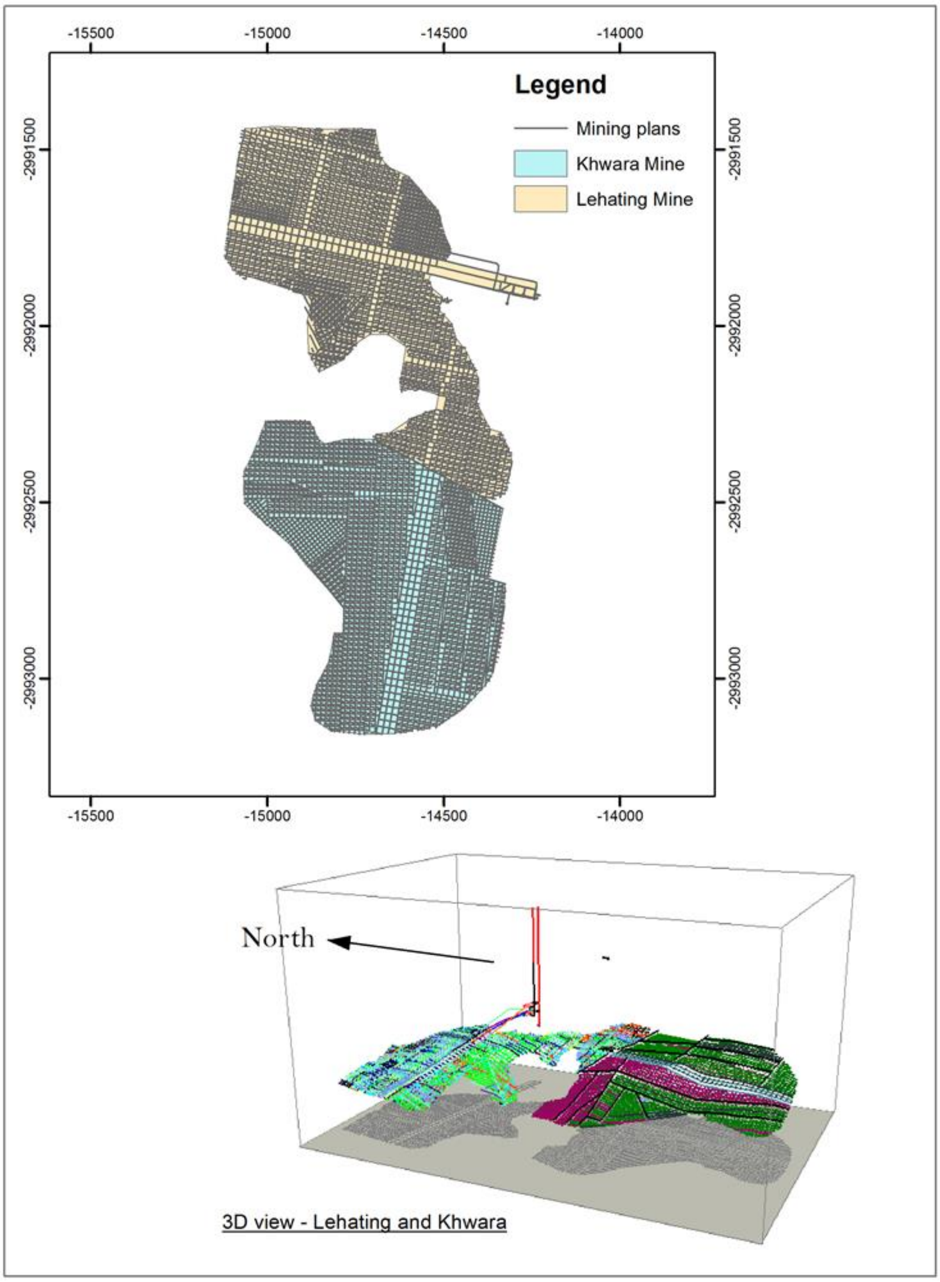

Figure 7: Mn48 – Lehating and Khwara underground mines.

9.5 CONCEPTUAL MODEL

Figure 8 illustrates the hydrogeological conceptual model which forms the basis of the groundwater numerical model. The conceptual model is simplification of the real-world conditions, but in the same time captures the main elements to be simulated in the numerical model.

The Kalahari layer is included across the full extent of the groundwater model as the deposits are surficial and aeolian. The Kalahari overlies the calcrete layer, which is a minor aquifer in this area. The deeper aquifer is represented by the banded ironstone formation (Hotazel). To avoid numerical non-convergence during the model run, the model is extended to a depth elevation of 300 mamsl, represented by the Basement formations.

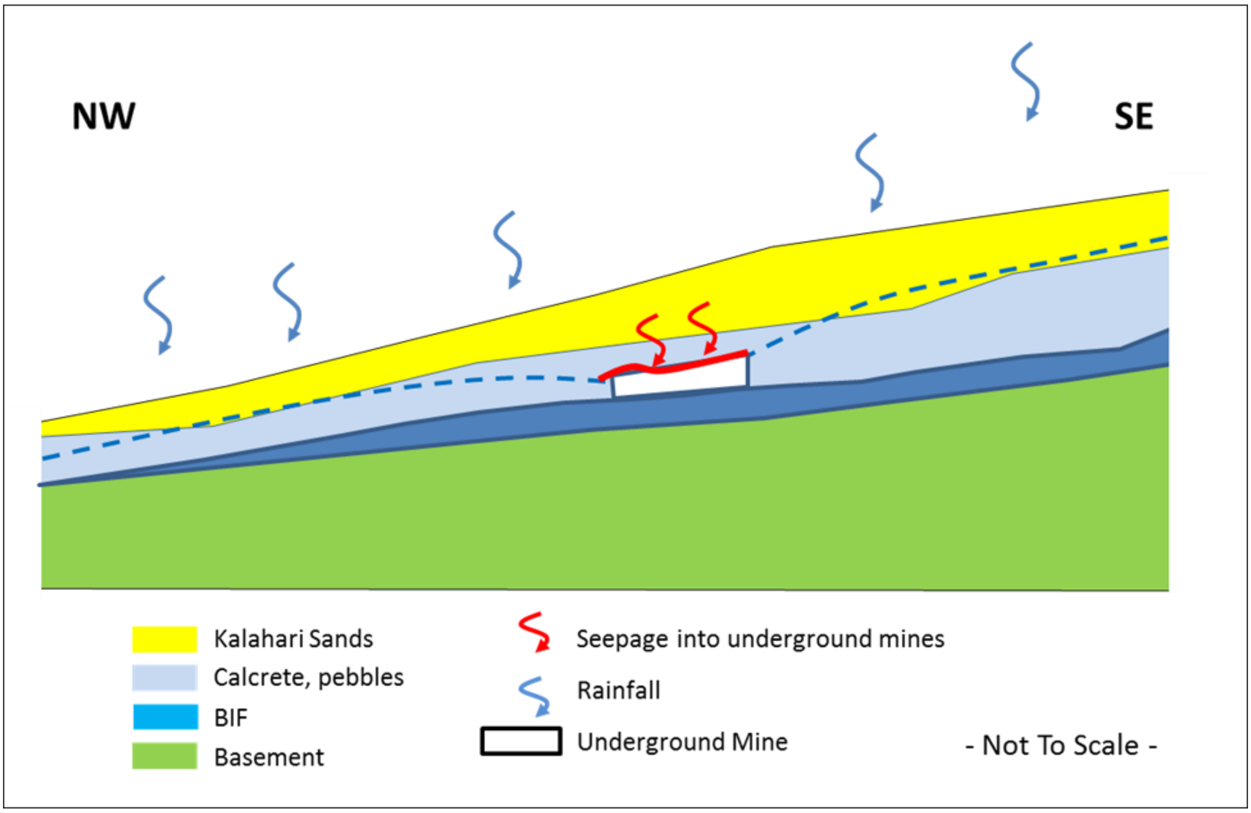

Figure 8: Mn48 – Hydrogeological conceptual model.

9.6 MODEL DISCRETISATION

The horizontal discretization of the model domain takes into consideration the geology and both underground mines, Khwara and Lehating. The resulting horizontal finite elements mesh is showed in Figure 9. The initial vertical discretization was based on the simplified geology described in the area (Table 12). This was further refined considering the mining levels (existing and future).

Table 12: Vertical layers (AGES, 2007).

No	Zone	Hydraulic conductivity (K)	Thick (m)	Trans-missivity (m^2/d)	Head gradient (1)	Darcy flux (m/d)	Recharge (mm/y)	Recharge (m/d)	Seep Vel (m/y)
1	Sand	6.00	5	30	0.005	0.030	344	9.42E-04	110
2	Calcrete	1.50	20	30	0.005	0.008	344	9.42E-04	27
3	BIF	1.00	30	30	0.005	0.005	344	9.42E-04	18
4	Faults	2.40	25	60	0.005	0.012	344	9.42E-04	44

The final vertical layering of Khwara groundwater model is shown in Table 13.

Table 13: Mn48 groundwater model – vertical discretisation.

Layer	Description	Top slice description
1	Kalahari	topo
2	Dwyka	top Dwyka
3	BIF1	top BIF
4	BIF2	Mining layer

Layer	Description	Top slice description
5	Lava	top Lava
6	Lava	interm

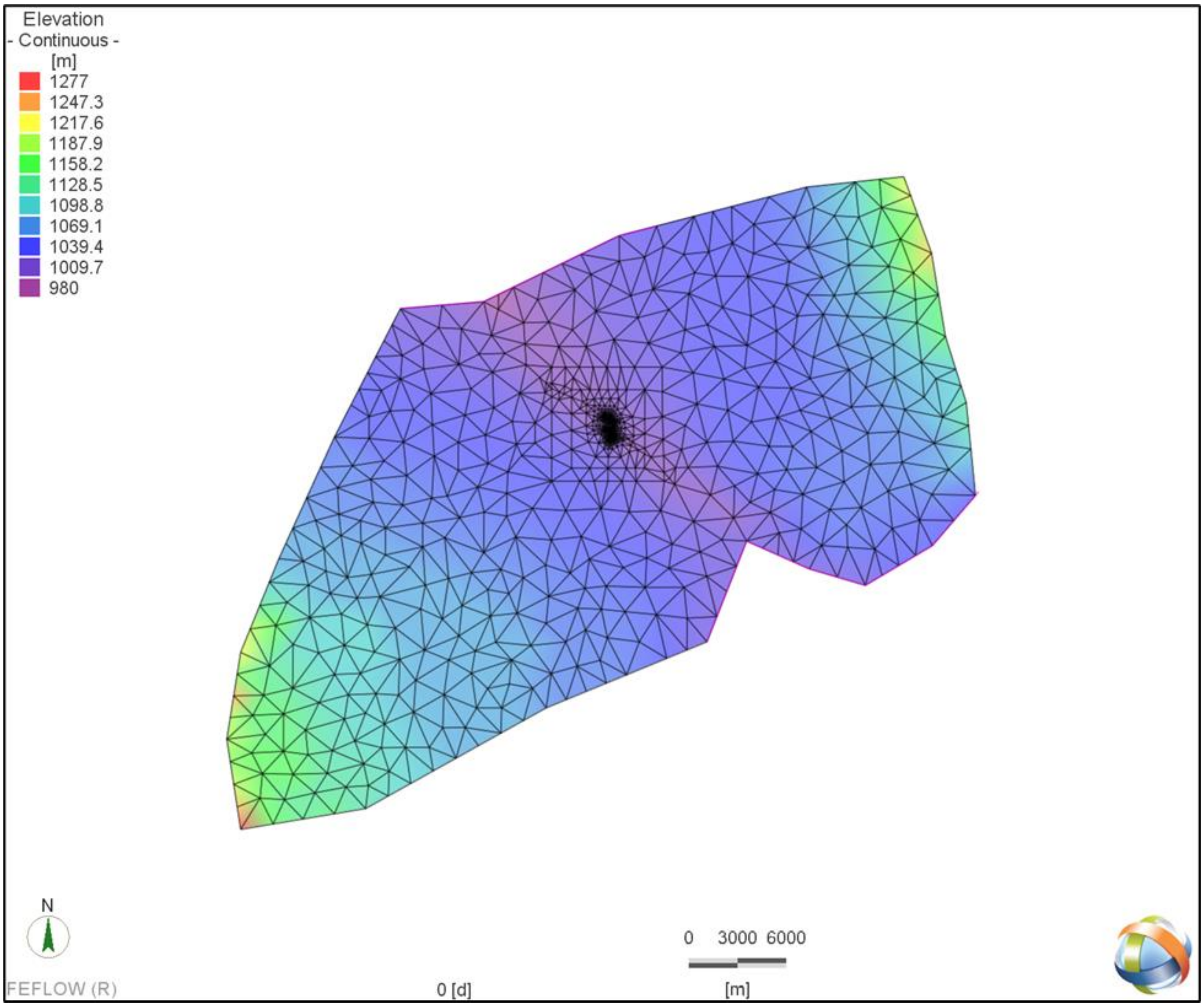

Figure 9: Mn48 groundwater model – Horizontal mesh.

The resulting 3-dimensional numerical model is illustrated in Figure 10, and can be summarized as follows:

- Model area: 600 km2
- Model bottom elevation: 500 mamsl
- Numbers of elements: 222,075
- Number of nodes: 119,488

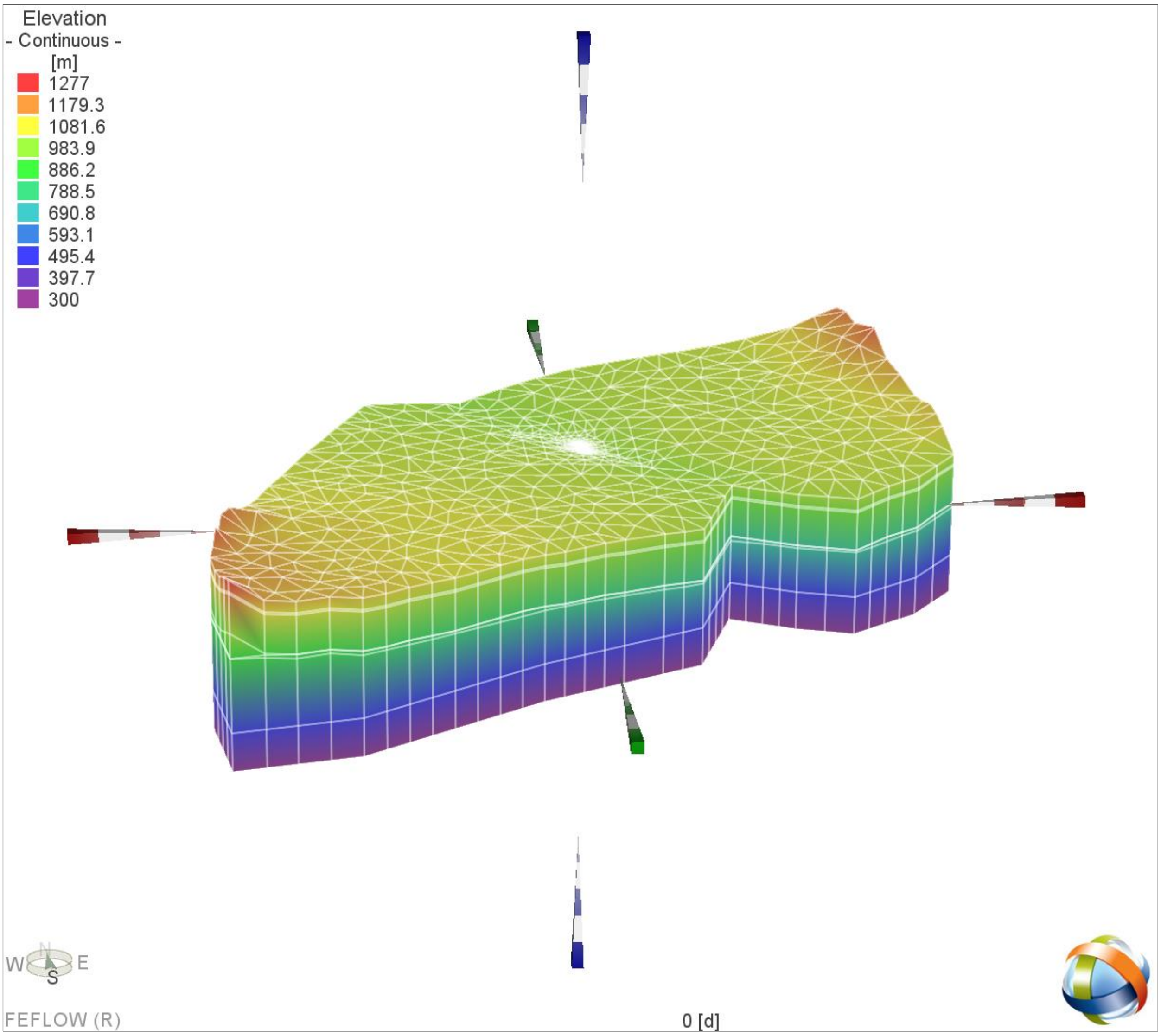

Figure 10: Mn48 – 3D numerical model.

9.7 NUMERICAL MODEL

9.7.1 Model Initials

Once the 3-D numerical model is constructed, hydraulic properties are assigned to the model elements.

The table below (Table 14) details the hydraulic properties assigned to the formations represented in the model.

Table 14: Mn48 groundwater model – hydraulic properties.

Aquifer	Kh	Kv
Kalahari Deposits	0.7	0.01
Dwyka/Diamictites	0.01	0.001
Olifantshoek/Granite	0.01	0.001
Hotazel/BIF	0.01	0.001
Ongeluk/Basalt	0.001	0.0001

The initial recharge assigned as in-out flow from top/bottom is 2 x 10^{-4} m/d, representing 2 % of M.A.P.

9.7.2 Model Calibration

The steady state calibration is performed to determine the suitability of hydraulic properties which allow groundwater flow and to compare the simulated hydraulic heads with the measure hydraulic heads in the observation points.

The calibration of the Mn48 groundwater model was run using the initial hydraulic properties assigned together with the hydraulic head values and average annual groundwater recharge computed from the average rainfall data throughout the model domain. Figure 11 shows the plot of measured hydraulic heads vs. simulated hydraulic heads.

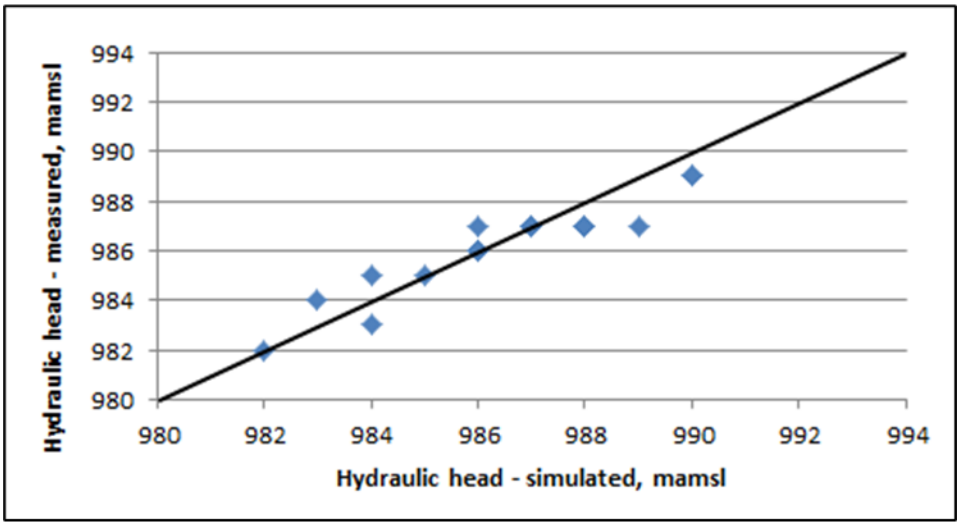

Figure 11: Hydraulic head – Measured vs simulated.

The differences between the measured hydraulic head and computed hydraulic head are very small, and the calibration was considered satisfactory. The RMSE and NRMSE, which represent the quantitative measure of the model calibration are within the prescribed groundwater model calibration guidelines (ASTM Guidelines) – Table 15.

A Normalised Residual Mean Square Error (NRMSE) value below 10 % is considered as an acceptable calibration.

Table 15: Mn48 groundwater model calibration.

Name	computed	measured	head_diff	Head diff^2
LEX19	987	987	0	0
LEX14	989	987	2	4
BH01	987	987	0	0
BH02	988	987	1	1
BOER06	983	984	-1	1
BH03	986	986	0	0
BOER07	984	983	1	1
BH04	986	986	0	0
LEX15	987	987	0	0
LEX02	988	987	1	1
LEX17	986	986	0	0
LEH04	990	989	1	1
BH05	986	986	0	0

Name	computed	measured	head_diff	Head diff^2
BH06	986	986	0	0
BH07	987	987	0	0
BH08	986	986	0	0
LEX03	987	987	0	0
MOLL01	982	982	0	0
ELIZ01	988	987	1	1
BH09	984	985	-1	1
DW10	985	985	0	0
BH10	988	987	1	1
BH11	986	986	0	0
LEX24	986	987	-1	1
BH12	990	989	1	1
			RMSE	**0.72**
			NRMSE	**9%**

9.7.3 Simulation of Mining – Transient Mode

Underground mining was simulated for the Mn48 mine in a transient mode, as shown in Figure 12.

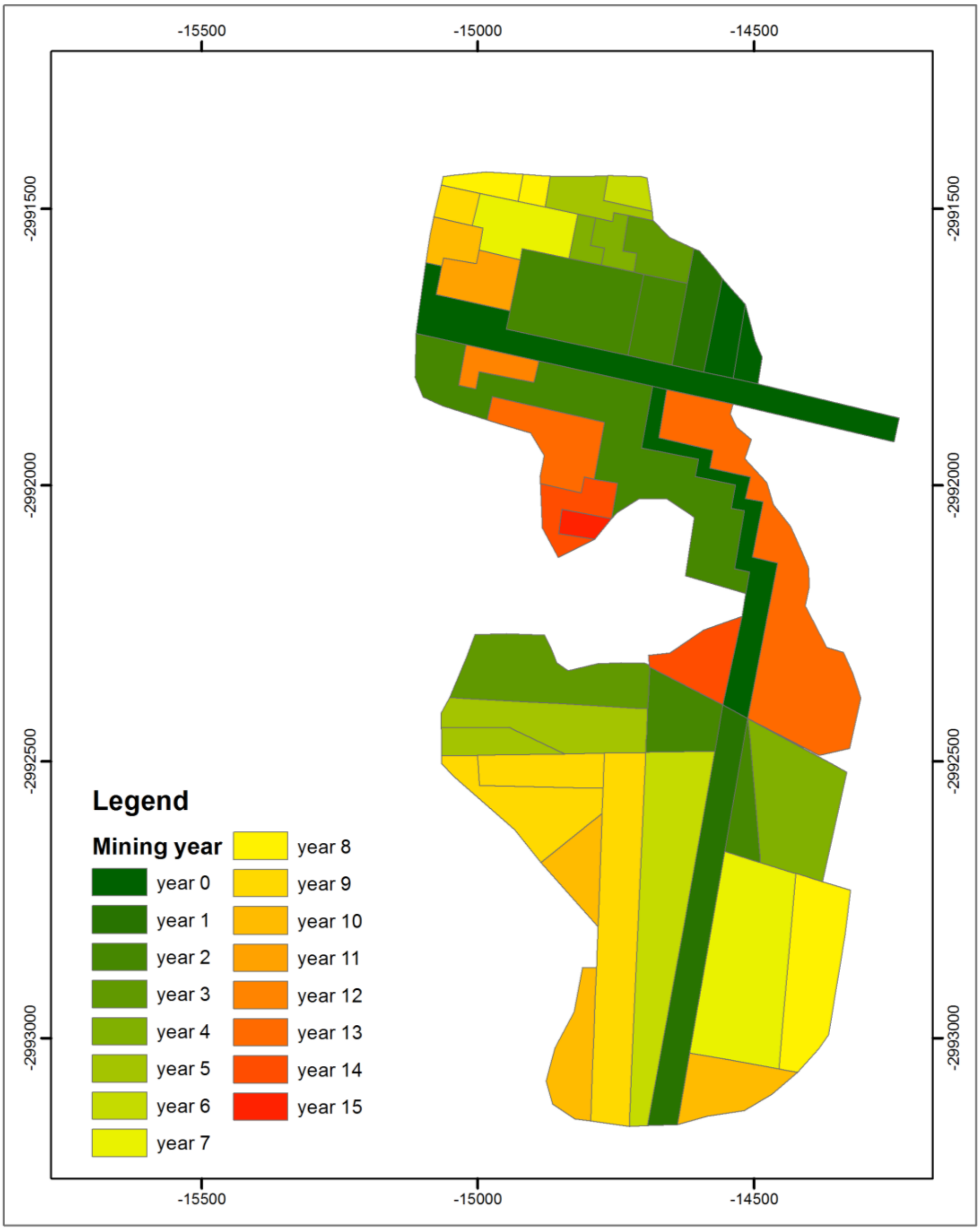

Figure 12: Annual mining schedule.

9.7.4 Simulation of Recharge – Transient Mode

In transient mode, the recharge was assigned as cyclic monthly time series, as shown in Figure 13, considering 2% on monthly rainfall averages.

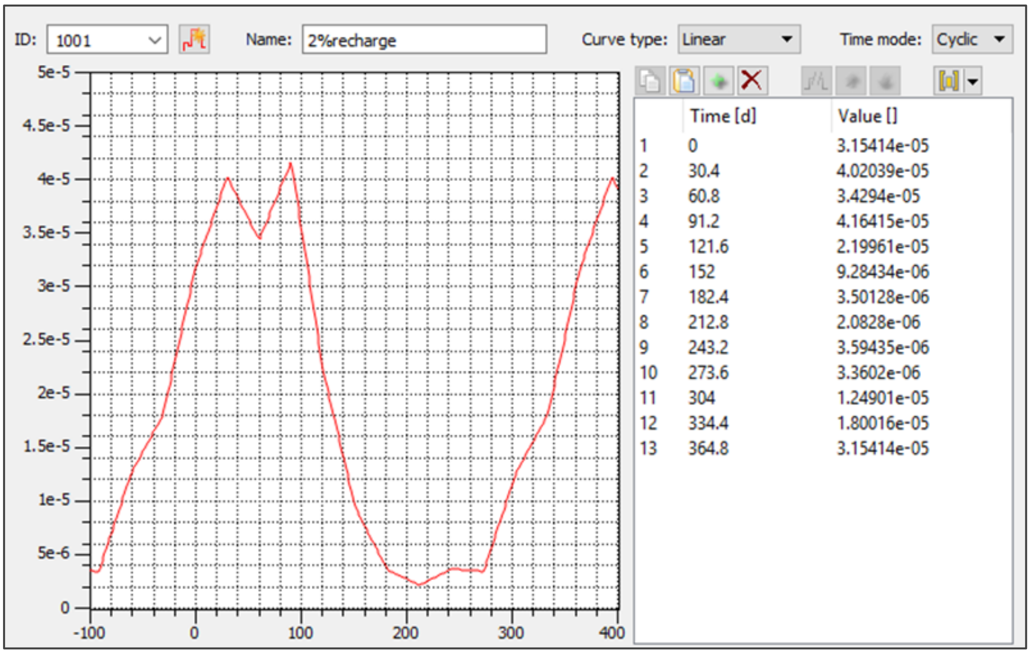

Figure 13: Mn48 groundwater model – transient recharge.

9.8 RESULTS OF THE MODEL

The Mn48 3D groundwater numerical model was run in transient mode for a period of 100 years. This will cover 12 years of mining and 88 years post-mining. The model results were extracted at the following time-steps:

- Year 5
- Year 10 – End of mining (Khwara resource)
- Year 12 – End of mining (Lehating resource)
- Year 50
- Year 100 – End of simulation.

9.8.1 Development of Cone of Drawdown

As mining is progressing it is expected that a cone of drawdown will develop as a result of groundwater passive inflows (ingress) into the underground excavation. The following figures show the development of the cone of drawdown during simulations:

- Year 5 - Figure 14
- Year 10 - Figure 15
- Year 12 - Figure 16
- Year 50 - Figure 17
- Year 100 - Figure 18.

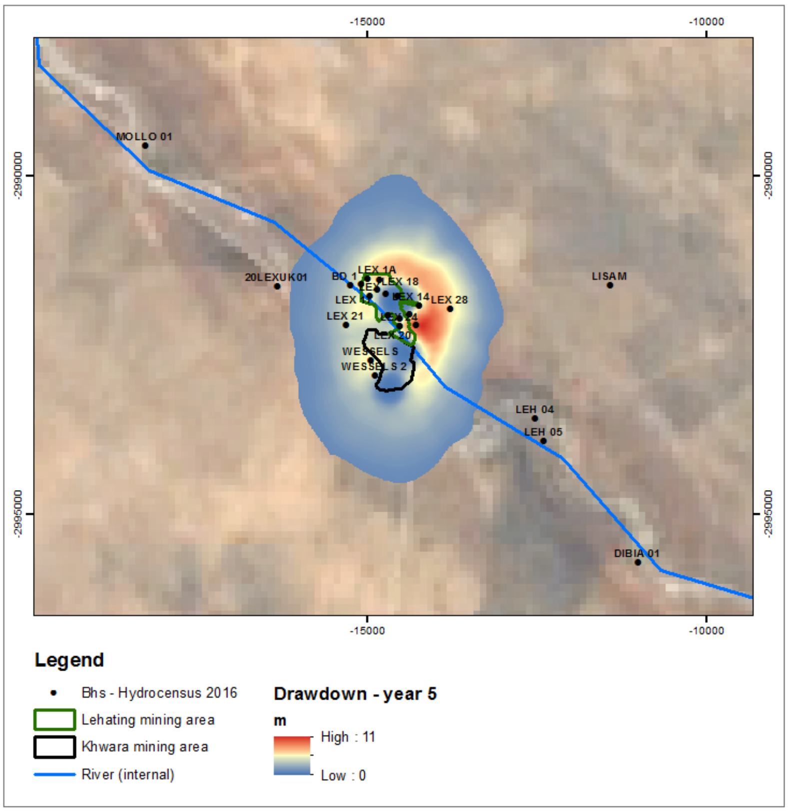

Figure 14: Cone of drawdown – Year 5.

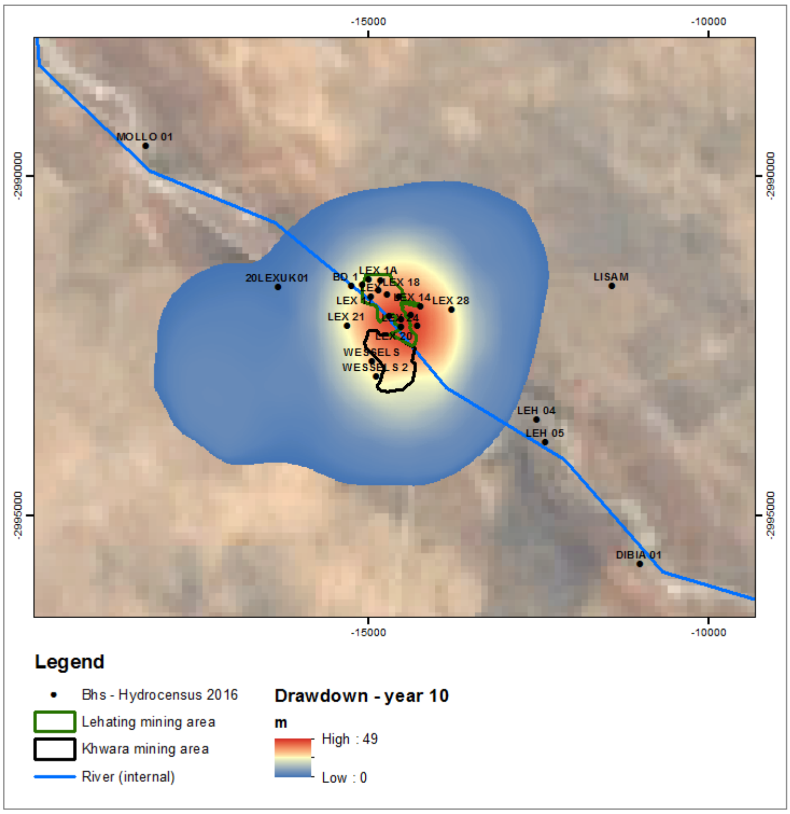

Figure 15: Cone of drawdown – Year 10.

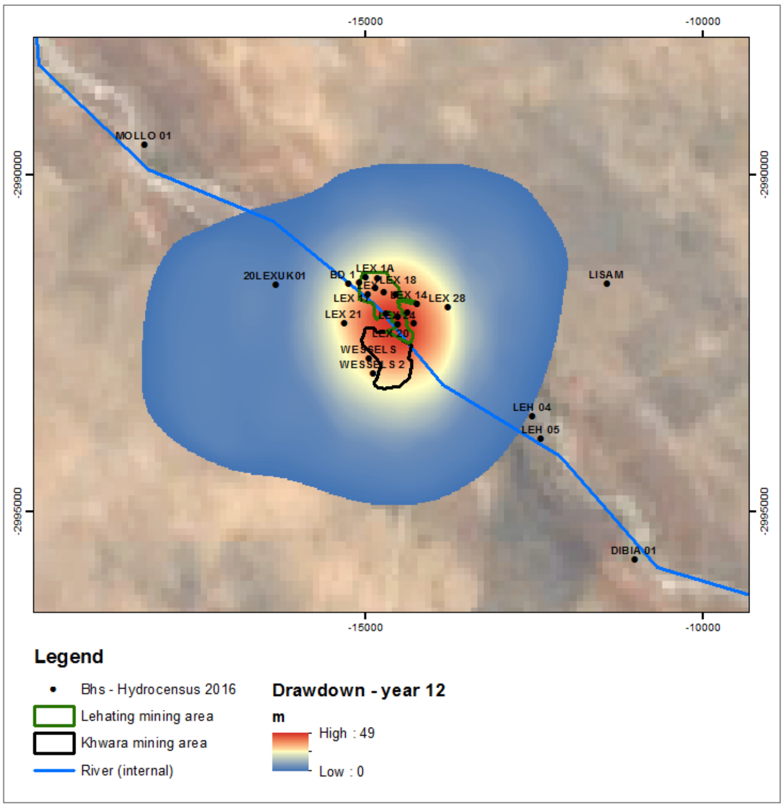

Figure 16: Cone of drawdown – Year 12.

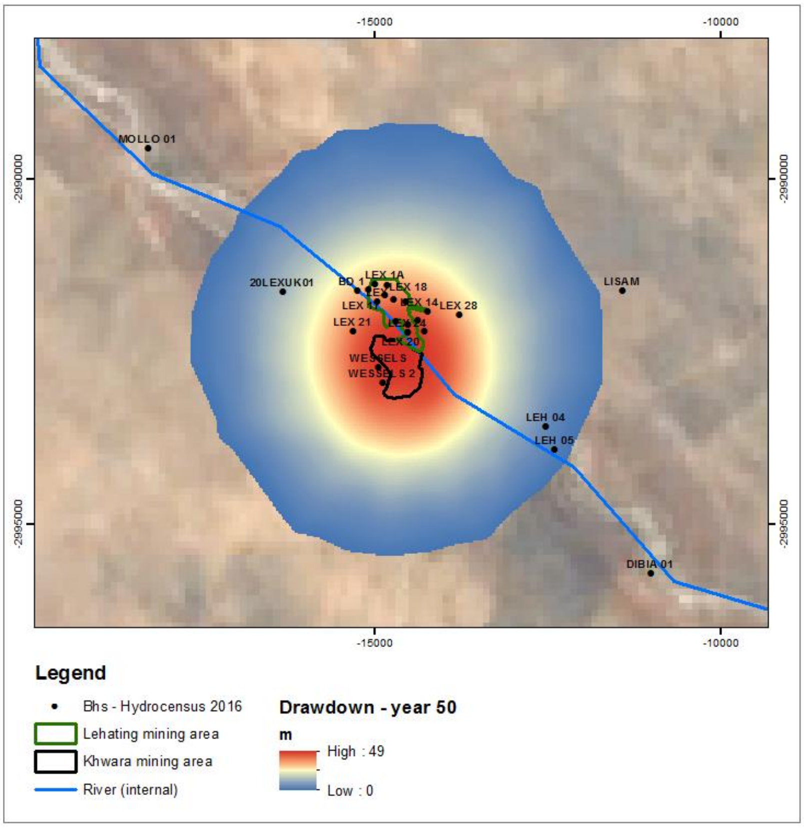

Figure 17: Cone of drawdown – Year 50.

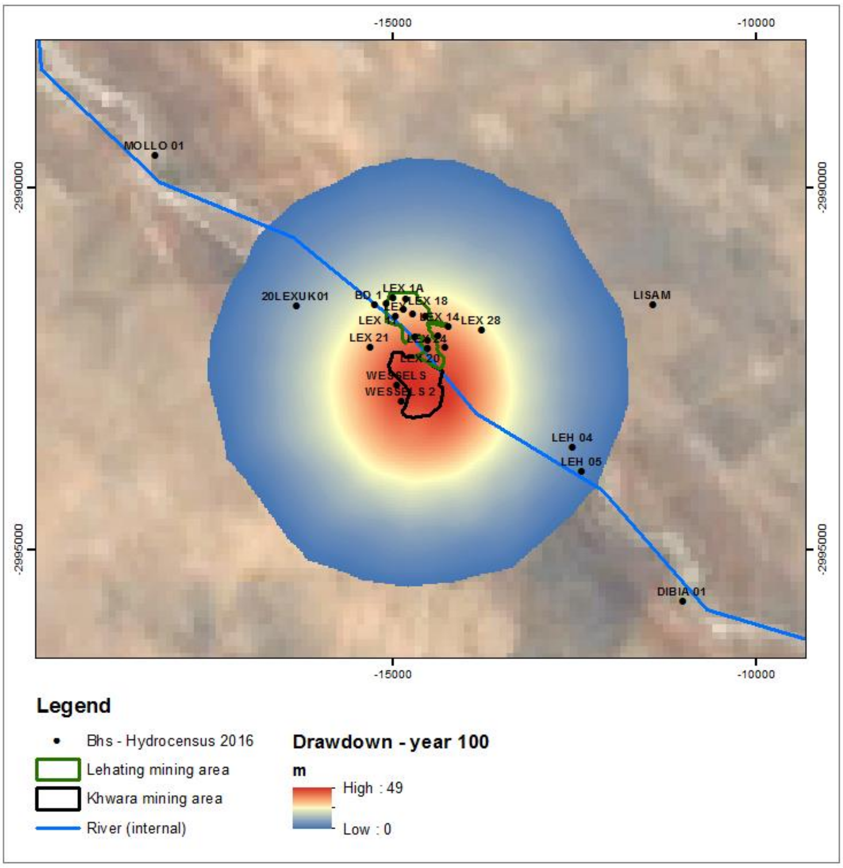

Figure 18: Cone of drawdown – Year 100.

9.8.2 Conclusions

Mining will create a cone of drawdown which extends during the mining period. Maximum depth of the cone of drawdown is 49 m. The cone of drawdown shows a slight recovery trend post-mining.

10.GROUNDWATER IMPACTS

10.1 ISSUE: REDUCTION OF GROUNDWATER LEVELS AND AVAILABILITY

10.1.1 Introduction

It is necessary to dewater the underground mining area to create a safe working environment. With dewatering the concern is that third party groundwater users may be negatively affected. This activity will take place during operations and will cease in the decommissioning phase. Upon closure, the groundwater levels will be allowed to rebound naturally.

Table 16: Activities and infrastructure – link to mine phases.

Operation	Decommissioning	Closure
Dewatering	Recovery of groundwater levels	Recovery of groundwater levels

10.1.2 Rating Impact

Severity/ nature

Dewatering activities will take place during the operational phase. The cone of drawdown has been simulated to reach its maximum extent in year 12 of the simulation, with a maximum drop in water levels of 49 m close to the underground mine area. The cone of drawdown shows a slight recovery trend in the post-mining simulation. Table 17 shows the development of the cone of drawdown during and post-mining. The simulation included the mining void at the entire Mn48 mining area in order to assess the dewatering impacts cumulatively. Limited movement of water between the shallow and deep aquifers is expected due to the presence of a geological layer with lower permeability between these aquifers. The drawdown is therefore considered to affect the deep aquifer, with no significant impacts on the shallow aquifer expected.

Table 17: Cone of drawdown extent and drop in water level (SLR, August 2017B).

Simulation year	Max. extent
5	2.2 km radius
10	3.4 km radius
12	3.6 km radius
50	3.1 km radius
100	2.8 km radius

Figure 16 shows the cone of drawdown at its maximum extent and Figure 18 shows the drawdown post closure. The following third-party water users have been identified within the cone of drawdown:

- Wessels 2 is a borehole is located within Ntsimbintle Mining Company (Pty) Ltd's property, however this land is used by Mr Willem Strauss for cattle grazing and his staff resides on this property. This borehole is therefore used for domestic use and livestock watering and is located at the edge of the underground mining area. It is however understood that there is also access to Sedibeng water on this property.
- Leh05 is a borehole owned by ER Van Schalkwyke (Waltwyk CC) and is used for domestic use and livestock watering.
- Boer 1 is a borehole owned by Mr. Gert Stols and is used for domestic use.

Borehole logs for the construction of these boreholes are not available and therefore it cannot be accurately determined whether these boreholes access the shallow or the deep aquifer. Taking a precautionary approach which assumes that these boreholes access the deep aquifer, Boer 1 and Wessels 2 could experience a drop in groundwater levels ranging from 3 metres in year 5 of mining, up to 49 m towards the end of mining, and LEH05 could experience a slight drop (less than 3 m) in water levels after closure as shown in Figure 17. The predicted drop in water levels in Boer 1 and Wessels 2 would render these boreholes unusable.

The simulation showed that groundwater levels would not recover within the 100 year simulation period and shows a sustained depressed water level, therefore no decant is expected. However the persistent depressed water level will continue to negatively affect Wessels 2 and LEH05 boreholes after closure. The potential impact on third parties is rated as having a high severity, but can be reduced to low with mitigation.

Duration

The duration of the impacts is linked to the duration of the dewatering and the recharge time thereafter. Based on groundwater model predictions, the dewatering cone of depression will extend well after closure. It follows that in both the unmitigated and mitigated scenarios the duration is high.

Spatial scale / extent

The spatial scale of the predicted dewatering cone extends beyond the mining area in both the mitigated and unmitigated scenarios.

Consequence

The consequence is high and can be reduced to moderate with mitigation.

Probability

The probability of impacting on third party water users is high given that there are third party boreholes identified within the simulated impact zone. With mitigation the probability reduces to low.

Significance

The impact significance is high in the unmitigated scenario and low in the mitigated scenario.

Summary of the rated dewatering impact per phase of the project

Mitigation	Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
All phases						
Unmitigated	H	H	M	H	H	H
Mitigated	L	H	M	M	L	L

11.GROUNDWATER MONITORING SYSTEM

11.1 GROUNDWATER MONITORING NETWORK

Boreholes currently used by third parties for domestic use and livestock watering have been identified within and around the simulated cone of depression to be monitored for any changes in water levels. In addition various prospecting and mine boreholes will also be monitored within the simulated cone of depression to monitor water levels. These monitoring points are shown in Figure 19.

In addition, these boreholes will be monitored for quality in a bi-annual basis as good practice. Water quality analyses results should be classified in terms of the SANS 241 (2015) Water Quality Standards and the DWAF Target Quality Range for Livestock Watering (1996) or whichever is applicable at the time. The monitoring results should be assessed by a suitably-qualified professional registered with the South African Council for Natural Scientific Professional (SACNASP). The parameters that need to be analysed include:

pH
Conductivity in mS/m at 25 ° c
Total dissolved solids (TDS) at 180 ° c
Alkalinity as $CaCO_3$
Carbonate as CO_3
Bicarbonate as HCO_3
Boron as B
Nitrate as N
Chloride as Cl
Sulphate as SO_4
Fluoride as F
Sodium as Na
Potassium as K
Calcium as Ca
Magnesium as Mg
Manganese as Mn
Full metal scan - Inter Coupled Plasma Scan (ICP) (via Mass Spectrometry (MS)

11.2 MONITORING FREQUENCY

Water levels in the identified boreholes will be monitored on a quarterly basis. Water quality monitoring will be limited to bi-annual monitoring.

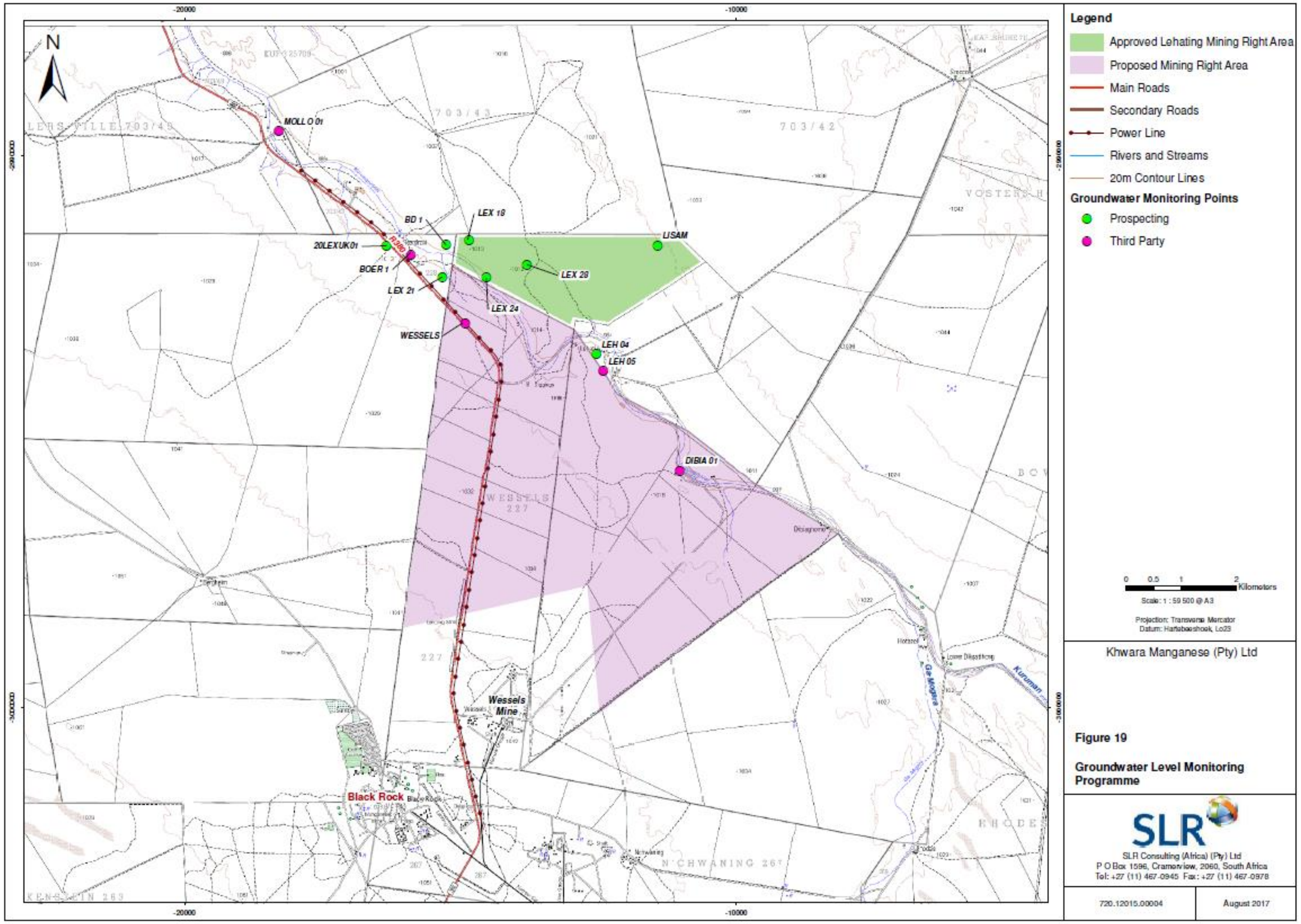

Figure 19: Monitoring points.

12. GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

12.1 CURRENT GROUNDWATER CONDITIONS

The baseline groundwater conditions are described in Section 7 of this report.

12.2 PREDICTED IMPACTS OF FACILITY (MINING)

The results of the simulations are provided in Section 9.8 and the impact assessment is provided in Section 10 of this report.

12.3 MITIGATION MEASURES

12.3.1 Lowering of Groundwater Levels During Facility Operation

The objective of the mitigation measures is to prevent water losses to third party water users.

Mitigation must include:

- Khwara will update the hydrocensus to check for any new third party water uses prior to mining
- Khwara will monitor groundwater levels in third party boreholes identified within the cone of depression on a quarterly basis during operations and for a period of 8 years after decommissioning and closure.
- Where Khwara's dewatering causes a loss of water supply to third parties, Khwara will provide compensation, which could include an alternative water supply of equivalent water quality and quantity, until such time as the dewatering impacts cease.
- With respect to the potential drop in water levels in Boer 1 and Wessels 2 boreholes, the mine will report water level measurements to the land users on request in order to closely monitor and allow for ongoing meaningful discussions with respect to managing water supply impacts.

12.3.2 Rise of Groundwater Levels Post-Facility Operation

The simulation shows that groundwater levels will not recover well after mine closure. Therefore, the monitoring and compensation measures stated above must continue after mine closure until no further significant dewatering impacts are experienced by third parties.

13. POST CLOSURE MANAGEMENT PLAN

No surface infrastructure and waste facilities will be established on the Mn48 mine site and therefore no rehabilitation costs are relevant. In addition, no latent post closure impacts have been identified. Groundwater recharge/rebound is not expected to have any impact i.e. no seepage/decant at surface requiring attention, furthermore groundwater quality is not expected to change as a result of mining activities. Therefore post closure groundwater level monitoring is considered relevant to monitor the recovery of water levels. However, post closure groundwater quality monitoring will be included as good practice.

14. ASSUMPTIONS AND LIMITATIONS

A numerical groundwater flow and transport model is a representation of some or all characteristics of a real system on an appropriate scale. It is a management tool that is typically used to understand why a system is behaving in a particular observed manner or to predict how it will behave in the future. Its precision depends on chosen simplifications (in a conceptual model) as well as on the completeness and accuracy of input parameters. In particular, data on input parameters like water levels and aquifer properties is often scare and limits the precision and confidence of numerical groundwater models. Impact predictions are based on numerical model results, the precision of which depends obviously on the chosen simplifications as well as the accuracy of input parameters like hydraulic conductivities, porosities or source concentrations.

It should be noted that no significant faults, fractures or other lineaments were observed and therefore no geological structures have been included in the model. Should such structures be encountered, further hydrogeological work will be needed, and the groundwater model will need to be updated.

Aquifer characteristics and hydraulic properties was based on previous studies groundwater studies completed for the Lehating Mine EIA. No new pump tests were performed to define the site-specific anisotropy of hydraulic properties. It is possible that the predicted cone of drawdown and the rate of recovery could have a different configuration to the simulation in this report. Recording of groundwater levels during the operational phase in Boreholes Boer 1, Wessels 2 and Leh05 will allow further calibration of the model.

The model only simulated cone of drawdown. No contaminant mass transport was simulated as no residue material will be placed on surface as part of the proposed project. Similarly, it is considered unlikely that the mine void will generate pollution.

15.INTERESTED AND AFFECTED PARTY COMMENTS

As part of the environmental impact assessment and environmental management programme process, groundwater related concerns were raised by interested and affected parties (IAP). These concerns are summarised in the table below, along with a response.

IAP concern	Response
If the mine's activities results in a loss of underground water on the remaining extent, which is private property, the mine will be held responsible.	Key management measures include monitoring groundwater levels in third party boreholes identified within the simulated cone of depression and where Mn48's dewatering causes a loss of water supply to third parties, Mn48 will provide compensation, which could include an alternative water supply of equivalent water quality and quantity, until such time as the dewatering impacts cease.
Has the cumulative effects of the surrounding mines been taken into account?	A hydrocensus was undertaken for the proposed project to characterise the existing groundwater quality and quantity prior to the commencement of the project. From a cumulative perspective, the hydrocensus characterises the current baseline condition taking into account the effects that existing mining operations have had towards groundwater quality and quantity. Further to this, the groundwater model takes into consideration the impacts associated with the approved Lehating Mine.

16.CONCLUSION AND RECOMMENDATIONS

A groundwater modelling exercise was conducted to determine potential dewatering impact of the proposed Mn48 Project. The resource will be accessed and mined from the approved Lehating mine (underground). Approved surface infrastructure at the Lehating Mine will be used to support the mining of the underground resource on the farms Wessels 227 and Dibiaghomo 226 and as such no surface infrastructure will be established as part of the proposed project.

The main conclusions of the groundwater study include:

- Dewatering activities will take place during the operational phase. The cone of drawdown has been simulated to reach its maximum extent in year 12 of the simulation, with a maximum drop in water levels of 49 m close to the underground mine area. The drawdown is considered to affect the deep aquifer, with no significant impacts on the shallow aquifer expected.
- Third parties could experience a significant drop in water level during operations which could render the boreholes unusable. An additional third-party user could experience a slight drop in water level after closure.
- The simulation showed that groundwater levels would not recover within the 100-year simulation period and shows a sustained depressed water level, therefore no decant is expected.
- The potential impact on third parties is rated as high but can be reduced to low with mitigation.
- Key mitigation includes monitoring of water levels and compensation which could include an alternative water supply of equivalent water quality and quantity, until such time as the dewatering impacts cease.
- The Mn48 groundwater model should be updated to incorporate any changes to the mine plan (mining area, final depths and areas, scheduling) and surface infrastructure.
    - Subsequent updates of the groundwater model should be done every two (2) years as updated geology, groundwater level and quality data become available.

Based on the above assessment, and assuming that the relevant mitigation measures will be effectively implemented; there are no apparent reasons why the project should not be authorised.

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Raymond Minnaar	**Natasha Smyth**	**Mihai Muresan**
(Report Author)	(Project Manager)	(Reviewer)

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APPENDIX A: CURRICULUM VITAE

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MN48 MR CONSOLIDATION & EMP AMENDMENT SPECIALIST STUDY: UPDATED GROUNDWATER ASSESSMENT - LEHATING MINE

Mn48

Prepared for: Mn48 (Pty) Ltd

Authority References:

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BASIS OF REPORT

EXECUTIVE SUMMARY

Mn48 (Pty) Ltd (Mn48) is developing a new underground manganese mining operation near Black Rock in the John Taolo Gaetsewe District Municipality, Northern Cape Province.

A groundwater assessment that included groundwater flow and contaminate transport modelling was conducted by SLR in 2013 in order to provide specialist groundwater input into the Environmental Impact Assessment (EIA) for the development of the proposed mine within the then named Lehating Mine site (SLR, 2013).

Subsequent to this report, Khwara Manganese (Pty) Ltd, who holds an approved EMPr for underground mining of manganese immediately adjacent and to the south of Lehating Mine and Mn48, entered into an agreement to combine the two adjacent mineral resources and surface rights comprising the Khwara and Lehating Mines into a single, high-grade manganese mining company that will be known as Mn48 (Pty) Ltd. Khwara Manganese (Pty) Ltd (Khwara) holds an approved EMPr for underground mining of manganese on Portion 2 of the farm Wessels 227 and the Remaining Extent and Portions 3 and 4 of the farm Dibiaghomo 226, while Mn48 has approval for a mine located on a portion of Portion 1 of the farm Lehating 741. The Khwara underground resource will be accessed via the Lehating mine, using Mn48's approved surface infrastructure. In this regard, no surface infrastructure will be established as part of the Khwara Mine.

Since this new agreement is proposing the consolidation of Mn48 and Khwara mining right areas, the groundwater assessment conducted in 2013 is required to be updated to reflect the change in name of the site. The results of the SLR (2013) groundwater assessment will remain unchanged, but recommendation will be made in order to address any potential gaps due to the change in Mn48's approved surface infrastructure and mine layout.

The Surface geology at Mn48 comprises predominantly of Cenozoic deposits (Kalahari Formation). The Kalahari Formation is approximately 80 metres thick and overlies the Dwyka Formation which forms the basal part of the Karoo Supergroup. The Dwyka Formation is approximately 200 metres thick and overlies the Hotazel Formation (Transvaal Supergroup). The Hotazel Formation contains important mineral commodities and Mn48 (Pty) Ltd will target this formation for its rich manganese and iron bands. The Hotazel Formation is approximately 20 metres thick in the area of investigation and overlies the Ongeluk Formation (Transvaal Supergroup).

Based on the conceptual understanding of the geology Mn48 mining area's aquifer characterisation can be presented by shallow and deep weathered sedimentary rocks (i.e. mainly sandstones). The sedimentary deposit can be classified as an 'intergranular aquifer' system. The primary porosity of the rocks provide the storage capacity with limited groundwater movements while secondary features such as fractures / faults and bedding planes enhance the groundwater flow. The majority of study area is regarded a "poor aquifer" while the aquifer adjacent (west) to the proposed Mn48 portion is regarded as "minor" aquifer class. A "poor aquifer" is described as an insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality or aquifer that will never be utilised for water supply and that will not contaminate other aquifers

The dominant groundwater flow is in a north-western direction, driven by the mountain range located towards the west and east flowing towards the Kuruman River. Localised groundwater flow within and around the Mn48 Mine area shows a dominant groundwater flow direction in a north-western direction with slight localised groundwater flow towards the Kuruman River.

Also, a total of 2 pumping tests were conducted. Borehole LEX3A is characterised by a transmissivity value of ~117 m^2/day, typical for an unconfined aquifer and appears plausible for a shallow primary aquifer in the Kalahari Formation. As a result, the hydraulic conductivity of the Kalahari Formation is estimated to be 2 m/d. Results from the pumping test for borehole LEX3A indicate that the borehole can be pumped at a recommended rate of 8.0 L/s for 12 hours with a maximum groundwater level drawdown of 8 metre. This will allow a 12-hour recovery time for the aquifer to recover to its original water level. The hydraulic test for borehole LEX 4 shows a transmissivity value of ~0.95 m^2/day. Borehole LEX4 was cased-off to a depth of 180mbgl and the transmissivity value(s) may be representative of the deeper Dwyka, Hotazel and upper Ongeluk formations. Due to the low yielding capability of the deeper Dwyka, Hotazel and upper Ongeluk formations borehole LEX4 is not recommended for water supply use.

The groundwater sample collected at borehole LEX3A presented a Mg-HCO3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. The groundwater sample collected at borehole LEX4 presented a Na-Cl water type with elevated concentrations of chloride, sodium and magnesium. The elevated sodium and chloride concentrations may represent deeper and/or older groundwater within an evolved groundwater regime. This water type is probably characteristic of the groundwater within the deeper, confined Hotazel and Ongeluk aquifers. The groundwater samples for LEX3A and LEX4 are thus indicative of two distinctive groundwater regimes.

Furthermore, during the hydrocensus a total of 76 boreholes were visited. The majority of boreholes are for either domestic use and/or cattle/game feedlots or prospecting boreholes. A number of boreholes are not in use or unequipped. The water levels measured during the hydrocensus vary from a minimum of 9.8 mbgl to more than 110 mbgl with an average of 54 mbgl. Water levels located in and around Mn48 mine portion has an average depth of 37 mbgl.

A regional groundwater flow model was developed based on the available and determined (i.e. site specific) aquifer parameters to evaluate the potential impacts of mining activities on groundwater flow and quality. The numerical model is used to predict the spreading of potential contaminants within the groundwater system based on a worst-case scenario assuming conservative, non-retarded contaminant transport behaviour. The potential contaminant sources (i.e. mine residue deposits) include the proposed tailings storage facility (TSF), waste rock stock yard and other stockpile. Furthermore, the numerical model also estimates groundwater inflow rates into the underground mine and the extent of the lowered groundwater levels surrounding the underground mine.

The estimated inflow rate into the mine workings is in the order of 292 m^3/d (approximately 3.4L/s) during year 18 of mine development.

It is expected that the potential impacts associated with the deep mine inflows (i.e. dewatering) on the regional groundwater flow are:

- Insignificant w.r.t. the Kalahari Aquifer;
- Unlikely to impact third party groundwater users or groundwater contribution to baseflow;
- The cone of depression will be limited to the mine lease for the Kalahari Aquifer; and
- Reversible over time once dewatering stops.

As result boreholes outside the mine lease area are unlikely to be impacted (w.r.t. lowered groundwater levels) due to mine dewatering. A shallow and wide-spread cone (less than 5 km) of depression is associated with high hydraulic conductivities suck as the Kalahari formation.

Groundwater contribution to baseflow represents high frequency low flows during the dry season. Such flows are not evident for the non-perennial Kuruman River.

The proposed well field consist of four (4) boreholes drilled to a depth between 80 to 85 metres below ground level. The proposed well field is located within the Kalahari formation. Based on the simulated well field, i.e. four boreholes abstracting 2.5L/s, a predicted cone of depression extends 800metres in a radial direction away from the well field with a drawdown of 1 meter. The predicted impact associated with the well field indicates a maximum groundwater depth of less than 4 metres.

The results of the pumping test (for Borehole LEX3A) is comparable to the outcome of the simulated well field development since the pumping test consider a smaller, more heterogeneous volume of aquifer material.

It is expected that the potential impacts associated with the well field (i.e. well dewatering) on the regional groundwater flow are:

- Likely to occur w.r.t. groundwater as resource;
- Unlikely to impact any third party groundwater users;

- Limited (up to 1 km) impact slightly beyond the mine lease area w.r.t.
  - Interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River;
  - Development of intersecting cones of depression, i.e. the lowering of the groundwater levels due to well field dewatering
- Reversible over time once well field stops abstracting groundwater; and
- The cone of depression associated with the proposed well field does not impact (w.r.t. lowering the groundwater level more than 1 meter) any third party boreholes (boreholes not belonging to the mine).

The cone of depression extends beyond the mining boundary and extent below the non-perennial Kuruman River. However, measured groundwater levels are far below the base of the non-perennial Kuruman River. As a result an impact on the non-perennial Kuruman River due to dewatering of the well field is not expected

The contaminant transport model estimates the dispersion of the contaminant plume. The dominant spreading of the potential contaminants/pollutants associated with the TSF, Waste rock stockpile and other stockpiles (potential pollutant sources) occur in a radial manner and towards the north-west. This is due to a groundwater mounding effect due to the seepage and hydrodynamic dispersion (including diffusion) within the groundwater system. The groundwater mound cause preferential potential pollutant spreading in a circular direction during the first 15 years. The potential contaminants spread away from the potential pollutant sources for the weathered aquifer system due to its relatively higher hydraulic conductivity values. The potential pollutant spread occurs within the mining boundary. It should be noted that localised pollutant spreading might occur towards the Kuruman River; however from the predicted spreading plume no potential pollutants reach the Kuruman River within the first 100 years.

The potential impacts associated with the sources on groundwater quality are:

- Highly likely to occur w.r.t groundwater as resource;
- Localised within the wider mine site boundaries if surface run-off is contained;
- Long-term but within the site boundaries beyond closure; and
- The intensity of the impact is likely to be a moderate deterioration in the ambient groundwater quality for the site.

The contamination plume will in all likelihood be contained within the mine lease area due to the simulated cone of depression as result of mine dewatering.

The simulated pollution plume spread (up to 100 years) will impact the groundwater as resource; however, no indication of third party groundwater users or surface water will be impacted.

Based on the outcomes of the current groundwater modelling study, the following recommendations are given:

- Initiation of a ground- and surface water monitoring system with monthly monitoring of groundwater levels and quarterly sampling intervals for full chemical analyses (all major constituents and trace elements of concern, especially Arsenic).
- The development of a standard operating procedure for water level monitoring and water sampling according to best practice (e.g. filters and acidify on site for metal analyses, purge boreholes prior to sampling).
- Other mitigation measures such as installing curtain drains, the use of existing boreholes as capture zones to control potential plume migration will limit spreading of the contaminant plume.
- The Mn48 groundwater model should be updated to incorporate any changes to the mine plan (mining area, final depths and areas, scheduling) and surface infrastructure.

- Subsequent updates of the groundwater model should be done every two (2) years as updated geology, groundwater level and quality data become available.

CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
BH	Borehole
DEM	Digital Elevation Model
MAP	Mean Annual Precipitation
mamsl	Meters above mean sea level
mbgl	Meters below ground level
TSF	Tailings Storage Facility

1. INTRODUCTION

Mn48 (Pty) Ltd (Mn48) is developing a new underground manganese mining operation near Black Rock in the John Taolo Gaetsewe District Municipality, Northern Cape Province.

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Since this new agreement is proposing the consolidation of Mn48 and Khwara mining right areas, the groundwater assessment conducted in 2013 is required to be updated to reflect the change in name of the site. The results of the SLR (2013) groundwater assessment will remain unchanged, but recommendation will be made in order to address any potential gaps due to the change in Mn48's approved surface infrastructure and mine layout.

1.1 PROJECT OBJECTIVE

The overall project objectives are as follows;

- To characterise and conceptualise the site specific aquifer(s);
- To develop a site specific groundwater contaminant transport model using available data;
- To predict the transport of potential pollutants emanating from the project within the groundwater system using the numerical flow and transport model;
- To revisit (Metago Water Geosciences reporting) groundwater inflow rates and to assess the proposed well field for potential dewatering impacts that might occur; and
- To document the findings of the above studies in a report suitable for inclusion in an environmental impact assessment report.

The flow and contaminant transport modelling report is based on the Barnet et al. (2012) Australian Groundwater Modelling Guidelines to adhere to international standards for groundwater modelling studies. This document is also based on the Waterlines Report Series promoting a consistent approach to the development of groundwater flow and solute transport models. However, recommended sensitivity analysis was not included in the reporting although used in the setup of the groundwater flow model.

1.2 MODELLING OBJECTIVES

A regional groundwater flow model was developed based on the available and determined (i.e. site specific) aquifer parameters to evaluate the potential impacts of mining activities on groundwater flow and quality. The numerical model is used to predict the spreading of potential contaminants within the groundwater system based on a worst case scenario assuming conservative, non-retarded contaminant transport behaviour. The potential contaminant sources (i.e. mine residue deposits and stockpiles) include the proposed tailings storage facility (TSF). Furthermore, in addition to well field impacts, reporting from Metago Water Geosciences to investigate the potential impact of dewatering during mining activity was also incorporated into the overall groundwater impact assessment.

1.3 DATA SOURCES AND DEFICIENCIES

Numerous data sources were consulted to complete the model input parameters, boundary conditions, and calibration of the data. All the data were converted to common horizontal and vertical model datums. The horizontal datum used in this model is metres LO23 Transverse Mercator with vertical datum presented as metres above mean sea level (mamsl). The development of the hydrogeological conceptual and numerical groundwater models were based on the following information and data made available to the project team or gathered as part of the groundwater investigations:

- Geological information retrieved from borehole logs;
- Regional hydrogeological map (GRA I dataset);
- Digital Elevation Model (DEM) based on 45m contours and converted into a 50m x 50m grid;
- Digital TSF layouts and estimated leakage rates provided by SLR project team;
- Groundwater elevation data received from the site; and
- Results of hydraulic tests (based on packer and pumping tests).

The deficiencies in the hydrogeological datasets include (but are not limited to):

- Long term rainfall data in and around Mn48 area;
- Long term evapotranspiration data in and around Mn48 area;
- Long term groundwater level monitoring data;
- Large spatial distances between groundwater monitoring points for mine area;
- Long term river flow monitoring data;
- The quantification of groundwater-surface water interaction;
- Source concentration for mine residue deposits / wastes; and
- Chemical and biological reaction rates for contaminants in the subsurface.

Therefore, the final groundwater model confidence level is low to moderate due to the limited hydrogeological data available. Once additional data (i.e. long term monitoring data) becomes available, transient modelling of the existing conditions and future impacts can be undertaken and the confidence level of the model would be increased (not part of the scope for the current hydrogeological investigation).

1.4 MODEL LIMITATIONS

The conceptualisation of a complex groundwater flow system into a simplified groundwater management tool, i.e. numerical model, has a number of uncertainties, assumptions and limitations. These limitations include (but are not limited to these only):

- Input data on the types and thickness of hydrogeological units, water levels, and hydraulic properties are only estimates of actual values;
- All the physical and chemical processes in a catchment cannot be represented completely in a numerical model;

- The numerical model developed for Mn48 can't be used for any other purpose than the defined model objectives;
- The numerical model is a non-unique solution that can calibrated with an unlimited number of acceptable parameters; and
- The numerical model is a simplification of the natural world.

2. HYDROGEOLOGICAL CONCEPTUAL MODEL

2.1 MN48 MINE LOCALITY

The investigated portion 1 'FARM LEHATING 741' and portion 2 Wessels 227 are located to the northeast of the R380 Road approximately 10 km north of Black Rock, situated in the Northern Cape Province. The study area includes quaternary catchment D41M (Figure 2-1).

The Lehating study area can be divided into two main topographic domains;

- The broad flat Kalahari sedimentary deposits that lie between 900-1000 m above mean sea level characterising a central strip from the northern to southern catchment boundary (Quarterly catchment D41M), and
- The mountainous domain to the west and east at approximately 1550 and 1200m above mean sea level respectively.

2.2 GEOLOGY

2.2.1 Lithostratigraphy

Surface geology (Figure 2-2) at Lehating comprises predominantly of Cenozoic deposits (Kalahari Formation). The Kalahari Formation is approximately 80 metres thick and overlies the Dwyka Formation which forms the basal part of the Karoo Supergroup. The Dwyka Formation is approximately 200 metres thick and overlies the Hotazel Formation (Transvaal Supergroup). The Hotazel Formation contains important mineral commodities and Lehating Mining Pty Ltd will target this formation for its rich manganese and iron bands. The Hotazel Formation is approximately 20 metres thick in the area of investigation and overlies the Ongeluk Formation (Transvaal Supergroup). Rocks of the Olifantshoek Supergroup outcrop approximately 30 km southwest of the mine forming a distinct topographic high. Rocks of the Asbestos Hill Subgroup (Transvaal Supergroup) outcropping approximately 20 km towards to the east of Lehating also form a distinctive topographic high.

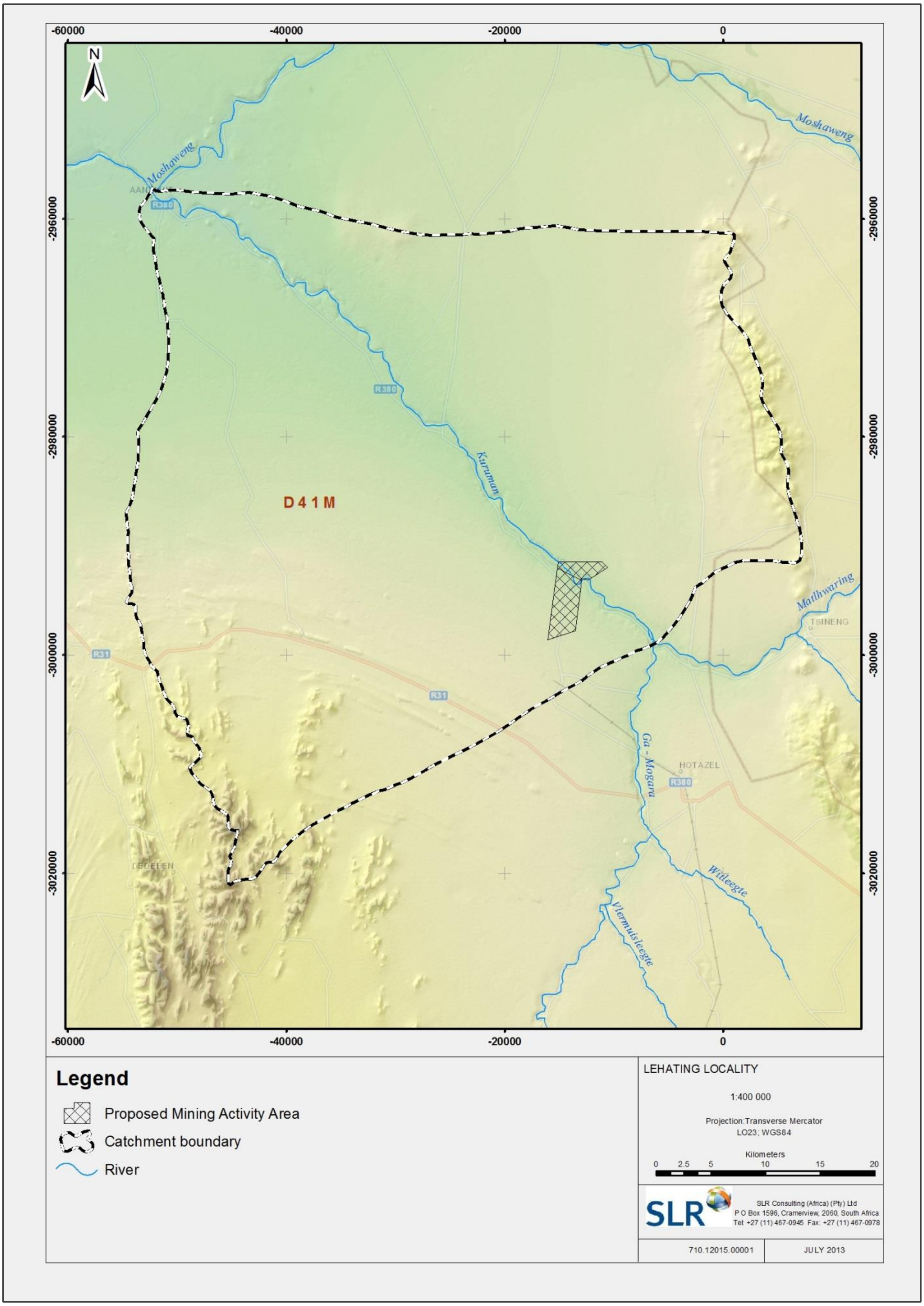

Figure 2-1: Location of the Mn48 Mining Right Area.

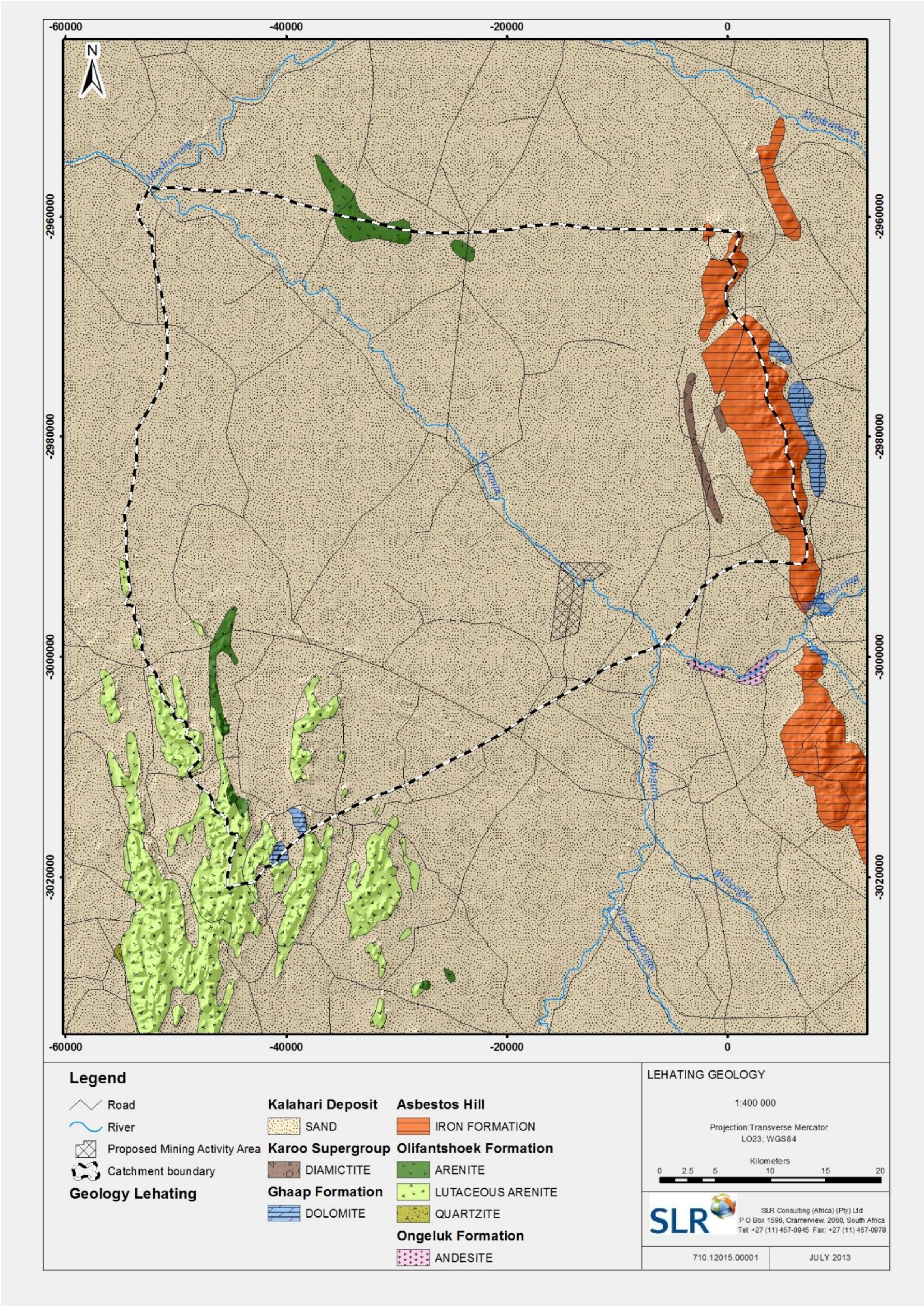

Figure 2-2: Regional geology of Mn48 Mine (Quaternary Catchment D41M).

Kalahari Formation

The Kalahari Formation consists of various units and constitutes the most extensive body of terrestrial sediments from the Cenozoic age in Southern Africa. Throughout the area the thickest parts of the Kalahari Formation appear to coincide with the occurrence of rocks of the Dwyka Group. The presence of faulting and graben formation in pre-Kalahari rocks also has a strong influence on the distribution of the Kalahari sediments (Partridge et al, 2006). The overall lithology and main stratigraphic units of the Kalahari Formation are represented in Figure 2-3 (Partridge et al, 2006).

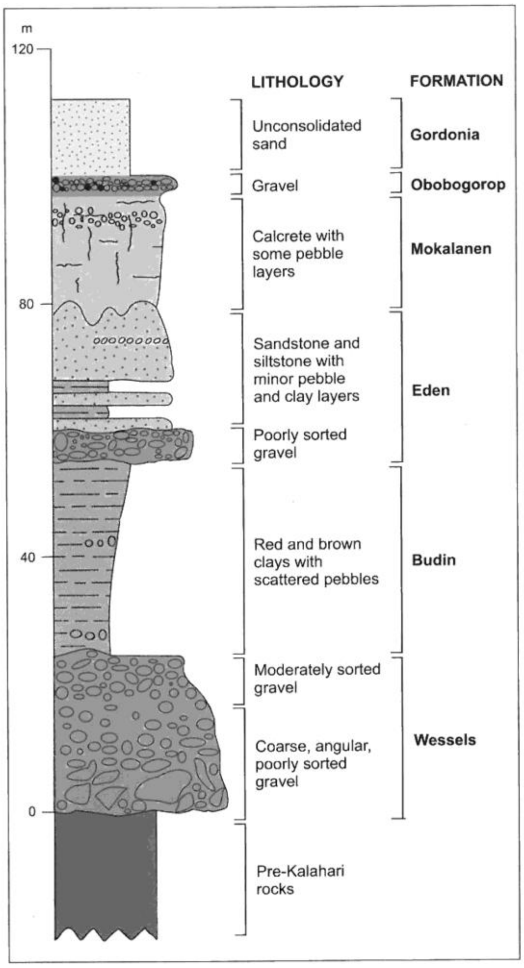

Figure 2-3: Generalised stratigraphy representation of the Kalahari Formation (Partridge et al., 2006).

- The Wessels Formation forms the base of the Kalahari formation and is characterized by clayey gravel. Thicker and better-developed clayey gravel of this formation is located in deeper palaeo-valleys and doesn't occur extensively where the Kalahari formation is at its thickest.
- The Budin Formation consists mostly of red and brown calcareous clays, which were possibly deposited in shallow saline lakes. It may also consist of thin pebble layers near its base.
- The Eden formation consists mainly of red, brown or yellowish sandstone with thin pebble layers. This formation becomes more disaggregated and calcified towards the top and was probably deposited from braided streams (Partridge et al, 2006).
- The Mokalanen Formation can be divided into a sandy limestone and overlying conglomerate with a calcareous mixture. This formation reflects more arid depositional conditions than the underlying fluvial conditions.

- The Obobogorop Formation is characterized by pebble and boulder clasts consisting of calcrete. These clasts are derived from the weathering of Dwyka tillites.
- The Gordonia Formation consists of red aeolian sands (windblown sands / dunes) and rounded quartz grains coloured by a thin coating of hematite. The hematite is absent in river bottom areas subject to hydromorphic influences, where the sand is white in colour. Based on the borehole logs it appears that the Gordonia Formation rests directly on pre-Kalahari bedrock, namely Karoo sediments. According to Baillieul (1975) the Gordonia Formation originates from local sources with some additional material transported into the basin over short distances. Aeolian overprinting of sands originally deposited by streams and sheet wash is evident in some areas (Moore and Dignle, 1998). Linear dunes, stabilized by vegetation, characterise the Gordonia Formation. This is evident in the Mn48 mining area.

Dwyka Formation (Karoo Supergroup)

A variety of lithofacies types have been identified in the Dwyka Group (Visser, 1986). The Dwyka Group is considered to be deposited in a marine basin. The Dwyka Group formed from eroded debris deposited by a ground ice sheet with fluctuations in the ice sheet resulting in bedded diamictons and subglacial outwash sediments (Visser et al 1987). Climate warming caused floating ice and eventually melting of the ice where rain-out debris accumulated and formed valley fill deposits.

The massive diamictite facies consists mostly of highly compacted, stratified diamictite with poorly to well defined bedding planes and alternating diamictite, mudrock, sandstone and conglomerates. The massive carbonate rich diamictite facies contains small angular stones, concretions and irregular bodies of carbonate rock. The conglomerate facies ranges from single-layered boulder beds to poorly sorted pebbles and granular conglomerates. The sandstone facies consists of either very fine to medium graded laminated or coarser grained cross-bedded sandstone. Turbudite deposits characterize the formation of these sandstones that also contains interbedded mudrock. The mudrock facies consist of dark-coloured carbonaceous mudstone, shale or silty rhythmite. These facies formed from suspension settling of mud as well as fall-out of silt from sediments.

Olifantshoek Supergroup

Arenaceous sediments of the Olifantshoek Supergroup form a prominent north trending mountain range in the vicinity of Boegoeberg dam northwards to the Korannaberg, where rocks of the Olifantshoek Supergroup is progressively covered by Kalahari sediments. The supergroup consists of interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The whole supergroup has been deformed into a succession with an east-verging dip (Cornell et al., 1998). The Olifantshoek Supergroup overlies sediments of the Transvaal Supergroup with a regional unconformity as seen in Figure 2-4. The total thickness of the supergroup exceeds 5000 metres. The age of the Olifantshoek Supergroup as indicated by different isochrones is approximately 1900 Ma (Armstrong, 1987). The different subgroups and formations present in the study area include the Brulsand, Matsap and Lucknow units. Rocks of the Olifantshoek Supergroup outcrop in the western side of the quaternary catchment and form a topographically elevated area.

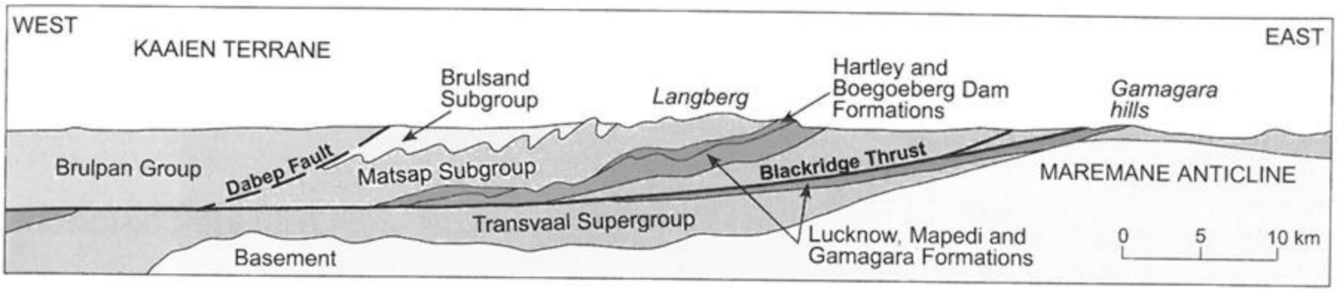

Figure 2-4: Illustration of the strata due to low-angle thrusting at the base of the Olifantshoek Supergroup (After: Beukes & Smit, 1987).

Ongeluk and Hotazel Formations (Transvaal Supergroup)

Extrusion of the tholeitic basaltic and andesitic lavas of the Ongeluk Formation, of Vaalian age (2222 Ma) (Cornell et al, 1996), formed part of Hekpoort-Ongeluk flood basalt volcanic event (Reczko et al, 1995b). Pillow lavas, hyaloclastites and massive flows support the subaqueous extrusion of the middle and upper part of the Ongeluk Formation (Cornell and Schutte, 1995). Basal flow of the Ongeluk Formation exhibits abundant pipe amygdales and flow structures indicating subaerial extrusion. The Ongeluk lavas are overlain by the jaspillites and inferred volcanic exhalative manganese deposits of the Hotazel Formation (Eriksson et al, 2006).

Asbestos Hill Subgroup (Transvaal Supergroup)

The Ghaap group in the Griqualand West basin (Transvaal Supergroup) is subdivided into different stratigraphical units; one of these is the Asbestos Hill Subgroup. There are three successive Banded Iron Formation (BIF) units in the Asbestos Hill Subgroup. The first of three BIF units is the Kliphuis Formation comprising of an intercalation of shales and haematitic cherts with a fairly uniform thickness of 8 to 13 metres. The second unit overlying the Kliphuis Formation is the Kuruman Formation consisting of different microcycles beginning with lutite, followed by a whitish chert increasing with magnetite upwards until a rhythmite oxide facies. The later formation is overlain by the third unit, the Danielskuil Formation, regarded as a reworked Kuruman type BIF. Rocks of the Asbestos Hill Subgroup outcrop in the eastern side of the quaternary catchment forming a topographically elevated area.

2.3 AQUIFER SYSTEM

The Mn48 mining area is underlain by deeply weathered sedimentary rocks (i.e. mainly sandstones). The sedimentary deposit can be classified as an ‘intergranular aquifer’ system. The primary porosity of the rocks provide the storage capacity with limited groundwater movements while secondary features such as fractures / faults and bedding planes enhance the groundwater flow.

Regionally an unconfined water table aquifer is proposed while isolated occurrences of silts and clay units may confine the groundwater flow locally.

Based on the aquifer classification map (Parsons and Conrad, 1998) the majority of study area is regarded a “poor aquifer” while the aquifer adjacent (west) to the proposed Mn48 portion is regarded as “minor” (Figure 2-6). A summary of the classification scheme is provided in Table 2-1. In this classification system, it is important to note that the concepts of Minor and Poor Aquifers are relative and that yield is not quantified. Within any specific area, all classes of aquifers should therefore, in theory, be present.

Therefore, Based on the 1:500 000 hydrogeological map sheet, Mn48 is located on an aquifer classed as a poor aquifer with potential groundwater yields between 0.1 L/s and 2 L/s.

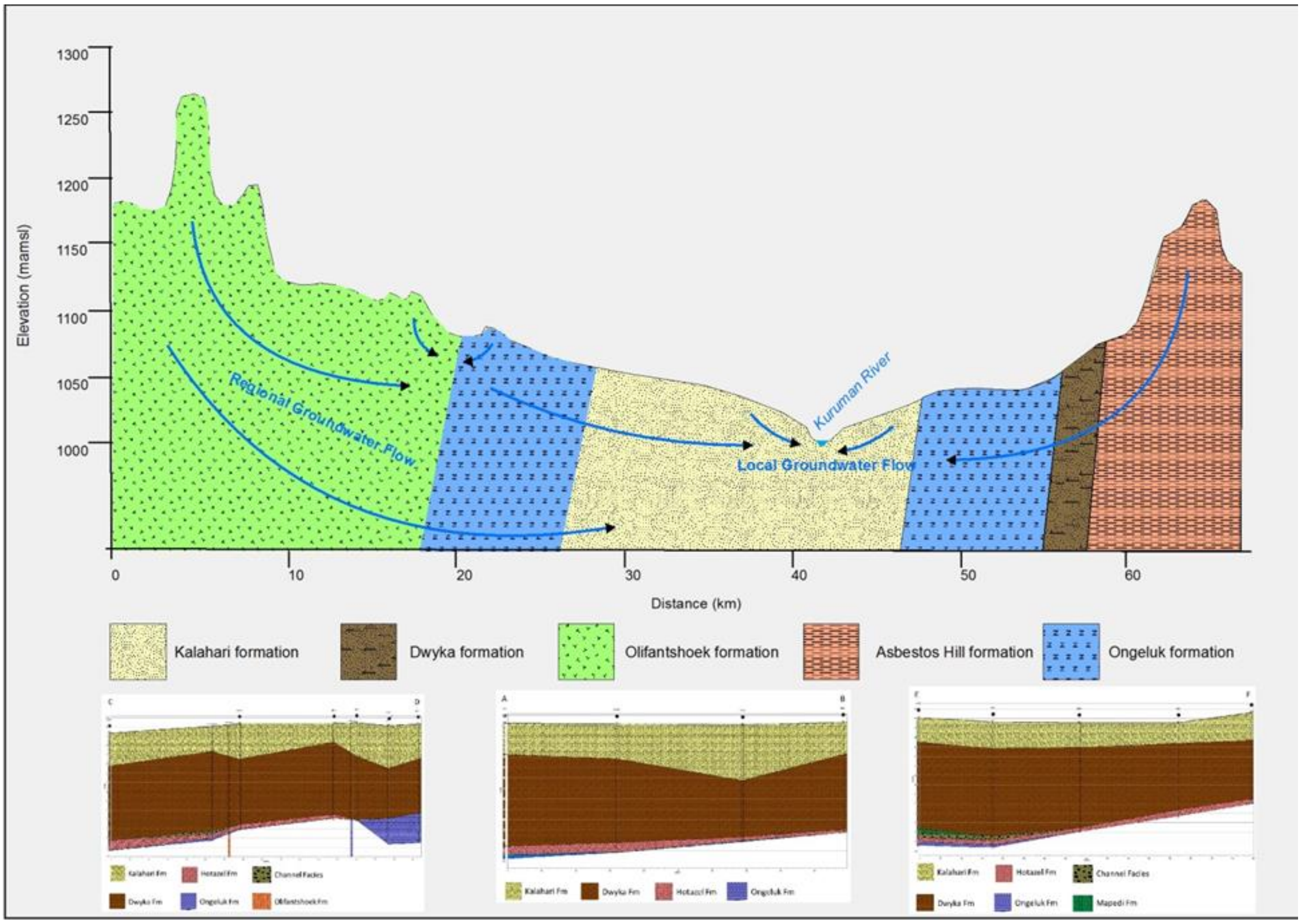

Figure 2-5: Regional and local conceptual hydrogeological model for Mn48 mine (not according to scale).

Table 2-1: Aquifer classification scheme (Parsons, 1995; Parsons and Conrad, 1998).

Sole source aquifer	An aquifer used to supply 50% or more of urban domestic water for a given area, for which there are no reasonably available alternative sources, should this aquifer be impacted upon or depleted.
Major aquifer region	High-yielding aquifer of acceptable quality water.
Minor aquifer region	Moderately yielding aquifer of acceptable quality or high yielding aquifer of poor quality water.
Poor aquifer region	Insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality, or aquifer that will never be utilised for water supply and that will not contaminate other aquifers.
Special aquifer region	An aquifer designated as such by the Minister of Water

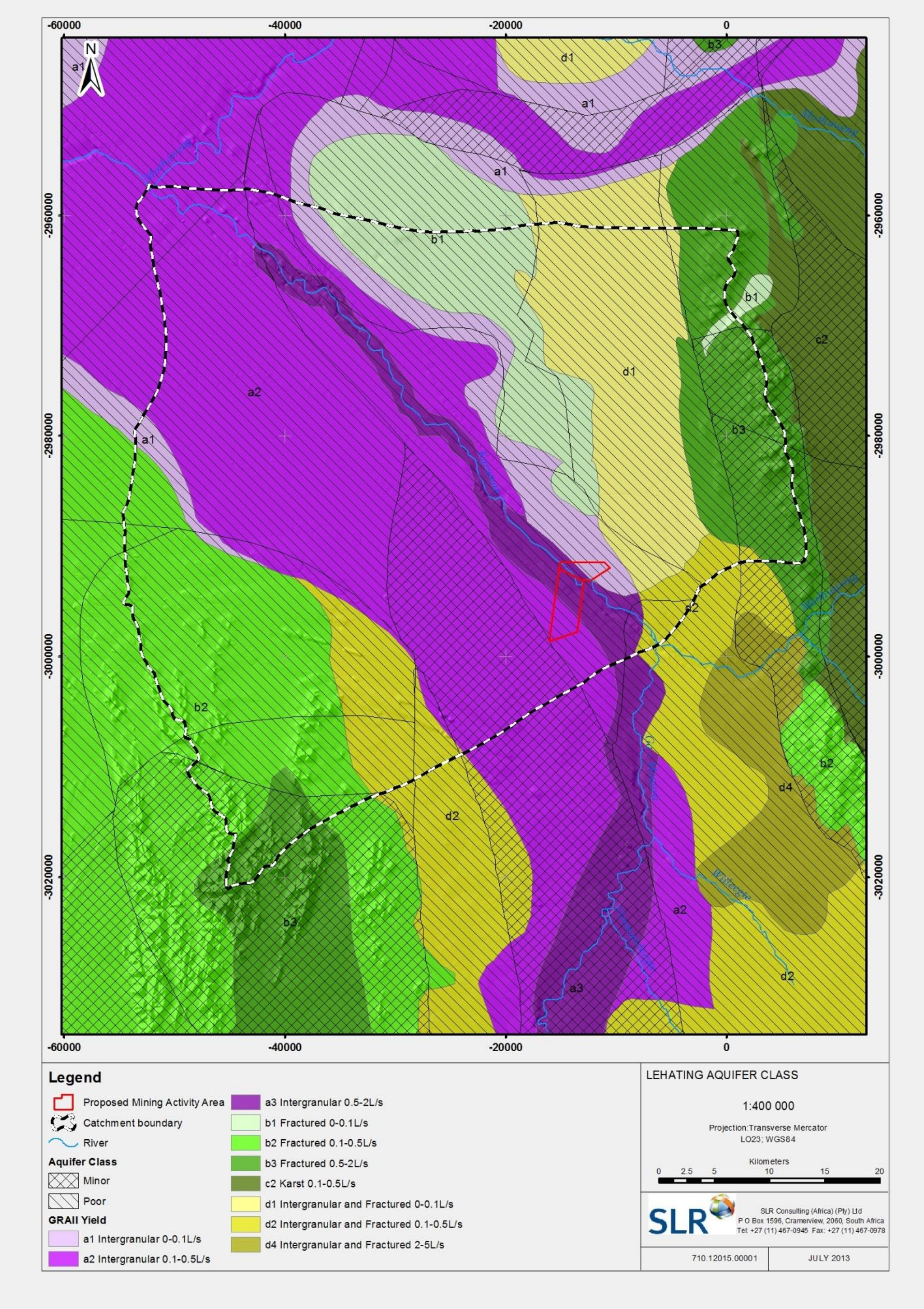

Figure 2-6: Hydrogeological (Aquifer class) map indicating location of Mn48.

2.3.1 Unconfined Kalahari Aquifer

The unconfined, intergranular Kalahari aquifer represents the upper-most aquifer in the regional model area, covering all other aquifer units, except for localized areas where rocks of the Olifantshoek Supergroup and Asbestos Hill Subgroup outcrop on the western and eastern boundaries of quaternary catchment (D41M) representing the model boundaries. The Kalahari aquifer consists of heterogeneous sedimentary deposits, changing in porosity over short distances, influencing both the groundwater flow and borehole yields. The Kalahari aquifer thickness decreases southwards away from the Kalahari basin that covers geographically most of Botswana and some parts of Namibia and South Africa. Exploration boreholes drilled within the Mn48 area indicate an average thickness of 80 metres for the Kalahari sediments. Typical borehole yields expected in the Kalahari aquifer are between 0.1 and 0.5 L/s. Localized paleo-channels typically occurring on (or close to) the contact between sediments of the Kalahari Formation and Dwyka Formation generally produce higher yielding boreholes.

The Kalahari Aquifer constitutes the main aquifer for water supply to surrounding farms for both domestic and agricultural use (as defined during the hydrocensus).

2.3.2 Confined Dwyka Aquifer

The confined, fractured Dwyka aquifer unconformably overlies older lithologies, i.e. rocks of the Hotazel / Ongeluk and Asbestos Hill units. The Dwyka aquifer consists of diamictites with clay lenses influencing the overall hydraulic properties of the aquifer. The Dwyka aquifer outcrops close to the eastern quaternary catchment (model) boundary at the contact between the overlying Kalahari sediments and Asbestos Hill Subgroup. The exploration boreholes drilled in Mn48 indicate an average thickness of 200 metres for the Dwyka aquifer. According to the GRA II data, expected borehole yield in this aquifer ranges between 0.5 and 2 L/s.

2.3.3 Olifansthoek Aquifer (Western geological boundary)

The semi-confined, fractured Olifantshoek aquifer unconformably overlies rocks of the Transvaal Supergroup units (i.e. Hotazel and Ongeluk formations). This aquifer unit outcrops on the western side of the catchment (model) boundary forming a topographical high and regional recharge zone. The expected borehole yields in this fractured aquifer unit range between 0.1 and 2.0 L/s. The Olifantshoek aquifer is covered extensively by a thin layer of Kalahari sediments.

2.3.4 Deeper Fractured Hotazel/ Ongeluk Aquifer

The confined, fractured Hotazel and Ongeluk aquifers are the deepest aquifer units characterised by the conceptual model. Both formations form part of the Pretoria Group (Transvaal Supergroup). The Hotazel Formation overlying the Ongeluk Formation is economically the most important unit due to the presence of manganese deposits. The unit is structurally confined within the Dimoten Syncline, plunging 8° in a north-western direction comprising mostly of banded iron with manganese bearing units. The exploration boreholes drilled on Mn48 indicate an average thickness of no more than 20 metres for the Hotazel Formation. The Ongeluk Formation underlies the Hotazel Formation and consists predominantly of lavas. Towards the eastern and western catchment (model) boundaries rocks of the Ongeluk Formation is directly overlain by Kalahari sediments. The expected borehole yields for the Ongeluk aquifer unit range between 0.1 and 0.5 L/s.

2.3.5 Asbestos Hill Aquifer (eastern geological boundary)

The semi-confined, fractured Asbestos Hill aquifer unit is overlain by the Hotazel / Ongeluk aquifer units except towards the eastern catchment (model) boundary where the unit outcrops. Rocks of the Asbestos Hill Subgroup dip 30° in a western direction and form a geological boundary on the west of the catchment (model) area. A thin of layer Kalahari sediments covers the Asbestos Hill Subgroup. The expected borehole yields for this aquifer unit range between 0.5 and 2.0 L/s.

2.4 HYDROGEOLOGICAL FIELD INVESTIGATION

2.4.1 Hydrocensus

Two groundwater samples were collected during mid-2011 from borehole LEX3A and LEX4. Prior to sampling the boreholes were purged until the field parameters stabilised (i.e. electrical conductivity, pH, etc.) or the stagnant borehole water was replaced three times. This was achieved by sampling the boreholes during the latter stages of the constant discharge tests. The samples were submitted to an accredited lab for analysis.

The accuracy of the chemical analyses were evaluated according to missing main components, plausibility of the single values as well as acceptable ion (charge) balance errors as determined by the electro neutrality (E.N):

$$\text{E.N.}[\%] = \frac{\sum cations\,[\text{meq/L}] - \left|\sum anions\,[\text{meq/L}]\right|}{\sum cations\,[\text{meq/L}] + \left|\sum anions\,[\text{meq/L}]\right|} \cdot 100\%$$

While aqueous solutions should be electrically neutral, an error of 5 % for a sample analysis is generally considered reasonable. The criterion is relaxed for low mineralised samples to 10%. Interpretations based on samples with larger errors in the ion balance should be generally treated with caution, though results for trace elements of concern (e.g. uranium) are not affected and remain valid.

Analytical results for groundwater samples collected at Mn48 during the pumping tests are presented in Table 2-2 below.

Table 2-2: Chemistry of groundwater samples collected during the pumping tests and colour coded according to SANS water quality guidelines.

Determinants	Units	Class I	Class II	Period of consumption (Class II)	LEX3A	LEX4
Physical and organoleptic requirements						
EC	mS/m	<150	150-370	7 years	98.6	204
TDS	mg/l	<1000	1000-2400	7 years	622	1236
pH	pH units	5.0-9.5	4.0-10	No limit	8.3	8.1
Chemical requirements						
Ca	mg/l	<150	150-300	7 years	67	106
Cl	mg/l	<200	200-600	7 years	84	416
F	mg/l	<1.0	1.0-1.5	1 year	0.2	0.5
Mg	mg/l	<70	70-100	7 years	82	72
NO_3 as N	mg/l	<10	10.0-20	7 years	3.3	1.1
K	mg/l	<50	50-100	7 years	3.5	6.9
Na	mg/l	<200	200-400	7 years	44	232
SO_4	mg/l	<400	400-600	7 years	45	113
Zn	mg/l	<5.0	5.0-10	1 year	<0.025	<0.025
Al	µg/l	<300	300-500	1 year	<0.1	<0.1
Sb	µg/l	<10	10-50	1 year	<0.01	<0.01
As	µg/l	<10	10-50	1 year	<0.01	<0.01
Cd	µg/l	<5	5.0-10	6 months	<0.005	<0.005
Cr	µg/l	<100	100-500	3 months	<0.025	<0.025
Co	µg/l	<500	500-1000	1 year	<0.025	<0.025
Cu	µg/l	<1000	1000-2000	1 year	<0.025	<0.025
Fe	µg/l	<200	200-2000	7 years	<0.025	0.316
Pb	µg/l	<20	20-50	3 months	<0.02	<0.02
Mn	µg/l	<100	100-1000	7 years	<0.025	0.443
Ni	µg/l	<150	150-350	1 year	<0.025	<0.025
Se	µg/l	<20	20-50	1 year	<0.02	<0.02
V	µg/l	<200	200-500	1 year	<0.025	<0.025
Carbon requirements						
Total Organic Carbon	mg/l	-	-		6.6	3.8
Dissolved Organic Carbon	mg/l	<10	10 - 20	3 months	5.3	2.6

The groundwater sample collected at borehole LEX3A presented a Mg-HCO3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. This is expected from the sample collected at borehole LEX3A as the borehole was drilled to a depth of 40 metres targeting higher yielding zones in the Kalahari Formation.

The groundwater sample collected at borehole LEX4 presented a Na-Cl water type with elevated concentrations of chloride, sodium and magnesium. The elevated sodium and chloride concentrations may represent deeper and/or older groundwater within an evolved groundwater regime. This water type is probably characteristic of the groundwater within the deeper, confined Hotazel and Ongeluk aquifers.

The groundwater samples for LEX3A and LEX4 are thus indicative of two distinctive groundwater regimes.

The first hydrocensus (site walkover) was conducted by SLR Africa (Pty) Ltd within the proposed mining as part of the conducted during mid-2011. A follow up hydrocensus was conducted during July 2013 to expand on the existing groundwater level dataset, focusing on farm around Mn48. A total of 76 boreholes were visited mainly for the purpose to identifying groundwater users and taking groundwater levels measurements. Details of the hydrocensus data collected are given in Appendix B.

The locality of the borehole sites are shown on Figure 2-7. The majority of boreholes are for either domestic use and/or cattle/game feedlots or prospecting boreholes. A number of boreholes are not in use or unequipped. The water levels measured during the hydrocensus vary from a minimum of 9.8 mbgl to more than 110 mbgl with an average of 54 mbgl. Water levels located in and around Mn48 mine portion has an average depth of 37 mbgl (Table 2-3).

Table 2-3: Water level data obtained from hydrocensus.

Borehole locations	Nr. Of BHs	Water Level (mbgl)		
		Min	Max	Mean
Hydrocensus (Catchment D41M)	76	9.8	114.8	54.0
Lehating Mine	24	9.8	58.7	36.7

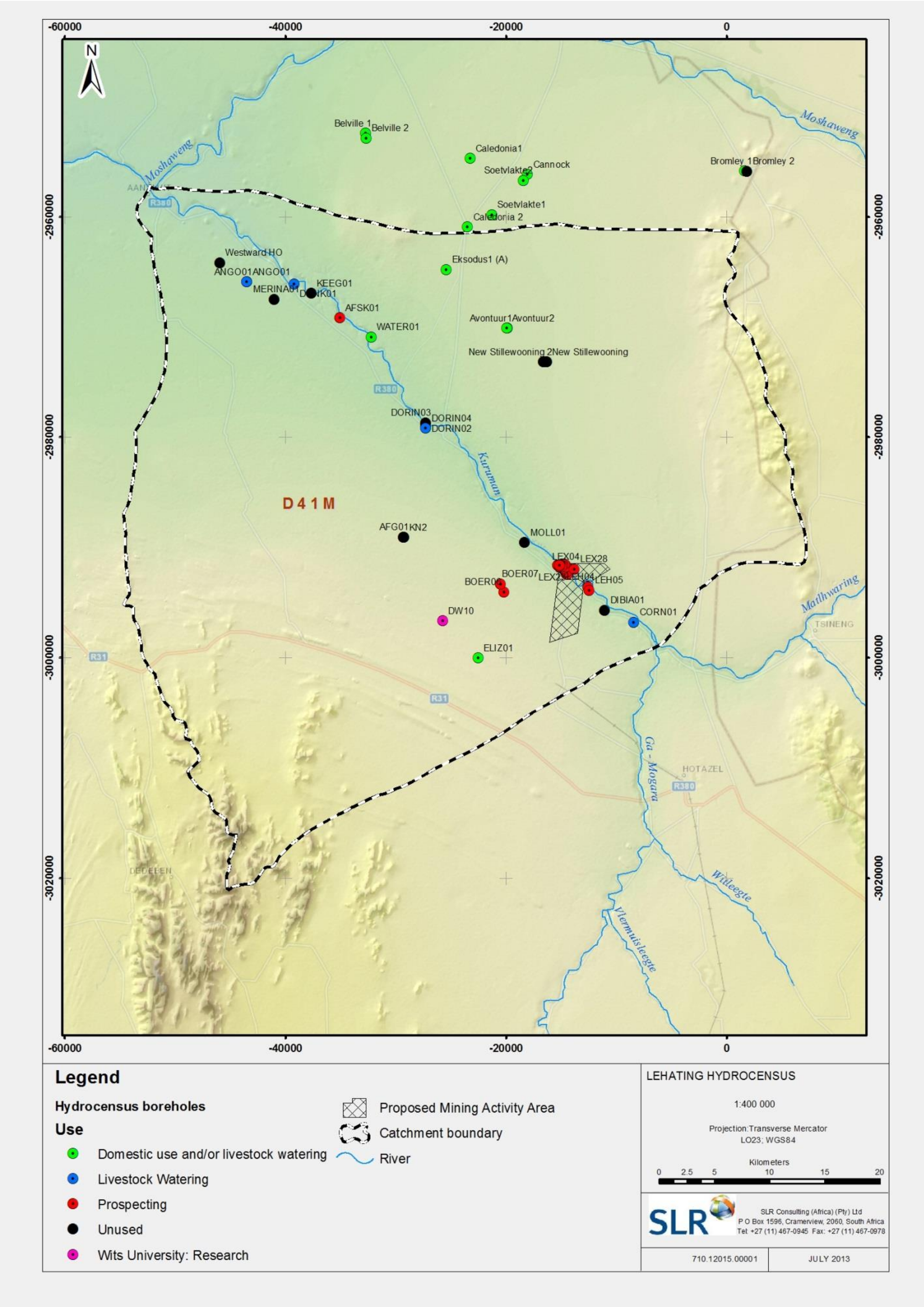

Figure 2-7: Hydrocensus conducted to identify groundwater use and water levels.

2.4.2 Hydraulic Properties

Packer tests

During the period May 2011 to June 2011 Metago Water Geosciences conducted packer tests on three exploration boreholes, at Mn48 mine.

Packer test consists of isolating specific horizons with inflatable packers in a borehole, targeting specific lithological units or specific depth intervals, a series of packer tests at different depths or targeted lithologies allow for the estimation of hydraulic conductivities for the selected intervals. Packer tests consist of measuring the rate of flow in the test interval over period of time. A constant head permeability double packer test method was used at Mn48 mine to derive at varied hydraulic conductivities at different depths. Water at constant pressure is injected into the rock mass through a slotted pipe (bounded by the packers). The test is conducted in different stages - keeping a constant water pressure over the test interval but increasing the water pressure for different stages. During each stage, water pressure and flow rate are recorded over time to determine the hydraulic conductivity.

Information on the exploration boreholes as well as the hydraulic conductivities, for selected borehole intervals, derived from the packer tests presented in Table 2-4. The formations targeted during the packer tests, based on the borehole intervals tested, were the Hotazel and upper Ongeluk formations.

Table 2-4: Borehole information and hydraulic conductivities derived from the packer tests targeting the Hotazel and parts of the Ongeluk Formations.

BH ID	Intervals Tested	Drilled Depth	Measured Depth	Water Level	K
	per Bh (m)	(mbgl)	(mbgl)	(mbgl)	(m/d)
Lex 4	285 - 312	316	292	58.9	2.4×10^{-4}
	250 - 312	-	-	-	2.5×10^{-4}
Lex 5	295 - 324	332	308.7	18.0	0
	250 - 324	-	-	-	0
Lex 12	235 - 256	256	247	36.6	3.9×10^{-4}
	220 - 256	-	-	-	3.1×10^{-4}

Pumping tests

Two existing boreholes were pump tested during early-2011. Borehole LEX 3A, drilled to a depth of approximately 50m, targeted a known higher yielding area of the Kalahari sediments. Borehole LEX 4, drilled to a depth of over 300m and cased off to a depth of 180m, targeted the deeper Dwyka Group and Hotazel / Ongeluk Formations (Table 2-5). These boreholes were selected to characterize two distinct groundwater regimes.

Two types of pumping tests were performed to assess the hydraulic properties of the identified aquifers at Mn48:

- Step drawdown tests (SDT), during which the borehole is pumped at a constant discharge rate for up to 60-minutes, where-after the step is repeated at a progressively higher discharge rate. After the test stopped, the residual drawdown over time is measured until ~95% recovery of the water level had been reached.
- Constant discharge test (CDT) during which a borehole is pumped for a pre-determined time (up to 24 hrs.) at a constant rate and the drawdown over time in at least the pumping borehole is recorded. Discharge measurements are taken at pre-determined time intervals to ensure that the constant discharge rate is maintained throughout the test period. The recovery follows directly after pump shut down and the residual drawdown over time is measured in the production and observation boreholes (if available) until a 95% recovery (of the initial water level) is reached.

Aquifer parameters are often estimated using data from the recovery phase rather than the drawdown curves of the pumping tests due to low discharge rates, wellbore storage, borehole skin effect, etc.

The following process was followed to estimate aquifer parameters based on the pumping test data:

- Develop a conceptual understanding of the geological setting relevant to the pumping tests.
- Create the diagnostic plots from pumping test data and define the flow regime.
- Choose the appropriate analytical method(s) (i.e. Theis, 1935; Cooper and Jacob, 1946; Hantush and Jacob 1955; Neuman, 1974; Moench, 1997) and determine the aquifer and well parameters from the curve fitting of the drawdown (and derivative) and/or the recovery data.
- Drawdown influenced by fluctuating pumping rates should rely on an accurate description of the recovery data. The water level recovery of a pumped aquifer can be interpreted in the same way as the drawdown by using diagnostic plots. Through a simple transformation of the time variable, Agarwal (1980) devised a procedure that uses solutions developed for drawdown analysis (i.e. the Theis type-curve) to analyse water level recovery data.

The pumping test diagnostic plots with fitted data are provided in subsequent sections.

Table 2-5: Boreholes used for pumping tests.

Name	Coordinates (WGS84)		BH Depth (m)	Casing (m)	Water strike depth (m)	Water Level (m)
LEX 3A	-27.040879	22.853137	49.95	40	unknown	26.49
LEX 4	-27.037270	22.848890	316.55	180	43 (cased off)	58.72

A summary of the estimated transmissivity (T) values based on the boreholes tested are provided below.

Pumping test analysis – LEX 3A

Borehole LEX 3A was pumped with a constant abstraction rate of 10 L/s for 18 hours. This abstraction rate resulted in a total drawdown of 20 metres. A number of analytical solutions were applied to describe the observed drawdown in the groundwater level for borehole LEX 3A, before the most applicable solutions were chosen for the final interpretation (Table 2-6).

A transmissivity value of ~117 m^2/day was determined using the analytical model (Figure 2-8) for an unconfined aquifer and appears plausible for a shallow primary aquifer in the Kalahari Formation. A similar good fit was achieved with the Cooper-Jacob model with a transmissivity value of 124.9 m^2/day. As a result, the hydraulic conductivity of the Kalahari Formation is estimated to be 2 m/d.

Results from the pumping test indicate that the borehole can be pumped at a recommended rate of 8.0 L/s for 12 hours with a maximum groundwater level drawdown of 8 metre. This will allow a 12-hour recovery time for the aquifer to recover to its original water level.

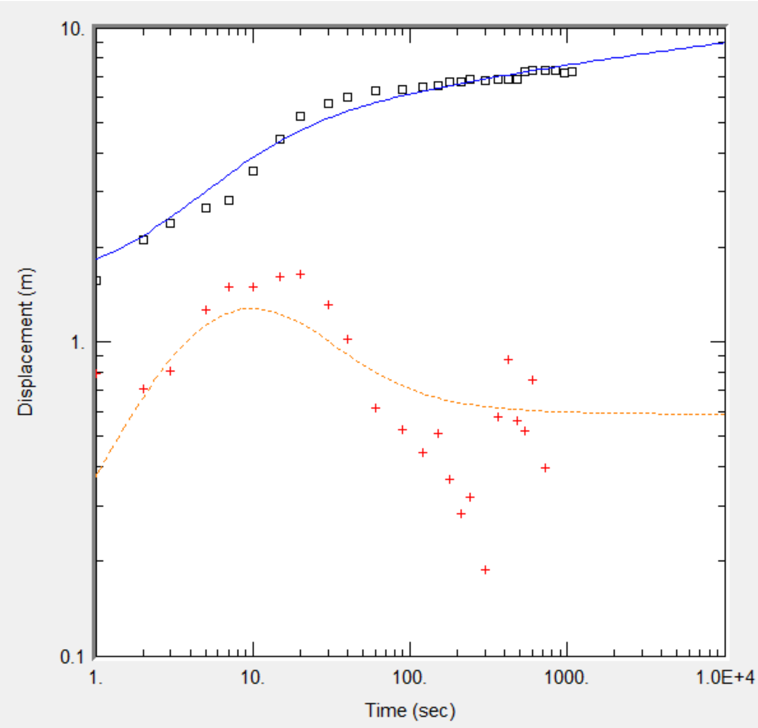

Figure 2-8: Log-log plot for a constant discharging pumping test (CDT) based on groundwater level fluctuations for LEX3A and fitted Neuman solution for an unconfined aquifer.

Table 2-6: Estimates of aquifer parameters based on pumping tests – LEX3A.

Parameter	Value	
Pump rate	10 L/s	
Time	1080 min	
Static WL	26.49 mbgl*	
Final Drawdown	33.76 mbgl*	
BH Depth	49.95 mbgl*	
Pump Depth	39.65 mbgl*	
Hydraulic parameter	**Value**	**Aquifer Model**
Transmissivity	117.1 m^2 /d	Neuman (Aqtesolv)
Transmissivity	124.9 m^2 /d	Cooper-Jacob

NOTES

mbgl*- meters below ground level

Pumping test analysis – LEX 4

Borehole LEX 4 was pumped with a constant abstraction rate of 0.13 L/s for 24 hours. A number of analytical solutions (Table 2.7) were applied to describe the observed drawdown in the groundwater level for borehole LEX 4, before the most applicable solutions were chosen for final interpretation.

The data (Figure 2-9) for the hydraulic test (borehole LEX 4) shows only a good fit during late times. During early time the effects of wellbore storage and/or skin effects renders an over-all fit difficult. A transmissivity value of ~0.95 m^2/day was determined based on the leaky aquifer solution. A similar good fit was achieved with the Hantush model for a leaky aquifer (transmissivity of 0.7 m^2/day). This borehole was cased off to a depth of 180 mbgl and the transmissivity value(s) may be representative of the deeper Dwyka, Hotazel and upper Ongeluk formations. Due to the low yielding capability of the deeper Dwyka, Hotazel and upper Ongeluk formations borehole LEX4 is not recommended for water supply use.

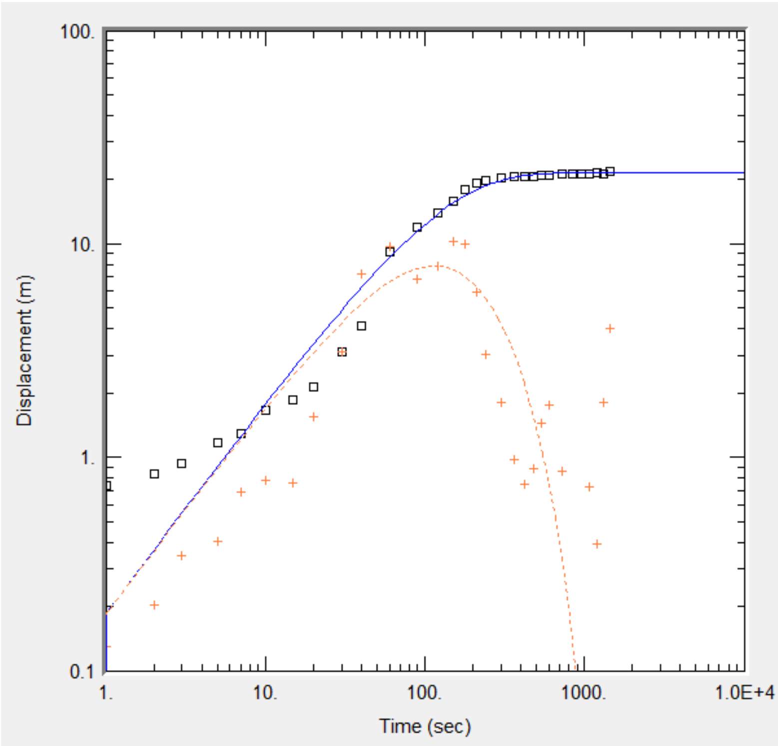

Figure 2-9: Log-log plot for a constant discharge pumping test (CDT) for LEX4 and fitted MOENCH solution for a leaky aquifer.

Table 2-7: Estimates of aquifer parameters based on pumping tests – LEX4.

Parameter	Value	
Pump rate	0.13 L/s	
Time	1440 min	
Static WL	58.72 mbgl*	
Final Drawdown	80.46 mbgl*	
BH Depth	316 mbgl*	
Pump Depth	142.5 mbgl*	
Hydraulic parameter	**Value**	**Aquifer Model**
Transmissivity	0.95 m^2 /d	Leaky – Moench (Aqtesolv)
Transmissivity	0.7 m^2 /d	Leaky – Hantush

NOTES

mbgl*- meters below ground level

2.5 GROUNDWATER ELEVATION AND FLOW DIRECTIONS

Of major importance for regional groundwater flow in the Mn48 Mine area is the continuous presence of an impermeable or semi-permeable interface between the upper, unconfined Kalahari aquifer and the deeper, confined Dwyka aquifer. This interface (i.e. a permeability contrast) prevents rapid vertical drainage of the Kalahari aquifer on a regional scale, thus permitting lateral groundwater flow in the Kalahari aquifer driven by topographic gradients. Vertical infiltration across this interface is controlled by the existence of major permeable zones such as regional fault systems, etc. The non-perennial Kuruman River must be further studied to understand the interaction between the groundwater and surface water and possible intermittent flooding events.

A total of 82 water level measurements were available (24 water levels from the hydrocensus, 24 water levels from prospecting boreholes and 34 water levels from the NGA dataset) for the regional interpretation of groundwater levels. In general, the water table is a subdued reflection of the topography, and groundwater flow is from areas of higher lying ground (Asbestos Hill and Olifantshoek mountain ranges) towards the central and northern areas of the model domain with the Kuruman River as the base-level of drainage in the quaternary catchment. The potential correlation between the measured head (static water level) and topography (surface elevation) was investigated by cross-plotting the data as presented in Figure 2-10.

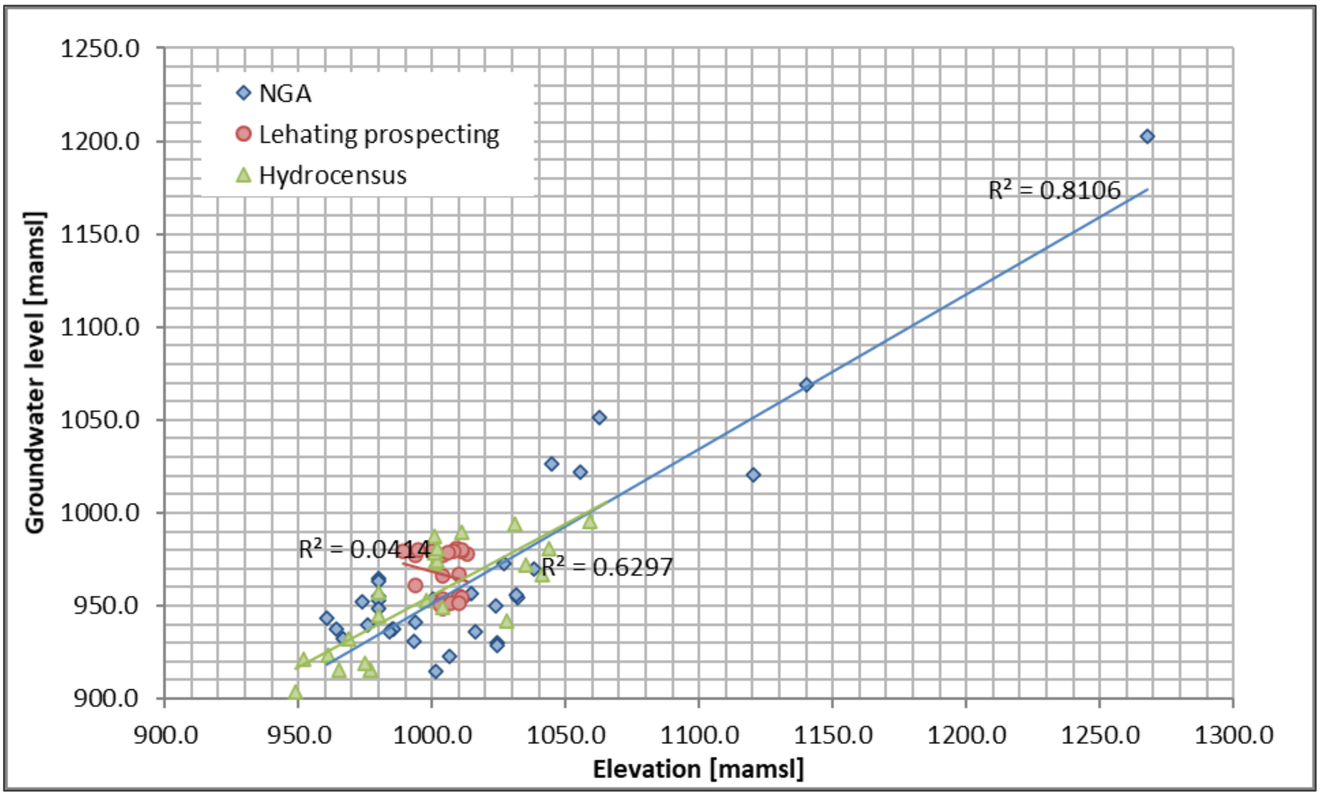

Figure 2-10: Correlation between surface topography and water level elevations in quaternary catchment D41M.

Based on the National Groundwater Achieve (NGA) groundwater data obtained from Department of Water Affairs (DWA) a relative good correlation between the measured head and topography (R^2 = 81%) can be seen and it can be assumed that the water table mimics the surface topography. However less good correlation between surface topography and measured head are seen (R^2 = 63%) based on the hydrocensus conducted in July 2013. The observed water level variations can be explained by variation in land surface and boreholes influenced by pumping (i.e. windmill water recordings). However, almost no correlation between measured head and topography exists based on the prospecting boreholes (R^2 = <10%) located on Mn48. The unrelated correlation between surface topography and water table based on the prospecting boreholes can be attributed to the boreholes being cased offed at varying depths.

2.6 HYDROLOGIC BOUNDARIES

Due to the established correlation between groundwater elevations and surface topography, surface watersheds (i.e. drainage catchment boundaries) represent groundwater divides and are used as no-flow boundaries for model domains incorporated into numerical models.

3. MODEL CONSTRUCTION

3.1 COMPUTER CODE

The hydrogeological conceptual model was converted into a numerical groundwater model to assess groundwater flow and contaminant transport rates and directions. Various pre- and post-processors are available for MODFLOW and MT3D, aimed at making data input and 2-D and 3-D visualisation faster and simpler. In the case of the Mn48 mine portion groundwater model, the internationally accepted package GMS 9 (Groundwater Modelling System) was used.

3.1.1 MODFLOW

The software code chosen for the numerical finite-difference modelling work is the modular 3D finite-difference ground-water flow model MODFLOW, developed by the United States Geological Survey (USGS) (MacDonald and Harbaugh, 1988). The code was first published in 1984, and since then has undergone a number of revisions. MODFLOW is widely accepted by environmental scientists and associated professionals. MODFLOW uses the finite-difference approximation to solve the groundwater flow equation. This means that the model area or domain is divided into a number of equal-sized cells – usually by specifying the number of rows and columns across the model domain. Hydraulic properties are assumed to be uniform within each cell, and an equation is developed for each cell, based on the surrounding cells. A series of iterations are then run to solve the resulting matrix problem, and the model is said to have “converged” when errors reduce to within an acceptable range. MODFLOW is able to simulate steady and non-steady flow, in aquifers of irregular dimensions, as well as confined and unconfined flow, or a combination of the two. Different model layers with varying thicknesses are possible. The edges of the model domain, or boundaries, typically need to be carefully defined, and fall into several standard categories.

3.1.2 MT3D

MT3DMS (MT3D package) is a modular 3-D transport model for the simulation of advection, dispersion and chemical reactions of dissolved constituents in groundwater systems, originally developed by Zheng (1990) at S.S. Papadopoulos and Associates Inc. MT3DMS is designed to work with any block centred finite difference flow model, such as MODFLOW (under assumption of constant fluid density and full saturation). MT3DMS is unique in that it includes three major classes of transport solution techniques in a single code, i.e., the standard finite difference method; the particle-tracking based Eulerian-Lagrangian methods; and the higher-order finite-volume TVD method. Since no single numerical technique has been shown to be effective for all transport conditions, the combination of these solution techniques, each having its own strengths and limitations, is believed to offer the best approach for solving the most wide-ranging transport problems (Zheng et al., 1999).

3.2 MODEL DOMAIN

3.2.1 Finite Difference Flow Model

The finite-difference model was set-up as a 3-dimensional, 4 layer steady-state groundwater model. The different model layers represent the Kalahari sediments (60-80m thick at hill) and the deeper Dwyka aquifer, BIF aquifer, Basalt/lava aquifer representing the Hotazel/Ongeluk formation and Granite aquifer representing the Olifantshoek formation. The top elevation of layer I was based on the 20m digital elevation model while the bottom elevation (layer IV) was offset by 350m.

The model domain (Figure 3-1) was discretised into a 181 X 184 grid block uniform mesh, with uniform horizontal grid block sizes of 500m X 500m and refined horizontal grid block size around the mine of 50m X50m with a total number of 133 216 cells.

It must be noted the finite difference model built by Metago Water Geosciences for the mine dewatering of the underground mine and associated cone of depression differs slightly from the model set-up for the contaminant transport model as presented in this report.

3.2.2 Finite Difference Contaminant Transport Model

The same finite-difference flow model was used for the contaminant transport model; i.e. a 3-dimensional, 4 layer steady-state groundwater model. The different model layers represent the Kalahari sediments (60-80m thick at hill) and the deeper Dwyka aquifer, BIF aquifer, Basalt/lava aquifer representing the Hotazel/Ongeluk formation and Granite aquifer representing the Olifantshoek formation. The top elevation of layer I was based on the 20m digital elevation model while the bottom elevation (layer IV) was offset by 350m.

The model domain (Figure 3-1) was discretised into a 181 X 184 grid block uniform mesh, with uniform horizontal grid block sizes of 500m X 500m and refined horizontal grid block size around the mine of 50m X50m with a total number of 133 216 cells.

Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 10m) transport of potential pollutants, without any retardation or transformation was assumed. Advection describes the transport of contaminants at the same velocity as groundwater and dispersion refers to the spreading of contaminants over a greater region than would be predicted only from the average groundwater velocity vector. Therefore, all impact assessments of potential pollution sources on the groundwater quality are considered worst case.

3.3 BOUNDARY CONDITIONS

The surface water (i.e. drainage) catchment boundaries and the groundwater divides were incorporated into the model as no-flow boundaries. The northern boundary of the model coincides with surface water catchment boundaries and was implemented in the model as a first-type no-flow boundary condition. Furthermore, constant head boundary conditions (Figure 3-1) based on water levels estimated at 5-10 metres below surface (i.e. river stage), were incorporated for different rivers / streams representing the boundary conditions in the north and south of the model domain.

Lastly, the boundary conditions were spatially chosen to have no or minimum impact on the flow and transport model based on the project and model objectives.

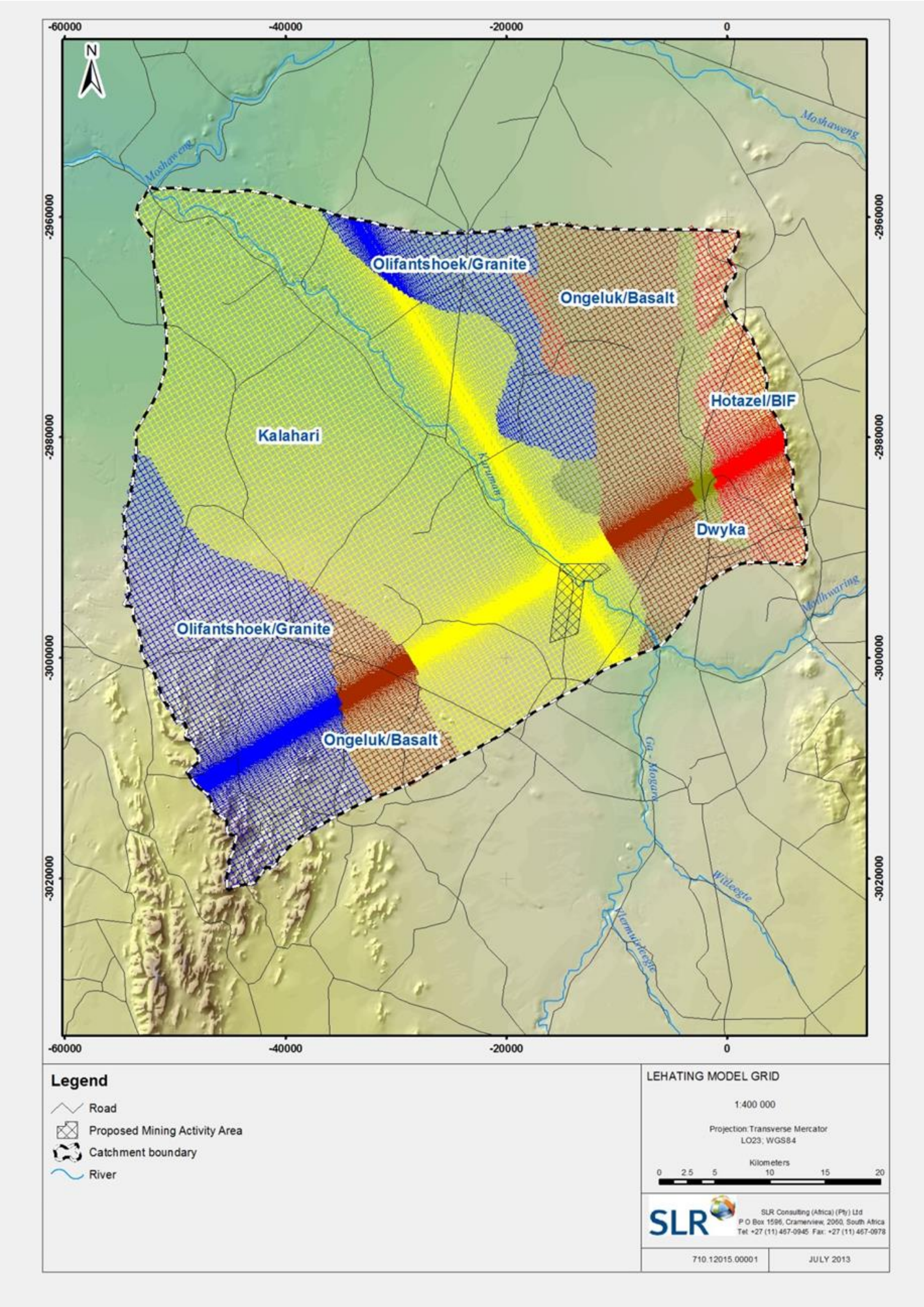

Figure 3-1: Mn48 groundwater finite-differences model setup showing refined grid and aquifer system.

3.4 SOURCES AND SINKS

3.4.1 Groundwater Recharge

Groundwater enters the model domain as direct recharge from rainfall or indirect as seepage from the mine residue deposits. A mean annual precipitation (MAP) of 350mm, for the region, was utilised in the model. Due to the lack in long term rainfall data and/or long term groundwater monitoring data recharge rates (or any other recharge data) were incorporated into the model as percentages of MAP. Based on Vegter's recharge map (Vegter, 1995) between 0.1 and 3 mm per year is estimated for the area. Furthermore, using Program to Estimate Groundwater Recharge and the GW Reserve (RECHARGE) developed by Gerrit van Tonder and Yongxin Xu (2000) an overall estimate of less than 3% of rainfall infiltrates as recharge. The recharge rate estimated for the Mn48 groundwater model were between 0.1% and 1.2% of MAP. This translates to a mean annual recharge rate between 0.2mm and 4.4mm.

3.4.2 River Courses

Water leaves the model domain perennial (i.e. Kuruman Rivers) and non-perennial rivers. Notwithstanding, all were classified as continuously gaining rivers. Groundwater therefore can only discharge into them and the river courses were described using MODFLOW's drain package with no exfiltration of water from the river. This approach ensures no water losses occur from the non-perennial rivers into the model domain. The elevation of each drain (MODFLOW) cell was carefully aligned with the height of the model DEM at that point and an incision of 5-10m below the surrounding topography was assumed. An equivalent drain or riverbed conductance of 2 m^2/day per meter of river or drain length was assumed.

3.4.3 Tailings Storage Facility, Waste Rock Stockpile, and product Stockpiles

The Tailing Storage Facility (TSF), Waste Dump and product Stock Pile were incorporated into the model domain for the predictive simulations as recharge boundaries with specified source concentrations. The source concentrations are initially represented as percentages. Following the precautionary principle, the leakage rate for the maximum (final) footprint area of the TSF at the end of its life (as provided by the project team), was used as the recharge estimate of the TSF footprint area. The source concentration represents a percentage as no defined source concentration could be obtained during writing of this report. Following the precautionary principle, the post-closure recharge rate is considered constant despite planned rehabilitation (i.e. surface coverage) of the dumps, which will reduce the actual recharge rate over time. The associated post-closure leakage rates from the TSF are therefore worse case projections.

Table 3-1: Source concentrations for the mine residue deposits (MRD's).

Scenario	Seepage rate [m/d]	Source concentration [%]
Tailing Storage Facility (TSF)	0.000432 (unlined)	100
Waste Rock stockpile	Natural Recharge	100
Other stockpiles	Natural Recharge	100

3.5 HYDRAULIC PARAMETERS FOR FINITE DIFFERENCE MODELS

The groundwater flow and transport models incorporate 4 different hydraulic conductivity zones, i.e. the different model layers represent the Kalahari sediments (60-80m thick at hill) and the deeper Dwyka aquifer, BIF aquifer, Basalt/lava aquifer representing the Hotazel/Ongeluk formation and Granite aquifer representing the

Olifantshoek formation. The top elevation of layer I was based on the 20m digital elevation model while the bottom elevation (layer IV) was offset by 350m.

The vertical anisotropy was set to a Kh/Kv ratio of 3:1 for layer 1 to layer 4. The effective porosity values (based from McWorter and Sunanda, 1977) were conservatively specified as 0.27 (sandstone) for the Kalahari zone. Porosity values affect only the transport model and do not influence the outcome of the steady-state flow model.

3.6 SELECTION OF CALIBRATION PARAMETERS AND TARGETS

The starting heads were set to 30m below surface elevation for the initial model run. Due to limited number of groundwater level measurements (also not spatially representative of the model domain), an interpolation of the groundwater levels representing the starting heads for the initial model run could not be completed.

In view of the chosen steady-state models, the available groundwater levels [in metres above mean sea level (mamsl)] observed in 43 boreholes were used as calibration targets. No discharge measurements in the river courses were available for calibration purposes and the leakage coefficients for the river courses therefore left constant.

Since the modelled groundwater levels are directly related to the recharge rates and hydraulic conductivities, an independent estimate of one or more of the other parameter is required to arrive at a potentially unique solution. The estimated regional recharge was therefore considered fixed for the calibration and only the hydraulic conductivities of the 5 different geological zones (see chapter 3.5) considered variable. No attempt was made to further vary hydraulic conductivity values within the different zones, in an attempt to achieve representative uniform aquifer parameters for the entire Mn48 Model Domain.

With no calibration targets specified by the client, the project team adopted a root mean square error (between modelled and simulated water levels) lower than 10 for all monitoring boreholes as the calibration target. The objective is therefore to represent the overall groundwater flow pattern for the Mn48 site using uniform aquifer parameters rather than to achieve a good fit for individual boreholes using a multitude of fitting parameters.

Furthermore, the head change criterion for convergence for the model domain has been set to 0.01m. The latter represents an acceptable convergence level as the model domain is represented by a 50m X 50m elevation grid based on a 20m digital elevation model.

4. CALIBRATION (STEADY-STATE)

4.1 FINITE DIFFERENCE FLOW MODEL

The model was run with the initial conditions and the hydraulic conductivities adjusted using sensible boundaries until a best fit between measured and computed heads was achieved.

The MODFLOW model uses iterative methods (iterations) to obtain the solution to the system of finite-difference equations for different time steps, i.e. calculate best fit groundwater heads to fit the model solutions. A procedure of calculation is initiated which alters estimated values, producing a new set of head values which are in closer agreement with the system of equations. This procedure is repeated successively until convergence is met, i.e. calculated groundwater heads resemble the measured groundwater heads. As stated in section 3.6, the head change criterion for convergence for the model domain reached convergence (=0.004m) meeting the set convergence criteria of 0.01m.

Using 43 groundwater level data points observed in the groundwater monitoring boreholes within the model domain (some measured groundwater levels were excluded due to irregularity of observed groundwater levels within the same vicinity); a steady-state calibration of the groundwater flow model was performed. Figure 4-1 illustrates the calibration achieved between the observed and modelled groundwater levels for the Mn48 groundwater model.

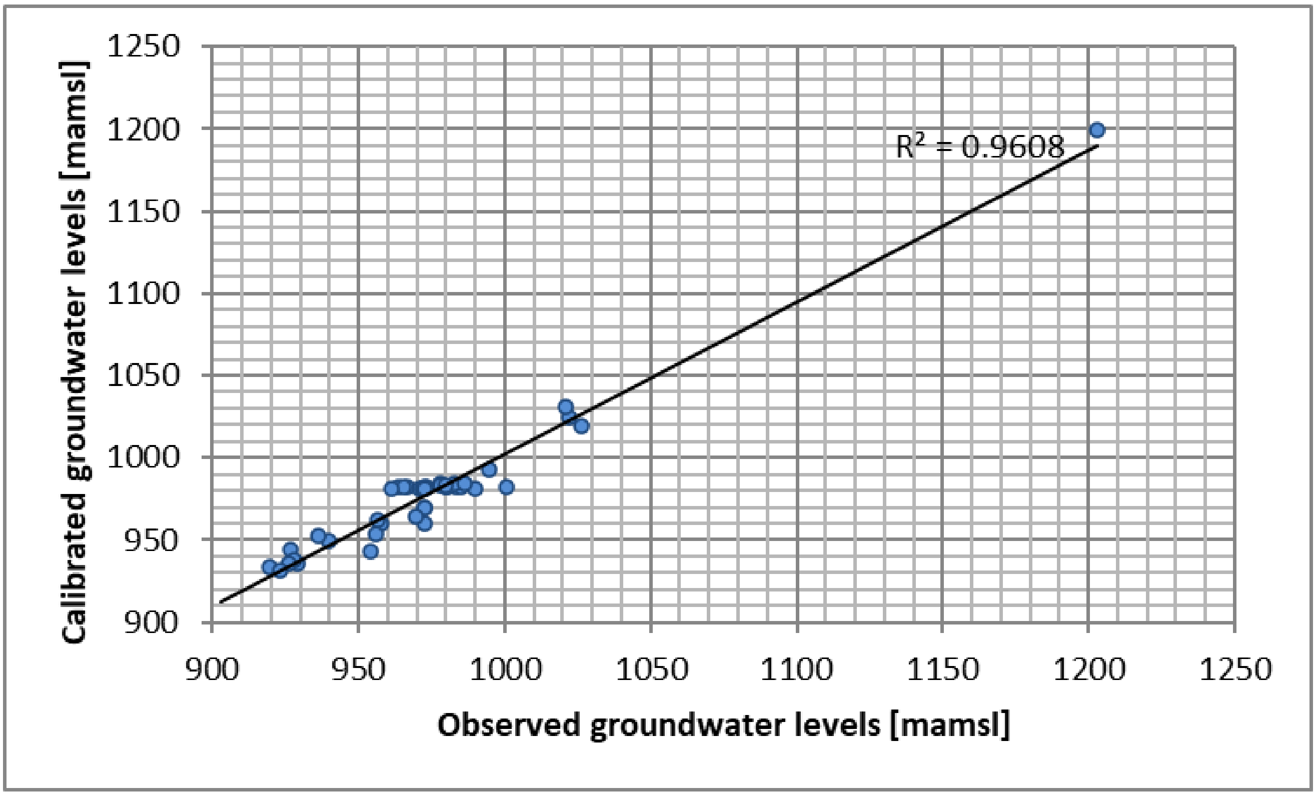

Figure 4-1: Steady-state calibration of Mn48 Mine model.

Despite this limitation, a root mean square error (RMSE) of 10 and a very good correlation coefficient R^2 between modelled and observed values (i.e. groundwater levels) of 96% was achieved for the steady-state calibration. The modelled groundwater contours (Figure 4-2) for the Mn48 Model are closely related to the topography, with groundwater flow from higher lying ground towards lower lying valleys (drainage lines).

The dominant groundwater flow is in a north-western direction, driven by the mountain range located towards the west and east flowing towards the Kuruman River. Localised groundwater flow within and around the Mn48 Mine area shows a dominant groundwater flow direction in a north-western direction with slight localised groundwater flow towards the Kuruman River.

Furthermore, of major importance for regional groundwater flow in the Mn48 Mine area is the continuous presence of an impermeable or semi-permeable interface between the upper, unconfined Kalahari aquifer and the deeper, confined Dwyka aquifer. This interface (i.e. a permeability contrast) prevents rapid vertical drainage of the Kalahari aquifer on a regional scale, thus permitting lateral groundwater flow in the Kalahari aquifer driven by topographic gradients. Vertical infiltration across this interface is controlled by the existence of major permeable zones.

The non-perennial Kuruman River must be further studied to understand the interaction between the groundwater and surface water and possible intermittent flooding events. However, for the purpose of this study groundwater and surface water interaction was not considered.

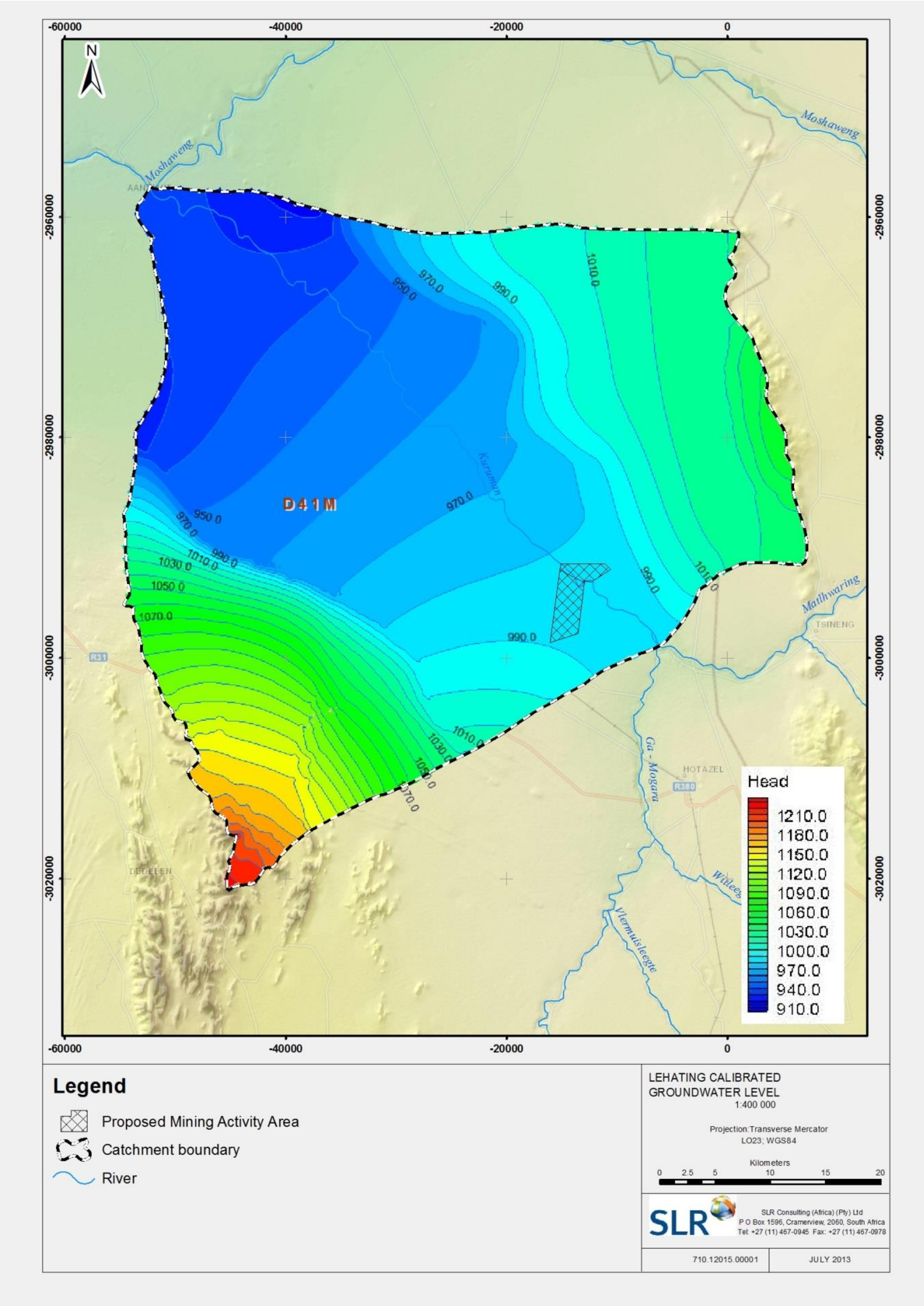

Figure 4-2: Steady-state calibrated groundwater levels of the Mn48 Mine model.

Table 4-1: Final hydraulic conductivities for the finite difference flow model.

Aquifer	Hydraulic conductivity [m/d] Model Setup
Kalahari Deposits	0.975
Dwyka/Diamictites	0.03 – 0.975
Olifantshoek/Granite	0.006 – 0.178
Hotazel/BIF	0.01 – 0.975
Ongeluk/Basalt	0.013 – 0.23

The flow budget, based on the steady state calibrated groundwater flow model, represents the total inflows and outflows for the model domain. The difference between the total inflow and total outflow represents and error of less than 1% contributing to the confidence level for the calibrated model for Mn48 Model (Table 4-2).

Table 4-2: Flow budget calculated from calibrated model parameters.

Sources and Sinks	Flow In	Flow Out
Constant Head	14104.37	-21571.98
Drain (River)	0	-2082.85
Recharge	9550.35	0
Total Flow	23654.72	-23654.83
Summary	**In – Out**	**% difference (error)**
TOTAL	-0.107	-0.00045

5. PREDICTIVE SIMULATIONS

5.1 ESTIMATED UNDERGROUND MINE INFLOW RATES

During mid-2011 Metago Water Geosciences was contracted to provide groundwater input to address the potential impact based on the flow regime due to mining activity, i.e. dewatering of the underground mine. The potential impact associated with the mine dewatering here in Section 5.1 (estimated pit inflow rates) are based on the Metago Water Geosciences report (Report: Groundwater Report – Lehating 741, Project number: WL005-01). The limitations for the development of the latter model are listed in the mentioned report.

The estimated mine inflow rates were estimated annually (year 3, year 8, year 13 and year 18). The groundwater inflows (steady-state) into the mine (only the groundwater recharge component) do not account for direct rainfall onto the mine, surface run-off into the mine or for potential seepages from a perched aquifer.

The calibrated groundwater model reported on by Metago Water Geosciences was included to address the potential impact and estimate groundwater likely inflow rates into the mine workings. The estimated inflow rate into the mine workings is in the order of 292 m^3/d (approximately 3.4 L/s) during year 18 of mine development (Table 5-1). The estimated inflow rates were computed for different periods over the life of mine.

Table 5-1: Estimated cumulative mine fissure inflows for selected periods over Life of Mine.

MINE WORKINGS	Zone 1	Zone 2	Zone 3	Zone 4
Years (Life of Mine)	3	8	13	18
Estimated (Cumulative) Inflows (m^3/d)	109.00	159.06	238.28	291.85
Estimated Inflows (L/s)	1.26	1.84	2.76	3.38

The hydraulic conductivity values for the Hotazel and upper Ongeluk formations as determined by the packer tests (x 10^{-4} m/d) are generally two orders of magnitude smaller than the hydraulic conductivity values estimated through a recent numerical groundwater model (x 10^{-2} m/d). The hydraulic conductivity values for the Hotazel Formation differs drastically when compared to the hydraulic conductivity values determined through slug tests on boreholes located in outcropping rocks of the formation. The differences in hydraulic conductivity values were expected since:

- Groundwater models generally apply the representative elementary volume (REV) (or EPM -equivalent porous medium) approach and integrate aquifer parameters over a much larger volume of aquifer material, incorporating both the rock matrix and inherent fractures,
- Packer tests target specific lithologies, or sections thereof, and represent in-situ tests on small volumes of rock conducted over pre-defined intervals in a borehole.
- The packer tests target specific lithologies units at depth and were conducted within un-cased boreholes at depths in excess of 220m below ground level.

Attributing smaller hydraulic conductivity values to the Hotazel and Ongeluk Formations (keeping all other parameters constant) in the calibrated groundwater model will lead to a reduction in the estimated, steady-state (i.e. long-term average) inflow rates into the mine workings. The smaller K- values derived from the packer tests points to reduced risks associated with mine fissure inflows. The estimated inflow rates of groundwater (i.e. mine fissure inflows) over the life of mine, derived from the groundwater model, is in agreement with dewatering rates of surrounding mines (pers. comm. Mn48 & TWP staff). As a result, a re-calibration of the existing groundwater model to account for the smaller K-values is not deemed necessary.

The estimated inflow rates of groundwater into the mine workings must be considered with reference to the following:

- No water was allowed to enter the deeper mine workings via the decline (assumed to be sealed), nor significant leakage which might be associated with the palaeo drainage channels intersected intermittently by boreholes.
- The regional groundwater flow model for Mn48 mine was used to estimate the steady-state (i.e. long-term average) inflow rates into the mine workings. The estimated inflow rate of 292 m^3/day in year 18 is based on the calibrated regional groundwater flow model that assumes representative elementary volume (REV) conditions for the heterogeneous, fractured aquifers; i.e. an equivalent porous medium (EPM) approach.
- Inflows into the mine workings should be continuously measured and used to update the regional groundwater model. As a result, the initial pit inflow estimate of 292 m^3/day represents the predicted dewatering rate at a low to medium confidence level.

5.1.1 Impacts Associated with Deep Mine Inflows

It is expected that the potential impacts associated with the deep mine inflows (i.e. dewatering) on the regional groundwater flow are:

- Insignificant w.r.t. the Kalahari Aquifer;
- Unlikely to impact third party groundwater users or groundwater contribution to baseflow;
- The cone of depression will be limited to the mine lease for the Kalahari Aquifer; and
- Reversible over time once dewatering stops.

As result boreholes outside the mine lease area are unlikely to be impacted (w.r.t. lowered groundwater levels) due to mine dewatering. A shallow and wide-spread cone (less than 5 km) of depression is associated with high hydraulic conductivities suck as the Kalahari formation.

Groundwater contribution to baseflow represents high frequency low flows during the dry season. Such flows are not evident for the non-perennial Kuruman River.

Based on the numerical groundwater model pit inflow calculations, the following assumption and limitation are noted:

- No seasonal rainfall effect (i.e. wet and dry seasons) have been accounted for; and
- No seepage from the mine shaft into the mine has been accounted for.

5.2 SIMULATED BOREHOLE/ WELLFIELD AS GROUNDWATER SUPPLY

Sustainable groundwater supply by abstraction from a borehole cannot be ‘sustainable’ or ‘unsustainable’ in isolation, but is dependent on other groundwater users, natural discharges, natural and induced recharge, storage and transmissivity, and on what changes to the system are acceptable to the parties concerned (Seward et al., 2006). It is common practice to try and maintain operational pumping levels above the level of the main yielding fracture. The sustainable pumping rate is in this context defined as the discharge rate that will not cause the water level in the well to drop below a prescribed limit, identified from the nature and thickness of the aquifer (especially water strikes) and the depth of the borehole/well. These monitoring design criteria’s (borehole operation philosophy) have been provided by the SLR team.

The proposed well field consist of four (4) boreholes drilled to a depth between 80 to 85 metres below ground level. The proposed well field is located within the Kalahari formation. Is must be noted that the Kalahari formation and surrounding mining area is classified as a poor aquifer class with expected yield between 0.1 and 0.5L/s. Therefore, it is essential to target preferential flow paths (i.e. fractures, faults, etc.) within the Kalahari aquifer. The hydraulic testing, i.e. pump test, conducted on borehole LEX3A intersected a paleoriver-channel on the contact between the Kalahari and Dwyka formations. These inter-formed paleoriver-channels are ideal targets for water supply boreholes.

The numerical groundwater flow model was used in the prediction of the behaviour of the well field. The four boreholes (with depths of 80mbgl) were incorporated into the steady state groundwater flow model as wells. Each well were populated to abstract groundwater with a rate of 216m3/d (2.5L/s). The simulation do not account for transient conditions or alternating well abstraction times and therefore predict worst case scenario as impact on the groundwater.

Bases on the simulated well field, i.e. four boreholes abstracting 2.5L/s, presented in Figure 5-1, a predicted cone of depression extends 800metres in a radial direction away from the well field with a drawdown of 1 meter. The predicted impact associated with the well field indicates a maximum groundwater depth of less than 4 metres. However, it must be noted that the simulation is based on steady-state conditions implying that the groundwater level will show higher impact in the starting phase (before steady state conditions are reached) under transient conditions.

The results of the pumping test (for Borehole LEX3A) are comparable to the outcome of the simulated well field development since the pumping test consider a smaller, more heterogeneous volume of aquifer material.

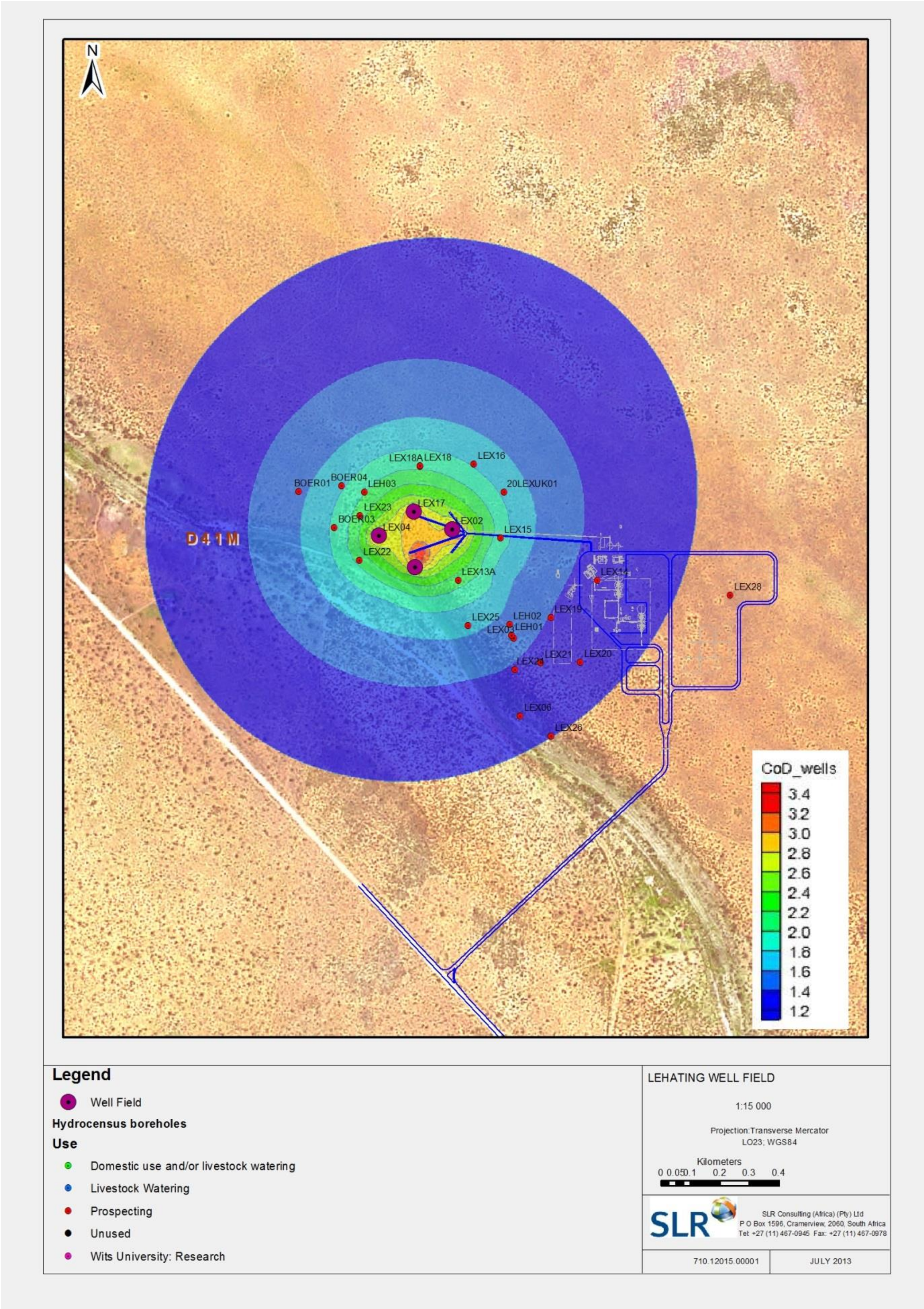

Figure 5-1: Simulated steady-state cone of depression for the proposed wellfield.

5.2.1 Impacts Associated with Wellfield

It is expected that the potential impacts associated with the well field (i.e. well dewatering) on the regional groundwater flow are:

- Likely to occur w.r.t. groundwater as resource;
- Unlikely to impact any third party groundwater users;
- Limited (up to 1 km) impact slightly beyond the mine lease area w.r.t.
    - Interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River;
    - Development of intersecting cones of depression, i.e. the lowering of the groundwater levels due to well field dewatering
- Reversible over time once well field stops abstracting groundwater; and
- The cone of depression associated with the proposed well field does not impact (w.r.t. lowering the groundwater level more than 1 meter) any third party boreholes (boreholes not belonging to the mine).

The cone of depression extends beyond the mining boundary and extent below the non-perennial Kuruman River. However, measured groundwater levels are far below the base of the non-perennial Kuruman River. As a result an impact on the non-perennial Kuruman River due to dewatering of the well field is not expected.

5.3 SIMULATED CONTAMINANT TRANSPORT FROM THE TAILINGS STORAGE FACILITY, WASTE ROCK STOCKPILE AND OTHER STOCKPILES

The model solutions of the calibrated steady-state groundwater models were used as the basis for the TSF, Waste Dump and Stockpile transport model using the internationally accepted MT3DMS (finite-difference) transport code. The TSF, Waste rock stockpile and other stockpiles (sources) were considered as potential sources of pollution and incorporated into the model domain as recharge boundaries with the source concentrations initially represented as percentages (Table 3-1). The post-closure recharge rates and source concentrations (as percentage) were considered constant and the associated long-term predictions are therefore worst-case projections. Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 10m) transport of potential pollutants without any retardation or transformation was assumed.

The predicted development of the contaminant plume (based on source concentrations) due to seepage from the TSF, Waste Dump and Stock Pile (using the finite-difference model) for up to 100 years after deposition started are shown in Figure 5-2. No consideration of unsaturated transport was incorporated into the finite-difference model, underrepresenting a dominance of vertical transport in the unsaturated zone underneath the sources (and subsequent less lateral spreading) and potentially smaller numerical dispersion effects. Also, no mining activities, i.e. dewatering, were incorporated into the transport model prediction.

The dominant spreading of the potential contaminants/pollutants associated with the sources occur in a radial manner and towards the north-west. This is due to a groundwater mounding effect due to the seepage and hydrodynamic dispersion (including diffusion) within the groundwater system. The groundwater mound cause preferential potential pollutant spreading in a circular direction during the first 15 years. The potential contaminants spread away from the potential pollutant sources for the weathered aquifer system due to its relatively higher hydraulic conductivity values. The potential pollutant spread occurs within the mining boundary. It should be noted that localised pollutant spreading might occur towards the Kuruman River; however, from the predicted spreading plume no potential pollutants reach the Kuruman River within the first 100 years.

The proximity of surface water drainages could considerably exaggerate the spreading of potential contaminants via surface streams and run-off. Furthermore, it must be emphasised that the spreading presented in Figure 5-2 shows the contaminant concentrations (as percentage) in the groundwater and not the potential spreading of contaminants in the surface water bodies.

Over time, without mitigation measures, the groundwater plumes may migrate to and discharge into the streams and rivers after mine closure. Similarly, off-site migration via surface flow might occur earlier if contaminant plumes are not contained / intercepted.

5.3.1 Impacts Associated with Seepage from the Sources

The potential impacts associated with the sources on groundwater quality are:

- Highly likely to occur w.r.t groundwater as resource;
- Localised within the wider mine site boundaries if surface run-off is contained;
- Long-term but within the site boundaries beyond closure; and
- The intensity of the impact is likely to be a moderate deterioration in the ambient groundwater quality for the site.

The contamination plume will in all likelihood be contained within the mine lease area due to the simulated cone of depression as result of mine dewatering.

The simulated pollution plume spread (up to 100 years) will impact the groundwater as resource; however no indication of third party groundwater users or surface water will be impacted.

The following assumptions and limitations are noted:

- Chemical reaction rates for the contaminants in the sub-surface have not been considered.
- Surface water drainages could exaggerate the spreading of potential contaminants.

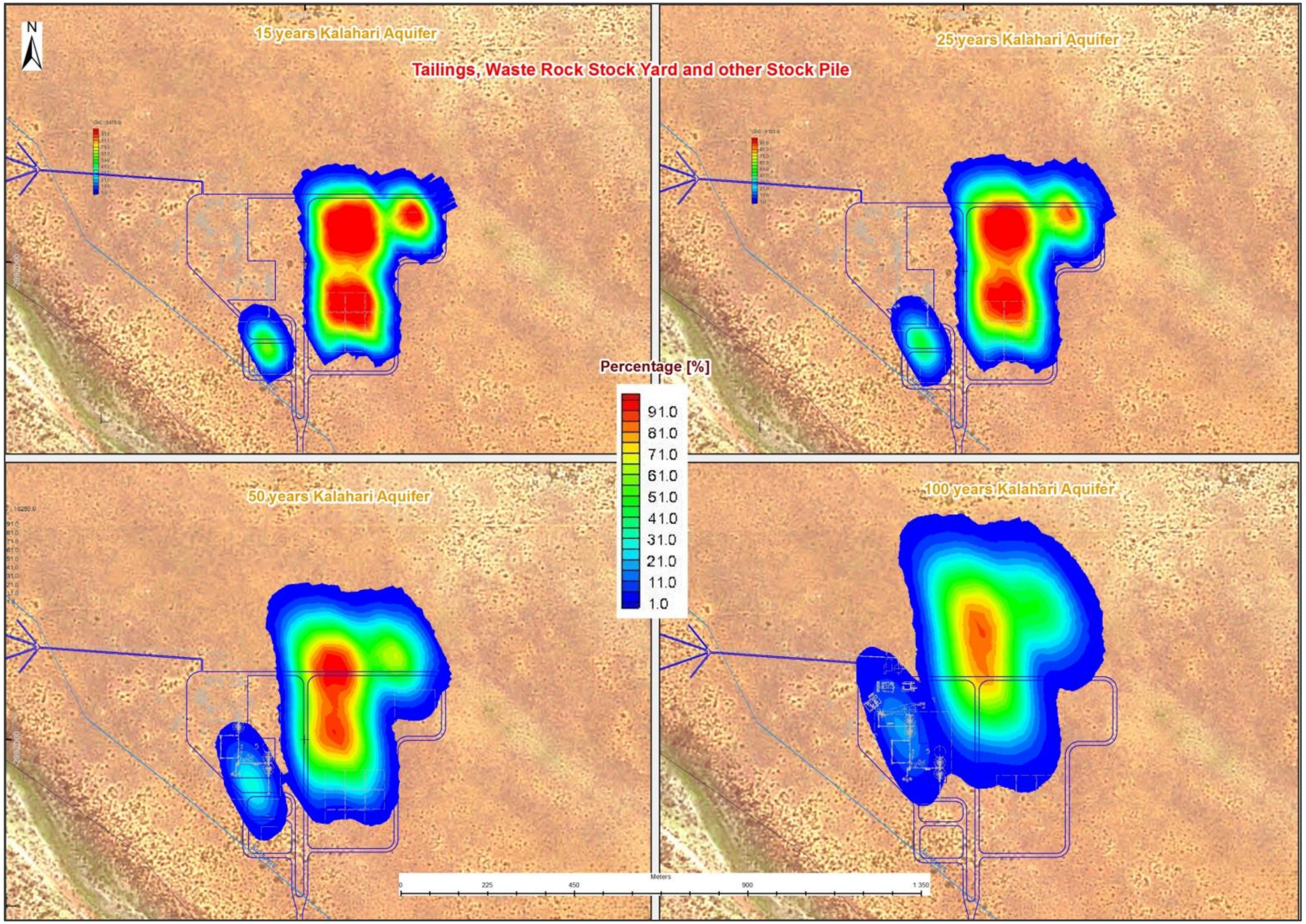

Figure 5-2: Contour maps of potential source concentrations (in percentage) after 15, 25, 50 and 100 years predicted with the finite-difference model for layer 1 (assuming constant source strength) for the waste rock stockpiles, fines and other stockpiles.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The main conclusions are grouped under various headings.

6.1.1 Geology

Surface geology at Mn48 comprises predominantly of Cenozoic deposits (Kalahari Formation). The Kalahari Formation is approximately 80 metres thick and overlies the Dwyka Formation which forms the basal part of the Karoo Supergroup. The Dwyka Formation is approximately 200 metres thick and overlies the Hotazel Formation (Transvaal Supergroup). The Hotazel Formation contains important mineral commodities and Mn48 (Pty) Ltd will target this formation for its rich manganese and iron bands. The Hotazel Formation is approximately 20 metres thick in the area of investigation and overlies the Ongeluk Formation (Transvaal Supergroup).

6.1.2 Aquifer Classification

The Mn48 mining area is underlain by deeply weathered sedimentary rocks (i.e. mainly sandstones). The sedimentary deposit can be classified as an 'intergranular aquifer' system. The primary porosity of the rocks provide the storage capacity with limited groundwater movements while secondary features such as fractures / faults and bedding planes enhance the groundwater flow. The majority of study area is regarded a "poor aquifer" while the aquifer adjacent (west) to the proposed Mn48 portion is regarded as "minor" aquifer class. A "poor aquifer" is described as an insignificantly yielding aquifer of good quality or moderately yielding aquifer of poor quality or aquifer that will never be utilised for water supply and that will not contaminate other aquifers

The dominant groundwater flow is in a north-western direction, driven by the mountain range located towards the west and east flowing towards the Kuruman River. Localised groundwater flow within and around the Mn48 Mine area shows a dominant groundwater flow direction in a north-western direction with slight localised groundwater flow towards the Kuruman River.

A total of 2 pumping tests were conducted. Borehole LEX3A is characterised by a transmissivity value of ~117 m^2/day, typical for an unconfined aquifer and appears plausible for a shallow primary aquifer in the Kalahari Formation. As a result, the hydraulic conductivity of the Kalahari Formation is estimated to be 2 m/d. Results from the pumping test for borehole LEX3A indicate that the borehole can be pumped at a recommended rate of 8.0 L/s for 12 hours with a maximum groundwater level drawdown of 8 metre. This will allow a 12-hour recovery time for the aquifer to recover to its original water level. The hydraulic test for borehole LEX 4 shows a transmissivity value of ~0.95 m^2/day. Borehole LEX4 was cased-off to a depth of 180 mbgl and the transmissivity value(s) may be representative of the deeper Dwyka, Hotazel and upper Ongeluk formations. Due to the low yielding capability of the deeper Dwyka, Hotazel and upper Ongeluk formations borehole LEX4 is not recommended for water supply use.

The groundwater sample collected at borehole LEX3A presented a Mg-HCO3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. The groundwater sample collected at borehole LEX4 presented a Na-Cl water type with elevated concentrations of chloride, sodium and magnesium. The elevated sodium and chloride concentrations may represent deeper and/or older groundwater within an evolved groundwater regime. This water type is probably characteristic of the groundwater within the deeper, confined Hotazel and Ongeluk aquifers. The groundwater samples for LEX3A and LEX4 are thus indicative of two distinctive groundwater regimes.

During the hydrocensus a total of 76 boreholes were visited. The majority of boreholes are for either domestic use and/or cattle/game feedlots or prospecting boreholes. A number of boreholes are not in use or unequipped. The water levels measured during the hydrocensus vary from a minimum of 9.8 mbgl to more than 110 mbgl with an average of 54 mbgl. Water levels located in and around Mn48 mine portion has an average depth of 37 mbgl.

6.1.3 Impacts based on Mine Dewatering

The estimated inflow rate into the mine workings is in the order of 292 m^3/d (approximately 3.4 L/s) during year 18 of mine development.

It is expected that the potential impacts associated with the deep mine inflows (i.e. dewatering) on the regional groundwater flow are insignificant (w.r.t. the Kalahari Aquifer) and unlikely to impact third party groundwater users or groundwater contribution to baseflow. The cone of depression will be limited to the mine lease for the Kalahari Aquifer and reversible over time once dewatering stops.

As result boreholes outside the mine lease area are unlikely to be impacted (w.r.t. lowered groundwater levels) due to mine dewatering. A shallow and wide-spread cone (less than 5 km) of depression is associated with high hydraulic conductivities suck as the Kalahari formation.

Groundwater contribution to baseflow represents high frequency low flows during the dry season. Such flows are not evident for the non-perennial Kuruman River.

6.1.4 Impacts based on Wellfield Development

The proposed well field consist of four (4) boreholes drilled to a depth between 80 to 85 metres below ground level. The proposed well field is located within the Kalahari formation. Based on the simulated well field, i.e. four boreholes abstracting 2.5 L/s, a predicted cone of depression extends 800metres in a radial direction away from the well field with a drawdown of 1 metre. The predicted impact associated with the well field indicates a maximum groundwater depth of less than 4 metres.

The results of the pumping test (for Borehole LEX3A) are comparable to the outcome of the simulated well field development since the pumping test consider a smaller, more heterogeneous volume of aquifer material.

It is expected that the potential impacts associated with the well field (i.e. well dewatering) on the regional groundwater flow are likely to occur w.r.t. groundwater as resource but unlikely to impact any third-party groundwater users. Furthermore, impact will be limited (up to 1 km) and slightly beyond the mine lease area with regard to interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River and reversible over time once well field stops abstracting groundwater; and

The cone of depression associated with the proposed well field does not impact (w.r.t. lowering the groundwater level more than 1 meter) any third party boreholes (boreholes not belonging to the mine).

The cone of depression extends beyond the mining boundary and extent below the non-perennial Kuruman River. However, measured groundwater levels are far below the base of the non-perennial Kuruman River. As a result an impact on the non-perennial Kuruman River due to dewatering of the well field is not expected

6.1.5 Impacts based on Seepage associated with the Tailings Storage Facility, Waste Rock Stockpile, and Other Stockpiles (Sources)

The dominant spreading of the potential contaminants/pollutants associated with sources occur in a radial manner and towards the north-west. This is due to a groundwater mounding effect due to the seepage and hydrodynamic dispersion (including diffusion) within the groundwater system. The groundwater mound cause preferential potential pollutant spreading in a circular direction during the first 15 years. The potential contaminants spread away from the potential pollutant sources for the weathered aquifer system due to its relatively higher hydraulic conductivity values. The potential pollutant spread occurs within the mining boundary. It should be noted that localised pollutant spreading might occur towards the Kuruman River; however, from the predicted spreading plume no potential pollutants reach the Kuruman River within the first 100 years.

The potential impacts associated with the sources on groundwater quality are highly likely to occur and long term w.r.t groundwater as resource. However, the pollution spread (plume migration) are localised within the wider mine site boundaries if surface run-off is contained; The contamination plume will in all likelihood be contained within the mine lease area due to the simulated cone of depression as result of mine dewatering. The simulated pollution plume spread (up to 100 years) will impact the groundwater as resource; however no indication of third party groundwater users or surface water will be impacted.

6.2 MONITORING REQUIREMENTS AND RECOMMENDATIONS

The shallow weathered aquifer underlying the mine residue deposits (i.e. TSF, Waste Dump and Stock Yard) will generally be the first receptor of potential contaminants, as well as a preferred pathway for their dispersion due to the higher hydraulic conductivity of the shallow aquifer. Potential interaction between groundwater and surface water may result in off-site migration of contaminants.

Groundwater monitoring boreholes have been strategically sited to assess any potential contaminant plume development downstream of the main sources. These strategically sited boreholes will consider both the dominant groundwater flow direction as well as localised flow towards the Kuruman River. Therefore, monitoring boreholes sited in close vicinity north-west of the sources should flag any potential contamination measurements as proposed in Figure 6-1.

A standard operating procedure (SOP) for water sampling should be developed according to best practice; i.e. filter and acidify on site for metal analyses, purge boreholes prior to sampling.

Furthermore, it is of crucial importance to initiate a ground- and surface water quality and groundwater level monitoring system. Levels will be monitored monthly and quality will be monitored on a quarterly basis – i.e. a full chemical analysis for all major constituents including the identified constituents of concern. During writing of this report currently no constituents of concern were flagged! However, during any further detailed studies addressing constituents of concern for both groundwater and surface water should be included in the water quality monitoring program.

Moreover, the following related activities should form part of the Environmental Management Program for the Mn48 Mine:

- A detailed groundwater quality hydrocensus should be conducted in the area around the proposed mine (10 km radius). The aim of this hydrocensus should be to identify all groundwater users in the area to establish groundwater quality baseline conditions prior to mining;
- The quarterly monitoring programme for on-site boreholes will also include third party boreholes that are in the potential impact zone.
- Monitor the chemistry of the mine fissure inflows as it may be indicative of the magnitude of the potential inflows.
- Daily recording of dewatering rates for the underground mine.
- Monthly monitoring rainfall and evapotranspiration measurements to understand groundwater recharge.
- Annual review and potential update of the groundwater flow and transport model utilising the latest monitoring data as they become available; and
- Digital storage of all monitoring data in a dedicated database on- and off-site.

An impact assessment, based on the Hacking method (Hacking, 1998), to determine the significance of the identified impacts (table presented below) is presented below. The impact assessment and associated rating relates to the following:

- Dewatering activities during the operational / mining phase; and
- Groundwater quality affected by the TSF, Waste Dump and Stock Yard during operational and post-close phase.

Based on the outcomes of the current groundwater modelling study, the following recommendations are given:

- Initiation of a ground- and surface water monitoring system with monthly monitoring of groundwater levels and quarterly sampling intervals for full chemical analyses (all major constituents and trace elements of concern, especially Arsenic).
- The development of a standard operating procedure for water level monitoring and water sampling according to best practice (e.g. filters and acidify on site for metal analyses, purge boreholes prior to sampling).
- Other mitigation measures such as installing curtain drains, the use of existing boreholes as capture zones to control potential plume migration will limit spreading of the contaminant plume.
- The Mn48 groundwater model should be updated to incorporate any changes to the mine plan (mining area, final depths and areas, scheduling) and surface infrastructure.
    - Subsequent updates of the groundwater model should be done every two (2) years as updated geology, groundwater level and quality data become available.

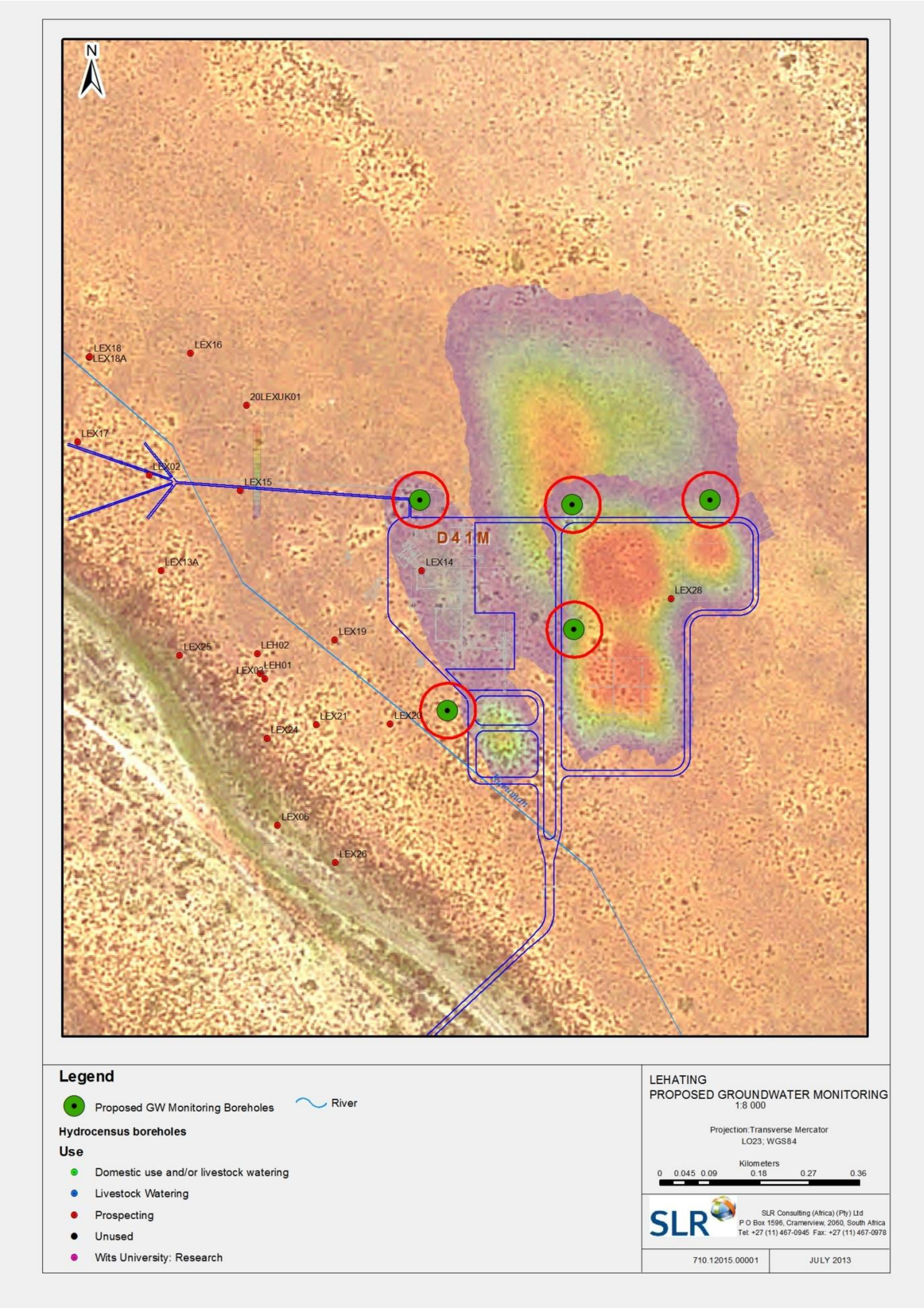

Figure 6-1: Proposed groundwater monitoring locations based on potential groundwater impacts.

Table 6-1: Unmitigated impact of mine dewatering, wellfield development and contaminant sources on groundwater flow and quality predictions for Mn48 mine project.

Activity	POTENTIAL IMPACT	CRITERIA	CONSEQUENCE	SIGNIFICANCE
Dewatering of underground mine (life of mine)	Insignificant and unlikely to impact third party groundwater users or groundwater contribution to baseflow; The cone of depression will be limited to the mine lease for the Kalahari Aquifer.	SEVERITY - L DURATION - H SPATIAL SCALE – M PROBABILITY – M-L	MEDIUM	MEDIUM TO LOW
Dewatering of the proposed well field	Likely to impact groundwater as resource; Unlikely to impact any third party groundwater users; Limited (up to 1 km) impact slightly beyond the mine lease area w.r.t. Interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River;	SEVERITY - L DURATION - H SPATIAL SCALE – L PROBABILITY – M-L	MEDIUM	MEDIUM TO LOW
Contamination sources life of mine and post closure	Impact is highly likely to occur Impact will affect both the groundwater flow and groundwater quality on a local scale. Localised impact but widespread impact may occur if the contaminated groundwater daylights into highly conductive alluvial systems and rivers.	SEVERITY - H DURATION – H SPATIAL SCALE – L PROBABILITY – M-L	HIGH	HIGH TO MEDIUM

NOTE: L – low

M – Medium

H – High

7. DEGREE OF CONFIDENCE IN PREDICTIONS AND MODEL UNCERTAINTY

Internationally excepted software (MODFLOW and MT3DMS) was used as a numerical groundwater flow and transport model, representing some or all characteristics of a real system on an appropriate scale. It is a management tool that is typically used to understand why a system is behaving in a particular observed manner or to predict how it will behave in the future. Its precision depends on chosen simplifications (in a conceptual model) as well as on the completeness and accuracy of input parameters. In particular, data on input parameters like water levels and aquifer properties is often scare and limits the precision and confidence of numerical groundwater models. While some of these uncertainties inherent in the regional numerical groundwater flow and transport models were addressed using a stochastic model approach, other sensitive model parameters like porosities or source concentrations for the transport model were chosen conservatively to present worst case scenarios of environmental impacts.

Overall, the model shows a good correlation between the observed and calibrated groundwater heads, after convergence iterations of 0.001m, with a root mean square error of 10%. Furthermore, the calibrated flow model indicates an acceptable groundwater flow budget (error less than 1%).

Additionally, the lack in rainfall, long term monitoring and evapotranspiration data increase parameters uncertainties such as recharge.

The overall confidence in the model predictions, especially transport predictions, is therefore classified as low to medium.

8. DISCLAIMER

SLR Consulting has executed this study along professional and thorough guidelines, within their scope of work. It is based largely on measured and analytical results provided by others. No representation or warranty with respect to the information, forecasts, opinions contained in neither this report nor the documents and information provided to SLR is given or implied. SLR does not accept any liability whatsoever for any loss or damage, however arising, which may directly or indirectly result from its use.

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APPENDIX A: IMPACT ASSESSMENT CRITERIA

PART A: DEFINITION AND CRITERIA		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity / nature, spatial extent and duration**
Criteria for ranking of the SEVERITY/NATURE of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. Irreplaceable loss of resources.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. Noticeable loss of resources.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. Limited loss of resources.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE/ EXTENT of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
			SEVERITY / NATURE = L		
DURATION	Long term	**H**	Medium	Medium	Medium
	Medium term	**M**	Low	Low	Medium
	Short term	**L**	Low	Low	Medium
			SEVERITY / NATURE = M		
DURATION	Long term	**H**	Medium	High	High
	Medium term	**M**	Medium	Medium	High
	Short term	**L**	Low	Medium	Medium
			SEVERITY / NATURE = H		
DURATION	Long term	**H**	High	High	High
	Medium term	**M**	Medium	Medium	High
	Short term	**L**	Medium	Medium	High
			L	**M**	**H**
			SPATIAL SCALE / EXTENT		

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	Medium	Medium	High
	Possible/ frequent	**M**	Medium	Medium	High
	Unlikely/ seldom	**L**	Low	Low	Medium
			L	**M**	**H**
			CONSEQUENCE		

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
High	It would influence the decision regardless of any possible mitigation.
Medium	It should have an influence on the decision unless it is mitigated.
Low	It will not have an influence on the decision.

***H = high, M= medium and L= low and + denotes a positive impact.**

APPENDIX B: HYDROCENSUS

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