Kudumane Manganese Resources

Kudumane Mine Expansion Projects – Groundwater Study

Project Number: Delh.2021.062-04

WATER SYSTEMS MODELLING

Contact: +2782 497 9088/+2772 506 1343
info@delta-h.co.za
www.delta-h.co.za
PO Box 11465
Silver Lakes
0054
Pretoria, South Africa

September 2021

Kudumane Manganese Resources

Kudumane Mine Expansion Projects – Groundwater Study

Project Number: Delh.2020.062-04

Document Information

Report Version	Draft Report
Reference Number	Delh.2021.062-4
Author(s)	Martin Holland, Theo Rossouw
Client Contact	Tshekedi Montshusi
Date	September 2021

Dr Martin Holland (Pr.Sci.Nat)

PRINCIPAL HYDROGEOLOGIST

Table of Contents

List of Figures and Tables

1. INTRODUCTION

1.1. BACKGROUND

Delta H (Delta-H Water System Modelling PTY Ltd) has been appointed by Kudumane Manganese Resources (KMR) to prepare the groundwater specialist study in support of the environmental authorisation for the expansion projects.

KMR intends to expand its current operations, in order to extend the life of its mine and improve production capacity, through the inclusion of the following mining related activities and infrastructure within its approved mining right areas:

- Expansion of the existing York and Hotazel Pits;
- Development of two in-stream attenuation dams within the Ga-Mogara River to allow for the expansion of the York and Hotazel Pits; and
- Development of new opencast pits on the farm Kipling 271.

The main expansion activities and infrastructure listed above will require the development and utilisation of the following secondary infrastructure and activities:

- Expansion of waste rock dumps;
- Expansion of ore stockpiles;
- Development of new roads and extension of existing roads;
- Construction on new Pollution Control Dams (PCDs);
- Storage and reticulation of water via tanks and pipelines;
- Development and expansion of sewerage treatment plants;
- Development of supporting infrastructure such as admin offices ancillary infrastructure;
- Waste and fuel storage areas;
- Development of a contractor’s camp; and
- Extension of existing powerlines.

1.2. SCOPE OF WORK

Based on the understanding of the request the following scope is proposed:

1) Intrusive investigation
    a. Hydrocensus (and sampling)
    b. Pumping (aquifer) tests
2) Numerical Groundwater Flow Model (update)
    a. Refinement of model mesh and re-calibration against monitoring datasets
    b. Predictive simulations
        i. Mine inflows during life of mine and post-closure
        ii. Contaminant transport during life of mine and post closure
3) Report documenting conceptual and numerical model development, simplifying assumptions and outcomes of predictive simulations, including monitoring recommendations.

The existing site-specific numerical groundwater flow model developed by Delta-H in 2016 and updated during March 2021 (Delta-H, 20201) will be updated with the proposed mine extension plans to inform the impact assessment.

1.3. DATA SOURCES

The update of the numerical groundwater flow and transport model was based on the following information and data made available to the project team:

- Local LIDAR contours for the KMR pit and related infrastructure (i.e. WRD).
- Digital layout (as provided by SRK)
    - York (york 22 02 2021.dxf
    - Hotazel (Hotazel 22 02 2021.dxf)
- Lithological information and other datasets
- Hydrocensus information
- Results from the ongoing groundwater monitoring by KMR.
- Various specialist reports conducted by specialist on behalf of KMR

2. GENERAL SETTING

2.1. LOCALITY AND DRAINAGE

The Kudumane mining area falls within the quaternary catchment D41K which has a total catchment area of 4216 km^2. The non-perennial Ga-Mogara River flows through the project area and drains the D41K catchment, subsequently joining the Kuruman River. The Kuruman River flows west, joining the Molopo River approximately 250 km from the confluence of the Ga-Mogara River and Kuruman River (Figure 3-6). The Molopo River, Harts River and the Vaal River are the major rivers draining the Lower Vaal WMA, within which the project area falls. All runoff from the project area is eventually drained westward into the Orange River.

The topography of the wider study area is shown in Figure 3-6. The Gamagara catchment is bounded to the west, south and east by a sharp outcrop of hills (Banded Iron Stone), with elevations of 1200 mamsl at the foot of these hills up to and exceeding 1700 mamsl in the highest points within these hills. Except for these hills, which form a minor part of the catchment, the gradients are gentle <1% and slope from the foot of the hills which is between 1200 – 1300 mamsl to the outlet of the Gamagara catchment at between 1000 and 1020 mamsl.

2.2. CLIMATE

The mine is in a semi-arid climatic region of South Africa characterised by seasonal rainfall, hot temperatures in summer, and colder temperatures in winter. The Gamagara catchment is classified as endoreic, with large areas which do not contribute to the overall catchment runoff within the water course. Rainfall data was extracted from the SRK (2021) Surface Water study. Details of monthly rainfall from these sources are shown Table 2-1. The study area receives approximately 350 mm of rain per year, with most rainfall occurring during summer (January) and the lowest rainfall in July. The WR2012 database was used for the assessment of evaporation within the region. Quaternary catchment D41K fall within evaporation zone 8A with a Mean Annual Evaporation (MAE) of 2351 mm.

Table 2-1: Summary of monthly rainfall (mm) for the larger project area.

Month	**0393083 W (Milner)** 1931-2009	**0392148 W (Winton)** 1926-2009	**0356636 W (Deben)** 1925-2009	**0356285 W (Hopkins)** 1920-2009	**0357592 W (Branksea)** 1920-2009	**WR2012 (D41K)** 1920-2009
October	20.4	17.1	21.0	19.5	15.2	19.0
November	33.8	26.1	27.2	27.3	33.0	30.0
December	47.4	44.2	40.7	44.3	46.0	44.7
January	68.4	62.3	57.9	60.6	58.8	61.5
February	61.6	61.2	52.6	61.8	66.4	60.1
March	67.1	57.4	58.8	67.8	71.7	63.6
April	35.6	31.4	28.1	34.9	35.6	32.3
May	15.9	13.6	12.3	14.7	17.9	14.2
June	6.3	4.1	5.3	4.7	5.6	5.0
July	1.9	2.5	2.3	3.0	1.9	2.3
August	4.0	4.8	6.6	6.1	4.8	5.2
September	6.0	6.8	7.4	6.8	6.6	6.7
Annual	**368.4**	**331.5**	**320.3**	**351.5**	**363.6**	**344.6**

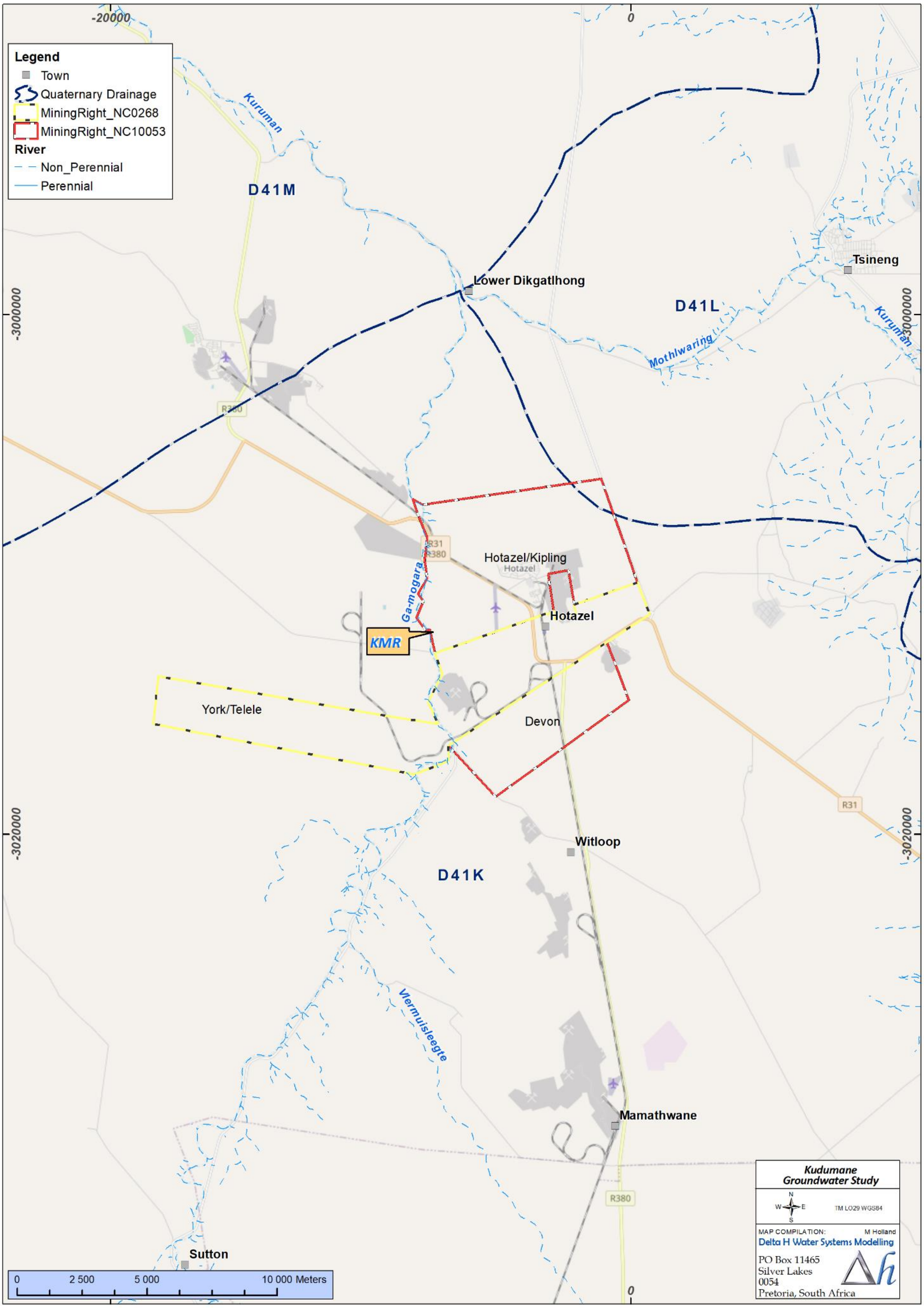


Figure 2-1. Locality of the Kudumane mine area.

3. PREVAILING GROUNDWATER CONDITIONS

3.1. GEOLOGY

The Kalahari manganese field, situated some 60 km northwest of Kuruman in the Northern Cape Province, contains the world's largest known land-based manganese deposits (Burger, 1994) (Figure 3-1). Manganese beds are confined to the Hotazel Formation. Together with the overlying carbonate rocks of the Mooidraai Formation, they make up the Voelwater Subgroup, which is a member of the Postmasburg Group of the Lower Proterozoic Transvaal Supergroup. In the central and northern parts of the basin, the Hotazel Formation is separated from the Kalahari Formation by lithologies of the Olifantshoek Supergroup and /or the Dwyka Formation of the Karoo Supergroup.

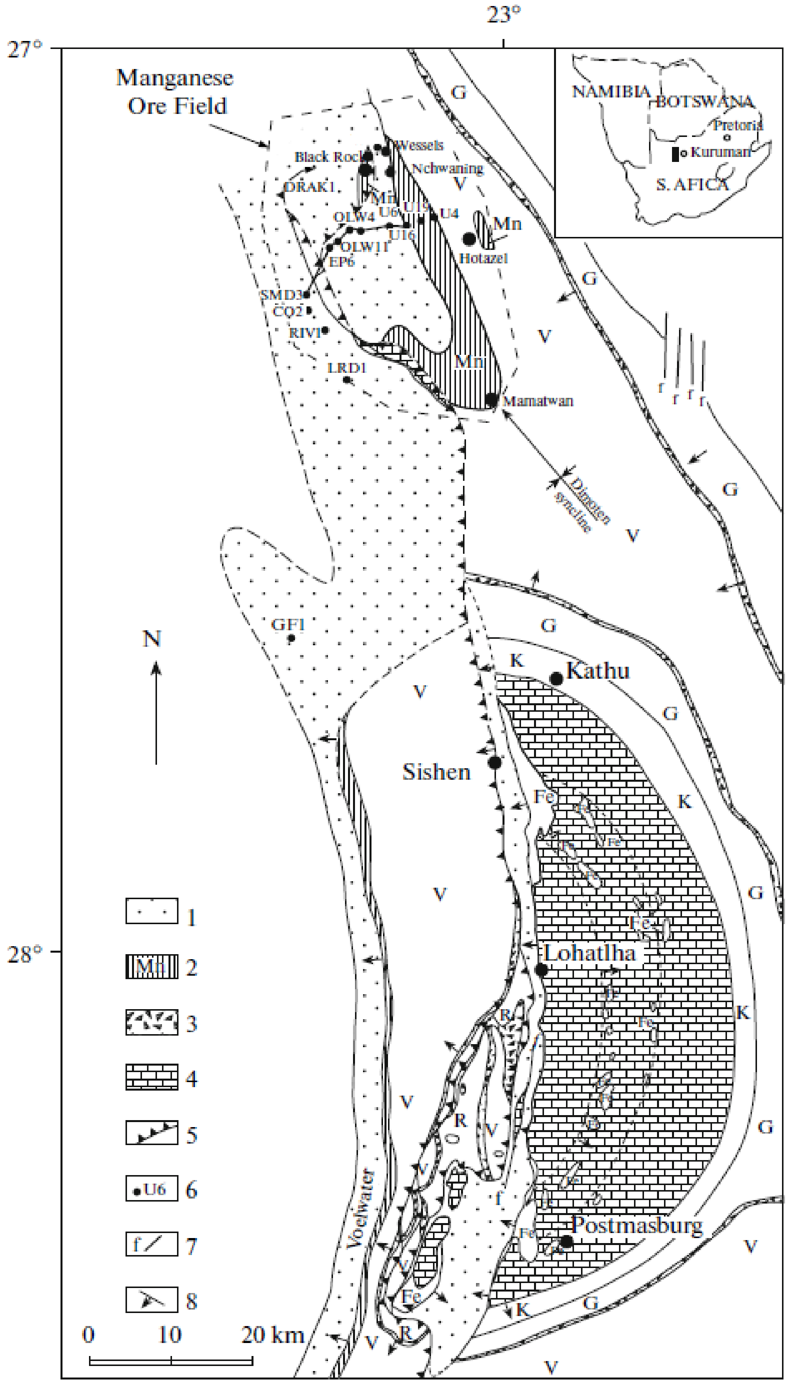


Figure 3-1. Fragment of the paleogeological sketch map of the area of deposits in the Kalahari manganese field and Postmasburg area (pre-Karoo geological time) (Adapted from Kuleshov, 2010).

The Dwyka Formation is in turn unconformably overlain by unconsolidated sediments of the Kalahari Formation composed of calcrete, gravels, clay and aeolian sand up to 125 metres thick. The Hotazel Formation is conformably overlying pillow lava and jaspilites of the Ongeluk Formation. The strata of the Hotazel Formation underlie the Kalahari Formation at a depth ranging from 8–10 to 60–70 m and plunge to west-south west at 5–8 to 10–15° (Figure 3-7). The manganese beds occur interbedded in host rock iron-formation and the ore member includes three (lower, middle, and upper) ore bodies (refer to Figure 3-3).

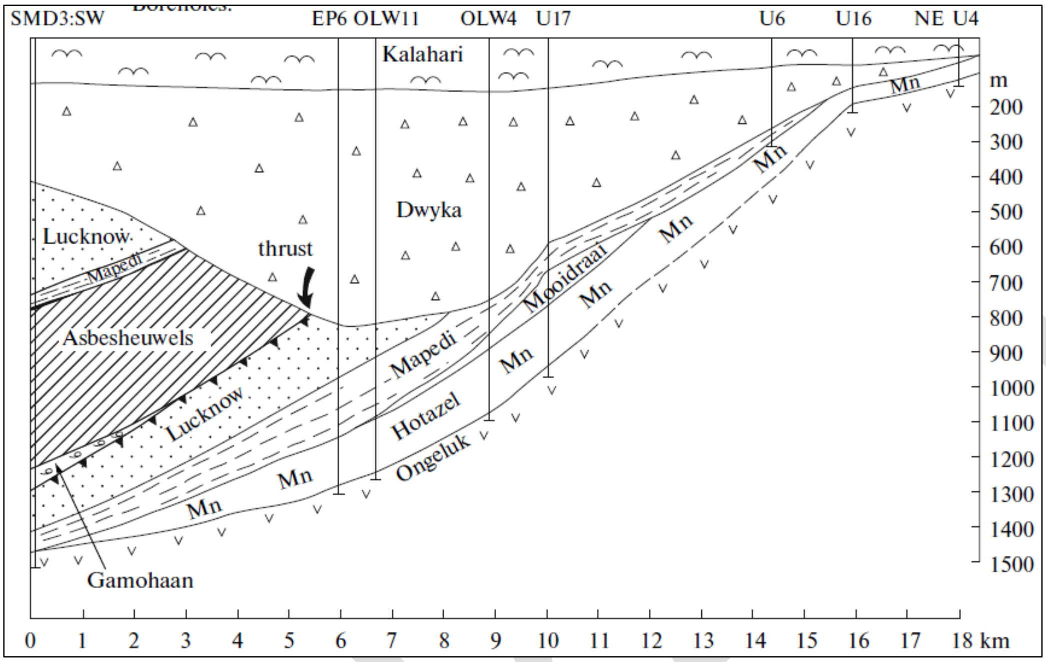


Figure 3-2. Schematic geological section of the northern parts of the Kalahari manganese field (Adapted from Kuleshov, 2010).

3.1.1. Structural geological overview

The Kalahari deposit is preserved in an old synclinal structure below the unconformity at the base of the Mapedi shale of the Olifantshoek Group. The cross-sections illustrate how the manganese ore beds and Hotazel Iron Formation are successively cut out by erosion to the east below the Dwyka and Kalahari unconformities, while the Olifantshoek Supergroup (Mapedi and Lucknow Formations) only appears below the Dwyka diamictite further to the west.

The main local, structural features in the Kudumane mining area are represented by north-east to south-west trending dykes. At York the dyke splits up into two entities, which continue roughly parallel to each other towards the south-west. The main resource is located on York to the north of the dykes. South of the dyke the resource is downfaulted by between 30 m and 60 m and largely eroded by younger Dwyka glacial activity (Saad et al., 2010).

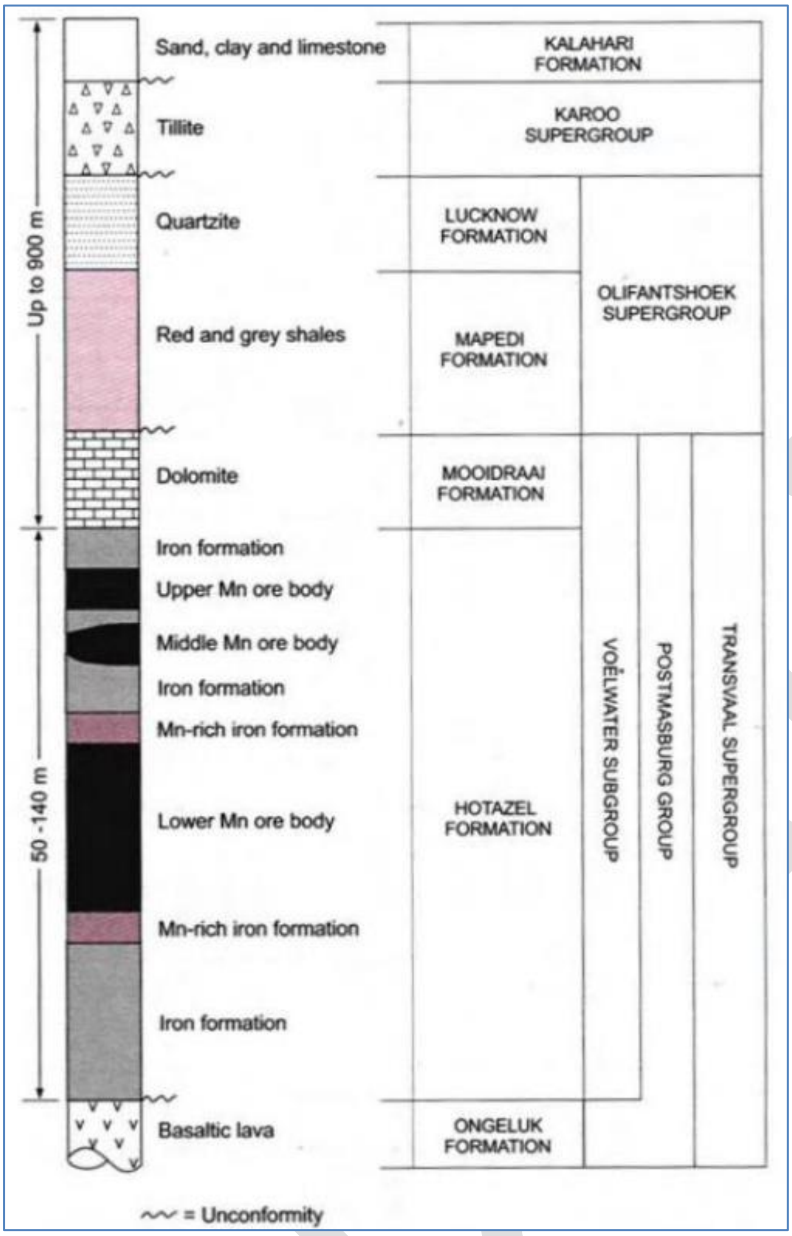


Figure 3-3. Generalized stratigraphic column for the Kalahari manganese field (Adapted from SLR, 2015).

3.1. ACID GENERATION CAPACITY

Geochemical tests and analyses provided by SLR (2014) indicate that the waste rock lithologies tested are non-acid generating, however some metals are leachable including aluminium (Al), iron (Fe) and manganese (Mn). SLR (2014b) simulated potential WRD seepage using the PHREEQC equilibrium geochemical modelling code and results suggest that seepage may have the following general characteristics:

- Neutral pH (controlled by calcite dissolution).
- High alkalinity.
- High salinity (in the form of elevated calcium, sodium, magnesium, chloride, nitrate and sulphate concentrations, see Table 8).
- Low or non-detect concentrations of most trace elements.
- Chemicals of concern indicated by the modelling include: fluoride, manganese, phosphorous, strontium and vanadium with the modelled concentrations as presented in Table 3-1.

Table 3-1: Waste rock seepage concentrations (Adapted from SLR, 2014).

Parameter	Low estimate (mg/L)	High estimate (mg/L)	SANS (241: 2011) (mg/l)
F	3.68	12	1.5*
Mn	0.52	3.4	0.1**
P	0.52	6.55	-
Sr	0.52	3.85	-
V	0.52	1.31	0.2*
Ca	68	632	-
Na	40	397	200**
Mg	40	239	-
Cl	23	340	300**
NO_3 as N	3.97	556	11*
SO_4 as S	42	289	250**

*Chroninc health, ** Aesthetic

3.2. HYDROCENSUS

The aim of the groundwater census was to determine the extent of groundwater users and forms part of a quantitative approach to determine baseline water conditions. The hydrocensus was conducted in the vicinity of KMR between the 2nd and 4th of August 2021. The hydrocensus reported on borehole location, status, depth, water level, distribution, use and ownership. A summary of the collated hydrocensus boreholes is listed in table 1 and shown spatially in figure. Thirty-seven (37) boreholes were verified while five (5) water samples were taken and submitted to the accredited laboratory (Waterlab PTY Ltd. Photos of the borehole headworks is provided in Appendix I. A total of 23 groundwater level measurements could be obtained during the hydrocensus. The water levels measured during the hydrocensus in the area ranged between 5.93 mbgl to 75.6 mbgl, with an average groundwater level of 29.8 mbgl.

Summary of the following geo-sites and observations were noted during the hydrocensus, based at each farm:

- Kudumane mining rights areas:
    - On the farm TELELE five (5) boreholes are currently being used for monitoring purposes. These boreholes, i.e. T1, T2, T3, T4 and T6, are unequipped. The water levels range from 10.3 mbgl to 37.36 mbgl.
    - On the farm YORK A six (6) boreholes were located. Most of these boreholes are unequipped and used for monitoring, i.e. YGW01, YGW03, YGW04 and YGW05, however boreholes YKDW04 and Windmill-4 are not used for monitoring purposes. The groundwater levels range from 17.54 mbgl to 31.17 mbgl.
    - On the farm HOTAZEL three (3) unequipped monitoring boreholes were identified, i.e. HTWM04, HTDW02 and HTWM05. The water levels range from 27.35 mbgl to 44.17 mbgl. Boreholes HTWM04 and HTDW02 are adjacent to the current opencast pit.Mokala Mine
    - Four (4) boreholes were identified at the Mokala Mine on the farm GLORIA. Borehole GL27 is equipped with a submersible pump, borehole WU06 is unequipped, with a water level of 13.3 mbgl, borehole MK01 is unequipped with a depth of more than 100m (dip meter max depth) and borehole MK02 is unequipped and dry at 25 mbgl.
- Kgalagadi Mine
    - On the farm UTMU four (4) boreholes were identified close to the Hotazel pit (Kudumane mine). Two boreholes, i.e. boreholes KU20-09 and KSX23 were dry around 12 mbgl and 17 mbgl. Boreholes KU20-12 and KU20-13 are unequipped with water levels at 37.26 and 35.8 mbgl, respectively.

Table 3-2: Summary of the data collated during the borehole hydrocensus.

Name	Latitude	Longitude	Elevation	Farm	Owner	RWL mbgl	Casing ID mm	Note
EM BH01D	-27.15640	22.91930	1015.7	EAST	East Manganese Mine	48.35	165	unequipped
EM BH01S	-27.15642	22.91931	1017.4	EAST			165	dry at 18m
EM HC06	-27.13544	22.93023	1010.7	RHODES				equipped, sub-pump
EP1	-27.20313	22.77943	1065.1	EPSON	Private Owner			equipped, Windmill
EP2	-27.20326	22.77951	1065.4	EPSON				equipped, sub-pump
EP3	-27.20915	22.79866	1064.0	OLIVE WOOD		75.6	165	unequipped
EP4	-27.21606	22.79872	1063.8	EPSON		5.93	165	unequipped
EP5	-27.21253	22.80097	1061.5	EPSON		50	165	DWS Logger
GL27	-27.18885	22.90103	1039.8	GLORIA	Mokala Mine			equipped
HTDW 002	-27.21100	22.91936	1028.0	HOTAZEL	Kudumane Mine	39.62	165	unequipped
HTWM 004	-27.20942	22.91894	1023.0	HOTAZEL		27.35	165	unequipped
HTWM005	-27.21187	22.92816	1043.3	HOTAZEL		44.17	140	unequipped
JB25	-27.36221	22.93434	1080.3	MIDDLEPLAATS	Private			Equipped, no access
KSX23	-27.21090	22.91742	1028.7	UMTU	Kgalagadi Mine			dry at 17m
KU20-09	-27.21089	22.91845	1023.8	UMTU			165	dry at 12.5m
KU20-12	-27.21182	22.91746	1025.5	UMTU		37.26	165	unequipped
KU20-13	-27.21181	22.91846	1024.1	UMTU		35.8	165	unequipped
MBH6	-27.22558	22.99540	1074.2	ANNEX LANGDON	York Wash Bay			equipped
MK01	-27.18703	22.89704	1040.1	GLORIA	Mokala Mine			more than 100m
MK02	-27.18563	22.91930	1013.4	GLORIA				dry at 25m
OW1	-27.18439	22.82140	1058.2	OLIVE WOOD	Private			equipped, windmill
T1	-27.25425	22.92326	1040.0	TELELE	Kudumane Mine	29.04	165	unequipped
T2	-27.25423	22.92531	1035.0	TELELE		10.3	165	unequipped
T3	-27.25420	22.92120	1046.0	TELELE		33.75	165	unequipped
T4	-27.25788	22.92335	1042.0	TELELE		32.75	165	unequipped
T6	-27.25773	22.91924	1045.0	TELELE		37.36	165	unequipped
TP1	-27.17283	22.79269	1060.0	TIGERPAN	Private			equipped, windmill
UMK4	-27.34735	23.04262	1107.0	LIZBETH				equipped, windmill
UMK7	-27.23968	23.02100	1082.3	LONDON		16.47	165	equipped, sub-pump
WH02	-27.19683	22.91909	1014.5	GLORIA	Mokala Mine	25.04	165	unequipped
WINDMILL 2	-27.34695	23.04252	1106.8	LIZBETH	Private			working
WINDMILL 3	-27.40107	22.95432	1093.9	MAMATWAN				not working
WINDMILL 1	-27.21770	23.00672	1073.7	ANNEX LANGDON				not working
WINDMILL 4	-27.23822	22.92638	1024.7	YORK A	Kudumane Mine	18		muddy at 18m
WU06	-27.22925	22.92290	1027.2	OLIVE PAN		13.3	165	unequipped
YGW01	-27.24806	22.93958	1048.0	YORK A		17.74	140	unequipped
YGW03	-27.23726	22.93379	1047.0	YORK A		17.54	140	unequipped
YGW04	-27.23740	22.92649	1030.0	YORK A		18.74	140	unequipped
YGW05	-27.24049	22.94313	1058.0	YORK A		31.17	140	unequipped
YKDW4	-27.23817	22.92639	1025.1	YORK A		20.97	140	unequipped

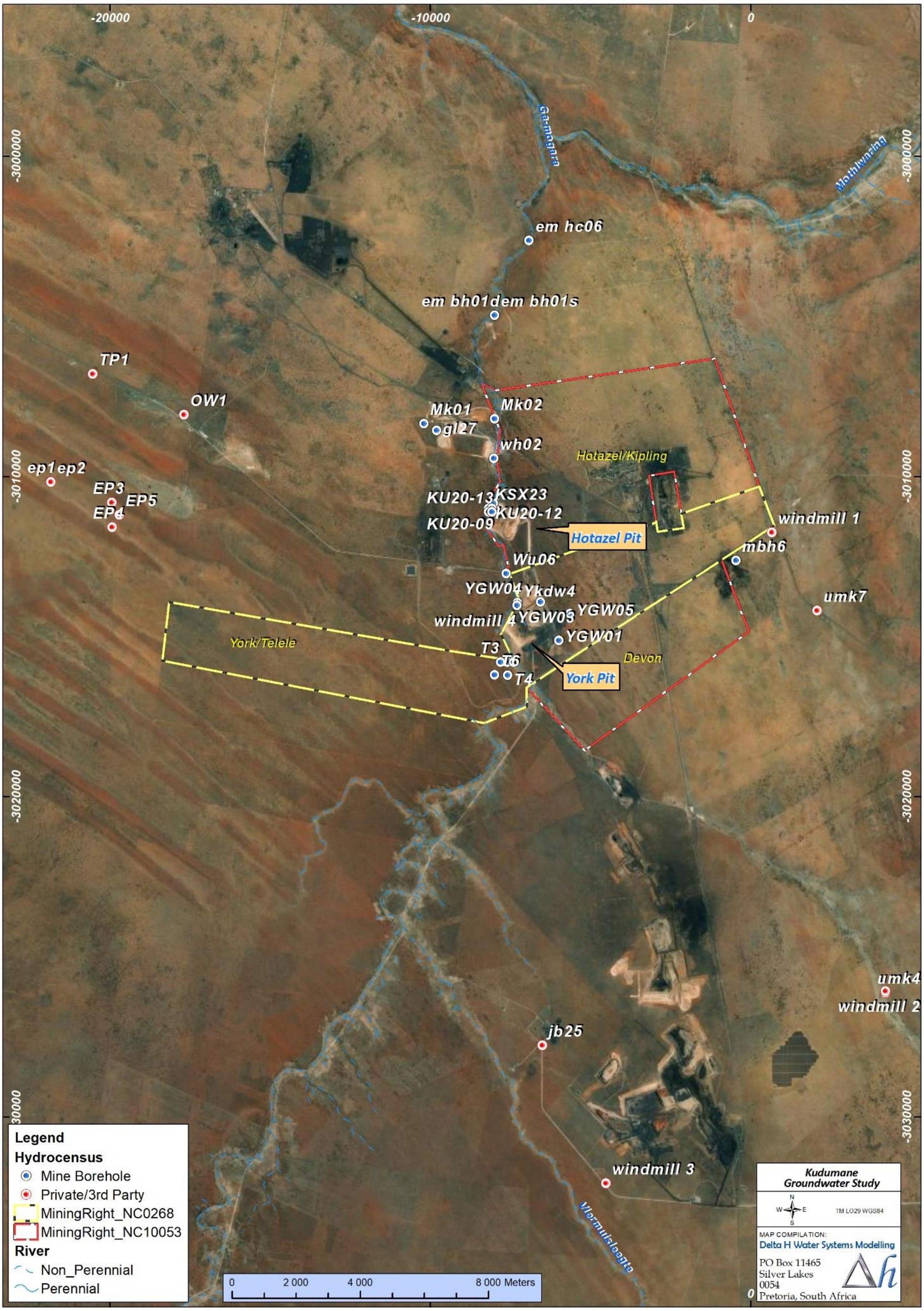


Figure 3-4. Spatial distribution of the borehole hydrocensus.

- North of East Manganese Mine
    - On the farm EAST two (2) monitoring boreholes were identified, borehole EM BH01D and EM BH01S. Borehole EM01S was dry at 18 mbgl and borehole EM BH01D had a water level of 48.35 mbgl.
    - On the farm RHODES one equipped (submersible pump) borehole, i.e. EM HC06, was identified.
    - On the farm ANNEX LANGDON two boreholes, i.e. MBH6 and Windmill-01, were identified at the York Wash Bay and next to the main Hotazel road, located east of the mining right area. Borehole MBH6 is equipped with a submersible pump whereas Windmill-06 is a broken windmill.
    - On the farm LONDON one borehole, i.e. UMK7, was identified at the fuel station, located east of the mining right area. Borehole UMK7 had a water level of 16.47 mbgl and is equipped with a submersible pump.
    - On the farm LIZBETH, two windmills (boreholes) were identified. It must be noted on the farm LIZBETH and adjacent farm ADAMS many windmills were seen; however, no access could be obtained. It is clear from the number of windmills at these farms that groundwater acts as a source of water / supply.
    - No access could be gained at Mamatwan mine.
    - On the farm MIDDLEPLAATS one borehole was identified, i.e. JB25. Borehole JB25 is equipped with a submersible pump.
    - A farmer owning the farms OLIVWOOD, EPSON and TIGERPAN had seven (7) boreholes. Boreholes OW1, EP1 and EP2 are equipped and used for domestic and cattle drinking lot use. Boreholes EP3, EP4 and EP5 are unequipped. Borehole TP1 is equipped with a windmill. The groundwater ranges from 5.93 to 75.6 mbgl.

The farms in the area use groundwater typically for domestic and garden irrigation purposes. Groundwater users (and households) typically abstract groundwater to store in tanks for water supply. The groundwater volumes are not pumped continuously for 24 hours but only on a need be basis. Overall, forms groundwater the main and only source of water for the surrounding farms.

3.2.1. Water quality

The water quality analysis from the five sampled boreholes were compared to the SANS 241-1:2015 Drinking Water Standard (Table 2-1). The laboratory certificates are provided in Appendix II. In general, the Electrical Conductivity (EC) of the groundwater ranged from 84 to 258 mS/m with pH values varying between 7.3 and 8.3 (pH units), indicating neutral to slightly alkaline conditions. The groundwater in the area is generally high in salt content (i.e. Na and Cl) with deeper chloride-enriched hydrochemical facies typical for the Kalahari beds with low recharge rates (slow movement of groundwater) and high evaporation. Private borehole EP4 show an extremely high ammonia content which may be related to the direct infiltration of the nearby feedlot's run-off. The elevated nitrate as N observed for boreholes UMK7 and EM-HC06 is often associated with the usage of nitrate-based explosives in the mining region.

Table 3-3: Summary of the hydrocensus water quality results.

BH ID	pH	EC (mS/m)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Alk. ($CaCO_3$)	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l) as N	F (mg/l)	NH_4 as N (mg/l)
SANS241-1:2015	5.0/9.7	170	1200	-	-	200	-	-	300	500	11	1.5	1.5
UMK7	7.3	219	1438	172.1	132.8	73.6	2.8	420	285	69	60	0.4	<0.1
HTWM4	8.3	112	638	9.0	17.2	212.4	3.6	340	143	26	<0.1	1.2	1
EP4	7.4	102	170	27.0	6.9	6.6	22.6	464	12	<2	<0.1	0.2	81
EM-HC06	7.3	258	1290	205.0	118.4	166.6	5.3	396	466	132	32	0.2	<0.1
OW1	7.5	84	518	70.6	35.8	50.0	7.8	260	81	27	10	<0.2	0.1

3.3. AQUIFERS

Based on the various hydrogeological studies undertaken in the area as summarized by SLR (2015) as well as newly developed conceptual understanding of the site, the aquifer systems can be differentiated within the study area as:

1. **Intergranular (Kalahari sediments) (unconfined)**
    - The calcrete with relatively low permeability retards and restricts the movement of water, but acts as a storage unit where saturated.
    - The intergranular aquifers are presented by the upper as well as basal sand and gravel beds of the Kalahari sediments. These aquifers have low exploitation potentials with borehole yields generally less than 2 l/s, but the ability to store large volumes of water. They are separated by the red clays of the Budin Formation, acting as a confining layer.
2. **Fractured aquifer (semi-confined)**
    - The Kalahari weathered aquifer is underlain by a deeper semi-confined to confined fractured aquifer in which fracture flow dominates.
    - In the project area the main hardrock formations considered in the modelling study are the Dwyka Formation, the Hotazel Formation and the Ongeluk Formation.
    - The Mooidraai (dolomite) Formation occur predominantly west of the KMR mining area. The Mooidraai Formation could potentially hold large volumes of water, but no evidence of significant dissolution cavities exists from available exploration drilling data (SLR, 2015).

3.3.1. Kalahari aquifer and aquiclude

The Kalahari sand, and the sediment beds with its associated underlying calcrete layer overlies the bedrock formations. According to the KMR exploration drilling data the thickness of the Kalahari Formation is approximately 40 m in areas east of the Ga-Mogara River (and is predominantly underlain by lava of the Ongeluk Formation), while it increases west of the river to a maximum observed thickness of approx. 110 m.

While the sediments and calcretes could have a relatively higher hydraulic conductivity, the clay must be assumed to be relatively impermeable (SLR, 2015). Hydraulic conductivities for the Kalahari sediments range from 0.01 to 10 m/d (SLR, 2015). The hydraulic connection between the upper, unconfined Kalahari aquifer and the deeper, confined fractured aquifer is largely determined by the thick clay bed, and the low permeability of the tillite horizon of the Dwyka Group.

3.3.2. Fractured aquifer

Dwyka Formation:

- The developed diamictite (tillite) with clay lenses of the Dwyka Group forms occur up to a depth range of 260 m below surface is generally thought to form an important vertical flow barrier (aquiclude) at the base of the Karoo rocks. Hydraulic conductivities for the Dyka tillite range from 0.24 to 1E-4 m/d (SLR, 2015).

Hotazel Formation (BIF):

- Groundwater associated with the Hotazel Formation rocks appears to be associated with fracture systems that are generally of limited extent. The observed average thickness of the manganese beds is 40 m, ranging between 1 m east of the Ga-Mogara River and at depths > 200 m towards the immediate west of the KMR mining area.
- The BIF aquifer and underlying dolomite aquifer can be regarded as one hydraulic unit or aquifer system.

Ongeluk Formation (lava):

- Towards the eastern parts of the mining area, the Ongeluk (lava) Formation is directly overlain by Kalahari sediments. The expected borehole yields for the Ongeluk aquifer unit range here between 0.1 and 0.5 L/s.

3.4. GROUNDWATER LEVELS

Using a total of 23 measured groundwater table elevations, Delta H established the correlation between surface topography and elevation of the groundwater level (Figure 3-5) for the wider study area. A rather poor correlation 52 %

(R^2 = 0.52) which may relate to the occurrence of two distinct aquifer systems (plus local perched aquifers) with different water levels and can be attributed to the semi-confined nature of the fractured aquifer, the occurrence of thick clay beds perching the aquifer above them, as well as hydraulic heads not yet in equilibrium with the surrounding aquifer due to low borehole yields. However, locally the current groundwater flow regime is towards the open pits due to the dewatering effects caused by the mining of the pits below the rest water level of the surrounding aquifer. As a result, the pit act as a local groundwater sink (where dewatering and evaporation exceeds inflows) and groundwater flow is towards the pit from the surrounding aquifer.

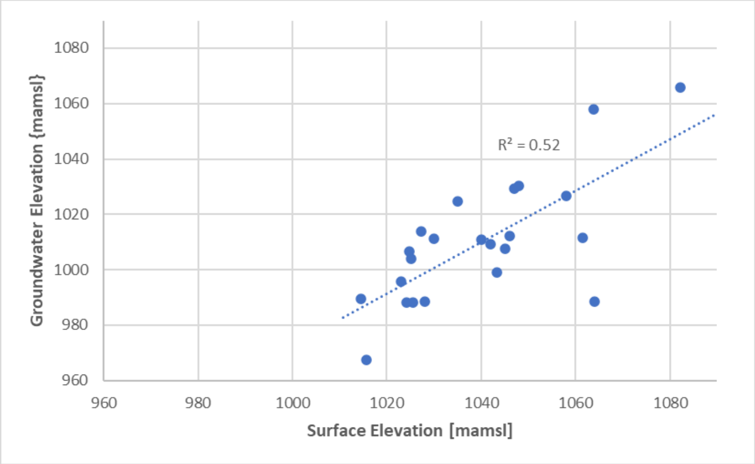


Figure 3-5. Correlation between surface topography and potentiometric heads.

3.5. GROUNDWATER (MONITORING) QUALITY

The spatial distribution of the monitoring boreholes in relation to the mine infrastructure is shown in Figure 3-6. The map also indicates the active and non-active monitoring boreholes. A summary of the 2020 groundwater quality results is shown in Table 3-4. The results were compared to the (WUL 2016) water quality limits as well as the SANS 241-1:2015 Drinking Water Standard.

Note that the comparison to drinking water standards and guidelines does not suggest that drainage from the emergency stockpile will be used for drinking purposes. Drinking water standards are understandably stringent, less stringent (mine) effluent guidelines should in this case be applied.

The water quality of the sampled groundwater monitoring boreholes can be described as neutral (pH levels range between 7.2 and 8.22), non-saline to saline (EC range between 76 mS/m to 303 mS/m) with elevated nitrate concentrations of up to 256 mg/l (more specifically the York Farm borehole (YGW03). Although several variables exceeded the limits set out in the WUL many of them are still within the SANS 241:2015 guideline. There are exceptions in terms of EC, TDS, Cl, NO_3, NH_4 and Mn which are above the recommended levels.

Given the hydrogeological setting and generally low hydraulic conductivities of the underlying aquifer/s, the groundwater quality is expected to be relatively saline with sodium and chloride dominating the cation and anion content respectively due to natural ion exchange reactions.

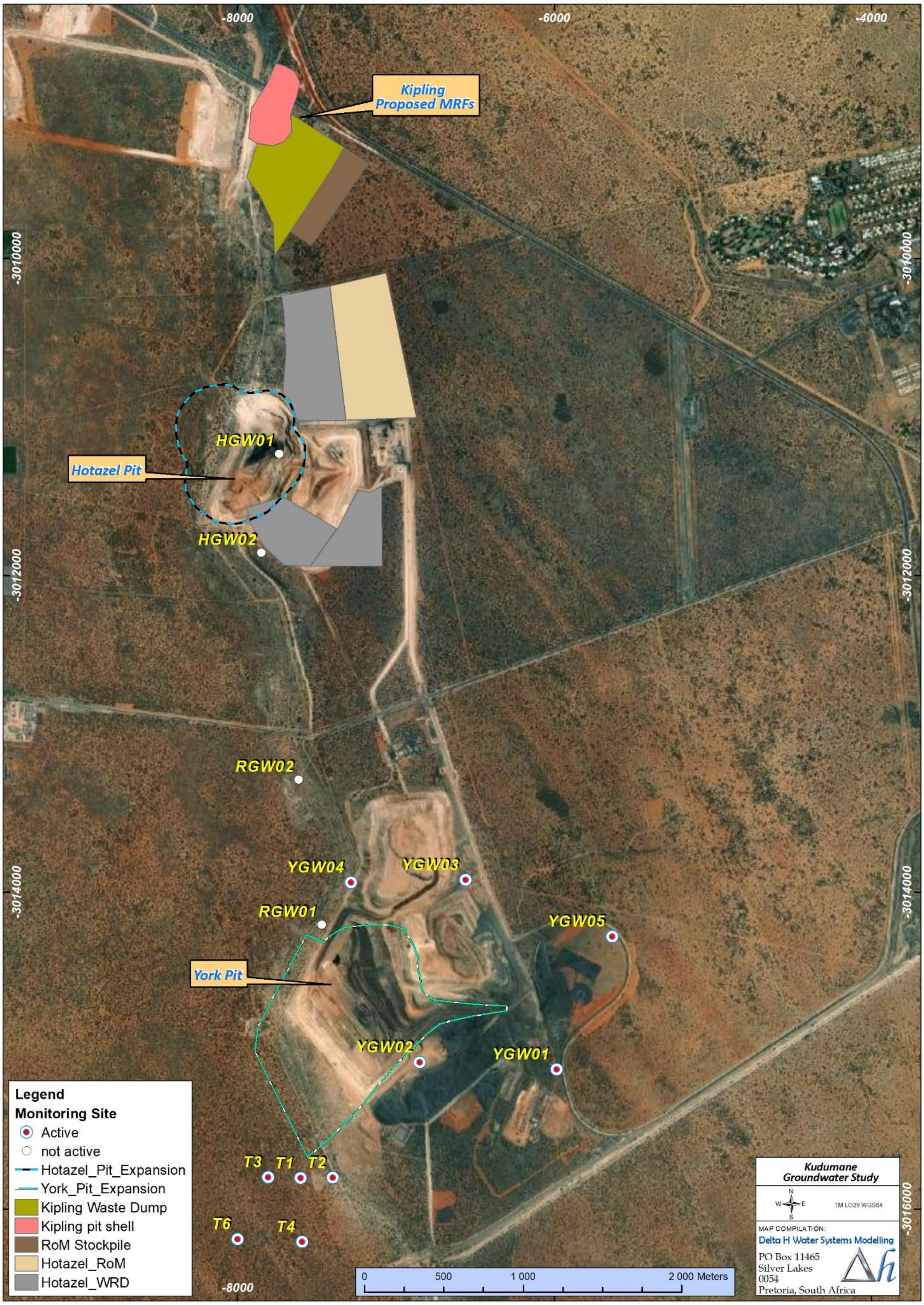


Figure 3-6. Location of the KMR monitoring boreholes in relation to the KMR mine and proposed activities.

Table 3-4: Summary of the groundwater monitoring quality (captured from the August 2021 report, Aquatico, 2021).

BH ID	Aug. 21 Status	GW level (mbgl)	pH	EC (mS/m)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Alk. ($CaCO_3$)	Cl (mg/l)	SO_4 (mg/l)	NO_3 (mg/l) as N	F (mg/l)	Mn	Al (mg/l)	NH_4 as N(mg/l)
WUL Table 09 GW Quality		-	8.69	106.65	-	90.48	66.44	27.01	-	-	118.8	36.17	10	0.39	0.4	-	-
SANS241-1:2015		-	5.0/9.7	170	1200	-	-	200	-	-	300	500	11	1.5	0.1	0.3	1.5
T1	Sampled	29.05	7.61	146	852	29.8	69.5	187	10.9	510	225	<0.141	0.272	<0.263	0.035	<0.002	2.35
T2	Sampled	10.29	7.93	107	574	21	48.8	127	11.7	360	127	<0.141	0.281	<0.263	0.112	<0.002	7.81
T3	Sampled	33.74	7.4	76.2	379	19.1	23.7	88.1	5.09	85.6	186	<0.141	0.272	<0.263	0.18	<0.002	0.424
T4	Sampled	32.74	7.69	159	913	26.6	47.3	205	14.6	522	258	<0.141	0.485	<0.263	0.05	<0.002	27.1
T6	Sampled	37.36	8.42	151	887	8.57	27.8	289	6.73	409	292	<0.141	0.326	0.506	0.071	<0.002	8.37
YGW01	Sampled	17.72	7.11	241	1637	188	124	114	5.22	296	315	53.1	137	<0.263	0.009	<0.002	0.082
YGW02	Demolished		7.14												0.013		
YGW03	Sampled	17.54	7.14	303	2248	274	160	77.6	7.18	281	309	26.7	256	<0.263	0.013	<0.002	0.068
YGW04	Sampled	18.85	7.19	211	1423	172	106	105	6.49	421	282	84.2	75.7	<0.263	0.015	<0.002	0.061
YGW05	Sampled	31.17	7.24	204	1283	169	107	77	4.93	284	280	34.7	85.7	<0.263	0.005	<0.002	0.081
HGW01	Demolished	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HGW02	Dry	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
RGW01	Sampled	9.9	7.85	194	1165	47.5	109	237	3.76	538	295	124	0.477	<0.263	0.261	<0.002	1.09
RGW02	No Access	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-

3.6. AQUIFER TESTS

A total of seven (7) existing boreholes were hydraulicly tested to determine the aquifer parameters for the surrounding aquifer during 24 to 28 August 2021. Four (4) boreholes were slug tested; the aquifer parameter estimates are based on the groundwater response of the groundwater level to slug displacement. Three (3) boreholes were pump tested; the aquifer parameters estimate re based on groundwater response of the groundwater level to abstraction volumes. A summary of the slug and pump tests are discussed below. The slug test and pump test diagnostic curves are shown in Appendix III.

3.6.1. Slug Tests

The four (4) slug tested field measured groundwater level response during the hydraulic tests are provided in Table 3-5, while a Summary of the estimated aquifer parameters are show in Table 3-6.

The following process was followed for estimating aquifer parameters based on the slug test data.

1) Develop a conceptual understanding of the geological setting of the test.
2) Create the diagnostic plots from pump and slug test data and define the flow regime.
3) Choose the appropriate analytical solution (e.g. (Bauwer-Rice, KGS Model, etc.) and determining the aquifer and well parameters from the curve fitting of the change in groundwater head lowering the slug in and taking the slug out.

Table 3-5: Hydraulic slug field measurements.

BH ID	Rest Water Level [mbgl]	Slug In		Slug Out	
		Water level [mbgl]	Recovered water level [mbgl]	Water level [mbgl]	Recovered water level [mbgl]
HTWM004	27.50	28.2	27.8	27.01	27.5
HTWM005	44.10	44.8	44.6	43.9	44.1
T4	32.85	33.1	32.9	32.6	32.8
YKDW4	24.00	24.3	24.2	23.9	24.1

Table 3-6: Summary of the aquifer parameters based on the slug tests.

BH ID	Slug input	Aquifer properties (Slug Test)	
		Bouwer-Rice	KGS Model
		K-value (m/day)	
HTWM004	Slug In	7.00E-04	2.00E-04
	Slug Out	4.00E-04	2.00E-04
HTWM005	Slug In	2.40E-04	1.30E-04
	Slug Out	7.80E-04	2.00E-02
T4	Slug In	1.00E-03	1.90E-04
	Slug Out	6.60E-04	9.00E-05
YKDW4	Slug In	3.50E-04	1.30E-05
	Slug Out	2.60E-03	2.30E-03

NOTE: Aquifer depth assumed based on borehole information

The estimated aquifer parameters were based on the best fit analytical model, namely a confined fractured aquifer system. The hydraulic conductivity values range from 1E-05 m/day to 2E-02 m/day with an average value of 2E-03 m/day. While the lithological logs as well as construction details was not available it can be inferred that these permeabilities represent largely the Kalahari sediments (with clay rich layers) as well as the fractured rock formations (e.g., Dwyka and Hotazel formations). The low permeability confirms the low groundwater potential of the underlying aquifer which results in a low vulnerability of the aquifer to pollution.

3.6.2. Pump Tests

Three (3) boreholes were pump tested, consisting of step drawdown test and constant drawdown tests, with a maximum duration of 210 minutes, with recovery up to 95% recovery. The aquifer parameter estimates are therefore based on drawdown and recovery data from the step and constant discharge test. Onley borehole HTDW002 could obtain a constant pump test rate. Boreholes T1 and T6 reached ump intake during the low yielding step test. The summary of the pumping tests is provided in Table 3-7.

Table 3-7: Summary of the pump tests.

BH ID	Rest Water Level [mbgl]	Available Drawdown (m)	Step Drawdown rates (l/s)	Step Drawdown (m)	Constant Discharge Rate (l/s)	CDT Duration (min)	CDT Final Drawdown (m)	Recovery
HTDW002	38.5	61.50	0.22 (min) to 0.33 (max)	34.43	0.28	210	20.32	75%
T1	25.16	74.84	0.22 (min) to 0.28 (max)	74.84	None	None	None	16%
T6	37.65	62.35	0.22 (min) to 0.33 (max)	64.55	None	None	None	4%

NOTE: Recovery is based on constant test for BH HTDW002 however based on step test for BH T1 and T6.

The following process was followed for estimating aquifer parameters based on the pumping test data.

1) Develop a conceptual understanding of the geological setting of the test.
2) Create the diagnostic plots from pumping test data and define the flow regime.
3) Choose the appropriate analytical solution (e.g. 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.
4) The 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 recovery data.

A summary of the borehole parameters and determined Transmissivity values is given in Table 3-8. Selected diagnostic plots with fitted data are shown in Appendix III. The pumping tests confirm the low yielding potential of the aquifer. Based on the pumping test results none of the tested boreholes will be fit for large scale groundwater supply.

Table 3-8: Transmissivity (in m^2/d) estimates based on pump test conducted.

BH ID	Analytical Method – Transmissivity Value			
	Theis	Cooper-Jacob	Papadopulos-Cooper	Recovery
HTDW002	0.613	0.566	0.276	0.5
T1	0.065	0.05	None	0.4
T6	0.1	0.15	None	3.9

NOTE: Papadopulos-Copper based on constant discharge test.

3.7. PIT DEWATERING (GROUNDWATER INGRESS)

Based on the recognisance site visit water seepage or inflow into the pits are managed in situ. Pit dewatering volumes are metered[1]. Monthly dewatering rates for York pit and Hotazel pit is shown in Figure 3-7. Average monthly flows relate to around 1180 m3/month and 179 m3/month, respectively. Based on the results it can be inferred that limited groundwater seepage into the pit is observed and water make within the pit is largely due to direct rainfall, rainfall-runoff, and interflow.

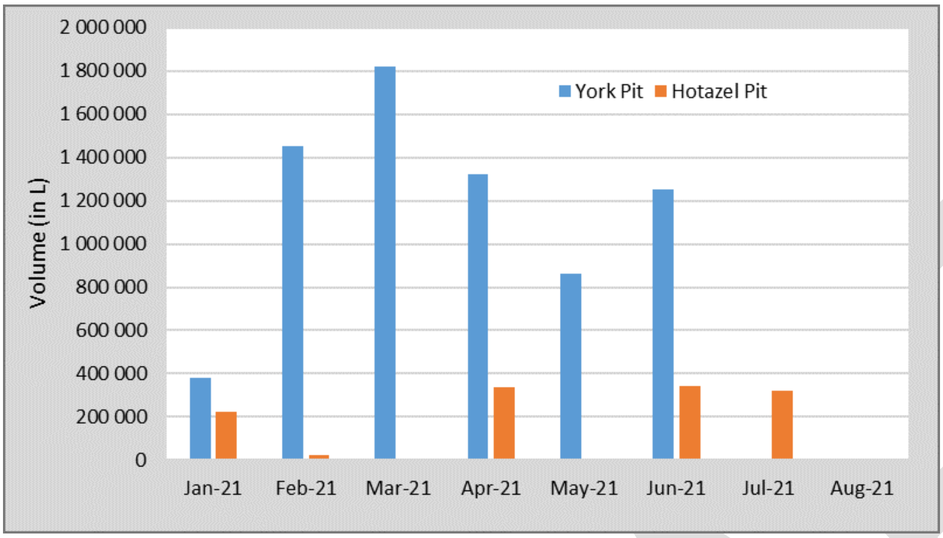


Figure 3-7. Pit dewatering volume measured from Jan-21 to Jul-21.

---

[1] E-mail Correspondence (26 August 2021) – Tshekedi Montshusi (Environmental Officer) Kudumane Manganese Resources

4. AQUIFER CHARACTERISATION

4.1. GROUNDWATER VULNERABILITY

Groundwater vulnerability gives an indication of how susceptible an aquifer is to contamination. Aquifer vulnerability is used to represent the intrinsic characteristics that determine the sensitivity of various parts of an aquifer to being adversely affected by a contaminant load imposed from surface.

Figure 4-1 shows the national groundwater vulnerability ratings underlying the project area, indicating the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. The method is based on the DRASTIC method which includes the following parameters: Depth to water table; Recharge (net); Aquifer media; Soil media; Topography; Impact of the vadose (unsaturated) zone; conductivity (hydraulic).

Based on the national results, the aquifer underlying the project area has a low to medium vulnerability rating. The underground mine workings fall towards the north and south within a medium vulnerability rating whereas the Shaft and surface infrastructure fall within a low vulnerability rating. The worst-case scenario, i.e. medium vulnerability rating, is used in the assessment.

However, it must be kept in mind that the compilation of groundwater vulnerability map, which rely on the intrinsic natural properties of an area and aquifer, are not very meaningful in the context of the historically undermined project area. The natural aquifer properties in the project area are extensively altered by the existence of open underground mine voids, land subsidence due to shallow undermining, neighbouring mining activities, mine residue deposits and acid rock drainage. The maps should therefore only be seen in regional context.

4.2. AQUIFER CLASSIFICATION

According to the Hydrogeological Map (1:500 000) series, the regional hydrogeology is characterized as an ‘intergranular and fractured aquifer’ with a typical potential yield of 0.1 – 0.5 litres per second (Figure 4-2). Based on the aquifer classification map (Parsons and Conrad, 1998), the aquifer system underlying the project area is regarded a “minor aquifer”.

A summary of the classification scheme is provided in Table 4-1. 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.

Table 4-1: Aquifer classification scheme after Parsons and Conrad (1998).

Aquifer	Description
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

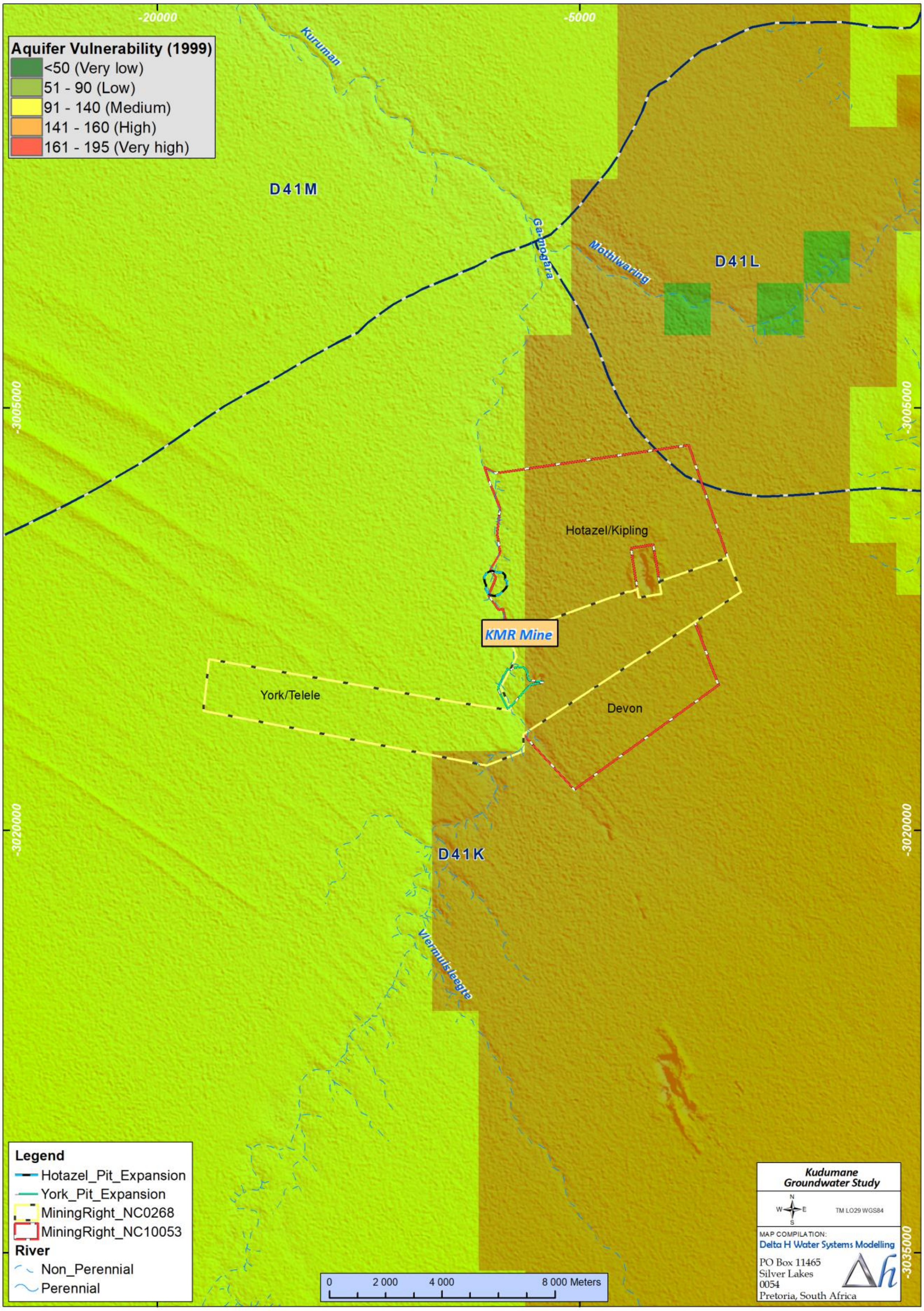


Figure 4-1. Groundwater vulnerability map.

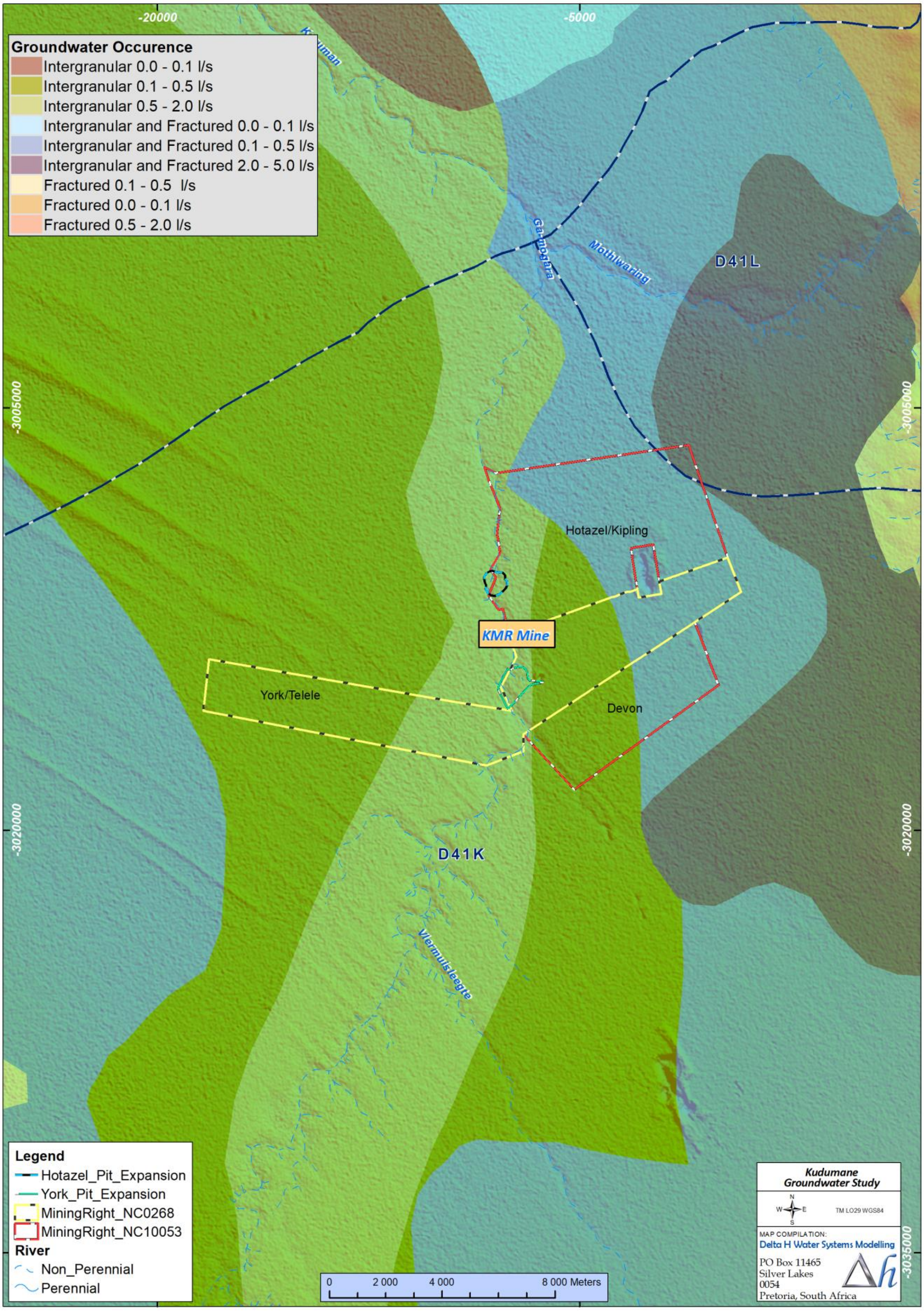


Figure 4-2. Aquifer classification.

4.3. AQUIFER PROTECTION CLASSIFICATION

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required (Parsons 1995). The point scoring system and classification of the site-specific project area are presented in Table 4-2.

Table 4-2: Groundwater Quality Management (GQM) Classification System.

Aquifer System Management Classification		
Class	Points	**Project area**
Sole Source Aquifer System: Major Aquifer System: Minor Aquifer System: Non-Aquifer System: Special Aquifer System:	6 4 2 0 0 – 6	**2**
Aquifer Vulnerability Classification		
Class	Points	**Project area**
High: Medium: Low:	3 2 1	**2**

The recommended level of groundwater protection based on the Groundwater Quality Management Classification is calculated as follows: GQM Index = Aquifer System Management x Aquifer Vulnerability = 2 x 2 = 4.

A Groundwater Quality Management Index of 4 was estimated for the project area from the ratings for the Aquifer System Management Classification Table 4-3). According to this estimate, a medium-level groundwater protection is required for the intergranular and fractured aquifer. Reasonable groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term. DWS's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is the protection of the underlying aquifer.

Table 4-3: GQM index for the project area.

Index	**Level of Protection**	**Project area**
<1 1 - 3 3 - 6 6 - 10 >10	Limited Low Level Medium Level High Level Strictly Non-Degradation	**4**

5. GROUNDWATER MODEL UPDATE

The existing regional groundwater model developed as part of the hydrogeological assessment in 2016 followed by further updates by Delta-H in 2021 will be used as basis to inform future groundwater flows as the mine is developed. The solute transport model code will be used to predict the development of plumes emanating from pollution sources during the life of mine as well as up to 50 years post closure.

5.1. SOURCES AND SINKS

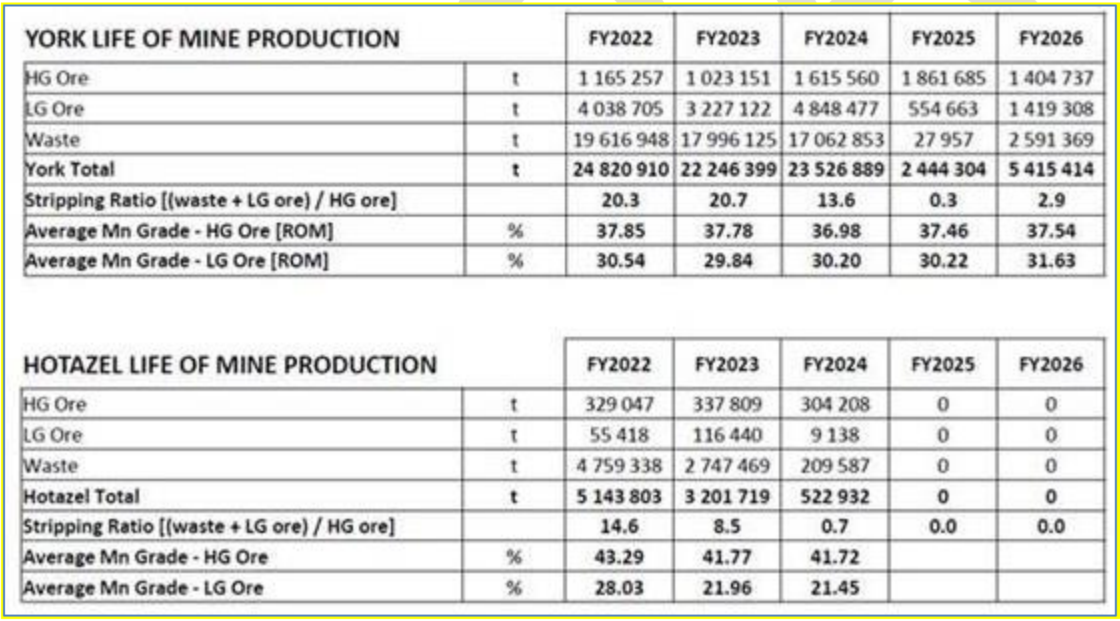
5.1.1. Recharge

Groundwater enters the model domains as direct recharge from rainfall. It was therefore implied that certain areas may have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer systems. SLR (2015) modelling results indicated recharge rates range between 0.2% and 0.5% of MAP, representing the lower bounds of reported values for the Kalahari.

5.1.2. Open pit mine

The maximum depth of the open pits will be approximately 80 m for the Hotazel pit and 130 m for the extended York pit. The current life of mine plan is based on a maximum combined 1.5 million tons of ore per annum extracted from Hotazel and extended York pits, subject to market demand (Kimopax, 2020). The Life of Mine schedule is provided in Figure 5-1.

The existing York (york 22 02 2021.dxf) and Hotazel (Hotazel 22 02 2021.dxf) open pits were integrated into the model domain for the predictive simulations by updating the digital elevation model for the pit area and assigning a free seepage boundary to the pit area. It is assumed that any groundwater entering the pit is removed (pumped out &/ seeping groundwater evaporates) and that the pit bottom represents therefore the lowest drainage elevation. In other words, groundwater can seep freely into the pit with a subsequent development of a cone of dewatering.



YORK LIFE OF MINE PRODUCTION		FY2022	FY2023	FY2024	FY2025	FY2026
HG Ore	t	1 165 257	1 023 151	1 615 560	1 861 685	1 404 737
LG Ore	t	4 038 705	3 227 122	4 848 477	554 663	1 419 308
Waste	t	19 616 948	17 996 125	17 062 853	27 957	2 591 369
York Total	**t**	**24 820 910**	**22 246 399**	**23 526 889**	**2 444 304**	**5 415 414**
Stripping Ratio [(waste + LG ore) / HG ore]		**20.3**	**20.7**	**13.6**	**0.3**	**2.9**
Average Mn Grade - HG Ore [ROM]	%	**37.85**	**37.78**	**36.98**	**37.46**	**37.54**
Average Mn Grade - LG Ore [ROM]	%	**30.54**	**29.84**	**30.20**	**30.22**	**31.63**

HOTAZEL LIFE OF MINE PRODUCTION		FY2022	FY2023	FY2024	FY2025	FY2026
HG Ore	t	329 047	337 809	304 208	0	0
LG Ore	t	55 418	116 440	9 138	0	0
Waste	t	4 759 338	2 747 469	209 587	0	0
Hotazel Total	**t**	**5 143 803**	**3 201 719**	**522 932**	**0**	**0**
Stripping Ratio [(waste + LG ore) / HG ore]		**14.6**	**8.5**	**0.7**	**0.0**	**0.0**
Average Mn Grade - HG Ore	%	**43.29**	**41.77**	**41.72**		
Average Mn Grade - LG Ore	%	**28.03**	**21.96**	**21.45**		

Figure 5-1: KMR life of Mine schedule.

5.1.3. Seepage quality

The existing York and the Hotazel waste rock dumps (WRDs) have the potential to impact on the ambient groundwater quantity and quality due to seepage with increased solute concentrations from these facilities. Geochemical tests and analyses provided indicate that the waste rock lithologies tested are non-acid generating, however a few metals are leachable including aluminium (Al), iron (Fe) and manganese (Mn). A Neutral pH (controlled by calcite dissolution) with a higher salinity (in the in the form of elevated calcium, sodium, magnesium, chloride, nitrate, and sulphate concentrations) can be expected. Based on the groundwater quality results a seepage source term of 2 100 mgL TDS concentration and the median nitrate concentration of 100 mg/l was applied in the transport predictions.

Following the precautionary principle, an advective-dispersive transport of the constituents of concern without any retardation or transformation was simulated. Since no element specific retardation or transformation is simulated, concentrations for individual elements of concern can be easily derived by multiplying given percentages with the respective source concentration for an element. The TDS and Nitrate (as n) source term legend table is shown in

Table 5-1: Contamination map legend used for the KMR model update.

Legend (Unit %)	**TDS (mg/l)**	**Nitrate as N (mg/l)**
	(2100)	**(100)**
🟦 10.00	210	10
🟦 20.00	420	20
🟩 30.00	630	30
🟩 40.00	840	40
🟨 50.00	1050	50
🟨 60.00	1260	60
🟨 70.00	1470	70
🟧 80.00	1680	80
🟧 90.00	1890	90
🟧 100.00	**2100**	**100**

5.2. MODEL CALIBRATION

The collated historical groundwater levels (in metres above mean sea level) as well as the site-specific monitoring borehole water levels was used as calibration targets for the update of the steady-state flow model calibration. The model was run with the initial 2016 boundary conditions and updated using sensible boundaries (i.e. permeabilities) until a best fit between initial and computed potential heads was observed. A good correlation between observed and modelled water levels was achieved (Figure 5-2).

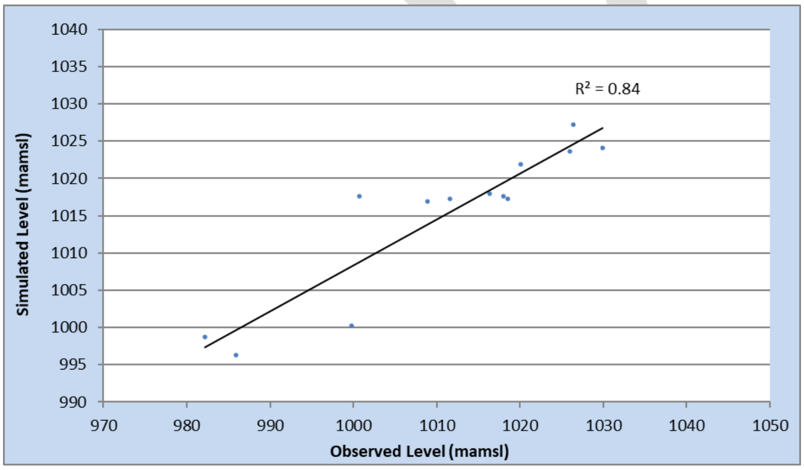


Figure 5-2: Steady state calibration of the KMR groundwater model.

The root mean square error (RMSE) and the normalised root mean square error (NRMSE) were used as quantitative indicators for the adequacy of the fit between the (=n) observed (h_{obs}) and simulated (h_{sim}) water levels:

$$RMSE = \sqrt{\frac{\sum(h_{obs} - h_{sim})^2}{n}}$$

The root mean square error of 7.5 for the observed heads are considered acceptable for the model update. The simulated steady-state head contours of regional model are shown in Figure 5-3, while an N-S cross-section along the Hotzel and York pits is shown in Figure 5-4.

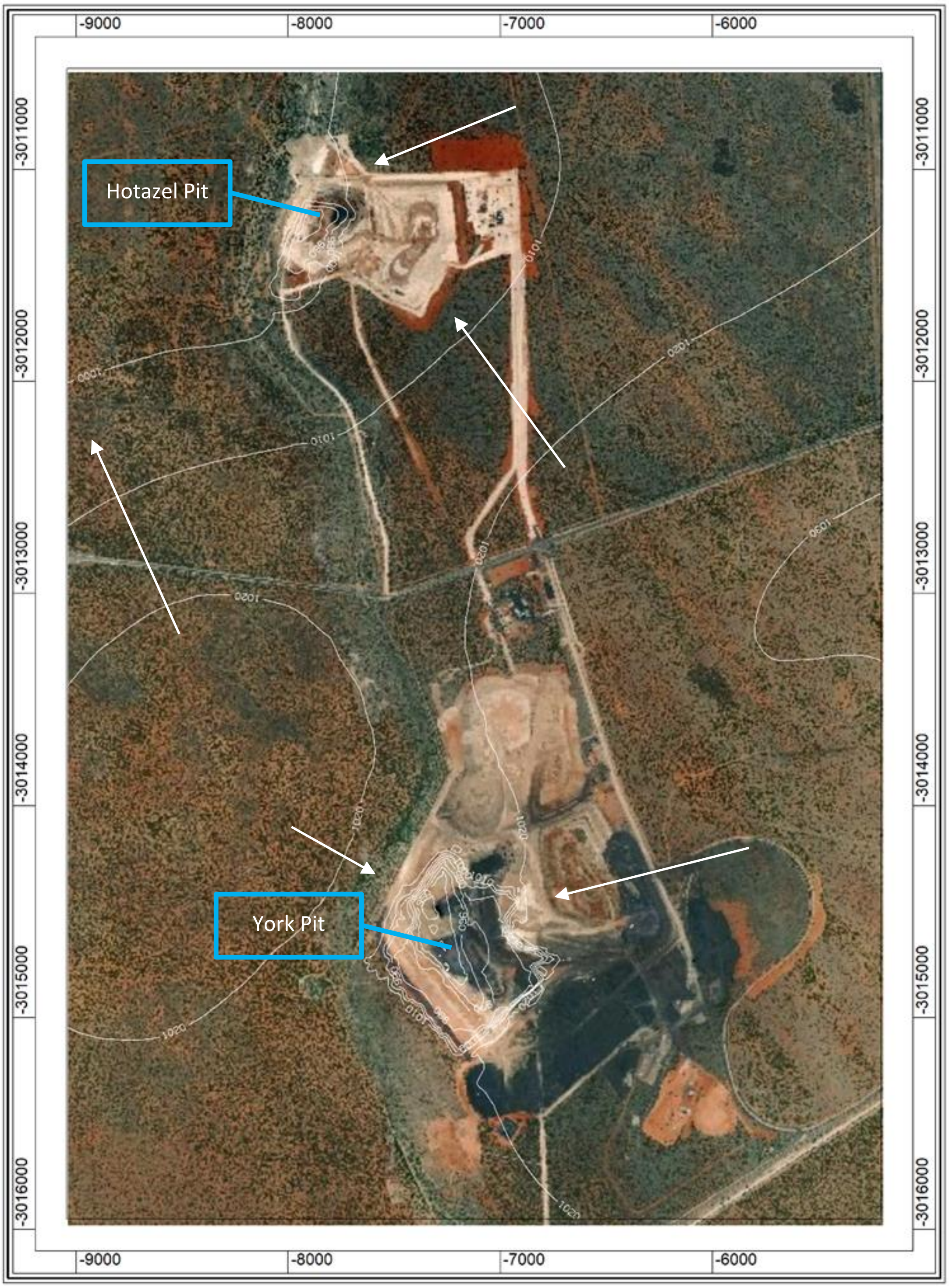


Figure 5-3: Simulated head contours of the KMR mine.

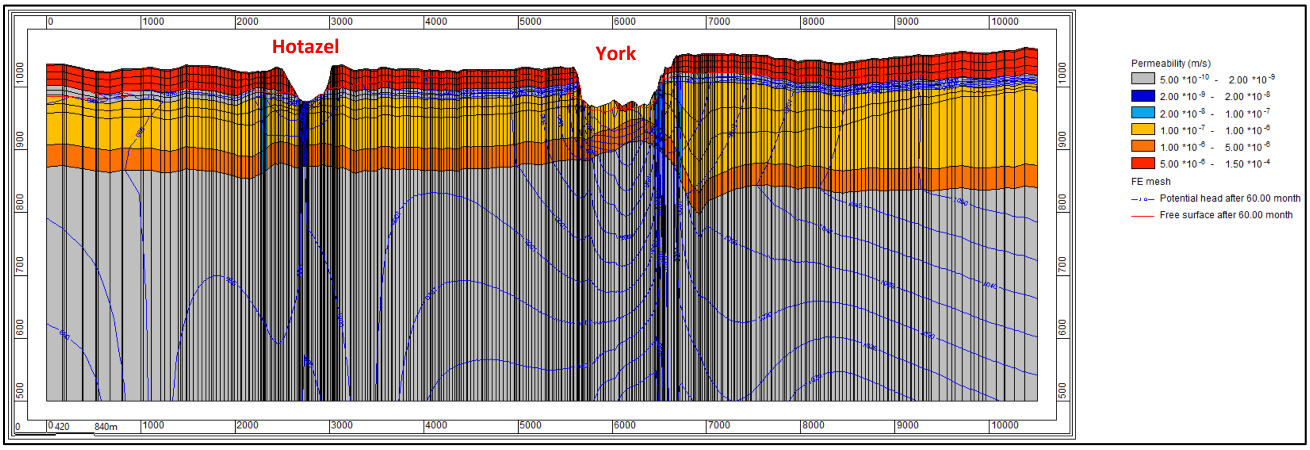


Figure 5-4: N-S cross-section showing simulated heads in relation to the York and Hotazel pit.

5.3. MODEL RESULTS

5.3.1. Current seepage plume simulated

he simulated groundwater seepage plume emanating from the York and the Hotazel mine residue facilities is shown in Figure 5-5. The seepage plume is expected to develop mainly in the upper Kalahari aquifer and within the footprint areas of the site. The simulated plume is in range with the concentrations observed at the York monitoring boreholes.

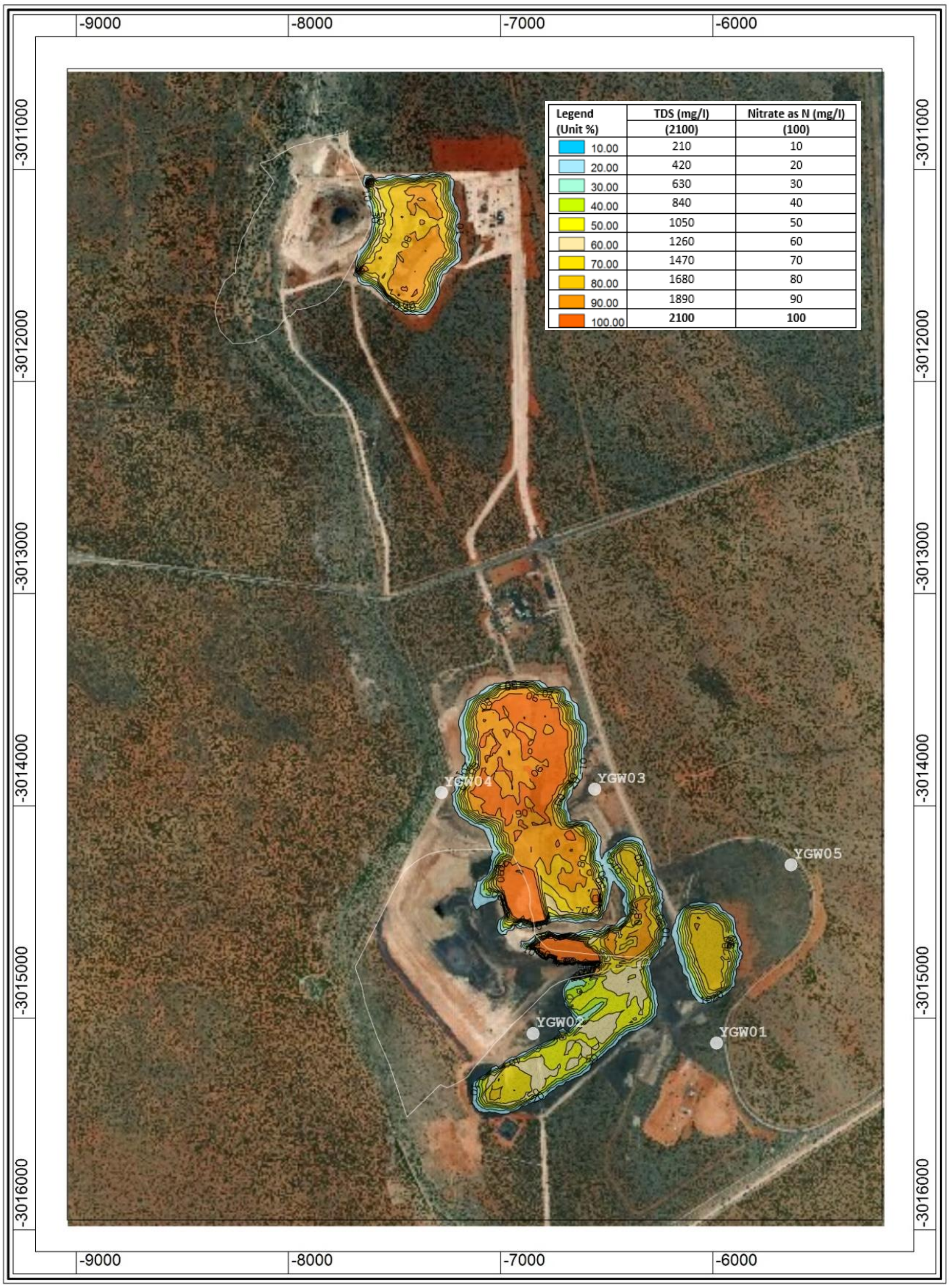
5.3.2. Life of mine

The calibrated groundwater flow model was used to estimate the annual average groundwater inflows into the final, fully developed Hotazel pit void, as well at the fully developed York open pit. To reflect the changing mine topography (mined out areas), the following changes to the boundary conditions were performed:

- The seepage boundary conditions were assigned to the LoM plan.
- The digital elevation model was updated for the proposed mining areas.
- Already mined out areas reflect the post closure topography, assuming timeously backfilling thereof, i.e., behind the active mining window.
- The recharge rate and porosity of the areas mined out and assumed to be backfilled were adjusted to reflect levelled and rehabilitated spoils (1% of MAP and 25% porosity).

The average mine inflows of 3.8 and 1.7 l/s were simulated for the Hotazel and York mining area, respectively. Which is slightly lower compared to the model predictions in 2016, due to the lower permeability estimates from the aquifer tests. The simulated partial dewatering of the upper Kalahari aquifer and the deeper fractured aquifer due to open pit mine inflows is depicted in Figure 5-6.
Note: the figure reflects the drawdown (in m) from the perceived pre-mining groundwater level to the LoM simulated groundwater level.

Conceptually, the actively mined Pits can be considered as a local groundwater sink (where dewatering and evaporation exceeds inflows) and groundwater flow is towards the pit from the surrounding aquifer. Potential seepage plume from the stockpiles and WRDs will be intersected in the pit and is managed as part of the dirty (process) water of the mine.



Legend (Unit %)	TDS (mg/l) (2100)	Nitrate as N (mg/l) (100)
🟦 10.00	210	10
🟦 20.00	420	20
🟩 30.00	630	30
🟩 40.00	840	40
🟨 50.00	1050	50
🟨 60.00	1260	60
🟨 70.00	1470	70
🟧 80.00	1680	80
🟧 90.00	1890	90
🟥 100.00	**2100**	**100**

Figure 5-5: Simulated plume for the current York and Hotazel mine residue facilities.

Figure 5-6: Cone of dewatering (in m) (LOM).

5.3.3. Post-closure

To reduce the overall water-make at the end of life of mine, KMR aims to backfill the open pit with waste rock material. The backfilled areas will also be top soiled and seeded to enhance vegetation growth and thereby minimise the infiltration of rainwater recharging the spoils material. It is assumed that the entire mine void will be backfilled with waste rock from the WRD and topsoil material, the WRD footprints will therefore be removed completely. However, residual pollution plumes underlying the footprint will form secondary pollution sources for as it longs as it takes for natural attenuation to occur. No reduction of post closure recharge rates was assumed for the backfilled area, however, a linear reduction of source concentrations for the backfill was assumed and used to simulate the gradual change in seepage concentration post-closure (Delta-H, 2016). The simulated plume development post-closure is shown in Figure 5-7 and Figure 5-8.

Figure 5-7: Simulated post-closure plume development (Year 20).

Figure 5-8: Simulated post-closure plume development (Year 50).

The horizontal extent of the plume is limited since the pits are still acting as a sink (groundwater flows still towards and not away from the pits). However, the backfilled material in the pit was considered as a potential pollution source. Based on the assigned source concentration, while acknowledging the conservative (worst case) seepage quality, relates to around 1890 mg/l of TDS and 90 mg/l Nitrate as N. However, nitrate is often retarded or transformed into other species in the sub-surface which is difficult to predict at this stage. At the end of the simulation period, the residual seepage plume of the WRDs and stockpiles has also diminished. Due to the low permeability of the mined aquifer the lateral pollution migration will remain limited.

6. GEOHYDROLOGICAL IMPACTS

6.1. METHODOLOGY

This methodology complies with Regulation 31(2)(l) of the National Environmental Management Act (Act 107 of 1998) as amended (NEMA[2]), which states the following:

(2) An environmental impact assessment report must contain all information that is necessary for the competent authority to consider the application and to reach a decision …, and must include –

(l) an assessment of each identified potentially significant impact, including –

(i) cumulative impacts;
(ii) the nature of the impact;
(iii) the extent and duration of the impact;
(iv) the probability of the impact occurring;
(v) the degree to which the impact can be reversed;
(vi) the degree to which the impact may cause irreplaceable loss of resources; and
(vii) the degree to which the impact can be mitigated.

Based on the above, the EIA Methodology will require that each potential impact identified is clearly described (providing the nature of the impact) and be assessed in terms of the following factors:

- extend (spatial scale) - will the impact affect the national, regional or local environment, or only that of the
- duration (temporal scale) - how long will the impact last;
- magnitude (severity) - will the impact be of high, moderate or low severity; and
- probability (likelihood of occurring) - how likely is it that the impact may occur.

To enable a scientific approach for the determination of the environmental significance (importance) of each identified potential impact, a numerical value has been linked to each factor. To comply with best practice principles, the evaluation of impacts will be conducted in terms of the criteria presented in Table 6-1.

Table 6-1: Impact assessment criteria.

Occurrence	**Duration (D):**	**Probability (P):**
	5 – Permanent	5 – Definite/don't know
	4 - Long-term (ceases with the operational life)	4 – Highly probable
	3 - Medium-term (5-15 years)	3 – Medium probability
	2 - Short-term (0-5 years)	2 – Low probability
	1 – Immediate	1 – Improbable
		0 – None
Severity	**Extent/scale (E):**	**Magnitude (M):**
	5 – International	10 - Very high/uncertain
	4 – National	8 – High
	3 – Regional	6 – Moderate
	2 – Local	4 – Low
	1 – Site only	2 – Minor
	0 – None	

Once the above factors had been ranked for each identified potential impact, the environmental significance of each impact can be calculated using the following formula:

Significance = (duration + extend + magnitude) x probability

---

[2] NEMA (1998): National Environmental Management Act (Act107 of 1998)

The maximum value that can be calculated for the environmental significance of any impact is 100. The environmental significance of any identified potential impact is then rated as either: high, moderate or low on the following basis:

- More than 60 significance value indicates a high (H) environmental significance impact;
- Between 30 and 60 significance value indicates a moderate (M) environmental significance impact; and
- Less than 30 significance value indicates a low (L) environmental significance impact.

In order to assess the degree to which the potential impact can be reversed and be mitigated, each identified potential impact will need to be assessed twice.

- Firstly, the potential impact will be assessed and rated prior to implementing any mitigation and management measures; and
- Secondly, the potential impact will be assessed and rated after the proposed mitigation and management measures have been implemented.

The purpose of this dual rating of the impact before and after mitigation is to indicate that the significance rating of the initial impact is and should be higher in relation to the significance of the impact after mitigation measures have been implemented. To assess the degree to which the potential impact can cause irreplaceable loss of resources, the following classes (%) will be used and will need to be selected based on your informed decision and discretion (Table 6-2):

Table 6-2: Loss of resources impact classes.

5	100% - Permanent loss
4	75% - 99% - significant loss
3	50% - 74% - moderate loss
2	25% - 49% - minor loss
1	0% - 24% - limited loss

Note: The Loss of Resources aspect will not affect the overall significant rating of the impact.

6.2. ENVIRONMENTAL ASPECTS

Impacts on the local and regional ambient groundwater environment may consist of changes in the groundwater quantity (i.e. groundwater levels), changes in the ambient groundwater quality, or both.
Note: Existing approved mining infrastructure will inherently be seen as part of the cumulative impact assessment for the expansion mining infrastructure.

Due to the Kudumane mine being operational for a long time, no pre-construction groundwater impacts were assessed separately, but as part of the operational phase.

It is considered that the most significant groundwater impacts could arise from the following activities / infrastructure:

- Operational
  - Contamination of groundwater caused by spillage (i.e. hydrocarbons)
    - Mitigation – The mine should maintain a Standard Operating Procedure to contain and remediate any accidental spillages of mine impacted water in line with the EMP.
  - Influx of groundwater into open void (i.e. lowering of groundwater levels due to dewatering) (refer to section) results in a potential loss to groundwater in storage and may impact on existing groundwater users.
    - Mitigation – Due to the low permeability of the host rock a steep hydraulic gradient towards the pit has formed which is reflected in the limited extent of the cone of dewatering.

        - Groundwater users are beyond the dewatering impact zone. If any mine related loss of water supply is experienced by the surrounding provision should for compensation that could include ana alternative water supply of equivalent water quality.
        - The existing monitoring programme will be augmented to include boreholes within the impact zone to continue to monitor the groundwater drawdown.
    - Diffuse (seepage) and run-off from WRDs (resulting in the contamination of groundwater) (refer to section).
        - Mitigation – Geochemical analyses indicate that the waste rock lithologies tested are non-acid generating. While some metals (Al, Fe and Mn) may have the potential to leach from the material these are most likely to be attenuated in the sub-surface resulting in a smaller actual plume extent.
        - Monitoring programme will be augmented to cover the expansion mining infrastructure and potential receptors to track pollution migration and impacts.

The potential groundwater impacts identified during the operational project phase and rated according to the environmental significance is summarised in Table 6-3.

- Closure/Post-closure
    - Backfilling and rehabilitation (during closure) of the open pit will lead to gradual recovery of groundwater levels. This will lead to the re-establishment of groundwater levels, flow directions and flow gradients to near pre-mining levels.
        - The quality of this groundwater may be affected by explosives residues and other contaminants from the mining operation. However, nitrate residues dissolve easily and once leached away in a period of years or less, no significant impacts are predicted.
        - Due to the low permeability of the host rock and the resulting slow movement of groundwater results in a limited pollution plume in extent which will likely dissipate over time.

The potential groundwater impacts identified during the closure project phase, and rated according to the environmental significance, are summarised in Table 6-4.

Table 6-3: Risk assessment for the operation phase impacts.

Nature of the impact		Significance of potential impact BEFORE mitigation							Mitigation Measures	Significance of potential impact AFTER mitigation							Degree of mitigation (%)
		P	D	E	M	LoR	Significance			P	D	E	M	LoR	Significance		
ACTIVITY: Open pit mining (and waste rock deposition)																	
Operational Phase																	
Lowering of groundwater levels due to dewatering (results in a potential loss to groundwater in storage and may impact on existing groundwater users)	-	3	4	1	4	1	**27**	**Low**	*Limited extent of the cone of dewatering* *Monitoring of the groundwater drawdown*	3	4	2	2	2	**24**	**Low**	11.1
Change of the ambient water quality due to open pit	-	4	4	1	2	2	**28**	**Low**	*Geochemical results indicate that the material to be exposed is non-acid generating* *Dewatering qualities must be measured at the transfer sumps* *Pits act as a sink (groundwater flows/plume migration towards and not away from the pits).*	3	4	1	4	2	**27**	**Low**	3.6
Diffuse pollution (seepage) from WRDs	-	4	4	2	2	2	**32**	**Moderate**	Waste rock lithologies tested are non-acid generating Monitoring of pollution plume migration Where monitoring results indicates that 3rd party water supply has been polluted (or yield) have been reduced an alternative equivalent water supply will be provided.	3	4	2	2	2	**24**	**Low**	3.6

Table 6-4: Risk assessment for the closure phase impacts.

Nature of the impact		Significance of potential impact BEFORE mitigation							Mitigation Measures	Significance of potential impact AFTER mitigation							Degree of mitigation (%)
		P	D	E	M	LoR	Significance			P	D	E	M	LoR	Significance		
ACTIVITY: Backfilling and rehabilitation of open pit mining																	
Closure/Rehabilitation Phase																	
Re-establishment of groundwater levels, flow directions and flow gradients to near pre-mining levels	-	3	3	2	4	1	**27**	**Low**	Monitoring of water qualities and water levels (quarterly for 5 years), thereafter annually until stabilised Pits will remain a local groundwater sink (where dewatering and evaporation exceeds inflows) and groundwater flow/plume migration is towards the pit	3	3	2	2	2	**21**	**Low**	22.2
Diffuse seepage of groundwater potentially contaminated	-	3	4	2	4	2	**30**	**Moderate**		3	4	2	2	2	**24**	**Low**	20.0

7. GROUNDWATER MONITORING PROGRAMME

7.1. CURRENT

A total of fifteen (15) boreholes are included in the quarterly groundwater monitoring program for KMR. However, not all boreholes are routinely monitored due to either dry conditions or no access/demolished (refer to Table 7-1). The spatial distribution of the monitoring boreholes is shown in Figure 3-6. Based on the location and status of the boreholes an updated monitoring programme is proposed.

Table 7-1: Existing groundwater monitoring boreholes for the KMR mine.

Borehole ID	Lat.	Long.	Area	Oct. 20 Status
HGW01	-27.213	22.92191	±3 km south-west of Hotazel next to Ga-Mogara riverbed	No Access
HGW02	-27.2186	22.92076	±3 km south-west of Hotazel next to Ga-Mogara riverbed	Demolished
RGW01	-27.2398	22.9246	Directly north of mine next to Ga-Mogara riverbed	Dry
RGW02	-27.2315	22.92313	±1 km north of mine next to Ga-Mogara riverbed	Dry
T1	-27.2543	22.92326	Upgradient from mine on Telele Farm	Sampled
T2	-27.2542	22.92531		
T3	-27.2542	22.9212		
T4	-27.2579	22.92335		
T6	-27.2577	22.91924		
YGW01	-27.2481	22.93958	Upgradient from mine and next to railway	Sampled
YGW02	-27.2477	22.93086	Next to diesel tank	Demolished
YGW03	-27.2373	22.93379	Next to tyre bay	Sampled
YGW04	-27.2374	22.92649	Directly north of mine next to Ga-Mogara riverbed	
YGW05	-27.2405	22.94313	Next to railway loop	Sampled

7.2. FUTURE MONITORING BOREHOLES (PROPOSED)

The following recommendations are proposed to augment the KMR groundwater monitoring programme (Table 7-2):

1) Drill new Kipling boreholes (KGW01 and KGw02) at the proposed Kipling mine activities.
2) Drill new Hotazel Pit and WRDs boreholes (HGW04, HGW05 and HGW06).
    a. Include existing borehole HTWM005 into routine monitoring programme.
3) Re-drill (YGW02R) at a different location (western edge of York expansion pit).
    a. Drill new, York Wasbay/Diesel Storage monitoring borehole (YGW06).
4) It is of the opinion that RGW01 and RGW02 is too shallow to be included into the routine monitoring programme.
    a. However, it advised to do measure <u>ad-hoc</u> water levels to confirm the status.
5) Drill new Devon pit rehabilitation monitoring borehole.
6) Perimeter boreholes T1 and T6 can be removed from the monitoring programme subject to agreement with authorities.

The spatial location of the proposed (future) groundwater monitoring boreholes is shown in Figure 7-1. The monitoring programme should be revised annually based on the results and the Life of Mine plans.

<u>Note:</u> The proposed drilling positions are preliminary until the future mining footprint becomes available. This will be addressed as part of the annual groundwater model update.

Table 7-2: Proposed future groundwater monitoring boreholes for the KMR mine.

Borehole ID	Lat.	Long.	Area	Mon. Frequency
HTWM005	-27.2118	22.9281	Upgradient of Hotazel Pit and WRDs	Quarterly quality (Monthly levels)
HGW04*	t.b.c		South of Hotazel pit (and WRD)	
HGW05*	t.b.c		Downgradient (north) of Hotazel pit (and WRD)	
HGW06*	t.b.c		Downgradient (west) of Hotazel pit (and WRD)	
RGW01	-27.2398	22.9246	Directly north of mine next to Ga-Mogara riverbed	Ad-Hoc
RGW02	-27.2315	22.92313	±1 km north of mine next to Ga-Mogara riverbed	
T2	-27.2542	22.92531	Upgradient from mine on Telele Farm	Quarterly quality (Monthly levels)
T3	-27.2542	22.9212		
T4	-27.2579	22.92335		
YGW01	-27.2481	22.93958	Upgradient from mine and next to railway	Quarterly quality (Monthly levels)
YGW02R*	t.b.c		Re-drill Borehole	
YGW03	-27.2373	22.93379	Next to tyre bay	
YGW04	-27.2374	22.92649	Directly north of mine next to Ga-Mogara riverbed	
YGW05	-27.2405	22.94313	Next to railway loop	
YGW06*	t.b.c		Wash bay/Diesel Storage Area	
KGW01*	t.b.c		Downgradient (east) of proposed Kipling pit	Quarterly quality (Monthly levels)
KGW02*	t.b.c		Downgradient (east) of proposed Kipling WRD	
DGW01*	t.b.c		East of abandoned (Devon) pit	Quarterly quality (Monthly levels

* - New borehole (or re-drill)

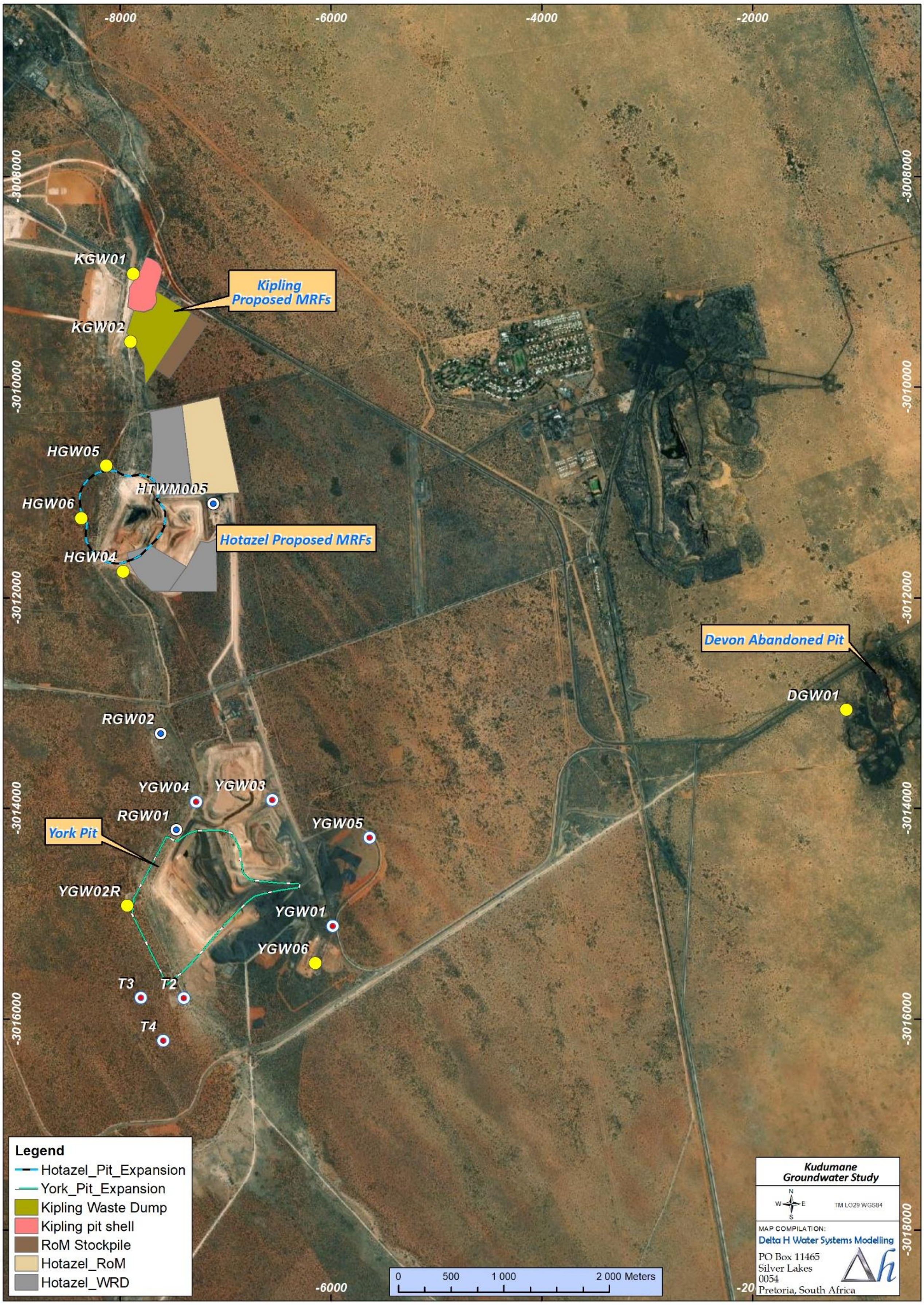


Figure 7-1: Location of the proposed (future) KMR monitoring boreholes in relation to the mine.

8. CONCLUSION AND RECOMMENDATIONS

8.1. SUMMARY FINDINGS

8.2. RECOMMENDATIONS

9. REFERENCES

Bouwer, H. and R.C. Rice (1976). A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Delta-H (2016). Kudumane Transient Groundwater Model – York and Hotazel Pits. Report No. Delh.2016.062-2.

Groundwater Complete (2020). Kudumane Manganese Mine – Annual Groundwater Monitoring Results for 2020.

Hyder, Z, J.J. Butler, Jr., C.D. McElwee and W. Liu (1994). Slug tests in partially penetrating wells, Water Resources Research, vol. 30, no. 11, pp. 2945-2957

Kimopax (2020). Integrated Water and Waste Management Plan (IWWMP). Update for Kudumane Manganese Mine. Project No. KIM-ENV-2019-240.

SANS (241: 2015). South African National Standard (241) Drinking Water. South Africa, Pretoria.

SLR (2014a): Groundwater Assessment Report in support of the Environmental Impact Assessment for the new mining rights. Kudumane Manganese Mine. SLR Project No.: 710.14003.00006.

SLR (2015): Groundwater Flow and Solute Transport Model for the Kudumane Manganese Mine. SLR Project No.: 2015-WG36.

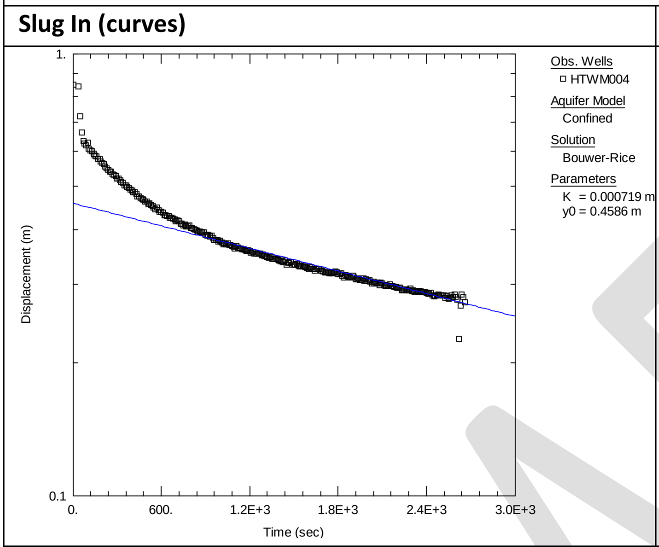
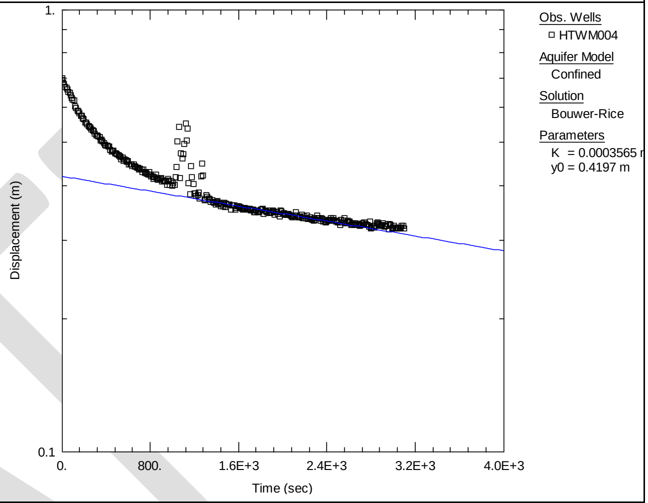
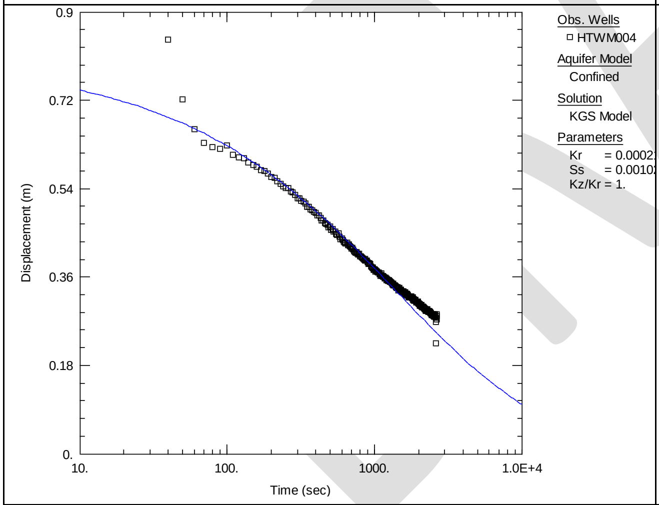
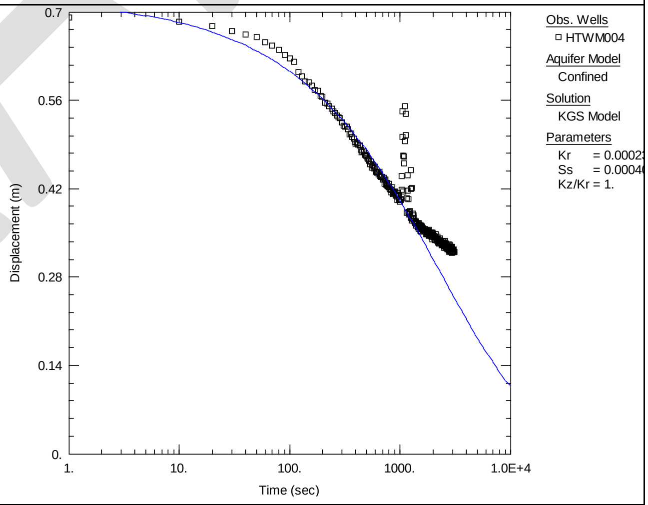
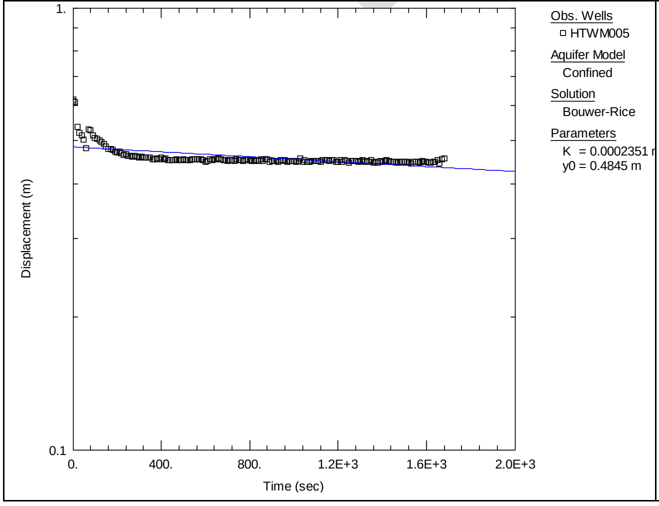
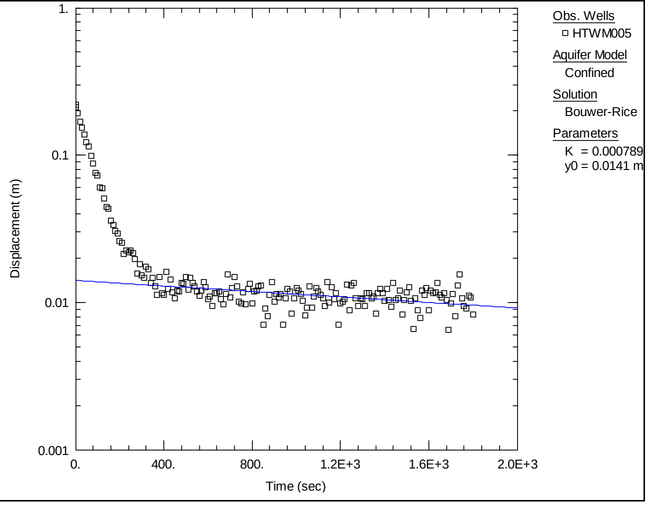
Water Use License (2016). License No. 07/041K/ABCFGIJ/4533. File. No. 27/2/2/01041/11/4.

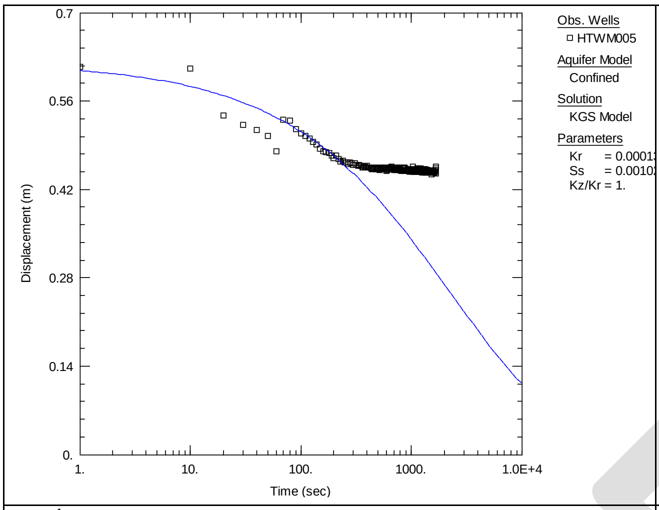
Water Use License (2018). License No. 07/041K/ABCFGIJ/4533. Amendment.

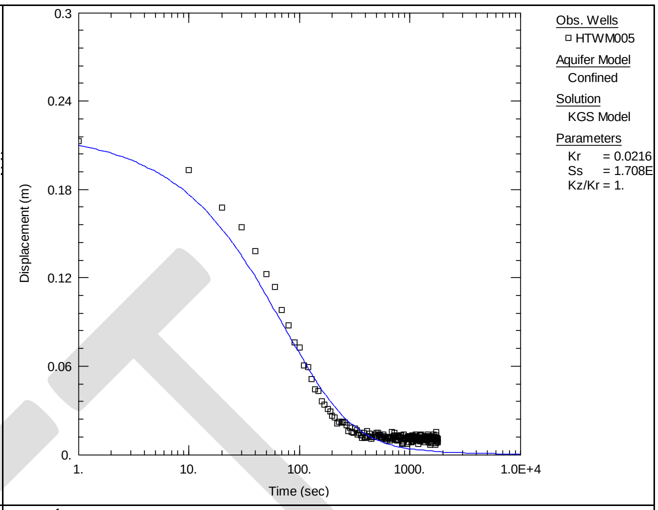
Appendix I – Photos

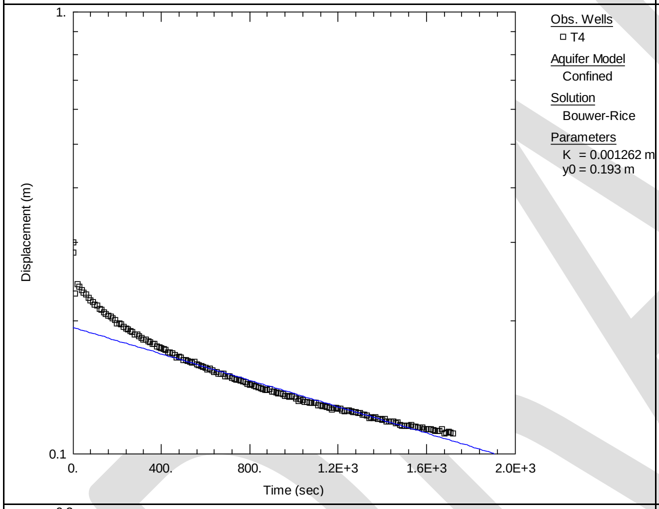
Appendix II – Laboratory Certificates

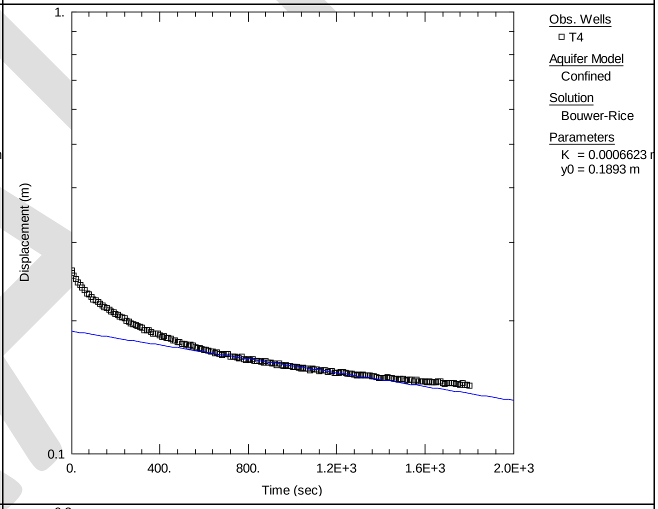
Slug Tests

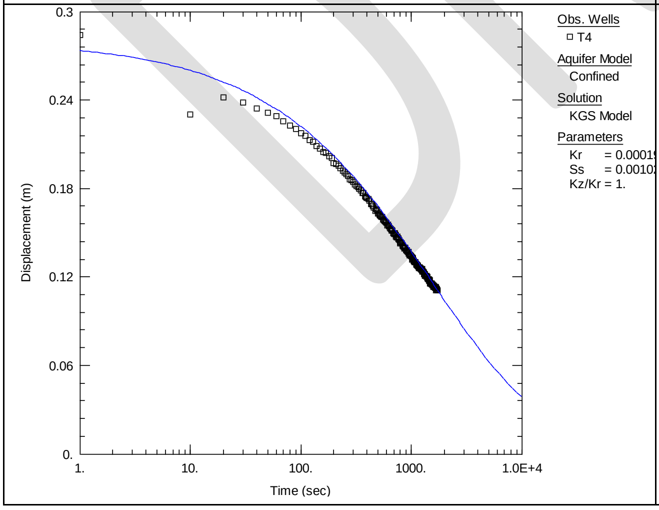
Slug In (curves)	**Slug Out (curves)**
	
	
	

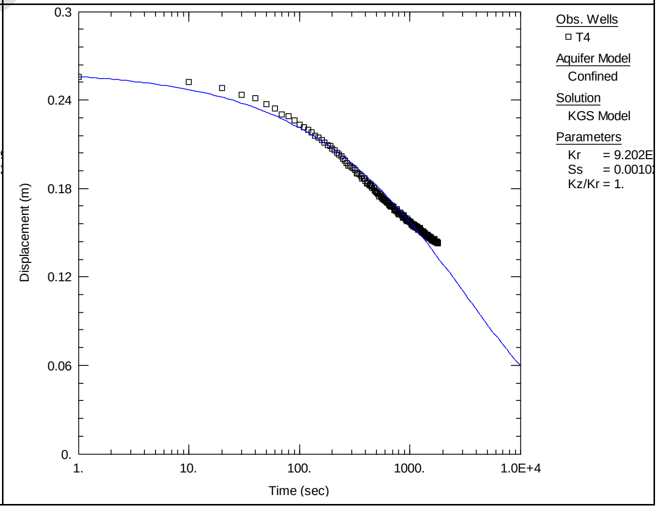

0.7
0.56
0.42
0.28
0.14
0.
Displacement (m)
1.
10.
100.
1000.
1.0E+4
Time (sec)
Obs. Wells
HTWM005
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 0.0001
Ss = 0.0010
Kz/Kr = 1.

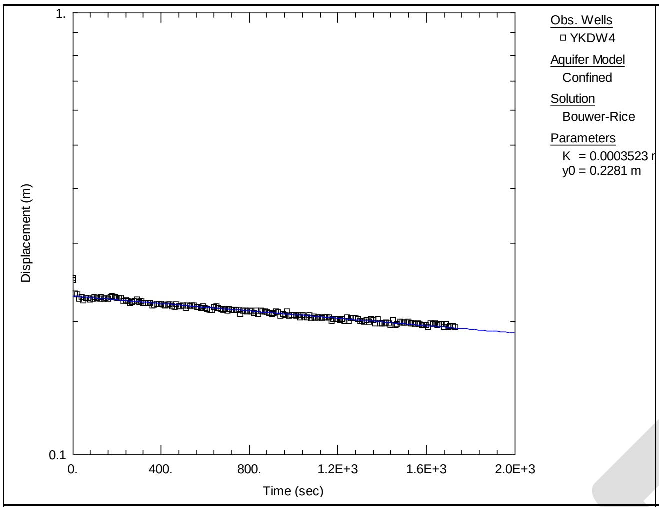

0.3
0.24
0.18
0.12
0.06
0.
Displacement (m)
1.
10.
100.
1000.
1.0E+4
Time (sec)
Obs. Wells
HTWM005
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 0.0216
Ss = 1.708E
Kz/Kr = 1.

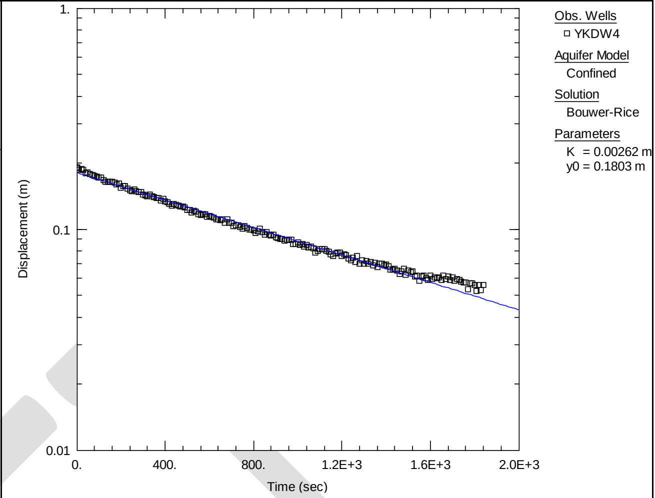

1.
0.1
Displacement (m)
0.
400.
800.
1.2E+3
1.6E+3
2.0E+3
Time (sec)
Obs. Wells
T4
Aquifer Model
Confined
Solution
Bouwer-Rice
Parameters
K = 0.001262 m
y0 = 0.193 m

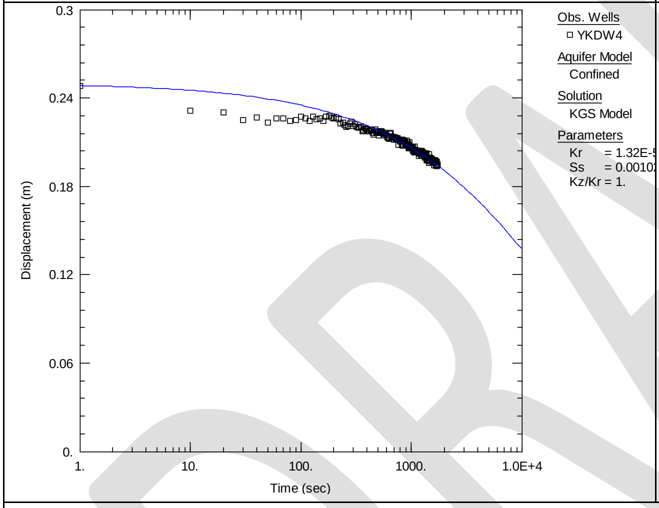

1.
0.1
Displacement (m)
0.
400.
800.
1.2E+3
1.6E+3
2.0E+3
Time (sec)
Obs. Wells
T4
Aquifer Model
Confined
Solution
Bouwer-Rice
Parameters
K = 0.0006623
y0 = 0.1893 m

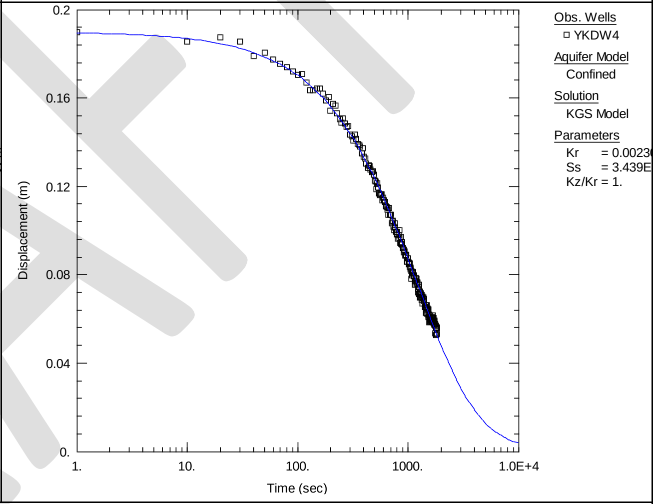

0.3
0.24
0.18
0.12
0.06
0.
Displacement (m)
1.
10.
100.
1000.
1.0E+4
Time (sec)
Obs. Wells
T4
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 0.0001
Ss = 0.0010
Kz/Kr = 1.


0.3
0.24
0.18
0.12
0.06
0.
Displacement (m)
1.
10.
100.
1000.
1.0E+4
Time (sec)
Obs. Wells
T4
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 9.202E
Ss = 0.0010
Kz/Kr = 1.

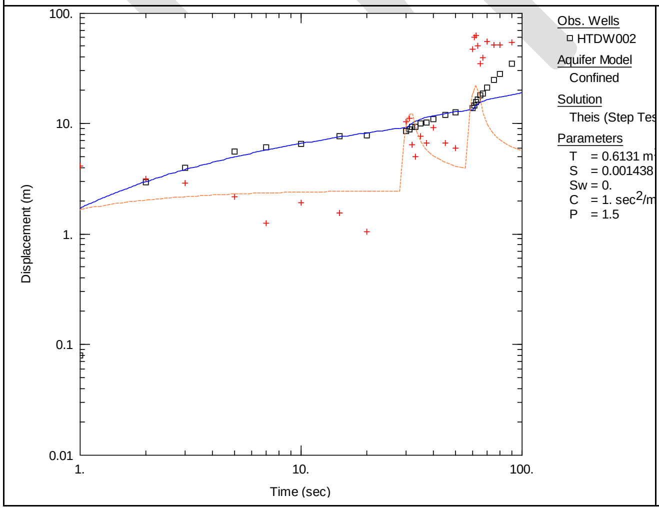

Obs. Wells
YKDW4
Aquifer Model
Confined
Solution
Bouwer-Rice
Parameters
K = 0.0003523
y0 = 0.2281 m
Displacement (m)
1.
0.1
0.
400.
800.
1.2E+3
1.6E+3
2.0E+3
Time (sec)

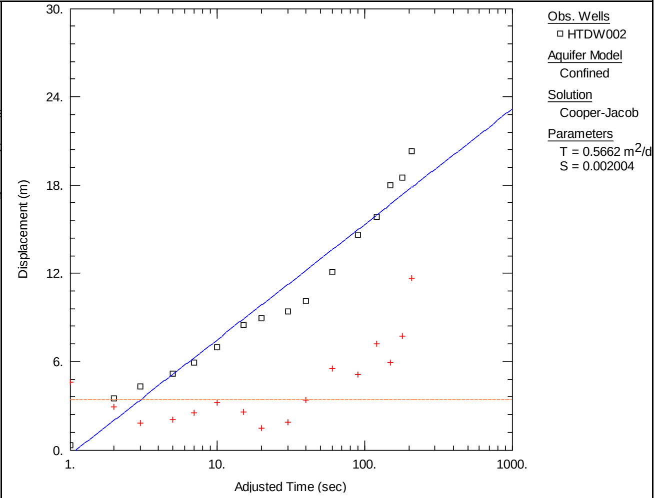

Obs. Wells
YKDW4
Aquifer Model
Confined
Solution
Bouwer-Rice
Parameters
K = 0.00262 m
y0 = 0.1803 m
Displacement (m)
1.
0.1
0.01
0.
400.
800.
1.2E+3
1.6E+3
2.0E+3
Time (sec)

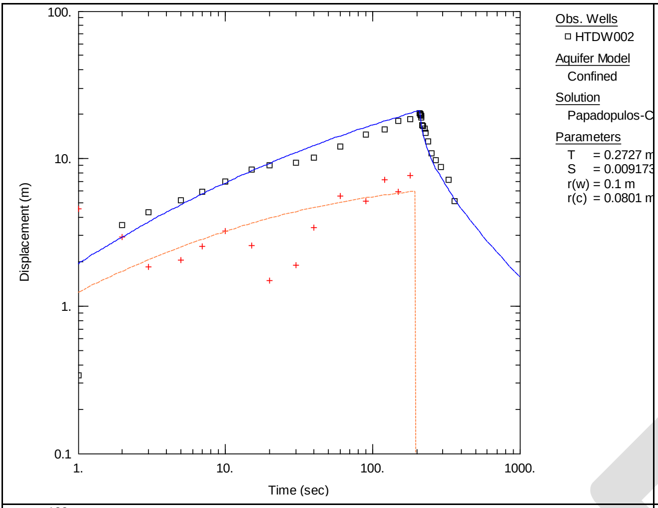

Obs. Wells
YKDW4
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 1.32E-
Ss = 0.0010
Kz/Kr = 1.
Displacement (m)
0.3
0.24
0.18
0.12
0.06
0.
1.
10.
100.
1000.
1.0E+4
Time (sec)

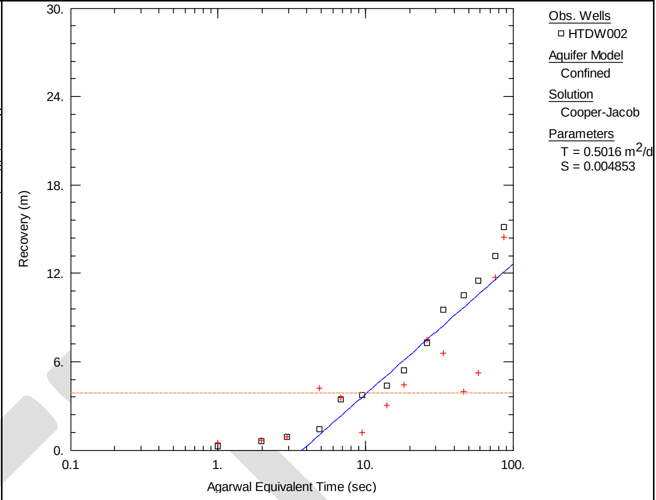

Obs. Wells
YKDW4
Aquifer Model
Confined
Solution
KGS Model
Parameters
Kr = 0.0023
Ss = 3.439E
Kz/Kr = 1.
Displacement (m)
0.2
0.16
0.12
0.08
0.04
0.
1.
10.
100.
1000.
1.0E+4
Time (sec)

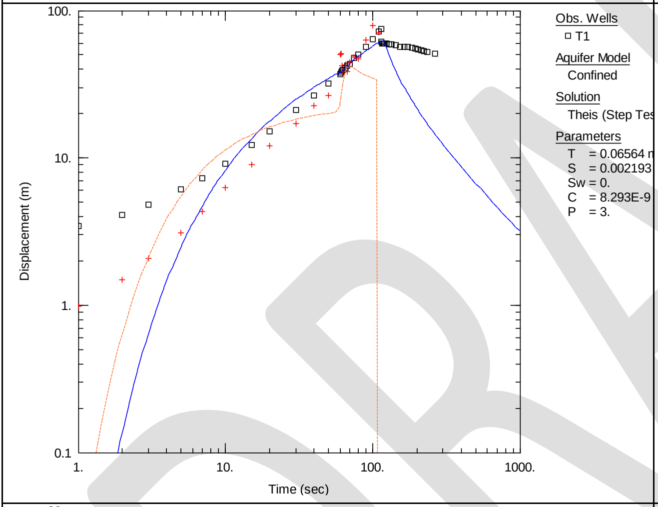
Pump Tests

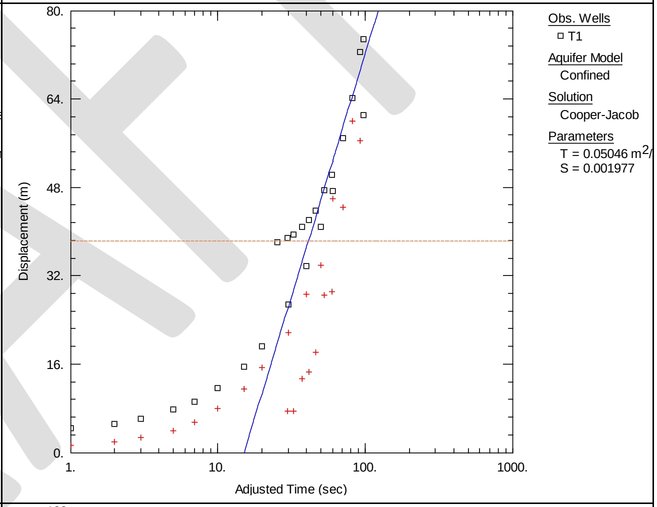

Obs. Wells
HTDW002
Aquifer Model
Confined
Solution
Theis (Step Tes
Parameters
T = 0.6131 m
S = 0.001438
Sw = 0.
C = 1. sec²/m
P = 1.5
Displacement (m)
100.
10.
1.
0.1
0.01
1.
10.
100.
Time (sec)

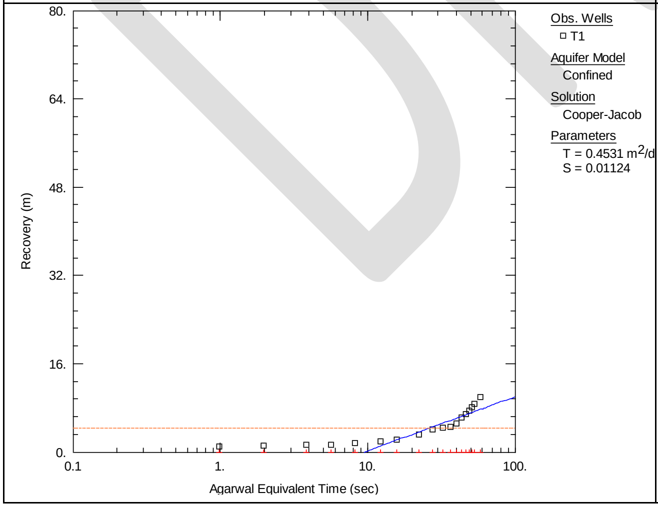

Obs. Wells
HTDW002
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 0.5662 m²/d
S = 0.002004
Displacement (m)
30.
24.
18.
12.
6.
0.
1.
10.
100.
1000.
Adjusted Time (sec)

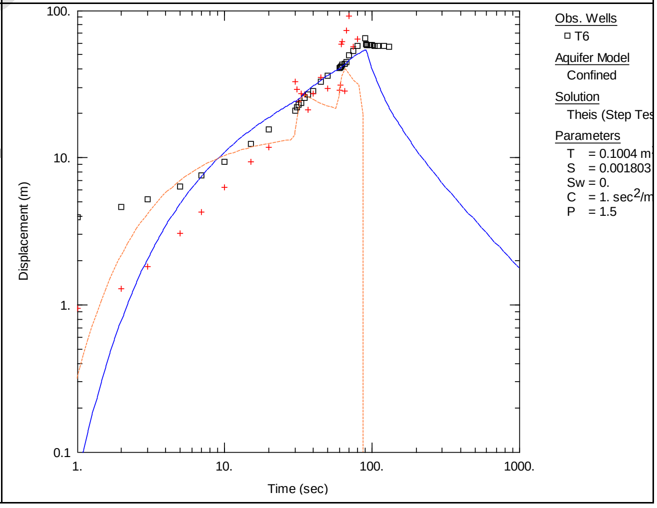

100.
10.
1.
0.1
Displacement (m)
1.
10.
100.
1000.
Time (sec)
Obs. Wells
□ HTDW002
Aquifer Model
Confined
Solution
Papadopulos-C
Parameters
T = 0.2727 m
S = 0.009173
r(w) = 0.1 m
r(c) = 0.0801 m

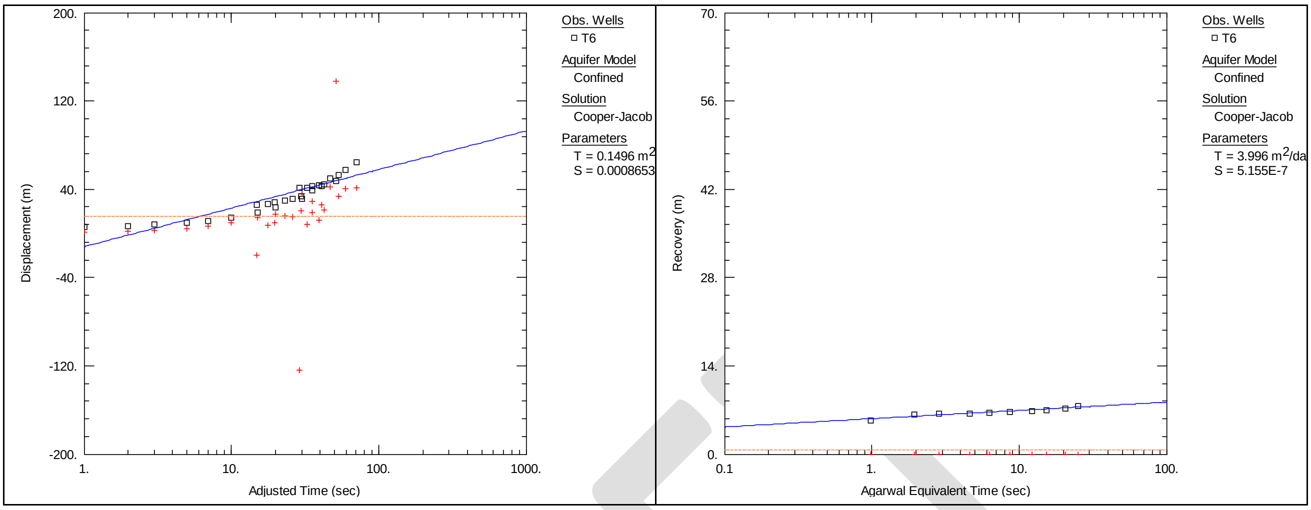

30.
24.
18.
12.
6.
0.
Recovery (m)
0.1
1.
10.
100.
Agarwal Equivalent Time (sec)
Obs. Wells
□ HTDW002
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 0.5016 m2/d
S = 0.004853


100.
10.
1.
0.1
Displacement (m)
1.
10.
100.
1000.
Time (sec)
Obs. Wells
□ T1
Aquifer Model
Confined
Solution
Theis (Step Tes
Parameters
T = 0.06564 r
S = 0.002193
Sw = 0.
C = 8.293E-9
P = 3.


80.
64.
48.
32.
16.
0.
Displacement (m)
1.
10.
100.
1000.
Adjusted Time (sec)
Obs. Wells
□ T1
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 0.05046 m2/
S = 0.001977


80.
64.
48.
32.
16.
0.
Recovery (m)
0.1
1.
10.
100.
Agarwal Equivalent Time (sec)
Obs. Wells
□ T1
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 0.4531 m2/d
S = 0.01124


100.
10.
1.
0.1
Displacement (m)
1.
10.
100.
1000.
Time (sec)
Obs. Wells
□ T6
Aquifer Model
Confined
Solution
Theis (Step Tes
Parameters
T = 0.1004 m
S = 0.001803
Sw = 0.
C = 1. sec2/m
P = 1.5


200.
120.
40.
-40.
-120.
-200.
Displacement (m)
1.
10.
100.
1000.
Adjusted Time (sec)
Obs. Wells
T6
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 0.1496 m2
S = 0.0008653
70.
56.
42.
28.
14.
0.
Recovery (m)
0.1
1.
10.
100.
Agarwal Equivalent Time (sec)
Obs. Wells
T6
Aquifer Model
Confined
Solution
Cooper-Jacob
Parameters
T = 3.996 m2/da
S = 5.155E-7