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Mokala Manganese Project

Groundwater Assessment
In Support of the Environmental Impact Assessment

SLR Project No.: 720.09012.00001

Report No.: 01

October 2015

MOKALA
MANGANESE MINE

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DOCUMENT INFORMATION

Title	Groundwater Assessment
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Client	Mokala Manganese (Pty) Ltd
Date last printed	03/11/2015 11:46:00 AM
Date last saved	03/11/2015 11:46:00 AM
Comments	
Keywords	Groundwater, manganese ore, numerical groundwater model
Project Number	720.09012.00001
Report Number	01
Revision Number	Revision No.: 01
Status	FINAL
Issue Date	October 2015

EXECUTIVE SUMMARY

As part of the EIA of the proposed Mokala Manganese Mine, this report documents the results of the groundwater specialist study and impact assessment.

Mokala Manganese (Pty) Limited ("Mokala" hereafter) is proposing to establish a new opencast manganese mine on the remaining extent of the farm Gloria 266, located 4 km north-west of Hotazel in the Joe Morolong Local Municipality, Northern Cape Province. The project area is located on the south-western outer rim of the Kalahari Manganese Field (KMF). Mokala wish to exploit the manganese from the Hotazel Formation (Transvaal Supergroup). The following stratigraphy (from surface to depth) is present at the proposed project site:

- Cenozoic Kalahari calcrete, clay and windblown sand
- Early Permian Dwyka diamictite (tillite) of the Karoo Supergroup
- The Hotazel Formation
- Hyaloclastic pillow and massive lavas of the Ongeluk Formation (Transvaal Supergroup)

SLR undertook the following field and analysis programme to characterise the local groundwater system:

- Hydrocensus. Fifteen locations were visited on five farms within a 5km radius of the project site. This indicated that groundwater is not used extensively. Three out of 13 boreholes surveyed are used for domestic, stock watering, and game watering. The remainder are monitoring boreholes used by neighbouring mines. Borehole yields are generally less than 0.3L/s.
- Aquifer testing. Eight existing boreholes from the Mokala geological exploration programme were tested using slug tests or pump out-recovery tests. Only borehole GL27 had a yield sufficient to sustain a constant discharge test at a yield of 1L/s. SLR selected test boreholes in which measured groundwater levels were within the Dwyka and Hotazel formations. Observations were made in selected boreholes during testing to assess the impact of pumping on surrounding groundwater levels.
- Laboratory analysis of groundwater samples from hydrocensus and tested boreholes. Results were compared to WHO, SANS, and SAWQG guidelines. One sample (GL27) is not potable due to high chloride and sulphate concentrations. Eight of 13 samples exceeded drinking water guidelines with respect to sodium, chloride and selenium.

Based on the available data and the results of the field and analysis programme, SLR developed a conceptual hydrogeological model. According to this model, groundwater at Mokala is held in two main aquifers, as summarised in the following table.

Aquifer	**Geology**	**Thickness**	**Likely aquifer characteristics**
Shallow aquifer (13-66 m)	Kalahari beds	45 to 135 m	• Water is held in the spaces between soil/sediment particles. • Water may rest on underlying clay-rich, low permeability formations ("perched water"). • Horizontal groundwater flow. • Fractures may allow vertical flow to the deeper aquifer? • Seepage through clay beds to deeper aquifer? • Unconfined (water table at atmospheric pressure) to semi-unconfined. • Low hydraulic conductivity (1 to 10 m/d)
Deep aquifer (>66m)	Dwyka Fm	0 to 103 m	• Low permeability, especially where weathered to clay.
	Mooidraai Fm Hotazel Fm	0 to 160 m	• Groundwater held in fracture systems in fresh bedrock. • Groundwater flow influenced by fracture orientation and size. • Confined (water under pressure). • Low hydraulic conductivity (less than 1 m/d, except along well-developed fracture systems).
	Ongeluk Fm	---	• Relatively impermeable.

Recharge of these aquifers is generally from rainfall at surface. Recharge is estimated as 1% of mean annual rainfall.

Shallow groundwater is expected to be perched on low permeability clay-rich layers in the Kalahari Beds. These groundwater bodies are likely to be irregular in extent and will vary in extent and thickness with rainfall.

Deeper groundwater levels are expected to show a regional flow direction. Site measurements during the hydrocensus indicate groundwater gradient towards the northwest and the Ga-Mogara catchment discharge into the Orange River system.

To assess the potential impact of the proposed Mokala Manganese mine on the local groundwater system, SLR developed a numerical groundwater flow model. The model simulates the groundwater system and its response to stresses, such as the excavation of the opencast pit, and the movement of dissolved contamination in the groundwater.

The model boundary encloses an area of approximately 724 km^2. Due to data limitations a rather large model area was chosen to limit interference of groundwater changes with boundary conditions during predictive simulations.

A finite element mesh was developed based on the conceptual hydrogeological model. Groundwater relevant features of the mine site (such as the mine pit and the proposed overburden stockpile) were incorporated into the numerical model. Four model layers were defined:

- Layer 1 represents the Kalahari Formation with a thickness of 15 m in areas east of the proposed mine.
- Layer 2 corresponds to the Dwyka Formation in the study area. The layer thickness ranges between 300 m at the western and 10 m at the eastern model boundary.
- Layer 3 represents the Hotazel Formation in the study area. The layer thickness increases from 10 m east of the Ga-Mogara River to 200 m at the western model boundary. It is between 10 m and 100 m in the proposed project area.
- Layer 4 corresponds to the Ongeluk Formation, and represents the base of the model. The bottom elevation was set at 400 mamsl.

Data from 48 boreholes were used as targets in the calibration of the steady state numerical groundwater flow model. The boreholes were selected based on a homogeneous distribution across the entire model area with special attention to the proposed project area. A good match was obtained between simulated and observed heads. Therefore, the model is assumed to provide a credible preliminary simulation of the groundwater system within the model domain and hence, the project site.

Predictive simulations were run in the calibrated numerical groundwater model. The simulation results indicate the potential impacts of mine dewatering and steady state conservative contaminant transport scenarios.

- Mine pit dewatering. The Radius of Influence (ROI) has an elliptical shape with an extent of approximately 5 km to the north and south and approximately 1 to 1.5 km towards the east and west. The simulated drawdown below the proposed Overburden Stockpile ranges between approximately 25 m and 35 m and it is likely that the water level will be drawn down below the sediments of the Kalahari Formation. Modelled pit inflow rates range between 217 m^3/d (2.5 L/s) and 438 m^3/d (5.0 L/s). The significance of this impact is rated LOW.
- Groundwater contamination. Approximately 200 m downstream from the overburden stockpile only 10% of the source concentration is observed. Considering the baseline saline and limited potability of local groundwater and the limited extent of the contaminant plume, SLR assesses the impact significance as LOW.
- Post-closure groundwater levels. Recovery of the groundwater level will take more than 100 years. The modelled long-term post-closure groundwater gradient is generally similar to the modelled pre-mining groundwater gradient. The significance of this impact is LOW.
- Post-closure groundwater contamination from pit backfill material. The simulation predicts a decrease of concentrations in the Kalahari Formation to less than 5% within a distance of approximately 320 m from the western edge of the pit. The impact significance is LOW.

Comments from Interested and Affected Parties are addressed in this report, based on the findings of the groundwater study and modelled impact predictions.

Although the significance of the simulated groundwater impacts is LOW, best practice groundwater management should be applied at the proposed project site. SLR recommends the following actions:

- Mokala should implement a groundwater monitoring programme with the features detailed in this report, including:
    - As preliminary guidance, SLR suggests that a network of six to eight boreholes be identified at various distances around the proposed pit. The borehole locations should be decided in consultation with an experienced groundwater professional.
    - Mokala should conduct groundwater quality monitoring using the procedure documented by Weaver et al (2007).
    - Groundwater levels should be measured every three months starting at least one year prior to mining, throughout mine operation, and for at least 10 years after closure.
    - Groundwater quality should be measured every six months starting at least one year prior to mining, throughout mine operation, and for at least 10 years after closure.
    - Mokala should appoint an experienced groundwater professional, registered with the SACNASP, to review the groundwater quality and level data every year. The professional should provide Mokala with a technical report evaluating the groundwater level trends and making recommendations as required to maintain/extend the monitoring network and record data.
- Prevent spills or accidental releases of contaminants (such as oils, fuels, explosives, etc.) in all areas of the site
- Maintain and inspect vehicles to reduce the occurrence of contaminant leaks.
- If there is a reduction in quality or quantity of water in 3rd party boreholes then Mokala should provide an alternative water supply of equal or better quality and quantity.
- Records should be kept of actual groundwater volumes abstracted and on-site daily rainfall data throughout the life of mine.
- Updates of the groundwater model (transform from steady state into transient) as groundwater level and quality data become available. This will increase the confidence in simulated recharge rates but also in results of predictive simulations.

Based on the evaluation of available data and model simulations the groundwater impacts of the proposed project are assessed to be LOW. Provided Mokala implements the project as considered in this report, and fully applies the groundwater impact mitigation measures recommended in this report, the anticipated project impacts on the physical and chemical groundwater system are likely to be limited.

GROUNDWATER ASSESSMENT

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LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	**Definition**
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
mamsl	Meters above mean sea level
MAP	Mean annual Precipitation
W	Winton
KMF	Kalahari Manganese Field
BIF	Banded Iron Formation
UMO	Upper Manganese Ore
MMO	Middle Manganese Ore
LMO	Lower Manganese Ore
mbgl	Meters below ground level
SDT	Step-discharge test
CDT	Constant discharge test
T	Transmissivity
SANAS	South African National Accreditation System
WHO	World Health Organisation
SANS	South African National Standards
DWAF	Department of Water Affairs
NGDB	National Groundwater Database
k	Hydraulic conductivity
BC	Baseline Conductivity
SRMS	Scaled Root Mean Squared
RMS	Root Mean Squared
ROI	Radius of Influence
REV	Representative Elementary Volume
IAP	Interested and Affected Parties

NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA) REGULATIONS (2014) APPENDIX 6: SPECIALIST REPORTING REQUIREMENTS CHECKLIST

Below is a checklist showing information required by specialists in terms of Appendix 6 of NEMA

Item	NEMA Regulations (2014): Appendix 6	Relevant Section in Report
1(a)(i)	Details of the specialist who prepared the report	Section 10
1(a)(ii)	The expertise of that person to compile a specialist report including a curriculum vitae	Appendix F
1(b	A declaration that the person is independent in a form as may be specified by the competent authority	Section 1.5
1(c)	An indication of the scope of, and the purpose for which, the report was prepared	Section 1.2
1(d)	The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 3
1(e)	A description of the methodology adopted in preparing the report or carrying out the specialised process	Section 1.2
1(f)	The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	No specific sensitive areas identified
1(g)	An identification of any areas to be avoided, including buffers	None identified
1(h)	A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Section 6
1(i)	A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 6
1(j)	A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Section 6
1(k)	Any mitigation measures for inclusion in the EMPr	Section 9
1(l)	Any conditions for inclusion in the environmental authorisation	None
1(m)	Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 9
1(n)(i)	A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 9
1(n)(ii)	If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	None
1(o)	A description of any consultation process that was undertaken during the course of carrying out the study	Section 7
1(p)	A summary and copies if any comments that were received during any consultation process	Section 7
1(q)	Any other information requested by the competent authority.	No other information

GROUNDWATER ASSESSMENT

1 INTRODUCTION

SLR Consulting (Pty) Ltd ("SLR" hereafter) is conducting an Environmental Impact Assessment (EIA) of the proposed Mokala Manganese Mine. The EIA is being conducted for Mokala Manganese (Pty) Limited ("Mokala" hereafter). The impact of the proposed mine on groundwater resources has been assessed by SLR. This report documents the results of the groundwater specialist study and impact assessment.

1.1 BACKGROUND

Mokala is proposing to establish a new opencast manganese mine on the remaining extent of the farm Gloria 266, located 4 km north-west of Hotazel in the Joe Morolong Local Municipality, Northern Cape Province (see Figure 1).

Since the proposed project has the potential to contaminate groundwater resources and to lower groundwater levels through abstraction which could impact the water availability to surrounding groundwater users, a 3-dimensional numerical groundwater flow model and solute transport model was developed as part of the groundwater specialist input to the EIA and Environmental Management Programme (EMPr). This model is used to investigate potential impacts on the groundwater environment due to the dewatering of the proposed open pit excavation and the spreading of potential plumes emanating from potential pollution sources.

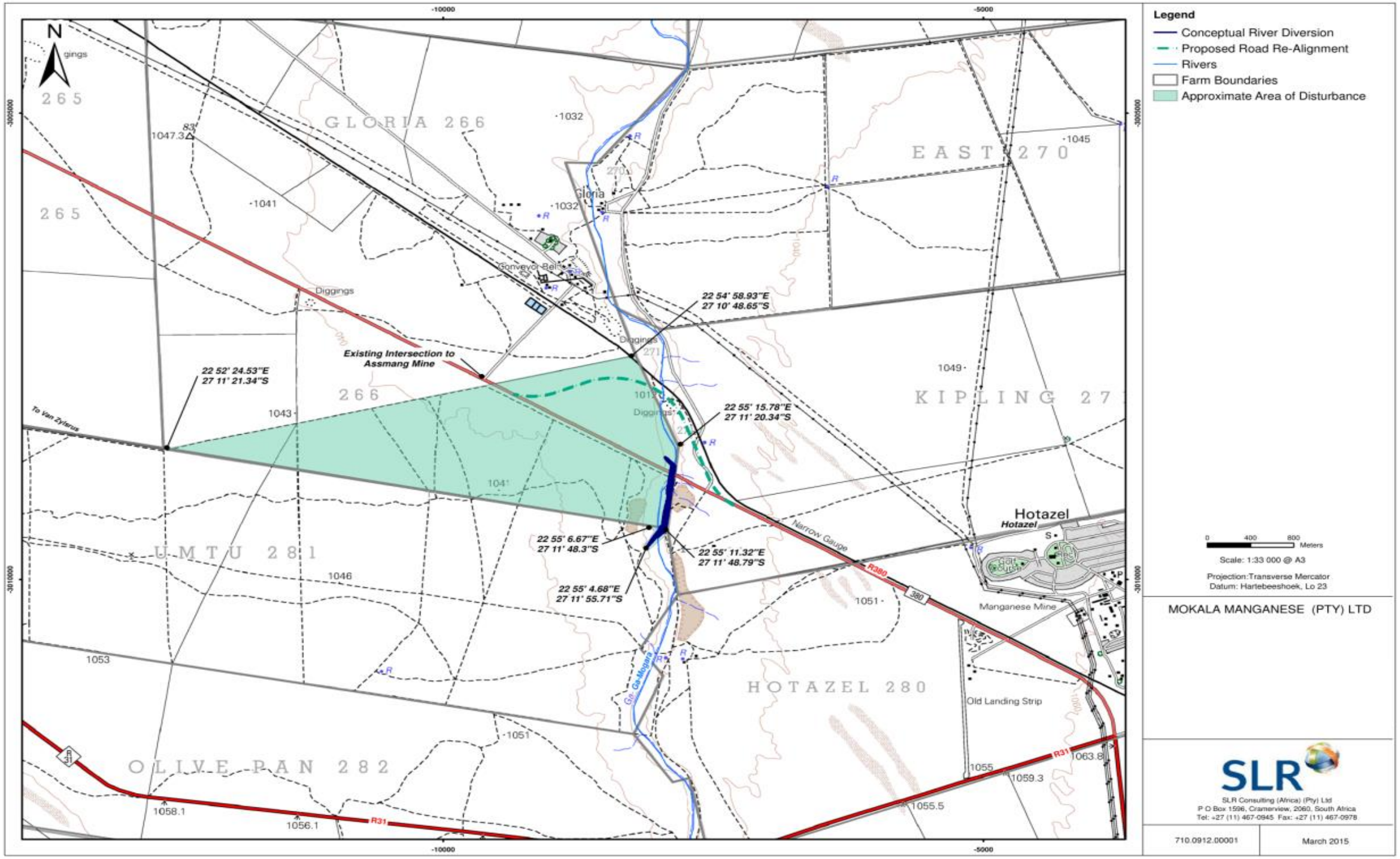

FIGURE 1: LOCATION OF MOKALA MANGANESE PROJECT AREA

1.2 SCOPE OF WORKS AND OBJECTIVES

The scope of this groundwater specialist study included:

- Reconnaissance site visit.
- Carry out six pumping tests (four on the drilled boreholes, two on selected exploration boreholes).
- Comment on groundwater supply potential.
- Conduct a hydrocensus.
- Develop a conceptual groundwater model.
- Develop a numerical groundwater model.
- Compile a groundwater assessment report.

The objectives of this groundwater specialist study are to:

- Characterise the groundwater system at the proposed project area.
- Estimate the magnitude, duration and severity of groundwater impacts from the proposed project.
- Identify mitigations to reduce impact magnitude, duration and severity.

1.3 LOCATION AND SITE LAYOUT

The Mokala proposed project area consists of the remaining extent of farm Gloria 266 (Gloria), the farm Kipling 271 and the farm Umtu 281 located approximately 4 km north-west of the town of Hotazel in the Northern Cape The proposed mine layout is presented in Figure 2.

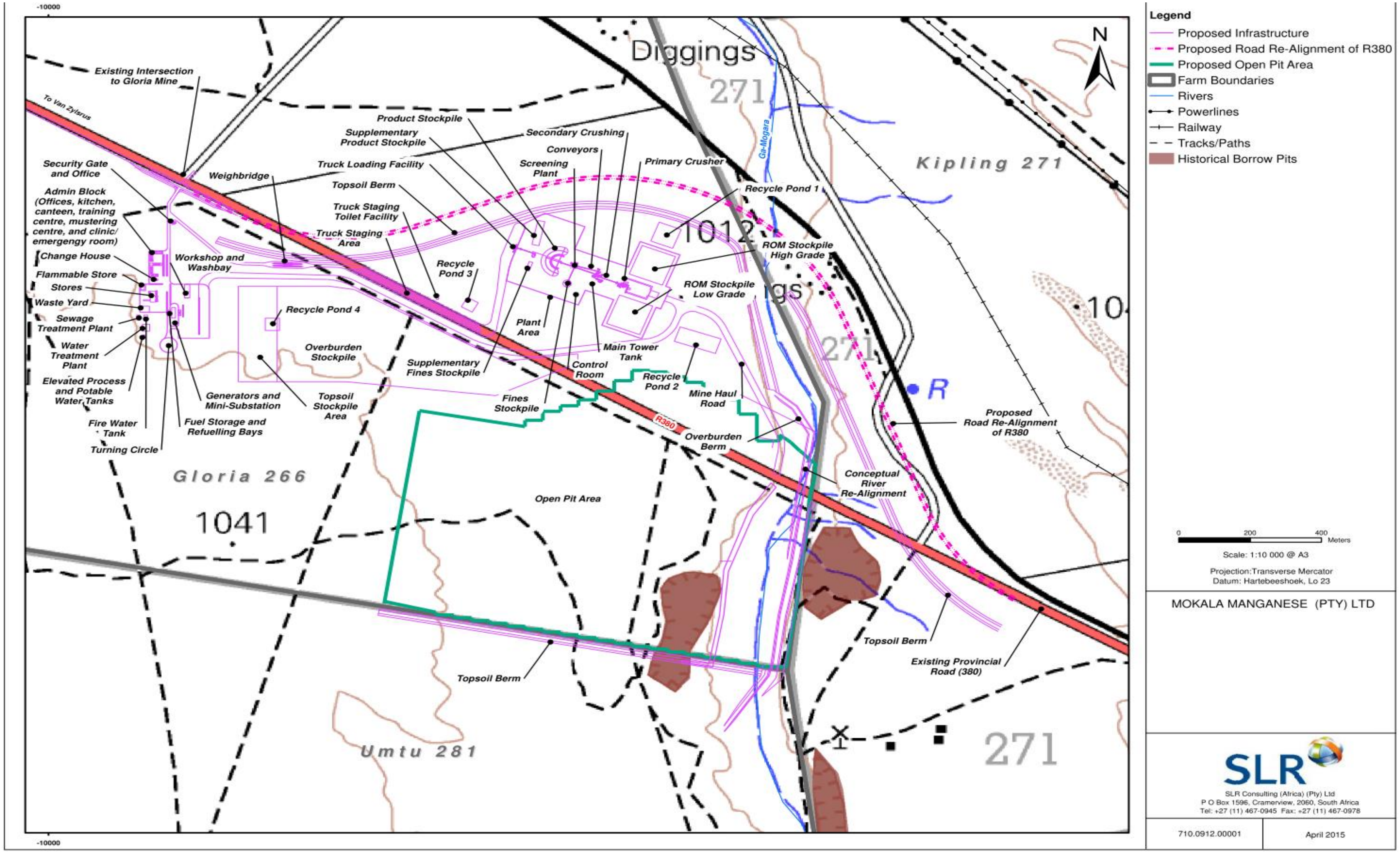

FIGURE 2: MINE LAYOUT

1.4 STRUCTURE OF THIS REPORT

This report systematically presents the work conducted and results obtained.

- Section 2 presents the results, as a summary of the topography, climate and geology of the proposed mine site and region.
- SLR conducted a fieldwork programme to establish the baseline groundwater conditions of the site. Section 3 outlines the fieldwork and results.
- Based on the desk study and fieldwork, SLR developed a conceptual hydrogeological model. Section 4 presents the conceptual model. This was used to guide the development of a numerical model.
- Section 5 summarises the process of numerical model development and calibration. Model simulations of the proposed mining activities, including the pit excavation and overburden stockpiling, indicated the impact on the local groundwater system.
- Section 6 presents details concerning the water supply from boreholes.
- Section 7 presents the results of the assessment of groundwater system impacts.
- Section 8 presents the comments made by the interested and affected parties (IAPs).
- Section 9 summarises the key conclusions of the groundwater study.
- Section 10 documents SLRs recommendations to manage groundwater impacts from the proposed mine.

1.5 DECLARATION

I, Terry Harck 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 hydrogeochemist with 24 years' experience conducting hydrogeological and geochemical assessments for the mining industry.

I am an Earth Science professional registered with the South African Council for Natural Scientific Professions. My registration number is 400088/95.

Curriculum Vitae of the report author Appendix F.

2 GENERAL DESCRIPTION OF SITE

Topography, climate and geology influence the occurrence of groundwater at the proposed project site. This section provides a brief description of these factors.

2.1 GEOMORPHOLOGY

The topography of the proposed project area is relatively flat with a gentle slope towards the east. The eastern section of the proposed project area falls relatively steeply towards the Ga-Mogara River, a non-perennial river that forms the eastern boundary of the proposed project area.

The elevation of the proposed project area ranges from approximately 1018 metres above mean sea level (mamsl) in the riverbed to 1040 mamsl towards the western end of the site. The pre-mining land use is a mixture of natural bushveld and farming activities such as livestock grazing and game farming.

2.2 HYDROLOGY

The Vlermuisleegte and Witleegte are tributaries of the Ga-Mogara River that is a tributary of the Kuruman River, located approximately 20 km north from the site. A large catchment of approximately 13 780 km^2 feeds the Kuruman River, and when the river is in flood, flows can become considerable. However, the Kuruman River is considered ephemeral as the river only produces surface flows during periods of heavy precipitation.

The Ga-Mogara River located just east of the proposed project site does not flow regularly and anecdotal evidence suggests that flow events are limited to a few exceptional occasions since the 1970s. The local farmers indicate that significant flows occurred in 1974, 1976 and 1988.

2.3 CLIMATE

The proposed project area is located in a semi-arid climatic region of South Africa characterised by seasonal rainfall, hot temperatures in summer, and colder temperatures in winter. The average annual precipitation, based on the mean annual precipitation (MAP) for Winton (0392148 W) weather station (approximately 40 km to the south-west of the sites) is 335 mm (SLR, 2015). Rainfall is usually intense, in the form of thunderstorms, and predominantly occurs during the summer months of October to April. Due to the semi-arid nature of the region, evaporation rates are high.

2.4 GEOLOGY

The Mokala proposed project area is located on the south-western outer rim of the Kalahari Manganese Field (KMF). Mokala wish to exploit the manganese from the Hotazel Formation (Transvaal Supergroup). The manganese deposits of the Kalahari Manganese Field (KMF) represent structurally preserved erosional relics of the Paleoproterozoic Hotazel Formation of the Voelwater Subgroup (Transvaal Supergroup) along the axis of the Dimoten Syncline. The Formation consists of Superior type iron-formation interbedded with manganese ore in three sedimentary cycles of which the lowermost unit is the most economically viable. The regional stratigraphic succession is presented in Figure 3.

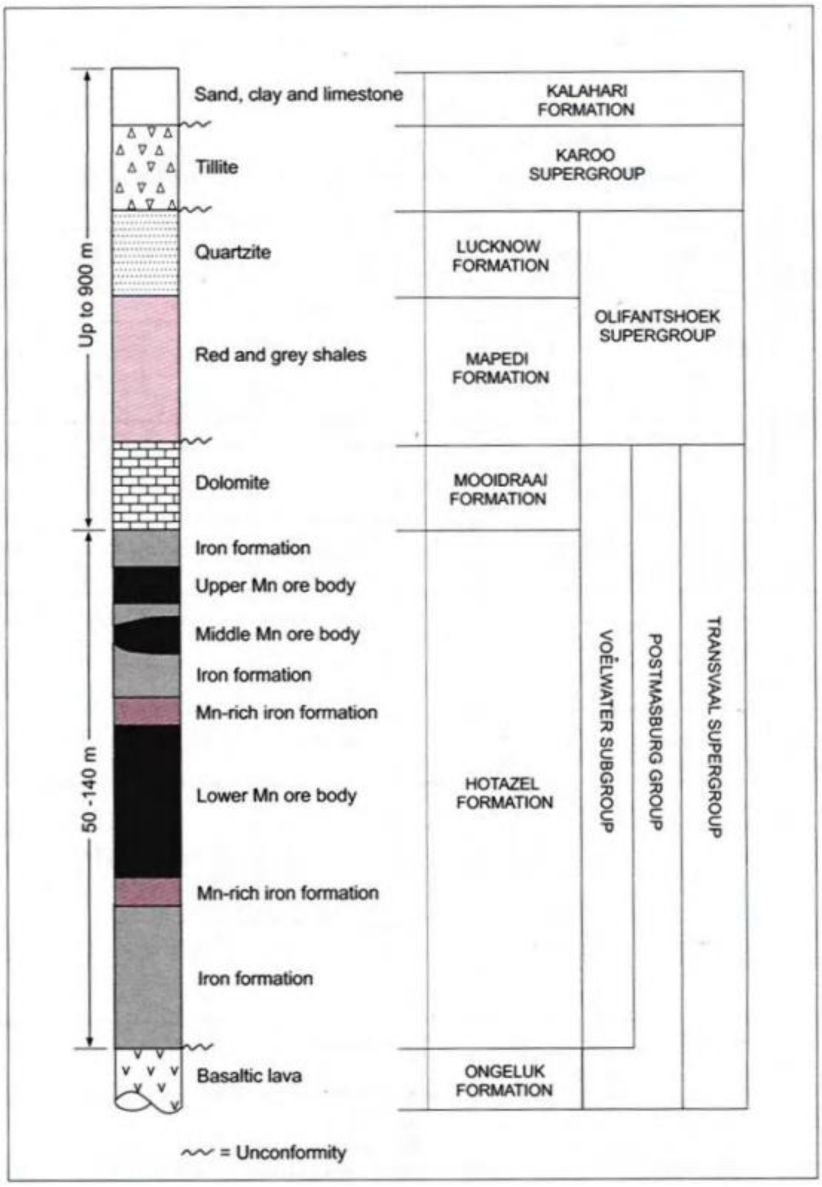

FIGURE 3: GENERALISED STRATIGRAPHIC COLUMN FOR THE KMF (CORNELL ET AL., 1995)

At the proposed project site, the Hotazel Formation is unconformably overlain by Early Permian Dwyka diamictite (tillite) of the Karoo Supergroup or Cenozoic Kalahari calcrete, clay and windblown sand. The Hotazel Formation is underlain by hyaloclastic pillow and massive lavas of the Ongeluk Formation (Transvaal Supergroup). The Dwyka glaciation of the Karoo Supergroup carved a deep SE-NW striking valley into the Proterozoic basement, which are now filled with thick beds of tillite (diamictite). The general stratigraphic column for the proposed project site is presented in Table 1.

TABLE 1: GENERAL STRATIGRAPHIC PROFILE FOR THE KALAHARI MANGANESE FIELD

Supergroup / Group / Subgroup / Formation				**Geological Description**	**Approximate Thickness (m)**
Kalahari Group				Sand, clay, gravels and calcrete	70
Kalahari Unconformity					
Karoo Supergroup				Dwyka Tillite	30
Dwyka Unconformity					
Olifantshoek Supergroup			*Lucknow Formation*	Quartzite	Not present
			Mapedi Formation	Red and Grey Shales and quartzites	Not present
Olifantshoek Unconformity					
Transvaal Supergroup	Postmansburg Group	Voelwater Subgroup	Mooidraai Formation	Dolomite	30
			Hotazel Formation	Upper Banded Iron Formation	20
				Upper Mn Ore Body (UMO)	10
				Middle Banded Iron Formation	10
				Middle Mn Ore Body (MMO)	-
				Middle Banded Iron Formation	15
				Lower Mn Ore Body (LMO)	20
				Lower Banded Iron Formation	5
		Ongeluk Formation		Basaltic Lava	-

Note: Thickness is based on average thickness from borehole logs

The Lucknow Formation and Mapedi Formation of the Olifantshoek Supergroup are not present beneath the proposed Project Area. It is understood that they have been entirely eroded away. Therefore, the site stratigraphy consists of:

- Kalahari Formation (or "beds"), consisting of sand, clay and limestone;
- Dwyka Formation, consisting of tillite (a sedimentary rock derived from glacial deposits and consisting of rock fragments in a clay-rich matrix);
- Mooidraai Formation, consisting of dolomite;
- Hotazel Formation which consists of Banded Iron Formation (BIF). The ore is contained within a mineralised zone which is made up of three manganese rich zones; the Upper Manganese Ore Body (UMO), the Middle Manganese Ore Body (MMO) and the Lower Manganese Ore Body (LMO).
- Ongeluk Formation, consisting of basaltic lava.

The strata of the Hotazel Formation dip gently towards the west at about 5° to 8°. The N-S to NNE-SSW trending faults may be of the order of a few tens of metres wide and more than a kilometre long. A second less well-pronounced system of E-W trending minor faults and veins is also present (Gutzmer and Beukes, 1995).

On a regional basis, the sedimentary rocks of the Transvaal Supergroup in the Northern Cape region are gently folded into a series of wide open synclinal (saucer-shaped) and anticlinal (dome-shaped) structures. The sequence generally dips at shallow angles, about 8° to the west (Evans et al, 2001 as cited in Saad, 2010) and has also been deformed by a series of north to south and to north-northeast to south-southwest trending normal faults.

In Figure 4 a simplified geological map of the main Kalahari manganese deposit is shown with the younger overlying cover removed. The entire deposit forms a saucer-shaped syncline where beds re duplicated by the Black Ridge thrust fault. Sections lines indicated in Figure 4 are presented in Figure 5 and Figure 6. 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.

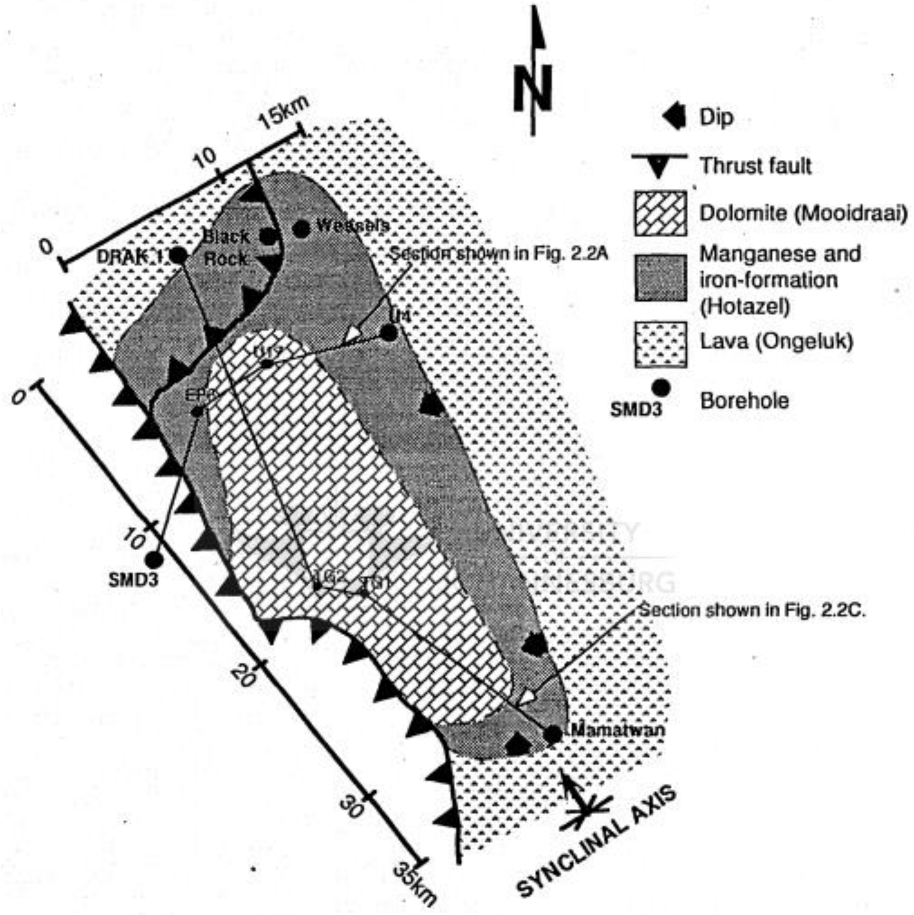

FIGURE 4: SIMPLIFIED GEOLOGICAL MAP OF THE MAIN KALAHARI ORE DEPOSIT (BEUKES, 1985 IN BURGER, 1994)

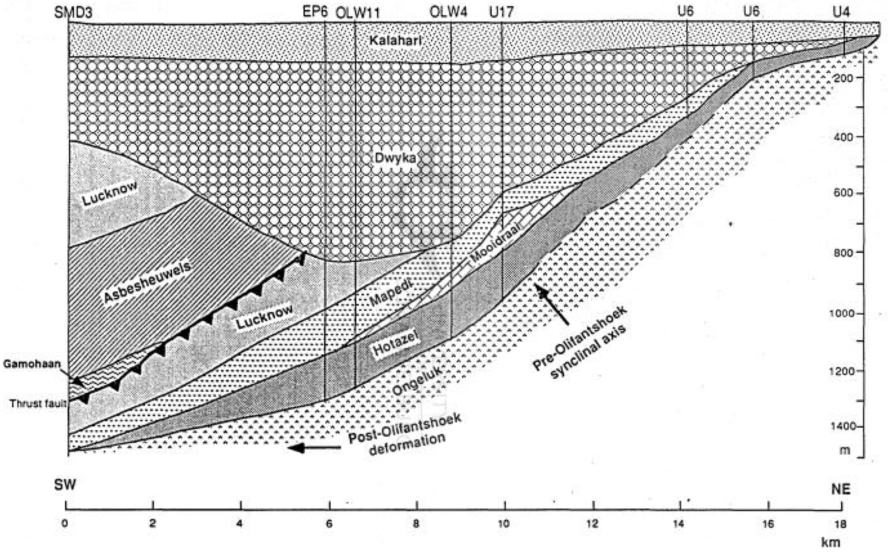

FIGURE 5: NE-SW STRATIGRAPHIC SECTION THROUGH THE KMF (BEUKES, 1985 IN BURGER, 1994)

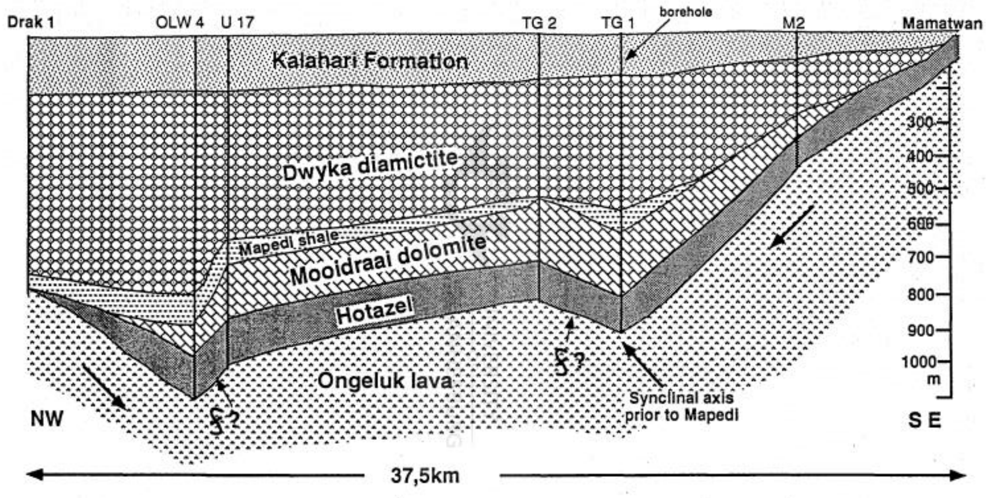

FIGURE 6: NW-SE STRATIGRAPHIC SECTION THROUGH THE KMF (BEUKES, 1985 IN BURGER, 1994)

The geological settings prevailing at the proposed project site are shown in Figure 7 (note, younger Kalahari and Karoo strata removed). The geological succession cut out by erosion is visible with lava of the Ongeluk Formation in the east and subsequent younger Formations towards the west. North and south of the focus area northeast south west trending dykes are mapped and a strike slip north of the dyke is visible.

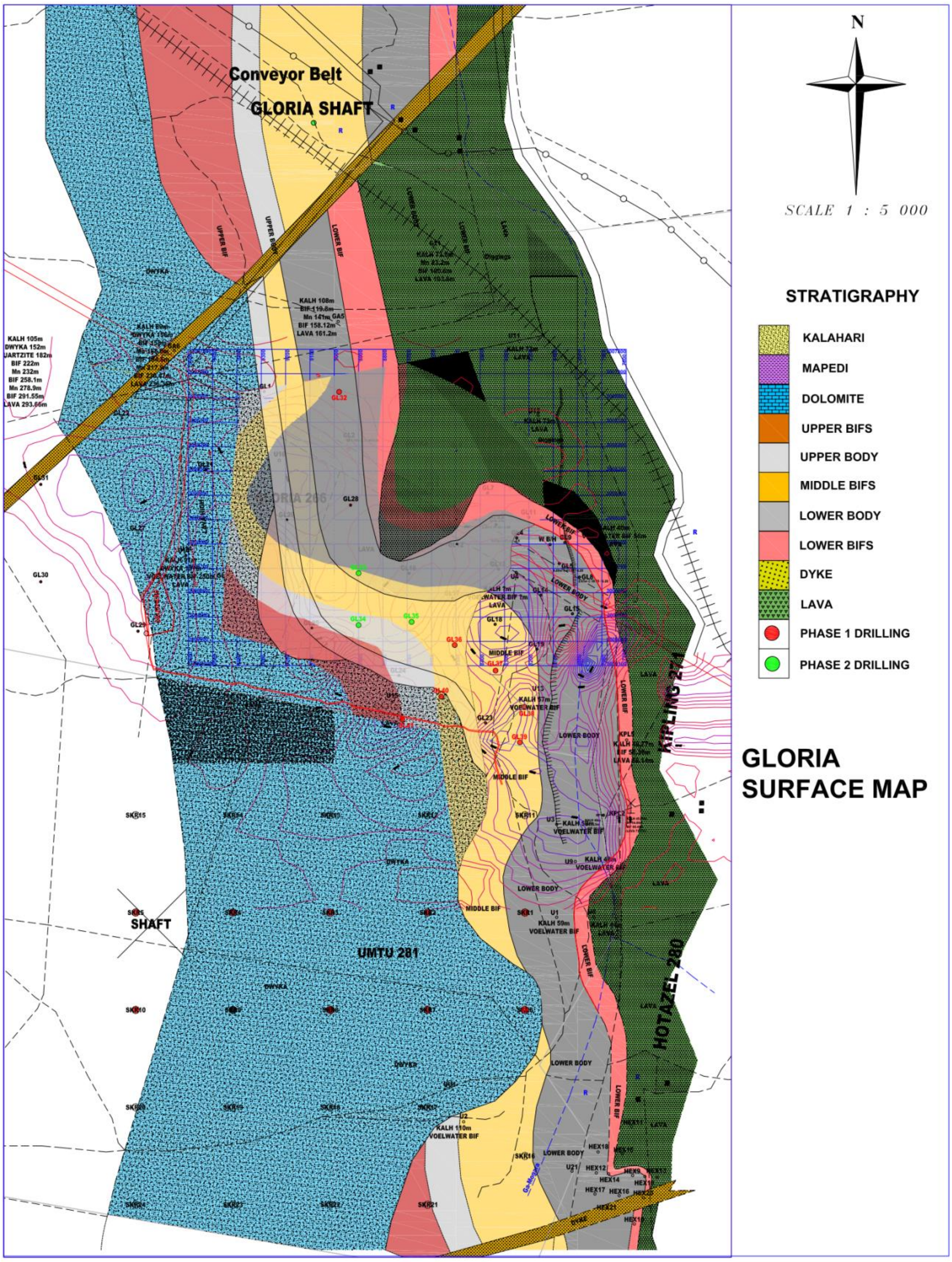

FIGURE 7: LOCAL GEOLOGICAL SETTINGS AT THE PROPOSED PROJECT AREA

3 FIELDWORK PROGRAMME

This section describes the site visit, hydrocensus and aquifer testing work conducted for the study. The dates and season in which the fieldwork was undertaken, as described below has no relevance to the outcome of this assessment.

3.1 SITE VISIT

A site visit was conducted on the 20th August 2014. The geological exploration drilling programme was underway. The exploration boreholes were drilled using air percussion through the Kalahari Beds, then cased with plain steel casing. The formations beneath the Kalahari Beds were then diamond drilled to obtain core for geological logging.

It was agreed that SLR would select geological exploration boreholes for testing, based on available geological and groundwater level data.

3.2 HYDROCENSUS

SLR conducted a hydrocensus during March 2015. The hydrocensus sought to identify groundwater users within a 5 km radius of the proposed project Area (Figure 8). Details such as depth of boreholes, water use and owners were recorded. Groundwater levels were measured and groundwater samples collected for analysis from selected locations. Groundwater level and quality data of hydrocensus boreholes is included in Section 3.4.

Fifteen locations were visited on five farms northeast, southeast, south and southwest of the site. The farms belonging to Assmang (Pty) Ltd (Assmang) adjacent to the Mokala proposed project area were not visited. These farms are Mukulu 264 and portion 1 of the farm Gloria 266 (northwest and north respectively) and Kipling (to the east). Mokala management were in the process of negotiating with Assmang regarding access to the farms Mukulu 264, Gloria 266 and Kipling 271 and the supply of groundwater monitoring data for these farms.

The farms Olive Pan 282 and Gama 284 belonging to Kalagadi Manganese (Pty) Ltd were also not visited as the Kalagadi personnel assisting with the hydrocensus did not have access to those farms. Appendix A includes tabulated hydrocensus data, including borehole uses. These indicate that groundwater is not used extensively in the vicinity of Mokala. Three out of 13 boreholes surveyed are used for domestic, stock watering, and game watering. Borehole yields are generally less than 0.3 L/s.

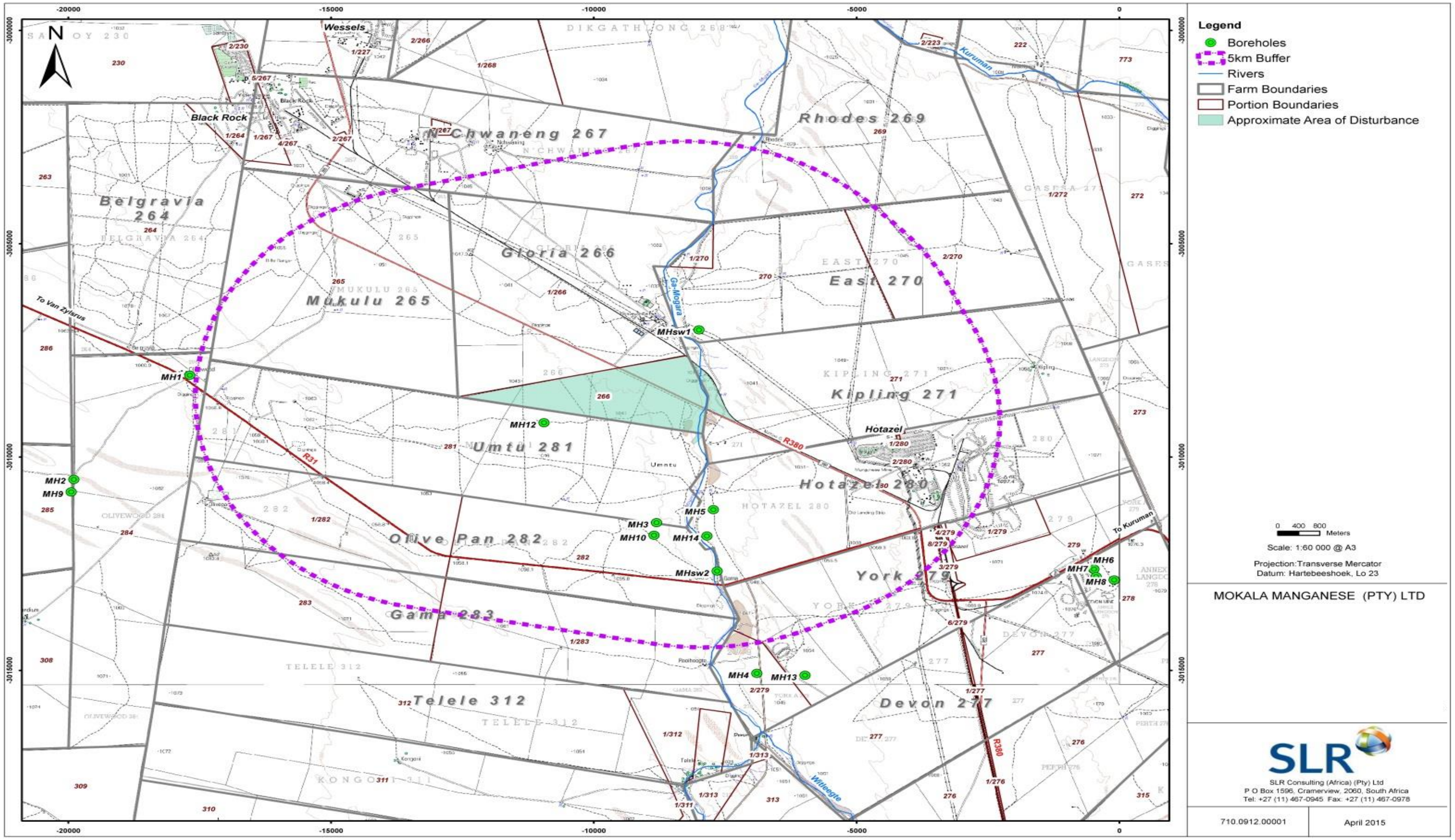

FIGURE 8: HYDROCENSUS BOREHOLES IDENTIFIED NEAR THE MOKALA PROJECT AREA

3.3 AQUIFER TESTING

Eight boreholes were tested and a further four boreholes were used for observation purposes. Further detail is provided below.

3.3.1 TEST BOREHOLE SELECTION

Mokala's drilling contractor indicated to SLR that the exploration drilling programme did not intersect significant groundwater. Therefore, SLR selected test boreholes in which measured groundwater levels were within the Dwyka and Hotazel Formations. These results would indicate the groundwater flow characteristics of the "hard rock" formations underlying the Kalahari Beds. During testing SLR made observations in selected boreholes to assess the impact of sustained pumping on surrounding groundwater levels. Table 2 shows a summary of the test programme.

TABLE 2: SUMMARY OF TEST PROGRAMME

Bore	Coordinates (WGS84)		Testing Date	Drilled Depth (m)	Observation Boreholes	Reason for testing
	Latitude	Longitude				
Pumped Boreholes						
WH1	-27.185525	22.919467	22/03/2015	30	N*	River bed hydrogeology
WH2	-27.196362	22.919031	17/03/2015	30	N*	River bed hydrogeology
GL15	-27.19188	22.918981	18/03/2015	63	N*	Hotazel Fm
GL27	-27.188818	22.901075	21/03/2015	255	Y	Hotazel Fm reported high yield during drilling
GL31	-27.186998	22.897018	24/03/2015	299	N*	Dwyka/Hotazel Fms
GL35	-27.192109	22.912379	17/03/2015	145	N*	Dwyka/Hotazel Fms
GL37	-27.193894	22.91588	21/03/2015	118	N*	Hotazel Fm
GL56	-27.192172	22.916845	19/03/2015	100	N*	Kalahari/Hotazel Fms
Observation Boreholes						
GL26	-27.190464	22.904637	-	-	-	-
GL29	-27.19244	22.901048	-	-	-	-
GL30	-27.19062	22.897028	-	-	-	-
GL31	-27.186998	22.897018	-	299	-	-

Note: * indicates borehole yield too low or unsustainable for observation boreholes during testing

3.3.2 TEST METHODS

Testing determines aquifer characteristics based on the groundwater level response to sustained pumping. However, preliminary testing demonstrated low recharge rates in six of the eight boreholes selected. Therefore, the boreholes were tested using methods selected on an individual basis, including a combination of slug tests, rising head tests, and constant discharge pumping tests. Table 3 summarises the testing carried out at each borehole.

TABLE 3: RESULTS OF THE PUMPING TESTS

Bore	Testing Date	Aquifer Testing Method	Drilled Depth (m)	Observation Boreholes Utilised
WH1	22/03/2015	Recovery	30	N
WH2	17/03/2015	Recovery	30	N
GL15	18/03/2015	Recovery	63	N
GL27	21/03/2015	Slug & Constant Discharge	255	Y (4)
GL31	24/03/2015	Slug	299	N
GL35	17/03/2015	Slug & Rising Head	145	N
GL37	21/03/2015	Recovery	118	N
GL56	19/03/2015	Recovery	100	N

3.3.3 TEST RESULTS

Test pumping had limited success. Of eight boreholes tested, transmissivities were obtained in five. Except for borehole GL27, the test yields were low. This suggests that the groundwater yield potential of the aquifers at Mokala is generally low.

3.3.3.1 WH1

Borehole WH1 was tested on 22 March 2015. Water level and total depth were measured with a graduated tape. Casing depth was measured with an electromagnet-equipped downhole probe provided a signal at surface as to the extent of the steel casing. Following measurements of current borehole construction, a down-hole pump was installed and pumping commenced at a rate of 0.008 L/s. The water level was drawn down from 15.50 to 17.04 metres below ground level (mbgl), 0.5 m above the pump inlet, after 15 min. Pumping was stopped and the recovering water level was measured for a period of 1 hour, after which the pump was removed from the borehole. Further measurement of recovering water levels was achieved via manual measurements. The final water level measured was 16.33 mbgl, 48 hrs after cessation of pumping; 58% recovery of initial drawdown.

3.3.3.2 WH2

Borehole WH2 was tested on 18 March 2015. After measurement of water level, casing and total depth, a down-hole pump was installed and pumping commenced. The water level was drawn down from 24.45 to 26.26mBGL, 1.2m above the pump inlet, after only 2 min, and before a flow rate could be determined. Pumping was stopped and the recovering water level was measured for a period of 18 hours, at which time the water level recovered to 24.64 mbgl demonstrating 90% recovery and indicating some dewatering of the aquifer.

3.3.3.3 GL15

Borehole GL15 was tested on 18 March 2015. After measurement of water level, casing and total depth, a down-hole pump was installed and pumping commenced at a rate of 0.07 L/s. The water level was drawn down from 44.65 to 54.47 mbgl, after 30 min. Pumping was stopped and the recovering water level was measured for a period of 24 hours, after which the pump was removed from the borehole. Further measurement of recovering water levels was achieved via the installation of a down-hole data logger. The final water level measured was 48.78 mbgl, 96 hrs after cessation of pumping, demonstrating a recovery of 58% and indicating significant dewatering of the aquifer.

3.3.3.4 GL27

Initial testing of GL27, by slug test method, indicated sufficient recharge volumes to perform a constant discharge test. The test comprised two phases, the first of which, a step-discharge test (SDT), conducted with increasing abstraction rates over three one-hour periods (steps), was conducted to stress the borehole and determine an appropriate abstraction rate for a subsequent, and longer, constant-discharge test (CDT) lasting 24 hours at a yield of 1 L/s.

Water level measurements in GL 27 were manually recorded at predetermined intervals during pumping and recovery phases.

Recovery was measured for 24 hours following cessation of pumping demonstrating 93% recovery of initial drawdown, indicating that the aquifer was likely dewatered.

Down-hole pressure transducing data loggers were installed in several nearby observation boreholes to determine the influence of pumping in each of these holes. The location of these boreholes and the initial water levels observed prior to commencement pumping in GL27, are listed in Table 4.

It is likely that GL27 intersects a fracture system in the ore body rocks. This provides an initial high yield, which is not sustained during pumping at the tested yield.

3.3.3.5 GL31

Testing of bore hole GL31 was attempted on 23 March 2014. Water level, hole depth and casing length were all able to be measured, however subsequent insertion of the pump was prevented by an apparent obstruction at around 60 mbgl. In lieu of test pumping a slug test was performed, with the slug, of more robust construction than the pumping equipment, able to pass the obstruction. Water level data from the slug test was recorded using a down-hole pressure transducer.

The slug became jammed on the same obstruction during retrieval necessitating several hours of work to successfully remove from the hole. Movement of the pressure transducer during this process resulted in the rising head data becoming unreliable and only the falling head test was used for analysis.

3.3.3.6 GL35

Testing of bore hole GL35 was attempted on 17 March 2015. The initial standing water level was measured as 80 mbgl. Total depth of hole and casing length were also measured, however, when pumping was initiated, a high quantity of fines in the water prevented the proper operation of the down-hole pump and testing was aborted after only 7 minutes. A second pump, capable of pumping water with higher concentrations of fine particles was installed however it was also unable to function properly with pumping ceasing after 22.99 m of drawdown.

Upon retrieval from the hole, the down-hole equipment, including the pipe and pump housing, was caked with thick purple sludge along the entire submerged length.

Due to the high concentration of fines, a slug test was attempted in borehole GL35, consisting of a falling head followed by a rising head test. Water level changes were recorded using a down-hole pressure transducer installed below the depth of the slug (Figure 9).

However, the data collected during slug testing demonstrated rising water levels independent of the placement of the slug; an indication that water levels in the bore were in a state of recharge or recovery at the time of the testing. The final water level measurement of 75.53 mbgl was 4.47 m above the initial static water level measured at the commencement of the pump testing programme.

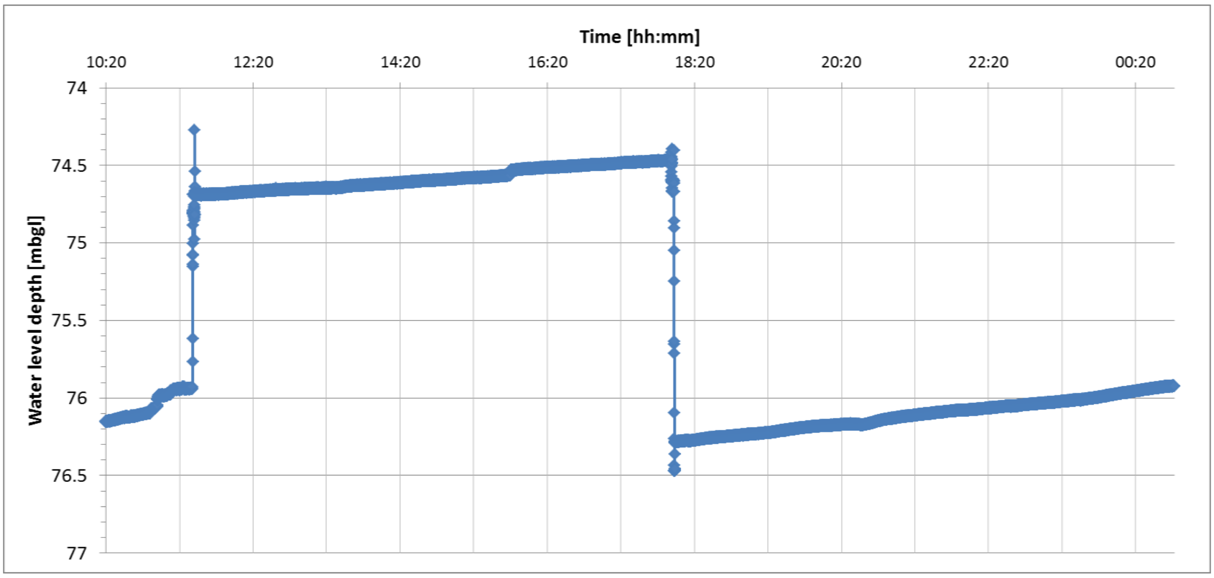

FIGURE 9: WATER LEVEL IN GL35 ON INTRODUCTION (11:31) AND REMOVAL (18:00) OF A SLUG

3.3.3.7 GL37

Borehole GL37 was tested on 21 March 2015. Following measurement of water level, casing length and total depth, a down-hole pump was installed and pumping commenced at a rate of 0.06 L/s. The water level was drawn down from 74.80 to 100.04 mbgl, 6m above the pump inlet, over a period of 200 min. Pumping was stopped and the recovering water level was measured for a period of 20 hours, after which the pump was removed from the borehole. Further measurement of recovering water levels was achieved via the installation of a down-hole data logger. After a total of 40 hours of recovery measurement, the borehole demonstrated 86% recovery.

3.3.3.8 GL56

GL56 was tested on 19 March 2015. A downhole pump was installed and, due to low-recharge, was used to lower the water level in the bore for rising head analysis. A pumping rate of 0.03 L/s resulted in a lowering of the water level to 76.57 mbgl after 220 min. Recovery was measured manually for a further 33 hours at which time the water level had recovered to 91% of initial drawdown. The pump was then removed and manual water levels were recorded for the following four days demonstrating a total of 96% recovery.

3.3.4 TEST ANALYSIS

The groundwater level data obtained from the aquifer testing of eight boreholes was analysed and interpreted to assist in determining the aquifer characteristics intersected by each borehole, using industry standard methods for rising head, slug and constant discharge tests.

Constant discharge analysis was performed, on data obtained from GL27, using AQTESOLV aquifer analysis software (HydroSOLVE, 2007). The Theis method for pumping analysis was applied to the drawdown data to determine transmissivity values for the intersected aquifer.

Analysis of slug test data, obtained from GL31, was performed using aquifer analysis software AQTESOLV (HydroSOLVE, 2007) and utilising the Bouwer-Rice method for slug test analysis in unconfined aquifers.

Rising head analysis was conducted on boreholes with very low recharge rates, including WH1, WH2, GL15, GL37 and GL56, using the observed residual drawdown data following the cessation of pumping. The data was analysed using the Theis recovery method - valid for confined aquifers, and un-confined aquifers for late time data - to determine transmissivity (T) in m^2/day.

Residual drawdown – time plots are presented in Appendix B.

3.3.5 OBSERVATION BOREHOLE DATA

Changes in water levels, measured in pumped and observation boreholes (GL27 and GL26, GL29, GL30, GL31), during the 24 hour pumping test of GL27, is presented in Figure 10, as measurements from standing water level. The small fluctuations evident in observation borehole data are a result of diurnal barometric pressure changes.

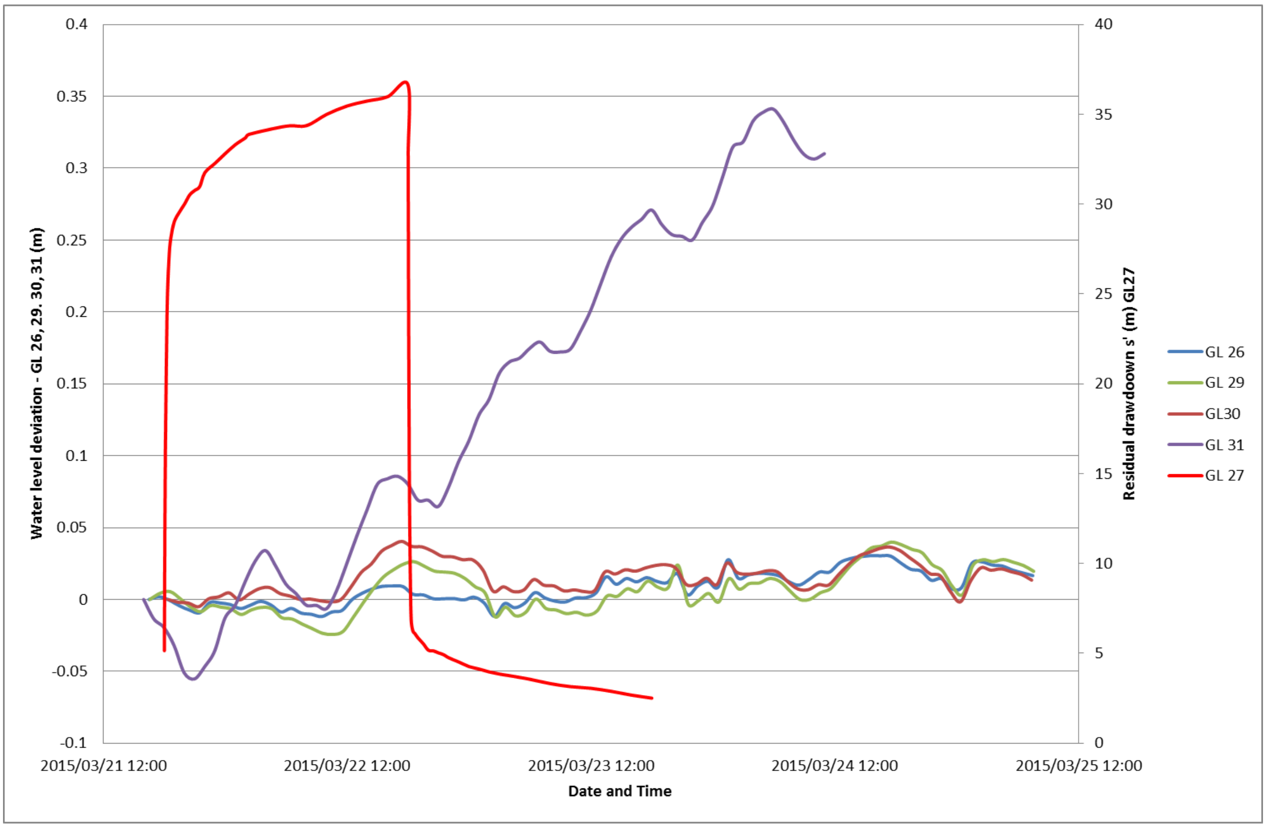

FIGURE 10: CHANGES IN WATER LEVELS IN PUMPED AND OBSERVATION BOREHOLES DURING PUMP TESTING OF GL 27

Water level data demonstrates a downward trend in all observation boreholes during the pumping test. In three of the boreholes, GL26, GL29 and GL30, this trend is slight and is possibly attributable to fluctuations due to other aquifer influences or diurnal barometric pressure fluctuations.

Although Figure 10 demonstrates a significant downward trend for water levels in GL31 during the pumping test (relative to other observation boreholes), continued, linear drawdown in the same boreholes after the cessation of pumping suggests drawdown is occurring in GL31 as a result of other influences. Therefore, it is not possible to ascertain connectivity between GL27 and any of the observation boreholes from this data.

However, the distinct difference between water levels deviation in GL37 and in GL26, GL29, and GL30, suggests that the latter three intersect a separate aquifer to GL37, which is consistent with the differences in drilled depths and intersected geology in these boreholes.

The aquifer parameters determined from the test pumping programme are summarised in Section 4.2.

3.4 GROUNDWATER QUALITY

Six groundwater samples were collected during the hydrocensus and seven during the aquifer testing (Table 4). Water samples were collected at the conclusion of each test using the installed pump. In the case of boreholes with very low inflow, a grab sample was collected using a bailer after measurement of recovery had taken place.

TABLE 4: SAMPLE BOREHOLE DEPTH AND WATER LEVELS

Borehole Type	Sample ID	Depth of Borehole (mbgl)	Water Level (mbgl)
Hydrocensus Boreholes	MH1 (Olivewood)	~100	50.15
	MH2 (UMTU)		Non measurable
	MH3 (UMTU)		64.03
	MH4 (YORK)	150	27.98
	MH5 (HOTAZEL)	50	37.23
	MH6 (YORK 279)	100	29.77
Pump Test Boreholes	GL15	64.17	
	GL27	175.70	>100
	GL35	136.85	80
	GL37	120.49	74.75
	GL56	86.77	48.33
	BH1		
	BH2	30.63	24.63

Sample filtration for dissolved heavy metals was undertaken in the field using 0.45µm in-line filters. One 250ml plastic bottle was filled with filtered water for analysis of dissolved metals and a second with unfiltered water for analysis of total metals. The first bottle contained nitric acid as a preservative. A third unfiltered, unpreserved sample was collected in a one litre plastic bottle.

Once collected, samples were labelled, placed in a cool box with ice blocks, and delivered to the laboratory with the relevant complete Chain of Custody form.

All samples were sent to Waterlab (Pty) Limited, in Pretoria, South Africa. Waterlab is a SANAS (South African National Accreditation System) accredited laboratory according to ISO/IEC 17025:2005 standards.

The results were compared to the following water quality standards (Table 5):

- World Health Organisation (WHO) Guidelines for drinking-water quality (WHO, 2011);
- South African National Standards (SANS) 241 (2011) water quality standards (SANS 241 (2011);
- Department of Water Affairs (DWAF) Target Water Quality Range Livestock watering (1996).

Tabulated data and copies of the laboratory reports are included in Appendix C.

TABLE 5: COMPARISON OF MOKALA GROUNDWATER QUALITY TO STANDARDS

SANS 241 (2011) Water Quality Standard		pH	Electrical Conductivity i	Alkalinity as $CaCO_3$	Chloride as Cl	Sulphate as SO_4	Nitrate as N	Fluoride as F	Al	Ca	Fe	K	Mg	Mn	Na	Se	Zn
		pH Value	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241 (2011) Operational		**5 - 9.7**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.3**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2011) Aesthetic		**N/A**	**170**	**N/A**	**300**	**250**	**N/A**	**N/A**	**N/A**	**N/A**	**0.3**	**N/A**	**N/A**	**0.1**	**200**	**N/A**	**5**
SANS 241 (2011) Acute Health		**N/A**	**N/A**	**N/A**	**N/A**	**500**	**11**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
SANS 241 (2011) Chronic Health		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**1.5**	**N/A**	**N/A**	**2**	**N/A**	**N/A**	**0.5**	**N/A**	**0.01**	**N/A**
WQG (1996): Livestock Watering		**N/A**	**N/A**	**N/A**	**1500**	**1000**	**200**	**4**	**5**	**1000**	**10**	**N/A**	**500**	**10**	**2000**	**50**	**20**
WHO DWQS (2011)		**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**50**	**1.5**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.04**	**N/A**
IFC Mining Effluent (2007)		**6 - 9**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**2**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.5**
	MH1	7.7	82	264	88	26	11	0.2	0.033	69.070	0.096	7.758	32.470	0.004	47.590	0.006	0.226
HYDROCENSUS	**MH2**	8.3	86	336	55	35	9.9	0.5	0.018	5.739	0.009	17.380	3.488	0.001	177.000	0.012	0.018
	MH3	9.2	140	20	362	128	0.2	0.3	0.050	28.340	0.002	8.275	40.910	0.062	154.800	0.028	0.016
	MH4	7.9	69	304	65	5	0.2	0.2	0.071	57.430	2.414	3.560	33.100	1.123	41.490	0.000	0.017
	MH5	7.8	118	476	116	5	0.2	0.9	0.066	62.480	0.145	4.850	44.930	1.709	149.700	0.012	0.016
	MH6	7.5	348	144	613	149	180	0.2	0.087	203.000	0.013	6.470	151.600	0.109	281.500	0.184	0.276
PUMPING TEST	**GL15**	7.7	289	188	704	251	2.2	1.3	0.027	113.100	0.013	7.475	102.400	1.755	327.400	0.216	1.340
	GL27	7.2	758	188	1783	1137	0.2	2.8	0.959	131.000	1.220	15.100	29.000	0.612	1535.000	0.206	5.430
	GL35	7.9	565	64	1478	646	14	0.5	0.074	262.600	0.009	30.660	315.500	5.943	490.800	0.133	0.698
	GL37	7.3	567	200	1289	722	3	1.8	0.080	119.000	0.007	8.800	87.000	0.065	757.000	0.000	2.670
	GL56	7.2	246	444	463	210	9.6	1	0.074	108.100	0.464	11.000	98.700	0.063	277.200	0.090	0.116
	BH1	7.3	369	316	913	191	49	0.8	0.077	217.300	0.252	9.520	205.500	0.645	249.300	0.174	0.122
	BH2	7.5	94.6	316	102	68	0.3	0.8	0.071	43.010	6.519	4.552	43.300	0.568	91.360	0.006	0.046

Note: Highlighted cells indicate the water quality standard that has been exceeded

The results from site and hydrocensus boreholes are generally similar. Eight of the samples show concentrations of manganese, iron, and selenium in excess of WHO (2011) and SANS 241 (2011) guidelines. Sodium and chloride exceed the SANS 241 (2011) aesthetic guideline in seven samples. One sample (GL27) is not potable due to high chloride and sulphate concentrations. There are several exceedances of sulphate, nitrate, and fluoride guidelines.

A range of chemical signatures are evident in the analyses (Figure 11). Most of the samples are of the Ca-Mg-Cl to Na-Cl type. This is consistent with groundwater that has undergone exchange of Ca/Mg for Na through contact with clay minerals. Several samples are of the Ca-Mg-HCO_3 type, which is similar to rain and therefore generally associated with recent recharge.

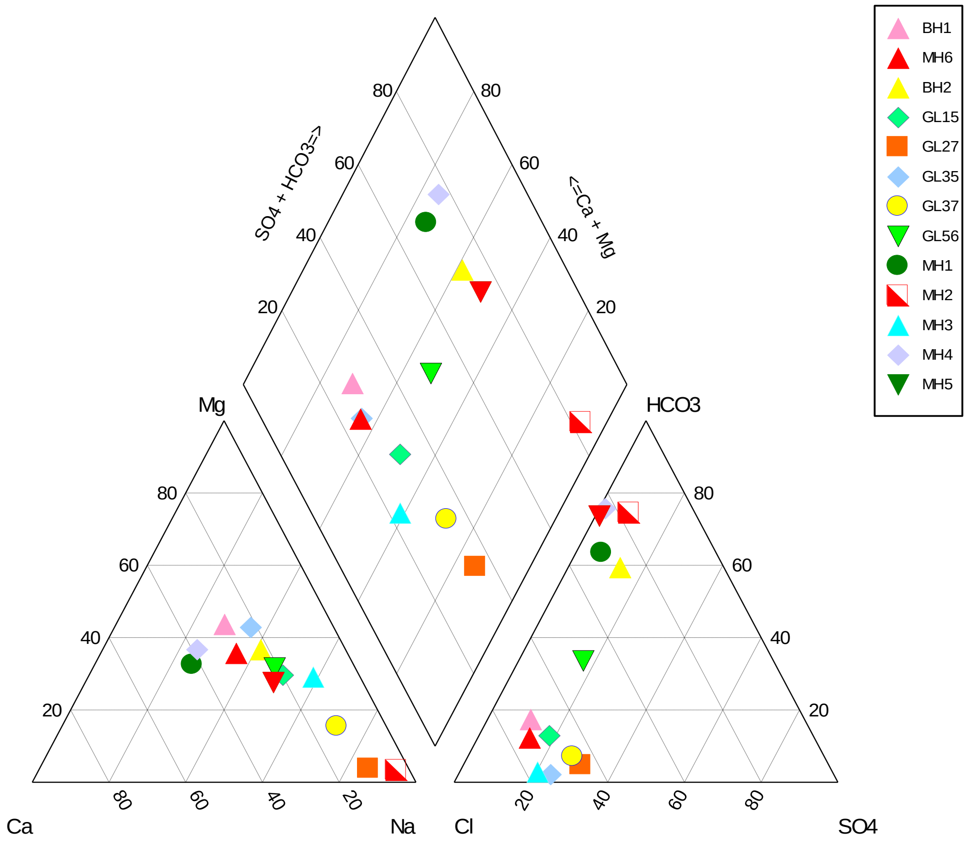

FIGURE 11: PIPER DIAGRAM FOR THE MOKALA WATER SAMPLES

4 CONSOLIDATED CONCEPTUAL HYDROGEOLOGICAL MODEL

Available drawdown in the two river boreholes was limited due to low water levels and shallow borehole depths. The test results indicate that there is a limited groundwater body accessed in these boreholes.

This groundwater body is likely to be perched on low permeability layers and is of limited extent. It is likely that this is the regional Kalahari aquifer and not linked to the river.

The test results from the "hard rock" aquifer suggest the boreholes intersected fracture systems. With the exception of GL27, the fracture systems generally have a low yield. Under sustained pumping, sufficient groundwater could not drain from connected fracture systems or the surrounding rock.

Based on SLR experience, site geology, and the aquifer test results, groundwater at Mokala is held in two main aquifers (Table 6).

TABLE 6: AQUIFER CHARACTERISATION

Aquifer	Geology	Thickness	Likely aquifer characteristics
Shallow aquifer (13-66 m)	Kalahari beds	45 to 135 m	• Water is held in the spaces between soil/sediment particles. • Water may rest on underlying clay-rich, low permeability formations ("perched water"). • Horizontal groundwater flow. • Fractures may allow vertical flow to the deeper aquifer? • Seepage through clay beds to deeper aquifer? • Unconfined (water table at atmospheric pressure) to semi-unconfined. • Low hydraulic conductivity (1 to 10 m/d)
Deep aquifer (>66m)	Dwyka Fm	0 to 103 m	• Low permeability, especially where weathered to clay.
	Mooidraai Fm Hotazel Fm	0 to 160 m	• Groundwater held in fracture systems in fresh bedrock. • Groundwater flow influenced by fracture orientation and size. • Confined (water under pressure). • Low hydraulic conductivity (less than 1 m/d, except along well-developed fracture systems).
	Ongeluk Fm	---	• Relatively impermeable.

Recharge of these aquifers is generally from rainfall at surface. This infiltrates to lower levels and deeper aquifers in the geological sequence through fracture systems. Recharge is estimated as 1% of mean annual rainfall.

Shallow groundwater is expected to be perched on low permeability clay-rich layers in the Kalahari Beds. These groundwater bodies are likely to be irregular in extent and will vary in extent and thickness with rainfall.

Deeper groundwater levels are expected to show a regional flow direction. Site measurements during the hydrocensus indicate groundwater gradient towards the northwest and the Ga-Mogara catchment discharge into the Orange River system.

4.1 AQUIFERS

The hydrogeology of the proposed project area is made up of two aquifer systems; these being the unconfined Kalahari Formation (primary aquifer) and the underlying confined fractured bedrock (secondary aquifer).

4.1.1 KALAHARI FORMATION

An unconfined, perched aquifer occurs in the sediments and calcretes of the Kalahari Formation or on the contact with Kalahari clay or the underlying Dwyka Formation. The thick clay bed, intersected in most of the exploration boreholes, acts as a confining layer. While the sediments and calcretes could have a moderate hydraulic conductivity, the clay must be assumed to be relatively impermeable.

This continuous presence of an impermeable or semi-permeable interface between the upper, unconfined Kalahari aquifer and the deeper, confined fractured aquifer is important to regional groundwater flow. It prevents rapid vertical drainage of the Kalahari aquifer and also permits lateral groundwater flow by topographic gradients. It also delays recharge to the underlying fractured aquifer(s).

Lithological logs and test pumping data of boreholes WH1 and WH2 located in the Ga-Mogara River indicate that there is a limited groundwater body accessed in these boreholes. This groundwater body is likely to be perched on low permeability layers and is of limited extent. It is consistent with the groundwater elevations showing a regional groundwater flow pattern towards the northeast. This suggests that the groundwater body accessed in these boreholes is the unconfined Kalahari aquifer. That is, there is no significant aquifer associated with the river.

4.1.2 FRACTURED AQUIFER(S)

The fractured aquifer is present in the bedrock formations below the Kalahari Formation. These formations consist of low permeability hard rock. Groundwater occurrence is dependent on secondary faults and fractures, joints and other discontinuities. Although borehole yields in the deeper aquifer are generally low, structural features such as faults and fractures can produce higher yielding boreholes. However, initially high borehole yields may decrease under sustained pumping, since water will be required to drain from the surrounding rock, or connected fracture systems which have a lower yield.

In the proposed project area the fractured aquifers are considered to occur in the Dwyka Formation, the Hotazel Formation and the Ongeluk Formation. Lithologies of the Olifantshoek Supergroup and

Mooidraai Formation are of less importance since they occur predominantly west of the proposed mine proposed project.

4.1.2.1 Dwyka Formation

The Dwyka aquifer consists of diamictite (tillite) with clay lenses influencing the overall hydraulic properties of this unit. The lithology is generally massive with little jointing, but it may be stratified in places. The Dwyka Group constitutes a very low-yielding fractured aquifer and water is confined within narrow discontinuities like jointing and fracturing. They therefore tend to form aquitards rather than aquifers (DWAF, 2011).

As shown in the simplified geological cross-sections in Figure 5 the thickness of the Dwyka Formation increases towards the west.

4.1.2.2 Hotazel Formation

The Hotazel Formation is the ore-bearing unit, comprised of Banded Ironstone (BIF) and Manganese Ore. Groundwater associated with the Hotazel Formation rocks appears to be associated with fracture systems that are generally of limited extent.

4.1.2.3 Ongeluk Formation

The lava of Ongeluk Formation underlies the Hotazel Formation and is of hydrogeological importance east of the proposed developments (east of the syncline) where younger bedrock is eroded and only preserved in down faulted grabens (e.g. at dormant mines on Hotazel and Devon).

4.1.3 GROUNDWATER LEVELS AND FLOW

The regional average water levels in the D41K catchment are 40 mbgl (WGC, 2010). The spatial distribution of groundwater levels and hydraulic heads is presented in Figure 12.

Water levels observed on site range between 13 m and approximately 100 m below surface. In some cases the clay layer may separate the Kalahari Formation into two distinct primary aquifers. Water levels measured on site do not show significant correlation to topography. Instead they vary considerably over short distances. This might be attributed to:

- Slow recharge after drilling in a low hydraulic conductivity environment,
- The influence of current and previous mining activities in the area,
- The influence of confined aquifer conditions in the underlying fractured bedrock,
- The local absence of the confining clay layer.

The fact that casing in the exploration boreholes have sealed off the Kalahari Formation renders a distinction between hydraulic groundwater heads in the different aquifers impossible. The observed groundwater levels are assumed to be influenced by both aquifers.

SLR determined the regional groundwater flow pattern by linear interpolation of available groundwater levels and hydraulic heads. Water levels measured during the hydrocensus, water level information in the National Groundwater Database (NGDB), and water level information from published literature were used to produce a regional groundwater contour map (Figure 12).

Figure 12 shows that the proposed project site groundwater levels increase towards the west while being shallow east of the river where the Kalahari is underlain by lava of the Ongeluk Formation. In general, the regional groundwater flow reflects topography, with groundwater flow from high lying areas in the east and south-west towards the north in the direction of low lying drainage features.

The regional groundwater flow is directed southeast-northwest in areas southeast of the Ga-Mogara River and south-north and southwest-northeast southwest of the Ga-Mogara River. Groundwater flow at the proposed project site is directed west-northwest towards the centre of the syncline.

Based on available geological information regional groundwater flow in the deeper fractured aquifer (Karoo Supergroup and Transvaal Supergroup) is inferred to be directed along the strike of the geological formations (and the Dimoten syncline). The north-south to north-northeast-south-southwest trending normal faults (Gutzmer and Beukes, 1995) are assumed to play an important role in this flow.

Regional cross-boundary flow from aquifers of the Voëlwater Subgroup to the Ongeluk Formation is assumed to be limited to areas characterised by major interconnected fracture systems.

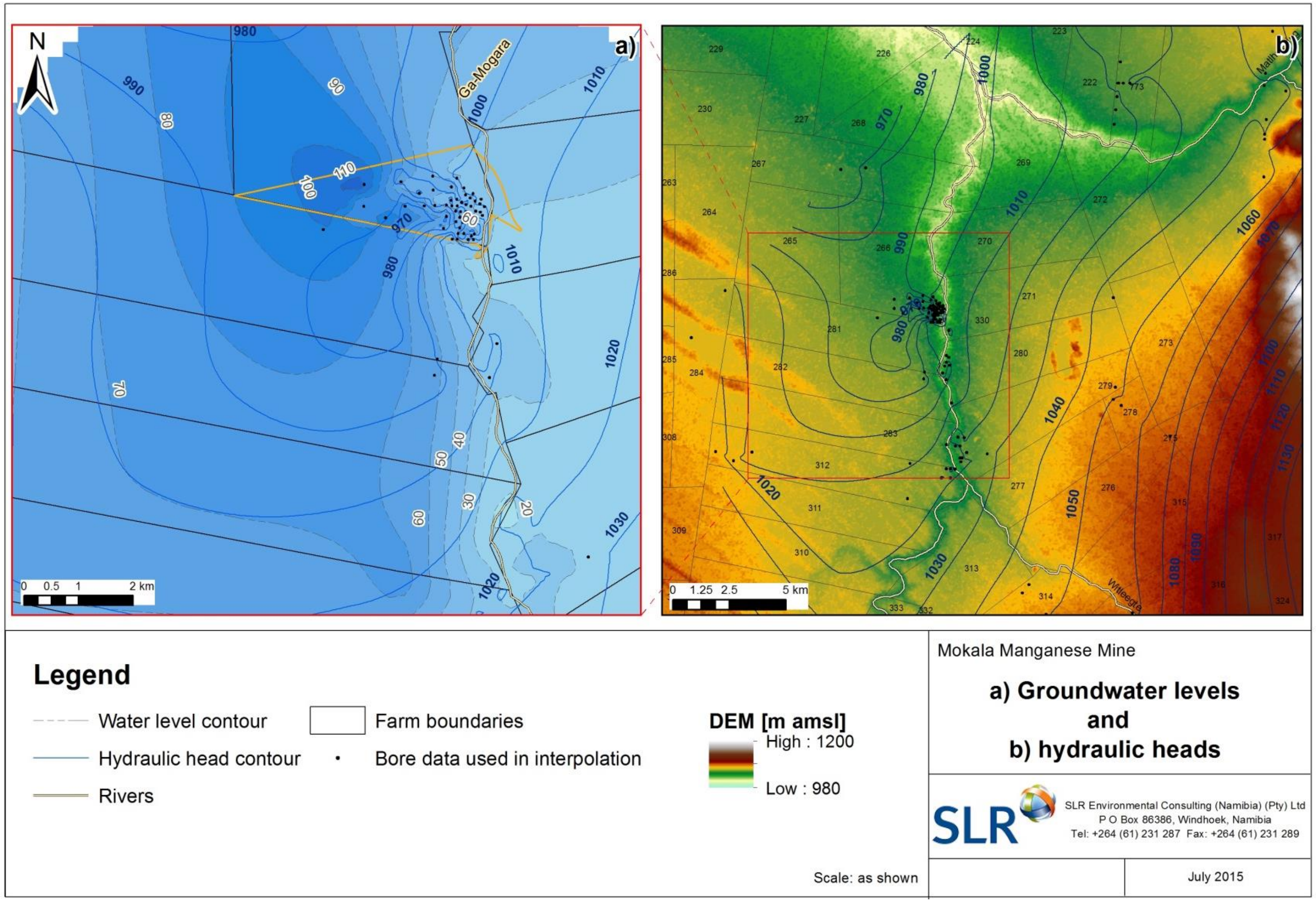

FIGURE 12: LOCAL GROUNDWATER LEVELS AND REGIONAL HYDRAULIC HEAD DISTRIBUTION

4.2 HYDRAULIC PARAMETERS

Test pumping activities carried out on site had limited success. Of eight boreholes tested, transmissivities were obtained in five. Except for exploration borehole GL27, the test yields were low. This suggests that the groundwater yield potential of the aquifers at Mokala is generally low. Pumping tests indicate that the yield for the shallow aquifer system is much lower than 1 L/s. The yield for the deep aquifer is approximately 1 L/s. Table 7 summarises the test results. In Table 8 reported conductivity ranges for prevailing geological formations are shown. The presented ranges will serve as parameter bounds during numerical groundwater model calibration.

TABLE 7: TEST PUMPING SUMMARY

Bore	Transmissivity (T) m^2/day	Hydraulic. Conductivity (k) m/day	Kalahari beds	Hotazel Fm	Hotazel Fm + Dwyka	Aquifer Thickness
WH1	---	2.9E-03	x			3.42
WH2	---	1.6E-03	x			6.18
GL15	0.2	1.0E-02		x		19.51
GL27	2	3.2E-02		x		63.03
GL31	---				x	131.19
GL35	0.1	1.8E-03			x	56.85
GL37	0.2	4.4E-03		x		45.69
GL56	0.02	5.2E-04		x		38.69

TABLE 8: REPORTED HYDRAULIC CONDUCTIVITY RANGES

Formation	Hydraulic Conductivity Range [m/day]
Kalahari (sand, calcrete, pebble bed, clay)	0.01– 10[#]
Karoo Supergroup (Dwyka tillite)	0.024 – 0.22[+] and 1*10E-07[+++]
Hotazel Formation (BIF)	0.03[+]– 14.7[#]
Ongeluk Formation (basalt/lava)	1.7E-06 – 0.04[++]

[#] GHT (WGC, 2010)

[+] WGC (2010)

[++] Domenico et al., 1990

[+++] DWAF (2011)

4.3 SOURCES AND SINKS

Sources of water in the proposed project area are direct recharge from rainfall and groundwater through-flow. Evapotranspiration, groundwater through-flow, and abstraction on neighbouring mines and farms represent sinks. There is no information regarding groundwater abstraction rates by other users or inflow/dewatering rates from neighbouring mines but the measured water levels are indicative of the cumulative impact of all existing users in the relevant geographic area..

4.3.1 RECHARGE

Recharge in the area occurs as diffuse recharge with slow percolation through the topsoil and relatively fast preferential flow through cracks, root channels, and fractures. Soil moisture and transpiration of vegetation have a great influence on recharge. In sand, usually 15% of soil moisture is needed to increase unsaturated zone hydraulic conductivity to levels at which all infiltrating water can percolate further down (SCHMITZ, 2004).

Bean (2003) correlated regional rainfall data with groundwater isotope values for Hotazel. Results indicate that monthly rainfall must exceed at least 150 mm before recharge occurs. Considering 40 years of monthly rainfall data for Hotazel, this suggests that recharge has occurred no more than 13 out of a possible 504 months during that period, and is thus episodic in character (Xu & Beekman, 2003).

A summary of recharge studies in Kalahari aquifers in Namibia, South Africa and Botswana is given in Figure 13. It shows a cluster of recharge percentages between 0.1 and 2.6 %, with some exceptionally high values. The elevated values have been derived from chloride concentrations in groundwater close to exposures of calcrete and probably represent the influence of preferential flow (Wrabel, 1999 in Külls, 2000).

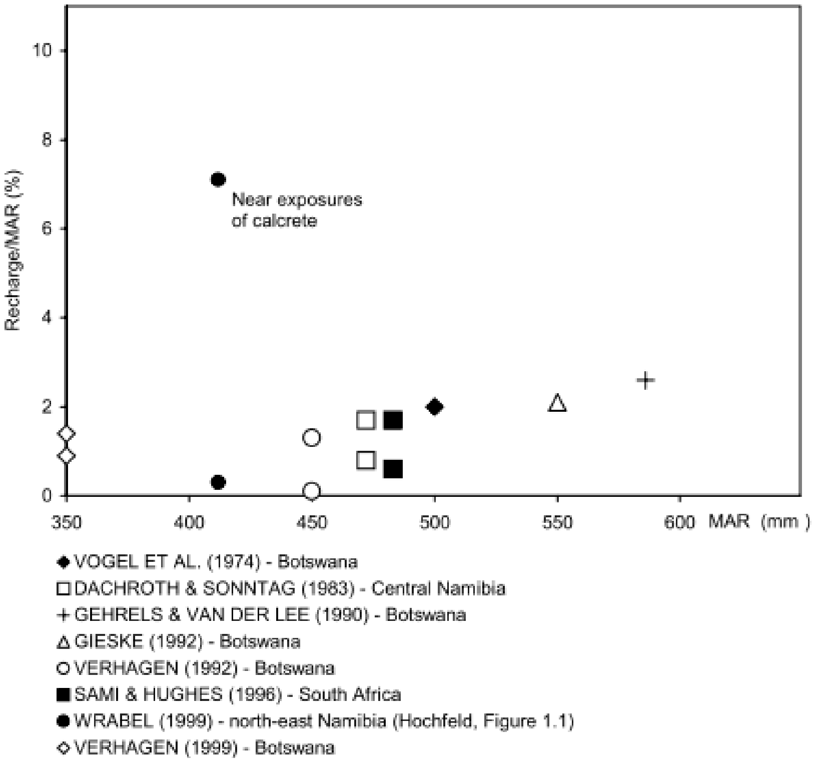

FIGURE 13: RELATIONSHIP BETWEEN MAP AND RECHARGE FROM STUDIES IN THE KALAHARI (KÜLLS, 2000)

Given the above and the characteristics of the prevailing Kalahari Formation strata, recharge rates within the proposed project area are assumed to be less than 1% of MAP (MAP = 335 mm). In the numerical groundwater model recharge is simulated as net recharge accounting for evaporation.

4.4 AQUIFER SYSTEM AND CLASSIFICATION

Based on the DWA Aquifer Classification map (Matoti et al 1999, recompiled 2012), the Mokala site falls in the "poor" aquifer region. This is defined as "A low to negligible yielding aquifer system of moderate to poor water quality". This refers to the shallow Kalahari bed aquifer. However, the yield in the deeper aquifer is also expected to be low.

5 NUMERICAL GROUNDWATER MODEL

To assess the potential impact of the proposed Mokala Manganese mine on the local groundwater system, SLR developed a numerical groundwater flow model. The model simulates the groundwater system and its response to stresses, such as the excavation of the opencast pit, and the movement of dissolved contamination in the groundwater. This section describes how the steady state groundwater model was developed.

To meet international standards, model development was guided by the *"Australian Groundwater Modelling Guidelines"* (Barnet et al, 2012). This document has been developed through the Waterlines Report Series and promotes a consistent and sound approach to the development of groundwater flow and solute transport models.

5.1 DELINEATION OF THE MODEL AREA

The proposed model boundary delineated is presented in Figure 14. It covers an area of approximately 724 km^2. Since sparse water level and lithological information is available in the wider area outside the proposed project area a rather large model area was chosen. This is intended to avoid possible interference of groundwater changes with boundary conditions during predictive simulations.

The Kuruman River was chosen as the north-eastern boundary and the eastern boundary at a topographic high (surface water divide). The south-eastern and southern boundaries were set along interpolated groundwater contours, while the south-western and western boundary follows the Black Ridge thrust fault (location adopted from Astrup & Tsikos (1998) in Preston (2001)). The north-western outflow boundary was set a significant distance from the study area, assuming a SE-NW regional groundwater flow pattern in the fractured aquifer.

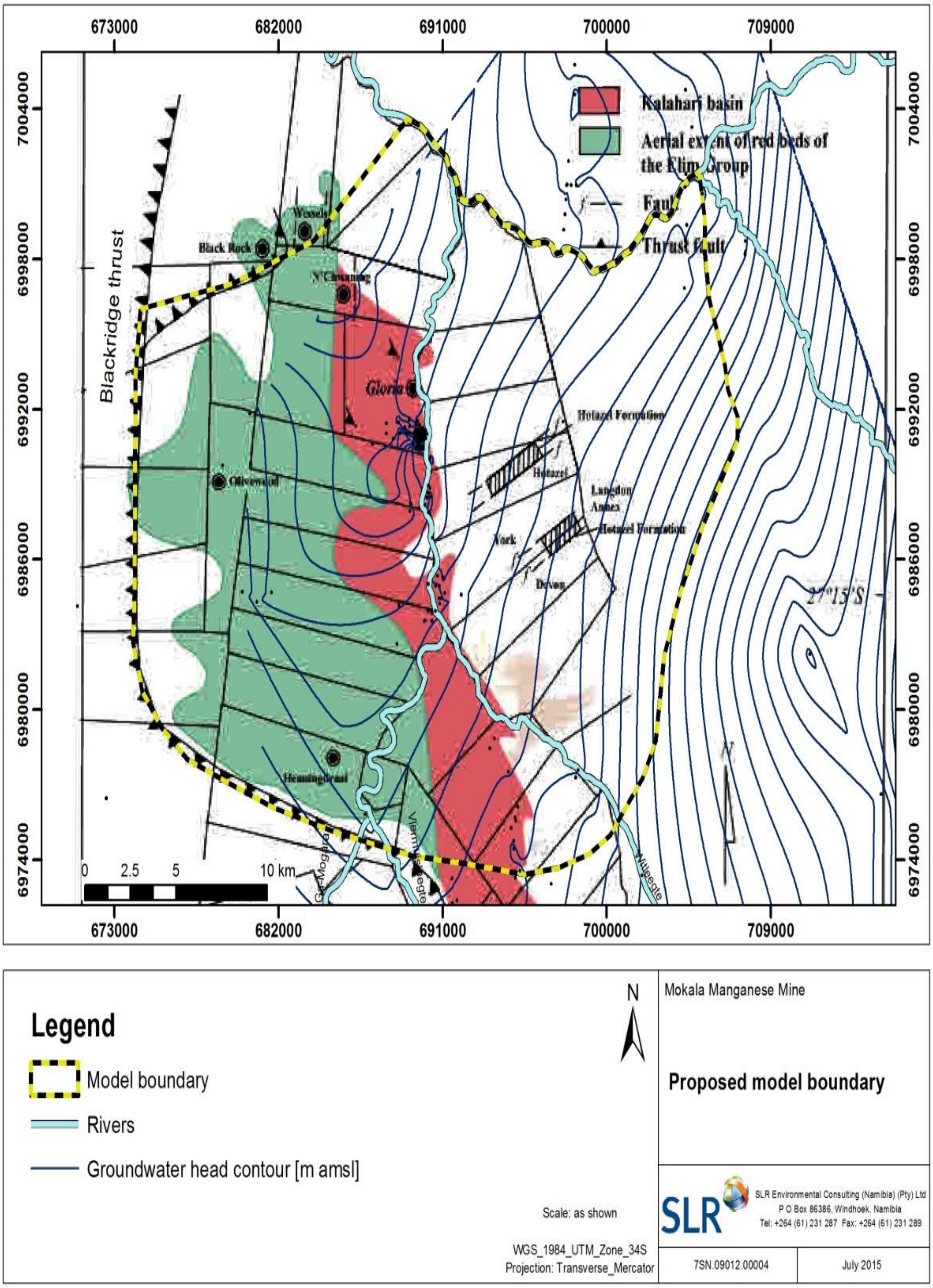

FIGURE 14: MODEL BOUNDARY UNDERLAIN BY LOCALITY MAP SHOWING THE DISTRIBUTION OF THE TRANSVAAL SUPERGROUP (ASTRUP & TSIKOS, 1998 IN PRESTON (2001))

5.2 MODEL DEVELOPMENT

Development of the model consisted of discretising the model domain into individual elements for which changes would be computed during simulations, setting of boundary conditions, and calibration. These are described in the following sections.

5.2.1 MODEL DISCRETISATION

AN INITIAL FINITE ELEMENT MESH WAS DEVELOPED BASED ON THE CONCEPTUAL HYDROGEOLOGICAL MODEL. GROUNDWATER RELEVANT FEATURES OF THE MINE SITE (SUCH AS THE MINE PIT AND THE PROPOSED OVERBURDEN STOCKPILE) WERE INCORPORATED INTO THE

NUMERICAL MODEL DURING LATER REFINEMENT OF THE FINITE-ELEMENT MESH (SEE

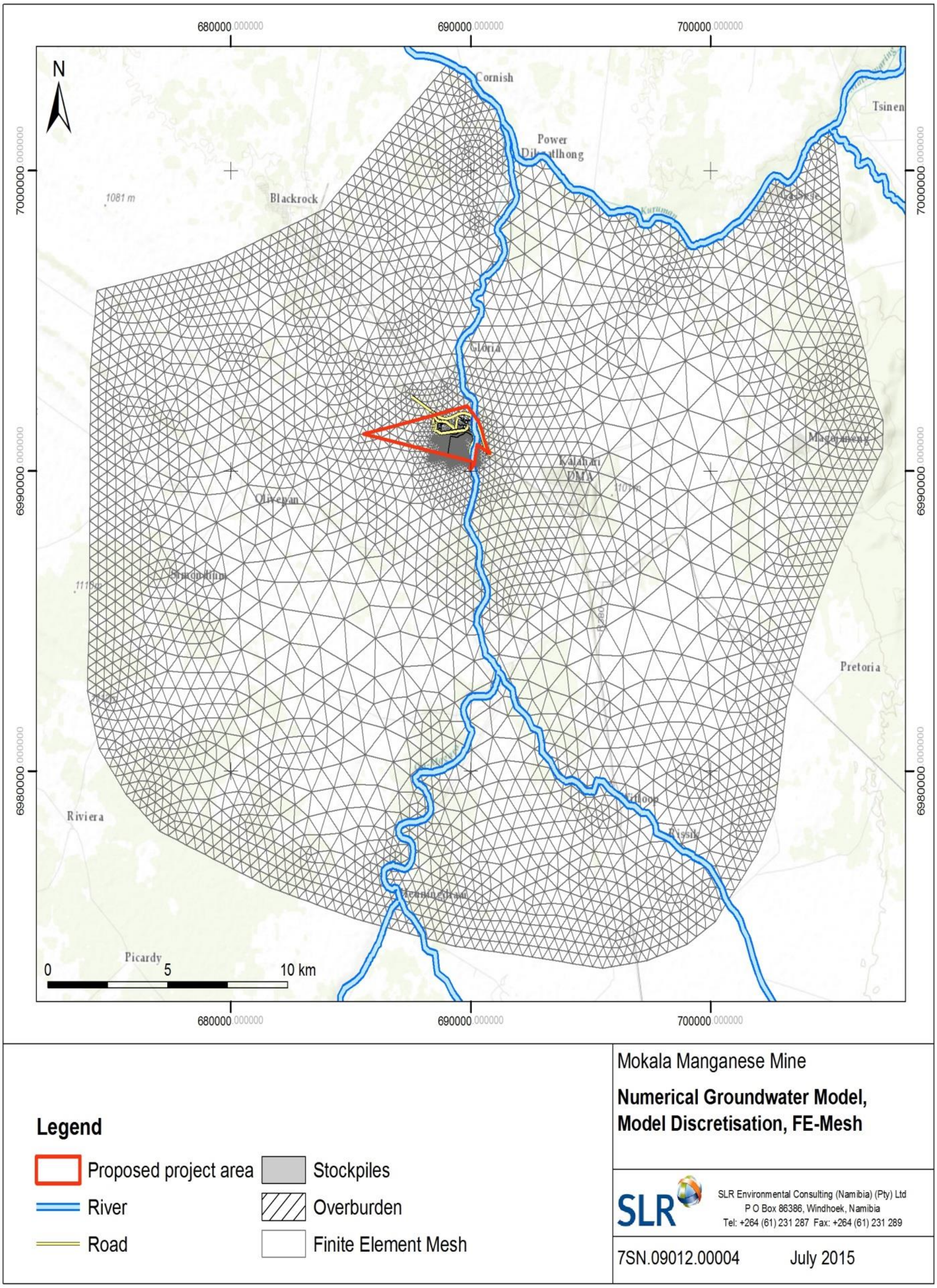

Figure 15 and Figure 16).

The two-dimensional finite element mesh was extended into three-dimensions by introducing four model layers. The layers were defined by considering data from exploration borehole logs and reported stratigraphy in manual extrapolation and linear interpolation. The model layers are characterised as follows:

- Layer 1 represents the Kalahari Formation with a thickness of 15 m in areas east of the proposed mine (underlain by the Ongeluk Formation), maximum thickness of about 100 m about 4 km west of the mine, and about 80 m at the western model boundary. The top elevation was specified as surface topography derived from the digital elevation model (SRTM data[1]).
- Layer 2 corresponds to the Dwyka Formation in the study area and in areas west of the Ga-Mogara River. In areas east of the mine Layer 2 is the weathered bedrock zone of the Ongeluk Formation (transition zone between Kalahari and Ongeluk Formations). The layer thickness ranges between 300 m at the western and 10 m at the eastern model boundary.
- Layer 3 represents the Hotazel Formation in the study area. East of the mine, it is the weathered bedrock zone of the Ongeluk Formation, and in western parts of the model domain it is the lithologies of the Olifantshoek Supergroup and Voëlwater Subgroup. Within the study area the layer dips between 5° and 8°. The layer thickness increases from 10 m east of the Ga-Mogara River to 200 m at the western model boundary. It is between 10 m and 100 m in the proposed project area.
- Layer 4 corresponds to the Ongeluk Formation, and the Voëlwater Subgroup in the western part of the model domain. Layer 4 represents the base of the model and the bottom slice was set at 400 mamsl.

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[1] http://gdex.cr.usgs.gov/gdex/

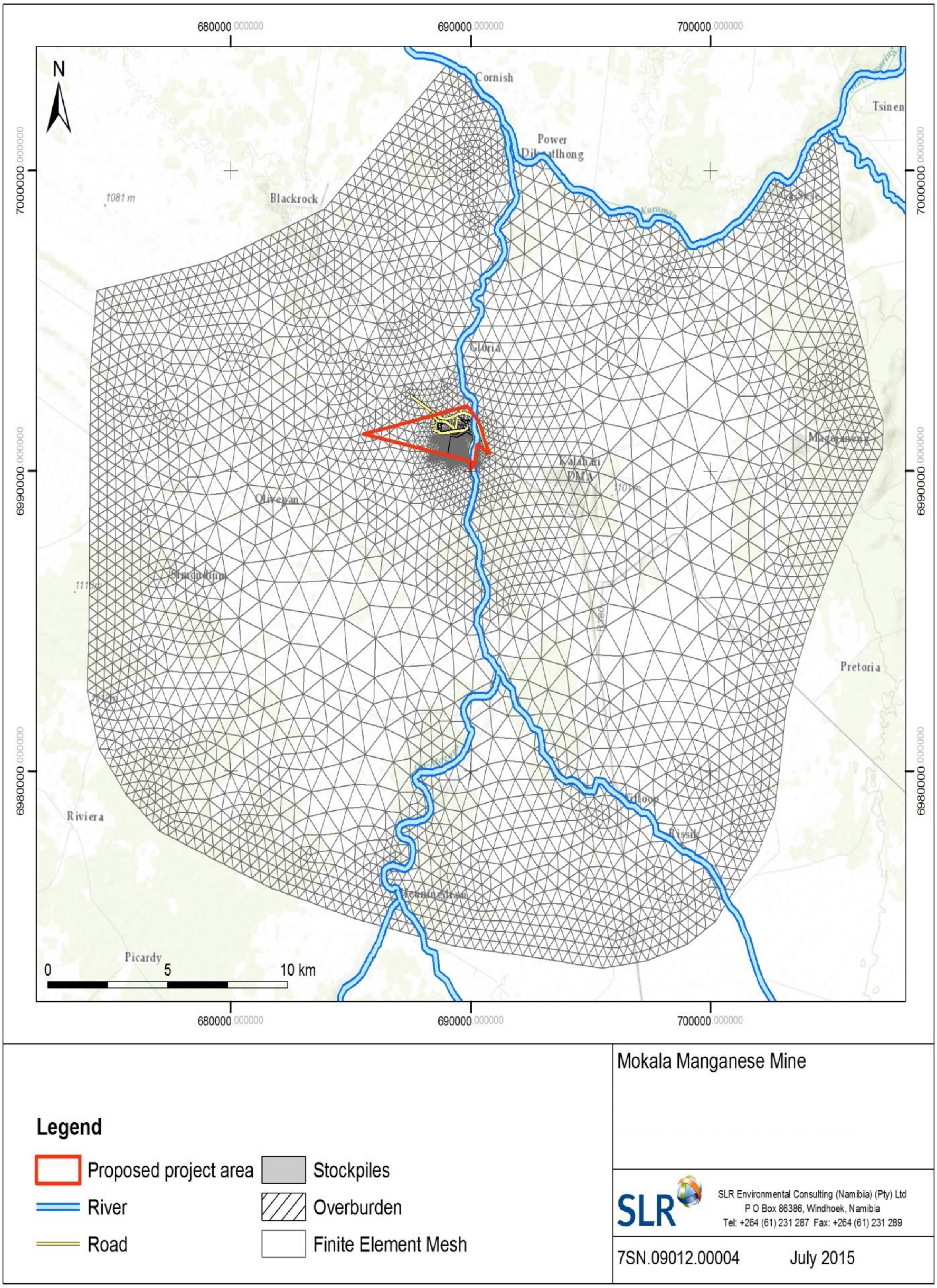


FIGURE 15: FINITE ELEMENT MESH

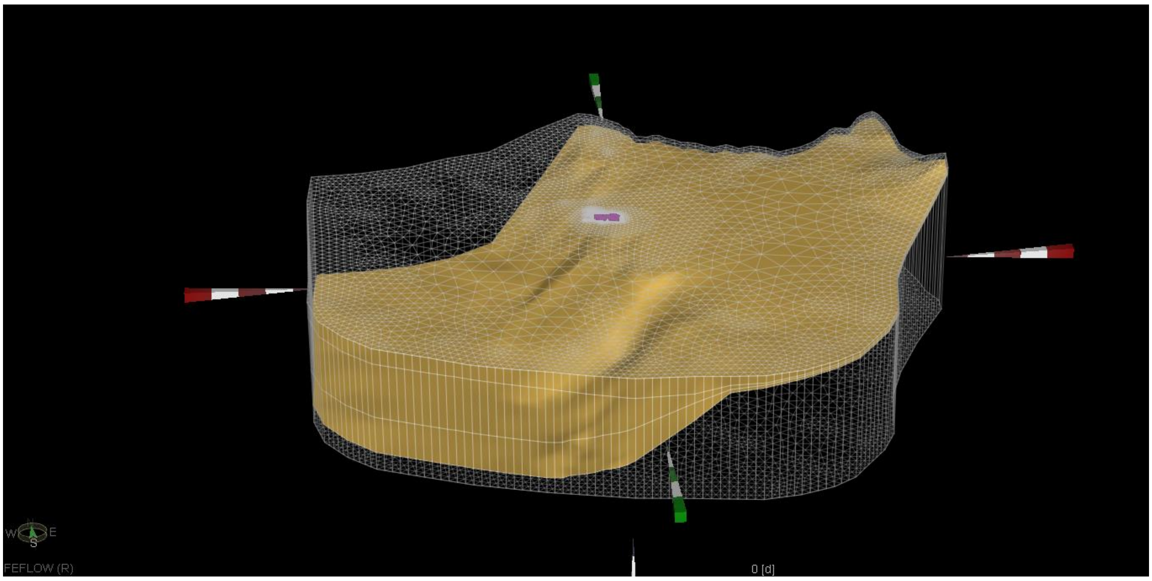


FIGURE 16: MODEL DISCRETISATION – 3D VIEW – BOTTOM OF MODEL LAYER 3 IN LIGHT BROWN

5.2.2 BOUNDARY CONDITIONS

Boundary conditions (BC) were set along the model boundary. Two different Dirichlet-BC have been used: Hydraulic head BC and hydraulic head BC with maximum flow constraints. The latter has been used to simulate a drain boundary at the Kuruman River in model layer 1 (see Figure 17). While inflow from the western and south eastern boundary is simulated in model layer 1, model layers 2 to 4 simulate inflow only from the south eastern boundary.

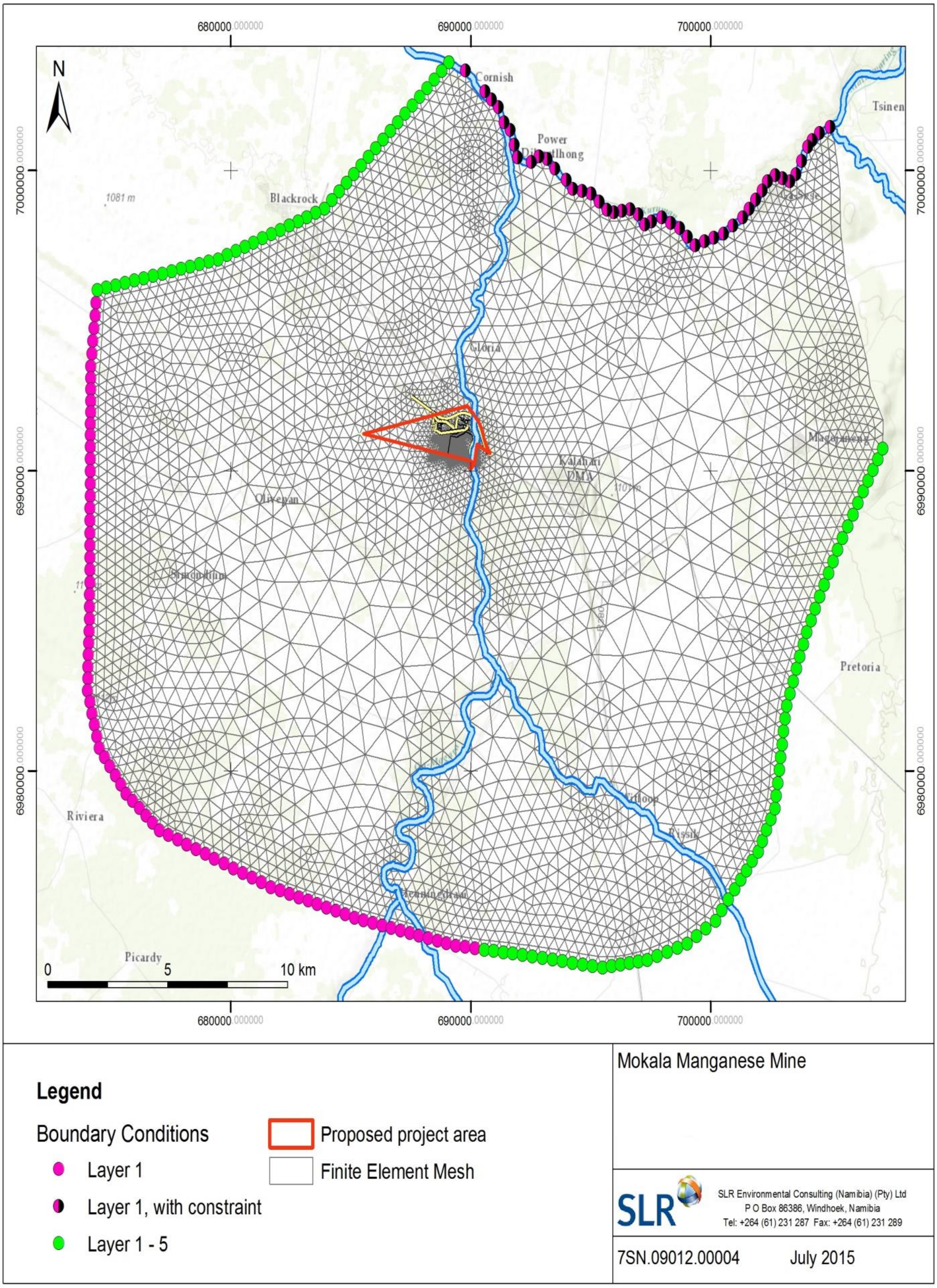


FIGURE 17: FLOW BOUNDARY CONDITIONS

5.2.3 SELECTION OF MODEL CALIBRATION TARGETS

Available water level information stems from readings taken in exploration boreholes on site, from regional hydrocensus campaigns carried out by SLR, from the NGDB and from information found in readily available literature on the area. 48 boreholes have been selected to serve as targets in the calibration of the steady state numerical groundwater flow model. They were selected based on a homogeneous distribution across the entire model area with special attention to the proposed project area. Boreholes with significant water level differences to adjacent boreholes were not considered. A list of the model calibration targets is given in Appendix D.

All selected boreholes are listed in Appendix D while locations are illustrated in Figure 18.

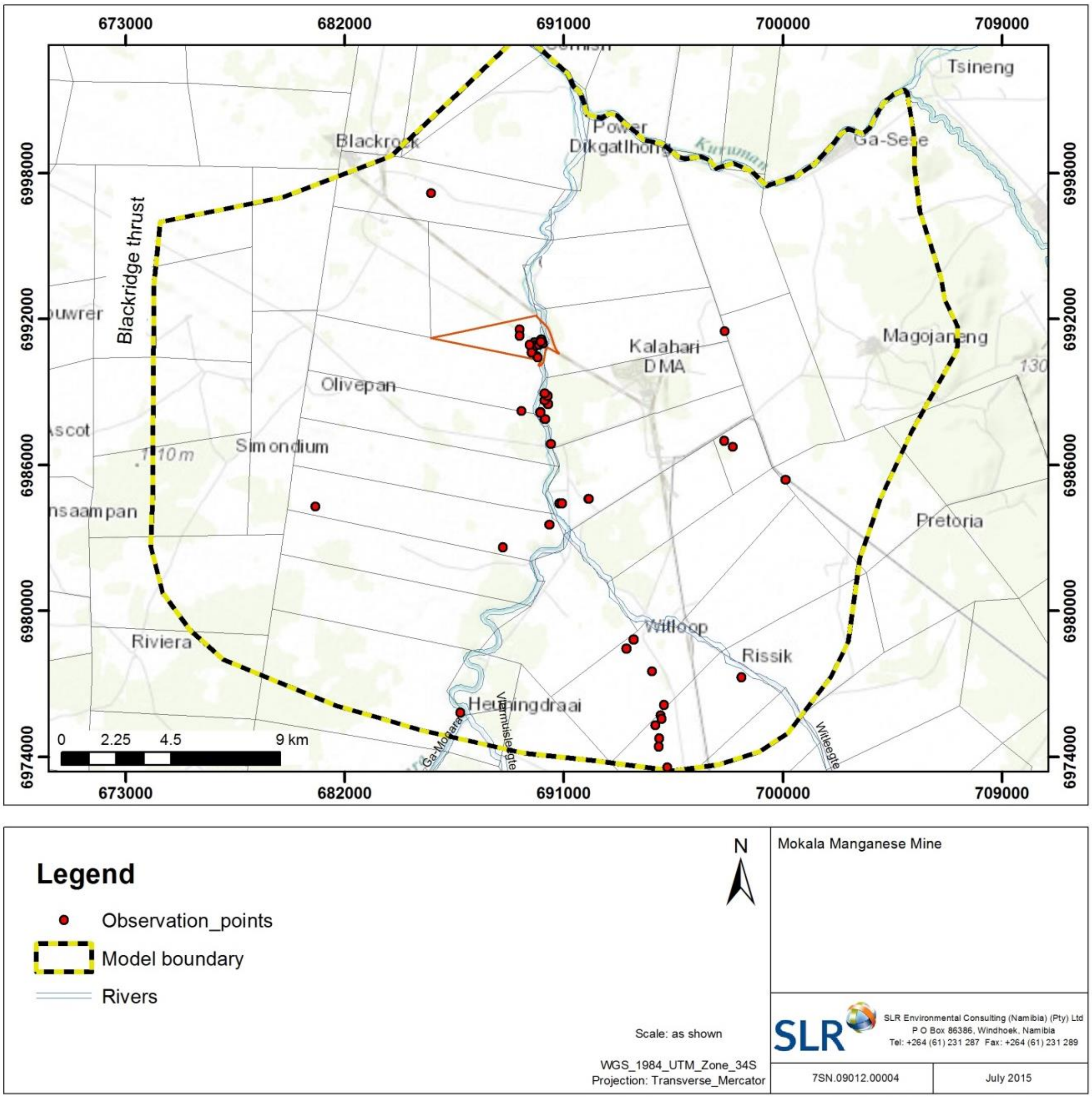


FIGURE 18: SPATIAL DISTRIBUTION OF MODEL CALIBRATION TARGETS

5.3 MODEL CALIBRATION

The steady state calibration carried out assimilates data from different points in time and is intended to provide an approximation of a long-term average hydrogeological condition prior to mining. The calibrated steady state numerical groundwater flow model provides the initial condition for predictive simulations.

5.3.1 MODEL ACCEPTANCE CRITERIA

Calibration involves changing of model parameters within realistic bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012). The quality of calibration is often assessed against a predefined value of goodness of fit between simulated and observed values. However, there are a number of other criteria that can be used to assess whether the model is fit for purpose. The following criteria are used herein to assess the model calibration quality:

- The Scaled Root Mean Squared (SRMS) error of less than 10% as an acceptable match between simulate and observed heads (Barnett et al. 2012);
- The model mass balance error of less than 1 % and model is numerically stable i.e. the simulated results are mathematically sound (Barnett et al. 2012);
- The model behaves in a manner consistent with the hydrogeological conceptual model;
- The hydrogeological parameters are realistic and within bounds of estimates derived from field investigations and previous experiences.

5.3.2 CALIBRATION STATISTICS

A semi-automatic calibration has been carried out using the Software PEST (Doherty, 2010). In Table 9 the achieved calibration statistics are shown. An acceptable calibration was achieved. The Root Mean Squared Error (RMS) for the regional model of 4.25 m results in a SRMS of 3.6% with an observed head range of 116.3 m, which is below the threshold of 10% for acceptable calibration. Calibration showed that the model is highly sensitive to recharge.

Figure 19 presents the scatter plot of observed versus simulated heads. Some computed heads differ from the observed heads significantly (see minimum and maximum residuals). This might be attributable to unknown hydraulic relevant fractures and/or faults in the model area.

TABLE 9: CALIBRATION STATISTICS

Statistical Term	**Value**
Residual Mean [m]	0.29
Res. Std. Dev. [m]	4.28
Sum of Squares	865.55
Abs. Res. Mean [m]	3.59
Min. Residual [m	-12.13

Statistical Term	Value
Max. Residual [m]	9.16
Range in Target Values [m]	116.30
Std. Dev./Range [m]	0.04
Coefficient of determination	0.9778
RMS [m]	4.25
SRMS [-]	0.088

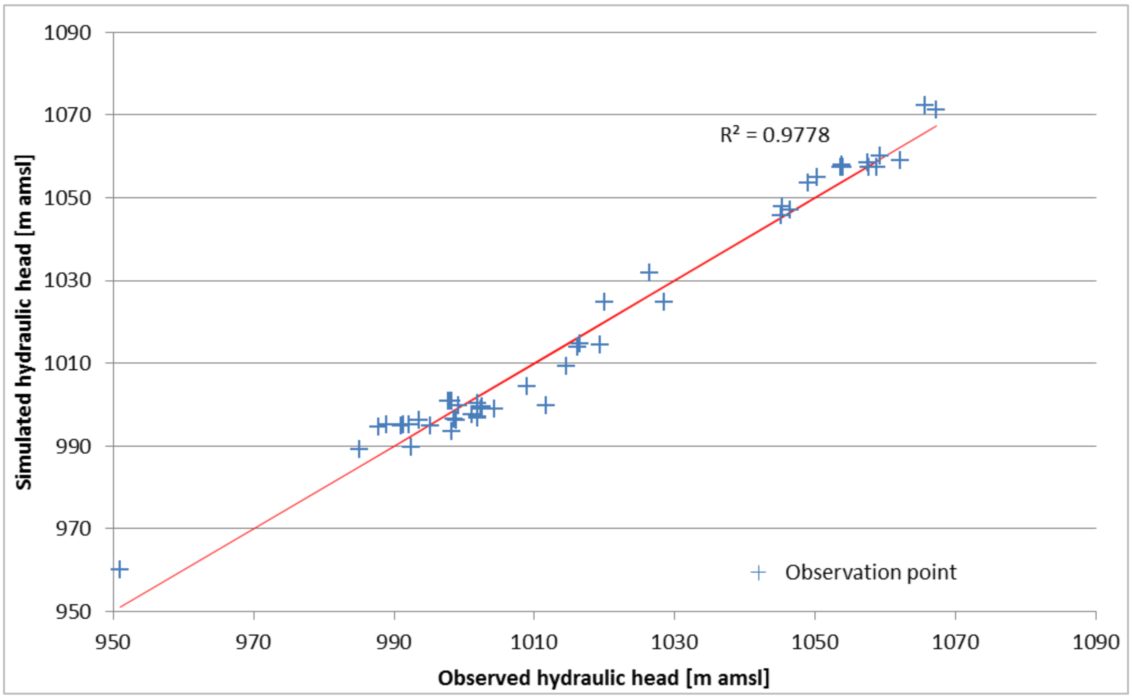


FIGURE 19: OBSERVED VERSUS SIMULATED HYDRAULIC HEADS

5.3.3 CALIBRATED HYDROGEOLOGICAL PARAMETERS

The best parameter estimates are presented in Table 10 while their spatial distribution in the corresponding layers is shown in Figure 20, Figure 21, Figure 22 and Figure 23.

TABLE 10: OBSERVED AND CALIBRATED HYDRAULIC CONDUCTIVITY RANGES

Layer	Unit	Calibrated Conductivity Ranges [m/day]	Reported Conductivity Ranges [m/day]
1	Kalahari West (underlain by Dwyka Fm)	0.4 – 0.7	0.01 – 10
2	Dwyka Fm West	0.001 – 0.1	1E-07 – 0.22
	Kalahari / Weathered Ongeluk Fm	0.5 – 0.7	n/a
3	Hotazel Fm	0.1 – 0.25	(5.2E-04)$^{+}$ – 14.7
	Voelwater Sg	0.3 – 0.5	n/a
	Weathered Ongeluk Fm	0.25 – 0.3	n/a
4	Ongeluk Fm	0.0005	1.7E-06 – 0.04
	Voelwater Sg	0.008	n/a

Note: + indicates value from site pump test results

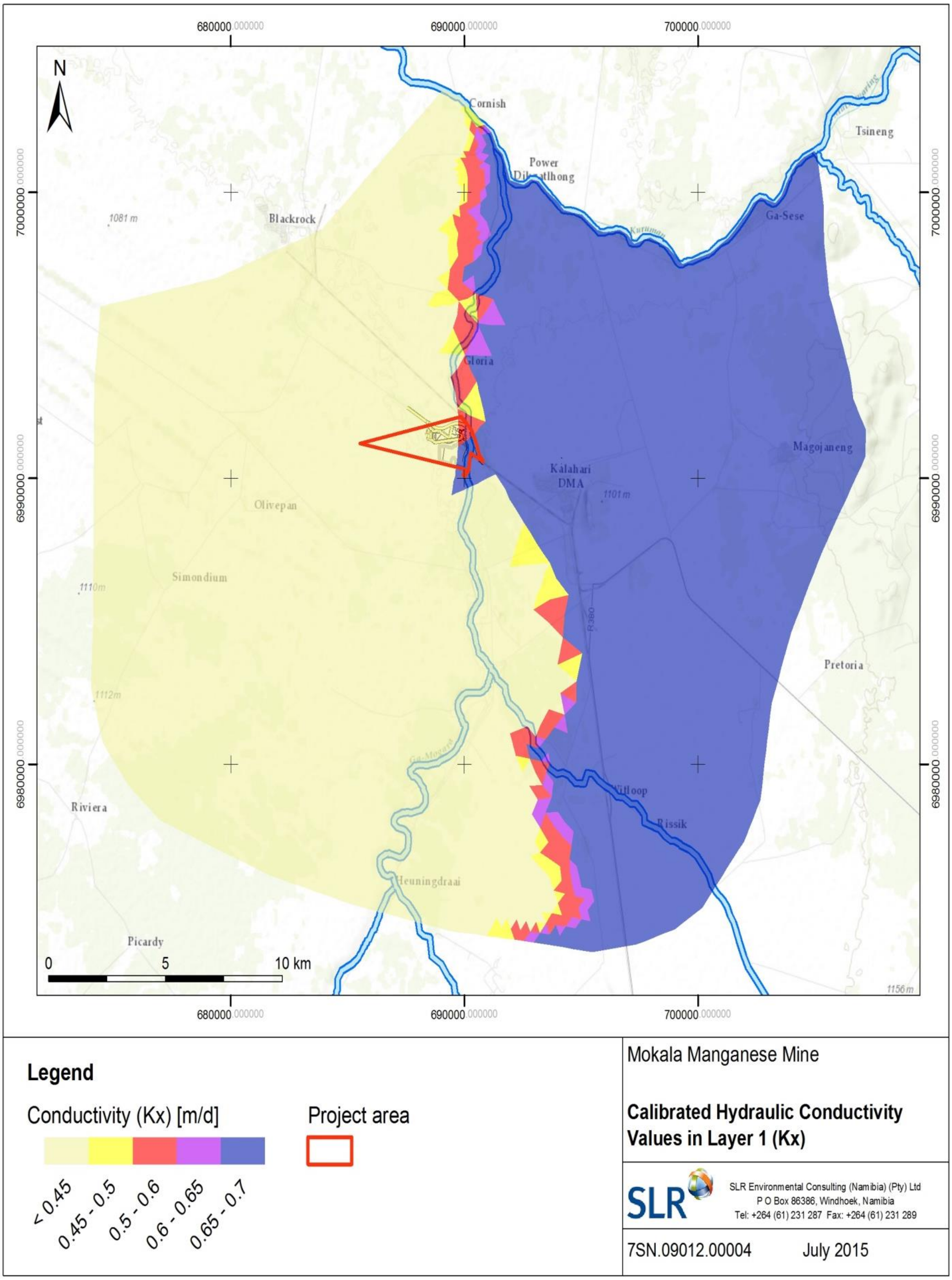


FIGURE 20: CALIBRATED HYDRAULIC CONDUCTIVITY VALUES IN LAYER 1

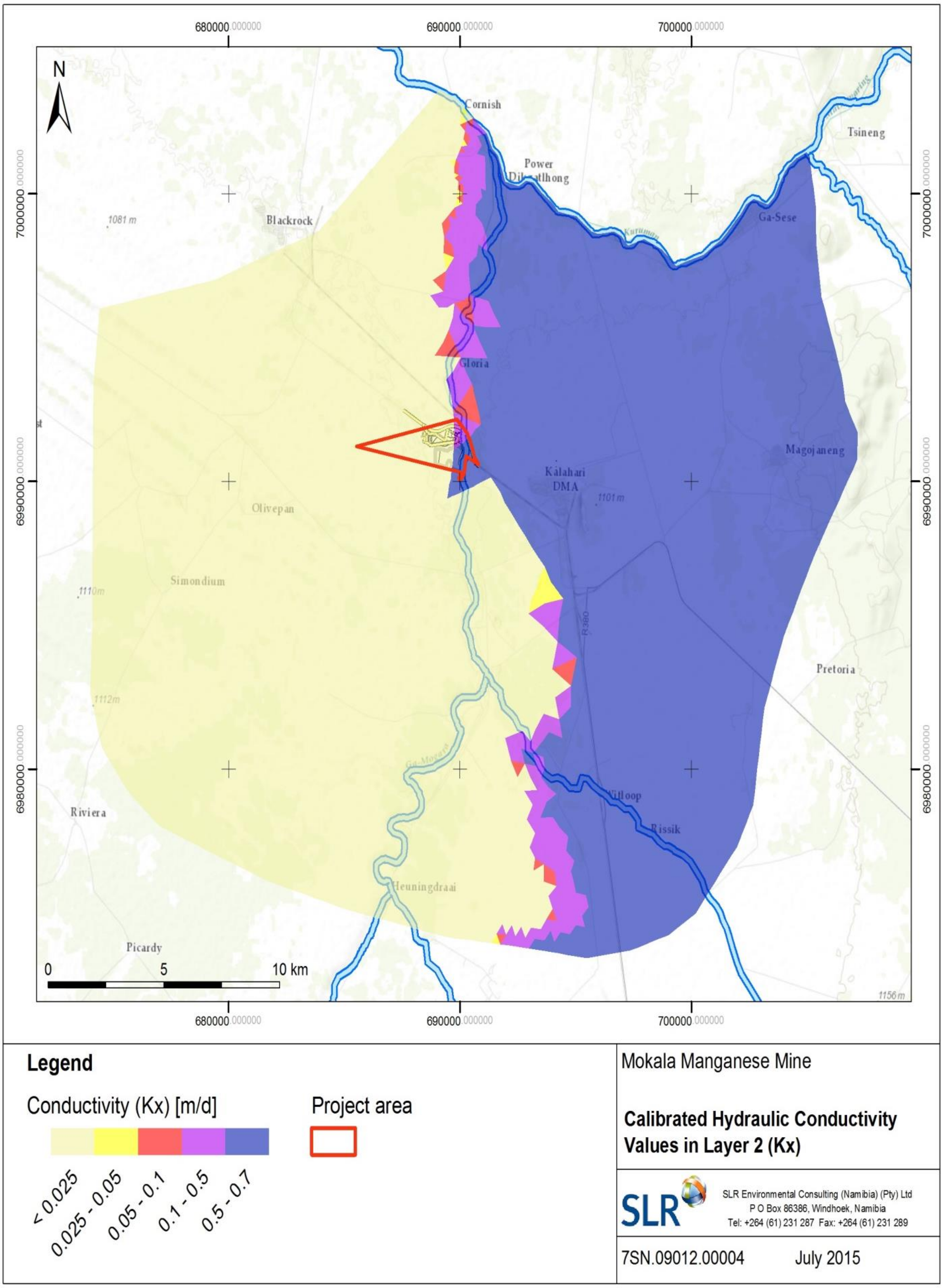


FIGURE 21: CALIBRATED HYDRAULIC CONDUCTIVITY VALUES IN LAYER 2

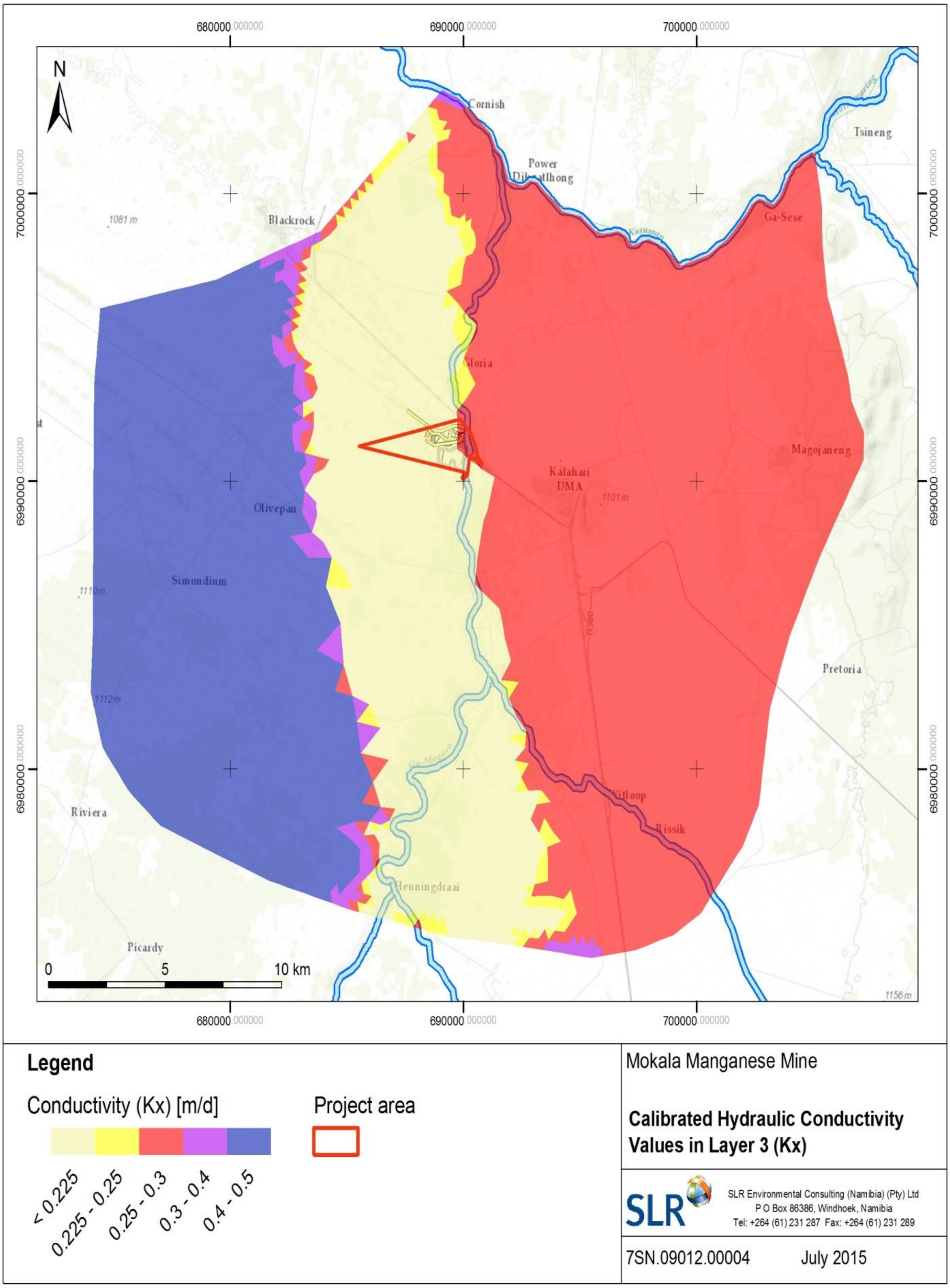


FIGURE 22: CALIBRATED HYDRAULIC CONDUCTIVITY VALUES IN LAYER 3

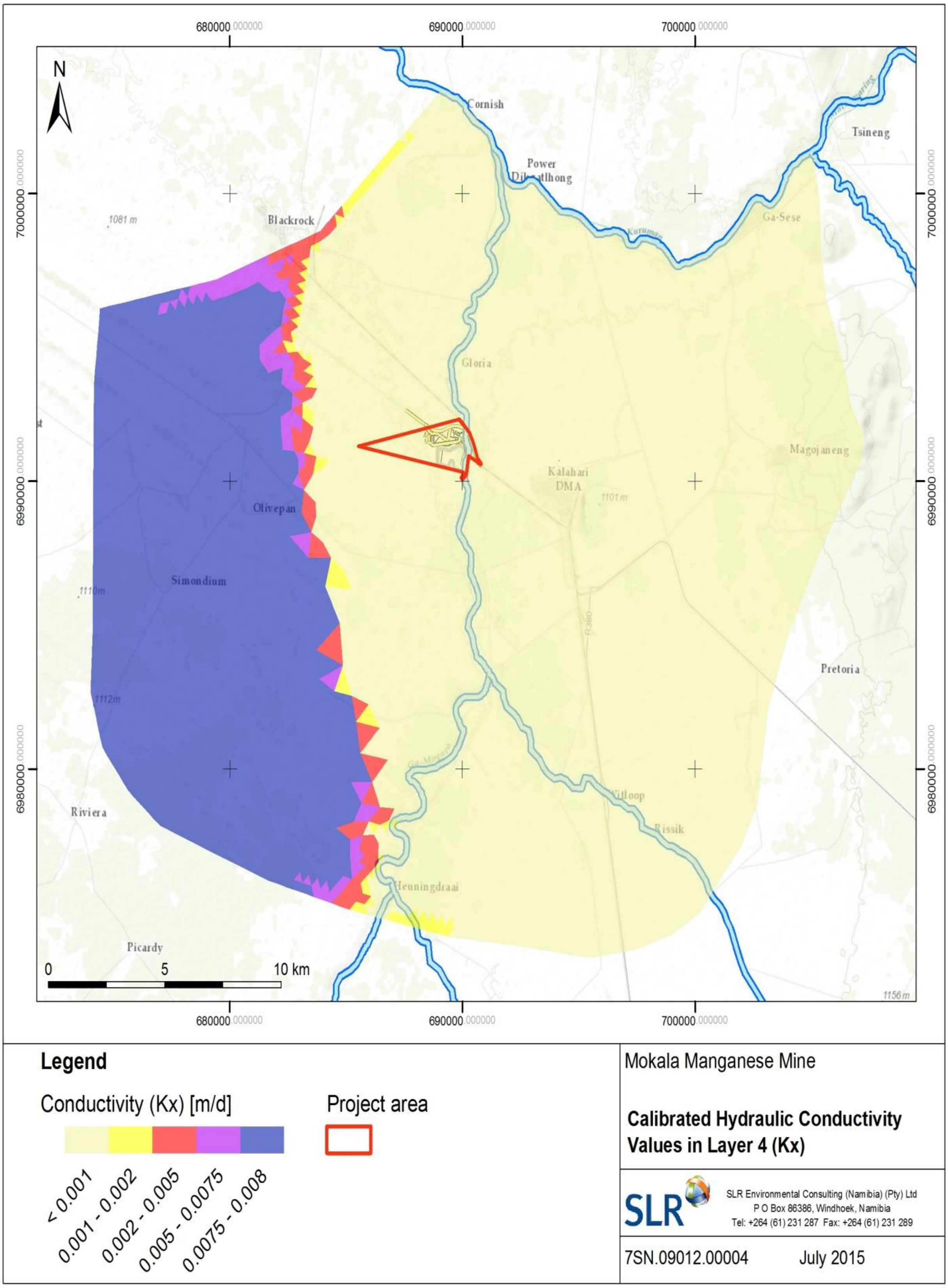


FIGURE 23: CALIBRATED HYDRAULIC CONDUCTIVITY VALUES IN LAYER 4

5.4 WATER BUDGET

The fluid mass balance (water budget) of the calibrated steady state numerical groundwater flow model is shown in Figure 24. Water enters the system via the south-eastern, southern and western model boundaries and outflow takes place via the “drain” boundary condition simulated at the Kuruman River and the constant head boundary in the northwest. A model mass balance error of less than 1.9% applies and the model is considered to be mathematically sound.

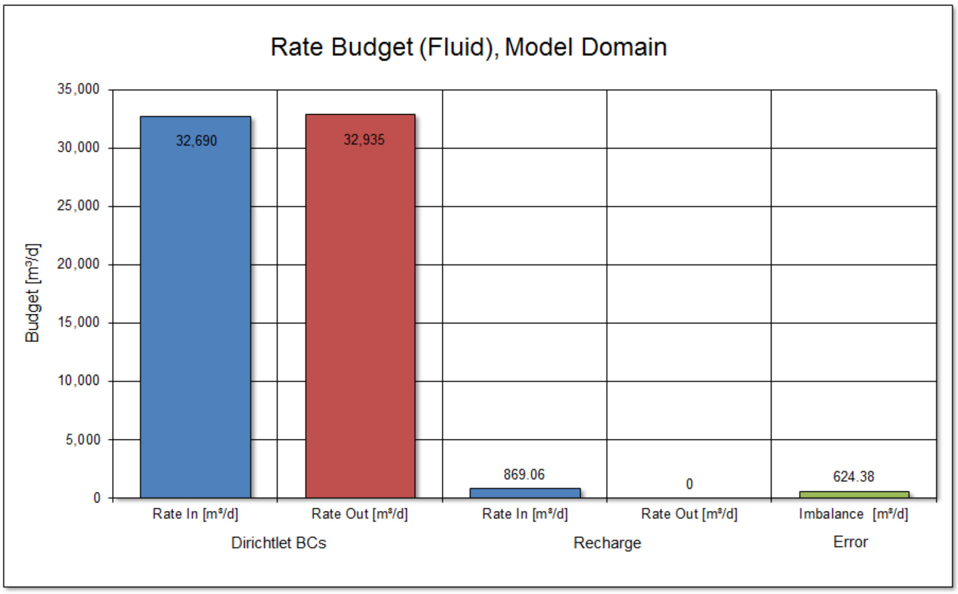


FIGURE 24: WATER BUDGET OF THE ENTIRE MODEL DOMAIN

5.4.1 SIMULATED GROUNDWATER ELEVATIONS

The simulated hydraulic head distribution in the confined, fractured aquifer (model layer 3) is depicted in Figure 25, representing the steady state groundwater flow field.

In general, groundwater flows from east to west but west of the proposed mining development it changes to north-west. A steeper groundwater gradient is visible in east of the Ga-Mogara River where Kalahari sediments are directly underlain by lava of the Ongeluk Formation, a relatively low permeability hydrogeological unit. A flatter gradient prevails west of the Ga-Mogara River attributable to higher simulated hydraulic conductivities.

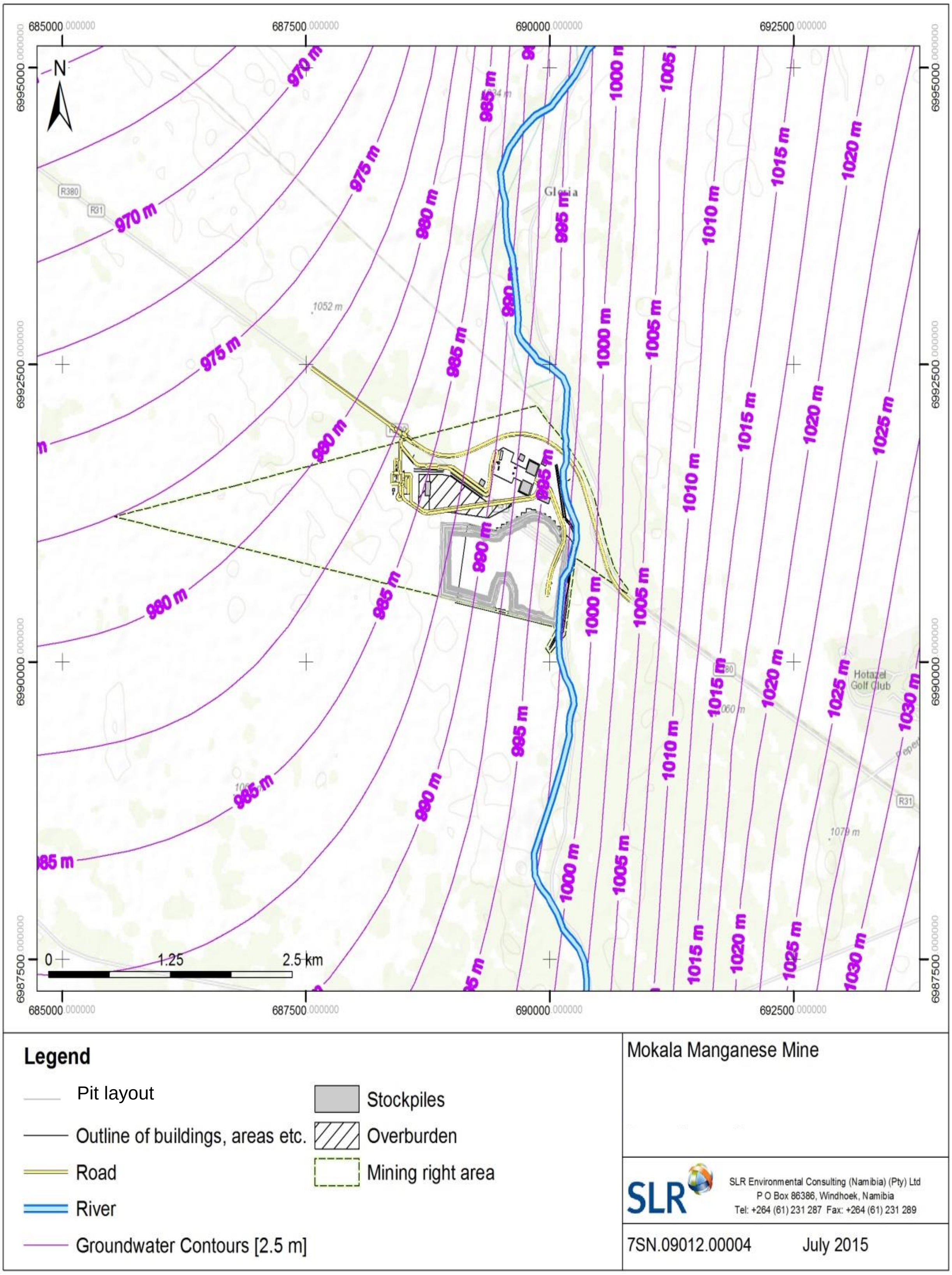


FIGURE 25: SIMULATED GROUNDWATER HEAD DISTRIBUTION IN MODEL LAYER 3

5.5 MODEL CONFIDENCE

The goodness of fit of the steady state calibrations can be described as adequate and predictions made for the study area are assumed to be authentic. Local hydrogeological features (such as dykes and faults) exist in the study area but are not included in the model. Instead, hydrogeological units are simulated as continuous porous media. This usually overestimates predicted radii of influence (ROIs) and inflow rates into mine excavations. Thus, despite the assumption and limitations of the model, the results of the predictive simulations are assumed to be conservative estimates of impacts.

The numerical model is highly sensitive to recharge. The simulation of diffuse recharge processes dependent on rainfall volumes as prevailing in the proposed project area (e.g. Bean 2003) is difficult to simulate accurately in steady state models. Water level time series are not available due to the early state of the project, but when available, should be used to model non-steady (transient) states. Transient modelling would increase the confidence in simulated recharge rates but also the results of predictive simulations. Groundwater flow patterns and predicted plume migration rates for later years of mine development can be improved significantly by taking into account observation data and using it to update of the groundwater model.

Considering the above, the model predictions are considered preliminary.

5.6 TRANSIENT SIMULATION

- After the steady state calibration, the groundwater model was setup and ran in transient mode to account for model variables changes during and after the mining operations: Monthly rainfall averages in the mine area, and
- Annual mining schedule.

5.6.1 MONTHLY RAINFALL TIME-SERIES

As discussed above, the groundwater model is highly sensitive to rainfall recharge. Therefore, monthly rainfall averages (Figure 26) were taken into consideration with the groundwater recharge calculated accordingly.

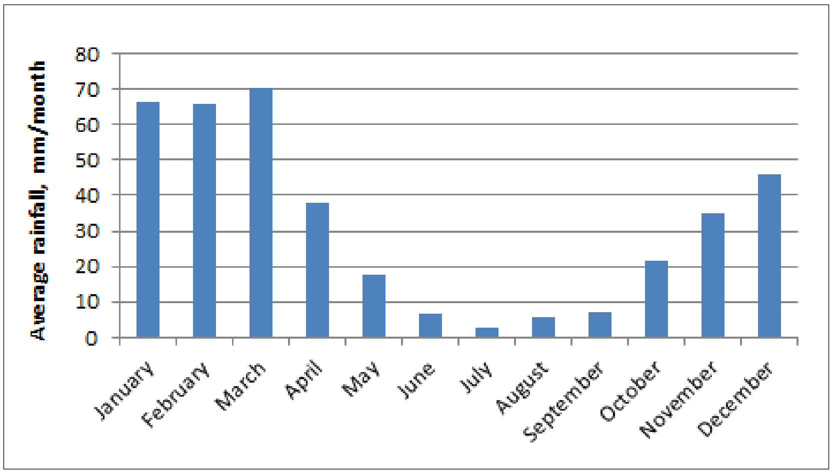
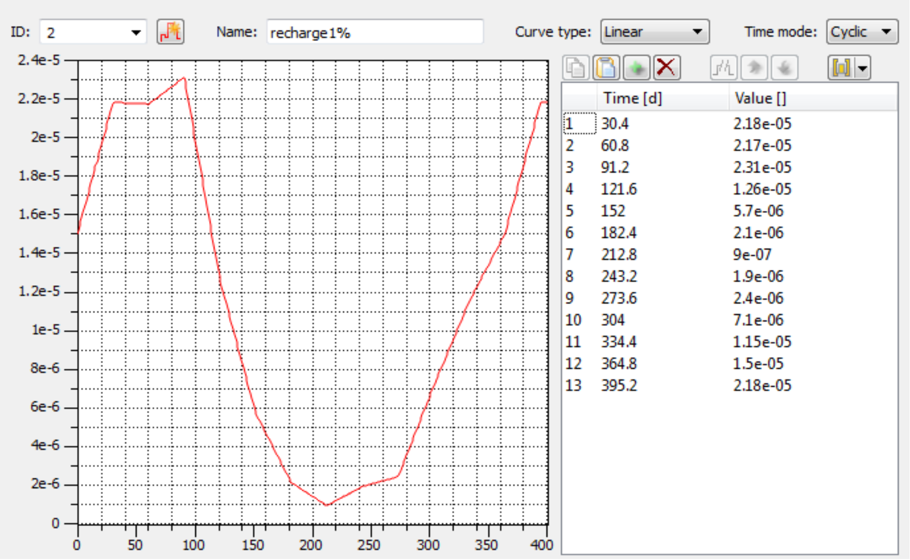


FIGURE 26: AVERAGE MONTHLY RAINFALL

The rainfall recharge to groundwater was considered at same percentage as in the steady-state calibration run, at 1% of rainfall values. The time-series used in the transient groundwater model is a 12-months cyclic series over the whole duration of the model run, as shown in Figure 27.



ID: 2 Name: recharge1% Curve type: Linear Time mode: Cyclic

	Time [d]	Value []
1	30.4	2.18e-05
2	60.8	2.17e-05
3	91.2	2.31e-05
4	121.6	1.26e-05
5	152	5.7e-06
6	182.4	2.1e-06
7	212.8	9e-07
8	243.2	1.9e-06
9	273.6	2.4e-06
10	304	7.1e-06
11	334.4	1.15e-05
12	364.8	1.5e-05
13	395.2	2.18e-05

FIGURE 27: CYCLIC RECHARGE TIME-SERIES

5.6.2 MINING

For more accurate representation of groundwater regime and development of contaminant plume during and post-mining, the mining schedule was incorporated in the groundwater model.

As per Client communication, open pit mining takes place over a period of 15 years. Mining operations consist of parallel stripping on an East-West direction. It is planned that no more than 40 parallel strips will be mined at Mokala (2 strips at the same time). To simplify the simulation of mining, the open pit area was divided into 15 parallel strips, representing the annual mining advancement (Figure 28).

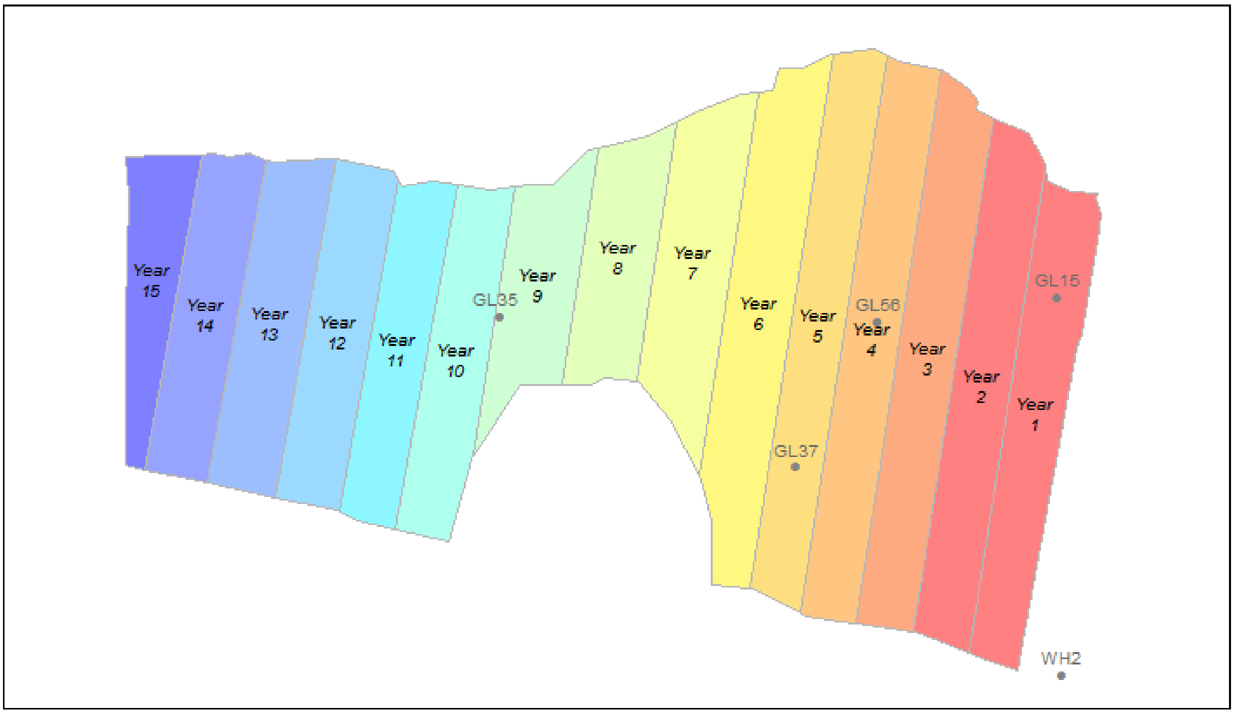


FIGURE 28: MINING SCHEDULE - ANNUAL ADVANCEMENT

Mining was simulated as following:

- Assign seepage face boundary condition to all nodes incorporated in the mining area (Figure 29); the seepage face nodes represent a hydraulic head boundary condition with a maximum constraint of zero; this allow only negative flows through the nodes when the hydraulic head is higher than the respective nodes elevation; the negative flow imposed by the zero maximum constraint implies that all groundwater is pumped out from the hydraulic system (sump pumping).
- Assign modulation functions to activate the seepage in each node at the respective time when mining takes place; the modulation function with the value = 1 applied to the seepage nodes activates the seepage face condition, and therefore flow is allowed through the respective nodes as per the seepage face condition (negative flow, as described above); the was used GAP in the modulation function to consider the nodes without any boundary condition or constraint until the time when these are activated (Figure 30).
- All boundary conditions and constraints for the model nodes within the open pit were deactivated after 15 years of mining, as passive groundwater inflow will not be pumped out from the open pit (closure scenario).

The transient simulation was run for a period of 100 years to allow sufficient time for the impact assessments.

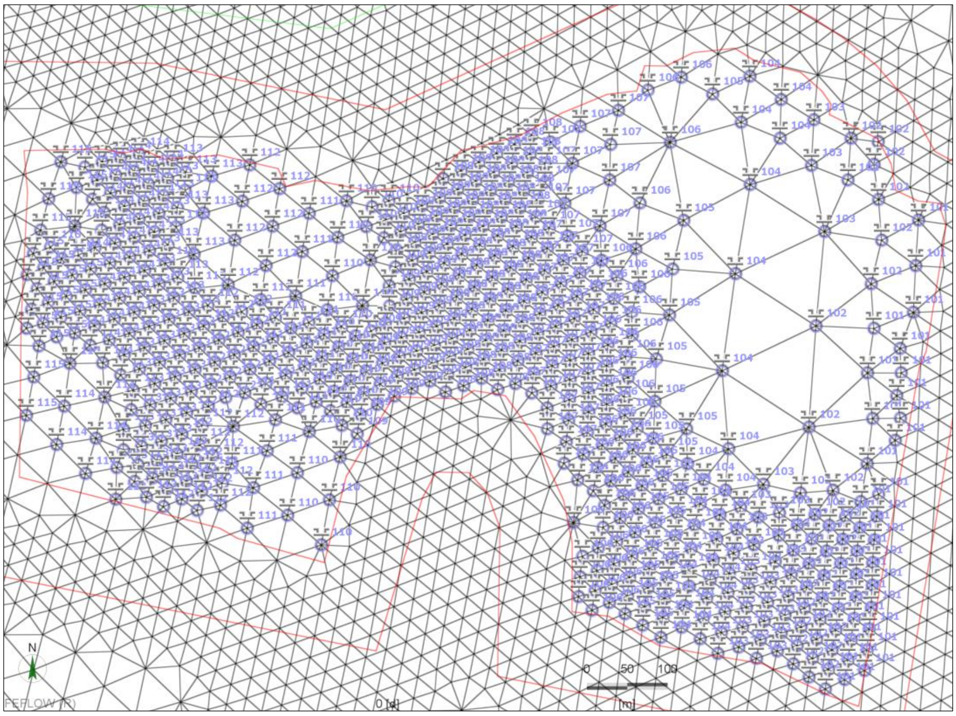
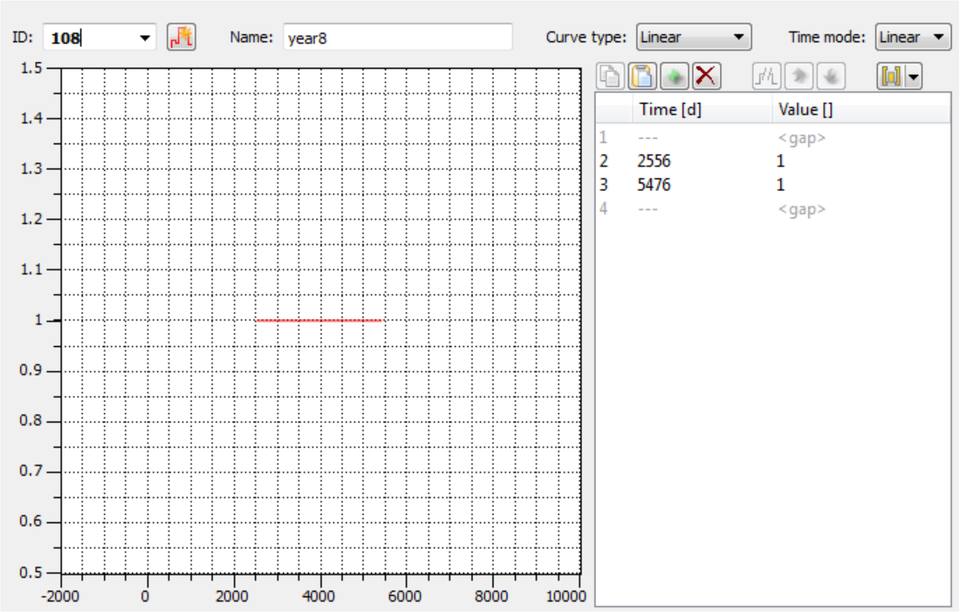


FIGURE 29: SEEPAGE FACE NODES WITHIN THE OPEN PIT


ID: 108

Name: year8

Curve type: Linear

Time mode: Linear

	Time [d]	Value []
1	---	<gap>
2	2556	1
3	5476	1
4	---	<gap>

FIGURE 30: MODULATION FUNCTION TO ACTIVATE/DEACTIVATE NODES CONDITIONS

6 WATER SUPPLY FROM GROUNDWATER BOREHOLES

The potential of production groundwater boreholes in the vicinity of Mokala Mine is described as generally low (Section 4.3).

From the eight tested boreholes, only one groundwater borehole (GL27) proved a reasonable pumping yield of 1.0 l/s, over 24 hrs testing period. The recovery was recorded over a period of 24 hrs and the borehole recovered to 93% of initial water level.

The rest water level measured in GL27 was 113.4 mbgl. The test pump was installed at 150 mbgl and provided approximately 36 m of available drawdown. The drawdown achieved during 24 hrs of pumping was measured at 36m.

Figure 31 shows the recorded water levels during the pumping and recovery stages at GL27.

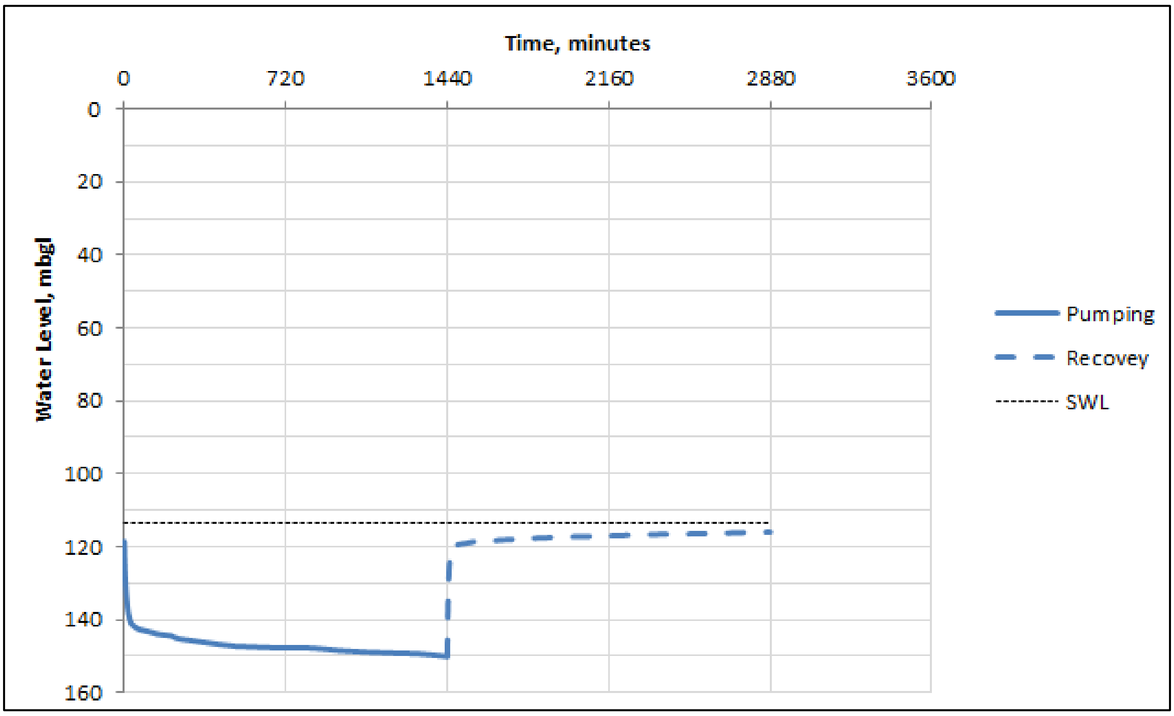


FIGURE 31: GL27 PUMPING TEST

GL27 can be used by the Mine as water supply borehole, with the following recommendation:

- Pump installation depth: 155 mbgl
- Pumping yield: 1.0 l./s
- Maximum pumping water level to be achieved: 150 mbgl
- Pumping duration: not more than 10 hrs/day, allowing for a maximum daily production of 36,000 litres of water to be pumped out.

- Note that the laboratory test results on groundwater from GL27 indicate that this water does not meet the prescribed concentrations for potable water quality and therefore should not be used for drinking.

7 IMPACT ASSESSMENT

Predictive simulations were run in the calibrated numerical groundwater model. The simulation results indicate the potential impacts of mine dewatering and steady state conservative contaminant transport scenarios. Relevant assumptions and limitations are detailed in the specific sections.

The impacts indicated by the model have been assessed according to the methodology described in Appendix E.

7.1 MINE PIT DEWATERING

7.1.1 ASSUMPTIONS AND LIMITATIONS

In the steady-state dewatering scenario the dewatering of the fully developed pit shell was simulated which displays a conservative approach to dewatering impacts. The footprint of the open pit shell that would mine a section of the Ga-Mogara River is presented in Figure 32.

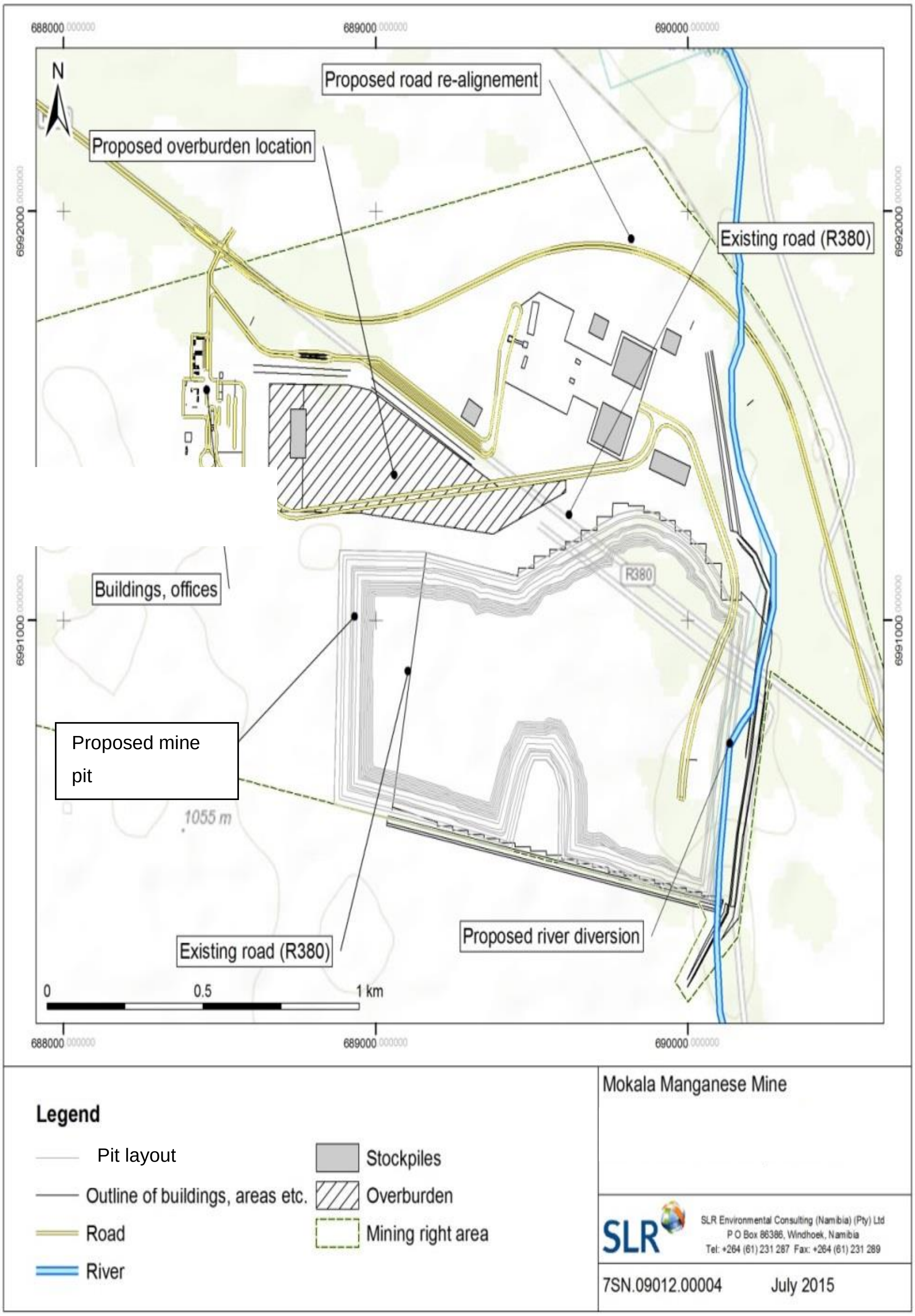


FIGURE 32: PROPOSED MINE LAYOUT INCLUDING THE FULL EXTENT OF THE OPEN PIT

The maximum pit floor elevation is 870 mamsl which equals to a maximum pit depth of approximately 170 mbgl. Figure 33 presents a south to north cross-section through the western part of the proposed pit shell.

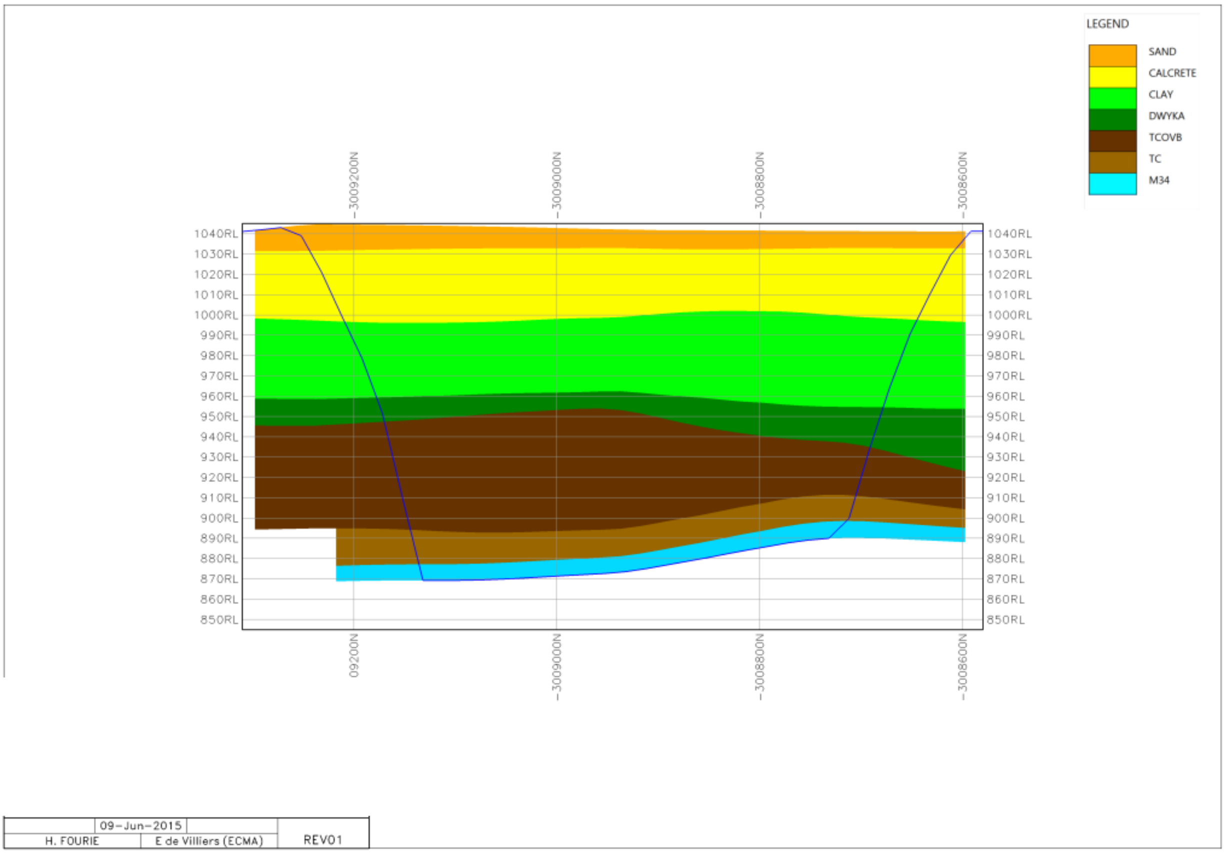


FIGURE 33: S-N CROSS SECTION THROUGH WESTERN PART OF THE PROPOSED PIT SHELL

The steady-state inflow to the pits was calculated using hydraulic head boundary conditions assigned at the pit bottom, acting as drains, removing water from the system without allowing flow back into the system. To account for the non-uniqueness in the calibration of the steady state numerical groundwater model and to provide an uncertainty range in calculated mine pit inflow rates the calibrated hydraulic conductivities were increased and lowered by 10% in additional scenarios.

The transient simulation considered the annual mining rate as shown in Figure 28. The nodes included in any specific mining year strip were activated at the time steps values corresponding with the mining year.

7.1.2 RESULTS

The groundwater head contour lines as a result of dewatering the fully developed pit shell (steady-state simulation) are shown in Figure 34. Due to the aquifer characteristics in the focus area, a north-south elongated cone of depression occurs following the geological strike direction. Steep groundwater gradients are simulated east of the mine in lava of the Ongeluk Formation. The result suggests that mine pit dewatering will have lower impact on water levels west and east of the pit.

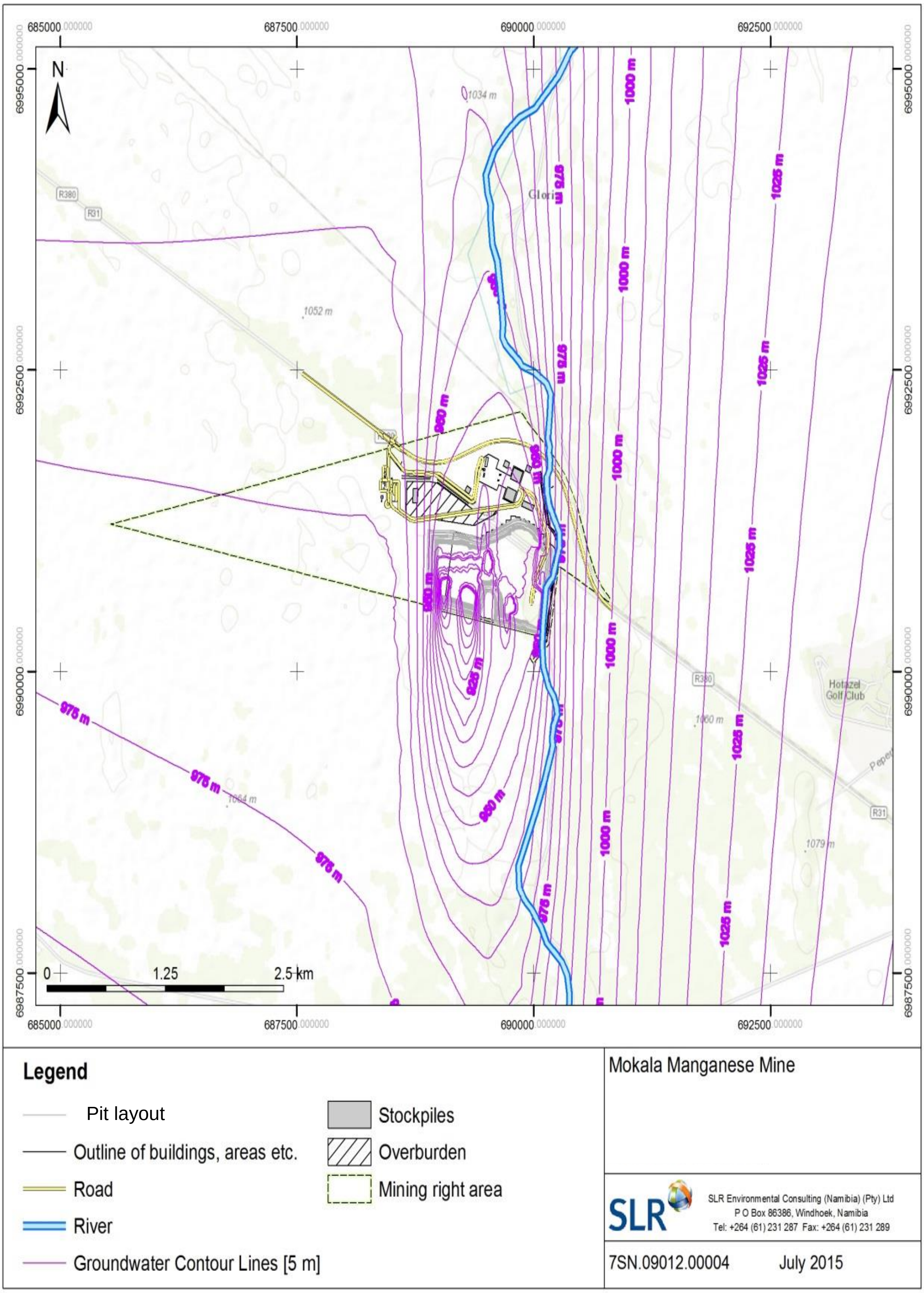


FIGURE 34: SIMULATED GROUNDWATER CONTOURS (MAMSL) FOR THE FRACTURED AQUIFER AFTER DEWATERING OF THE FULLY DEVELOPED PIT SHELL (STEADY-STATE SIMULATION)

The transient distribution of the hydraulic heads around the open pit are shown in the Figures below, as following:

- Figure 35 : Drawdown at the end of mining (Year 15).
- Figure 36 : Drawdown at the end of Year 30.
- Figure 37 : Drawdown at end of simulation (Year 100).

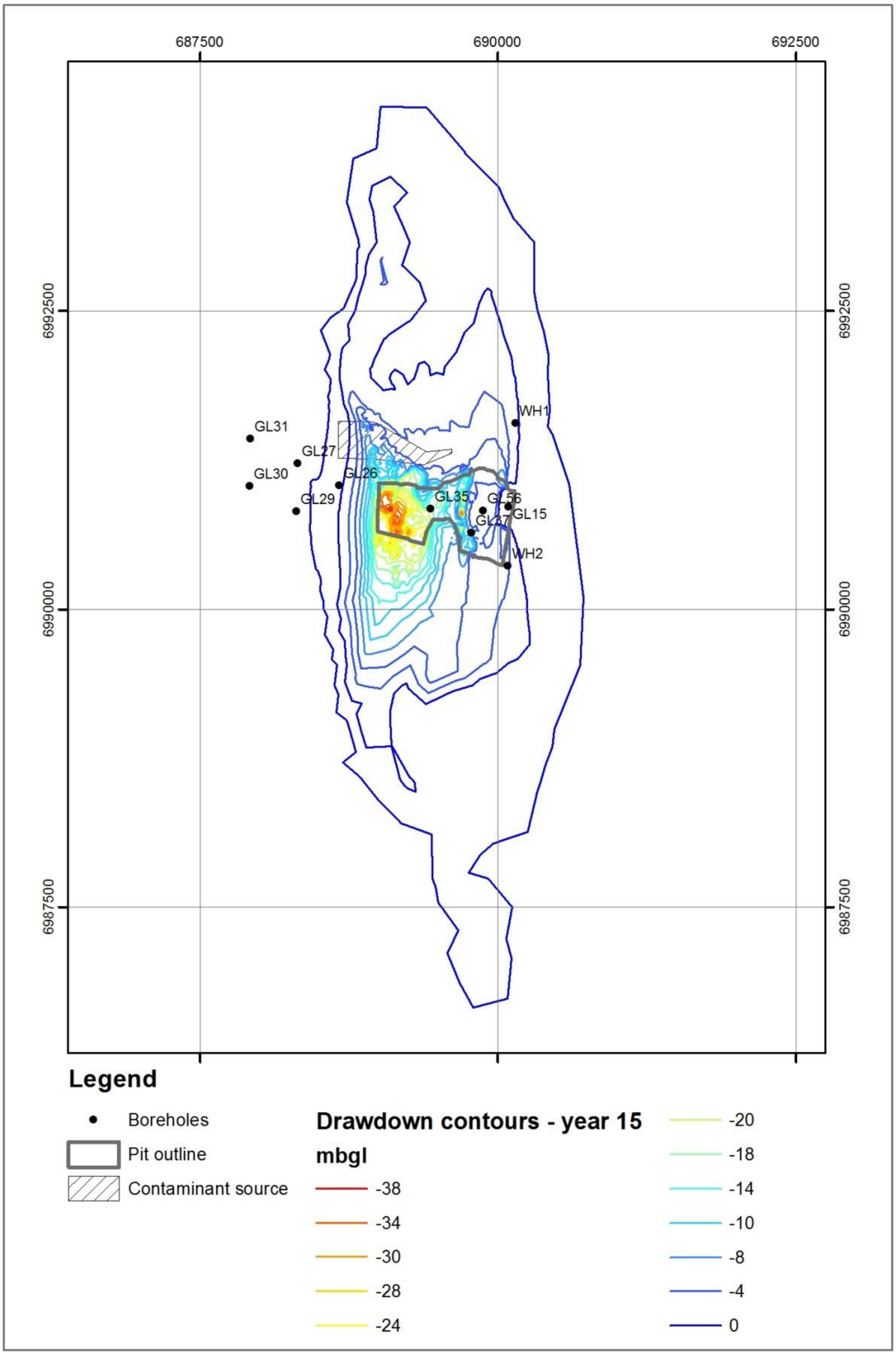


FIGURE 35: SIMULATED DRAWDOWN - YEAR 15 (END OF MINING)

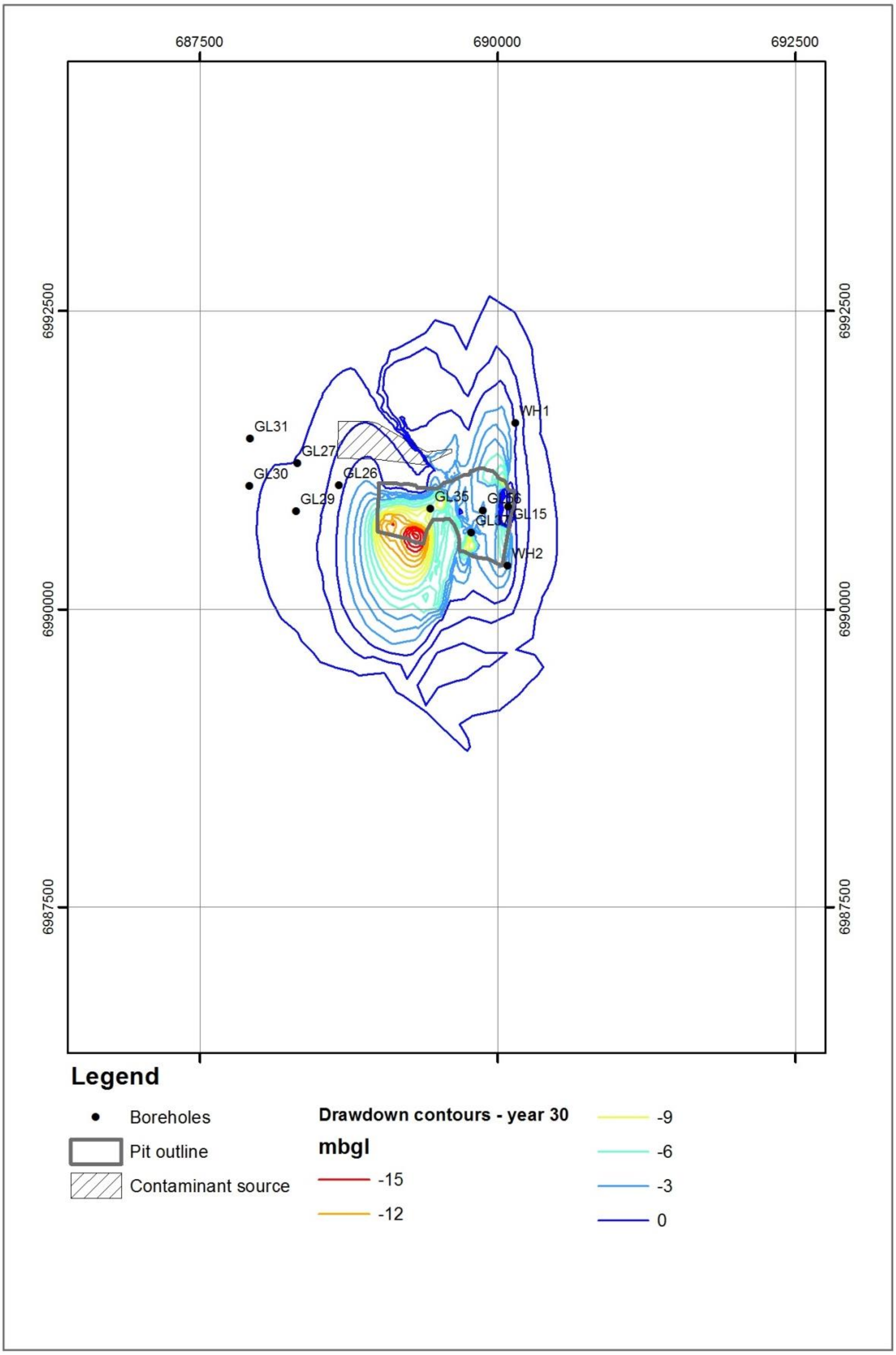


FIGURE 36: SIMULATED DRAWDOWN – YEAR 30 (15 YEARS POST-MINING)

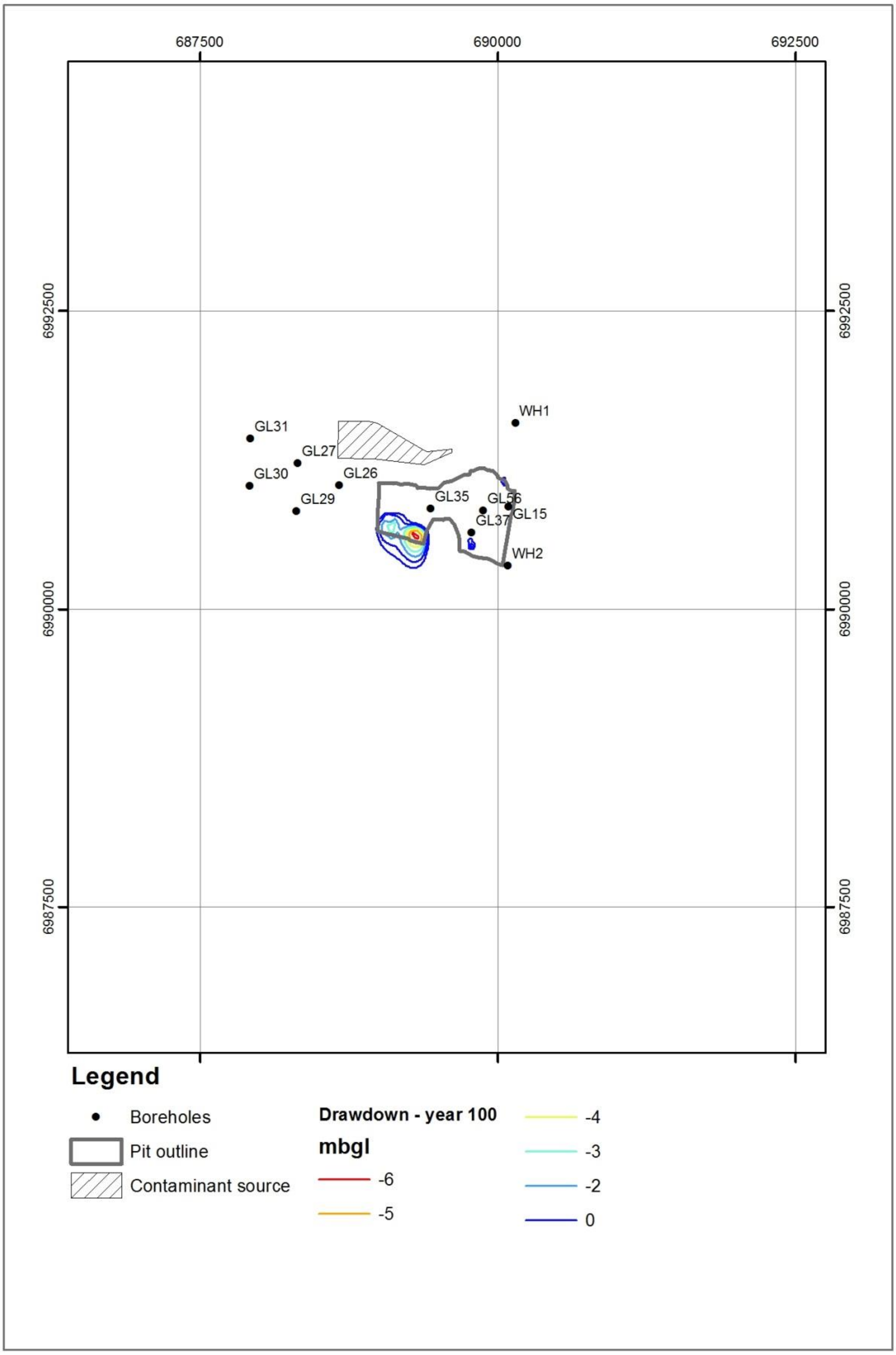


FIGURE 37: SIMULATED DRAWDOWN - YEAR 100 (END OF SIMULATION)

To visualise the Radius of Influence (ROI) around the dewatered mine pit the cone of depression is illustrated in the drawdown map presented in Figure 38. The ROI has an elliptical shape with an extent of approximately 5 km to the north and south and approximately 1 to 1.5 km towards the east and west. The simulated drawdown below the proposed Overburden Stockpile ranges between approximately 25 m and 35 m and it is likely that the water level will be drawn down below the sediments of the Kalahari Formation.

The highest impact on boreholes is expected in the direct vicinity to the proposed mining infrastructure and only a minor negative impact on borehole yields is expected for boreholes further away from the project site. It is unlikely that an additional water level drawdown will be observed that far from the mine pit. Structural features like faults and NNE-SSW trending bostonite dykes were not simulated in the model. Instead hydrogeological units were simulated as continuous units by applying the representative elementary volume (REV) principle in which aquifer parameters are integrated over a much larger volume of aquifer material, incorporating both the rock matrix and inherent fractures. This is unlikely to be the case in reality, where some form of barrier or impermeable matrix is likely to exist. The dykes in the area are inferred to represent such barriers.

It must furthermore be kept in mind that the water table in the area is already affected by inflows into the neighboring mines and impacts on water users in the area should therefore be considered as cumulative.

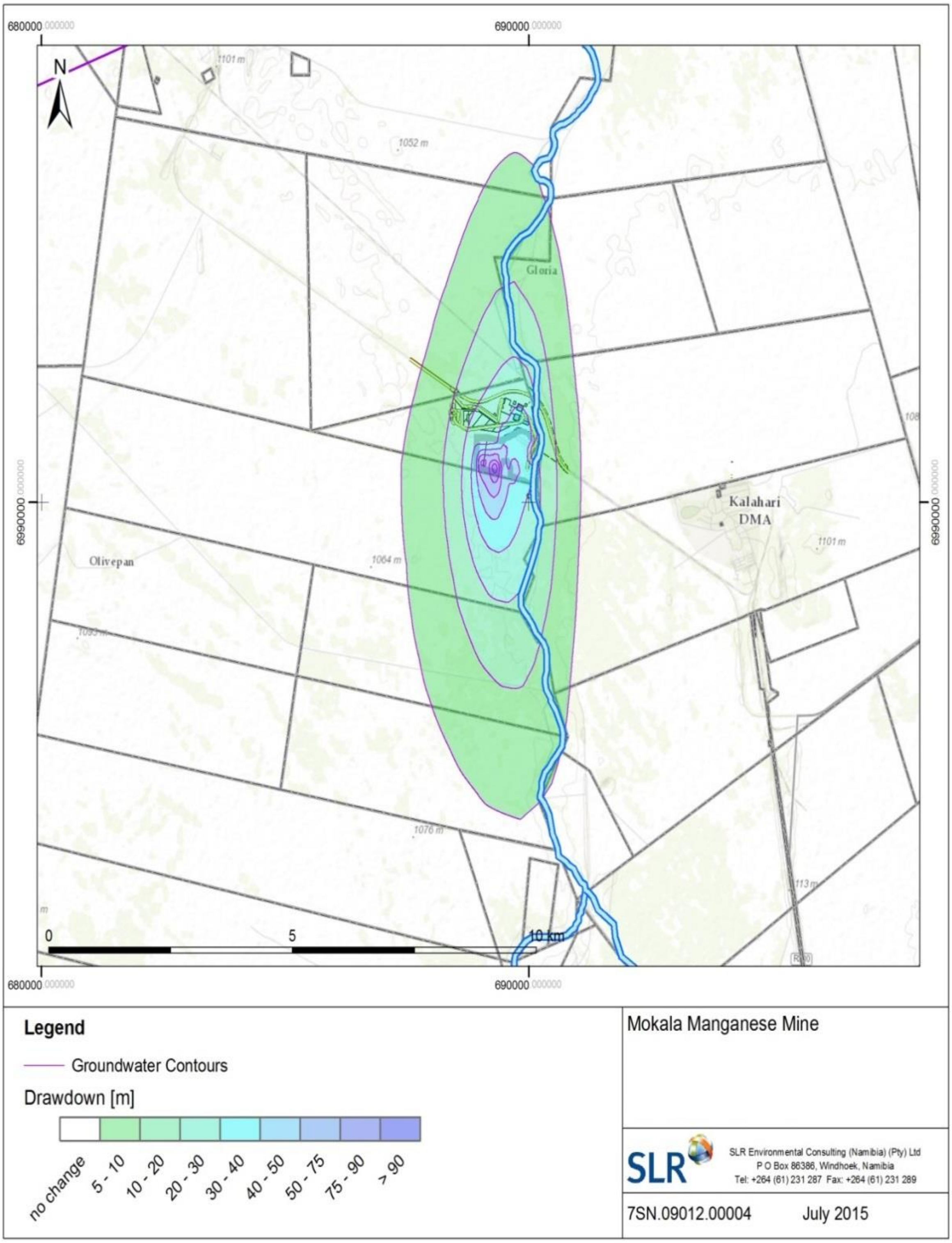


FIGURE 38: SIMULATED ADDITIONAL DRAWDOWN IN MODEL LAYER 3 DUE TO MINE DEWATERING

Estimates on mine pit inflow rates calculated using the base case model and the model scenarios assuming increased and decreased hydraulic conductivity values are presented in Figure 39. The inflow rates range between 217 m^3/d (2.5 L/s) and 438 m^3/d (5.0 L/s). Note that inflow rates are for modelled steady state conditions. Under transient conditions inflow rates would increase over time to the equilibrium steady state rate.

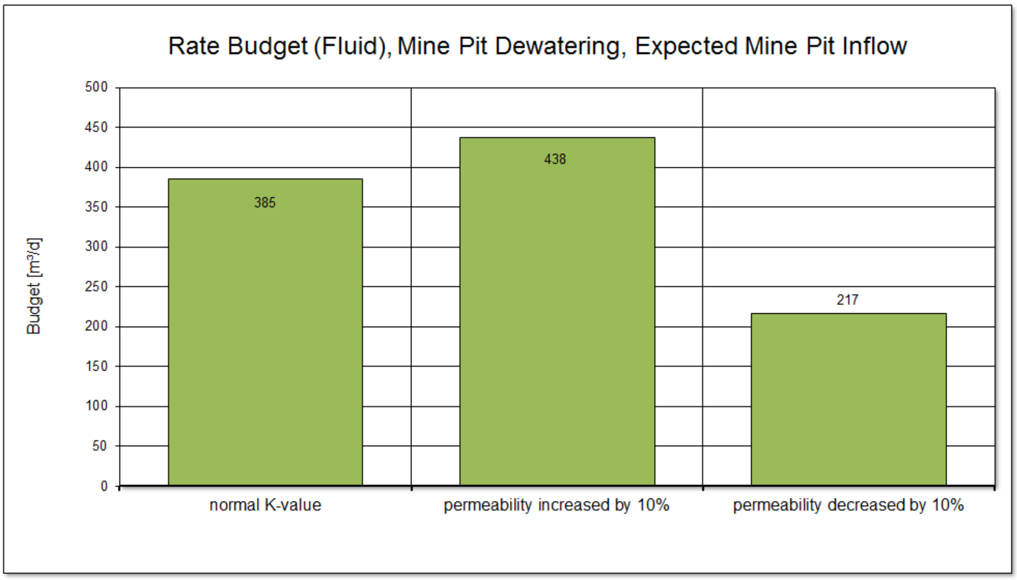


FIGURE 39: ESTIMATED PIT INFLOW RATES UNDER DIFFERENT SCENARIOS

The passive groundwater inflows into the Mokala open pit computed for 15 years of mining transient simulation (Figure 28) are shown in Figure 40.

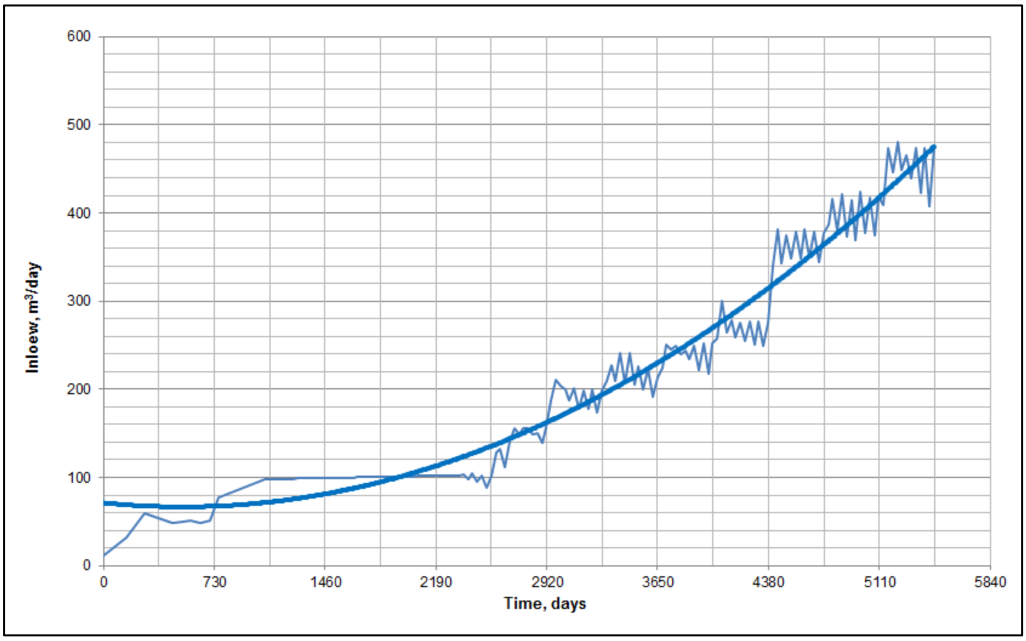


FIGURE 40: PASSIVE GROUNDWATER INFLOWS (TRANSIENT SIMULATION - 15 YEARS)

The analytical solution of passive groundwater inflows is matching the predicted passive inflows computed during the transient simulation, The transient passive groundwater inflow is increasing gradually, as mining is progressing reaching a maximum inflow of 473 m^3/day (5.5 L/s).

Mokala proposes to backfill the pit with material from the overburden stockpile. For the time after mine closure, groundwater level recovery in the pit backfill material was simulated. A hydraulic conductivity of 0.864 m/d ($1*10^{-5}$ m/s) and a porosity of 20% for the backfilled material was simulated based on SLR experience with similar materials elsewhere. This compares to calibrated hydraulic conductivities and porosities of 0.48 m/d / 10% (Kalahari sediments), 0.0014 m/d / 1% (Dwyka Formation) and 0.11 m/d / 2.5% (Hotazel Formation) of the surrounding host rocks.

The time for pit water level recovery was determined using an analytical approach. A stage/volume relationship was calculated using the pit shell information provided by Mokala and conservative porosity values of 10%, 15% and 20% for the backfill material. Factors such as the shape, size, and the degree of sorting of the backfill material play a major role in porosity and may also vary significantly within the backfilled opencast pit areas. The maximum mine pit inflow rate simulated in the dewatering scenario (438 m^3/d) was used as the maximum net inflow rate in the calculation. This was assumed to decrease linearly with rising pit water levels from 438 m^3/d (fully developed pit shell) to 0 m^3/d (fully recovered pit groundwater levels). At full recovery inflows to, and outflows from, the backfilled pit are equal.

In Figure 41 and Figure 42 the pit water level / pore volume relationship and the projected rise of the mean water level in the backfilled mine pit at different porosity estimates are presented, respectively. The results indicate that full recovery of pit water levels will take 300 to 600 years depending on the porosity of the backfilled material. While showing a steep rise in pit water levels during the first years after mine closure water levels continue to rise only slowly in later years. This implies that the backfilled mine pit will most likely continue to represent a local sink for several years capturing potential residual pollutants in the unsaturated and saturated zones below the overburden stockpile while also delaying the spreading of potential pollutants in the backfill material.

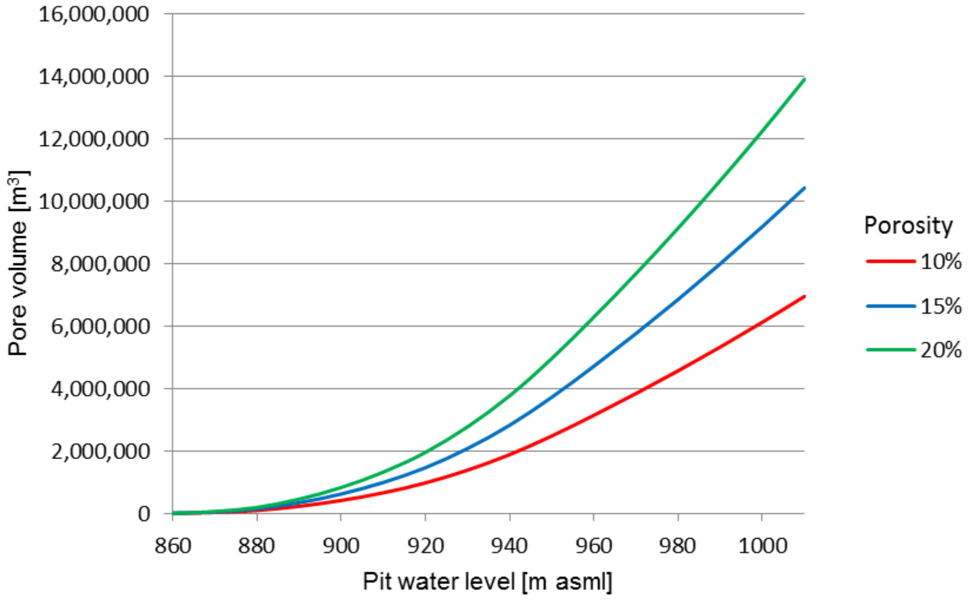


FIGURE 41: PIT WATER LEVEL/PORE VOLUME RELATIONSHIP

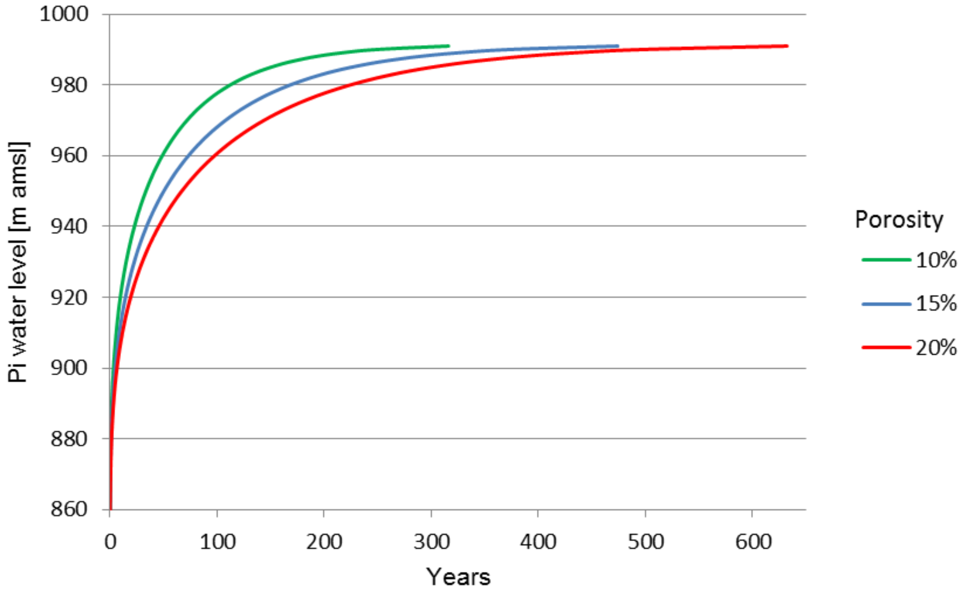


FIGURE 42: PROJECT RISE OF PIT WATER LEVELS

7.1.3 IMPACT ASSESSMENT

The field programme did not identify an aquifer associated with the Ga-Mogara River. Therefore, groundwater drawdown associated with the proposed Mokala pit is not expected to change base flow of the river.

The modelled zone of 20 m to 40 m of groundwater drawdown extends off the Mokala proposed project site onto the northeast corner of the farm Umtu 281. The hydrocensus identified no boreholes in this area. Further south, the modelled drawdown is less than 20 m. The hydrocensus identified four boreholes along the Ga-Mogara and on the farm Olive Pan 282. All of the boreholes are used by neighbouring manganese mines for groundwater monitoring. The anticipated drawdown in these boreholes will assist in characterising cumulative drawdown impacts from mining operations in the area. However, no users of groundwater for domestic or livestock use are likely to be affected. Therefore, the severity of the groundwater drawdown impact is assessed as LOW.

Based on the modelling, the duration of the groundwater drawdown will last several centuries. This extends beyond mine closure and is ranked as HIGH.

The modelled area of drawdown impact extends beyond the proposed project boundaries but is limited to the local area. Therefore, the spatial scale of the impact is ranked as MEDIUM.

Based on the assessed severity, duration, and spatial scale the consequence of the drawdown impact is ranked as LOW.

The drawdown impact has a small likelihood of affecting local groundwater users. Therefore, the probability of this impact is ranked as LOW.

Based on the consequence and probability of the drawdown impact, the significance is rated as LOW.

7.1.4 IMPACT MITIGATION

The drawdown in groundwater levels around the proposed Mokala pit cannot be prevented since it is the inevitable consequence of excavation below the groundwater table and subsequent mine pit dewatering. However, should it occur, the impact of lowered groundwater levels can be managed to reduce the effect on other groundwater users. SLR recommends the following mitigations of the groundwater drawdown impact:

- Mokala should operate a monitoring programme (see Recommendations sections for details)
- Although, a limited number of domestic/livestock supply boreholes were identified during the hydrocensus, SLR cannot exclude the possibility that the yield of some user's boreholes may be reduced or cut off by the groundwater level drawdown around the pit. Therefore, Mokala should budget for replacing the water supply of any domestic/livestock groundwater users affected by the groundwater level drawdown. The decision on whether groundwater supply has been impacted should be informed by the groundwater monitoring programme, and the model results presented in this report.
- Mokala should keep a record of groundwater volumes abstracted from boreholes and the open pit throughout the life of mine.

- Mokala should keep a record of rainfall throughout the life of mine.

With mitigation, the significance of the pit dewatering impact remains LOW.

7.2 GROUNDWATER CONTAMINATION

7.2.1 ASSUMPTIONS AND LIMITATIONS

Potential plumes emanating from the most significant potential sources (overburden stockpile) were simulated in a steady-state flow, non-reactive, transient solute transport model. No lining or base preparation of the stockpile footprint was assumed. No specific source concentration was simulated and the plumes are illustrated in percentages of the relative source concentration applied to the overburden stockpile. Consequently the concentration of a distinct parameter at a given location can be determined as the simulated percentage of its initial source concentration. Impacts associated with ad hoc sources such as spillages were not modelled. It is furthermore assumed that these ad hoc can be managed by Mokala using accepted management measures.

The calibrated steady state flow field served as the base in the transient non-reactive solute transport model. According to the dewatering scenario, the entire proposed mining infrastructure will be located within the cone of the depression of the dewatered mine pit. Therefore, it is assumed that the mine pit will eventually capture potential leachates and consequently a partial recycling of the seepage water with subsequent potential salt build-up within the water system of the mine is a possibility to be considered by Mokala.

Further, adsorption and potential degradation were not modelled and the solute was treated as a conservative tracer by simulating only advection, longitudinal and transversal dispersion. Hence, processes that could reduce transport of contaminants were not simulated. Since site-specific information on effective porosity, dispersivity and seepage rates and on the potential source concentration were not available the following assumption were made:

- No specific source concentration is simulated and the plumes are modelled in percentages of the relative source concentration applied to the overburden stockpile
- The ratio between longitudinal, transversal and vertical dispersivity (D_L, D_T, D_V) is 100:10:1 (Kinzelbach et al., 1995). A longitudinal dispersivity of 20 m was simulated.
- Simulated effective porosity for the Kalahari beds is 10% and 1% to 2.5 % for the underlying bedrock units (no site specific information available)
- Two times calibrated natural recharge was simulated over the overburden stockpile footprint to account for potential increased infiltration rates in the mostly unconsolidated overburden material.

- A constant seepage concentration is assumed (steady-state model). This is a worst case assumption as in reality seepage concentration will decline over time due to leaching processes in the stockpile. The stockpile will also only exist as a source during the life of mine.
- No transport in the unsaturated Kalahari beds is simulated, i.e. the initial source concentration is applied to the groundwater table. In reality potential seepage will flow through approximately 45 m of unsaturated Kalahari beds to reach the groundwater table resulting in an additional time lag and attenuation of contaminants in the unsaturated zone not depicted by the model

Effective porosity is the most significant uncertainty in the transport model. Reported effective porosity values for sediments of the Kalahari Formation applied in studies on neighbouring sites range between 15% and 30% (SLR, 2015b). These may be realistic for sand and fractured calcrete of Kalahari age. However, they are likely to be too high for clay, or clay-bearing sands and calcrete. Therefore, the Kalahari Formation was simulated with an effective porosity of 10%.

7.2.2 RESULTS

The simulated relative concentrations of the potential plume emanating from the overburden stockpile after 100 years are presented in Figure 43, Figure 44 and Figure 45 for model layers 1, 2 and 3, respectively.

A fast decrease of the source concentration in downstream direction within short distance is predicted for the Kalahari Aquifer. In approximately 200 m distance from the overburden stockpile only 10% of the initial concentration is observed. After 100 years maximum concentrations less 50% and 7.5% are predicted to be found in the Dwyka Formation and Hotazel Formation, respectively, while in the Hotazel Formation (fractured aquifer) concentration decrease to less than 0.25% of the source concentration in approximately 600 m distance northwest of the proposed overburden stockpile.

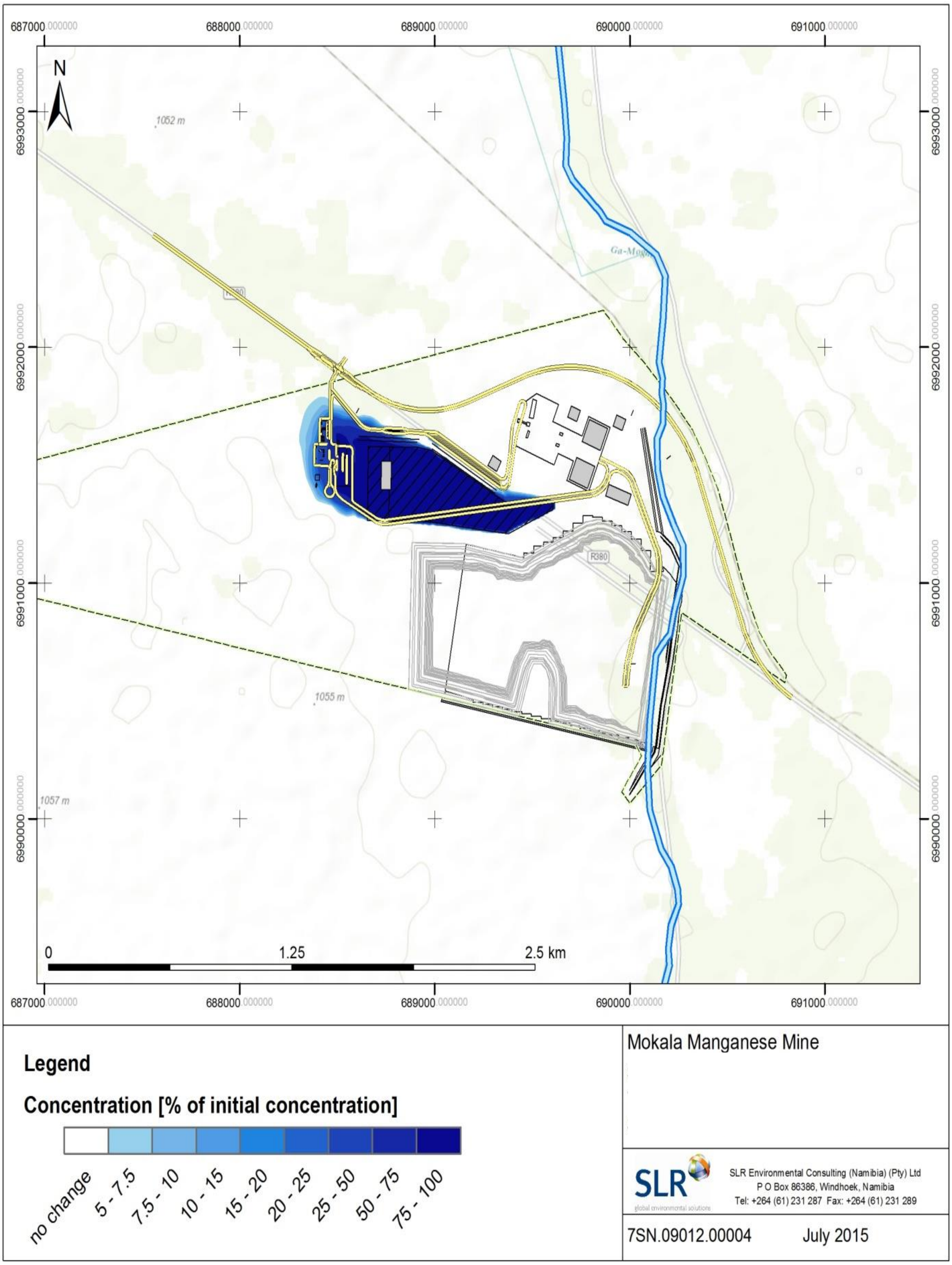


FIGURE 43: SPREADING OF POTENTIAL PLUME IN KALAHARI AQUIFER (MODEL LAYER 1) AFTER 100 YEARS

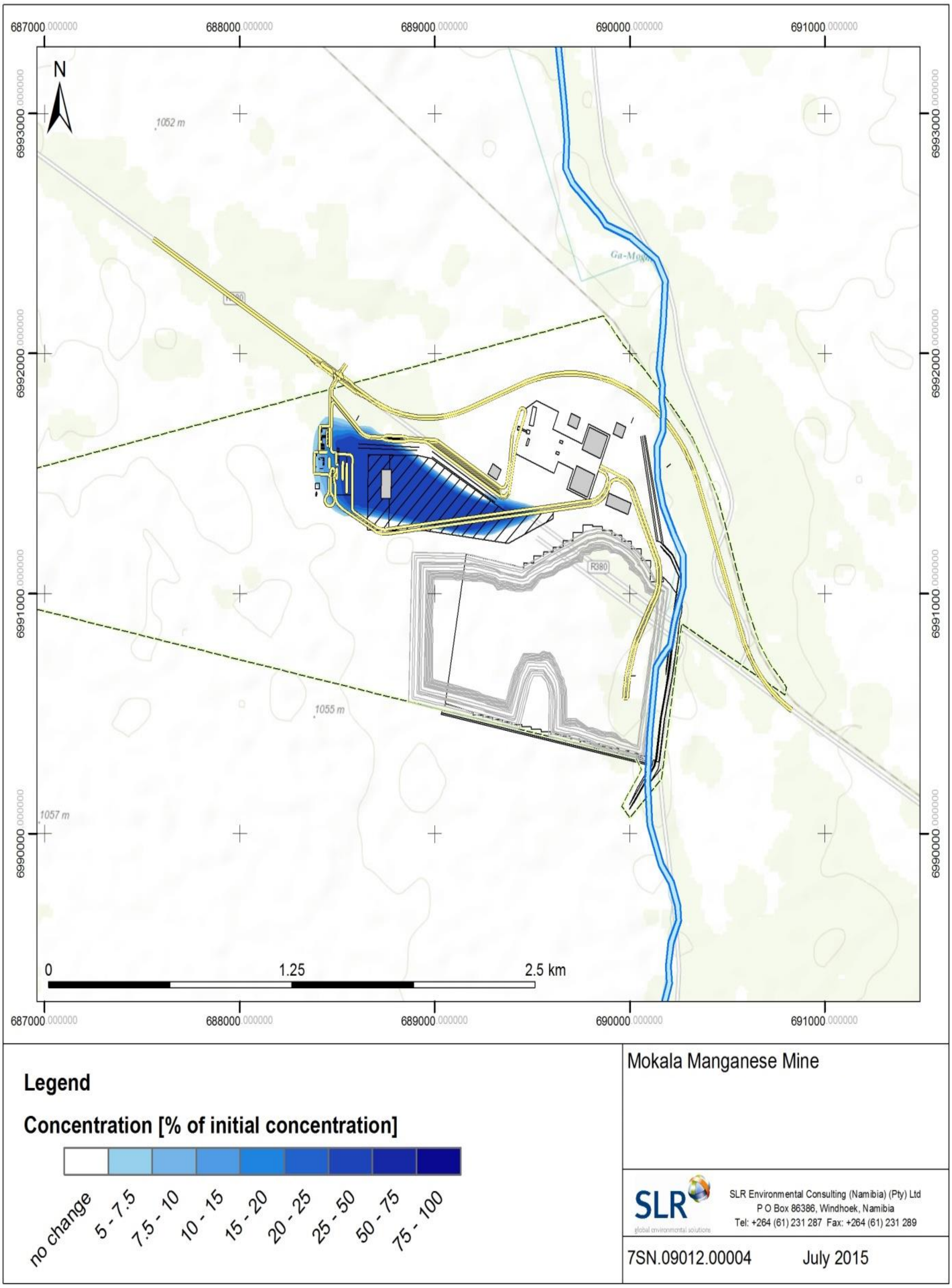


FIGURE 44: SPREADING OF POTENTIAL PLUME IN DWYKA FORMATION (MODEL LAYER 2) AFTER 100 YEARS

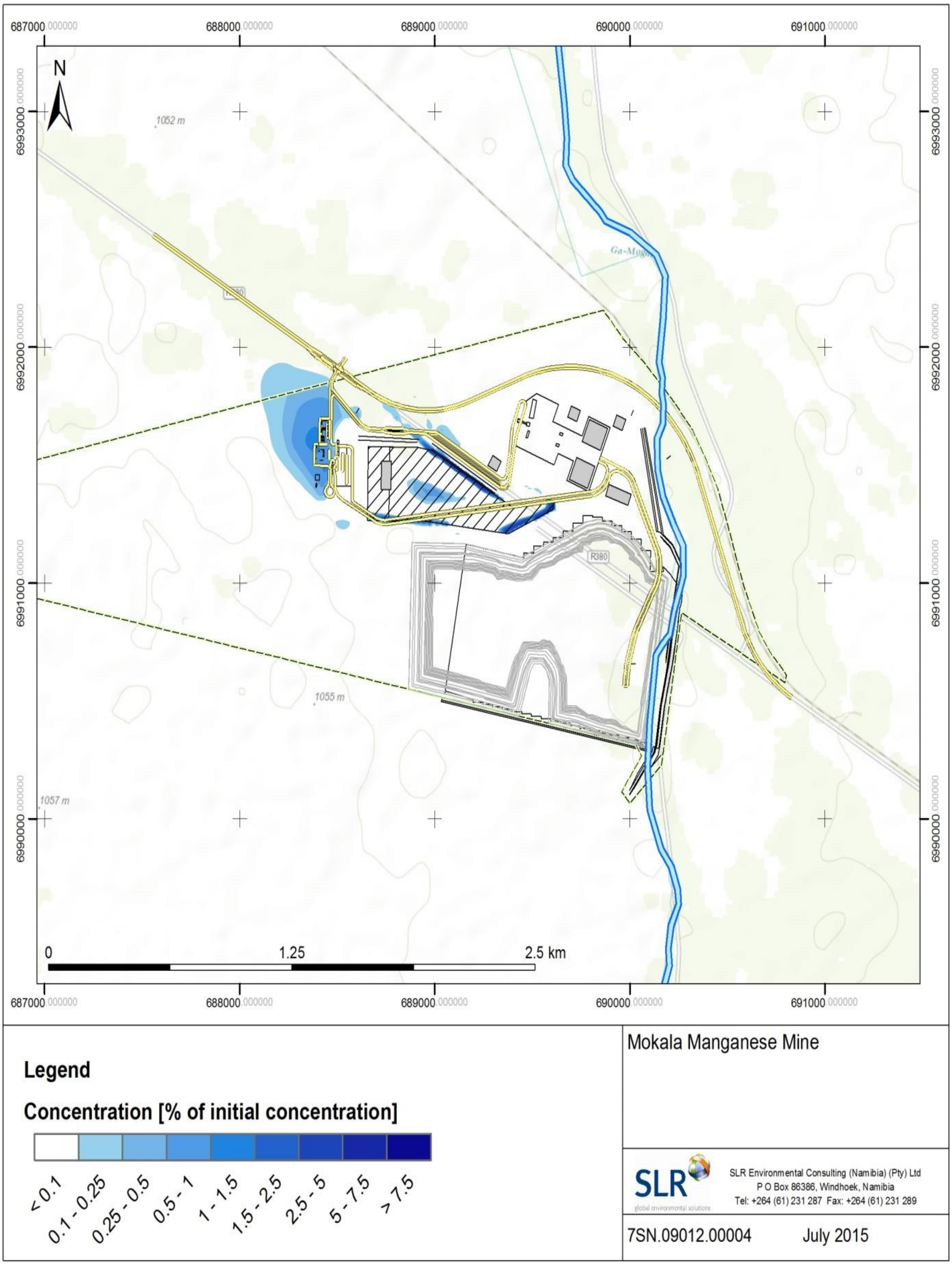


FIGURE 45: SPREADING OF POTENTIAL PLUME IN FRACTURED AQUIFER (MODEL LAYER 3) AFTER 100 YEARS

7.2.3 IMPACT ASSESSMENT

Given that groundwater is saline and of limited potability, SLR assesses the severity of the groundwater contamination impact as LOW.

Dewatering of the pit will persist for several hundred years. Therefore, groundwater gradients will keep groundwater contamination from the proposed Mokala project contained within the proposed project boundaries for that duration. The duration of the groundwater contamination downstream of the overburden stockpile will last several centuries. This extends beyond mine closure and is ranked as HIGH.

The modelled zone of potential groundwater contamination extends less than 500 m from the overburden stockpile after 100 years under the hypothetical and conservative assumption that pit dewatering does not affect groundwater movement at all. This means that groundwater contamination associated with the proposed Mokala project is likely to be contained within the boundaries of the farm Gloria. Therefore, the spatial scale of the impact is ranked as LOW.

Based on the assessed severity, duration, and spatial scale the consequence of the drawdown impact is ranked as MEDIUM.

While the overburden material may pollute the groundwater resource, no third parties or animals are expected to make use of the polluted water. In the unlikely event that humans or animals make use of the polluted water, is it unlikely that short-duration exposure to contaminant concentrations will cause a health impact. Long-duration exposure is unlikely due to aesthetic reasons. Therefore, the probability of this impact is ranked as LOW.

Based on the consequence and probability of the potential groundwater contamination impact, the significance is rated as LOW.

7.2.4 IMPACT MITIGATION

The probability and severity of groundwater contamination can be reduced by the following actions:

- Although, a limited number of domestic/livestock supply boreholes were identified during the hydrocensus, SLR cannot exclude the possibility that the quality of some user's boreholes may be reduced by the groundwater contamination impact. Therefore, Mokala should budget for replacing the water supply of any domestic/livestock groundwater users affected by deteriorating groundwater quality. The decision on whether the quality of groundwater has been impacted should be informed by the groundwater monitoring programme, and the model results presented in this report.

- Prevent spills or accidental releases of contaminants (such as oils, fuels, explosives, etc.) in all areas of the site
- Maintain and inspect vehicles to reduce the occurrence of leaks

Management of the groundwater resource should be informed with reliable data. Therefore, Mokala should operate a groundwater quality monitoring programme (see Recommendations sections for details).

With mitigation, the significance of the groundwater contamination impact remains LOW.

7.3 POST-CLOSURE GROUNDWATER LEVELS

7.3.1 RESULTS

Figure 46 compares simulated groundwater heads of the steady state base case model and the simulated heads after implementing a zone of higher conductivity in the area of the proposed pits. In general a minor drop in water levels is observed. Differences in water levels are larger in the eastern parts of the proposed mine pit compared to western parts which might be attributable to a damming effect due to lower permeabilities of the host rocks surrounding the pit.

The estimated mean, maximum and minimum pit water levels of the two simulations are shown in Table 11. Although minor differences between the pre-mining and post mine closure scenarios were simulated the results indicate that after mine closure pit water levels will recover to pre-mining levels. It is estimated that the water levels will take 300 to 600 years to recover to pre-mining levels.

TABLE 11: COMPARISON OF CALCULATED STEADY STATE PIT WATER LEVELS

Simulation	Mean [mamsl]	Minimum [mamsl]	Maximum [mamsl]
Steady State prior to mining	992.51	986.81	997.34
Backfill scenario after mine closure	991.39	986.68	995.46

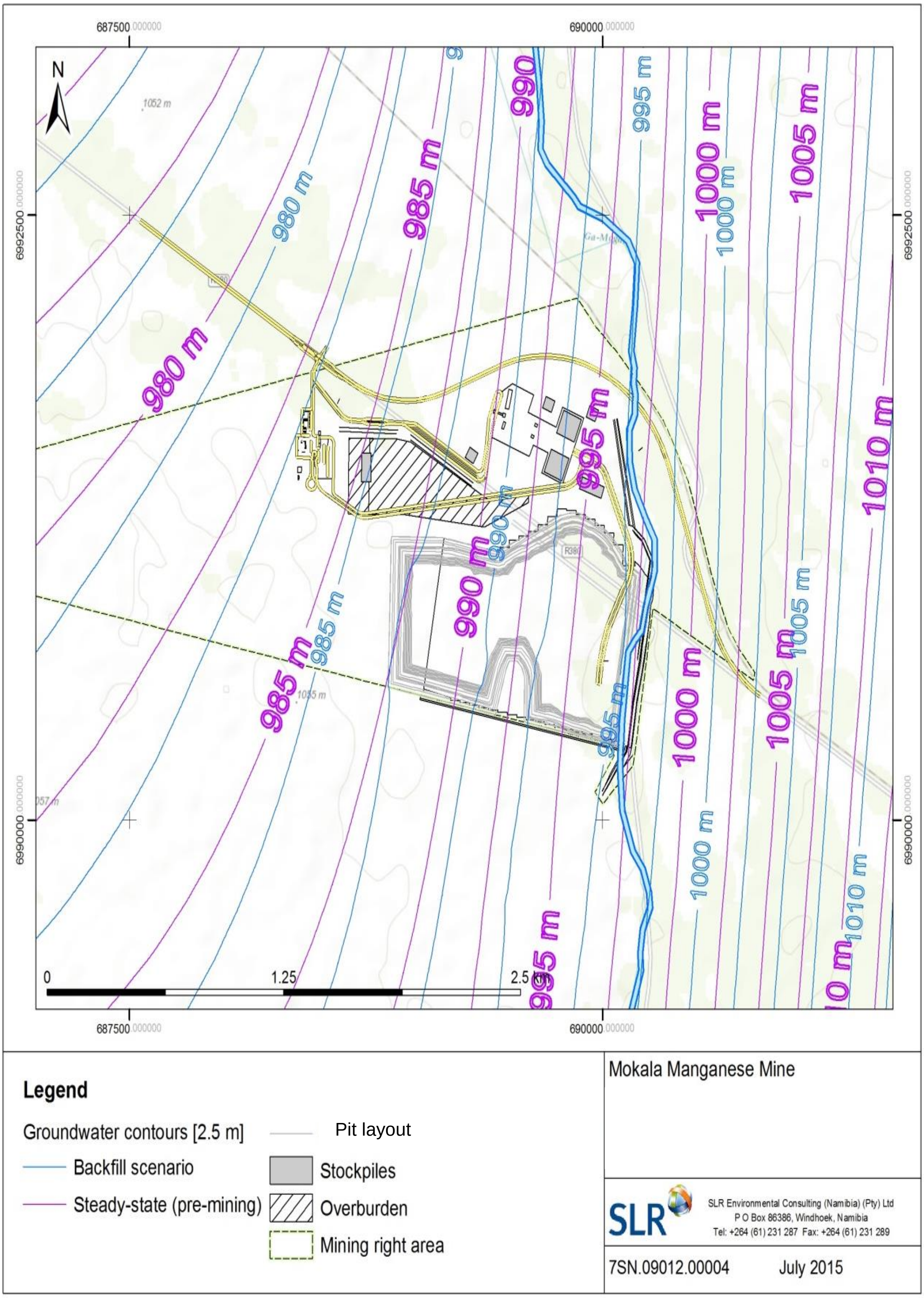


FIGURE 46: BACKFILL SCENARIO – GROUNDWATER HEAD COMPARISON

7.3.2 IMPACT ASSESSMENT

Based on the model results, groundwater contours will be displaced approximately 100 m to 300 m west of their current position after mining. That means that groundwater levels downstream of the backfilled pit will be slightly deeper than pre-mining. This constitutes a minor nuisance and the severity of the groundwater drawdown impact is assessed as LOW.

Based on the modelling, the duration of the post-closure drawdown is effectively permanent and is ranked as HIGH.

The change in groundwater levels extends beyond the site but is limited to the local area. Therefore, the spatial scale of the impact is ranked as MEDIUM.

Based on the assessed severity, duration, and spatial scale the consequence of the post-closure groundwater level change is ranked as MEDIUM.

The drawdown impact has a small likelihood of affecting local groundwater users. Therefore, the probability of this impact is ranked as LOW.

Based on the consequence and probability of the drawdown impact, the significance is rated as LOW.

7.3.3 IMPACT MITIGATION

Change in post-closure groundwater levels are the unavoidable consequence of replacing the original aquifer material with backfill that has significantly different hydraulic properties. It is practically impossible to change the backfill properties. In this case, mitigation should address the uncertainty associated with the impact significance.

The key source of uncertainty is the limited dataset on which the numerical model was based, in particular, aquifer characterisation and groundwater levels. Additional data can be obtained through a systematic groundwater monitoring programme. The data should be used to improve and update the numerical model and refine the model predictions of post-closure groundwater levels.

The monitoring programme is described in detail in sections 7.1.4 and 7.2.4.

With mitigation, the significance of the post-closure groundwater level impact remains LOW.

7.4 POST-CLOSURE GROUNDWATER CONTAMINATION

7.4.1 ASSUMPTIONS AND LIMITATIONS

To investigate the potential impacts on groundwater quality due to a backfilled mine pit with fully recovered pit water levels, the steady state flow field of the backfill scenario was used as the base of a transient, non-reactive STM simulating the spreading of potential plumes emanating from the backfilled mine pit.

7.4.2 RESULTS

Figure 47, Figure 48 and Figure 49 depict the simulated relative concentrations after 50 years for the Kalahari Formation (model layer 1), the Dwyka Formation (model layer 2) and the Hotazel Formation (model layer 3). The simulation predicts a decrease of concentrations in the Kalahari Formation to less than 5% within a distance of approximately 320 m from the western edge of the pit. The spreading of contamination decreases with depth due to the trapezoidal cross-sectional profile of the mine pit and lower permeabilities of the simulated bedrock aquifers.

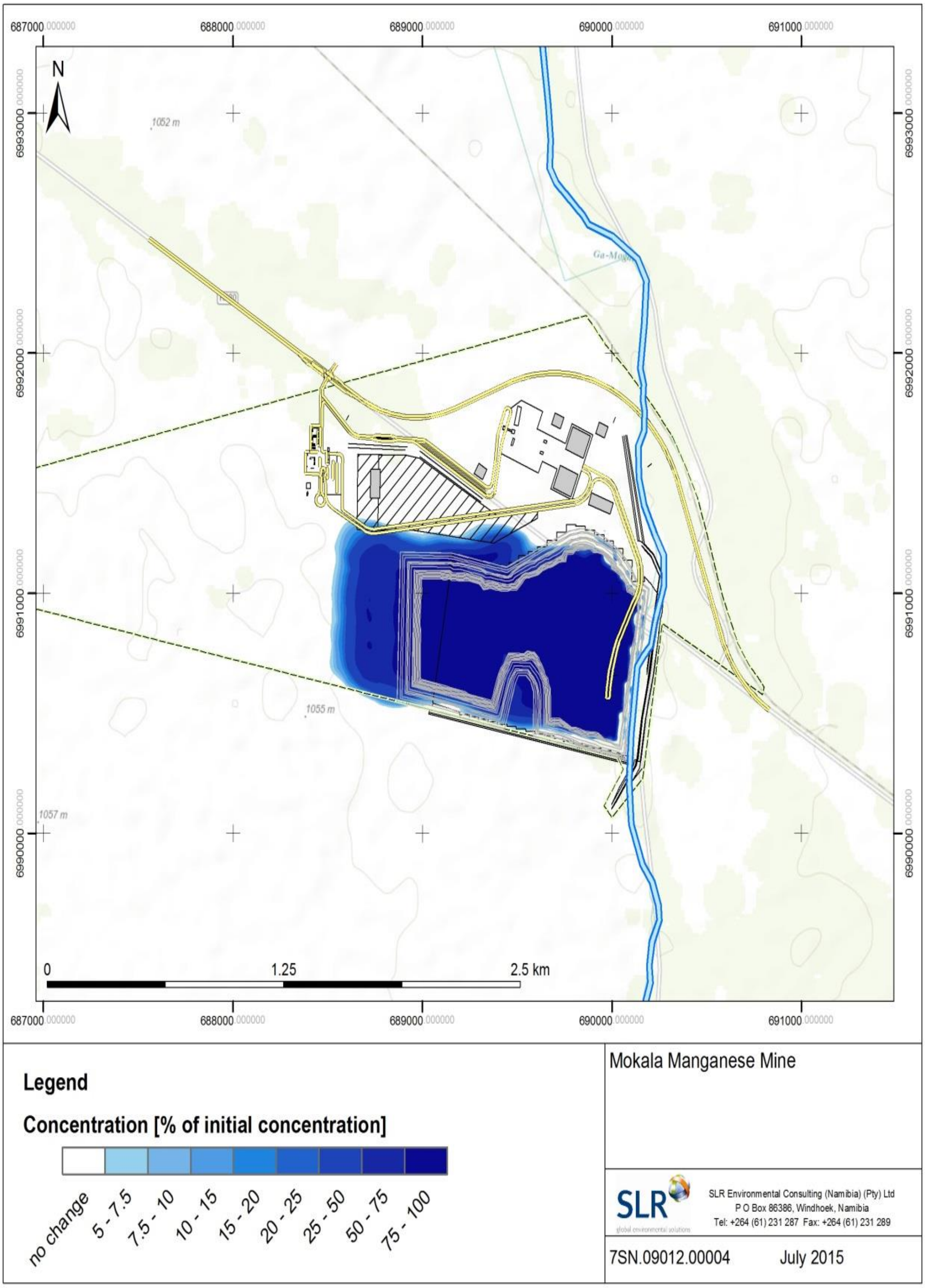


FIGURE 47: SPREADING OF POTENTIAL PLUME AFTER 50 YEARS EMANATING FROM THE BACKFILLED MINE PIT – MODEL LAYER 1 (KALAHARI FORMATION)

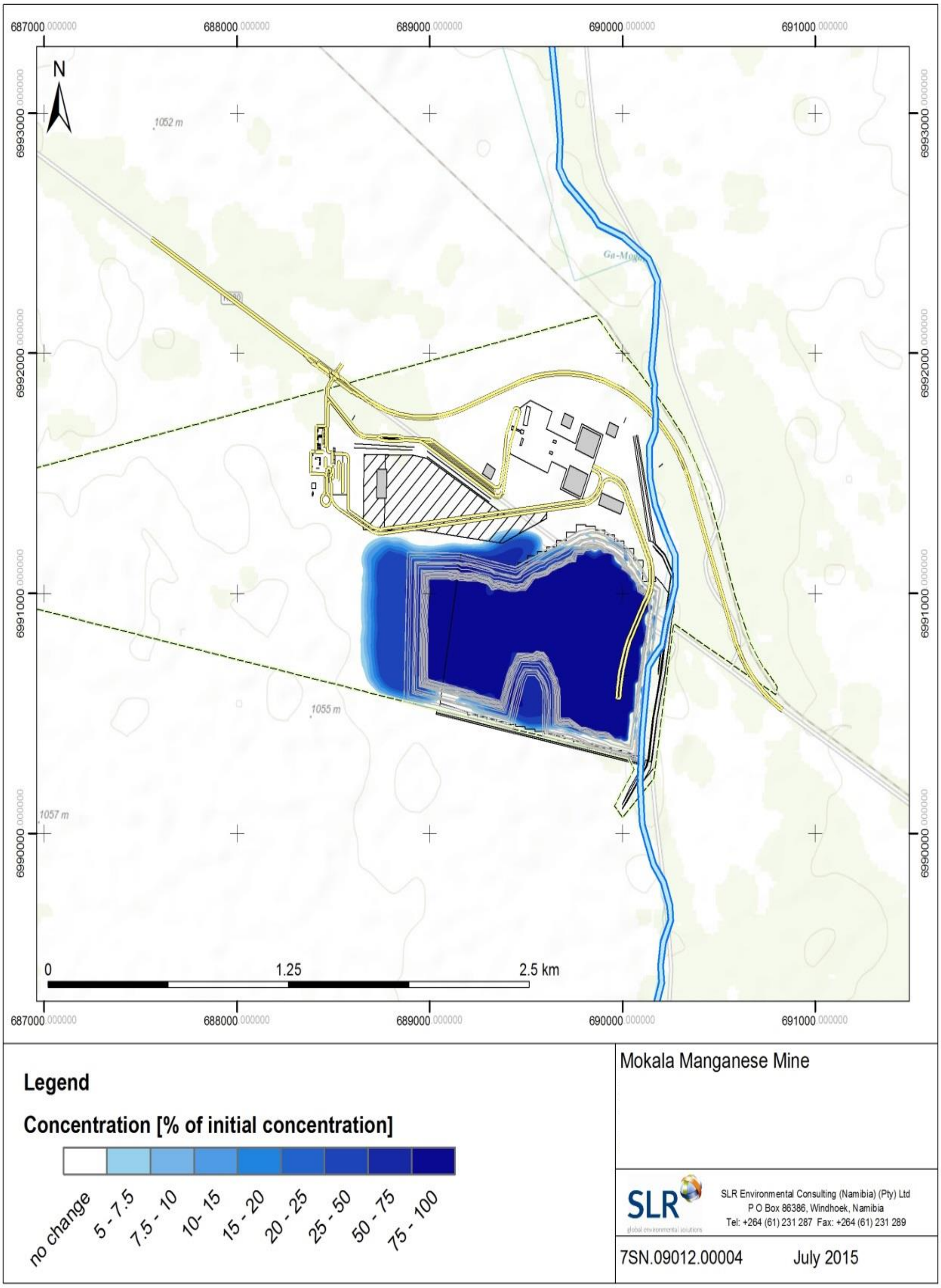


FIGURE 48: SPREADING OF POTENTIAL PLUME AFTER 50 YEARS EMANATING FROM BACKFILLED MINE PIT – MODEL LAYER 2 (DWYKA FORMATION)

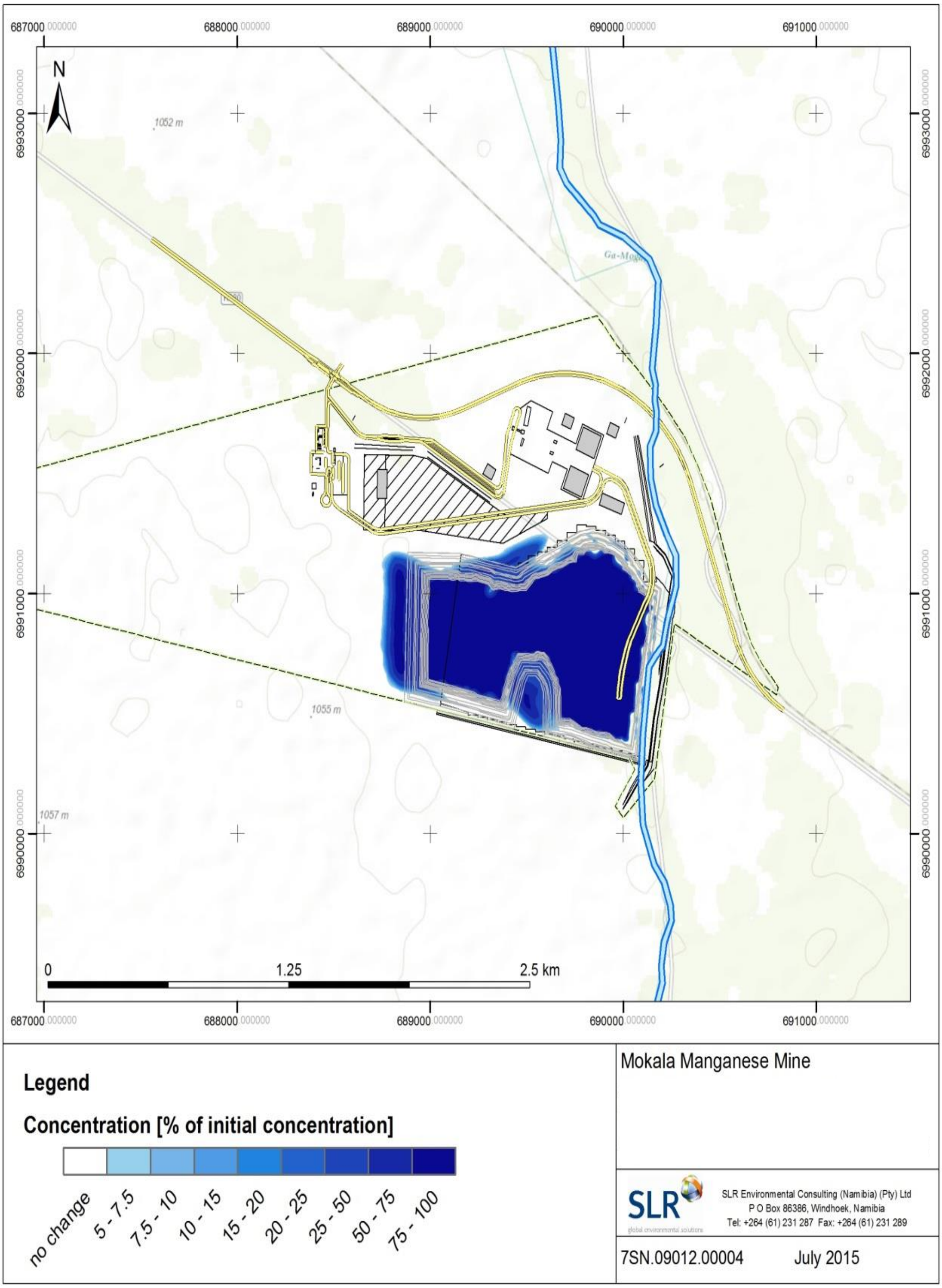


FIGURE 49: SPREADING OF POTENTIAL PLUME AFTER 50 YEARS EMANATING FROM BACKFILLED MINE PIT – MODEL LAYER 3

7.4.3 IMPACT ASSESSMENT

Groundwater contamination may be significant when measured within the plume, outside of the plume, there will be little if any indication of contamination. Groundwater quality in the proposed project area is saline and of limited potable use. Therefore, SLR assesses the severity of the post-closure groundwater contamination impact as LOW.

Groundwater levels around the backfilled mine pit will be deeper than in the undisturbed surrounding aquifers for several hundred years. Therefore, groundwater gradients will keep groundwater contamination from the proposed Mokala project contained within the proposed project boundaries for that duration. The simulation of post-closure groundwater contamination ignores the residual drawdown from the pit. The duration of the groundwater contamination downstream of the backfilled pit will begin centuries after closure and will continue as long as soluble salts are mobilised from the backfill. This is ranked as HIGH.

The modelled zone of potential groundwater contamination extends a few hundred metres from the pit after 50 years under the hypothetical and conservative assumption that pit dewatering does not affect groundwater movement at all. This means that groundwater contamination associated with the Mokala proposed project is likely to be contained within the boundaries of the farm Gloria. Therefore, the spatial scale of the impact is ranked as LOW.

Based on the assessed severity, duration, and spatial scale the consequence of the drawdown impact is ranked as MEDIUM.

While the backfill material may pollute the groundwater resource, no third parties or animals are expected to make use of the polluted water. In the unlikely event that humans or animals make use of the polluted water, is it unlikely that short-duration exposure to contaminant concentrations will cause a health impact. Long-duration exposure is unlikely due to aesthetic reasons. Therefore, the probability of this impact is ranked as LOW.

Based on the consequence and probability of the potential post-closure groundwater contamination impact, the significance is rated as LOW.

7.4.4 IMPACT MITIGATION

Change in post-closure groundwater quality is the unavoidable consequence of replacing the original aquifer material with backfill that has a modified composition, and a significantly modified potential for interaction with groundwater. It is practically impossible to change the backfill properties. In this case, mitigation should address the uncertainty associated with the impact significance.

The key source of uncertainty is the limited dataset on which the numerical model was based. Additional data can be obtained through a systematic monitoring programme beginning before mining commences and continuing through operations. The data should be used to improve and update the numerical model and refine the model predictions of post-closure movement of groundwater contamination.

The monitoring programme is described in detail in sections 7.1.4 and 7.2.4.

With mitigation, the significance of the post-closure groundwater contamination impact remains LOW.

7.5 BOREHOLE PUMPING WATER SUPPLY

Pumping of GL27 will not have an impact on the groundwater regime and will not be impacted by the extent of the cone of drawdown generated by mine dewatering since:

- Pumping will only take place for maximum 10 hrs/day.
- The borehole will recover for 14 hrs during a 24 hr cycle.
- The extent of the cone of drawdown does not have a significant effect at GL27 location.

8 INTERESTED AND AFFECTED PARTY COMMENTS

As part of the environmental impact assessment and environmental management programme process, interested and affected parties expressed concerns regarding potential impacts of the proposed project on groundwater. These concerns are captured in Table 12 with responses from the groundwater specialist.

TABLE 12: IAP COMMENTS ON GROUNDWATER

Interested And Affected Parties	Date Comments Received	Issues Raised	Specialist Response
Comment raised by E E Reynecke	01 March 2015 during the social scan	I am concerned about groundwater availability.	The groundwater model indicates that the cone of depression extends approximately 5km to the north and south of the proposed open pit area and approximately 1 to 1.5km to the east and west of the proposed open pit area. The hydrocensus identified six boreholes along the Ga-Mogara drainage channel that are located within the zone of influence. With reference to Figure 27, these include boreholes MH3, MH10, MH5, MH 14, MHsw2 and Mhsw1. All of these boreholes are used by neighbouring manganese mines for groundwater monitoring. It is therefore unlikely that the proposed project will influence groundwater availability within boreholes utilised for third party use. It is however important to note that in the event that Mokala's operations do result in the lowering of groundwater levels that influence third party users, Mokala is committed to supply third party users with an alternative source of water.
Comment raised by Ryno van Schalkwyk,	01 March 2015 during the social scan	I am concerned about the impact that the project will have towards groundwater availability.	
Comment raised by Lourika Delaport (L van der Merwe)	01 March 2015 during the social scan	My concern about the proposed project is groundwater availability.	
Comment raised by Gert A Noeth	01 March 2015 during the social scan	I am concerned about groundwater availability.	
Comment raised by Jurie Kriek	15 April 2015 at the public scoping meeting	There is a concern that the shallow aquifer is dry. This could be due to the sinkholes upstream at the Kumba Mine. This project will add additional pressure on the existing aquifers which will have an impact on downstream users.	
		I have boreholes in the area and I am concerned about the impacts that the project will have on existing groundwater levels.	
Comment raised by Eben Anthonissen		The Ga-Mogara drainage channel has limited surface water run-off. The first aquifer is not replenishing. This has a major impact on users as far as Kathu. The proposed project will only add additional pressure.	
Comment raised by Louis Hauman		A major problem in the area is underground water. The river does not flow and aquifers don't get water. In addition, the cumulative impacts by each mine must be calculated. The Kumba Mine is currently the biggest	The groundwater model indicates that the cone of depression extends approximately 5km to the north and south of the proposed open pit area and approximately 1 to 1.5km to the east and west of the proposed open pit area. As part of the groundwater study, a hydrocensus was

Interested And Affected Parties	Date Comments Received	Issues Raised	Specialist Response
		user of groundwater.	undertaken to determine the baseline environment (groundwater quality and quantity) which is used to inform the groundwater model. The baseline environment has already been influenced by existing mining operations. It follows that the development of the groundwater model took into account abstractions and ingress of water from neighbouring mines in so far as the baseline reflects historical and current regional impacts. In this way the potential dewatering cone of depression was modelled and assessed cumulatively within the context of existing conditions and water uses.
Comment raised by Gert Theart		We would like to know what the cone of depression is for the project taking into account other mines in the area. When considering the other mines in the area, Mokala will cause the existing cone of depression to extend. We are not interested in seeing a site specific cone of depression.	
Comment raised by Gert Theart		The groundwater resources in the area are already under pressure. The existing mining companies shift blame where groundwater shortages are concerned. There needs to be a proper way of managing water usage for each mining company in order to assess the cumulative impacts on groundwater.	
Comment raised by Eben Anthonissen		Groundwater usage by Mokala will just add more pressure on existing users. More pressure on the Vaal Ga-Mogara pipeline which also affect livestock.	The numerical model indicates a limited area around the mine pit will be affected by lowered groundwater levels. No user's boreholes were identified in this area. Mokala will replace a groundwater borehole that is clearly impacted by pit dewatering
Comment raised by Eben Anthonissen		What is the depth of the shallow aquifer?	The depth of the shallow aquifers varies from 13m to 66m below ground at the project site. The result of the groundwater study indicates that the shallow aquifer is of limited extent.

9 CONCLUSION

The objectives of this groundwater specialist study are to:

- Characterise the groundwater system at the proposed project site
- Estimate the magnitude, duration and severity of groundwater impacts from the proposed project
- Identify mitigations to reduce impact magnitude, duration and severity

Based on the outcome of the fieldwork and numerical modelling SLR has reached conclusions relevant to these objectives. The following sections present these conclusions.

9.1 MOKALA SITE GROUNDWATER SYSTEM

- Groundwater in the mining area is a scarce commodity, indicated by low recharge rates and low permeability of the aquifers.
- Groundwater at Mokala is held in two main aquifers:
  - Shallow semi-unconfined aquifer in the Kalahari Beds. The groundwater body rests on clay-rich, low permeability formations of the lower Kalahari, or weathered Dwyka Formations.
  - Deep fractured aquifer in fresh hard bedrock of the Mooidraai and Hotazel Formations.
- Potable use of groundwater at the site is limited since the groundwater is generally saline in excess of aesthetic and health risk guidelines. There are occasional exceedances of chronic health guidelines for iron, manganese, and selenium.
- Recharge from rainfall infiltrates to lower levels at an estimated rate of 1% of mean annual rainfall.
- The alluvial aquifer of the Ga-Mogara River does not represent drainage for regional groundwater flow.
- Regional groundwater flow at the proposed project site is directed towards the west-northwest away from the river.

9.2 GROUNDWATER IMPACTS OF THE PROPOSED PROJECT

9.2.1 MINE PIT DEWATERING

- Estimated groundwater inflow rates into the proposed open pit excavation ranges from 100 m^3/d (1.1 L/s) to 438 m^3/d (5.5 L/s).
- The modelled radius of influence of mine pit dewatering extends approximately 5 km to the north and south and 1 to 1.5 km east and west (worst-case scenario). It is unlikely that this extent will be observed in the field since the numerical model integrates aquifer parameters over a large rock volume and does not account for impermeable barriers, or preferential flow paths.
- The dewatering around the proposed Mokala pit will have a cumulative impact on regional groundwater levels, which are already affected by inflows to neighbouring mines.

- In the impacted zones outside the proposed project area a lowering of water tables in boreholes of up to 10 m with a subsequent reduction of borehole yields is to be expected and should be mitigated where required.
- The significance of the mine pit dewatering impact on the local groundwater system is assessed as LOW.

9.2.2 GROUNDWATER CONTAMINATION

- The proposed mining infrastructure is located within the modelled cone of depression induced by mine dewatering. Therefore, leachates from the proposed Overburden Stockpile will be captured by the proposed mine pit.
- It is likely that the water level beneath the proposed Overburden Stockpile will be drawn down below the sediments of the Kalahari Formation resulting in additional attenuation of potential contaminants in the unsaturated zone below the proposed Overburden Stockpile.
- The non-reactive transport simulation neglecting potential impacts on groundwater levels due to mine dewatering suggests that after 100 years initial concentrations of potential contaminants emanating from the Overburden Stockpile will decrease below 10% within a distance of 200 m and would not alter the hydrochemical signature of the already saline natural groundwater outside the mine lease area.
- The significance of the groundwater contamination impact is assessed as LOW.

9.2.3 POST-CLOSURE GROUNDWATER LEVELS

- The simulated backfill scenario indicates that only a minor change of the groundwater levels and flow pattern will be observed after full water level recovery within the backfilled mine pit and that post-closure pit water levels will be similar to pre-mining levels.
- It will take maximum 300 years for the pit groundwater levels to recover fully.
- This impact is rated as of LOW significance.

9.2.4 POST-CLOSURE GROUNDWATER CONTAMINATION

- The backfilled mine pit will continue to capture potential pollutants for many years after closure. The long-term groundwater sink caused by the slow inflow rates into the backfilled mine pit will also delay and slow spreading of potential groundwater contaminant plumes from the backfill.
- After full recovery of pit water levels potential contaminants within the backfilled material are predicted to spread in a downstream direction while not altering the hydrochemical signature of groundwater outside the mine lease area 50 years after the recovery of pit water levels.
- The modelled maximum movement of the contaminant plume from pit backfill is 320 m.
- The significance of the post-closure groundwater contamination impact is assessed as LOW.

Based on the above assessment, there are not apparent reasons why the project cannot be authorised.

10 RECOMMENDATIONS TO MITIGATE GROUNDWATER IMPACTS

Based on the outcomes of this groundwater specialist study, SLR recommends the following actions to mitigate groundwater impacts associated with the proposed Mokala proposed project:

- Mokala should implement a groundwater monitoring programme with the following features:
    - The objective of the programme is to characterise groundwater quality and groundwater levels in and outside the mine lease area on a regular basis.
    - As preliminary guidance, SLR suggests that a network of six to eight boreholes be identified at various distances around the proposed pit. The borehole locations should be decided in consultation with an experienced groundwater professional. Mokala should choose monitoring locations according to the following guidelines:
        - At least two boreholes should be upstream of the proposed project to sample background groundwater quality
        - At least two boreholes should be within 500 m of the pit margins
        - At least three boreholes should be within the modelled zone of dewatering
        - At least three boreholes should be within the project site near potential sources of groundwater contamination, such as the overburden stockpile
        - At least two boreholes should be outside the modelled zone of dewatering
        - At least two boreholes should be downstream of the proposed project site and at least one of these should be in the modelled groundwater plume
    - These could be boreholes identified in the hydrocensus, existing boreholes on site, and/or new boreholes drilled by Mokala for monitoring purposes. Preliminary suggestions for groundwater monitoring locations are indicated in Figure 50.
    - Mokala should conduct groundwater level monitoring by manual dipping or automated sensors.
    - Mokala should conduct groundwater quality monitoring using the procedure documented by Weaver et al (2007). This should include purging of the borehole prior to sampling, field measurement of selected water quality parameters, filtering of the sample through 0.45 µm polycarbonate filters, collection of the sample into laboratory-provided containers, preservation of samples, and analysis of samples by a SANAS-accredited laboratory
    - Groundwater levels should be measured every three months starting at least one year prior to mining, throughout mine operation, and for at least 10 years after closure.
    - Groundwater quality should be measured every six months starting at least one year prior to mining, throughout mine operation, and for at least 10 years after closure.
    - Mokala should appoint an experienced groundwater professional, registered with the SACNASP, to review the groundwater quality and level data every year. The professional should provide Mokala with a technical report evaluating the groundwater level trends and

making recommendations as required to maintain/extend the monitoring network and record data.

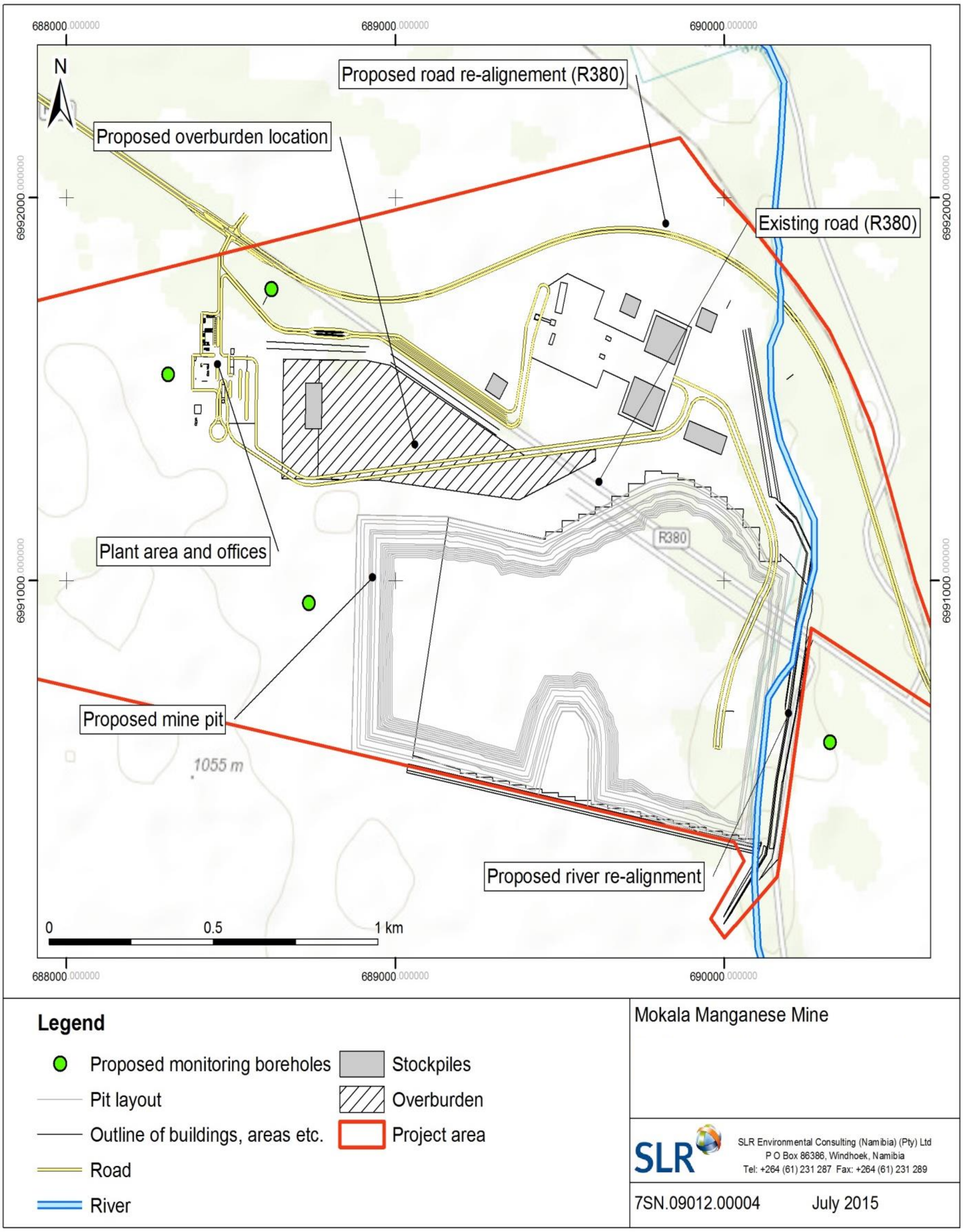


FIGURE 50 – PRELIMINARY RECOMMENDATIONS FOR GROUNDWATER MONITORING LOCATIONS

- Prevent spills or accidental releases of contaminants (such as oils, fuels, explosives, etc.) in all areas of the site
- Maintain and inspect vehicles to reduce the occurrence of contaminant leaks.
- If there is a reduction in quality or quantity of water in 3rd party boreholes then Mokala should provide an alternative water supply of equal or better quality and quantity.
- Records should be kept of actual groundwater volumes abstracted and on-site daily rainfall data throughout the life of mine.
- Periodically compare the predicted groundwater model results with the monitoring data and update the groundwater model when new data become available.

Terry Harck
(Report Author)

Brandon Stobart
(Project Reviewer)

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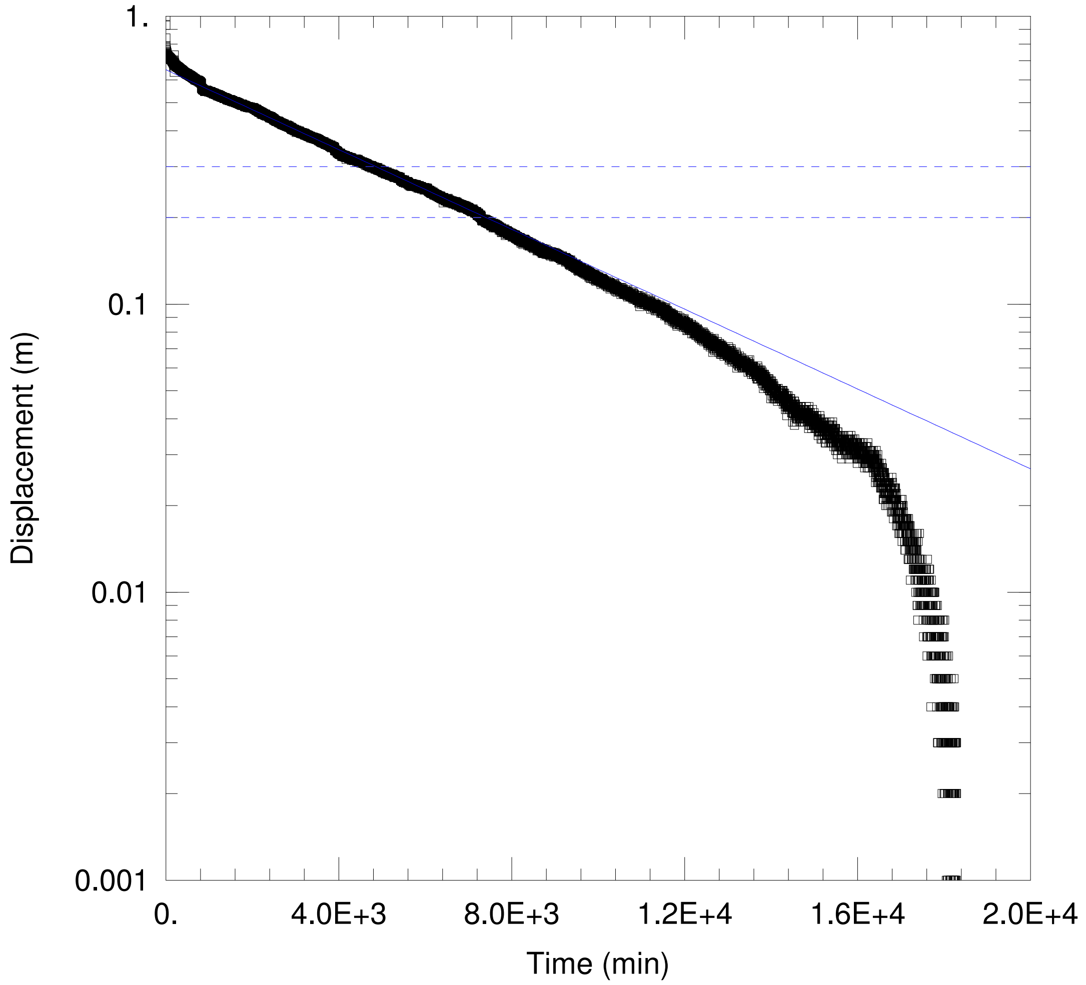
Appendix A – Hydrocensus Results

Sample ID	Co-ordinates		Elevation (mamsl)	Depth of Borehole (mbgl)	Water Level (mbgl)	Pump / Equipped	Field Parameters				Comments	Groundwater Use	Sampled for Quality Purposes
	X (m)	Y (m)					Temp (‘C)	pH	EC (uS/cm)	TDS (mg/L)			
MH1 (Olivewood)	3008081	0017689	1061	~100	50.15	Yes @50 mbgl	25.0	7.83	791		Clear, odourless water.	Domestic, and livestock use, Wind powered	Y
MH2 (UMTU)	3010527	0019896	1069	N/A	N/A	Yes	26.5	8.53	798		Water pumped onto reservoir then piped to watering points. Clear, odourless water	Wild animal supply point	Y
MH3 (UMTU)	3011540	0008808	1046	N/A	64.03	N/A	26.6	9.28	1332		Protected and lockable, used by DWS for monitoring. Drilling fluid still visible in water.	Monitoring	Y
MH4 (YORK)	*22°55'49.3"*	*27°14'51.5*	1040	150	27.98	N/A	29.7	5.98	832		Located adjacent to open pit and surrounded by calcrete RWD and Mn stockpile	Monitoring	Y
MH5 (HOTAZEL)	3011237	0007725	1034	50	37.23	N/A	27.1	7.81	1127		Only prospective drilling done	Monitoring	Y
MH6 (YORK 279)	3012629	0000463	1082	100	29.77	Yes @50 mbgl	25.3	7.32	3420		Murky water, not yet connected to livestock water supply	Not yet used but earmarked for livestock water supply	Y
MH7	3012806	0000443	1086	N/A			-	-	-		Drilled for livestock water supply but dry	N/A	N
MH8	3012883	0000098	1091	200	25.0		-	-	-		Used for livestock water supply but pump stolen.	N/A	N
MH9 (Olivewood)	3010822	0019945	1067	N/A	74.48	N/A	-	-	-			N/A	N
MH10 (Olivewood)	3011835	0008854	1048	N/A	63.49	N/A	-	-	-		Used by DWS for reagional water level monitoring.	SWL monitoring	N
MHsw1 (Gamagara upstream)	3007019	0008000	1012	N/A	N/A	N/A	-	-	-		Gamagara upstream of project area Dry river bed	N/A	N
MHsw2 (Gamagara downstream)	3012676	0007654	1024	N/A	N/A	N/A	-	-	-		Gamagara downstream of project area Dry river bed	N/A	N
MH12	3009197	0010948	1048	>300	>100		-	-	-				N
MH13	3015118	0005983	1047	150	25.44	N/A	-	-	-		Used for monitoring	Monitoring	N
MH14	3011855	0007847	1029	50	35.7		-	-	-		Only prospective drilling done	Monitoring	N

APPENDIX B: AQUIFER TEST RESULTS AND ANALYSIS

Aquifer test results



WELL TEST ANALYSIS

Data Set: \...\GL31 Slug Analysis.aqt
Date: 05/22/15 Time: 16:07:54

PROJECT INFORMATION

Company: SLR Consulting
Test Well: GL27
Test Date: 19/01/2015

AQUIFER DATA

Saturated Thickness: 1. m
Anisotropy Ratio (Kz/Kr): 1.

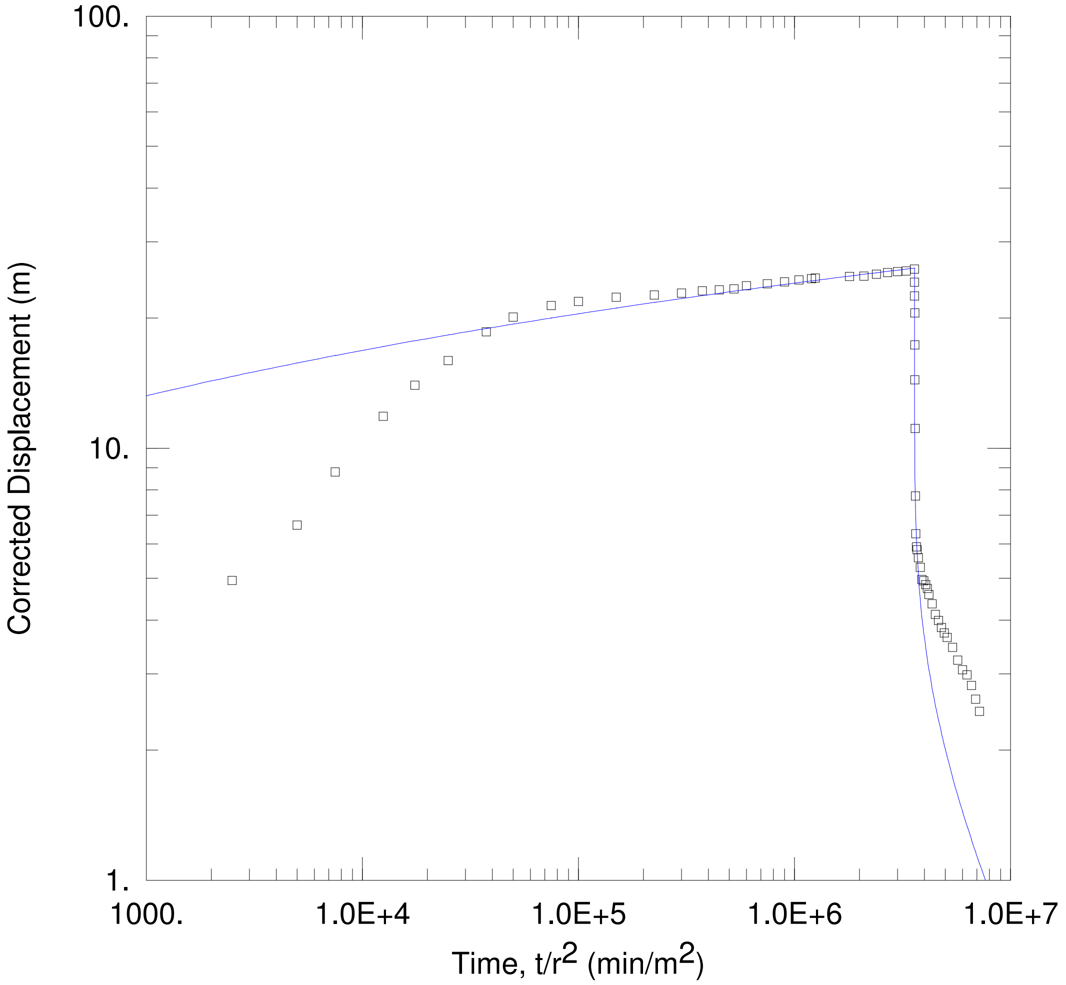
WELL DATA (GL31)

Initial Displacement: 1. m
Total Well Penetration Depth: 130.6 m
Casing Radius: 0.15 m
Static Water Column Height: 1. m
Screen Length: 121. m
Well Radius: 1. m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.003087 m/day
y0 = 0.6512 m



WELL TEST ANALYSIS

Data Set: \...\GL27 CDT Analysis.aqt
Date: 05/22/15
Time: 16:10:43

PROJECT INFORMATION

Company: SLR Consulting
Test Well: GL27
Test Date: 19/01/2015

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
GL 27	0	0

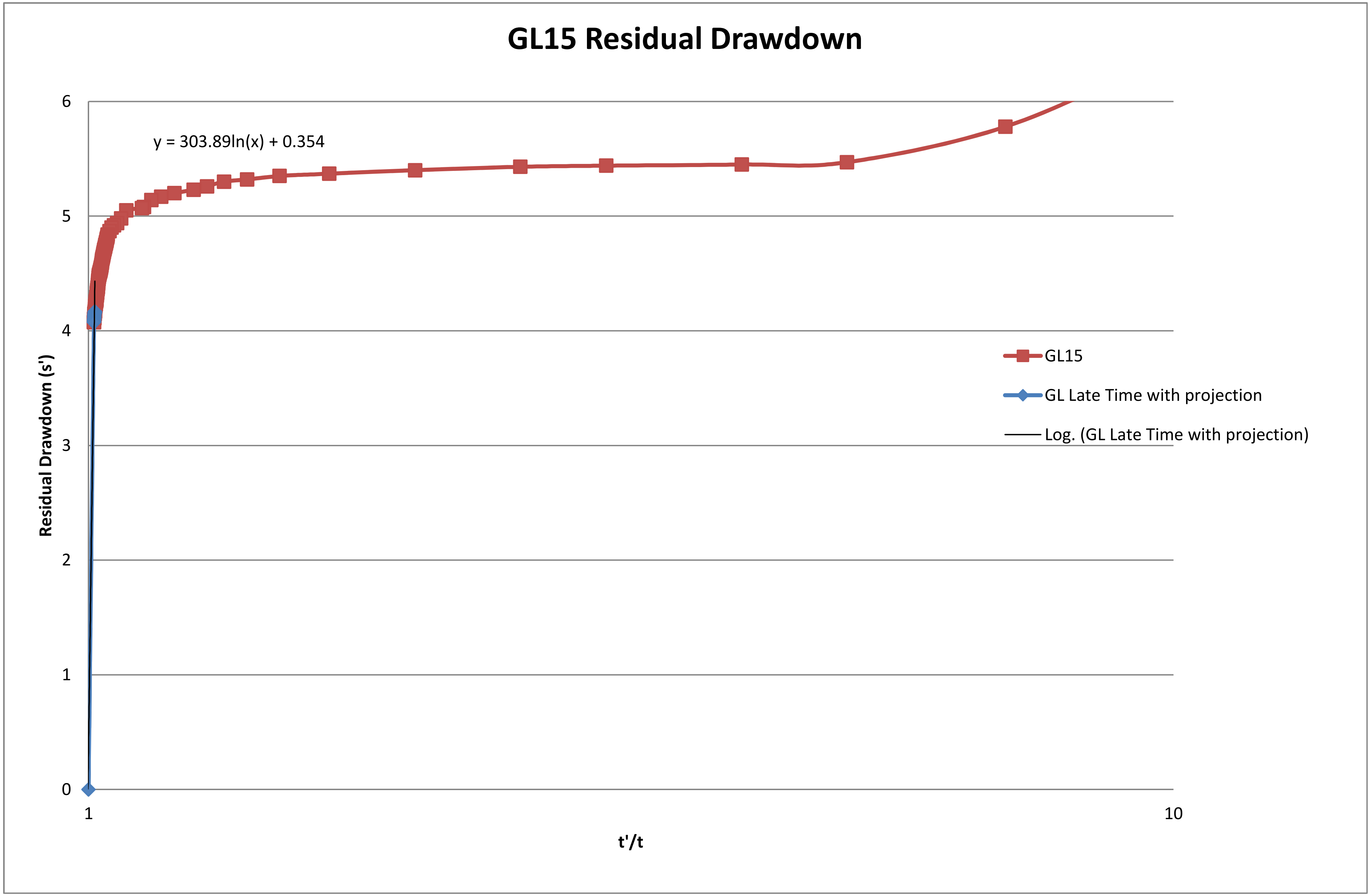
Observation Wells

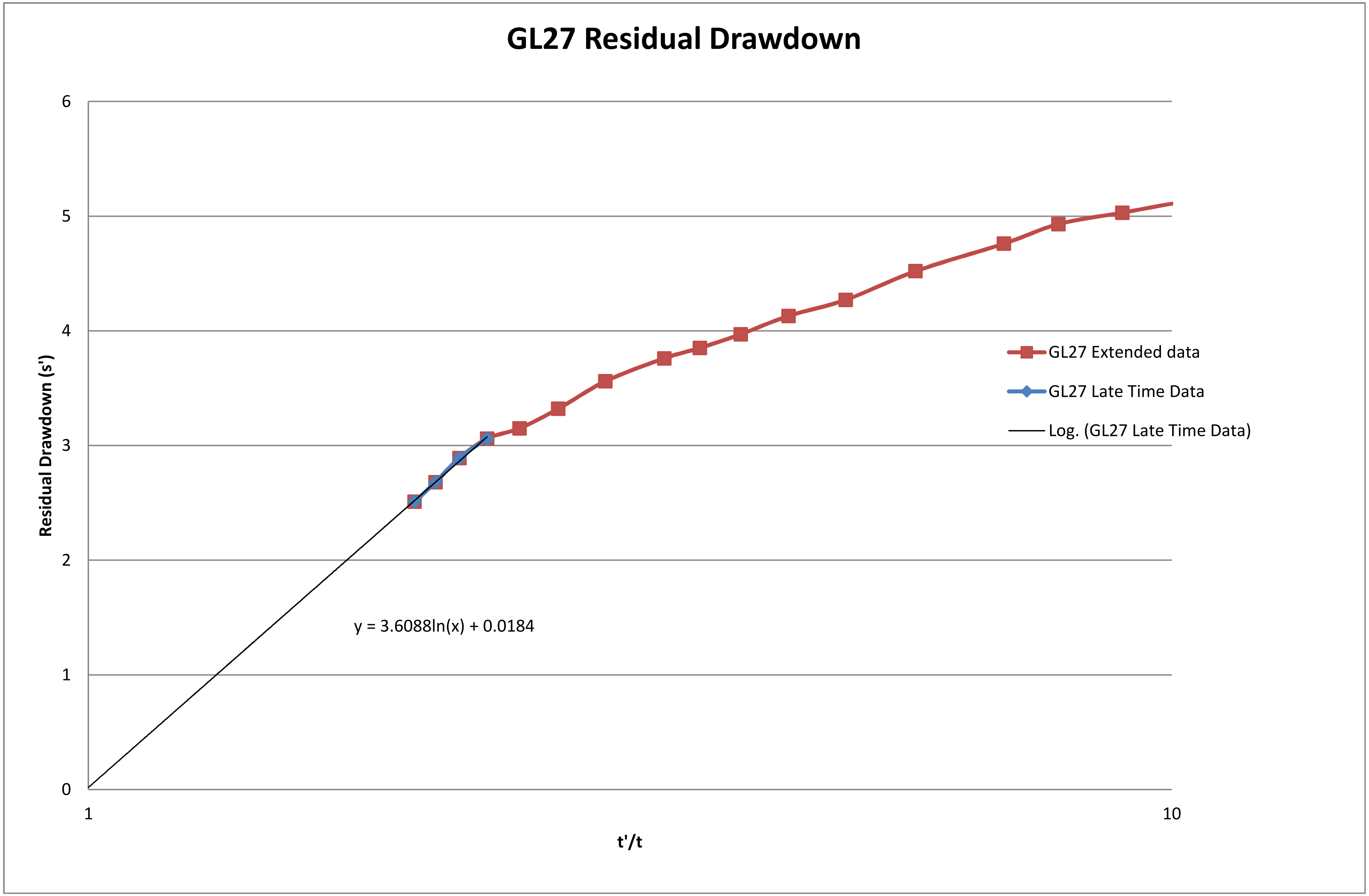
Well Name	X (m)	Y (m)
□ GL 27	0	0

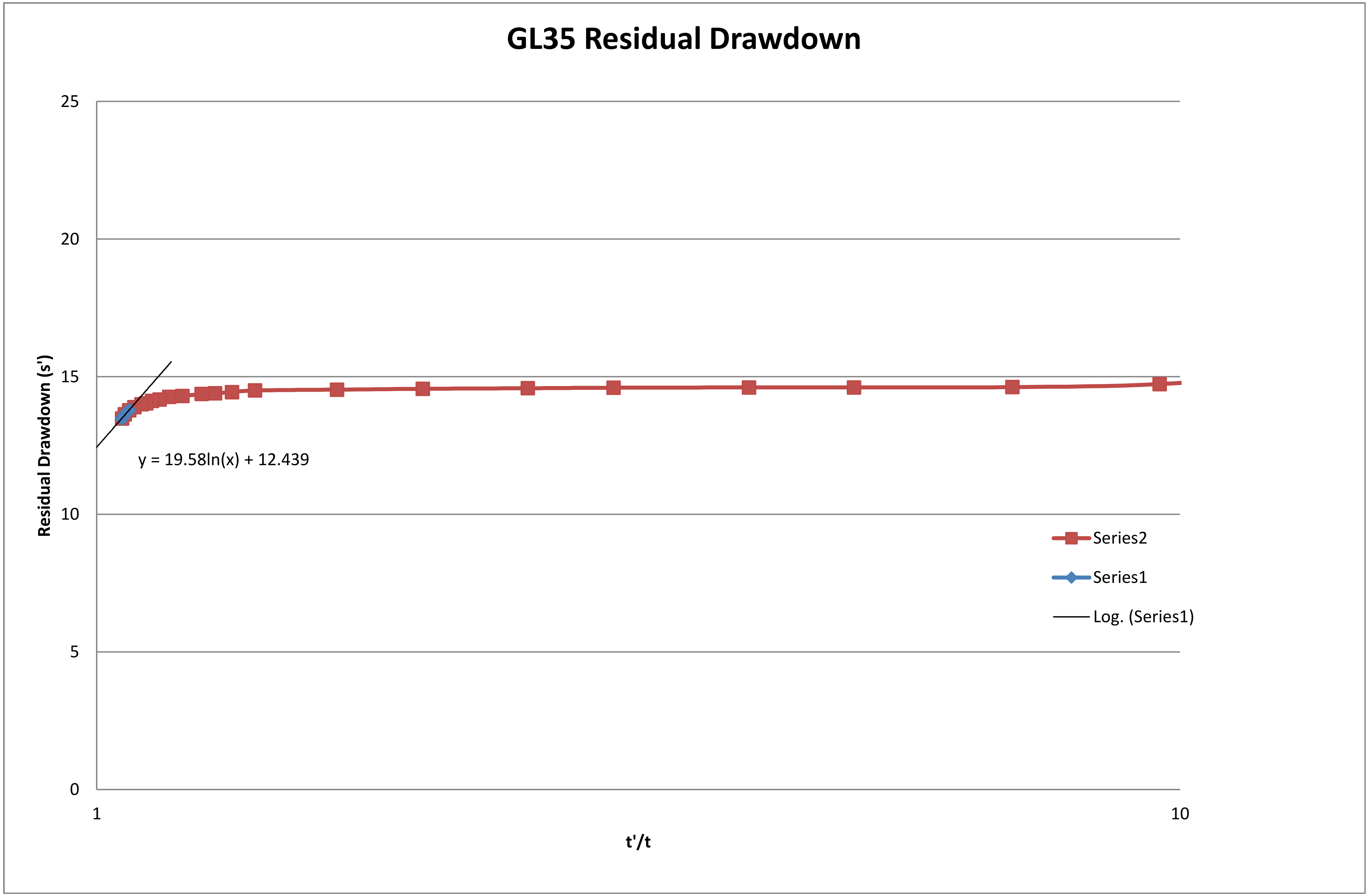
SOLUTION

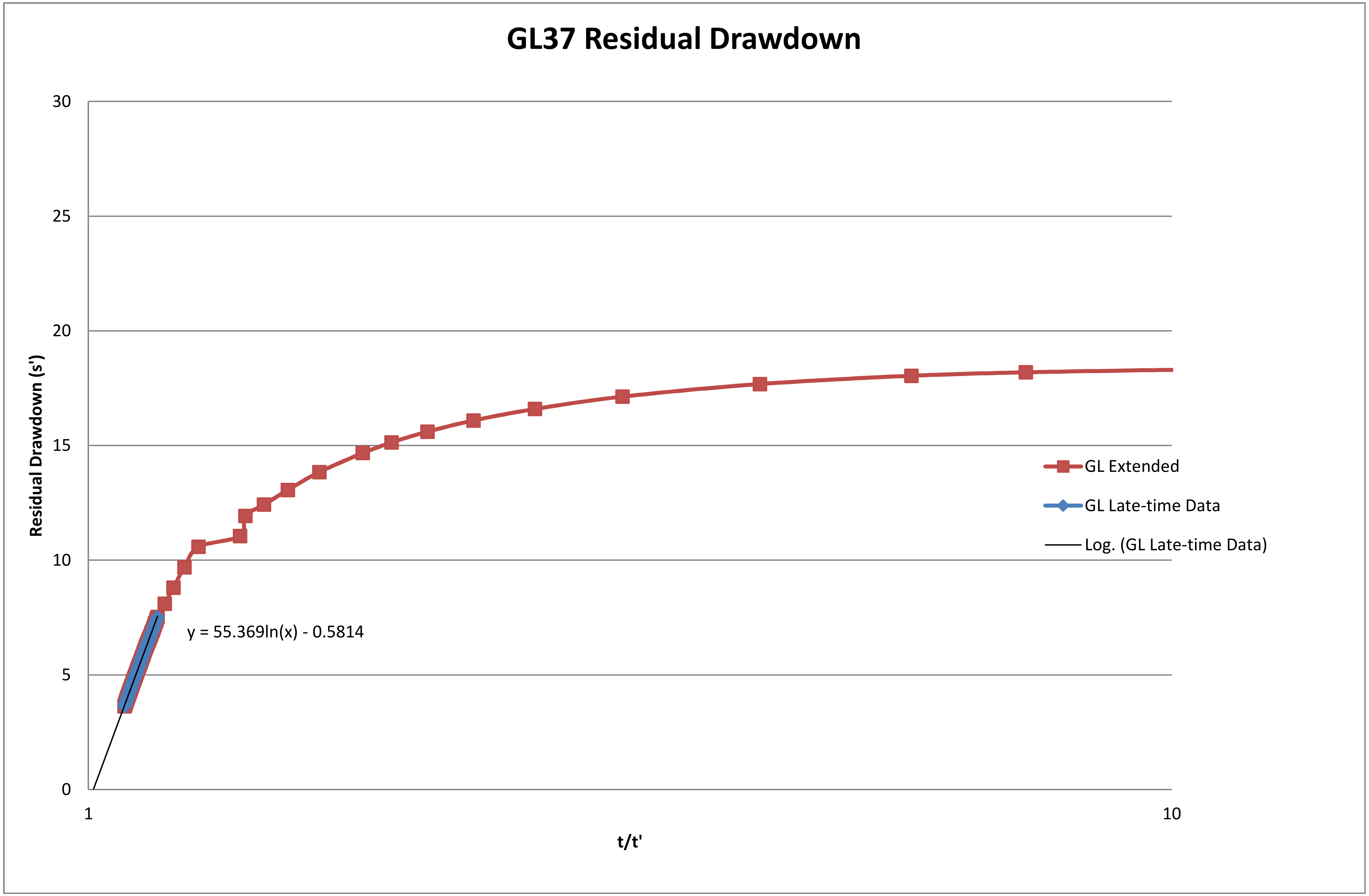
Aquifer Model: Unconfined
Solution Method: Theis

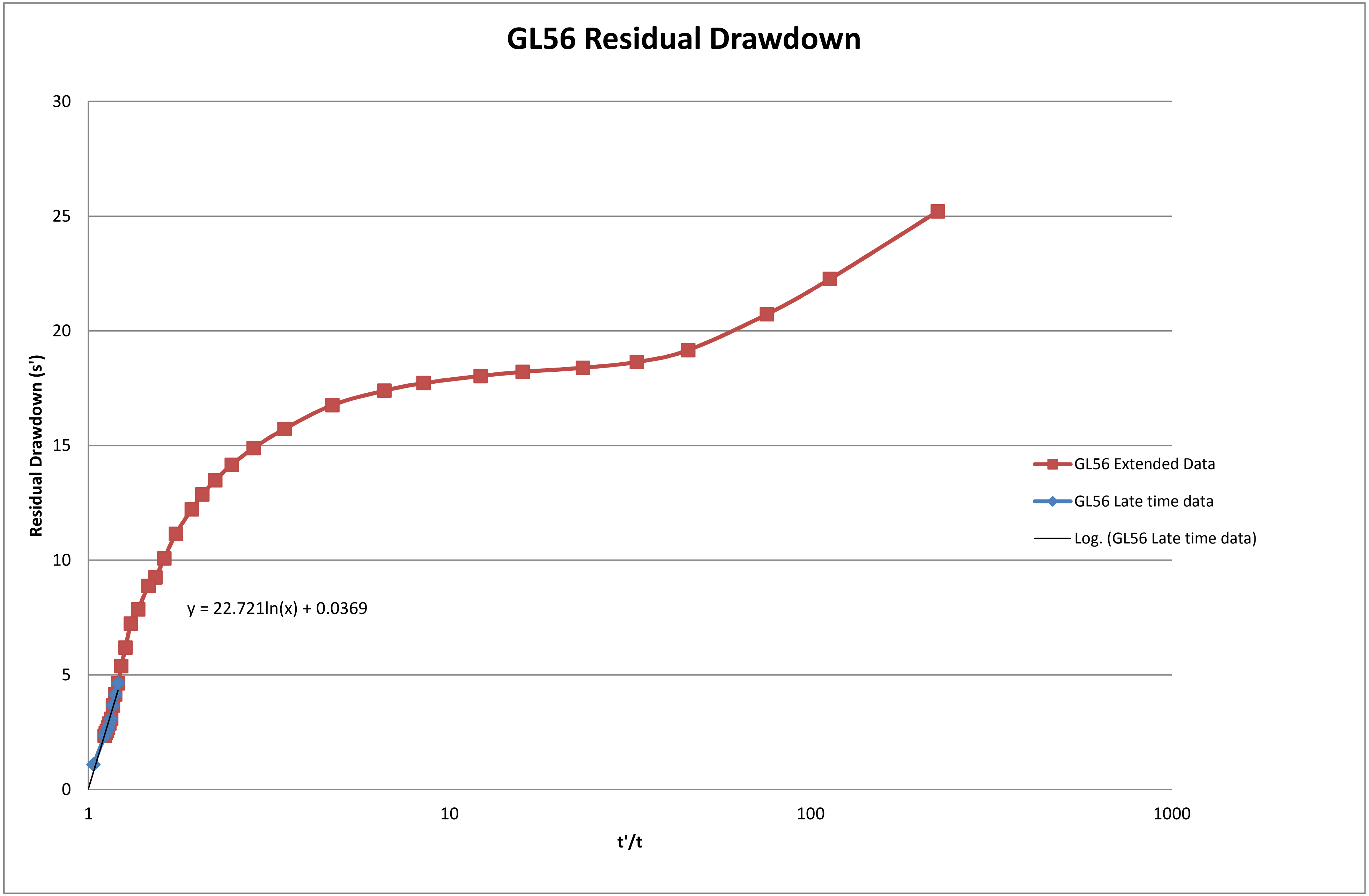
T = 4.368 m^2/day
S = 0.001541
Kz/Kr = 1.
b = 63. m

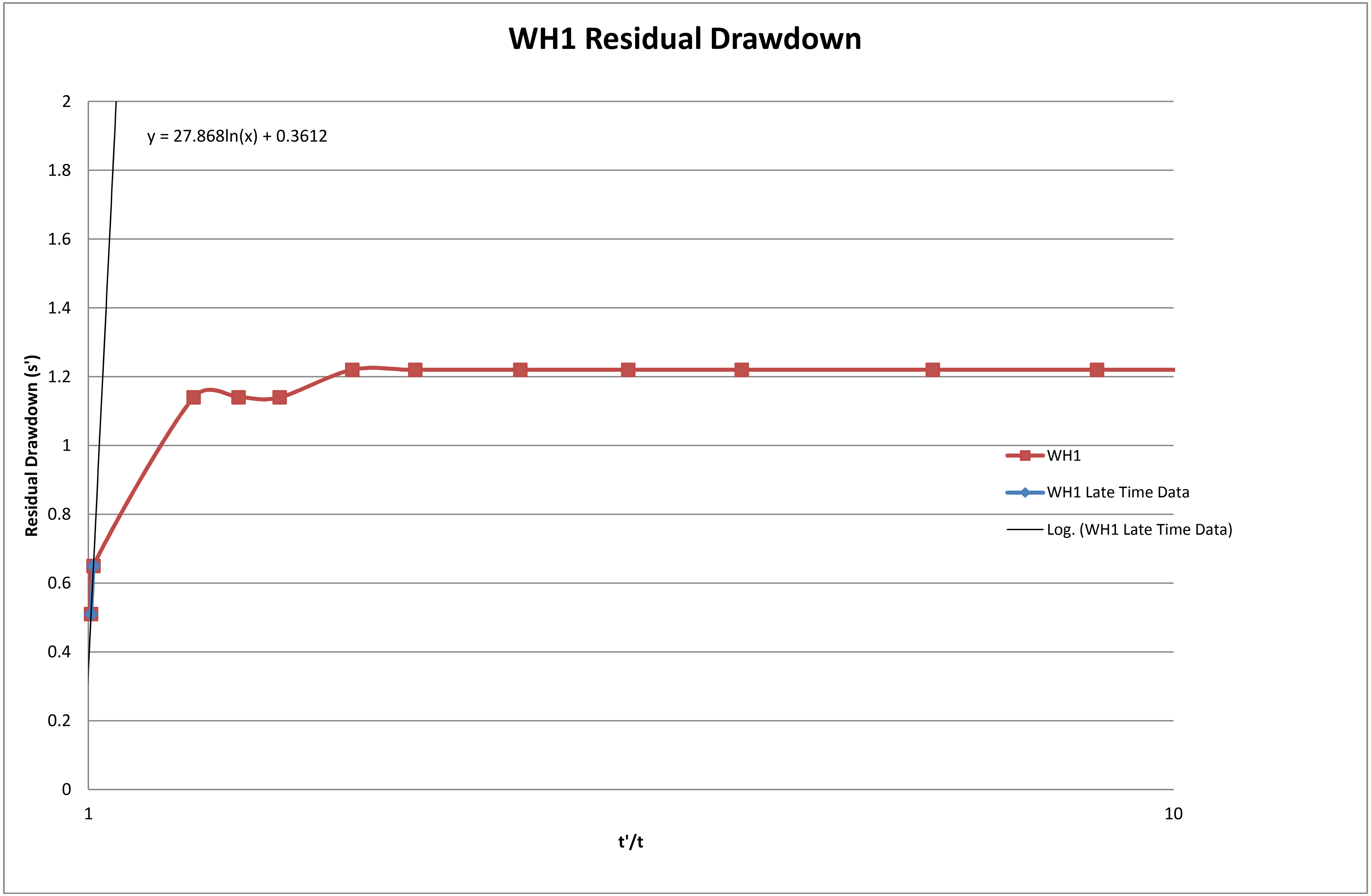

GL15 Residual Drawdown
y = 303.89ln(x) + 0.354
Residual Drawdown (s')
6
5
4
3
2
1
0
1
10
t'/t
GL15
GL Late Time with projection
Log. (GL Late Time with projection)

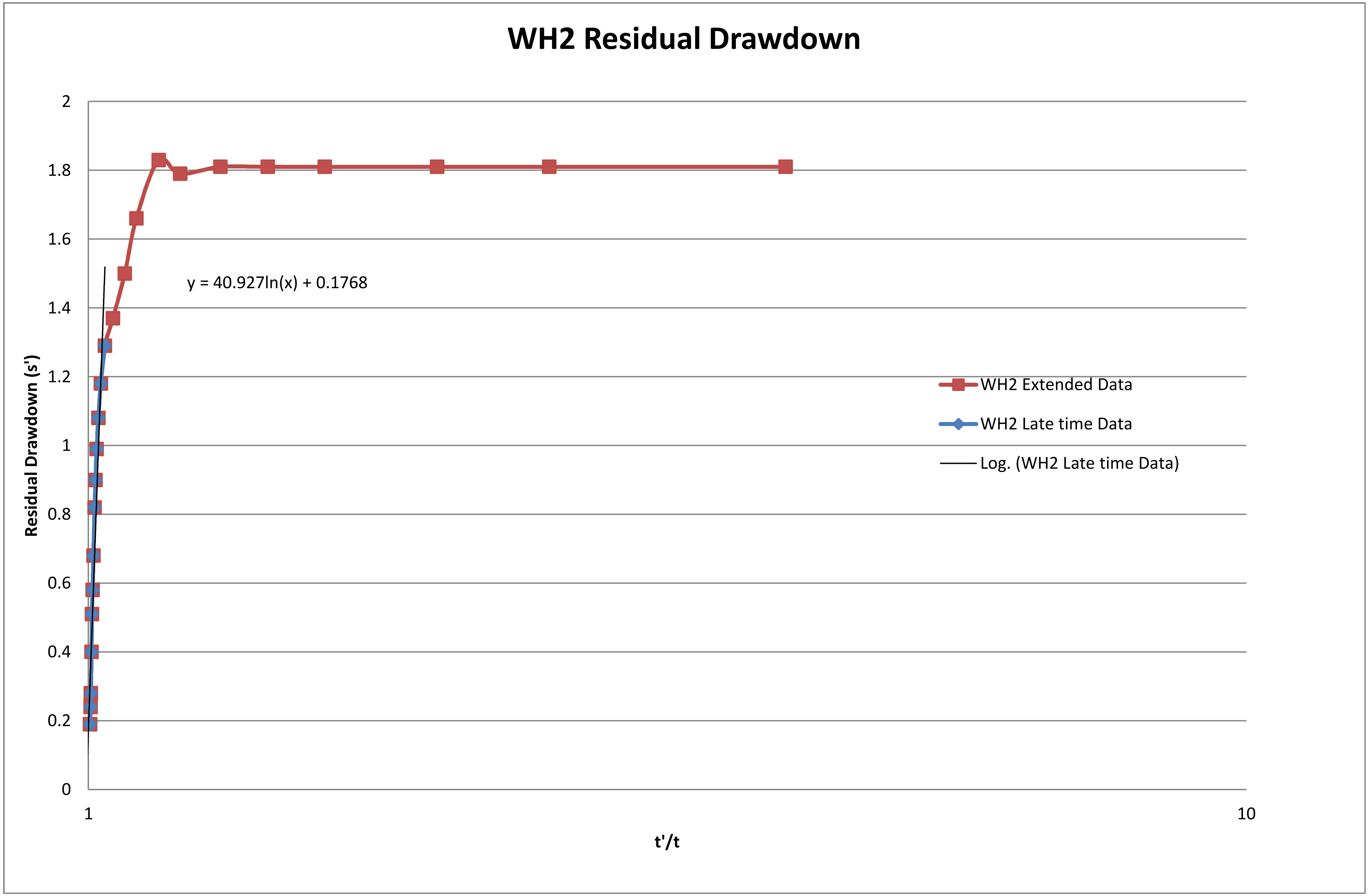

GL27 Residual Drawdown
6
5
4
3
2
1
0
Residual Drawdown (s')
1
10
t'/t
GL27 Extended data
GL27 Late Time Data
Log. (GL27 Late Time Data)
y = 3.6088ln(x) + 0.0184


GL35 Residual Drawdown
Residual Drawdown (s')
25
20
15
10
5
0
1
10
t'/t
y = 19.58ln(x) + 12.439
Series2
Series1
Log. (Series1)


GL37 Residual Drawdown
Residual Drawdown (s')
30
25
20
15
10
5
0
1
10
t/t'
y = 55.369ln(x) - 0.5814
GL Extended
GL Late-time Data
Log. (GL Late-time Data)


GL56 Residual Drawdown
Residual Drawdown (s')
30
25
20
15
10
5
0
1
10
100
1000
t'/t
y = 22.721ln(x) + 0.0369
GL56 Extended Data
GL56 Late time data
Log. (GL56 Late time data)


WH1 Residual Drawdown
y = 27.868ln(x) + 0.3612
Residual Drawdown (s')
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
t'/t
WH1
WH1 Late Time Data
Log. (WH1 Late Time Data)

WH2 Residual Drawdown
Residual Drawdown (s')
t'/t
y = 40.927ln(x) + 0.1768
WH2 Extended Data
WH2 Late time Data
Log. (WH2 Late time Data)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10

APPENDIX C: GROUNDWATER QUALITY

Tabulated groundwater quality data and laboratory reports

WATERLAB (Pty) Ltd
Reg. No.: 1983/009165/07 V.A.T. No.: 4130107891

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The Woods
41 De Havilland Cresent
Persequor Techno Park
Meiring Naudé Drive
Pretoria

P.O. Box 283
Persequor Park, 0020
Tel: +2712 – 349 – 1066
Fax: +2712 – 349 – 2064
e-mail: admin@waterlab.co.za

SANAS Accredited Testing Laboratory
No. T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2015 - 03 - 25
Date completed: 2015 - 04 - 10
Project number: 139
Report number: 51260
Order number: 0196

Client name: SLR Consulting (Africa) (Pty) Ltd
Contact person: Mrs. J. Ellerton
Address: P.O. Box 1596 Cramerview 2060
e-mail: jellerton@slrconsulting.com
e-mail: bmagagula@slrconsulting.com
Telephone: 011 467 0945
Facsimile: 011 467 0978
Mobile: 072 077 7463

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification: Mokala**				
		GL27	**GL37**	**GL56**	**BH1**	**BH2**
Sample Number		2157	2158	2159	2160	2161
pH – Value at 25°C	WLAB001	7.2	7.3	7.2	7.3	7.5
Electrical Conductivity in mS/m at 25°C	WLAB002	758	567	246	369	94.6
Total Dissolved Solids at 180°C *	WLAB003	4 792	3 632	1 570	3 294	540
Total Alkalinity as $CaCO_3$	WLAB007	188	200	444	316	316
Bicarbonate as HCO_3 *	WLAB023	229	244	541	385	385
Carbonate as CO_3 *	WLAB023	<5	<5	<5	<5	<5
Chloride as Cl	WLAB046	1 783	1 289	463	913	102
Sulphate as SO_4	WLAB046	1 137	722	210	191	68
Fluoride as F	WLAB014	2.8	1.8	1.0	0.8	0.8
Nitrate as N	WLAB046	<0.2	3.0	9.6	49	0.3
ICP-MS Scan (Dissolved) *	WLAB050	See Attached Report: 51260-A				
% Balancing *	---	89.4	90.9	97.9	99.1	97.0

*** = Not SANAS Accredited**
Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

A. van de Wetering

Technical Signatory

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number : 139
Client : SLR Consulting
Report Number : 51209-A

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
MH2	1976	0.000	0.018	0.003	0.001	0.175	0.093	0.000	0.000	5.7	0.000	0.000	0.000
MH3	1977	0.000	0.050	0.001	0.006	1.24	0.072	0.000	0.000	28	0.000	0.000	0.000
MH4	1978	0.000	0.071	0.000	0.001	0.099	0.140	0.000	0.000	57	0.000	0.000	0.000
MH5	1979	0.000	0.066	0.000	0.002	1.43	0.632	0.000	0.000	62	0.000	0.000	0.001
MH6	1980	0.014	0.087	0.008	0.014	1.54	0.122	0.000	0.001	203	0.000	0.000	0.000
GL35	1981	0.000	0.074	0.005	0.018	2.15	0.081	0.001	0.000	263	0.000	0.000	0.000

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
MH2	1976	0.012	0.000	0.001	0.000	0.000	0.000	0.009	0.015	0.000	0.000	0.000	0.000
MH3	1977	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.013	0.000	0.000	0.000	0.000
MH4	1978	0.001	0.000	0.001	0.000	0.000	0.000	2.41	0.023	0.000	0.000	0.000	0.000
MH5	1979	0.000	0.000	0.000	0.000	0.000	0.000	0.145	0.107	0.000	0.000	0.000	0.000
MH6	1980	0.001	0.001	0.001	0.000	0.000	0.000	0.013	0.021	0.000	0.000	0.000	0.000
GL35	1981	0.000	0.003	0.003	0.000	0.000	0.000	0.009	0.011	0.000	0.000	0.001	0.000

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
MH2	1976	0.000	0.000	0.000	17.4	0.000	0.010	0.000	3.5	0.001	0.000	177	0.000
MH3	1977	0.000	0.000	0.000	8.3	0.000	0.019	0.000	41	0.062	0.001	155	0.000
MH4	1978	0.000	0.000	0.000	3.6	0.000	0.014	0.000	33	1.12	0.000	41	0.000
MH5	1979	0.000	0.000	0.000	4.9	0.000	0.042	0.000	45	1.71	0.008	150	0.000
MH6	1980	0.000	0.000	0.001	6.5	0.000	0.027	0.000	152	0.109	0.008	282	0.000
GL35	1981	0.000	0.000	0.001	31	0.000	0.091	0.000	316	5.94	0.011	491	0.000

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)	Sc (mg/L)
MH2	1976	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
MH3	1977	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
MH4	1978	0.000	0.015	0.000	0.091	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000
MH5	1979	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000
MH6	1980	0.000	0.004	0.001	0.271	0.000	0.003	0.000	0.006	0.000	0.000	0.002	0.001
GL35	1981	0.000	0.005	0.001	0.000	0.002	0.002	0.000	0.040	0.000	0.000	0.001	0.000

Sample Origin	Sample ID	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)	Tl (mg/L)	Tm (mg/L)
MH2	1976	0.012	26	0.000	0.000	0.043	0.000	0.000	0.000	0.000	0.003	0.000	0.000
MH3	1977	0.028	0.257	0.000	0.000	0.298	0.000	0.000	0.000	0.000	0.023	0.000	0.000
MH4	1978	0.000	10.3	0.000	0.000	0.221	0.000	0.000	0.000	0.000	0.046	0.000	0.000
MH5	1979	0.012	11.1	0.000	0.000	0.449	0.000	0.000	0.000	0.000	0.050	0.000	0.000
MH6	1980	0.184	16.5	0.000	0.000	1.55	0.001	0.000	0.000	0.001	0.148	0.001	0.000
GL35	1981	0.133	3.2	0.000	0.000	2.61	0.001	0.000	0.001	0.000	0.222	0.000	0.000

Sample Origin	Sample ID	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
MH2	1976	0.002	0.035	0.000	0.000	0.000	0.018	0.000
MH3	1977	0.000	0.000	0.000	0.000	0.000	0.016	0.000
MH4	1978	0.000	0.001	0.000	0.000	0.000	0.017	0.000
MH5	1979	0.004	0.000	0.000	0.000	0.000	0.016	0.000
MH6	1980	0.004	0.003	0.001	0.000	0.000	0.276	0.000
GL35	1981	0.001	0.001	0.009	0.000	0.000	0.698	0.000

WATERLAB

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sanas Testing Laboratory

SANAS Accredited Testing Laboratory
No. T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2015 - 03 - 23

Date completed: 2015 - 04 - 09

Project number: 139

Report number: 51209

Order number: 1096

Client name: SLR Consulting (Africa) (Pty) Ltd

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Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification: Mokala**					
		MH2	**MH3**	**MH4**	**MH5**	**MH6**	**GL35**
Sample Number		1976	1977	1978	1979	1980	1981
pH – Value at 25°C	WLAB001	8.3	9.2	7.9	7.8	7.5	7.9
Electrical Conductivity in mS/m at 25°C	WLAB002	85.5	140	68.7	118	348	565
Total Dissolved Solids at 180°C *	WLAB003	568	942	392	932	3 068	4 338
Total Alkalinity as $CaCO_3$	WLAB007	336	20	304	476	144	64
Bicarbonate as HCO_3 *	WLAB023	410	24	371	580	176	78
Chloride as Cl	WLAB046	55	362	65	116	613	1 478
Sulphate as SO_4	WLAB046	35	128	<5	<5	149	646
Fluoride as F	WLAB014	0.5	0.3	0.2	0.9	0.2	0.5
Nitrate as N	WLAB046	9.9	<0.2	<0.2	<0.2	180	14
ICP-MS Scan (Dissolved) *	WLAB050	See Attached Report: 51209-A					
% Balancing *	---	94.5	93.8	97.2	97.6	98.5	96.6

*** = Not SANAS Accredited**
Tests marked “Not SANAS Accredited” in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

A. van de Wetering

Technical Signatory

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WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number : **139**
Client : **SLR Consulting**
Report Number : **51127-A**

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
MH1	1717	0.000	0.033	0.001	0.003	0.124	0.149	0.000	0.000	69	0.000	0.000	0.000
GL15	1718	0.000	0.027	0.002	0.017	2.34	0.075	0.000	0.000	113	0.000	0.000	0.002

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
MH1	1717	0.002	0.000	0.001	0.000	0.000	0.000	0.096	0.025	0.000	0.000	0.000	0.000
GL15	1718	0.000	0.000	0.003	0.000	0.000	0.000	0.013	0.014	0.000	0.000	0.001	0.000

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
MH1	1717	0.000	0.000	0.000	7.8	0.000	0.005	0.000	32	0.004	0.000	48	0.000
GL15	1718	0.000	0.000	0.001	7.5	0.000	0.078	0.000	102	1.76	0.001	327	0.000

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)	Sc (mg/L)
MH1	1717	0.000	0.002	0.000	0.011	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
GL15	1718	0.000	0.004	0.001	0.095	0.000	0.000	0.000	0.004	0.000	0.000	0.001	0.000

Sample Origin	Sample ID	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)	Tl (mg/L)	Tm (mg/L)
MH1	1717	0.006	7.11	0.000	0.000	0.459	0.000	0.000	0.000	0.000	0.060	0.000	0.000
GL15	1718	0.216	2.07	0.000	0.000	0.205	0.000	0.000	0.000	0.000	0.094	0.000	0.000

Sample Origin	Sample ID	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
MH1	1717	0.004	0.009	0.000	0.000	0.000	0.226	0.000
GL15	1718	0.001	0.002	0.001	0.000	0.000	1.34	0.000

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SANAS Accredited Testing Laboratory
No. T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2015 - 03 - 19
Date completed: 2015 - 04 – 09
Project number: 139
Report number: 51127
Order number: 0196

Client name: SLR Consulting (Africa) (Pty) Ltd
Contact person: Mrs. J. Ellerton
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Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification: Mokala**	
		MH1	**GL15**
Sample Number		1717	1718
pH – Value at 25°C	WLAB001	7.7	7.7
Electrical Conductivity in mS/m at 25°C	WLAB002	81.9	289
Total Dissolved Solids at 180°C *	WLAB003	572	2 040
Total Alkalinity as $CaCO_3$	WLAB007	264	188
Bicarbonate as HCO_3 *	WLAB023	322	229
Chloride as Cl	WLAB046	88	704
Sulphate as SO_4	WLAB046	26	251
Fluoride as F	WLAB014	0.2	1.3
Nitrate as N	WLAB046	11	2.2
ICP-MS Scan (Dissolved) *	WLAB050	See Attached Report: 51127-A	
% Balancing *	---	95.8	98.9

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A. van de Wetering

Technical Signatory

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number	**: 139**
Client	**: SLR Consulting**
Report Number	**: 51260-A**

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
GL27	2157	0.000	0.959	0.024	0.012	2.09	0.054	0.001	0.000	131	0.000	0.000	0.000
GL37	2158	0.000	0.080	0.001	0.009	2.60	0.060	0.000	0.000	119	0.000	0.000	0.000
GL56	2159	0.000	0.074	0.001	0.005	2.22	0.088	0.000	0.000	108	0.000	0.000	0.000
BH1	2160	0.000	0.077	0.002	0.008	1.15	0.157	0.001	0.000	217	0.000	0.000	0.004
BH2	2161	0.000	0.071	0.000	0.001	0.611	0.174	0.000	0.000	43	0.000	0.000	0.003

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
GL27	2157	0.000	0.003	0.000	0.000	0.000	0.000	1.220	0.009	0.000	0.000	0.000	0.000
GL37	2158	0.001	0.000	0.001	0.000	0.000	0.000	0.007	0.008	0.000	0.000	0.000	0.000
GL56	2159	0.000	0.000	0.001	0.000	0.000	0.000	0.464	0.018	0.000	0.000	0.000	0.000
BH1	2160	0.001	0.000	0.001	0.000	0.000	0.000	0.252	0.030	0.000	0.000	0.000	0.000
BH2	2161	0.000	0.000	0.001	0.000	0.000	0.000	6.52	0.028	0.000	0.000	0.000	0.000

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
GL27	2157	0.000	0.000	0.000	15.1	0.000	0.374	0.000	29	0.612	0.009	1220	0.000
GL37	2158	0.000	0.000	0.000	8.8	0.000	0.130	0.000	87	0.065	0.003	757	0.000
GL56	2159	0.000	0.000	0.000	11.0	0.000	0.037	0.000	99	0.063	0.001	277	0.000
BH1	2160	0.000	0.000	0.000	9.5	0.000	0.016	0.000	206	0.645	0.001	249	0.000
BH2	2161	0.000	0.000	0.000	4.6	0.000	0.012	0.000	43	0.568	0.001	91	0.000

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)	Sc (mg/L)
GL27	2157	0.000	0.002	0.000	0.102	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000
GL37	2158	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.001	0.000
GL56	2159	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000
BH1	2160	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
BH2	2161	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000

Sample Origin	Sample ID	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)	Tl (mg/L)	Tm (mg/L)
GL27	2157	0.206	6.3	0.000	0.000	3.06	0.000	0.000	0.000	0.000	0.085	0.000	0.000
GL37	2158	0.000	6.1	0.000	0.000	0.758	0.000	0.000	0.001	0.000	0.100	0.000	0.000
GL56	2159	0.090	11.6	0.000	0.000	1.01	0.000	0.000	0.000	0.000	0.098	0.000	0.000
BH1	2160	0.174	11.4	0.000	0.000	1.58	0.000	0.000	0.000	0.000	0.198	0.000	0.000
BH2	2161	0.006	4.4	0.000	0.000	0.256	0.000	0.000	0.000	0.000	0.035	0.000	0.000

Sample Origin	Sample ID	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
GL27	2157	0.000	0.000	0.000	0.000	0.000	5.43	0.000
GL37	2158	0.004	0.001	0.000	0.000	0.000	2.670	0.000
GL56	2159	0.012	0.002	0.000	0.000	0.000	0.116	0.000
BH1	2160	0.021	0.001	0.000	0.000	0.000	0.122	0.000
BH2	2161	0.000	0.000	0.000	0.000	0.000	0.046	0.000

APPENDIX D: MODEL CALIBRATION TARGETS – SPECIFICATIONS AND RESIDUALS

Aquifer test results and analysis

MODEL CALIBRATION TARGETS – SPECIFICATIONS AND RESIDUALS

Name	Source	X	Y	Z [m] (SRTM)	Water level [m]	Observed Heads [m]	Simulated Heads [m]	Residual [m]
GL13	Mokala	689795.400	6991054.118	1037.00	48.00	989.00	995.07	6.07
GL14	Mokala	689967.472	6990944.320	1034.00	35.10	998.90	996.32	-2.58
GL17	Mokala	689604.355	6990940.276	1041.00	42.73	998.27	993.59	-4.68
GL18	Mokala	689774.841	6990828.460	1036.00	43.80	992.20	995.14	2.94
GL2	Mokala	689185.165	6991586.287	1041.00	55.95	985.05	989.24	4.19
GL28	Mokala	689191.851	6991325.515	1042.00	49.47	992.53	989.69	-2.84
GL38	Mokala	689890.548	6990484.225	1029.00	35.44	993.56	996.16	2.60
GL44	Mokala	689931.507	6990418.560	1030.00	31.37	998.63	996.49	-2.14
GL49	Mokala	689678.847	6990630.628	1037.00	41.76	995.24	994.75	-0.49
GL5	Mokala	690043.627	6991070.586	1036.00	34.07	1001.93	996.78	-5.15
GL55	Mokala	689678.007	6990828.675	1043.00	55.20	987.80	994.48	6.68
GL59	Mokala	689792.593	6990926.863	1039.00	47.71	991.29	995.15	3.86
GL8	Mokala	690126.732	6991017.453	1034.00	32.84	1001.16	997.45	-3.71
GL9	Mokala	690068.643	6991160.365	1036.00	34.08	1001.92	996.91	-5.01
Hot2	SLR Hydrocensus	690458.268	6986857.166	1031.00	22.10	1008.90	1004.28	-4.62
Hot3	SLR Hydrocensus	690216.276	6988648.713	1031.00	31.72	999.28	999.64	0.36
Hot4	SLR Hydrocensus	690218.055	6988945.697	1033.00	30.51	1002.49	999.37	-3.12
Hot5	SLR Hydrocensus	690041.907	6988184.370	1036.00	33.60	1002.40	998.97	-3.43
Hot6	SLR Hydrocensus	690043.445	6988155.421	1037.00	32.67	1004.33	999.03	-5.30
Hot1	SLR Hydrocensus	690324.422	6988851.859	1039.00	37.00	1002.00	1000.35	-1.65
JB12	SLRdatabase	694626.931	6977520.463	1080.00	31.00	1049.00	1053.44	4.44
JB14	SLRdatabase	693863.432	6978831.386	1070.00	24.60	1045.40	1047.88	2.48
JB2	SLRdatabase	695251.576	6973576.124	1090.00	30.80	1059.20	1059.97	0.77
JB9	SLRdatabase	694759.045	6975289.590	1084.00	26.30	1057.70	1057.42	-0.28
K1	SLR Hydrocensus	697611.049	6991505.348	1065.00	19.90	1045.10	1045.50	0.40
MH13	SLR Hydrocensus	692033.967	6984600.951	1054.00	25.44	1028.56	1024.76	-3.80
MH14	SLR Hydrocensus	690222.250	6987893.483	1034.00	35.70	998.30	1000.76	2.46
MH5	SLR Hydrocensus	690354.109	6988509.484	1035.00	37.23	997.77	1000.93	3.16
MH6	SLR Hydrocensus	697593.417	6987001.588	1080.00	29.77	1050.23	1054.85	4.62
MH8	SLR Hydrocensus	697954.343	6986741.768	1079.00	25.00	1054.00	1057.22	3.22
MP1	SLR Hydrocensus	686758.827	6975825.519	1062.00	35.60	1026.40	1031.87	5.47
RP19	SLRdatabase	694916.216	6974775.073	1087.00	29.50	1057.50	1058.47	0.97
RP21	SLRdatabase	694977.568	6975713.944	1086.00	32.30	1053.70	1057.37	3.67
RP40	SLRdatabase	695030.640	6975564.593	1087.00	33.25	1053.75	1057.72	3.97
RP46	SLRdatabase	694910.929	6974440.449	1091.00	28.90	1062.10	1058.93	-3.17
SP16	SLRdatabase	693577.370	6978456.836	1074.00	27.60	1046.40	1047.05	0.65
SP30	SLRdatabase	695118.809	6976132.867	1084.00	25.30	1058.70	1057.26	-1.44
TL1	SLR Hydrocensus	690399.824	6983544.929	1053.00	33.60	1019.40	1014.31	-5.09
TL2	SLR Hydrocensus	688495.754	6982630.393	1062.00	47.50	1014.50	1009.35	-5.15
TL3	SLR Hydrocensus	680810.424	6984298.312	1072.00	60.27	1011.73	999.60	-12.13
UMK3	SLRdatabase	698300.031	6977285.815	1090.00	24.30	1065.70	1072.28	6.58
UMK7	SLRdatabase	700114.054	6985387.253	1086.00	18.70	1067.30	1071.12	3.82
YO1	SLR Hydrocensus	690218.535	6987891.521	1034.00	36.00	998.00	1000.74	2.74
YO2	SLR Hydrocensus	690814.783	6984436.010	1048.00	31.82	1016.18	1013.81	-2.37
YO3	SLR Hydrocensus	690914.926	6984436.129	1050.00	33.50	1016.50	1014.72	-1.78
YO4	SLR Hydrocensus	692026.232	6984598.709	1054.00	34.00	1020.00	1024.68	4.68
YO6	SLR Hydrocensus	689266.361	6988223.803	1055.00	64.03	990.97	994.79	3.82
2722BB00021	SLR database	685548.923	6997173.747	1047.00	96.00	951.00	960.16	9.16

Appendix E

CRITERIA FOR ASSESSING IMPACTS

Note: Part A provides the definition for determining impact consequence (combining severity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	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 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 = L

DURATION	Long term	**H**	**Medium**	**Medium**	**Medium**
	Medium term	**M**	**Low**	**Low**	**Medium**
	Short term	**L**	**Low**	**Low**	**Medium**

SEVERITY = M

DURATION	Long term	**H**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**

SEVERITY = H

DURATION	Long term	**H**	**High**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Medium**	**Medium**	**High**
			L	**M**	**H**
			Localised Within site boundary Site	Fairly widespread Beyond site boundary Local	Widespread Far beyond site boundary Regional/ national
			SPATIAL SCALE		

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 F: CURRICULUM VITAE

Terry Harck
Solution[H+]
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www.solutionhplus.com

PROFESSIONAL PROFILE

Environmental Geochemist. Mine drainage quality prediction. Acid Mine Drainage (AMD) assessment. Mine water management. Integration of geochemistry, groundwater and surface water studies.

BIOGRAPHY

Terry advises Southern African and international clients on the management of acid rock drainage and contaminated seepage at mine sites. He has been practicing as a consultant for over 20 years. He was the manager and lead consultant of a team of 11 specialists before going solo as Solution[H+].

Terry is a member of the International Mine Water Association (IMWA), the Groundwater Division of the Geological Society of South Africa (GWD-GSSA), and the South African chapter of the International Association of Hydrogeologists (IAH-SA), for which he serves as Treasurer.

PROFESSIONAL EXPERIENCE

Solution[H+], Pretoria, South Africa
Principal Consultant
Environmental Geochemist
February 2012 – present

Golder Associates Africa, Johannesburg, South Africa
Senior Geochemist and Divisional Leader
May 2004 – February 2012
Specialist impact prediction studies with special reference to the geochemistry and groundwater aspects of mining impacts. Integration of hydrogeological and geochemical aspects of contamination assessment projects for the mining and related industries.

Responsible for 10 professionals: internal coordination, marketing, developing proposals, project management, commissioning specialists, report development, client liaison and budget management.

Coffey Geosciences, Sydney, Australia
Senior Geoscientist
July 1997 – December 2003
Led a business unit comprising four employees. Project managed mine environmental specialist studies. Business development. Internal auditor for office Quality Management System

Wates, Meiring and Barnard, Johannesburg, South Africa
Contaminant Geohydrologist/Geochemist
July 1996 – June 1997
Specialist hydrogeological and geochemical studies for mining and industrial clients.

Steffen, Robertson and Kirsten, Johannesburg, South Africa
Contaminant Hydrogeologist/Geochemist
May 1995 – June 1996
Specialist hydrogeological and geochemical studies for mining and industrial clients.

E Martinelli and Associates, Johannesburg, South Africa
Geologist
Geophysical surveys, contractor supervision, groundwater development work.
January 1991 – December 1993

EDUCATION

University of Cape Town, Cape Town, South Africa
M.Sc. in Environmental Geochemistry **1995**
Thesis: "A Geochemical Investigation of the Aquatic Sediments, Groundwater and Surface water of the Verlorenvlei Coastal Lake, With Special Reference to Nitrate Transformations."

University of the Witwatersrand, Johannesburg, South Africa
M.Sc. in Geology **1994**
Thesis: "Depositional Systems and Syndepositional Tectonics of the Basal Griqualand West Sequence, Northern Cape"

University of the Witwatersrand, Johannesburg, South Africa
B.Sc. Honours in Geology **1987**

PUBLICATIONS AND PAPERS

Pretorius JA, Harck T, and Gunther P "Brine Disposal / Storage of Brine in Underground Mining Compartments – A Case Study" Solution Mining Research Institute (SMRI) Fall 2011 Conference, 2-5 October 2011, York, UK.

T Harck "Mobilisation of salts from mine waste. A pinch or a pound?" Symposium of the International Mine Water Association. September 2010, Sydney, Nova Scotia

T Harck and M Peters "Reprocessing Kimberlite tailings: A square contaminant source in a big hole?" 11th International Mine Water Association Congress. October 2009, Pretoria, South Africa

T Harck et al "Impact prediction of the reactivation of an unused tailings dam," 11th International Mine Water Association Congress. October 2009, Pretoria, South Africa

Ochieng L, Harck T, and Peters M "Net Neutralisation Potential NNP) in Kimberley Diamond Tailings and Slimes Waste Materials" 11th International Mine Water Association Congress. October 2009, Pretoria, South Africa

T Harck "Managing the Groundwater Impact of Mine Water Treatment Waste", 10th International Mine Water Association Congress. June 2008, Karlovy Vary, Czech Republic.

T Harck "Are biodiversity offsets a licence to plunder natural resources?", IAIAsa Newsletter. August 2005, South Africa.

T Harck "Old mines yield history", Australian Geographic. July – September 2002, Australia

T Harck, Willis JP, and Fey MV "Denitrification of nitrate-rich ground water entering Verlorenvlei Lake on the west coast of South Africa" Proceedings of the 4th International symposium on Environmental Geochemistry, Oct. 5-10 1997, Vail, CO, United States

T Harck "Identification and Characterisation of a Source of Contaminated Seepage", Young Water, Environmental & Geotechnical Engineers Conference, July 1996, KwaZulu Natal, South Africa.

PRESENTATIONS AND TEACHING

University of Pretoria, Pretoria, South Africa **2012-2014**
Volunteer lecturer: "Environmental Geochemistry" GTX715

Principles of low temperature geochemistry, geochemistry and origin of acid mine water, acid-mineral reactions; industrial effluents, remediation methods, waste disposal, environmental sampling and data analysis, geochemical modelling.

North West University, Potchefstroom, South Africa **2012-2013**
Extraordinary lecturer

Presented course "An introduction to Hydrogeochemistry". This included themes such as: Chemical equilibrium, Contents of Water, and Solids and water. Topics included: equilibrium constants, pH, pe, solubility, dissolved gases, alkalinity, speciation, redox reactions, ion exchange, colloids, sulphide mineral oxidation and introduction to the PHREEQC geochemical modelling code.
Supervised honours degree student during their honours project fieldwork and write-up

Golder Associates, Johannesburg, South Africa **2012-2014**
Facilitator: "Understanding and Applying Best Practice Management of Acid Rock Drainage"

Developed syllabus and course structure, and coordinated the course

Golder Associates, Johannesburg, South Africa **2011**
Facilitator: "Technical Writing"

Co-presented training material developed in-house

Department of Water Affairs and Forestry and Water Institute of South Africa – Mine Water Division **2008-2010**
Presenter: "The value of impact prediction from case studies." Second Symposium on Best Practice Guidelines"

Three geochemical prediction studies from project experience

Geological Society of South Africa – Ground Water Division **11-12 February 2009**
Presenter: "Re-evaluation of Cr(VI) Contamination After Remediation"

Case study not included in the conference proceedings

International Association for Impact Assessment – South African chapter (IAIAsa) **October 2007**
Presenter: "Does the new Mining Act further sustainability in the mining industry?"

Discussion paper not included in the conference proceedings

University of Cape Town, Cape Town, South Africa **October 2005**
Tutor

Teaching support for laboratory sessions

SLR Consulting (South Africa) (Pty) Limited

RECORD OF REPORT DISTRIBUTION

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Kelly Byrne	Mokala Manganese (Pty) Ltd	1	October 2015	T Harck
Carol Kenyon	SLR Consulting (South Africa) (Pty) Ltd	1	October 2015	T Harck

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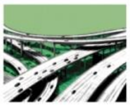
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