global environmental solutions

Lehating 741

Groundwater Flow and Contaminate Transport Modelling

SLR Project No.: 710.12015.00001

Report No.: 01

August 2013

FINAL

Lehating Mining Pty Ltd

Lehating 741

Groundwater Flow and Contaminate Transport Modelling

SLR Project No.: 710.12015.00001

Report No.: 01

August 2013

FINAL

Lehating Mining Pty Ltd

DOCUMENT INFORMATION

Title	Groundwater Transport and Contaminate Flow Modelling
Project Manager	
Project Manager e-mail	rtitus@slrconsulting.com
Author	Theo Rossouw & Rian Titus
Reviewer	Rian Titus
Client	Lehating Mining Pty Ltd
Date last printed	
Date last saved	16/08/2013 11:43:00 AM
Comments	
Keywords	Hydrogeology, groundwater model, contaminant flow
Project Number	710.12015.00001
Report Number	01
Status	FINAL
Issue Date	August 2013

GROUNDWATER FLOW AND CONTAMINATE TRANSPORT MODELLING

CONTENTS

EXECUTIVE SUMMARY I
1 INTRODUCTION 1
1.1 PROJECT OBJECTIVE 1
1.2 MODELLING OBJECTIVE 1
1.3 DATA SOURCES AND DEFICIENCIES 1
1.4 MODEL LIMITATIONS 2
2 HYDROGEOLOGICAL CONCEPTUAL MODEL 4
2.1 LEHATING MINE LOCALITY 4
2.2 GEOLOGY 6
2.2.1 LITHOSTRATIGRAPHY 6
2.3 AQUIFER SYSTEM 10
2.3.1 UNCONFINED KALAHARI AQUIFER 14
2.3.2 CONFINED DWYKA AQUIFER 14
2.3.3 OLIFANTSHOEK AQUIFER (WESTERN GEOLOGICAL BOUNDARY) 14
2.3.4 DEEPER FRACTURED HOTAZEL / ONGELUK AQUIFER 14
2.3.5 ASBESTOS HILL AQUIFER (EASTERN GEOLOGICAL BOUNDARY) 15
2.4 HYDROGEOLOGICAL FIELD INVESTIGATION 15
2.4.1 HYDROCENSUS 15
2.4.2 HYDRAULIC PROPERTIES 19
2.5 GROUNDWATER ELEVATION AND FLOW DIRECTIONS 23
2.6 HYDROLOGIC BOUNDARIES 24
3 MODEL CONSTRUCTION 25
3.1 COMPUTER CODE 25
3.1.1 MODFLOW 25
3.1.2 MT3D 25
3.2 MODEL DOMAIN 26
3.2.1 FINITE DIFFERENCE FLOW MODEL 26
3.2.2 FINITE DIFFERENCE CONTAMINANT TRANSPORT MODEL 28
3.3 BOUNDARY CONDITIONS 28
3.4 SOURCES AND SINKS 28
3.4.1 GROUNDWATER RECHARGE 28
3.4.2 RIVER COURSES 29
3.4.3 TAILING STORAGE FACILITY, WASTE ROCK STOCKPILE AND PRODUCT STOCK PILES 29
3.5 HYDRAULIC PARAMETERS FOR FINITE DIFFERENCE MODELS 30
3.6 SELECTION OF CALIBRATION PARAMETERS AND TARGETS 30
4 CALIBRATION (STEADY STATE) 32
4.1 FINITE DIFFERENCE FLOW MODEL 32
5 PREDICTIVE SIMULATIONS 36
5.1 ESTIMATED UNDERGROUND MINE INFLOW RATES 36
5.1.1 IMPACTS ASSOCIATED WITH DEEP MINE INFLOWS 37
5.2 SIMULATED BOREHOLE / WELL FIELD AS GROUNDWATER SUPPLY 39
5.2.1 IMPACTS ASSOCIATED WITH WELL FIELD 41
5.3 SIMULATED CONTAMINANT TRANSPORT FROM THE TAILING STORAGE FACILITY, WASTE ROCK STOCK PILE AND OTHER STOCKPILES 42
5.3.1 IMPACTS ASSOCIATED WITH SEEPAGE FROM THE SOURCES 45
6 CONLUSIONS AND RECOMMENDATIONS 46
6.1 CONCLUSIONS 46
6.1.1 GEOLOGY 46

6.1.2 AQUIFER CLASSIFICATION 46
6.1.3 IMPACTS BASED ON MINE DEWATERING 47
6.1.4 IMPACTS BASED ON WELL FIELD DEVELOPMENT 48
6.1.5 IMPACTS BASED ON SEEPAGES ASSOCIATED WITH THE TAILING STORAGE FACILITY, WASTE ROCK STOCKPILE AND OTHER STOCKPILES (SOURCES) 48
6.2 MONITORING REQUIREMENTS AND RECOMMENDATIONS 50
7 DEGREE OF CONFIDENCE IN PREDICTIONS AND MODEL UNCERTAINTY 55
8 DISCLAIMER 56
9 REFERENCES 57

LIST OF FIGURES

FIGURE 2-1: LOCATION OF THE LEHATING MINING PORTION 5
FIGURE 2-2: REGIONAL GEOLOGY OF LEHATING MINE (QUATERNARY CATCHMENT D41M) 7
FIGURE 2-3: GENERALIZED STRATIGRAPHIC REPRESENTATION OF THE KALAHARI FORMATION (PARTRIDGE ET AL, 2006) 8
FIGURE 2-4: ILLUSTRATION OF THE STRATA DUE TO LOW ANGLE THRUSTING AT THE BASE OF THE OLIFANTSHOEK SUPERGROUP (AFTER: BUEKES AND SMIT, 1987). 10
FIGURE 2-5: REGIONAL AND LOCAL CONCEPTUAL HYDROGEOLOGICAL MODEL FOR LEHATING MINE (NOT ACCORDING TO SCALE). 11
FIGURE 2-6: HYDROGEOLOGICAL (AQUIFER CLASS) MAP INDICATING LOCATION OF LEHATING 13
FIGURE 2-7: HYDROCENSUS CONDUCTED TO IDENTIFY GROUNDWATER USE AND WATER LEVELS 18
FIGURE 2-8: LOG- LOG PLOT FOR A CONSTANT DISCHARGE PUMPING TEST (CDT) BASED ON GROUNDWATER LEVEL FLUCTUATIONS FOR LEX 3A AND FITTED NEUMAN SOLUTION FOR AN UNCONFINED AQUIFER. 21
FIGURE 2-9: LOG- LOG PLOT FOR A CONSTANT DISCHARGE PUMPING TEST (CDT) FOR LEX 4 AND FITTED MOENCH SOLUTION FOR A LEAKY AQUIFER. 22
FIGURE 2-10: CORRELATION BETWEEN SURFACE TOPOGRAPHY AND WATER LEVEL ELEVATIONS IN QUATERNARY CATCHMENT D41M. 24
FIGURE 3-1: LEHATING GROUNDWATER FINITE-DIFFERENCES MODEL SETUP SHOWING REFINED GRID AND AQUIFER SYSTESM 27
FIGURE 4-1: STEADY-STATE CALIBRATION OF LEHATING MINE MODEL. 32
FIGURE 4-2: STEADY-STATE CALIBRATED GROUNDWATER LEVELS OF THE LEHATING MINE MODEL. 34
FIGURE 5-1: SIMULATED STEADY STATE CONE OF DEPRESSION FOR THE PROPOSED WELL FIELD 40
FIGURE 5-2: CONTOUR MAPS OF POTENTIAL SOURCE CONCENTRATIONS (IN PERCENTAGE) AFTER 15, 25, 50 AND 100 YEARS PREDICTED WITH THE FINITE-DIFFERENCE MODEL FOR LAYER 1 (ASSUMING CONSTANT SOURCE STRENGTH) FOR THE WASTE ROCK STOCK PILES, FINES AND OTHER STOCK PILE. 44
FIGURE 6-1: PROPOSED GROUNDWATER MONITORING LOCATIONS BASED ON POTENTIAL GROUNDWATER IMPACTS 51

LIST OF TABLES

TABLE 2.1: AQUIFER CLASSIFICATION SCHEME (PARSONS, 1995; PARSONS AND CONRAD, 1998). 12
TABLE 2.2: CHEMISTRY OF GROUNDWATER SAMPLES COLLECTED DURING THE PUMPING TESTS AND COLOUR CODED ACCORDING TO SANS WATER QUALITY GUIDELINES. 16
TABLE 2.3:: WATER LEVEL DATA OBTAINED FROM HYDROCENSUS. 17
TABLE 2.4: BOREHOLE INFORMATION AND HYDRAULIC CONDUCTIVITIES DERIVED FROM THE PACKER TESTS TARGETING THE HOTAZEL AND PARTS OF THE ONGELUK FORMATIONS. 19
TABLE 2.5:: BOREHOLES USED FOR PUMPING TESTS. 20
TABLE 2.6: ESTIMATES OF AQUIFER PARAMETERS BASED ON PUMPING TESTS – LEX 3A. 22
TABLE 2.7: ESTIMATES OF AQUIFER PARAMETERS BASED ON PUMPING TESTS – LEX 4. 23
TABLE 3.1: SOURCE CONCENTRATIONS FOR THE MINE RESIDUE DEPOSITS (MRD'S). 29
TABLE 4.1: FINAL HYDRAULIC CONDUCTIVITIES FOR THE FINITE DIFFERENCE FLOW MODEL. 35
TABLE 4.2: FLOW BUDGET CALCULATED FROM CALIBRATED MODEL PARAMETERS 35
TABLE 5.1: ESTIMATED, CUMULATIVE MINE FISSURE INFLOWS FOR SELECTED PERIODS OVER LIFE OF MINE. 36

ACRONYMS AND ABBREVIATIONS

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

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

EXECUTIVE SUMMARY

SLR Consulting (Africa) (PTY) LTD was contracted to provide specialist groundwater input during the development of the Lehating Mine. The input comprised input for the Environmental Impact Assessment. The aim of the groundwater specialist report was to provide the conceptualisation and characterisation the aquifer systems in the study area (i.e. the Lehating Mine area) and conceptualize the groundwater regime and potential impacts on the flow regime due to mine development.

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

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

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

Also, a total of 2 pumping tests were conducted. Borehole LEX3A is characterised by a transmissivity value of ~117m^2/day, typical for an unconfined aquifer and appears plausible for a shallow primary aquifer in the Kalahari Formation. As a result, the hydraulic conductivity of the Kalahari Formation is estimated to be 2m/d. Results from the pumping test for borehole LEX3A indicate that the borehole can be pumped at a recommended rate of 8.0L/s for 12 hours with a maximum groundwater level drawdown of 8 metre. This will allow a 12 hour recovery time for the aquifer to recover to its original water level. The hydraulic test for borehole LEX 4 shows a transmissivity value of ~0.95m^2/day. Borehole LEX4 was cased-off to a depth of 180mbgl and the transmissivity value(s) may be representative of the deeper

Dwyka, Hotazel and upper Ongeluk formations. Due to the low yielding capability of the deeper Dwyka, Hotazel and upper Ongeluk formations borehole LEX4 is not recommended for water supply use.

The groundwater sample collected at borehole LEX3A presented a Mg-HCO_3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. The groundwater sample collected at borehole LEX4 presented a Na-Cl water type with elevated concentrations of chloride, sodium and magnesium. The elevated sodium and chloride concentrations may represent deeper and/or older groundwater within an evolved groundwater regime. This water type is probably characteristic of the groundwater within the deeper, confined Hotazel and Ongeluk aquifers. The groundwater samples for LEX3A and LEX4 are thus indicative of two distinctive groundwater regimes.

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

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

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

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

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

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

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

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

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

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

- Likely to occur w.r.t. groundwater as resource;
- Unlikely to impact any third party groundwater users;
- Limited (up to 1 km) impact slightly beyond the mine lease area w.r.t.
    - Interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River;
    - Development of intersecting cones of depression, i.e. the lowering of the groundwater levels due to well field dewatering
- Reversible over time once well field stops abstracting groundwater; and

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

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

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

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

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

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

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

GROUNDWATER FLOW AND CONTAMINATE TRANSPORT MODELLING

1 INTRODUCTION

1.1 Project Objective

The overall project objectives are as follows;

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

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

1.2 Modelling Objective

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

1.3 Data Sources and Deficiencies

Numerous data sources were consulted to complete the model input parameters, boundary conditions, and calibration of the data. All the data were converted to common horizontal and vertical model datums. The horizontal datum used in this model is metres Lo23 Transverse Mercator with vertical datum presented as metres above mean sea level (mamsl). The development of the hydrogeological conceptual and numerical groundwater models were based on the following information and data made available to the project team or gathered as part of the groundwater investigations:

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

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

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

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

1.4 MODEL LIMITATIONS

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

- Input data on the types and thickness of hydrogeological units, water levels, and hydraulic properties are only estimates of actual values;
- All the physical and chemical processes in a catchment cannot be represented completely in a numerical model;
- The numerical model developed for Lehating can't be used for any other purpose than the defined model objectives;

- The numerical model is a non-unique solution that can calibrated with an unlimited number of acceptable parameters; and
- The numerical model is a simplification of the natural world.

2 HYDROGEOLOGICAL CONCEPTUAL MODEL

2.1 LEHATING MINE LOCALITY

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

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

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

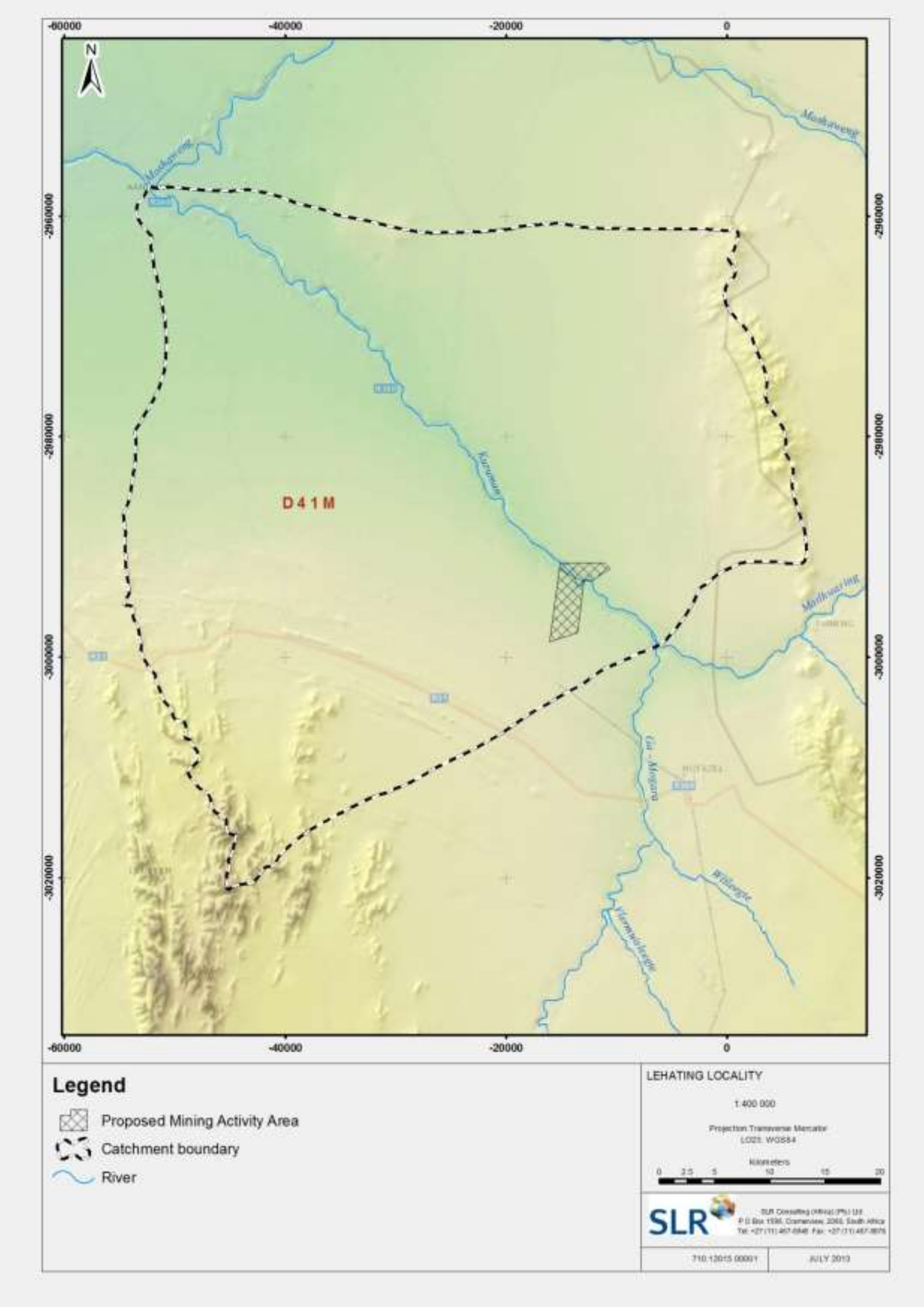


FIGURE 2-1: LOCATION OF THE LEHATING MINING PORTION

2.2 GEOLOGY

2.2.1 LITHOSTRATIGRAPHY

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

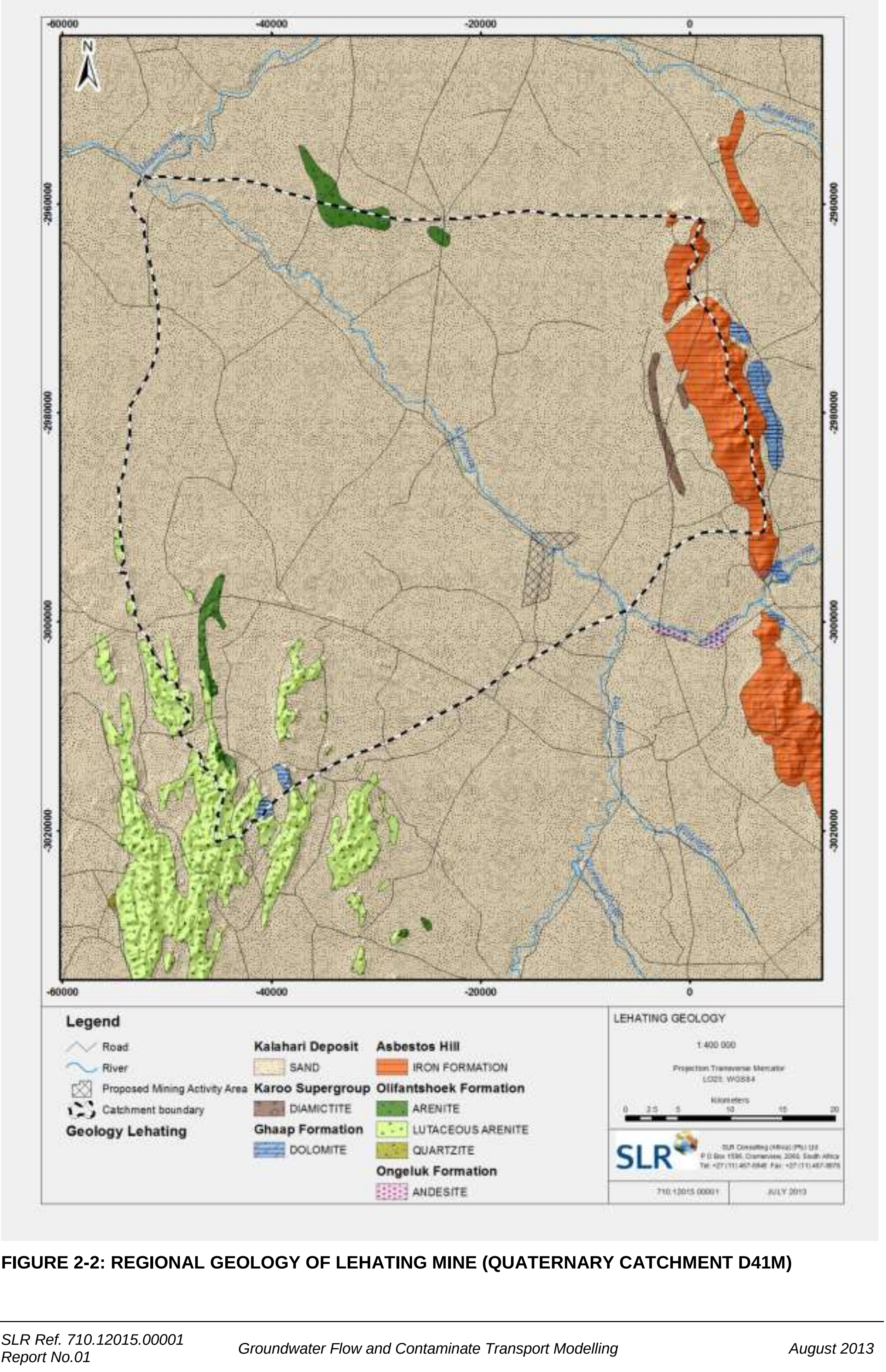


FIGURE 2-2: REGIONAL GEOLOGY OF LEHATING MINE (QUATERNARY CATCHMENT D41M)

2.2.1.1 Kalahari Formation

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

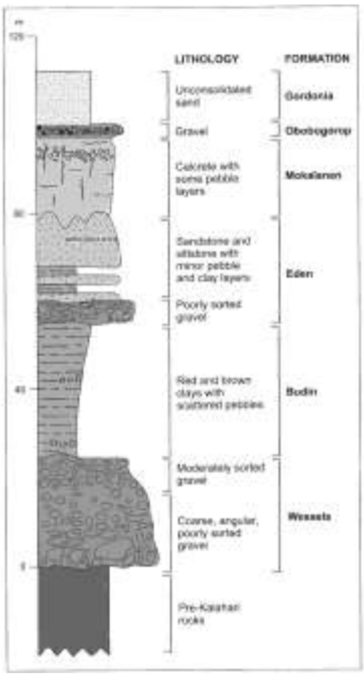


FIGURE 2-3: GENERALIZED STRATIGRAPHIC REPRESENTATION OF THE KALAHARI FORMATION (PARTRIDGE ET AL, 2006)

- The Wessels Formation forms the base of the Kalahari formation and is characterized by clayey gravel. Thicker and better-developed clayey gravel of this formation is located in deeper palaeo-valleys and doesn’t occur extensively where the Kalahari formation is at its thickest.
- The Budin Formation consists mostly of red and brown calcareous clays, which were possibly deposited in shallow saline lakes. It may also consist of thin pebble layers near its base.
- The Eden formation consists mainly of red, brown or yellowish sandstone with thin pebble layers. This formation becomes more disaggregated and calcified towards the top and was probably deposited from braided streams (Partridge et al, 2006).
- The Mokalanen Formation can be divided into a sandy limestone and overlying conglomerate with a calcareous mixture. This formation reflects more arid depositional conditions than the underlying fluvial conditions.
- The Obobogorop Formation is characterized by pebble and boulder clasts consisting of calcrete. These clasts are derived from the weathering of Dwyka tillites.
- The Gordonia Formation consists of red aeolian sands (windblown sands / dunes) and rounded quartz grains coloured by a thin coating of hematite. The hematite is absent in river bottom areas

subject to hydromorphic influences, where the sand is white in colour. Based on the borehole logs it appears that the Gordonia Formation rests directly on pre-Kalahari bedrock, namely Karoo sediments. According to Baillieul (1975) the Gordonia Formation originates from local sources with some additional material transported into the basin over short distances. Aeolian overprinting of sands originally deposited by streams and sheet wash is evident in some areas (Moore and Dignle, 1998). Linear dunes, stabilized by vegetation, characterize the Gordonia Formation. This is evident in the Lehating mining area.

2.2.1.2 Dwyka Formation (Karoo Supergroup)

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

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

2.2.1.3 Olifantshoek Supergroup

Arenaceous sediments of the Olifantshoek Supergroup form a prominent north trending mountain range in the vicinity of Boegoeberg dam northwards to the Korannaberg, where rocks of the Olifantshoek Supergroup is progressively covered by Kalahari sediments. The supergroup consists of interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The whole supergroup has been deformed into a succession with an east-verging dip (Cornell et al., 1998). The Olifantshoek Supergroup overlies sediments of the Transvaal Supergroup with a regional unconformity as seen in **Error! eference source not found.**. The total thickness of the supergroup exceeds 5000 metres. The age of the Olifantshoek Supergroup as indicated by different isochrones is approximately 1900 Ma (Armstrong, 1987). The different subgroups and formations present in the study area include the Brulsand, Matsap and Lucknow units. Rocks of the Olifantshoek Supergroup outcrop in the western side of the quaternary catchment and form a topographically elevated area.

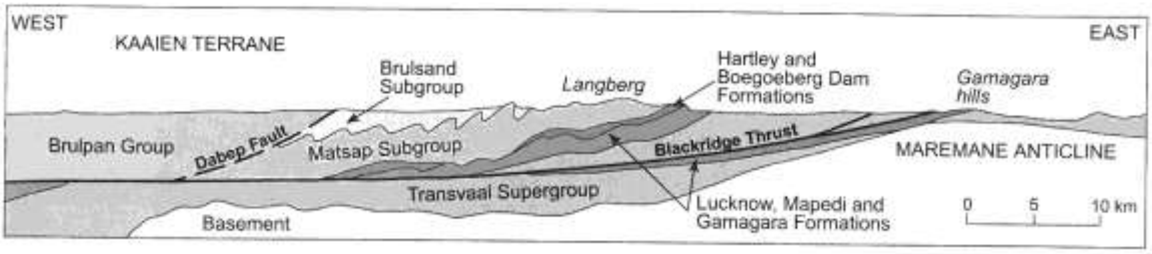


FIGURE 2-4: ILLUSTRATION OF THE STRATA DUE TO LOW ANGLE THRUSTING AT THE BASE OF THE OLIFANTSHOEK SUPERGROUP (AFTER: BUEKES AND SMIT, 1987).

2.2.1.4 Ongeluk and Hotazel Formations (Transvaal Supergroup)

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

2.2.1.5 Asbestos Hill Subgroup (Transvaal Supergroup)

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

2.3 AQUIFER SYSTEM

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

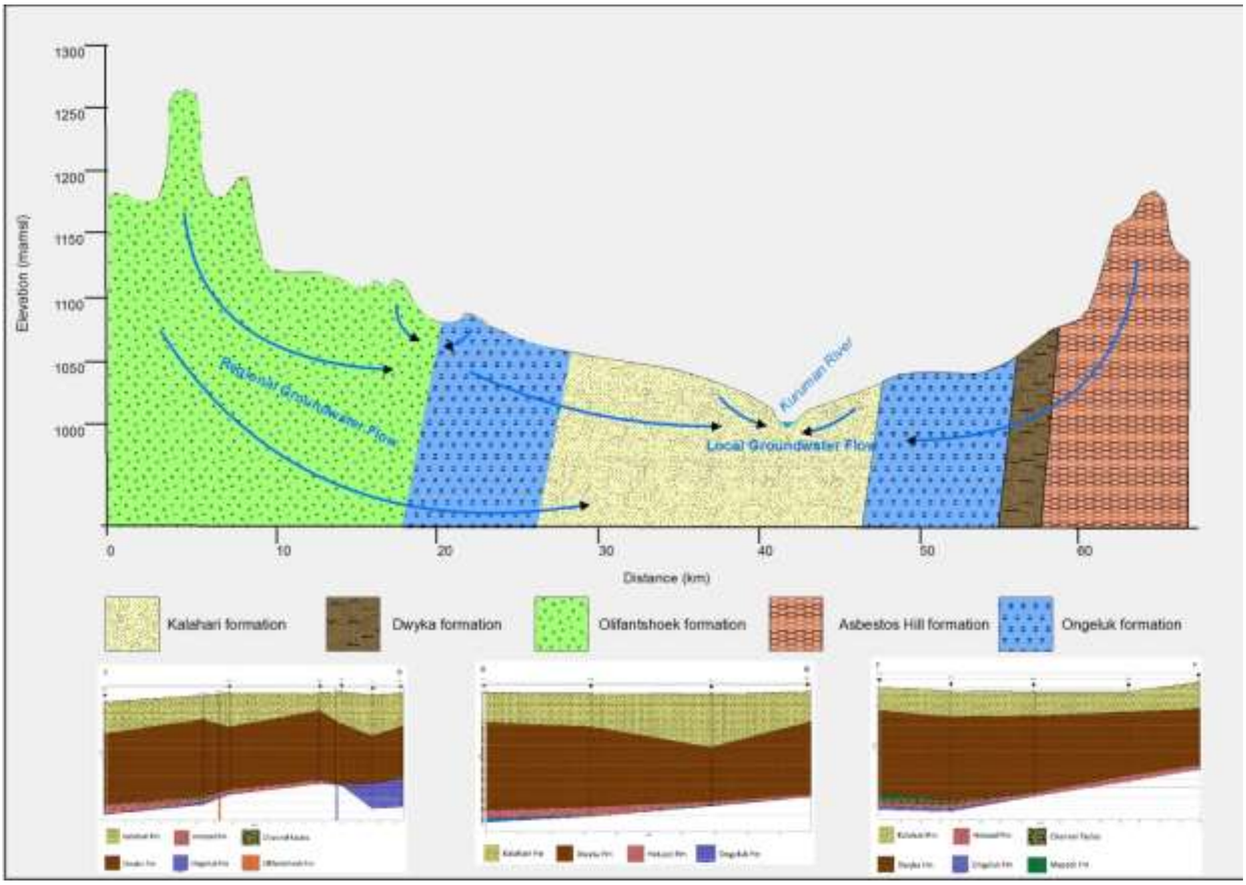


FIGURE 2-5: REGIONAL AND LOCAL CONCEPTUAL HYDROGEOLOGICAL MODEL FOR LEHATING MINE (NOT ACCORDING TO SCALE).

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

Based on the aquifer classification map (Parsons and Conrad, 1998) the majority of study area is regarded a "poor aquifer" while the aquifer adjacent (west) to the proposed Lehating portion is regarded as "minor" (**FIGURE 2-6**). A summary of the classification scheme is provided in Table 2.1. In this classification system, it is important to note that the concepts of Minor and Poor Aquifers are relative and that yield is not quantified. Within any specific area, all classes of aquifers should therefore, in theory, be present.

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

TABLE 2.1: AQUIFER CLASSIFICATION SCHEME (PARSONS, 1995; PARSONS AND CONRAD, 1998).

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

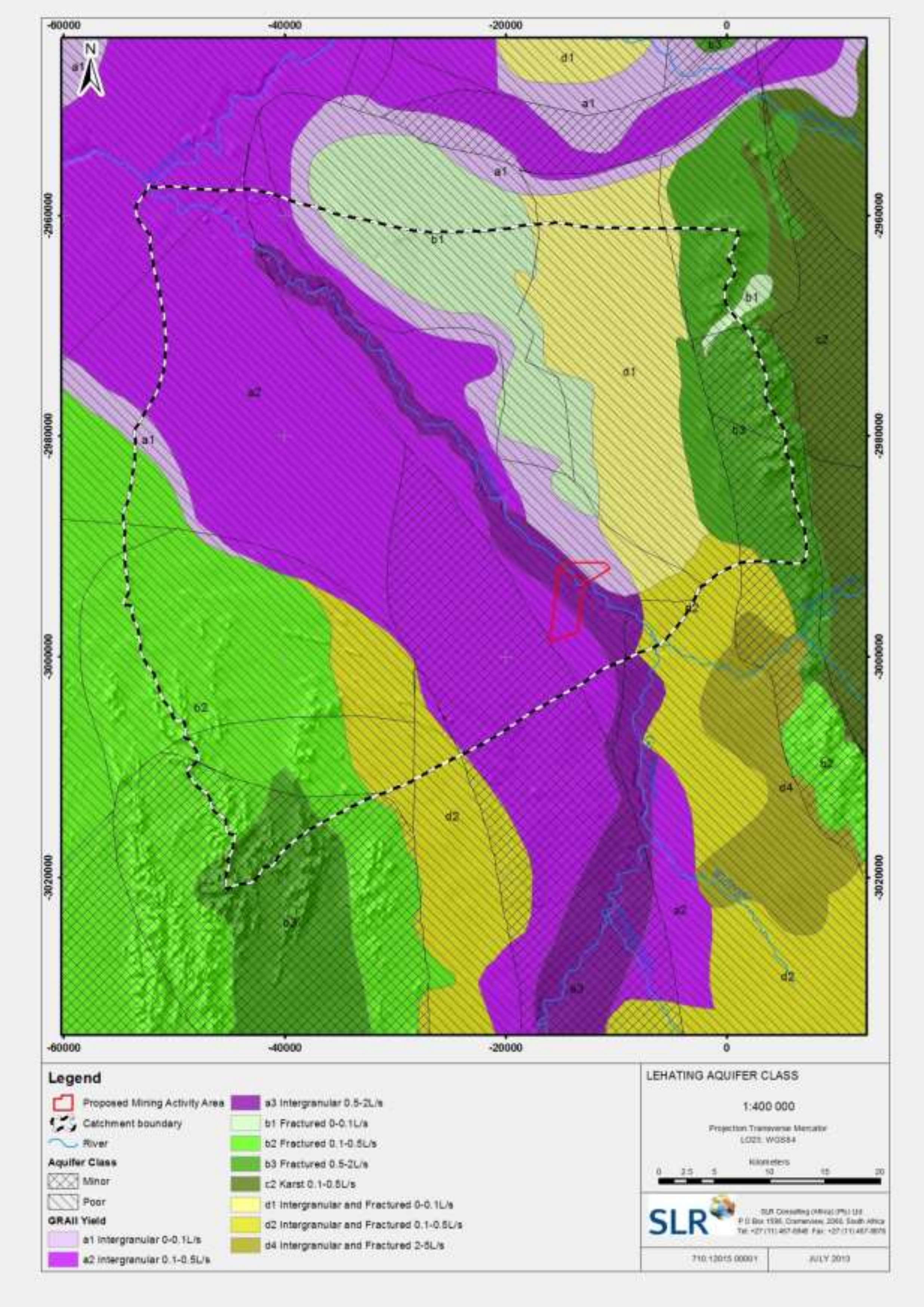


FIGURE 2-6: HYDROGEOLOGICAL (AQUIFER CLASS) MAP INDICATING LOCATION OF LEHATING

2.3.1 UNCONFINED KALAHARI AQUIFER

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

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

2.3.2 CONFINED DWYKA AQUIFER

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

2.3.3 OLIFANTSHOEK AQUIFER (WESTERN GEOLOGICAL BOUNDARY)

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

2.3.4 DEEPER FRACTURED HOTAZEL / ONGELUK AQUIFER

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

2.3.5 ASBESTOS HILL AQUIFER (EASTERN GEOLOGICAL BOUNDARY)

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

2.4 HYDROGEOLOGICAL FIELD INVESTIGATION

2.4.1 HYDROCENSUS

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

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

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

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

Analytical results for groundwater samples collected at Lehating during the pumping tests are presented in the table presented below.

TABLE 2.2: CHEMISTRY OF GROUNDWATER SAMPLES COLLECTED DURING THE PUMPING TESTS AND COLOUR CODED ACCORDING TO SANS WATER QUALITY GUIDELINES.

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

The groundwater sample collected at borehole LEX3A presented a Mg-HCO_3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. This is expected from the sample collected at borehole LEX3A as the borehole was drilled to a depth of 40 metres targeting higher yielding zones in the Kalahari Formation.

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

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

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

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

TABLE 2.3: WATER LEVEL DATA OBTAINED FROM HYDROCENSUS.

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

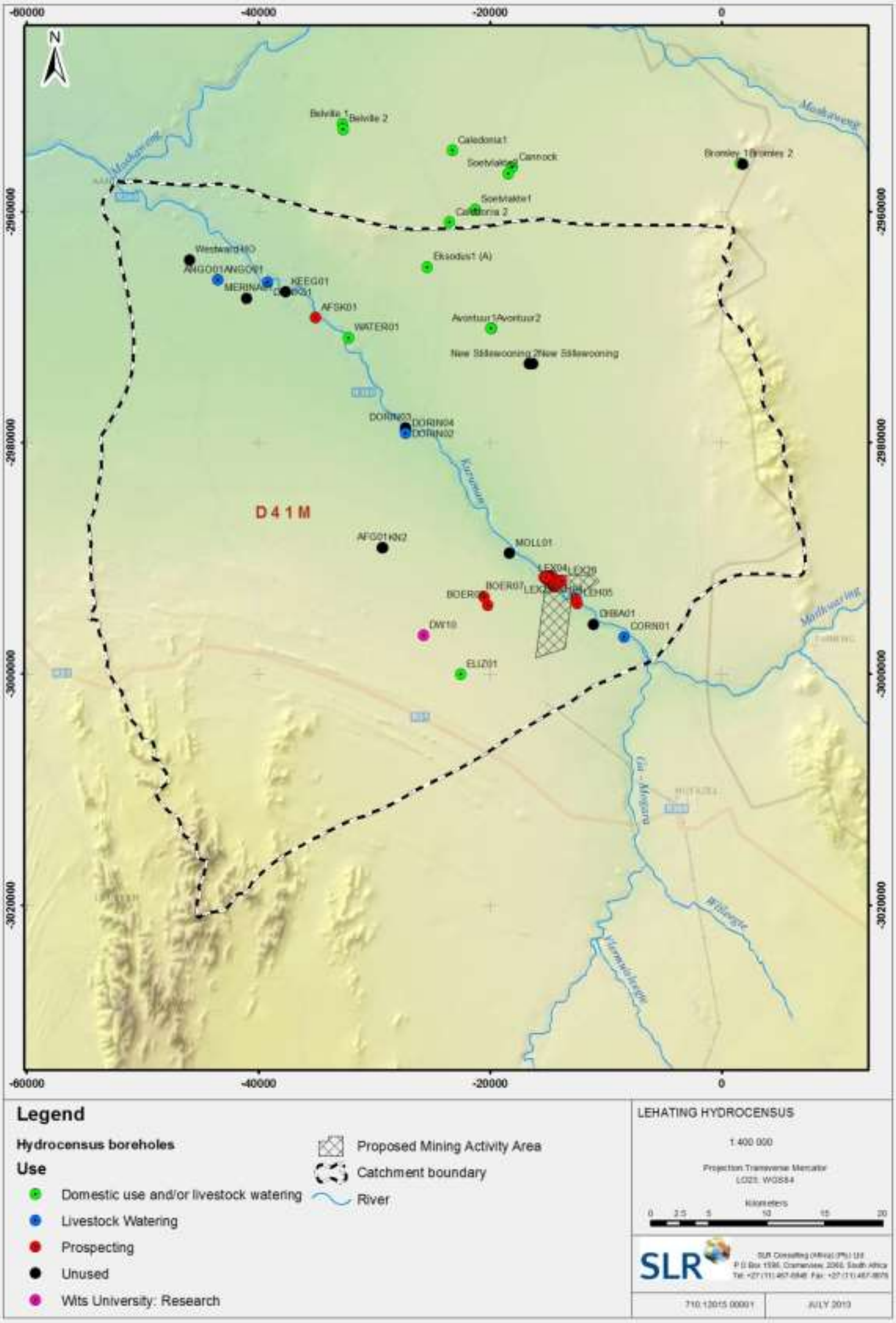


FIGURE 2-7: HYDROCENSUS CONDUCTED TO IDENTIFY GROUNDWATER USE AND WATER LEVELS

2.4.2 HYDRAULIC PROPERTIES

2.4.2.1 Packer Test

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

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

Information on the exploration boreholes as well as the hydraulic conductivities, for selected borehole intervals, derived from the packer tests presented in **TABLE 2.4.** The formations targeted during the packer tests, based on the borehole intervals tested, were the Hotazel and upper Ongeluk formations.

TABLE 2.4: BOREHOLE INFORMATION AND HYDRAULIC CONDUCTIVITIES DERIVED FROM THE PACKER TESTS TARGETING THE HOTAZEL AND PARTS OF THE ONGELUK FORMATIONS.

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

2.4.2.2 Pumping test

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

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

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

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

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

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

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

TABLE 2.5: BOREHOLES USED FOR PUMPING TESTS.

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

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

2.4.2.2.1 Pumping test analysis – LEX 3A

Borehole LEX 3A was pumped with a constant abstraction rate of 10L/s for 18 hours. This abstraction rate resulted in a total drawdown of 20 metres. A number of analytical solutions were applied to describe the observed drawdown in the groundwater level for borehole LEX 3A, before the most applicable solutions were chosen for the final interpretation (Table 2.6).

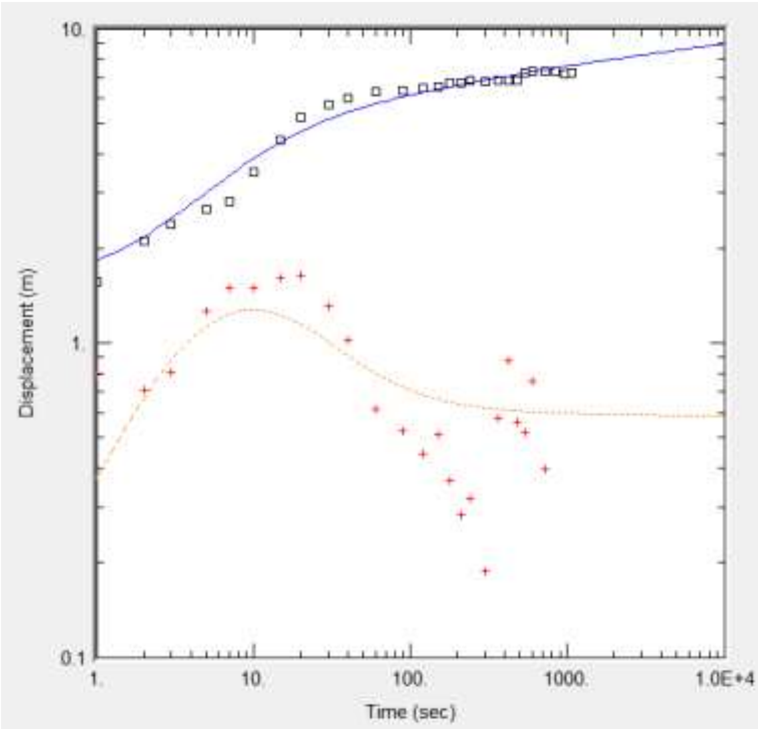


FIGURE 2-8: LOG- LOG PLOT FOR A CONSTANT DISCHARGE PUMPING TEST (CDT) BASED ON GROUNDWATER LEVEL FLUCTUATIONS FOR LEX 3A AND FITTED NEUMAN SOLUTION FOR AN UNCONFINED AQUIFER.

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

TABLE 2.6: ESTIMATES OF AQUIFER PARAMETERS BASED ON PUMPING TESTS – LEX 3A.

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

NOTES

mbgl*- meters below ground level

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

2.4.2.2.2 Pumping test analysis – LEX 4

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

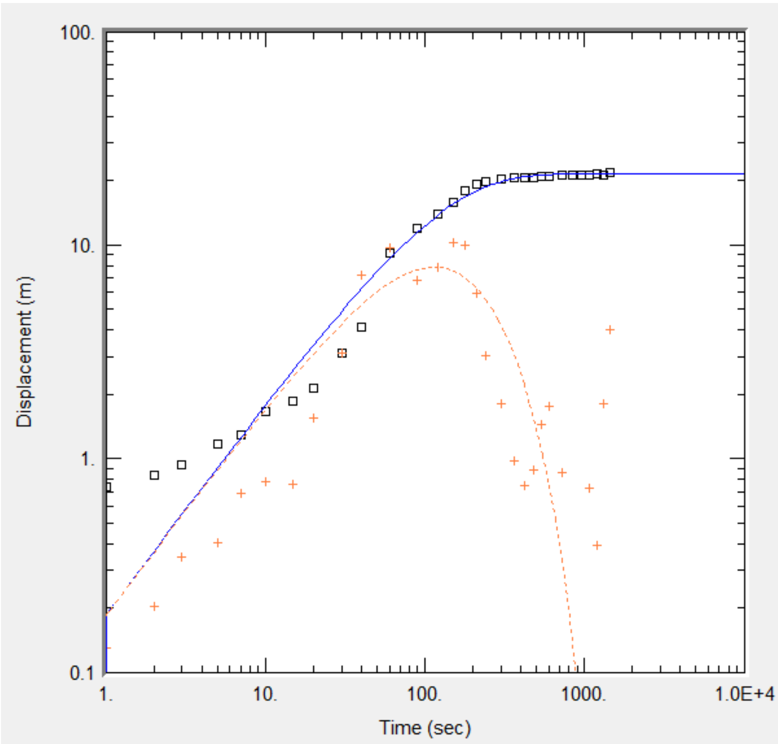


FIGURE 2-9: LOG- LOG PLOT FOR A CONSTANT DISCHARGE PUMPING TEST (CDT) FOR LEX 4 AND FITTED MOENCH SOLUTION FOR A LEAKY AQUIFER.

TABLE 2.7: ESTIMATES OF AQUIFER PARAMETERS BASED ON PUMPING TESTS – LEX 4.

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

NOTES
mbgl*- meters below ground level

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

2.5 GROUNDWATER ELEVATION AND FLOW DIRECTIONS

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

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

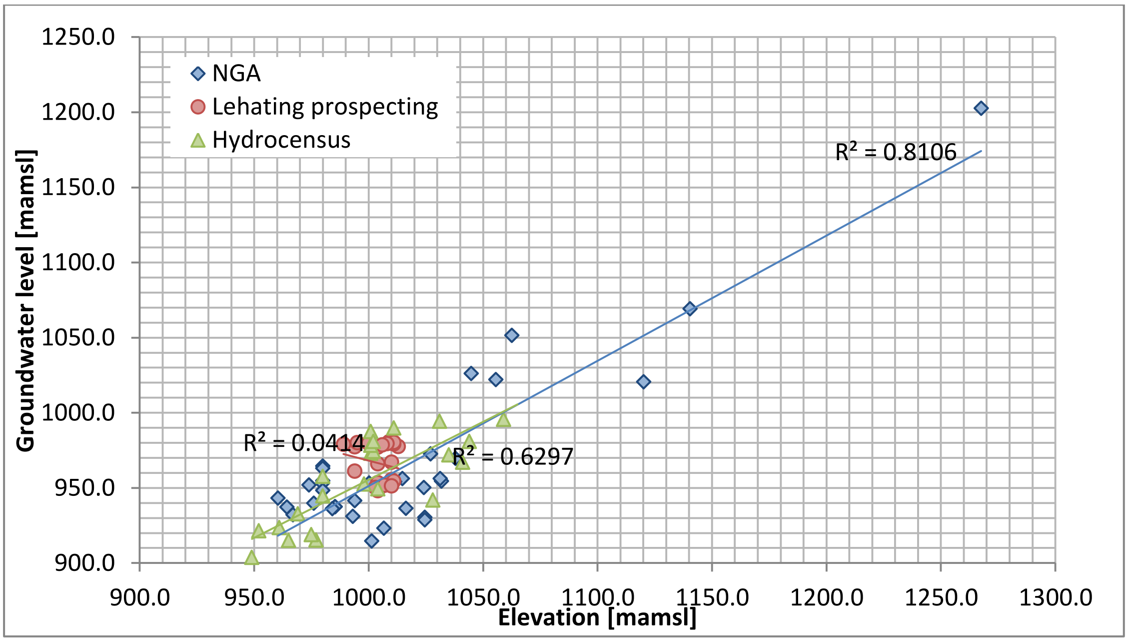


FIGURE 2-10: CORRELATION BETWEEN SURFACE TOPOGRAPHY AND WATER LEVEL ELEVATIONS IN QUATERNARY CATCHMENT D41M.

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

2.6 HYDROLOGIC BOUNDARIES

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

3 MODEL CONSTRUCTION

3.1 COMPUTER CODE

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

3.1.1 MODFLOW

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

3.1.2 MT3D

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

3.2 MODEL DOMAIN

3.2.1 FINITE DIFFERENCE FLOW MODEL

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

The model domain (Figure 3-1) was discretised into a 181 X 184 grid block uniform mesh, with uniform horizontal grid block sizes of 500m X 500m and refined horizontal grid block size around the mine of 50m X50m with a total number of 133216 cells.

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

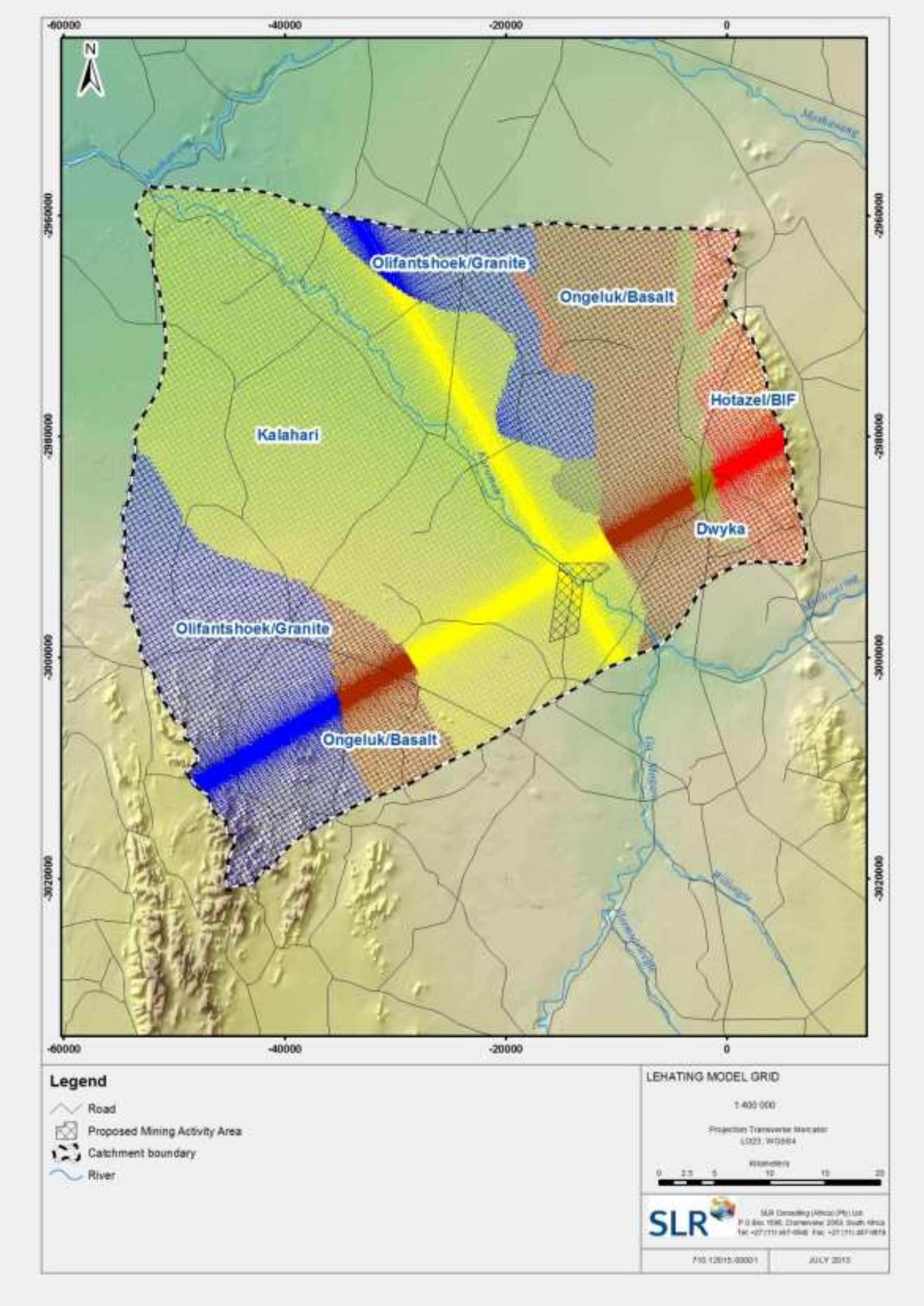


FIGURE 3-1: LEHATING GROUNDWATER FINITE-DIFFERENCES MODEL SETUP SHOWING REFINED GRID AND AQUIFER SYSTESM

3.2.2 FINITE DIFFERENCE CONTAMINANT TRANSPORT MODEL

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

The model domain (Figure 3-1) was discretised into a 181 X 184 grid block uniform mesh, with uniform horizontal grid block sizes of 500m X 500m and refined horizontal grid block size around the mine of 50m X50m with a total number of 133216 cells.

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

3.3 BOUNDARY CONDITIONS

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

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

3.4 SOURCES AND SINKS

3.4.1 GROUNDWATER RECHARGE

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

3.4.2 RIVER COURSES

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

3.4.3 TAILING STORAGE FACILITY, WASTE ROCK STOCKPILE AND PRODUCT STOCK PILES

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

TABLE 3.1: SOURCE CONCENTRATIONS FOR THE MINE RESIDUE DEPOSITS (MRD'S).

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

3.5 HYDRAULIC PARAMETERS FOR FINITE DIFFERENCE MODELS

The groundwater flow and transport models incorporate 4 different hydraulic conductivity zones, i.e. the different model layers represent the Kalahari sediments (60-80m thick at hill) and the deeper Dwyka aquifer, BIF aquifer, Basalt/lava aquifer representing the Hotazel/Ongeluk formation and Granite aquifer representing the Olifantshoek formation. The top elevation of layer I was based on the 20m digital elevation model while the bottom elevation (layer IV) was offset by 350m.

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

3.6 SELECTION OF CALIBRATION PARAMETERS AND TARGETS

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

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

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

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

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

4 CALIBRATION (STEADY STATE)

4.1 FINITE DIFFERENCE FLOW MODEL

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

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

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

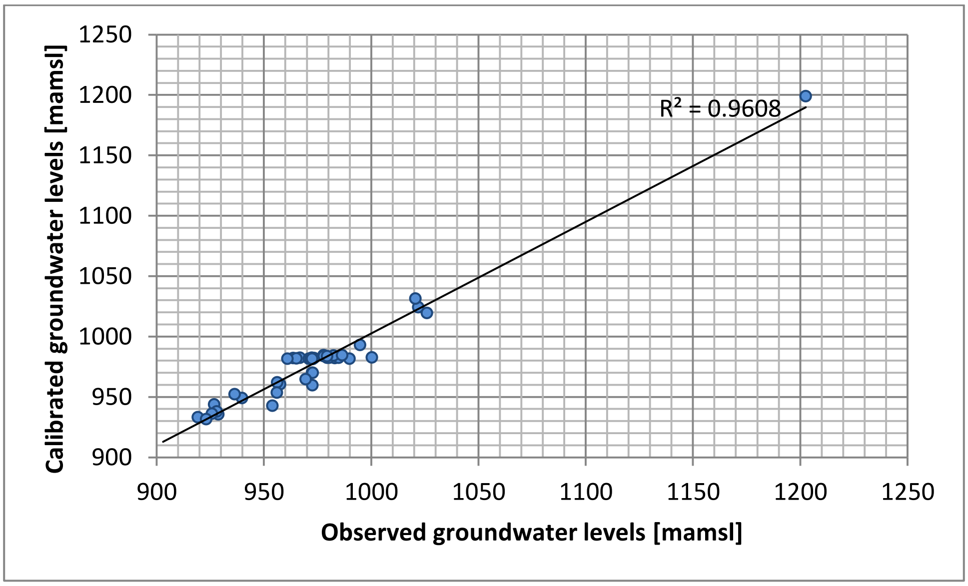


FIGURE 4-1: STEADY-STATE CALIBRATION OF LEHATING MINE MODEL.

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

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

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

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

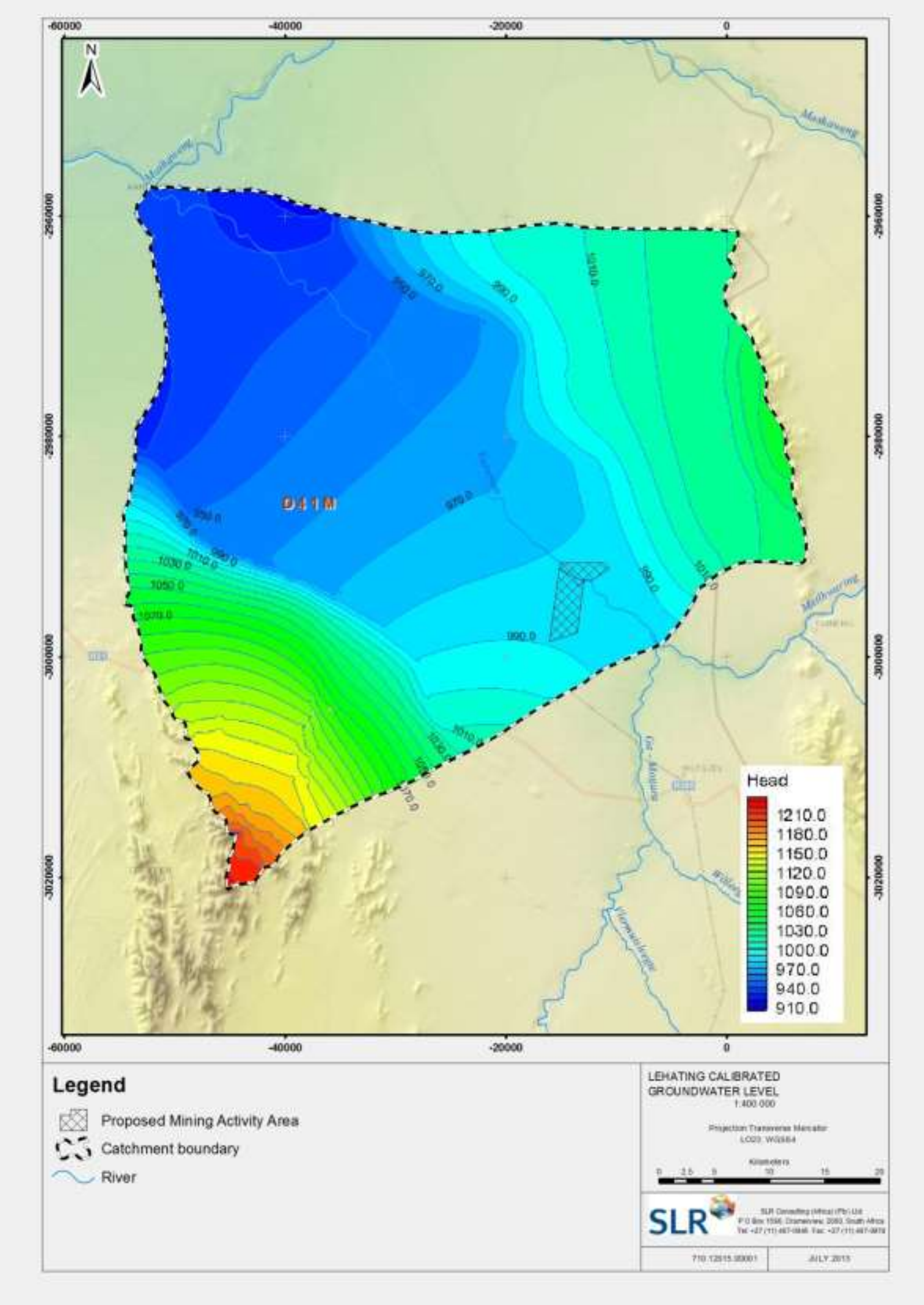


FIGURE 4-2: STEADY-STATE CALIBRATED GROUNDWATER LEVELS OF THE LEHATING MINE MODEL.

TABLE 4.1: FINAL HYDRAULIC CONDUCTIVITIES FOR THE FINITE DIFFERENCE FLOW MODEL.

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

The flow budget, based on the steady state calibrated groundwater flow model, represents the total inflows and outflows for the model domain. The difference between the total inflow and total outflow represents and error of less than 1% contributing to the confidence level for the calibrated model for Lehating Model (Table 4.2).

TABLE 4.2: FLOW BUDGET CALCULATED FROM CALIBRATED MODEL PARAMETERS

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

5 PREDICTIVE SIMULATIONS

5.1 ESTIMATED UNDERGROUND MINE INFLOW RATES

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

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

The calibrated groundwater model reported on by Metago Water Geosciences was included to address the potential impact and estimate groundwater likely inflow rates into the mine workings. The estimated inflow rate into the mine workings is in the order of 292 m^3/d (approximately 3.4 L/s) during year 18 of mine development (Table 5.1). The estimated inflow rates were computed for different periods over the life of mine.

TABLE 5.1: ESTIMATED, CUMULATIVE MINE FISSURE INFLOWS FOR SELECTED PERIODS OVER LIFE OF MINE.

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

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

- Groundwater models generally apply the representative elementary volume (REV) (or EPM - equivalent porous medium) approach and integrate aquifer parameters over a much larger volume of aquifer material, incorporating both the rock matrix and inherent fractures,

- Packer tests target specific lithologies, or sections thereof, and represent in-situ tests on small volumes of rock conducted over pre-defined intervals in a borehole.
- The packer tests target specific lithologies units at depth and were conducted within un-cased boreholes at depths in excess of 220m below ground level.

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

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

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

5.1.1 IMPACTS ASSOCIATED WITH DEEP MINE INFLOWS

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

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

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

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

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

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

5.2 SIMULATED BOREHOLE / WELL FIELD AS GROUNDWATER SUPPLY

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

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

The numerical groundwater flow model was used in the prediction of the behaviour of the well field. The four boreholes (with depths of 80mbgl) were incorporated into the steady state groundwater flow model as wells. Each well were populated to abstract groundwater with a rate of 216m^3/d (2.5L/s). The simulation do not account for transient conditions or alternating well abstraction times and therefore predict worst case scenario as impact on the groundwater.

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

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

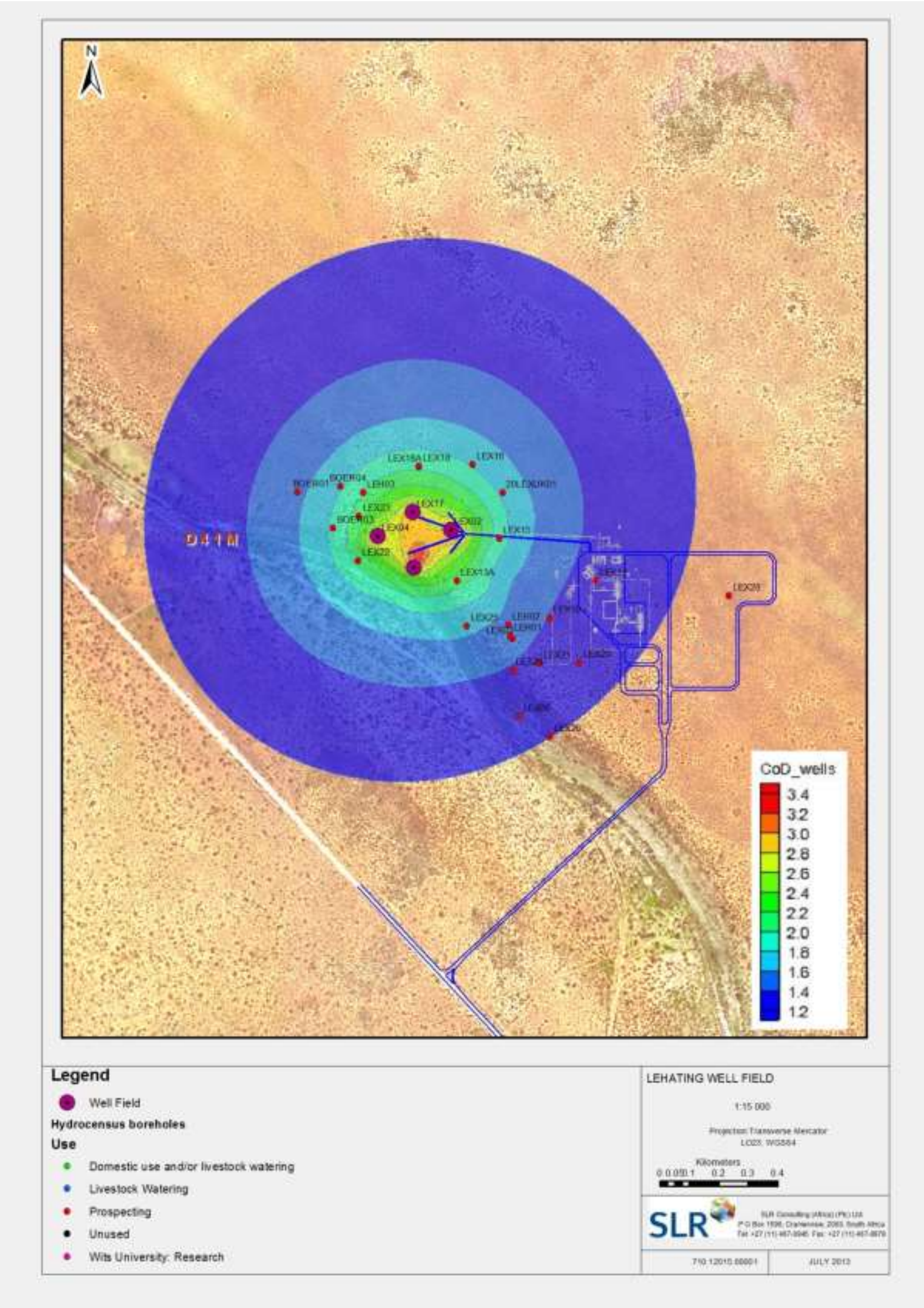


FIGURE 5-1: SIMULATED STEADY STATE CONE OF DEPRESSION FOR THE PROPOSED WELL FIELD

5.2.1 IMPACTS ASSOCIATED WITH WELL FIELD

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

- Likely to occur w.r.t. groundwater as resource;
- Unlikely to impact any third party groundwater users;
- Limited (up to 1 km) impact slightly beyond the mine lease area w.r.t.
    - Interception of recharge and potentially result in partial reduction in subsurface contribution to baseflow to Kuruman River;
    - Development of intersecting cones of depression, i.e. the lowering of the groundwater levels due to well field dewatering
- Reversible over time once well field stops abstracting groundwater; and

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

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

5.3 SIMULATED CONTAMINANT TRANSPORT FROM THE TAILING STORAGE FACILITY, WASTE ROCK STOCK PILE AND OTHER STOCKPILES

The model solutions of the calibrated steady-state groundwater models were used as the basis for the TSF, Waste Dump and Stock Pile transport model using the internationally accepted MT3DMS (finite-difference) transport code. The TSF, Waste rock stockpile and other stockpiles (sources) were considered as potential sources of pollution and incorporated into the model domain as recharge boundaries with the source concentrations initially represented as percentages (Table 3.1). The post-closure recharge rates and source concentrations (as percentage) were considered constant and the associated long-term predictions are therefore worst case projections. Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 10m) transport of potential pollutants without any retardation or transformation was assumed.

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

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

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

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

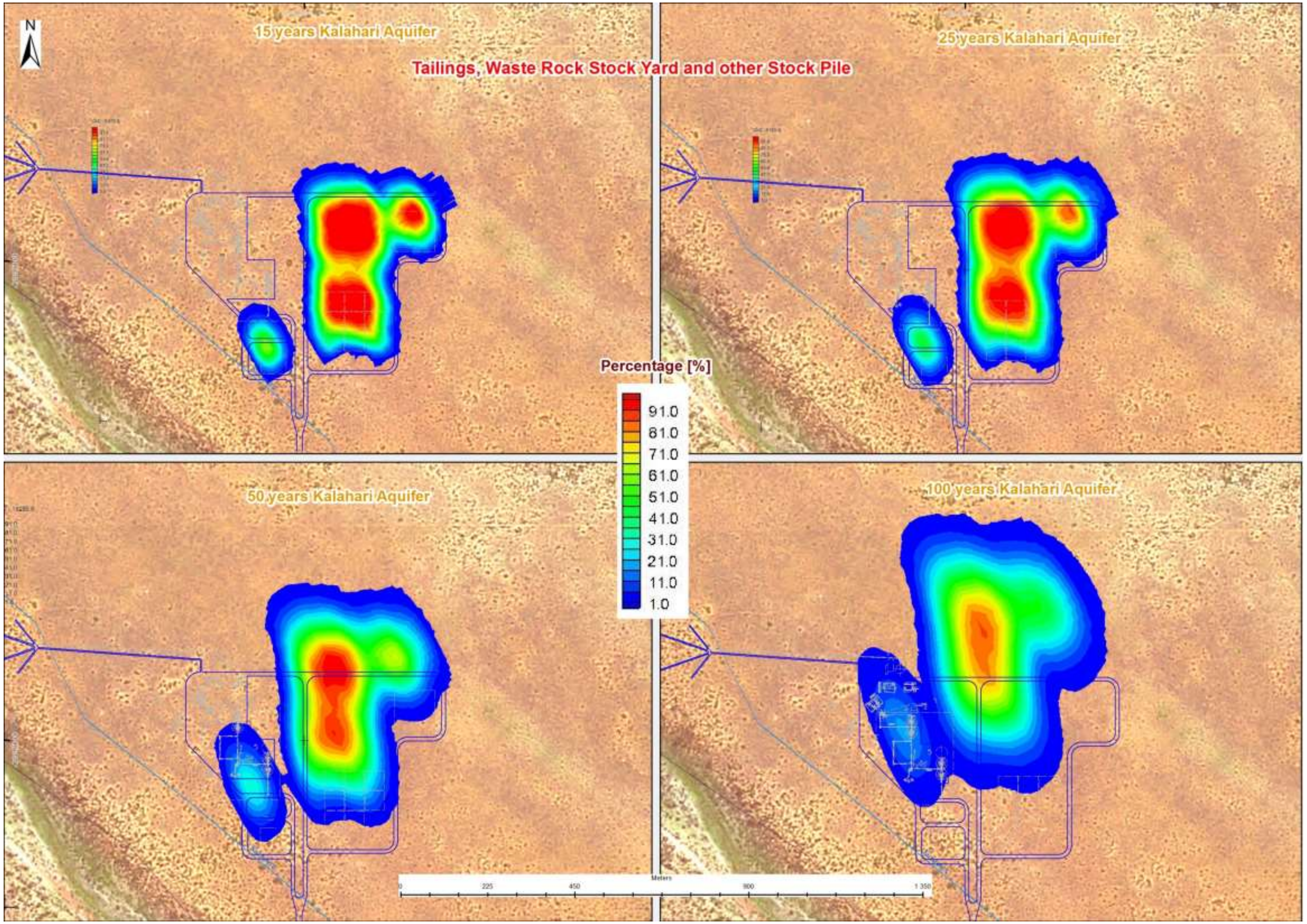


FIGURE 5-2: CONTOUR MAPS OF POTENTIAL SOURCE CONCENTRATIONS (IN PERCENTAGE) AFTER 15, 25, 50 AND 100 YEARS PREDICTED WITH THE FINITE-DIFFERENCE MODEL FOR LAYER 1 (ASSUMING CONSTANT SOURCE STRENGTH) FOR THE WASTE ROCK STOCK PILES, FINES AND OTHER STOCK PILE.

5.3.1 IMPACTS ASSOCIATED WITH SEEPAGE FROM THE SOURCES

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

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

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

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

The following assumptions and limitations are noted:

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

6 CONLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The main conclusions are grouped under various headings.

6.1.1 GEOLOGY

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

6.1.2 AQUIFER CLASSIFICATION

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

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

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

The groundwater sample collected at borehole LEX3A presented a Mg-HCO_3 water type with an elevated magnesium concentration. The enriched bicarbonate type water indicates shallow, younger groundwater conditions possibly associated with the weathering of calcareous and limestone units within the Kalahari sediments. The groundwater sample collected at borehole LEX4 presented a Na-Cl water type with elevated concentrations of chloride, sodium and magnesium. The elevated sodium and chloride concentrations may represent deeper and/or older groundwater within an evolved groundwater regime. This water type is probably characteristic of the groundwater within the deeper, confined Hotazel and Ongeluk aquifers. The groundwater samples for LEX3A and LEX4 are thus indicative of two distinctive groundwater regimes.

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

6.1.3 IMPACTS BASED ON MINE DEWATERING

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

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

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

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

6.1.4 IMPACTS BASED ON WELL FIELD DEVELOPMENT

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

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

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

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

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

6.1.5 IMPACTS BASED ON SEEPAGES ASSOCIATED WITH THE TAILING STORAGE FACILITY, WASTE ROCK STOCKPILE AND OTHER STOCKPILES (SOURCES)

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

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

6.2 MONITORING REQUIREMENTS AND RECOMMENDATIONS

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

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

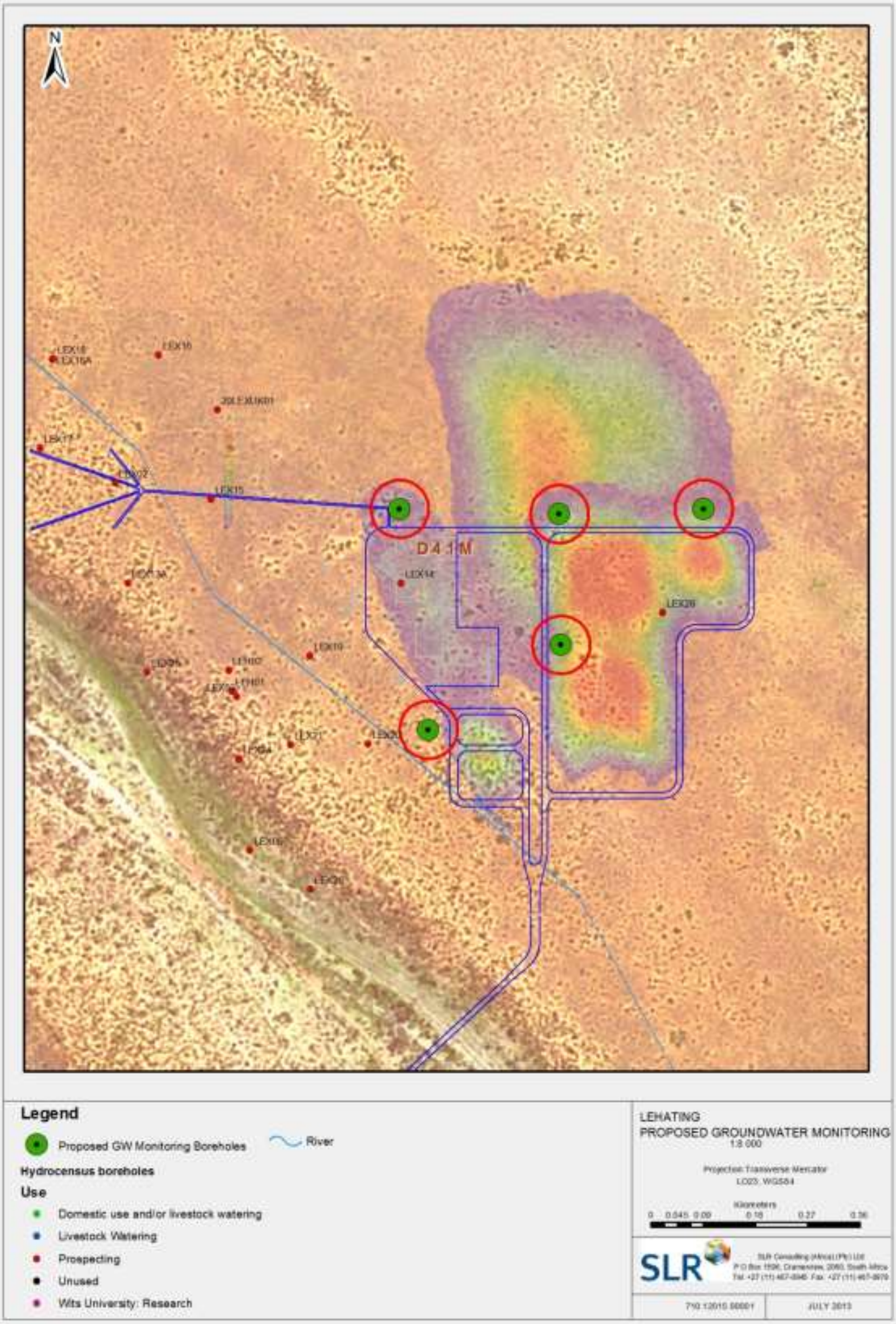


FIGURE 6-1: PROPOSED GROUNDWATER MONITORING LOCATIONS BASED ON POTENTIAL GROUNDWATER IMPACTS

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

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

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

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

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

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

UNMITIGATED IMPACT OF MINE DEWATERING, WELL FILED DEVELOPMENT AND CONTAMINATION SOURCES ON GROUNDWATER FLOW AND QUALITY PREDICTIONS FOR LEHATING MINE PROJECT.

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

NOTE: L – low

M – Medium

H – High

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

- Initiation of a ground- and surface water monitoring system with monthly monitoring of groundwater levels and quarterly sampling intervals for full chemical analyses (all major constituents and trace elements of concern, especially Arsenic).
- The development of a standard operating procedure for water level monitoring and water sampling according to best practice (e.g. filters and acidify on site for metal analyses, purge boreholes prior to sampling).
- Annual updates of the groundwater model as groundwater level and quality data become available.
- Other mitigation measures such as installing curtain drains, the use of existing boreholes as capture zones to control potential plume migration will limit spreading of the contaminant plume.

7 DEGREE OF CONFIDENCE IN PREDICTIONS AND MODEL UNCERTAINTY

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

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

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

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

8 DISCLAIMER

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

9 REFERENCES

Anderson, M.P. and Woessner, W.W., 1992. *Applied groundwater modelling. Simulation of flow and advection transport*. Academic Press, Inc. San Diago, Californai.

Barnett, B., Townley L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardsdon, S., Wenrner, A.D., Knapton, A. and Boronkay, A. 2012. *Australian groundwater modelling guidelines*. Sinclair Knight Merz and National Centre for Groundwater Research and Training. Waterlines Report Series No.82, June 2012.

McDonald, M.G., and Harbaugh, A.W. 1988. *A modular three-dimensional finite-difference ground-water flow model.* Techniques of Water-Resources Investigations, Book 6. U.S. Geological Survey. http://pubs.usgs.gov/twri/twri6a1/.

McWorter, D.B. and Sundana D.K. 1977. *Groundwater hydrology and hydraulics*. Water reserve publications, Ft. Collins, CO.

Zheng, C. 1990. *MT3D, A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems*, Report to the U.S. Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

Zheng, C. and Wang, P.P. 1999. *MT3DMS, A Modular Three Dimensional Multispecies Transport Model*. Prepared for; U.S. Army Corps of Engineers, Washington, DC 20314-1000.

APPENDIX A

IMPACT ASSESSMENT CRITERIA

CRITERIA FOR ASSESSING IMPACTS

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

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

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

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

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

APPENDIX B

HYDROCENSUS

global environmental solutions

LEHATING MANGANESE MINE

Hydrocensus Report

SLR Project No.: 710.12015.00001

Report No.: 01

July 2013

LEHATING MINING (PTY) LTD

DOCUMENT INFORMATION

Title	Hydrocensus Report for Lehating Mine
Project Manager	Victoria Tucker
Project Manager e-mail	vtucker@slrconsulting.com
Author	Samantha Scott and Rudolf De Jager
Reviewer	Rian Titus
Client	Lehating Mining (Pty) Ltd
Comments	
Keywords	Hydrocensus, Water Levels, Manganese, Underground Mine
Project Number	710.12015.00001
Report Number	01
Status	Final
Issue Date	July 2013

HYDROCENSUS REPORT FOR LEHATING MINE

CONTENTS

1 INTRODUCTION....1

2 METHODS....1

3 RESULTS....2

3.1 LEHATING HYDROCENSUS....2

3.2 GRAVENHAGE GROUNDWATER MONITORING DATA....8

3.2.1 MONITORING NETWORK....8

3.2.2 GROUNDWATER LEVELS....9

3.2.3 GROUNDWATER QUALITY....10

4 ADDITIONAL COMMENTS AND OBSERVATIONS....I

5 REFERENCES....I

LIST OF TABLES

TABLE 3.1: WATER LEVEL, DEPTH AND CASING INFORMATION FOR BOREHOLES SAMPLED DURING THE HYDROCENSUS....3

TABLE 3.2: LANDOWNER INFORMATION....8

TABLE 3.2: CO-ORDINATES (WGS 84) OF PRIVATE BOREHOLES INCLUDED IN THE GRAVENHAGE MONITORING PROGRAMME....9

FIGURE 3.1: GROUNDWATER LEVELS RECORDED AT BOREHOLES SURROUNDING THE GRAVENHAGE PROJECT SITE FOR THE 2011/2012 MONITORING PERIOD....10

TABLE 3.3: WATER QUALITY RESULTS FROM BOREHOLES SURROUNDING THE GRAVENHAGE PROJECT SITE FOR THE 2011/2012 MONITORING PERIOD NOTE: NUMBERS ARE HIGHLIGHTED IN RED WHERE THEY EXCEED THE SANS 241 (2011) DRINKING WATER STANDARD LIMITS FOR THE PARTICULAR CONSTITUENT. NUMBERS ARE HIGHLIGHTED IN PURPLE WHERE A HIGHER LIMIT, E.G. CHRONIC OR ACUTE HEALTH, IS EXCEEDED....12

ACRONYMS AND ABBREVIATIONS

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

Acronyms	Definition
~	Approximately
BH	Borehole
EC	Electrical Conductivity
GPS	Global Positioning System
SANAS	South African National Accreditation System

HYDROCENSUS REPORT FOR LEHATING MINE

1 INTRODUCTION

Lehating Mining (Pty) Ltd (Lehating) has proposed the future development of an underground manganese mine on portion 1 of the farm Lehating 741, situated approximately 20 km north west of Hotazel, in the John Taolo Gaetsewe District Municipality in the Northern Cape.

Lehating Mining has requested that a hydrocensus be conducted in order to record a baseline of water levels in the boreholes at the project site (Farm Lehating 741) and surrounding farms. The objective of this is to collect data on current prevailing conditions at and around the proposed project site against which any future impacts that the mine may have on groundwater resources in the area can later be measured. Water quality was not sampled in this study but will likely be in future.

Lehating Mining appointed SLR Consulting (Africa) (Pty) Ltd (SLR) to conduct the hydrocensus survey.

This brief field report summarises the results from the July hydrocensus for Lehating Mine.

2 METHODS

The hydrocensus was conducted from Tuesday 9 July to Friday 12 July 2013 by Rudi de Jager and Samantha Scott of SLR Consulting. All data were collected within a demarcated model domain surrounding Lehating Farm (See Figure 3.1). The boreholes visited all lie within a 40 km radius of the proposed location of the new mine. Specific attention was given to farms in close proximity to the proposed mine.

A Solinst 101 Water Level Meter was used to measure water levels within each borehole. The location and elevation of each borehole was recorded using a Global Positioning System (GPS).

This hydrocensus focussed on unused boreholes in order to accurately assess current natural groundwater levels in the area surrounding the mine. Used boreholes were only measured in the event that they had not been used in at least 8 hours, or where only small quantities were being pumped from the borehole.

In addition to the data recorded during this hydrocensus, Aquila Steel S. Africa (Pty) Ltd (Aquila) granted SLR Consulting permission to use groundwater data from private boreholes monitored as part of their Gravenhage Manganese Project. Aquila monitors groundwater levels and quality of boreholes surrounding their Gravenhage Project site, situated on portion 114 of Farm 703 (gravenhage). The groundwater monitoring network currently consists of 15 private boreholes on surrounding farms.

Although groundwater quality was not measured during this hydrocensus, ground water quality results attained from the Gravenhage Project Annual Groundwater Monitoring Report, 2011-2012, are provided (Synergistics, 2013). Water quality was analysed by Waterlab (Pty) Ltd, a South African National Accreditation System (SANAS) accredited laboratory situated in Pretoria. Please see the Gravenhage Project Report for further information with regards to the sampling methods utilised (Synergistics, 2013).

3 RESULTS

3.1 LEHATING HYDROCENSUS

Within the four day sampling period a total of 61 boreholes were located of which the water levels of 48 boreholes were measured. The locations of all boreholes located are displayed on Figure 3.1. Data on all boreholes located is summarised in Table 3.1.

The majority of boreholes sampled were unused at the time of the hydrocensus and comprised prospecting boreholes or boreholes that had previously been used for livestock watering and domestic use. The unused boreholes were not equipped with pumping equipment at the time of the hydrocensus. The boreholes that were used at the time of sampling had not been pumped for at least 8 hours prior to sampling and would therefore provide a good measure of natural groundwater levels in the area. Several boreholes were found to be blocked or dry (Table 3.1).

Several of the boreholes on Lehating Farm had oil in them (Table 3.1). This may have been due to the disposal of oil into the boreholes.

Table 3.3 lists the details of the landowners on whose farms boreholes were sampled.

.

TABLE 3.1: WATER LEVEL, DEPTH AND CASING INFORMATION FOR BOREHOLES SAMPLED DURING THE HYDROCENSUS

GPS ID	Date	Time	Latitude (S)	Longitude (E)	Elevation (m)	BH Depth (m)	Borehole Use	Casing Material	Water Level (m.b.g)	Casing Diameter (mm)		Farm Ptn	Photo #	Notes
										Inner	Outer			
03LEX14	09/07/213	11:28	27°2'19.15"	22°51'23.21"	1004	-	Prospecting	Metal	55.76	125	160	Lehating	7973-7975	-
07LEX19	09/07/2013	11:50	27°2'23.21"	22°51'17.49"	1004	-	Prospecting	Metal	37.948	165	220	Lehating	7976-7977	-
08LEX20	09/07/2013	12:00	27°2'28.17"	22°51'21.12"	1004	-	Prospecting	Metal	50.47	155	220	Lehating	7978-7980	-
17LEX03	09/07/2013	12:10	27°2'25.5"	22°51'12.9"	1004	-	Prospecting	Metal	53.98	160	210	Lehating	7981-7982	-
LEH01	09/07/2013	12:15	27°2'25.2"	22°51'12.6"	1004	-	?	Metal	26.945	160	-	Lehating	7983-7985	-
LEH02	09/07/2013	12:25	27°2'24.0"	22°51'12.4"	1003	-	?	Metal	52.625	195	-	Lehating	7986	-
10LEX25	09/07/2013	12:35	27°2'24.10"	22°51'7.29"	994	-	Prospecting	Metal	16.697	160	220	Lehating	7987-7988	-
13LEX22	09/07/2013	12:50	27°2'16.90"	22°50'53.91"	989	-	Prospecting	Metal	9.865	160	220	Lehating	7989-7990	-
19LEX06	09/07/2013	12:55	27°2'34.1"	22°51'13.7"	994	-	Prospecting	Metal	32.882	160	220	Lehating	7991	-
14LEX26	09/07/2013	13:00	27°2'36.32"	22°51'17.51"	995	-	Prospecting	Metal	14.918	130	220	Lehating	7992-7994	Oil
12LEX24	09/07/2013	13:20	27°2'29.01"	22°51'13.02"	1000	-	Prospecting	Metal	20.38	160	220	Lehating	7995-7996	-
11LEX21	09/07/2013	13:30	27°2'28.20"	22°51'16.25"	1009	-	Prospecting	Metal	28.17	160	220	Lehating	7997-7998	-
02LEX13A	09/07/2013	13:40	27°2'19.13"	22°51'6.10"	1013	-	Prospecting	Metal	35.4	160	220	Lehating	7999-8000	Oil
19LEX02	09/07/2013	14:00	27°2'13.5"	22°51'05.3"	1010	-	Prospecting	Metal	56.9	-	-	Lehating	8001-8003	-
20LEXUK01	09/07/2013	14:10	27°2'09.4"	22°51'11.7"	1010	-	Prospecting	Metal	54.68	160	220	Lehating	8004-8005	Unknown BH – no lid or marker
15LEX15	09/07/2013	14:15	27°2'14.42"	22°51'11.30"	1010	-	Prospecting	Metal	54.382	160	220	Lehating	8006-8007	-
04LEX16	09/07/2013	14:20	27°2'6.32"	22°51'8.02"	1010	-	Prospecting	Metal	42.886	160	220	Lehating	8008-8009	Oil
05LEX18A	09/07/2013	14:30	27°2'6.54"	22°51'1.37"	1011	-	Prospecting	Metal	31.65	160	220	Lehating	8010-8012	Oil
21LEX18	09/07/2013	14:35	27°2'6.5"	22°51'01.4"	1011	-	Prospecting	Metal	30.67	160	220	Lehating	8013-8015	Oil
06LEX17	09/07/2013	14:40	27°2'11.52"	22°51'0.59"	1011	-	Prospecting	Metal	56.485	160	220	Lehating	8016-8018	-
LEH03	09/07/2013	14:50	27°2'09.4"	22°50'54.5"	1007	-	Prospecting	Metal	55.21	185	-	Lehating	8019-8020	Concrete cover

GPS ID	Date	Time	Latitude (S)	Longitude (E)	Elevation (m)	BH Depth (m)	Borehole Use	Casing Material	Water Level (m.b.g)	Casing Diameter (mm)		Farm Ptn	Photo #	Notes
										Inner	Outer			
09LEX23	09/07/2013	14:55	27°2'11.99"	22°50'53.96"	1008	-	Prospecting	Metal	28.578	125	220	Lehating	8021-8022	-
22LEX04	09/07/2013	15:00	27°2'14.2"	22°50'56.3"	1010	-	Prospecting	Metal	58.69	160	220	Lehating	8023-8024	Oil
16LEX28	09/07/2013	15:15	27°2'20.8"	22°51'39.6"	1006	-	Prospecting	Metal	57.32	160	220	Lehating	8025-8027	-
HAR01DW10	10/07/2013	10:20	27°4'53.1"	22°44'26.2"	1041	-	Wits University: Research	Metal	73.925	160	220	Lehating	8028-8030	BH original name was DW10
HAR02	10/07/2013	10:40	27°5'05.1"	22°45'02.4"	1052	-	N/A	-	-	-	-	Harefield	8031-8032	BH dry & covered with sand
ELIZ01	10/07/2013	11:10	27°06'42.7"	22°46'22.6"	1059	86.2	Livestock Watering & Domestic Use	Metal	63.33	-	-	Elizabethville	8033-8035	This measure is from Casper from 2 years ago because the BH is currently being pumped and is not accessible.
BERG01	10/07/2013	12:00	27°05'25.3"	22°48'06.7"	1046	-	Unused	Metal	-	160	-	Berghelm	8036-8038	BH is blocked. Two BH here but both blocked.
ARC01SMC	10/07/2013	13:10	27°09'32.8"	22°43'33.0"	1065	-	?	Metal	-	-	-	Arcadia	8039-8040	Hole closed.
AFG01	10/07/2013	16:10	27°00'45.7"	22°42'19.7"	1044	-	Unused	Metal	63.08	160	-	Afguns	8041-8042	Previously used for livestock watering
AFG02KN2	10/07/2013	16:15	27°00'46.5"	22°42'18.3"	1035	-	Livestock Watering & Domestic Use	Metal	62.92	160	-	Afguns	8043-8044	Has a pump but not been pumped in 2 months.
DONK01	10/07/2013	17:40	26°48'19.1"	22°36'21.4"	952	-	Livestock Watering	Metal	30.59	160	-	Donkerdraai	8045-8047	-
AFSK01	11/07/2013	7:40	26°49'59.1"	22°38'50.2"	949	-	Prospecting	Metal	45.2	160	-	Afskeid	8048	Initially used for prospecting but

GPS ID	Date	Time	Latitude (S)	Longitude (E)	Elevation (m)	BH Depth (m)	Borehole Use	Casing Material	Water Level (m.b.g)	Casing Diameter (mm)		Farm Ptn	Photo #	Notes
										Inner	Outer			
														no longer used.
AFSK02	11/07/2013	7:45	26°49'56.1"	22°38'51.9"	965	-	Unused	Metal	-	160	-	Afskeid	8049-8050	Previously used for livestock watering
AFSK03	11/07/2013	7:55	26°49'56.0"	22°38'52.4"	966	-	Unused	Metal	-	160	-	Afskeid	8051-8052	Had to cut open with grinder. Previously used for livestock watering
AROG01	11/07/2013	8:30	26°46'59.9"	22°35'17.1"	959	-	Unused	Metal	-	160	-	Arogna	8053-8054	Not been pumped in last 5 years because pump is broken. Previously used for livestock watering
AROG02	11/07/2013	8:40	26°46'59.8"	22°35'18.2"	957	-	Unused	Metal	-	160	-	Arogna	8055-8056	Previously used for livestock watering
ANGO01	11/07/2013	9:10	26°48'12.4"	22°33'45.5"	977	-	Livestock Watering	Metal	61.65	160	-	Angora	8057-8058	Solar pump that was switched off to measure water level. Only been active for 6 months.
KEEG01	11/07/2013	10:00	26°48'46.4"	22°37'16.7"	961	-	Livestock Watering	PVC Plastic	37.45	180	-	Keega	8058-8060	
DORIN01	11/07/2013	10:30	26°55'16.9"	22°43'26.5"	980	-	Unused	Metal	-	150	-	Doorndraai	8061-8062	Previously used for livestock watering
DORIN02	11/07/2013	10:40	26°55'17.5"	22°43'32.2"	980	-	Cattle & Domestic	Metal	35.36	-	-	Doorndraai	8063-8064	48 hrs. since last pumped. Monopump

GPS ID	Date	Time	Latitude (S)	Longitude (E)	Elevation (m)	BH Depth (m)	Borehole Use	Casing Material	Water Level (m.b.g)	Casing Diameter (mm)		Farm Ptn	Photo #	Notes
										Inner	Outer			
														installed - pumps ~ 36 000 L/hr.
DORIN03	11/07/2013	10:50	26°55'09.0"	22°43'31.4"	980	-	Livestock Watering and Domestic Use	Metal	22.295	155	-	Doorndraai	8065-8067	-
VOOR01	11/07/2013	11:40	26°55'37.1"	22°47'45.6"	1011	-	Unused	Metal	-	160	-	Blyvooruitzicht	8070-8073	Previously used for livestock watering
MOLL01	11/07/2013	12:50	27°01'02.1"	22°48'56.3"	998	-	Back-up Borehole for Domestic Use and Livestock Watering	Metal	45.29	160	-	Mollersville	8074-8075	Monopump. Has not been pumped in a year.
CORN01	11/07/2013	15:05	27°04'57.5"	22°54'56.4"	1011	-	Livestock Watering	Metal	21.17	-	-	Cornish	8076-8077	Not pumped since last Thursday. Water pumped to a dam
DIBIA01	11/07/2013	15:20	27°04'22.2"	22°53'20.1"	1001	-	Back-up	Metal	13.395	160	-	Dibiaghomo	8078-8079	Another BH on property but no access.
WATER01	11/07/2013	17:00	26°50'56.0"	22°40'34.0"	969	-	Livestock Watering and Domestic Use	Metal	36.26	160	-	Waterdraai	8080-8081	Has not been used in years. There are several BH but all are closed.
MERINA01	11/07/2013	18:30	26°49'03.6"	22°35'15.8"	975	-	Unused	Metal	56.06	160	-	Merinavale	8082	-
WANG01	11/07/2013	19:15	26°56'24.2"	22°39'30.1"	983	-	Livestock Watering and Domestic Use	Metal	-	-	-	Wanganella	8083	No access due to equipment installed -

GPS ID	Date	Time	Latitude (S)	Longitude (E)	Elevation (m)	BH Depth (m)	Borehole Use	Casing Material	Water Level (m.b.g)	Casing Diameter (mm)		Farm Ptn	Photo #	Notes
										Inner	Outer			
DORIN04	12/07/2013	7:35	26°55'25.2"	22°43'32.0"	965	-	Livestock Watering	Metal	49.85	160	220	Doorndraai	8084-8085	Windmill but not being pumped.
BOER01	12/07/2013	8:30	27°02'09.3"	22°50'46.4"	1001	-	Prospecting	Metal	27.95	160	270	Boerdraai	8086-8087	Hole perforated at 40 m.
BOER02	12/07/2013	8:35	27°02'12.8"	22°50'51.0"	1002	-	Prospecting	Metal	-	220	-	Boerdraai	8088-8089	-
BOER03	12/07/2013	8:40	27°02'13.3"	22°50'50.8"	1002	-	Prospecting	Metal	27.65	160	220	Boerdraai	8090-8091	-
BOER04	12/07/2013	8:45	27°02'08.7"	22°50'51.7"	1004	-	Prospecting	Metal	54.54	160	-	Boerdraai	8092-8093	Mud at the bottom.
BOER05	12/07/2013	9:10	27°02'23.9"	22°50'37.0"	999	-	Prospecting	Metal	-	220	-	Boerdraai	8094-8095	Dry
BOER06	12/07/2013	9:35	27°03'27.7"	22°47'48.5"	1031	-	Prospecting	Metal	36.655	160	-	Boerdraai	8096-8097	Two next to one another but one closed.
BOER07	12/07/2013	9:55	27°03'04.6"	22°47'37.1"	1028	-	Prospecting	Metal	85.98	160	-	Boerdraai	8098-8099	-
LEH04	12/07/2013	11:15	27°03'13.3"	22°52'25.2"	1001	111	Prospecting	Metal	22.49	160	-	Lehating	8100-8101	-
LEH05	12/07/2013	11:30	27°03'23.7"	22°52'29.5"	1002	34	Prospecting	Metal	21.06	160	-	Lehating	8102-8104	Monopump. Gets pumped daily but last pumped yesterday evening.
LEH06	12/07/2013	11:45	27°03'27.4"	22°52'36.9"	997	-	-	Metal	-	-	-	Lehating	-	Broken. Not working.

TABLE 3.2: LANDOWNER INFORMATION

Farm Name	Landowner/Contact Person	Contact Number	Email
Afguns	Peet Du Plooy	082-873-5765	-
Afskeid	Johan Pienaar	082-752-6087	-
Angora	Martinus Strydom		
Arcadia	Bouka		
Arogna	Paul Strydom		
Berghelm	Bonolo Lekwa of Assmang	082 739 1909	bonolol@brmo.org.za
Blyvooruitzicht	Johnny Markam	072-239-2398	Marita.markam@gmail.com
Boerdraai	Gawie Stols	083-310-0480	-
Cornish	Cules Lamprecht	079-665-5444	Mecca.guesthouse@gmail.com
Dibiaghomo	Joseph van der Walt	082-517-6104	dibaslaghuis@gmail.com
Donkerdraai	Francois Erasmus	076-891-0303	-
Doorndraai	Juri Kriek	082-664-1996	juriekr@gmail.com
Elizabethville	Casper Du Plessis	082-827-6787	-
Harefield	Mr Willem van der Walt	073-788-1068	wwalt@lantic.net
Keega	Pieter Botes	083-208-8090	-
Lehating	Ryno van Schalkwyk (Renting)	082-663-5193	-
Merinavale	Donnie du Plessis	073-404-6700	-
Mollersville	Johan Moller	082-395-9998	-
Wanganella	Donnie du Plessis	073-404-6700	-
Waterdraai	Hein Le Roux	073-754-2649	-

3.2 GRAVENHAGE GROUNDWATER MONITORING DATA

The following information was taken from the Gravenhage Project Annual Groundwater Monitoring Report for the 2011/2012 monitoring period (Synergistics, 2013).

3.2.1 MONITORING NETWORK

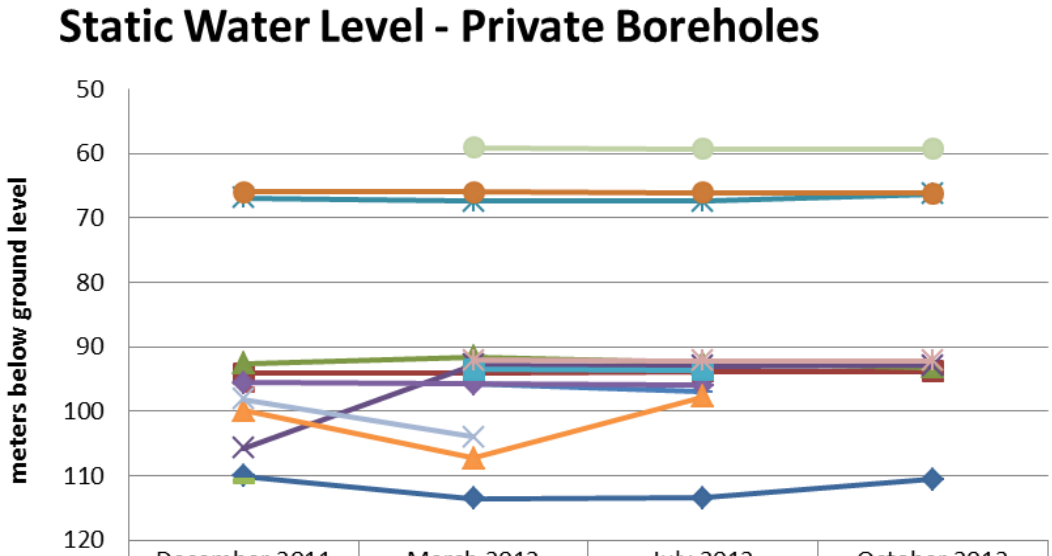
Aquila provided information for 15 boreholes on 10 farms surrounding their Gravenhage Project site. The boreholes are monitored on a quarterly basis as part of their baseline groundwater monitoring programme. The co-ordinates (WGS 84) of the boreholes in question are provided in Table 3.2 below.

TABLE 3.3: CO-ORDINATES (WGS 84) OF PRIVATE BOREHOLES INCLUDED IN THE GRAVENHAGE MONITORING PROGRAMME

Borehole ID	Latitude	Longitude	Borehole Use
Avontuur1	26° 50' 31.20" S	22° 48' 1.04" E	Drinking water and/or livestock watering
Avontuur2	26° 50' 31.20" S	22° 47' 58.67" E	Drinking water and/or livestock watering
Eksodus1 (A)	26° 47' 38.40" S	22° 44' 40.81" E	Drinking water and/or livestock watering
Belville 1	26° 40' 55.20" S	22° 40' 17.62" E	Drinking water and/or livestock watering
Belville 2	26° 41' 9.60" S	22° 40' 18.60" E	Drinking water and/or livestock watering
Bromley 1	26° 42' 48.29" S	23° 1' 0.58" E	Drinking water and/or livestock watering
Bromley 2	26° 42' 49.08" S	23° 1' 8.57" E	Un-used
Caledonia1	26° 42' 10.80" S	22° 45' 59.44" E	Drinking water and/or livestock watering
Caledonia 2	26° 45' 32.40" S	22° 45' 51.19" E	Drinking water and/or livestock watering
Cannock	26° 42' 58.79" S	22° 49' 7.76" E	Drinking water and/or livestock watering
New Stillewooning	26° 52' 10.79" S	22° 50' 9.99" E	Un-used
Soetvlakte1	26° 44' 56.40" S	22° 47' 11.36" E	Drinking water and/or livestock watering
Soetvlakte2	26° 43' 15.60" S	22° 48' 54.43" E	Drinking water and/or livestock watering
New Stillewooning 2	26° 52' 10.86" S	22° 49' 59.10" E	Un-used
Westward HO	26° 47' 16.80" S	22° 32' 16.98" E	Un-used

3.2.2 GROUNDWATER LEVELS

Groundwater levels measured on farms surrounding the Gravenhage Project for the 2011/2012 monitoring period are presented in Figure 3.1. Groundwater levels at these boreholes were generally stable with significant fluctuation in water level (>3 m) recorded at 4 of the 15 boreholes monitored, namely Soetvlakte 1, Soetvlakte 2, Avontuur 1, and Belville 2. Water levels did however recover to previous levels. Such fluctuations can be attributed to abstraction of water rather than seasonal fluctuations.



	December 2011	March 2012	July 2012	October 2012
Avontuur1	110.04	113.55	113.39	110.56
Avontuur2	94.09	94.13	93.77	93.76
Belville 1	92.62	91.52	92.48	93.2
Belville 2	105.75	92.73	92.99	92.84
Bromley 1	66.83	67.34	67.36	66.27
Bromley 2	65.91	66	66.05	66.11
Caledonia1		95.8	96.98	
Caledonia2	96.71			
Cannock	110.9			
Eksodus1 (A)	95.51	95.76	95.95	
New Stillewooning		93.48	93.56	
Soetvlakte1	99.9	107.25	97.69	
Soetvlakte2	98.08	104.01		
Stillewooning 2		92.07	92.12	92.14
Westward Ho		59.02	59.22	59.25

FIGURE 3.1: GROUNDWATER LEVELS RECORDED AT BOREHOLES SURROUNDING THE GRAVENHAGE PROJECT SITE FOR THE 2011/2012 MONITORING PERIOD

3.2.3 GROUNDWATER QUALITY

With respect to the groundwater quality, a number of constituents, including the electrical conductivity (EC), total dissolved solids, sulphate, chloride, sodium, and manganese are elevated at a majority of the monitored boreholes, making the water generally unpalatable for human consumption. It is important to note that this is the natural quality of water found in the underground aquifers and is not representative of anthropogenic pollution sources. Overall, the majority of boreholes utilised by farmers are considered safe for livestock watering. Water quality results for the 2011/2012 monitoring period are provided in Table 3.3 below.

TABLE 4.3: WATER QUALITY RESULTS FROM BOREHOLES SURROUNDING THE GRAVENHAGE PROJECT SITE FOR THE 2011/2012 MONITORING PERIOD NOTE: NUMBERS ARE HIGHLIGHTED IN RED WHERE THEY EXCEED THE SANS 241 (2011) DRINKING WATER STANDARD LIMITS FOR THE PARTICULAR CONSTITUENT. NUMBERS ARE HIGHLIGHTED IN PURPLE WHERE A HIGHER LIMIT, E.G. CHRONIC OR ACUTE HEALTH, IS EXCEEDED.

GRAVENHAGE MINE MONITORING BOREHOLE AVONTUUR 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	N	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.2	288	1728	19.3	392	448	340	0.6	10	<0.2	384	19.9	97	74	<0.100	<0.010	<0.010	0.664	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	0.02	<0.025	<0.025
July 2012	7.47	214	1490	21	412	438	328	0.6	11	0.8	367	22	114	86	<0.100	<0.010	<0.010	0.697	<0.025	<0.025	<0.025	<0.020	0.071	<0.001	<0.025	0.023	<0.025	<0.025

GRAVENHAGE MINE MONITORING BOREHOLE AVONTUUR 2

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.6	266	1620	27	368	413	343	0.7	8.9	<0.2	365	19.3	79	64	<0.100	<0.010	<0.010	0.631	<0.025	<0.025	0.075	<0.020	<0.025	<0.001	<0.025	<0.020	<0.025	<0.025
July 2012	7.49	202	1530	29	408	439	333	0.5	11	0.4	378	23	112	88	<0.100	<0.010	<0.010	0.69	<0.025	<0.025	<0.025	<0.020	0.091	<0.001	<0.025	0.023	<0.025	<0.025

GRAVENHAGE MINE MONITORING BOREHOLE EKSODUS 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	6.5	294	1780		152	252	467	351	1.4	0.2	<0.2	402	19.2	68	<0.100	<0.010	<0.010	0.089	<0.025	<0.025	16	<0.020	4.09	<0.001	<0.025	<0.020	<0.025	0.599
July 2012	7.38	626	435	58	180	487	582	1.2	0.6	<0.2	478	22	82	74	<0.100	<0.010	<0.010	0.23	0.075	<0.025	0.317	<0.020	3.65	<0.001	0.044	<0.020	<0.025	1.1

GRAVENHAGE MINE MONITORING BOREHOLE BELVILLE 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.3	338	2038		488	585	266	0.5	9.9	<0.2	490	28	98	59	<0.10	<0.010	<0.010	0.53	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	<0.02	0.02	<0.025
July 2012	7.86	938	647	18.7	644	597	325	0.5	10	<0.2	592	30	115	59	<0.100	<0.010	<0.010	0.68	<0.025	0.055	0.185	<0.020	0.086	<0.001	0.028	0.024	<0.025	0.148

GRAVENHAGE MINE MONITORING BOREHOLE BELVILLE 2

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.4	332	2088		464	640	280	0.5	10	<0.2	490	30	108	67	<0.100	<0.010	<0.010	0.519	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	<0.020	<0.025	<0.025
July 2012	7.93	958	668	33	492	637	304	0.4	11	<0.2	532	33	128	74	<0.100	<0.010	<0.010	0.563	<0.025	0.028	0.085	<0.020	0.142	<0.001	<0.025	0.021	<0.025	0.255

GRAVENHAGE MINE MONITORING BOREHOLE BELVILLE 3

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.3	292	1 444		404	412	156	0.5	9.2	0.2	350	28	58	51	<0.100	<0.010	<0.010	0.484	<0.025	<0.025	0.438	0.438	<0.025	<0.001	<0.025	<0.020	<0.025	0.138
March 2012																												
July 2012	Monitoring at borehole halted on request from farmer																											

GRAVENHAGE MINE MONITORING BOREHOLE BROMLEY 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
March 2012	7.82	51.5	352	6.7	280	28	19	0.2	3.9		21	4.7	73	33	0.102	<0.010	0.031	0.1	<0.025	<0.025	<0.025	<0.020	0.059	<0.001	<0.025	<0.020	<0.025	<0.025

October 2012	Monitoring at borehole halted on request from farmer

GRAVENHAGE MINE MONITORING BOREHOLE BROMLEY 2

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	No Sample, borehole too small to drop bailer																											

GRAVENHAGE MINE MONITORING BOREHOLE CALEDONIA 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	Borehole not monitored on request from farmer																											
July 2012	7.66	642	452		29	424	450	368	0.4	<0.020	<0.2	359	64	214	0.101	<0.100	<0.010	<0.010	0.447	<0.025	<0.025	0.153	<0.025	<0.020	0.09	<0.025	<0.001	0.07

GRAVENHAGE MINE MONITORING BOREHOLE CALEDONIA 2

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.5	397	2678	45	360	488	340	0.5	166	<0.2	346	56	158	163	<0.100	<0.010	<0.010	0.445	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	0.094	<0.025	<0.025
March 2012	Monitoring at borehole halted on request from farmer																											

GRAVENHAGE MINE MONITORING BOREHOLE CALEDONIA 3

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	Borehole not monitored on request from farmer																											
July 2012	7.79	738	516	4.7	564	199	168	1	5.3	<0.2	317	24	49	38	<0.100	<0.010	<0.010	0.65	<0.025	<0.025	<0.025	<0.020	0.039	<0.001	0.035	<0.020	<0.025	<0.025

GRAVENHAGE MINE MONITORING BOREHOLE CANNOCK

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.5	100	630	47	380	53	93	0.6	1.2	<0.2	107	7.4	50	38	<0.100	<0.010	<0.010	0.238	<0.025	0.031	0.078	<0.020	<0.025	<0.001	<0.025	<0.020	0.026	<0.025
July 2012	7.84	329	231	12	400	55	94	0.5	1.7	<0.2	109	8.1	57	42	<0.100	<0.010	<0.010	0.271	<0.025	<0.025	0.134	<0.020	0.064	<0.001	<0.025	<0.020	<0.025	0.033

GRAVENHAGE MINE MONITORING BOREHOLE NEW STILLEWOONING

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.2	259	1626	28	344	429	264	0.5	10	<0.2	315	9.6	119	70	<0.100	<0.010	<0.010	0.519	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	0.055	<0.020	<0.025	<0.025
July 2012	7.35	1689	1210	67	420	426	138	0.5	0.6	0.2	280	13.2	103	65	0.301	<0.010	<0.010	0.687	0.039	<0.025	4.22	<0.020	0.758	<0.001	<0.025	<0.020	<0.025	<0.025

GRAVENHAGE MINE MONITORING BOREHOLE SOETVLAKTE 1

Analysis Results (mg/l unless otherwise indicated)

Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.4	187	1128	8.7	544	191	145	0.7	4.8	<0.2	314	22	44	33	<0.100	<0.010	<0.010	0.218	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	<0.020	<0.025	<0.025
July 2012	7.78	289	201	8	384	52	97	0.5	1.7	<0.2	109	7.7	57	41	<0.100	<0.010	<0.010	0.258	<0.025	<0.025	0.036	<0.020	0.038	<0.001	0.032	<0.020	<0.025	0.134

GRAVENHAGE MINE MONITORING BOREHOLE SOETVLAKTE 2																														
Analysis Results (mg/l unless otherwise indicated)																														
Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.6	96.3	576	<1.0	364	49	91	0.6	1.1	<0.2	103	22	41	32	<0.100	<0.010	<0.010	0.616	<0.025	<0.025	<0.025	<0.020	<0.025	<0.001	<0.025	<0.020	<0.025	<0.025
March 2012	Monitoring at borehole halted on request from farmer																												

GRAVENHAGE MINE MONITORING BOREHOLE STILLEWOONING 2																												
Analysis Results (mg/l unless otherwise indicated)																												
Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
December 2011	7.6	240	1480	131	240	428	255	0.6	2.9	<0.2	309	6.8	77	55	0.484	<0.010	<0.010	1.3	<0.025	<0.025	1.5	<0.020	0.075	<0.001	<0.025	<0.020	0.383	<0.025
July 2012	7.51	198	1396	73	360	379	261	0.5	6.6	0.3	287	12.7	118	72	0.213	<0.010	<0.010	1.01	<0.025	<0.025	2.93	<0.020	0.131	<0.001	<0.025	<0.020	<0.025	<0.025

GRAVENHAGE MINE MONITORING BOREHOLE WESTWARD HO																												
Analysis Results (mg/l unless otherwise indicated)																												
Date	pH	EC	TDS	SS	Alkalinity	Cl	SO_4	F	NO3	Ammonia	Na	K	Ca	Mg	Al	Sb	As	B	Co	Cu	Fe	Pb	Mn	Hg	Mo	Se	Ti	Zn
July 2012	8.52	96.5	665	70	216	156	89	0.4	0.6	0.3	148	12	9	31	<0.100	<0.010	<0.010	0.235	<0.025	<0.025	5.13	<0.020	0.073	<0.001	<0.025	<0.020	<0.025	<0.025

4 ADDITIONAL COMMENTS AND OBSERVATIONS

Few houses used water from the municipal pipe connections and therefore groundwater is the major water supply for human and animal use in the area.

The Kuruman River was dry at the time of the hydrocensus and we were told that it had last flowed in 2006 (Ryno van Schalkwyk, *Pers. Comm.*). According to the farmers in the area, the area has been experiencing a drought in the last few years.

Many farmers also complained that water levels in their boreholes had dropped considerably since mining operations began at Black Rock Mine approximately 20 years ago. Black Rock Mine is situated near the town Santoy, just south of the study area.

According to information gathered from surrounding farmers, Eersbejint Farm has several prospecting boreholes on their property that could also potentially be monitored. We were however unable to access the property because the landowner (Hendrik Venter) was unavailable and the gate to the farmed was locked. It may be valuable to include these boreholes in future assessments.

5 REFERENCES

Synergistics Environmental Services (Synergistics). (2013*). Gravenhage Manganese Project Groundwater Monitoring Annual Report 2011/2012,* Report No. SO280/GWM.

Samantha Scott **Rudolf De Jager**

(Project Assistant) **(Project Assistant)**

Victoria Tucker **Rian Titus**

(Project Manager) **(Project Reviewer)**