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Tharisa Mine

Tharisa Groundwater Model Report

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August 2014

Tharisa Minerals (Pty) Ltd

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THARISA GROUNDWATER MODEL REPORT

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ACRONYMS AND ABBREVIATIONS

Below is a list of acronyms and abbreviations used in this report:

Acronym / Abbreviation	Definition
AMD	Acid Mine Drainage
ARD	Acid Rock Drainage
BIC	Bushveld Igneous Complex
DWA	Department of Water Affairs
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
GMS	Groundwater Modelling System
l/s	Litres per second
Ma	Million years
MAMSL	Metres above mean sea level
MAP	Mean Annual Precipitation
mbgl	Metres below ground level
mg/L	Milligrams per litre
PAF	Potentially Acid Forming
RLS	Rustenberg Layered Suite
SANS 241	South African National Standard: Drinking Water Guideline Limits
SWL	Static Water Level
TDS	Total Dissolved Solids
TPM	Tonnes per month
TSF	Tailings Storage Facility
UTM	Universal Transverse Mercator
WHO	World Health Organisation
WRD	Waste Rock Dump

EXECUTIVE SUMMARY

SLR Consulting (South Africa) (Pty) Ltd (SLR) was appointed to develop a site-specific numerical groundwater flow and contaminant transport model for the development of open pits and tailings storage facilities (TSFs) at Tharisa Mine near Rustenburg in the North West Province. The numerical groundwater model is needed to understand potential impacts due to changes in mine infrastructure. This report is based on, and updates, a previous groundwater modeling report completed by Water Geosciences Consulting (now part of SLR Consulting) in 2007 (WGC, 2007).

Tharisa Mine is located about 30 km southeast of Rustenburg, south of the town of Marikana, in quaternary drainage catchment A21K. The mine has two main open-cast pits, separated by a narrow strip of land on which the Sterkstroom River flows. An existing quarry ("Hernic Quarry") close to the river is currently used for temporary storage of water arising from the West Pit, and this facility has also been taken into account in this study.

This report outlines the site-specific hydrogeological conceptual model as well as the numerical groundwater flow and contaminant transport models. The numerical groundwater model is used to estimate inflows into the two open pits and to visualize the potential contaminant plumes associated with the TSFs, WRDs and the quarry. The two-layer, steady-state numerical groundwater model was developed using the widely accepted code MODFLOW, with GMS 8.2 as pre- and post-processor. Model calibration was done using twelve boreholes near the mine with water levels measured in 2012. A reasonable correlation coefficient R^2 between modelled and observed values of 83% with a Root Mean Squared Residual (Head) of 4.94% was achieved for the steady-state calibration of water levels.

The predicted modelled inflow rate into both open pits combined when they are at their full depth is 3900 m³/d, or about 45 L/s. Pit dewatering will result in a lowering of groundwater heads in the vicinity of the open pit areas (at full pit development). The final cone of depression (i.e. additional drawdown of the groundwater table due to pit inflows/dewatering) extends beyond the mine lease area (about 0.5 to 2.0 km from the pits, elongated in a northerly direction with the regional groundwater flow).

The estimated inflow rates are based on annual average (steady-state) groundwater inflows into the pits and do not account for direct rainfall (only the groundwater recharge component thereof) and surface runoff into the pit or for potential seepage from a perched aquifer. Any steady-state groundwater model is likely to overestimate groundwater inflows, as it does not account for the increasing dewatering of the aquifer with time due to pit inflows and hence reduced yields. It also does not account for the partial backfilling of the pits that will take place. The values presented are intrinsically of low to medium confidence and should be verified once initial pit inflow rates become available.

The impacts on the groundwater quality due to leakage from the TSFs, WRDs and the quarry were evaluated with a 2-layer contaminant transport model using the internationally accepted MT3DMS code.

Following the precautionary principle, only advective-dispersive transport of potential pollutants without any retardation or transformation was considered. The impacts of potential pollution sources on the groundwater quality are therefore conservative. The TSFs will not have an artificial liner but will be situated on about 2 m of compacted clay-rich soil. Based on estimates by Epoch Resources (Epoch, 2012b) the recharge flux (downward movement of leachate) in the area of the combined TSF footprint would be very similar to the regional recharge – about 27 mm/a.

A constant unit (recharge) source concentration was assumed and all initial concentrations were set to zero. The calculated concentrations presented are therefore fractions of the unit source concentration and must be added to any potential background concentration. When actual leachate compositions are known, the model concentrations can be easily updated by multiplying the predicted fractions by the actual concentration. A continuous source-strength (i.e. concentration) was assumed for the operational phase of the mine (i.e. the first 40 years of operation). The source concentration was reduced by half for a post closure phase (extending to 150 years after mining started). A localised impact (in the vicinity of the mine TSF) on the groundwater flow is expected as a result of the mound effect due to continuous leakage from the potential pollution sources.

The waste rock material is expected to be non-acid generating, but increased salinity including elevated concentrations of aluminium and manganese are expected. As the waste rock dumps are adjacent to the pits, it is likely that leachate arising from the waste rock dumps will report to the pits, and become part of the mine dirty water circuit.

The potential impacts of the TSFs, WRDs and quarry on the groundwater quality are highly likely to occur and are likely to extend beyond mine lease boundaries for the groundwater regime. The associated impacts will be long-term with moderate increases of contaminant concentrations beyond mine closure. The intensity of the impact is likely to be a moderate deterioration in the ambient groundwater quality. The impacts on groundwater associated with the quarry are only likely to occur if the water level in the quarry regularly exceeds the ambient groundwater level, which is considered to be unlikely.

The plumes from the TSFs are expected to migrate around 700 meters northwards after 20 years, and about 1200 meters after 40 years from their respective footprints, and reach the northern WRD. After 150 years the TSF plumes will cumulatively migrate northwards along with the associated northern WRD's plume. The source concentration after 150 years is less than 30% of the original source concentration associated with the TSFs.

The plumes from the WRDs are expected to migrate northwards and extend between 600 and 800 meters after 20 years, between 1200 and 1500 meters after 40 years, and more than 3000 meters after 150 years, from their initial respective footprints. After 150 years the source concentration associated with the most western WRD is less than 10% and the northern WRD is less than 40% of the original source

concentration. The higher percentage associated with the northern WRD can be attributed to the cumulative impact from the TSFs.

The current groundwater monitoring programme should be continued (and may require the drilling of new monitoring boreholes to replace any lost to mine infrastructure development) to assess the lowering of the groundwater levels associated with dewatering of the open pits and to assess potential contamination emanating from the TSFs, WRDs and the quarry. The numerical groundwater model should be updated once more monitoring data becomes available to improve the accuracy of forward predictions.

THARISA GROUNDWATER MODEL REPORT

1 INTRODUCTION

1.1 SCOPE OF WORK

SLR Consulting (South Africa) (Pty) Ltd (SLR) was appointed to develop a site-specific numerical groundwater flow and contaminant transport model for the expansion of open pits and changes to mine residue deposits (Tailings Storage Facility or TSF and Waste Rock Dumps or WRDs) at Tharisa Mine near Rustenburg in North West Province.

A decision was taken to construct a new numerical groundwater flow and transport model for this study, since the 2007 model (developed in MODFLOW-PMWIN) would have required a complete update. This report outlines the site-specific hydrogeological conceptual model as well as the numerical groundwater flow and contaminant transport models. The numerical groundwater model was used to estimate inflows into the open pits and to estimate the potential contaminant plumes associated with the TSF, WRDs and the quarry.

This report is intended as an update of the report “Groundwater Investigation for Tharisa Mine” produced by Water Geosciences Consulting (now part of SLR Consulting) in 2007 (WGC, 2007) which described the aquifer systems, the conceptual hydrogeology, the geochemistry, and which provided details of a numerical groundwater flow and transport model done at that time.

1.2 MODELLING OBJECTIVE

A regional groundwater flow model was developed based on the available aquifer parameters to evaluate the potential impacts of mining activities on groundwater flow and quality. The numerical model was 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 Tailings Storage facilities (TSFs), Waste Rock Dump (WRDs) and quarry. Furthermore, the numerical model also estimates groundwater inflow rates into the different open pits and the extent of the lowered groundwater levels surrounding the open pits.

1.3 DATA SOURCES AND DEFICIENCIES

The development of the hydrogeological conceptual and numerical groundwater model was based partly on the following information and data made available to the project team or gathered as part of the groundwater investigations:

- 1:250 000 Geology Map of the area (Council for Geoscience).
- 1:500 000 Hydrogeological Map sheet (2526 Johannesburg, DWA).
- 25 m digital elevation model (Directorate Survey & Mapping) and converted into a 100m x 100m grid.
- 1:50 000 digital topographic data (raster and vector data) (Directorate Survey & Mapping).
- Previous groundwater reports including a numerical model report written by Water Geosciences Consulting in 2007.
- Environmental reports by Metago Environmental Engineers (now part of SLR Consulting (Africa) (Pty) Ltd).
- Digital data on the TSF and WRDs provided by Epoch Resources (Pty) Ltd in 2012/13.
- A Seepage Assessment Report prepared by Epoch Resources (Pty) Ltd in 2012

No field data was collected for the development of the groundwater flow and contaminant transport model, existing available information was used. These include a database of boreholes in the vicinity of Tharisa mine, of which twelve had water levels recorded in 2012. These twelve boreholes were used as observation boreholes to calibrate the numerical groundwater flow model. Borehole records held in the National Groundwater Archive (NGA) maintained by the Department of Water Affairs (DWA) were also obtained, but these were of limited use since only two boreholes in the catchment are still being monitored by DWA. No field investigations (i.e. drilling, pumping tests, etc.) were conducted specifically for this modelling study, but field data obtained during the 2007 study (WGC, 2007) was used in the development of this model. The locations of the WRDs are adjacent to the pits and are expected to be within the cone of depression surrounding each pit. Leachate from the WRDs is therefore likely to be captured by the pits and become part of the mine dirty water circuit during mining operations. Much of the waste rock is expected to be used to backfill the pits as mining progresses, and only a small amount of waste rock will remain on closure. There is likely to be a smaller plume of leachate in local groundwater that emanates from the remaining waste rock after mining ceases, and this will depend on the volume of waste rock left and its exact location.

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

2 DESCRIPTION OF STUDY AREA

2.1 SITE LOCATION

The Tharisa mining operation is situated approximately 30 km southeast of Rustenburg, south of the town of Marikana, in the North West Province of South Africa (Figure 2-1). The area of investigation is bordered by numerous active mines immediately to the north, west and east. The mining area is located within the A21K quaternary catchment in the Crocodile West and Marico Water Management Area. The Mareltwane stream flows into the main Sterkstoom River towards the northern boundary of the quaternary catchment. The mean annual rainfall (MAR) and mean annual runoff for the catchment are 718 mm and 100 mm respectively (Ref. WR90).

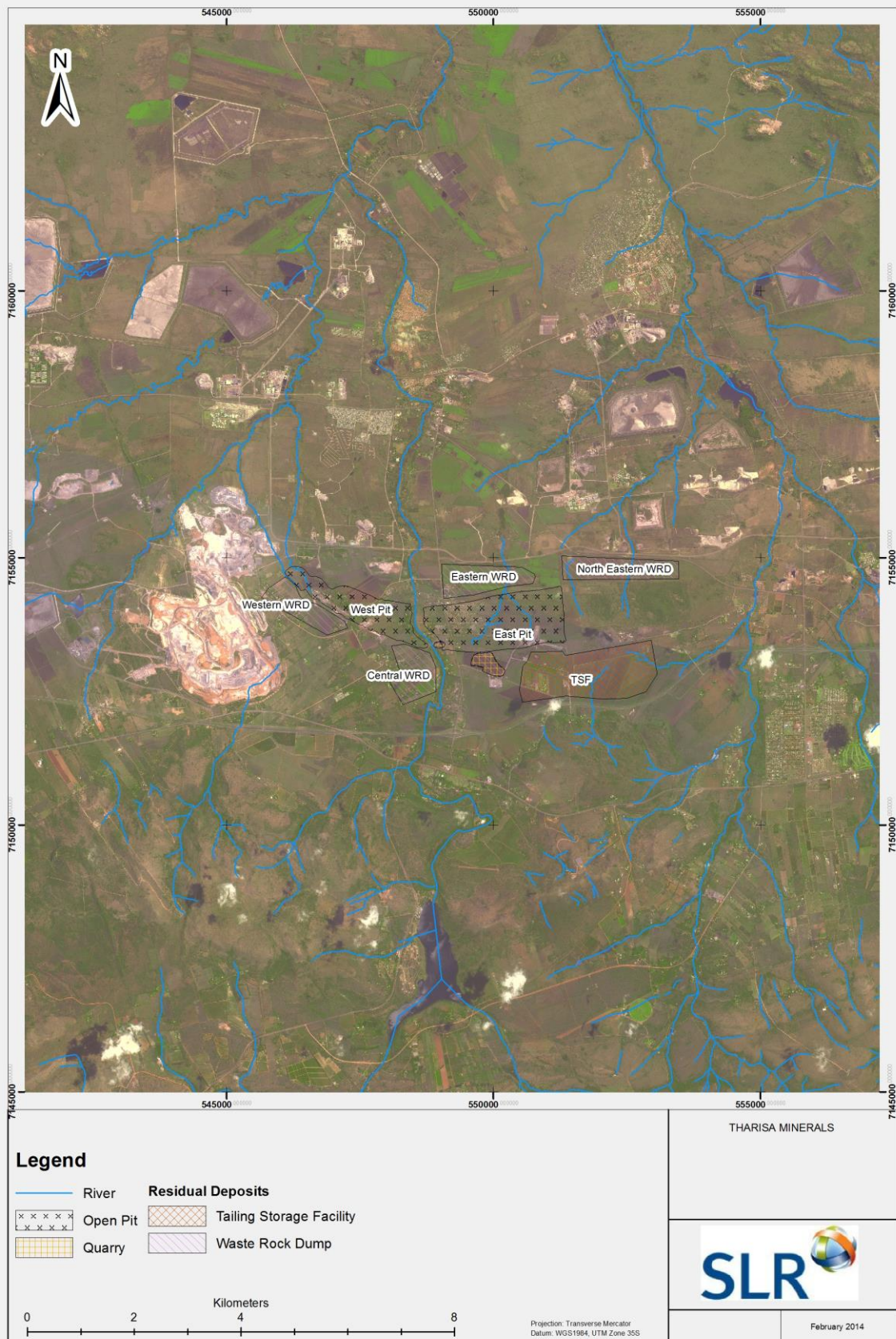


FIGURE 2-1 LOCATION OF THARISA MINE INFRASTRUCTURE

2.2 REGIONAL GEOLOGY

The following section on geology draws mainly on the 2007 model report (WGC, 2007). The study area is underlain by igneous rocks of the Rustenburg Layered Suite (RLS), part of the approximately 2 050 million year-old Bushveld Igneous Complex (BIC). In this area the generally planar nature of the layered sequences of the Rustenburg Layered Suite appear gently folded around a thickened part of the floor rocks (quartzites of the Magaliesberg Formation). The primary permeability of the RLS and the underlying quartzites is very low, and groundwater flow occurs along joints, fractures and other discontinuities in the rock.

The dominant lineaments (including linear geological features visible on satellite images or detectable with geophysical equipment) trend NNW-SSE. Both the RLS and Magaliesberg floor rocks are similarly cross-cut by NNW-SSE striking joints and normal faults (reflecting ENE-WSW extension). It is likely that all these structures relate to the post-Bushveld Brits Graben extensional event. However, a strong set of joints in the RLS, which strike approximately E-W, is not well represented in the underlying Magaliesberg Formation rocks. It is possible that these structures may have formed as a result of extension during thermal collapse of the Bushveld towards the centre of the Complex, as their strike is approximately parallel to the strike of the layering of the RLS. Such an event, being connected to the cooling of the Bushveld magmas, could be expected not to have strongly affected the floor rocks.

Data recorded from underground workings (approximately at a depth of 2000 m) in adjacent areas of the RLS shows that many reverse faults dip moderately steeply towards the south in this area. Normal faults, in contrast, generally dip moderately steeply towards the NE and SW, suggesting that a conjugate set of normal faulting may exist, sub-parallel to the neighbouring Brits Graben structure. Steeply southward-dipping reverse faults suggest vergence towards the centre of the Bushveld.

The discontinuities in the BIC and floor rocks described above together contribute to the hydraulic characteristics of the fractured aquifer in the area. For the purposes of this study it has been assumed that the aquifer can be represented as an equivalent porous medium at scales of tens of metres and smaller. Local heterogeneities due to preferential joint or fracture orientations are likely to exist, but could not be represented in the model due to the lack of information on these features.

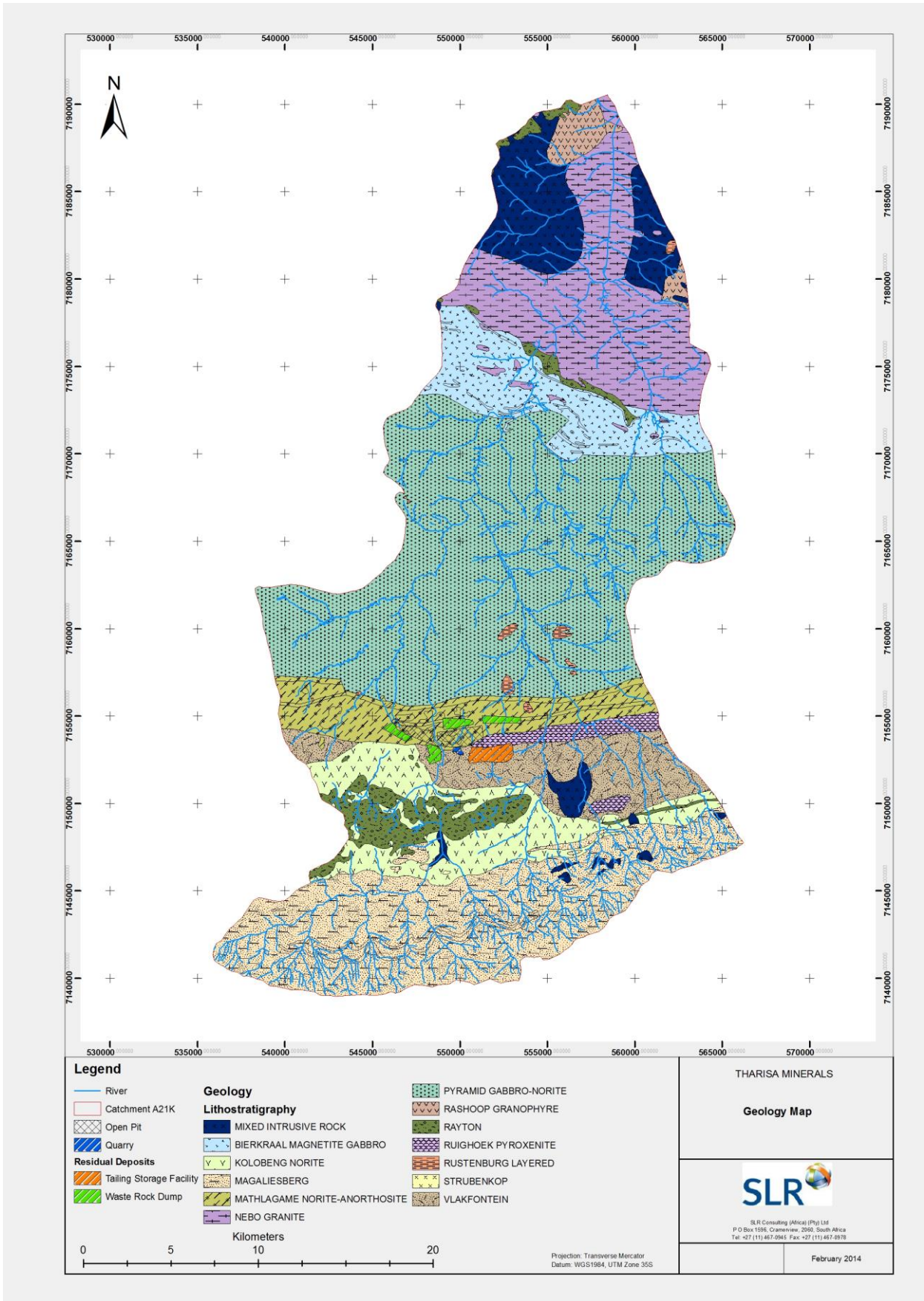


FIGURE 2-2 BASIC GEOLOGY OF A21K

3 GROUNDWATER CONCEPTUAL MODEL

3.1 GROUNDWATER RESERVE

Quaternary catchment A21K receives mean annual precipitation (MAP) of 651 mm/a and an estimated average annual groundwater recharge of 24.4 million m³ (Mm³), of which 3.4 Mm³ per annum or 13.8% is required for the Reserve, consisting of both basic human needs (BHN, estimated at 0.5 Mm³/a) and an ecological component (estimated at 2.9 Mm³/a). This equates to an approximate recharge across the catchment of about 28 mm/a. The groundwater contribution to the ecology (maintenance of low flow in-stream flow requirement) was based on a Present Ecological Status Category of C (moderately modified). A summary of the Reserve determination is given in Table 3-1 below (Groundwater Resource Directed Measures software, DWAF, 2006).

TABLE 3-1 SUMMARY OF THE QUANTITY COMPONENT OF THE RESERVE (A21K)

Catchment	Area (km ²)	Recharge ¹ (Mm ³ /a)	Population	Baseflow ² (Mm ³ /a)	IFR ³ derived from baseflow (Mm ³ /a)	BHN ⁴ Reserve (Mm ³ /a)	Reserve as % of Recharge
A21K	864.1	24.4	55 258	19	2.872	0.5	13.8

- **Recharge¹**: Water reaching the aquifer directly from precipitation and the infiltration of surface water.
- **Baseflow²**: Baseflow is that part of stream flow that derives from groundwater and shallow subsurface storage. During the dry season, the stream flow is typically composed entirely of baseflow.
- **Groundwater component of baseflow**: This is the component of Baseflow that derives from the aquifer adjacent to a surface water body, and excludes interflow in the vadose zone or short-term storm events which saturate the subsurface soil and discharge to a surface water body before reaching the aquifer. The Herold Baseflow Separation Model is used.
- **Baseflow required by IFR³**: The volume of baseflow required by the instream flow requirements set for the surface water component of the Reserve.
- **The Reserve** constitutes the sum of the baseflow required by IFR plus the BHN reserve expressed as a percentage of the Recharge.

The allocable groundwater is therefore estimated at 21 Mm³/a, with groundwater abstraction set at 0.9 Mm³/a. However, it must be determined whether the cumulative groundwater use by mines and irrigators does not exceed the above abstraction figures since the current groundwater Reserve is based on limited data.

3.2 AQUIFER SYSTEMS

Crystalline material such as the norites, anorthosites and pyroxenites (i.e. Rustenburg Layered Suite of the Bushveld Igneous Complex) in the Tharisa mining area, consists of (a) an unweathered and intact rock matrix with negligible porosity and permeability, and (b) planes of discontinuity in the rock matrix, including both faults and joint planes (collectively referred to as fractures). These discontinuities are often infilled by precipitates from late phase fluids (i.e. vein infill).

The following two layer aquifer model, based on field work and knowledge of similar geological settings, is proposed for the Tharisa mine area:

- A shallow weathered bedrock aquifer system with intergranular porosity and permeability. The shallow unconfined (no upper confining layer of impermeable or low permeability soil or rock material) to semi-confined water table aquifer formed as a result of intensive in-situ weathering of the norites, anorthosites and pyroxenites (i.e. regolith). It includes the differentially weathered and fractured bedrock underlying the regolith and is treated as a single weathered aquifer unit.
- A deeper unweathered and fractured bedrock aquifer system. The unweathered bedrock aquifer comprises of the fractured and faulted norites, anorthosites and pyroxenites. The intact bedrock matrix itself is assumed to have very low matrix permeability, while its effective bulk permeability is enhanced by faults and mine openings.

3.2.1 SHALLOW WEATHERED BEDROCK AQUIFER SYSTEM

The weathered overburden is highly variable in thickness from 3 m to more than 30 m based on existing borehole logs and evidence of borehole depths. This differentially weathered overburden in the vicinity of Tharisa is a whitish to greenish/brownish, fine to coarse grained sandy soil derived from the in-situ decomposition of the underlying norites, anorthosites and pyroxenites.

In the immediate vicinity of the Sterkstroom River course the weathered overburden is partially or totally replaced by alluvium (river sediments). So-called alluvial aquifers are present in locally distributed unconsolidated gravel, sand, silt and clay sediments deposited along the Sterkstroom River (close to Tharisa mine). Recharge is through downward leakage from the overlying stream, lateral groundwater flow from the shallow weathered aquifer and by rainfall events. The thickness of the alluvial sediments has been estimated at 3 to 5 m with its lateral distribution restricted to the immediate banks of the current active channel. Due to their limited size, low permeability and relatively low groundwater storage, the alluvial aquifers are not considered suitable groundwater production targets.

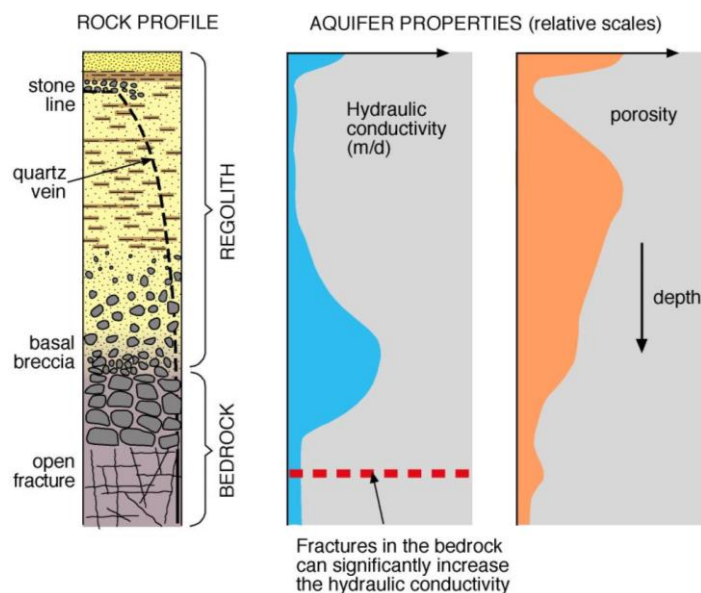


FIGURE 3-1 TYPICAL WEATHERED PROFILE FOR PRECAMBRIAN BASEMENT ROCKS (AFTER MACDONALD ET AL. 2005)

The weathered aquifer, as well as the alluvial aquifer along the Sterkstroom River, probably supports most irrigation and domestic water-supply boreholes throughout the region. The boreholes present in the study area appear to target the shallow weathered bedrock aquifer, which is highly variable in depth. Water strikes were mostly encountered during drilling at depths varying from 19 meters below ground level (mbgl) to 33 mbgl (i.e. lower part of the upper weathered aquifer) (WGC, 2007). Typical transmissivity values (measure of the ease with which groundwater flows in the subsurface) range between 15 to 30 m²/d and storativity (S) values (volume of water released from or taken into storage as a result of a change in head per volume of the aquifer) of 10⁻⁵.

3.2.2 DEEPER FRACTURED BEDROCK AQUIFER

A deeper unweathered and fractured semi-confined bedrock aquifer is associated with the fractured norites, anorthosites and pyroxenites underlying the weathered aquifer. The deeper fractured bedrock aquifer is characterized by very low matrix permeability, poorly connected joint/fractures and dolerite/diabase dykes (that may act as barriers to groundwater flow), ensuring that the aquifer system is semi-confined and poorly connected with the overlying weathered or alluvial aquifers. Its effective permeability is determined by interconnected and open fracture systems. However, these fracture systems can in places potentially allow for rapid vertical groundwater flow from the weathered overburden and from surface water bodies to greater depths in the fractured aquifer. Whilst in general the weathered aquifer and lower fractured aquifer are poorly connected, this is not always the case (see below).

3.3 GROUNDWATER FLOW REGIMES

The inferred presence of a relatively impermeable interface between the upper shallow weathered aquifer and the deeper, fractured aquifer is thought to be important for groundwater flow in the Tharisa

area. This semi- to impermeable interface prevents rapid vertical drainage of the shallow aquifer on a regional scale, thus permitting lateral groundwater flow in the shallow aquifer driven by groundwater gradients related to local topography. In addition, the weathered bedrock zone (Figure 3-1) is also characterised by relatively higher hydraulic conductivities/permeabilities that supports lateral groundwater flow. The weathered overburden is highly variable in thickness with 'depressions and highs' that 'canalize' shallow groundwater flow above this interface. Vertical infiltration across this interface is controlled by the existence of permeable zones such as fracture systems "cutting" through the interface. The infiltration of water from the weathered overburden to the fractured bedrock thus only occurs at specific sites where a combination of suitable geological features (such as fracture zones) and hydrological variables (i.e. thickness of overburden) occur.

In the vicinity of river courses, relatively low-permeability alluvium overlies or replaces the weathered overburden. The interaction of alluvial aquifers (along river courses) and the river depends, amongst other factors, on the differences between surface water and groundwater levels (i.e. the river might lose or gain water from the aquifer), and the presence (and thickness) or lack of clogging, semi-permeable layers in the streambed resulting in an imperfect hydraulic connection as well as on the aquifer properties.

Due to mine dewatering the local groundwater flow directions in the deeper fractured aquifer are generally re-directed towards the mine. This may result in locally different groundwater flow directions for the two aquifer systems. In addition, the upper weathered aquifer is gradually drained within the area affected by mine dewatering except where localized sources of water exist or where upwards directed groundwater flow along deeper fractures supports the groundwater levels in shallow weathered aquifers.

3.4 AQUIFER CLASSIFICATION

The classification of the aquifer system in the Mooinooi / Buffelspoort (Tharisa) area is based on the following modified aquifer system management classes (Parsons and Conrad, 1998):

- **Sole Aquifer System:** An aquifer used to supply 50% or more of urban domestic water for a given area and for which there are no reasonably available alternative sources of water.
- **Major Aquifer System:** A high-yielding aquifer system of good quality water.
- **Minor Aquifer System:** A moderately-yielding aquifer system of variable water quality. (Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers).
- **Poor Groundwater Region:** A low to negligible yielding aquifer system of moderate to poor water quality.
- **Special Aquifer Region:** An aquifer designated as such by the Minister of Water Affairs and Forestry, after due process.

The area within which Tharisa mine is located is classed as a **minor aquifer region** in terms of the Aquifer Classification Map of South Africa (Parsons and Conrad, 1998). Pumping tests indicate that the

average yield for the upper weathered aquifer system varies between about 1 l/s and 2.5 l/s. Isolated occurrences of anomalous higher yielding areas are sometimes found (WGC, 2007). The weathered aquifer, in particular, is important for local groundwater supply to farmers. The interaction between surface water systems (i.e. Sterkstroom River and tributaries) and groundwater was considered in the groundwater model (described later). It must be kept in mind that the information contained in the Aquifer Classification Map of South Africa is intended to facilitate planning at a national scale and not necessarily intended for site-specific use.

3.5 AQUIFER PARAMETERS

WGC (2007) report on pumping tests carried out at nine boreholes in the vicinity of Tharisa mine. Where possible, both step-drawdown tests and constant rate tests were performed on these boreholes. Values for transmissivity ranged from 7.5 m²/d to 269 m²/day, and Storativity (S) values were in the range 10⁻³ to 10⁻⁵. For full details of the pumping tests and analyses see WGC (2007). A considerable amount of local heterogeneity is to be expected, due to the presence of alluvium, discrete fracture systems and a weathered zone which varies considerably in thickness. Little is known about these features in the vicinity of Tharisa mine, and for the purposes of a regional groundwater model parameters were assigned on the basis of the main geological units and the model layers only.

Water level fluctuations for boreholes at the Tharisa Mine site are provided in Figure 3-2 below (SLR, 2012b). Slight rises in water levels are observed for most of the boreholes since monitoring began in 2008, implying a system that is still equilibrating. Fluctuations in some of the borehole water levels (e.g. TRH52A, B and C) are observed since these boreholes are equipped with pumps.

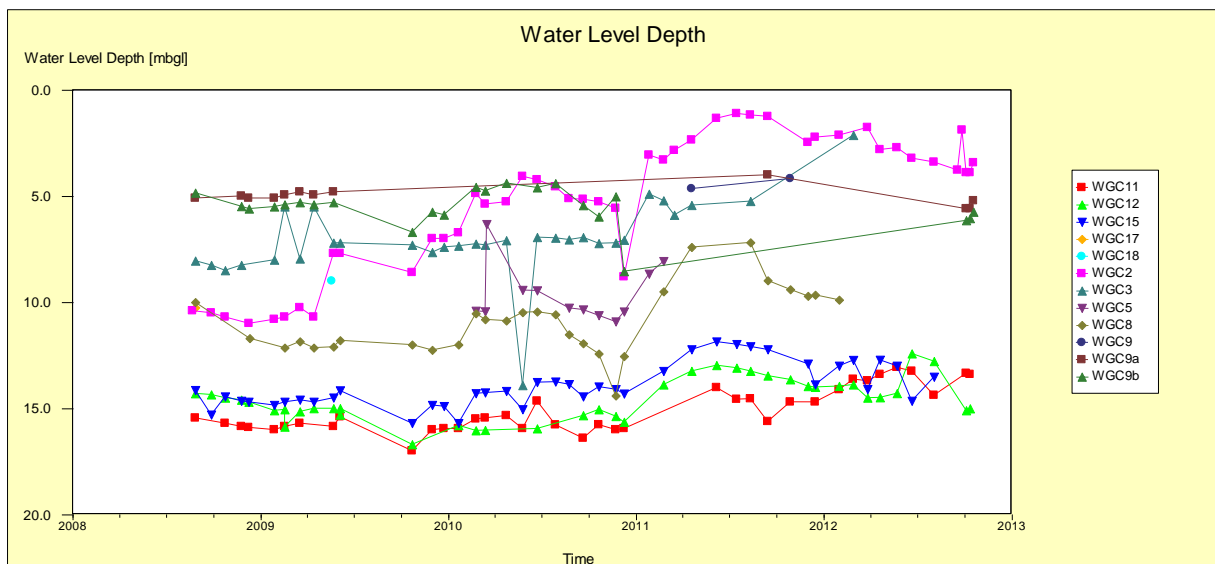


FIGURE 3-2 BOREHOLE WATER LEVEL FLUCTUATIONS AT THARISA MINE

3.6 ARD POTENTIAL

A geochemical study carried out in 2008 (Metago, 2008) included a mineralogical assessment, acid-base accounting and leach testing on the following materials associated with Tharisa mine:

1. Waste Rock
2. Concentrator Tailings
3. Venturi Scrubber Slurry
4. Slag

The report (Metago, 2008:33) states the following: “Based on the tests results, none of the wastes are expected to be acid generating. The design of pollution abatement measures need only consider the leachability of the waste under natural pH conditions to mildly acidic conditions”. All of the waste streams were however classified as “hazardous” due to the leaching potential, with the leaching of aluminium under conditions of neutral pH likely. In the long term the different waste streams are likely to have similar pollution potential.

3.7 AMBIENT GROUNDWATER QUALITY

The pre-mining water quality (as sampled during the 2007 wet season hydrocensus) indicated that groundwater was generally of good quality and could either be classified as ideal or good – refer to Table 3-2. In some boreholes, elevated nitrates dropped the general classification to that of marginal water quality. One borehole (WGC 15, located north east of the tailings dam complex), presented marginal water quality concentrations (Class II) with respect to magnesium (Mg) and total dissolved solids (TDS) and dangerous water quality concentrations with respect to nitrate (NO_3 as N). Refer to Figure 3-3 for the location of these points. Note that the borehole naming conventions have been changed slightly to include the letters “TRH” before the borehole numbers.

TABLE 3-2: PRE-MINING GROUNDWATER QUALITY

SampleID	StationID	Ca	Mg	K	Na	Mn	Fe	F	Cl	NO ₃ as N	SO ₄	Si	TDS	Cond	Alk	HCO ₃	pH
1	Borehole 17a	27.91	63.48	0.23	18.19	<0.01	<0.01	<0.2	14.00	5.70	43.00	9.19	432.00	62.00	276.00	356.87	7.6
2	Borehole 18	55.44	80.64	0.20	20.55	<0.01	<0.01	<0.2	83.00	18.00	88.00	9.61	680.00	97.00	260.00	336.18	7.2
3	Borehole 38	33.14	28.01	0.16	22.01	<0.01	<0.01	<0.2	<5	1.40	16.00	9.07	342.00	44.20	224.00	289.63	7.5
4	Borehole 30	36.90	45.62	0.18	23.42	<0.01	1.46	<0.2	5.00	1.30	8.00	7.07	416.00	58.60	328.00	424.10	7.5
5	Borehole 33a	38.60	92.46	0.96	16.68	0.18	<0.01	<0.2	13.00	9.10	84.00	8.25	618.00	84.00	364.00	470.65	7.7
6	Borehole 36	49.59	83.94	0.73	22.34	<0.01	<0.01	<0.2	18.00	11.00	73.00	8.76	612.00	87.40	388.00	501.68	7.7
7	Borehole 41	48.19	59.61	0.00	13.20	<0.01	<0.01	<0.2	22.00	8.30	102.00	3.27	552.00	72.40	252.00	325.84	7.6
8	Borehole 40	23.55	30.13	0.17	7.58	<0.01	<0.01	<0.2	11.00	2.70	12.00	2.42	294.00	37.10	160.00	206.88	7.5
9	Borehole 46	37.17	64.07	0.02	12.89	<0.01	<0.01	<0.2	21.00	14.00	75.00	5.75	516.00	68.90	228.00	294.80	7.6
10	Borehole 50a	24.13	20.71	0.25	9.03	<0.01	<0.01	<0.2	10.00	2.60	<5	4.36	290.00	32.00	148.00	191.36	7.3
11	Borehole 14	45.23	66.12	0.19	14.20	0.03	<0.01	<0.2	28.00	9.90	72.00	2.73	504.00	71.20	260.00	336.18	7.4
12	Borehole 15	22.51	33.07	0.00	9.24	<0.01	<0.01	<0.2	14.00	7.80	29.00	2.70	360.00	43.00	156.00	201.71	7.7

Classification according to the guideline compiled by Water Research Commission (WRC) together with DWAF and the Department of Health

Class 0	Ideal water quality-suitable for lifetime use.
Class 1	Good water quality-suitable for use, rare instances of negative effects.
Class 2	Marginal water quality-conditionally acceptable. Negative effects may occur in some sensitive groups.
Class 3	Poor water quality-unsuitable for use without treatment. Chronic effects may occur.
Class 4	Dangerous water quality-totally unsuitable for use. Acute effects may occur.

Tharisa monitors a number of boreholes located within and surrounding the mine as part of its groundwater monitoring programme. The water quality results from 2008 to 2014 have been compared to the South African National Standard (SANS) standards for domestic use (241:2011) as well as DWAF's guidelines for irrigation and livestock watering. The average concentration data is provided for the period 2008 to 2014 in Appendix A.

The monitoring results show the following:

- Consistent exceedance of the electrical conductivity and total dissolved solids agricultural guideline for all boreholes sampled. It is noted that the pre-mining water quality also exceeded these guidelines
- Consistent exceedance of the cadmium agricultural guideline for all boreholes sampled during 2008 to 2013; however no exceedance is shown in the 2013 and 2014 data. It is therefore suggested that Tharisa investigate this further as outlined below
- Frequent exceedance of the nitrate agricultural and domestic use guidelines for most boreholes sampled. It is noted that the pre-mining water quality also exceeded these guidelines
- Sporadic exceedance of the selenium domestic use guidelines in boreholes WGC15 and 18 in 2008, TMGWCOMM2 in 2009, TRH36 in 2009 and 2011, TRH14 and 25 in 2009, TMGWCOMM1 in 2011. The 2013 and 2014 data records selenium concentration at 0.025 for boreholes TMGWCOMM1, 5, 6, 8, TMGWTSF1, 2 and TMGWMCC. It is therefore suggested that Tharisa investigate this further as outlined below
- The 2013 and 2014 data for mercury and arsenic concentrations in TMGWCOMM1, 5, 6 and 8 as well as TMGWTSF1, 2 and TMGWMCC were all reported to be 0.015 and 0.023 respectively, which exceed the livestock and domestic use guidelines. However, no exceedances were noted in the preceding years for boreholes TMGWTSF1 and TMGWCOMM1. No monitoring data is available before 2013 and 2014 for the other boreholes where mercury or arsenic were elevated. No pre-mining mercury or arsenic concentrations are available. It is therefore suggested that Tharisa investigate this further as outlined below
- Manganese concentrations exceeded the agricultural guideline at TRH41 and TMGWTSF01 in 2008 to 2011 (no subsequent data is available for these boreholes), TMGWCOMM1 in 2008 to 2010, WGC3,11 and 12 in 2008 to 2013 (no subsequent data is available), WGC8 in 2008 to 2012 (no subsequent data is available), as well as other more sporadic exceedances. No exceedance was noted in the 2013 and 2014 monitoring data. Manganese was however not shown to be elevated in the pre-mining water quality data available. It is therefore suggested that Tharisa investigate this further as outlined below

In order to understand the inconsistent mercury, arsenic, manganese, selenium and cadmium and it is suggested that the following be conducted:

- Background samples should be taken further afield within the catchment where mining and other anthropogenic activities are not likely to impact on water quality and compare the results against

that found in 2013 and 2014, with particular reference to those community boreholes being monitored which are located upstream of the mine infrastructure

- Conduct a round robin laboratory analysis in an effort to determine the accuracy of laboratory testwork. This involves taking duplicate or triplicate samples and sending the samples to different laboratories in order to compare the results

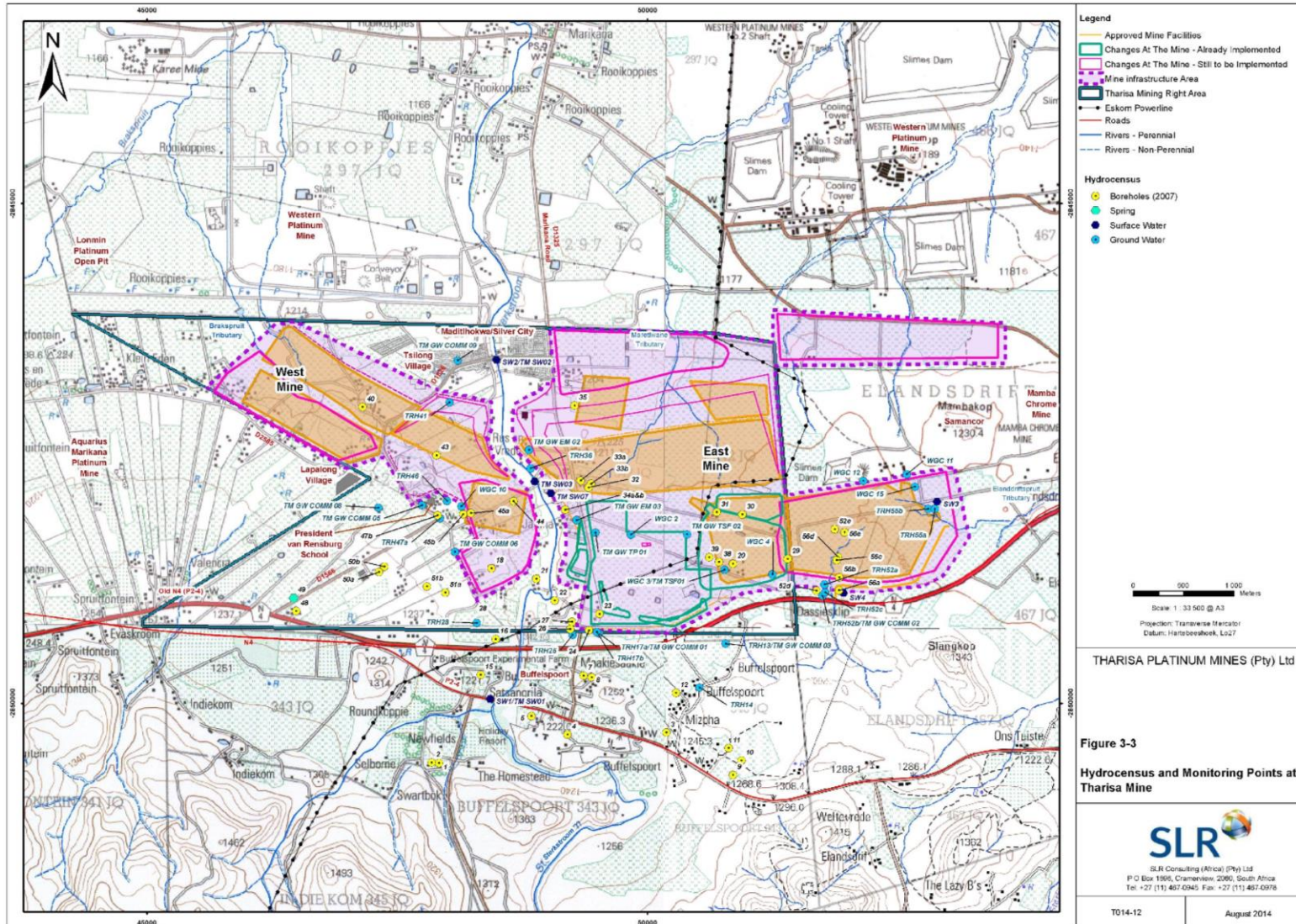


FIGURE 3-3 HYDROCENSUS AND MONITORING POINTS AT THARISA MINE

4 NUMERICAL MODEL CONSTRUCTION

4.1 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 Tharisa Mine groundwater model, the internationally accepted package GMS 8.3 (Groundwater Modelling System) was used. GMS allows the user to import spatial and other data into the model software, and is able to map this data (e.g. ArcGIS shapefiles, CAD files, etc) rapidly and accurately to the MODFLOW grid. This can allow for a more realistic depiction of the model area, and saves considerable time. GMS also incorporates various tools for the interpolation of 2D and 3D point data. Furthermore, GMS supports common auxiliary packages such as MT3D, MT3DMS, MOC3D, PMPATH for Windows, PEST2000, and UCODE.

4.1.1 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-state and transient flow conditions, 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.

4.1.2 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).

4.2 MODEL DOMAIN

4.2.1 FINITE DIFFERENCE FLOW MODEL

A regional two-layer steady-state groundwater model was chosen. The model domain was discretised into a 200 X 100 grid block uniform mesh (approximately 33.4 x 56.8 km in extent). The Z dimension was set at 2000 m. The top elevation of the model was based on the 25 m x 25 m digital elevation model obtained from the Chief Directorate: National Geo-spatial Information (formerly the Chief Directorate: Surveys and Mapping) of the Department of Rural Development and Land Reform. The bottom of the first layer was off-set to 30 m below this surface to represent the shallow weathered aquifer, with the deeper fractured aquifer (i.e. second layer) extending to 300 m below the surface.

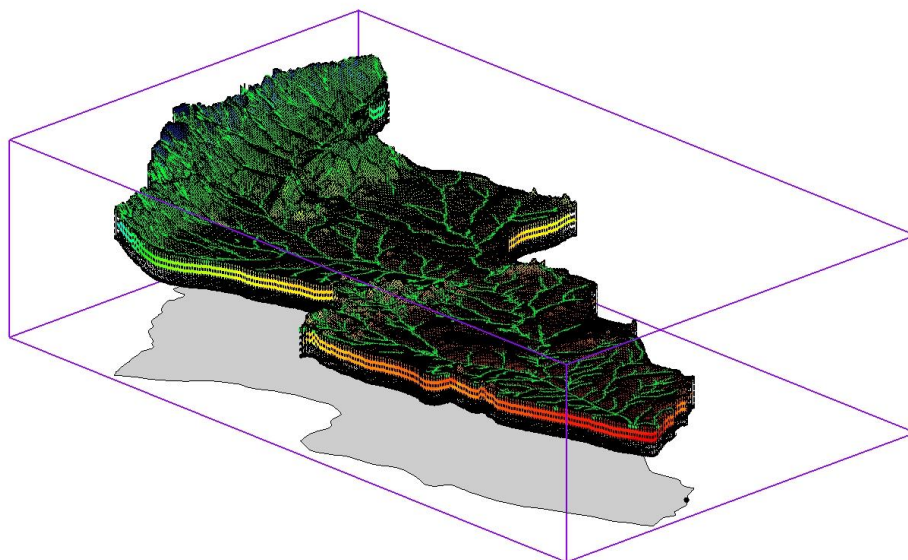


FIGURE 4-1 MODEL DOMAIN SHOWING DRAIN NETWORK

The numerical model was divided into three zones based on the geological outcrops mapped in the area – the Magaliesberg quartzite (Vp) in the south, the ultramafic BIC (Vr) in the middle, and the granitoid BIC (Mle) in the north (Figure 4-2). These zones were considered to extend vertically downwards to the model base for the purposes of the model.

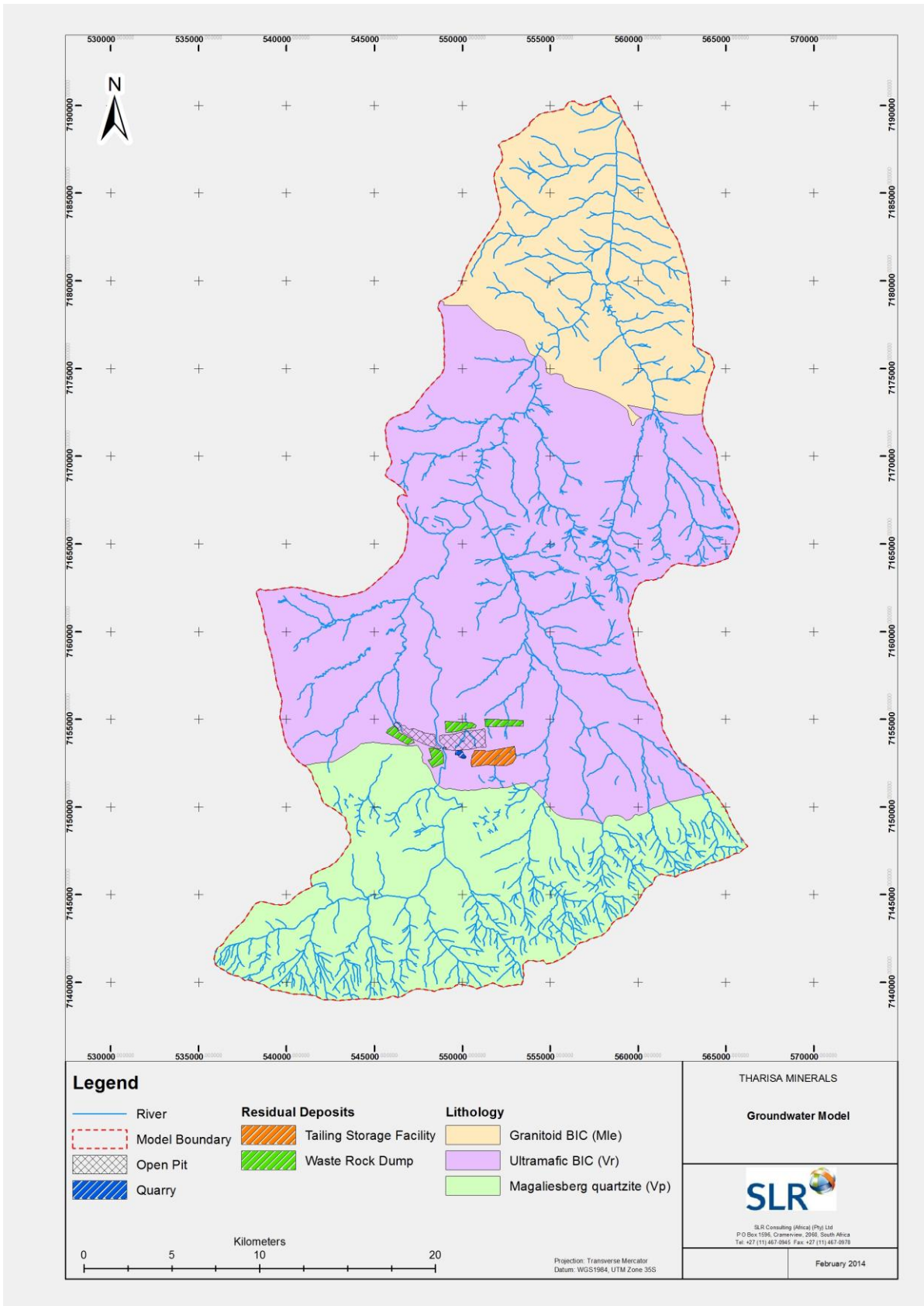


FIGURE 4-2: SPATIAL EXTENT OF MODEL BOUNDARY WITH HYDRAULIC CONDUCTIVITY ZONES (I.E. GEOLOGICAL UNITS)

4.2.2 FINITE DIFFERENCE CONTAMINANT TRANSPORT MODEL

The same finite-difference flow model was used as a basis for the contaminant transport model; i.e. the 3-dimensional, regional two-layer steady-state groundwater model. However due to the intensive computer calculations required for each grid dimension (cell) and associated computer resource limitations the model grid was adapted to be coarser away from the Tharisa Mine site, with decreased cell sizes (more refined model grid) towards Tharisa Mine. The model domain was discretised into a 133 X 114 grid block refined mesh (approximately 33.4 x 56.8 km in extent). The Z dimension was set at 2000 m. The top elevation of the model was based on the 25 m x 25 m digital elevation model. The bottom of the first layer was off-set to 30 m below this surface to represent the shallow weathered aquifer, with the deeper fractured aquifer (i.e. second layer) extending to 300 m below the surface.

Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 50 m) 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 from the average groundwater velocity vector only. Therefore, all impact assessments of potential pollution sources on the groundwater quality are considered to be conservative.

4.2.3 BOUNDARY CONDITIONS

The chosen model domain extended over the entire quaternary catchment A21K. This was due to the lack of information regarding groundwater flow boundaries within the quaternary catchment, and also to ensure that the model boundaries were sufficiently far from the mining area of interest. Due to the established correlation between groundwater elevations and surface topography, surface water catchment boundaries were considered to also represent groundwater divides and were incorporated as no-flow boundaries into the numerical model. The outer boundary of the model domain coincided with surface water catchment boundaries and was implemented in the model as a first-type (or no-flow) boundary condition.

The initial groundwater levels (i.e. starting heads) for the model domain were set at 16 m below ground level, which is the mean groundwater level reported by the Department of Water Affairs for catchment A21K (GRAII dataset). Vertical anisotropy (i.e. K_H/K_V) was set to 1.5.

4.2.4 SOURCES AND SINKS

4.2.4.1 Groundwater Recharge

Groundwater enters the model domain as direct recharge from rainfall or as seepage from the TSFs or other facilities. According to the GRA II datasets average recharge for the entire catchment is about 28 mm/a, or about 0.000077 m/d. Higher recharge values were assumed for the higher-lying areas in the

southern part of the catchment. Final, calibrated recharge values used for the model are shown in Table 4-1 below:

TABLE 4-1 RECHARGE VALUES USED IN THE NUMERICAL MODEL

Unit	Recharge (m/d)	Recharge (mm/a)	Recharge (% MAP)
Magaliesberg Quartzite (Vp)	0.0002	73.0	11.2
BIC (Vr)	0.00015	54.75	8.4
Granite (Mle)	0.000077	28.1	4.3

4.2.4.2 River Courses

Water leaves the model domain via numerous perennial (e.g. Sterkstroom River) and non-perennial rivers and streams. This imposes a constraint on the model in that groundwater can only discharge into rivers /streams (described using MODFLOW's drain package) with no water transfer occurring from the rivers / streams into the model domain. It was considered that the alternative – modelling rivers in the model domain which could both discharge and receive water – would not be supported by the available data. Drain locations were based on GIS derived polylines for the catchment. The elevation of each drain cell was aligned with the height of the model DEM at that point and an incision of 2.5 m below the surrounding topography was assumed. A drain conductance of 0.8 m²/day per meter of drain length was assigned.

4.2.4.3 Pits

The pit shells representing the final extent of the open-pit mine workings (pit shells) were provided by Tharisa in September 2012 as .dxf files. Two pits are planned, an east pit and a west pit (Figure 4-5). A pit depth of 230m was assumed. Given that the Tharisa plans to mine to an average depth of 180, up to a maximum depth of 200m, the predicted cone of depression presents a worst case scenario. The pit shells were integrated into the model domain for the predictive simulations using MODFLOW's drain package which prevents the possibility of artificially discharging water back into the model domain. A hydraulic conductance of 0.5 m²/day per m² was assigned to the drain polygons representing the pits. It is assumed that any groundwater entering the pits is removed (i.e. pumped out) and that the pit bottoms represent therefore the lowest drainage elevation. The model assumed a “worst-case scenario” – i.e. that no backfilling of the pits would occur - and groundwater inflows are therefore in reality likely to be lower than the modelled values.

4.2.4.4 TSF, WRDs and Quarry

The TSF, WRDs and quarry were incorporated into the model domain for the predictive simulations as single recharge polygons with a unit source concentration for sulphate (SO₄). Following the precautionary principle, a uniform leakage rate for the maximum (final) footprint area for the TSF, WRDs and quarry was used as the recharge estimate of the footprint areas and incorporated into the transport model. It is indicated that the TSF will not be lined with an artificial liner. Approximately 2 m of clay-rich

soil (residual clay “black turf” soil) underlies the TSF site (Epoch, 2012b). This may act to inhibit downward movement of leachate, but such soils are prone to swelling and cracking and more work on the likely leachate movement may be needed, particularly if compaction of the clay soil is done. The Epoch report (Epoch, 2012b) also states that the black turf has a “shattered and slickensided structure” and is potentially highly active – and may therefore have preferred pathways for leachate movement. Furthermore, The Department of Water Affairs and Sanitation (DWS) has recommended that the in-situ clay layer beneath the TSF walls (consisting of waste rock) be removed so as to avoid differential settlement of the walls and to improve the overall stability of the TSF (Epoch, 2012b).

Epoch (2012b) have provided estimates of downward flux of leachate through the TSF footprint using the 2-D finite element modelling package Geo-Slope, based on a variety of scenarios (Table 4-2 below):

TABLE 4-2 SCENARIOS FOR TSF SEEPAGE

Analysis	Operational toe-drain	Operational seepage cut-off trench	Type of pool (normal / flooded)	Volume of clay removed beneath walls	Seepage into the basin of the TSF (m³/s)
1	Yes	No	Normal	Outer third	2.91 x 10 ⁻⁴
2	Yes	Yes	Normal	Outer third	5.12 x 10 ⁻⁵
3	No	Yes	Normal	Outer third	5.20 x 10 ⁻⁵
4	No	No	Normal	Outer third	4.49 x 10 ⁻⁴
5	Yes	No	Flooded	Outer third	4.13 x 10 ⁻⁴
6	Yes	Yes	Flooded	Outer third	5.42 x 10 ⁻⁵
7	No	Yes	Flooded	Outer third	5.6 x 10 ⁻⁵
8	Yes	Yes	Normal	Full key	5.13 x 10 ⁻⁵
9	Yes	Yes	Normal	Outer and inner third	5.13 x 10 ⁻⁵

A mean seepage rate of 0.0000748 m/d for both the TSF and the WRDs was used for groundwater modelling purposes. This is a higher rate (i.e. more conservative) than the seepage scenarios shown in Table 4-2 above. The modelled seepage rate is very similar to the average “natural” recharge calculated for the catchment as a whole of 0.000077 m/d. The seepage rate for the quarry was assumed to be 0.00015 m/d, the same as the geological unit in which it is located.

A continuous source strength (i.e. concentration) was assumed for the operational phase of the mine (i.e. the first 18 years of operation). The source concentration was reduced by half for a post closure phase (extending to 150 years after mining started) due to the cessation of deposition and possible closure measures (e.g. capping or re-vegetation).

4.2.4.5 Waste Rock Dumps

It is assumed that most leachate arising from the waste rock dumps will be captured by the water flowing into the open pits during mining, where it will become part of the mine's dirty water cycle. Footprint areas of the WRDs, two on the west side of the Sterkstroom and to the south of the west pit, and two on the east side of the Sterkstroom to the north of the east pit, are shown below (Table 4-3).

TABLE 4-3 FOOTPRINT AREAS OF WRDS AT THARISA

	Eastern WRD	Central WRD	Western WRD	North Eastern WRD
Footprint	78.022 Ha	65.434 Ha	65.005 Ha	86.641 Ha

Some of the waste rock material will be used in the construction of the containment walls for the TSFs and for other facilities such as roads, with most of the rest being used as pit backfill material. Any waste rock remaining after mining ceases and the pits have been backfilled will be landscaped in-situ and vegetated (SLR 2012c).

During mining operations, when waste rock deposition is occurring, it is likely that most of the leachate from the west and central WRDs will be captured by the west pit. Leachate arriving at the west pit will become part of the mine's dirty water circuit, and will not be discharged into the environment (SLR 2012c). There is a likelihood however that some leachate from the central WRD will also discharge into the Sterkstroom, which is down-gradient of, and approximately 150 m from, the eastern edge of the central WRD. This flux will depend heavily on local subsurface hydraulic properties. Most leachate from the eastern WRD is likely to be captured by the east pit, but some is likely to move northwards with the prevailing groundwater flow in the same direction as leachate from the TSFs and the quarry. The clay-rich soil on which the WRDs are sited is expected to retard the downward migration of contaminants (SLR 2012c). New leachate generation from the WRDs will cease from those portions that are removed at the end of mining, but any leachate plumes will remain, with concentrations of leachate remaining in the subsurface diminishing with natural groundwater flow (dilution and dispersion). If portions of the WRDs remain once mining ceases, then leachate plumes from these will extend in the direction of groundwater flow, modified by the compacted soil lining of the WRDs and any cap or cover that is used.

4.2.4.6 Mined out workings

Existing information indicates that a portion of the north east waste rock dump lies above mined out underground workings. The depth of these workings is expected to be >300m below surface. These mine workings have not been taken into account in the groundwater flow and transport model, since the hydraulic properties of the rock and therefore the capacity of the aquifer to transport pollutants is likely to decrease exponentially with depth. Most groundwater flow will occur well above the mine workings, and it is therefore unlikely that the presence of mined out underground workings below and in the vicinity of the north east waste rock dump would influence any pollution plume potential from this facility to an appreciable extent.

4.2.5 HYDRAULIC PARAMETERS

Catchment A21K is underlain by rocks of the Magaliesberg Quartzite in the south, Bushveld Igneous Complex (BIC) in the central part of the domain, and Granite in the north. The groundwater model consisted of two layers, each divided into three zones based on the surface outcrop of the three lithologies. Geological contacts were assumed to be vertical, in order to minimise complications with grid set-up. Typical hydraulic properties were initially retrieved from literature values, and from the previous groundwater model (WGC, 2007).

Effective porosity values were conservatively specified as 0.3 for the model domain. Porosity values affect only the transport model and do not influence the outcome of the steady-state flow model.

4.3 MODEL CALIBRATION

Using the 12 groundwater level data points (observation boreholes) in the vicinity of the mine (Table 4-4), a steady-state calibration of the groundwater flow model was performed.

TABLE 4-4 BOREHOLES USED IN THE MODEL CALIBRATION

Site Name	Date measured	Water Level (mbgl)	X Coordinate*	Y Coordinate*
13a	2012/04/19	12.12	27.505910000	-25.752550000
Trh17a	2012/05/22	5.36	27.493150000	-25.749950000
Trh17b	2012/04/19	7.50	27.493110000	-25.749880000
Trh47a	2012/04/19	7.40	27.477460000	-25.739650000
Trh52b	2012/04/19	9.85	27.515220000	-25.749210000
Trh52c	2012/04/19	9.80	27.515510000	-25.748960000
WGC11	2012/05/22	13.07	27.523450000	-25.736650000
WGC12	2012/05/22	14.29	27.516310000	-25.737500000
WGC15	2012/05/22	13.0	27.525140000	-25.737670000
WGC2	2012/05/22	2.72	27.497880000	-25.741920000
WGC3	2012/02/27	2.13	27.505520000	-25.744300000
WGC8	2012/01/31	9.89	27.476910000	-25.734870000

*Coordinates in Universal Transverse Mercator Zone 35S

The model was run with the initial conditions and the hydraulic conductivities adjusted using sensible boundaries and the automatic MODFLOW calibration package PEST until a best fit between measured and computed heads was achieved. A reasonable correlation coefficient R^2 between modelled and observed values of 83% with a Root Mean Squared Residual (Head) of 4.94% was achieved for the steady-state calibration of water levels (Figure 4-3). Despite all efforts it proved difficult to obtain a good correlation between observed and modelled heads for all of the observation boreholes. Since the observation boreholes are mainly located near to areas of active mining it is probable that water levels in at least some of them are affected by dewatering activities. The slight rise in groundwater levels seen in some monitoring boreholes since 2008 (Figure 3-2) may imply that natural groundwater levels in the area

are still establishing themselves following abstractions, earlier mining activities, or other activities that are not yet documented – but the exact cause of this observation is not known.

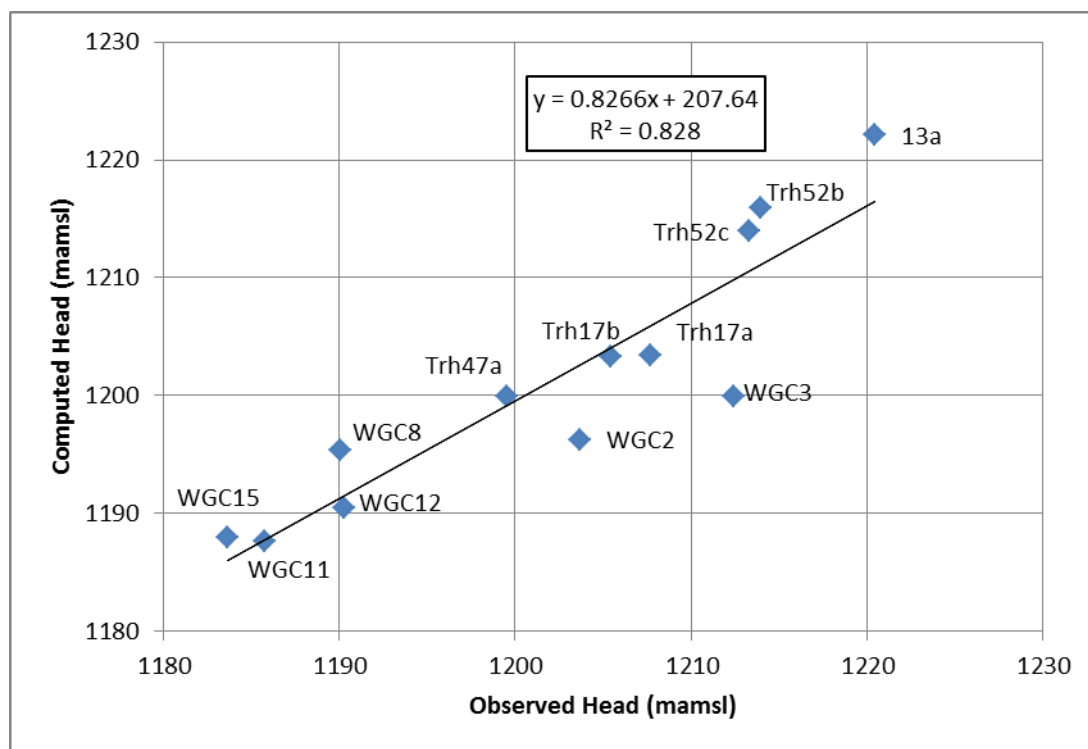


FIGURE 4-3: CORRELATION BETWEEN OBSERVED AND MODELED GROUNDWATER HEADS (STEADY-STATE CALIBRATION)

The corresponding calibrated hydraulic conductivity values (Table 4-5) compare reasonably well with the values obtained from the literature review).

TABLE 4-5: SUMMARY OF CALIBRATED HYDRAULIC CONDUCTIVITY VALUES

Unit	Upper (weathered) Layer, m/d	Lower (fractured) Layer, m/d
Magaliesberg Quartzite (Vp)	1.0	0.006
BIC (Vr)	1.4	0.006
Granite (Mle)	1.0	0.002

The regional steady-state groundwater contours (Figure 4-4) are, as expected, closely related to the topography, and groundwater flows from higher lying ground towards lower lying areas, where it discharges into the drains / rivers.

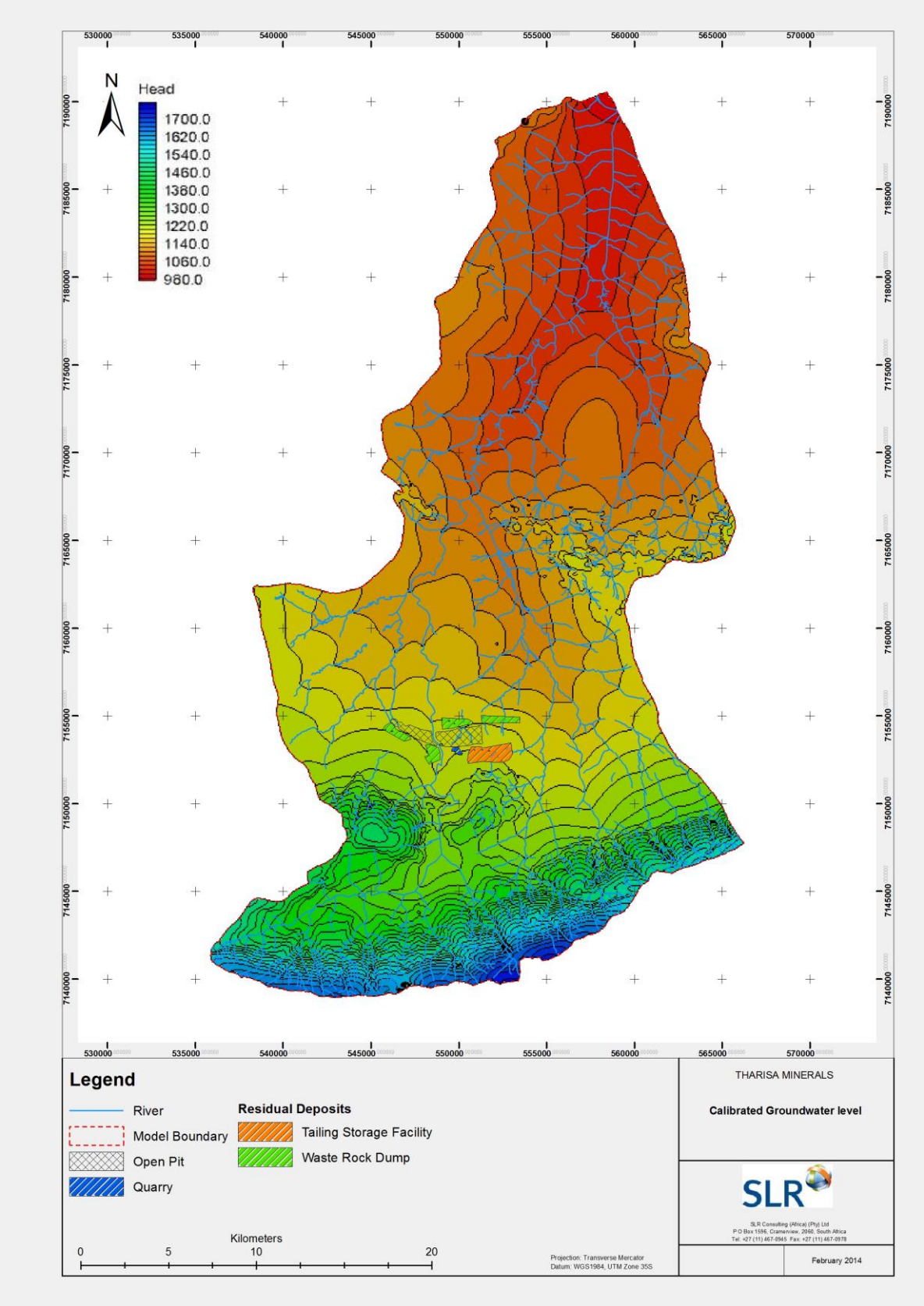


FIGURE 4-4: MODELED GROUNDWATER CONTOURS FOR THE MODEL DOMAIN

4.4 PREDICTIVE SIMULATIONS

The estimated inflow rates are based on annual average (steady-state) groundwater inflows into the pits and do not account for direct rainfall (only the groundwater recharge component thereof) and surface run-off into the pit or for potential seepage from a perched aquifer. Any steady-state groundwater model is likely to overestimate groundwater inflows, as it does not account for the increasing dewatering of the aquifer with time due to pit inflows and hence reduced yields. However, in the absence of groundwater level measurements over time (e.g. hydrological year) the chosen approach appears justified.

Despite all efforts to account for data uncertainties, the values presented are intrinsically of low to medium confidence. Groundwater inflows into mining voids are generally dependent on the excavation (including potential blasting) method as well as on other mining related disturbances of the natural aquifer system (e.g. compaction), and are therefore difficult to predict based on the hydraulic properties of the undisturbed aquifer system. The model predictions should therefore be verified once sufficient information on pit inflow rates is available. Predicted inflow rates for later years of mine development can significantly be improved by observation data from earlier years and subsequent updates of the groundwater model. As a result, any numerical groundwater model should be regarded as a management tool subject to continual improvement thereof as more data becomes available.

Tharisa mine currently uses between 3 064 m³/month (wet season) and 6 347 m³/month (dry season) of makeup water, sourced from a wellfield (SLR, 2014). This is the equivalent of about 1.2 L/s (wet season) and 2.4 L/s (dry season), if pumping continuously. These volumes are only a small proportion of the anticipated total groundwater inflows into the pits at full depth, and have not been modelled separately. At full pit depth, when groundwater inflows into the pits are at their highest, it may not be necessary to abstract water from the wellfield at all.

4.4.1 ESTIMATED PIT INFLOW RATES

Pit inflows were calculated by running the model before and after incorporating the pits as drains, and subtracting the pre-pit model run from the model run incorporating the pits. It is assumed that all water draining into the pits is pumped out and that this does not contribute to recharge locally. The predicted modelled groundwater inflow rate for both pits combined is **3900 m³/d, or about 45 L/s**. This can be divided into approximately 2053 m³/d for the east pit and 1847 m³/d for the west pit. This compares with total inflow rates of 34.1 L/s calculated for the previous pit shells (WGC, 2007). Dewatering associated with the open pits is likely to lead to a cone of depression extending about 0.5 to 2.0 km from the pit boundary (Figure 4-5) elongated in a northerly direction with the regional groundwater flow. These calculations do not take into account the effect of partially backfilling the pits as mining progresses, which is likely to reduce inflows of groundwater into the remaining open parts of the pits, and should therefore be seen as a worst-case scenario.

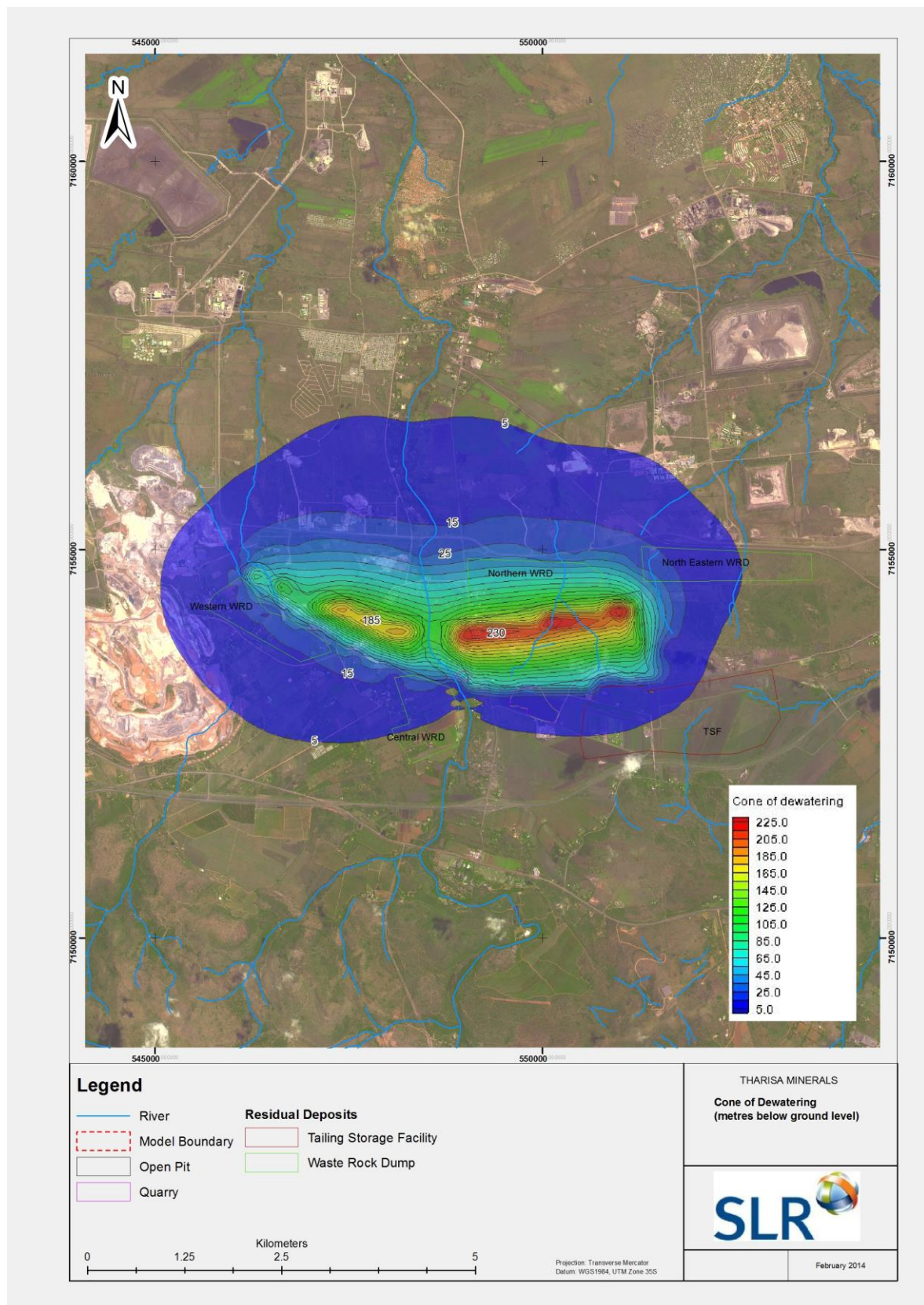


FIGURE 4-5: GROUNDWATER CONTOURS AROUND THE PITS

The figure above (Figure 4-5) shows modelled groundwater contours around the pits when they are at full depth and being dewatered. The water levels refer to both the upper weathered and the lower fractured aquifers. Contour values are in metres below ground level. The drawdowns close to the pits are likely to be substantial but reduce to within a few metres at a distance of 0.5 to 1 km from the pits. It can be seen that there is a stretch of the perennial Sterkstroom River approximately 2 km long that falls within the cone of depression. For this stretch of the river, groundwater flow to the river (i.e. baseflow) is likely to be reduced or stopped altogether and the river could lose some water to the aquifer along this stretch (but is likely to continue to flow). The exact volume of water lost will depend on the hydraulic characteristics of the river bed as well as the presence of any perched groundwater or surface water (e.g. the full quarry) within the cone of depression which could continue to contribute baseflow in places or at certain times (e.g. following rainfall). This volume has not been calculated due to uncertainties about the various parameters, but could be estimated by measuring river flows upstream and downstream of the mining area. Perched groundwater and poor contact between the two aquifers (upper and lower) in places could also leave the upper aquifer partially or fully saturated whilst the piezometric surface in the lower aquifer drops, moderating the impact on shallow third-party boreholes in the cone of depression and on the river. As a worst-case scenario it should be assumed that all other groundwater users (e.g. third-party boreholes) falling within the cone of depression, with boreholes in either the upper or the lower aquifer, will be impacted by the cone of depression.

Assuming re-use or other environmentally acceptable disposal practices of the groundwater entering the pits, the environmental impacts associated with the pit inflows are primarily associated with the interception of ambient groundwater flow. The pits capture groundwater, which would have under natural conditions fed springs, discharged into the alluvial aquifers, provided baseflow to the streams/ivers, been abstracted by third-party users, or contributed to regional groundwater flow. It is expected that the potential impacts of the pit inflows on the regional groundwater flow and availability are (at full pit development):

- Highly likely to occur.
- Extending beyond the mine lease area boundary.
- Of moderate to high severity (localized) with partial loss of recharge, the interception of regional groundwater flow and a reduction in groundwater availability in the vicinity of the pits.
- Reversible (i.e. partly) over time once pit dewatering stops.

After cessation of mining operations the water level in the pits is expected to slowly rebound. It is expected that the pits will be partially backfilled (roll-over), but it is difficult to predict whether a significant pit lake will form in the remaining pit portion/s as no comprehensive pit-lake study has been performed. However, it is expected that due to evaporation exceeding inflow (evapotranspiration is predicted to be greater than rainfall and runoff) the remaining open pit portion/s will therefore always act as a sink with a zone of depressed water levels. If the pit/s are completely backfilled then groundwater levels will most likely recover to pre-mining levels over several years, and the backfill material is likely to have higher porosities and permeabilities than the surrounding rock.

4.4.2 SIMULATION OF TRANSPORT FROM THE TAILINGS STORAGE FACILITY, WASTE ROCK DUMP AND QUARRY

The impacts on the groundwater quality due to leakage from the TSFs, WRDs and quarry were evaluated with a 2-layer contaminant transport model using the internationally accepted MT3DMS code. The TSF, WRDs and quarry were incorporated into the model domain as recharge polygons. The TSF facility was assumed to be clay lined (Epoch 2012b) and a leakage rate approximately equal to the regional recharge rate was chosen to simulate the leachate flux that is expected (i.e. 0.0000748 m/d, or approximately 27 mm/a) (see Table 4-2). The quarry was assumed to have a “recharge rate” equal to the ambient rate (i.e. 0.00015 m/d). Following the precautionary principle, only advective-dispersive transport of potential pollutants without any retardation or transformation is considered. It was also assumed that no capture of the plume by the pits would occur. The impacts of potential pollution sources on the groundwater quality are therefore considered to be conservative.

A constant unit (recharge) source concentration was assumed and all initial concentrations set to zero. The calculated concentrations presented are therefore fractions of the unit source concentration and must be added to any potential background concentration. All source concentrations were specified as 100% and the modelled plumes represent therefore percentages of actual source concentrations. Since no element specific retardation or transformation is modelled, concentrations for individual elements of concern can be easily derived by multiplying given percentages with the respective source concentration for an element.

Note that Metago (2008) estimated that seepage from the Tharisa tailings facility would have a total dissolved solids (TDS) concentration of between 450 mg/L and 2500 mg/L, based on an assessment of underdrain water from similar tailings facilities. A source term concentration of 500mg/l sulphate was used in the EIA conducted by Metago (Metago, 2008).

Sulphate was modelled as the contaminant source with the initial source concentration set to 100%. A continuous source strength (i.e. 100% of concentration) was assumed for the operational phase of the mine (i.e. the first 18 years of operation). The source concentration was reduced by half (i.e. 50% of concentration) for a set post closure phase (years 19 to 150). The predicted development of the sulphate plume (due to seepage from the potential pollution sources) for the operational phase (life-of-mine expected to be 18 years) and the post closure phase (i.e. 132 years beyond operational phase) are shown in Figure 4-6 below. Structural heterogeneities (e.g. fault zones) in the subsurface unaccounted for in the model due to lack of specific information can enhance contaminant transport and partially invalidate the model predictions, and groundwater quality monitoring in the vicinity of the TSFs is therefore strongly recommended in order to verify the model predictions.

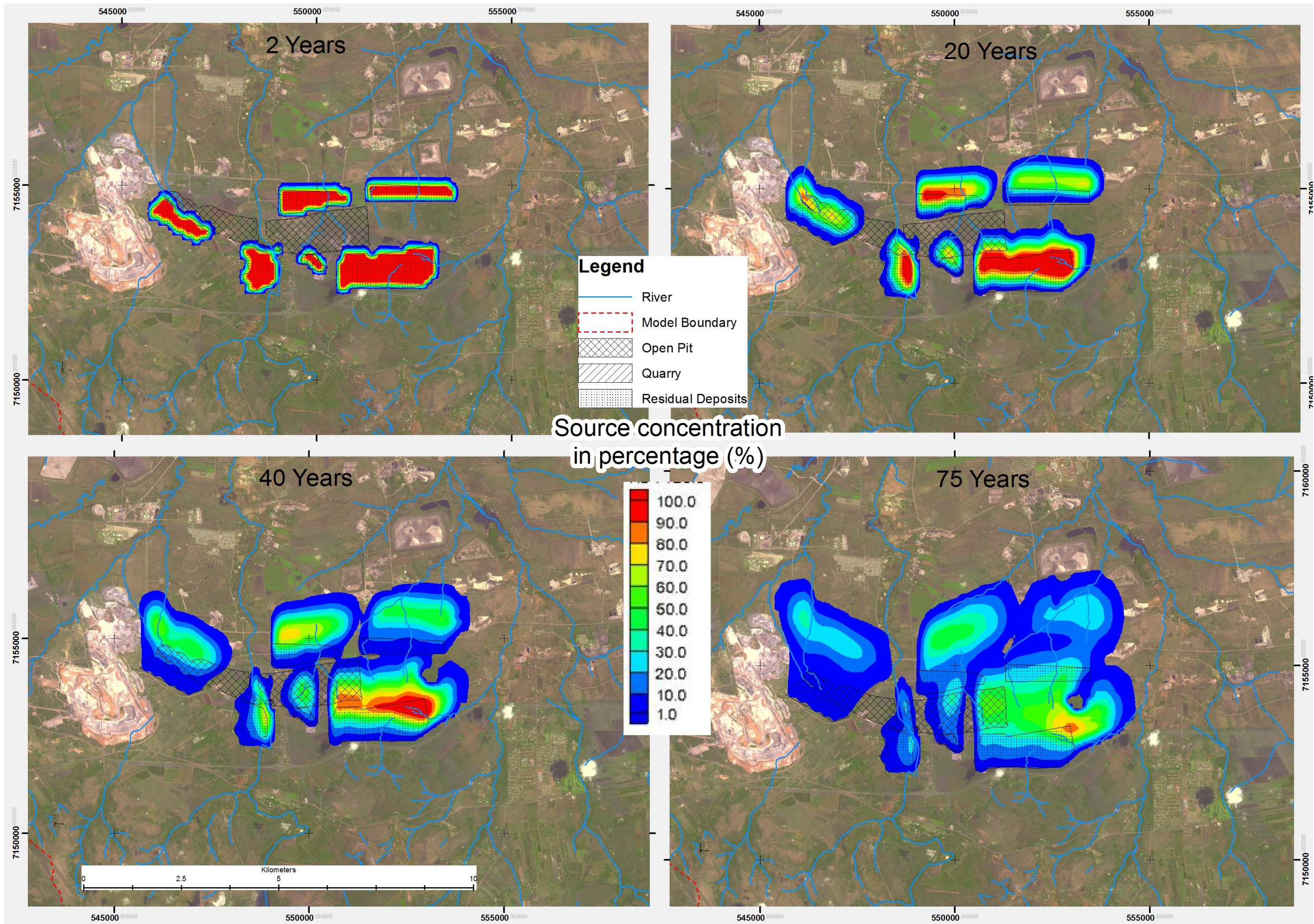
The potential of surface-groundwater interaction along drainage systems downstream of the pollution sources, due to the groundwater mounding effect below the mine residue deposits, is recognised as providing the potential for off-site migration. However, associated contaminant concentrations are expected to become quickly diluted along the surface water courses.

The dominant spreading direction of the potential pollutants from the residual deposits (i.e. TSF, WRDs and quarry) is predominantly in a northerly direction. The simulated plumes emanating from the residual deposits show a comparatively fast migration rate associated with large distance migrations in the aquifer in accordance with their (assumed) higher seepage rates.

The plumes from the TSFs migrate northwards and after 2 years extend around 100 meters, after 20 years around 700 meters, and after 40 years around 1200 meters from their respective footprints and reach the northern WRD. Pollution of both the northern WRD and TSF has a cumulative impact on the plume migrations. After 150 years the TSF plume migrates northwards together with the associated northern WRD's plume. The source concentration after 150 years is less than 30% of the original source concentration associated with the TSFs. It must be noted that the TSFs plume migrate over the extent of the open pit mine and will be intersected by the cone of dewatering during mining operations. It is likely that the seepage plumes emanating from the residue facilities reach surface watercourses via groundwater baseflow within the first few years of deposition of waste rock and tailings, which provides the potential for off-site migration. However, contaminant concentrations are expected to become quickly diluted along the surface watercourses.

The plumes from the WRDs migrate northwards and extend between 600 and 800 meters after 20 years, between 1200 and 1500 meters after 40 years, and more than 3000 meters after 150 years from their respective footprints. After 150 years the source concentration associated with the most westerly WRD is less than 10% and the northern WRD is less than 40% of the original source concentration. The higher percentage associated with the northern WRD can be attributed to the cumulative impact from the TSFs. The simulated plume emanating from the residual deposits will be partially captured by the open pit and cone of dewatering.

It is likely that the seepage plume emanating from the residual deposits reaches surface water drainages via groundwater baseflow, which provide the potential for off-site migration (if surface runoff or shallow groundwater flow is not contained). The groundwater contamination plume will not be contained within the mining area. The proximity of surface water drainages could considerably exaggerate the spreading of potential contaminants via surface streams and run-off in the valley bottoms. Over time, contaminant plumes are likely to migrate to and discharge into the streams and rivers after mine closure. Off-site migration via surface flow might occur earlier if contaminant plumes are not contained / intercepted. However, contaminant concentrations are expected to become quickly diluted along the surface water courses.



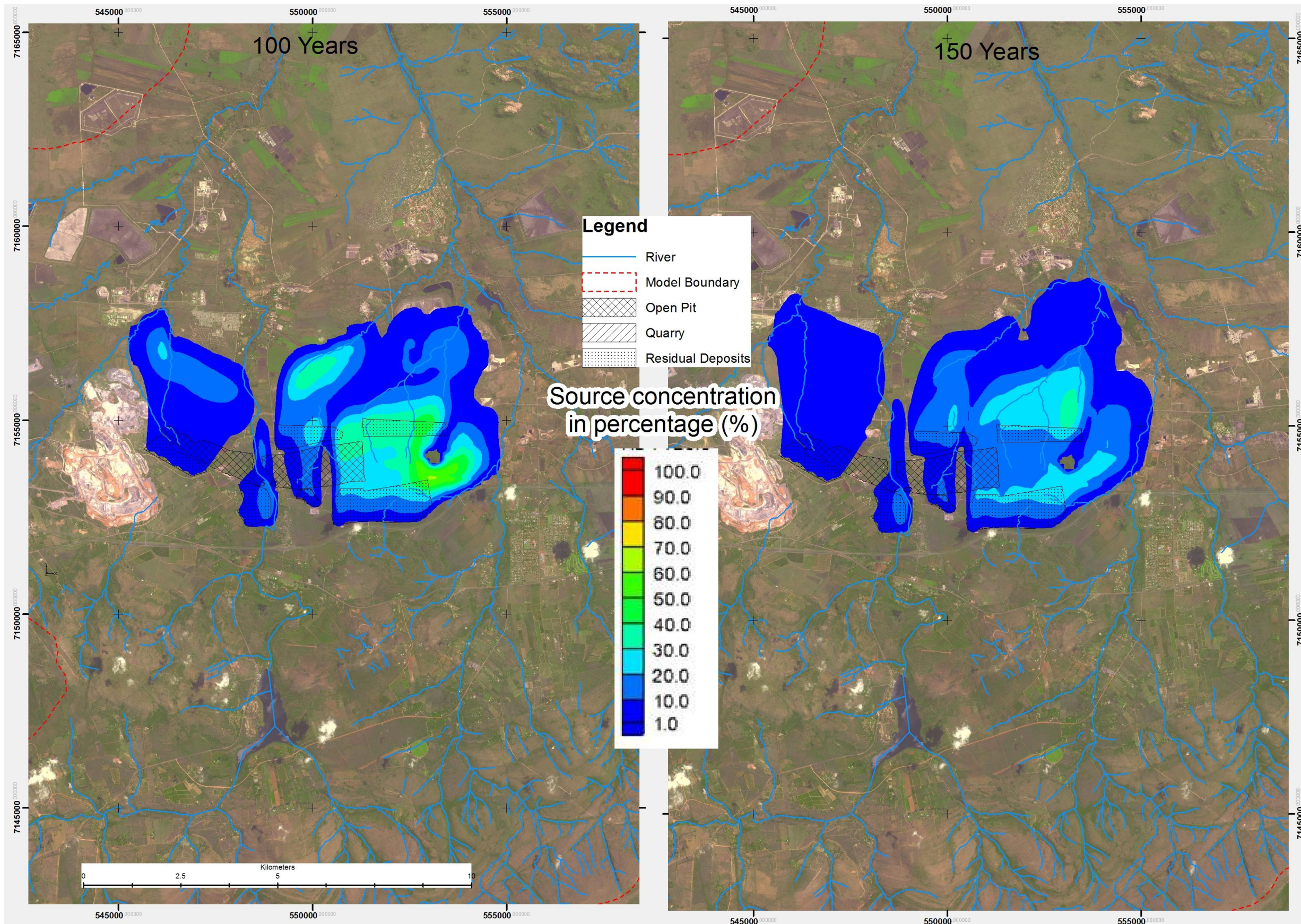


FIGURE 4-6 SO₄ PLUME ASSOCIATED WITH THE TSFS, WRDS AND QUARRY (SCALE IN % OF UNIT CONCENTRATION)

4.4.2.1 HERNIC QUARRY

Hernic quarry is located on the western edge of the eastern pit, and will most likely be eventually destroyed once the eastern pit reaches its full development. The western-most edge of the quarry is situated about 20 to 30 metres from the Sterkstroom River at its nearest point, and the quarry is about 16 m deep at its deepest point. The quarry is used as a water overflow or storage facility by the mine, including as a holding facility for water that has been polluted by mine activities. Actual water levels in the quarry fluctuate according to the mine's requirements, rainfall, and other factors, but are thought to be below the Sterkstroom River bed elevation for most or all of the time.

The quarry has been incorporated into the numerical groundwater flow and transport model as a continuous recharge source at ground level (a conservative approach), but in reality the flow of water from the quarry (and associated contaminant flux) will depend on the difference between the water level in the quarry, the ambient groundwater level, and the level of water in the Sterkstroom River. When (or if) the quarry water level exceeds that of the river (or the ambient groundwater level) then water (and associated contaminants if present) will slowly percolate from the quarry into the river and into the ambient groundwater (Figure 4-7). When the water level in the quarry is lower than the water level in the river or aquifer, river water and ambient groundwater can be expected to leak into the quarry at a rate determined by the difference in the two levels and the hydraulic properties of the intervening material (particularly the river bed material hydraulic conductivity) (Figure 4-8). The water level in the quarry is expected to vary due to mine-water storage requirements; and the river and ambient groundwater levels are also not constant. However, the water level in the quarry is thought to be always or nearly always below the level of water in the Sterkstroom River. This is confirmed by the presence of a dry 7 m deep borehole between the river and the quarry observed in November 2013. The modelled situation showing a plume extending from the quarry assumes that the quarry is continuously full and leaks leachate to the surrounding groundwater. This can be considered a worst-case scenario. The hydraulic properties of the rock between the river and the quarry are likely to be dominated by fractures, weathered zones or other discrete features which may give rise to different properties compared with the bulk properties assumed for the model as a whole. All of this suggests a relatively complex and time-dependent relationship, with the additional issues of dewatering of the nearby pits and the ultimate destruction of the quarry to consider. Local monitoring of groundwater levels and quality in the vicinity of the quarry, but particularly to the north of the quarry (direction of anticipated plume development) and between the quarry and the Sterkstroom River, are recommended. This will allow for early warning of adverse impacts, help to update the conceptual groundwater model and inform environmental planning.

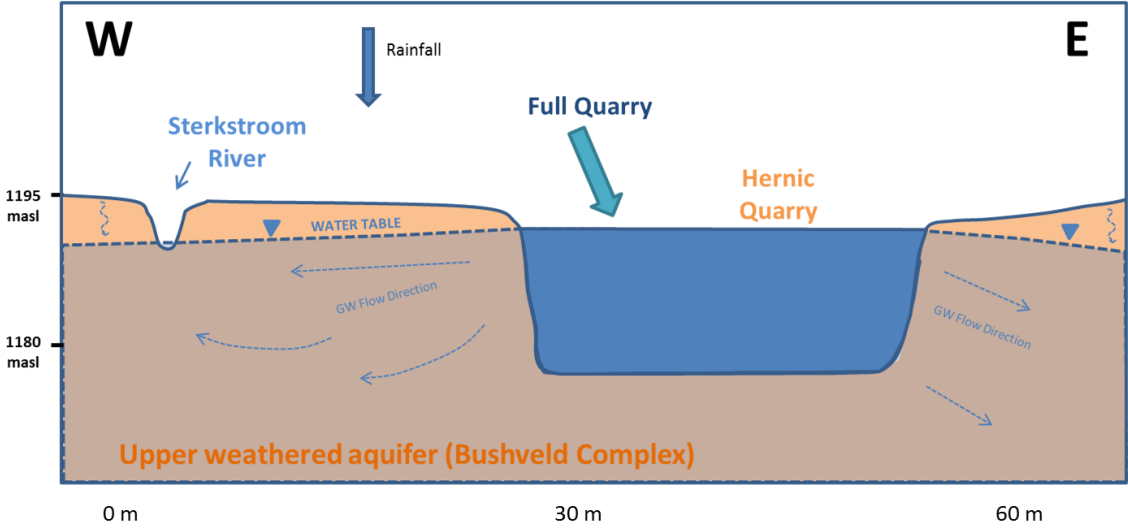


FIGURE 4-7 GROUNDWATER FLOW WHEN QUARRY FULL

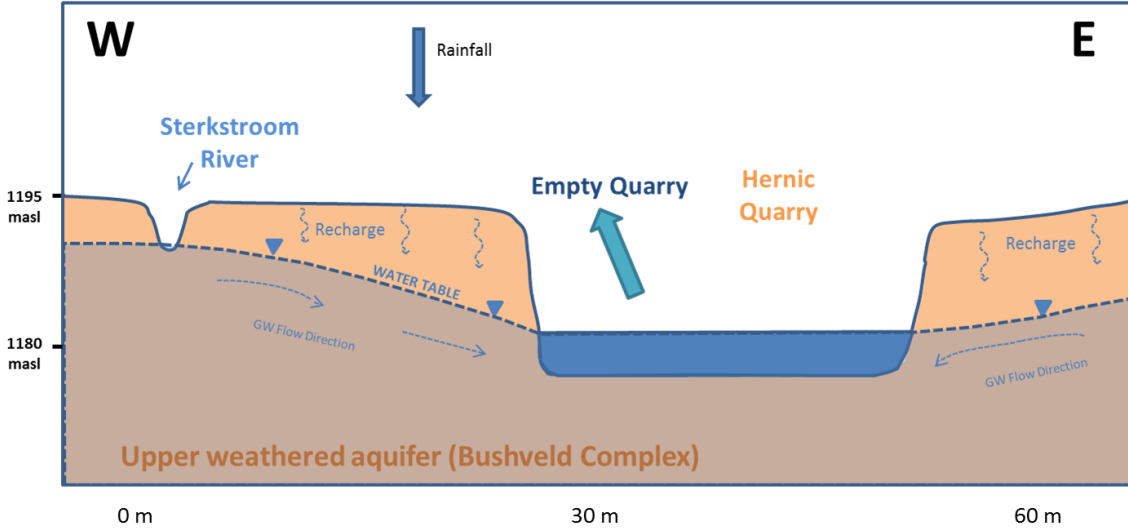


FIGURE 4-8 GROUNDWATER FLOW WHEN QUARRY EMPTY

A preliminary analytical calculation (Figure 4-9) shows that the flow of contaminated water from Heric quarry to the river is unlikely: It can be assumed that river bed hydraulic conductivity is 0.01 m/d, and the shallow aquifer conductivity is 0.1 m/d (Epoch, 2013a). Using the expression $v = Ki$ (specific discharge), water from the Sterkstroom is likely to take $0.5 \text{ m}/(0.01 \times 1)$ or about 50 days to move through the river bed (a), plus $20 \text{ m}/(0.1 \times 0.35)$ or about 571 days to move from the river bed to the quarry (b).

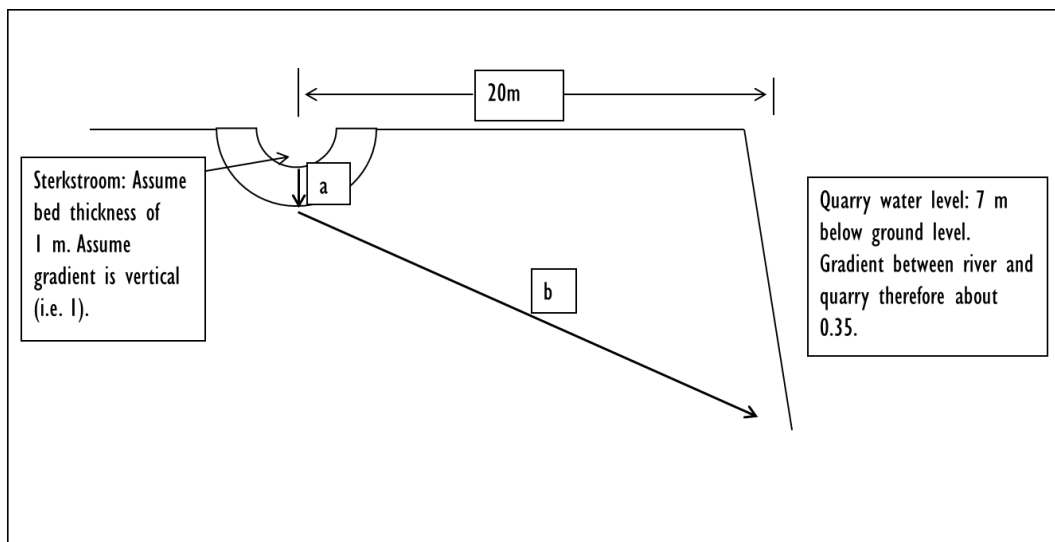


FIGURE 4-9 CONCEPTUAL FLOW FROM STERKSTROOM TO QUARRY

These calculations are highly sensitive to the exact groundwater gradient, and to the hydraulic properties of the river bed and aquifer material. However they do indicate that, based on these assumptions, movement of water from the Sterkstroom to Heric quarry is likely to be of the order of hundreds of days. Movement in the other direction is likely to be slower, since the gradient between a full quarry and the river will be smaller – even in those circumstances when a full quarry exists. All of this assumes that preferential flow (e.g. through fractures) does not occur – if such pathways do exist then flow could take tens of days or less. For this reason a continuation of the current mine monitoring programme that logs salinity and dissolved species both upstream of the mine and downstream of the mine is endorsed.

4.4.2.2 Impacts associated with the TSFs, WRDs and Quarry

A localised impact on the groundwater flow is expected as a result of the mound effect due to continuous leakage from the potential pollution sources. The associated impacts on the **groundwater flow** are:

- Highly likely to occur.
- Localised mounding of groundwater within site boundaries.
- The mound effect dissipate over time once deposition stops during the post closure phase, and
- Of minor to moderate severity that may result in enhanced surface-groundwater interaction for streams in the vicinity of the potential pollution sources.

The potential impacts of the pollution sources on the **groundwater quality** are:

- Highly likely to occur.
- Extending beyond mine lease boundaries for the groundwater regime and if surface run-off from potential seeps in drainage systems is not contained. This spatial extent is expected since the pollution sources are located near the boundary of the mine lease area and a synthetic TSF liner is not planned. The plume is expected to have migrated about 2.5 km down-gradient of the source after 150 years, with the edge of the plume being between less than 10 % of the source concentration (Figure 4-6).
- Long-term, with moderate increases of contaminant concentrations beyond mine closure.

The intensity of the impact is likely to be a moderate to high deterioration in the ambient groundwater quality if mitigation measures are not implemented.

4.4.3 MONITORING REQUIREMENTS

It is recommended that a monitoring programme should be established (that should include the drilling of new monitoring boreholes, to replace those that will fall within the new pit, WRD or TSF footprints) to assess the lowering of the groundwater levels associated with dewatering of the open pits and to assess potential contamination emanating from the TSFs, quarry and WRDs. Monitoring borehole locations should favour the areas down-gradient (i.e. to the north) of the pollution sources, since this is where the likely plumes are anticipated. However, water level and water quality monitoring upstream of the mine and mine facilities is also recommended so that water quality and water levels that are not affected by the mine development are also recorded. An important monitoring location, with an existing borehole that is already part of the mine's monitoring programme, is the small area between the quarry and the Sterkstroom River.

The boreholes should generally be drilled to a depth of 60 metres below ground level (deeper in close vicinity of the open pits) and completed according to best practice (e.g. screened casing in areas of water intersection, sanitary surface seal and lockable steel caps). New boreholes should be incorporated into the mine's existing groundwater monitoring programme. Tharisa mine conducts its own water monitoring programme at present. The monitoring borehole recommendations are thus restricted to suggestions only – and may already be part of the current monitoring infrastructure.

4.4.4 DEGREE OF CONFIDENCE IN MODEL PREDICTIONS

The impact predictions are based on numerical model results, the precision of which depends on the chosen simplifications as well as the accuracy of input parameters like hydraulic conductivities, porosities or source concentrations. And sensitive model parameters like porosities or source concentrations for the transport model were chosen conservatively to present worst case scenarios of environmental impacts. The overall confidence in the model predictions, especially transport predictions, is therefore classified as low to medium.

The modelling of the pollution plumes was sensitive to dispersivity, with higher values giving larger plumes. A relatively conservative dispersivity coefficient of 30 (i.e. producing longer plumes) was used for the contaminant transport modelling.

It is important to note that a numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that are available. This implies that there are always errors associated with groundwater models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes.

5 CONCLUSION AND RECOMMENDATIONS

The main findings of the conceptual and numerical modelling work at Tharisa are summarised below:

- The Tharisa mining area falls within quaternary catchment A21K.
- The mining area is underlain by rocks of the Bushveld Igneous Complex (BIC) with a weathering depth of about 30 m. Rocks of the Transvaal Supergroup (mainly Magaliesberg Formation quartzite) outcrop to the south of the project area, and granites are found to the north.
- Two main aquifer types exist in the study area:
 - An upper, shallow weathered aquifer, and
 - A deeper fractured aquifer.
- Groundwater flows locally from the higher lying areas to lower lying discharge systems.

In general, groundwater will flow naturally from the surrounding upper weathered and underlying fractured aquifers to the open pits due to the head differences between the ambient groundwater levels and the pit depth (i.e. depth of dewatering).

- The predicted, median groundwater inflow at full pit development (combined for the two pits) is estimated at 45 L/s once the pits reach their planned total depths, and ignoring the effects of partial backfilling.
- The groundwater levels in the vicinity of the open pits will be lowered due to continual dewatering of the open pits. Boreholes within the cone of depression (an irregular zone) will be affected due to the dewatering of the open pits.
- Preferential groundwater flow zones (i.e. fractures, compartmentalization, etc.), when intersected during pit development, may result in temporally higher groundwater inflows. Due to a lack of local geological data these potential structures have not been incorporated into the numerical model.
- The potential impacts of the pit inflows on the regional groundwater flow and availability (at full pit development) are highly likely to occur and will extend beyond the mine lease area boundary.
- It is expected that water levels in the pits will recover slowly after mine closure but will not recover to pre-dewatering levels as evaporation will exceed inflows, unless the pits are backfilled. Modeling has been carried out assuming a worst-case scenario however – i.e. no capture of the contaminant plumes from the TSF / WRDs by the pits.

The shallow weathered aquifer is the first receptor of contaminants from surface sources and represents the pathway through which contaminants will migrate to surface drainages downstream of the pollution sources.

- The TSF and WRDs are likely to have an impact on ground water quality even with the drainage provisions and compaction of underlying clay-rich soil that is planned. Ideally, pollution control

facilities (e.g. storm water control dam, return water dam) would be lined to limit seepage towards the underlying shallow groundwater system.

- Heric quarry will potentially act as a source of pollution of both local groundwater and the Sterkstroom River if its water level exceeds that of the receiving environment. It has been modelled conservatively as a surface source. The actual relationship between potential contaminants in the quarry and the local environment (including the river) is more complex since it depends on the relative water levels, the hydraulic characteristics of the surrounding area (and the river bed), and pumping at the nearby pits. In reality it is considered unlikely that the water level in the quarry will exceed the water level in the river for enough time to allow pollutants to move from the quarry to the river.
- The potential impacts of the pollution sources on the groundwater quality are highly likely to occur, and will extend beyond the mine lease area.

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

- The current groundwater monitoring network should be extended to replace boreholes that will be lost due to the pit, WRDs and TSF construction.
- Current monitoring of river water quality upstream and downstream of mine operations should continue.
- Groundwater monitoring should be concentrated in the vicinity of the open pits and around the TSF, WRDs and quarry.
- Groundwater monitoring points must be located both up-stream and down-gradient of the potential impacts, but particularly between potential pollution sources and the receptors of polluted groundwater (i.e. down-gradient (north) of mine infrastructure in particular).
- The volumes of water pumped from the open pits should be recorded as accurately as possible, together with water pumped into and out of the quarry. These volumes could be used in future to further calibrate the numerical model and improve the accuracy of forward predictions, and is a highly cost-effective way of improving the understanding of the system.
- Basic environmental data collection / groundwater monitoring will give rise to a database that will potentially be very valuable in terms of improving the conceptual and numerical models, and fine-tuning the mine's environmental policy, and is highly recommended.
- The existing groundwater model should be updated once additional information on water levels, pit inflows, and contaminant source concentrations / seepage rates for the TSFs becomes available.
- A transient groundwater flow model could be constructed once groundwater levels over a (hydrological) year become available, which would result in better prediction of local water levels

6 REFERENCES

- Epoch Resources 2012a Tharisa Minerals Mine Platinum Mine Residue Disposal Facilities and Associated Infrastructure Design Report. Unpublished Report. Epoch Resources (Pty) Ltd, Johannesburg.
- Epoch Resources 2012b Seepage Assessment of the Tailings Storage Facility for the Tharisa Minerals Mine. Unpublished Report. Epoch Resources (Pty) Ltd, Johannesburg.
- Epoch Resources 2013a Tharisa Minerals Mine, Eastern Waste Rock Dump Design Report and Operating Guidelines. Unpublished Report. Epoch Resources (Pty) Ltd, Johannesburg
- Epoch Resources 2013b Tharisa Minerals Mine, Central Waste Rock Dump Design Report and Operating Guidelines. Draft unpublished Report. Epoch Resources (Pty) Ltd, Johannesburg
- MacDonald A, Davies J, Calow R and Chilton J 2005 Developing Groundwater A Guide for Rural Water Supply. ITDG Publishing, Loughborough.
- Metago 2008 Geochemical characterisation of waste materials at Tharisa Platinum Mine. Metago Environmental Engineers, Fourways, Johannesburg.
- Metago 2011 Water Quality Monitoring Report for the July 2011 quarterly monitoring exercise. Quarterly monitoring report produced for Tharisa Minerals. Metago Environmental Engineers. Fourways, Johannesburg.
- McDonald MG and Harbaugh AW 1988 A modular three-dimensional finite-difference ground-water flow model. Techniques of Water-Resources Investigations, Book 6. United States Geological Survey. <http://pubs.usgs.gov/twri/twri6a1/>.
- Parsons R and Conrad J 1998 Explanatory notes for the aquifer classification map of South Africa. WRC Report No. 116/98, Water Research Commission, Pretoria.
- SLR 2012a Water Quality Monitoring Report for the July 2012 quarterly monitoring exercise. Quarterly monitoring report produced for Tharisa Minerals. SLR Consulting (Africa) (Pty) Ltd. Fourways, Johannesburg.
- SLR 2012b Tharisa Mine Weekly Groundwater Level Report. Weekly monitoring report produced for Tharisa Minerals. 22 October 2012. SLR Consulting (Africa) (Pty) Ltd. Fourways, Johannesburg.
- SLR 2012c Conceptual Design of the Waste Rock Dumps for Tharisa. Report produced for Tharisa Minerals. SLR Consulting (Africa) (Pty) Ltd. Fourways, Johannesburg.
- SLR 2014 Hydrology Assessment for a Chrome Sand Drying Plant, changes to the Tailings Dam Design and other Operational and Surface Infrastructure changes. Report produced for Tharisa Minerals. SLR Consulting (Africa) (Pty) Ltd. Fourways, Johannesburg.
- WGC 2007 Groundwater Investigation for Tharisa Mine: Hydrogeological Report submitted to Metago Environmental Engineers (Pty) Ltd. Water Geosciences Consulting, Pretoria.
- Zheng C 1999 MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide. University of Alabama, Dept. Geological Sciences.



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APPENDIX A: GROUNDWATER QUALITY SUMMARY TABLES

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh14				TMGWCOMM01/Trh17				
	Water quality standards for Domestic use			2008	2009	2010	2013	2008	2009	2010	2011	2012
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.50	7.53	7.37	7.90	7.66	7.77	7.30	7.68	7.50
Electrical cond	<170	N/A	≤ 40	68.27	85.67	99.67	19.8	54.70	52.33	54.00	69.33	63.40
Total Dissolve	<1200	0-1000	≤ 40	640.00	696.67	711.00	133.00	333.00	362.67	366.33	455.00	438.00
Acidity as Ca	N/A	N/A	N/A	23.08	16.00	10.17	2.50	11.00	5.25	6.17	25.00	32.00
Alkalinity as C	N/A	N/A	N/A	258.00	286.67	314.67	84.00	160.00	189.33	202.67	270.00	258.00
Chloride as C	<300	0-1500	<100	35.67	49.67	57.67	2.50	10.67	12.33	14.00	18.25	18.00
Sulphate as S	<500	0-1000	N/A	94.67	116.33	114.00	7.00	35.33	35.67	32.00	58.25	48.50
Fluoride as F	<1.5	0-2	<2.0	0.05	0.05	0.20	0.05	0.05	0.05	0.20	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	11.00	17.67	19.33	0.90	10.63	10.00	9.17	7.13	6.55
Anmomia	<1.5	N/A	N/A	0.550	0.1	0.1	0.1	0.55	0.1	0.1	0.1	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.005	0.0035	0.005	0.005	0.016333333	0.018666667	0.014333333	0.005	0.005
Mercury	<0.006	0 – 0.001	N/A	0.001	0.0005	0.0005		0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	14.33	14.33	16.67	5.00	12.00	10.67	12.67	14.25	16.50
Potassium	N/A	N/A	0 – 100	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	60.00	70.00	79.00	13.00	24.00	23.00	23.67	36.75	26.50
Magnesium	N/A	0 - 500	N/A	67.33	84.33	90.67	14.00	47.67	49.67	49.67	64.50	61.50
Aluminium	<0.3	0 - 5	0 - 5	0.005	0.05	0.05	0.05	0.02	0.05	0.05	0.05	0.05
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0065	0.0095
Barium	N/A	N/A	N/A		0.035	0.0383	0.013		0.013	0.013	0.01825	0.013
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.003	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0250	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0179	0.0125
Iron	<2	0 - 10	0 - 5	0.025	0.013	0.782	0.013	0.035	0.013	0.013	0.013	0.013
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.014	0.010	0.010	0.010	0.010	0.010	0.017	0.010
Zinc	<5	0 – 20	0 - 1	0.022	0.013	0.093	0.034	0.035	0.013	0.013	0.036	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh25							Trh28	
	Water quality standards for Domestic use			2013	2008	2009	2010	2011	2012	2013	2008	2008
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	8.10	7.54	7.40	7.45	7.76	7.60	8.10	2.28	7.44
Electrical cond	<170	N/A	≤ 40	57.70	84.50	102.50	97.00	88.85	92.50	88.30	77.20	79.13
Total Dissolve	<1200	0-1000	≤ 40	402.00	681.00	669.00	553.50	625.50	644.00	576.00	648.00	606.67
Acidity as Ca	N/A	N/A	N/A	8.00	29.25	8.00	22.00	24.63	36.00	12.00	12.00	20.83
Alkalinity as C	N/A	N/A	N/A	240.00	382.00	388.00	410.00	390.00	398.00	400.00		352.00
Chloride as C	<300	0-1500	<100	17.00	20.50	22.50	20.50	18.50	19.50	19.00	25.00	19.67
Sulphate as S	<500	0-1000	N/A	54.00	97.00	89.50	76.00	87.75	86.00	75.00	86.00	81.00
Fluoride as F	<1.5	0-2	<2.0	0.05	0.05	0.05	0.28	0.05	0.05	0.05	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	7.30	12.00	14.50	9.10	7.48	10.00	11.00	13.00	9.77
Anmomia	<1.5	N/A	N/A	0.1	0.55		0.1	0.2	0.1	0.1		0.55
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.005	0.005	0.003	0.0085	0.005	0.005	0.005	0.005	0.012666667
Mercury	<0.006	0 – 0.001	N/A		0.0005	0.0005	0.0005	0.0005	0.0005		0.0005	0.0005
Sodium	<200	0-2000	0 – 70	12.00	19.50	19.00	21.50	20.50	22.00	20.00	20.00	21.33
Potassium	N/A	N/A	0 – 100	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	26.00	64.50	71.50	64.00	66.00	57.00	58.00	66.00	55.00
Magnesium	N/A	0 - 500	N/A	53.00	78.00	90.00	85.00	80.50	79.50	76.00	85.00	78.33
Aluminium	<0.3	0 - 5	0 - 5	0.05	0.005	0.05	0.05	0.063	0.078	0.116	0.005	0.005
Arsenic	<0.01	0 - 1	0 – 0.1	0.013	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Barium	N/A	N/A	N/A	0.013			0.0395	0.03725	0.0435	0.038		
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0125	0.0125	0.0125	0.0656	0.0238	0.0125	0.0125	0.0850
Iron	<2	0 - 10	0 - 5	0.013	0.013	0.013	0.055	0.057	0.013	0.013	0.013	0.022
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.010	0.020	0.010	0.010	0.010	0.010	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.013	0.069	0.013	0.055	0.073	0.028	0.031	0.013	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh36				Trh41			Trh46	
	Water quality standards for Domestic use			2009	2010	2011	2013	2008	2009	2011	2008	2009
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.60	7.40	8.60	8.30	7.18	7.10	7.70	7.50	7.50
Electrical cond	<170	N/A	≤ 40	89.30	84.75	109.85	99.00	68.20	83.00	73.60	46.97	82.27
Total Dissolve	<1200	0-1000	≤ 40	592.00	544.75	773.00	670.00	590.00	576.00	538.00	592.00	608.00
Acidity as Ca	N/A	N/A	N/A	14.00	12.63	2.50	2.50	5.25	16.00	28.00	40.83	10.00
Alkalinity as C	N/A	N/A	N/A	377.33	376.00	300.00	400.00	308.00	252.00	224.00	230.00	257.33
Chloride as C	<300	0-1500	<100	17.67	18.50	49.00	43.00	31.00	28.00	16.00	27.33	27.00
Sulphate as S	<500	0-1000	N/A	75.00	58.25	124.00	99.00	105.50	106.00	120.00	91.00	95.67
Fluoride as F	<1.5	0-2	<2.0	0.05	0.16	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	8.17	8.30	18.00	14.00	10.20	14.00	12.00	13.67	14.67
Anmomia	<1.5	N/A	N/A	0.1	0.1	0.2	0.1			0.1	0.55	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.015666667	0.0135	0.016	0.024	0.005	0.005	0.005	0.005	0.003666667
Mercury	<0.006	0 – 0.001	N/A	0.0005	0.0005	0.0005		0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	20.33	22.00	25.00	28.00	13.00	12.00	11.00	13.67	14.33
Potassium	N/A	N/A	0 – 100	0.57	0.44	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	54.33	53.75	46.00	60.00	62.50	67.00	47.00	48.33	52.00
Magnesium	N/A	0 - 500	N/A	84.00	81.00	89.50	82.00	64.50	70.00	50.00	64.33	73.33
Aluminium	<0.3	0 - 5	0 - 5	0.05	0.05	0.05	0.129	0.005	0.05	0.356	0.02	0.05
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.007	0.005	0.005	0.005	0.005	0.005		
Barium	N/A	N/A	N/A	0.044	0.042	0.038	0.0065			0.013		0.041
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0439	0.0125	0.0125	0.0125	0.0125	0.1310	0.0125	0.0125
Iron	<2	0 - 10	0 - 5	0.013	0.017	0.013	0.013	0.197	0.539	0.641	0.013	0.013
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.013	0.013	0.027	0.059	0.030	0.013	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.015	0.010	0.021	0.010	0.010	0.010	0.010	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.032	0.018	0.013	0.013	0.013	0.013	0.067	0.009	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh47					TMGWCOMM02/Trh52			
	Water quality standards for Domestic use			2010	2008	2009	2010	2012	2008	2009	2010	2011
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.40	7.31	7.20	8.70	7.60	7.32	7.47	7.33	7.57
Electrical cond	<170	N/A	≤ 40	43.00	66.95	52.00	46.50	88.90	162.27	68.43	77.43	74.93
Total Dissolve	<1200	0-1000	≤ 40	580.00	341.00	424.00	238.00	620.00	551.33	567.33	449.50	505.33
Acidity as Ca	N/A	N/A	N/A	2.50	33.25	2.50	2.50	50.00	57.33	16.00	13.63	21.33
Alkalinity as C	N/A	N/A	N/A	240.00	172.00	176.00	244.00	344.00	302.00	384.00	368.00	373.33
Chloride as C	<300	0-1500	<100	28.00	13.50	15.00	10.00	35.50	21.00	22.33	16.50	15.33
Sulphate as S	<500	0-1000	N/A	88.00	41.50	58.00	9.00	98.50	72.67	126.67	45.25	49.33
Fluoride as F	<1.5	0-2	<2.0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.19	0.10
Nitrate as N	<11	0-100	≤5.0**	18.00	2.70	3.30	0.80	13.45	0.97	1.17	0.93	2.13
Anmomia	<1.5	N/A	N/A	0.1	1		0.1	0.1	0.55	0.4	0.1	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.005	0.005	0.005	0.005	0.005	0.005	0.003666667	0.009	0.005
Mercury	<0.006	0 – 0.001	N/A	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	15.00	7.00	7.00	20.00	16.00	23.67	25.67	20.75	16.67
Potassium	N/A	N/A	0 – 100	0.25	0.25	0.25	1.10	0.25	0.90	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	49.00	27.00	37.00	4.00	55.00	80.00	95.00	74.50	69.00
Magnesium	N/A	0 - 500	N/A	68.00	32.00	42.00	55.00	81.50	46.33	57.33	57.75	57.00
Aluminium	<0.3	0 - 5	0 - 5	0.05	0.005	0.05	0.567	0.107	0.055	0.12	0.08175	0.05
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0065	0.005
Barium	N/A	N/A	N/A	0.041			0.013	0.053		0.031	0.01825	0.013
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0125	0.0360	0.0125	0.0125	0.0125	0.0570	0.0125	0.0125
Iron	<2	0 - 10	0 - 5	0.039	0.047	0.013	6.780	0.024	0.428	0.680	1.017	0.013
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.013	0.128	0.013	0.084	0.029	0.022	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.010	0.010	0.010	0.010	0.010	0.017	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.026	0.565	0.013	0.013	0.031	0.025	0.034	0.053	0.018

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh55						Trh60		
	Water quality standards for Domestic use			2012	2013	2008	2009	2010	2011	2008	2008	2009
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.40	7.90	7.57	7.90	7.80	7.35	7.88	7.53	7.67
Electrical cond	<170	N/A	≤ 40	91.33	87.20	92.90	220.00	169.00	163.50	35.30	40.23	62.50
Total Dissolve	<1200	0-1000	≤ 40	613.33	568.00	1699.33	1606.00	1554.00	1676.00	376.00	316.00	439.33
Acidity as Ca	N/A	N/A	N/A	57.33	8.00	62.67	5.25	2.50	30.00	40.00	13.17	7.25
Alkalinity as C	N/A	N/A	N/A	396.00	400.00	280.00	310.00	300.00	306.00	220.00	200.00	222.67
Chloride as C	<300	0-1500	<100	42.33	29.00	85.67	79.50	80.00	86.50	2.50	39.00	42.67
Sulphate as S	<500	0-1000	N/A	62.33	72.00	180.33	173.50	157.00	188.50	19.00	24.00	38.67
Fluoride as F	<1.5	0-2	<2.0	0.05	0.20	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	6.93	3.70	145.33	147.50	142.00	162.50	1.30	1.55	4.50
Anmomia	<1.5	N/A	N/A	0.1	0.1	0.7	0.4	0.1	0.075	0.4	1	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.005	0.005	0.012666667	0.023	0.005	0.018	0.005	0.003666667	0.003666667
Mercury	<0.006	0 – 0.001	N/A	0.0005		0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	18.33	18.00	41.67	41.50	44.00	45.00	23.00	5.50	5.67
Potassium	N/A	N/A	0 – 100	0.25	0.25	1.50	1.25	1.20	1.70	0.25	0.98	0.25
Calcium	N/A	0-1000	N/A	77.33	71.00	122.33	119.50	114.00	136.50	39.00	38.50	47.00
Magnesium	N/A	0 - 500	N/A	67.67	65.00	165.00	166.00	165.00	195.50	24.00	41.50	51.00
Aluminium	<0.3	0 - 5	0 - 5	0.1	0.129	0.093333333	0.5	0.005	0.668	0.005	0.122	0.05
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.003666667	0.005
Barium	N/A	N/A	N/A	0.023333333	0.013		0.072	0.07	0.1035			0.029
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.002	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0087	0.0125
Iron	<2	0 - 10	0 - 5	0.013	0.013	0.255	0.024	0.013	0.581	0.013	4.302	0.442
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.007	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.025	0.013	0.013	0.076	0.013	0.225	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.007	0.010
Zinc	<5	0 – 20	0 - 1	0.028	0.013	0.009	0.013	0.013	0.013	0.040	0.009	0.385

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh62				Trh63				
	Water quality standards for Domestic use			2010	2011	2012	2013	2008	2009	2010	2011	2012
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.53	7.98	7.40	8.30	7.73	7.90	7.75	7.98	7.87
Electrical cond	<170	N/A	≤ 40	72.50	77.75	90.40	61.50	46.80	79.60	98.00	84.58	97.80
Total Dissolve	<1200	0-1000	≤ 40	425.50	522.00	611.33	404.00	294.00	576.00	547.25	588.00	703.67
Acidity as Ca	N/A	N/A	N/A	9.63	12.25	52.00	2.50	20.00	2.50	9.25	13.25	33.33
Alkalinity as C	N/A	N/A	N/A	285.00	262.00	349.33	288.00		258.67	302.00	305.00	401.33
Chloride as C	<300	0-1500	<100	46.00	55.00	62.33	25.00	23.00	64.00	60.75	56.00	60.67
Sulphate as S	<500	0-1000	N/A	39.50	44.75	55.33	40.00	22.00	51.33	49.00	63.50	67.33
Fluoride as F	<1.5	0-2	<2.0	0.11	0.05	0.05	0.05	0.20	0.05	0.11	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	5.65	7.90	8.67	3.90	2.30	6.40	6.98	8.38	9.87
Anmomia	<1.5	N/A	N/A	0.1	0.175	0.1	0.05		0.1	0.15	0.15	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.009	0.005	0.005	0.005	0.003	0.005	0.005	0.007	0.005
Mercury	<0.006	0 – 0.001	N/A	0.0005	0.0005	0.0005		0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	7.00	8.00	8.33	8.00	4.00	5.67	6.25	5.75	7.00
Potassium	N/A	N/A	0 – 100	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	61.75	58.50	74.67	44.00	38.00	63.67	72.50	74.75	90.00
Magnesium	N/A	0 - 500	N/A	60.75	60.75	77.00	51.00	37.00	61.67	68.00	69.75	95.00
Aluminium	<0.3	0 - 5	0 - 5	0.05	0.05	0.098333333	0.102	0.003	0.05	0.05	0.05	0.101666667
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.005	0.005	0.005	0.003	0.005	0.005	0.005	0.005
Barium	N/A	N/A	N/A	0.0255	0.03025	0.040333333	0.026		0.028	0.02875	0.025	0.042333333
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025	0.0025	0.00175	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0125	0.0125	0.0125	0.0068	0.0125	0.0125	0.0125	0.0347
Iron	<2	0 - 10	0 - 5	0.013	0.023	0.023	0.013	0.013	0.013	0.013	0.013	0.053
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010	0.010	0.006	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.013	0.013	0.013	0.007	0.013	0.013	0.013	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.010	0.010	0.010	0.006	0.010	0.010	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.013	0.013	0.044	0.013	0.007	0.043	0.050	0.013	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Trh64					WGC2			
	Water quality standards for Domestic use			2013	2008	2009	2010	2011	2008	2009	2010	2011
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	8.10	7.88	7.97	7.23	8.60	7.35	7.57	8.10	8.43
Electrical cond	<170	N/A	≤ 40	86.80	7.18	33.27	79.67	37.60	69.10	92.63	63.00	84.10
Total Dissolve	<1200	0-1000	≤ 40	598.00	158.50	214.67	496.33	238.00	775.00	649.33	341.33	586.50
Acidity as Ca	N/A	N/A	N/A	2.50	5.17	2.50	15.50	2.50	52.00	5.25	7.00	11.25
Alkalinity as C	N/A	N/A	N/A	380.00	68.00	141.33	301.33	60.00	328.00	334.67	212.00	182.00
Chloride as C	<300	0-1500	<100	50.00	5.25	8.67	54.00	14.00	12.00	12.33	12.00	18.50
Sulphate as S	<500	0-1000	N/A	42.00	14.50	13.00	46.67	20.00	91.00	171.33	37.50	96.50
Fluoride as F	<1.5	0-2	<2.0	0.05	0.05	0.05	0.10	0.05	0.05	0.13	0.23	0.05
Nitrate as N	<11	0-100	≤5.0**	12.00	0.85	1.97	6.37	2.20	4.15	13.20	13.27	39.50
Anmomia	<1.5	N/A	N/A	0.1	1	0.1	0.1	0.3	1	0.4	0.23333333	0.875
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.005	0.004	0.004	0.005	0.005	0.005	0.009	0.017	0.013
Mercury	<0.006	0 – 0.001	N/A		0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	7.00	2.50	3.33	8.00	3.00	18.00	19.67	19.67	17.25
Potassium	N/A	N/A	0 – 100	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calcium	N/A	0-1000	N/A	66.00	20.50	31.00	69.00	22.00	54.50	62.67	29.00	35.50
Magnesium	N/A	0 - 500	N/A	71.00	14.50	24.33	67.33	18.00	67.50	83.67	53.00	68.50
Aluminium	<0.3	0 - 5	0 - 5	0.129	0.003666667	0.05	0.05	0.05	0.01	0.05	0.166333333	0.0625
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.003666667	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Barium	N/A	N/A	N/A	0.031		0.013	0.032333333	0.013		0.045	0.025333333	0.032
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.002	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0087	0.0197	0.0125	0.0125	0.0125	0.0233	0.0183	0.0125
Iron	<2	0 - 10	0 - 5	0.013	0.027	0.013	0.013	0.013	6.105	6.793	4.197	5.450
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.007	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.013	0.009	0.013	0.013	0.013	0.125	0.024	0.073	0.028
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.007	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.013	0.009	0.013	0.013	0.075	0.013	0.013	0.017	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		WGC12					WGC15			
	Water quality standards for Domestic use			2009	2010	2011	2012	2013	2008	2009	2010	2011
	Health related limits	Livestock	Irrigation									
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.60	8.20	7.60	7.93	8.00	7.89	7.60	8.20	7.55
Electrical cond	<170	N/A	≤ 40	68.40	56.00	118.00	158.00	99.70	98.60	147.00	63.00	119.00
Total Dissolve	<1200	0-1000	≤ 40	429.00	438.00	435.00	1254.00	668.00	988.67	1068.00	350.00	994.00
Acidity as Ca	N/A	N/A	N/A	8.00	2.50	82.00	23.50	12.00	12.33	10.00	2.50	30.00
Alkalinity as C	N/A	N/A	N/A	344.00	308.00	344.00	312.00	380.00	264.00	297.33	168.00	298.00
Chloride as C	<300	0-1500	<100	8.50	11.00	13.50	87.33	19.00	67.33	65.67	15.00	63.00
Sulphate as S	<500	0-1000	N/A	23.50	39.00	23.00	254.00	100.00	168.00	171.67	38.00	178.00
Fluoride as F	<1.5	0-2	<2.0	0.13	0.05	0.13	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate as N	<11	0-100	≤5.0**	2.10	2.10	4.80	78.27	26.00	50.33	62.33	3.70	60.50
Anmomia	<1.5	N/A	N/A	0.1	0.1	0.4	4.77	1.2	0.7	0.1	0.1	0.1
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.004	0.005	0.005	0.013	0.005	0.005	0.016	0.005	0.027
Mercury	<0.006	0 – 0.001	N/A	0.0005	0.0005	0.0005	0.0005		0.0005	0.0005	0.0005	0.0005
Sodium	<200	0-2000	0 – 70	19.00	20.00	19.50	57.67	22.00	43.67	48.00	8.00	47.00
Potassium	N/A	N/A	0 – 100	1.45	3.20	1.55	2.47	1.60	1.70	1.70	0.25	1.60
Calcium	N/A	0-1000	N/A	53.50	37.00	55.50	73.33	65.00	51.00	85.33	30.00	83.00
Magnesium	N/A	0 - 500	N/A	55.50	59.00	60.00	129.33	81.00	109.67	119.67	35.00	120.50
Aluminium	<0.3	0 - 5	0 - 5	0.130666667	0.294	0.05	0.141333333	137.00	0.021666667	0.067333333	0.05	0.0875
Arsenic	<0.01	0 - 1	0 – 0.1	0.003666667	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Barium	N/A	N/A	N/A	0.039	0.031	0.0305	0.056333333	0.045		0.057	0.013	0.064
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.002	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0188	0.0125	0.0125	0.0125	0.0125	0.0317	0.0207	0.0125	0.0125
Iron	<2	0 - 10	0 - 5	3.960	8.470	1.280	5.200	6.890	8.623	12.788	0.031	5.265
Lead	<0.01	0 – 0.1*	0 – 0.2	0.007	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.133	0.120	0.034	0.040	0.047	0.044	0.065	0.013	0.037
Selenium	<0.01	0 - 50	0 – 0.02	0.007	0.010	0.010	0.010	0.010	0.013	0.010	0.010	0.010
Zinc	<5	0 – 20	0 - 1	0.016	0.013	0.013	0.013	0.013	0.025	0.018	0.013	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		WGC18		
	Water quality standards for Domestic use			2012	2013	2008
	Health related limits	Livestock	Irrigation			
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.73	8.00	7.52
Electrical cond	<170	N/A	≤ 40	107.87	104.00	71.90
Total Dissolve	<1200	0-1000	≤ 40	774.67	708.00	490.00
Acidity as Ca	N/A	N/A	N/A	41.33	2.50	2.50
Alkalinity as C	N/A	N/A	N/A	336.00	340.00	356.00
Chloride as C	<300	0-1500	<100	41.00	36.00	10.00
Sulphate as S	<500	0-1000	N/A	135.67	113.00	31.00
Fluoride as F	<1.5	0-2	<2.0	0.05	0.20	0.05
Nitrate as N	<11	0-100	≤5.0**	31.87	30.00	7.10
Anmonia	<1.5	N/A	N/A	0.3	0.1	6.6
Hexavalent ch	N/A	0 - 1	0 – 0.1	0.028	0.027	0.005
Mercury	<0.006	0 – 0.001	N/A	0.0005		0.0005
Sodium	<200	0-2000	0 – 70	41.67	40.00	20.00
Potassium	N/A	N/A	0 – 100	1.47	1.30	3.60
Calcium	N/A	0-1000	N/A	56.00	54.00	45.00
Magnesium	N/A	0 - 500	N/A	100.33	77.00	57.00
Aluminium	<0.3	0 - 5	0 - 5	0.238666667	0.124	0.01
Arsenic	<0.01	0 - 1	0 – 0.1	0.005	0.005	0.005
Barium	N/A	N/A	N/A	0.047333333	0.047	
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.0025	0.0025	0.0025
Copper	<2	0 – 0.50*	0 – 0.2	0.0125	0.0125	0.0900
Iron	<2	0 - 10	0 - 5	7.919	7.360	0.371
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.079	0.013	0.013
Selenium	<0.01	0 - 50	0 – 0.02	0.010	0.010	0.020
Zinc	<5	0 – 20	0 - 1	0.013	0.013	0.013

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		Hernic Quarry	TM GW COMM 01		TM GW COMM 02		TMGWCOMM03
	Water quality standards for Domestic use			2014	2013	2014	2013	2014	2013
	Health related limits	Livestock	Irrigation						
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	8.19	7.72	7.75	7.61	7.49	7.53
Electrical conductivity in mS/m	<170	N/A	≤ 40	75.36	60.75	69.40	85.85	80.10	22.60
Total Dissolved Solids	<1200	0-1000	≤ 40	449.20		402.50		429.00	
Acidity as CaCO ₃	N/A	N/A	N/A						
Alkalinity as CaCO ₃	N/A	N/A	N/A	146.00		282.00		326.00	
Chloride as Cl	<300	0-1500	<100	20.60	13.17	12.65	23.00	20.00	0.70
Sulphate as SO ₄	<500	0-1000	N/A	72.33	54.88	69.60	74.90	63.10	5.25
Fluoride as F	<1.5	0-2	<2.0	0.19	0.12	0.18	0.20	0.19	0.09
Nitrate as N	<11	0-100	≤5.0**	30.85	6.21	5.53	3.03	1.16	0.90
Ammomia	<1.5	N/A	N/A	0.261	0.034	0.024	0.203	0.024	0.087
Hexavalent chrome	N/A	0 - 1	0 – 0.1						
Mercury	<0.006	0 – 0.001	N/A			0.015			
Sodium	<200	0-2000	0 – 70	31.31	9.51	22.00	18.80	18.40	0.02
Potassium	N/A	N/A	0 – 100	5.34	0.92	0.59	0.02	0.43	0.02
Calcium	N/A	0-1000	N/A	38.53	29.50	32.35	78.00	66.80	18.00
Magnesium	N/A	0 - 500	N/A	53.64	62.98	63.90	66.20	56.60	18.00
Aluminium	<0.3	0 - 5	0 - 5	0.006	0.003	0.006	0.003	0.006	0.003
Arsenic	<0.01	0 - 1	0 – 0.1			0.023			
Barium	N/A	N/A	N/A						
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.001	0.001	0.001	0.001	0.001	0.001
Copper	<2	0 – 0.50*	0 – 0.2	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Iron	<2	0 - 10	0 - 5	0.006	0.003	0.006	0.003	0.006	0.003
Lead	<0.01	0 – 0.1*	0 – 0.2	0.010	0.005	0.010	0.005	0.010	0.005
Manganese	<0.50	0 - 10	0 – 0.02	0.001	0.001	0.001	0.001	0.001	0.001
Selenium	<0.01	0 - 50	0 – 0.02			0.025			
Zinc	<5	0 – 20	0 - 1	0.0040	0.0020	0.0040	0.0020	0.0040	0.0020
Cr	0.05	N/A	N/A	0.002	0.001	0.002	0.001	0.002	0.001
PO ₄	N/A	N/A	N/A	0.025	0.020	0.026	0.013	0.027	0.013
NO ₂ -N	<0.9	N/A	N/A	1.003	0.095	0.073	0.097	0.057	0.101
CN	<70	N/A	N/A			0.01			

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		TM GW COMM 05		TM GW COMM 06		TM GW COMM 08		TM GW COMM 09
	Water quality standards for Domestic use			2013	2014	2013	2014	2013	2014	2013
	Health related limits	Livestock	Irrigation							
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	7.47	7.35	7.39	7.42	7.55	7.46	6.90
Electrical conductivity in mS/m	<170	N/A	≤ 40	42.63	45.10	48.90	55.45	83.00	78.70	94.65
Total Dissolved Solids	<1200	0-1000	≤ 40		246.00		298.50		435.50	
Acidity as CaCO ₃	N/A	N/A	N/A							
Alkalinity as CaCO ₃	N/A	N/A	N/A		194.00		210.50		300.00	
Chloride as Cl	<300	0-1500	<100	5.29	11.95	16.65	26.50	25.73	32.80	173.00
Sulphate as SO ₄	<500	0-1000	N/A	30.68	34.45	19.55	22.75	29.12	44.30	32.35
Fluoride as F	<1.5	0-2	<2.0	0.09	0.18	0.09	0.20	0.09	0.18	0.28
Nitrate as N	<11	0-100	≤5.0**	0.81	0.92	3.82	6.12	4.85	7.41	0.25
Ammomia	<1.5	N/A	N/A	0.027	0.025	0.044	0.021	0.022	0.027	0.045
Hexavalent chrome	N/A	0 - 1	0 – 0.1							
Mercury	<0.006	0 – 0.001	N/A		0.015		0.015		0.015	
Sodium	<200	0-2000	0 – 70	4.05	9.46	9.67	14.50	8.53	16.60	6.14
Potassium	N/A	N/A	0 – 100	0.10	0.49	0.09	0.60	0.64	0.53	0.87
Calcium	N/A	0-1000	N/A	29.98	28.45	39.35	41.00	60.70	69.70	122.00
Magnesium	N/A	0 - 500	N/A	36.80	38.80	35.85	38.05	46.13	55.20	2.09
Aluminium	<0.3	0 - 5	0 - 5	0.003	0.006	0.003	0.006	0.003	0.006	0.003
Arsenic	<0.01	0 - 1	0 – 0.1		0.023		0.023		0.023	
Barium	N/A	N/A	N/A							
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Copper	<2	0 – 0.50*	0 – 0.2	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Iron	<2	0 - 10	0 - 5	0.003	0.006	0.003	0.006	0.003	0.006	0.003
Lead	<0.01	0 – 0.1*	0 – 0.2	0.005	0.010	0.005	0.010	0.005	0.010	0.005
Manganese	<0.50	0 - 10	0 – 0.02	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Selenium	<0.01	0 - 50	0 – 0.02		0.025		0.025		0.025	
Zinc	<5	0 – 20	0 - 1	0.0020	0.0040	0.0020	0.0040	0.0020	0.0040	0.0020
Cr	0.05	N/A	N/A	0.001	0.002	0.001	0.002	0.001	0.002	0.001
PO ₄	N/A	N/A	N/A	0.026	0.025	0.019	0.025	0.016	0.025	0.013
NO ₂ -N	<0.9	N/A	N/A	0.094	0.0725	0.096	0.073	0.097	0.074	0.106
CN	<70	N/A	N/A		0.01		0.01		0.01	

Parameter	SANS 241:2011	DWA SA Water Quality Guidelines		TM GW TSF 01		TM GW TSF 02		TM GW MCC
	Water quality standards for Domestic use			2013	2014	2013	2014	2014
	Health related limits	Livestock	Irrigation					
pH (pH units)	5.0 – 9.7	N/A	6.5 – 8.4	8.14	7.69	8.03	7.82	7.96
Electrical conductivity in mS/m	<170	N/A	≤ 40	51.77	50.40	92.53	118.00	57.90
Total Dissolved Solids	<1200	0-1000	≤ 40		287.00		709.50	331.00
Acidity as CaCO ₃	N/A	N/A	N/A					
Alkalinity as CaCO ₃	N/A	N/A	N/A		177.00		329.50	231.50
Chloride as Cl	<300	0-1500	<100	5.79	8.83	15.88	44.35	6.28
Sulphate as SO ₄	<500	0-1000	N/A	16.70	19.70	98.40	129.00	50.70
Fluoride as F	<1.5	0-2	<2.0	0.09	0.19	0.25	0.19	0.23
Nitrate as N	<11	0-100	≤5.0**	16.13	14.25	35.70	29.20	8.81
Ammomia	<1.5	N/A	N/A	0.032	0.023	0.034	0.028	0.027
Hexavalent chrome	N/A	0 - 1	0 – 0.1					
Mercury	<0.006	0 – 0.001	N/A		0.015		0.015	0.015
Sodium	<200	0-2000	0 – 70	8.45	11.80	14.14	31.85	11.60
Potassium	N/A	N/A	0 – 100	0.04	0.62	0.19	0.53	1.10
Calcium	N/A	0-1000	N/A	39.47	38.25	52.27	74.80	27.90
Magnesium	N/A	0 - 500	N/A	40.27	36.35	93.90	97.90	53.05
Aluminium	<0.3	0 - 5	0 - 5	0.003	0.006	0.003	0.006	0.006
Arsenic	<0.01	0 - 1	0 – 0.1		0.023		0.023	0.023
Barium	N/A	N/A	N/A					
Cadmium	<0.003	0 – 0.01	0 – 0.01	0.001	0.001	0.001	0.001	0.001
Copper	<2	0 – 0.50*	0 – 0.2	0.0010	0.0010	0.0010	0.0010	0.0010
Iron	<2	0 - 10	0 - 5	0.003	0.006	0.003	0.006	0.006
Lead	<0.01	0 – 0.1*	0 – 0.2	0.005	0.010	0.005	0.010	0.010
Manganese	<0.50	0 - 10	0 – 0.02	0.001	0.001	0.001	0.001	0.001
Selenium	<0.01	0 - 50	0 – 0.02		0.025		0.025	0.025
Zinc	<5	0 – 20	0 - 1	0.0020	0.0040	0.0020	0.0040	0.0040
Cr	0.05	N/A	N/A	0.001	0.002	0.001	0.002	0.002
PO ₄	N/A	N/A	N/A	0.013	0.025	0.013	0.025	0.025
NO ₂ -N	<0.9	N/A	N/A	0.103	0.073	0.108	0.079	0.4065
CN	<70	N/A	N/A		0.01		0.01	0.01

