MAMATWAN GROUNDWATER STUDY

Mamatwan Mine

Prepared for: South 32

Authority References:

SLR Project No.: 720.19136.00002
Report No.: 1
Revision No.:
November 2021

DOCUMENT INFORMATION

Title	Mamatwan Groundwater Study
Project Manager	Mihai Muresan
Project Manager Email	mmuresan@slrconsulting.com
Author	Mihai Muresan
Reviewer	Sharon Meyer
Keywords	numerical modelling, open pit, underground pumping, cone of drawdown, contaminant plume, impact assessment
Status	Draft
Report No.	1
SLR Company	SLR Consulting (South Africa) (Pty) Ltd

DOCUMENT REVISION RECORD

Rev No.	Issue Date	Description	Issued By
A			

REPORT SIGN OFF AND APPROVALS

Mihai Muresan
(Project Manager)

Sharon Meyer
(Reviewer)

BASIS OF REPORT

This document has been prepared by an SLR Group company with reasonable skill, care and diligence, and taking account of the manpower, timescales and resources devoted to it by agreement with **South 32** (the Client) as part or all of the services it has been appointed by the Client to carry out. It is subject to the terms and conditions of that appointment.

SLR shall not be liable for the use of or reliance on any information, advice, recommendations and opinions in this document for any purpose by any person other than the Client. Reliance may be granted to a third party only in the event that SLR and the third party have executed a reliance agreement or collateral warranty.

Information reported herein may be based on the interpretation of public domain data collected by SLR, and/or information supplied by the Client and/or its other advisors and associates. These data have been accepted in good faith as being accurate and valid.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

The copyright and intellectual property in all drawings, reports, specifications, bills of quantities, calculations and other information set out in this report remain vested in SLR unless the terms of appointment state otherwise.

This document may contain information of a specialised and/or highly technical nature and the Client is advised to seek clarification on any elements which may be unclear to it.

Information, advice, recommendations and opinions in this document should only be relied upon in the context of the whole document and any documents referenced explicitly herein and should then only be used within the context of the appointment.

CONTENTS

1. INTRODUCTION 1
1.1 Proposed Project Scope 1
2. BASELINE CONDITIONS 1
2.1 Locality 1
2.2 Climate 2
2.3 Geology 3
2.4 Hydrogeology 4
2.4.1 Aquifers Description 4
2.4.2 Groundwater Levels 5
2.4.3 Groundwater quality 6
2.5 Geochemistry 8
2.5.1 Mineralogy 8
2.5.2 Acid-base Counting 8
3. FIELD WORK 9
4. NUMERICAL MODEL 9
4.1 Model Software Choice 9
4.2 Model Setup and Boundary Conditions 10
4.3 Simulation of Mining 11
4.4 Processing Middleplaats Underground Mine 12
4.5 Model Discretization 14
4.6 Model Properties 17
4.7 Model Results 19
4.7.1 Predicted groundwater inflows 19
4.7.2 Cone of drawdown 21
4.7.3 Development of a contaminant plume 24
5. CONCLUSIONS AND RECOMMENDATIONS 30
5.1 Recommended Monitoring Network 31
6. GROUNDWATER IMPACTS 34
6.1 Methodology used in Determining The Significance of Impacts 34
6.2 Issue: Developemnt of the Cone of Drawdown as a result of Mining and Production Pumping 36
6.3 Issue: Contamination of Groundwater Resources as a Result of the In-Pit Backfill, WRD Deposition and Adam's Pit Deposition 37
7. REFERENCES 41

LIST OF TABLES

TABLE 1: MAMATWAN NUMERICAL MODEL - HYDRAULIC PROPERTIES....17
TABLE 2: TOTAL GROUNDWATER (OPEN PIT, UNDERGROUND, PRODUCTION WELLS) 20
TABLE 3: WASTE ROCK MODEL RESULTS 24
TABLE 4: MODELLING RESULTS FOR THE STOCKPILE IN ADAM'S PIT 25
TABLE 5: PREDICTED DISTANCE PLUME MIGRATION....31
TABLE 6: PROPOSED NEW MONITORING BOREHOLES....33
TABLE 7: OPERATIONAL & CLOSURE PHASE IMPACT SUMMARY – IMPACT ON GROUNDWATER LEVEL AND GRADIENT 36
TABLE 8: OPERATIONAL & CLOSURE PHASE IMPACT SUMMARY – IMPACT ON GROUNDWATER QUALITY 37

LIST OF FIGURES

FIGURE 1: MAMATWAN LOCALITY MAP.... 2
FIGURE 2: AVERAGE TEMPERATURES AND PRECIPITATION BASED ON 30 YEARS OF HOURLY WEATHER MODEL SIMULATIONS (SOURCE: DIGBY WELLS, 2020) 3
FIGURE 3: STRATIGRAPHIC COLUMN.... 4
FIGURE 4: MONITORING LOCATIONS 6
FIGURE 5: GROUNDWATER HYDROGRAPHS 6
FIGURE 6: MAMATWAN MODEL DOMAIN....10
FIGURE 7: MAMATWAN OPEN PIT - MINING AND BACKFILL....11
FIGURE 8: MIDDLEPLAATS UNDERGROUND VOIDS 12
FIGURE 9: PROCESSING OF MIDDLEPLAATS UNDERGROUND 13
FIGURE 10: VOLUMES ESTIMATION....14
FIGURE 11: HYDRAULIC AND GEOCHEMICAL STRESSES 15
FIGURE 12: 2D FINITE ELEMENTS MESH....16
FIGURE 13: MAMATWAN MODEL - CROSS SECTION....16
FIGURE 14: 3D NUMERICAL MODEL 17
FIGURE 15: INITIAL HYDRAULIC HEAD 18
FIGURE 16: GROUNDWATER PASSIVE INFLOW INTO THE OPEN PIT 19
FIGURE 17: GROUNDWATER PASSIVE INFLOWS INTO MIDDLEPLAATS UNDERGROUND VOIDS 20
FIGURE 18: CONE OF DRAWDOWN IN YEAR 2037 (END OF MINING) 22
FIGURE 19: CONE OF DRAWDOWN IN YEAR 2121 (100 YEARS OF SIMULATION, 84 YEARS POST MINING) 23
FIGURE 20: PREDICTED NITRATE PLUME IN YEAR 2037 (END OF MINING) 26
FIGURE 21: PREDICTED NITRATE PLUME IN YEAR 2121 (END OF SIMULATION, 84 YEARS POST-MINING) 27
FIGURE 22: PREDICTED MANGANESE PLUME IN YEAR 2037 (END OF MINING) 28
FIGURE 23: PREDICTED MANGANESE PLUME IN YEAR 2121 (END OF SIMULATION, 84 YEARS POST-MINING) 29
FIGURE 24: TOTAL PUMPING 30
FIGURE 25: PROPOSED NEW MONITORING LOCATIONS....32

ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
CoC	Constituents of concern
K, m/d	Hydraulic Conductivity, m/day
Mbgl	Meters below ground level
Mamsl	Meters above mean sea level
WRD	Waste Rock Dump
Mg/l	Milligram per litre
M3/d	Cubic meters per day
M3/hr	Cubic meters per hour

Mamatwan Groundwater Study

1. INTRODUCTION

SLR Consulting (SLR) has been requested by South32 to undertake a groundwater study in support of their Mamatwan Manganese Mine (Mamatwan Mine) IRP.
The operation is an open pit mine in the well-known manganese mining area.
The objective of the Hydrogeological Study is to assess possible impacts to groundwater from open pit mining (including Adams Pit) and pumping the underground storage water hosted in the derelict Middleplaats Underground Mine.

1.1 PROPOSED PROJECT SCOPE

Mamatwan Mine is making an application to the Department of Mineral Resources and Energy (DMRE) for an integrated Environmental Authorisation (including Waste Management License) and update of the mine's current Environmental Management Programme to address a number of layout and activity changes that have already taken place at the Mamatwan Mine, as well as proposed layout and activity changes.

A list of layout and/or activity changes that have already taken place include:

- Expansion of the north and south- eastern Waste Rock Dumps (WRDs);
- Changes to the rehabilitation criteria of WRDs;
- Expansion of the product stockyard;
- Establishment of potable and process water storage facilities; and
- Expansion of an existing road.

A list of the proposed layout and/or activity changes include:

- Establishment of a top-cut stockpile and associated mobile crushing and screening plant;
- Establishment of stormwater management infrastructure including a Pollution Control Dam (PCD) and evaporation channels;
- Change in height of the WRD (this excludes rehabilitated WRD's);
- Establishment of a pipeline to transfer water abstracted from the decommissioned Middelplaats Mine to MMT;
- Upgrading the railway line and the railway loadout station;
- Sale of waste rock as aggregate; and
- Re-processing of material located in Adams Pit.

2. BASELINE CONDITIONS

2.1 LOCALITY

Mamatwan Mine is situated in the Northern Cape, near Hotazel – Figure 1.

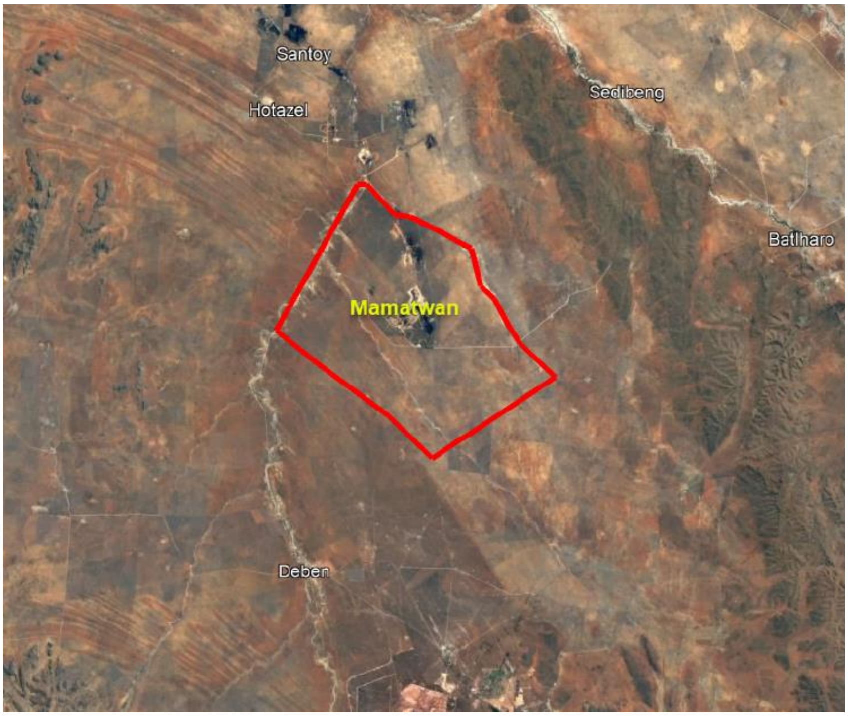

Figure 1: Mamatwan Locality Map

2.2 CLIMATE

The Greater Hotazel Manganese Mining Area falls within a semi-arid climate region of Southern Africa, where rainfall is sporadic with high seasonal variations during wet and dry seasons. The wet (or rainy) season occurs during the summer months from October to March and is characterised by short and intense storms.

Dry seasons occur during wintertime (April - September) and are characterized by dry cold weather conditions (Figure 2). Governing the variation in seasonal rainfall is the latitudinal movement of the ITCZ, which migrates to the south of the equator during summer months and back to the north of the equator in winter (Mphale et al., 2014).

Average daily maximum temperatures in January (the hottest month) vary between 30°C and 15°C, whilst temperatures can reach up to 45°C during hotter periods. Average daily maximum temperatures vary between 0°C and 17°C in July whilst daily minimum temperatures of 1°C are expected in the mid-winter months.

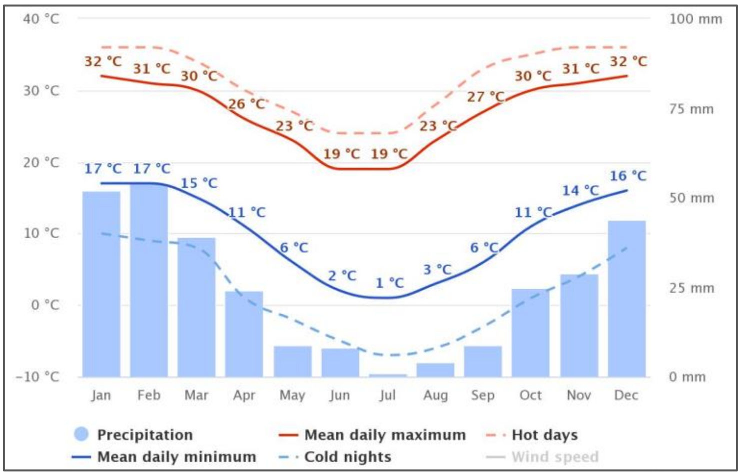

Figure 2: Average Temperatures and Precipitation Based on 30 Years of Hourly Weather Model Simulations (source: Digby Wells, 2020)

The Mean Annual Precipitation (MAP) in and around Kuruman (the nearest official recording station) is approximately 300 mm/year while the annual evaporation rate is more than 2600 mm/year. Generally, evaporation exceeds mean annual rainfall by a factor of 5-7 times which indicates that rainfall recharge into aquifers is only likely to occur after periods of intense rainfall. This results in mostly seasonal flow in streams and generally low recharge rates to the underlying aquifers.

2.3 GEOLOGY

The project area is located within the Kalahari Manganese Field (KMF) hosted by the early Proterozoic Transvaal Supergroup, in the Griqualand West Basin along the western margin of the Kaapvaal Craton.

Mamatwan Mine is located within the south-western outer rim of the Kalahari Manganese Field. The KMF is dived into two ore types based on the geochemical characteristics of the manganese ore (Evans *et al.,* 2001):

- The low grade, sedimentary, Mamatwan-type ore found in the south-east; and
- The high grade, hydrothermally altered, Wessels-type ore in the north-west.

The high-grade Wessels-type ore makes up to 3% of the total manganese resource while the low-grade Mamatwan-type ore makes up the remaining 97% (Gutzmer and Cairncross, 2002).

The Hotazel Formation was deposited between 2 200 and 2 300 million years ago and the formation is structurally confined within the Dimoten Syncline, a north-westerly plunging basin containing more than 80% of global land-based manganese reserves within an area of approximately 525 km^2.

The Hotazel Formation includes the Banded Iron Form (BIF). The ore is contained within a 30-40 metres thick mineralised zone which occurs across the entire area and is made up of three manganese-rich zones as follows (Figure 3):

- The upper Manganese Ore Body (UMO);
- The Middle Manganese Ore Body (MMO); and
- The Lower Manganese Ore Body (LMO).

The Hotazel Formation is underlain by basaltic lava of the Ongeluk Formation (Transvaal Supergroup) and directly overlain by dolomite of the Mooidraai Formation (Transvaal Supergroup). The Transvaal Supergroup is overlain unconformable by the Olifantshoek Supergroup which consists of arenaceous sediments, typically interbedded shale, quartzite and lavas overlain by coarser quartzite and shale. The different formations present in the project area include the Mapedi and Lucknow units. The whole Supergroup has been deformed into a succession with an east-verging dip (GHT, 2018).

The Olifantshoek Supergroup is overlain by Dwyka Formation which forms the basal part of the Karoo Supergroup. At the mine, this consists of tillite (diamictite) which is covered by sands, claystone and calcrete of the Kalahari Group (GHT, 2018).

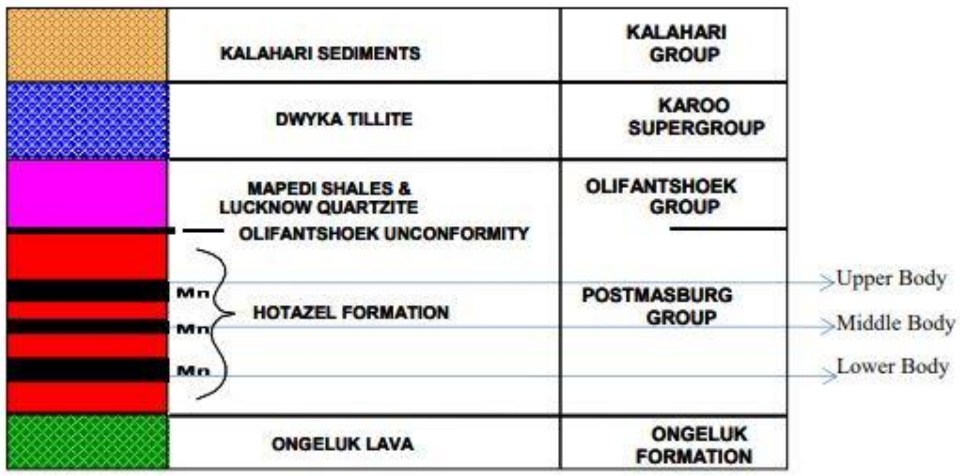

Figure 3: Stratigraphic column

2.4 HYDROGEOLOGY

2.4.1 Aquifers Description

Four aquifers are present in the Ongeluk, Hotazel, Mooidraai, and Kalahari Formations. The aquifers are described as follows (GHT, 2018):

The Ongeluk Formation: being an older geological formation, the aquifer is primarily associated with weathered horizons and zones adjacent to regional-scale structures. This aquifer is generally not favoured as a source of water supply due to its general low yield.

Hotazel Formation: typically has a higher yield in the Kalahari Manganese Field, with the groundwater stored in voids that developed following bed separation, within faults and periphery fractures, and along the dolerite dykes that have partially filled regional faults. The formation is regarded as semi-confined on the Smartt-Rissik and Mamatwan prospects where its sub-crops at shallow depth. The higher aquifer yields are associated with the preferentially fractured, brittle BIF's adjacent to regional faults. With increasing depth, however, the Hotazel Formation aquifer can be confined, particularly when the overlying Kalahari Formation contains thick inter-beds of highly plastic red clay as observed along the southern edge of the Mamatwan Mine property.

Mooidraai Formation: a dolomitic aquifer occurring in the southwest of the study area in the vicinity of the now-derelict Middleplaats Mine. This aquifer is of local significance due to its high yielding characteristics

(>10 L/s) and is currently exploited by Mamatwan Mine as an emergency supply source. It is noted that there is no evidence to suggest that these aquifers have been recharged in recent times.

Kalahari Formation: On a regional scale the Kalahari Formation behaves as a semi-confined aquifer, which is hydraulically connected with aquifers in underlying formations at those sites where extensive red clay or clay-bearing Dwyka Formation beds are absent. While the aquifer is generally more porous than other site aquifers, the characteristics of the aquifer vary from site to site. Yields vary significantly spatially. A paleo-channel deposit has been identified to the north of the Mamatwan pit, containing significant quantities of groundwater, however, this aquifer contains high nitrate concentrations and therefore it cannot be classed as an important groundwater resource.

2.4.2 Groundwater Levels

The groundwater levels monitored by Mamatwan mine at locations shown in Figure 4, are shown in Figure 5.

The water level of boreholes TB04, TB05, TB17 and TB22 appear to be relatively stable. However, boreholes TB04, TB05 and TB22 show slightly decreasing, much deeper water levels, and it can be assumed that these boreholes are being influenced by mine dewatering. Borehole TB20 has demonstrated an unsteady state from 2012 until 2020, there is an indication of a recharge for the first 6 months of the year 2018. In the first 3 quarters of the year 2020, a slight drop in water level elevation is observed in boreholes TB19, TB20 and TB21. In 2015, borehole TB21 shows an increase in water level elevation until the start of 2016, after which the water level decreased. TB20 showed a water level increase in late 2017 and at the start of 2019, thereafter a significant decrease was observed.

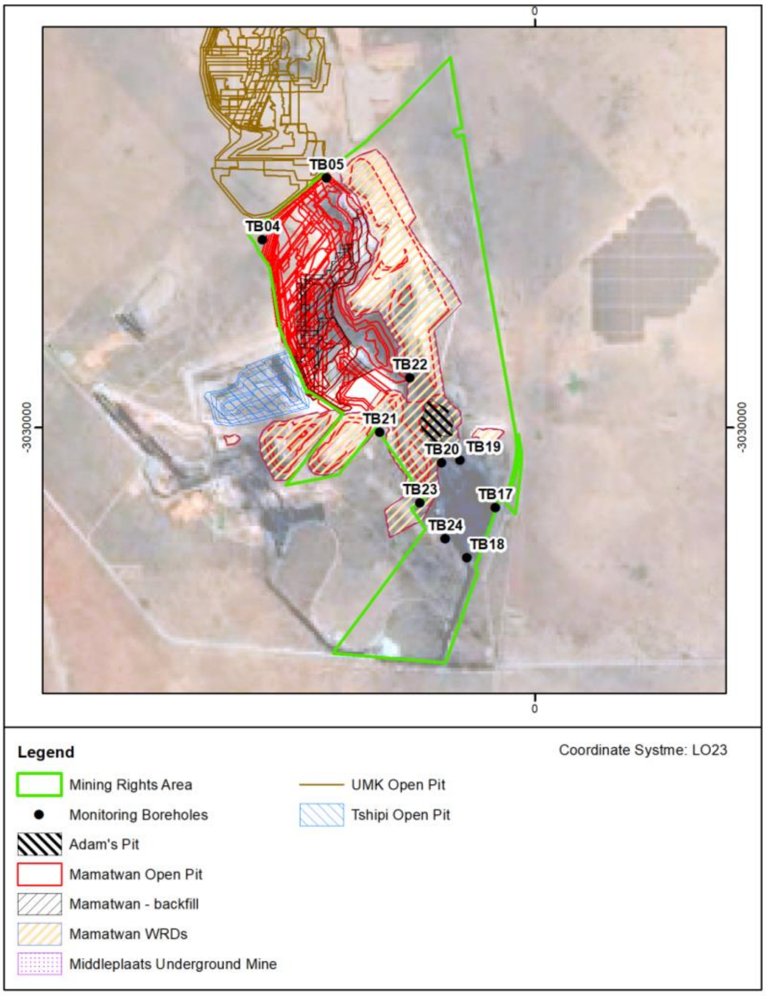

Figure 4: Monitoring locations

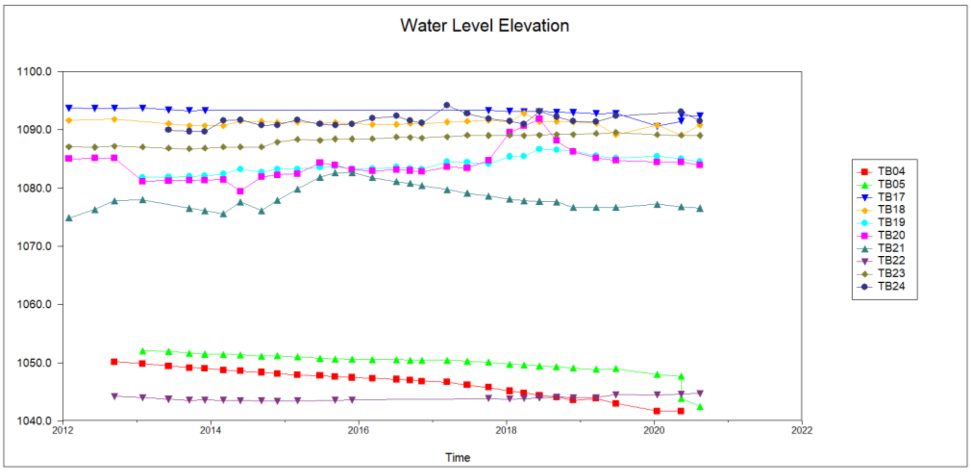

Figure 5: Groundwater hydrographs

2.4.3 Groundwater quality

In 2002 eight boreholes were installed north of Mamatwan mine, with borehole JB19 (now referred to as TB19) being used for domestic water supply. Two additional boreholes installed in 2003 were included in the Mamatwan Mine monitoring program to allow for monitoring between Smartt-Rissik, Mamatwan and

Middelplaas prospects for a better comparison of the water quality between the sites. "*The Regional Geohydrology of the Kalahari Manganese Field: Study conducted at Wessels Mine, Hotazel Mine, Mamatwan and Middelplaats Mine"* report of 2002/2003 indicates that at least two water quality investigations were carried out in 1996 and 1997. In both reports, water quality was characterised as "being of poor quality". In the 2002/2003 report, chemical analyses were taken from private and the mine monitoring boreholes. The results indicated the following:

- The water type is highly variable across the region with Ca and Mg as predominant cations, and anion composition varying between HCO3 and Cl + NO3 with a SO4 signature slightly dominant at some sites;
- Water is classified as a "Class 4" type according to the Department of Water Affairs and Forestry (DWAF) guidelines. This is normally an unacceptable water quality for domestic use. This is mainly due to high nitrate concentrations. If nitrate concentrations would be ignored then site waters would be generally classified as a Class 1 or Class 2 type, i.e. good to marginally good;
- However, it must be noted that observations from other mines, indicate high nitrates concentration.
- There is an observed linear relationship between Mg and Ca, and this is due to the occurrence of dolomite mineralisation in lithologies. A non-linear relationship exists between Ca and Total Alkalinity (mg/L) for the site aquifers, which suggests that alkalinity within the system is not merely a function of pH and dolomite dissolution – other geochemical processes may also be of significance;
- Isotopic data indicate that the plots of 18O and 2H groundwater data indicate recharged water was partially exposed to evaporation before infiltrating in the underlying aquifer;

The time series analysis of groundwater quality data, (Digby Wells, 2020) indicate:

- The pH is relatively stable and varies between 6.9 and 8.7, indicative of neutral to alkaline waters. All the samples analysed to date are within the Mamatwan WUL. The pH of TB18 was slightly above the WUL limit.
- Fluoride: the trends are all relatively stable compared to the 2016 and 2018 monitoring period. Currently, all samples are within the recommended limit for fluoride of 0.36 mg/L. When compared to guidelines for domestic use (1.0 mg/L) and livestock watering (2 mg/L) all samples are within the recommended water quality guidelines.
- Chloride: five boreholes (TB05, TB19, TH20, TH22 and TB24) exceeded the WUL limit. The highest concentration is recorded at TB24 which is located north of the Old Slime Dams, and it currently shows an erratic trend and largely exceeds the WUL since 2014.
- Nitrate: All the monitoring points indicate nitrate to be above the recommended WUL limit apart from TB24. The exceedances have been above the WUL limit for almost the entire monitoring period since 2012.
- Sulphate: All groundwater monitoring locations exceed the WUL, except for TB04, TB05 and TB21.

2.5 GEOCHEMISTRY

2.5.1 Mineralogy

In 2002/2003 a geochemical study was conducted and the results were included in "*The Regional Geohydrology of the Kalahari Manganese Field, Study conducted at Wessels Mine, Hotazel Mine, Mamatwan and Middelplaats Mines*" (GMT, 2003). X-Ray Fluorescence was conducted on the following:

- Ongeluk Formation
  - A debrite sample (lithology comprising lenticular and in some cases brecciated chert deposits within a dolerite-type matrix) indicates low Silica Dioxide (SiO_2), relatively high Iron (III) Oxide (Fe_2O_3) meaning debrite is mafic. Loss of Ignition (LOI) is relatively high also indicating the presence of calcareous minerals in the samples;
- Hotazel Formation
  - A blast face sample was taken from the Mamatwan Mine and a high manganese concentration was observed, as the sample was taken from the manganese ore;

In 2020 a geochemical study was carried out and the results were included in *"Geochemical Characterisation in support of the Section 24G process: Mamatwan Mine"* (GMT, 2020) was conducted and reported. The four samples that were analysed were collected from Adams pit for the following:

(i) a Sinter de-dust sample;
(ii) a tailings sample;
(iii) a slimes sample; and
(iv) Dense Medium Separation (DMS) grit sample.

The mineralogy indicates that dominant phases in the samples in Adam's Pit are manganese and carbonates rich minerals. Due to the oxidation and hydrolysis of Mn (II) minerals found in Adam's Pit materials, acid generation may occur but due to the association with carbonates, this will be neutralised.

2.5.2 Acid-base Counting

Two Mamatwan discard samples and one slimes dam sample were analyzed, and the results were included in the hydrogeological report (GMT, 2003). The following was summarized:

- The pH of the samples indicates that it is more neutral; and
- The NNP of all samples demonstrates a high concentration of neutralising minerals which will likely prevent acid generation.

The 2002/2003 results were also included in the 2016 report and additional samples (two from the Waste Rock Dump and two from the Tailings Dam) were analysed (GHT, 2016). The results indicate the following:

- A leachate test (static test) was undertaken on the Mamatwan discards and slimes and indicates that constituents are not readily soluble in water, even when completely oxidised;
- Acid Generation Potential of all tested samples of the Mamatwan was classified as "very low risk" this is because of relative abundance of neutralising minerals (i.e. calcite and dolomite);
- According to the pH values (7.19 and 11.25), the samples pose a low risk for acid generations;
- The NNP (Net Neutralising Potential) values for both open (346.50 to 646.25) and closed (346.37 to 645.18) systems indicate that the discards contain an excess of neutralising minerals (NPR > 4, high neutralising potential, AMD very unlikely); and
- The NPR [Neutralising Potential Ratio (NP/AP)] values further indicate that there is no acid potential for both open and closed systems.

As part of *"Geochemical Characterisation in support of the Section 24G process: Mamatwan Mine"* (SLR, 2020), four samples collected: a Sinter de-dust sample, a tailings sample, a slimes sample, and Dense Medium Separation (DMS) grit sample.

Acid-Base Accounting (ABA) Test Results

The ABA results indicate that the total sulphur concentration in the sinter de-dust material (MMT-AP01) is above the 0.3% threshold with the sulphate sulphur not posing a risk of acid production. The main Constituents of Concerns (CoCs) identified in the Adam's Pit Sinter de-dust samples were B, pH, TDS, EC, Cl and SO_4. No leachable CoCs were identified in the tailings (M2FT) or slimes samples.

3. FIELD WORK

No hydrogeological field work was done during the study.
Drilling and testing was recommended for the Middleplaats Underground Mine, however, this will be performed at a later stage.

4. NUMERICAL MODEL

4.1 MODEL SOFTWARE CHOICE

The FEFLOW (Finite Element subsurface FLOW and transport system v 7.3.0.18422) modelling code developed by DHI-WASY (Diersch, 2015) was used for the UMK groundwater model update. This code is an industry standard groundwater modelling tool widely used in mining and environmental applications. FEFLOW handles a broad variety of physical processes for subsurface flow and transport modelling and simulates groundwater level behaviour indirectly by means of a governing equation that represents the Darcy groundwater flow processes that occur in a groundwater system.
In the Finite Element (FE) method, the problem domain is subdivided into elements that are defined by nodes. The dependent variable (e.g., head) is defined as a continuous solution within elements in contrast to the Finite Difference (FD) method where head is defined only at the nodes and is considered piecewise constant between nodes. The FE solution is piecewise continuous, as individual elements are joined along edges. The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial_x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial_y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial_z}\left(K_{zz}\frac{\partial h}{\partial x}\right)\pm W=S_S\frac{\partial h}{\partial t} \qquad \text{Equation 1}$$

where:
Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

- h is the potentiometric head (L).
- W is a volumetric flux per unit volume representing sources and/or sinks of water, with:
    - W < 0.0 for flow out of
    - W > 0.0 for flow in the groundwater system
- Ss is the specific storage of the porous material (L-1).
- t is time (T).

FEFLOW offers multiple iterative and two direct equation solvers. By default, FEFLOW uses iterative solvers because they are suited for problems of arbitrary size. Separate iterative solver types can be selected for the symmetric (flow) and unsymmetric (transport) equation systems.

The UMK model solver options were set to preconditioned conjugate-gradient (PCG) solver for flow and a BICGSTABP-type solver for transport. PCG show fast convergence and have proven efficient for typical problems over a wide range of applications in subsurface flow and transport problems (Diersch, 2015).

4.2 MODEL SETUP AND BOUNDARY CONDITIONS

Mamatwan Mine is situated between Tshipi and UMK Mines. The model domain is represented in Figure 6.

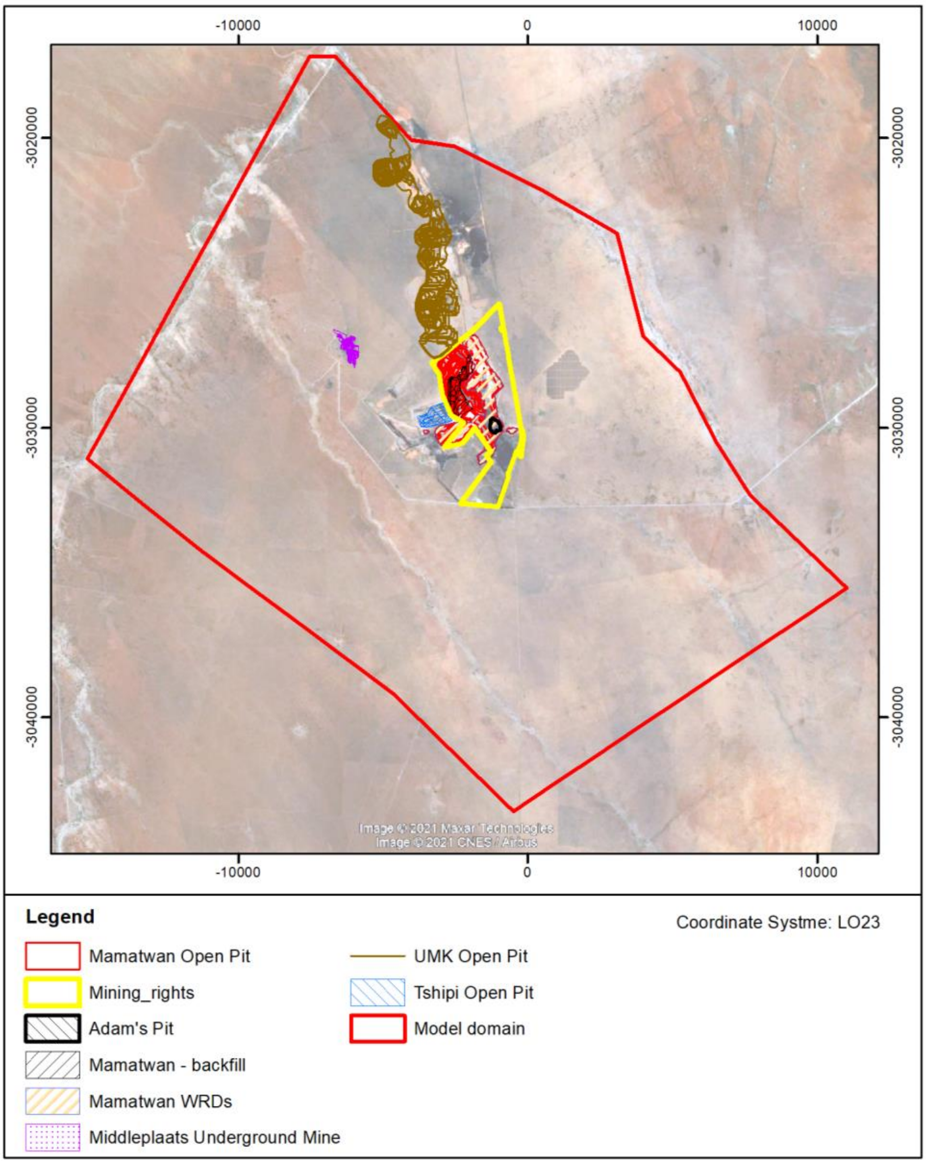

Figure 6: Mamatwan model domain

The model domain was selected based mainly on topography and the sub-catchments identified on the topographic data (RSA topography 50.000 series).

The western model boundary was selected as Specified head boundary, where groundwater flow in- and out- the model domain is allowed during predictive simulations.

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

The model domain covers a complex mining area, with several open pit mines being present in close proximity. Mamatwan Mine is situated immediately to the East of Tshipi and UMK Mine is situated approximately 2 km to the North of Tshipi.

From a groundwater flow point of view, all these mines will have a cumulative effect on groundwater flow and therefore the groundwater model has to take all these into consideration for a reasonable impact assessment.

4.3 SIMULATION OF MINING

Mining at Mamatwan open pit will take place until 2037. Concurrent backfill will also take place.
Figure 7 shows the mining and concurrent backfill, at 4 years timesteps.

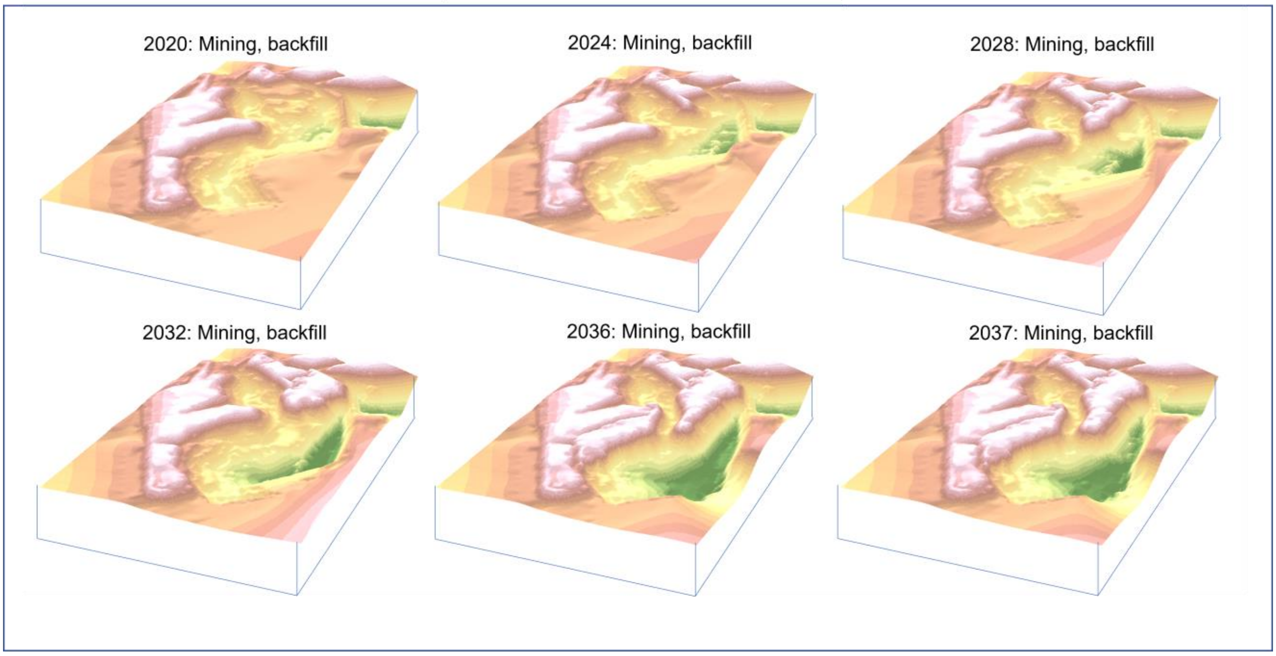

Figure 7: Mamatwan Open Pit - mining and backfill

The numerical model will take into consideration mining and backfill as following:

- Areas and depth of active mining are simulated as seepage face
- Backfill areas: seepage face nodes become inactive at backfill timesteps and backfill is simulated with its hydraulic properties.

The Middleplaats underground mine is (shown in Figure 8) is simulated as seepage face nodes which are active until 2037,

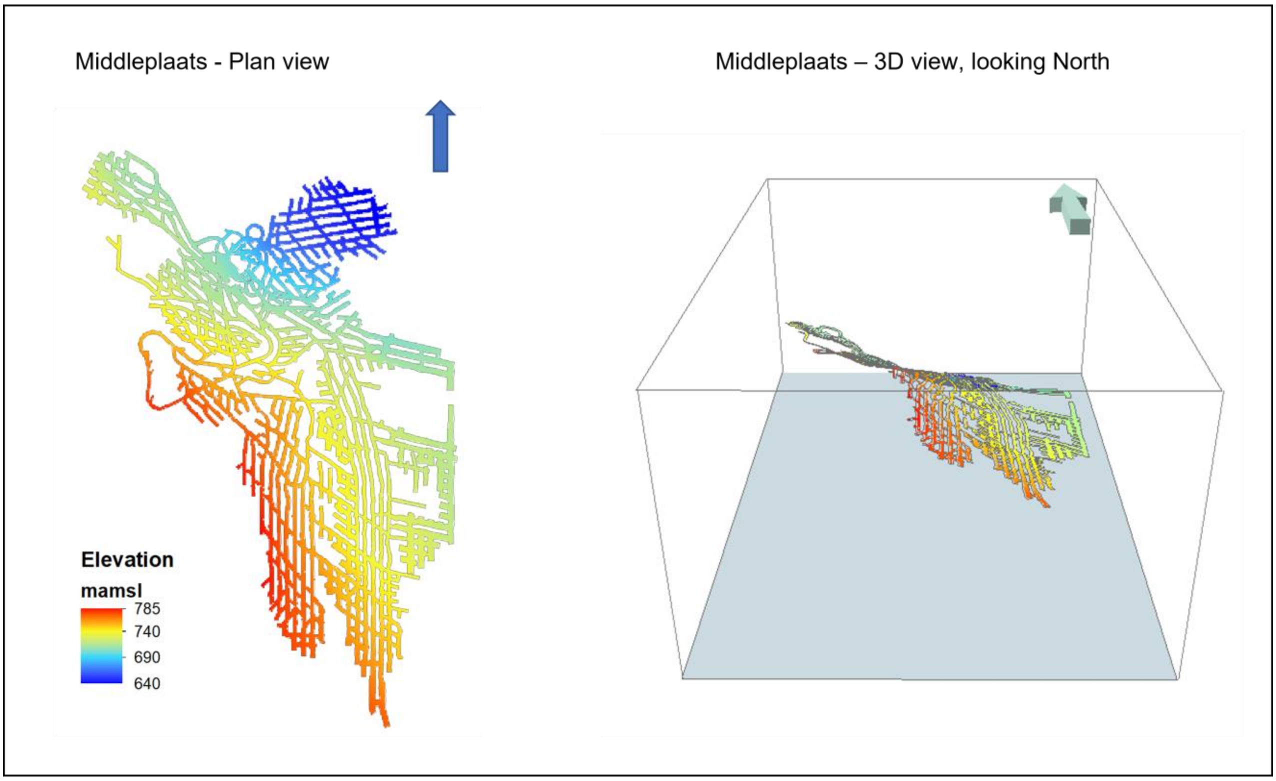

Figure 8: Middleplaats Underground Voids

4.4 PROCESSING MIDDLEPLAATS UNDERGROUND MINE

One objective of the Groundwater Study for the Mamatwan IRP Project is to demonstrate the availability and sustinability of groundwater from the old Middelplaats undeground workings to supply water to the Mamatwan operation.

The first effort to calculated the volumes of groundwater stored in the Middelplaats workings was done by Jones and Wagener in 2008.

SLR received the underground mine plans from South32. The plan, in MicroStation format (dgn) does not contain elevation values for the 3D features. The only elevation information is contained in the point component of the dgn file, with a sum total of 415 points .

The processing undertaken to obtain elevations for the underground mine features consited of:

1. Extract the elevation points from the points objects of the dgn (total of 415 points).
2. Contouring of the elevation points and create a surface corresponding to the geometry of the underground mine.
3. Drape the underground mine over the surface created,

The processing of the underground mine is illustrated in Figure 9. The resulting 3D underground mine draped over the surface created is shown in Figure 8.

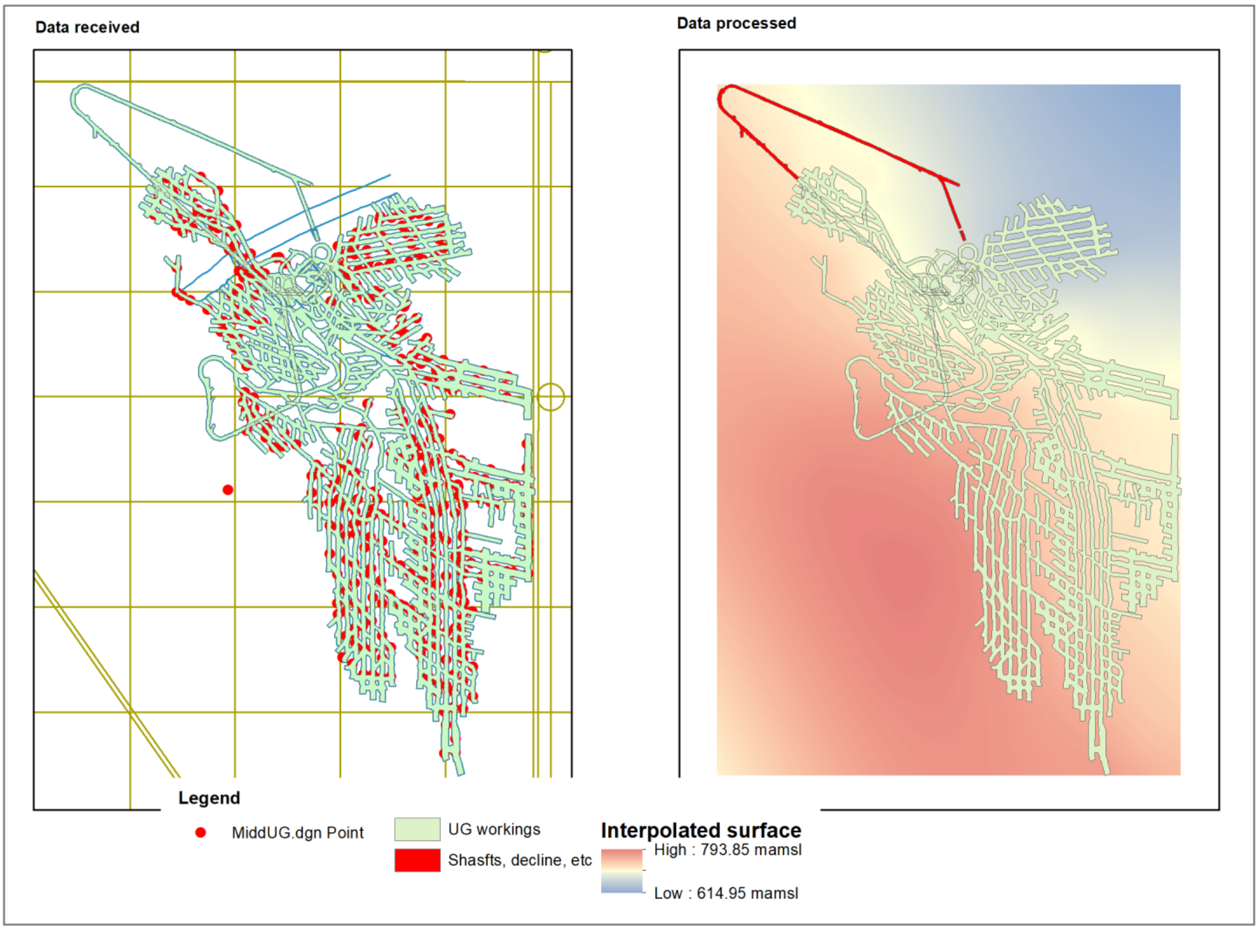

Figure 9: Processing of Middleplaats Underground

In the absence of any actual information and/or drilling data, the voids volumes have been calculated based on the polygon configuration of the underground mine plans.

The uncertainty of available groundwater volumes in the underground mine is derived from the height of the galleries or whether or not some of these have collapsed. Therefore, the voids volumes have been calculated using:

- Height of 3 m,
- Height of 5 m,
- Height of 7 m,
- Height of 10 m,
- Height of 14 m

For each of the height options the following was applied:

- 25% opened
- 50% opened
- 75% opened
- 100 opened

Figure 10 shows the possible volumes of water stored in the underground workings, considering different height and opening. The volumes of water estimated previously by Jones and Wagener are also included.

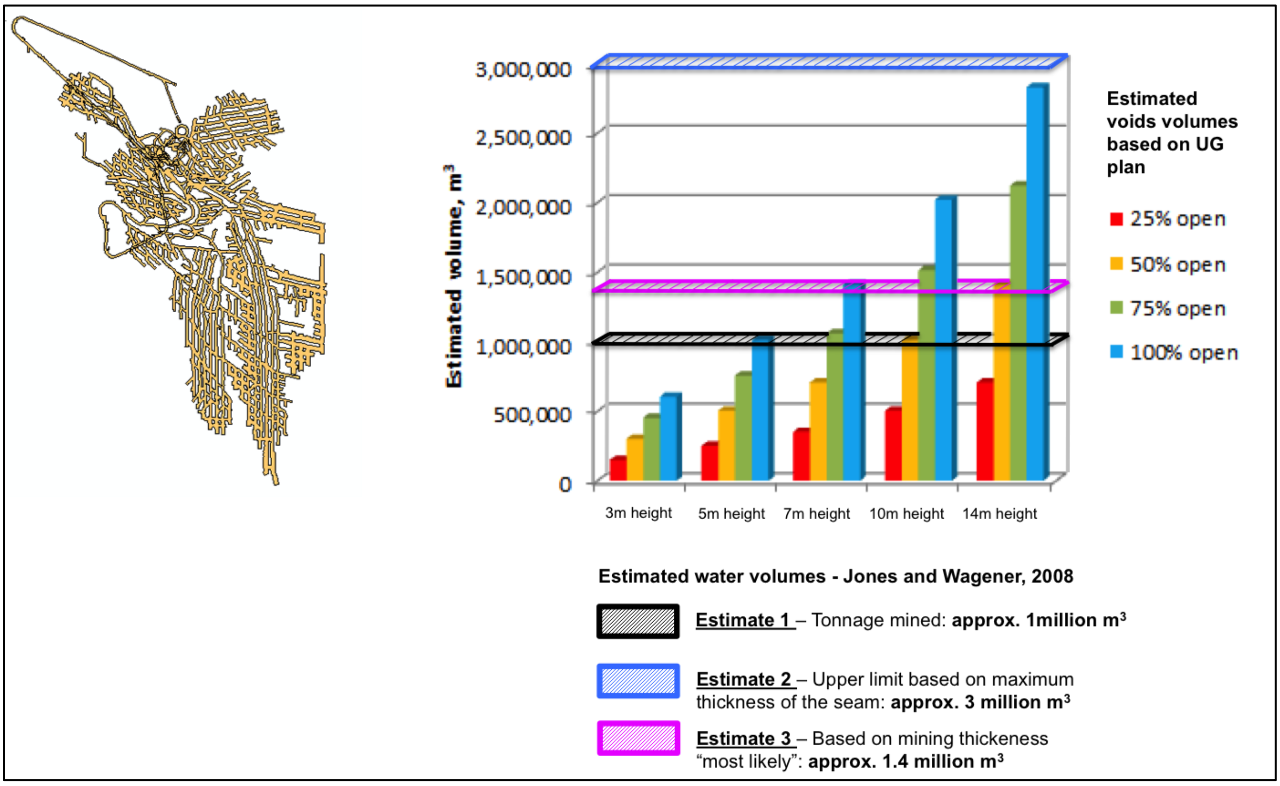

Figure 10: Volumes estimation

The volumes calculated compared to previous calculations (Jones and Wagener, 2008) indicate that a value of 7m height and 100% open leads to a reasonable storage of 1.4 million m^3 of water.

SLR recommends that this configuration (7m high and 100% open) can be further used for numerical modelling,

From the correspondence between SLR and Mamatwan it was concluded that for the purpose of groundwater preservation, the optimum volume to be pumped out is 1500m^3/day.

4.5 MODEL DISCRETIZATION

The model domain was discretized to allow for the simulation of hydraulic and geochemical elements, as shown in Figure 11:

- Mamatwan Mine: mining and backfilling
- Middleplaats Underground Mine
- Mamatwan WRDs
- Tshipi Mine
- UMK Mine
- Adams Pit

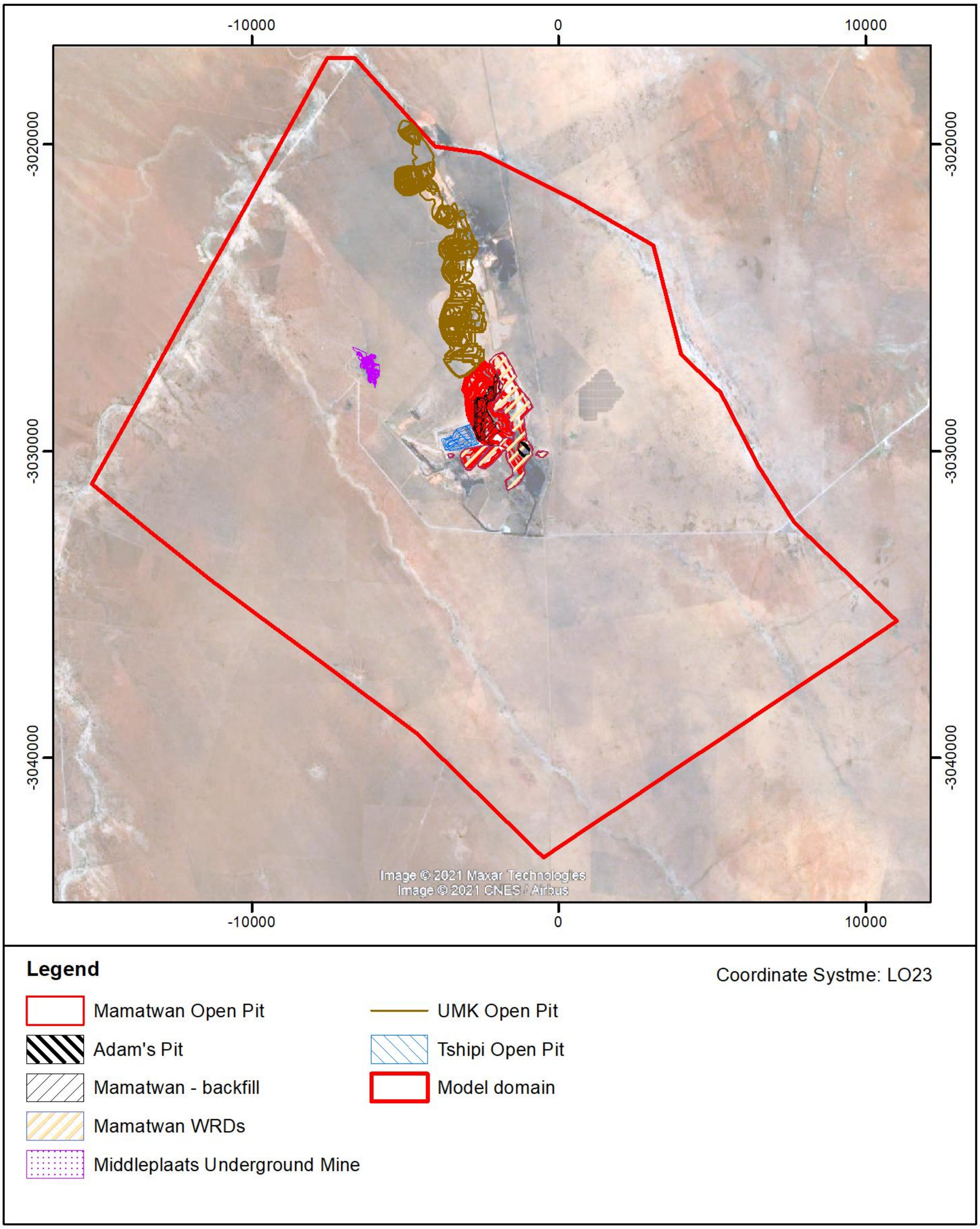

Figure 11: Hydraulic and Geochemical stresses

The resulting 2D finite elements mesh is shown in Figure 12:

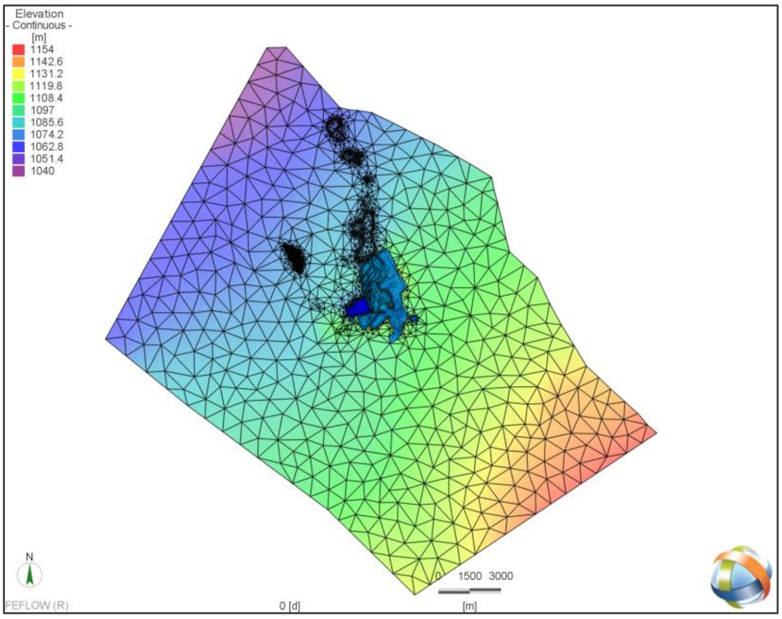

Figure 12: 2D Finite Elements Mesh

The vertical discretization was done based on the vertical layers selected for the Mamatwan model. The vertical layers were selected based on lithology, open pit mining levels, the underground mine levels. A cross section through the Middleplaats Underground and the Mamatwan Open pit is shown in Figure 13.

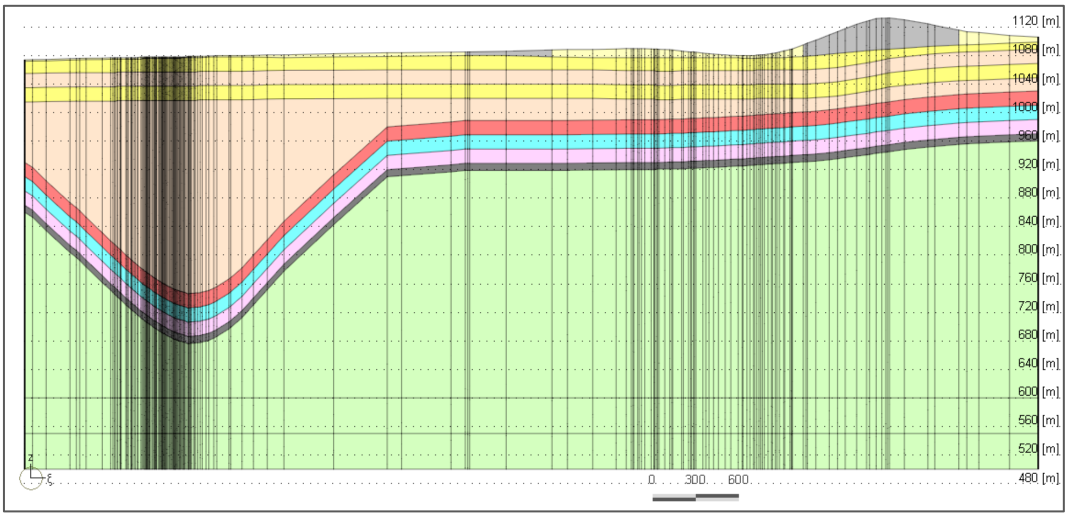

Figure 13: Mamatwan model - Cross section

The Mamatwan numerical model has a total of 12 vertical layers.

The resulting 3D model has:

- 198948 elements
- 108277 nodes

Figure 14 shows the Mamatwan 3D Numerical Model.

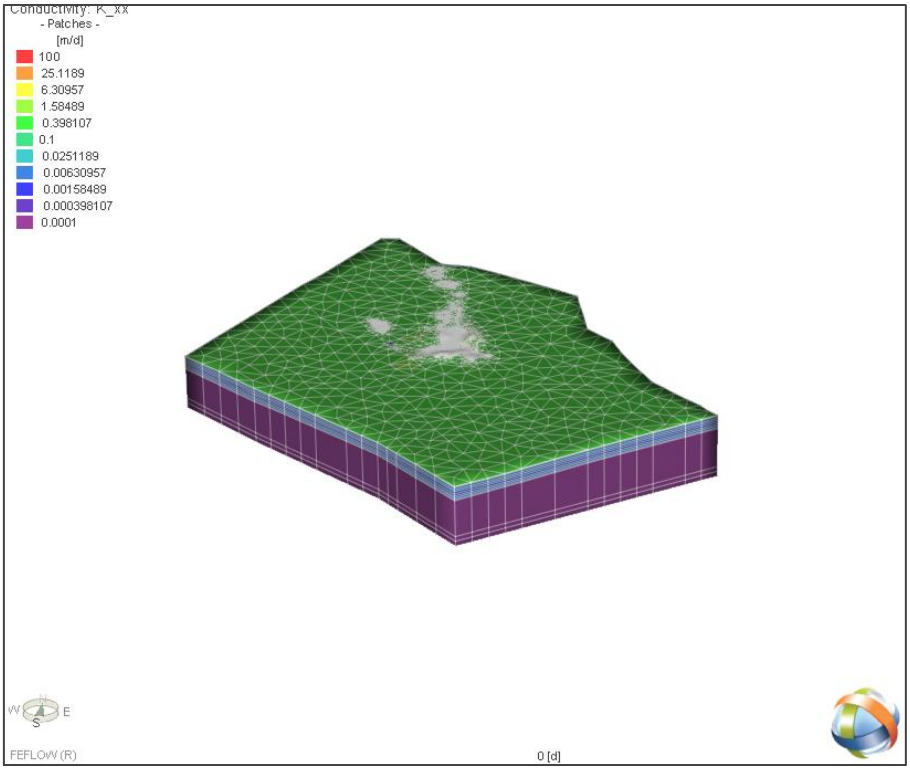

Figure 14: 3D Numerical Model

4.6 MODEL PROPERTIES

Table 1 shows the 12 layers selected based on mining and lithology, and their assigned hydraulic properties.

Table 1: Mamatwan Numerical Model - Hydraulic properties

MMT - Open Pit						Hydrogeology		
Slice	Description	Slice Z (Mine)	Layer	Mine Layer	Stratigraphy	K_h	K_v	S_s
1	topo flat	1080	Layer 1	1080 - 1060	Kalahari - Sands	0.5	0.05	0.001
2	topo -2m	1078						
2	topo -2m	1078	Layer 2		Kalahari - Sands	0.01	0.001	0.001
3	topo - 20m	1060						
3	topo - 20m	1060	Layer 3	1060 - 1040	Kalahari - Calcrete	0.005	0.0005	0.001
4	topo - 40m	1040						
4	topo - 40m	1040	Layer 4	1040 - 1020	Kalahary - Sands	0.01	0.001	0.001
5	topo - 60m	1020						
5	topo - 60m	1020	Layer 5	1020 - 1000	Kalahari - Clay, Conglomerate	0.05	0.005	0.005
6	topo - 80m	1000						
6	topo - 80m	1000	Layer 6	1000 - 980	Dwyka - Diamictite	0.001	0.0001	0.0001
7	topo - 100m	980						
7	topo - 100m	980	Layer 7	980 - 960	Mooidraai - Dolomite	0.009	0.0009	0.001
8	topo - 120m	960						
8	topo - 120m	960	Layer 8	960 - 940	Hotazel - BIF	0.008	0.0008	0.0001
9	topo - 140	940						
9	topo - 140	940	Layer 9	940 - 930	Mn ore layer, UG	0.0008	0.00008	0.0001
10	topo - 150	930						
10	topo - 150	930	Layer 10	930 - 600	Ongeluk Lava	0.0001	0.00001	0.0001
11	600 m	600						
11	600 m	600	Layer 11	600 - 550	Ongeluk Lava	0.0001	0.00001	0.0001
12	550 m	550						
12	550 m	550	Layer 12	550 - 500	Ongeluk Lava	0.0001	0.00001	0.0001
13	500 m	500						

The initial water levels have been interpreted over the entire model domain, using the measure water levels in observation boreholes throughout the domain.

Figure 15 shows the initial hydraulic head for the Mamatwan Numerical Model.

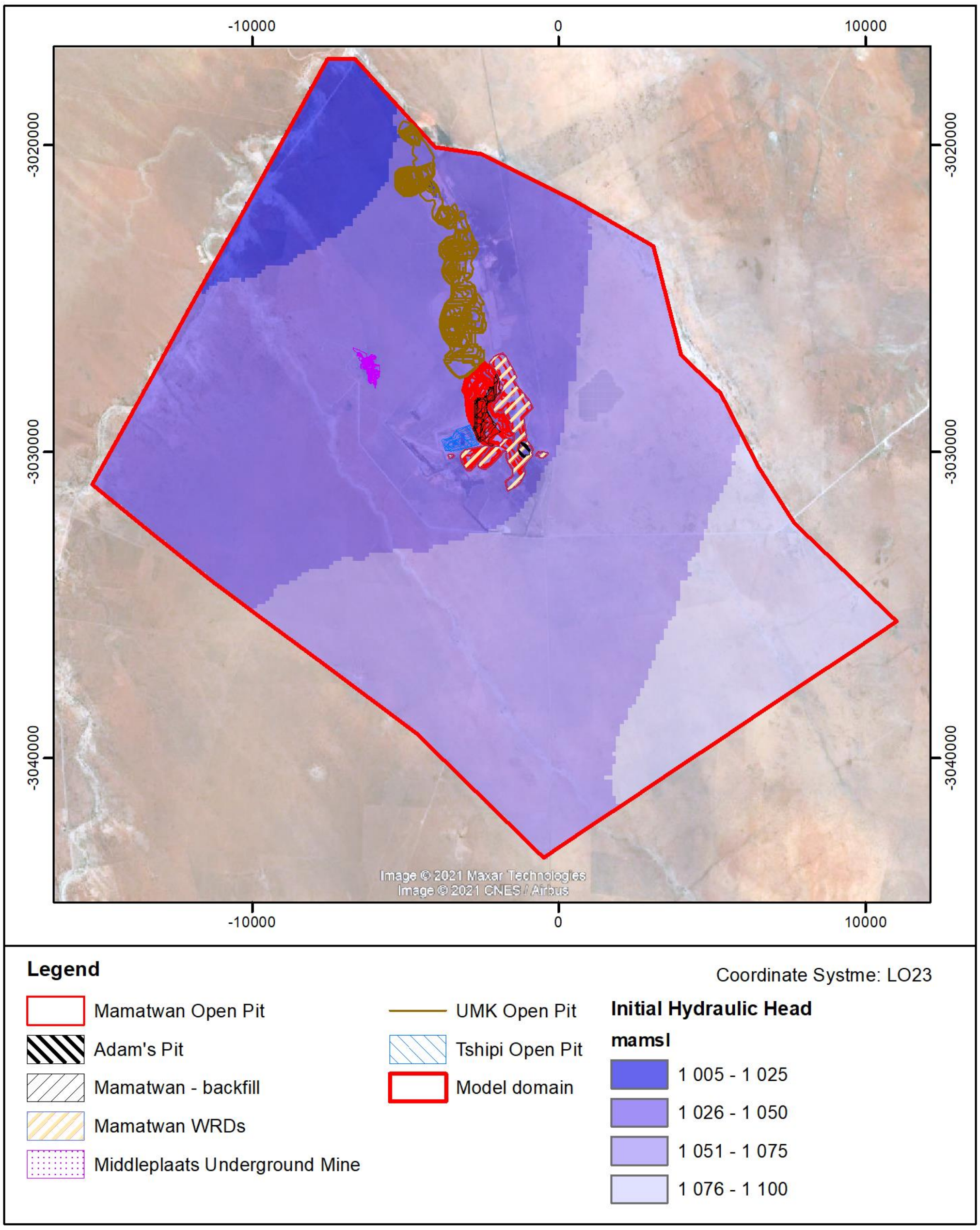

Figure 15: Initial Hydraulic Head

The groundwater gradient is estimated at 0.003 in a North-Eastern direction.
The rainfall recharge considered for the is 1% from MAP (Section 2.2) at a value of 3 mm/year.

4.7 MODEL RESULTS

The numerical model was run for a period of 100 years, as following:

- 2021 – 2037: 16 years of mining
- 2037 – 2121: 84 years post-mining

The results of the numerical modelling consist of:

- Predicted groundwater inflows
- Predicted cone of drawdown
- Predicted contaminant plume

4.7.1 Predicted groundwater inflows

Mamatwan Open Pit

It is assumed that the groundwater seepage into the Mamatwan Open Pit is pumped out from the pit sump. The groundwater passive inflows into the Mamatwan Pit are shown is Figure 16.

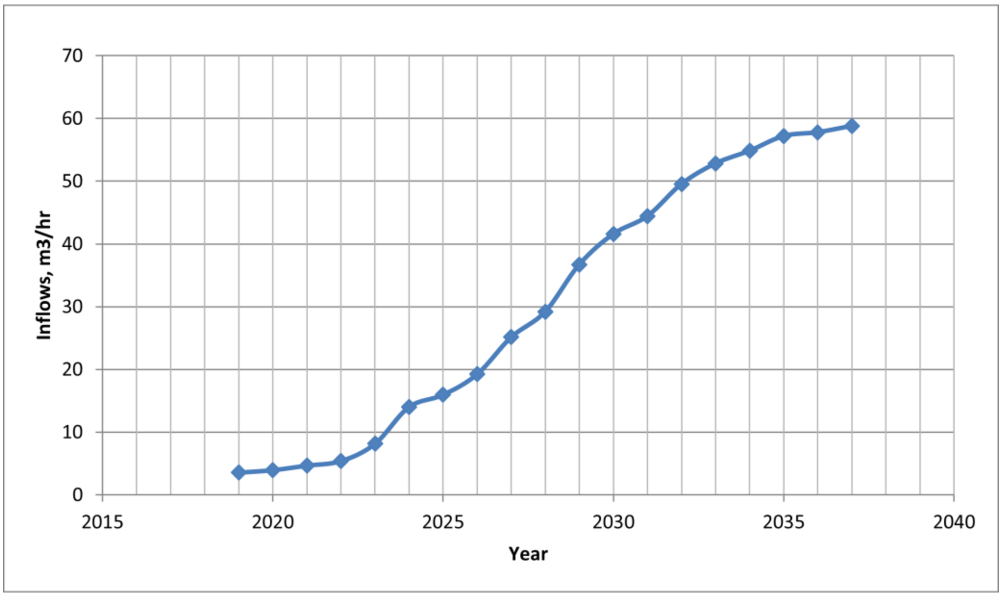

Figure 16: Groundwater passive inflow into the open pit

Middleplaats Underground Mine

The following assumptions have been made for the underground mine:

1- The total volume of water stored in the underground voids = 1,400,000 m^3
2- Two production boreholes will pump from the underground storage a total of 1,500 m^3/day; this volume will be depleted in approximately 3 years;
3- The groundwater available in the underground mine after the production pumping consists in passive groundwater flow (seepage) into the underground voids.

The groundwater passive inflows predicted for the Middleplaats Underground Mine are shown in Figure.

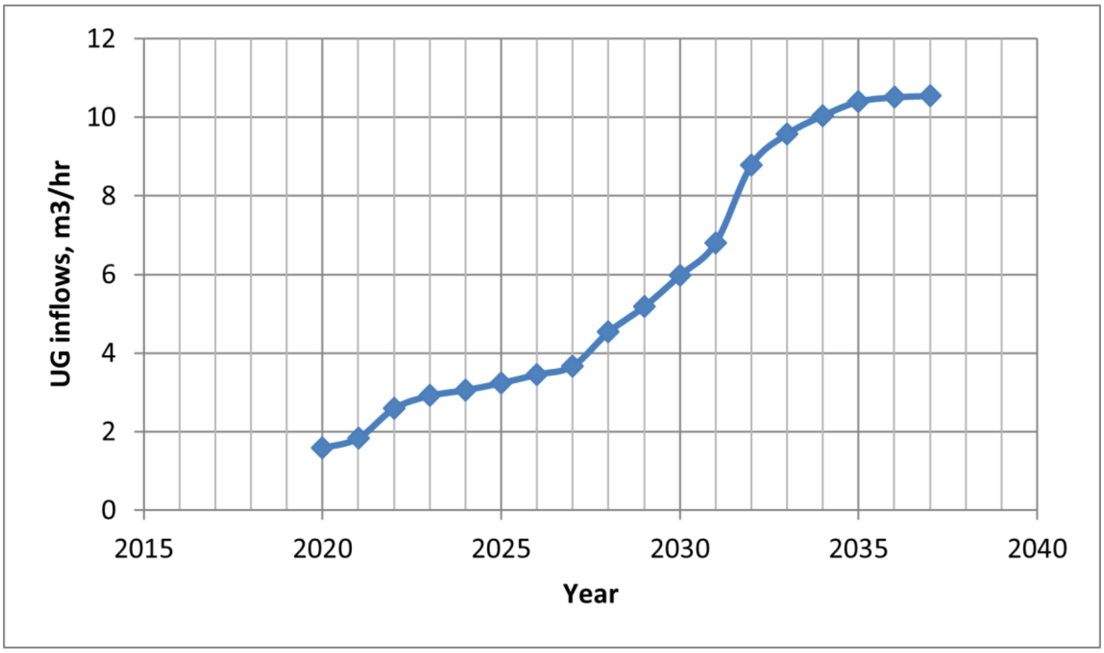

Figure 17: Groundwater passive inflows into Middleplaats underground voids

Table shows the total inflows predicted, from the open pit, underground and the planned underground pumping from 2 (two) production wells pumping for a total of 1,500 m^3/day = 62.5 m^3/hr (together).

Table 2: Total Groundwater (open pit, underground, production wells)

Year	Open pit pumping	UG inflows	UG storage pumping	Total	Total
	m3/hr	m3/hr	m3/hr	m3/hr	m3/day
2019	3.564				
2020	3.96	1.584	62.5	68.044	1633.056
2021	4.68	1.836	62.5	69.016	1656.384
2022	5.4	2.592	62.5	70.492	1691.808
2023	8.136	2.916		11.052	265.248
2024	14.004	3.06		17.064	409.536
2025	15.948	3.24		19.188	460.512
2026	19.224	3.456		22.68	544.32

Year	Open pit pumping	UG inflows	UG storage pumping	Total	Total
	m3/hr	m3/hr	m3/hr	m3/hr	m3/day
2027	25.128	3.672		28.8	691.2
2028	29.196	4.536		33.732	809.568
2029	36.72	5.184		41.904	1005.696
2030	41.58	5.976		47.556	1141.344
2031	44.424	6.804		51.228	1229.472
2032	49.536	8.784		58.32	1399.68
2033	52.812	9.576		62.388	1497.312
2034	54.828	10.044		64.872	1556.928
2035	57.168	10.404		67.572	1621.728
2036	57.78	10.512		68.292	1639.008
2037	58.788	10.548		69.336	1664.064

4.7.2 Cone of drawdown

The cone of drawdown develops during mining. After mining activities are stopped, it is expected that the water levels recover to a certain level.
Due to the sensitivity of the information, the adjacent mines have been simulated as follows:

- UMK Mine: assumed that the open pit will be pumped dry until 2037; after that the recovery period starts;
- Tshipi Mine: assumed that the open pit will be pumped dry until 2037; after that the recovery period is starting;

The cone of drawdown associated to Mamatwan open pit mining, UMK open pit mining and Tshipi open pit mining, together with pumping from the Middleplaats underground mine as per Table 2, is shown in Figure 18 and Figure 19.

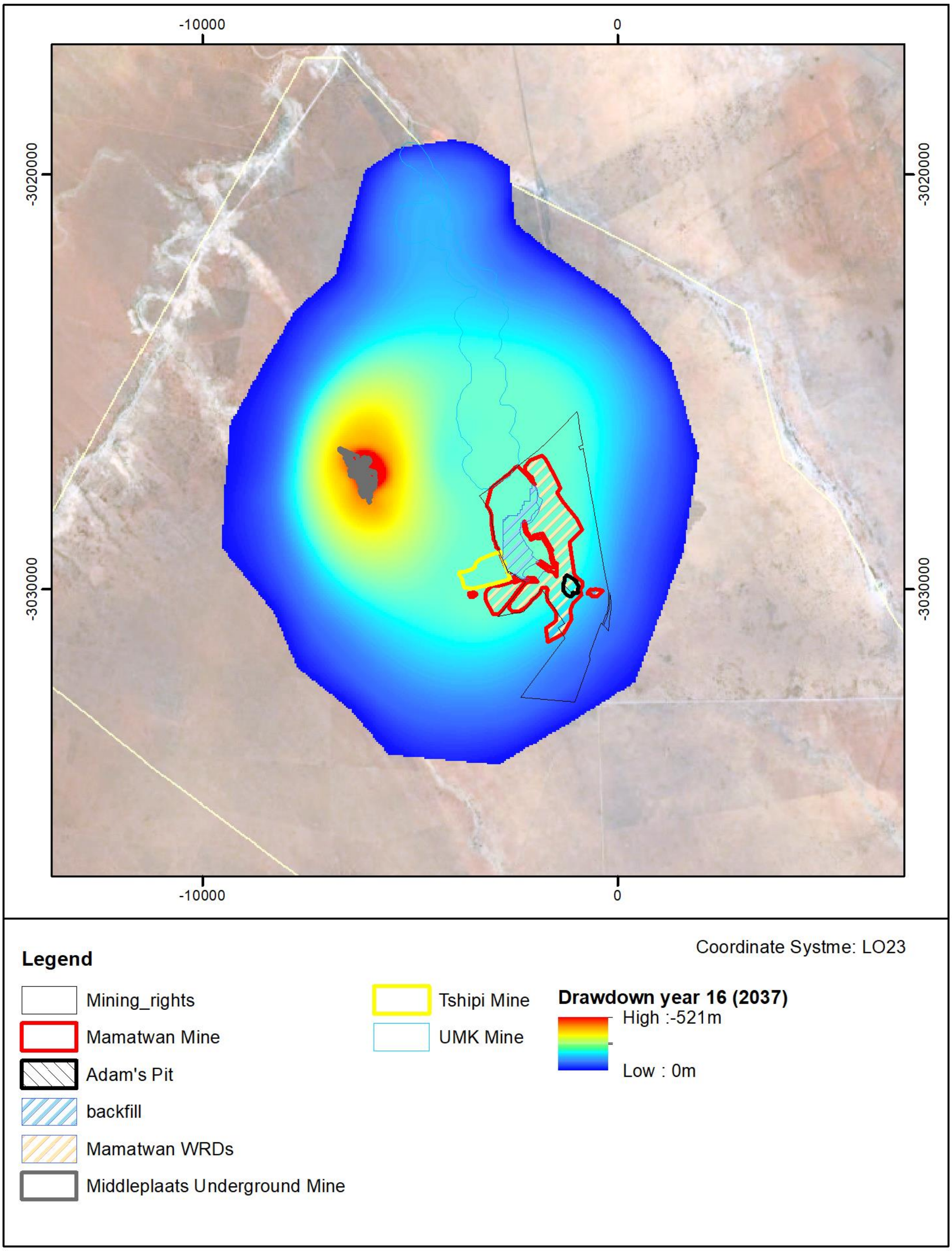

Figure 18: Cone of drawdown in year 2037 (end of mining)

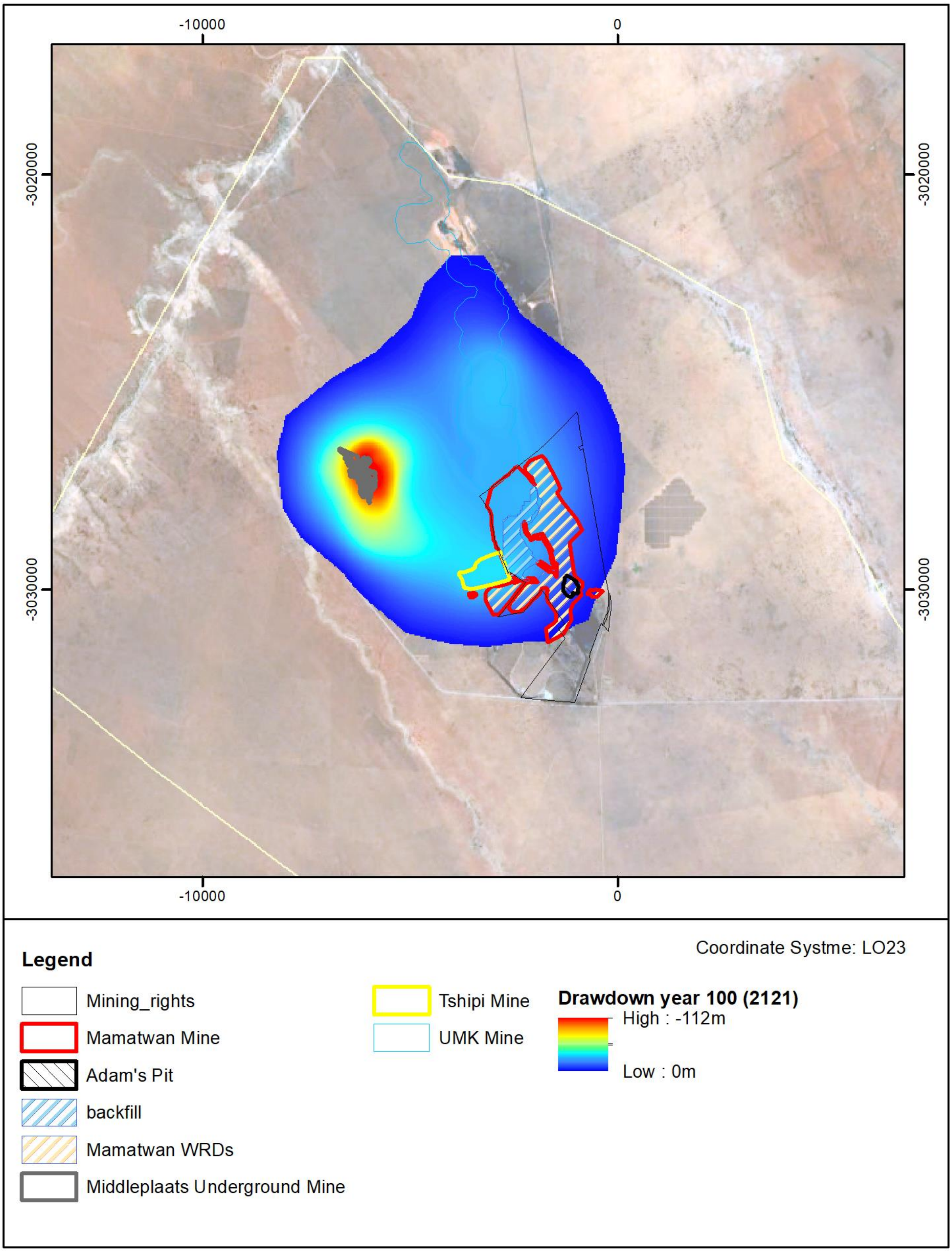

Figure 19: Cone of drawdown in year 2121 (100 years of simulation, 84 years post mining)

4.7.3 Development of a contaminant plume

The sources for the contaminant transport are:

- Mamatwan WRD
- Mamatwan in-pit backfill
- Adams Pit

The Waste Assessment and Geochemical Characterization report (SLR, June 2021) states that due to a low sulphide and high neutralisation potential of samples they are all classified as non-PAG. The dominant phases in the samples in Adam's Pit are manganese and carbonates rich minerals.

Source concentrations were determined for the waste rock, slimes (pumped into Adam's pit) and the Adam's pit stockpile (DMS grit, Sinter de-dust and tailings (M2FT)). These results can be used as input to the groundwater modelling and risk evaluation.

For the waste rock the modelled results (Table 3) indicate values above drinking water quality guidelines for aluminium, barium, boron, fluoride, nitrate and pH.

Table 3: Waste rock model results

Constituent	Unit	SANS 241:2015	DWAF TWQG	MMT-WR10 Laboratory Composite	MMT-WR10 WRD mix PhREEQC estimate	MMT-WR01 (Worst Sample)	Top cut: WR Comp MMT-06: MMT-WR10 25,5% : 74,5%
pH	pH Unit	5 - 9.7	N/A	7,45	6,89	12,22	9,22
Al	mg/l	0.3	5	0,12	0,61	0,27	0,01
B	mg/l	2.4	5	0,34	2,24	11,94	0,02
Ba	mg/l	0.7	N/A	1,58	2,76	12,72	0,10
Alkalinity	mg/l as CaCO3	N/A	N/A	220,09	360,85	0,47	18,77
Ca	mg/l	N/A	1000	69,01	128,97	798,35	7,18
Cl	mg/l	300	1500	14,40	8,15	6,11	1,14
F	mg/l	1.5	2	1,55	1,08	0,98	0,09
Fe	mg/l	2	10	0,00	0,00	0,03	0,00
K	mg/l	N/A	N/A	9,71	8,67	8,33	0,81
Mg	mg/l	N/A	500	2,85	5,15	0,96	0,28
Mn	mg/l	0.4	10	0,00	0,01	0,00	0,00
NO3 as N	mg/l	11	22	18,55	10,58	6,10	6,67
Na	mg/l	200	2000	57,73	23,70	11,02	3,75
Ni	mg/l	0.07	1	0,00	0,01	0,03	0,00
SO4	mg/l	500	1000	76,33	18,26	53,56	4,25

Si	mg/l	N/A	N/A	6,13	17,36	65,61	0,47
Sr	mg/l	N/A	N/A	0,37	0,47	1,63	0,02
V	mg/l	N/A	1	0,17	0,06	0,02	0,01
W	mg/l	N/A	N/A	0,06	0,02	0,01	0,00
Zn	mg/l	5	20	0,01	0,06	0,03	0,00
TDS	mg/l	1200	N/A	468,67	564,34	884,90	42,85

Adam's Pit contains a number of different waste types. A source terms model was developed for Adam's pit using the following proportions:

- Tailings (M2FT) – 86%
- Slimes - 6%
- Sinter de-dust – 3%
- DMS grit – 5%

The modelled results (Table 4) indicate the possibility of above threshold manganese and lead leachate concentrations for the mixture of waste types found in Adam's pit .

Table 4: Modelling results for the stockpile in Adam's Pit

Constituent	Unit	SANS 241:2015	DWAF TWQG	Adam's Pit Stockpile Mix
pH	pH Unit	5 - 9.7	N/A	7,89
Al	mg/l	0.3	5	0,19
B	mg/l	2.4	5	1,63
Ba	mg/l	0.7	N/A	0,50
Alkalinity	mg/l as CaCO3	N/A	N/A	87,01
Ca	mg/l	N/A	1000	43,60
Cl	mg/l	300	1500	10,37
Cr	mg/l	0.05	1	0,00
F	mg/l	1.5	2	0,50
Fe	mg/l	2	10	0,00
K	mg/l	N/A	N/A	5,44
Mg	mg/l	N/A	500	30,28
Mn	mg/l	0.4	10	0,62
Mo	mg/l	N/A	0.01	0,01
NO3 (as N)	mg/l	11	22	15,65
Na	mg/l	200	2000	11,64
Ni	mg/l	0.07	1	0,01
Pb	mg/l	0.01	0.1	0,01
Rb	mg/l	N/A	N/A	0,01
SO4	mg/l	500	1000	141,01
Si	mg/l	N/A	N/A	6,17
Sr	mg/l	N/A	N/A	0,39
V	mg/l	N/A	1	0,00
W	mg/l	N/A	N/A	0,00

Constituent	Unit	SANS 241:2015	DWAF TWQG	Adam's Pit Stockpile Mix
Zn	mg/l	5	20	0,01

The mass transport simulation were run for the following source terms:

- Nitrate: source concentration = 18.55 mg/l from the WRD and in-pit backfill,
- Manganese: source concentration = 0.62 mg/l from Adam's Pit.

Figure 20 and Figure 21 show the development of the Nitrate plume from the Mamatwan WRD and in-pit backfill.

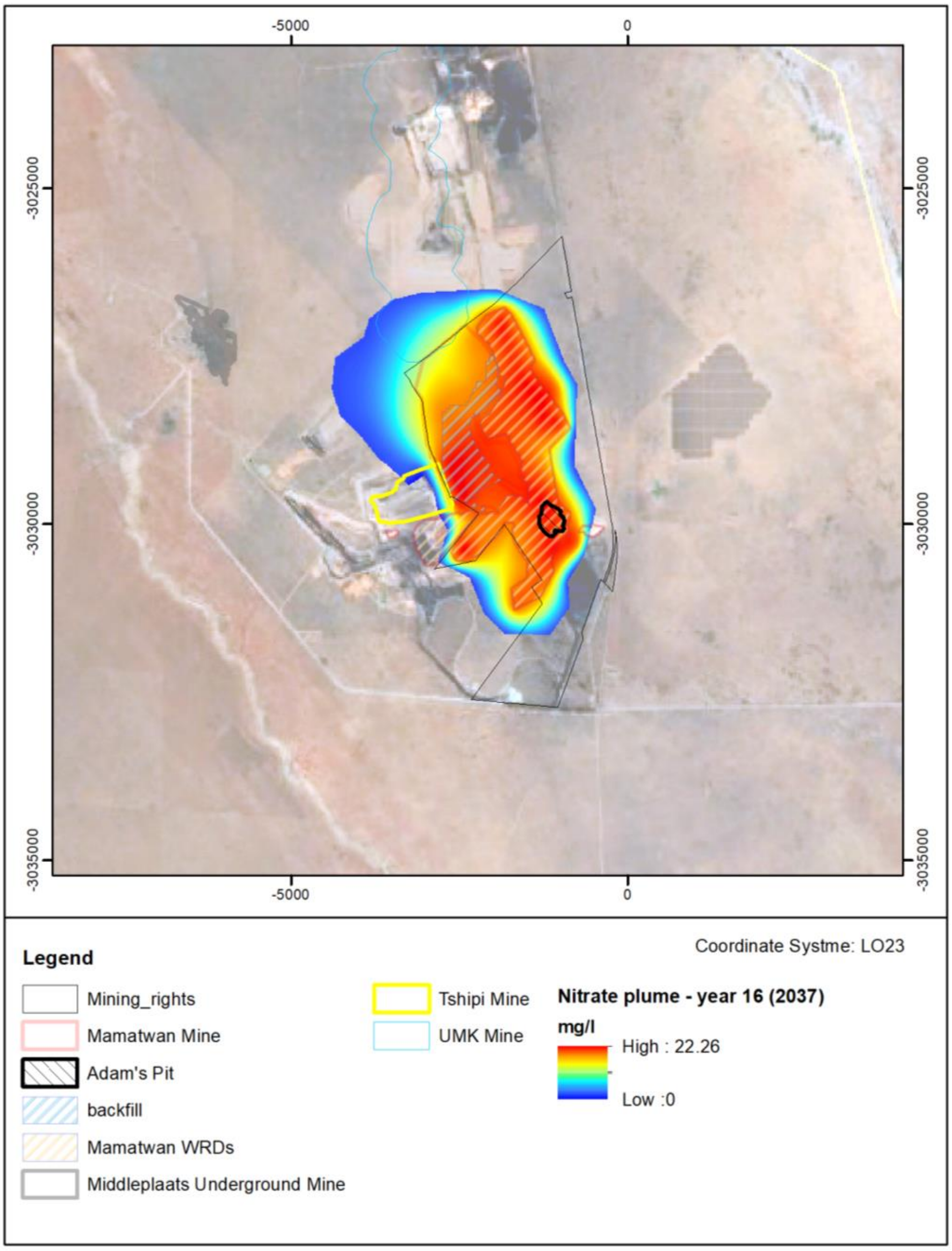

Figure 20: Predicted Nitrate plume in year 2037 (end of mining)

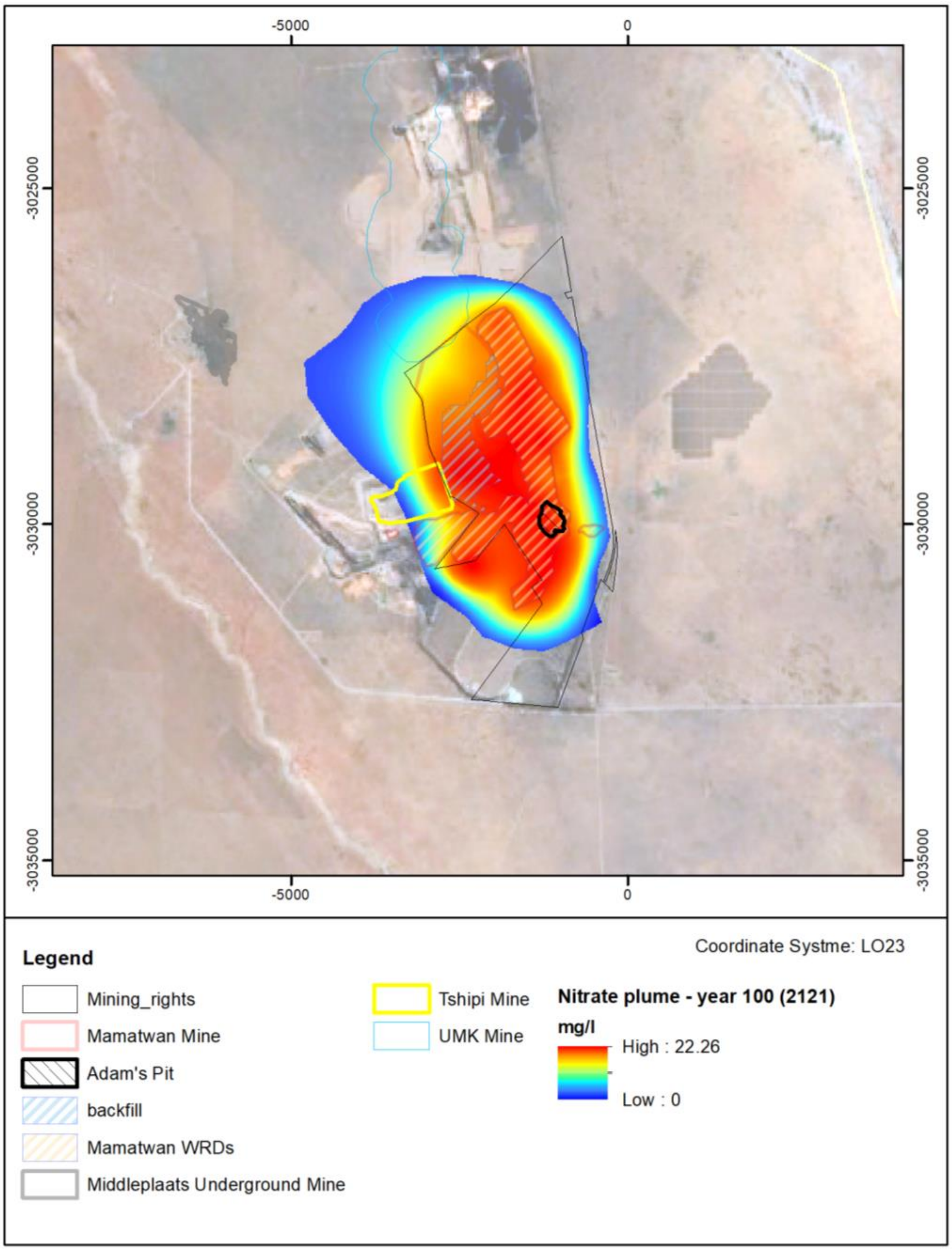

Figure 21: Predicted Nitrate plume in year 2121 (end of simulation, 84 years post-mining)

Figure 22 and Figure 23 show the development of the Manganese plume originated from Adam's Pit.

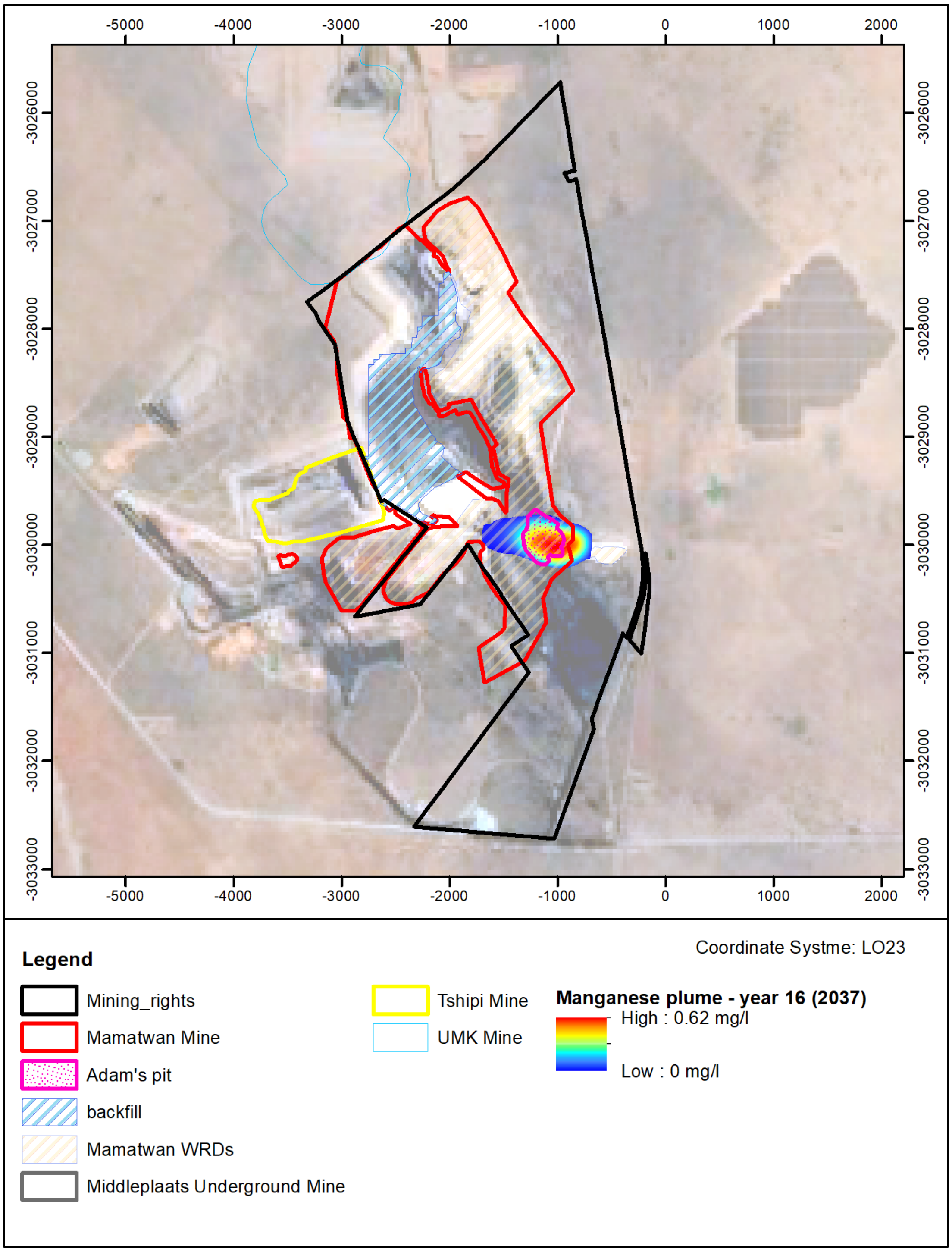

Figure 22: Predicted Manganese plume in year 2037 (end of mining)

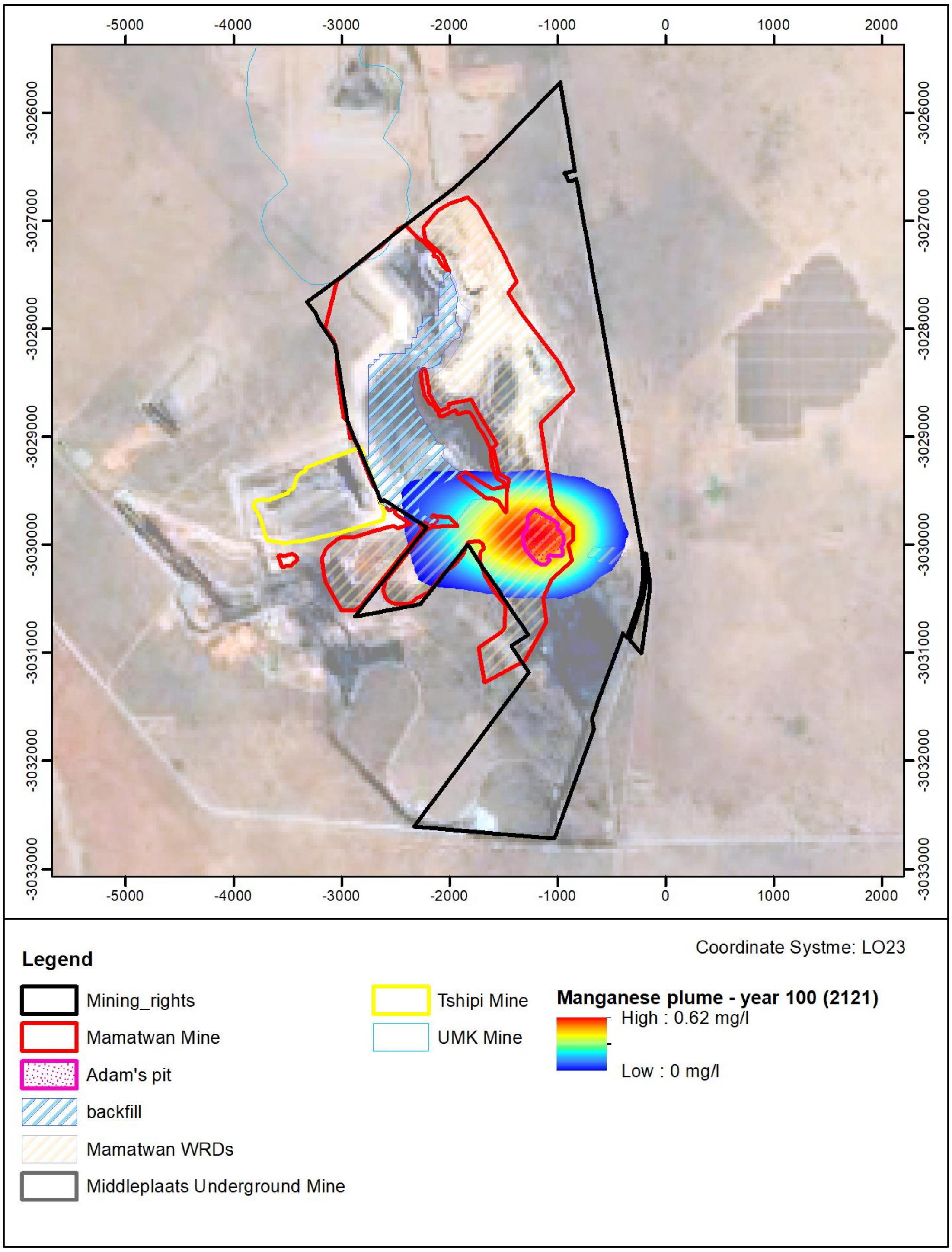

Figure 23: Predicted Manganese plume in year 2121 (end of simulation, 84 years post-mining)

5. CONCLUSIONS AND RECOMMENDATIONS

The groundwater inflows into the Mamatwan Open Pit, Middleplaats Underground and the total production pumping are shown in Figure.

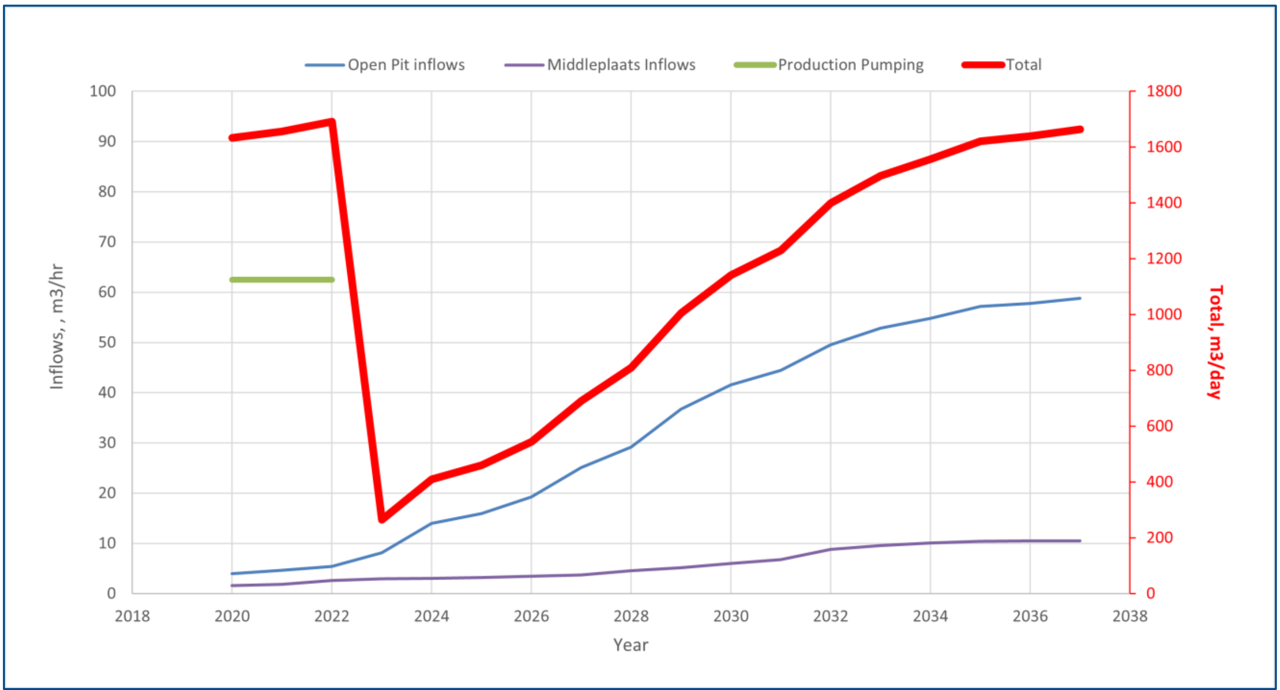

Figure 24: Total Pumping

After the 4th Year of production pumping, once the underground storage is depleted, there will be a deficit of groundwater available for pumping.

As mining is progressing and the Mamatwan open pit becomes deeper and larger, the inflow increase and for the last 5 years of mining (2022 – 2937) the available groundwater will be closer to 1,500 m3/day.

If the water demand will remain constant at 1,500 m3/day, then Mamatwan Mine should make alternative plans for water supply.

The cone of drawdown will be at maximum development at the end of the mining period (2037) – assuming that Middleplaats underground will be pumped continuously until 2037. The drawdown created will recover intime, however, a residual drawdown is predicted at the end of the 100 years of simulation (84 years post-mining).

The contaminant plume will be restricted at the end of mining (2037) due to the hydraulic gradients into the Mamatwan Open Pit and Middleplaats Underground.

As the cone of drawdown starts recovering, the plumes start migrating, as shown in Table 5.

Table 5: Predicted Distance Plume Migration

CoC	Source Term	Maximum Distance	Maximum direction
Nitrate	Mamatwan WRD, backfill	1600 m (year 2121)	West
Manganese	Adam's Pit	1071 m (year 2121)	West

However, it must be noted that the Manganese plume, at it largest development (year 100 of simulation), is well within the Mining Rights Area.

5.1 RECOMMENDED MONITORING NETWORK

Some of the boreholes included in the monitoring network might be damaged/lost due to Mamatwan pit expansion and WRD/backfill expansion.

Therefore, SLR recommends that replacement boreholes, as well as cone of drawdown and contaminant plume monitoring boreholes to be drilled and added to the monitoring network.

Figure 25 shows the existing and the proposed groundwater monitoring boreholes for the Mamatwan Monitoring System. Unfortunately, the Tshipi Mine property and WRD are situated on the Western side of Mamatwan boundary. If suitable location can be found, then it is advisable to locate one monitoring borehole on the Western side of Mamatwan Pit.

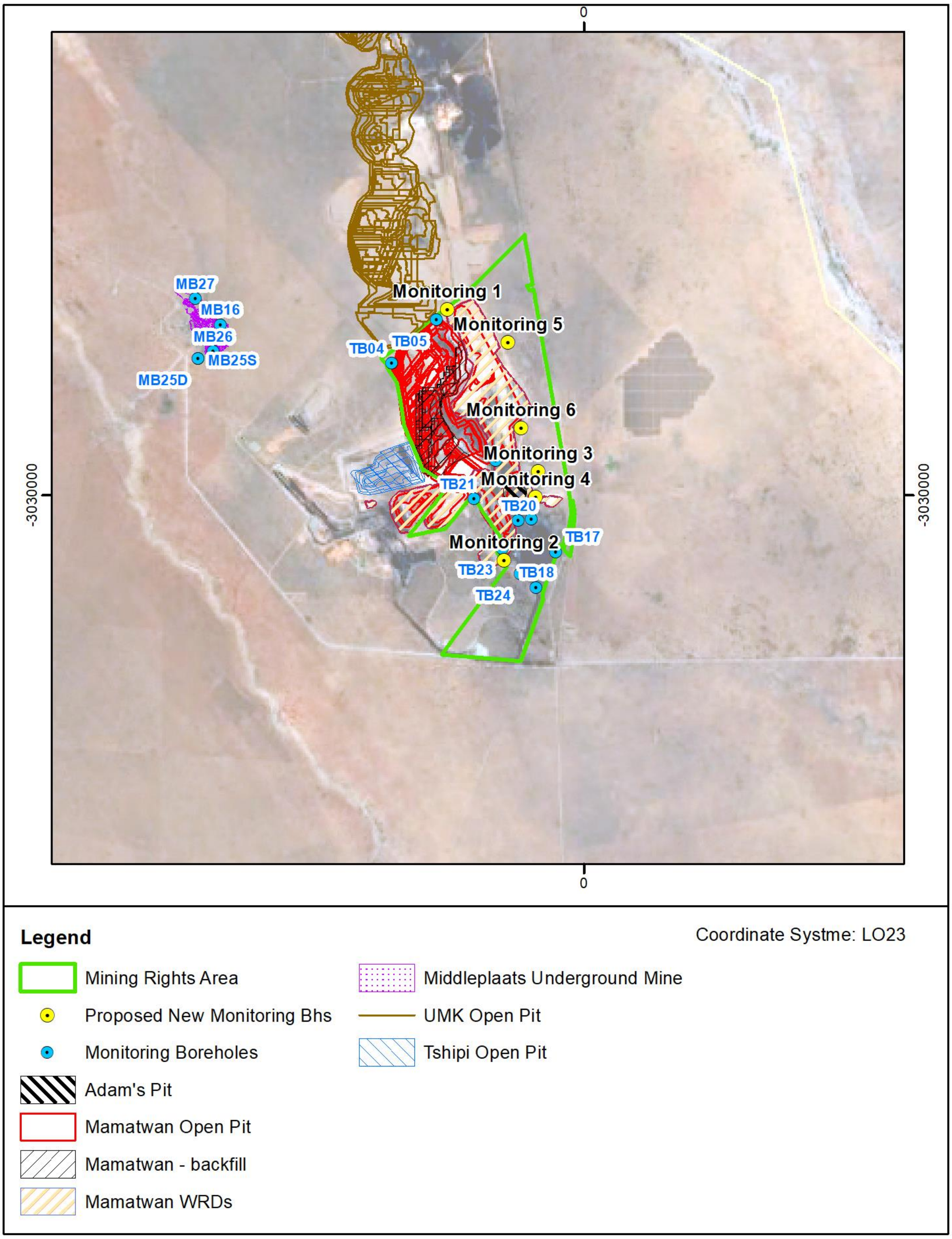

Figure 25: Proposed new monitoring locations

Table shows the coordinates (LO23) for the proposed new monitoring boreholes.

Table 6: Proposed new monitoring boreholes

Name	X	Y
Monitoring 1	-2237.85	-3026946.57
Monitoring 2	-1303.49	-3031070.54
Monitoring 3	-744.83	-3029613.59
Monitoring 4	-789.03	-3030028.59
Monitoring 5	-1236.85	-3027486.59
Monitoring 6	-1019.53	-3028895.89

Please note that the proposed locations must be verified to confirm accessibility, and that the locations are safe (they will not be covered by waste).

6. GROUNDWATER IMPACTS

6.1 METHODOLOGY USED IN DETERMINING THE SIGNIFICANCE OF IMPACTS

Assessment methodology enables the assessment of environmental issues including cumulative impacts, the severity of impacts (including the nature of impacts and the degree to which impacts may cause irreplaceable loss of resources), the extent of the impacts, the duration and reversibility of impacts, the probability of the impact occurring, and the degree to which the impacts can be mitigated.

IMPACT ASSESSMENT METHODOLOGY

Note: Part A provides the definition for determining impact consequence (combining intensity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D. **PART A: DEFINITIONS AND CRITERIA***		
Definition of SIGNIFICANCE		Significance = consequence x probability
Definition of CONSEQUENCE		Consequence is a function of intensity, spatial extent and duration
Criteria for ranking of the INTENSITY of environmental impacts	VH	Severe change, disturbance or degradation. Associated with severe consequences. May result in severe illness, injury or death. Targets, limits and thresholds of concern continually exceeded. Substantial intervention will be required. Vigorous/widespread community mobilization against project can be expected. May result in legal action if impact occurs.
	H	Prominent change, disturbance or degradation. Associated with real and substantial consequences. May result in illness or injury. Targets, limits and thresholds of concern regularly exceeded. Will definitely require intervention. Threats of community action. Regular complaints can be expected when the impact takes place.
	M	Moderate change, disturbance or discomfort. Associated with real but not substantial consequences. Targets, limits and thresholds of concern may occasionally be exceeded. Likely to require some intervention. Occasional complaints can be expected.
	L	Minor (Slight) change, disturbance or nuisance. Associated with minor consequences or deterioration. Targets, limits and thresholds of concern rarely exceeded. Require only minor interventions or clean-up actions. Sporadic complaints could be expected.
	VL	Negligible change, disturbance or nuisance. Associated with very minor consequences or deterioration. Targets, limits and thresholds of concern never exceeded. No interventions or clean-up actions required. No complaints anticipated.
	VL+	Negligible change or improvement. Almost no benefits. Change not measurable/will remain in the current range.
	L+	Minor change or improvement. Minor benefits. Change not measurable/will remain in the current range. Few people will experience benefits.
	M+	Moderate change or improvement. Real but not substantial benefits. Will be within or marginally better than the current conditions. Small number of people will experience benefits.
	H+	Prominent change or improvement. Real and substantial benefits. Will be better than current conditions. Many people will experience benefits. General community support.
	VH+	Substantial, large-scale change or improvement. Considerable and widespread benefit. Will be much better than the current conditions. Favourable publicity and/or widespread support expected.
Criteria for ranking the DURATION of impacts	VL	Very short, always less than a year. Quickly reversible
	L	Short-term, occurs for more than 1 but less than 5 years. Reversible over time.
	M	Medium-term, 5 to 10 years.
	H	Long term, between 10 and 20 years (likely to cease at the end of the operational life of activity).
	VH	Very long, permanent, +20 years (Irreversible, Beyond closure).
Criteria for ranking the EXTENT of impacts	VL	A part of the site/property.
	L	Whole site.
	M	Beyond the site boundary, affecting immediate neighbours.
	H	Local area, extending far beyond site boundary.
	VH	Regional/National

PART B: DETERMINING CONSEQUENCE							
INTENSITY = VL							
DURATION	Very long	VH	Low	Low	Medium	Medium	High
	Long term	H	Low	Low	Low	Medium	Medium
	Medium term	M	Very Low	Low	Low	Low	Medium
	Short term	L	Very low	Very Low	Low	Low	Low
	Very short	VL	Very low	Very Low	Very Low	Low	Low
INTENSITY = L							
DURATION	Very long	VH	Medium	Medium	Medium	High	High
	Long term	H	Low	Medium	Medium	Medium	High
	Medium term	M	Low	Low	Medium	Medium	Medium
	Short term	L	Low	Low	Low	Medium	Medium
	Very short	VL	Very low	Low	Low	Low	Medium
INTENSITY = M							
DURATION	Very long	VH	Medium	High	High	High	Very High
	Long term	H	Medium	Medium	Medium	High	High
	Medium term	M	Medium	Medium	Medium	High	High
	Short term	L	Low	Medium	Medium	Medium	High
	Very short	VL	Low	Low	Low	Medium	Medium
INTENSITY = H							
DURATION	Very long	VH	High	High	High	Very High	Very High
	Long term	H	Medium	High	High	High	Very High
	Medium term	M	Medium	Medium	High	High	High
	Short term	L	Medium	Medium	Medium	High	High
	Very short	VL	Low	Medium	Medium	Medium	High
INTENSITY = VH							
DURATION	Very long	VH	High	High	Very High	Very High	Very High
	Long term	H	High	High	High	Very High	Very High
	Medium term	M	Medium	High	High	High	Very High
	Short term	L	Medium	Medium	High	High	High
	Very short	VL	Low	Medium	Medium	High	High
			VL	L	M	H	VH
			A part of the site/ property	Whole site	Beyond the site, affecting neighbours	Extending far beyond site but localised	Regional/ National
			EXTENT				

PART C: DETERMINING SIGNIFICANCE							
PROBABILITY (of exposure to impacts)	Definite/ Continuous	VH	Medium	Medium	High	Very High	Very High
	Probable	H	Low	Medium	Medium	High	Very High
	Possible/ frequent	M	Low	Low	Medium	Medium	High
	Conceivable	L	Very Low	Low	Low	Medium	Medium
	Unlikely/ improbable	VL	Negligible	Very Low	Low	Low	Medium
			VL	L	M	H	VVH
			CONSEQUENCE				

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	Decision guideline
Very High	Potential fatal flaw unless mitigated to lower significance.
High	It must have an influence on the decision. Substantial mitigation will be required.
Medium	It should have an influence on the decision. Mitigation will be required.
Low	Unlikely that it will have a real influence on the decision. Limited mitigation is likely required.
Very Low	It will not have an influence on the decision. Does not require any mitigation
Negligible	Inconsequential, not requiring any consideration.

***VH = very high, H = high, M= medium, L= low and VL= very low and + denotes a positive impact**

6.2 ISSUE: DEVELOPEMNT OF THE CONE OF DRAWDOWN AS A RESULT OF MINING AND PRODUCTION PUMPING

Introduction

During mining, groundwater will be removed from the open pit and also from the underground storage. The groundwater volumes removed are increasing as the open pit becomes deeper and larger.
At the end of the mining period, the removal of groundwater for the system will cease and the groundwater is allowed to recover.

Mine phase and link to project specific activities/infrastructure

Construction	Operational	Decommissioning	Closure
Mining	Mining Production pumping from underground		Formation of pit lake

Table 7: Operational & closure phase impact summary – Impact on groundwater level and gradient

Issue: DEVELOPEMNT OF THE CONE OF DRAWDOWN AS A RESULT OF MINING AND PRODUCTION PUMPING		
Phases: Operational & closure phases		
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Moderate	Low
Duration	Long term – during Life of Mine	Long term – during Life of Mine
Extent	Medium	Medium
Consequence	Medium	Medium
Probability	Probable	Possible/ frequent
Significance	Medium	Low
Nature of cumulative impacts	Medium contribution to cumulative impacts, impacts would remain within the range previously assessed	
Degree to which impact may cause irreplaceable loss of resources	Medium during operational phase and groundwater levels will start to rebound during closure phase, but impact can be minimised if management measures are put in place and followed	

Issue: DEVELOPEMNT OF THE CONE OF DRAWDOWN AS A RESULT OF MINING AND PRODUCTION PUMPING	
Phases: Operational & closure phases	
Degree to which impact can be mitigated	Medium during operational phase, but impact can be minimised if management measures are put in place and followed
Degree to which impact can be reversed	Low during operational phase, but impact can be minimised if management measures are put in place and followed. Groundwater levels will start to rebound during closure phase

6.3 ISSUE: CONTAMINATION OF GROUNDWATER RESOURCES AS A RESULT OF THE IN-PIT BACKFILL, WRD DEPOSITION AND ADAM'S PIT DEPOSITION

Introduction

There are a number of sources in all mine phases that have the potential to pollute groundwater. Some sources are permanent (WRDs) and some sources are transient (starting later and at different time-steps) and becoming permanent (pit backfilling). Even though some sources are temporary in nature, related potential pollution can be long term. The operational phase will present more long-term potential sources (waste rock dumps and pit backfill, as the major source term) and the closure phase included in the period of simulation will present final land forms, such as the backfilled open pit may have the potential to pollute water resources through long term seepage and/or run-off.

The watercourses in the project area are not expected to be in hydraulic continuity with the main water table and therefore no groundwater related quality impacts are expected on rivers. This impact is therefore not assessed further and the discussion below focusses on potential human health impacts.

Mine phase and link to project specific activities/infrastructure

Construction	Operational	Decommissioning	Closure
Mineralised waste management Non-mineralised waste management Water use and management Support services Transportation system	Mineralised waste management Non-mineralised waste management Water use and management Support services Transportation system Continued use of approved facilities and services Open pit mining and backfilling	Mineralised waste management Non-mineralised waste management Water use and management Support services Transportation system Continued use of approved facilities and services Backfilling of open pit	Final land forms

The groundwater quality impact during the operational phase is summarised in Table 8.

Table 8: Operational & closure phase impact summary – Impact on groundwater quality

Issue: CONTAMINATION OF GROUNDWATER RESOURCES AS A RESULT OF THE PROPOSED ADDITIONAL SURFACE INFRASTRUCTURE (see Section 1.1)		
Phases: Operational & closure phases		
Criteria	**Without Mitigation**	**With Mitigation**
Intensity	Moderate	Low
Duration	High	High

Issue: CONTAMINATION OF GROUNDWATER RESOURCES AS A RESULT OF THE PROPOSED ADDITIONAL SURFACE INFRASTRUCTURE (see Section 1.1)		
Phases: Operational & closure phases		
Extent	Medium	Medium
Consequence	Medium	Medium
Probability	High	Low
Significance	Medium	Low
Nature of cumulative impacts	Minor contribution to cumulative impacts, impacts would remain within the range previously assessed	
Degree to which impact may cause irreplaceable loss of resources	Low during operational phase, but impact can be minimised if management measures are put in place and followed	
Degree to which impact can be mitigated	Low during operational phase, but impact can be minimised if management measures are put in place and followed	
Degree to which impact can be reversed	Low during operational phase, but impact can be minimised if management measures are put in place and followed	

Rating of impacts

Intensity

The contaminant transport modelling assumed that responsible housekeeping, management of diffuse pollution sources, and the draw down effect of the open cast pits on any contaminants from the temporary overburden/waste rock dumps, would limit the sources of significant groundwater contamination to the tailings dam facility. Modelling assumed a seepage rate that falls between that of the unlined scenarios for the WRD and backfill.

The conservatively predicted impact was that over a eighty-four year period, contamination of Nitrate concentrations would have migrated approximately 1600 m from maximum source concentration (in-pit). This impact was rated as being of medium significance.

The mass transport modelling conducted for the project has been completed in a non-reactive mode, which is conservative, and eliminating any diffusion, dispersion, attenuation, etc. The model assumed no barrier systems on the pollution sources. A waste assessment conducted in terms of R 635 found that the leachable concentrations did exceed in some instances the defined limit for the parameters assessed, and these included manganese and nitrate, as predicted by the geochemical modelling.

The simulations show that the maximum nitrate and manganese plumes developed from the sources extend as shown in Table 5, at the end of the simulation at year 100. Please note that this is nitrate/manganese concentrations resulting from the WRD/backfill load/deposition, which is added to the general water chemistry.
The predicted contamination plume is therefore not expected to impact on third party water users. When considered incrementally this has a low severity in the unmitigated and mitigated scenarios.

The cumulative severity rating assessing the impact of the changes to the operation within the context of the approved mining operations is low in the unmitigated scenario because the migration of the pollution plume is not expected to impact on third party water users.

Duration

Groundwater contamination is long term in nature, occurring for periods longer than the life of mine in both the unmitigated and mitigated scenarios.

Spatial scale / extent

The pollution plume will extend beyond the mining area in both the unmitigated and mitigated scenarios.

Consequence

The consequence is moderate in the unmitigated and mitigated scenarios.

Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources?
- Will people and animals utilise this contaminated water?
- Is the contamination level harmful?

The first element is that contamination reaches the groundwater resources underneath or adjacent to the mining area. Pollution plume modelling shows that contaminants could reach groundwater resources.

The second element is that third parties and/or livestock use this contaminated water for drinking purposes. There are no known third-party water users located within the predicted contaminant plume.

The third element is whether contamination is at concentrations which are harmful to users. Based on predicted groundwater modelling, mine related contamination could be at relatively increased concentrations for a small area to the west of the mining right area.

As a combination, the unmitigated probability is medium, and low with mitigation.

Significance

The unmitigated and mitigated scenario significance are medium and low, respectively.

Management objective

The objective is to prevent pollution of groundwater resources and related harm to other water users.

Management actions

Mamatwan will continue to implement the following management actions:

- Mamatwan will update the hydrocensus to check for any new third party water uses prior to initiating activities associated with the proposed surface infrastructural changes.
- Mamatwan should continue groundwater monitoring per existing monitoring protocols for the existing monitoring network, taking note of recommendation made in section 5.1.
- All potentially affected boreholes will be included in the water monitoring programme for boreholes located both on and off the mine site.
- If any mine related loss of water supply through a reduction in quality is experienced by third party borehole users, Mamatwan will provide compensation which could include an alternative water supply of equivalent water quality.
- Should any off-site contamination be detected, the mine will immediately notify DWS. The mine, in consultation with DWS and an appropriately qualified person, will then notify potentially affected

users, identify the source of contamination, identify measures for the prevention of this contamination (in the short term and the long term) and then implement these measures.

- At decommissioning, the potential pollution sources (residual waste rock left on surface) will either be removed or rehabilitated to manage rainfall and seepage.

The environmental manager is responsible for implementing these actions from prior to construction through to closure.

7. REFERENCES

Digby Wells, 2020, Groundwater Investigation for Mamatwan Mine, Northern Cape

GHT Consulting Scientists, 2018, Hotaxel Manganese Mines, Geohydrological Report for Mamatwan Mine

SLR Consulting, June 2021, Waste Assessment and Geochemical Characterization

RECORD OF REPORT DISTRIBUTION

SLR Reference:	720.19136.00002
Title:	Mamatwan Groundwater Study
Report Number:	1
Client:	South 32

Name	Entity	Copy No.	Date Issued	Issuer

AFRICAN OFFICES

South Africa

CAPE TOWN
T: +27 21 461 1118

JOHANNESBURG
T: +27 11 467 0945

DURBAN
T: +27 11 467 0945

Ghana

ACCRA
T: +233 24 243 9716

Namibia

WINDHOEK
T: + 264 61 231 287