APPENDIX F: HYDROGEOLOGICAL STUDY

Pilanesberg Platinum Mine Plant Expansion Hydrogeological Specialist Investigation

Groundwater Specialist Study
Draft report

Technical Report: **H44700075-7**
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Pilanesberg Platinum Mines:
Plant Expansion Hydrogeological Specialist Investigation

Groundwater Specialist Study

14 March 2019

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Notations and terms

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A *confined aquifer* is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The *darcy flux*, is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

A *fault* is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (**K**) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity, but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head (ϕ) is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a *piezometric surface*, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage (S_0)*,* of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, water table) aquifer, *specific yield* is the water that is released or drained from storage per unit decline in the water table.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids (TDS) is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

An *unconfined, water table or phreatic aquifer* are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

LIST OF ABBREVIATIONS

Abbreviation	Description
%	Percent
˚C	Degree Celsius
3D	Three-dimensional
cm	Centimetre
DTM	Digital Terrain Model
DWS	Department of Water and Sanitation
Etc.	Et cetera
ha	Hectare
K/h	Hydraulic Conductivity Horizontal
K/v	Hydraulic Conductivity Vertical
km^2	Square Kilometre
LoM	Life of Mine
mm/a	Millimetre per Annum
mg/ℓ	Milligram per Litre
m	Meter
m/d	Meter per Day
m^2	Square Meter
m^3/d	Cubic Meter per Day
Mm^3/a	Million Cubic Meter per Annum
magl	Meters Above Ground Level
mamsl	Meter Above Mean Sea Level
mbgl	Meter Below Ground Level (i.e. depth)
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
Ni	Nickel
PGM	Platinum Group Metal
PPM	Pilanesberg Platinum Mine
R^2	Correlation
RoM	Run of Mine
SANS	South African National Standard
SO_4	Sulphate
STP	Sewage Treatment Plant
SWD	Surface Water Dam
TSF	Tailings Storage Facility
WM	With Mitigation
WMA	Water Management Area
WOM	Without Mitigation
WRD	Waste Rock Dump

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1 INTRODUCTION

Exigo Sustainability (Pty) Ltd (Exigo) was appointed by Pilanesberg Platinum Mines (PPM) to perform a groundwater specialist investigation to assess the expansion of the PPM processing facilities.

This report focusses on the management of the Tailings Storage Facility (TSF) and potential migration of seepage flows from this facility to determine the potential impacts.

1.1 Objective

The objective of the study was to:

- Groundwater specialist investigation to determine the potential groundwater impacts for the proposed plant expansion.

1.2 Scope of work

The scope of work for the groundwater specialist investigation included the following:

- Review of monitoring data and hydrogeological information
- Groundwater contaminant transport modelling to quantify the potential impacts
- Mine site water balance and water management
- Environmental geohydrological assessment and reporting

2 METHODOLOGY

2.1 Project Team

This report is compiled by Mr. WJ Meyer and the project team comprise of:

- Dr JJP Vivier, PhD Environmental Management; M.Sc Hydrogeology Pr.Sci.Nat - Specialist technical input and review
- Mr JC Barratt M.Sc. Hydrogeology –Technical input, groundwater flow modelling and reporting

2.2 Existing information sources used

The model setup and construction were obtained during the previous groundwater flow model update. The monitoring data was used in the calibration processes to assist in updating the groundwater flow model. The data included but is not limited to:

1. The current and historical modelled TSF seepage volumes.
2. Mass concentrations of the boreholes located around the TSF, records of water quality in the boreholes located around the TSF, from before deposition commenced to present day values.
3. Transient groundwater level and quality measurements from 2009 to 2018 (commissioning of TSF until present day) used in the transient calibration.

2.3 Declarations of independence

Exigo Sustainability (Pty) Ltd is an independent consultant company and does not have any financial interest in the proposed project other than the remuneration for work performed in terms of this hydrogeological investigation.

3 SITE DESCRIPTION

3.1 Study area and project location

The study area is located on the north western side of the Pilanesberg Volcanic Complex (PVC) in the North West Province. It is situated approximately 65 km north-northeast of Rustenburg, in the Bojanala Platinum (DC37) district, Moses Kotane (NW375) municipal area.

The study area is in the Crocodile West and Marico Water Management Area (WMA), and includes the A24D, A24E quaternary catchments.

3.2 Topography and drainage

The study area is situated immediately to the north of the Pilanesberg Volcanic Complex and is characterised by a slightly undulating landscape with an average height of 1100 mamsl. The area is drained by several non-perennial streams and drainage lines i.e. Kolobeng-, Mothlabe-, Wilgerspruit- and Lesele River, the main non-perennial streams. These streams flow towards the north of the site, before joining the Bofule River approximately 10 km to the north. The Pilanesberg situated immediately south of the site is a mountainous area with an average elevation ranging between 1 300 and 1 500 mamsl (Exigo 2017, AS-R-2017-04-17).

Dry winters lead to streams and rivers only flowing during and immediately after heavy rain in the summer months. This leads to higher stress being applied on groundwater as a resource due to the lack of sustainable surface water reservoirs being available.

3.3 Climate and rainfall

The climate of the area exhibits bushveld conditions with warm and dry winters and hot to very hot and wet summers. The average maximum temperature in summer is approximately 30 ˚C and the average minimum temperature is 18 ˚C. The average maximum temperature in winter is 22 ˚C and the minimum temp 7 ˚C.

The rainfall data used was recorded at Station 0548280 at Saulspoort Hospital. This is not on site and the distance could show minor influences on the rainfall recorded. No daily rates were used as the model time steps were monthly, which is an adequate transient resolution to characterize the system.

A sensitivity analysis on the rainfall data shows that January, February, March, and December have the largest positive influence on the MAP. These months are the wettest months in the year and correspond to the summer rainfall region in which the site is located. The driest months, months with the least contribution to the MAP are June, July, August and September. An analysis of the data showed that the MAP is 630 mm. The statistically derived parameters are shown in Table 3-1.

A rainfall distribution chart is shown in Figure 3-1. This chart augmented by a logical test of the data shows that 1:50 year wet events occurred in 1967, 1997 and 2000. 1:20 year wet events occurred in 1939, 1961 and 1991. The 1:50 year dry events occurred in consecutive years from 2005 to 2007, preceded by the 1:20 year dry events in 2003 and 2004 and subsequently in 2015.

No other dry events occurred from 1904 to 2003, showing that the dry period from 2003 to 2007 was an exceptional event. This shows that although the probability of a dry event may be in the order of 2 times a century (1:50 year drought) when they do occur, “dry” years occur incessantly, in this case 5 years. Thus, in 115 years’ record, 5 consecutive dry years can be expected, instead of 5 isolated dry years, such as the pattern portrayed by the wet events.

Table 3-1 Rainfall statistical parameters

Parameter	mm/a
Average	630
Maximum	1196.8
Minimum	176
Standard Deviation	167.9
1:20 year wet	883
1:20 year dry	323.4

The Mean Annual Evaporation for the region is 2400 mm/a. This value will affect the water loss and salt concentration in the mine water cycle and thus will affect the water balance. The biggest influence of the MAE on the water balance will be at the Return Water Dam (RWD), Storm Water Dam (SWD) and the Tailings Storage Facility (TSF).

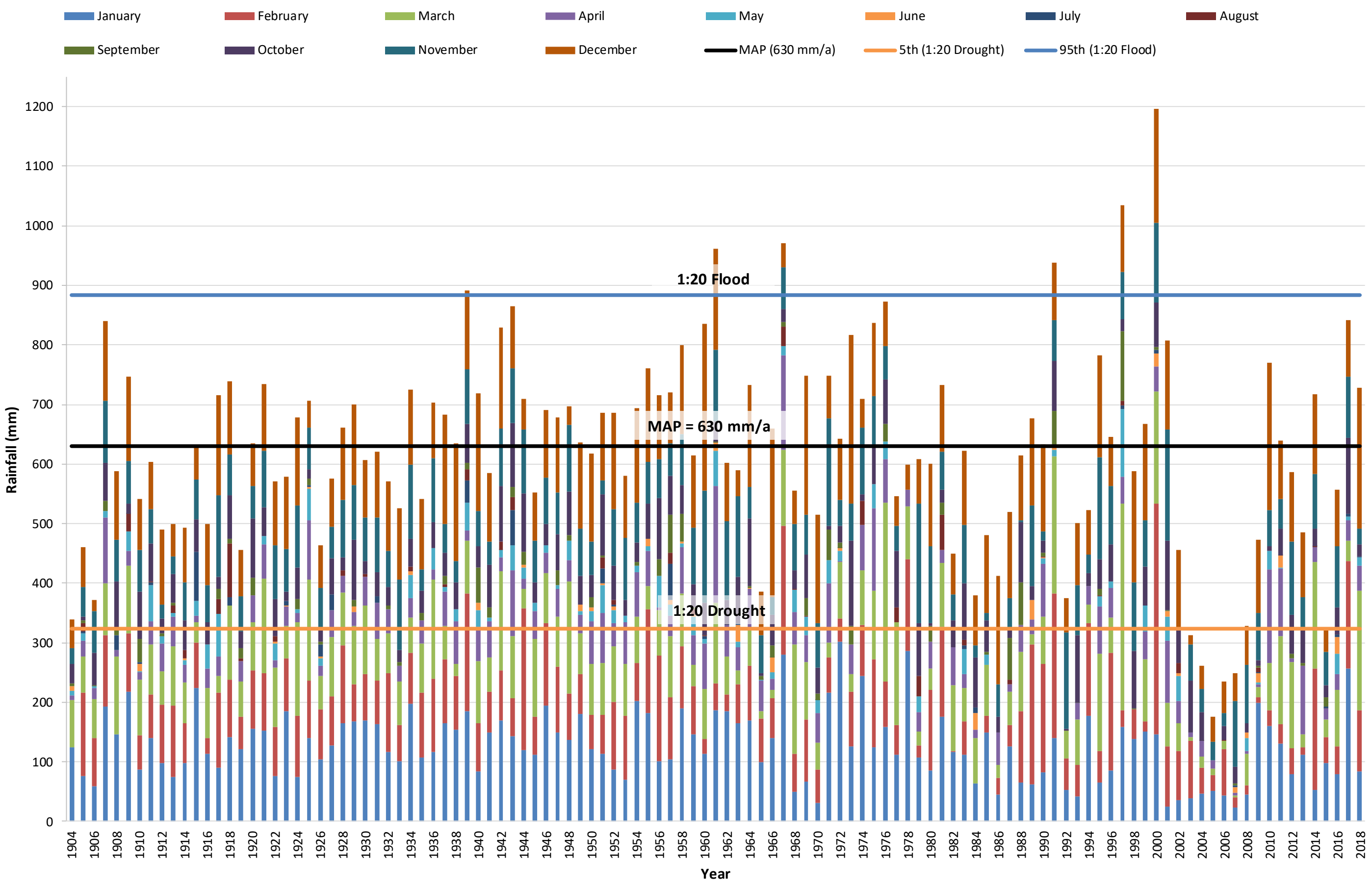

Figure 3-1 **Rainfall chart for Station 0548280 at Saulspoort Hospital**

3.4 Hydrogeology, geology and catchment area

The mining area falls within quaternary catchment A24D which forms part of the Crocodile West and Marico Water Management Area (WMA). The area has a MAP of 630 mm/a with an average expected recharge percentage of between 1.7% and 2.5% of MAP.

The hydrogeology is primarily controlled by the subsurface geology which includes the following important geological layers and features (AGES 2010, AS-R-2010-12-09).

- The perennial river aquifer, which is a primary alluvial and weathered aquifer zone adjacent to the rivers.
- Weathering and fracturing of the topographic low-lying areas which form an important aquifer zone for community water supply.

- Fault and fracture zones which form major aquifers in the study area.
- Weathered norite/gabbro.
- The fractured/solid bedrock (norite/gabbro) aquifer that underlies the weathered zone.
- Dolerites, which may act as flow impediments.

The mining site is underlain mainly by Gabbro Norite (Vg) as basement rock. A weathered zone which includes the few meters at surface could be considered as the shallow weathered aquifer with the basement rocks as the deeper aquifer system. The general groundwater movement follows the topography and is towards the north. Surface drainage within the western catchment is mostly towards the Kolobeng River. Recent water level monitoring data (2016 - 2017) and results from the hydrocensus provided information on the current groundwater regime.

4 WATER MONITORING

4.1 Monitoring objectives

The monitoring objectives are to detect and manage the possible impacts of the projects and related infrastructure on the hydrological environment.

The main objective of the monitoring is to:

- Obtain information of the chemical, micro biological and physical characteristics of the receiving environment
- The timely detection of any changes in the chemical, micro biological and physical characteristics of the receiving environment
- The timely detection of any changes in the chemical, micro biological and physical characteristics of waste released into the environment.
- To obtain information that can be used to update the environmental management plan.
- To determine if applicable environmental laws and standards are adhered to.
- Refine and update the conceptual and numerical (management) models.
- Provide an on-going performance record for effectively controlling possible pollution.

This will ensure that management personnel at the mines are aware of problems and unexpected impacts that arise, and are in a position to implement additional mitigation measures at an early stage.

4.1.1 Possible pollution sources

Potential pollution sources include the following:

1. Offices, Change House etc
2. Diesel storage tanks
3. Sewage tanks and drain networks
4. Waste rock dumps and stock piles
5. Tailings Storage Facilities

4.1.2 Receiving environment

The following hydrological units may be impacted by mining and related activities:

- The weathered overburden
- The recharge zone
- Fractured rock aquifer

- Several drainage lines in the project area
- Level 1 NFEPA – Bofule wetland[1]

4.1.3 Sampling locations

Water Monitoring at the Pilanesberg Platinum Mine consists of two facets. The first is the monitoring of the water quantity and quality impacts by mining and mining related activities on the receiving environment. The development of the project consists of an open cast operation located on the farm Tuschenkomst and a Tailings Storage Facility (TSF) located on the farm Witkleifontein. Associated with the open cast mine are waste rock dumps, 4 x Storm Water Dams (SWD's) and topsoil stockpiles. Associated with the TSF is a Return Water Dam, and 1 x control SWD that form part of the general mine layout. Concentrator plant complex (Back-End and Front-End) was constructed on the south-eastern portion of the farm Tuschenkomst.

The second facet is the monitoring of the wellfields from which water is abstracted for the mining activities. The water supply boreholes are tentatively divided into seven wellfields and will be developed in phases. At this stage the monitoring will only focus on the wellfields 1 water supply boreholes.

The various surface and groundwater monitoring locations are detailed in Figure 4-2.

4.2 Monitoring results

The annual 2018 water monitoring report can be referred to for results and interpretation (Exigo 2019, E-R-2019-01-22: Annual Water Monitoring Report 2018: Pilanesberg Platinum Mines). The water quality- and level baselines are also discussed within the Exigo 2019, E-R-2019-01-22: Annual Water Monitoring Report 2018: Pilanesberg Platinum Mines report. The Exigo 2017, AS-R-2017-04-17 report also refers to the baseline and background values of the surface- and groundwater qualities as well as the groundwater levels.

4.2.1 Nickel

Besides the existing reports referring the water quality, the Solution[H+] (2019) report indicated that nickel (Ni) may be a constituent of concern with regards to the addition of the KELL tailings to the existing TSF. It is the opinion of the author that nickel's impact has been predicted in a highly conservative method. This is due to from the 63 sampling occurrences since June 2009 at the return water dam (RWD) downstream of the TSF, Ni has only been detected on 23 instances of which none of the samples have exceeded the SANS 241:2015 drinking water limit of 0.07 mg/ℓ. The highest measured Ni-concentration was measured in July 2011 at 0.033 mg/ℓ. Ni was last detected in the RWD in September 2014 at a concentration of 0.004 mg/ℓ.

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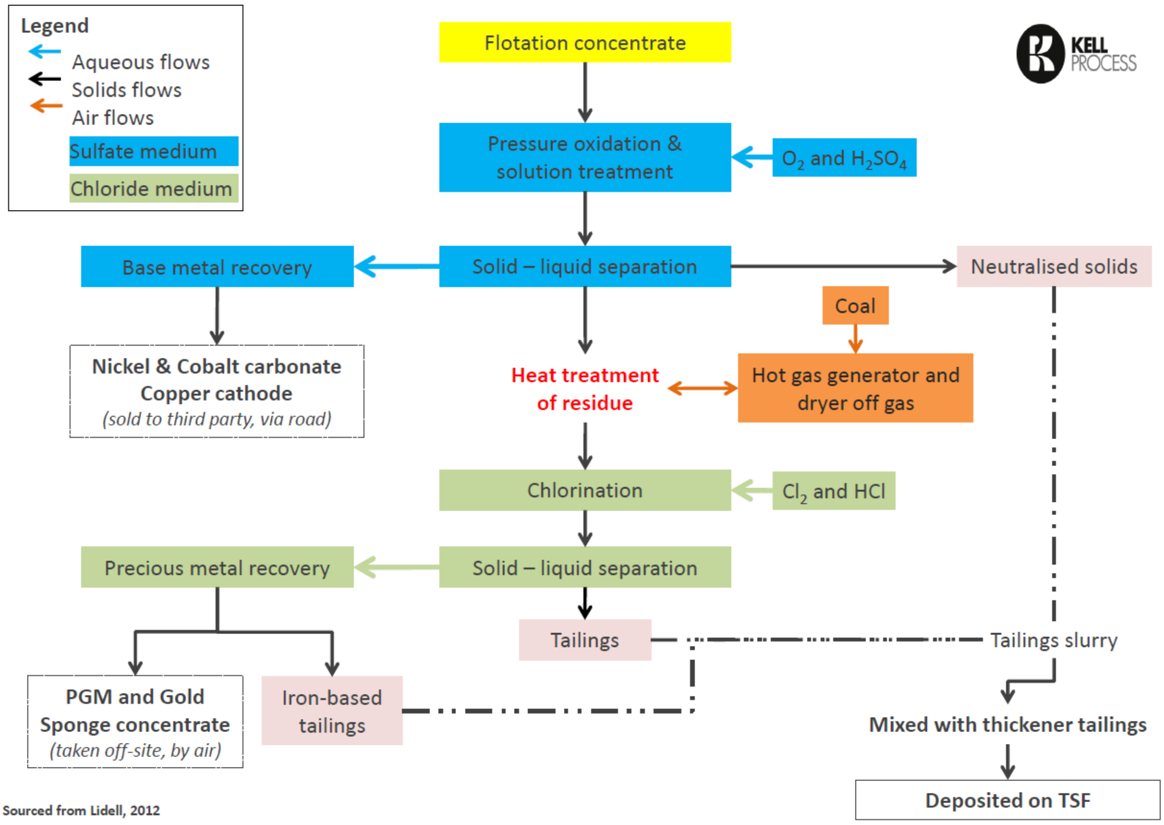
[1] This wetland is not groundwater support as concluded by a hydrogeological study (AGES, 2014)?

The new KELL supernatant has an elevated Ni-concentration at 93 mg/ℓ compared to the current supernatant that has a Ni-concentration of 0.018 mg/ℓ. The composite of the two tailings material's Ni-concentration is 1.4 mg/ℓ. These values are considered highly conservative as the KELL process includes the removal of base metals before transporting to a TSF for deposition (Figure 4-1) and will comprise only 1% of the tailings feed.



Sourced from Lidell, 2012

Figure 4-1 Schematic flow diagram of the KELL process

The average Ni-concentration from 2009 until 2018 was calculated to determine the Kd-value for nickel based on the current PPM supernatant's quality (Table 4-1). Baseline Ni-concentrations were not considered. (*ND denotes Not Detected*)

Table 4-1 Ni-concentration comparisons between supernatant and surrounding boreholes

	Unit	Supernatant Pond (Source)	RWD	PPMMON3	PPMMON4	UB40	AGES6	PPMMON1	BH5	PPMMON2	Mr Phiri	BH104	BH117
Distance to Source	m	0	1150	1090	1080	1170	1540	1680	1980	1910	1200	1130	1220
Average Concentration	mg/ℓ	0.018	0.016	ND	ND	0.009	0.013	ND	ND	ND	ND	ND	0.013
P5 Concentration	mg/ℓ		0.003	ND	ND	0.005	0.012	ND	ND	ND	ND	ND	0.012
P50 Concentration	mg/ℓ		0.018	ND	ND	0.009	0.013	ND	ND	ND	ND	ND	0.013
P95 Concentration	mg/ℓ		0.028	ND	ND	0.013	0.013	ND	ND	ND	ND	ND	0.013
Calculated Kd	ℓ/mg		**1.1**			**2.0**	**1.4**						**1.4**


Pilansberg Platinum Mine
Water Monitoring
Aerial Photograph
Legend
Process Water Dam
Storm Water Dam
Return Water Dam
Sewage Effluent
Raw Sewage
Tuschenkomst Pit
Oil Separator
Monitoring BH
Water Supply BH
Bullfrog Buffer Zone
Surface Water
Client: PPM Pty Ltd
Scale: 1:27 000
0
1
2 km
Project: Water Monitoring
Date: 23 May 2016
Compiled by: PJ Bouwer
Datum: WGS84
N
NGWEDING
MOTHLABE
Mothlabe
Manyedime
Wilgespruit
Wilgespruit River Diversion
SW7
BH107
WN3
WN1
SW4
FF15
BG1
BH7
BG2
SW8
PPMMON2
BH5
PPMMON1
SW9
AGES6
SWD2
RWD
PPMMON4
UB40
PPMMON3
BH92
AGES4
SW12
BH4A
SWD3
SWPT
Mr Phiri Borehole
SWD1
BH117
BH104
PWDam
STPR
Emergency Dam
STPE
SWD5
OWS2
SWD4
BH116
SW10
SW11

5 GROUNDWATER MASS TRANSPORT MODEL UPDATE

5.1 Introduction to groundwater model update

The model used for this mass transport model update has been calibrated steady state pre-mining (pre-2009) conditions as indicated in Exigo 2017, AS-R-2017-04-17 and has since been extended to transient during the operational phase.

The focus of the current numerical model is the TSF and the management of the mass migrations and proposed mitigations measures i.e. seepage capturing to determine the impact any mass potentially may have leaching from the facility.

5.2 Model Objectives

The aim of the updated groundwater flow model is to simulate the groundwater system to determine the groundwater mass transport associated with the TSF. The aim of this updated model is to gain an understanding of the groundwater flow dynamics and will be used to:

1. Contaminant transport scenarios simulating sulphates migration from the TSF and possible mitigations measures and the impact there-off on the current status quo.

5.3 1-D Analytical Mass Model

The Ogata & Banks (1961) equation used to determine the longitudinal dispersion in a porous media was utilised to determine the possible zone influenced by the elevated Ni-concentrations referred to in the Solution[H+] (2019) report. The Solution[H+] (2019) Composite A supernatant Ni-concentration (1.4 mg/ℓ) was used along with the calculated minimum Kd-value in Table 4-1 as well as referenced Ni Kd-values (Table 5-1) to determine the plausibility of Ni-migration within the groundwater environment.

Table 5-1 Referenced Ni Kd-values in porous media

Author/s	Ni Kd-value (mℓ/g)
Reddy & Dunn (1986)	152 - 388
Krupka et al (2004)	50 - 2500
Thibault et al (1990)	300 (loam) - 400 (sand)

If the lowest calculated Ni Kd-value (1.1 mℓ/g) is used from Table 4-1, the mass migration will not exceed 50 m from the source (Figure 5-1). The lowest referenced Ni Kd-value (50 mℓ/g) from literature, has a mass migration plume for nickel that does not exceed 5 m from the source (Figure 5-2).

Figure 5-1Figure 5-2 illustrate that the nickel will have limited mobility within the groundwater environment.

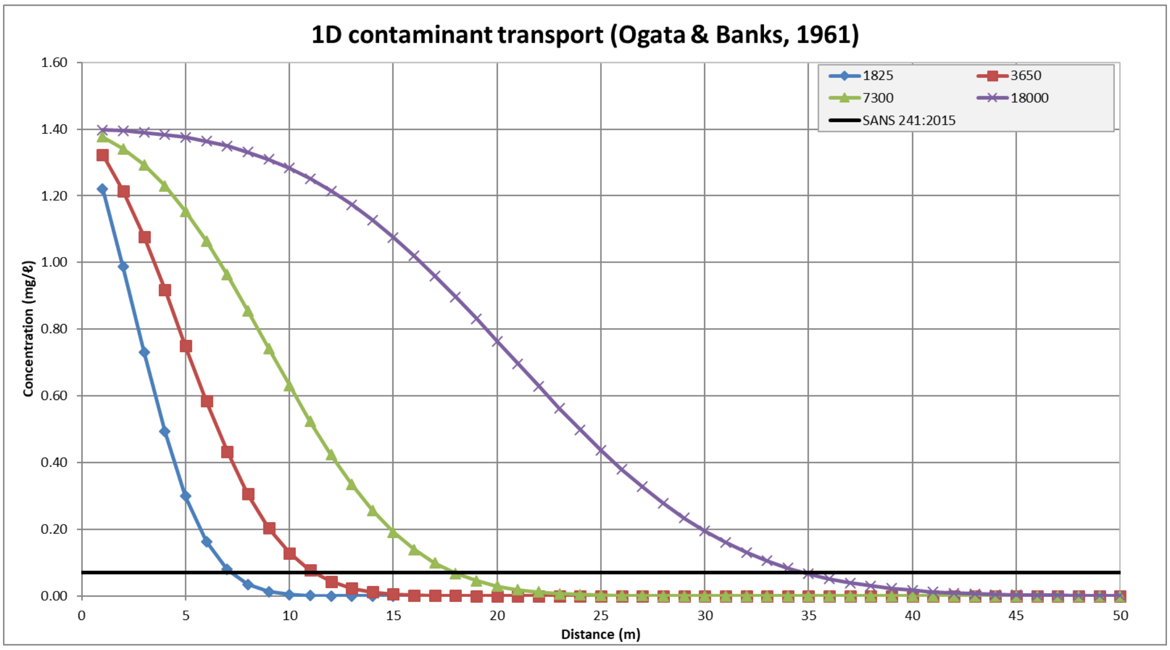


Figure 5-1 1D contaminant Ni transport with lowest calculated Kd-value – 1.1 mℓ/g (Table 4-1)

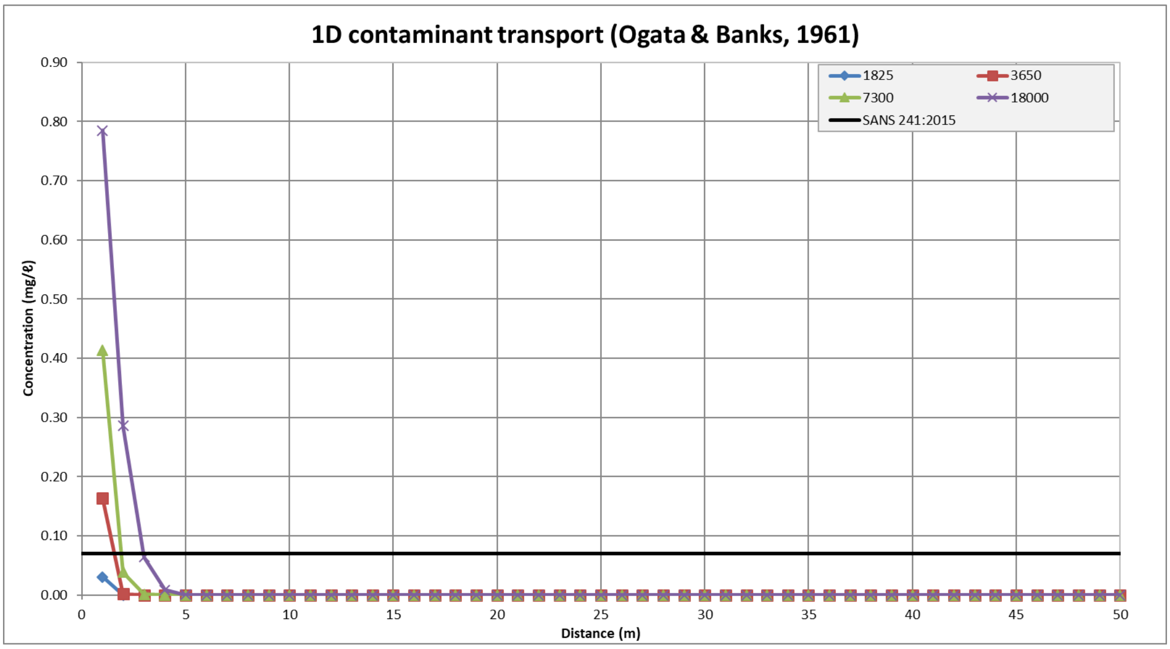


Figure 5-2 1D contaminant Ni transport with lowest references Kd-value – 50 mℓ/g (Table 5-1)

5.4 Numerical Model Setup

The numerical groundwater flow model developed during the various pit flooding simulations was used for this update, with addition of the transient water quality qualification. The groundwater model has 221 463 elements and 148 796 nodes. The model has three layers; three dimensions i.e. a clay layer 2 m thick, a weathered layer 18 m thick and a fractured/bedrock layer 280 m thick.

The model domain covers an area of 374 km² that was differentiated into a finite element network.

The rivers and faults are included explicitly to enhance simulation results and accuracy. Important modelling zones are delineated to simulate the impact on groundwater flow more accurately.

5.5 Assumptions and model limitations

The following assumptions were made:

1. Prior to development, the flow system is in equilibrium and therefore in steady state.
2. Recharge from rainfall over the area is between 1.7% and 2.5% (10.7 mm/annum to 15.7 mm/annum) of MAP i.e. 630 mm/a.
3. The aquifer system is represented by a three-dimensional system consisting of 4 hydraulic zones in layer 1 (2m thick – clay and highly weathered) and 6 hydraulic zones in layer 2 and 3(18 m and 280 m thick respectively, weathered and fractured rock aquifers). The faults, dykes and drainage weathered zones were modelled discretely and form part of the total number of hydraulic zones.
4. The modelling approach was based on the precautionary principle in areas where there were little or a lack of data. This means that the simulated impacts should be larger than would be in the actual case. The real effect of the mining activities will only be quantified by additional site characterisation and monitoring that should be used to update the model before the implementation and on an on-going basis.
5. The faults are 100 m wide in their horizontal influence and are believed to be more than 100 m deep vertically. It is planar and vertical in orientation and is connected to smaller faults which were also assigned higher transmissivity parameters.
6. The geochemical modelling completed by Solution[H+] (2019) is deemed very conservative as the post-drainage SO_4 concentration of 1595 mg/ℓ is more elevated than expected. The report by Solution[H+] (2019) also states that the TSF has a life of 12 years, which is not the case as the TSF as a life of another 12 years. The operational phase's geochemical results were thus assigned into the model as stated by Solution[H+] (2019).
7. When assumptions were made or reference values used, a conservative approach was followed. A groundwater model is a representation of the real system. It is therefore an approximation, and the level of accuracy depends on the quality of the data that is available. The purpose of the model was not to simulate the actual field conditions (i.e. every dyke and fracture), but to simulate the proposed mining and related activities and influence on the receiving environment.
8. The reprocessing and disposing of the tailings material is assumed to be of a better quality than the current predictions as the PGM plant will remove additional minerals

during the reprocessing process. The reprocessed materials seepage quality and impact still need to be determined through additional investigations and simulations.

Information Box A (Figure 5-3)

In natural steady-state conditions, the net groundwater inflow from recharge is balanced by base flow and losses (+spring flow if springs exist) (Figure 5-3). The groundwater balance is given by $+Q_r - Q_{BF-}Q_{GFL} = 0$. The piezometric gradient, which can be measured from site characterization and monitoring boreholes are known and the boreholes can be pump tested to determine the transmissivity and hydraulic conductivity.

The outflow per unit length (L) of aquifer are given by Darcy's law as, $q = (K\frac{dh}{dl})xD$ where q is the Darcy flux in m/d (or m³/m²/d) and K is the hydraulic conductivity, D the aquifer thickness and dh/dl the piezometric gradient. Since K, D and the head gradient can be measured, a steady-state model can be calibrated by changing the recharge value until the measured and simulated head gradients have a small (or acceptable) error. An acceptable error is usually less than 10 % of the aquifer thickness. If the aquifer is for example 40 m thick, then an error of less than 4 m between the measured and simulated head elevations could be considered as acceptable.

Note that in a steady-state flow model, the term for aquifer storativity disappears making it easier to calibrate the model with less variables.

A perfectly flat head gradient of 0 will imply an infinite hydraulic conductivity. This process can be used to calibrate a regional steady-state model for recharge and transmissivity where a groundwater head distribution (i.e. head gradient) is known from field measurements. If e.g. transmissivity ranges are known from field tests, recharge can be quantified.

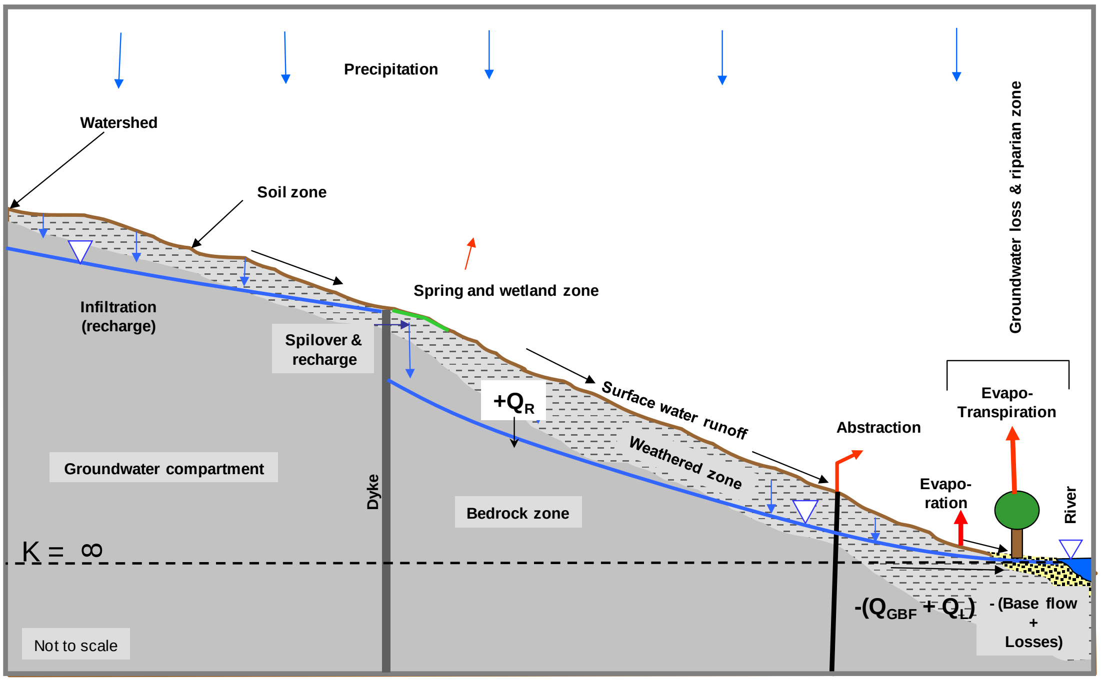


Figure 5-3 Conceptual model of the steady-state flow scenario (Refer to Information Box A)

5.6 Model Boundaries

Boundary conditions determines the reaction of the simulated environment, thus they represent natural conditions such as fluxes in or out of the model domain as well as hydraulic heads.

Application of these boundary conditions in various methods results in different solutions, thus ensuring correct application and assumptions through-out the modelling process.

Boundary conditions in a groundwater flow model can be specified either as:

- Dirichlet Type (or constant head) boundary conditions or;
- Neumann Type (or specified flux) boundary conditions; and
- Or a mixture of the above.

5.6.1 Internal model boundaries

The groundwater system within the area is recharged via precipitation which results in infiltration through the weathered zone. However, in this region, a clay overburden largely affects the infiltration rates and decreased rates were assumed on various parts of the model. These clay formations also cause a perched aquifer with shallow water levels different to that measured in the fractured rock aquifer. Shallow wells used locally could show no effect due to potential mine dewatering due this isolation from the fractured rock aquifer. The water levels in this area are located at depths ranging from 5 – 80 mbgl. The drainages were assigned constant head boundary conditions along the non-perennial rivers to receive base flow from groundwater, if any. Values equal to topographical elevations at the positions of the drainages were assigned as the constant head values.

The constant head boundary condition allows groundwater to discharge, in this case, from the model area at a rate dependent on the hydraulic conductivity and hydraulic gradient across the boundary. The constant head boundaries were constrained on all drainages so that water can only be removed from the system – a reversal of the hydraulic gradient back towards the aquifer from the surface system would therefore not allow water to enter the aquifer from the surface water system. This therefore represents a true “drain type” boundary condition.

5.6.2 Model base boundary condition

The model domain was assigned to extend vertically to a depth of 300 m. It is assumed that the base of the model is impermeable.

5.6.3 Boundary conditions

The modelled catchment consists partially of the quaternary catchments A24D and partially A24F. The modelled catchment covers an area of 582 km².

The model boundaries are formed by:

1. The topographic high in the south, the Pilanesberg surface water shed was used as a no-flow boundary.

2. The eastern boundary is formed by the non-perennial Sefathlane River, acting as an outflow boundary in the model domain.
3. The majority of the northern boundary is formed by the non-perennial[2] Kolobeng River which is a tributary of the Bierspruit River, acting as an outflow boundary in the model domain.
4. The western boundary is formed by tributaries of the Kolobeng- and Mothlabe Rivers, acting as outflow boundaries, until it reaches the no flow boundary formed by the topographical high in the south at the Pilanesberg Mountains.
5. Boreholes and drains were included as internal boundary conditions.
6. The initial and boundary conditions, sources, sinks, and aquifer parameters are specified in the steady state model, which is calibrated so that the flow model has the same behaviour as the actual system. Discrete features like the fault zones were included as line elements in the network.

Table 5-2 Model context, data, boundary conditions and assumptions

Input parameter	Scale	Source, parameter or assumption description
Topography (DTM)	1:50 000	The topographic elevations were interpolated from the 1:50 000 scale 20 m contour intervals. The DTM was obtained from Giscoe.
Rivers, streams, drainages	1:50 000	Obtained from Giscoe as GIS shape files.
Dams	1:50 000	Obtained from Giscoe as GIS shape files.
Geology	1:250 000	Obtained from Giscoe as GIS raster image files.
Boreholes and pumping rates		Data sourced from hydrocensus and monitoring done in the area. Groundwater explorations done by AGES assess the groundwater regime. In total, a combination of 25 boreholes was used to calibrate the transient model.
Rainfall (recharge)		Rainfall data was obtained from the WRIMS data base for station 469435.
Steady State Modelling Parameters		
Recharge		Recharge was set at 1.7 to 2.5 % of MAP. The recharge values were calibrated to obtain acceptable flow equilibrium.
Transmissivity		Transmissivity parameters obtained from aquifer tests conducted on water supply and groundwater exploration boreholes.

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[2] These streams are generally storm-event driven and flow occurs less than 20% of the time; these streams have a limited (if any) baseflow component with no groundwater discharge.

Input parameter	Scale	Source, parameter or assumption description
Hydraulic Conductivity		Horizontal hydraulic conductivity calculated from transmissivity values and saturated aquifer thickness. Vertical hydraulic conductivity was assumed at 10% of horizontal hydraulic conductivity.
Aquifer thickness		The aquifer has a total thickness of 300 m. The lithologies vary in the three layers and were modelled discretely.
Transient State Modelling Parameters		
Initial Hydraulic Heads		Calibrated water levels obtained from steady state model calibration scenario used as initial hydraulic heads
Specific Storage		The volume of water that a unit volume of aquifer releases from or takes into storage per unit change in head.
Specific Yield		The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium. Assumed at approximately 10 times the value of Storativity.
Storativity / Storage Coefficient		The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Assumption of 0.001 to 0.005 for fractured aquifers and 0.01-0.05 for alluvial aquifer zones. No field test data were available for storativity values.
Effective Porosity		Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.

5.7 Summary of Model Calibration

Under steady state conditions the groundwater flow equation is reduced to exclude storativity and only transmissivity (or hydraulic conductivity) and recharge are considered in the model calibration process. Qualification is the process of adjusting model parameters (hydraulic conductivity and recharge) until a suitable error between simulated and measured hydraulic heads is achieved[3].

The head elevation data from 25 observation boreholes were used to re-calibrate the steady-state flow model (Figure 5-4). The calibration was satisfactory when the correlation between the measured and simulated head data was $R^2 > 0.9$ (Figure 5-6 and Table 5-3) and the Root Mean Square Error (RMSE) < 15%.

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[3] Spitz and Moreno (1996) specify a normalized root mean square error of less than 5% is deemed suitable for model qualifications

Table 5-3 Summary of regional calibration points

	Water Level (mbgl)	Measured Head (mamsl)	Simulated Head (mamsl)	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
Average	**-23.25**	**1049.39**	**1053.69**	**6.88**	**-4.30**	**77.70**
Minimum	**-48.85**	**1009.84**	**1028.89**	**0.24**	**-24.84**	**0.06**
Maximum	**-13.57**	**1079.35**	**1074.19**	**24.84**	**5.96**	**617.03**
Correlation	**0.91**			Σ = 171.95	Σ = -107.50	Σ = 1942.55
				1/n = 6.87	1/n = -3.98	1/n = 77.70
						SQRT = 8.81
				RMS% of water level range = 12.68%		

5.7.1 Hydraulic Zones

There are 16 main hydraulic zones that influence the groundwater flow balance within the aquifer (Table 5-4). The hydraulic values marked in Table 5-4 were obtained from existing groundwater data, field tests as well as the model calibration process. A major aquifer within the catchment is the Frank Fault located to the west of the mining operations. Generally, the fault zones in this area are regarded as water supply targets.

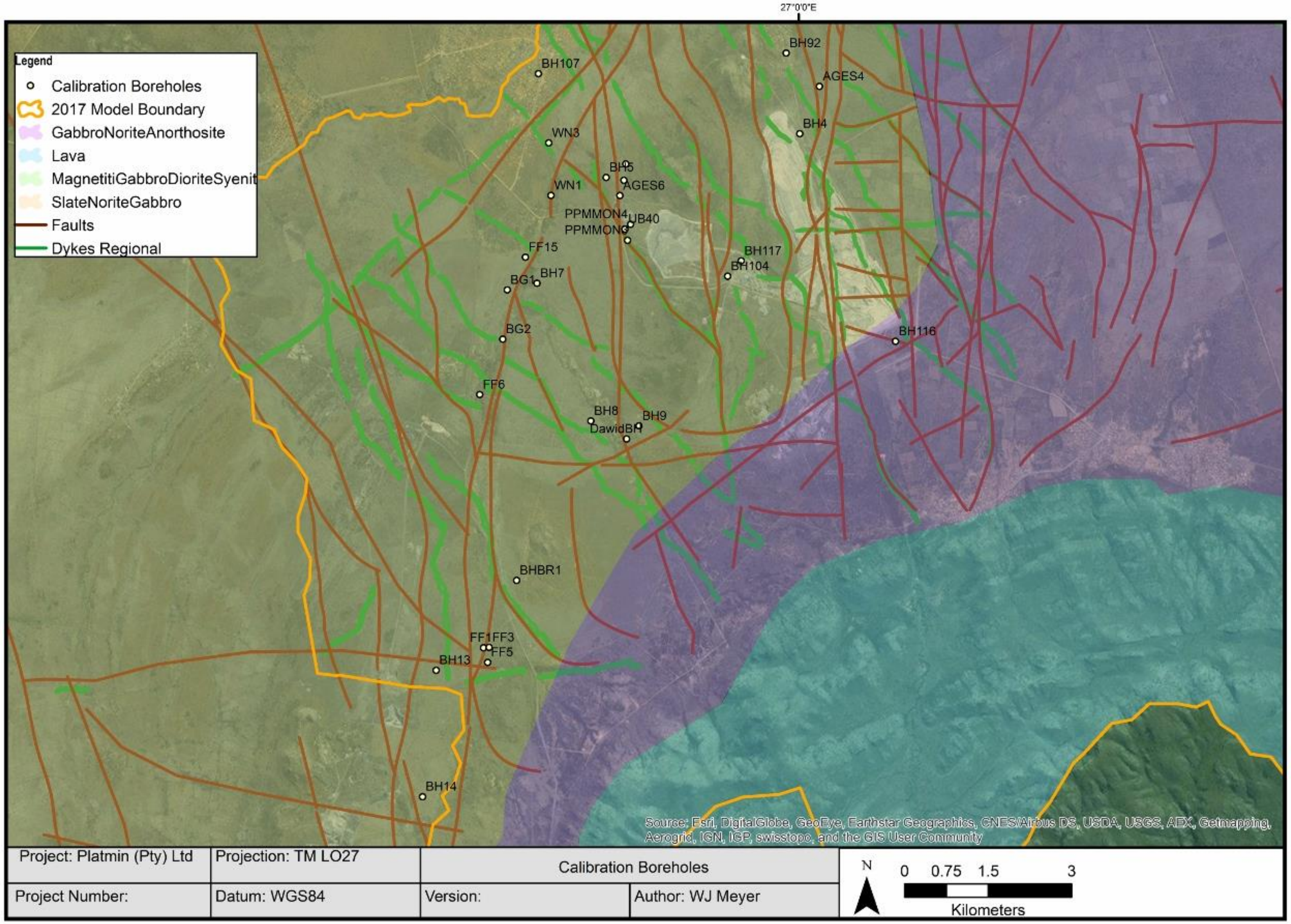

Figure 5-4 Calibration boreholes, modelled geology (faults and dykes included)

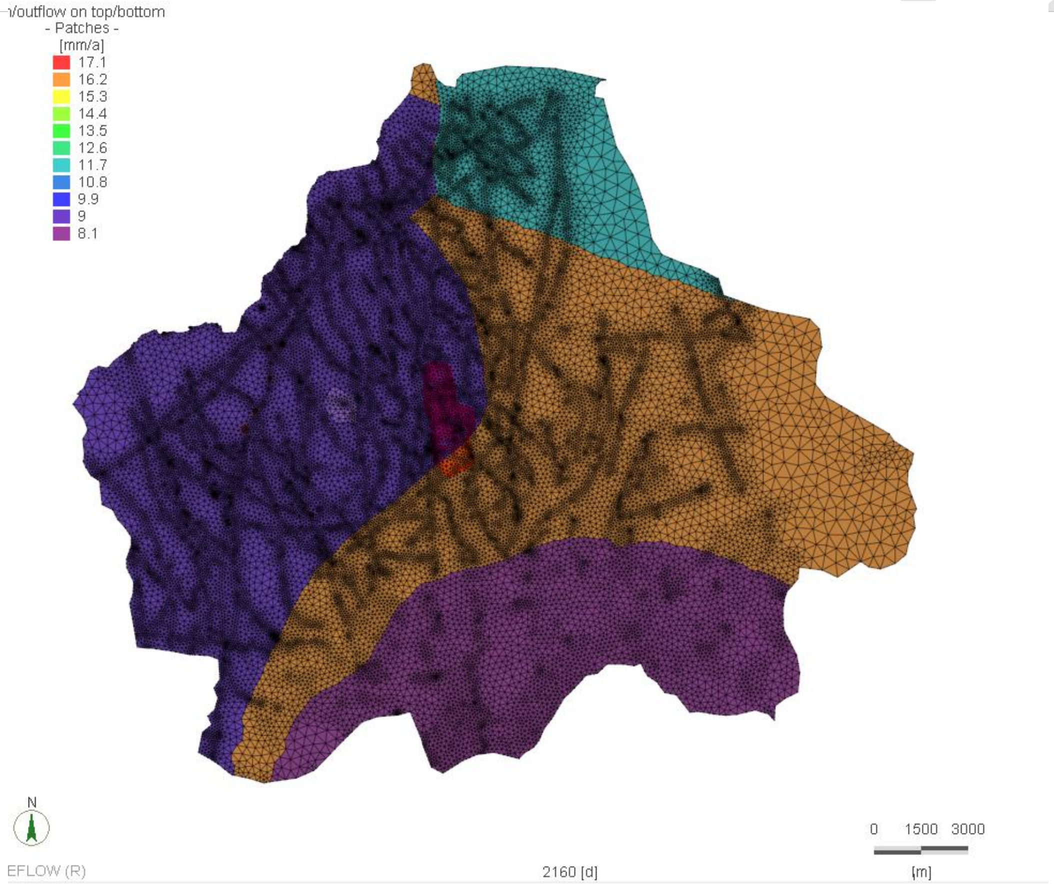

Figure 5-5 Calibrated recharge values used in the calibration process

Table 5-4 Hydraulic Zones and parameters – calibrated model (Figure 5-6)

	Lithology	Layer	Layer Thickness	T (m^2/d)	Kx,y	Kz
Top Layer	Slate Norite Gabbro	1	2	20.00	10.0000	1.0000
	MagnetiteGabbroDioriteSyenite	1	2	25.00	12.5000	1.2500
	Gabbro Norite Anorthosite	1	2	21.00	10.5000	1.0500
	Lava	1	2	5.00	2.5000	0.2500
Weathered Aquifer	Slate Norite Gabbro	2	18	20.00	1.1111	0.1111
	MagnetiteGabbroDioriteSyenite	2	18	25.00	1.3889	0.1389
	Gabbro Norite Anorthosite	2	18	21.00	1.1667	0.1167
	Lava	2	18	5.00	0.2778	0.0278
	Faults	2	18	200.00	11.1111	1.1111
	Dykes	2	18	0.00	0.0001	0.0000
Fractured Rock Aquifer	Slate Norite Gabbro	3	280	2.00	0.0071	0.0007
	MagnetiteGabbroDioriteSyenite	3	280	2.50	0.0089	0.0009
	Gabbro Norite Anorthosite	3	280	2.30	0.0082	0.0008
	Lava	3	280	0.50	0.0018	0.0002
	Faults	3	280	40.00	0.1429	0.0143
	Dykes	3	280	0.00	0.0000	0.0000

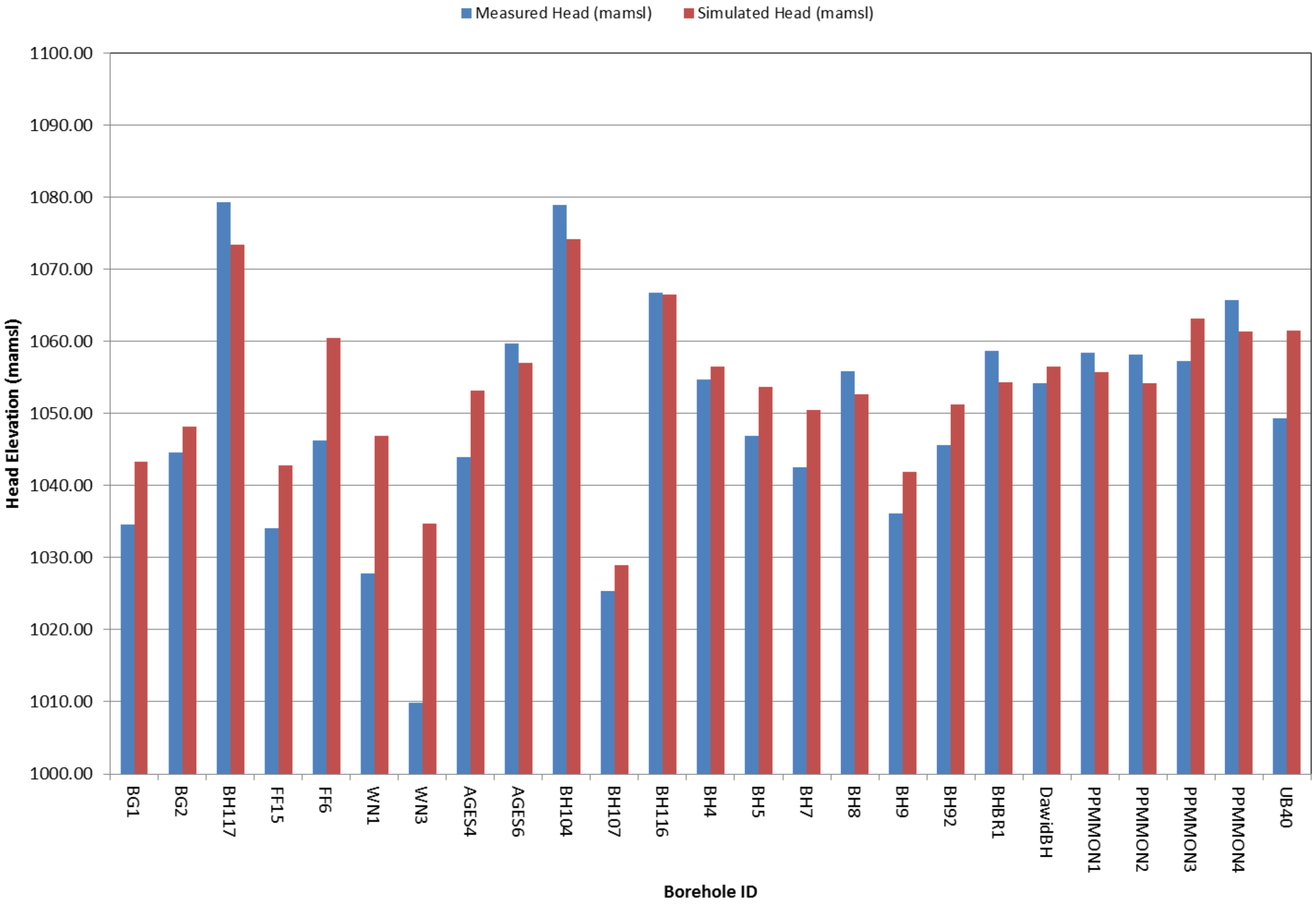

Figure 5-6 Graphic presentation of measured versus simulated heads

The correlation of measured heads and elevation < 0.90 (Figure 5-7), indicates an aquifer system currently stressed by anthropological processes i.e. water abstraction, fluxes both in and out of the modelled domain.

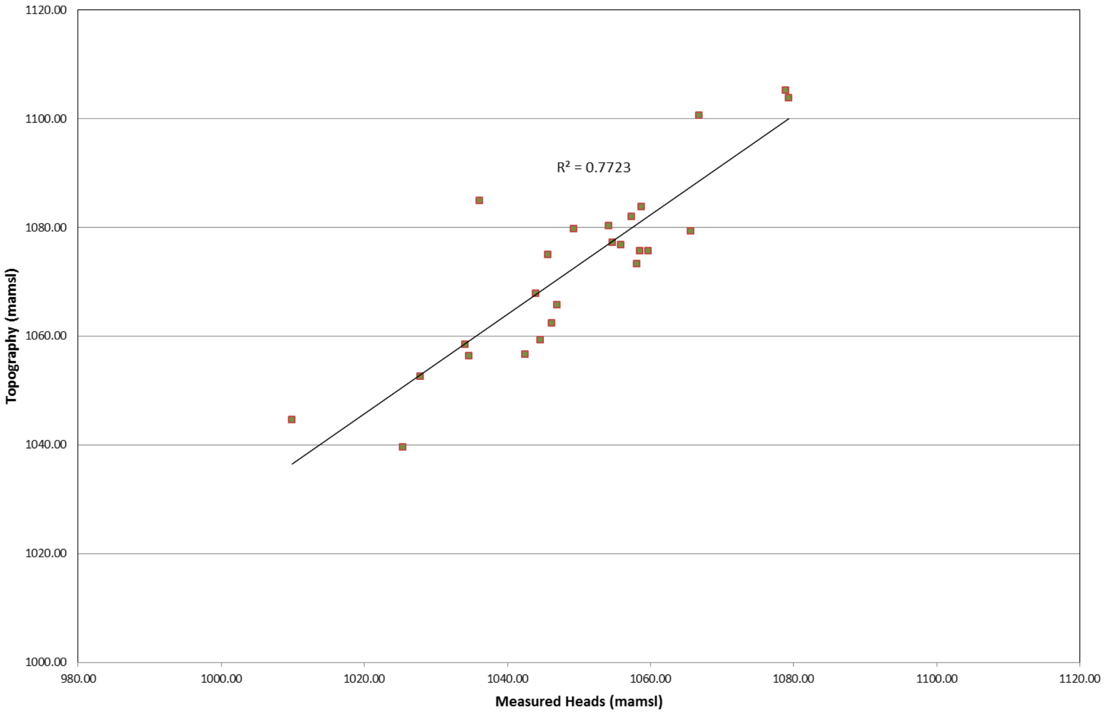

Figure 5-7 **Correlation of topography and measured heads**

Key notes on calibration process:

1. The current water supply boreholes were assigned abstraction rates equal to the monitoring rates of the past year (Table 5-5).

Table 5-5 **Assigned abstraction rates**

Pumped BH's	X	Y	Abstraction rate (m³/d)	Measured Abstraction rate (m³/month)
FF15	-4906	-2777416	89.03	2760
BG1	-5233	-2778002	104.71	3246
BG2	-5313	-2778885	61.23	1898
FF1	-5601	-2784673	88.16	2733
WN1	-4449	-2776308	21.77	675
WN3	-4488	-2775365	20.35	631

2. The calibration process indicated that various boreholes are abstracted from, although the records did not indicate this. These boreholes and assigned abstraction rates are provided

in Table 5-6

Table 5-6 Privately owned boreholes and assigned abstraction rates

Site name	X	Y	Abstraction rate (m³/d)
BH8	-3730	-2780350	43.6
BH9	-2868	-2780440	43.6
BHBR1	-5065	-2783211	43.6
DawidBH	-3090	-2780673	43.6
BH107	-4674	-2774124	43.6

3. The water levels around the TSF were the focus of the calibration process. The water levels of BH117 and BH104 indicated an increase. Exigo were also provided the dewatering volumes of the Tuschenkomst Pit (Figure 5-8). The dry cycles indicated in Figure 5-8 would supply the groundwater component of the seepage captured in the open pit. On average, this equates to approximately 340 m³/d. The groundwater flow model was calibrated and volumes dewatered from the open pit ranges between 1100 and 1300 m³/d. This would seem incorrect. However, if evaporation of 2400 mm/a would be applied to the pit perimeter of 4000 m to a depth of 40 m, possible evaporation rates vary between 900 and 1100 m³/d. This would confirm the model provides the correct volumes of possible groundwater dewatering, roughly 1000 m³/d is lost to evaporation.

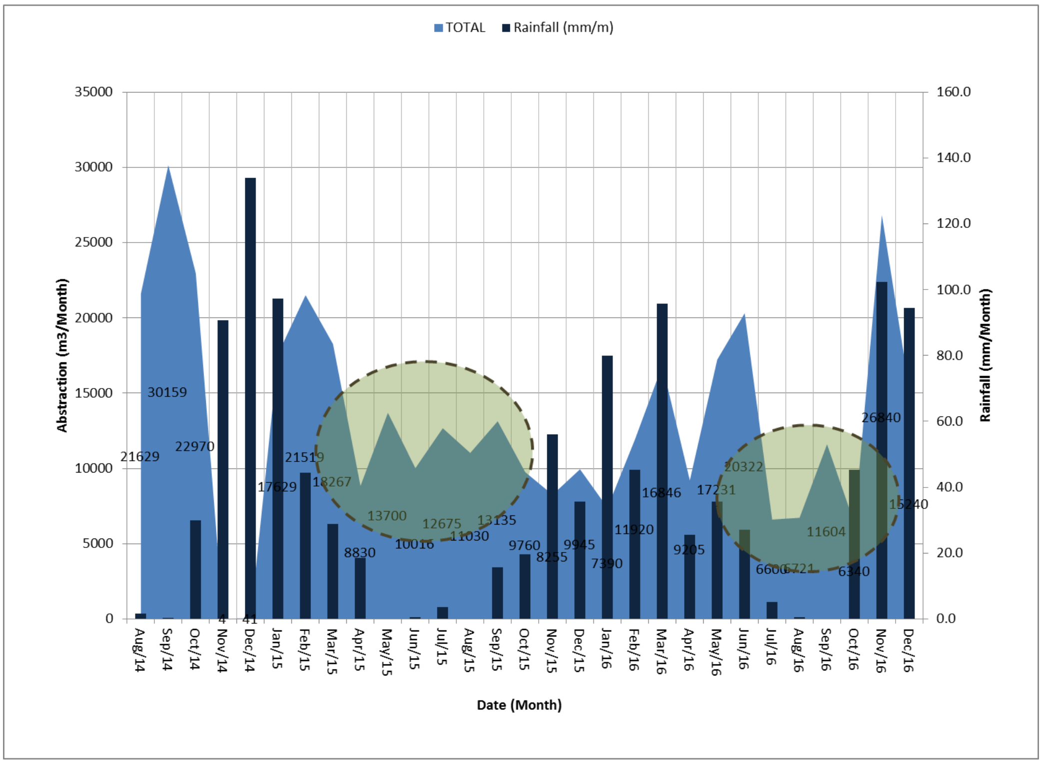

Figure 5-8 Dewatering volumes of the Tuschenkomst Open Pit.

4. The obtain the water levels as measured around the TSF i.e. upstream and downstream, a flux had to be applied to the footprint of the TSF. The slurry depositions do contribute to the constant head in this area, and from Epoch Resources, a flux value of 0.0043 m/d were applied to various aerial extents to obtain the best possible fit to the measured water levels. At the end, a flux of 3100 m³/d was required to calibrated the water levels to acceptable levels when compared to the measured levels. This indicates that in this area i.e. TSF plus surroundings (which includes pipelines, dams, plant area etc.) a total flux of 3100 m³/d contributes to the groundwater regime and influences the water levels as measured (Figure 5-9).

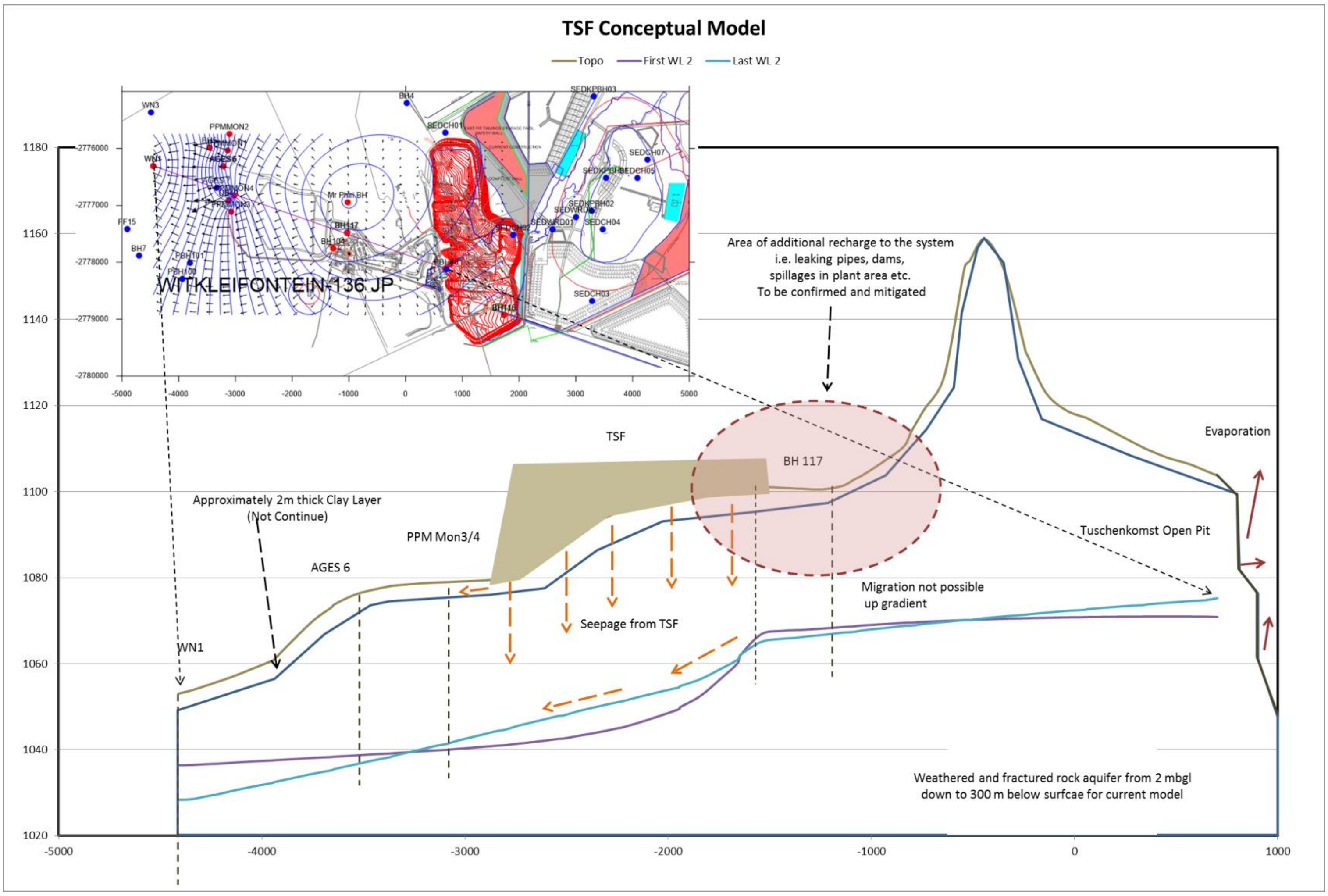

Figure 5-9 TSF conceptual model

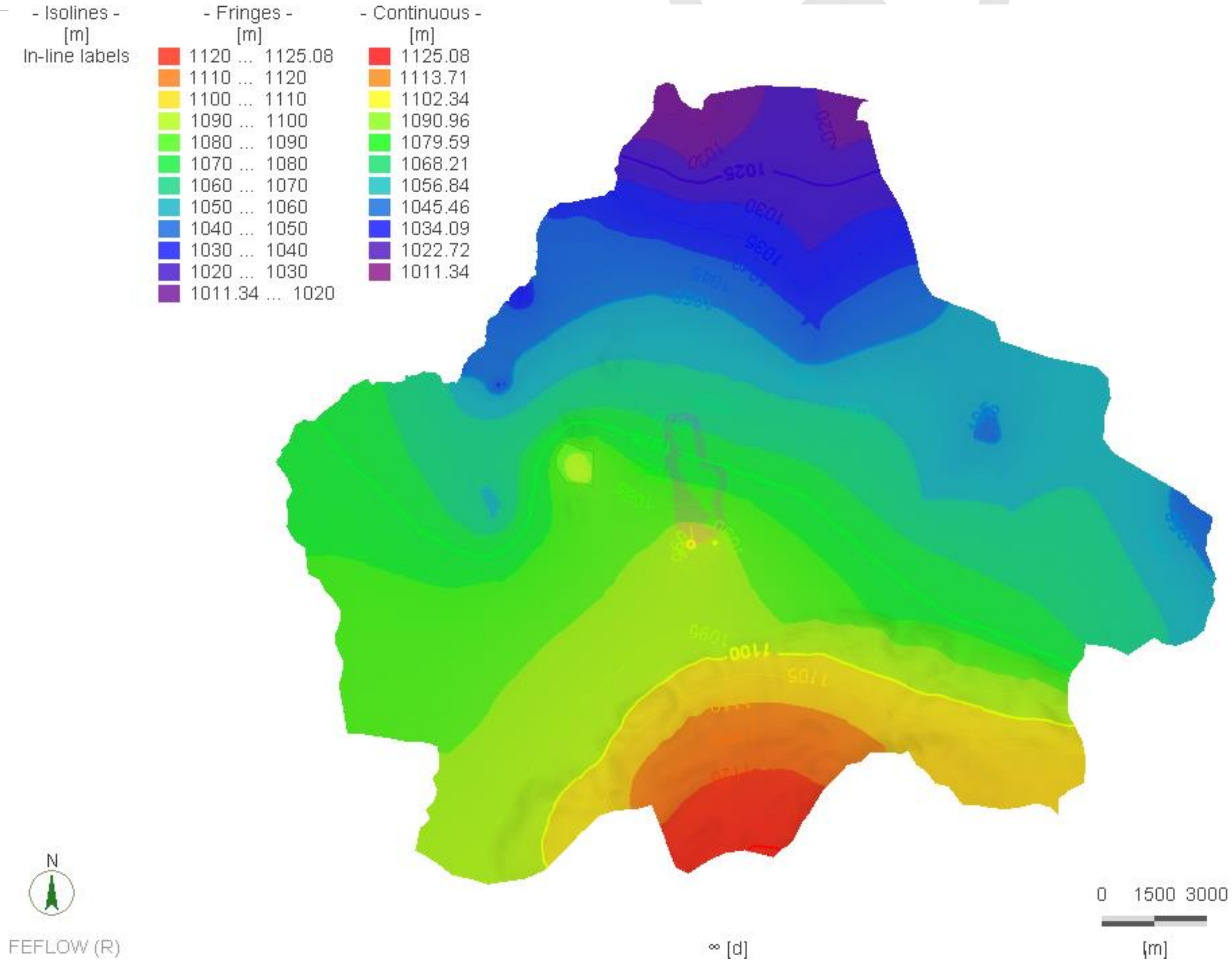

Figure 5-10 **Steady state calibrated water levels and flow directions**

5.8 Simulation of Scenarios

Scenarios were simulated during this update study to quantify the impact on the groundwater due to the expansion of the PPM processing facilities updated geochemical properties of the new KELL tailings. These scenarios assist in the decision-making process regarding the management of the groundwater resource and potential impacts in this area and neighbouring groundwater users. Scenarios were simulated using transient state circumstances.

For these mass transport scenarios, advective transport was used. Reactive transport can be used in a next numerical model update as the SO_4 mass migration is expected to be slower due to the precipitation and adsorption of SO_4. The geochemical modelling should also then be updated in conjunction with the numerical groundwater modelling to represent the reactive environment.

The following model scenarios were simulated:

1. **Scenario 1**: Transient state mass migration simulation from 2009 to 2018 (current) of the source's (TSF) measured $S0_4$-concentration (208 mg/ℓ) correlated with the SO4-concentrations measured at the monitoring boreholes with time-dependant actual abstraction from boreholes surrounding the current TSF.
2. **Scenario 2a**: Transient state mass migration simulation from 2019 to 2030 (end of current TSF's life) of the source's (TSF) measured $S0_4$-concentration as indicated by Solution[H+] (2019). Mass migration time of the new tailing's $S0_4$-concentration (435 mg/ℓ) was considered as calculated by Solution[H+] (2019).
3. **Scenario 2b**: Transient state mass migration simulation from 2019 to 2030 (end of current TSF's life) of the source's (TSF) measured $S0_4$-concentration as indicated by Solution[H+] (2019) with time-dependant conceptual abstraction from the current and 10 additional conceptual boreholes surrounding the TSF's extent. Mass migration time of the new tailing's $S0_4$-concentration (435 mg/ℓ) was considered as calculated by Solution[H+] (2019).

Scenario 3a, 3b, 3c, and 3d were run for a duration of 50 years post the operational. Longer time-periods can be simulated but were restricted to 50 years during this model update due to the conservative concentrations resulting from the geochemical assessment and modelling. The conservative results from the numerical model are compounded with scenarios of longer duration, i.e. the longer the simulation, the more conservative the results become and may be skewed further away from the expected concentrations.

4. **Scenario 3a**: Transient state mass migration simulation from 2031 to 2080 (50 years post TSF's operational phase) of the source's (TSF) post-drainage modelled $S0_4$-concentration (1595 mg/ℓ) as indicated by Solution[H+] (2019) with time-dependant abstraction from current boreholes surrounding the TSF's extent until 5 years post operational phase (2035). The recharge fluid flux from the TSF was simulated as 10% of recharge from 5 years post operational phase.

5. **Scenario 3b**: Transient state mass migration simulation from 2031 to 2080 (50 years post TSF's operational phase) of the source's (TSF) post-drainage modelled $S0_4$-concentration (1595 mg/ℓ) as indicated by Solution[H+] (2019) with time-dependant abstraction from the current and conceptual boreholes surrounding the TSF's extent until 5 years post operational phase (2035). The recharge fluid flux from the TSF was simulated as 10% of recharge from rainfall from 5 years post operational phase.
6. **Scenario 3c**: Transient state mass migration simulation from 2031 to 2080 (50 years post TSF's operational phase) of the source's (TSF) post-drainage modelled $S0_4$-concentration (1595 mg/ℓ) as indicated by Solution[H+] (2019) with time-dependant abstraction from current boreholes surrounding the TSF's extent until 5 years post operational phase (2035). The recharge fluid flux from the TSF was simulated as 3% of recharge from rainfall from 5 years post operational phase.
7. **Scenario 3d**: Transient state mass migration simulation from 2031 to 2080 (50 years post TSF's operational phase) of the source's (TSF) post-drainage modelled $S0_4$-concentration (1595 mg/ℓ) as indicated by Solution[H+] (2019) with time-dependant abstraction from the current and conceptual boreholes surrounding the TSF's extent until 5 years post operational phase (2035). The recharge fluid flux from the TSF was simulated as 3% of recharge from 5 years post operational phase.

6 RESULTS

6.1 Scenario 1: Numerical transient state mass migration simulation vs analytical measured data

The mass migration was qualified by correlating the measured SO_4 and the simulated SO_4 to indicate the level of accuracy that can be expected from the numerical simulation (Table 6-1; Figure 6-1). The R^2 = 71% which is a sufficiently good fit for an acceptable calibration.

A constant fluid flux seepage rate was assigned to the model of approximately 2300 m^3/d during the operational phase of the facility (Exigo, 2016). The boreholes in the vicinity of TSF were pumped at the same rate at which the historic pumping data dating back to 2013 indicates.

This scenario's results accuracy can cause the following scenario's results to be skewed and thus is an important step of the qualification of the numerical model.

Table 6-1 Measured vs simulated SO_4 concentrations at boreholes surrounding TSF

	AGES6	BH104	BH117	BH5	PPMMON1	PPMMON2	PPMMON3	PPMMON4	UB40
Measured SO_4	123	63	37	26	77	45	206	175	86
Simulated SO_4	116	28	15	35	94	43	166	175	167

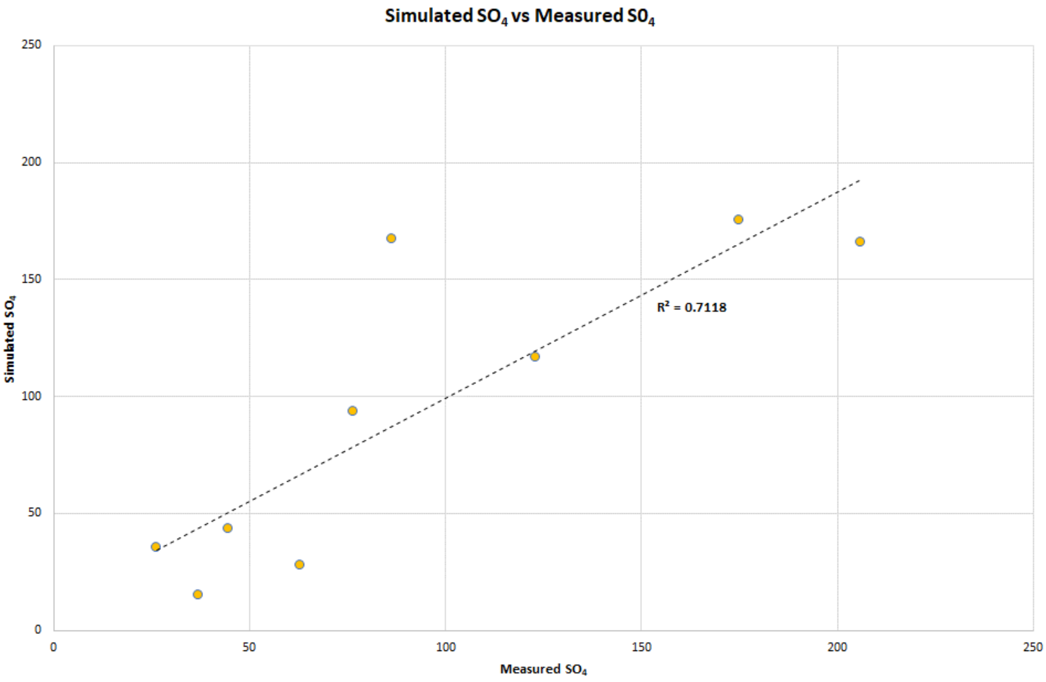

Figure 6-1 Correlation between simulated vs measured SO_4 (Table 6-1)

Figure 6-2 Scenario 1: Sulphate mass migration by the end of 2018

As the current source only contains a SO_4 concentration of 208 mg/ℓ, the surrounding mass migration does not exceed the SANS 241:2015 drinking water limits but does exceed DWS's Class 1 water type's limits (Figure 6-2).

6.2 Scenario 2a and 2b -operational

These scenarios were simulated to determine the possible mass migration from the TSF from the current day until the end of the life of the facility in 2030. Scenario 2a (Figure 6-3) represents a scenario in which the current seepage capturing boreholes are only pumped at 70% of their current average flow rates to take mechanical breakdowns, power failures, theft, and maintenance into account. Scenario 2b (Figure 6-4) represents a scenario in the which the current boreholes are pumped as indicated in scenario 2a, with exception to 10 additional conceptual boreholes being placed where the mass migrates downgradient to mitigate the possible impact of the SO_4 mass migration.

The new tailing's SO_4 concentration was measured at 435 mg/ℓ, which is still under the SANS 241:2015 drinking water limit, and deposition of this material was assumed to commence in 2019. According to Solution[H+] (2019), the tailing's seepage quality will take approximately 7 years to seep from a TSF pool of 20 m of tailings. The new tailing's seepage mass was also applied in the numerical model to reach the bottom of the tailings by 2025.

The 10 additional seepage capturing boreholes assigned in Scenario 2b were realistically assigned at 70% of the average pumping rate of all of the existing boreholes surrounding the TSF.

The additional conceptual boreholes located around the TSF impact the mass migration of SO_4 by decreasing the impacted area. The area which exceeds the DWS's Class 1 water type's limits is 36% smaller (Table 6-2) with the mitigating boreholes (Scenario 2b). From Table 6-2 the additional seepage capturing borehole's impact is clearly evident. The $S0_4$ mass migration does not exceed the baseline groundwater concentration at the Mothlabe drainage flowing north approximately 1.5 km west of the current TSF in scenario 1, 2a, and 2b.

Table 6-2 Scenario 2a and 2b mass migration plume area comparison to illustrate the efficiency of mitigation

	Baseline - 40 mg/ℓ mass area (ha)	**DWS Class 1 - 200 mg/ℓ mass area (ha)**
Scenario 2a without mitigation	1 013	505.6
Scenario 2b with mitigation	568	324.6
Difference	**-44%**	**-36%**

Figure 6-3 Scenario 2a: Sulphate mass migration 2030 without additional seepage capturing boreholes

Figure 6-4 Scenario 2b: Sulphate mass migration end 2030 - 10 additional seepage capturing boreholes

6.3 Scenario 3a, 3b, 3c, and 3d – post-operational phase

Scenarios were simulated to determine the possible mass migration from the TSF as a source for 50 years post-operational from 2031 until 2080. In Scenarios 3a and 3c only the current seepage capturing boreholes were pumped as in Scenario 2a. In Scenarios 3b and 3d the current and conceptual seepage capturing boreholes were pumped as in Scenario 2b. In all four of these scenarios all pumped was ceased 5 years post operations at the current TSF. Scenarios 3a and 3b had an unmitigated TSF surfaces post-operational which has an assumed fluid flux therefrom of 10% of MAP. Scenarios 3c and 3d had mitigated (plant growth, clay capping, etc.) TSF surfaces post-operational which has an assumed fluid flux at of 3% of MAP.

The lowering of the fluid flux in the numerical model will assist with mitigating the plume migration and can represent rehabilitation of the facility.

Based on Solution[H+] (2019) post-operational (post-drainage) phase geochemical modelling, it was predicted that the SO_4 source's concentration at the TSF would be 1595 mg/ℓ. This source does exceed the SANS 241:2015 drinking water limit as well as the DWS's Class 1 water type limits.

Figure 6-5,Figure 6-6,Figure 6-7, and Figure 6-8 illustrate the various scenario's mass migrations. It is important to note that in none of the simulations, any other boreholes besides the mine's boreholes are impacted. Besides the boreholes being impacted, the areas which may have SO_4 concentrations that exceed the SANS 241:2015 and DWS Class 1 water type limits decrease as the migration plume reaches further away from the TSF. The modelled SO_4 mass migration does exceed the baseline groundwater concentration at the Mothlabe drainage flowing north approximately 1.5 km west of the current TSF in scenario 3a, 3b, 3c, and 3d, but does not exceed the SANS 241:2015 drinking water limit and therefore has an insignificant impact on the receiving environment.

Table 6-3 illustrates the benefit of implementing mitigation measures. Areas that may be impacted by SO_4 migration can still be utilised and can provide a source of drinking water for the nearby communities.

Table 6-3 Scenario 3a, 3b, 3c, and 3d mass migration plume area comparisons to show mitigation efficiency

	Baseline - 40 mg/ℓ mass area (ha)	DWS Class 1 - 200 mg/ℓ mass area (ha)	SANS 241:2015 Drinking Water Limit - 500 mg/ℓ mass area (ha)
Scenario 3a	1 538	1 022	721
Scenario 3b	1 362	966.	703
Scenario 3c	1 418.	906.	627
Scenario 3d	1 213	843	605
Difference between 3a and 3d	**-21%**	**-17%**	**-16%**

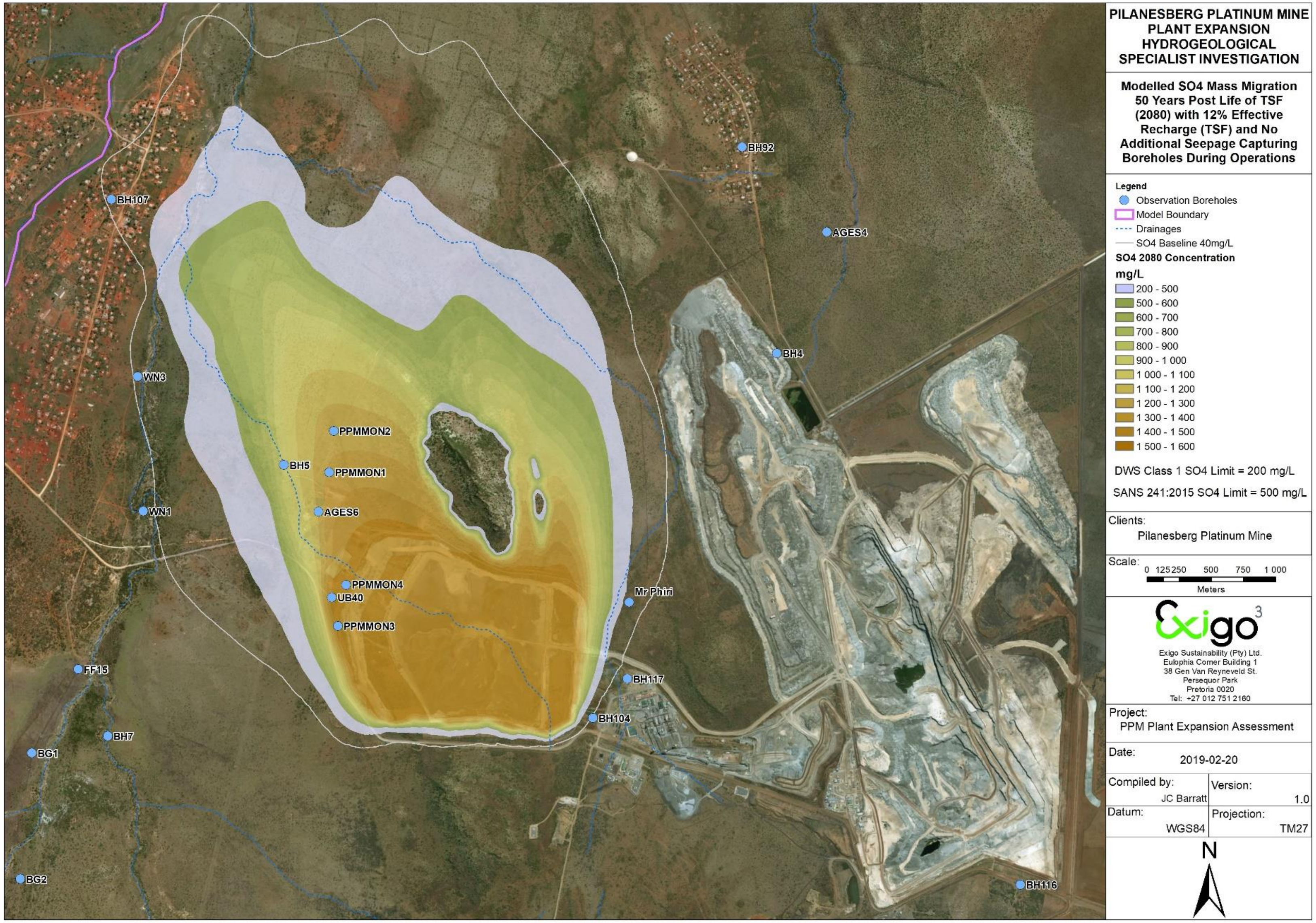

Figure 6-5 Scenario 3a: Sulphate migration with 12% effective recharge by the end of 2080 without any additional seepage capturing boreholes

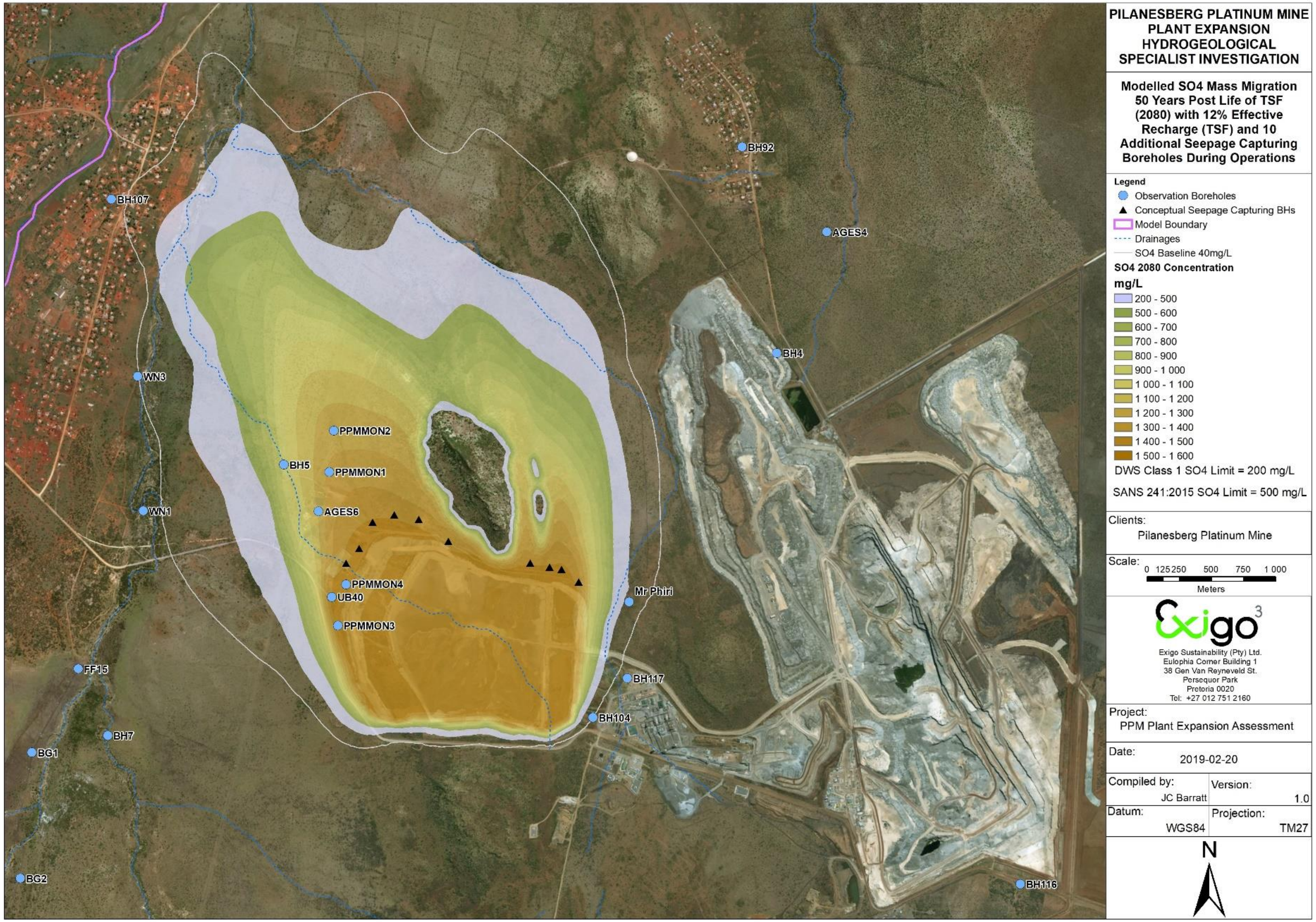

Figure 6-6 Scenario 3b: Sulphate migration with 12% effective recharge by the end of 2080 with 10 additional seepage capturing boreholes

Figure 6-7 Scenario 3c: Sulphate migration with 5% effective recharge by the end of 2080 additional seepage capturing boreholes

Figure 6-8 Scenario 3d: Sulphate migration with 5% effective recharge by the end of 2080 with 10 additional seepage capturing boreholes

7 IMPACT MATRIX

A detailed impacts assessment is presented in Appendix A: IMPACT MATRIX.

The probability index is an assessment which is not based on the possible groundwater quality, but rather on the probability of this water being provided to humans for consumption. The scenarios simulated in the numerical groundwater model provide an indication of the groundwater quality and are subsequently rated in the impact matrix on whether humans will consume the groundwater, and not the impact on the groundwater quality itself.

The following important impacts and controls were included as part of this hydrogeological assessment:

7.1 Construction phase

7.1.1 Possible impacts

- Contamination to groundwater systems from oil, grease and diesel spillages from construction vehicles
- On-site sanitation
- Storage of chemicals and building materials during construction of waste facilities

7.1.2 Mitigation measures

- Road compaction and service facilities for mine vehicles with spillage sumps
- Monitoring systems to detect leaking and as well as visual observations of facilities conditions

7.2 Operational phase

7.2.1 Possible impacts

- Mass transport and seepage from existing PPM residue facilities at the proposed mine along preferential groundwater pathways
- Chemical reagents used within process plant

7.2.2 Mitigation and management measures

- Abstraction volume monitoring and observations if geological fractures are intersected at depth during construction groundwater level monitoring
- Location of and barrier design and/or seepage capturing for mine residue facilities
- Backfilling of open pits
- Water quality monitoring and seepage capturing from boreholes
- Ensure proper environmental management principles are followed and no additional water supply boreholes are added within the plume area

7.3 Closure and decommissioning phase

7.3.1 Possible impacts

- Re-watering and decanting of open pits
- Seepage and mass transport from mine residue facilities and back fill material on groundwater quality

7.3.2 Mitigation and management measures

- Post-operational closure planning and land use design
- Location of and barrier design and/or seepage capturing for mine residue facilities
- Rehabilitation and revegetation of the TSF and Waste Rock Dumps to minimise infiltration
- Water quality monitoring and seepage capturing from boreholes
- Ensure proper environmental management principles are followed and no additional water supply boreholes are added within the plume area

7.4 Post operational phase

7.4.1 Possible impacts

- Re-watering and decanting of open pits
- Seepage and mass transport from mine residue facilities and back fill material on groundwater quality

7.4.2 Mitigation and management measures

- Post-operational closure planning and land use design
- Location of and barrier design and/or seepage capturing for mine residue facilities
- Rehabilitation and revegetation of the TSF and Waste Rock Dumps to minimise infiltration
- Water quality monitoring and seepage capturing from boreholes
- Evaporation ponds, water treatment, or re-use
- Ensure proper environmental management principles are followed and no additional water supply boreholes are added within the plume area

8 CONCLUSIONS

The main conclusions from the 7 scenarios simulated during this model update are listed below per scenario:

1. TDS values averaged between 224 mg/L and 892 mg/L at these boreholes during 2018. Nitrate concentrations were below 4 mg/L, except at B15a where it averaged 26 mg/L. Sulphate concentrations were below 20 mg/L, except at B15a where it averaged 31 mg/L (Exigo 2019, E-R-2019-01-22: Annual Water Monitoring Report 2018: Pilanesberg Platinum Mines).
2. Statistically significant increasing trends in nitrate and sulphate concentrations were observed at both the eastern (BH104 & BH117) and western (UB40, AGES6, PPMMON1 to PPMMON4 and BH5) TSF monitoring boreholes (Exigo 2019, E-R-2019-01-22: Annual Water Monitoring Report 2018: Pilanesberg Platinum Mines).
3. Additional groundwater monitoring locations are required around the TSF to observe the groundwater pathways towards the receptors.
4. The geochemical modelling indicated that the TSF source's SO_4 concentration is currently measured at 208 mg/ℓ which is below the SANS 241:2015 drinking water limits. The new KELL process tailings will increase the SO_4 concentration to 435 mg/ℓ while the post-drainage SO_4 concentration will increase to 1595 mg/ℓ (Solution[H+], 2019).
5. The TSF seeps at 2300 m^3/d during the operational phase and decreases to 85 m^3/d during the post-operational phase.
6. During the operational phase (2019 – 2030) the sulphate mass migration extent which exceeds the baseline is decreased by 44% in Scenario 2b in comparison with Scenario 2a when additional seepage capturing boreholes are applied.
7. Additional methods to lower recharge (planting trees, clay lining, etc.) during the simulated post-operational phase (2031 – 2080) can decrease the mass migration extent which exceeds the baseline is by 21% when additional seepage boreholes are also applied during the operational phase.
8. The sulphate mass migration does not exceed the baseline groundwater concentration at the Mothlabe drainage flowing north approximately 1.5 km west of the current TSF in scenario 1, 2a, and 2b. The baseline groundwater concentration is exceeded in scenario 3a, 3b, 3c, and 3d, but does not exceed the SANS 241:2015 drinking water limit and therefore has an insignificant impact on the receiving environment.

9 RECOMMENDATIONS FOR FUTURE ACTIONS

The main recommendations going forward listed below need to be implemented immediately to reduce the environmental impact the TSF could have.

1. The geochemical modelling needs to be reviewed to verify results therein as the current results can be considered conservative.
2. Update the geochemical numerical modelling to include reactive transport.
3. Update the numerical groundwater model to include reactive transport to take the possible precipitation and adsorption of sulphate into account. The simulation period can also be increased once the geochemical modelling and results have been reviewed and verified.
4. The monitoring programme needs to be reviewed to observe additional gaps in data collection and mass migration monitoring.
5. Surface geophysical surveys need be completed surrounding the TSF to identify preferential flow paths where additional seepage capturing boreholes can be drilled. The model simulations were based on 10 conceptual additional seepage capturing boreholes.
6. Drilling, equipping, and pumping of additional seepage capturing boreholes need be done to reduce the mass migration impact. These seepage capturing boreholes should be properly maintained and the efficiency audited.
7. Aquifer tests need to be performed on the newly drilled seepage capturing boreholes to determine the recommended rates at which each hole needs to be pumped.
8. Telemetry needs to be installed at all relevant boreholes to monitor the real-time aquifer conditions.
9. Reduction of recharge onto TSF surface during the post-operational needs to be achieved by rehabilitation and revegetation e.g. planting trees which have a high evapotranspiration rate to effectively minimise nett infiltration water from the facility. A clay sealing cap also needs to be installed post operations to thwart recharge to the de-commissioned TSF. The rehabilitated scenarios must be included in an updated model to demonstrate the efficiency.
10. The current seepage capturing boreholes need to be pumped as per the recommended rates to ensure the desired impacts of each hole.

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11 APPENDIX A: IMPACT MATRIX

Nr	Activity	Impact	Without or With Mitigation	Probability	Duration	Spatial Scale	Severity	Consequence	Significance	Interpretation of Significance	Mitigtion Measures	Mitigation Effect
				Magnitude	Magnitude	Magnitude	Magnitude	Magnitude				
Construction Phase												
1	Contamination to groundwater systems from oil, grease and diesel spillages from construction vehicles	Contamination to groundwater systems	**WOM**	Possible	Medium Term	Site	Low	Low	Medium	It should have an influence on the decision unless it is mitigated	Road compaction and service facilities for mine vehicles with spillage sumps	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated
2	On-site sanitation	Contamination to groundwater systems	**WOM**	Possible	Medium Term	Site	Medium	Medium	Medium	It should have an influence on the decision unless it is mitigated	Monitoring systems to detect leaking and as well as visual observations of facilities conditions	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It should have an influence on the decision unless it is mitigated		Can be reversed
3	Storage of chemicals and building materials during construction of waste facilities	Contamination to groundwater systems	**WOM**	Possible	Long Term	Site	Medium	Medium	Medium	It should have an influence on the decision unless it is mitigated	Monitoring systems to detect leaking and as well as visual observations of facilities conditions	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated
Operational Phase												
5	Mass transport and seepage from existing PPM residue facilities at the proposed mine along preferential groundwater pathways	Contamination to groundwater systems	**WOM**	Unlikely	Medium Term	Site	Low	Low	Low	It will not have an influence on the decision	Water quality monitoring and seepage capturing from boreholes; ensure proper environmental management prnciples are followed and no additional water supply boreholes are added within the plume area	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It will not have an influence on the decision		Can be avoided, managed or mitigated
6	Chemical reagents used within process plant	Contamination to groundwater systems	**WOM**	Possible	Medium Term	Site	Medium	Medium	Medium	It would influence the decision regardless of any possible mitigation	Water quality monitoring and seepage capturing from boreholes; spills should be dealt with appropriately	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It will not have an influence on the decision		Can be avoided, managed or mitigated
Closure and Decommissioning Phase												
7	Re-watering and decanting of open pits	Oxidation of backfilled material	**WOM**	Possible	Long Term	Site	Low	Medium	Medium	It should have an influence on the decision unless it is mitigated	Water quality monitoring and seepage capturing from boreholes; ensure proper environmental management prnciples are followed and no additional water supply boreholes are added within the plume area; evaporation ponds, water treatment, or re-use	Can be avoided, managed or mitigated
			WM	Possible	Medium Term	Site	Low	Low	Medium	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated
8	Seepage and mass transport from mine residue facilities and back fill material on groundwater quality	Contamination to groundwater systems	**WOM**	Possible	Medium Term	Local	Low	Low	Medium	It should have an influence on the decision unless it is mitigated	Water quality monitoring and seepage capturing from boreholes; ensure proper environmental management prnciples are followed and no additional water supply boreholes are added within the plume area	Can be avoided, managed or mitigated
			WM	Unlikely	Short Term	Site	Low	Low	Low	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated
Post Operational Phase												
9	Re-watering and decanting of open pits	Contamination to groundwater systems	**WOM**	Possible	Long Term	Site	Medium	Medium	Medium	It should have an influence on the decision unless it is mitigated	Evaporation ponds, water treatment, or re-use	Can be avoided, managed or mitigated

			WM	Possible	Medium Term	Site	Low	Low	Medium	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated
10	Seepage and mass transport from mine residue facilities and back fill material on groundwater quality	Contamination to groundwater systems	**WOM**	Possible	Medium Term	Local	Medium	Medium	Medium	It should have an influence on the decision unless it is mitigated	Water quality monitoring and seepage capturing from boreholes; no additional water supply should be drilled within the impacted area without proper investigation	Can be avoided, managed or mitigated
			WM	Possible	Medium Term	Site	Low	Low	Medium	It should have an influence on the decision unless it is mitigated		Can be avoided, managed or mitigated