TSHIPI BORWA MANGANESE MINE

EMP Amendment No.3 Specialist Report: Pit Closure Water Balance and Geochemical Modelling

Prepared for: Tshipi é Ntle Manganese Mining (Pty) Limited

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Executive Summary

Tshipi é Ntle Manganese Mining (Pty) Ltd (Tshipi) operates the Tshipi Borwa manganese opencast mine in the Kalahari Manganese Basin in the Northern Cape Province of the Republic of South Africa. Currently, Tshipi's approved commitment is to restore the surface to pre-mining status i.e. to wilderness and grazing and includes complete backfilling of the open pit. SLR Consulting Limited (SLR) has been appointed to prepare a specialist hydrological and geochemical report to form part of an additional EIA/EMP Amendment (EMP3), to examine the equivalent enviro-socio-economic benefits that can/may be achieved for the mine closure by exploring different (selected) backfilling options.

There are four mine closure backfilling options addressed in this assessment, these are:

1. Complete backfill;
2. Partial backfill;
3. Concurrent Backfill; and
4. No backfill.

This has included probabilistic hydrological and geochemical modelling to predict the pit lake water quality generated over closure time scales. Comparison with the livestock drinking water standards was used to measure the comparative success of the various mine closure options. This specialist report has been prepared with due reference to the requirements held in Appendix 6 of National Environment Management Act (NEMA, December 2014). The results of the study conclude:

Backfilling closure option	Water quality summary (Failure analyte (s) - exceed Livestock DWS limits)	Comments
Option 1 Complete backfill	• Fe ≈ 25 years	The water is useable for c. 25 years without treatment. Therefore, is more restrictive than Option 3. Water quality will largely remain equivalent to groundwater quality or worse over closure timescales as the pit is flow-through. The iron is in solution due to the anticipated reducing redox conditions.
Option 2 Fill to regional groundwater level	• Fe ≈ 25 years	The water is useable for c. 25 years without treatment. Therefore, is more restrictive that Option 3. Water quality will largely remain equivalent to groundwater quality or

Backfilling closure option	Water quality summary (Failure analyte (s) - exceed Livestock DWS limits)	Comments
		worse over closure timescales as the pit is a partial flow-through. The iron is in solution due to the anticipated reducing redox conditions.
Option 3 Concurrent backfill	- NO_3 ≈ 200 years - TDS ≈ 200 years - Se ≈ 200 years	The water is useable for c. 200 years without treatment. TDS will have a restricted use but is still viable as a resource. Therefore the water will have less restrictions on its use for a longer period of time than the other options The longer term modelling trend indicates that water quality will eventually deteriorate over an extended time due to evapoconcentration and eventually fail for most analytes.
Option 4 No Backfill	- Cd ≈ 100 years - Cl ≈ 100 years - F ≈ 50 years - Hg ≈ 50 years - Mg ≈ 100 years - Mo ≈ 50 years - NO_3 ≈ 100 years - Pb ≈ 100 years - Se ≈ 100 years - TDS ≈ 50 years	The water is useable for c. 50 years without treatment. The long term modelling trend indicates that water quality will deteriorate over time due to evapoconcentration and eventually fail for most analytes.

A benefit/liability comparative assessment for short- and long-term water use is provided below:

Benefit/liability comparitive assessment

Backfilling closure option	Short term benefits/liabilities	Long term benefits/liabilities
Option 1 Complete backfill	Water use benefit for only 25 years before treatment Water extraction requires wells, pumps etc Wells/screens likely to clog up with Iron	Requires less treatment for long term use Flow through pit means contamination plumes released to wider groundwater system
Option 2 Fill To Regional Groundwater level	Water use benefit for only 25 years before treatment Water extraction requires wells, pumps etc. Wells/screens likely to clog up with Iron	Requires less treatment for long term use Flow through pit means contamination plumes released to wider groundwater system
Option 3 Concurrent backfill	Water use benefit for 200 years before treatment Water extraction requires much less infrastructure than option 1 & 2	Requires more treatment for long term use, but this can potentially include passive treatment (refer section 10.3 and Section 11). Hydraulic sink benefit as cone of depression captures wider pollution plumes from other mine areas and sources (WRDs etc)
Option 4 No Backfill	Water use benefit for 50 years before treatment Water extraction requires much less infrastructure than option 1 & 2	Requires most treatment for long term use. Hydraulic sink benefit as cone of depression captures wider pollution plumes from other mine areas and sources (WRDs etc)

It is apparent that the beneficial use of the pit lake for water supply purposes will be limited to short term use (tens to hundreds of years) before water treatment is likely to be required to continue its use. In the short term, concurrent backfill offers the best water quality solution. Complete backfill of the pit may result in enhanced permeability which may enhance storage of water but water qualities are not necessarily automatically useable and that solution would also need a means of extraction (bores, screens, pumps etc).

Preserving a hydraulic sink (Option 3 and 4) may also in fact be a more sustainable long term solution as water (and any "pollutants" contained within) will be drawn towards the pit and effectively containing them as the cone of depression has its centre at the pit. This may have more regional & widespread benefits to groundwater resources. A passive water treatment solution has the potential to address some of the pit lake closure water quality issues in the long term and it is recommended that this approach is tested further at pilot scale in the pit lake.

1.0 Technical specialists

Matthew Goode BSc MSc **Hydrologist**

Matt has approximately 17 years of experience with expertise of working on mining projects throughout Europe, Africa, Asia and Australia. Matt is a project manager and technical lead for large scale engineering design, water supply and hydrological projects with particular technical expertise in hydrology, water resources, sediment studies and water balance modelling for mining projects. Matt combines the ability to coordinate complex projects with hands-on experience and is effective in leading high performing, multi-disciplinary teams. He is accomplished at directing multiple operations across the world to achieve project and client objectives. He combines excellent analytical skills (collating and interpreting complex data) with strong verbal and written communication skills at all levels of multinational and smaller scale organisations.

Jamie Robinson BSc MSc C.Geol SILC SQP **Geochemist**

As a technical leader in the field of geochemistry Jamie has over 29 years' experience in the prediction and treatment of acidic metalliferous mine drainage and designs passive treatment technologies globally. Jamie also uses a number of hydrochemical and geochemical models to model the pit lakes in Australia and South Africa. Jamie has developed a variety of innovative and award-winning investigation and remediation techniques for the assessment and mitigation of soil and groundwater contamination. This work has led to over twenty publications in the scientific community. Jamie has lectured in Australia and UK and is an examiner for the Specialist in Land Condition (SiLC) qualification and a scrutineer for the Royal Geological Society. Jamie also acted as an external examiner for Strathclyde University and Glasgow University. Jamie was awarded the status of Suitably Qualified Person (through the National Quality Mark Scheme) in 2017 and has also acted as Expert Witness in the UK regarding hydrogen cyanide exposure.

1.1 Declaration

We hereby declare that the specialists listed are independent in a form as may be specified by the competent authority.

Signed

Date:	Jamie Date:
Matthew Goode SLR Consulting Limited	Jamie Robinson SLR Consulting Limited

2.0 Introduction

Tshipi é Ntle Manganese Mining (Pty) Ltd (Tshipi) operates the Tshipi Borwa manganese opencast mine in the Kalahari Manganese Basin in the Northern Cape Province of the Republic of South Africa. Currently the mine produces approximately three million tonnes per annum of Run-of-Mine ore and has a remaining opencast life of approximately twenty-five years.

Tshipi currently holds a Mining Right and an Environmental Management Programme Report (EMPr) approved by the Department of Mineral Resources (DMR) and an Environmental Authorisation for an EIA/EMP Amendment (EMP1) submitted in November 2017 and approved in January 2018. Tshipi also holds a Water Use License (WUL) issued in April 2015.

Currently, Tshipi's approved commitment is to restore the surface to pre-mining status i.e. to wilderness and grazing and includes complete backfilling of the open pit.

2.1 Scope of this report

SLR Consulting Limited (SLR) has been appointed to prepare a specialist report to form part of an additional EIA/EMP Amendment (EMP3), to examine the equivalent enviro-socio-economic benefits that can/may be achieved for the mine closure by exploring different (selected) backfilling options. This report will assess the likely water quality of pit lake water once mining operations have ceased.

There are four mine closure backfilling options addressed in this assessment, these are:

5. Complete backfill;
6. Partial backfill;
7. Concurrent Backfill; and
8. No backfill.

This technical report has been prepared to examine these four options regarding the closure of the mine and presents the predicted impact on the hydrological environment, in particular the long term, predicted pit lake water chemistry. This has included probabilistic hydrological and geochemical modelling to predict the pit lake water quality generated over closure time scales.

This specialist report has been prepared with due reference to the requirements held in Appendix 6 of National Environment Management Act (NEMA, December 2014).

2.2 Mine pit lake formation

Mine pit lakes differ physically from natural lakes in having a markedly higher ratio of depth to surface area. This is described by percent relative depth, which is defined as the percentage of a lake's maximum depth compared to its width calculated from its surface area by assuming the lake is approximately circular. A typical natural lake has a relative depth of less than 2%, although some may exceed 5%. Pit lakes commonly have relative depths between 10 and 40%. The Tshipi pit will have a percent relative depth of 13%. This will cause the pit lake to easily stratify with the consequential changes in chemical characteristics with depth (layering). Total dissolved solids and electrolytic conductivity tend to increase with depth; values near the base are often several times those at the surface. The hypolimnion (lower stratum) of a stratified lake has the tendency to contain low dissolved oxygen concentrations, oxygen demand (chemical and/or biological) is high enough. The existence of a sub-oxic or anoxic (no oxygen) layer in a pit lake can have significant effects on the lake's chemical and biological characteristics and thus on its potential for remediation and ongoing use.

More detail on the layering is discussed in the geochemical modelling held in Section 8.0.

2.3 Overall objective

In arid climates, pit lake evaporation rates exceed water influx rates by several times, causing a lake to function as a hydraulic terminal sink if not backfilled. This means that water levels in the pit remaining below surrounding groundwater levels. Determining the rate of pit filling, the quasi-static water level, type of pit (hydraulic sink or flow-through) and the chemistry of the pit for closure timescales are key outcomes for this study.

The predicted quality of the water in this lake is of profound importance, especially in this area of scarce water resources.

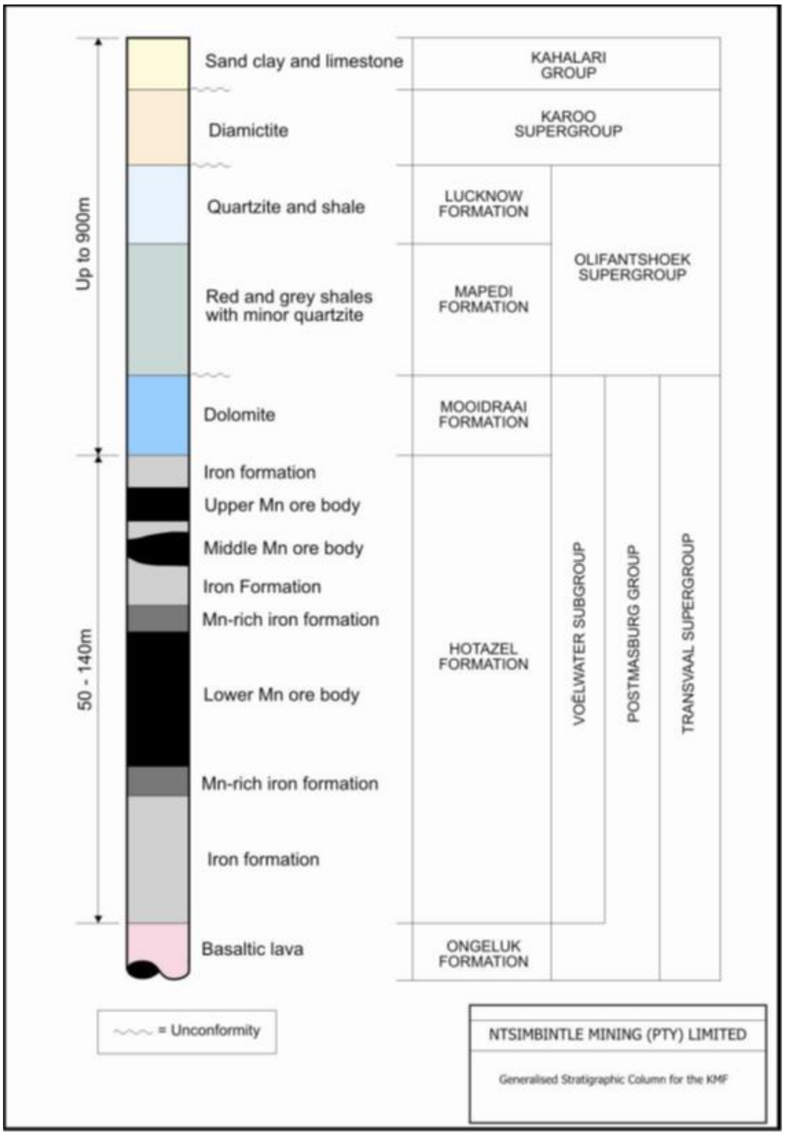
3.0 Site setting

The Tshipi Borwa Mine is located in the Kalahari Manganese Field (KMF) in South Africa. It is one of the largest open pit mining projects in the KMF basin. In this climate zone, evaporation rates exceed rainfall by many times. This environment is likely to cause a passive pit closure lake to function as a terminal hydraulic sink with water levels in the pits remaining below surrounding groundwater levels and which will develop evapo-concentrated water quality over time. There are no perennial surface water flows in the area and the annual runoff volume is concentrated in the form of ephemeral and storm water surface water flows during the wet periods; even the natural drainage lines surrounding the mining area are not well defined.

3.1 Geological setting

The Tshipi Borwa Mine is located on the south western outer rim of the Kalahari Manganese Field (KMF). The mine is exploiting the manganese from the Hotazel Formation (Transvaal Supergroup). A general Stratigraphic column for the KMF is presented in Figure 3-1.

Figure 3-1
Generic Stratigraphic Column for the Kalahari Manganese Field



3.1.1 Kalahari Deposits

The site is directly underlain by sands, claystone and calcrete of the **Kalahari Group.**

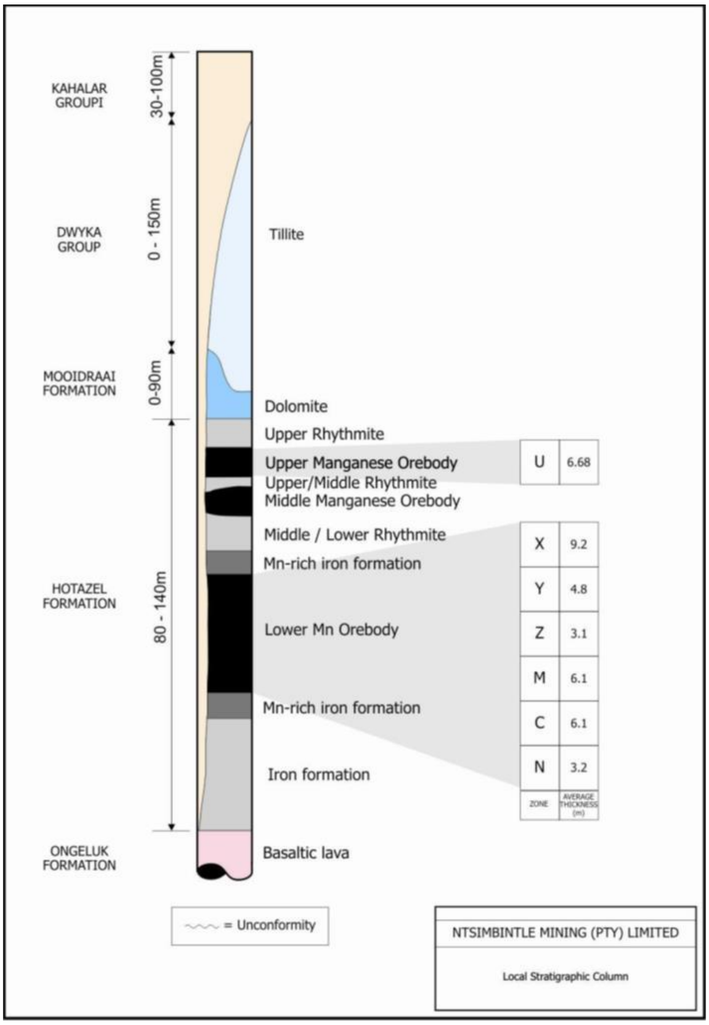
The manganese resource is hosted by the Hotazel Formation and consists of three ore bodies (Lower, Middle and Upper) that are intercalated with BIF and rhythmites. The Lower manganese orebody varies in thickness from 5 to 40 m and contains the highest manganese grades. It is the main ore horizon that is mined.

The Middle orebody has a maximum of 2 m thickness, is poorly mineralised and is considered uneconomic. The Upper orebody is moderately mineralised and is stockpiled at the mine for possible future use. The dominant ore minerals are braunite and hausmanite. The ore is carbonate rich and sulphide minerals are rare.

The overburden consists of the 0-84 m thick dolomites of the Mooidraai Formation, which overlies the Hotazel Formation. Above the dolomites is the Dwyka Group, which consists of glacial diamitites/tillites that vary in thickness from 0 m to 90 m. These are covered by 30-100 m thick gravels, clays, calcretes and aeolian sands of the Kalahari Group. The Mooidraai Formation and upper parts of the Hotazel Formation have been eroded in the southern portion of the mine area.

This stratigraphy and the hydrogeological characteristics are captured represented in the groundwater model.

Figure 3-2
Local Stratigraphic Column for the Kalahari Manganese Field in the Project Area



3.2 Key sources of background information

The following sources of background information were reviewed as part of the study.

Table 3-1
Sources of Information

Project	Document Title	Author and Reference	Document Date
Hydrocensus	Tshipi Hydrocensus field report	Metago Environmental Engineers (Pty) Ltd U002-01	June 2006
Ntsimbintle Groundwater Assessment	Groundwater investigation for Ntsimbintle mine	Water Geosciences Consulting Ntsimbintle 27/02/09	February 2009

Project	Document Title	Author and Reference	Document Date
Hydrocensus	Tshipi Borwa Mine: Hydrocensus Study	Knight Pièsold Consulting RI301-00321/02	August 2012
Pit Lake Study	Hydrogeological Assessment for Mine Closure Planning - Pit Lake Formation - Site Report and Analytical Model	SLR Consulting (Africa) (Pty) Ltd 721.20008.00015	November 2012
Geochemical Assessment	Geochemical and Groundwater Assessment	SLR Consulting (Africa) (Pty) Ltd 710.20008.00008	March 2014
Groundwater Risk Assessment	Tshipi Borwa New Waste Rock Dump Groundwater Risk Assessment	SLR Consulting (Africa) (Pty) Ltd 710.20008.00028	April 2015
Waste Type Assessment	Waste classification assessment for Tshipe e Ntle Mine	Golder Associates Africa (Pty) Ltd 1541973-301423-1	February 2016
Environmental Monitoring Report	4th Quarterly Water Monitoring Report and Annual Water Quality Report: 2015-2016.	SLR Consulting (Africa) (Pty) Ltd 755.20029.00005	February 2016
Environmental Monitoring Report	Tshipi Borwa Mine: Water Monitoring Report Quarter 2: October 2016	SLR Consulting (Africa) (Pty) Ltd 710.20008.00035	December 2016

4.0 Overall modelling approach

The individual technical components (Surface water, groundwater, climate and geochemistry) will be integrated into one model as this best represents the likely behaviour of the water environmental conditions at Tshipi under each selected closure scenario. SLR has utilised the GoldSim modelling platform to achieve this. The site-specific GoldSim model will combine and integrate the predicted behaviour into one model. The approach and how each technical element's dependencies are presented in Figure 4-1.

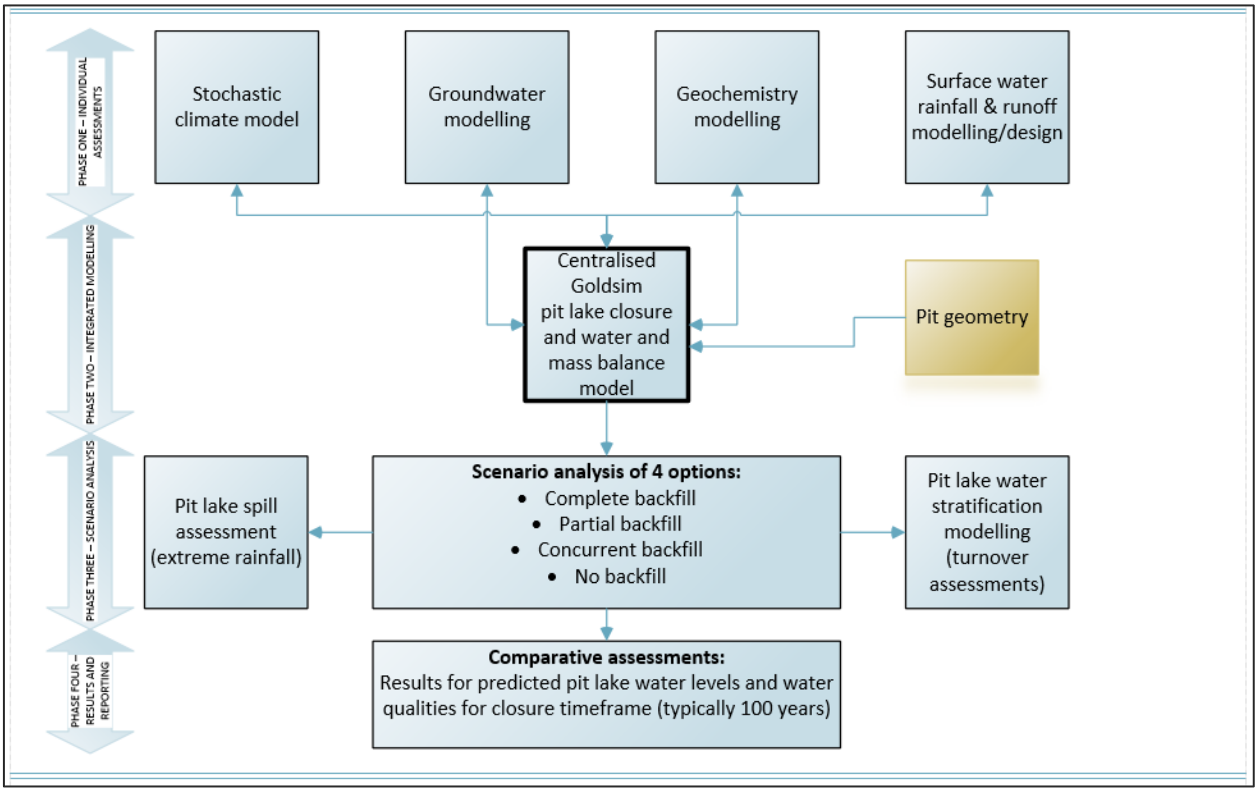


Figure 4-1 Integrated modelling approach

This study has utilised a number of hydrotechnical specialist modelling packages and methods to achieve the project objective, these models and methods are described in the following sections.

4.1.1 Climate model – type and description

Accurate, future rainfall predictions are required for mine closure applications. Mathematical models of the physical processes involved in generating rainfall are often used to make these evaluations. In addressing the response of these processes to weather inputs, it is seldom sufficient to examine only responses to observed weather events. For closure timescales (often measured in centuries from date of closure) It is desirable to have the capability of generating synthetic weather & rainfall data with the same statistical characteristics as the actual weather at the location of the mine. Therefore, the purpose of this study a computer simulation model called WGEN (Weather Generator) has been adopted to generate values for precipitation. WGEN is a stochastic weather generator originally developed in the 1980s in FORTRAN at the US Department of Agriculture Agricultural Research Service (Richardson and Wright 1984). It uses monthly and annual statistics to generate daily time series of precipitation, minimum temperature, maximum temperature and solar radiation into the future. This will be developed in GoldSim and used in the centralised model.

The precipitation component of WGEN is a Markov chain-gamma model. A first order Markov chain is used to generate the occurrence of wet or dry days. When a wet day is generated, the two-parameter gamma distribution is used to generate the precipitation amount. With the first-order Markov chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with c. 0.25 mm of rain or more.

Further comparison of modelled vs observed data include:

- Modelled precipitation amounts and seasonal variation were accurately represented in the model
- No significant difference occurred between observed and generated mean monthly and annual precipitation amounts at any location
- Mean numbers of wet days per month accurately simulated
- Persistence of wet days (max length of consecutive wet days for each month) & occurrence of daily precipitation in excess of 50 mm compared favourably
- Mean monthly precipitation amounts are excellent representations of the observed data

The WGEN model has been implemented through the GoldSim modelling platform (section 4.1.5).

4.1.2 Geochemistry model – type and description

The prediction of water quality in the pit lake which will from upon mine closure was completed using PHREEQC Version 3 geochemical modelling software. PHREEQC is a computer program written in the C programming language that is designed to perform a wide variety of aqueous geochemical calculations. PHREEQC is based on an ion-association aqueous model and has capabilities for; speciation and saturation-index calculations, reaction-path and advective-transport calculations involving specified irreversible reactions, mixing of solutions, mineral and gas equilibria, surface-complexation reactions, ion-exchange reactions, and also inverse modelling.

4.1.3 External catchments - surface water runoff method

The SCS Runoff Curve Number (CN) method has been adopted to estimate the rainfall-runoff generated from the external catchments of the Pit which likely discharge into the Pit post closure. The method was developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall. The SCS method is a widely used and efficient method for determining the approximate amount of runoff from a rainfall event in a particular area. Although the method is designed for a single storm event, it has been used here to find average annual runoff values. The data requirements for this method require only rainfall and CN. The CN is based on the area's hydrologic soil group, land use, hydrologic conditions and professional judgement.

4.1.4 Groundwater model – type and description

FEFLOW has been used to predict the head driven groundwater rebound inflow rates into the Tshipi pit. FEFLOW (Finite Element subsurface FLOW and transport system) is an interactive groundwater modelling software package. FEFLOW is used in the mining industry to describe the spatial and temporal distribution and reactions of groundwater contaminants, to model geothermal processes, to estimate the duration and travel times of chemical species in aquifers, to plan and design remediation strategies and interception techniques, and to assist in designing alternatives and effective monitoring schemes.

4.1.5 GoldSim model description

GoldSim is the premier Monte Carlo simulation software solution for dynamically modelling complex systems for mining projects. GoldSim supports decision-making and risk analysis by simulating future performance while quantitatively representing the uncertainty and risks inherent in all complex systems associated with pit lake closure situations. Monte Carlo simulations are a class of computational algorithms that rely on repeated random sampling of those components of the model with inherent uncertainty in their estimation when undertaking the simulations. Monte Carlo methods are especially useful for simulating systems with many coupled degrees of freedom, such as water.

GoldSim provides a visual and hierarchical modelling environment, which allows SLR to construct models by adding “elements” (model objects) that represent data, equations, processes or events, and linking them together into graphical representations that resemble influence diagrams that represents the Tshipi conceptual closure scenarios. It is primarily a continuous simulator and is therefore ideal for pit lake closure studies. Because GoldSim was originally developed for complex environmental applications, in which many inputs are uncertain and/or stochastic, in addition to being a dynamic simulator, GoldSim allows inputs defined as distributions and the entire system simulated a large number of times to provide probabilistic outputs (realisations).

4.1.6 Extreme rainfall method (PMP)

The probable maximum precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed. The World Meteorological Organization’s (WMO) Manual on Estimation of PMP describes numerous methodologies to estimate the PMP in locations world-wide. The PMP has been used in this study to assess the likelihood of a pit spillage occurring during the most extreme rainfall event.

A robust method for determining the PMP is the statistical method of Herschfield (1965) described in the WMO report[1]. This approximate method provides an estimate of PMP for point rainfall or small watersheds up to 1000 km2 in area using the following equation:

PMP = Pmean + K x Sdev

Where:

- Pmean = the mean of the annual maximum 24-h rainfall series (mm) subject to adjustment
- K = a factor dependent on the magnitude of Pmean
- Sdev = the standard deviation of the annual maximum 24-h rainfall series (mm)

Available rainfall records have been used for the analysis and include daily rainfall totals dating back to 1931 providing a total record length of 69 years for PMP analysis. This is deemed sufficient for the purpose as a direct estimation can be made from records lengths of greater than 50 years (record lengths of less than 50 years should be adjusted due to its small sample size).

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[1] Section 4 of Manual on Estimation of Probable Maximum Precipitation (PMP); World Meteorological Organization, 2009; [ISBN 978-92-63-11045-9]

5.0 Key modelling data inputs

5.1 Rainfall and evaporation

Rainfall data utilised for this project is provided by the South African Weather Service. The period of record extends from 1931 until 2018. Daily rain (mm) data for station [Number: 0393083 1] is provided in Figure 5-1 displayed as monthly averages. This figure also includes the monthly average evaporation rates (ARC, 2008) which are several times greater than rainfall.

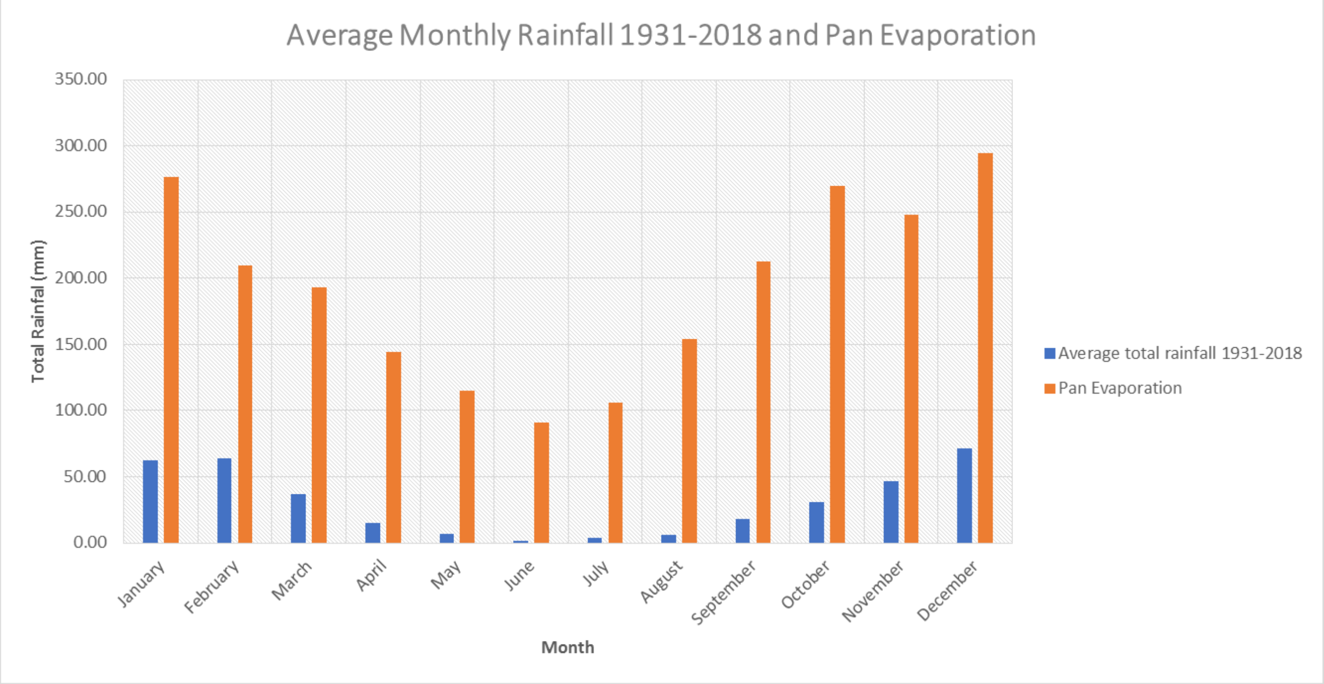


Figure 5-1 Average monthly rainfall and evaporation

5.1.1 PMP estimate

The available rainfall record was analysed to determine the annual maximum 24-h rainfall depth and these results are shown in Figure 5-2. The mean of the annual maximum 24-h rainfall series and the standard deviation were calculated to be approximately 52 and 24 mm respectively.

The final parameter of the equation, K, is determined using the value of Pmean, 52mm. Figure 5-3 shows the relationship between K and Pmean relative to rainfall duration. As the rainfall records are daily totals, the 24-h curve is used to determine the value of K, which is estimated to be 17.5.

With the 3 parameters determined, the PMP at site was estimated to be approximately 470 mm for a 24-h rainfall duration. This was implemented in the model with a probability of occurrence of 1 in 10 000 years.

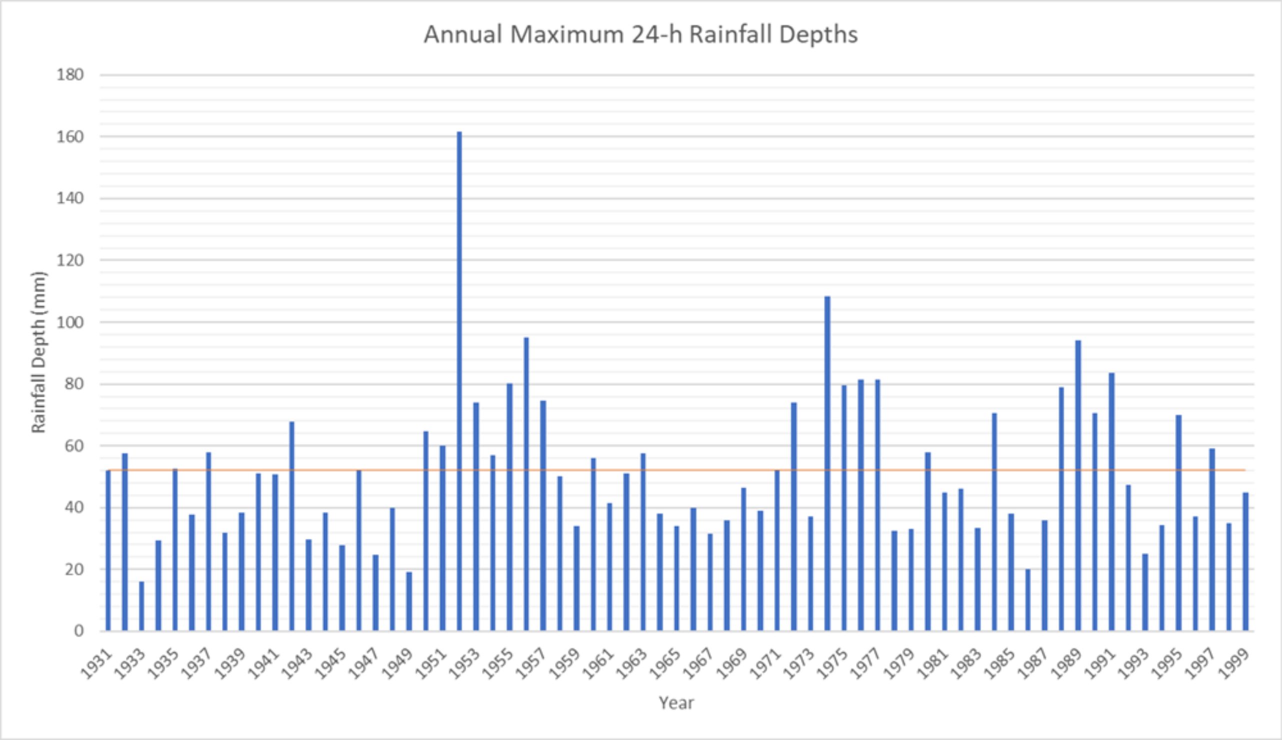


Figure 5-2 Daily Annual Maximum Rainfall Depths for analysed rainfall

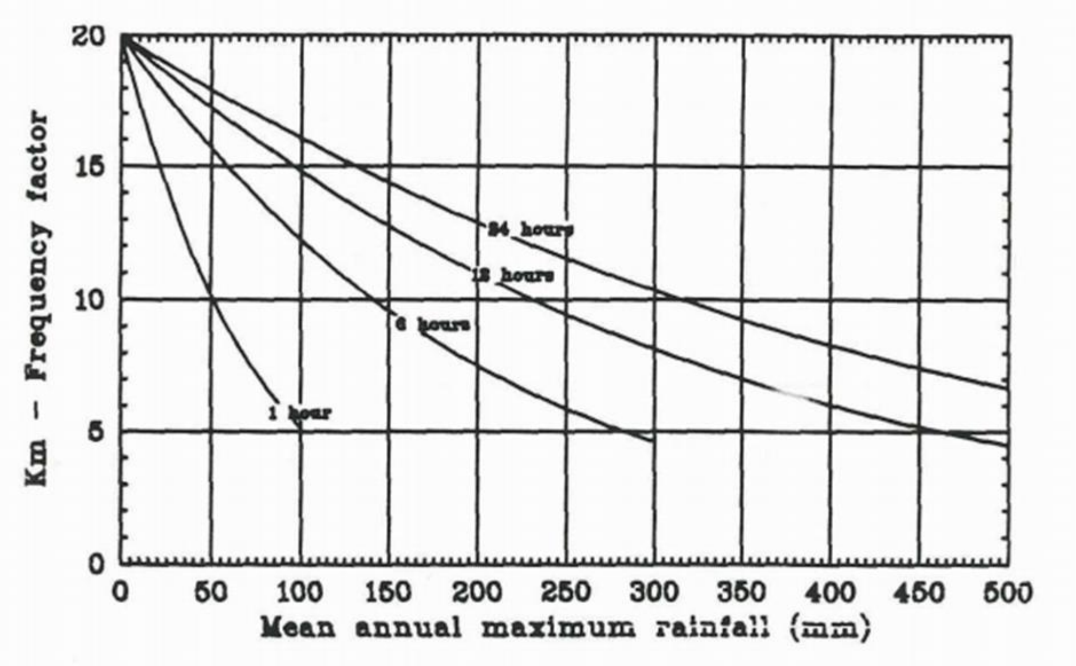


Figure 5-3 K as a Function of Rainfall Duration and Mean of Annual Series

5.2 Final pit geometry

The end of pit wireframe data was provided by the client has been used as the “base” pit shell for modelling purposes. An oblique CAD image of this is provided in

Figure 5-4.

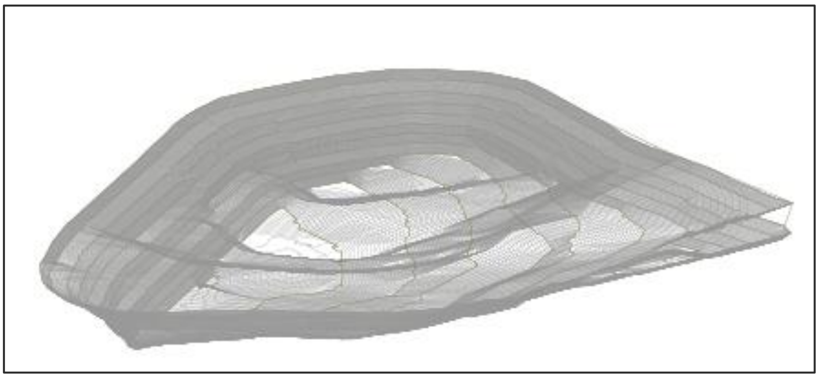


Figure 5-4 Final wireframe pitshell for Tshipi

5.2.1 Closure geometries and concepts

As described previously, there are four mine closure options addressed in this assessment, these are:

1. Complete backfill;
2. Partial backfill;
3. Concurrent Backfill; and
4. No backfill.

The concepts and key modelling inputs for these scenarios are provided in Drawing 01.

5.3 In-pit waste rock porosity

Clearly, the porosity of any waste rock backfilled into the pit will affect the rate of water which infills the pore spaces and thus the volume of water allowed into the spaces between each clast of rock. For the purposes of this study, a conservative porosity value of 30% has been used for all the selected closure concepts.

5.4 Mineralogy

Mine waste rock drainage quality is generally a function of mineral present dissolution (or precipitation) during interaction of rocks with water. X-ray Diffraction (XRD) analysis identifies the main crystalline mineral phases in each sample. SLR has collated information from the general area which shows that the following minerals are likely to be present in the waste rock.

Table 5-1
Typical Mineralogy for Lithologies in Tshipi Waste Rock

Mineral	Ideal Mineral Compositions	Relative Abundance
Calcite	$CaCO_3$	High
Ankerite	$Ca(Fe,Mg,Mn)(CO_3)^2$	Low
Chlorite	$(Mg,Fe)_5Al(AlSi_3O_{10})(OH)_8$	Low
Cristobalite	SiO_2	Moderate
Hematite	Fe_2O_3	High
Magnetite	Fe_3O_4	Moderate
Microcline	$KAlSi_3O_8$	Moderate
Palygorskite	$(Mg,Al)_2Si_4O_{10}(OH)_4(H_2O)$	Moderate to high in clays
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$	Low
Quartz	SiO_2	High
Smectite	$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$	Moderate to high in clays

5.5 Surface water inputs

5.5.1 Storm water management

It is imperative at an early stage in the modelling process to assess storm water management and how that will flow into or around the closed pit. A brief appraisal for storm water management is provided in the following section as:

a) The status quo approach where some of the current storm water flows from the surrounding area (veld) and the WRDs into the pit. This option is attractive due to the limited cost, on-going progress of the closure option, the addition of additional storm water infrastructure not being required.
b) Various passive management solution (s) where the storm water flows from the surrounding area (veld) and the WRDs are maximised to allow maximum storm water flows into the pit. The area contributing storm water into the pit lake is made larger through an updated storm water management system and thus contributing more storm water into the pit lake. The surrounding WRD’s are shaped and manipulated so that they drain into the pit lake a s much as possible. The veld area contributing into the pit are also maximised through channels flowing towards the pit. This option does not add any real benefit to the formation of a pit-lake as the storm water runoff is such a small driver in terms of the pit lake formation. The cost of building storm water infrastructure for minimal increase in storm water runoff into the pit is deemed not practical.

The preferred option is with the storm water infrastructure staying the same as the status quo infrastructure. The status quo approach makes use of the current storm water flows from the surrounding area (veld) and the WRDs into the pit. This option is attractive due to the limited cost, on-going progress of the closure option, the addition of additional storm water infrastructure not being required.

The catchment areas draining into the pit were analysed to estimate the volume of storm water runoff that may enter the pit. These areas are available in Figure 5-5 External catchment plan.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 5-5 External catchment plan

The catchment plan was modelled from a storm water perspective showing the amount of storm water that would enter the pit. The model (implemented in the GoldSim platform) was based on the SCS equation and the Curve Number (CN) was area weighted to incorporate all land types. The CN was set to be 50 for veld and 83 for the Waster Rock Dumps (WRD) in their present configuration. The sub-catchment areas used in the model are shown in Figure 5-5. The veld sub-catchments totalled 76.6 ha and the WRD sub-catchments added up to 148.5 ha.

5.6 Groundwater inputs

The monitoring of groundwater and surface water (when it is present) at the site has been undertaken at the following locations shown in Figure 5-6.

5.6.1 Aquifer types

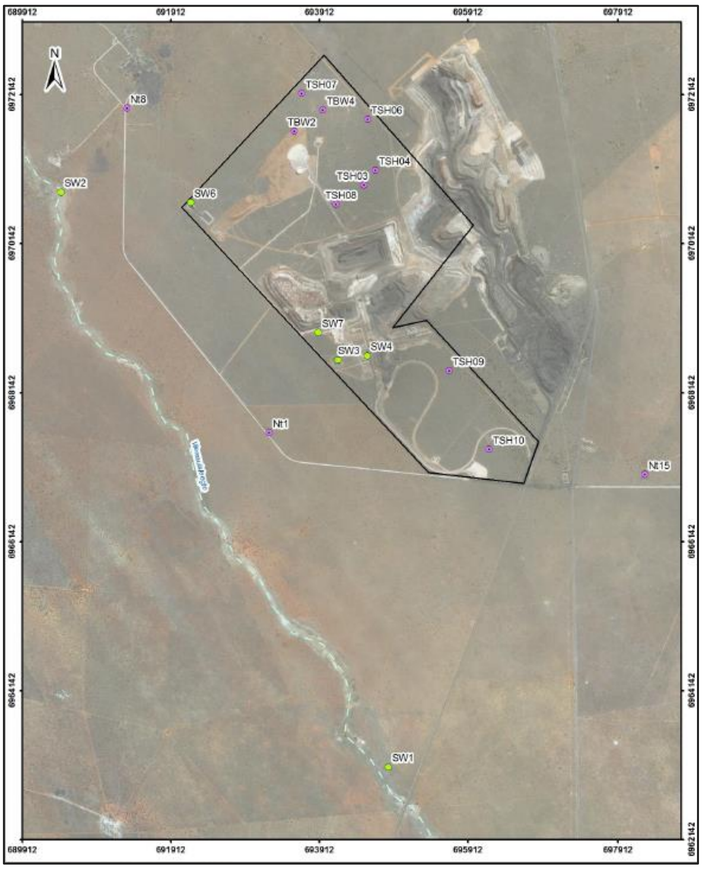
The area within the Tshipi Borwa Mine is located is generally classified as poor/minor aquifer region. Two aquifers are distinguished in the project area and these are:

- Shallow aquifer: Kalahari Beds , sand and calcrete; and
- Deep fractured aquifer II: Dwyka clay and the Mooidraai dolomite formation.

The Kalahari sand and the sediment beds with its associated underlying calcrete layer, overlie the low permeability Dwyka clay bed. Beneath a thick clay layer, which acts as a confining layer, the Mooidraai dolomite formation and Dwyka clay contact forms the deeper fractured bedrock aquifer.

Pumping tests indicated that the average yield for the shallow aquifer system was less than 0.1 l/s and less than 1 l/s for the deeper aquifer. The higher yielding deeper aquifer is of local importance for water supply to farmers in the area.

Figure 5-6
Water Sampling Locations



5.6.2 Groundwater levels

The groundwater elevation has been monitored over a number of years; the pre-mining and regional groundwater level is measured at 1045 m AMSL (Above Mean Sea Level). This is approximately 35 m below ground level.

5.6.3 Groundwater inflow rates

It is understood that there is no dewatering being undertaken at the currently operating pit via dewatering bores. The sump at the base of the pit collects rainfall runoff and any groundwater. During the site visit (30/01/2019) there was no seepage from the pit wall or discrete fractures within the pit.

Groundwater modelling results have been used to estimate the rate of inflow into the pit as head-driven inflows once mining has ceased and a pit lake begins to form. These rates are provided in Table 5-2.

Table 5-2 Head-driven groundwater inflow rates into the Pit[2]

Hydraulic head (m AMSL)	Inflows (m3/day)
855	396
880	213
910	1631
943	4423
970	10202
995	8851
1009	8915
1019	6628
1027	5974
1032	11381
1038	4552
1041	759
1043	379

5.6.4 Groundwater quality

Groundwater quality has been monitored from the installed wells around the Tshipi Pit over a number of years. This information is summarised below. In addition, the results have been compared to the relevant South African regulatory standards for water quality. Only those analytes which have corresponding regulatory standards are included in Table 5-3.

Those analytes which have not been detected over the sampling period (2008 – 2018), are not included in the tables or future analysis and predictions. A more extended table of results used in the geochemical modelling is present in section 7.0

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[2] This value considers the influence of the neighbouring Mamatwam pit

Table 5-3
Summary of Groundwater Chemistry

Sample Point		Determinands																							
		Al	As	B	Ba	Cd	Chloride as Cl	Cr (total)	Cu	Electrical Conductivity	Fe	Fluoride as F	Free & Saline Ammonia	Mn	Na	Ni	Nitrate as N	Pb	pH	Sb	Se	Sulphate as SO4	Total Dissolved Solids	Zn	Nitrite as N
Units		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ph unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Livestock Drinking Water Standards		**5**	**1**		**5**	**0.01**	**1500 – 3000**	**1 (CrVI)**	**0.5 – 5**		**10**	**2**		**10**	**2000**	**1**	**100**	**0.1**			**0.05**	**1000**	**1000 – 3000**	**20**	
NT1	Count	4	5	21	19	n.d	22	n.d	6	21	9	17	4	7	22	4	21	n.d	21	1	2	22	21	20	n.d
	Min	0.01	0.01	0.024	0.019		22		0.01	52	0.019	0.2	0.1	0.009	11	0.009	0.7		7.2	0.003	0.014	8	284	0.012	
	Average	0.09	0.012	0.24	0.081		44		0.041	75	0.093	0.3	0.2	0.027	30	0.022	5.4		8.1	0.003	0.016	48	463	0.4	
	max	0.24	0.014	2.90	0.13		184		0.11	154	0.29	1	0.3	0.047	153	0.054	12		8.5	0.003	0.018	336	1010	5.7	
NT13	Count	n.d	n.d	1	1	n.d	1	1	1	1	1	1	n.d	1	1	n.d	1	n.d	1	n.d	n.d	1	1	1	n.d
	Min			0.017	0.093		61	1.09	0.063	80	6.92	0.3		0.17	39		2.2		8.3			58	504	0.2	
	Average			0.017	0.093		61	1.09	0.063	80	6.92	0.3		0.17	39		2.2		8.3			58	504	0.2	
	max			0.017	0.093		61	1.09	0.063	80	6.92	0.3		0.17	39		2.2		8.3			58	504	0.2	
NT14	Count	n.d	n.d	1	1	n.d	1	n.d	n.d	1	1	1	n.d	n.d	1	n.d	1	n.d	1	n.d	1	1	1	1	n.d
	Min			0.23	0.064		56			101	0.15	0.2			45		16		7.5		0.046	47	592	0.2	
	Average			0.23	0.064		56			101	0.15	0.2			45		16		7.5		0.046	47	592	0.2	
	max			0.23	0.064		56			101	0.15	0.2			45		16		7.5		0.046	47	592	0.2	
NT15	Count	2	5	25	26	n.d	26	n.d	1	25	10	18	6	5	26	5	25	n.d	25	n.d	20	25	24	13	n.d
	Min	0.05	0.02	0.05	0.02		126		0.014	70	0.01	0.2	0.1	0.01	38	0.01	45		6.8		0.01	25	354	0.012	
	Average	0.07	0.06	0.13	0.22		677		0.014	357	0.25	0.3	2.4	0.11	63	0.03	168		7.4		0.06	45	2712	0.6	
	max	0.09	0.13	0.34	0.51		805		0.014	412	1.90	0.9	14	0.47	98	0.08	197		8.2		0.24	53	4166	3.4	
NT17	Count	n.d	n.d	1	1	n.d	1	n.d	n.d	1	1	1	n.d	n.d	1	n.d	1	n.d	1	n.d	1	1	n.d	1	n.d
	Min			0.27	0.21		172			186	0.11	0.4			85		111		7.4		0.06	52		0.1	
	Average			0.27	0.21		172			186	0.11	0.4			85		111		7.4		0.06	52		0.1	
	max			0.27	0.21		172			186	0.11	0.4			85		111		7.4		0.06	52		0.1	
NT18	Count	n.d	n.d	1	1	n.d	1	n.d	1	1	1	1	n.d	n.d	1	n.d	1	n.d	1	n.d	n.d	1	n.d	1	n.d
	Min			0.25	0.17		304		0.025	243	0.037	0.4			88		101		7.2			126		0.1	
	Average			0.25	0.17		304		0.025	243	0.037	0.4			88		101		7.2			126		0.1	
	max			0.25	0.17		304		0.025	243	0.037	0.4			88		101		7.2			126		0.1	
NT6	Count	2	1	10	10	n.d	11	n.d	4	10	10	11	n.d	4	11	n.d	10	n.d	10	n.d	1	11	10	9	n.d
	Min	0.02	0.01	0.07	0.012		50		0.015	73	0.014	0.3		0.001	34		1.3		7.3		0.074	15	432	0.01	
	Average	0.069	0.01	0.70	0.11		82		0.027	99	0.15	0.5		0.012	63		9.7		7.9		0.074	71	631	0.09	

Sample Point		Determinands																							
	max	0.12	0.01	2.51	0.20		182		0.045	157	0.52	0.7		0.025	158		21		8.7		0.074	312	1068	0.2	
NT8	Count	4	10	23	19	n.d	25	n.d	3	24	15	24	7	18	25	5	14	n.d	24	n.d	10	22	23	20	1
	Min	0.02	0.012	0.14	0.008		62		0.015	56	0.013	0.3	0.6	0.002	45	0.010	0.10		7.6		0.011	2	314	0.01	0.4
	Average	0.09	0.02	1.53	0.091		171		0.024	123	0.28	0.7	4.3	0.12	125	0.016	5		8.1		0.029	227	781	0.2	0.4
	max	0.15	0.043	3.11	0.31		275		0.029	179	2.16	1	24	0.41	237	0.022	32		8.7		0.076	481	1158	1.8	0.4
NT9	Count	n.d	n.d	1	n.d	n.d	1	n.d	n.d	1	n.d	1	n.d	n.d	1	n.d	1	n.d	1	n.d	1	1	1	0	n.d
	Min			0.40			40			82		0.2			74		14		7.9		0.042	25	420		
	Average			0.40			40			82		0.2			74		14		7.9		0.042	25	420		
	max			0.40			40			82		0.2			74		14		7.9		0.042	25	420		
TSH01	Count	6	3	17	17	n.d	17	n.d	n.d	17	7	17	3	10	17	3	16	1	17	n.d	8	17	17	16	n.d
	Min	0.070	0.011	0.39	0.01		125			88	0.12	0.3	0.1	0.011	63	0.01	18	0.21	7.6		0.010		384	0.037	
	Average	0.20	0.015	1.44	0.082		141			102	7.58	0.6	0.1	0.56	87	0.014	21	0.21	7.9		0.019	65	594	0.5	
	max	0.33	0.021	2.15	0.27		160			111	21.9	0.8	0.2	3.52	125	0.02	2	0.21	8.3		0.038	78	681	3.2	
TSH02	Count	2	n.d	8	9	1	9	n.d	1	9	4	8	1	5	9	1	8	n.d	9	1	3	9	9	5	n.d
	Min	0.01		0.16	0.011	0.002	106		0.024	86	0.030	0.3	8.9	0.014	65	0.01	0.3		7.9	0.003	0.011	28	435	0.01	
	Average	0.021		0.23	0.103	0.002	165		0.024	141	0.051	0.4	8.9	0.089	89	0.01	54		8.4	0.003	0.012	66	875	0.03	
	max	0.032		0.35	0.16	0.002	345		0.024	169	0.092	0.5	8.9	0.27	122	0.01	90		8.8	0.003	0.012	128	1188	0.06	
TSH03	Count	3	n.d	19	20	n.d	20	n.d	2	20	16	20	6	20	20	5	12	1	20	3	4	7	20	13	n.d
	Min	0.013		0.23	0.073		26		0.015	38	0.049	0.2	1.2	0.095	14	0.015	0.1	0.015	7.7	0.003	0.013	2	215	0.01	
	Average	0.046		0.38	0.19		110		0.018	64	1.56	0.7	4.3	0.30	50	0.035	0.6	0.015	8.0	0.007	0.025	6	339	0.04	
	max	0.070		0.59	0.59		131		0.021	77	5.18	1.2	7.9	0.74	127	0.10	2.7	0.015	8.9	0.015	0.033	21	444	0.2	
TSH04	Count	6	n.d	19	20	1	20	1	1	20	17	17	7	19	20	6	10	1	20	1	6	7	20	16	n.d
	Min	0.101		0.091	0.01	0.001	33	0.002	0.017	78	0.04	0.2	24	0.042	16	0.002	0.1	0.046	7.5	0.003	0.01	2	268	0.01	
	Average	0.48		0.41	0.16	0.001	139	0.002	0.017	126	4.54	0.4	96	0.89	70	0.052	1.6	0.046	8.1	0.003	0.02	8	494	0.04	
	max	1.37		0.64	0.60	0.001	168	0.002	0.017	233	21.3	0.7	163	3.22	99	0.11	13	0.046	9.4	0.003	0.029	22	734	0.1	
TSH05	Count	5	n.d	9	10	n.d	10	n.d	n.d	10	8	2	n.d	9	10	3	8	n.d	10	n.d	5	10	10	2	n.d
	Min	0.098		0.07	0.021		321			165	0.027	0.2		0.044	37	0.012	0.2		7.5		0.010	44	842	0.01	
	Average	0.24		0.15	0.058		353			182	2.80	0.2		0.37	92	0.021	22		8.5		0.020	63	994	0.01	
	max	0.67		0.21	0.11		379			204	8.37	0.2		1.01	123	0.030	77		9.4		0.029	76	1362	0.01	
TSH06	Count	n.d	1	7	7	n.d	7	n.d	n.d	7	5	7	6	7	7	2	4	1	7	n.d	3	4	7	4	n.d
	Min		0.011	0.52	0.047		167			139	0.060	0.3	50	0.089	62	0.002	0.1	0.053	6.9		0.034	3	350	0.03	
	Average		0.011	0.70	0.12		179			151	1.57	0.4	100	0.50	64	0.016	14	0.053	7.8		0.043	3	469	0.04	
	max		0.011	0.82	0.42		186			163	4.42	0.6	115	1.82	67	0.030	55	0.053	8.1		0.051	4	677	0.04	
TSH07	Count	n.d	n.d	4	4	n.d	4	n.d	n.d	4	1	4	4	4	4	1	4	n.d	4	1	1	4	4	1	1
	Min			0.33	0.027		77.6			64	0.44	0.2	0.8	0.056	58	0.003	0.3		7.5	0.003	0.042	25	430	0.04	5.6
	Average			0.508	0.11		131			120	0.44	0.5	3	0.35	60	0.003	33		7.8	0.003	0.042	34	728	0.04	5.6

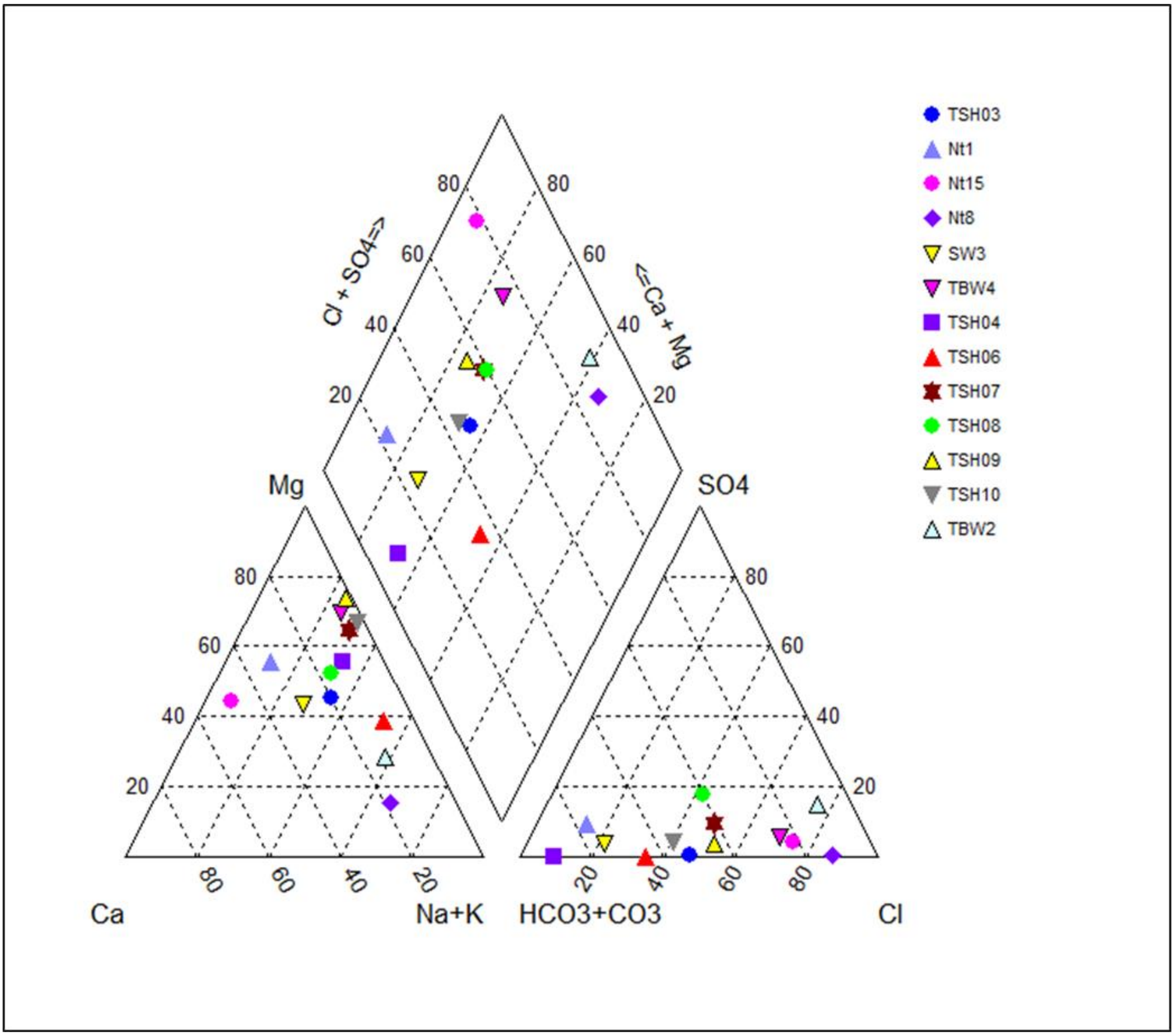
Sample Point		Determinands																							
	max			1.01	0.16		153			152	0.44	0.6	8	0.52	64	0.003	60		8.1	0.003	0.042	43	949	0.04	5.6
TSH08	Count	n.d	n.d	3	3	n.d	3	n.d	n.d	3	1	3	2	2	3	n.d	3	n.d	3	2	1	3	3	2	n.d
	Min			0.164	0.006		133			97	0.034	0.2	11	0.022	57		0.4		8.0	0.002	0.033	56	511	0.02	
	Average			0.248	0.027		138			103	0.034	0.3	14	0.025	67		8.7		8.2	0.002	0.033	87	578	0.03	
	max			0.413	0.068		144			113	0.034	0.5	16	0.027	73		14		8.4	0.002	0.033	105	641	0.04	
TSH09	Count	n.d	2	5	4	n.d	5	n.d	n.d	5	n.d	3	5	4	5	n.d	5	n.d	5	n.d	2	5	5	3	n.d
	Min		0.015	0.14	0.016		183			138		0.4	0.1	0.008	70		0.1		7		0.051	21	802	0.009	
	Average		0.015	0.76	0.070		251			172		0.7	12	0.15	94		66		8		0.051	74	1065	0.07	
	max		0.015	2.55	0.173		317			237		0.9	20	0.42	158		146		8.5		0.051	231	1608	0.13	
TSH10	Count	n.d	0	5	5	n.d	5	n.d	n.d	5	n.d	2	4	5	5	n.d	5	n.d	5	3	2	5	5	3	2
	Min			0.228	0.024		165			115		0.5	18	0.005	80		0.3		7.7	0.003	0.052	24	601	0.01	0.6
	Average			0.243	0.065		194			138		0.5	21	0.049	83		18		8.2	0.004	0.052	27	754	0.03	0.6
	max			0.272	0.159		210			174		0.5	24	0.14	87		66		8.5	0.004	0.052	29	1014	0.04	0.6

Those results which are shaded exceed the relevant guidance values.

Determinands removed from the table as they were not detected at all over the monitoring period: Au, Be, Bi, Cs, Dy, Er, Eu, Gd, Ge, Hg, Ho, In, Ir, La, Lu, Nb, Nd, Pr, Re, Rh, Sm, Sn, Ta, Tb, Te, Th, Tl, U, Yb

When considering the water chemistry of the groundwater that is likely to enter the pit during pit lake development, Piper Plots have been prepared. These help to establish which waters are indicative of the groundwater up-gradient and also which waters are considered part of the same water quality facies. The diagram is presented below.

Figure 5-7
Piper Diagram for Groundwater Sampled September 2018



This coupled with the known locations of the boreholes suggest the up gradient TSH09 and TSH10 are most representative of the likely groundwater which will enter the pit once pumping has ceased. Whilst Nt15 is up-gradient, the Piper Diagram indicates this is groundwater has a distinct signature and seems different to the groundwater sampled immediately down gradient. There appears to be some degradation of the nitrogen species from NT15 towards the mine and therefore it is considered this would continue after pumping has ceased. Therefore the NT15 is not used in generating a groundwater quality source term.

The nitrate concentration in the immediate up-gradient wells does appear to be reducing with time during 2017 and 2019 as shown in Figure 5-8. In addition, the unionised ammonia also appears to be reducing with time as shown below. A recent sample of water was taken from the pit pumped water and this had relatively elevated nitrate. It is possible therefore explosive residues might also be contributing to the nitrogen compounds in the area.

Figure 5-8
Nitrate in Groundwater Sampled 2017 – 2019 Up gradient Wells

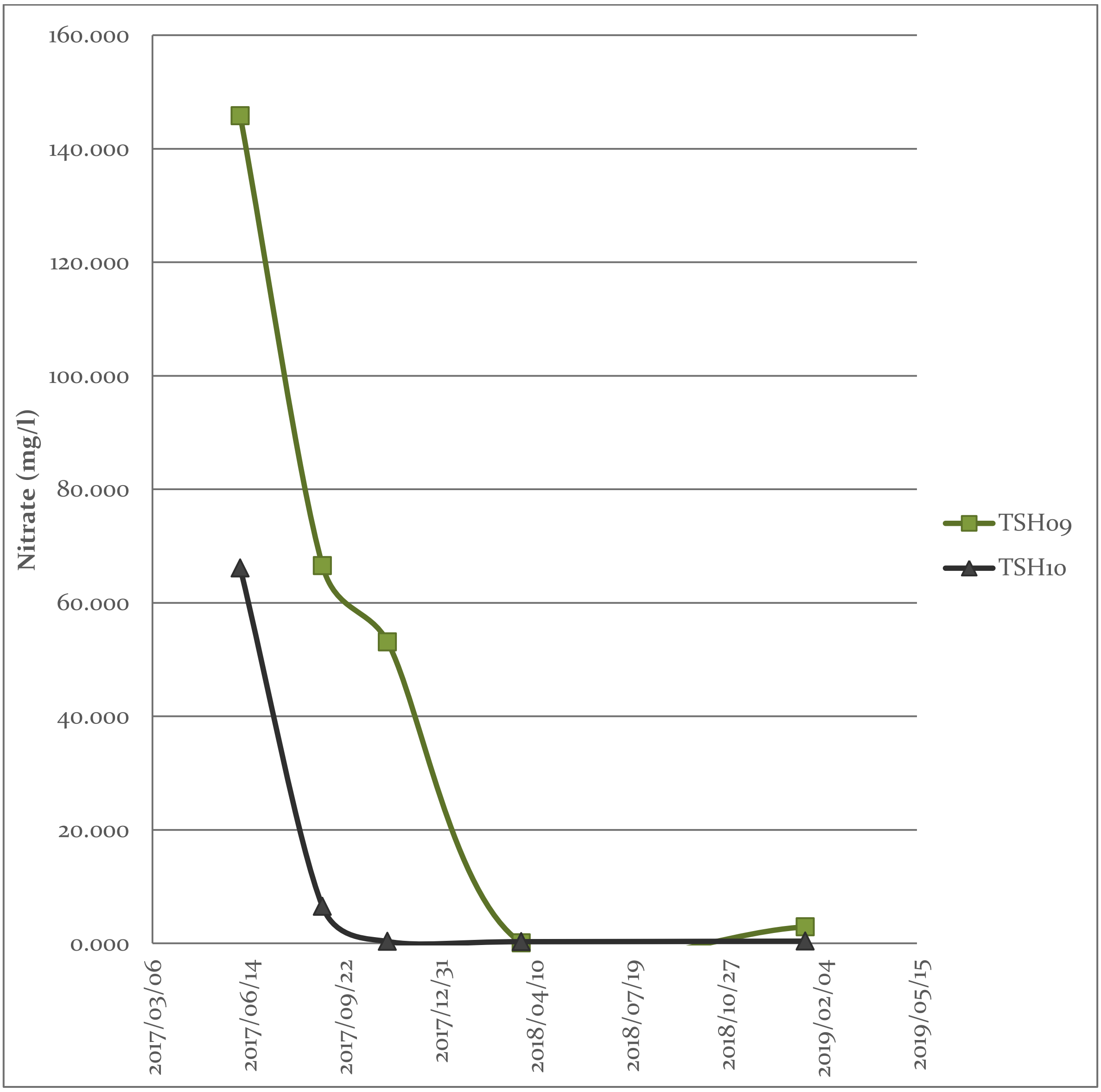
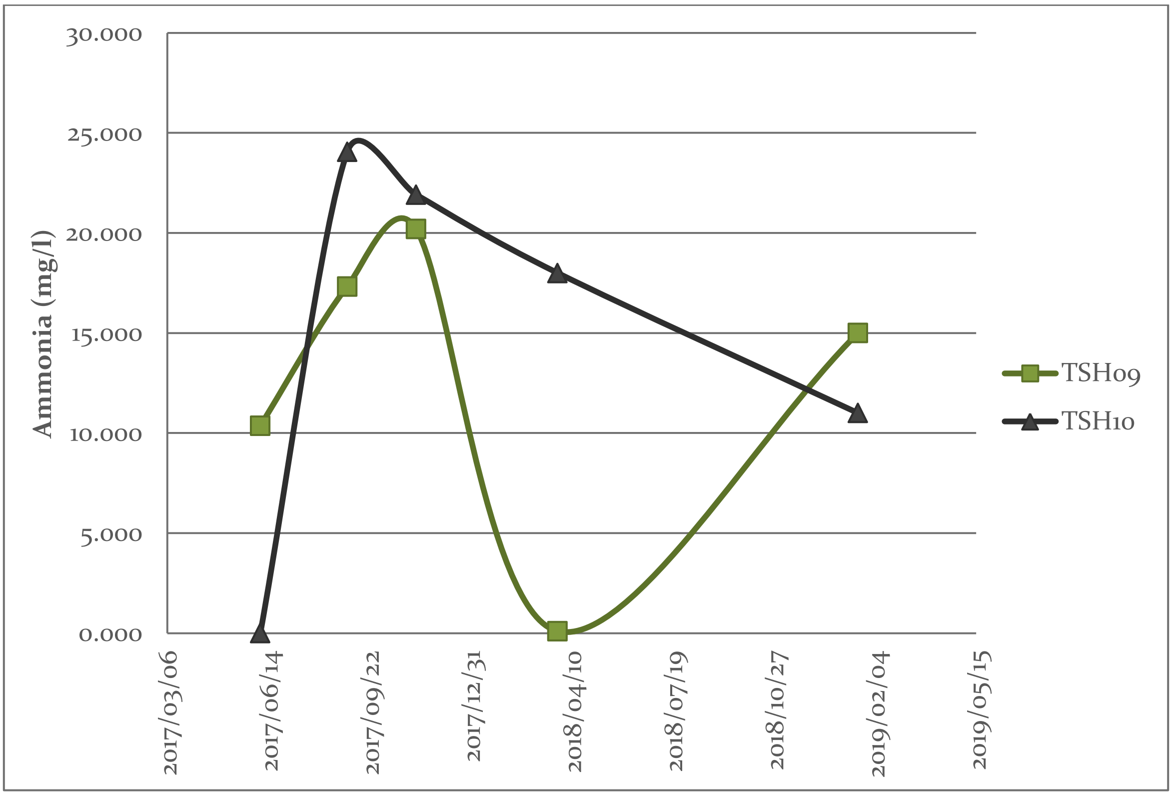


Figure 5-9
Ammonia in Groundwater Sampled 2017 – 2019 Up gradient Wells



The redox condition of the groundwater in this area may be reducing and hence ammonification may be occurring in the groundwater, however overall the nitrogen concentration does appear to be decreasing.

A pre-mining hydro census was conducted in 2009 for the Tshipi mine and included groundwater quality testing. The sampling results showed that the groundwater quality in the area ranged from marginal to dangerous for domestic use (DWAF classification of Class 2 and 4). This was mainly due to elevated nitrate levels. In addition, calcium and magnesium exceeded the resource water quality objectives stipulated in the Tshipi Integrated Water Use Licence.

A review has also been undertaken of the groundwater quality monitored at the adjacent Mamatwan Mine.[3] This has concluded that the water quality is classified as “Above Regional Standard” in general due to elevated nitrate (NO3-N), electrical conductivity (EC), magnesium (Mg), sodium (Na), calcium (Ca), boron (B), and chloride (Cl) concentrations. The elevated nitrate concentration is of a natural origin as can be expected for most semi-arid regions. Two background ‘hydrocensus’ sampling phases of private properties around the mine lease and further away has confirmed the elevated nitrate concentration as a ‘natural phenomenon’ for the area.

The elevated nitrate concentration could lead to elevated ammonia/ammonium through the process of bacterial nitrate reduction in the presence of natural organic matter. Therefore the ammonia concentrations are also an influence from natural process. This is also relevant given that it is understood that the Mamatwan Sewage Plant and the sewage ponds are lined and are not leaking. It is noted that the treated effluent from the plant is used as irrigation water for the veld which might contribute to the nitrogen loading to the groundwater.

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[3] GHT (2015) Hotazel Manganese Mines. Assessment Report: Ground/Surface Water monitoring Phase 30 as part of the water management plan. 1st Quarter 2015 for BHP Billiton Pty Ltd. Ref: RVN725.1/1558

Elevated boron (and Mg, Na, Ca and Cl) should not be unexpected in semi-arid regions. Boron is often used as a tracer for saline intrusion studies because it behaves conservatively and is also present at elevated concentrations in sea water.[4] Therefore their increased concentration in groundwater in the region should not be considered anomalous.

There is also a possibility that elevated nitrogen compounds could be related to the use of explosives in this and other mining areas in the region. Therefore under closure timeframes the nitrogen compounds in the groundwater could be expected to reduce (as has been evidenced in the latest monitoring) to the natural background concentrations. Therefor it is prudent that these “operational” influences have been reconciled out of closure predictive modelling.

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[4] Richter B.C and C.W Kreitler 1991. Identification of sources of groundwater salinization using geochemical techniques. Ref: EPA/600/2-91/064

6.0 Pit lake water balance

A water balance model for each of the closure scenarios was modelled using GoldSim software platform (Version 12.1). An example of the developed Tshipi GoldSim modelling domain is provided in Figure 6-1.

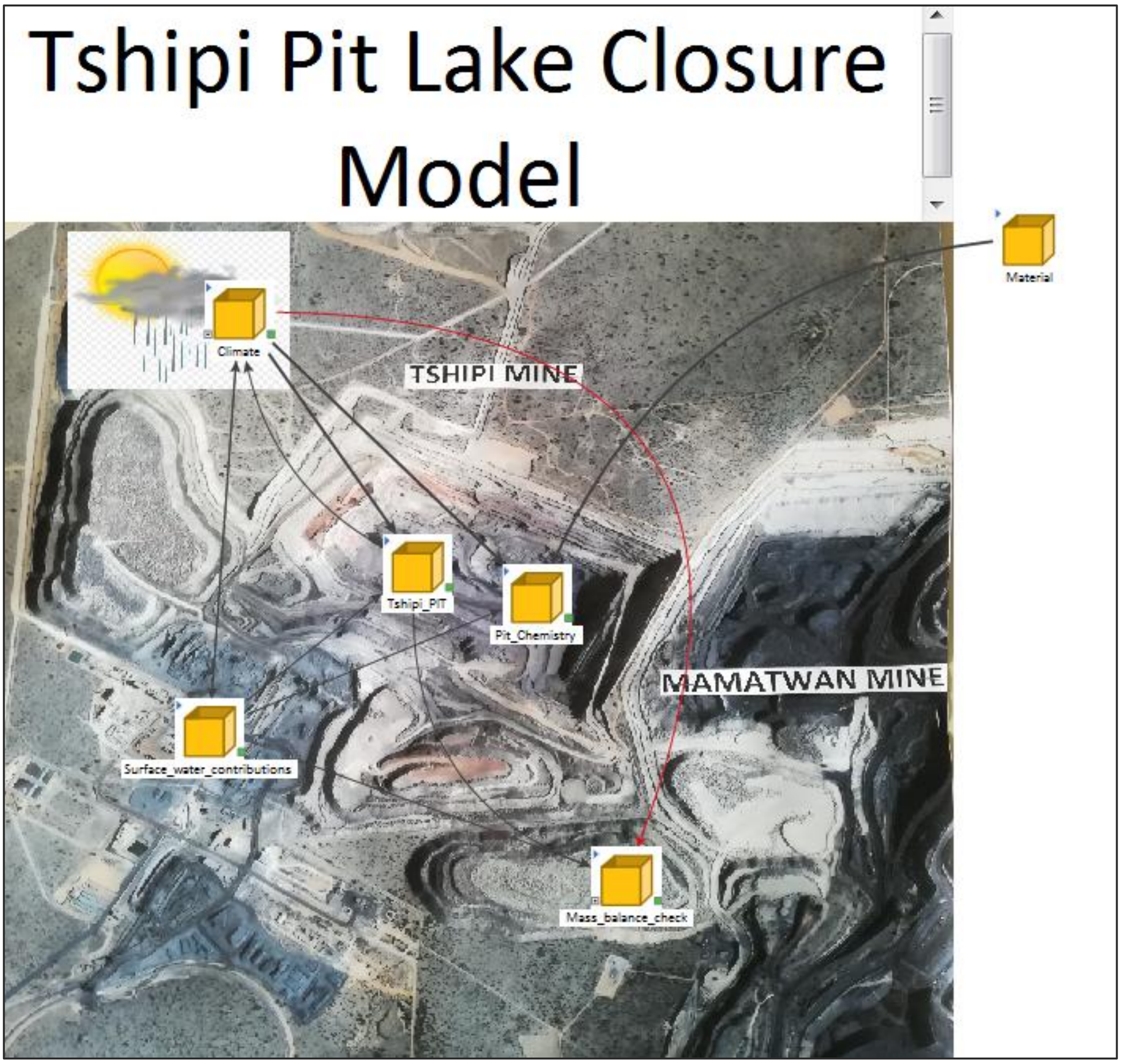


Figure 6-1 Goldsim model domain example

For the Tshipi models, ‘Monte Carlo simulations’ are used to describe the method for propagating (translating) uncertainties in model inputs (in particular the future climate) into uncertainties in model outputs (results). Hence, it is a type of simulation that explicitly and quantitatively represents uncertainties. Monte Carlo simulation relies on the process of explicitly representing uncertainties by specifying inputs as probability distributions. If the inputs describing a system are uncertain, the prediction of future performance is necessarily uncertain. That is, the result of any analysis based on inputs represented by probability distributions is itself a probability distribution.

The entire Tshipi pit lake closure system has been simulated a large number (100) of times using a monthly time-step. Each simulation is equally likely, referred to as a realization of the system. For each realization, all of the uncertain parameters are sampled (i.e., a single random value is selected from the specified distribution describing each parameter). The system is then simulated through time (given the particular set of input parameters) such that the performance of the system can be computed until a quasi-static level is reached. This result is a large number of separate and independent results, each representing a possible “future” level for the level of the lake. The results of the independent system realizations are assembled into probability distributions of possible outcomes. As a result, the levels of the lake are not single values, but probability distributions.

6.1 Water balance fundamental equations

The GoldSim modelling platform allows an expert user to build a representative model of the specific integrated water system expected at Tshipi. On cessation of mining, groundwater levels will begin to rebound. The water level will begin to rise back towards the pre-mining level. If there is void space, a pit lake will form and the final water level of the pit lake will be determined by the eventual balance between all water inflows and evaporation and any other losses. A simple water balance is Inflows = Outflows ± Change in storage

The main water sources (inflows) to the proposed pits are:

- Direct rainfall onto the surface of a pit lake/flood of pit;
- Runoff from rainfall falling onto the pit walls (high-wall runoff);
- Groundwater which seeps into the pits;
- Any storm water from external catchments that is directed towards the pit.

Water losses (outflows) occur as follows:

- Evaporation from the pits;
- Seepage to groundwater through the base of the pit (assumed to be zero here in closure timeframes).

If inflows exceed outflows, on average, then a pit lake will form and the level of water in the pit lake will rise. Note that all of these components of the water balance, with the exception of storm water into the pit, are functions of the level of the pit lake. As the pit lake level rises inflows usually diminish until a quasi-stasis is reached. The lake level at which this equilibrium exists (and the quality of that water) is of great importance to closure planning.

There are two basic types of pit lakes (1) Terminal hydraulic sink; and (2) Flow-through. Terminal pit lakes are normally found in arid climates. Initially, inflows will be high, because the hydraulic gradient driving inflows from the aquifer would be at a maximum due to the water level being at base of the pit. Due to evaporative loses and pit geometry the terminal lake becomes a cone of depression in the water table with the groundwater gradient towards the pit (a groundwater discharge zone). As evaporation is the only discharge pathway, soluble metals accumulate due to evapoconcentration.

The rate of infilling of the pit is greatest during early recovery and decreases with time. The pit lake water balance at Tshipi can be described as: $P + SW + PW + GW - E = \Delta S$

Where:

- P = direct precipitation on lake surface
- SW = storm water from external catchments
- PW = Runoff from the pit walls
- GW = Groundwater inflow
- E = Evaporation
- ΔS = change in lake storage volume (determined by the geometry of the final pit void/backfill arrangements)

Closure pit lake analysis consists of two important components:

- estimating the final pit lake elevation; and
- timing of pit lake formation.

The water levels in the Tshipi pit were calculated based on the volume of the pit per depth and accumulated water within them for all four closure scenarios. This calculation was done at monthly time steps until quasi-stasis conditions were achieved. The "stasis" condition is defined as the hydraulic condition when mean annual, or longer period, outflows equals inflows.

6.2 Pit lake – final water level predictions

The following four figures illustrate the four differing filling scenarios and rates.

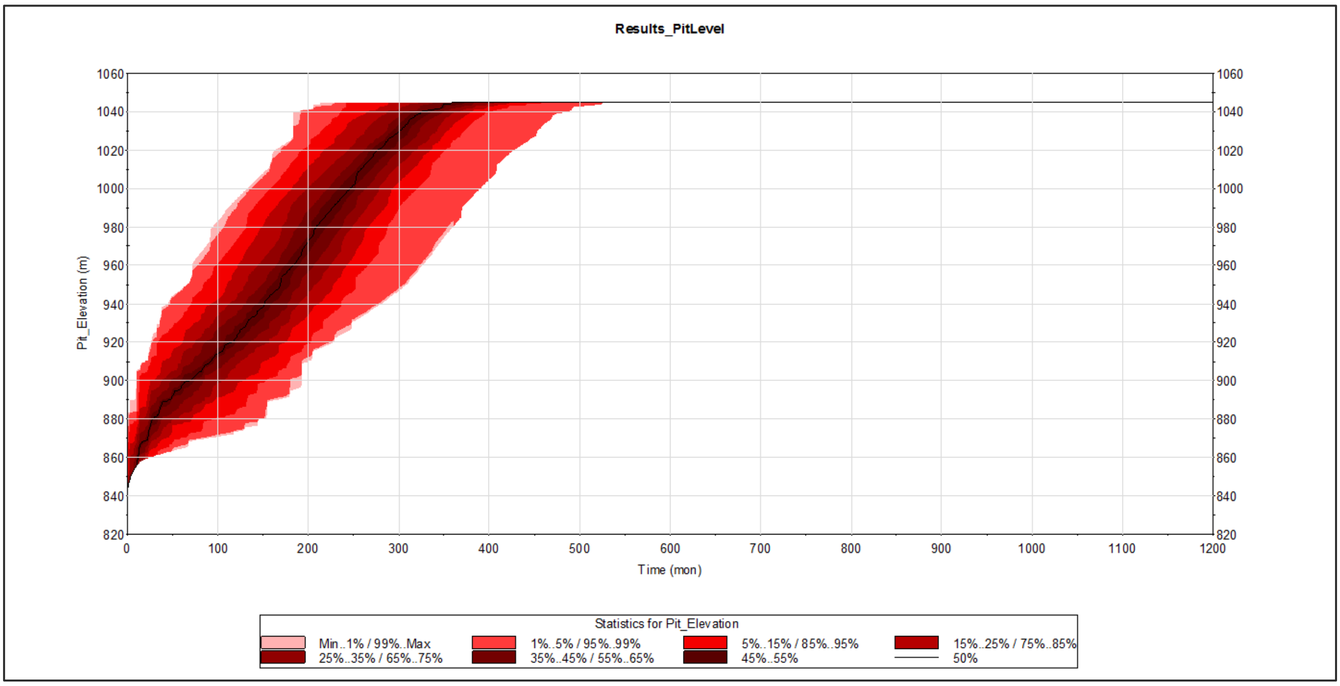


Figure 6-2 Option 1 - Pit lake filling rates

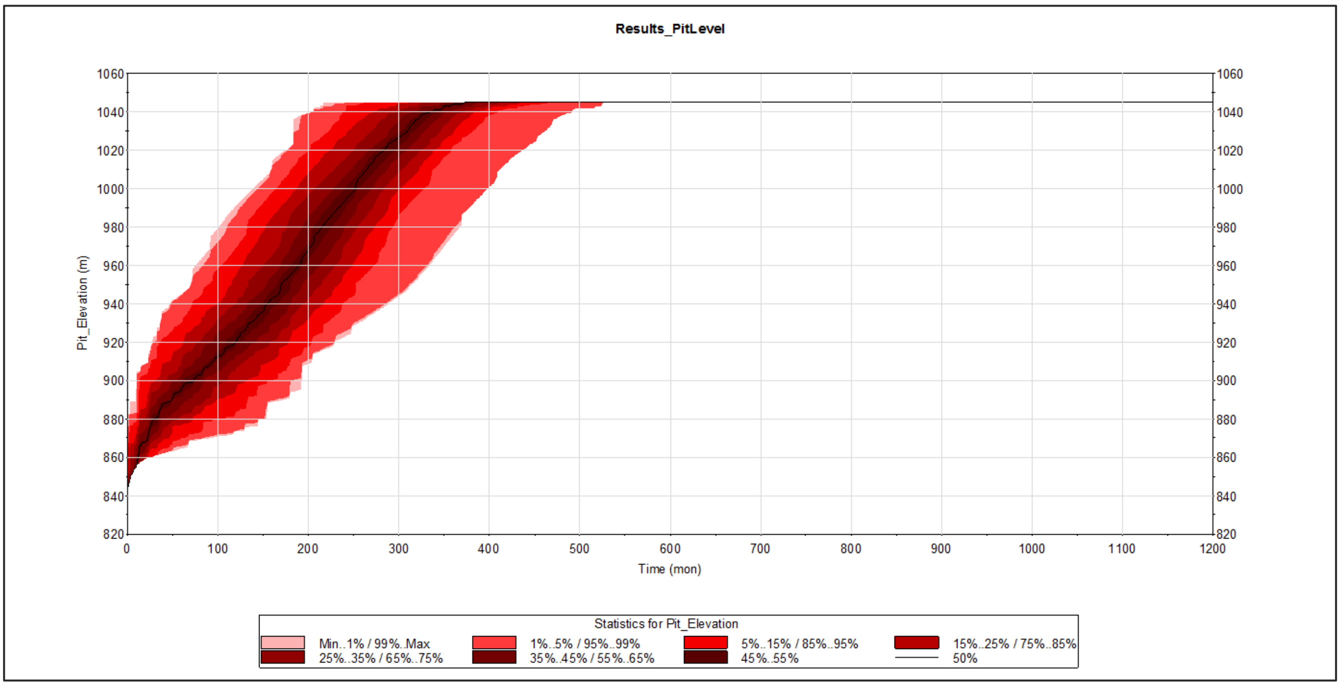


Figure 6-3 Option 2 - Pit lake filling rates

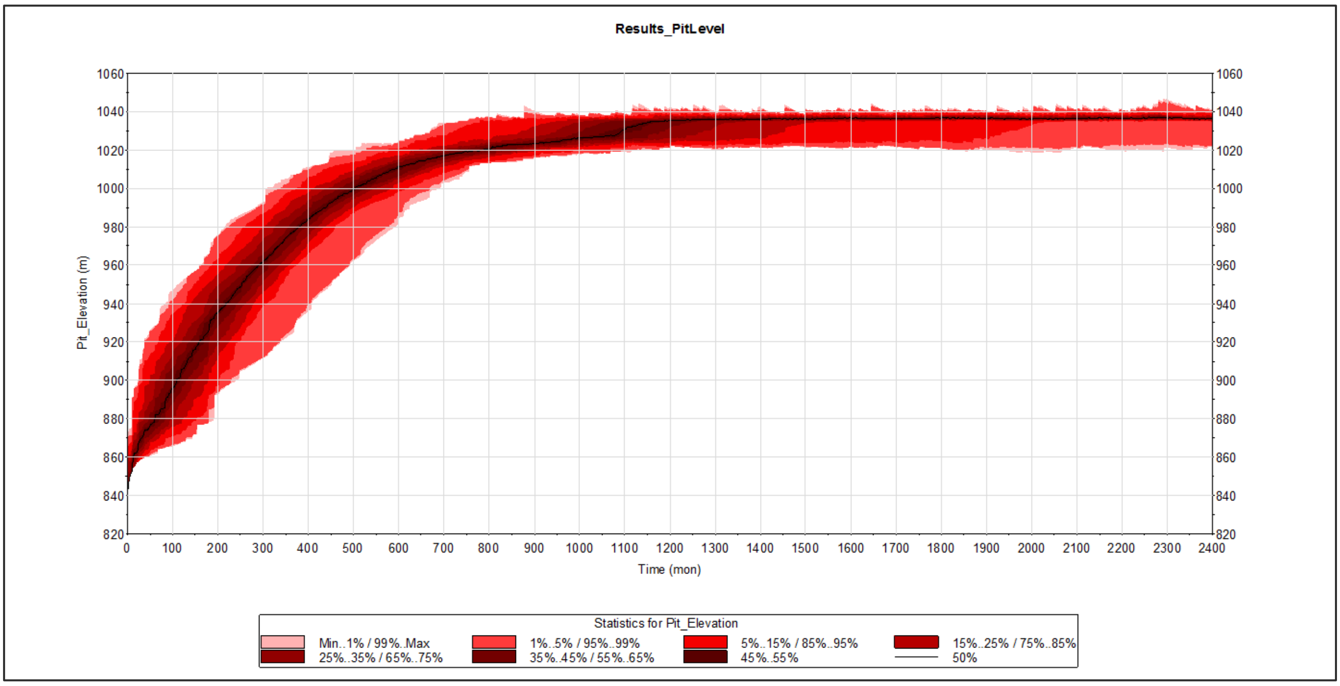


Figure 6-4 Option 3 – Pit lake filling rates

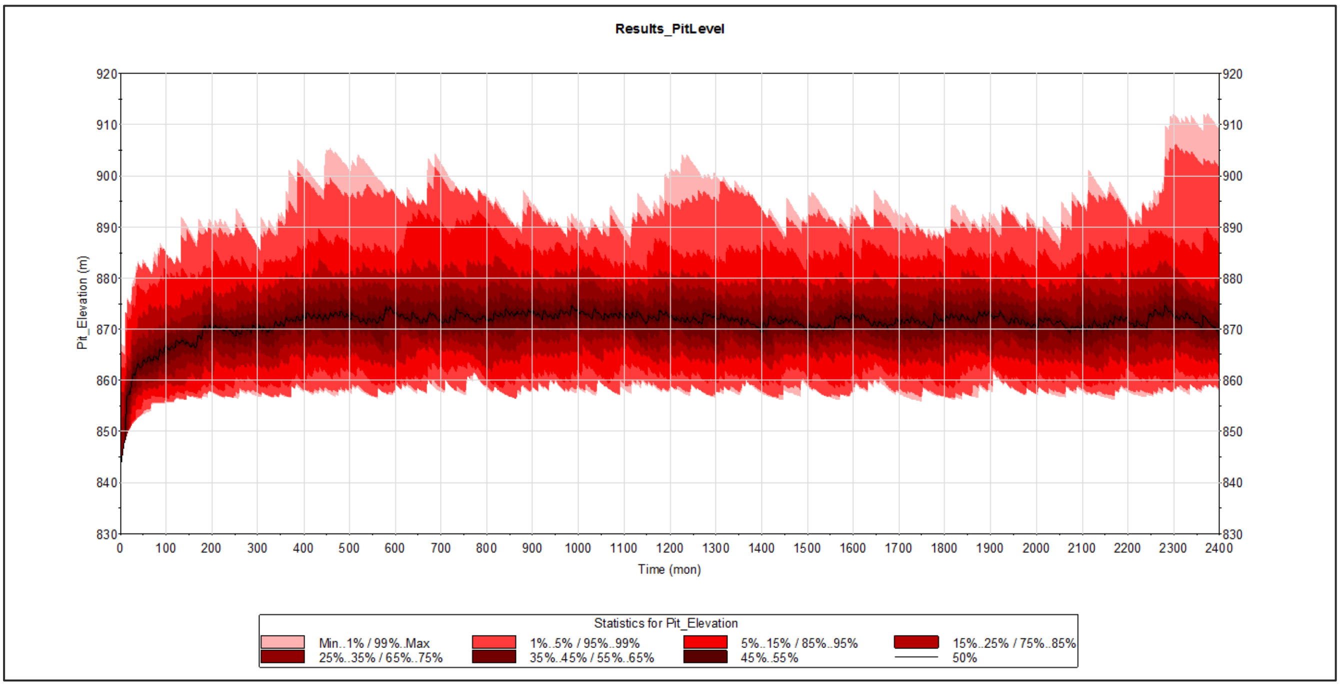


Figure 6-5 Option 4 - Pit lake filling rates

Table 6-1 displays the results of the GoldSim modelling and highlights the most important closure information required for planning purposes. These results are discussed in more detail in the summary section.

Table 6-1 Pit filling rates and final levels

Backfilling closure option	Time to fill to quasi-static water levels (mean level)	Quasi-static water level in pit (m AMSL)	Regional groundwater level (m AMSL)	Terminal hydraulic sink or flow-through pit	Pit lake spilling
Option 1 Complete Backfill	39 years	1045	1045	Flow-through	-
Option 2 Fill to Regional Groundwater level	36 years	1045	1045	Partial flow-through	-
Option 3 Concurrent backfill	153 years	1039	1045	Hydraulic sink	No
Option 4 No Backfill	42 years	873	1045	Hydraulic sink	No

6.2.1 Pit spilling

Under all the closure options that preserve a topographical sink, there is no risk of a pit spill from a PMP rainfall event.

6.2.2 Mass balance check

Each model has been checked for mass balance error. Figure 6-7 shows a mass balance output example from a GoldSim model built for this study – the error should be (and is) extremely small over the period indicating that mass is not lost or created in the system. The mass balance equation has been implemented within the model is shown in Figure 6-6, where Q = flow, V = discrete change and S is storage, where:

$$\boxed{\int Q_{in}\,dt + V_{in} - \left[\int Q_{out}\,dt + V_{out} \right] - (S_i - S_0) \approx 0}$$

Figure 6-6 Mass balance equation

Figure 6-7 Example mass balance error check output from the GoldSim modelling (100 realisations) over a 200 year period

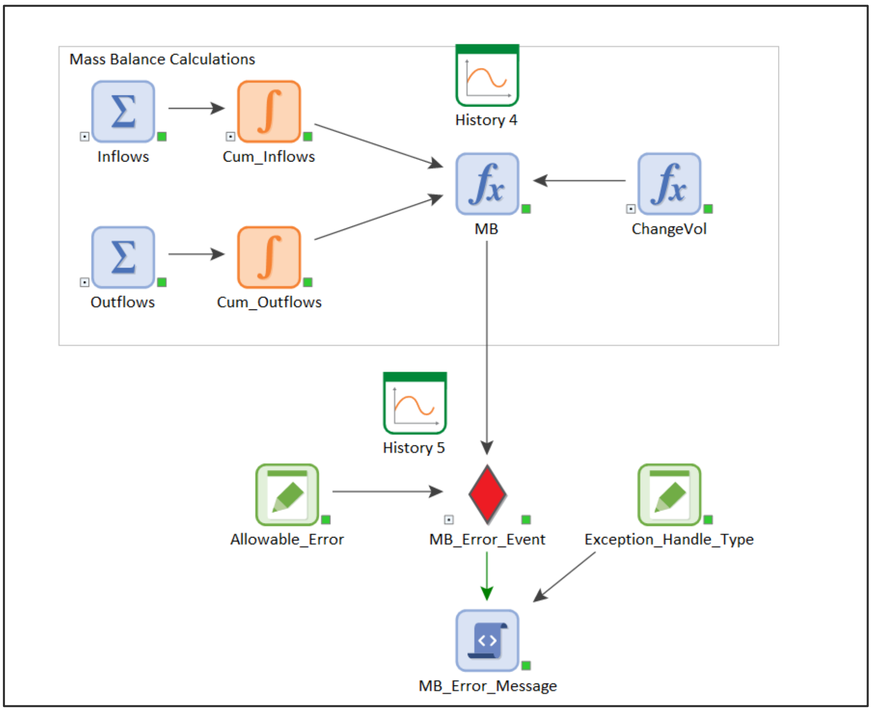


Figure 6-8 Mass balance calculation implemented in GoldSim

Figure 6-8 is an example of a mass balance calculation that has been implemented in this GoldSim modelling study. The allowable error was set at 1 litre.

7.0 Water Quality Prediction

The prediction of water quality in the pit lake which will form upon mine closure was completed using PHREEQC Version 3[5] geochemical modelling software coupled with Goldsim. The purpose of the modelling was as follows:

1. To generate source terms to be used in the geochemical and GoldSIm modelling. These source terms are populated following the development of a Conceptual Site Model for the pit lake generation; and
2. Assessing the likely geochemical changes and layer development in the pit lake upon filling.

There are a number of databases that can be used in the PHREEQC model for the thermodynamic data. For this study the LLNL.dat data base has been used. The source term modelling approach was undertaken as shown in Drawing 01.

These describe the four options which are being considered as part of the project. The preferred option of concurrent infilling and pit lake generation is being modelled in detail. The remaining three options will use the same source terms although certain geochemical reactions will not apply and this is described on each of the figures for each of the options.

---

[5] Parkhurst, D.L. and Appelo, C.A.J. (2013) Description of Input and Examples for PHREEQC Version 3 – A Computer Program for Speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. U.S. Geological Survey Techniques and Methods, Book 6, chap. A43, 497 p., available only at http://pubs.usgs.gov/tm/06/a43

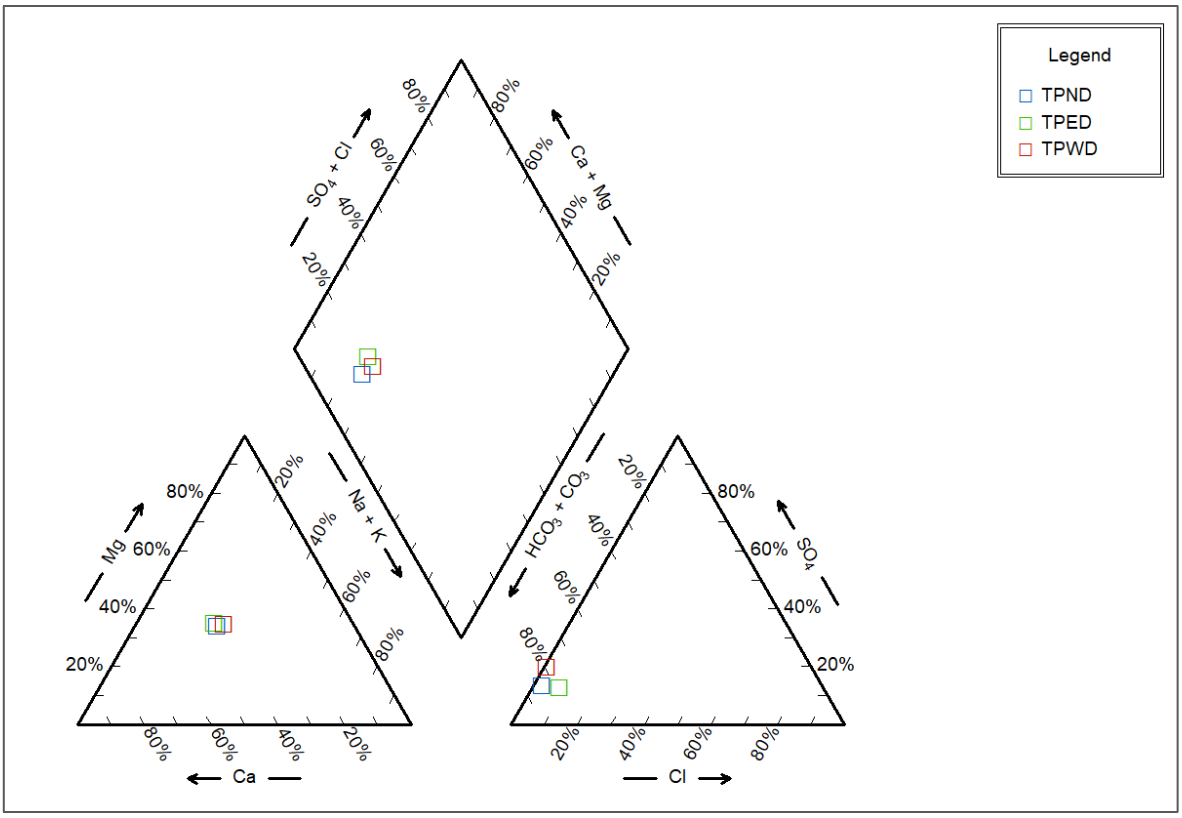
7.1 Geochemical Source Terms

7.1.1 Wall Rock Runoff Water Chemistry

The chemistry of the wall rock runoff was established by review of the waste classification work undertaken for the site.[6] As part of the waste classification 20:1 leach testing was undertaken to predict the leaching of acidity and metals from the waste rock. The results, coupled with whole rock analysis, confirmed the rock is not acid producing with low to moderate leaching of metals.

The leach testing water types are classified as calcium bicarbonate type which reflects the calcrete in the waste rock. The calcrete is likely to comprise calcite and dolomite of varying proportion. This is supported by the major oxides and trace metal analysis of the waste rocks which report inorganic carbon (1% – 3%), calcium oxide (5%-10%) and magnesium oxide (6%-9%). A Piper Diagram for the leach data is presented below:

Figure 7-1
Piper Diagram for Leach Data



The leach testing was undertaken on samples of stockpiled waste rock which is considered indicative of what will be present in the waste rock in the pit and the wall rock of the mine. The ions selected for geochemical modelling comprised the mean of the samples analysed. Where corresponding ions contained detected and non-detected results for different samples, half the detection limit of the non-detected result was used in calculating the mean for the three samples. Where analytes were recorded as non-detected in all three samples, the analyte was not included in the assessment.

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[6] Golder Assocoaites (2016) Waste Classification Assessment for Tshipi E Ntle Mine. Ref: 1541973-301423-1

The equilibration of the water chemistry in the leach with mineralogy in the wall rock will be considered as part of the modelling. The equilibration of minerals with relatively static bodies of water is not instantaneous and take days/weeks/years (depending on the mineral) to reach equilibrium; therefore because any surface runoff is likely to be generated during flashy time rain fall events it is considered less likely that the water chemistry will have sufficient time to equilibrate with the wall rock mineralogy.

7.1.2 Groundwater Chemistry Source Term

The groundwater component source terms involves a slightly different approach. The rising groundwater will interact with the mineralogy of the waste rock in the base of the pit (for options 1 – 3). The chemistry of the up gradient groundwater monitoring well data surrounding the mine has been used as that which infills the pit. The mean concentration of the analytes have been prepared for all analysis from 2008-2018, with on-detects assumed to be half the detection limit when calculating the mean. This information is deemed suitable for use as the water quality source term for the groundwater entering the pit.

Table 7-1
Mean SPLP Chemistry

Analyte	Al	As	B	Ba	HCO3	Ca	Cd	Cl	Co	Cr	Cu	Fe	F	Free NH3	Hg	K	Mg	Mn	Mo	Na	Ni	NO3	P	Pb	Rb	pH	Sb	Se	Si	SO4	Sr	Ti	TDS	U	V	W	Zn
Units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l	mg/l	mg/L	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	pH Unit	mg/l	mg/l	mg/l	mg/l	Mg/l	Mg/l	mg/l	Mg/l	mg/l	Mg/l	mg/l
Mean of SPLP Results	0.131	0.0013	0.081	0.109	36	8.5	<0.001	0.98	0.0007	0.002	0.0017	0.146	0.26	NA	0.00017	2.44	4.33	0.019	0.003	4.59	<0.01	3.52	<0.01	0.0023	0.0013	7.95	0.0013	0.0012	5.32	5.2	0.033	0.0087	79	0.0001	0.616	0.0013	0.014

<LOD assumed to be 50% of the detection limit when calculating mean of the samples. Where analyte is detected in groundwater and where all results are <LOD, the LOD is recorded as the mean.

Analytes removed: Ag,Au, Be, Bi, Ce, Cs, Ga, Ge, Hf, Ho, Ir, La, Li, Nb, Nd, Sn, Te and Th.

NA – not analysed.

Table 7-2
Mean Groundwater Chemistry (TSH9 and TSH10) Used in the Geochemical Modelling

Analyte	Al	As	B	Ba	HCO3	Ca	Cd	Cl	Co	Cr	Cu	EC	Fe	F	Free NH3	Hg	K	Mg	Mn	Mo	Na	Ni	NO3	P	Pb	Rb	pH	Sb	Se	Si	SO4	Sr	TDS	Ti	V	Zn
Units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mS/m	mg/l	mg/l	mg/L	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Mg/l	pH Unit	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	Mg/l	mg/l	mg/l
TSH09 and 10 Average Concentration From 4 samples 2017 -2018	0.031	0.006	0.5	0.059	267	21	<0.005	223	<0.001	0.002	<0.005	155	0.011	0.3	14	<0.001	6	104	0.08	0.002*	88	<0.001	42 (1.5)	0.006	0.003	0.01	8.1	0.003	0.014	4	50	0.11	909	0.01	0.002	0.024
Livestock Drinking Water Standard	5	1	5			1000	0.01	1500-3000	1	1 (as Cr(VI))	0.5-5		10	2		0.001		500	10	0.01	2000	1	100		0.1				0.05		1000		1000-3000		1	20

*excludes removal of one outlier over 1000 times higher than running average. Nitrate is seen to be reducing significantly over time and is currently a mean shown in brackets. This may be related to ANFO reduction.

The minerology of the waste rock has been reviewed and those minerals deemed to be sufficiently reactive have been used to equilibrate with the chemistry of the incoming and rising groundwater. The relatively dissolution or weathering rate of minerals can be used to indicate their long term stability and therefore whether they will equilibrate with the infiltrating groundwater.[7] The geological information from the site indicates the most likely reactive mineral phases are iron (such as haematite) and carbonates (such as calcite and dolomite).

Whilst other mineral phases are likely to be present, the kinetics of their dissolution (particularly those of silicates and recalcitrant minerals (such as rutile etc) are unlikely to react quickly enough to influence the groundwater chemistry. There is some doubt as to the rate at which dolomite will dissolve, especially when compared to calcite, however given the propensity for the mineral in the waste rock; this has been included in the equilibration modelling.

Comparisons between silicates, carbonates and iron oxide dissolution indicate it is the carbonate and iron oxide which is likely to dominate any mineral equilibration process. Carbonate and iron oxide (haematite) mineral dissolution are higher than common silicates minerals (in some cases by orders of magnitude). The iron minerals most likely to be present in the waste rock are hematite and magnetite. Equilibration with these minerals will be slow, when compared to iron oxides. Studies on solubility controls of iron at other pits lakes [8] have shown the most likely form of iron is ferrihydrite and this has been used as the equilibration phase for this modelling.

Therefore, the minerals in the waste rock which will be allowed to equilibrate with the groundwater are:

- Calcite ($CaCO_3$)
- Dolomite ($CaMgCO_3$)
- Ferrihydrite ($Fe(OH)_3$)

The resulting source term has been used in the modelling of the water quality entering the pit from the groundwater interaction with the waste rock mineralogy. The chemistry of the surrounding groundwater has been obtained from regular monitoring over a number of years.

The results of the groundwater investigation has also been used to populate a Piper Diagram and compared to the leach chemistry as shown below. The mean groundwater is presented as a magnesium chloride water type which is likely to be reflective of the dolomite mineralogy in the area.

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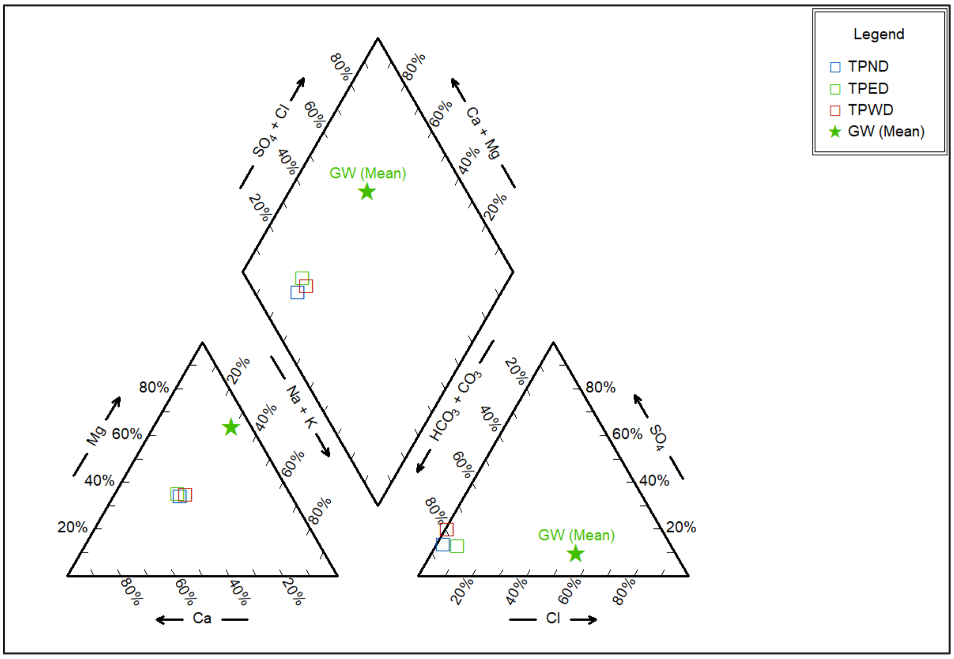
[7] http://epsc511.wustl.edu/Mineral_Dissolution_Kinetics.pdf

[8] Eary, L.E. 1999. Geochemical and equilibrium trends in mine pit lakes. Applied Geochemistry 14, 963-987. http://dx.doi.org/10.1016/S0883-2927(99)00049-9

Figure 7-2
Piper Diagram for Leach Data and Mean Up-Gradient Groundwater Data



7.1.3 Rainwater Chemistry

Rainfall, whilst not considered a significant water source, has a chemistry which will enter the pit directly during rain fall events. The chemistry of the rainfall has been reviewed and literature values have been adopted for the model.[9] In the absence of data for South Africa the rainwater data is for rainwater chemistry in the Africa Region and has been summarised from data collected at Mali, Niger, Benin, Cote D'Avoire and Cameroon.

7.1.4 Redox Conditions

The redox data is measured as redox voltage (Eh) and this needed to be altered to electron activity (pE) to be used in the geochemical modelling. This involves using the following equation:

$$\text{pE} = \frac{Eh.F}{2.303.R.T}$$

Where:

Eh = Redox (mV)

F = Faraday Constant (cal/V)

R = Gas Constant (cal/degree)

T = Temperature (degrees Kelvin)

There is no redox data recorded for the SPLP leach testing and the groundwater analysis, although the latter includes nitrogen ion species. Using this as a redox paring – it is possible to estimate the redox for the groundwater entering the pit:

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[9] World Data Centre for Precipitation Chemistry. http://www.wdcpc.org/content/global-assessment-data-sets

The reduction of nitrate in water to form ammonium is shown below:

$$NO_3^- + 10H^+ + 8e^- \leftrightarrow NH_4^+ + 3H_2O_{(l)}$$

The redox or Eh (Volts) can be calculated if the activities of H^+, NO_3^-, and NH_4^+ are known using the Nernst equation for this reaction:

$$Eh = E^0 - \frac{0.0592}{8}\log\left(\frac{a_{NH_4^+}}{a_{NO_3^-}a_{H^+}^{10}}\right)$$

In addition the E^0 (Standard Electrode Potential) will need to be calculated using:

$$E^0 = \frac{-\Delta G_r^o}{n\Im}$$

For the nitrate reduction, the E^0 is calculated to be 0.88 volts.

The Nernst equation then becomes:

$$Eh = 0.88 - \frac{0.0592}{8}\log\left(\frac{a_{NH_4^+}}{a_{NO_3^-}a_{H^+}^{10}}\right)$$

The above can be used to generate a redox value (mV) and this approximates to 0.8mV. When this is converted the pE = 12 and this is used in the modelling which involve the generation of a pit lake where atmospheric interaction is most pronounced. Where options include the absence of a pit lake and water held in pore space of waste rock, the redox conditions are likely to be more reducing and this will be included in the relevant modelling.

7.2 Option 1: Complete Backfill Source Term Generation

This option assumes that there is no pit lake generated because the entire pit is backfilled with waste rock up to ground level. Therefore, the dominant geochemical controls on the water within the backfilled pit will be:

1. Infiltrating rainwater equilibrating with the waste rock; and
2. Rising groundwater equilibrating with the waste rock.

Consequently, the source terms will be similar to those shown above in Table 7-6. The main difference is that infiltrating rainwater will also equilibrate with the reactive minerals in the water rock. Therefore, the source terms for this option are presented below:

Table 7-3
Options 1 Source Terms Generated for Goldsim Modelling

Analyte All mg/l unless shown.	Groundwater pre-Equilibration with minerals	Groundwater Post Equilibration (used in the preferred option model)	Infiltrating Chemistry Pre-Equilibration (SPLP Leach)	Infiltrating Chemistry Post Equilibration
pH	8	7.225	7.95	9.8
Redox (pE)	12	12.6	12	-6.2
Alkalinity	268	282	37	21.5
Bicarbonate (TIC)	267	275	36	29.5
Fluoride	0.3	0.3	0.26	0.26
Chloride	223	223	0.98	0.98
Nitrate	1.5	1.5	3.5	3.5
Sulfate	50	50	5.2	5.2
Aluminium	0.031	0.031	0.13	0.13
Arsenic	0.006	0.006	0.0013	0.0013
Boron	0.5	0.5	0.081	0.081
Barium	0.059	0.059	0.11	0.11
Calcium	21	144	8.46	8.8
Cadmium	<0.001	<0.001	<0.001	<0.001
Copper	<0.001	<0.001	0.0017	0.0017
Chromium	0.002	0.002	0.0023	0.0023
Iron	0.3	0.097	0.15	33
Lead	0.003	0.003	0.0023	0.0023
Mercury	<0.001	<0.001	0.0002	0.0002
Potassium	6	6	2.44	2.44
Magnesium	104	7.55	4.33	0.39
Manganese	0.08	0.08	0.012	0.012
Nickel	<0.001	<0.001	<0.01	<0.01
Sodium	88	88	4.6	4.6
Selenium	0.014	0.014	0.0012	0.0012
Vanadium	0.002	0.002	0.016	0.016
Zinc	0.024	0.024	0.0414	0.041

Table 7-4

Option 1 Post Equilibration Changes in Mole Assemblage

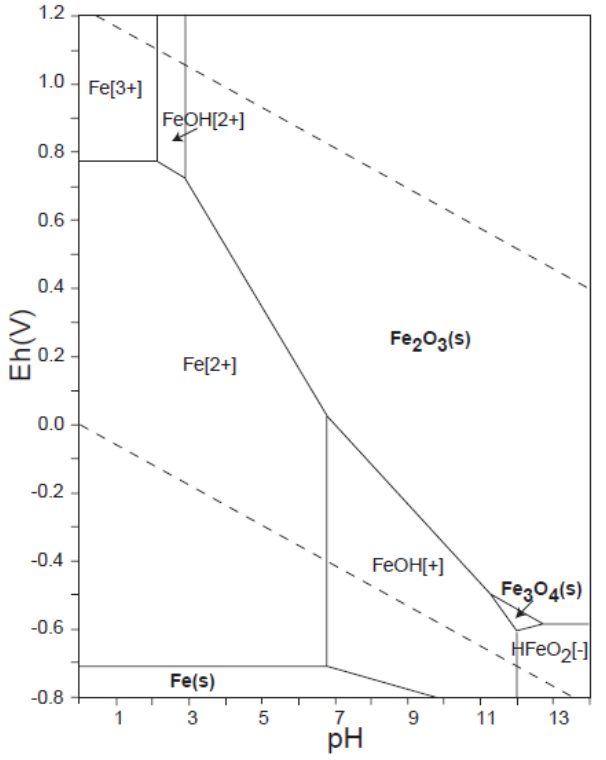
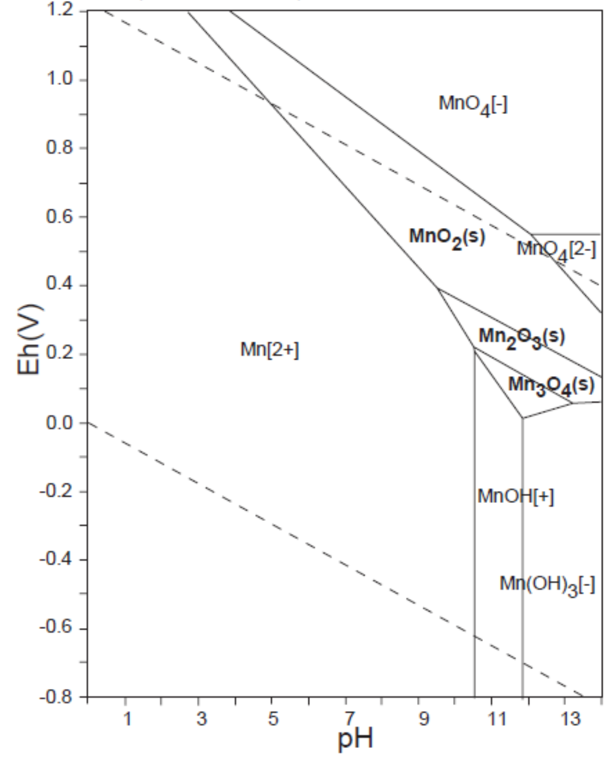
Phase	Formula	Changes of Moles in Assemblage
Calcite	$CaCO_3$	-0.00017
Dolomite	$CaMgCO_3$	0.00016
Ferrihydrite	$Fe(OH)_3$	-0.00059

There is a net gain in calcium ions and magnesium (from dolomite) with increase in iron after the equilibration. The latter has the potential to precipitate, however this has not been included at this stage such that a worst case is presented.

When these pore waters interact and equilibrate with the minerals in the waste rock. Unlike with the pit lake modelling, there is likely to be minimal atmospheric connection/interaction with the pore water in the waste rock- especially when compared to the pit lake interaction with atmosphere. Furthermore, it is likely that reducing conditions will be present or be generated which would most likely prevent precipitation of oxidised mineral phases. This is particularly relevant for iron and manganese species which for which the divalent ion is likely to dominate in reducing conditions at the pH conditions in the waste rock, as shown below Table 7-5 below.

Table 7-5

Typical Eh-pH Diagrams for Iron and Manganese

	
Iron Eh-pH Diagram	**Manganese Eh-pH Diagram**

Consequently, the modelling does not include allowance for the iron and manganese oxyhydroxide and sulfate minerals to precipitate. However, carbonate in the form of calcite and aluminium hydroxide (in the form of Gibbsite) will be allowed to precipitate if it becomes oversaturated because it is redox independent.

These source terms were then used in the Goldsim model to mix and predict the chemistry over a number of time steps

7.3 Option 2: Partial Backfill Source Term Generation

This option assumes that the pit is backfilled with waste rock to a level that coincides with the final recovery level of the groundwater in the pit. A pit lake will not form with this option and therefore the source term relates to the interaction between the rising groundwater and the waste rock backfill material.

The geochemical controls within the waste rock will be those described in Option 1 above.

The Goldsim modelling for this option will take into the account that the waste rock backfill will terminate at the level of the anticipated final groundwater level in the pit.

7.4 Option 3: Concurrent Backfill Source Term Generation

This assumes concurrent backfilling (also termed ‘in-pit dumping) with the pit lake recovery. Examples of the results of the source term PHREEQC modelling are held in Appendix 02. The results are summarised below in Table 7-6

Table 7-6
Option 3 Source Terms Generated for Goldsim Modelling

Analyte All mg/l unless shown.	Groundwater pre-Equilibration with minerals	Groundwater Post Equilibration (used in the preferred option model)	Runoff (SPLP Leach)	Rainwater (2005 – 2007)
pH	8	7.225	7.95	5.3
Redox (pE)	12	12.6	12	12
Alkalinity	268	282	37	7
Bicarbonate (TIC)	267	275	36	*6.6
Fluoride	0.3	0.3	0.26	ND
Chloride	223	223	0.98	0.37
Nitrate	42	42	3.5	0.14
Sulfate	50	50	5.2	0.14
Aluminium	0.031	0.031	0.13	
Arsenic	0.006	0.006	0.0013	
Boron	0.5	0.5	0.081	
Barium	0.059	0.059	0.11	
Calcium	21	144	8.46	0.4

Cadmium	<0.001	<0.001	<0.001	
Copper	<0.001	<0.001	0.0017	
Chromium	0.002	0.002	0.0023	
Iron	0.3	0.097	0.15	
Lead	0.003	0.003	0.0023	
Mercury	<0.001	<0.001	0.0002	
Potassium	6	6	2.44	
Magnesium	104	7.55	4.33	
Manganese	0.08	0.08	0.012	
Nickel	<0.001	<0.001	<0.01	
Sodium	88	88	4.6	0.24
Selenium	0.014	0.014	0.0012	
Vanadium	0.002	0.002	0.016	
Zinc	0.024	0.024	0.0414	
***Calculated using :** 1.7177*Log (pH)+4.1333[10] Half detection limit used for rainfall data.				

The changes in bulk chemistry which resulted from the equilibration is summarised below:

Table 7-7
Option 3 Post Equilibration Changes in Groundwater Mole Assemblage

Phase	Formula	Changes of Moles in Assemblage
Calcite	$CaCO_3$	-0.007105
Dolomite	$CaMgCO_3$	0.004
Ferrihydrite	$Fe(OH)_3$	0.0000037

This indicates that there is a net gain in calcium ions but reduction in iron and magnesium after the equilibration.

These source terms were then used in the GoldSim model to mix and predict the chemistry in the pit. Once entered into the pit, a number of other geochemical processes will operate, and this is related to the potential for layer formation in the pit lake.

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[10] http://www.veoliawatertech.com/crownsolutions/ressources/documents/2/21967,Water-pp424-425.pdf

7.5 Option 4: No Backfill Source Term Generation

The final of the four options being considered assumes that there is no backfilling of the pit with waste rock and the pit lake is allowed to form by infiltrating groundwater, pit wall runoff and rainfall. Therefore, the source terms for this option are included as the chemistry of the mean groundwater (with no equilibration with waste rock), rainwater and runoff from the pit walls presented in Table 7-6.

In addition, as the pit lake forms, there will be the same geochemical reactions as described in Section 5.2 to characterise the different layers which will form over time.

It is fully appreciated that the neighbouring mine will have a proportion of backfilled rock and this may alter the chemistry of rising groundwater in this area which may drain into the Tshipi pit (which has no backfill in this scenario). The mineralogy in this waste rock is deemed to be the same as that in the waste rock used in the Tshipi pit and the model equilibrated this mineralogy as described previously.

Notwithstanding, the proportion of groundwater flow into the pit from the neighbouring mine area is relatively low and therefore it is considered less likely that it will have a significant impact on the chemistry of the pit lake being generated. The major dominant chemistry in this scenario is from the pit wall contributions.

7.6 Rainwater chemistry

As part of the assessment, the inclusion of rainwater runoff from the surrounding area will be assessed. The local topography has been mapped and runoff from these areas is included in the Goldsim model. In terms of quality, this runoff is assumed to have chemistry similar to that of rain water albeit it is likely that suspended solids will be more elevated.

Geochemical modelling of this water is not appropriate because the flashy nature and there rapid flow rate of such runoff will not provide sufficient time for minerals in the land surface soils to equilibrate with the rainwater.

8.0 Layer Formation

For the options where pit lakes are generated (Option 3 and 4), the application of geochemical control within the layers formed will be dictated by their formation rate. The water balance suggests that it might take approximately 150 years for the pit lake to reach steady state conditions and therefore the lake dimensions will develop over time. As described below the layer thickness is characterised by empirical calculation from the length of free standing water in the put. This thickness dictates if a layer is likely to form by comparing the thickness of the upper layer with the total lake depth. The calculation process of this stage of the assessment is described below.

8.1 Layer Development

One of the aspects to consider when modelling the chemistry of the pit lake involves the consideration of layer formation as the water rises and approaches steady state. While the water is exposed to solar radiation and thermal contact, deeper layers in the pit are sheltered form the major sources of heat[11]. This can form an upper layer called an epilimnion with the deeper second layer termed a hypolimnium. The project has undertaken a study to establish the following:

1. Is layering likely to occur? ; and
2. What is the most appropriate method to model the hydrogeochemistry of the layers if they are generated?

The epilimnion thickness is generally determined by wind with few exceptions, the one exception being where light penetrates beyond the mixing depth.. A number of empirical studies have been undertaken which have developed regression equations to calculate the epilimnion thickness and also the thickness of thermoclines in the lake.[12] These studies are summarised and discussed below:

Table 8-1
Predictive Models for Epilimnion Depth (De)

Region	Regression Equation	Correlation (r2)	Number of lakes (n)
Japan[13]	$4.6\ f^{0.304}$	-	32
Poland[14]	$4.6\ F^{0.41}$	0.85	88
Canada[15]	$7.0\ MEL^{0.42}$	0.79	33
New Zealand[16]	$7.69\ f^{0.463}$	0.94	33

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[11] Boehrer B and M Schultze. 2009. Stratification and Circulation of Pit Lakes in Mine Pit lakes: Characteristics, predictive Modelling and Sustainability. Volume 3 ed. D.N Castendyk and L.E Eary. Pp 46-50 Society for Mining Metallurgy and Exploration (SME).

[12] Lyle A.A and A.E Bailey-Watts (1993) Contributions to the Scotland and Northern Ireland Forum for Environmental research (SNIFFER) Programme on Eutrophication Risk Assessment: II Factors Controlling Lake Stratification. Institute of Freshwater Ecology.

[13] Arai, T (1981) Climatic and geomorphological influences on lake temperature. *Verhandlungen, Internatioanle Vereinigung fur Theoretische und Angewandte Limnologie* Vol 21 130-134

[14] Patalas, K(1984). Mi-summer mixing depths in lakes of different latitudes. *Verhandlungen, Internatioanle Vereinigung fur Theoretische und Angewandte Limnologie* Vol 22 97-102

[15] Green, J.D.,Viner, A.B.,Lowe.D.J. (29187) The effect of climate on lake mixing patterns and temperatures, in Inalnd Waters if New Zealand (Ed. V.B. Viner) pp65-95 Dept of Sci and Ind Red Bull 241, Wellington.

[16] Davis-Colley, R.J (1988). Mixing depths in New Zealand lakes. New Zealand Journal of Marine and freshwater research Vol 22 pp517-527

	$6.85\ F^{0.446}$	0.918	22
$f = A^{0.5}$ Where $A = km^2$ **F = (length + width)/2 in meters** **MEL = Effective Length (m) – this is maximum uninterrupted water length**			

Table 8-2
Predictive Models for Thermocline Depth (Dt)

Region	Regression Equation	Correlation (r2)	Number of lakes (n)
Germany[17]	$4.72\ F^{0.39}$	-	30
North America[18]	$4.0\ f^{0.5}$	-	18
Japan[19]	$6.22\ f^{0.304}$	0.53	32
New Zealand[20]	$9.52\ f^{0.425}$	0.954	22
	$8.58\ F^{0.408}$	0.928	22
Northern Hemisphere[21]	$0.569\ MEL^{0.336}$	0.85	123
$f = A^{0.5}$ Where A = km2 **F = (length + width)/2 in meters** **MEL = Effective Length (m) – this is maximum uninterrupted water length**			

The Hanna study referend above considered over 100 sites in thermally stable continental climates and is considered relatively close to the likely conditions of the mine pit. However sensitivity will be undertaken using the other models with high correlation coefficients (such as those in New Zealand).

More recent studies of thermoclines[22] as shown in Figure 8-1 below, predicts the thermocline and also compares the result from Hanna (1990). In addition recent coal mine pit lake in South Africa[23] have been reviewed and the thermocline/lake depth for four lakes are also presented in Table 8-3

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[17] Ventz, D.(1973). Die Einzugsgebietsgrosse, ein Geofaktor fur den Trophiczustand stehender gewasser. Fortschnitte der Easserchemis und ihere

[18] Ragotskie, R.A (1978). Heat budgets of lakes in Lakes (Ed. A. lerman) pp 1-19 Springer-Verlag, new York

[19] Arai, T (1981) Climatic and geomorphological influences on lake temperature. *Verhandlungen, Internatioanle Vereinigung fur Theoretische und Angewandte Limnologie* Vol 21 130-134

[20] Davis-Colley, R.J (1988). Mixing depths in New Zealand lakes. New Zealand Journal of Marine and freshwater research Vol 22 pp517-527

[21] Hanna, M.(1990). Evaluation of models predicting mixing depth. Canadian Journal of Fisheries and Aquatic Science. Vol 47 pp940-947

[22] Jewell, P.W. 2009 Stratification control of pit lakes, Mining Engineering Technical paper February 2009. Pp40-45

[23] Johnstone,A. and L Kennedy 2017. Coal Pit Lakes in South Africa. Mine Water and Circular Economy IMWA 2017 in Lappeenranta,Finland.

Figure 8-1
Predicted vs. measured thermocline depths of pit mine Lakes (Jewell, 2009)

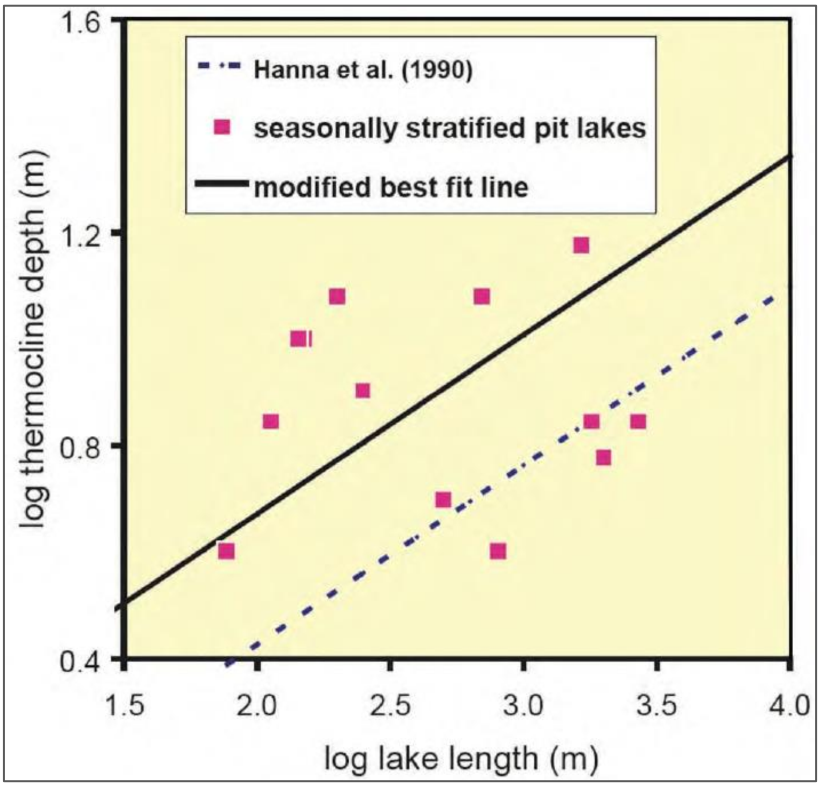

Table 8-3
Thermocline Depth and Pit Lake Depth in South Africa (Johnstone and Kennedy, 2017)

Lake	Rainfall (mm/years)	Evaporation (mm/year)	Depth of Thermocline (m)	Log Thermocline Depth (m)	Depth of Pit Lake (m)
A	400	2000	13.93	1.8	68.5
B	711	1730	14.91	1.3	19.25
C	670	1600	1	0.5	3
D	700	1700	2.85	1	10.1

The South African pit lakes are located in areas with negative water balance similar to that at Tshipi. The log thermocline depth is also presented and compares well to the other thermocline depths presented in Figure 3.

The likelihood of stratification forming in the lake depends on there being sufficient depth for such a structure to become established. The studies quoted in Table 3-1 has been compiled[24] and the following method has been devised to predict if the epilimnion will form and be stable:

Table 8-4
Classification of Lake Mixing using Epilimion (D_e) and Maximum Lake Depth (D_{max})

Classification Ration	Lake Condition
D_e / D_{max} >2	Turbulent, well mixed lakes
1.0 < D_e/D_{max} <2.0	Mixed isothermal lakes
0.5 < D_e/D_{max} <1.0	Occasional unstable stratification
D_e/D_{max} <0.5	Stable seasonal stratification

The above process will be used to establish the likelihood layers will form but also at what point these might form based on the depth of the lake. Where the epilimnion is predicted to form geochemical modelling will be used to predict the chemistry of this layer as opposed to that in the underlying hypolimnium layer.

For Tshipi the above relationship between thermocline depth and site dimensions has been used. The uninterrupted water length of the pit lake is shown below with the corresponding calculated thermocline depth.

Table 8-5
Depth of Thermocline and Mixing Classification

Uninterrupted Length of Pit Lake (m)	Potential Total Depth of Pit Lake (m)	Calculated Thermocline (m)	Thermocline Calculation Method	Mixing Classification
400	60	6.31	Figure 8-1	Stable Seasonal Stratification
400	60	4.3	Hanna et al (1990)	Stable Seasonal Stratification

These results appear to be similar to those previously recorded in South Africa where there is a negative water balance (Table 8-3).

Jewell (2009) summarises the thermocline depth during summer stratification in pit lakes as a function of the length of the pit lake (see Figure 8-1). Tshipi pit has a length of approximately 400 m, and so based on the relationship of Jewell (2009) the thermocline depth during summer stratification is expected to be approximately 6 m.

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[24] Lyle A.A and A.E Bailey-Watts (1993) Contributions to the Scotland and Northern Ireland Forum for Environmental research (SNIFFER) Programme on Eutrophication Risk Assessment: II Factors Controlling Lake Stratification. Institute of Freshwater Ecology.

8.2 Geochemical Modelling of Layers

The source terms for the geochemical modelling have been discussed previously. These mixtures will form homogenised lake water for which the modelling of the chemistry within the potential layers requires consideration.

The source terms (rainwater and groundwater) when mixed form a bulk water chemistry which is modelled geochemically as follows:

1. Layer 2 (hypolimnium) water chemistry is calculated from the bulk chemistry of the source terms mixture as calculated using Goldsim which is speciated using PHREEQC allowing specific mineral phases to precipitate if they become oversaturated.

2. Layer 1 (epilimnium) the Layer 2 chemistry will be equilibrated with atmospheric carbon dioxide (partial pressure = 0.00033 bar or $10^{-3.5}$ atm) and oxygen gas (partial pressure = 0.21 bar or $10^{-0.68}$ atm). The equilibration may also result in specific mineral phases becoming oversaturated and these will also be allowed to precipitate.

3. Most natural waters [25] have neutral to alkaline pH, where Ca and carbonate alkalinity concentrations are affected by the solubility of calcite [CaCO3]. In pit lakes, the values of saturation indices (SI) for calcite show an increase over the pH range of 6.8 ± 9. Pit lakes with a pH>7 generally have calcite SI values>0, (as is the case for the Tshipi lake) which indicate oversaturation conditions are typical. The apparent oversaturation with calcite is common in natural aqueous systems and is often attributed to slow precipitation kinetics.

4. The degree of calcite oversaturation is also related to the solubility of CO_2(g) in solution and the rate of CO_2(g) loss or gain by the solution. Calculations based on measured pH and alkalinity values, show that most pit lakes are oversaturated with CO_2(g) compared to the atmospheric level of $10^{-3.5}$ atm, ranging up to levels of $10^{-2.0}$ atm.

5. Other studies into pit lake predictive chemical modelling indicate that gypsum is included in the geochemical model as a mineral phase allowed to precipitate[26]. This is particularly relevant in waters which have a pH >7 which is the case at Tshipi.

The specific mineral phases which will be allowed to precipitate have been taken from a review[27] of solubility controls in 24 No. existing hard-rock pit lakes and 66 No. existing coal mine pit lakes and are shown below. This has been supplemented by other plausible minerals controlling the major ion in the pit lake as the layering develops.

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[25] http://www.resolutionmineeis.us/sites/default/files/references/eary-1999.pdf

[26] Eary L.E. and W.M Schafer Approaches for Evaluating the Predictive Reliability of Pit Lake Numerical Models in Mine Lakes Characteristics, Predictive Modelling and Sustainability Volume 3 ed D.N Castendykand L.E Eary, Society for Mining, Metallurgy and Exploration 2009 Vol 15 pp 167 - 177

[27] Eary, L.E. 1999. Geochemical and equilibrium trends in mine pit lakes. Applied Geochemistry 14, 963-987. http://dx.doi.org/10.1016/S0883-2927(99)00049-9

Table 8-6
Mineral Phases Allowed to Precipitate

Phase Name	Equations Used In Modelling
Ferrihydrite [$Fe(OH)_3$]	$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 2H^+$
Manganite [$MnO(OH)$]	$Mn^{3+} + 2H_2O \rightarrow MnO(OH) + 3H^+$
Amorphous gibbsite [$Al(OH)_3$]	$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$
Barite [$BaSO_4$]	$Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$
Calcite [$CaCO_3$]	$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$
Gypsum [$CaSO_4$]	$Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4$

8.2.1 Modelling pH

One of the challenges for using Goldsim to evaporate and concentration water chemistry is that pH is ultimately dictated by the composition of the solution and is not a simple numeric calculation based on hydrogen ion enrichment over time. Therefore pH can be calculated in PHREEQ using a number of approaches:

1. *Charge Balance*

The charge balance can be used to estimate pH, but this is to be sued with caution because all analytical errors and unanalysed species are grouped together (trace elements) into the estimate of pH. In reality it is the major ions alone which will dictate the pH.

2. *Using Alkalinity and Total Inorganic Carbon*

Alkalinity and total inorganic carbon can be used to calculate pH. Both Alkalinity and TIC are included in the solution definition and pH will be calculated. An example of the input definition is included below:

Table 8-7
Input Definition for Calculating pH Using Alkalinity and TIC

```
SOLUTION
Alkalinity  1
C(4)  1.5
END
```

3. *Use Partial Pressure Carbon Dioxide*

Alkalinity and PCO_2 can be used to calculate the pH. This calculation assumes air equilibrium an example of how this is presented in PHREEQ is shown below

Table 8-8
Input Definition for Calculating pH Using Alkalinity and Atmospheric CO_2

```
SOLUTION
pH    7    CO2(g) -3.5
Alkalinity 1
END
```

Of the three pH modelling options – option 2 and 3 are considered the most robust because it uses the analytical results from the monitoring at the site and therefore the Goldsim result of the mixing are more robust. In addition in terms of developing the chemistry of the upper layer in the pit lake, equilibration with the atmosphere will be undertaken using PHREEQ. It should be noted that monitoring data of the pit lake stratification is always a preferred method for predicting longer term pH values and, with time, geochemical models can be updated with such information.

9.0 Water quality results

The results of the water quality prediction are presented in the following tables. This includes the composition of the layers in the pit lake at the various time steps. This demonstrates the likely changes in composition with time. The time steps used in the pit lake water quality generation have been adopted based on the likely time to achieve quasi steady state of the pit lake water level.

The results presented include those parameters which are required to classify the water in terms of suitability for use as livestock drinking water. In addition, those parameters which are used to determine the bulk chemistry (such bicarbonate and pH) are also presented as these dictate the changes imparted by the equilibration processes being modelled. The water quality result modelling time slices were developed directly from the predicted time to fill to quasi-stasis level as outlined in Table 9-1.

Table 9-1 Water quality time slices

Backfilling closure option	Time to fill to quasi-static water levels (mean level)	Water quality modelling time slices
Option 1 Complete Backfill	39 years	2 (25 and 50 years)
Option 2 Fill To Regional Groundwater level	36 years	2 (25 and 50 years)
Option 3 Concurrent backfill	153 years	4 (50, 100, 150 and 200 years)
Option 4 No Backfill	42 years	2 (50 and 100 years)

9.1 Option 1: Complete Backfill and No Pit Lake

The anticipated pore water chemistry in the backfill is shown below (exceeded parameters highlighted):

Table 9-2
Results of Predicted Water Quality for Option 1

	Livestock	25 Years	50 Years
	DWS		
Al	5	0.0007	0.0012
As	1	0.004	0.0032
B	5	0.34	0.28

	Livestock	25 Years	50 Years
Ba		0.08	0.09
HCO_3		145	107
Ca	1000	67	45
Cd	0.01	0.0005	0.0005
Cl	1500 3000	133	95
Cu	0.5 1.0	0.00091	0.0011
Fe	10	12.5	18.1
F	2	0.28	0.27
Hg	0.001	0.0004	0.00034
Mg	500	5	4
Mn	10	0.05	0.04
Mo	0.01	0.0023	0.0024
Na	2000	54	40
Ni	1	0.005	0.005
NO_3 as N	100	10	35
Pb	0.1	0.003	0.003
pH		7.47	7.47
Se	0.05	0.009	0.007
SO_4	1000	33	25
TDS	1000 2000 3000	407	371
V	1	0.007	0.009
Zn	20	0.03	0.03

The mole assemblage changes indicate that the minerals precipitate in the pore space which increases the concentration of aluminium and reduces that of calcium and bicarbonate with time.

Table 9-3
Option 2 Change in Mole Assemblage for Each Phase

Phase	Change of Moles in Assemblage 25 Years	Change of Moles in Assemblage 50 Years
Calcite ($CaCO_3$)	$5.737\text{x}10^{-04}$	$1.479\text{x}10^{-04}$
Gibbsite ($Al(OH)_3$)	$2.461\text{x}10^{-06}$	$1.231\text{x}10^{-06}$

An important consideration when reviewing these results relates to how Goldsim has modelled this scenario. The main assumption being that once pit water level in the rock backfill, reaches regional groundwater, the groundwater contribution becomes negligible in the model to allow functionality. In reality there would be a flow-through scenario. Any chemical mass & water mass then above the pit water level (within the waste rock backfill) is transported out of the system (effectively into the surrounding groundwater and is mixed and diluted) and the only chemical influx from that point onwards within the pit infill comes only from surface water runoff from the pit walls areas and direct rainfall into the fill in the pit. There is, therefore, no evaporation and the time step to fill the waste rock is much quicker than those options which involve a pit lake. Consequently the water quality is better overall. Notwithstanding the reducing conditions will mean the iron is soluble and fails the drinking water limit for livestock.

The chemistry of the pore water would change should this be pumped through a borehole to the surface where evaporation would take pace and the analytes would concentrate.

9.2 Option 2: Partial Backfill and No Pit Lake

The anticipated pore water chemistry in the backfill is shown below:

Table 9-4
Results of Predicted Water Quality for Option 2

	Livestock	25 Years	50 Years
	DWS		
Al	5	0.00071	0.0013
As	1	0.004	0.0033
B	5	0.34	0.275
Ba		0.075	0.075
HCO_3		146	107
Ca	1000	66	44
Cd	0.01	0.0004	0.0005

	Livestock	25 Years	50 Years
Cl	1500 3000	134	98
Cu	0.5 1.0	0.0009	0.001
Fe	10	11	15
F	2	0.28	0.27
Hg	0.001	0.0004	0.0003
Mg	500	5	4
Mn	10	0.05	0.04
Mo	0.01	0.0023	0.0022
Na	2000	55	42
Ni	1	0.005	0.001
NO_3 as N	100	10	35
Pb	0.1	0.003	0.003
pH		7.49	7.76
Se	0.05	0.009	0.007
SO_4	1000	33	27
TDS	1000 2000 3000	460	371
V	1	0.007	0.009
Zn	20	0.03	0.03

An important consideration when reviewing these results relates to how Goldsim has modelled this scenario. The main assumption being that once pit water level in the rock backfill, reaches regional groundwater, the groundwater contribution becomes negligible in the model to allow functionality. In reality there would be a complex flow-through scenario. Any chemical mass & water mass then above the pit water level (within the waste rock backfill) is transported out of the system (effectively into the surrounding groundwater and is mixed and diluted) and the only chemical influx from that point onwards within the pit backfill comes only from surface water runoff from the pit walls areas and direct rainfall into the fill in the pit. There is, therefore, no evaporation and the time step to fill the waste rock is much quicker than those options which involve a pit lake. Consequently, the water quality is better overall. Notwithstanding the reducing conditions will mean the iron is soluble and fails the drinking water limit for livestock.

Table 9-5
Option 3 Change in Mole Assemblage for Each Phase

Phase	Change of Moles in Assemblage 25 Years	Change of Moles in Assemblage 50 Years
Calcite ($CaCO_3$)	6.024×10^{-04}	2.094×10^{-04}
Gibbsite ($Al(OH)_3$)	2.439×10^{-06}	1.066×10^{-06}

The mole assemblage changes indicate that the minerals precipitate in the pore space which reduces the concentration of aluminium, calcium and bicarbonate with time.

The chemistry of the pore water would change should this be pumped through a borehole to the surface where evaporation would take pace and the analytes would concentrate

9.3 Options 3: Concurrent Backfill and Pit Lake Formation

The results of the assessment for Option 3 are presented below. This includes the concentration of each layer formed as part of the pit lake development. Steady state is likely to form after +150 years and hence geochemical modelling is terminated at 200 years.

Table 9-6
Results of Predicted Water Chemistry for Option 3

Analyte	Livestock DWS	50 Years		100 Years		150 Years		200 Years	
Layer		1	2	1	2	1	2	1	2
Al	5	0.00055	0.00055	0.0003	0.0003	0.00034	0.00034	0.00045	0.00045
As	1	0.0077	0.0077	0.015	0.015	0.0196	0.0196	0.025	0.025
B	5	0.64	0.64	1.26	1.26	1.67	1.67	2.17	2.17
Ba		0.059	0.059	0.041	0.041	0.034	0.034	0.033	0.033
HCO_3		207	244	312	421	355	467	415	525
Ca	1000	61	61	104	104	85	85	61	61
Cd	0.01	0.00076	0.00076	0.0014	0.0014	0.0018	0.0018	0.002	0.002
Cl	1500 3000	269	269	523	523	685	685	872	872
Cu	0.5 1.0	0.001	0.001	0.0019	0.0019	0.0025	0.0025	0.003	0.003

Analyte	Livestock	50 Years		100 Years		150 Years		200 Years	
Fe	10	0.027	0.027	0.03	0.03	0.03	0.03	0.03	0.03
F	2	0.4	0.4	0.79	0.79	1.05	1.05	1.36	1.36
Hg	0.001	0.00064	0.00064	0.0012	0.0012	0.0016	0.0016	0.002	0.002
Mg	500	10	10	19.4	19.4	25	25	32	32
Mn	10	0.000031	0.000031	0.000028	0.000028	0.000021	0.000021	0.000019	0.000019
Mo	0.01	0.002	0.002	0.0043	0.0043	0.0058	0.0058	0.008	0.008
Na	2000	108	108	212	212	280	280	360	360
Ni	1	0.0076	0.0076	0.014	0.014	0.018	0.018	0.023	0.023
NO_3 as N	100	3	3	15	15	65	65	300	300
Pb	0.1	0.037	0.037	0.072	0.072	0.0095	0.0095	0.12	0.12
pH		8.76	7.32	8.9	7.01	8.95	7.08	9	7.22
Se	0.05	0.017	0.017	0.033	0.033	0.044	0.044	0.056	0.056
SO_4	1000	64	64	127	127	171	171	224	224
TDS	1000 2000 3000	735	773	1365	1475	1894	2007	2272	2382
V	1	0.19	0.19	0.29	0.29	0.36	0.36	0.46	0.46
Zn	20	0.033	0.033	0.063	0.063	0.083	0.083	0.11	0.11

The extent of changes caused by mineral precipitation can be understood by examining the changes in mole concentrations over time. This is examined in Table 9-7 below.

Table 9-7
Option 3 Change in Mole Assemblage for Each Phase in Layer 2

Phase	Change of Moles in Assemblage 50 Years	Change of Moles in Assemblage 100 Years	Change of Moles in Assemblage 150 Years	Change of Moles in Assemblage 200 Years
Barite ($BaSO_4$)	3.4 x10^{-07}	7.8x10-^{07}	5.0x10-^{07}	4.5x10-^{07}
Calcite ($CaCO_3$)	2.9x10^{-03}	3.3x10^{-03}	3.4x10^{-03}	3.4x10^{-03}

Phase	Change of Moles in Assemblage 50 Years	Change of Moles in Assemblage 100 Years	Change of Moles in Assemblage 150 Years	Change of Moles in Assemblage 200 Years
Iron Hydroxide $Fe(OH)_3$	$2.4x10^{-06}$	$2.5x10^{-06}$	$1.8x10^{-06}$	$1.7x10^{-06}$
Gibbsite ($Al(OH)_3$)	$2.8x10^{-06}$	$2.3x10^{-06}$	$1.6x10^{-06}$	$1.5x10^{-06}$
Gypsum ($CaSO_4$)	0	0	0	0
Manganite (MnOOH)	$1.8x10^{-06}$	$1.9x10^{-06}$	$1.3x10^{-06}$	$1.2x10^{-06}$

This indicates that with the exception of gypsum, all of the most likely minerals will have the potential to precipitate in pit lake model. Gypsum is undersaturated in the water over time and therefore will not precipitate.

The results also indicate the following:

- The difference in the layer chemistry relates to the bicarbonate and pH which is a function of atmospheric equilibration in this surface water and results in a lower total dissolved solid (TDS) content in Layer 1;
- After 100 years the mercury concentration is marginally above the DWS for livestock. However it should be remembered that the mercury is not detected in the groundwater analysis to date and therefore the detection limit was used in the modelling. This concentration is therefore theoretical and based on non-detection in the groundwater. Consequently the modelling is conservative and at 100 years, the mercury may remain non-detectable;
- The lower boundary of TDS suitable for certain livestock is also exceeded after 100 years, although it is lower than the 3000mg/l threshold indicating the water will be suitable for some livestock; and
- After 200 years the nitrogen concentration (as nitrate) and selenium (marginally) exceeds the livestock drinking water standards.

9.4 Option 4: No Backfill and Pit Lake Formation

The results of the assessment for Option 4 are presented below. This includes the concentration of each layer formed as part of the pit lake development. The hydraulic modelling indicates the pit lake will reach steady state at c.100 years and this is where the geochemical modelling is terminated.

Table 9-8
Results of Predicted Water Chemistry for Option 4

Analyte	Livestock DWS	50 Years		100 Years	
Layer		1	2	1	2
Al	5	0.003	0.0030	0.012	0.012

Analyte	Livestock	50 Years		100 Years	
As	1	0.021	0.021	0.09	0.09
B	5	1.57	1.57	6.8	6.8
Ba		0.062	0.062	0.043	0.043
HCO_3		564	678	2222	2879
Ca	1000	5.3	5.3	0.99	0.99
Cd	0.01	0.005	0.005	0.02	0.02
Cl	1500 3000	397	397	1698	1698
Cu	0.5 1.0	0.015	0.015	0.065	0.065
Fe	10	0.026	0.026	0.028	0.028
F	2	2.7	2.7	11	11
Hg	0.001	0.0025	0.0025	0.01	0.01
Mg	500	215	215	917	917
Mn	10	2.356E-06	2.356E-06	2.061E-06	2.061E-06
Mo	0.01	0.028	0.028	0.12	0.12
Na	2000	195	195	839	839
Ni	1	0.05	0.05	0.051	0.051
NO_3 as N	100	33	33	142	142
Pb	0.1	0.024	0.024	0.1	0.1
pH		8.1	9.09	9.4	8.67
Se	0.05	0.034	0.034	0.15	0.15
SO_4	1000	136	136	597	597
TDS	1000 2000 3000	1550	1664	6436	7093
V	1	0.14	0.14	0.6	0.6
Zn	20	0.4	0.4	1.6	1.6

Table 9-9
Option 4 Change in Mole Assemblage for Each Phase in Layer 2

Phase	Change of Moles in Assemblage 50 Years	Change of Moles in Assemblage 100 Years
Barite ($BaSO_4$)	6.9×10^{-06}	8.0×10^{-06}
Calcite ($CaCO_3$)	2.7×10^{-03}	3.0×10^{-03}
Iron Hydroxide $Fe(OH)_3$	3.1×10^{-05}	3.1×10^{-05}
Gibbsite ($Al(OH)_3$)	4.2×10^{-05}	3.8×10^{-05}
Gypsum ($CaSO_4$)	0	0
Manganite ($MnOOH$)	4.4×10^{-06}	4.2×10^{-06}

This indicates that that mineral precipitation does occur and control some of the major ions. The only difference in the layer chemistry relates to the bicarbonate and pH which is a function of atmospheric equilibration in this surface water and results in a lower total dissolved solid (TDS) content in Layer 1.

The results indicate that at 50 years some of the analytes fail the relevant livestock drinking water guidance concentrations. After 100 years a wider suite of analytes fail the guidance values.

9.5 Conclusion for Pit Lake Water Quality

There are two scenarios modelled which will generate pit lakes, namely Option 3 and 4. Of these two options the pit lake developed in association with concurrent filling has concentrations which do not exceed the relevant water quality standards for livestock until after 100 years. The mercury concentration is not 'real' because it uses a non-detected concentration in the idle (namely half the detection limit). Likewise, TDS will not restrict the use of the water for livestock until 100 years of pit lake water generation. Indeed, the concentration does not exceed 3000mg/l after 200 years of modelling the threshold beyond which the water cannot be sued for any livestock watering. Option 4 however shows exceedance for a larger number of analytes during the 50-year pit lake generation and therefore the water quality deteriorates more rapidly than Option 3., with TDS making the water unusable for livestock watering after only 50 years.

Hydraulic and geochemical modelling has indicated therefore that of the two options which generate pit lakes, the pit lake water for Option 3 (Concurrent or In-pit Dumping) produces more favourable water quality concentrations for livestock drinking water suitability.

9.5.1 Pit Lake Model Uncertainties

The geochemical modelling will not be able to consider microbial induced changes to the water quality in the pit and these may include:

Table 9-10
Complex Processes not included in the Pit Lake Modelling

Geochemical Process Not Included in the Modelling
Photochemical reactions in the epiliminion (Layer 1), (e.g photo-reduction of Fe^{3+} to Fe $^{2+}$)
Biological reactions, such as algal photosynthesis (e.g CO_2 consumption and O_2 production) and respiration by decomposers (i.e O_2 consumption and CO_2 production)
Uptake or cell wall sorption of metals by microorganisms in the water columns
Trace metal adsorption onto organic surfaces, Al and Mn hydroxide surfaces, and clay surfaces
Sediment processes including sulfate reduction, sulfide precipitation, hydrogen sulfide formation, reductive dissolution of Fe and Mn coupled with release of adsorbed metals.
Eddy diffusion that transports dissolved metals between layers.

Removing such processes does not weaken the pit lake model in terms of the water quality prediction, as it produces a conservative model. For example the majority of the processes above will remove potential ions from solution and hence the predicted water quality without including these processes is considered conservative.

The validity of the geochemical model is greatest for the epilimnion and hypolimnion as this is in contact with terrestrial ecology. Deeper layers are unlikely to form but will have larger uncertainty in terms of their geochemical make up and therefore have not be considered in the modelling. If they did form then they will only become important if massive pit slope failure or extreme weather events course turnover.

9.5.2 Porewater Quality and Comparison with Pit lake Quality

Those options which do not generate a pit lake and relate to pore water concentrations (i.e. Options 1 and 2.) indicate that the iron content will prohibit the use of the water for direct livestock dewatering within 50 years. As this water is below ground in the pore space of the rock infill, it will need to be pumped to surface for use. There would be a risk that the iron will clog pipework and this itself will cause issues with distribution.

10.0 Summary results, discussion, assumptions and possible passive treatment options

The predicted quality of the water in this pit lake (s) is of profound importance, especially in this area of scarce water resources. This technical study has been completed and has examined the long-term water quantity and quality predictions that can/may be achieved for the planned mine closure by exploring selected backfilling options of waste rock (or not) within the closed pit.

10.1 Results summary tables (no mitigation)

The four options regarding the closure of the mine and the predicted impact on the hydrological environment, in particular the long term, predicted pit lake water chemistry and how this has been derived has been presented in the previous sections. Determining the rate of pit filling, the quasi-static water level (QSWL), type of pit (hydraulic sink or flow-through) and the chemistry of the pit for closure timescales have now been derived for each option.

The results of the key objectives for this study are available in Table 10-1 and Table 10-2. The water quality results presented include those parameters which are required to classify the water in terms of suitability for use as livestock drinking water (local guideline limits used).

Table 10-1 Modelling results for key objectives – water quantity

Backfilling closure option	Time to fill to quasi-static water levels (mean level)	Quasi-static water level in pit (m AMSL)	Regional groundwater level (m AMSL)	Terminal hydraulic sink or flow-through pit	Pit lake spilling	Depth to QSWL from ground surface (m)
Option 1 Complete Backfill	39 years	1045	1045	Flow-through	n/a	n/a
Option 2 Fill To Regional Groundwater level	36 years	1045	1045	Partial flow-through	No	n/a
Option 3 Concurrent backfill	153 years	1039	1045	Hydraulic sink	No	41
Option 4 No Backfill	42 years	873	1045	Hydraulic sink	No	207

Table 10-2 Modelling results for key objectives – water quality

Backfilling closure option	Water quality summary (Failure analyte (s) - exceed Livestock DWS limits)	Comments
Option 1 Complete backfill	• Fe ≈ 25 years	The water is useable for c. 25 years without treatment. Therefore, is more restrictive that Option 3. Water quality will largely remain equivalent to groundwater quality or worse over closure timescales as the pit is flow-through. The iron is in solution due to the anticipated reducing redox conditions.
Option 2 Fill to regional groundwater level	• Fe ≈ 25 years	The water is useable for c. 25 years without treatment. Therefore, is more restrictive that Option 3. Water quality will largely remain equivalent to groundwater quality or worse over closure timescales as the pit is a partial flow-through. The iron is in solution due to the anticipated reducing redox conditions.
Option 3 Concurrent backfill	• NO_3 ≈ 200 years • TDS ≈ 200 years • Se ≈ 200 years	The water is useable for c. 200 years without treatment. TDS will have a restricted use but is still viable as a resource. Therefore the water will have less restrictions on its use for a longer period of time than the other options

Backfilling closure option	Water quality summary (Failure analyte (s) - exceed Livestock DWS limits)	Comments
		However, the longer term modelling trend indicates that water quality will eventually deteriorate over an extended time due to evapoconcentration and eventually fail for most analytes.
Option 4 No Backfill	• Cd ≈ 100 years • Cl ≈ 100 years • F ≈ 50 years • Hg ≈ 50 years • Mg ≈ 100 years • Mo ≈ 50 years • NO_3 ≈ 100 years • Pb ≈ 100 years • Se ≈ 100 years • TDS ≈ 50 years	The water is useable for c. 50 years without treatment. However, the long term modelling trend indicates that water quality will deteriorate over time due to evapoconcentration and eventually fail for most analytes.

10.2 Discussion

Climate is the single most important factor on the hydrologic processes associated with Tshipi pit lake formation. In general, surface hydrologic processes (e.g. direct precipitation, evaporation, surface water runoff) are defined by regional climate. Groundwater inflows are generated from precipitation recharge and tend to buffer short-term climatic changes, but long-term climatic changes will be reflected in groundwater inflows over the long-term. The impacts of a changing climate are largely unknown but have been somewhat incorporated in the climate model as changing patterns of rainfall.

Mine closure is increasingly recognised as a whole-landscape development exercise which must consider all closure landform elements and how they will interact over time. The water quality options presented herein present strong arguments that completely backfilled & partial backfilled pit may not be the best solution to risks presented by pit lakes at mine closure when considering “short term” benefits in a water scarce area. The water quality of the hydraulic sink lake options is expected to deteriorate over time through evaporation and the consequent entrapment of solutes. Although not desirable in itself, this water quality deterioration indicates that the pit lake is functioning as it should as an evaporative ‘terminal’ sink and would better protect the surrounding groundwater environment from potentially contaminated waters resulting from the surrounding waste rock dumps and other mine facilities that may cause pollution to groundwater.

There are two scenarios modelled which will generate pit lakes, namely Option 3 and 4. Hydraulic and geochemical modelling has indicated that of the two options which generate pit lakes, the pit lake water for Option 3 (Concurrent or In-pit Dumping) produces more favourable water quality concentrations for livestock suitability, than all other options in the short term.

The final pit lake elevation at Tshipi Borwa Mine is projected to reach quasi-equilibrium level at varying heights depending on the backfilling options. The projected pit lake quasi-equilibrium elevation represents long-term equilibrium conditions and has considered occurrences of drought and floods in the future using WGEN and probabilistic climate modelling. Expectations are that it will take an extremely long time before the pit lake water levels rise to near their final equilibrium elevations for the non-backfilled options. Because the pit lake will be a sink for groundwater it is not expected to impact on regional groundwater quality which is an important long term sustainable consideration.

A benefit/liability comparative assessment for short- and long-term water use is provided in Table 10-3.

Table 10-3 Benefit/liability comparitive assessment

Backfilling closure option	Short term benefits/liabilities	Long term benefits/liabilities
Option 1 Complete backfill	Water use benefit for only 25 years before treatment Water extraction requires wells, pumps etc Wells/screens likely to clog up with Iron	Requires less treatment for long term use Flow through pit means contamination plumes released to wider groundwater system
Option 2 Fill To Regional Groundwater level	Water use benefit for only 25 years before treatment Water extraction requires wells, pumps etc. Wells/screens likely to clog up with Iron	Requires less treatment for long term use Flow through pit means contamination plumes released to wider groundwater system
Option 3 Concurrent backfill	Water use benefit for 200 years before treatment Water extraction requires much less infrastructure than option 1 & 2	Requires more treatment for long term use, but this can potentially include passive treatment (refer section 10.3 and Section 11). Hydraulic sink benefit as cone of depression captures wider pollution plumes from other mine areas and sources (WRDs etc)
Option 4 No Backfill	Water use benefit for 50 years before treatment Water extraction requires much less infrastructure than option 1 & 2	Requires most treatment for long term use. Hydraulic sink benefit as cone of depression captures wider pollution plumes from other mine areas and sources (WRDs etc)

From the assessment contained in Table 10-3, it is apparent that the beneficial use of the pit lake for water supply purposes will be limited to short term use (<100 years) before water treatment is likely to be required. In the short term, concurrent backfill offers the best water quality solution. Complete backfill of the pit may result in enhanced permeability which may enhance storage of water but water qualities are not necessarily automatically useable and that solution would also need a means of extraction (bores, screens, pumps etc). Preserving a hydraulic sink (Option 3 and 4) may also in fact be a more sustainable long term solution as water (and any pollutants contained within) will be drawn towards the pit and effectively containing them as the cone of depression has its centre at the pit. This may have more regional & widespread benefits to groundwater resources as described in Table 10-3.

It may be that there is a passive water treatment solution to the pit lake closure water quality issues in the long term. The feasibility of this (in particular floating wetlands) is discussed in Section 10.3.

10.2.1 Assumptions and caveats

- Groundwater is currently not entering the open pit. It is assumed that the mining at Mamatwan has dewatered the area and that once mining & dewatering ceases at both pits, groundwater levels will begin to rebound as predicted by groundwater modelling.
- The high nitrate in the pit water samples are nearfield bores is due to ANFO and won’t be an issue for long term closure
- An open water evaporation factor of 0.8 has been applied to the pan evaporation data.
- Historical rainfall data has been used to develop a stochastic WGEN climate model
- As Option 3 and 4 has been determined to be hydraulic sinks, Evapoconcentration will continue for ever. This means that eventually the water within the pit will become unfit for human or animal consumption without intervention.
- Water held within the pore spaces in the WRD mass is assumed to be instantaneously mixed with the pit lake water.
- It is assumed that there is an infinite supply of leachable constituents from the waste material and host geology.
- The information and results contained within the report are subject to the availability and integrity of the data sources. The potential impacts of the neighbouring Mamatwan mine was considered from a groundwater inflow and quality perspective. No other neighbouring mine (s) influence has been considered
- The GoldSim and PHREEQC modelling results contained in this report are predictive forecasts of likely future behaviour only.

10.3 Passive Treatment Options Feasibility

The modelling option (3 and 4) that includes the development of a pit lake has indicated that there may be elevated concentrations of nitrogen compounds in the upper layer of the lake over time. A future safeguard regarding the nitrogen concentrations could be to put in place a passive treatment solution to reduce nitrogen compounds in the pit water. The feasibility of using a passive treatment solution is examined such that it can lead to a potential treatment option, if required. It should be noted that water with elevated nitrogen compounds is currently being used for dust suppression at the site and therefore it may not be required to treat the nitrogen compounds in the pit lake. Notwithstanding, a passive approach for the treatment warrants discussion and is included in the following sections.

When considering the treatment of nitrogen in water using passive wetland type systems, a fundamental principle which will need to be considered in the outline design is that passive systems should not dry out completely for significant lengths of time. Therefore, there are two options which might be viable:

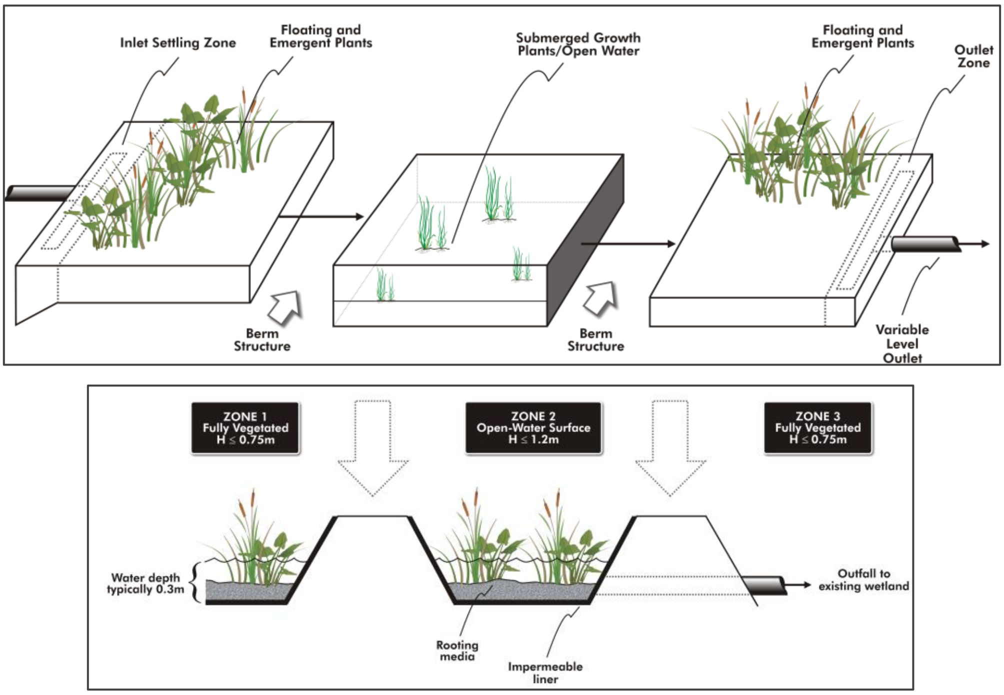
1. Surface water flow systems (potentially on waste rock beaches); and
2. Floating wetland systems.

The former might be developed along benches of the open pit but would not necessarily accommodate a rising pit lake water level over time or indeed the expected fluctuating water levels once quasi-static levels are attained, so this has been discounted and is not considered further.

10.3.1 Traditional Surface Flow Wetlands

A surface flow wetland system can incorporate a number of different treatment zones. A typical system is shown below in Figure 10-1.

Figure 10-1
Typical Surface Water Flow Wetland Treatment Layout



10.3.2 Water Budget

The annual water budget forms the basis for understanding pollutant reductions and the passive wetland area required. Assuming a constant water level in the wetland, the inflow and meteorological data are used to compute the wetland outflows:

$$Qo = Qi + A \,.\, (P - ET - I)$$

Where

A = Wetland area, m^2

ET = Evapotranspiration rate (m/d)

I = Infiltration rate (m/d)

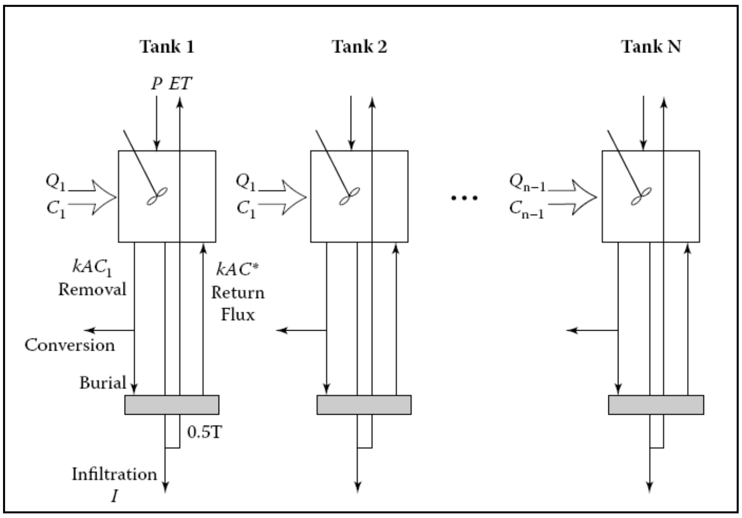
P = precipitation rate (m/d)

Q = flow rate (m^3/d)

The infiltration from the wetland will be an important consideration. A constructed system will most probably be lined with low permeability material. For a fully vegetated wetland transpiration can account for up to one half of the evapotranspiration. At this site evaporation is much higher than precipitation and therefore for this study the ET data will be multiplied by a theta value of 0.5

The pollutant mass balance for this wetland will use a cell by cell basis in accordance with the following[28]. In this model the concentrations (C_I) enters into a cell at a flow rate (Q_I) with the effluent concentration being reduce by the removal mechanisms shown.

Figure 10-2
Tank IN Series (TIS) Model For Sizing Wetland Treatment Systems (after Kadlec and Knight 2009)



The water balance results are distributed or apportioned according to the number of Tank In Series (TIS). USEPA (2000)[29] indicate that at least three cells should be used in a wetland and therefore the TIS for this preliminary sizing have been set to 3.

10.3.3 Nitrogen Treatment

The TIS model established above is carried forward using a sequential treatment for each of the 'tanks'. A first order model with a rate constant (k) is used with an associated background wetland concentration (C*). This follows the P-k-C* design model which has been used in a number of wetland designs [30] [31]

The concentration exiting the first of the tanks in series is given (assuming no pollutant from rainfall) by:

$$C_1 = \frac{Qi\ .Cin+(k\ .A1\ .C*)}{Q1+\left((\alpha ET)A1\right)+(I\ .A1)+(k\ .A1)}$$

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[28] Kadlec R.H and Wallace, S (2009) Treatment Wetlands, Second Edition, CRC Press, Taylor and Francis Group, US.

[29] US EPA (2000) Constructed Wetlands Treatment of Municipal Wastewaters, EPA 625/R-99/010 Office of Research and Development, Washington DC.

[30] Kadlec R.H and Wallace, S (2009) Treatment Wetlands, Second Edition, CRC Press, Taylor and Francis Group, US.

[31] Kadlec R.H and Knight (1996) Treatment Wetlands, First Edition, CRC Press, Taylor and Francis Group, US.

C_1 = Concentration leaving the first tank

C_{in} = Input concentration

C^* = Background concentration

k = First Order Rate coefficient

Theta (ά) = Transpiration fraction

A_1 = Area of tank

There is an interconnection between the biotransformation of the nitrogen species and a further integration of the P-k-C* is required. The wetland degradation can produce ammonium and therefore this needs to be accommodated in the design. Assuming the relatively simple nitrogen biotransformation of:

Table 10-4
Nitrogen Transformation within a Treatment Wetland

Nitrogen Controls	Organic N →	Ammoniacal N	→ Oxidise N	→ Nitrogen Gas
Wetland Processes	Ammonification		Nitrification	Denitrification

The mass balance for these become linked such that production terms for ammonification in the ammonia balance – and nitrification in the oxidise nitrogen balance are included. Therefore the outlet concentration of the nitrogen species is dictated by :

$$C_{o1} = \frac{Qin\ Coin + kA1Co*}{Q1 + (\alpha ET)A1 + IA1 + koA1}$$

$$C_{a1} = \frac{Qin\ CAin + Ka\ A1\ Ca* + ko(Co1 - Co*)}{Q1 + (\alpha ET)A1 + IA1 + KaA1}$$

$$C_{n1} = \frac{Qin\ Cnin + Ka\ A1\ Cn* + ka(Ca1 - Ca*)}{Q1 + (\alpha ET)A1 + IA1 + KnA1}$$

Where

Co = organic nitrogen concentration, mg/l

Ca = ammonia N concentration, mg/l

Cn = oxidised N concentration, mg/l

ko = organic N rate coefficient, m/d

ka = ammonia N rate coefficient, m/d

kn = oxidised N rate coefficient, m/d

The above equations are there solved sequentially to account for the potential ammonium production within the wetland.

10.3.4 Design Parameters

The equations provided thus far require a provenance that is clear and well established. The P-k-C* model requires three input parameters which have been sourced from literature. Where and when possible some of this information will be obtained from the site and the existing wetland. For example the back ground concentration of parameters within the existing wetland will be useful in establishing the ultimate treatment goals for any new wetland.

Degradation Rate Coefficients

This preliminary analysis uses rate coefficients which have been calculated from the fitting of annual data from existing wetlands by Kadlec and Wallace (2009). The data has been selected from frequency distribution of the fitted k-value using the 50 percentile of the distribution (median). The selected rate coefficients are shown below.

Table 10-5
Rate Coefficients Used In Surface Wetland Sizing

Parameter	Rate Coefficient
Organic Nitrogen	17.3 m/yr
Ammoniacal Nitrogen	14.7 m/yr
Oxidised Nitrogen	26.5 m/yr

Organic nitrogen content is estimate by undertaking a Total Kjeldahl Nitrogen content analysis and subtracting the total inorganic nitrogen content (ammonia and nitrate in this site). Currently there is no Total N analysed and therefore this will be estimated from the analyses already presented, but additional analysis would be recommended before design stage is commenced for the wetland.

It is appreciated that such first order decay rates can be site and process water specific. If possible it is recommended that treatability studies should be undertaken using bench scale testing to establish the optimum treatment rate.

10.3.5 Floating Wetlands

In addition floating wetland treatment systems can be very effective in treating nitrogen compounds[32]. Such systems are an established science which promotes:

- Nitrification & Denitrification;

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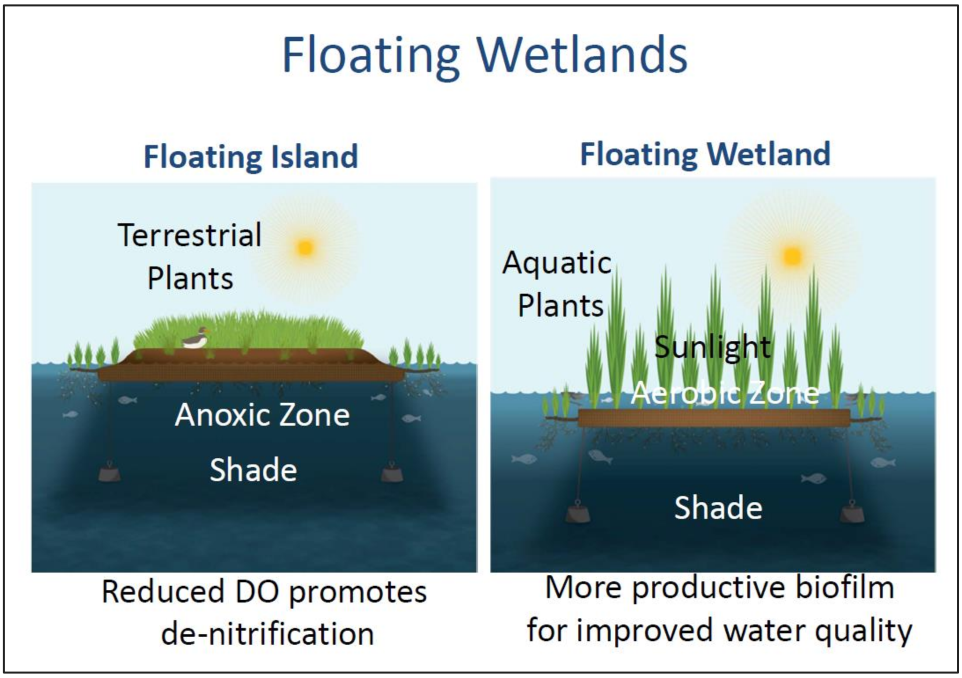
[32] https://www.chesapeakewea.org/docs/Session_1G_-_FloatingWetlandsSolutions_CaseStudies.pdf

- Biological & physical Filtration:
  – Total Suspended Solids (TSS) Filtration
  – Colloidal Particle Filtration
  – Pathogens – coliform bacteria, E coli
  – Heavy metals
- Oxygenation & photosynthesis; and
- Nutrient sequestration & plant uptake.

Therefore given the transient nature of the lake infilling, this might be a viable option but it depends on the rate of treatment.

Figure 10-3
Examples of Floating Wetlands



10.3.6 Degradation Rates

As opposed to surface flow systems, the rates used for floating wetlands are based on substance remove per unit area. For floating systems the following is quoted[33]

Table 10-6
Removal Rate Used In Floating Wetland Sizing (assuming anoxic shade)

Substance	Removal Rates (US) (Llbs per square foot per year)	Removal Rates (metric) (mg per square meter per day)

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[33] https://www.chesapeakewea.org/docs/Session_1G_-_FloatingWetlandsSolutions_CaseStudies.pdf

Substance	Removal Rates (US) (Llbs per square foot per year)	Removal Rates (metric) (mg per square meter per day)
Ammonia	0.6	69
Nitrate	0.9	104
Total Nitrogen	1.7	197

Therefore the application relies upon a load of nitrogen being predicted from the concentration and the flow rate in the lake. The latter will need to consider the velocity of the water in the lake to establish the treatment that can be realised.

10.3.7 Preliminary Calculated Nitrogen Reduction

Using the above assumptions the following reduction in nitrogen could be realised following integration of the water budget into the sizing equation. A preliminary assessment has included used site data estimates and examined the areas of wetland that might be required to reduce the nitrogen compound in the pit lake as it evolves.

Given the climate in the area I it is considered that a floating system is most realistic, however the sizing is put into context by comparing the sizing with a surface flow, traditional wetland system. To provide an estimate of wetland size, the nitrogen compounds have been taken from the existing groundwater at the site which will enter the pit. The size of the wetland is calculated based on meeting the requirements of the regulatory standards. The input parameters are shown below:

Table 10-7
Input Conditions for Wetland Sizing

Annualised Rainfall (m/d)	Annualised Evapotranspiration (m/d)	Depth of Wetland (m)	Mean Nitrate N (mg/l)	Mean Ammonia –N (mg/l)	Estimated Mean Organic – N (mg/l)	Flow Rates (m3/d)		
0.001	0.01	0.3	42	14	5	86	430	860

Table 10-8
Wetland Sizing Based on Different Flows

Wetland Type	Size Based (hectares)		
Flow Rate (m3/d)	86	430	860
Surface Flow	0.5	1.5	2
Floating	2.4	4.8	7.2

The likely area of the surface water in the pit will be between 420 000 and 1 400 000 m^2 (Option 3 and 4 respectively) at maximum extent which indicates the fraction of wetland treatment area will be relatively small assuming the flow rates used are realistic. In terms of conceptual design there could be a combination of approaches which are worth exploring:

1. Construction of a surface flow system which might be fed by solar pumps;
2. Use of surface flow system in combination with floating system; or
3. Use of surface flow system alone.

It is considered that these options are explored further as part of future design stage in the closure process if required.

10.4 Metal Treatment

There are some important aspects of the water quality which will require consideration of part of the pit lake development. The key water quality issues are:

1. The use of floating and traditional wetlands is a proven technology for reducing the nitrogen species in the pit lake water. Such systems are also well known for removing metals from water in a variety of scenarios ranging from mine drainage, landfill leachate and highway runoff.[34]
2. Heavy metals such as mercury and metalloids such as selenium have been successfully removed form water using wetland treatment technology. It should be remembered that the modelled mercury concentration is only a theoretical risk because the limit of detection was used as a source term in the groundwater (the dominant component) in the modelling. Therefore, it is equally as likely that mercury may remain below the limit of detection after 100 years.
3. Notwithstanding there are a number of studies which have shown engineered wetlands and floating wetlands can remove heavy metals from water, through the processes demonstrated diagrammatically in Figure 10-4 below.[35] For example over 50% removal of mercury has been has been removed in wetland systems and detailed studies have shown it partitions mostly into solid phase sediment, as shown in Figure 10-5 below.[36]

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[34] Kadlec R.H and Wallace, S (2009) Treatment Wetlands, Second Edition, CRC Press, Taylor and Francis Group, US.

[35] Ladislas S., C.Gérente, F.Chazarenc, J.Brisson and Y.Andrès.2015. Floating treatment wetlands for heavy metal removal in highway stormwater ponds. Ecological Engineering Vol 80, pp 85-91

[36] Mercury mass balances for the Everglades Nutrient Removal Project, 1994–1997. (From South Florida Water Management District (1999a) Everglades Consolidated Report. South Florida Water Management District, West Palm Beach, Florida.)

Figure 10-4
Metal Removal Using Floating Wetlands

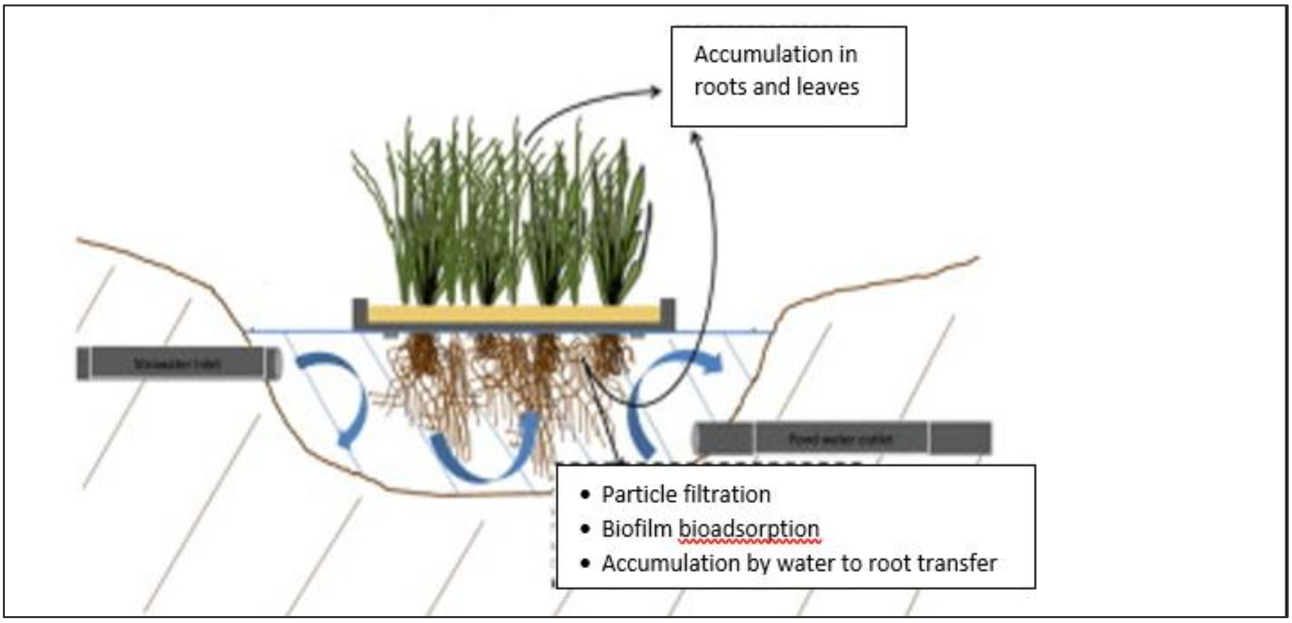
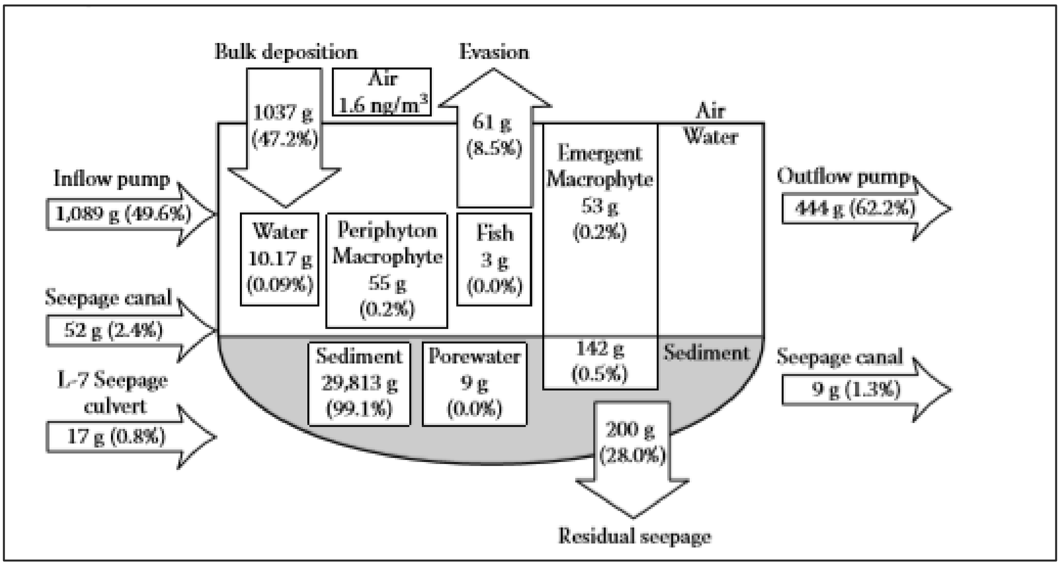


Figure 10-5
Mercury Mass Balance (1994-1997)



4. There are several studies which show selenium has also been effectively removed in wetland systems[37] were up to 89% of the selenium has been successfully removed with inflow concentrations of 20−30 μg L^{-1} decreased to <5 μg L^{-1} in the outflow. Most of the selenium was removed by immobilization into sediments and plant tissues where concentrations reached 5 and 15 mg kg^{-1}, respectively. Biological volatilization may have accounted for as much as 10−30% of the Se removed. The highest mean rates of volatilization for vegetated sites were 190, 180, and 150 μg of Se m^{-2} day^{-1} (rabbitfoot grass, cattail, and saltmarsh bulrush, respectively). Rates for the most dominant species, saltmarsh bulrush, varied during the year: the mean rates were 150, 70, and 25 μg of Se m^{-2} day^{-1} in February, June, and October, respectively.
5. Some aspects of total dissolved solids such as fluoride and nitrate can be treatment in a wetland. Nitrogen species have been discussed earlier; fluoride partitions more strongly to soils and sediments than do other main contributors to the TDS such as bromide and chloride. The Langmuir adsorption capacities of soils ranges from 100–400 mg/kg for silts and loams[38]. However, the oxyhydroxides of iron and aluminium have much higher binding capacities, 30,000–50,000 mg/kg and these are likely to be present as precipitates in the pit lake. It is also likely the fluoride would be most efficiently removed in a organic rich anaerobic system, indeed experiment with biochar have demonstrated removal rates of 1-3m^2/g.[39] Therefore whilst the chloride concentration are unlikely to be removed by the wetland, fluoride and consequently the TDS would be expected to be reduced slightly through introduction of the wetlands.

The biodiversity report for this project[40] also recommends the use of floating wetland to provide biodiversity enhancement of the pit lake. Therefore, the use of a wetland system for the longer-term management of the water quality accords with best practise in terms of treatment and biodiversity.

10.4.1 Impacts on Lake Evaporation using Wetland Treatment

The presence of vegetation retards evaporation in surface flow wetlands.[41] This is to be expected for several reasons, including shading of the surface, increased humidity near the surface, and reduction of the wind at the surface. The presence of a litter layer can create a mulching effect that reduces open water evaporation. The reported magnitude of this reduction is c. 50%, as indicated by a sample of available reduction percentages when compared to open water of: 47%[42]; and 41–48%[43]. Therefore, this would mean that the concentration of substances in the pit lake would decrease because there is effectively more dilution available in the water quality/Goldsim model.

However, this does not necessarily mean that the wetland conserves water, because wetland plant transpiration can offset this reduction. With plant transpiration offsetting reductions in open water evaporation, large surface flow wetland evapotranspiration and lake evaporation are roughly equal. Some studies report[44] this equality for a low arctic site, and a review[45] of swamps/bogs transpiration concluded

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[37] Hansen D, P. J. Duda, A.Zayed and N.Terry 1998. Selenium Removal by Constructed Wetlands: Role of Biological Volatilization. Environmental Science and Technology 32(5)

[38] Bower C.A., Hatcher J.T. (1967) Adsorption of fluoride by soils and minerals. Soil Science 103(3): 151–154

[39] Mohan D., R Sharma, V K. Singh, P Steele and C U. Pittman Jr. 2012. Fluoride Removal from Water using Bio-Char, a Green Waste, Low-Cost Adsorbent: Equilibrium Uptake and Sorption Dynamics Modeling. *Ind. Eng. Chem. Res.*, **2012**, *51* (2), pp 900–914

[40] Scientific Aquatic Services (2019) Ref: SAS 218211

[41] Kadlec R.H and Wallace, S (2009) Treatment Wetlands, Second Edition, CRC Press, Taylor and Francis Group, US.

[42] Bernatowicz S., Leszczynski S., Tyczynska S. (1976) The influence of transpiration by emergent plants on the water balance in lakes. Aquatic Botany 2: 275–288

[43] Koerselman W., Beltman B. (1988) Evapotranspiration from fens in relation to Penman's potential free water evaporation (Eo) and pan evaporation. Aquatic Botany 31: 307–320.

[44] Roulet N.T., Woo M.K. (1986) Wetland and lake evaporation in the low arctic. Arctic and Alpine Research 18: 195–200

rough equality with lakes is probably the most reasonable assumption. More recent studies have indicated that when comparing with open water evaporation, the plant type is important as some promote higher evapotranspiration than open water evaporation and some are equivalent[46].

Therefore, it is not likely that the inclusion of a wetland will dramatically change the modelling of evaporation. It is clear from the literature that the impact on evaporation is plant type, and site, specific and therefore it is recommended that a trial of wetland system is established once the pit lake has started to recover.

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[45] Linacre E.T. (1976) Swamps. In: Vegetation and Atmosphere, Volume II: Case Studies, Monteith J.L. (ed.) Academic Press: London, United Kingdom, pp. 329–347.

[46] Jiménez-Rodríguez C.D, C.Esquivel-Vargas, M.Coenders-Gerrits and M.Sasa-Marín (2019). Quantification of the Evaporation Rates from Six Types of Wetland Cover in Palo Verde National Park, Costa Rica. *Water* **2019**, *11*(4), 674

11.0 Quantitative Water Quality Modelling of a floating wetland treatment system – Option 3

At this stage, Option 3 is seen as the preferred closure option. As part of this assessment, the positive impact of the passive treatment option on the water quality in the pit lake has been made for the selected option (3). This has assumed the following:

1. A floating wetland is used in the system. A floating system has been assumed as it is relatively easy to implement and also increase in area if required due to changes in water chemistry;
2. The area required has been selected as the earliest it might be possible to apply such that the system will function. This realise upon sufficient coverage of water in the pit and enough depth to propagate the system. To this end an area of 2.4 ha has been selected. The corresponding time for the pit to reach that area has been assessed using Goldsim and the modelled water quality predicted at that point. The time from pit lake formation until wetland installation has been assumed to be 10 years.
3. Once implemented the percentage decrease in the nitrate, selenium, mercury (albeit this may not be relevant as it may not be elevated in the pit lake water for reasons described earlier) and TDS has been assessed. These percentage decreases are described in Table 11-1.

Table 11-1
Key Metal, Metalloid and Inorganic Analyte Reduction in Surface Flow Wetlands

Metal/Metalloid	Reduction in Wetland (%)
NO3	74
Se	86
Hg	50
TDS	1.5 % (due to reduction in N and F)

It is also evident that there will perhaps be a positive influence on the chemistry of the pit lake water for other water quality parameters. To make a preliminary assessment of the impact of using a wetland system, literature[47] has been searched to establish the likely reduction of other key water quality parameters. The following median reduction of metals and metalloids through surface flow wetlands has been obtained. These reductions are compiled from a global review of wetland performance and the removal rates published can be used to size surface flow systems. At this stage given that a floating system is envisaged, these removal rates will require confirming at a trial stage in the treatability – however they are a useful guide to estimating the longer-term water quality.

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[47] Kadlec R.H and S.D Wallace. 2009 Treatment Wetlands, 2nd Edition. CRC Press

Table 11-2
Typical Metal and Metalloid Reduction in Surface Flow Wetlands

Metal/Metalloid	Reduction in Wetland (%)
Al	50
As	90
B	5
Cd	79
Cu	66
Fe	78
Mn	47
Ni	34
Pb	62
Zn	68
SO4	50*
Sulfate can be reduced by sulfate reducing bacteria to 100-300 moles/m3/d in a wetland and there this reduction can be enhanced significantly under the correct conditions. In addition, this will also enhance the precipitation of insoluble metal sulfides which will also mean the metals in this table could be removed at an enhanced rate if the correct conditions exist.	

11.1 Predictive modelling water quality results

The values in Table 11-1 and Table 11-2 are used as part of the predictive water quality modelling in this section but should be viewed as a preliminary assessment. Site specific conditions may improve or reduce the reduction in the wetland and this will need to be established at treatability stages.

The results of the Goldsim & PHREEQC modelling and consequently the predicted chemistry of the pit lake are provided in Table 11-3.

Table 11-3 Predictive modelling results for a wetland included for Option 3

Analyte	Livestock DWS	10 Years		50 Years		100 Years		150 Years		200 Years	
Layer		1	2	1	2	1	2	1	2	1	2
Al	5	0.0025	0.0025	0.00035	0.00035	0.0003	0.0003	0.0003	0.0003	0.00038	0.00038
As	1	0.0027	0.00275	0.001	0.001	0.0015	0.0015	0.002	0.002	0.003	0.003
B	5	0.21	0.21	0.64	0.64	0.99	0.99	1.4	1.4	1.85	1.85
Ba		0.093	0.093	0.11	0.11	0.085	0.085	0.066	0.066	0.033	0.033

Analyte	Livestock	10 Years		50 Years		100 Years		150 Years		200 Years	
HCO_3		206	217	232	295	371	279	323	428	377	485
Ca	1000	10	10	93	92	101	101	89	89	66	66
Cd	0.01	0.0005	0.0005	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005
Cl	1500 3000	69	69	280	280	433	433	596	596	780	780
Cu	0.5 1.0	0.0013	0.0013	0.0005	0.0005	0.0007	0.0007	0.0009	0.0009	0.001	0.001
Fe	10	0.026	0.026	0.029	0.029	0.03	0.03	0.03	0.03	0.03	0.03
F	2	0.27	0.27	0.46	0.46	0.69	0.69	0.95	0.95	1.25	1.25
Hg	0.001	0.0002	0.0002	0.0007	0.0007	0.001	0.001	0.0013	0.0013	0.002	0.002
Mg	500	5.25	5.25	5.7	5.7	8.5	8.5	11	11	15	15
Mn	10	3.1E-05	3.1E-05	1.3-05	1.3E-05	2.2E-05	2.2E-05	2.13-05	2.13E-05	1.5E-05	1.5E-05
Mo	0.01	0.00012	0.00012	0.0025	0.0025	0.004	0.004	0.006	0.006	0.007	0.007
Na	2000	31	31	113	113	177	177	245	245	323	323
NO_3 as N	100	2.97	2.97	1.1	1.1	1.39	1.39	1.8	1.8	2.31	2.31
Ni	1	0.0005	0.0005	0.005	0.005	0.0075	0.0075	0.01	0.01	0.013	0.013
Pb	0.1	0.0018	0.0018	0.014	0.014	0.022	0.022	0.03	0.03	0.04	0.04
pH		8.8	8.07	8.8	7.12	8.8	7.03	8.9	7.05	8.9	7.13
Se	0.05	0.005	0.005	0.003	0.003	0.0044	0.0044	0.006	0.006	0.007	0.007
SO_4	1000	20	20	35	35	54	54	75	75	101	101
TDS	1000 2000 3000	345	356	762	825	1056	1148	1345	1450	1670	1778
V	1	0.19	0.19	0.15	0.15	0.21	0.21	0.28	0.28	0.37	0.37
Zn	20	0.016	0.016	0.013	0.013	0.018	0.018	0.024	0.024	0.037	0.037

11.2 Proposed wetland system – results discussion

The predictive modelling results indicate that the use of wetland treatment may well have a positive impact on the water quality of the pit lake in the long term. The modelling indicates that up to 200 years all analytes are below the assessed relevant quality criteria for livestock[48].

11.2.1 Comparative assessment for Option 3

Table 11-4 Comparative assessment

Analyte	Livestock DWS	200 Years		200 Years	
		No Wetland		With Wetland	
Layer		1	2	1	2
Al	5	0.00045	0.00045	0.00038	0.00038
As	1	0.025	0.025	0.003	0.003
B	5	2.17	2.17	1.85	1.85
Ba	n/a	0.033	0.033	0.033	0.033
HCO_3	n/a	415	525	377	485
Ca	1000	61	61	66	66
Cd	0.01	0.002	0.002	0.0005	0.0005
Cl	1500 3000	872	872	780	780
Cu	0.5 1.0	0.003	0.003	0.001	0.001
Fe	10	0.03	0.03	0.03	0.03
F	2	1.36	1.36	1.25	1.25
Hg*	0.001	0.002	0.002	0.002	0.002
Mg	500	32	32	15	15
Mn	10	0.000019	0.000019	1.5E-05	1.5E-05
Mo	0.01	0.008	0.008	0.007	0.007
Na	2000	360	360	323	323
NO_3 as N	100	300	300	2.31	2.31
Ni	1	0.023	0.023	0.013	0.013

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[48] *The mercury concentration is theoretical because it is not detectable in the groundwater around the site and hence the limit of detection is used in the modelling and, it may never be detectable in the pit lake water over time in any case

Analyte	Livestock	200 Years		200 Years	
Pb	0.1	0.12	0.12	0.04	0.04
pH		9	7.22	8.9	7.13
Se	0.05	0.056	0.056	0.007	0.007
SO_4	1000	224	224	101	101
TDS	1000 2000 3000	2272	2382	1670	1778
V	1	0.46	0.46	0.37	0.37
Zn	20	0.11	0.11	0.037	0.037

Table 11-4 in the previous section indicates that significant betterment of all modelled water quality parameters in a pit lake for option 3 can be achieved over time utilising a floating wetland as a mitigation measure. This is when compared to not having a wetland. In particular, for the three parameters that exceeded the Livestock DWS standards after 200 years for the no-wetland option; these are Nitrate, TDS and Selenium.

As stated previously, mine closure is a whole-landscape development exercise which must consider all closure landform, engineering and environmental elements and how they will interact over time not just the water quality and quantity. The water quality of the hydraulic sink lake Option 3, even with a wetland as mitigation for a 200 years period described herein, is still expected to deteriorate over time through evaporation and the consequent entrapment of solutes.

Engineered wetland systems require ongoing maintenance to function correctly. However, as far as capitalising on an opportunity to use water, in a water scarce region for Livestock from an open pit lake is perhaps a viable option. Creating and managing a pit lake rather than backfilling will have additional groundwater benefits by creating a groundwater hydraulic sink. However, It should be stressed that a provision in the closure planning process needs to be made for the pit lake when the water quality reaches a water quality standard which renders it not fit for purpose.

12.0 Water abstractions comparison

If water is to be utilised as a resource after closure of the pits, it should be considered that the mechanism for water abstraction will differ depending on whether a pit lake is created for Option 3 or the pit backfilled as for Option 1.

12.1.1 Option 1 – Complete backfill water abstractions

In this closure scenario it would be required that a groundwater abstraction well is drilled and installed following the backfilling of the pit, alternatively a abstraction well could be installed during backfilling. The well would be drilled using either cable tool or rotary techniques, either of which are likely to require the use of advanced casing during drilling and installation due to the unconsolidated nature of the backfilled material.

The dimensions of the well would be dependent upon the hydrogeological conditions of the backfill material, the required yield of the well and the required pumped head but would typically range between 40 cm and 90 cm diameter to allow for the installation of well screen of between 5 cm and 40 cm diameter.

A typical installation is presented in Figure 12-1.

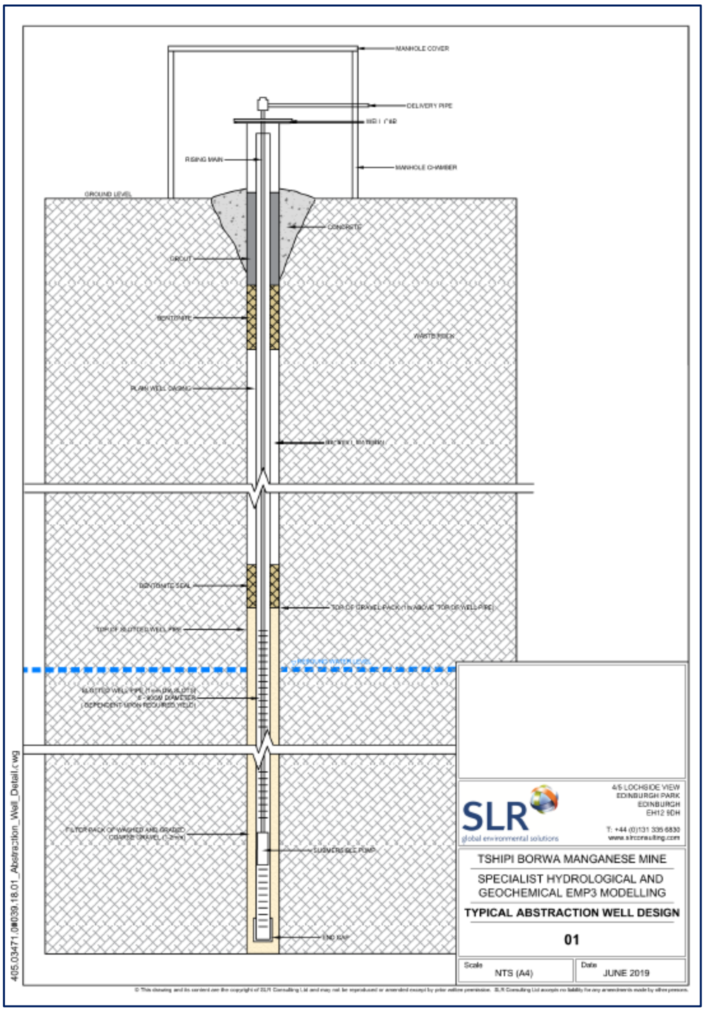

Figure 12-1 typical abstraction well design

To allow for suitable well design it would be proposed that test boreholes are drilled following backfilling of the site to allow for permeability testing of the material to estimate potential yields and to obtain site specific permeabilities to allow for estimates of the appropriate well diameter, slotted screen slot size and suitable gravel pack dimensions.

12.1.2 Option 3 – Pit lake water abstractions

In Option 3 scenario it would be recommended that water abstraction is provided through the use of submersible pumps which would be installed on floating Platform on the water surface. This will allow them to rise and fall with water levels within the pit lake, a typical arrangement is presented in Figure 12-2.

The pumps would be powered via either electric or diesel generator located above the predicted rebound water level within the void. The pump specification required would be dependent upon the head and yield required.

Figure 12-2 Floating submersible pump arrangement on an open water surface

Any water abstraction units will require ongoing monitoring and maintenance.

13.0 Recommendations

Any wetland system should be bench tested in the very first instance. Then as the water enters the pit and the lake starts to form, there will be an opportunity to trial the use of different floating wetland systems once a successful bench test has been completed. The design and implementation of a trial should consider the native vegetation and be established in accordance with international best practise. This may also present an opportunity to engage with the local community to establish the initial maintenance scheme (s) for the wetland system going forwards.

14.0 REFERENCES

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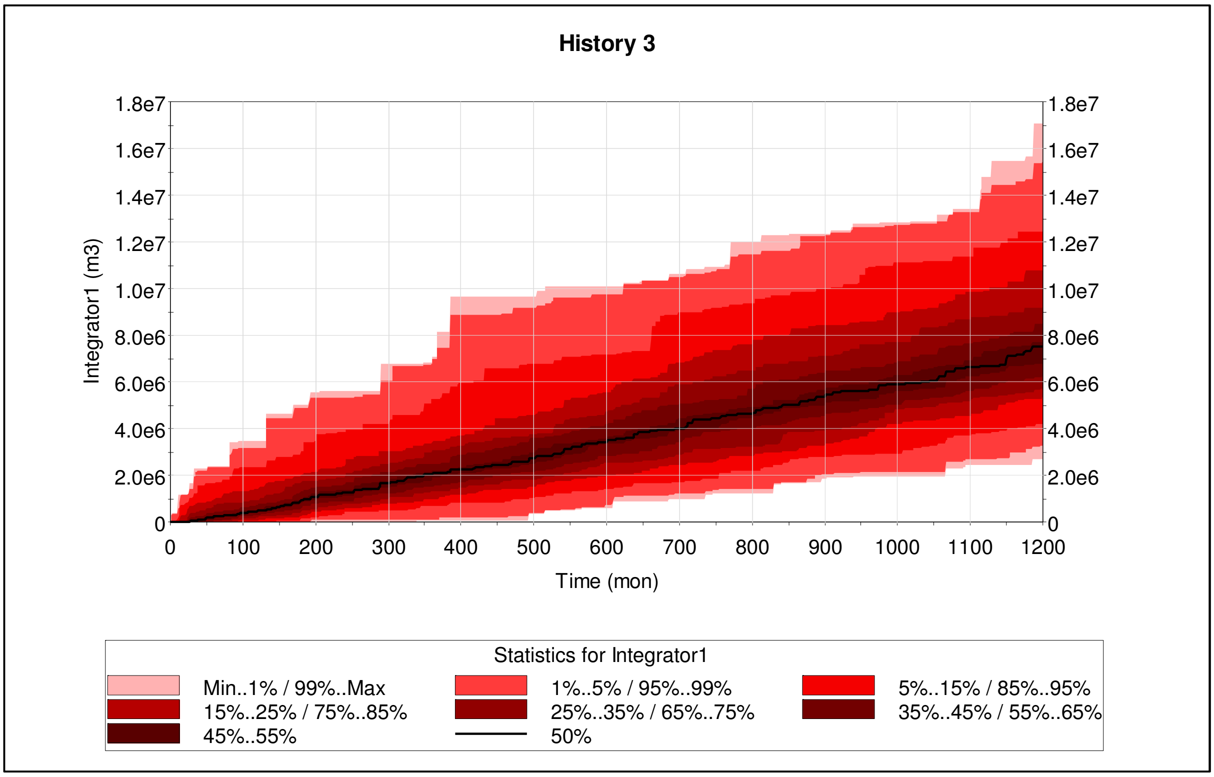
- WGEN: A Model for Generating Daily Weather Variables By C. W. Richardson and D. A. Wright United States Department of Agriculture Agriculture Research Service ARS-8, August 1984
- Tshipi Borwa Mine Stormwater Management and Water Balance for EMPr. SLR Project No.: 710.20029.00011. July2017

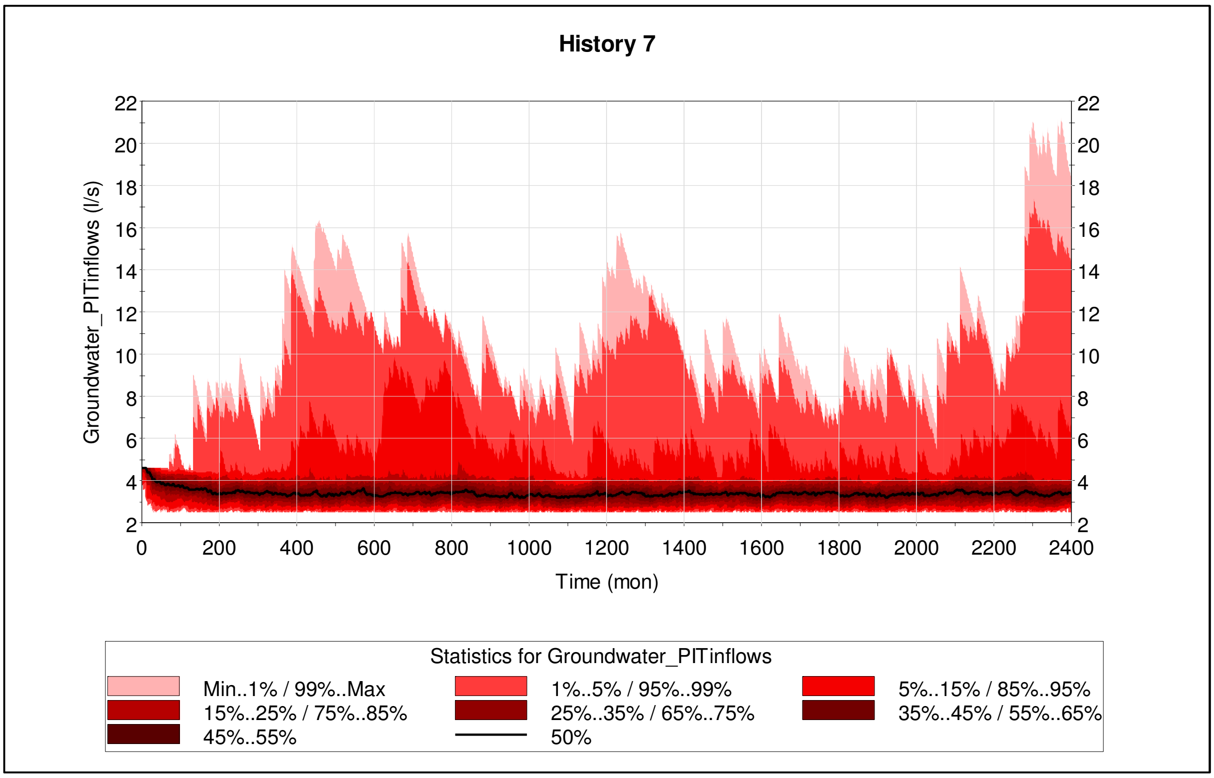
APPENDIX 01: EXAMPLE OF GOLDSIM OUTPUT

Option 4 - No Backfill (mean results for pit lake elevation) over 200 years

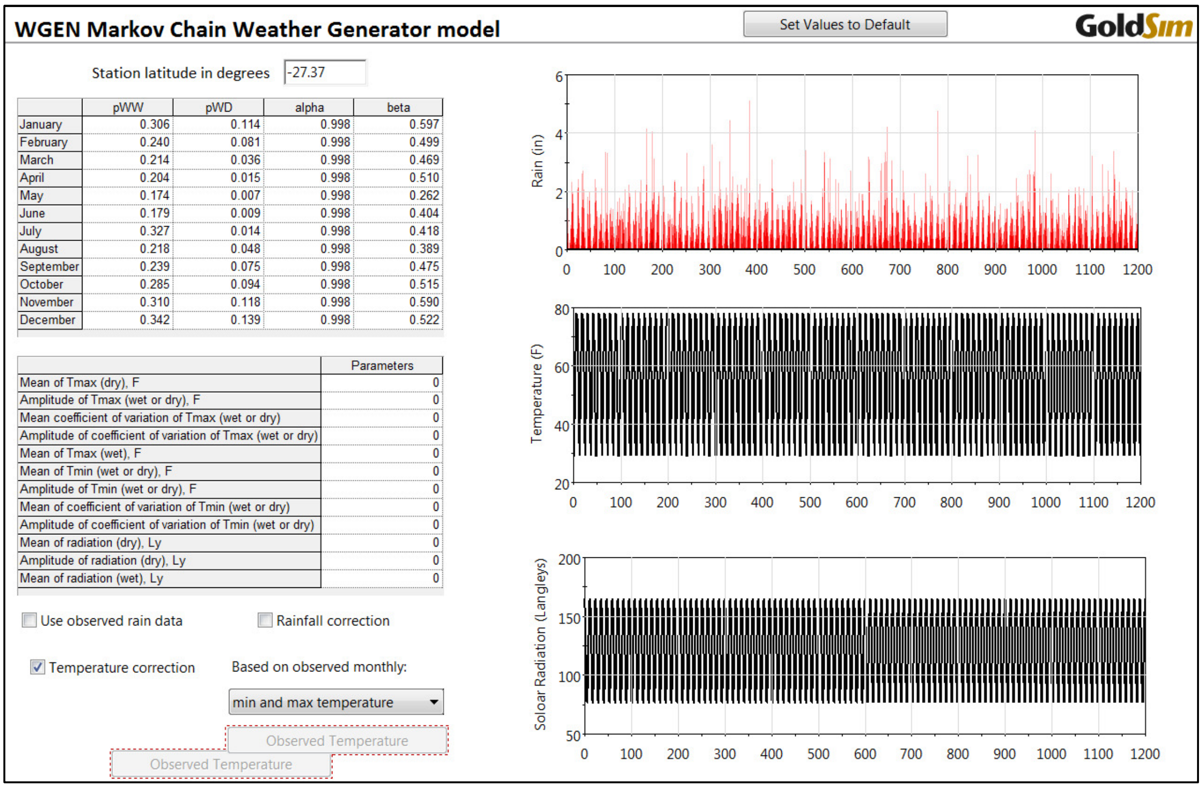
Option 1 – Stochastic variations in storm water contributions (Integrated) over 100 years



Option 4 – stochastic variations in groundwater inflows over 200 years



WGEN weather generator model output



WGEN Markov Chain Weather Generator model

Station latitude in degrees -27.37

	pWW	pWD	alpha	beta
January	0.306	0.114	0.998	0.597
February	0.240	0.081	0.998	0.499
March	0.214	0.036	0.998	0.469
April	0.204	0.015	0.998	0.510
May	0.174	0.007	0.998	0.262
June	0.179	0.009	0.998	0.404
July	0.327	0.014	0.998	0.418
August	0.218	0.048	0.998	0.389
September	0.239	0.075	0.998	0.475
October	0.285	0.094	0.998	0.515
November	0.310	0.118	0.998	0.590
December	0.342	0.139	0.998	0.522

	Parameters
Mean of Tmax (dry), F	0
Amplitude of Tmax (wet or dry), F	0
Mean coefficient of variation of Tmax (wet or dry)	0
Amplitude of coefficient of variation of Tmax (wet or dry)	0
Mean of Tmax (wet), F	0
Mean of Tmin (wet or dry), F	0
Amplitude of Tmin (wet or dry), F	0
Mean of coefficient of variation of Tmin (wet or dry)	0
Amplitude of coefficient of variation of Tmin (wet or dry)	0
Mean of radiation (dry), Ly	0
Amplitude of radiation (dry), Ly	0
Mean of radiation (wet), Ly	0

☐ Use observed rain data ☐ Rainfall correction

☑ Temperature correction Based on observed monthly:

min and max temperature ▾

Observed Temperature

Observed Temperature

APPENDIX 02: EXAMPLE OF PHREEQC OUTPUT

```
   Input file: C:\Users\jrobinson\Documents\Tshipi Study\PHREEQ\Option 1 - Inpit Filling
\Tshipi_Layering_Option1_50 Years.pqi
  Output file: C:\Users\jrobinson\Documents\Tshipi Study\PHREEQ\Option 1 - Inpit Filling
\Tshipi_Layering_Option1_50 Years.pqo
Database file: C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.3-10424\database
\llnl.dat

------------------
Reading data base.
------------------

      LLNL_AQUEOUS_MODEL_PARAMETERS
      NAMED_EXPRESSIONS
      SOLUTION_MASTER_SPECIES
      SOLUTION_SPECIES
      PHASES
      EXCHANGE_MASTER_SPECIES
      EXCHANGE_SPECIES
      SURFACE_MASTER_SPECIES
      SURFACE_SPECIES
      RATES
      END
------------------------------------
Reading input data for simulation 1.
------------------------------------

      DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.3.3-10424\database
\llnl.dat
      SOLUTION 1 Pit Chemistry after 50 Years Before Layering
          temp      25
          pH
          pe        12
          redox     pe
          units     mg/l
          density   1
          Alkalinity  476
          Al        0.077
          As        0.0077
          B         0.63
          Ba        0.105
          C(4)      421
          Ca        178
          Cd        0.00076
          Cl        272
          Cu        0.0011
          F         0.4
          Fe        0.16
          Hg        0.00064
          Mg        10.6
          Mn        0.1
          Mo        0.002
          N(5)      2.95
          Na        108
          Ni        0.0076
          Pb        0.037
          S(6)      62.5
          Se        0.017
          V         0.185
          Zn        0.033
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Inpitfilling: Layer 2 After 50 Years
          Fe(OH)3   0 10 precipitate_only
          Manganite 0 10 precipitate_only
          Gibbsite  0 10 precipitate_only
          Barite    0 10 precipitate_only
          Calcite   0 10 precipitate_only
          Gypsum    0 10 precipitate_only
      SAVE SOLUTION 1
```

```
      END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.     Pit Chemistry after 50 Years Before Layering


pH will be adjusted to obtain desired alkalinity.

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                2.861e-06   2.861e-06
      Alkalinity        9.537e-03   9.537e-03
      As                1.030e-07   1.030e-07
      B                 5.842e-05   5.842e-05
      Ba                7.665e-07   7.665e-07
      C(4)              6.919e-03   6.919e-03
      Ca                4.453e-03   4.453e-03
      Cd                6.778e-09   6.778e-09
      Cl                7.692e-03   7.692e-03
      Cu                1.735e-08   1.735e-08
      F                 2.111e-05   2.111e-05
      Fe                2.872e-06   2.872e-06
      Hg                3.199e-09   3.199e-09
      Mg                4.372e-04   4.372e-04
      Mn                1.825e-06   1.825e-06
      Mo                2.090e-08   2.090e-08
      N(5)              2.111e-04   2.111e-04
      Na                4.710e-03   4.710e-03
      Ni                1.298e-07   1.298e-07
      Pb                1.790e-07   1.790e-07
      S(6)              6.524e-04   6.524e-04
      Se                2.158e-07   2.158e-07
      V                 3.641e-06   3.641e-06
      Zn                5.059e-07   5.059e-07

----------------------------Description of solution----------------------------

                                       pH  =   9.431      Adjust alkalinity
                                       pe  =  12.000
                        Activity of water  =   0.991
                           Ionic strength  =   1.698e-02
                       Mass of water (kg)  =   1.000e+00
                       Total CO2 (mol/kg)  =   6.919e-03
                         Temperature (°C)  =  25.00
                  Electrical balance (eq)  =  -4.261e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  = -16.71
                               Iterations  =  39
                                  Total H  = 1.110552e+02
                                  Total O  = 5.659455e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             2.936e-05   2.574e-05    -4.532    -4.589    -0.057     (0)
   H+              4.137e-10   3.709e-10    -9.383    -9.431    -0.047      0.00
   H2O             5.553e+01   9.907e-01     1.744    -0.004     0.000     18.07
Al            2.861e-06
   AlO2-           2.856e-06   2.510e-06    -5.544    -5.600    -0.056     (0)
   HAlO2           2.717e-09   2.717e-09    -8.566    -8.566     0.000     (0)
   NaAlO2          1.962e-09   1.962e-09    -8.707    -8.707     0.000     (0)
   Al(OH)2+        7.881e-13   6.925e-13   -12.103   -12.160    -0.056     (0)
   AlOH+2          1.865e-16   1.116e-16   -15.729   -15.952    -0.223     (0)
```

```
   AlF2+            5.580e-18   4.902e-18   -17.253   -17.310    -0.056     (0)
   AlF+2            1.132e-18   6.778e-19   -17.946   -18.169    -0.223     (0)
   AlF3             1.121e-18   1.121e-18   -17.950   -17.950     0.000     (0)
   Al+3             1.009e-20   3.731e-21   -19.996   -20.428    -0.432     (0)
   AlF4-            5.824e-21   5.117e-21   -20.235   -20.291    -0.056     (0)
   AlSO4+           1.414e-21   1.242e-21   -20.850   -20.906    -0.056     (0)
   Al(SO4)2-        3.572e-23   3.139e-23   -22.447   -22.503    -0.056     (0)
   Al2(OH)2+4       1.476e-29   2.027e-30   -28.831   -29.693    -0.862     (0)
   Al3(OH)4+5       7.355e-37   3.482e-38   -36.133   -37.458    -1.325     (0)
   Al13O4(OH)24+7    0.000e+00   0.000e+00   -60.029   -62.626    -2.597     (0)
As(-3)           0.000e+00
   AsH3             0.000e+00   0.000e+00  -206.793  -206.793     0.000     (0)
As(3)            0.000e+00
   H2AsO3-          0.000e+00   0.000e+00   -73.058   -73.115    -0.056     (0)
   AsO2-            0.000e+00   0.000e+00   -73.074   -73.130    -0.056     (0)
   HAsO2            0.000e+00   0.000e+00   -73.269   -73.269     0.000     (0)
   As(OH)3          0.000e+00   0.000e+00   -73.332   -73.332     0.000     (0)
   AsO2OH-2         0.000e+00   0.000e+00   -74.467   -74.694    -0.227     (0)
As(5)            1.030e-07
   AsO3F-2          1.030e-07   6.110e-08    -6.987    -7.214    -0.227     (0)
   HAsO3F-          1.915e-11   1.683e-11   -10.718   -10.774    -0.056     (0)
   HAsO4-2          1.430e-40   0.000e+00   -39.845   -40.072    -0.227     (0)
   AsO4-3           0.000e+00   0.000e+00   -41.720   -42.232    -0.511     (0)
   H2AsO4-          0.000e+00   0.000e+00   -42.666   -42.722    -0.056     (0)
   H3AsO4           0.000e+00   0.000e+00   -49.907   -49.907     0.000     (0)
B(-5)            0.000e+00
   BH4-             0.000e+00   0.000e+00  -231.735  -231.791    -0.056     (0)
B(3)             5.842e-05
   BO2-             3.364e-05   2.956e-05    -4.473    -4.529    -0.056     (0)
   B(OH)3           2.025e-05   2.025e-05    -4.693    -4.693     0.000     (0)
   CaB(OH)4+        3.741e-06   3.287e-06    -5.427    -5.483    -0.056     (0)
   MgB(OH)4+        5.513e-07   4.843e-07    -6.259    -6.315    -0.056     (0)
   NaB(OH)4         2.354e-07   2.354e-07    -6.628    -6.628     0.000     (0)
   BaB(OH)4+        3.968e-10   3.486e-10    -9.401    -9.458    -0.056     (0)
   BF2(OH)2-        1.180e-17   1.037e-17   -16.928   -16.984    -0.056     (0)
   B2O(OH)5-        2.599e-19   2.284e-19   -18.585   -18.641    -0.056     (0)
   BF3OH-           3.424e-25   3.009e-25   -24.465   -24.522    -0.056     (0)
   BF4-             1.544e-34   1.356e-34   -33.811   -33.868    -0.056     (0)
Ba               7.665e-07
   Ba+2             6.749e-07   4.077e-07    -6.171    -6.390    -0.219     (0)
   BaCO3            8.952e-08   8.952e-08    -7.048    -7.048     0.000     (0)
   BaCl+            1.046e-09   9.187e-10    -8.981    -9.037    -0.056     (0)
   BaNO3+           6.750e-10   5.931e-10    -9.171    -9.227    -0.056     (0)
   BaB(OH)4+        3.968e-10   3.486e-10    -9.401    -9.458    -0.056     (0)
   BaOH+            4.200e-11   3.690e-11   -10.377   -10.433    -0.056     (0)
   BaF+             5.808e-12   5.103e-12   -11.236   -11.292    -0.056     (0)
C(4)             6.919e-03
   HCO3-            4.276e-03   3.757e-03    -2.369    -2.425    -0.056     (0)
   CaCO3            1.673e-03   1.673e-03    -2.777    -2.777     0.000     (0)
   CO3-2            7.507e-04   4.495e-04    -3.125    -3.347    -0.223     (0)
   MgCO3            9.456e-05   9.456e-05    -4.024    -4.024     0.000     (0)
   CaHCO3+          8.139e-05   7.151e-05    -4.089    -4.146    -0.056     (0)
   NaHCO3           2.203e-05   2.203e-05    -4.657    -4.657     0.000     (0)
   MgHCO3+          9.879e-06   8.680e-06    -5.005    -5.061    -0.056     (0)
   NaCO3-           7.336e-06   6.446e-06    -5.135    -5.191    -0.056     (0)
   CO2              3.249e-06   3.263e-06    -5.488    -5.486     0.002     (0)
   PbCO3            1.121e-07   1.121e-07    -6.951    -6.951     0.000     (0)
   BaCO3            8.952e-08   8.952e-08    -7.048    -7.048     0.000     (0)
   Pb(CO3)2-2       5.932e-08   3.518e-08    -7.227    -7.454    -0.227     (0)
   ZnCO3            4.413e-08   4.413e-08    -7.355    -7.355     0.000     (0)
   Cu(CO3)2-2       9.412e-09   5.582e-09    -8.026    -8.253    -0.227     (0)
   CuCO3            6.972e-09   6.972e-09    -8.157    -8.157     0.000     (0)
   ZnHCO3+          1.289e-09   1.132e-09    -8.890    -8.946    -0.056     (0)
   Cd(CO3)2-2       7.947e-10   4.713e-10    -9.100    -9.327    -0.227     (0)
   CuCO3(OH)2-2     7.131e-10   4.229e-10    -9.147    -9.374    -0.227     (0)
   CdCO3            3.949e-10   3.949e-10    -9.404    -9.404     0.000     (0)
   CdHCO3+          1.124e-10   9.874e-11    -9.949   -10.006    -0.056     (0)
   MnCO3            5.923e-13   5.923e-13   -12.227   -12.227     0.000     (0)
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   MnHCO3+          1.226e-15   1.077e-15   -14.912   -14.968    -0.056     (0)
   FeCO3+           2.523e-16   2.217e-16   -15.598   -15.654    -0.056     (0)
   FeCO3            2.273e-20   2.273e-20   -19.643   -19.643     0.000     (0)
   FeHCO3+          1.999e-21   1.756e-21   -20.699   -20.755    -0.056     (0)
Ca            4.453e-03
   Ca+2             2.613e-03   1.606e-03    -2.583    -2.794    -0.211     (0)
   CaCO3            1.673e-03   1.673e-03    -2.777    -2.777     0.000     (0)
   CaHCO3+          8.139e-05   7.151e-05    -4.089    -4.146    -0.056     (0)
   CaSO4            7.635e-05   7.635e-05    -4.117    -4.117     0.000     (0)
   CaB(OH)4+        3.741e-06   3.287e-06    -5.427    -5.483    -0.056     (0)
   CaCl+            2.602e-06   2.287e-06    -5.585    -5.641    -0.056     (0)
   CaNO3+           1.678e-06   1.474e-06    -5.775    -5.831    -0.056     (0)
   CaOH+            6.897e-07   6.060e-07    -6.161    -6.218    -0.056     (0)
   CaF+             1.688e-07   1.483e-07    -6.773    -6.829    -0.056     (0)
   CaCl2            1.806e-08   1.806e-08    -7.743    -7.743     0.000     (0)
Cd            6.778e-09
   CdCl+            3.228e-09   2.836e-09    -8.491    -8.547    -0.056     (0)
   Cd+2             1.375e-09   8.310e-10    -8.862    -9.080    -0.219     (0)
   Cd(CO3)2-2       7.947e-10   4.713e-10    -9.100    -9.327    -0.227     (0)
   Cd(OH)Cl         5.504e-10   5.504e-10    -9.259    -9.259     0.000     (0)
   CdCO3            3.949e-10   3.949e-10    -9.404    -9.404     0.000     (0)
   CdOH+            2.125e-10   1.867e-10    -9.673    -9.729    -0.056     (0)
   CdHCO3+          1.124e-10   9.874e-11    -9.949   -10.006    -0.056     (0)
   CdCl2            8.259e-11   8.259e-11   -10.083   -10.083     0.000     (0)
   Cd(OH)2          2.709e-11   2.709e-11   -10.567   -10.567     0.000     (0)
   CdSO4            2.745e-13   2.745e-13   -12.561   -12.561     0.000     (0)
   CdCl3-           1.620e-13   1.423e-13   -12.791   -12.847    -0.056     (0)
   CdSeO4           1.981e-14   1.981e-14   -13.703   -13.703     0.000     (0)
   Cd(OH)3-         9.349e-15   8.214e-15   -14.029   -14.085    -0.056     (0)
   Cd2OH+3          2.367e-18   7.600e-19   -17.626   -18.119    -0.493     (0)
   Cd(OH)4-2        3.335e-19   1.978e-19   -18.477   -18.704    -0.227     (0)
   Cd4(OH)4+4       0.000e+00   0.000e+00  -359.879  -360.741    -0.862     (0)
Cl(-1)        7.692e-03
   Cl-              7.683e-03   6.717e-03    -2.114    -2.173    -0.058     (0)
   NaCl             4.839e-06   4.839e-06    -5.315    -5.315     0.000     (0)
   CaCl+            2.602e-06   2.287e-06    -5.585    -5.641    -0.056     (0)
   MgCl+            1.187e-06   1.043e-06    -5.926    -5.982    -0.056     (0)
   CaCl2            1.806e-08   1.806e-08    -7.743    -7.743     0.000     (0)
   Zn(OH)Cl         6.027e-09   6.027e-09    -8.220    -8.220     0.000     (0)
   CdCl+            3.228e-09   2.836e-09    -8.491    -8.547    -0.056     (0)
   BaCl+            1.046e-09   9.187e-10    -8.981    -9.037    -0.056     (0)
   Cd(OH)Cl         5.504e-10   5.504e-10    -9.259    -9.259     0.000     (0)
   ZnCl+            1.502e-10   1.319e-10    -9.823    -9.880    -0.056     (0)
   CdCl2            8.259e-11   8.259e-11   -10.083   -10.083     0.000     (0)
   NiCl+            6.044e-11   5.310e-11   -10.219   -10.275    -0.056     (0)
   PbCl+            1.369e-11   1.203e-11   -10.864   -10.920    -0.056     (0)
   ZnCl2            1.035e-12   1.035e-12   -11.985   -11.985     0.000     (0)
   HCl              5.595e-13   5.595e-13   -12.252   -12.252     0.000     (0)
   PbCl2            3.075e-13   3.075e-13   -12.512   -12.512     0.000     (0)
   CdCl3-           1.620e-13   1.423e-13   -12.791   -12.847    -0.056     (0)
   CuCl+            3.401e-14   2.988e-14   -13.468   -13.525    -0.056     (0)
   ZnCl3-           4.371e-15   3.840e-15   -14.359   -14.416    -0.056     (0)
   PbCl3-           1.179e-15   1.036e-15   -14.928   -14.985    -0.056     (0)
   MnCl+            6.128e-16   5.384e-16   -15.213   -15.269    -0.056     (0)
   ZnCl4-2          3.297e-16   1.955e-16   -15.482   -15.709    -0.227     (0)
   CuCl2            1.057e-16   1.057e-16   -15.976   -15.976     0.000     (0)
   PbCl4-2          7.458e-18   4.423e-18   -17.127   -17.354    -0.227     (0)
   MnCl3-           6.040e-21   5.307e-21   -20.219   -20.275    -0.056     (0)
   CuCl2-           3.029e-21   2.661e-21   -20.519   -20.575    -0.056     (0)
   CuCl3-2          1.936e-22   1.148e-22   -21.713   -21.940    -0.227     (0)
   FeCl+            4.960e-24   4.358e-24   -23.304   -23.361    -0.056     (0)
   FeCl2+           5.915e-25   5.197e-25   -24.228   -24.284    -0.056     (0)
   FeCl+2           1.596e-25   9.558e-26   -24.797   -25.020    -0.223     (0)
   CuCl4-2          1.509e-25   8.949e-26   -24.821   -25.048    -0.227     (0)
   FeCl2            1.571e-28   1.571e-28   -27.804   -27.804     0.000     (0)
   FeCl4-2          3.453e-32   2.048e-32   -31.462   -31.689    -0.227     (0)
   FeCl4-           3.209e-32   2.819e-32   -31.494   -31.550    -0.056     (0)
Cl(1)         4.341e-18
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   ClO-            4.289e-18   3.768e-18   -17.368   -17.424    -0.056     (0)
   HClO            5.183e-20   5.183e-20   -19.285   -19.285     0.000     (0)
Cl(3)         3.067e-26
   ClO2-           3.067e-26   2.695e-26   -25.513   -25.569    -0.056     (0)
   HClO2           1.478e-32   1.478e-32   -31.830   -31.830     0.000     (0)
Cl(5)         1.565e-20
   ClO3-           1.565e-20   1.371e-20   -19.806   -19.863    -0.057     (0)
   PbClO3+         5.824e-31   5.117e-31   -30.235   -30.291    -0.056     (0)
   Pb(ClO3)2       0.000e+00   0.000e+00   -50.446   -50.446     0.000     (0)
Cl(7)         3.974e-19
   ClO4-           3.974e-19   3.483e-19   -18.401   -18.458    -0.057     (0)
   ZnClO4+         8.768e-26   7.704e-26   -25.057   -25.113    -0.056     (0)
Cu(1)         4.235e-21
   CuCl2-          3.029e-21   2.661e-21   -20.519   -20.575    -0.056     (0)
   Cu+             1.013e-21   8.902e-22   -20.994   -21.050    -0.056     (0)
   CuCl3-2         1.936e-22   1.148e-22   -21.713   -21.940    -0.227     (0)
Cu(2)         1.735e-08
   Cu(CO3)2-2      9.412e-09   5.582e-09    -8.026    -8.253    -0.227     (0)
   CuCO3           6.972e-09   6.972e-09    -8.157    -8.157     0.000     (0)
   CuCO3(OH)2-2    7.131e-10   4.229e-10    -9.147    -9.374    -0.227     (0)
   CuOH+           2.550e-10   2.241e-10    -9.593    -9.650    -0.056     (0)
   Cu+2            2.646e-12   1.626e-12   -11.577   -11.789    -0.211     (0)
   CuSO4           1.212e-13   1.212e-13   -12.916   -12.916     0.000     (0)
   CuO2-2          5.050e-14   2.995e-14   -13.297   -13.524    -0.227     (0)
   CuCl+           3.401e-14   2.988e-14   -13.468   -13.525    -0.056     (0)
   CuF+            5.330e-16   4.683e-16   -15.273   -15.330    -0.056     (0)
   CuCl2           1.057e-16   1.057e-16   -15.976   -15.976     0.000     (0)
   CuCl4-2         1.509e-25   8.949e-26   -24.821   -25.048    -0.227     (0)
F             2.111e-05
   F-              2.073e-05   1.817e-05    -4.683    -4.741    -0.057     (0)
   CaF+            1.688e-07   1.483e-07    -6.773    -6.829    -0.056     (0)
   AsO3F-2         1.030e-07   6.110e-08    -6.987    -7.214    -0.227     (0)
   MgF+            9.926e-08   8.721e-08    -7.003    -7.059    -0.056     (0)
   NaF             7.965e-09   7.965e-09    -8.099    -8.099     0.000     (0)
   HAsO3F-         1.915e-11   1.683e-11   -10.718   -10.774    -0.056     (0)
   HF              1.034e-11   1.034e-11   -10.985   -10.985     0.000     (0)
   BaF+            5.808e-12   5.103e-12   -11.236   -11.292    -0.056     (0)
   ZnF+            3.415e-12   3.001e-12   -11.467   -11.523    -0.056     (0)
   PbF+            8.641e-15   7.592e-15   -14.063   -14.120    -0.056     (0)
   CuF+            5.330e-16   4.683e-16   -15.273   -15.330    -0.056     (0)
   HF2-            5.181e-17   4.553e-17   -16.286   -16.342    -0.056     (0)
   MnF+            2.095e-17   1.841e-17   -16.679   -16.735    -0.056     (0)
   BF2(OH)2-       1.180e-17   1.037e-17   -16.928   -16.984    -0.056     (0)
   AlF2+           5.580e-18   4.902e-18   -17.253   -17.310    -0.056     (0)
   AlF+2           1.132e-18   6.778e-19   -17.946   -18.169    -0.223     (0)
   AlF3            1.121e-18   1.121e-18   -17.950   -17.950     0.000     (0)
   PbF2            8.404e-19   8.404e-19   -18.076   -18.076     0.000     (0)
   AlF4-           5.824e-21   5.117e-21   -20.235   -20.291    -0.056     (0)
   VO2F            6.364e-22   6.364e-22   -21.196   -21.196     0.000     (0)
   H2F2            2.661e-22   2.661e-22   -21.575   -21.575     0.000     (0)
   FeF+2           3.886e-23   2.327e-23   -22.410   -22.633    -0.223     (0)
   FeF2+           7.785e-24   6.840e-24   -23.109   -23.165    -0.056     (0)
   VO2F2-          3.796e-24   3.335e-24   -23.421   -23.477    -0.056     (0)
   FeF+            4.219e-25   3.707e-25   -24.375   -24.431    -0.056     (0)
   BF3OH-          3.424e-25   3.009e-25   -24.465   -24.522    -0.056     (0)
   BF4-            1.544e-34   1.356e-34   -33.811   -33.868    -0.056     (0)
   VOF+            3.691e-35   3.243e-35   -34.433   -34.489    -0.056     (0)
   VOF2            3.550e-37   3.550e-37   -36.450   -36.450     0.000     (0)
Fe(2)         2.710e-20
   FeCO3           2.273e-20   2.273e-20   -19.643   -19.643     0.000     (0)
   FeHCO3+         1.999e-21   1.756e-21   -20.699   -20.755    -0.056     (0)
   Fe+2            1.449e-21   8.906e-22   -20.839   -21.050    -0.211     (0)
   FeOH+           8.563e-22   7.524e-22   -21.067   -21.124    -0.056     (0)
   FeSO4           4.594e-23   4.594e-23   -22.338   -22.338     0.000     (0)
   Fe(OH)2         1.596e-23   1.596e-23   -22.797   -22.797     0.000     (0)
   FeCl+           4.960e-24   4.358e-24   -23.304   -23.361    -0.056     (0)
   Fe(OH)3-        1.932e-24   1.698e-24   -23.714   -23.770    -0.056     (0)
   FeF+            4.219e-25   3.707e-25   -24.375   -24.431    -0.056     (0)
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   FeCl2           1.571e-28   1.571e-28   -27.804   -27.804     0.000     (0)
   Fe(OH)4-2       7.646e-30   4.535e-30   -29.117   -29.343    -0.227     (0)
   FeCl4-2         3.453e-32   2.048e-32   -31.462   -31.689    -0.227     (0)
Fe(3)         2.872e-06
   Fe(OH)3         1.628e-06   1.628e-06    -5.788    -5.788     0.000     (0)
   Fe(OH)4-        1.243e-06   1.092e-06    -5.906    -5.962    -0.056     (0)
   Fe(OH)2+        1.483e-09   1.303e-09    -8.829    -8.885    -0.056     (0)
   FeOH+2          2.460e-15   1.473e-15   -14.609   -14.832    -0.223     (0)
   FeCO3+          2.523e-16   2.217e-16   -15.598   -15.654    -0.056     (0)
   Fe+3            2.310e-22   8.539e-23   -21.636   -22.069    -0.432     (0)
   FeF+2           3.886e-23   2.327e-23   -22.410   -22.633    -0.223     (0)
   FeF2+           7.785e-24   6.840e-24   -23.109   -23.165    -0.056     (0)
   FeSO4+          3.060e-24   2.689e-24   -23.514   -23.570    -0.056     (0)
   FeCl2+          5.915e-25   5.197e-25   -24.228   -24.284    -0.056     (0)
   FeNO3+2         2.612e-25   1.564e-25   -24.583   -24.806    -0.223     (0)
   FeCl+2          1.596e-25   9.558e-26   -24.797   -25.020    -0.223     (0)
   Fe(SO4)2-       1.684e-26   1.479e-26   -25.774   -25.830    -0.056     (0)
   Fe2(OH)2+4      4.252e-28   5.838e-29   -27.371   -28.234    -0.862     (0)
   FeCl4-          3.209e-32   2.819e-32   -31.494   -31.550    -0.056     (0)
   Fe3(OH)4+5      3.356e-34   1.589e-35   -33.474   -34.799    -1.325     (0)
H(0)          0.000e+00
   H2              0.000e+00   0.000e+00   -45.964   -45.962     0.002     (0)
Hg(1)         7.658e-11
   Hg2+2           3.829e-11   2.271e-11   -10.417   -10.644    -0.227     (0)
Hg(2)         3.122e-09
   Hg+2            3.122e-09   1.886e-09    -8.506    -8.724    -0.219     (0)
Mg            4.372e-04
   Mg+2            3.137e-04   1.989e-04    -3.504    -3.701    -0.198     (0)
   MgCO3           9.456e-05   9.456e-05    -4.024    -4.024     0.000     (0)
   MgSO4           1.729e-05   1.729e-05    -4.762    -4.762     0.000     (0)
   MgHCO3+         9.879e-06   8.680e-06    -5.005    -5.061    -0.056     (0)
   MgCl+           1.187e-06   1.043e-06    -5.926    -5.982    -0.056     (0)
   MgB(OH)4+       5.513e-07   4.843e-07    -6.259    -6.315    -0.056     (0)
   MgF+            9.926e-08   8.721e-08    -7.003    -7.059    -0.056     (0)
   Mg4(OH)4+4      1.032e-16   1.417e-17   -15.986   -16.849    -0.862     (0)
Mn(2)         6.614e-13
   MnCO3           5.923e-13   5.923e-13   -12.227   -12.227     0.000     (0)
   Mn+2            6.125e-14   3.765e-14   -13.213   -13.424    -0.211     (0)
   MnSO4           3.023e-15   3.023e-15   -14.520   -14.520     0.000     (0)
   MnOH+           2.942e-15   2.585e-15   -14.531   -14.588    -0.056     (0)
   MnHCO3+         1.226e-15   1.077e-15   -14.912   -14.968    -0.056     (0)
   MnCl+           6.128e-16   5.384e-16   -15.213   -15.269    -0.056     (0)
   MnF+            2.095e-17   1.841e-17   -16.679   -16.735    -0.056     (0)
   Mn(OH)2         1.695e-17   1.695e-17   -16.771   -16.771     0.000     (0)
   MnNO3+          1.244e-17   1.093e-17   -16.905   -16.962    -0.056     (0)
   MnSeO4          1.297e-18   1.297e-18   -17.887   -17.887     0.000     (0)
   Mn(OH)3-        4.833e-20   4.247e-20   -19.316   -19.372    -0.056     (0)
   MnCl3-          6.040e-21   5.307e-21   -20.219   -20.275    -0.056     (0)
   Mn(NO3)2        5.026e-21   5.026e-21   -20.299   -20.299     0.000     (0)
   Mn2(OH)3+       3.871e-23   3.401e-23   -22.412   -22.468    -0.056     (0)
   Mn(OH)4-2       1.620e-24   9.607e-25   -23.791   -24.017    -0.227     (0)
   Mn2OH+3         3.247e-28   1.043e-28   -27.489   -27.982    -0.493     (0)
Mn(3)         3.127e-27
   Mn+3            3.127e-27   1.004e-27   -26.505   -26.998    -0.493     (0)
Mn(6)         6.104e-09
   MnO4-2          6.104e-09   3.620e-09    -8.214    -8.441    -0.227     (0)
Mn(7)         1.819e-06
   MnO4-           1.819e-06   1.594e-06    -5.740    -5.797    -0.057     (0)
Mo            2.090e-08
   MoO4-2          2.090e-08   1.251e-08    -7.680    -7.903    -0.223     (0)
N(5)          2.111e-04
   NO3-            2.095e-04   1.831e-04    -3.679    -3.737    -0.058     (0)
   CaNO3+          1.678e-06   1.474e-06    -5.775    -5.831    -0.056     (0)
   BaNO3+          6.750e-10   5.931e-10    -9.171    -9.227    -0.056     (0)
   NiNO3+          3.888e-11   3.416e-11   -10.410   -10.466    -0.056     (0)
   PbNO3+          2.181e-13   1.916e-13   -12.661   -12.717    -0.056     (0)
   Ni(NO3)2        3.972e-15   3.972e-15   -14.401   -14.401     0.000     (0)
   HNO3            3.552e-15   3.552e-15   -14.449   -14.449     0.000     (0)
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   MnNO3+          1.244e-17   1.093e-17    -16.905    -16.962    -0.056     (0)
   Mn(NO3)2        5.026e-21   5.026e-21    -20.299    -20.299     0.000     (0)
   FeNO3+2         2.612e-25   1.564e-25    -24.583    -24.806    -0.223     (0)
Na            4.710e-03
   Na+             4.665e-03   4.099e-03     -2.331     -2.387    -0.056     (0)
   NaHCO3          2.203e-05   2.203e-05     -4.657     -4.657     0.000     (0)
   NaSO4-          1.003e-05   8.814e-06     -4.999     -5.055    -0.056     (0)
   NaCO3-          7.336e-06   6.446e-06     -5.135     -5.191    -0.056     (0)
   NaCl            4.839e-06   4.839e-06     -5.315     -5.315     0.000     (0)
   NaB(OH)4        2.354e-07   2.354e-07     -6.628     -6.628     0.000     (0)
   NaOH            1.820e-08   1.820e-08     -7.740     -7.740     0.000     (0)
   NaF             7.965e-09   7.965e-09     -8.099     -8.099     0.000     (0)
   NaAlO2          1.962e-09   1.962e-09     -8.707     -8.707     0.000     (0)
Ni            1.298e-07
   Ni+2            1.208e-07   7.426e-08     -6.918     -7.129    -0.211     (0)
   Ni(OH)2         5.420e-09   5.420e-09     -8.266     -8.266     0.000     (0)
   NiSO4           3.317e-09   3.317e-09     -8.479     -8.479     0.000     (0)
   Ni(OH)3-        1.667e-10   1.465e-10     -9.778     -9.834    -0.056     (0)
   NiCl+           6.044e-11   5.310e-11    -10.219    -10.275    -0.056     (0)
   NiNO3+          3.888e-11   3.416e-11    -10.410    -10.466    -0.056     (0)
   NiSeO4          4.446e-12   4.446e-12    -11.352    -11.352     0.000     (0)
   Ni(NO3)2        3.972e-15   3.972e-15    -14.401    -14.401     0.000     (0)
   Ni2OH+3         9.152e-16   2.939e-16    -15.038    -15.532    -0.493     (0)
   Ni4(OH)4+4      2.354e-18   3.233e-19    -17.628    -18.490    -0.862     (0)
O(0)          1.045e+00
   O2              5.225e-01   5.247e-01     -0.282     -0.280     0.002     (0)
Pb(2)         1.790e-07
   PbCO3           1.121e-07   1.121e-07     -6.951     -6.951     0.000     (0)
   Pb(CO3)2-2      5.932e-08   3.518e-08     -7.227     -7.454    -0.227     (0)
   PbOH+           3.806e-09   3.344e-09     -8.420     -8.476    -0.056     (0)
   Pb(OH)2         3.596e-09   3.596e-09     -8.444     -8.444     0.000     (0)
   Pb(OH)3-        1.106e-10   9.718e-11     -9.956    -10.012    -0.056     (0)
   Pb+2            1.036e-10   6.204e-11     -9.985    -10.207    -0.223     (0)
   PbCl+           1.369e-11   1.203e-11    -10.864    -10.920    -0.056     (0)
   PbCl2           3.075e-13   3.075e-13    -12.512    -12.512     0.000     (0)
   PbNO3+          2.181e-13   1.916e-13    -12.661    -12.717    -0.056     (0)
   PbF+            8.641e-15   7.592e-15    -14.063    -14.120    -0.056     (0)
   PbCl3-          1.179e-15   1.036e-15    -14.928    -14.985    -0.056     (0)
   Pb3(OH)4+2      2.675e-17   1.601e-17    -16.573    -16.796    -0.223     (0)
   Pb2OH+3         1.289e-17   4.139e-18    -16.890    -17.383    -0.493     (0)
   PbCl4-2         7.458e-18   4.423e-18    -17.127    -17.354    -0.227     (0)
   PbF2            8.404e-19   8.404e-19    -18.076    -18.076     0.000     (0)
   Pb4(OH)4+4      7.234e-24   9.934e-25    -23.141    -24.003    -0.862     (0)
   Pb6(OH)8+4      2.960e-29   4.064e-30    -28.529    -29.391    -0.862     (0)
   PbClO3+         5.824e-31   5.117e-31    -30.235    -30.291    -0.056     (0)
   Pb(ClO3)2       0.000e+00   0.000e+00    -50.446    -50.446     0.000     (0)
Pb(4)         0.000e+00
   Pb+4            0.000e+00   0.000e+00    -42.523    -43.385    -0.862     (0)
S(6)          6.524e-04
   SO4-2           5.487e-04   3.254e-04     -3.261     -3.488    -0.227     (0)
   CaSO4           7.635e-05   7.635e-05     -4.117     -4.117     0.000     (0)
   MgSO4           1.729e-05   1.729e-05     -4.762     -4.762     0.000     (0)
   NaSO4-          1.003e-05   8.814e-06     -4.999     -5.055    -0.056     (0)
   NiSO4           3.317e-09   3.317e-09     -8.479     -8.479     0.000     (0)
   ZnSO4           7.995e-10   7.995e-10     -9.097     -9.097     0.000     (0)
   HSO4-           1.388e-11   1.219e-11    -10.858    -10.914    -0.056     (0)
   CdSO4           2.745e-13   2.745e-13    -12.561    -12.561     0.000     (0)
   CuSO4           1.212e-13   1.212e-13    -12.916    -12.916     0.000     (0)
   MnSO4           3.023e-15   3.023e-15    -14.520    -14.520     0.000     (0)
   AlSO4+          1.414e-21   1.242e-21    -20.850    -20.906    -0.056     (0)
   VO2SO4-         2.204e-22   1.936e-22    -21.657    -21.713    -0.056     (0)
   FeSO4           4.594e-23   4.594e-23    -22.338    -22.338     0.000     (0)
   Al(SO4)2-       3.572e-23   3.139e-23    -22.447    -22.503    -0.056     (0)
   H2SO4           4.266e-24   4.266e-24    -23.370    -23.370     0.000     (0)
   FeSO4+          3.060e-24   2.689e-24    -23.514    -23.570    -0.056     (0)
   Fe(SO4)2-       1.684e-26   1.479e-26    -25.774    -25.830    -0.056     (0)
   VOSO4           1.754e-35   1.754e-35    -34.756    -34.756     0.000     (0)
   VSO4+           0.000e+00   0.000e+00    -58.911    -58.967    -0.056     (0)
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Se(-2)        0.000e+00
   HSe-            0.000e+00   0.000e+00  -106.498  -106.554    -0.056     (0)
   Se-2            0.000e+00   0.000e+00  -111.843  -112.070    -0.227     (0)
   H2Se            0.000e+00   0.000e+00  -112.163  -112.163     0.000     (0)
Se(4)         3.128e-21
   SeO3-2          3.112e-21   1.846e-21   -20.507   -20.734    -0.227     (0)
   HSeO3-          1.601e-23   1.407e-23   -22.796   -22.852    -0.056     (0)
   H2SeO3          1.982e-30   1.982e-30   -29.703   -29.703     0.000     (0)
Se(6)         2.158e-07
   SeO4-2          2.158e-07   1.280e-07    -6.666    -6.893    -0.227     (0)
   NiSeO4          4.446e-12   4.446e-12   -11.352   -11.352     0.000     (0)
   ZnSeO4          2.318e-13   2.318e-13   -12.635   -12.635     0.000     (0)
   CdSeO4          1.981e-14   1.981e-14   -13.703   -13.703     0.000     (0)
   HSeO4-          4.596e-15   4.038e-15   -14.338   -14.394    -0.056     (0)
   MnSeO4          1.297e-18   1.297e-18   -17.887   -17.887     0.000     (0)
V(3)          0.000e+00
   V(OH)2+         0.000e+00   0.000e+00   -45.820   -45.876    -0.056     (0)
   VOH+2           0.000e+00   0.000e+00   -51.420   -51.643    -0.223     (0)
   V+3             0.000e+00   0.000e+00   -58.317   -58.810    -0.493     (0)
   VSO4+           0.000e+00   0.000e+00   -58.911   -58.967    -0.056     (0)
   V2(OH)2+4       0.000e+00   0.000e+00  -101.704  -102.566    -0.862     (0)
V(4)          1.160e-30
   VOOH+           1.160e-30   1.019e-30   -29.935   -29.992    -0.056     (0)
   VO+2            2.981e-34   1.785e-34   -33.526   -33.748    -0.223     (0)
   VOF+            3.691e-35   3.243e-35   -34.433   -34.489    -0.056     (0)
   VOSO4           1.754e-35   1.754e-35   -34.756   -34.756     0.000     (0)
   VOF2            3.550e-37   3.550e-37   -36.450   -36.450     0.000     (0)
   (VO)2(OH)2+2    0.000e+00   0.000e+00   -55.091   -55.313    -0.223     (0)
V(5)          3.641e-06
   VO3OH-2         3.296e-06   1.955e-06    -5.482    -5.709    -0.227     (0)
   HVO4-2          3.281e-07   1.946e-07    -6.484    -6.711    -0.227     (0)
   H2VO4-          9.971e-09   8.761e-09    -8.001    -8.057    -0.056     (0)
   VO2(OH)2-       6.369e-09   5.596e-09    -8.196    -8.252    -0.056     (0)
   VO4-3           9.403e-11   2.897e-11   -10.027   -10.538    -0.511     (0)
   VO(OH)3         2.075e-14   2.075e-14   -13.683   -13.683     0.000     (0)
   VO2+            1.781e-20   1.565e-20   -19.749   -19.806    -0.056     (0)
   VO2F            6.364e-22   6.364e-22   -21.196   -21.196     0.000     (0)
   VO2SO4-         2.204e-22   1.936e-22   -21.657   -21.713    -0.056     (0)
   VO2F2-          3.796e-24   3.335e-24   -23.421   -23.477    -0.056     (0)
Zn            5.059e-07
   Zn(OH)2         3.918e-07   3.918e-07    -6.407    -6.407     0.000     (0)
   ZnCO3           4.413e-08   4.413e-08    -7.355    -7.355     0.000     (0)
   ZnOH+           3.898e-08   3.425e-08    -7.409    -7.465    -0.056     (0)
   Zn+2            1.902e-08   1.169e-08    -7.721    -7.932    -0.211     (0)
   Zn(OH)Cl        6.027e-09   6.027e-09    -8.220    -8.220     0.000     (0)
   Zn(OH)3-        3.693e-09   3.244e-09    -8.433    -8.489    -0.056     (0)
   ZnHCO3+         1.289e-09   1.132e-09    -8.890    -8.946    -0.056     (0)
   ZnSO4           7.995e-10   7.995e-10    -9.097    -9.097     0.000     (0)
   ZnCl+           1.502e-10   1.319e-10    -9.823    -9.880    -0.056     (0)
   ZnF+            3.415e-12   3.001e-12   -11.467   -11.523    -0.056     (0)
   Zn(OH)4-2       2.491e-12   1.478e-12   -11.604   -11.830    -0.227     (0)
   ZnCl2           1.035e-12   1.035e-12   -11.985   -11.985     0.000     (0)
   ZnSeO4          2.318e-13   2.318e-13   -12.635   -12.635     0.000     (0)
   ZnCl3-          4.371e-15   3.840e-15   -14.359   -14.416    -0.056     (0)
   ZnCl4-2         3.297e-16   1.955e-16   -15.482   -15.709    -0.227     (0)
   ZnClO4+         8.768e-26   7.704e-26   -25.057   -25.113    -0.056     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(298 K,   1 atm)

  Ahlfeldite      -23.37    -27.87   -4.50  NiSeO3:2H2O
  Al             -141.85      8.07  149.91  Al
  Al(g)          -192.55      8.07  200.62  Al
  Al2(SO4)3       -70.22    -51.32   18.90  Al2(SO4)3
  Al2(SO4)3:6H2O  -52.90    -51.34    1.56  Al2(SO4)3:6H2O
  AlF3            -17.38    -34.65  -17.27  AlF3
  Alstonite         2.24      4.83    2.58  BaCa(CO3)2
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Anglesite        -5.79    -13.69   -7.91  PbSO4
Anhydrite        -1.93     -6.28   -4.35  CaSO4
Antarcticite    -11.26     -7.16    4.09  CaCl2:6H2O
Antlerite        -9.88     -1.15    8.73  Cu3(SO4)(OH)4
Aragonite         2.24      4.21    1.97  CaCO3
Arsenolite     -145.24   -165.08  -19.84  As2O3
Artinite         -1.18     18.44   19.63  Mg2CO3(OH)2:3H2O
As             -125.01    -82.33   42.68  As
As2O5          -106.43   -104.29    2.14  As2O5
As4O6(cubi)    -290.33   -330.16  -39.82  As4O6
As4O6(mono)    -290.11   -330.16  -40.05  As4O6
Atacamite        -9.21      5.06   14.26  Cu4Cl2(OH)6
Azurite         -11.62     -2.50    9.12  Cu3(CO3)2(OH)2
B              -114.03     -4.48  109.56  B
B(g)           -205.32     -4.48  200.84  B
B2O3            -14.92     -9.37    5.55  B2O3
Ba             -128.62     12.61  141.23  Ba
Ba(OH)2:8H2O    -12.06     12.43   24.49  Ba(OH)2:8H2O
BaCl2           -12.96    -10.74    2.23  BaCl2
BaCl2:2H2O      -10.95    -10.74    0.21  BaCl2:2H2O
BaCl2:H2O       -11.56    -10.74    0.82  BaCl2:H2O
BaMnO4           -4.74    -14.83  -10.09  BaMnO4
BaO             -35.33     12.47   47.80  BaO
Barite            0.14     -9.88  -10.01  BaSO4
Barytocalcite     2.09      4.83    2.74  BaCa(CO3)2
BaSeO3          -20.55    -27.12   -6.57  BaSeO3
BaSeO4           -5.83    -13.28   -7.46  BaSeO4
Bassanite        -2.58     -6.28   -3.71  CaSO4:0.5H2O
BF3(g)          -44.21    -47.20   -2.98  BF3
Birnessite       30.80    -54.75  -85.55  Mn8O14:5H2O
Bischofite      -12.46     -8.07    4.39  MgCl2:6H2O
Bixbyite          3.54      2.58   -0.96  Mn2O3
Bloedite        -12.99    -15.47   -2.48  Na2Mg(SO4)2:4H2O
Boehmite          0.31      7.86    7.55  AlO2H
Borax           -16.75     -4.71   12.04  Na2(B4O5(OH)4):8H2O
Boric_acid       -4.54     -4.69   -0.16  B(OH)3
Brochantite      -9.50      5.92   15.42  Cu4(SO4)(OH)6
Brucite          -1.13     15.15   16.28  Mg(OH)2
Bunsenite        -0.73     11.73   12.46  NiO
Burkeite        -23.78    -14.29    9.49  Na6CO3(SO4)2
C               -75.72    -11.57   64.15  C
C(g)           -193.34    -11.57  181.77  C
Ca             -123.63     16.20  139.83  Ca
Ca(g)          -148.87     16.20  165.07  Ca
Ca2Al2O5:8H2O   -11.76     47.81   59.57  Ca2Al2O5:8H2O
Ca2Cl2(OH)2:H2O -17.37      8.92   26.29  Ca2Cl2(OH)2:H2O
Ca2V2O7          -5.81    -45.52  -39.71  Ca2V2O7
Ca3(AsO4)2      -73.91    -56.10   17.80  Ca3(AsO4)2
Ca3Al2O6        -49.13     63.91  113.03  Ca3Al2O6
Ca3V2O8         -11.14    -29.46  -18.32  Ca3V2O8
Ca4Al2Fe2O10    -48.08     92.40  140.48  Ca4Al2Fe2O10
Ca4Al2O7:13H2O  -27.34     79.92  107.25  Ca4Al2O7:13H2O
Ca4Al2O7:19H2O  -23.79     79.89  103.68  Ca4Al2O7:19H2O
Ca4Cl2(OH)6:13H2O -27.34      40.99   68.33  Ca4Cl2(OH)6:13H2O
CaAl2O4         -15.13     31.78   46.91  CaAl2O4
CaAl2O4:10H2O    -6.26     31.74   37.99  CaAl2O4:10H2O
CaAl4O7         -21.10     47.50   68.59  CaAl4O7
Cadmoselite     -87.29   -121.15  -33.86  CdSe
Calcite           2.39      4.21    1.82  CaCO3
Calomel           2.84    -14.99  -17.83  Hg2Cl2
CaSeO3:2H2O     -18.90    -23.54   -4.63  CaSeO3:2H2O
CaSeO4           -6.60     -9.69   -3.09  CaSeO4
CaSO4:0.5H2O(beta)  -2.75     -6.28   -3.54  CaSO4:0.5H2O
CaV2O6          -10.22    -61.59  -51.36  CaV2O6
Cd              -46.67      9.92   56.59  Cd
Cd(BO2)2         -9.43      0.40    9.83  Cd(BO2)2
Cd(g)           -60.21      9.92   70.13  Cd
Cd(OH)2          -3.96      9.77   13.73  Cd(OH)2
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Cd(OH)Cl         -5.36     -1.83    3.54  Cd(OH)Cl
Cd3(AsO4)2      -79.03    -74.96    4.06  Cd3(AsO4)2
Cd3(SO4)(OH)4   -15.60      6.98   22.57  Cd3(SO4)(OH)4
Cd3(SO4)2(OH)2  -22.08    -15.36    6.72  Cd3(SO4)2(OH)2
CdCl2           -12.77    -13.43   -0.66  CdCl2
CdCl2:H2O       -11.75    -13.43   -1.68  CdCl2:H2O
CdF2            -17.40    -18.56   -1.16  CdF2
CdSeO3          -20.99    -29.81   -8.82  CdSeO3
CdSeO4          -13.75    -15.97   -2.22  CdSeO4
CdSO4           -12.45    -12.57   -0.12  CdSO4
CdSO4:2.667H2O  -10.77    -12.58   -1.81  CdSO4:2.667H2O
CdSO4:H2O       -10.91    -12.57   -1.66  CdSO4:H2O
Cerussite         0.04     -3.20   -3.24  PbCO3
Chalcanthite    -12.67    -15.30   -2.63  CuSO4:5H2O
Chalcocyanite   -18.19    -15.28    2.91  CuSO4
Chloromagnesite -29.86     -8.05   21.82  MgCl2
Cl2(g)          -26.34    -23.34    2.99  Cl2
Claudetite     -145.28   -165.08  -19.80  As2O3
Clausthalite    -86.01   -122.28  -36.27  PbSe
Clinochalcomenite -25.73    -32.53   -6.80  CuSeO3:2H2O
CO2(g)           -4.02    -11.85   -7.83  CO2
Colemanite      -17.53      3.98   21.51  Ca2B6O11:5H2O
Corundum         -2.57     15.72   18.29  Al2O3
Cotunnite        -9.70    -14.55   -4.85  PbCl2
Cu              -24.29      7.21   31.50  Cu
Cu(g)           -76.45      7.21   83.66  Cu
CuCl2           -19.86    -16.13    3.72  CuCl2
CuF             -32.87    -25.79    7.08  CuF
CuF2            -20.65    -21.27   -0.62  CuF2
CuF2:2H2O       -16.73    -21.28   -4.55  CuF2:2H2O
Cuprite         -21.34    -23.24   -1.91  Cu2O
CuSeO3          -24.85    -32.52   -7.68  CuSeO3
Dawsonite        -1.30      3.04    4.34  NaAlCO3(OH)2
Delafossite       1.03     -5.40   -6.44  CuFeO2
Diaspore          0.71      7.86    7.15  AlHO2
Dolomite          5.04      7.52    2.47  CaMg(CO3)2
Dolomite-dis      3.50      7.52    4.01  CaMg(CO3)2
Dolomite-ord      5.05      7.52    2.46  CaMg(CO3)2
Downeyite       -32.80    -39.59   -6.79  SeO2
Epsomite         -5.25     -7.22   -1.96  MgSO4:7H2O
Ettringite      -17.53     44.93   62.46  Ca6Al2(SO4)3(OH)12:26H2O
F2(g)           -84.19    -28.48   55.71  F2
Fe              -61.07     -2.05   59.02  Fe
Fe(OH)2         -16.09     -2.20   13.89  Fe(OH)2
Fe(OH)3           0.57      6.21    5.64  Fe(OH)3
Fe2(SO4)3       -57.65    -54.60    3.05  Fe2(SO4)3
FeF2            -28.11    -30.53   -2.42  FeF2
FeF3            -17.03    -36.29  -19.26  FeF3
FeO             -15.72     -2.19   13.52  FeO
Ferrite-Ca        7.00     28.50   21.50  CaFe2O4
Ferrite-Cu        9.22     19.50   10.28  CuFe2O4
Ferrite-Dicalcium -12.24     44.56   56.80  Ca2Fe2O5
Ferrite-Mg        6.57     27.59   21.02  MgFe2O4
Ferrite-Zn       11.66     23.36   11.70  ZnFe2O4
Ferroselite    -174.88   -255.71  -80.82  FeSe2
FeSO4           -27.15    -24.54    2.61  FeSO4
FeV2O4         -343.80    -63.24  280.56  FeV2O4
Fluorite         -2.21    -12.28  -10.07  CaF2
Frankdicksonite -10.11    -15.87   -5.76  BaF2
Gaylussite       -4.74      6.42   11.16  CaNa2(CO3)2:5H2O
Gibbsite          0.11      7.85    7.74  Al(OH)3
Glauberite       -9.07    -14.54   -5.47  Na2Ca(SO4)2
Goethite          5.69      6.22    0.53  FeOOH
Gypsum           -1.76     -6.29   -4.53  CaSO4:2H2O
H2(g)           -42.86    -45.96   -3.10  H2
H2O(g)           -1.59     -0.00    1.59  H2O
Halite           -6.12     -4.56    1.56  NaCl
Hausmannite      -2.14      8.01   10.14  Mn3O4
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HCl(g)          -17.91    -11.60    6.30  HCl
Hematite         12.36     12.44    0.08  Fe2O3
Hercynite       -15.28     13.52   28.80  FeAl2O4
Hexahydrite      -5.49     -7.21   -1.73  MgSO4:6H2O
Hg(g)            -9.45     10.27   19.73  Hg
Hg(l)            -3.86     10.27   14.14  Hg
Hg2SeO3         -17.16    -31.38  -14.21  Hg2SeO3
Hg2SO4           -8.00    -14.13   -6.13  Hg2SO4
HgSeO3          -15.56    -29.46  -13.90  HgSeO3
Huntite           3.91     14.12   10.22  CaMg3(CO3)4
Hydroboracite   -17.29      3.07   20.36  MgCaB6O11:6H2O
Hydrocerussite    0.39      2.24    1.85  Pb3(CO3)2(OH)2
Hydromagnesite   -2.39     28.35   30.74  Mg5(CO3)4(OH)2:4H2O
Hydrophilite    -18.89     -7.14   11.75  CaCl2
Hydrozincite      0.60     30.91   30.31  Zn5(OH)6(CO3)2
Ice              -0.14     -0.00    0.14  H2O
Jarosite-Na     -13.56    -19.01   -5.45  NaFe3(SO4)2(OH)6
Karelianite     -70.99    -61.05    9.95  V2O3
Katoite         -15.06     63.88   78.94  Ca3Al2H12O12
Kieserite        -6.93     -7.19   -0.27  MgSO4:H2O
Klockmannite    -82.24   -123.86  -41.62  CuSe
Krutaite       -147.23   -254.93 -107.70  CuSe2
Lammerite       -84.64    -83.09    1.55  Cu3(AsO4)2
Lanarkite        -4.56     -5.04   -0.48  Pb2(SO4)O
Lansfordite      -1.56      3.28    4.84  MgCO3:5H2O
Lawrencite      -34.45    -25.40    9.05  FeCl2
Lime            -16.51     16.06   32.57  CaO
Litharge         -3.99      8.65   12.64  PbO
Magnesite         1.03      3.30    2.27  MgCO3
Magnetite        -0.18     10.24   10.42  Fe3O4
Malachite        -3.62      2.28    5.90  Cu2CO3(OH)2
Manganite         1.45      1.29   -0.16  MnO(OH)
Manganosite     -12.48      5.43   17.92  MnO
Massicot         -4.17      8.65   12.82  PbO
Matlockite       -7.69    -17.12   -9.43  PbFCl
Mayenite       -191.38    302.77  494.15  Ca12Al14O33
Melanterite     -22.17    -24.57   -2.40  FeSO4:7H2O
Mg             -107.22     15.30  122.52  Mg
Mg(g)          -126.95     15.30  142.25  Mg
Mg1.25SO4(OH)0.5:0.5H2O  -8.60     -3.40    5.20  Mg1.25SO4(OH)0.5:0.5H2O
Mg1.5SO4(OH)     -8.82      0.39    9.21  Mg1.5SO4(OH)
Mg2V2O7         -16.43    -47.34  -30.90  Mg2V2O7
MgCl2:2H2O      -20.79     -8.06   12.73  MgCl2:2H2O
MgCl2:4H2O      -15.36     -8.06    7.30  MgCl2:4H2O
MgCl2:H2O       -24.12     -8.05   16.07  MgCl2:H2O
MgOHCl          -12.34      3.55   15.89  MgOHCl
MgSeO3          -26.11    -24.44    1.67  MgSeO3
MgSeO3:6H2O     -21.02    -24.46   -3.44  MgSeO3:6H2O
MgSO4           -12.02     -7.19    4.83  MgSO4
MgV2O6          -16.65    -62.49  -45.85  MgV2O6
Minium           -4.63     11.63   16.26  Pb3O4
Mirabilite       -7.15     -8.30   -1.15  Na2SO4:10H2O
Mn              -77.36      5.57   82.93  Mn
Mn(OH)2(am)      -9.88      5.43   15.31  Mn(OH)2
Mn(OH)3          -5.06      1.28    6.34  Mn(OH)3
MnCl2:2H2O      -21.78    -17.78    4.00  MnCl2:2H2O
MnCl2:4H2O      -20.54    -17.79    2.75  MnCl2:4H2O
MnCl2:H2O       -23.32    -17.77    5.54  MnCl2:H2O
MnO2(gamma)       5.19    -10.93  -16.13  MnO2
MnSe           -114.80   -125.49  -10.70  MnSe
MnSeO3          -26.89    -34.16   -7.27  MnSeO3
MnSeO3:2H2O     -27.83    -34.17   -6.33  MnSeO3:2H2O
MnSO4           -19.52    -16.91    2.61  MnSO4
MnV2O6          -20.14    -72.22  -52.08  MnV2O6
Mo             -135.61    -26.34  109.27  Mo
Molysite        -42.06    -28.59   13.47  FeCl3
Monohydrocalcite   1.53      4.21    2.68  CaCO3:H2O
Monteponite      -5.32      9.78   15.09  CdO
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Montroydite       7.69     10.13    2.44  HgO
Morenosite       -8.58    -10.65   -2.06  NiSO4:7H2O
MoSe2          -233.35   -288.47  -55.12  MoSe2
Na              -60.26      7.11   67.37  Na
Na(g)           -73.75      7.11   80.86  Na
Na2CO3           -8.93      2.23   11.16  Na2CO3
Na2CO3:7H2O      -7.74      2.20    9.94  Na2CO3:7H2O
Na2O            -53.33     14.08   67.42  Na2O
Na2Se          -128.67   -116.84   11.83  Na2Se
Na2Se2         -186.56   -247.91  -61.35  Na2Se2
Na3H(SO4)2      -22.68    -23.57   -0.89  Na3H(SO4)2
Na4Ca(SO4)3:2H2O -16.92    -22.81   -5.89  Na4Ca(SO4)3:2H2O
NaFeO2           -6.62     13.26   19.88  NaFeO2
Nahcolite        -4.67     -4.81   -0.14  NaHCO3
Nantokite       -16.46    -23.22   -6.77  CuCl
Natron           -7.40      2.19    9.59  Na2CO3:10H2O
Nesquehonite     -2.00      3.29    5.29  MgCO3:3H2O
Ni              -39.11     11.87   50.98  Ni
Ni(OH)2          -1.02     11.72   12.75  Ni(OH)2
Nickelbischofite -14.65    -11.50    3.15  NiCl2:6H2O
NiCl2           -20.08    -11.47    8.60  NiCl2
NiCl2:2H2O      -15.41    -11.48    3.92  NiCl2:2H2O
NiCl2:4H2O      -15.34    -11.49    3.85  NiCl2:4H2O
NiCO3            -3.64     -0.12    3.51  NiCO3
NiF2            -17.43    -16.61    0.82  NiF2
NiF2:4H2O       -12.57    -16.63   -4.06  NiF2:4H2O
NiSO4           -15.89    -10.62    5.28  NiSO4
NiSO4:6H2O(alpha)  -8.62    -10.64   -2.02  NiSO4:6H2O
Nitrobarite     -11.37    -13.86   -2.49  Ba(NO3)2
NO2(g)          -21.44    -13.10    8.35  NO2
O2(g)             2.61     -0.28   -2.89  O2
Otavite          -0.30     -2.07   -1.77  CdCO3
Oxychloride-Mg   -7.14     18.69   25.83  Mg2Cl(OH)3:4H2O
Paralaurionite   -3.15     -2.95    0.20  PbClOH
Pb              -38.38      8.79   47.17  Pb
Pb(g)           -66.82      8.79   75.61  Pb
Pb2Cl2CO3        -8.14    -17.75   -9.62  Pb2Cl2CO3
Pb3SO6           -6.97      3.61   10.58  Pb3SO6
Pb4Cl2(OH)6      -5.89     11.39   17.28  Pb4Cl2(OH)6
Pb4SO7           -9.46     12.26   21.71  Pb4SO7
PbCO3.PbO        -4.21      5.45    9.66  PbCO3.PbO
PbF2            -14.43    -19.69   -5.25  PbF2
PbFCl            -8.13    -17.12   -8.99  PbFCl
PbSeO4          -10.15    -17.10   -6.95  PbSeO4
Penroseite     -151.45   -250.27  -98.81  NiSe2
Pentahydrite     -5.82     -7.21   -1.39  MgSO4:5H2O
Periclase        -6.17     15.16   21.33  MgO
Phosgenite       -8.10    -17.75   -9.65  Pb2(CO3)Cl2
Pirssonite       -4.89      6.43   11.32  Na2Ca(CO3)2:2H2O
Plattnerite       2.30     -5.67   -7.97  PbO2
Portlandite      -6.49     16.06   22.55  Ca(OH)2
Pyrolusite        6.73    -10.93  -17.66  MnO2
Rhodochrosite    -6.20     -6.42   -0.22  MnCO3
Scacchite       -26.51    -17.77    8.74  MnCl2
Se              -65.41    -39.31   26.10  Se
Se2O5           -74.83    -65.34    9.49  Se2O5
SeCl4          -100.33    -86.00   14.33  SeCl4
Sellaite         -3.74    -13.18   -9.44  MgF2
SeO3            -44.91    -25.75   19.16  SeO3
Shcherbinaite   -19.30    -20.75   -1.45  V2O5
Siderite        -13.83    -14.04   -0.22  FeCO3
Smithsonite      -1.37     -0.93    0.44  ZnCO3
Spinel           -6.73     30.87   37.61  Al2MgO4
Starkeyite       -6.21     -7.21   -1.00  MgSO4:4H2O
Stilleite       -96.02   -120.00  -23.98  ZnSe
Tachyhydrite    -40.43    -23.28   17.14  Mg2CaCl6:12H2O
Tenorite         -0.58      7.07    7.65  CuO
Thenardite       -7.90     -8.26   -0.36  Na2SO4
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  Thermonatrite    -8.71      2.23   10.94  Na2CO3:H2O
  Tiemannite      -62.56   -120.79  -58.23  HgSe
  Todorokite       26.24    -19.58  -45.82  Mn7O12:3H2O
  Trevorite        14.38     24.16    9.78  NiFe2O4
  Umangite       -184.18   -278.03  -93.85  Cu3Se2
  V              -137.26    -30.31  106.94  V
  V2O4            -38.34    -29.78    8.56  V2O4
  V3O5            -89.37    -75.94   13.43  V3O5
  V4O7           -109.63    -90.83   18.80  V4O7
  Wilkmanite     -335.74   -488.66 -152.92  Ni3Se4
  Witherite         3.63      0.62   -3.02  BaCO3
  Wustite         -13.59     -1.19   12.40  Fe.947O
  Zincite          -0.27     10.93   11.20  ZnO
  Zn              -57.72     11.07   68.79  Zn
  Zn(BO2)2         -6.76      1.55    8.31  Zn(BO2)2
  Zn(ClO4)2:6H2O  -50.51    -44.87    5.63  Zn(ClO4)2:6H2O
  Zn(g)           -74.34     11.07   85.41  Zn
  Zn(NO3)2:6H2O   -18.83    -15.43    3.40  Zn(NO3)2:6H2O
  Zn(OH)2(beta)    -1.01     10.92   11.93  Zn(OH)2
  Zn(OH)2(epsilon)  -0.74     10.92   11.66  Zn(OH)2
  Zn(OH)2(gamma)   -0.96     10.92   11.88  Zn(OH)2
  Zn2(OH)3Cl       -5.05     10.24   15.29  Zn2(OH)3Cl
  Zn2SO4(OH)2      -8.08     -0.50    7.58  Zn2SO4(OH)2
  Zn3(AsO4)2      -80.83    -71.52    9.31  Zn3(AsO4)2
  Zn3O(SO4)2      -31.00    -11.91   19.09  Zn3O(SO4)2
  Zn5(NO3)2(OH)8  -14.39     28.28   42.67  Zn5(NO3)2(OH)8
  ZnCl2           -19.36    -12.28    7.08  ZnCl2
  ZnCO3:H2O        -1.07     -0.93    0.14  ZnCO3:H2O
  ZnF2            -16.92    -17.41   -0.49  ZnF2
  ZnSeO3:H2O      -21.92    -28.67   -6.75  ZnSeO3:H2O
  ZnSO4           -14.95    -11.42    3.53  ZnSO4
  ZnSO4:6H2O       -9.74    -11.44   -1.70  ZnSO4:6H2O
  ZnSO4:7H2O       -9.57    -11.45   -1.88  ZnSO4:7H2O
  ZnSO4:H2O       -10.87    -11.42   -0.55  ZnSO4:H2O

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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Beginning of batch-reaction calculations.
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Reaction step 1.

Using solution 1. Pit Chemistry after 50 Years Before Layering
Using pure phase assemblage 1.      Inpitfilling: Layer 2 After 50 Years

-------------------------------Phase assemblage--------------------------------

                                                      Moles in assemblage
Phase               SI  log IAP  log K(T, P)   Initial       Final       Delta

Barite            0.00   -10.01    -10.01    1.000e+01   1.000e+01   3.371e-07
Calcite           0.00     1.82      1.82    1.000e+01   1.000e+01   2.917e-03
Fe(OH)3           0.00     5.64      5.64    1.000e+01   1.000e+01   2.387e-06
Gibbsite          0.00     7.74      7.74    1.000e+01   1.000e+01   2.841e-06
Gypsum           -1.96    -6.49     -4.53    1.000e+01   1.000e+01   0.000e+00
Manganite         0.00    -0.16     -0.16    1.000e+01   1.000e+01   1.824e-06

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al               2.035e-08   2.035e-08
      As               1.030e-07   1.030e-07
      B                5.842e-05   5.842e-05
      Ba               4.294e-07   4.294e-07
      C                4.002e-03   4.002e-03
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      Ca              1.536e-03   1.536e-03
      Cd              6.778e-09   6.778e-09
      Cl              7.692e-03   7.692e-03
      Cu              1.735e-08   1.735e-08
      F               2.111e-05   2.111e-05
      Fe              4.856e-07   4.856e-07
      Hg              3.199e-09   3.199e-09
      Mg              4.372e-04   4.372e-04
      Mn              5.633e-10   5.633e-10
      Mo              2.090e-08   2.090e-08
      N               2.111e-04   2.111e-04
      Na              4.710e-03   4.710e-03
      Ni              1.298e-07   1.298e-07
      Pb              1.790e-07   1.790e-07
      S               6.521e-04   6.521e-04
      Se              2.158e-07   2.158e-07
      V               3.641e-06   3.641e-06
      Zn              5.059e-07   5.059e-07

----------------------------Description of solution----------------------------

                                       pH  =   7.352      Charge balance
                                       pe  =  14.079      Adjusted to redox equilibrium
                        Activity of water  =   0.991
                           Ionic strength  =   1.295e-02
                       Mass of water (kg)  =   1.000e+00
                 Total alkalinity (eq/kg)  =   3.694e-03
                       Total CO2 (mol/kg)  =   4.002e-03
                         Temperature (°C)  =  25.00
                  Electrical balance (eq)  =  -4.261e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  = -20.22
                               Iterations  =  15
                                  Total H  = 1.110551e+02
                                  Total O  = 5.658578e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             2.412e-07   2.146e-07    -6.618    -6.668    -0.051      (0)
   H+              4.912e-08   4.449e-08    -7.309    -7.352    -0.043      0.00
   H2O             5.553e+01   9.908e-01     1.744    -0.004     0.000     18.07
Al             2.035e-08
   AlO2-           1.815e-08   1.618e-08    -7.741    -7.791    -0.050      (0)
   HAlO2           2.101e-09   2.101e-09    -8.678    -8.678     0.000      (0)
   Al(OH)2+        7.208e-11   6.423e-11   -10.142   -10.192    -0.050      (0)
   NaAlO2          1.285e-11   1.285e-11   -10.891   -10.891     0.000      (0)
   AlF2+           7.587e-12   6.760e-12   -11.120   -11.170    -0.050      (0)
   AlOH+2          1.963e-12   1.242e-12   -11.707   -11.906    -0.199      (0)
   AlF3            1.572e-12   1.572e-12   -11.804   -11.804     0.000      (0)
   AlF+2           1.453e-12   9.195e-13   -11.838   -12.036    -0.199      (0)
   Al+3            1.226e-14   4.979e-15   -13.912   -14.303    -0.391      (0)
   AlF4-           8.182e-15   7.291e-15   -14.087   -14.137    -0.050      (0)
   AlSO4+          2.038e-15   1.816e-15   -14.691   -14.741    -0.050      (0)
   Al(SO4)2-       5.640e-17   5.026e-17   -16.249   -16.299    -0.050      (0)
   Al2(OH)2+4      1.483e-21   2.509e-22   -20.829   -21.601    -0.772      (0)
   Al3(OH)4+5      6.159e-27   3.999e-28   -26.210   -27.398    -1.188      (0)
   Al13O4(OH)24+7   0.000e+00   0.000e+00   -47.196   -49.525    -2.328      (0)
As(-3)         0.000e+00
   AsH3            0.000e+00   0.000e+00  -204.705  -204.705     0.000      (0)
As(3)          0.000e+00
   HAsO2           0.000e+00   0.000e+00   -71.182   -71.182     0.000      (0)
   As(OH)3         0.000e+00   0.000e+00   -71.245   -71.245     0.000      (0)
   H2AsO3-         0.000e+00   0.000e+00   -73.056   -73.106    -0.050      (0)
   AsO2-           0.000e+00   0.000e+00   -73.072   -73.122    -0.050      (0)
   AsO2OH-2        0.000e+00   0.000e+00   -76.563   -76.765    -0.202      (0)
   HAsS2           0.000e+00   0.000e+00  -361.712  -361.712     0.000      (0)
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As(5)         1.030e-07
   AsO3F-2         1.007e-07   6.325e-08     -6.997    -7.199    -0.202     (0)
   HAsO3F-         2.345e-09   2.089e-09     -8.630    -8.680    -0.050     (0)
   HAsO4-2         0.000e+00   0.000e+00    -41.941   -42.143    -0.202     (0)
   H2AsO4-         0.000e+00   0.000e+00    -42.664   -42.714    -0.050     (0)
   AsO4-3          0.000e+00   0.000e+00    -45.927   -46.382    -0.455     (0)
   H3AsO4          0.000e+00   0.000e+00    -47.820   -47.820     0.000     (0)
B(-5)         0.000e+00
   BH4-            0.000e+00   0.000e+00   -233.366  -233.416    -0.050     (0)
B(3)          5.842e-05
   B(OH)3          5.756e-05   5.756e-05     -4.240    -4.240     0.000     (0)
   BO2-            7.858e-07   7.002e-07     -6.105    -6.155    -0.050     (0)
   CaB(OH)4+       5.058e-08   4.507e-08     -7.296    -7.346    -0.050     (0)
   MgB(OH)4+       1.710e-08   1.524e-08     -7.767    -7.817    -0.050     (0)
   NaB(OH)4        5.669e-09   5.669e-09     -8.247    -8.247     0.000     (0)
   BaB(OH)4+       6.201e-12   5.525e-12    -11.208   -11.258    -0.050     (0)
   BF2(OH)2-       4.100e-15   3.653e-15    -14.387   -14.437    -0.050     (0)
   B2O(OH)5-       1.726e-20   1.538e-20    -19.763   -19.813    -0.050     (0)
   BF3OH-          1.450e-20   1.292e-20    -19.839   -19.889    -0.050     (0)
   BF4-            7.971e-28   7.103e-28    -27.098   -27.149    -0.050     (0)
Ba            4.294e-07
   Ba+2            4.278e-07   2.727e-07     -6.369    -6.564    -0.196     (0)
   BaCl+           7.002e-10   6.239e-10     -9.155    -9.205    -0.050     (0)
   BaNO3+          4.535e-10   4.041e-10     -9.343    -9.393    -0.050     (0)
   BaCO3           4.247e-10   4.247e-10     -9.372    -9.372     0.000     (0)
   BaB(OH)4+       6.201e-12   5.525e-12    -11.208   -11.258    -0.050     (0)
   BaF+            3.894e-12   3.470e-12    -11.410   -11.460    -0.050     (0)
   BaOH+           2.309e-13   2.058e-13    -12.636   -12.687    -0.050     (0)
C(-2)         0.000e+00
   C2H4            0.000e+00   0.000e+00   -273.270  -273.270     0.000     (0)
C(-3)         0.000e+00
   C2H6            0.000e+00   0.000e+00   -247.244  -247.244     0.000     (0)
C(-4)         0.000e+00
   CH4             0.000e+00   0.000e+00   -153.381  -153.381     0.000     (0)
C(2)          0.000e+00
   CO              0.000e+00   0.000e+00    -51.376   -51.376     0.000     (0)
C(4)          4.002e-03
   HCO3-           3.588e-03   3.197e-03     -2.445    -2.495    -0.050     (0)
   CO2             3.319e-04   3.330e-04     -3.479    -3.478     0.001     (0)
   CaHCO3+         3.952e-05   3.521e-05     -4.403    -4.453    -0.050     (0)
   NaHCO3          1.905e-05   1.905e-05     -4.720    -4.720     0.000     (0)
   MgHCO3+         1.100e-05   9.806e-06     -4.958    -5.009    -0.050     (0)
   CaCO3           6.867e-06   6.867e-06     -5.163    -5.163     0.000     (0)
   CO3-2           5.037e-06   3.188e-06     -5.298    -5.497    -0.199     (0)
   MgCO3           8.905e-07   8.905e-07     -6.050    -6.050     0.000     (0)
   PbCO3           1.511e-07   1.511e-07     -6.821    -6.821     0.000     (0)
   NaCO3-          5.213e-08   4.646e-08     -7.283    -7.333    -0.050     (0)
   ZnHCO3+         2.616e-08   2.331e-08     -7.582    -7.633    -0.050     (0)
   CuCO3           1.569e-08   1.569e-08     -7.804    -7.804     0.000     (0)
   ZnCO3           7.571e-09   7.571e-09     -8.121    -8.121     0.000     (0)
   Pb(CO3)2-2      5.357e-10   3.365e-10     -9.271    -9.473    -0.202     (0)
   BaCO3           4.247e-10   4.247e-10     -9.372    -9.372     0.000     (0)
   Cu(CO3)2-2      1.419e-10   8.912e-11     -9.848   -10.050    -0.202     (0)
   CdHCO3+         1.353e-10   1.205e-10     -9.869    -9.919    -0.050     (0)
   CdCO3           4.018e-12   4.018e-12    -11.396   -11.396     0.000     (0)
   MnCO3           2.142e-12   2.142e-12    -11.669   -11.669     0.000     (0)
   FeCO3+          8.154e-13   7.266e-13    -12.089   -12.139    -0.050     (0)
   MnHCO3+         5.244e-13   4.673e-13    -12.280   -12.330    -0.050     (0)
   CuCO3(OH)2-2    1.053e-13   6.617e-14    -12.977   -13.179    -0.202     (0)
   Cd(CO3)2-2      5.415e-14   3.401e-14    -13.266   -13.468    -0.202     (0)
   FeHCO3+         6.462e-18   5.758e-18    -17.190   -17.240    -0.050     (0)
   FeCO3           6.212e-19   6.212e-19    -18.207   -18.207     0.000     (0)
Ca            1.536e-03
   Ca+2            1.438e-03   9.295e-04     -2.842    -3.032    -0.190     (0)
   CaSO4           4.840e-05   4.840e-05     -4.315    -4.315     0.000     (0)
   CaHCO3+         3.952e-05   3.521e-05     -4.403    -4.453    -0.050     (0)
   CaCO3           6.867e-06   6.867e-06     -5.163    -5.163     0.000     (0)
   CaCl+           1.508e-06   1.344e-06     -5.822    -5.872    -0.050     (0)
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   CaNO3+          9.753e-07   8.690e-07    -6.011    -6.061    -0.050     (0)
   CaF+            9.792e-08   8.726e-08    -7.009    -7.059    -0.050     (0)
   CaB(OH)4+       5.058e-08   4.507e-08    -7.296    -7.346    -0.050     (0)
   CaCl2           1.078e-08   1.078e-08    -7.967    -7.967     0.000     (0)
   CaOH+           3.281e-09   2.924e-09    -8.484    -8.534    -0.050     (0)
Cd            6.778e-09
   CdCl+           4.636e-09   4.131e-09    -8.334    -8.384    -0.050     (0)
   Cd+2            1.870e-09   1.192e-09    -8.728    -8.924    -0.196     (0)
   CdHCO3+         1.353e-10   1.205e-10    -9.869    -9.919    -0.050     (0)
   CdCl2           1.222e-10   1.222e-10    -9.913    -9.913     0.000     (0)
   Cd(OH)Cl        6.685e-12   6.685e-12   -11.175   -11.175     0.000     (0)
   CdCO3           4.018e-12   4.018e-12   -11.396   -11.396     0.000     (0)
   CdOH+           2.507e-12   2.234e-12   -11.601   -11.651    -0.050     (0)
   CdSO4           4.314e-13   4.314e-13   -12.365   -12.365     0.000     (0)
   CdCl3-          2.398e-13   2.137e-13   -12.620   -12.670    -0.050     (0)
   Cd(CO3)2-2      5.415e-14   3.401e-14   -13.266   -13.468    -0.202     (0)
   CdSeO4          3.010e-14   3.010e-14   -13.521   -13.521     0.000     (0)
   Cd(OH)2         2.701e-15   2.701e-15   -14.568   -14.568     0.000     (0)
   Cd2OH+3         3.598e-20   1.304e-20   -19.444   -19.885    -0.441     (0)
   Cd(OH)3-        7.663e-21   6.828e-21   -20.116   -20.166    -0.050     (0)
   CdNO2+          4.726e-26   4.212e-26   -25.325   -25.376    -0.050     (0)
   Cd(OH)4-2       2.182e-27   1.371e-27   -26.661   -26.863    -0.202     (0)
   Cd(NH3)+2       0.000e+00   0.000e+00   -78.787   -78.986    -0.199     (0)
   CdN3+           0.000e+00   0.000e+00  -121.399  -121.449    -0.050     (0)
   Cd(NH3)2+2      0.000e+00   0.000e+00  -149.017  -149.215    -0.199     (0)
   Cd(N3)2         0.000e+00   0.000e+00  -234.508  -234.508     0.000     (0)
   Cd(NH3)4+2      0.000e+00   0.000e+00  -291.778  -291.976    -0.199     (0)
   Cd(N3)3-        0.000e+00   0.000e+00  -347.815  -347.865    -0.050     (0)
   Cd4(OH)4+4      0.000e+00   0.000e+00  -367.658  -368.430    -0.772     (0)
   Cd(N3)4-2       0.000e+00   0.000e+00  -461.318  -461.520    -0.202     (0)
Cl(-1)        7.692e-03
   Cl-             7.684e-03   6.820e-03    -2.114    -2.166    -0.052     (0)
   NaCl            4.993e-06   4.993e-06    -5.302    -5.302     0.000     (0)
   MgCl+           1.578e-06   1.406e-06    -5.802    -5.852    -0.050     (0)
   CaCl+           1.508e-06   1.344e-06    -5.822    -5.872    -0.050     (0)
   CaCl2           1.078e-08   1.078e-08    -7.967    -7.967     0.000     (0)
   CdCl+           4.636e-09   4.131e-09    -8.334    -8.384    -0.050     (0)
   ZnCl+           3.637e-09   3.241e-09    -8.439    -8.489    -0.050     (0)
   PbCl+           2.606e-09   2.322e-09    -8.584    -8.634    -0.050     (0)
   Zn(OH)Cl        1.234e-09   1.234e-09    -8.909    -8.909     0.000     (0)
   BaCl+           7.002e-10   6.239e-10    -9.155    -9.205    -0.050     (0)
   CdCl2           1.222e-10   1.222e-10    -9.913    -9.913     0.000     (0)
   HCl             6.815e-11   6.815e-11   -10.167   -10.167     0.000     (0)
   NiCl+           6.621e-11   5.900e-11   -10.179   -10.229    -0.050     (0)
   PbCl2           6.028e-11   6.028e-11   -10.220   -10.220     0.000     (0)
   ZnCl2           2.582e-11   2.582e-11   -10.588   -10.588     0.000     (0)
   CuCl+           1.081e-11   9.629e-12   -10.966   -11.016    -0.050     (0)
   Cd(OH)Cl        6.685e-12   6.685e-12   -11.175   -11.175     0.000     (0)
   MnCl+           3.129e-13   2.788e-13   -12.505   -12.555    -0.050     (0)
   CdCl3-          2.398e-13   2.137e-13   -12.620   -12.670    -0.050     (0)
   PbCl3-          2.314e-13   2.062e-13   -12.636   -12.686    -0.050     (0)
   ZnCl3-          1.091e-13   9.724e-14   -12.962   -13.012    -0.050     (0)
   CuCl2           3.458e-14   3.458e-14   -13.461   -13.461     0.000     (0)
   ZnCl4-2         8.002e-15   5.027e-15   -14.097   -14.299    -0.202     (0)
   PbCl4-2         1.423e-15   8.938e-16   -14.847   -15.049    -0.202     (0)
   MnCl3-          3.179e-18   2.833e-18   -17.498   -17.548    -0.050     (0)
   FeCl2+          2.779e-19   2.476e-19   -18.556   -18.606    -0.050     (0)
   FeCl+2          7.087e-20   4.485e-20   -19.150   -19.348    -0.199     (0)
   FeCl+           1.914e-20   1.705e-20   -19.718   -19.768    -0.050     (0)
   CuCl2-          8.148e-21   7.261e-21   -20.089   -20.139    -0.050     (0)
   CuCl3-2         5.063e-22   3.180e-22   -21.296   -21.498    -0.202     (0)
   CuCl4-2         4.806e-23   3.019e-23   -22.318   -22.520    -0.202     (0)
   FeCl2           6.241e-25   6.241e-25   -24.205   -24.205     0.000     (0)
   FeCl4-          1.554e-26   1.385e-26   -25.809   -25.859    -0.050     (0)
   FeCl4-2         1.335e-28   8.387e-29   -27.874   -28.076    -0.202     (0)
Cl(1)         1.060e-17
   HClO            6.310e-18   6.310e-18   -17.200   -17.200     0.000     (0)
   ClO-            4.292e-18   3.824e-18   -17.367   -17.417    -0.050     (0)
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Cl(3)         3.068e-26
   ClO2-           3.068e-26   2.733e-26    -25.513   -25.563    -0.050     (0)
   HClO2           1.798e-30   1.798e-30    -29.745   -29.745     0.000     (0)
Cl(5)         1.563e-20
   ClO3-           1.563e-20   1.390e-20    -19.806   -19.857    -0.051     (0)
   PbClO3+         1.107e-28   9.865e-29    -27.956   -28.006    -0.050     (0)
   Pb(ClO3)2       0.000e+00   0.000e+00    -48.155   -48.155     0.000     (0)
Cl(7)         3.969e-19
   ClO4-           3.969e-19   3.530e-19    -18.401   -18.452    -0.051     (0)
   ZnClO4+         2.119e-24   1.888e-24    -23.674   -23.724    -0.050     (0)
Cu(1)         1.130e-20
   CuCl2-          8.148e-21   7.261e-21    -20.089   -20.139    -0.050     (0)
   Cu+             2.644e-21   2.356e-21    -20.578   -20.628    -0.050     (0)
   CuCl3-2         5.063e-22   3.180e-22    -21.296   -21.498    -0.202     (0)
Cu(2)         1.735e-08
   CuCO3           1.569e-08   1.569e-08     -7.804    -7.804     0.000     (0)
   Cu+2            7.987e-10   5.162e-10     -9.098    -9.287    -0.190     (0)
   CuOH+           6.655e-10   5.930e-10     -9.177    -9.227    -0.050     (0)
   Cu(CO3)2-2      1.419e-10   8.912e-11     -9.848   -10.050    -0.202     (0)
   CuSO4           4.216e-11   4.216e-11    -10.375   -10.375     0.000     (0)
   CuCl+           1.081e-11   9.629e-12    -10.966   -11.016    -0.050     (0)
   CuF+            1.696e-13   1.511e-13    -12.771   -12.821    -0.050     (0)
   CuCO3(OH)2-2    1.053e-13   6.617e-14    -12.977   -13.179    -0.202     (0)
   CuCl2           3.458e-14   3.458e-14    -13.461   -13.461     0.000     (0)
   CuO2-2          7.310e-20   4.592e-20    -19.136   -19.338    -0.202     (0)
   CuCl4-2         4.806e-23   3.019e-23    -22.318   -22.520    -0.202     (0)
   CuNO2+          9.140e-27   8.145e-27    -26.039   -26.089    -0.050     (0)
   Cu(NO2)2        0.000e+00   0.000e+00    -43.901   -43.901     0.000     (0)
   CuNH3+2         0.000e+00   0.000e+00    -77.640   -77.839    -0.199     (0)
   Cu(NH3)2+2      0.000e+00   0.000e+00   -146.799  -146.997    -0.199     (0)
   Cu(NH3)3+2      0.000e+00   0.000e+00   -216.570  -216.769    -0.199     (0)
F             2.111e-05
   F-              2.077e-05   1.847e-05     -4.683    -4.734    -0.051     (0)
   MgF+            1.321e-07   1.177e-07     -6.879    -6.929    -0.050     (0)
   AsO3F-2         1.007e-07   6.325e-08     -6.997    -7.199    -0.202     (0)
   CaF+            9.792e-08   8.726e-08     -7.009    -7.059    -0.050     (0)
   NaF             8.228e-09   8.228e-09     -8.085    -8.085     0.000     (0)
   HAsO3F-         2.345e-09   2.089e-09     -8.630    -8.680    -0.050     (0)
   HF              1.261e-09   1.261e-09     -8.899    -8.899     0.000     (0)
   ZnF+            8.280e-11   7.378e-11    -10.082   -10.132    -0.050     (0)
   AlF2+           7.587e-12   6.760e-12    -11.120   -11.170    -0.050     (0)
   BaF+            3.894e-12   3.470e-12    -11.410   -11.460    -0.050     (0)
   PbF+            1.647e-12   1.467e-12    -11.783   -11.833    -0.050     (0)
   AlF3            1.572e-12   1.572e-12    -11.804   -11.804     0.000     (0)
   AlF+2           1.453e-12   9.195e-13    -11.838   -12.036    -0.199     (0)
   CuF+            1.696e-13   1.511e-13    -12.771   -12.821    -0.050     (0)
   MnF+            1.071e-14   9.543e-15    -13.970   -14.020    -0.050     (0)
   AlF4-           8.182e-15   7.291e-15    -14.087   -14.137    -0.050     (0)
   HF2-            6.333e-15   5.643e-15    -14.198   -14.249    -0.050     (0)
   BF2(OH)2-       4.100e-15   3.653e-15    -14.387   -14.437    -0.050     (0)
   VO2F            7.592e-16   7.592e-16    -15.120   -15.120     0.000     (0)
   PbF2            1.651e-16   1.651e-16    -15.782   -15.782     0.000     (0)
   FeF+2           1.727e-17   1.093e-17    -16.763   -16.961    -0.199     (0)
   VO2F2-          4.538e-18   4.044e-18    -17.343   -17.393    -0.050     (0)
   H2F2            3.957e-18   3.957e-18    -17.403   -17.403     0.000     (0)
   FeF2+           3.666e-18   3.266e-18    -17.436   -17.486    -0.050     (0)
   BF3OH-          1.450e-20   1.292e-20    -19.839   -19.889    -0.050     (0)
   FeF+            1.630e-21   1.452e-21    -20.788   -20.838    -0.050     (0)
   VOF+            5.209e-27   4.641e-27    -26.283   -26.333    -0.050     (0)
   BF4-            7.971e-28   7.103e-28    -27.098   -27.149    -0.050     (0)
   VOF2            5.165e-29   5.165e-29    -28.287   -28.287     0.000     (0)
Fe(2)         1.264e-17
   FeHCO3+         6.462e-18   5.758e-18    -17.190   -17.240    -0.050     (0)
   Fe+2            5.311e-18   3.432e-18    -17.275   -17.464    -0.190     (0)
   FeCO3           6.212e-19   6.212e-19    -18.207   -18.207     0.000     (0)
   FeSO4           1.939e-19   1.939e-19    -18.712   -18.712     0.000     (0)
   FeOH+           2.713e-20   2.417e-20    -19.567   -19.617    -0.050     (0)
   FeCl+           1.914e-20   1.705e-20    -19.718   -19.768    -0.050     (0)
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   FeF+            1.630e-21   1.452e-21   -20.788   -20.838    -0.050      (0)
   Fe(OH)2         4.276e-24   4.276e-24   -23.369   -23.369     0.000      (0)
   FeCl2           6.241e-25   6.241e-25   -24.205   -24.205     0.000      (0)
   Fe(OH)3-        4.254e-27   3.790e-27   -26.371   -26.421    -0.050      (0)
   FeCl4-2         1.335e-28   8.387e-29   -27.874   -28.076    -0.202      (0)
   Fe(OH)4-2       1.344e-34   8.441e-35   -33.872   -34.074    -0.202      (0)
Fe(3)         4.856e-07
   Fe(OH)3         4.359e-07   4.359e-07    -6.361    -6.361     0.000      (0)
   Fe(OH)2+        4.696e-08   4.184e-08    -7.328    -7.378    -0.050      (0)
   Fe(OH)4-        2.736e-09   2.438e-09    -8.563    -8.613    -0.050      (0)
   FeOH+2          8.967e-12   5.675e-12   -11.047   -11.246    -0.199      (0)
   FeCO3+          8.154e-13   7.266e-13   -12.089   -12.139    -0.050      (0)
   Fe+3            9.716e-17   3.947e-17   -16.012   -16.404    -0.391      (0)
   FeF+2           1.727e-17   1.093e-17   -16.763   -16.961    -0.199      (0)
   FeF2+           3.666e-18   3.266e-18   -17.436   -17.486    -0.050      (0)
   FeSO4+          1.528e-18   1.361e-18   -17.816   -17.866    -0.050      (0)
   FeCl2+          2.779e-19   2.476e-19   -18.556   -18.606    -0.050      (0)
   FeNO3+2         1.163e-19   7.362e-20   -18.934   -19.133    -0.199      (0)
   FeCl+2          7.087e-20   4.485e-20   -19.150   -19.348    -0.199      (0)
   Fe(SO4)2-       9.206e-21   8.203e-21   -20.036   -20.086    -0.050      (0)
   Fe2(OH)2+4      5.123e-21   8.667e-22   -20.290   -21.062    -0.772      (0)
   Fe3(OH)4+5      1.167e-25   7.577e-27   -24.933   -26.120    -1.188      (0)
   FeCl4-          1.554e-26   1.385e-26   -25.809   -25.859    -0.050      (0)
   FeNO2+2         1.327e-32   8.400e-33   -31.877   -32.076    -0.199      (0)
H(0)          0.000e+00
   H2              0.000e+00   0.000e+00   -45.963   -45.962     0.001      (0)
Hg(1)         5.874e-15
   Hg2+2           2.937e-15   1.845e-15   -14.532   -14.734    -0.202      (0)
Hg(2)         3.199e-09
   Hg+2            3.199e-09   2.039e-09    -8.495    -8.691    -0.196      (0)
Mg            4.372e-04
   Mg+2            3.985e-04   2.641e-04    -3.400    -3.578    -0.179      (0)
   MgSO4           2.514e-05   2.514e-05    -4.600    -4.600     0.000      (0)
   MgHCO3+         1.100e-05   9.806e-06    -4.958    -5.009    -0.050      (0)
   MgCl+           1.578e-06   1.406e-06    -5.802    -5.852    -0.050      (0)
   MgCO3           8.905e-07   8.905e-07    -6.050    -6.050     0.000      (0)
   MgF+            1.321e-07   1.177e-07    -6.879    -6.929    -0.050      (0)
   MgB(OH)4+       1.710e-08   1.524e-08    -7.767    -7.817    -0.050      (0)
   Mg4(OH)4+4      1.258e-24   2.128e-25   -23.900   -24.672    -0.772      (0)
Mn(2)         3.441e-11
   Mn+2            2.971e-11   1.920e-11   -10.527   -10.717    -0.190      (0)
   MnCO3           2.142e-12   2.142e-12   -11.669   -11.669     0.000      (0)
   MnSO4           1.689e-12   1.689e-12   -11.772   -11.772     0.000      (0)
   MnHCO3+         5.244e-13   4.673e-13   -12.280   -12.330    -0.050      (0)
   MnCl+           3.129e-13   2.788e-13   -12.505   -12.555    -0.050      (0)
   MnOH+           1.233e-14   1.099e-14   -13.909   -13.959    -0.050      (0)
   MnF+            1.071e-14   9.543e-15   -13.970   -14.020    -0.050      (0)
   MnNO3+          6.370e-15   5.676e-15   -14.196   -14.246    -0.050      (0)
   MnSeO4          7.006e-16   7.006e-16   -15.155   -15.155     0.000      (0)
   MnCl3-          3.179e-18   2.833e-18   -17.498   -17.548    -0.050      (0)
   Mn(NO3)2        2.660e-18   2.660e-18   -17.575   -17.575     0.000      (0)
   Mn(OH)2         6.007e-19   6.007e-19   -18.221   -18.221     0.000      (0)
   Mn(OH)3-        1.408e-23   1.255e-23   -22.851   -22.901    -0.050      (0)
   Mn2(OH)3+       5.751e-24   5.125e-24   -23.240   -23.290    -0.050      (0)
   Mn2OH+3         6.236e-25   2.261e-25   -24.205   -24.646    -0.441      (0)
   Mn(OH)4-2       3.767e-30   2.366e-30   -29.424   -29.626    -0.202      (0)
Mn(3)         1.694e-22
   Mn+3            1.694e-22   6.142e-23   -21.771   -22.212    -0.441      (0)
Mn(6)         1.418e-14
   MnO4-2          1.418e-14   8.907e-15   -13.848   -14.050    -0.202      (0)
Mn(7)         5.289e-10
   MnO4-           5.289e-10   4.704e-10    -9.277    -9.328    -0.051      (0)
Mo            2.090e-08
   MoO4-2          2.090e-08   1.323e-08    -7.680    -7.879    -0.199      (0)
N(-03)        0.000e+00
   N3-             0.000e+00   0.000e+00  -113.973  -114.023    -0.050      (0)
   HN3             0.000e+00   0.000e+00  -116.672  -116.672     0.000      (0)
   ZnN3+           0.000e+00   0.000e+00  -120.079  -120.129    -0.050      (0)
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   CdN3+           0.000e+00   0.000e+00  -121.399  -121.449    -0.050     (0)
   Zn(N3)2         0.000e+00   0.000e+00  -233.398  -233.398     0.000     (0)
   Cd(N3)2         0.000e+00   0.000e+00  -234.508  -234.508     0.000     (0)
   Cd(N3)3-        0.000e+00   0.000e+00  -347.815  -347.865    -0.050     (0)
   Cd(N3)4-2       0.000e+00   0.000e+00  -461.318  -461.520    -0.202     (0)
N(-3)         0.000e+00
   NH4+            0.000e+00   0.000e+00   -70.651   -70.704    -0.053     (0)
   NH3             0.000e+00   0.000e+00   -72.592   -72.592     0.000     (0)
   Zn(NH3)+2       0.000e+00   0.000e+00   -76.889   -77.088    -0.199     (0)
   CuNH3+2         0.000e+00   0.000e+00   -77.640   -77.839    -0.199     (0)
   Cd(NH3)+2       0.000e+00   0.000e+00   -78.787   -78.986    -0.199     (0)
   NH4SO4-         0.000e+00   0.000e+00   -82.402   -82.452    -0.050     (0)
   Cu(NH3)2+2      0.000e+00   0.000e+00  -146.799  -146.997    -0.199     (0)
   Ni(NH3)2+2      0.000e+00   0.000e+00  -146.993  -147.192    -0.199     (0)
   Zn(NH3)2+2      0.000e+00   0.000e+00  -147.275  -147.473    -0.199     (0)
   Cd(NH3)2+2      0.000e+00   0.000e+00  -149.017  -149.215    -0.199     (0)
   Cu(NH3)3+2      0.000e+00   0.000e+00  -216.570  -216.769    -0.199     (0)
   Zn(NH3)3+2      0.000e+00   0.000e+00  -217.660  -217.859    -0.199     (0)
   Zn(NH3)4+2      0.000e+00   0.000e+00  -288.320  -288.518    -0.199     (0)
   Cd(NH3)4+2      0.000e+00   0.000e+00  -291.778  -291.976    -0.199     (0)
   Ni(NH3)6+2      0.000e+00   0.000e+00  -433.676  -433.875    -0.199     (0)
N(0)          1.469e-29
   N2              7.346e-30   7.346e-30   -29.134   -29.134     0.000     (0)
N(3)          1.698e-19
   NO2-            1.698e-19   1.507e-19   -18.770   -18.822    -0.052     (0)
   HNO2            1.144e-23   1.144e-23   -22.942   -22.942     0.000     (0)
   CdNO2+          4.726e-26   4.212e-26   -25.325   -25.376    -0.050     (0)
   CuNO2+          9.140e-27   8.145e-27   -26.039   -26.089    -0.050     (0)
   FeNO2+2         1.327e-32   8.400e-33   -31.877   -32.076    -0.199     (0)
   Cu(NO2)2        0.000e+00   0.000e+00   -43.901   -43.901     0.000     (0)
N(5)          2.111e-04
   NO3-            2.102e-04   1.865e-04    -3.677    -3.729    -0.052     (0)
   CaNO3+          9.753e-07   8.690e-07    -6.011    -6.061    -0.050     (0)
   BaNO3+          4.535e-10   4.041e-10    -9.343    -9.393    -0.050     (0)
   NiNO3+          4.273e-11   3.808e-11   -10.369   -10.419    -0.050     (0)
   PbNO3+          4.166e-11   3.712e-11   -10.380   -10.430    -0.050     (0)
   HNO3            4.341e-13   4.341e-13   -12.362   -12.362     0.000     (0)
   MnNO3+          6.370e-15   5.676e-15   -14.196   -14.246    -0.050     (0)
   Ni(NO3)2        4.510e-15   4.510e-15   -14.346   -14.346     0.000     (0)
   Mn(NO3)2        2.660e-18   2.660e-18   -17.575   -17.575     0.000     (0)
   FeNO3+2         1.163e-19   7.362e-20   -18.934   -19.133    -0.199     (0)
Na            4.710e-03
   Na+             4.675e-03   4.165e-03    -2.330    -2.380    -0.050     (0)
   NaHCO3          1.905e-05   1.905e-05    -4.720    -4.720     0.000     (0)
   NaSO4-          1.101e-05   9.810e-06    -4.958    -5.008    -0.050     (0)
   NaCl            4.993e-06   4.993e-06    -5.302    -5.302     0.000     (0)
   NaCO3-          5.213e-08   4.646e-08    -7.283    -7.333    -0.050     (0)
   NaF             8.228e-09   8.228e-09    -8.085    -8.085     0.000     (0)
   NaB(OH)4        5.669e-09   5.669e-09    -8.247    -8.247     0.000     (0)
   NaOH            1.542e-10   1.542e-10    -9.812    -9.812     0.000     (0)
   NaAlO2          1.285e-11   1.285e-11   -10.891   -10.891     0.000     (0)
Ni            1.298e-07
   Ni+2            1.257e-07   8.126e-08    -6.901    -7.090    -0.190     (0)
   NiSO4           3.976e-09   3.976e-09    -8.401    -8.401     0.000     (0)
   NiCl+           6.621e-11   5.900e-11   -10.179   -10.229    -0.050     (0)
   NiNO3+          4.273e-11   3.808e-11   -10.369   -10.419    -0.050     (0)
   NiSeO4          5.153e-12   5.153e-12   -11.288   -11.288     0.000     (0)
   Ni(OH)2         4.122e-13   4.122e-13   -12.385   -12.385     0.000     (0)
   Ni(NO3)2        4.510e-15   4.510e-15   -14.346   -14.346     0.000     (0)
   Ni(OH)3-        1.042e-16   9.285e-17   -15.982   -16.032    -0.050     (0)
   Ni2OH+3         8.093e-18   2.934e-18   -17.092   -17.533    -0.441     (0)
   Ni4(OH)4+4      1.323e-26   2.239e-27   -25.878   -26.650    -0.772     (0)
   Ni(NH3)2+2      0.000e+00   0.000e+00  -146.993  -147.192    -0.199     (0)
   Ni(NH3)6+2      0.000e+00   0.000e+00  -433.676  -433.875    -0.199     (0)
O(0)          1.045e+00
   O2              5.225e-01   5.242e-01    -0.282    -0.281     0.001     (0)
Pb(2)         1.790e-07
   PbCO3           1.511e-07   1.511e-07    -6.821    -6.821     0.000     (0)
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   Pb+2            1.864e-08   1.180e-08     -7.730    -7.928    -0.199     (0)
   PbOH+           5.949e-09   5.301e-09     -8.226    -8.276    -0.050     (0)
   PbCl+           2.606e-09   2.322e-09     -8.584    -8.634    -0.050     (0)
   Pb(CO3)2-2      5.357e-10   3.365e-10     -9.271    -9.473    -0.202     (0)
   PbCl2           6.028e-11   6.028e-11    -10.220   -10.220     0.000     (0)
   Pb(OH)2         4.753e-11   4.753e-11    -10.323   -10.323     0.000     (0)
   PbNO3+          4.166e-11   3.712e-11    -10.380   -10.430    -0.050     (0)
   PbF+            1.647e-12   1.467e-12    -11.783   -11.833    -0.050     (0)
   PbCl3-          2.314e-13   2.062e-13    -12.636   -12.686    -0.050     (0)
   Pb(OH)3-        1.202e-14   1.071e-14    -13.920   -13.970    -0.050     (0)
   Pb2OH+3         3.442e-15   1.248e-15    -14.463   -14.904    -0.441     (0)
   PbCl4-2         1.423e-15   8.938e-16    -14.847   -15.049    -0.202     (0)
   PbF2            1.651e-16   1.651e-16    -15.782   -15.782     0.000     (0)
   Pb3(OH)4+2      8.404e-19   5.318e-19    -18.076   -18.274    -0.199     (0)
   Pb4(OH)4+4      3.708e-23   6.274e-24    -22.431   -23.202    -0.772     (0)
   PbClO3+         1.107e-28   9.865e-29    -27.956   -28.006    -0.050     (0)
   Pb6(OH)8+4      2.650e-32   4.483e-33    -31.577   -32.348    -0.772     (0)
   Pb(ClO3)2       0.000e+00   0.000e+00    -48.155   -48.155     0.000     (0)
Pb(4)         6.661e-37
   Pb+4            6.661e-37   1.127e-37    -36.176   -36.948    -0.772     (0)
S(-2)         0.000e+00
   HS-             0.000e+00   0.000e+00   -148.470  -148.521    -0.051     (0)
   H2S             0.000e+00   0.000e+00   -148.863  -148.863     0.000     (0)
   S-2             0.000e+00   0.000e+00   -153.900  -154.095    -0.196     (0)
   S2-2            0.000e+00   0.000e+00   -263.719  -263.921    -0.202     (0)
   HAsS2           0.000e+00   0.000e+00   -361.712  -361.712     0.000     (0)
   S3-2            0.000e+00   0.000e+00   -373.586  -373.788    -0.202     (0)
   S4-2            0.000e+00   0.000e+00   -483.680  -483.882    -0.202     (0)
   S5-2            0.000e+00   0.000e+00   -593.991  -594.193    -0.202     (0)
S(2)          0.000e+00
   S2O3-2          0.000e+00   0.000e+00   -154.306  -154.508    -0.202     (0)
   HS2O3-          0.000e+00   0.000e+00   -160.796  -160.846    -0.050     (0)
S(3)          0.000e+00
   S2O4-2          0.000e+00   0.000e+00   -139.381  -139.577    -0.196     (0)
S(4)          0.000e+00
   SO3-2           0.000e+00   0.000e+00    -49.727   -49.926    -0.199     (0)
   HSO3-           0.000e+00   0.000e+00    -49.996   -50.046    -0.050     (0)
   H2SO3           0.000e+00   0.000e+00    -55.416   -55.416     0.000     (0)
   SO2             0.000e+00   0.000e+00    -55.512   -55.512     0.000     (0)
   S2O6-2          0.000e+00   0.000e+00    -72.622   -72.824    -0.202     (0)
   S3O6-2          0.000e+00   0.000e+00   -184.971  -185.173    -0.202     (0)
   S4O6-2          0.000e+00   0.000e+00   -281.416  -281.618    -0.202     (0)
   S5O6-2          0.000e+00   0.000e+00   -406.739  -406.941    -0.202     (0)
S(5)          0.000e+00
   S2O5-2          0.000e+00   0.000e+00   -104.716  -104.918    -0.202     (0)
S(6)          6.521e-04
   SO4-2           5.675e-04   3.565e-04     -3.246    -3.448    -0.202     (0)
   CaSO4           4.840e-05   4.840e-05     -4.315    -4.315     0.000     (0)
   MgSO4           2.514e-05   2.514e-05     -4.600    -4.600     0.000     (0)
   NaSO4-          1.101e-05   9.810e-06     -4.958    -5.008    -0.050     (0)
   ZnSO4           2.119e-08   2.119e-08     -7.674    -7.674     0.000     (0)
   NiSO4           3.976e-09   3.976e-09     -8.401    -8.401     0.000     (0)
   HSO4-           1.798e-09   1.602e-09     -8.745    -8.795    -0.050     (0)
   CuSO4           4.216e-11   4.216e-11    -10.375   -10.375     0.000     (0)
   MnSO4           1.689e-12   1.689e-12    -11.772   -11.772     0.000     (0)
   CdSO4           4.314e-13   4.314e-13    -12.365   -12.365     0.000     (0)
   AlSO4+          2.038e-15   1.816e-15    -14.691   -14.741    -0.050     (0)
   VO2SO4-         2.793e-16   2.489e-16    -15.554   -15.604    -0.050     (0)
   Al(SO4)2-       5.640e-17   5.026e-17    -16.249   -16.299    -0.050     (0)
   FeSO4+          1.528e-18   1.361e-18    -17.816   -17.866    -0.050     (0)
   FeSO4           1.939e-19   1.939e-19    -18.712   -18.712     0.000     (0)
   H2SO4           6.725e-20   6.725e-20    -19.172   -19.172     0.000     (0)
   Fe(SO4)2-       9.206e-21   8.203e-21    -20.036   -20.086    -0.050     (0)
   VOSO4           2.706e-27   2.706e-27    -26.568   -26.568     0.000     (0)
   VSO4+           0.000e+00   0.000e+00    -48.650   -48.700    -0.050     (0)
   NH4SO4-         0.000e+00   0.000e+00    -82.402   -82.452    -0.050     (0)
S(7)          0.000e+00
   S2O8-2          0.000e+00   0.000e+00    -43.989   -44.191    -0.202     (0)
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S(8)           7.071e-29
   HSO5-            7.071e-29   6.301e-29   -28.151   -28.201    -0.050     (0)
Se(-2)         0.000e+00
   HSe-             0.000e+00   0.000e+00  -104.399  -104.449    -0.050     (0)
   H2Se             0.000e+00   0.000e+00  -107.979  -107.979     0.000     (0)
   Se-2             0.000e+00   0.000e+00  -111.842  -112.044    -0.202     (0)
Se(4)          5.120e-21
   SeO3-2           3.114e-21   1.956e-21   -20.507   -20.709    -0.202     (0)
   HSeO3-           2.007e-21   1.788e-21   -20.697   -20.748    -0.050     (0)
   H2SeO3           3.023e-26   3.023e-26   -25.520   -25.520     0.000     (0)
Se(6)          2.158e-07
   SeO4-2           2.158e-07   1.356e-07    -6.666    -6.868    -0.202     (0)
   ZnSeO4           5.939e-12   5.939e-12   -11.226   -11.226     0.000     (0)
   NiSeO4           5.153e-12   5.153e-12   -11.288   -11.288     0.000     (0)
   HSeO4-           5.757e-13   5.130e-13   -12.240   -12.290    -0.050     (0)
   CdSeO4           3.010e-14   3.010e-14   -13.521   -13.521     0.000     (0)
   MnSeO4           7.006e-16   7.006e-16   -15.155   -15.155     0.000     (0)
V(3)           1.754e-40
   V(OH)2+          1.754e-40   1.563e-40   -39.756   -39.806    -0.050     (0)
   VOH+2            0.000e+00   0.000e+00   -43.296   -43.494    -0.199     (0)
   V+3              0.000e+00   0.000e+00   -48.141   -48.582    -0.441     (0)
   VSO4+            0.000e+00   0.000e+00   -48.650   -48.700    -0.050     (0)
   V2(OH)2+4        0.000e+00   0.000e+00   -85.497   -86.269    -0.772     (0)
V(4)           1.391e-24
   VOOH+            1.343e-24   1.197e-24   -23.872   -23.922    -0.050     (0)
   VO+2             3.971e-26   2.513e-26   -25.401   -25.600    -0.199     (0)
   VOF+             5.209e-27   4.641e-27   -26.283   -26.333    -0.050     (0)
   VOSO4            2.706e-27   2.706e-27   -26.568   -26.568     0.000     (0)
   VOF2             5.165e-29   5.165e-29   -28.287   -28.287     0.000     (0)
   (VO)2(OH)2+2     0.000e+00   0.000e+00   -42.975   -43.174    -0.199     (0)
V(5)           3.641e-06
   VO3OH-2          2.116e-06   1.329e-06    -5.674    -5.876    -0.202     (0)
   H2VO4-           8.018e-07   7.145e-07    -6.096    -6.146    -0.050     (0)
   VO2(OH)2-        5.122e-07   4.564e-07    -6.291    -6.341    -0.050     (0)
   HVO4-2           2.106e-07   1.323e-07    -6.676    -6.878    -0.202     (0)
   VO(OH)3          2.031e-10   2.031e-10    -9.692    -9.692     0.000     (0)
   VO4-3            4.681e-13   1.642e-13   -12.330   -12.785    -0.455     (0)
   VO2+             2.061e-14   1.836e-14   -13.686   -13.736    -0.050     (0)
   VO2F             7.592e-16   7.592e-16   -15.120   -15.120     0.000     (0)
   VO2SO4-          2.793e-16   2.489e-16   -15.554   -15.604    -0.050     (0)
   VO2F2-           4.538e-18   4.044e-18   -17.343   -17.393    -0.050     (0)
Zn             5.059e-07
   Zn+2             4.376e-07   2.828e-07    -6.359    -6.548    -0.190     (0)
   ZnHCO3+          2.616e-08   2.331e-08    -7.582    -7.633    -0.050     (0)
   ZnSO4            2.119e-08   2.119e-08    -7.674    -7.674     0.000     (0)
   ZnOH+            7.752e-09   6.908e-09    -8.111    -8.161    -0.050     (0)
   ZnCO3            7.571e-09   7.571e-09    -8.121    -8.121     0.000     (0)
   ZnCl+            3.637e-09   3.241e-09    -8.439    -8.489    -0.050     (0)
   Zn(OH)Cl         1.234e-09   1.234e-09    -8.909    -8.909     0.000     (0)
   Zn(OH)2          6.588e-10   6.588e-10    -9.181    -9.181     0.000     (0)
   ZnF+             8.280e-11   7.378e-11   -10.082   -10.132    -0.050     (0)
   ZnCl2            2.582e-11   2.582e-11   -10.588   -10.588     0.000     (0)
   ZnSeO4           5.939e-12   5.939e-12   -11.226   -11.226     0.000     (0)
   ZnCl3-           1.091e-13   9.724e-14   -12.962   -13.012    -0.050     (0)
   Zn(OH)3-         5.103e-14   4.547e-14   -13.292   -13.342    -0.050     (0)
   ZnCl4-2          8.002e-15   5.027e-15   -14.097   -14.299    -0.202     (0)
   Zn(OH)4-2        2.748e-19   1.726e-19   -18.561   -18.763    -0.202     (0)
   ZnClO4+          2.119e-24   1.888e-24   -23.674   -23.724    -0.050     (0)
   Zn(NH3)+2        0.000e+00   0.000e+00   -76.889   -77.088    -0.199     (0)
   ZnN3+            0.000e+00   0.000e+00  -120.079  -120.129    -0.050     (0)
   Zn(NH3)2+2       0.000e+00   0.000e+00  -147.275  -147.473    -0.199     (0)
   Zn(NH3)3+2       0.000e+00   0.000e+00  -217.660  -217.859    -0.199     (0)
   Zn(N3)2          0.000e+00   0.000e+00  -233.398  -233.398     0.000     (0)
   Zn(NH3)4+2       0.000e+00   0.000e+00  -288.320  -288.518    -0.199     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(298 K,   1 atm)
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Ahlfeldite      -23.31    -27.81   -4.50  NiSeO3:2H2O
Al             -141.96      7.96  149.91  Al
Al(g)          -192.66      7.96  200.62  Al
Al2(SO4)3       -57.85    -38.95   18.90  Al2(SO4)3
Al2(SO4)3:6H2O  -40.53    -38.97    1.56  Al2(SO4)3:6H2O
Alabandite     -151.47   -151.89   -0.42  MnS
AlF3            -11.24    -28.50  -17.27  AlF3
Alstonite        -2.47      0.12    2.58  BaCa(CO3)2
Anglesite        -3.47    -11.38   -7.91  PbSO4
Anhydrite        -2.13     -6.48   -4.35  CaSO4
Antarcticite    -11.48     -7.39    4.09  CaCl2:6H2O
Antlerite       -10.65     -1.92    8.73  Cu3(SO4)(OH)4
Aragonite        -0.15      1.82    1.97  CaCO3
Arsenolite     -141.06   -160.90  -19.84  As2O3
Arsenopyrite   -286.76   -301.21  -14.45  FeAsS
Artinite         -7.24     12.38   19.63  Mg2CO3(OH)2:3H2O
As             -122.92    -80.24   42.68  As
As2O5          -102.26   -100.12    2.14  As2O5
As4O6(cubi)    -281.98   -321.81  -39.82  As4O6
As4O6(mono)    -281.76   -321.81  -40.05  As4O6
Atacamite       -11.66      2.61   14.26  Cu4Cl2(OH)6
Azurite         -12.57     -3.45    9.12  Cu3(CO3)2(OH)2
B              -113.58     -4.02  109.56  B
B(g)           -204.86     -4.02  200.84  B
B2O3            -14.02     -8.47    5.55  B2O3
Ba             -132.96      8.28  141.23  Ba
Ba(OH)2:8H2O    -16.39      8.10   24.49  Ba(OH)2:8H2O
BaCl2           -13.13    -10.90    2.23  BaCl2
BaCl2:2H2O      -11.11    -10.90    0.21  BaCl2:2H2O
BaCl2:H2O       -11.73    -10.90    0.82  BaCl2:H2O
BaMnO4          -10.52    -20.61  -10.09  BaMnO4
BaO             -39.66      8.14   47.80  BaO
Barite            0.00    -10.01  -10.01  BaSO4
Barytocalcite    -2.63      0.12    2.74  BaCa(CO3)2
BaS            -163.98   -147.73   16.24  BaS
BaSeO3          -20.70    -27.27   -6.57  BaSeO3
BaSeO4           -5.97    -13.43   -7.46  BaSeO4
Bassanite        -2.78     -6.48   -3.71  CaSO4:0.5H2O
BF3(g)          -37.50    -40.48   -2.98  BF3
Birnessite       19.19    -66.36  -85.55  Mn8O14:5H2O
Bischofite      -12.33     -7.93    4.39  MgCl2:6H2O
Bixbyite          0.64     -0.33   -0.96  Mn2O3
Bloedite        -12.77    -15.25   -2.48  Na2Mg(SO4)2:4H2O
Boehmite          0.19      7.74    7.55  AlO2H
Borax           -19.08     -7.04   12.04  Na2(B4O5(OH)4):8H2O
Boric_acid       -4.08     -4.24   -0.16  B(OH)3
Bornite        -571.41   -673.94 -102.53  Cu5FeS4
Brochantite     -11.93      3.49   15.42  Cu4(SO4)(OH)6
Brucite          -5.17     11.12   16.28  Mg(OH)2
Bunsenite        -4.85      7.61   12.46  NiO
Burkeite        -25.81    -16.32    9.49  Na6CO3(SO4)2
C               -73.71     -9.56   64.15  C
C(g)           -191.33     -9.56  181.77  C
Ca             -128.02     11.81  139.83  Ca
Ca(g)          -153.26     11.81  165.07  Ca
Ca2Al2O5:8H2O   -20.77     38.80   59.57  Ca2Al2O5:8H2O
Ca2Cl2(OH)2:H2O -21.99      4.30   26.29  Ca2Cl2(OH)2:H2O
Ca2V2O7          -6.62    -46.33  -39.71  Ca2V2O7
Ca3(AsO4)2      -82.92    -65.12   17.80  Ca3(AsO4)2
Ca3Al2O6        -62.54     50.50  113.03  Ca3Al2O6
Ca3V2O8         -16.34    -34.66  -18.32  Ca3V2O8
Ca4Al2Fe2O10    -67.03     73.45  140.48  Ca4Al2Fe2O10
Ca4Al2O7:13H2O  -45.14     62.11  107.25  Ca4Al2O7:13H2O
Ca4Al2O7:19H2O  -41.59     62.09  103.68  Ca4Al2O7:19H2O
Ca4Cl2(OH)6:13H2O -40.75     27.57   68.33  Ca4Cl2(OH)6:13H2O
CaAl2O4         -19.75     27.16   46.91  CaAl2O4
CaAl2O4:10H2O   -10.87     27.12   37.99  CaAl2O4:10H2O
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CaAl4O7         -25.94     42.65   68.59  CaAl4O7
Cadmoselite     -87.11   -120.97  -33.86  CdSe
Calcite           0.00      1.82    1.82  CaCO3
Calomel          -1.23    -19.07  -17.83  Hg2Cl2
CaSeO3:2H2O     -19.11    -23.75   -4.63  CaSeO3:2H2O
CaSeO4           -6.81     -9.90   -3.09  CaSeO4
CaSO4:0.5H2O(beta)  -2.95     -6.48   -3.54  CaSO4:0.5H2O
CaV2O6           -6.64    -58.00  -51.36  CaV2O6
Cd              -50.68      5.92   56.59  Cd
Cd(BO2)2        -12.52     -2.69    9.83  Cd(BO2)2
Cd(g)           -64.21      5.92   70.13  Cd
Cd(OH)2          -7.96      5.77   13.73  Cd(OH)2
Cd(OH)Cl         -7.28     -3.74    3.54  Cd(OH)Cl
Cd3(AsO4)2      -86.86    -82.79    4.06  Cd3(AsO4)2
Cd3(SO4)(OH)4   -23.40     -0.83   22.57  Cd3(SO4)(OH)4
Cd3(SO4)2(OH)2  -25.69    -18.97    6.72  Cd3(SO4)2(OH)2
CdCl2           -12.60    -13.26   -0.66  CdCl2
CdCl2(NH3)2    -149.64   -158.44   -8.80  CdCl2(NH3)2
CdCl2(NH3)4    -296.81   -303.62   -6.82  CdCl2(NH3)4
CdCl2(NH3)6    -444.05   -448.81   -4.76  CdCl2(NH3)6
CdCl2:H2O       -11.58    -13.26   -1.68  CdCl2:H2O
CdF2            -17.23    -18.39   -1.16  CdF2
CdS            -134.18   -150.09  -15.92  CdS
CdSeO3          -20.81    -29.63   -8.82  CdSeO3
CdSeO4          -13.57    -15.79   -2.22  CdSeO4
CdSO4           -12.25    -12.37   -0.12  CdSO4
CdSO4:2.667H2O  -10.57    -12.38   -1.81  CdSO4:2.667H2O
CdSO4:H2O       -10.71    -12.38   -1.66  CdSO4:H2O
Cerussite         0.17     -3.07   -3.24  PbCO3
CH4(g)         -150.54   -153.38   -2.84  CH4
Chalcanthite    -10.13    -12.76   -2.63  CuSO4:5H2O
Chalcocite     -147.68   -182.43  -34.74  Cu2S
Chalcocyanite   -15.65    -12.74    2.91  CuSO4
Chalcopyrite   -276.49   -309.09  -32.60  CuFeS2
Chloromagnesite -29.73     -7.91   21.82  MgCl2
Cinnabar       -110.87   -149.86  -38.99  HgS
Cl2(g)          -22.17    -19.17    2.99  Cl2
Claudetite     -141.11   -160.90  -19.80  As2O3
Clausthalite    -83.71   -119.97  -36.27  PbSe
Clinochalcomenite -23.20    -30.00   -6.80  CuSeO3:2H2O
CO(g)           -48.38    -51.38   -3.00  CO
CO2(g)           -2.01     -9.84   -7.83  CO2
Colemanite      -23.60     -2.09   21.51  Ca2B6O11:5H2O
Corundum         -2.80     15.49   18.29  Al2O3
Cotunnite        -7.41    -12.26   -4.85  PbCl2
Covellite      -127.60   -150.46  -22.86  CuS
Cu              -25.94      5.55   31.50  Cu
Cu(g)           -78.10      5.55   83.66  Cu
CuCl2           -17.34    -13.62    3.72  CuCl2
CuF             -32.44    -25.36    7.08  CuF
CuF2            -18.13    -18.75   -0.62  CuF2
CuF2:2H2O       -14.21    -18.76   -4.55  CuF2:2H2O
Cuprite         -24.65    -26.56   -1.91  Cu2O
CuSeO3          -22.32    -30.00   -7.68  CuSeO3
Dawsonite        -1.47      2.87    4.34  NaAlCO3(OH)2
Delafossite      -1.20     -7.63   -6.44  CuFeO2
Diaspore          0.60      7.74    7.15  AlHO2
Dolomite          0.63      3.10    2.47  CaMg(CO3)2
Dolomite-dis     -0.91      3.10    4.01  CaMg(CO3)2
Dolomite-ord      0.64      3.10    2.46  CaMg(CO3)2
Downeyite       -28.62    -35.41   -6.79  SeO2
Epsomite         -5.09     -7.05   -1.96  MgSO4:7H2O
Ettringite      -31.54     30.93   62.46  Ca6Al2(SO4)3(OH)12:26H2O
F2(g)           -80.02    -24.31   55.71  F2
Fe              -61.64     -2.62   59.02  Fe
Fe(OH)2         -16.66     -2.77   13.89  Fe(OH)2
Fe(OH)3           0.00      5.64    5.64  Fe(OH)3
Fe2(SO4)3       -46.20    -43.15    3.05  Fe2(SO4)3
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FeF2            -24.51    -26.93   -2.42  FeF2
FeF3            -11.35    -30.60  -19.26  FeF3
FeO             -16.29     -2.76   13.52  FeO
Ferrite-Ca        1.46     22.96   21.50  CaFe2O4
Ferrite-Cu        6.42     16.70   10.28  CuFe2O4
Ferrite-Dicalcium -22.17     34.63   56.80  Ca2Fe2O5
Ferrite-Mg        1.39     22.41   21.02  MgFe2O4
Ferrite-Zn        7.74     19.44   11.70  ZnFe2O4
Ferroselite    -167.09   -247.91  -80.82  FeSe2
FeSO4           -23.52    -20.91    2.61  FeSO4
FeV2O4         -336.39    -55.83  280.56  FeV2O4
Fluorite         -2.43    -12.50  -10.07  CaF2
Frankdicksonite -10.27    -16.03   -5.76  BaF2
Galena         -134.22   -149.10  -14.88  PbS
Gaylussite       -9.26      1.90   11.16  CaNa2(CO3)2:5H2O
Gibbsite          0.00      7.74    7.74  Al(OH)3
Glauberite       -9.22    -14.69   -5.47  Na2Ca(SO4)2
Goethite          5.11      5.64    0.53  FeOOH
Gypsum           -1.96     -6.49   -4.53  CaSO4:2H2O
H2(g)           -42.86    -45.96   -3.10  H2
H2O(g)           -1.59     -0.00    1.59  H2O
H2S(g)         -147.88   -155.87   -7.99  H2S
Halite           -6.11     -4.55    1.56  NaCl
Hausmannite      -6.49      3.66   10.14  Mn3O4
HCl(g)          -15.82     -9.52    6.30  HCl
Heazlewoodite  -316.95   -288.77   28.18  Ni3S2
Hematite         11.22     11.29    0.08  Fe2O3
Hercynite       -16.08     12.73   28.80  FeAl2O4
Hexahydrite      -5.32     -7.05   -1.73  MgSO4:6H2O
Hg(g)           -13.58      6.15   19.73  Hg
Hg(l)            -7.99      6.15   14.14  Hg
Hg2SeO3         -21.23    -35.44  -14.21  Hg2SeO3
Hg2SO4          -12.05    -18.18   -6.13  Hg2SO4
HgSeO3          -15.50    -29.40  -13.90  HgSeO3
Huntite          -4.56      5.66   10.22  CaMg3(CO3)4
Hydroboracite   -23.00     -2.64   20.36  MgCaB6O11:6H2O
Hydrocerussite   -1.22      0.62    1.85  Pb3(CO3)2(OH)2
Hydromagnesite  -14.53     16.21   30.74  Mg5(CO3)4(OH)2:4H2O
Hydrophilite    -19.11     -7.36   11.75  CaCl2
Hydrozincite     -9.25     21.06   30.31  Zn5(OH)6(CO3)2
Ice              -0.14     -0.00    0.14  H2O
Jarosite-Na      -8.95    -14.40   -5.45  NaFe3(SO4)2(OH)6
Karelianite     -63.01    -53.07    9.95  V2O3
Katoite         -28.47     50.47   78.94  Ca3Al2H12O12
Kieserite        -6.76     -7.03   -0.27  MgSO4:H2O
Klockmannite    -79.71   -121.33  -41.62  CuSe
Krutaite       -140.52   -248.21 -107.70  CuSe2
Lammerite       -85.44    -83.88    1.55  Cu3(AsO4)2
Lanarkite        -4.12     -4.61   -0.48  Pb2(SO4)O
Lansfordite      -3.58      1.26    4.84  MgCO3:5H2O
Lawrencite      -30.85    -21.80    9.05  FeCl2
Lime            -20.90     11.67   32.57  CaO
Litharge         -5.86      6.77   12.64  PbO
Magnesite        -1.00      1.28    2.27  MgCO3
Magnetite        -1.89      8.53   10.42  Fe3O4
Malachite        -4.92      0.98    5.90  Cu2CO3(OH)2
Manganite         0.00     -0.16   -0.16  MnO(OH)
Manganosite     -13.93      3.98   17.92  MnO
Massicot         -6.05      6.77   12.82  PbO
Matlockite       -5.40    -14.83   -9.43  PbFCl
Mayenite       -245.69    248.46  494.15  Ca12Al14O33
Melanterite     -18.54    -20.94   -2.40  FeSO4:7H2O
Metacinnabar   -111.24   -149.86  -38.62  HgS
Mg             -111.26     11.26  122.52  Mg
Mg(g)          -130.98     11.26  142.25  Mg
Mg1.25SO4(OH)0.5:0.5H2O  -9.44     -4.25    5.20  Mg1.25SO4(OH)0.5:0.5H2O
Mg1.5SO4(OH)    -10.68     -1.47    9.21  Mg1.5SO4(OH)
Mg2V2O7         -16.52    -47.43  -30.90  Mg2V2O7
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MgCl2:2H2O      -20.65     -7.92   12.73  MgCl2:2H2O
MgCl2:4H2O      -15.23     -7.93    7.30  MgCl2:4H2O
MgCl2:H2O       -23.99     -7.91   16.07  MgCl2:H2O
MgOHCl          -14.29      1.60   15.89  MgOHCl
MgSeO3          -25.96    -24.29    1.67  MgSeO3
MgSeO3:6H2O     -20.88    -24.31   -3.44  MgSeO3:6H2O
MgSO4           -11.85     -7.03    4.83  MgSO4
MgV2O6          -12.70    -58.55  -45.85  MgV2O6
Millerite      -140.20   -148.26   -8.06  NiS
Minium          -10.27      5.99   16.26  Pb3O4
Mirabilite       -7.09     -8.25   -1.15  Na2SO4:10H2O
Mn              -78.81      4.12   82.93  Mn
Mn(OH)2(am)     -11.33      3.98   15.31  Mn(OH)2
Mn(OH)3          -6.51     -0.17    6.34  Mn(OH)3
MnCl2:2H2O      -19.05    -15.06    4.00  MnCl2:2H2O
MnCl2:4H2O      -17.82    -15.07    2.75  MnCl2:4H2O
MnCl2:H2O       -20.59    -15.05    5.54  MnCl2:H2O
MnO2(gamma)       3.74    -12.38  -16.13  MnO2
MnSe           -112.06   -122.76  -10.70  MnSe
MnSeO3          -24.16    -31.43   -7.27  MnSeO3
MnSeO3:2H2O     -25.10    -31.43   -6.33  MnSeO3:2H2O
MnSO4           -16.77    -14.16    2.61  MnSO4
MnV2O6          -13.61    -65.68  -52.08  MnV2O6
Mo             -131.43    -22.16  109.27  Mo
Molysite        -36.37    -22.90   13.47  FeCl3
Monohydrocalcite  -0.86      1.82    2.68  CaCO3:H2O
Monteponite      -9.32      5.78   15.09  CdO
Montroydite       3.57      6.01    2.44  HgO
Morenosite       -8.50    -10.57   -2.06  NiSO4:7H2O
MoSe2          -220.80   -275.92  -55.12  MoSe2
N2(g)           -25.96    -29.13   -3.18  N2
Na              -62.33      5.04   67.37  Na
Na(g)           -75.82      5.04   80.86  Na
Na2CO3          -11.07      0.10   11.16  Na2CO3
Na2CO3:7H2O      -9.87      0.07    9.94  Na2CO3:7H2O
Na2O            -57.48      9.94   67.42  Na2O
Na2Se          -128.63   -116.80   11.83  Na2Se
Na2Se2         -182.33   -243.69  -61.35  Na2Se2
Na3H(SO4)2      -20.50    -21.39   -0.89  Na3H(SO4)2
Na4Ca(SO4)3:2H2O -17.01    -22.91   -5.89  Na4Ca(SO4)3:2H2O
NaFeO2           -9.27     10.61   19.88  NaFeO2
Nahcolite        -4.73     -4.88   -0.14  NaHCO3
Nantokite       -16.03    -22.79   -6.77  CuCl
Natron           -9.53      0.06    9.59  Na2CO3:10H2O
Nesquehonite     -4.02      1.27    5.29  MgCO3:3H2O
NH3(g)          -74.39    -72.59    1.80  NH3
NH4HSe         -177.28   -199.34  -22.06  NH4HSe
Ni              -43.23      7.75   50.98  Ni
Ni(OH)2          -5.14      7.61   12.75  Ni(OH)2
Nickelbischofite -14.60    -11.45    3.15  NiCl2:6H2O
NiCl2           -20.02    -11.42    8.60  NiCl2
NiCl2:2H2O      -15.35    -11.43    3.92  NiCl2:2H2O
NiCl2:4H2O      -15.29    -11.44    3.85  NiCl2:4H2O
NiCO3            -5.75     -2.23    3.51  NiCO3
NiF2            -17.38    -16.56    0.82  NiF2
NiF2:4H2O       -12.51    -16.57   -4.06  NiF2:4H2O
NiSO4           -15.81    -10.54    5.28  NiSO4
NiSO4:6H2O(alpha)  -8.54    -10.56   -2.02  NiSO4:6H2O
Nitrobarite     -11.53    -14.02   -2.49  Ba(NO3)2
NO(g)           -26.84    -26.10    0.74  NO
NO2(g)          -19.36    -11.01    8.35  NO2
O2(g)             2.61     -0.28   -2.89  O2
Orpiment       -549.03   -628.51  -79.49  As2S3
Otavite          -2.30     -4.07   -1.77  CdCO3
Oxychloride-Mg  -13.13     12.70   25.83  Mg2Cl(OH)3:4H2O
Paralaurionite   -2.94     -2.75    0.20  PbClOH
Pb              -40.26      6.91   47.17  Pb
Pb(g)           -68.69      6.91   75.61  Pb
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Pb(N3)2(mono)  -227.60   -235.97   -8.37  Pb(N3)2
Pb(N3)2(orth)  -227.16   -235.97   -8.81  Pb(N3)2
Pb2Cl2CO3        -5.71    -15.33   -9.62  Pb2Cl2CO3
Pb2Cl5NH4       -87.00   -106.63  -19.63  Pb2Cl5NH4
Pb2O(N3)2      -215.50   -229.20  -13.71  Pb2O(N3)2
Pb3SO6           -8.41      2.17   10.58  Pb3SO6
Pb4Cl2(OH)6      -9.24      8.04   17.28  Pb4Cl2(OH)6
Pb4SO7          -12.78      8.94   21.71  Pb4SO7
PbCO3.PbO        -5.96      3.70    9.66  PbCO3.PbO
PbF2            -12.14    -17.40   -5.25  PbF2
PbFCl            -5.83    -14.83   -8.99  PbFCl
PbSeO4           -7.85    -14.80   -6.95  PbSeO4
PbSO4(NH3)2    -154.53   -156.56   -2.03  PbSO4(NH3)2
PbSO4(NH3)4    -303.23   -301.74    1.49  PbSO4(NH3)4
Penroseite     -147.21   -246.02  -98.81  NiSe2
Pentahydrite     -5.66     -7.05   -1.39  MgSO4:5H2O
Periclase       -10.20     11.12   21.33  MgO
Phosgenite       -5.68    -15.33   -9.65  Pb2(CO3)Cl2
Pirssonite       -9.41      1.91   11.32  Na2Ca(CO3)2:2H2O
Plattnerite       0.42     -7.55   -7.97  PbO2
Polydymite     -518.60   -567.53  -48.93  Ni3S4
Portlandite     -10.88     11.66   22.55  Ca(OH)2
Pyrite         -255.37   -280.07  -24.70  FeS2
Pyrolusite        5.28    -12.38  -17.66  MnO2
Pyrrhotite     -154.89   -158.63   -3.74  FeS
Realgar        -221.56   -281.84  -60.28  AsS
Rhodochrosite    -5.64     -5.86   -0.22  MnCO3
S              -110.90   -156.01  -45.11  S
S2(g)          -235.69   -242.88   -7.19  S2
Scacchite       -23.79    -15.05    8.74  MnCl2
Se              -61.22    -35.13   26.10  Se
Se2O5           -66.46    -56.98    9.49  Se2O5
SeCl4           -87.81    -73.47   14.33  SeCl4
Sellaite         -3.60    -13.05   -9.44  MgF2
SeO3            -40.73    -21.57   19.16  SeO3
Shcherbinaite   -11.32    -12.77   -1.45  V2O5
Siderite        -12.39    -12.61   -0.22  FeCO3
Smithsonite      -2.14     -1.69    0.44  ZnCO3
SO2(g)          -55.69    -55.51    0.18  SO2
Sphalerite     -136.25   -147.72  -11.47  ZnS
Spinel          -10.99     26.61   37.61  Al2MgO4
Starkeyite       -6.04     -7.04   -1.00  MgSO4:4H2O
Stilleite       -94.61   -118.59  -23.98  ZnSe
Tachyhydrite    -40.38    -23.23   17.14  Mg2CaCl6:12H2O
Tenorite         -2.23      5.41    7.65  CuO
Thenardite       -7.85     -8.21   -0.36  Na2SO4
Thermonatrite   -10.84      0.09   10.94  Na2CO3:H2O
Tiemannite      -62.51   -120.73  -58.23  HgSe
Todorokite       16.09    -29.74  -45.82  Mn7O12:3H2O
Trevorite         9.12     18.90    9.78  NiFe2O4
Troilite       -154.79   -158.63   -3.84  FeS
Umangite       -180.78   -274.63  -93.85  Cu3Se2
V              -133.27    -26.32  106.94  V
V2O4            -30.36    -21.80    8.56  V2O4
V3O5            -77.39    -63.97   13.43  V3O5
V4O7            -93.66    -74.87   18.80  V4O7
Vaesite        -242.92   -269.70  -26.77  NiS2
Wilkmanite     -331.36   -484.29 -152.92  Ni3Se4
Witherite         1.31     -1.71   -3.02  BaCO3
Wurtzite       -138.55   -147.72   -9.17  ZnS
Wustite         -14.13     -1.73   12.40  Fe.947O
Zincite          -3.05      8.15   11.20  ZnO
Zn              -60.50      8.29   68.79  Zn
Zn(BO2)2         -8.63     -0.32    8.31  Zn(BO2)2
Zn(ClO4)2:6H2O  -49.11    -43.48    5.63  Zn(ClO4)2:6H2O
Zn(g)           -77.12      8.29   85.41  Zn
Zn(NO3)2:6H2O   -17.43    -14.03    3.40  Zn(NO3)2:6H2O
Zn(OH)2(beta)    -3.79      8.15   11.93  Zn(OH)2
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  Zn(OH)2(epsilon)   -3.51      8.15   11.66  Zn(OH)2
  Zn(OH)2(gamma)    -3.74      8.15   11.88  Zn(OH)2
  Zn2(OH)3Cl        -8.51      6.78   15.29  Zn2(OH)3Cl
  Zn2SO4(OH)2       -9.43     -1.85    7.58  Zn2SO4(OH)2
  Zn3(AsO4)2       -84.98    -75.67    9.31  Zn3(AsO4)2
  Zn3O(SO4)2       -30.93    -11.84   19.09  Zn3O(SO4)2
  Zn5(NO3)2(OH)8   -24.09     18.58   42.67  Zn5(NO3)2(OH)8
  ZnCl2            -17.96    -10.88    7.08  ZnCl2
  ZnCl2(NH3)2     -149.06   -156.06   -7.01  ZnCl2(NH3)2
  ZnCl2(NH3)4     -294.54   -301.25   -6.71  ZnCl2(NH3)4
  ZnCl2(NH3)6     -441.69   -446.43   -4.74  ZnCl2(NH3)6
  ZnCO3:H2O         -1.84     -1.70    0.14  ZnCO3:H2O
  ZnF2             -15.52    -16.02   -0.49  ZnF2
  ZnSeO3:H2O       -20.51    -27.26   -6.75  ZnSeO3:H2O
  ZnSO4            -13.53    -10.00    3.53  ZnSO4
  ZnSO4:6H2O        -8.32    -10.02   -1.70  ZnSO4:6H2O
  ZnSO4:7H2O        -8.15    -10.02   -1.88  ZnSO4:7H2O
  ZnSO4:H2O         -9.45    -10.00   -0.55  ZnSO4:H2O

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 2.
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      EQUILIBRIUM_PHASES 3-4 Inpit Fillng:  Layer 1 Equilibration with Atmosphere
          CO2(g)   -3.5
          O2(g)    -0.68
      USE Solution 1
      END
------------------------------------------
Beginning of batch-reaction calculations.
------------------------------------------

Reaction step 1.

Using solution 1. Solution after simulation 1.
Using pure phase assemblage 3.      Inpit Fillng:  Layer 1 Equilibration with Atmosphere

-------------------------------Phase assemblage---------------------------------

                                                       Moles in assemblage
Phase               SI  log IAP   log K(T, P)   Initial       Final       Delta

CO2(g)           -3.50   -11.33      -7.83    1.000e+01   1.000e+01   6.024e-04
O2(g)            -0.68    -3.57      -2.89    1.000e+01   1.052e+01   5.222e-01

------------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                 2.035e-08   2.035e-08
      As                 1.030e-07   1.030e-07
      B                  5.842e-05   5.842e-05
      Ba                 4.294e-07   4.294e-07
      C                  3.400e-03   3.400e-03
      Ca                 1.536e-03   1.536e-03
      Cd                 6.778e-09   6.778e-09
      Cl                 7.692e-03   7.692e-03
      Cu                 1.735e-08   1.735e-08
      F                  2.111e-05   2.111e-05
      Fe                 4.856e-07   4.856e-07
      Hg                 3.199e-09   3.199e-09
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	Mg                4.372e-04   4.372e-04
	Mn                5.633e-10   5.633e-10
	Mo                2.090e-08   2.090e-08
	N                 2.111e-04   2.111e-04
	Na                4.710e-03   4.710e-03
	Ni                1.298e-07   1.298e-07
	Pb                1.790e-07   1.790e-07
	S                 6.521e-04   6.521e-04
	Se                2.158e-07   2.158e-07
	V                 3.641e-06   3.641e-06
	Zn                5.059e-07   5.059e-07

----------------------------Description of solution----------------------------

                                       pH  =   8.765      Charge balance
                                       pe  =  11.841      Adjusted to redox equilibrium
                        Activity of water  =   1.000
                           Ionic strength  =   1.264e-02
                       Mass of water (kg)  =   1.000e+00
                 Total alkalinity (eq/kg)  =   3.694e-03
                       Total CO2 (mol/kg)  =   3.400e-03
                         Temperature (°C)  =  25.00
                  Electrical balance (eq)  =  -4.261e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  = -20.78
                               Iterations  =   6
                                  Total H  = 1.110551e+02
                                  Total O  = 5.554009e+01

----------------------------Distribution of species----------------------------

                                                    Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             6.298e-06   5.608e-06    -5.201    -5.251    -0.050     (0)
   H+              1.894e-09   1.717e-09    -8.723    -8.765    -0.043      0.00
   H2O             5.553e+01   9.997e-01     1.744    -0.000     0.000     18.07
Al            2.035e-08
   AlO2-           2.025e-08   1.806e-08    -7.694    -7.743    -0.050     (0)
   HAlO2           9.056e-11   9.056e-11   -10.043   -10.043     0.000     (0)
   NaAlO2          1.437e-11   1.437e-11   -10.842   -10.842     0.000     (0)
   Al(OH)2+        1.198e-13   1.069e-13   -12.922   -12.971    -0.050     (0)
   AlOH+2          1.243e-16   7.906e-17   -15.905   -16.102    -0.197     (0)
   AlF2+           1.852e-17   1.652e-17   -16.732   -16.782    -0.050     (0)
   AlF3            3.849e-18   3.849e-18   -17.415   -17.415     0.000     (0)
   AlF+2           3.528e-18   2.243e-18   -17.452   -17.649    -0.197     (0)
   Al+3            2.961e-20   1.212e-20   -19.529   -19.916    -0.388     (0)
   AlF4-           2.005e-20   1.789e-20   -19.698   -19.747    -0.050     (0)
   AlSO4+          5.015e-21   4.474e-21   -20.300   -20.349    -0.050     (0)
   Al(SO4)2-       1.404e-22   1.253e-22   -21.853   -21.902    -0.050     (0)
   Al2(OH)2+4      5.902e-30   1.016e-30   -29.229   -29.993    -0.764     (0)
   Al3(OH)4+5      4.040e-38   2.695e-39   -37.394   -38.569    -1.176     (0)
   Al13O4(OH)24+7   0.000e+00   0.000e+00   -74.857   -77.162    -2.305     (0)
As(-3)        0.000e+00
   AsH3            0.000e+00   0.000e+00  -199.520  -199.520     0.000     (0)
As(3)         0.000e+00
   HAsO2           0.000e+00   0.000e+00   -70.939   -70.939     0.000     (0)
   As(OH)3         0.000e+00   0.000e+00   -70.997   -70.997     0.000     (0)
   H2AsO3-         0.000e+00   0.000e+00   -71.396   -71.446    -0.050     (0)
   AsO2-           0.000e+00   0.000e+00   -71.416   -71.465    -0.050     (0)
   AsO2OH-2        0.000e+00   0.000e+00   -73.491   -73.691    -0.200     (0)
   HAsS2           0.000e+00   0.000e+00  -353.952  -353.952     0.000     (0)
As(5)         1.030e-07
   AsO3F-2         1.029e-07   6.498e-08    -6.987    -7.187    -0.200     (0)
   HAsO3F-         9.287e-11   8.286e-11   -10.032   -10.082    -0.050     (0)
   HAsO4-2         0.000e+00   0.000e+00   -40.515   -40.714    -0.200     (0)
   H2AsO4-         0.000e+00   0.000e+00   -42.650   -42.700    -0.050     (0)
   AsO4-3          0.000e+00   0.000e+00   -43.090   -43.540    -0.450     (0)
   H3AsO4          0.000e+00   0.000e+00   -49.219   -49.219     0.000     (0)
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B(-5)         0.000e+00
   BH4-            0.000e+00   0.000e+00  -225.499  -225.549    -0.050     (0)
B(3)          5.842e-05
   B(OH)3          4.230e-05   4.230e-05    -4.374    -4.374     0.000     (0)
   BO2-            1.481e-05   1.321e-05    -4.830    -4.879    -0.050     (0)
   CaB(OH)4+       8.921e-07   7.958e-07    -6.050    -6.099    -0.050     (0)
   MgB(OH)4+       3.163e-07   2.822e-07    -6.500    -6.550    -0.050     (0)
   NaB(OH)4        1.090e-07   1.090e-07    -6.962    -6.962     0.000     (0)
   BaB(OH)4+       1.170e-10   1.044e-10    -9.932    -9.981    -0.050     (0)
   BF2(OH)2-       1.155e-16   1.031e-16   -15.937   -15.987    -0.050     (0)
   B2O(OH)5-       2.411e-19   2.151e-19   -18.618   -18.667    -0.050     (0)
   BF3OH-          1.567e-23   1.398e-23   -22.805   -22.855    -0.050     (0)
   BF4-            3.300e-32   2.944e-32   -31.481   -31.531    -0.050     (0)
Ba            4.294e-07
   Ba+2            4.189e-07   2.683e-07    -6.378    -6.571    -0.194     (0)
   BaCO3           9.246e-09   9.246e-09    -8.034    -8.034     0.000     (0)
   BaCl+           6.888e-10   6.145e-10    -9.162    -9.211    -0.050     (0)
   BaNO3+          4.463e-10   3.982e-10    -9.350    -9.400    -0.050     (0)
   BaB(OH)4+       1.170e-10   1.044e-10    -9.932    -9.981    -0.050     (0)
   BaOH+           5.931e-12   5.291e-12   -11.227   -11.276    -0.050     (0)
   BaF+            3.833e-12   3.419e-12   -11.417   -11.466    -0.050     (0)
C(-2)         0.000e+00
   C2H4            0.000e+00   0.000e+00  -266.358  -266.358     0.000     (0)
C(-3)         0.000e+00
   C2H6            0.000e+00   0.000e+00  -238.682  -238.682     0.000     (0)
C(-4)         0.000e+00
   CH4             0.000e+00   0.000e+00  -148.276  -148.276     0.000     (0)
C(2)          0.000e+00
   CO              0.000e+00   0.000e+00   -51.216   -51.216     0.000     (0)
C(4)          3.400e-03
   HCO3-           3.061e-03   2.731e-03    -2.514    -2.564    -0.050     (0)
   CaCO3           1.397e-04   1.397e-04    -3.855    -3.855     0.000     (0)
   CO3-2           1.110e-04   7.055e-05    -3.955    -4.151    -0.197     (0)
   CaHCO3+         3.100e-05   2.766e-05    -4.509    -4.558    -0.050     (0)
   MgCO3           1.900e-05   1.900e-05    -4.721    -4.721     0.000     (0)
   NaHCO3          1.630e-05   1.630e-05    -4.788    -4.788     0.000     (0)
   CO2             1.085e-05   1.088e-05    -4.965    -4.963     0.001     (0)
   MgHCO3+         9.053e-06   8.076e-06    -5.043    -5.093    -0.050     (0)
   NaCO3-          1.154e-06   1.030e-06    -5.938    -5.987    -0.050     (0)
   PbCO3           1.570e-07   1.570e-07    -6.804    -6.804     0.000     (0)
   ZnCO3           6.343e-08   6.343e-08    -7.198    -7.198     0.000     (0)
   CuCO3           1.382e-08   1.382e-08    -7.860    -7.860     0.000     (0)
   Pb(CO3)2-2      1.225e-08   7.735e-09    -7.912    -8.112    -0.200     (0)
   BaCO3           9.246e-09   9.246e-09    -8.034    -8.034     0.000     (0)
   ZnHCO3+         8.449e-09   7.537e-09    -8.073    -8.123    -0.050     (0)
   Cu(CO3)2-2      2.751e-09   1.736e-09    -8.561    -8.760    -0.200     (0)
   CdHCO3+         1.103e-10   9.838e-11    -9.958   -10.007    -0.050     (0)
   CdCO3           8.497e-11   8.497e-11   -10.071   -10.071     0.000     (0)
   CuCO3(OH)2-2    6.305e-11   3.980e-11   -10.200   -10.400    -0.200     (0)
   MnCO3           3.348e-11   3.348e-11   -10.475   -10.475     0.000     (0)
   Cd(CO3)2-2      2.522e-11   1.592e-11   -10.598   -10.798    -0.200     (0)
   MnHCO3+         3.160e-13   2.819e-13   -12.500   -12.550    -0.050     (0)
   FeCO3+          9.626e-16   8.588e-16   -15.017   -15.066    -0.050     (0)
   FeCO3           1.271e-19   1.271e-19   -18.896   -18.896     0.000     (0)
   FeHCO3+         5.098e-20   4.548e-20   -19.293   -19.342    -0.050     (0)
Ca            1.536e-03
   Ca+2            1.317e-03   8.545e-04    -2.881    -3.068    -0.188     (0)
   CaCO3           1.397e-04   1.397e-04    -3.855    -3.855     0.000     (0)
   CaSO4           4.502e-05   4.502e-05    -4.347    -4.347     0.000     (0)
   CaHCO3+         3.100e-05   2.766e-05    -4.509    -4.558    -0.050     (0)
   CaCl+           1.386e-06   1.237e-06    -5.858    -5.908    -0.050     (0)
   CaNO3+          8.970e-07   8.003e-07    -6.047    -6.097    -0.050     (0)
   CaB(OH)4+       8.921e-07   7.958e-07    -6.050    -6.099    -0.050     (0)
   CaF+            9.009e-08   8.037e-08    -7.045    -7.095    -0.050     (0)
   CaOH+           7.876e-08   7.026e-08    -7.104    -7.153    -0.050     (0)
   CaCl2           9.934e-09   9.934e-09    -8.003    -8.003     0.000     (0)
Cd            6.778e-09
   CdCl+           4.430e-09   3.952e-09    -8.354    -8.403    -0.050     (0)
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   Cd+2            1.779e-09   1.139e-09    -8.750    -8.943    -0.194      (0)
   Cd(OH)Cl        1.671e-10   1.671e-10    -9.777    -9.777     0.000      (0)
   CdCl2           1.170e-10   1.170e-10    -9.932    -9.932     0.000      (0)
   CdHCO3+         1.103e-10   9.838e-11    -9.958   -10.007    -0.050      (0)
   CdCO3           8.497e-11   8.497e-11   -10.071   -10.071     0.000      (0)
   CdOH+           6.252e-11   5.578e-11   -10.204   -10.254    -0.050      (0)
   Cd(CO3)2-2      2.522e-11   1.592e-11   -10.598   -10.798    -0.200      (0)
   Cd(OH)2         1.763e-12   1.763e-12   -11.754   -11.754     0.000      (0)
   CdSO4           4.170e-13   4.170e-13   -12.380   -12.380     0.000      (0)
   CdCl3-          2.297e-13   2.049e-13   -12.639   -12.688    -0.050      (0)
   CdSeO4          2.890e-14   2.890e-14   -13.539   -13.539     0.000      (0)
   Cd(OH)3-        1.306e-16   1.165e-16   -15.884   -15.934    -0.050      (0)
   Cd2OH+3         8.496e-19   3.112e-19   -18.071   -18.507    -0.436      (0)
   Cd(OH)4-2       9.685e-22   6.113e-22   -21.014   -21.214    -0.200      (0)
   CdNO2+          1.999e-24   1.783e-24   -23.699   -23.749    -0.050      (0)
   Cd(NH3)+2       0.000e+00   0.000e+00   -73.634   -73.831    -0.197      (0)
   CdN3+           0.000e+00   0.000e+00  -111.081  -111.130    -0.050      (0)
   Cd(NH3)2+2      0.000e+00   0.000e+00  -138.689  -138.886    -0.197      (0)
   Cd(N3)2         0.000e+00   0.000e+00  -213.851  -213.851     0.000      (0)
   Cd(NH3)4+2      0.000e+00   0.000e+00  -271.100  -271.297    -0.197      (0)
   Cd(N3)3-        0.000e+00   0.000e+00  -316.819  -316.869    -0.050      (0)
   Cd4(OH)4+4      0.000e+00   0.000e+00  -362.076  -362.840    -0.764      (0)
   Cd(N3)4-2       0.000e+00   0.000e+00  -419.985  -420.185    -0.200      (0)
Cl(-1)        7.692e-03
   Cl-             7.684e-03   6.829e-03    -2.114    -2.166    -0.051      (0)
   NaCl            5.007e-06   5.007e-06    -5.300    -5.300     0.000      (0)
   MgCl+           1.521e-06   1.357e-06    -5.818    -5.867    -0.050      (0)
   CaCl+           1.386e-06   1.237e-06    -5.858    -5.908    -0.050      (0)
   Zn(OH)Cl        1.223e-08   1.223e-08    -7.913    -7.913     0.000      (0)
   CaCl2           9.934e-09   9.934e-09    -8.003    -8.003     0.000      (0)
   CdCl+           4.430e-09   3.952e-09    -8.354    -8.403    -0.050      (0)
   ZnCl+           1.377e-09   1.228e-09    -8.861    -8.911    -0.050      (0)
   BaCl+           6.888e-10   6.145e-10    -9.162    -9.211    -0.050      (0)
   Cd(OH)Cl        1.671e-10   1.671e-10    -9.777    -9.777     0.000      (0)
   PbCl+           1.223e-10   1.091e-10    -9.913    -9.962    -0.050      (0)
   CdCl2           1.170e-10   1.170e-10    -9.932    -9.932     0.000      (0)
   NiCl+           6.632e-11   5.917e-11   -10.178   -10.228    -0.050      (0)
   ZnCl2           9.798e-12   9.798e-12   -11.009   -11.009     0.000      (0)
   PbCl2           2.836e-12   2.836e-12   -11.547   -11.547     0.000      (0)
   HCl             2.634e-12   2.634e-12   -11.579   -11.579     0.000      (0)
   CuCl+           4.298e-13   3.835e-13   -12.367   -12.416    -0.050      (0)
   CdCl3-          2.297e-13   2.049e-13   -12.639   -12.688    -0.050      (0)
   MnCl+           2.209e-13   1.971e-13   -12.656   -12.705    -0.050      (0)
   ZnCl3-          4.142e-14   3.695e-14   -13.383   -13.432    -0.050      (0)
   PbCl3-          1.089e-14   9.711e-15   -13.963   -14.013    -0.050      (0)
   ZnCl4-2         3.030e-15   1.913e-15   -14.519   -14.718    -0.200      (0)
   CuCl2           1.379e-15   1.379e-15   -14.860   -14.860     0.000      (0)
   PbCl4-2         6.678e-17   4.215e-17   -16.175   -16.375    -0.200      (0)
   MnCl3-          2.251e-18   2.008e-18   -17.648   -17.697    -0.050      (0)
   CuCl2-          5.617e-20   5.011e-20   -19.250   -19.300    -0.050      (0)
   CuCl3-2         3.482e-21   2.198e-21   -20.458   -20.658    -0.200      (0)
   FeCl+           1.769e-22   1.578e-22   -21.752   -21.802    -0.050      (0)
   FeCl2+          1.486e-23   1.326e-23   -22.828   -22.878    -0.050      (0)
   FeCl+2          3.772e-24   2.398e-24   -23.423   -23.620    -0.197      (0)
   CuCl4-2         1.912e-24   1.207e-24   -23.719   -23.918    -0.200      (0)
   FeCl2           5.784e-27   5.784e-27   -26.238   -26.238     0.000      (0)
   FeCl4-2         1.235e-30   7.794e-31   -29.908   -30.108    -0.200      (0)
   FeCl4-          8.331e-31   7.432e-31   -30.079   -30.129    -0.050      (0)
Cl(1)         1.025e-19
   ClO-            9.700e-20   8.654e-20   -19.013   -19.063    -0.050      (0)
   HClO            5.511e-21   5.511e-21   -20.259   -20.259     0.000      (0)
Cl(3)         1.567e-29
   ClO2-           1.567e-29   1.398e-29   -28.805   -28.855    -0.050      (0)
   HClO2           3.549e-35   3.549e-35   -34.450   -34.450     0.000      (0)
Cl(5)         1.804e-25
   ClO3-           1.804e-25   1.607e-25   -24.744   -24.794    -0.050      (0)
   PbClO3+         5.995e-35   5.349e-35   -34.222   -34.272    -0.050      (0)
   Pb(ClO3)2       0.000e+00   0.000e+00   -59.358   -59.358     0.000      (0)
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Cl(7)         1.035e-25
   ClO4-           1.035e-25   9.219e-26   -24.985   -25.035    -0.050      (0)
   ZnClO4+         2.093e-31   1.867e-31   -30.679   -30.729    -0.050      (0)
Cu(1)         7.784e-20
   CuCl2-          5.617e-20   5.011e-20   -19.250   -19.300    -0.050      (0)
   Cu+             1.818e-20   1.622e-20   -19.740   -19.790    -0.050      (0)
   CuCl3-2         3.482e-21   2.198e-21   -20.458   -20.658    -0.200      (0)
Cu(2)         1.735e-08
   CuCO3           1.382e-08   1.382e-08    -7.860    -7.860     0.000      (0)
   Cu(CO3)2-2      2.751e-09   1.736e-09    -8.561    -8.760    -0.200      (0)
   CuOH+           6.910e-10   6.164e-10    -9.161    -9.210    -0.050      (0)
   CuCO3(OH)2-2    6.305e-11   3.980e-11   -10.200   -10.400    -0.200      (0)
   Cu+2            3.163e-11   2.053e-11   -10.500   -10.688    -0.188      (0)
   CuSO4           1.696e-12   1.696e-12   -11.771   -11.771     0.000      (0)
   CuCl+           4.298e-13   3.835e-13   -12.367   -12.416    -0.050      (0)
   CuF+            6.748e-15   6.020e-15   -14.171   -14.220    -0.050      (0)
   CuCl2           1.379e-15   1.379e-15   -14.860   -14.860     0.000      (0)
   CuO2-2          1.327e-15   8.374e-16   -14.877   -15.077    -0.200      (0)
   CuCl4-2         1.912e-24   1.207e-24   -23.719   -23.918    -0.200      (0)
   CuNO2+          1.609e-26   1.436e-26   -25.793   -25.843    -0.050      (0)
   Cu(NO2)2        0.000e+00   0.000e+00   -42.008   -42.008     0.000      (0)
   CuNH3+2         0.000e+00   0.000e+00   -73.868   -74.065    -0.197      (0)
   Cu(NH3)2+2      0.000e+00   0.000e+00  -137.852  -138.048    -0.197      (0)
   Cu(NH3)3+2      0.000e+00   0.000e+00  -202.448  -202.645    -0.197      (0)
F             2.111e-05
   F-              2.078e-05   1.850e-05    -4.682    -4.733    -0.050      (0)
   MgF+            1.274e-07   1.137e-07    -6.895    -6.944    -0.050      (0)
   AsO3F-2         1.029e-07   6.498e-08    -6.987    -7.187    -0.200      (0)
   CaF+            9.009e-08   8.037e-08    -7.045    -7.095    -0.050      (0)
   NaF             8.256e-09   8.256e-09    -8.083    -8.083     0.000      (0)
   HAsO3F-         9.287e-11   8.286e-11   -10.032   -10.082    -0.050      (0)
   HF              4.878e-11   4.878e-11   -10.312   -10.312     0.000      (0)
   ZnF+            3.137e-11   2.798e-11   -10.504   -10.553    -0.050      (0)
   BaF+            3.833e-12   3.419e-12   -11.417   -11.466    -0.050      (0)
   PbF+            7.732e-14   6.898e-14   -13.112   -13.161    -0.050      (0)
   MnF+            7.567e-15   6.751e-15   -14.121   -14.171    -0.050      (0)
   CuF+            6.748e-15   6.020e-15   -14.171   -14.220    -0.050      (0)
   HF2-            2.451e-16   2.186e-16   -15.611   -15.660    -0.050      (0)
   BF2(OH)2-       1.155e-16   1.031e-16   -15.937   -15.987    -0.050      (0)
   AlF2+           1.852e-17   1.652e-17   -16.732   -16.782    -0.050      (0)
   PbF2            7.776e-18   7.776e-18   -17.109   -17.109     0.000      (0)
   AlF3            3.849e-18   3.849e-18   -17.415   -17.415     0.000      (0)
   AlF+2           3.528e-18   2.243e-18   -17.452   -17.649    -0.197      (0)
   VO2F            6.612e-20   6.612e-20   -19.180   -19.180     0.000      (0)
   AlF4-           2.005e-20   1.789e-20   -19.698   -19.747    -0.050      (0)
   H2F2            5.918e-21   5.918e-21   -20.228   -20.228     0.000      (0)
   FeF+2           9.198e-22   5.848e-22   -21.036   -21.233    -0.197      (0)
   VO2F2-          3.955e-22   3.528e-22   -21.403   -21.452    -0.050      (0)
   FeF2+           1.963e-22   1.751e-22   -21.707   -21.757    -0.050      (0)
   BF3OH-          1.567e-23   1.398e-23   -22.805   -22.855    -0.050      (0)
   FeF+            1.508e-23   1.345e-23   -22.822   -22.871    -0.050      (0)
   VOF+            1.158e-31   1.033e-31   -30.936   -30.986    -0.050      (0)
   BF4-            3.300e-32   2.944e-32   -31.481   -31.531    -0.050      (0)
   VOF2            1.152e-33   1.152e-33   -32.939   -32.939     0.000      (0)
Fe(2)         2.355e-19
   FeCO3           1.271e-19   1.271e-19   -18.896   -18.896     0.000      (0)
   FeHCO3+         5.098e-20   4.548e-20   -19.293   -19.342    -0.050      (0)
   Fe+2            4.888e-20   3.173e-20   -19.311   -19.499    -0.188      (0)
   FeOH+           6.547e-21   5.841e-21   -20.184   -20.234    -0.050      (0)
   FeSO4           1.814e-21   1.814e-21   -20.741   -20.741     0.000      (0)
   FeCl+           1.769e-22   1.578e-22   -21.752   -21.802    -0.050      (0)
   Fe(OH)2         2.701e-23   2.701e-23   -22.569   -22.569     0.000      (0)
   FeF+            1.508e-23   1.345e-23   -22.822   -22.871    -0.050      (0)
   Fe(OH)3-        7.015e-25   6.258e-25   -24.154   -24.204    -0.050      (0)
   FeCl2           5.784e-27   5.784e-27   -26.238   -26.238     0.000      (0)
   FeCl4-2         1.235e-30   7.794e-31   -29.908   -30.108    -0.200      (0)
   Fe(OH)4-2       5.771e-31   3.643e-31   -30.239   -30.439    -0.200      (0)
Fe(3)         4.856e-07
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   Fe(OH)3          4.157e-07   4.157e-07     -6.381    -6.381     0.000     (0)
   Fe(OH)4-         6.813e-08   6.078e-08     -7.167    -7.216    -0.050     (0)
   Fe(OH)2+         1.711e-09   1.527e-09     -8.767    -8.816    -0.050     (0)
   FeOH+2           1.246e-14   7.921e-15    -13.905   -14.101    -0.197     (0)
   FeCO3+           9.626e-16   8.588e-16    -15.017   -15.066    -0.050     (0)
   Fe+3             5.147e-21   2.108e-21    -20.288   -20.676    -0.388     (0)
   FeF+2            9.198e-22   5.848e-22    -21.036   -21.233    -0.197     (0)
   FeF2+            1.963e-22   1.751e-22    -21.707   -21.757    -0.050     (0)
   FeSO4+           8.244e-23   7.354e-23    -22.084   -22.133    -0.050     (0)
   FeCl2+           1.486e-23   1.326e-23    -22.828   -22.878    -0.050     (0)
   FeNO3+2          6.194e-24   3.938e-24    -23.208   -23.405    -0.197     (0)
   FeCl+2           3.772e-24   2.398e-24    -23.423   -23.620    -0.197     (0)
   Fe(SO4)2-        5.026e-25   4.484e-25    -24.299   -24.348    -0.050     (0)
   Fe2(OH)2+4       9.806e-27   1.689e-27    -26.008   -26.772    -0.764     (0)
   FeCl4-           8.331e-31   7.432e-31    -30.079   -30.129    -0.050     (0)
   Fe3(OH)4+5       8.077e-33   5.387e-34    -32.093   -33.269    -1.176     (0)
   FeNO2+2          3.127e-35   1.988e-35    -34.505   -34.702    -0.197     (0)
H(0)           0.000e+00
   H2               0.000e+00   0.000e+00    -44.313   -44.312     0.001     (0)
Hg(1)          1.596e-10
   Hg2+2            7.979e-11   5.036e-11    -10.098   -10.298    -0.200     (0)
Hg(2)          3.039e-09
   Hg+2             3.039e-09   1.946e-09     -8.517    -8.711    -0.194     (0)
Mg             4.372e-04
   Mg+2             3.827e-04   2.546e-04     -3.417    -3.594    -0.177     (0)
   MgSO4            2.452e-05   2.452e-05     -4.610    -4.610     0.000     (0)
   MgCO3            1.900e-05   1.900e-05     -4.721    -4.721     0.000     (0)
   MgHCO3+          9.053e-06   8.076e-06     -5.043    -5.093    -0.050     (0)
   MgCl+            1.521e-06   1.357e-06     -5.818    -5.867    -0.050     (0)
   MgB(OH)4+        3.163e-07   2.822e-07     -6.500    -6.550    -0.050     (0)
   MgF+             1.274e-07   1.137e-07     -6.895    -6.944    -0.050     (0)
   Mg4(OH)4+4       4.982e-19   8.580e-20    -18.303   -19.066    -0.764     (0)
Mn(2)          5.635e-11
   MnCO3            3.348e-11   3.348e-11    -10.475   -10.475     0.000     (0)
   Mn+2             2.088e-11   1.356e-11    -10.680   -10.868    -0.188     (0)
   MnSO4            1.206e-12   1.206e-12    -11.919   -11.919     0.000     (0)
   MnHCO3+          3.160e-13   2.819e-13    -12.500   -12.550    -0.050     (0)
   MnOH+            2.273e-13   2.028e-13    -12.643   -12.693    -0.050     (0)
   MnCl+            2.209e-13   1.971e-13    -12.656   -12.705    -0.050     (0)
   MnF+             7.567e-15   6.751e-15    -14.121   -14.171    -0.050     (0)
   MnNO3+           4.500e-15   4.014e-15    -14.347   -14.396    -0.050     (0)
   MnSeO4           4.971e-16   4.971e-16    -15.304   -15.304     0.000     (0)
   Mn(OH)2          2.898e-16   2.898e-16    -15.538   -15.538     0.000     (0)
   MnCl3-           2.251e-18   2.008e-18    -17.648   -17.697    -0.050     (0)
   Mn(NO3)2         1.884e-18   1.884e-18    -17.725   -17.725     0.000     (0)
   Mn(OH)3-         1.774e-19   1.582e-19    -18.751   -18.801    -0.050     (0)
   Mn2(OH)3+        5.115e-20   4.563e-20    -19.291   -19.341    -0.050     (0)
   Mn2OH+3          8.043e-24   2.946e-24    -23.095   -23.531    -0.436     (0)
   Mn(OH)4-2        1.236e-24   7.800e-25    -23.908   -24.108    -0.200     (0)
Mn(3)          6.839e-25
   Mn+3             6.839e-25   2.505e-25    -24.165   -24.601    -0.436     (0)
Mn(6)          2.334e-12
   MnO4-2           2.334e-12   1.473e-12    -11.632   -11.832    -0.200     (0)
Mn(7)          5.047e-10
   MnO4-            5.047e-10   4.494e-10     -9.297    -9.347    -0.050     (0)
Mo             2.090e-08
   MoO4-2           2.090e-08   1.329e-08     -7.680    -7.877    -0.197     (0)
N(-03)         0.000e+00
   N3-              0.000e+00   0.000e+00   -103.634  -103.684    -0.050     (0)
   HN3              0.000e+00   0.000e+00   -107.747  -107.747     0.000     (0)
   ZnN3+            0.000e+00   0.000e+00   -110.163  -110.212    -0.050     (0)
   CdN3+            0.000e+00   0.000e+00   -111.081  -111.130    -0.050     (0)
   Zn(N3)2          0.000e+00   0.000e+00   -213.143  -213.143     0.000     (0)
   Cd(N3)2          0.000e+00   0.000e+00   -213.851  -213.851     0.000     (0)
   Cd(N3)3-         0.000e+00   0.000e+00   -316.819  -316.869    -0.050     (0)
   Cd(N3)4-2        0.000e+00   0.000e+00   -419.985  -420.185    -0.200     (0)
N(-3)          0.000e+00
   NH4+             0.000e+00   0.000e+00    -66.890   -66.942    -0.052     (0)
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   NH3             0.000e+00   0.000e+00    -67.417   -67.417     0.000     (0)
   Zn(NH3)+2       0.000e+00   0.000e+00    -72.138   -72.335    -0.197     (0)
   Cd(NH3)+2       0.000e+00   0.000e+00    -73.634   -73.831    -0.197     (0)
   CuNH3+2         0.000e+00   0.000e+00    -73.868   -74.065    -0.197     (0)
   NH4SO4-         0.000e+00   0.000e+00    -78.636   -78.685    -0.050     (0)
   Ni(NH3)2+2      0.000e+00   0.000e+00   -136.645  -136.842    -0.197     (0)
   Zn(NH3)2+2      0.000e+00   0.000e+00   -137.349  -137.546    -0.197     (0)
   Cu(NH3)2+2      0.000e+00   0.000e+00   -137.852  -138.048    -0.197     (0)
   Cd(NH3)2+2      0.000e+00   0.000e+00   -138.689  -138.886    -0.197     (0)
   Cu(NH3)3+2      0.000e+00   0.000e+00   -202.448  -202.645    -0.197     (0)
   Zn(NH3)3+2      0.000e+00   0.000e+00   -202.560  -202.756    -0.197     (0)
   Zn(NH3)4+2      0.000e+00   0.000e+00   -268.044  -268.241    -0.197     (0)
   Cd(NH3)4+2      0.000e+00   0.000e+00   -271.100  -271.297    -0.197     (0)
   Ni(NH3)6+2      0.000e+00   0.000e+00   -402.628  -402.825    -0.197     (0)
N(0)          3.692e-24
   N2              1.846e-24   1.846e-24    -23.734   -23.734     0.000     (0)
N(3)          7.515e-18
   NO2-            7.515e-18   6.678e-18    -17.124   -17.175    -0.051     (0)
   HNO2            1.957e-23   1.957e-23    -22.708   -22.708     0.000     (0)
   CdNO2+          1.999e-24   1.783e-24    -23.699   -23.749    -0.050     (0)
   CuNO2+          1.609e-26   1.436e-26    -25.793   -25.843    -0.050     (0)
   FeNO2+2         3.127e-35   1.988e-35    -34.505   -34.702    -0.197     (0)
   Cu(NO2)2        0.000e+00   0.000e+00    -42.008   -42.008     0.000     (0)
N(5)          2.111e-04
   NO3-            2.102e-04   1.869e-04     -3.677    -3.729    -0.051     (0)
   CaNO3+          8.970e-07   8.003e-07     -6.047    -6.097    -0.050     (0)
   BaNO3+          4.463e-10   3.982e-10     -9.350    -9.400    -0.050     (0)
   NiNO3+          4.282e-11   3.820e-11    -10.368   -10.418    -0.050     (0)
   PbNO3+          1.955e-12   1.745e-12    -11.709   -11.758    -0.050     (0)
   HNO3            1.678e-14   1.678e-14    -13.775   -13.775     0.000     (0)
   Ni(NO3)2        4.532e-15   4.532e-15    -14.344   -14.344     0.000     (0)
   MnNO3+          4.500e-15   4.014e-15    -14.347   -14.396    -0.050     (0)
   Mn(NO3)2        1.884e-18   1.884e-18    -17.725   -17.725     0.000     (0)
   FeNO3+2         6.194e-24   3.938e-24    -23.208   -23.405    -0.197     (0)
Na            4.710e-03
   Na+             4.676e-03   4.172e-03     -2.330    -2.380    -0.050     (0)
   NaHCO3          1.630e-05   1.630e-05     -4.788    -4.788     0.000     (0)
   NaSO4-          1.114e-05   9.940e-06     -4.953    -5.003    -0.050     (0)
   NaCl            5.007e-06   5.007e-06     -5.300    -5.300     0.000     (0)
   NaCO3-          1.154e-06   1.030e-06     -5.938    -5.987    -0.050     (0)
   NaB(OH)4        1.090e-07   1.090e-07     -6.962    -6.962     0.000     (0)
   NaF             8.256e-09   8.256e-09     -8.083    -8.083     0.000     (0)
   NaOH            4.036e-09   4.036e-09     -8.394    -8.394     0.000     (0)
   NaAlO2          1.437e-11   1.437e-11    -10.842   -10.842     0.000     (0)
Ni            1.298e-07
   Ni+2            1.254e-07   8.139e-08     -6.902    -7.089    -0.188     (0)
   NiSO4           4.029e-09   4.029e-09     -8.395    -8.395     0.000     (0)
   Ni(OH)2         2.821e-10   2.821e-10     -9.550    -9.550     0.000     (0)
   NiCl+           6.632e-11   5.917e-11    -10.178   -10.228    -0.050     (0)
   NiNO3+          4.282e-11   3.820e-11    -10.368   -10.418    -0.050     (0)
   NiSeO4          5.187e-12   5.187e-12    -11.285   -11.285     0.000     (0)
   Ni(OH)3-        1.862e-12   1.661e-12    -11.730   -11.780    -0.050     (0)
   Ni(NO3)2        4.532e-15   4.532e-15    -14.344   -14.344     0.000     (0)
   Ni2OH+3         2.101e-16   7.694e-17    -15.678   -16.114    -0.436     (0)
   Ni4(OH)4+4      6.108e-21   1.052e-21    -20.214   -20.978    -0.764     (0)
   Ni(NH3)2+2      0.000e+00   0.000e+00   -136.645  -136.842    -0.197     (0)
   Ni(NH3)6+2      0.000e+00   0.000e+00   -402.628  -402.825    -0.197     (0)
O(0)          5.338e-04
   O2              2.669e-04   2.677e-04     -3.574    -3.572     0.001     (0)
Pb(2)         1.790e-07
   PbCO3           1.570e-07   1.570e-07     -6.804    -6.804     0.000     (0)
   Pb(CO3)2-2      1.225e-08   7.735e-09     -7.912    -8.112    -0.200     (0)
   PbOH+           7.287e-09   6.501e-09     -8.137    -8.187    -0.050     (0)
   Pb(OH)2         1.524e-09   1.524e-09     -8.817    -8.817     0.000     (0)
   Pb+2            8.704e-10   5.535e-10     -9.060    -9.257    -0.197     (0)
   PbCl+           1.223e-10   1.091e-10     -9.913    -9.962    -0.050     (0)
   Pb(OH)3-        1.006e-11   8.972e-12    -10.998   -11.047    -0.050     (0)
   PbCl2           2.836e-12   2.836e-12    -11.547   -11.547     0.000     (0)
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   PbNO3+            1.955e-12   1.745e-12    -11.709   -11.758    -0.050    (0)
   PbF+              7.732e-14   6.898e-14    -13.112   -13.161    -0.050    (0)
   PbCl3-            1.089e-14   9.711e-15    -13.963   -14.013    -0.050    (0)
   Pb2OH+3           1.960e-16   7.179e-17    -15.708   -16.144    -0.436    (0)
   PbCl4-2           6.678e-17   4.215e-17    -16.175   -16.375    -0.200    (0)
   Pb3(OH)4+2        4.033e-17   2.564e-17    -16.394   -16.591    -0.197    (0)
   PbF2              7.776e-18   7.776e-18    -17.109   -17.109     0.000    (0)
   Pb4(OH)4+4        8.241e-23   1.419e-23    -22.084   -22.848    -0.764    (0)
   Pb6(OH)8+4        6.051e-29   1.042e-29    -28.218   -28.982    -0.764    (0)
   PbClO3+           5.995e-35   5.349e-35    -34.222   -34.272    -0.050    (0)
   Pb(ClO3)2         0.000e+00   0.000e+00    -59.358   -59.358     0.000    (0)
Pb(4)         0.000e+00
   Pb+4              0.000e+00   0.000e+00    -41.990   -42.753    -0.764    (0)
S(-2)         0.000e+00
   HS-               0.000e+00   0.000e+00   -143.296  -143.346    -0.050    (0)
   H2S               0.000e+00   0.000e+00   -145.102  -145.102     0.000    (0)
   S-2               0.000e+00   0.000e+00   -147.313  -147.507    -0.194    (0)
   S2-2              0.000e+00   0.000e+00   -255.021  -255.220    -0.200    (0)
   HAsS2             0.000e+00   0.000e+00   -353.952  -353.952     0.000    (0)
   S3-2              0.000e+00   0.000e+00   -362.775  -362.975    -0.200    (0)
   S4-2              0.000e+00   0.000e+00   -470.757  -470.957    -0.200    (0)
   S5-2              0.000e+00   0.000e+00   -578.956  -579.156    -0.200    (0)
S(2)          0.000e+00
   S2O3-2            0.000e+00   0.000e+00   -150.545  -150.745    -0.200    (0)
   HS2O3-            0.000e+00   0.000e+00   -158.447  -158.496    -0.050    (0)
S(3)          0.000e+00
   S2O4-2            0.000e+00   0.000e+00   -137.266  -137.459    -0.194    (0)
S(4)          0.000e+00
   SO3-2             0.000e+00   0.000e+00    -48.078   -48.275    -0.197    (0)
   HSO3-             0.000e+00   0.000e+00    -49.759   -49.808    -0.050    (0)
   H2SO3             0.000e+00   0.000e+00    -56.592   -56.592     0.000    (0)
   SO2               0.000e+00   0.000e+00    -56.692   -56.692     0.000    (0)
   S2O6-2            0.000e+00   0.000e+00    -73.799   -73.998    -0.200    (0)
   S3O6-2            0.000e+00   0.000e+00   -184.036  -184.236    -0.200    (0)
   S4O6-2            0.000e+00   0.000e+00   -278.368  -278.568    -0.200    (0)
   S5O6-2            0.000e+00   0.000e+00   -401.580  -401.779    -0.200    (0)
S(5)          0.000e+00
   S2O5-2            0.000e+00   0.000e+00   -104.246  -104.446    -0.200    (0)
S(6)          6.521e-04
   SO4-2             5.714e-04   3.607e-04     -3.243    -3.443    -0.200    (0)
   CaSO4             4.502e-05   4.502e-05     -4.347    -4.347     0.000    (0)
   MgSO4             2.452e-05   2.452e-05     -4.610    -4.610     0.000    (0)
   NaSO4-            1.114e-05   9.940e-06     -4.953    -5.003    -0.050    (0)
   ZnSO4             8.114e-09   8.114e-09     -8.091    -8.091     0.000    (0)
   NiSO4             4.029e-09   4.029e-09     -8.395    -8.395     0.000    (0)
   HSO4-             7.013e-11   6.257e-11    -10.154   -10.204    -0.050    (0)
   CuSO4             1.696e-12   1.696e-12    -11.771   -11.771     0.000    (0)
   MnSO4             1.206e-12   1.206e-12    -11.919   -11.919     0.000    (0)
   CdSO4             4.170e-13   4.170e-13    -12.380   -12.380     0.000    (0)
   VO2SO4-           2.453e-20   2.189e-20    -19.610   -19.660    -0.050    (0)
   AlSO4+            5.015e-21   4.474e-21    -20.300   -20.349    -0.050    (0)
   FeSO4             1.814e-21   1.814e-21    -20.741   -20.741     0.000    (0)
   Al(SO4)2-         1.404e-22   1.253e-22    -21.853   -21.902    -0.050    (0)
   H2SO4             1.014e-22   1.014e-22    -21.994   -21.994     0.000    (0)
   FeSO4+            8.244e-23   7.354e-23    -22.084   -22.133    -0.050    (0)
   Fe(SO4)2-         5.026e-25   4.484e-25    -24.299   -24.348    -0.050    (0)
   VOSO4             6.083e-32   6.083e-32    -31.216   -31.216     0.000    (0)
   VSO4+             0.000e+00   0.000e+00    -53.891   -53.941    -0.050    (0)
   NH4SO4-           0.000e+00   0.000e+00    -78.636   -78.685    -0.050    (0)
S(7)          0.000e+00
   S2O8-2            0.000e+00   0.000e+00    -48.457   -48.657    -0.200    (0)
S(8)          6.233e-32
   HSO5-             6.233e-32   5.561e-32    -31.205   -31.255    -0.050    (0)
Se(-2)        0.000e+00
   HSe-              0.000e+00   0.000e+00    -99.227   -99.277    -0.050    (0)
   H2Se              0.000e+00   0.000e+00   -104.220  -104.220     0.000    (0)
   Se-2              0.000e+00   0.000e+00   -105.258  -105.458    -0.200    (0)
Se(4)         1.412e-19
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   SeO3-2          1.378e-19   8.697e-20   -18.861   -19.061    -0.200      (0)
   HSeO3-          3.440e-21   3.069e-21   -20.463   -20.513    -0.050      (0)
   H2SeO3          2.003e-27   2.003e-27   -26.698   -26.698     0.000      (0)
Se(6)         2.158e-07
   SeO4-2          2.158e-07   1.362e-07    -6.666    -6.866    -0.200      (0)
   NiSeO4          5.187e-12   5.187e-12   -11.285   -11.285     0.000      (0)
   ZnSeO4          2.259e-12   2.259e-12   -11.646   -11.646     0.000      (0)
   CdSeO4          2.890e-14   2.890e-14   -13.539   -13.539     0.000      (0)
   HSeO4-          2.230e-14   1.990e-14   -13.652   -13.701    -0.050      (0)
   MnSeO4          4.971e-16   4.971e-16   -15.304   -15.304     0.000      (0)
V(3)          0.000e+00
   V(OH)2+         0.000e+00   0.000e+00   -42.167   -42.217    -0.050      (0)
   VOH+2           0.000e+00   0.000e+00   -47.126   -47.323    -0.197      (0)
   V+3             0.000e+00   0.000e+00   -53.392   -53.828    -0.436      (0)
   VSO4+           0.000e+00   0.000e+00   -53.891   -53.941    -0.050      (0)
   V2(OH)2+4       0.000e+00   0.000e+00   -93.161   -93.925    -0.764      (0)
V(4)          7.801e-28
   VOOH+           7.791e-28   6.950e-28   -27.108   -27.158    -0.050      (0)
   VO+2            8.783e-31   5.585e-31   -30.056   -30.253    -0.197      (0)
   VOF+            1.158e-31   1.033e-31   -30.936   -30.986    -0.050      (0)
   VOSO4           6.083e-32   6.083e-32   -31.216   -31.216     0.000      (0)
   VOF2            1.152e-33   1.152e-33   -32.939   -32.939     0.000      (0)
   (VO)2(OH)2+2    0.000e+00   0.000e+00   -49.449   -49.646    -0.197      (0)
V(5)          3.641e-06
   VO3OH-2         3.240e-06   2.045e-06    -5.489    -5.689    -0.200      (0)
   HVO4-2          3.225e-07   2.036e-07    -6.491    -6.691    -0.200      (0)
   H2VO4-          4.757e-08   4.244e-08    -7.323    -7.372    -0.050      (0)
   VO2(OH)2-       3.039e-08   2.711e-08    -7.517    -7.567    -0.050      (0)
   VO4-3           1.846e-11   6.545e-12   -10.734   -11.184    -0.450      (0)
   VO(OH)3         4.656e-13   4.656e-13   -12.332   -12.332     0.000      (0)
   VO2+            1.789e-18   1.596e-18   -17.747   -17.797    -0.050      (0)
   VO2F            6.612e-20   6.612e-20   -19.180   -19.180     0.000      (0)
   VO2SO4-         2.453e-20   2.189e-20   -19.610   -19.660    -0.050      (0)
   VO2F2-          3.955e-22   3.528e-22   -21.403   -21.452    -0.050      (0)
Zn            5.059e-07
   Zn(OH)2         1.704e-07   1.704e-07    -6.769    -6.769     0.000      (0)
   Zn+2            1.649e-07   1.071e-07    -6.783    -6.970    -0.188      (0)
   ZnOH+           7.661e-08   6.835e-08    -7.116    -7.165    -0.050      (0)
   ZnCO3           6.343e-08   6.343e-08    -7.198    -7.198     0.000      (0)
   Zn(OH)Cl        1.223e-08   1.223e-08    -7.913    -7.913     0.000      (0)
   ZnHCO3+         8.449e-09   7.537e-09    -8.073    -8.123    -0.050      (0)
   ZnSO4           8.114e-09   8.114e-09    -8.091    -8.091     0.000      (0)
   ZnCl+           1.377e-09   1.228e-09    -8.861    -8.911    -0.050      (0)
   Zn(OH)3-        3.446e-10   3.074e-10    -9.463    -9.512    -0.050      (0)
   ZnF+            3.137e-11   2.798e-11   -10.504   -10.553    -0.050      (0)
   ZnCl2           9.798e-12   9.798e-12   -11.009   -11.009     0.000      (0)
   ZnSeO4          2.259e-12   2.259e-12   -11.646   -11.646     0.000      (0)
   Zn(OH)4-2       4.834e-14   3.051e-14   -13.316   -13.516    -0.200      (0)
   ZnCl3-          4.142e-14   3.695e-14   -13.383   -13.432    -0.050      (0)
   ZnCl4-2         3.030e-15   1.913e-15   -14.519   -14.718    -0.200      (0)
   ZnClO4+         2.093e-31   1.867e-31   -30.679   -30.729    -0.050      (0)
   Zn(NH3)+2       0.000e+00   0.000e+00   -72.138   -72.335    -0.197      (0)
   ZnN3+           0.000e+00   0.000e+00  -110.163  -110.212    -0.050      (0)
   Zn(NH3)2+2      0.000e+00   0.000e+00  -137.349  -137.546    -0.197      (0)
   Zn(NH3)3+2      0.000e+00   0.000e+00  -202.560  -202.756    -0.197      (0)
   Zn(N3)2         0.000e+00   0.000e+00  -213.143  -213.143     0.000      (0)
   Zn(NH3)4+2      0.000e+00   0.000e+00  -268.044  -268.241    -0.197      (0)

------------------------------Saturation indices--------------------------------

  Phase               SI** log IAP   log K(298 K,   1 atm)

  Ahlfeldite      -21.65    -26.15   -4.50  NiSeO3:2H2O
  Al             -140.86      9.06  149.91  Al
  Al(g)          -191.56      9.06  200.62  Al
  Al2(SO4)3       -69.06    -50.16   18.90  Al2(SO4)3
  Al2(SO4)3:6H2O  -51.72    -50.16    1.56  Al2(SO4)3:6H2O
  Alabandite     -145.03   -145.45   -0.42  MnS
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AlF3            -16.85    -34.11  -17.27  AlF3
Alstonite         0.18      2.76    2.58  BaCa(CO3)2
Anglesite        -4.79    -12.70   -7.91  PbSO4
Anhydrite        -2.16     -6.51   -4.35  CaSO4
Antarcticite    -11.49     -7.40    4.09  CaCl2:6H2O
Antlerite        -9.18     -0.45    8.73  Cu3(SO4)(OH)4
Aragonite         1.16      3.13    1.97  CaCO3
Arsenolite     -140.58   -160.42  -19.84  As2O3
Arsenopyrite   -279.50   -293.94  -14.45  FeAsS
Artinite         -3.08     16.54   19.63  Mg2CO3(OH)2:3H2O
As             -120.21    -77.53   42.68  As
As2O5          -105.06   -102.93    2.14  As2O5
As4O6(cubi)    -281.02   -320.84  -39.82  As4O6
As4O6(mono)    -280.79   -320.84  -40.05  As4O6
Atacamite        -8.76      5.51   14.26  Cu4Cl2(OH)6
Azurite         -11.25     -2.13    9.12  Cu3(CO3)2(OH)2
B              -111.25     -1.69  109.56  B
B(g)           -202.54     -1.69  200.84  B
B2O3            -14.29     -8.75    5.55  B2O3
Ba             -128.49     12.74  141.23  Ba
Ba(OH)2:8H2O    -13.53     10.96   24.49  Ba(OH)2:8H2O
BaCl2           -13.13    -10.90    2.23  BaCl2
BaCl2:2H2O      -11.11    -10.90    0.21  BaCl2:2H2O
BaCl2:H2O       -11.73    -10.90    0.82  BaCl2:H2O
BaMnO4           -8.31    -18.40  -10.09  BaMnO4
BaO             -36.84     10.96   47.80  BaO
Barite           -0.00    -10.01  -10.01  BaSO4
Barytocalcite     0.02      2.76    2.74  BaCa(CO3)2
BaS            -157.39   -141.15   16.24  BaS
BaSeO3          -19.06    -25.63   -6.57  BaSeO3
BaSeO4           -5.98    -13.44   -7.46  BaSeO4
Bassanite        -2.81     -6.51   -3.71  CaSO4:0.5H2O
BF3(g)          -41.89    -44.87   -2.98  BF3
Birnessite       30.77    -54.78  -85.55  Mn8O14:5H2O
Bischofite      -12.32     -7.93    4.39  MgCl2:6H2O
Bixbyite          4.35      3.39   -0.96  Mn2O3
Bloedite        -12.76    -15.24   -2.48  Na2Mg(SO4)2:4H2O
Boehmite         -1.17      6.38    7.55  AlO2H
Borax           -16.77     -4.72   12.04  Na2(B4O5(OH)4):8H2O
Boric_acid       -4.22     -4.37   -0.16  B(OH)3
Bornite        -545.14   -647.67 -102.53  Cu5FeS4
Brochantite      -9.03      6.40   15.42  Cu4(SO4)(OH)6
Brucite          -2.35     13.94   16.28  Mg(OH)2
Bunsenite        -2.02     10.44   12.46  NiO
Burkeite        -24.45    -14.96    9.49  Na6CO3(SO4)2
C               -71.90     -7.76   64.15  C
C(g)           -189.52     -7.76  181.77  C
Ca             -123.58     16.25  139.83  Ca
Ca(g)          -148.82     16.25  165.07  Ca
Ca2Al2O5:8H2O   -17.89     41.68   59.57  Ca2Al2O5:8H2O
Ca2Cl2(OH)2:H2O -19.23      7.06   26.29  Ca2Cl2(OH)2:H2O
Ca2V2O7          -6.32    -46.03  -39.71  Ca2V2O7
Ca3(AsO4)2      -77.35    -59.54   17.80  Ca3(AsO4)2
Ca3Al2O6        -56.89     56.14  113.03  Ca3Al2O6
Ca3V2O8         -13.25    -31.57  -18.32  Ca3V2O8
Ca4Al2Fe2O10    -58.64     81.84  140.48  Ca4Al2Fe2O10
Ca4Al2O7:13H2O  -36.65     70.60  107.25  Ca4Al2O7:13H2O
Ca4Al2O7:19H2O  -33.08     70.60  103.68  Ca4Al2O7:19H2O
Ca4Cl2(OH)6:13H2O -32.34     35.98   68.33  Ca4Cl2(OH)6:13H2O
CaAl2O4         -19.69     27.22   46.91  CaAl2O4
CaAl2O4:10H2O   -10.78     27.22   37.99  CaAl2O4:10H2O
CaAl4O7         -28.61     39.98   68.59  CaAl4O7
Cadmoselite     -80.55   -114.40  -33.86  CdSe
Calcite           1.31      3.13    1.82  CaCO3
Calomel           3.20    -14.63  -17.83  Hg2Cl2
CaSeO3:2H2O     -17.50    -22.13   -4.63  CaSeO3:2H2O
CaSeO4           -6.84     -9.93   -3.09  CaSeO4
CaSO4:0.5H2O(beta)  -2.98     -6.51   -3.54  CaSO4:0.5H2O
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CaV2O6             -9.14    -60.50  -51.36  CaV2O6
Cd                -46.22     10.37   56.59  Cd
Cd(BO2)2           -9.99     -0.16    9.83  Cd(BO2)2
Cd(g)             -59.76     10.37   70.13  Cd
Cd(OH)2            -5.15      8.59   13.73  Cd(OH)2
Cd(OH)Cl           -5.88     -2.34    3.54  Cd(OH)Cl
Cd3(AsO4)2        -81.23    -77.17    4.06  Cd3(AsO4)2
Cd3(SO4)(OH)4     -17.79      4.79   22.57  Cd3(SO4)(OH)4
Cd3(SO4)2(OH)2    -22.90    -16.19    6.72  Cd3(SO4)2(OH)2
CdCl2             -12.62    -13.27   -0.66  CdCl2
CdCl2(NH3)2      -139.31   -148.11   -8.80  CdCl2(NH3)2
CdCl2(NH3)4      -276.13   -282.94   -6.82  CdCl2(NH3)4
CdCl2(NH3)6      -413.02   -417.78   -4.76  CdCl2(NH3)6
CdCl2:H2O         -11.59    -13.27   -1.68  CdCl2:H2O
CdF2              -17.25    -18.41   -1.16  CdF2
CdS              -127.61   -143.52  -15.92  CdS
CdSeO3            -19.18    -28.00   -8.82  CdSeO3
CdSeO4            -13.58    -15.81   -2.22  CdSeO4
CdSO4             -12.27    -12.39   -0.12  CdSO4
CdSO4:2.667H2O    -10.57    -12.39   -1.81  CdSO4:2.667H2O
CdSO4:H2O         -10.72    -12.39   -1.66  CdSO4:H2O
Cerussite           0.18     -3.06   -3.24  PbCO3
CH4(g)           -145.43   -148.28   -2.84  CH4
Chalcanthite      -11.50    -14.13   -2.63  CuSO4:5H2O
Chalcocite       -139.42   -174.16  -34.74  Cu2S
Chalcocyanite     -17.04    -14.13    2.91  CuSO4
Chalcopyrite     -266.74   -299.35  -32.60  CuFeS2
Chloromagnesite -29.74     -7.93   21.82  MgCl2
Cinnabar         -104.30   -143.29  -38.99  HgS
Cl2(g)            -26.64    -23.65    2.99  Cl2
Claudetite       -140.63   -160.42  -19.80  As2O3
Clausthalite      -78.45   -114.72  -36.27  PbSe
Clinochalcomenite -22.95    -29.75   -6.80  CuSeO3:2H2O
CO(g)             -48.22    -51.22   -3.00  CO
CO2(g)             -3.50    -11.33   -7.83  CO2
Colemanite        -18.83      2.68   21.51  Ca2B6O11:5H2O
Corundum           -5.53     12.76   18.29  Al2O3
Cotunnite          -8.74    -13.59   -4.85  PbCl2
Covellite        -122.41   -145.27  -22.86  CuS
Cu                -22.87      8.63   31.50  Cu
Cu(g)             -75.03      8.63   83.66  Cu
CuCl2             -18.74    -15.02    3.72  CuCl2
CuF               -31.60    -24.52    7.08  CuF
CuF2              -19.53    -20.15   -0.62  CuF2
CuF2:2H2O         -15.60    -20.15   -4.55  CuF2:2H2O
Cuprite           -20.14    -22.05   -1.91  Cu2O
CuSeO3            -22.07    -29.75   -7.68  CuSeO3
Dawsonite          -2.91      1.44    4.34  NaAlCO3(OH)2
Delafossite         1.03     -5.41   -6.44  CuFeO2
Diaspore           -0.77      6.38    7.15  AlHO2
Dolomite            3.27      5.74    2.47  CaMg(CO3)2
Dolomite-dis        1.73      5.74    4.01  CaMg(CO3)2
Dolomite-ord        3.28      5.74    2.46  CaMg(CO3)2
Downeyite         -29.80    -36.59   -6.79  SeO2
Epsomite           -5.08     -7.04   -1.96  MgSO4:7H2O
Ettringite        -25.86     36.61   62.46  Ca6Al2(SO4)3(OH)12:26H2O
F2(g)             -84.49    -28.78   55.71  F2
Fe                -59.20     -0.18   59.02  Fe
Fe(OH)2           -15.86     -1.97   13.89  Fe(OH)2
Fe(OH)3            -0.02      5.62    5.64  Fe(OH)3
Fe2(SO4)3         -54.73    -51.68    3.05  Fe2(SO4)3
FeF2              -26.54    -28.96   -2.42  FeF2
FeF3              -15.62    -34.87  -19.26  FeF3
FeO               -15.49     -1.97   13.52  FeO
Ferrite-Ca          4.20     25.70   21.50  CaFe2O4
Ferrite-Cu          7.80     18.08   10.28  CuFe2O4
Ferrite-Dicalcium -16.64      40.16   56.80  Ca2Fe2O5
Ferrite-Mg          4.15     25.17   21.02  MgFe2O4
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Ferrite-Zn       10.10     21.80   11.70  ZnFe2O4
Ferroselite    -160.43   -241.25  -80.82  FeSe2
FeSO4           -25.55    -22.94    2.61  FeSO4
FeV2O4         -337.59    -57.03  280.56  FeV2O4
Fluorite         -2.47    -12.53  -10.07  CaF2
Frankdicksonite -10.28    -16.04   -5.76  BaF2
Galena         -128.96   -143.84  -14.88  PbS
Gaylussite       -6.59      4.57   11.16  CaNa2(CO3)2:5H2O
Gibbsite         -1.36      6.38    7.74  Al(OH)3
Glauberite       -9.24    -14.71   -5.47  Na2Ca(SO4)2
Goethite          5.09      5.62    0.53  FeOOH
Gypsum           -1.98     -6.51   -4.53  CaSO4:2H2O
H2(g)           -41.21    -44.31   -3.10  H2
H2O(g)           -1.59     -0.00    1.59  H2O
H2S(g)         -144.12   -152.11   -7.99  H2S
Halite           -6.11     -4.55    1.56  NaCl
Hausmannite      -0.09     10.05   10.14  Mn3O4
HCl(g)          -17.23    -10.93    6.30  HCl
Heazlewoodite  -299.30   -271.11   28.18  Ni3S2
Hematite         11.16     11.24    0.08  Fe2O3
Hercynite       -18.01     10.79   28.80  FeAl2O4
Hexahydrite      -5.31     -7.04   -1.73  MgSO4:6H2O
Hg(g)            -9.12     10.61   19.73  Hg
Hg(l)            -3.53     10.61   14.14  Hg
Hg2SeO3         -15.15    -29.36  -14.21  Hg2SeO3
Hg2SO4           -7.61    -13.74   -6.13  Hg2SO4
HgSeO3          -13.88    -27.77  -13.90  HgSeO3
Huntite           0.74     10.96   10.22  CaMg3(CO3)4
Hydroboracite   -18.21      2.16   20.36  MgCaB6O11:6H2O
Hydrocerussite    0.31      2.16    1.85  Pb3(CO3)2(OH)2
Hydromagnesite   -6.37     24.36   30.74  Mg5(CO3)4(OH)2:4H2O
Hydrophilite    -19.15     -7.40   11.75  CaCl2
Hydrozincite     -0.17     30.14   30.31  Zn5(OH)6(CO3)2
Ice              -0.14     -0.00    0.14  H2O
Jarosite-Na     -13.26    -18.70   -5.45  NaFe3(SO4)2(OH)6
Karelianite     -65.01    -55.06    9.95  V2O3
Katoite         -22.80     56.14   78.94  Ca3Al2H12O12
Kieserite        -6.77     -7.04   -0.27  MgSO4:H2O
Klockmannite    -74.52   -116.15  -41.62  CuSe
Krutaite       -133.22   -240.92 -107.70  CuSe2
Lammerite       -83.96    -82.40    1.55  Cu3(AsO4)2
Lanarkite        -3.94     -4.43   -0.48  Pb2(SO4)O
Lansfordite      -2.23      2.61    4.84  MgCO3:5H2O
Lawrencite      -32.88    -23.83    9.05  FeCl2
Lime            -18.11     14.46   32.57  CaO
Litharge         -4.36      8.27   12.64  PbO
Magnesite         0.33      2.61    2.27  MgCO3
Magnetite        -1.15      9.27   10.42  Fe3O4
Malachite        -3.54      2.36    5.90  Cu2CO3(OH)2
Manganite         1.86      1.69   -0.16  MnO(OH)
Manganosite     -11.25      6.66   17.92  MnO
Massicot         -4.54      8.27   12.82  PbO
Matlockite       -6.73    -16.16   -9.43  PbFCl
Mayenite       -231.31    262.85  494.15  Ca12Al14O33
Melanterite     -20.54    -22.94   -2.40  FeSO4:7H2O
Metacinnabar   -104.67   -143.29  -38.62  HgS
Mg             -106.80     15.72  122.52  Mg
Mg(g)          -126.52     15.72  142.25  Mg
Mg1.25SO4(OH)0.5:0.5H2O  -8.75     -3.55    5.20  Mg1.25SO4(OH)0.5:0.5H2O
Mg1.5SO4(OH)     -9.28     -0.07    9.21  Mg1.5SO4(OH)
Mg2V2O7         -16.18    -47.09  -30.90  Mg2V2O7
MgCl2:2H2O      -20.66     -7.93   12.73  MgCl2:2H2O
MgCl2:4H2O      -15.23     -7.93    7.30  MgCl2:4H2O
MgCl2:H2O       -24.00     -7.93   16.07  MgCl2:H2O
MgOHCl          -12.89      3.01   15.89  MgOHCl
MgSeO3          -24.33    -22.65    1.67  MgSeO3
MgSeO3:6H2O     -19.22    -22.66   -3.44  MgSeO3:6H2O
MgSO4           -11.87     -7.04    4.83  MgSO4
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MgV2O6          -15.18    -61.02  -45.85  MgV2O6
Millerite      -133.61   -141.67   -8.06  NiS
Minium           -7.41      8.85   16.26  Pb3O4
Mirabilite       -7.05     -8.20   -1.15  Na2SO4:10H2O
Mn              -74.48      8.45   82.93  Mn
Mn(OH)2(am)      -8.65      6.66   15.31  Mn(OH)2
Mn(OH)3          -4.65      1.69    6.34  Mn(OH)3
MnCl2:2H2O      -19.20    -15.20    4.00  MnCl2:2H2O
MnCl2:4H2O      -17.95    -15.20    2.75  MnCl2:4H2O
MnCl2:H2O       -20.74    -15.20    5.54  MnCl2:H2O
MnO2(gamma)        4.78    -11.35  -16.13  MnO2
MnSe           -105.63   -116.33  -10.70  MnSe
MnSeO3          -22.66    -29.93   -7.27  MnSeO3
MnSeO3:2H2O     -23.60    -29.93   -6.33  MnSeO3:2H2O
MnSO4           -16.92    -14.31    2.61  MnSO4
MnV2O6          -16.22    -68.30  -52.08  MnV2O6
Mo             -129.32    -20.05  109.27  Mo
Molysite        -40.64    -27.17   13.47  FeCl3
Monohydrocalcite   0.46      3.13    2.68  CaCO3:H2O
Monteponite      -6.51      8.59   15.09  CdO
Montroydite       6.38      8.82    2.44  HgO
Morenosite       -8.47    -10.53   -2.06  NiSO4:7H2O
MoSe2          -214.47   -269.60  -55.12  MoSe2
N2(g)           -20.55    -23.73   -3.18  N2
Na              -60.09      7.28   67.37  Na
Na(g)           -73.58      7.28   80.86  Na
Na2CO3           -9.72      1.44   11.16  Na2CO3
Na2CO3:7H2O      -8.50      1.44    9.94  Na2CO3:7H2O
Na2O            -54.65     12.77   67.42  Na2O
Na2Se          -122.05   -110.22   11.83  Na2Se
Na2Se2         -173.64   -234.99  -61.35  Na2Se2
Na3H(SO4)2      -21.90    -22.79   -0.89  Na3H(SO4)2
Na4Ca(SO4)3:2H2O -17.02    -22.92   -5.89  Na4Ca(SO4)3:2H2O
NaFeO2           -7.88     12.00   19.88  NaFeO2
Nahcolite        -4.80     -4.94   -0.14  NaHCO3
Nantokite       -15.19    -21.96   -6.77  CuCl
Natron           -8.15      1.44    9.59  Na2CO3:10H2O
Nesquehonite     -2.68      2.61    5.29  MgCO3:3H2O
NH3(g)          -69.21    -67.42    1.80  NH3
NH4HSe         -168.35   -190.41  -22.06  NH4HSe
Ni              -38.75     12.23   50.98  Ni
Ni(OH)2          -2.31     10.44   12.75  Ni(OH)2
Nickelbischofite -14.58    -11.42    3.15  NiCl2:6H2O
NiCl2           -20.02    -11.42    8.60  NiCl2
NiCl2:2H2O      -15.34    -11.42    3.92  NiCl2:2H2O
NiCl2:4H2O      -15.27    -11.42    3.85  NiCl2:4H2O
NiCO3            -4.40     -0.89    3.51  NiCO3
NiF2            -17.38    -16.55    0.82  NiF2
NiF2:4H2O       -12.50    -16.56   -4.06  NiF2:4H2O
NiSO4           -15.81    -10.53    5.28  NiSO4
NiSO4:6H2O(alpha)  -8.51    -10.53   -2.02  NiSO4:6H2O
Nitrobarite     -11.54    -14.03   -2.49  Ba(NO3)2
NO(g)           -25.78    -25.05    0.74  NO
NO2(g)          -19.95    -11.60    8.35  NO2
O2(g)            -0.68     -3.57   -2.89  O2
Orpiment       -537.27   -616.75  -79.49  As2S3
Otavite          -0.97     -2.74   -1.77  CdCO3
Oxychloride-Mg   -8.89     16.94   25.83  Mg2Cl(OH)3:4H2O
Paralaurionite   -2.85     -2.66    0.20  PbClOH
Pb              -37.11     10.06   47.17  Pb
Pb(g)           -65.55     10.06   75.61  Pb
Pb(N3)2(mono)  -208.25   -216.62   -8.37  Pb(N3)2
Pb(N3)2(orth)  -207.82   -216.62   -8.81  Pb(N3)2
Pb2Cl2CO3        -7.03    -16.64   -9.62  Pb2Cl2CO3
Pb2Cl5NH4       -85.89   -105.52  -19.63  Pb2Cl5NH4
Pb2O(N3)2      -194.64   -208.35  -13.71  Pb2O(N3)2
Pb3SO6           -6.73      3.85   10.58  Pb3SO6
Pb4Cl2(OH)6      -6.05     11.23   17.28  Pb4Cl2(OH)6
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Pb4SO7           -9.59     12.12   21.71  Pb4SO7
PbCO3.PbO        -4.44      5.22    9.66  PbCO3.PbO
PbF2            -13.47    -18.72   -5.25  PbF2
PbFCl            -7.16    -16.16   -8.99  PbFCl
PbSeO4           -9.17    -16.12   -6.95  PbSeO4
PbSO4(NH3)2    -145.50   -147.53   -2.03  PbSO4(NH3)2
PbSO4(NH3)4    -283.86   -282.37    1.49  PbSO4(NH3)4
Penroseite     -138.51   -237.32  -98.81  NiSe2
Pentahydrite     -5.65     -7.04   -1.39  MgSO4:5H2O
Periclase        -7.39     13.94   21.33  MgO
Phosgenite       -6.99    -16.64   -9.65  Pb2(CO3)Cl2
Pirssonite       -6.75      4.58   11.32  Na2Ca(CO3)2:2H2O
Plattnerite       0.27     -7.69   -7.97  PbO2
Polydymite     -496.72   -545.65  -48.93  Ni3S4
Portlandite      -8.08     14.46   22.55  Ca(OH)2
Pyrite         -248.71   -273.41  -24.70  FeS2
Pyrolusite        6.31    -11.35  -17.66  MnO2
Pyrrhotite     -150.34   -154.08   -3.74  FeS
Realgar        -216.74   -277.02  -60.28  AsS
Rhodochrosite    -4.45     -4.67   -0.22  MnCO3
S              -108.79   -153.90  -45.11  S
S2(g)          -231.47   -238.65   -7.19  S2
Scacchite       -23.94    -15.20    8.74  MnCl2
Se              -59.11    -33.02   26.10  Se
Se2O5           -70.48    -60.99    9.49  Se2O5
SeCl4           -94.65    -80.31   14.33  SeCl4
Sellaite         -3.62    -13.06   -9.44  MgF2
SeO3            -43.56    -24.40   19.16  SeO3
Shcherbinaite   -16.61    -18.06   -1.45  V2O5
Siderite        -13.08    -13.30   -0.22  FeCO3
Smithsonite      -1.21     -0.77    0.44  ZnCO3
SO2(g)          -56.87    -56.69    0.18  SO2
Sphalerite     -130.08   -141.55  -11.47  ZnS
Spinel          -10.91     26.69   37.61  Al2MgO4
Starkeyite       -6.04     -7.04   -1.00  MgSO4:4H2O
Stilleite       -88.44   -112.43  -23.98  ZnSe
Tachyhydrite    -40.40    -23.25   17.14  Mg2CaCl6:12H2O
Tenorite         -0.80      6.84    7.65  CuO
Thenardite       -7.84     -8.20   -0.36  Na2SO4
Thermonatrite    -9.49      1.44   10.94  Na2CO3:H2O
Tiemannite      -55.94   -114.17  -58.23  HgSe
Todorokite       26.63    -19.20  -45.82  Mn7O12:3H2O
Trevorite        11.90     21.68    9.78  NiFe2O4
Troilite       -150.24   -154.08   -3.84  FeS
Umangite       -167.33   -261.18  -93.85  Cu3Se2
V              -131.80    -24.85  106.94  V
V2O4            -34.00    -25.45    8.56  V2O4
V3O5            -81.22    -67.79   13.43  V3O5
V4O7            -99.31    -80.51   18.80  V4O7
Vaesite        -234.22   -261.00  -26.77  NiS2
Wilkmanite     -309.50   -462.42 -152.92  Ni3Se4
Witherite         2.65     -0.37   -3.02  BaCO3
Wurtzite       -132.38   -141.55   -9.17  ZnS
Wustite         -13.46     -1.06   12.40  Fe.947O
Zincite          -0.64     10.56   11.20  ZnO
Zn              -56.44     12.35   68.79  Zn
Zn(BO2)2         -6.50      1.81    8.31  Zn(BO2)2
Zn(ClO4)2:6H2O  -62.68    -57.04    5.63  Zn(ClO4)2:6H2O
Zn(g)           -73.06     12.35   85.41  Zn
Zn(NO3)2:6H2O   -17.83    -14.43    3.40  Zn(NO3)2:6H2O
Zn(OH)2(beta)    -1.37     10.56   11.93  Zn(OH)2
Zn(OH)2(epsilon)  -1.10     10.56   11.66  Zn(OH)2
Zn(OH)2(gamma)   -1.32     10.56   11.88  Zn(OH)2
Zn2(OH)3Cl       -5.10     10.19   15.29  Zn2(OH)3Cl
Zn2SO4(OH)2      -7.44      0.15    7.58  Zn2SO4(OH)2
Zn3(AsO4)2      -80.56    -71.25    9.31  Zn3(AsO4)2
Zn3O(SO4)2      -29.36    -10.27   19.09  Zn3O(SO4)2
Zn5(NO3)2(OH)8  -14.86     27.81   42.67  Zn5(NO3)2(OH)8
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  ZnCl2            -18.38    -11.30    7.08  ZnCl2
  ZnCl2(NH3)2     -139.13   -146.14   -7.01  ZnCl2(NH3)2
  ZnCl2(NH3)4     -274.26   -280.97   -6.71  ZnCl2(NH3)4
  ZnCl2(NH3)6     -411.06   -415.80   -4.74  ZnCl2(NH3)6
  ZnCO3:H2O         -0.91     -0.77    0.14  ZnCO3:H2O
  ZnF2             -15.94    -16.44   -0.49  ZnF2
  ZnSeO3:H2O       -19.28    -26.03   -6.75  ZnSeO3:H2O
  ZnSO4            -13.95    -10.41    3.53  ZnSO4
  ZnSO4:6H2O        -8.71    -10.41   -1.70  ZnSO4:6H2O
  ZnSO4:7H2O        -8.54    -10.41   -1.88  ZnSO4:7H2O
  ZnSO4:H2O         -9.86    -10.41   -0.55  ZnSO4:H2O

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 3.
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End of Run after 0.719 Seconds.
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APPENDIX 03: IMPACT ASSESSMENT AND MONITORING REQUIREMENTS

ISSUES: ALTERATION OF NATURAL DRAINAGE PATTERNS

Information in this section was sourced from the approved EMPr's (SLR, August 2017 and April 2019) and the pit lake study compiled for the proposed project (SLR, June 2019).

Introduction

During the closure phase, stormwater management infrastructure to contain dirty water as required by legislation will be required around the perimeter of the waste rock dumps. In this regard the collection of rainfall and runoff will be via toe paddocks. The toe paddocks will remain until such time as the waste rock dumps have been rehabilitated successfully, after which they can be removed. Further to this, natural surface water run-off and rainfall will also be collected in the partially open pit. The collected rain-fall and run-off will therefore be lost to the catchment and can result in the alteration of drainage patterns in a similar manner to what is currently occurring on site and will perpetuate during the decommissioning phase.

All decommissioning and post closure activities and infrastructure will be located within the Tshipi Borwa Mine area and as such will not result in the physical alteration of any nearby water resources such as the ephemeral Vlermuisleegte and Witleegte Rivers.

Link to project specific activities/infrastructure

Key decommissioning and post closure infrastructure associated with the impact includes:

- Partially open pit (result of in-pit dumping); and
- Waste rock dumps remaining on surface.

Rating of impact

Severity/ nature

Rainfall and surface water run-off will be collected in all areas that have been designed with water containment infrastructure and through collection into the partially open pit. The collected rainfall and run-off will therefore be lost to the catchment and can result in the alteration of drainage patterns. The total MAR for the quaternary catchment D41K is 6.53 million cubic meters (mcm). The proposed project will result in a loss to the quaternary catchment by less than one percent (<1%). In the unmitigated scenario the severity is medium to low because although the reduction is measurable, it will remain in the current range. In the mitigated scenario the severity is low.

Duration

In the unmitigated scenario, the alteration of drainage patterns associated with the waste rock dumps is long term. In the mitigated scenario, the duration of the alterations is short term as the toe paddocks will be removed once vegetation has been established. This is a low duration in the mitigated scenario.

In terms of the open pit, in the unmitigated and mitigated scenarios the loss of run-off to the catchment through the collection in the partially open pit is long term. This is a high duration.

Spatial scale / extent

In the mitigated and unmitigated scenario the physical alteration of drainage patterns will extend beyond the site boundary as flow reduction impacts could extend further downstream. This is a medium spatial scale.

Consequence

In the unmitigated scenario the consequence is high to medium and low in the mitigated scenario with management actions.

Probability

The probability of the alteration of drainage patterns is definite, but the magnitude of the reduced flows is unlikely to result in substantial deterioration and related flow impacts downstream due to the relatively flat topography and high infiltration rates therefore the probability is low in both the mitigated and unmitigated scenarios.

Significance

The significance of this potential impact is medium to low in the unmitigated scenario and low in the mitigated scenario.

No cumulative or additional latent impacts have been identified.

Unmitigated and Mitigated – summary of the impact

Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
Unmitigated					
M-L	H	M	H-M	L	M-L
Mitigated/Residual impact					
L	H (Low for waste rock dumps)	M	M	L	L

Project impact within the context of approved closure commitments

The impact associated with the alteration of natural drainage patterns was assessed as part of the approved EMPr's (SLR, August 2017 and April 2019). In this regard, the significance of the impact was rated medium in the unmitigated scenario and reduced to low with mitigation given that rehabilitation at closure will allow for the restoration of drainage patterns. In terms of the proposed project, the impact rating is similar. Although the alteration of natural drainage patterns for the partially open pit cannot be mitigated, it is important to note that the collection of rainfall and run-off in the partially open pit does contribute to the development of the pit lake which can be used for alternative uses. This is discussed in further detail in the section below.

Summary of the impact significance rating in the context of the approved commitments

Management	Approved EMPr (August 2017)	Proposed project
Unmitigated	Medium	Medium to Low
Mitigated	Low	Low

Management objective

The objective is to prevent unacceptable alteration of drainage patterns and related reduction of downstream surface water flow.

Management actions

Implement the following management actions:

- *Once all infrastructure, equipment and services have been removed, the remaining surface areas will be landscaped, topsoiled and revegetated to promote natural drainage patterns. This is mainly in the decommissioning phase; and*

- *Once the waste rock dumps have been rehabilitated successfully, the toe paddocks will be removed. This will happen in both the decommissioning and closure phases.*

ISSUE: CONTAMINATION OF SURFACE WATER RESOURCES

Information in this section was sourced from the approved EMPr's (SLR, August 2017 and April 2019), the pit lake study compiled for the proposed project (SLR, June 2019).

Introduction

There are a number of pollution sources that have the potential to pollute surface water, particularly in the unmitigated scenario. In the decommissioning phase these potential pollution sources are temporary in nature. Although these sources may be temporary, the potential pollution may be long term. The closure phase will present final land forms such as the waste rock dumps that may have the potential to contaminate surface water through long term seepage and/or run-off.

Link to project specific activities/infrastructure

Decommissioning activities and post closure infrastructure associated with the impact includes waste rock dumps remaining on surface and partially open pit (access to pit lake).

Rating of impact

Severity/nature

The decommissioning and closure infrastructure and activities present numerous sources of pollution that can contaminate surface water resources. In the unmitigated scenario, potential decommissioning phase pollution sources associated include:

- Sedimentation from erosion;
- Spillage of waste material, dirty water, fuel, lubricants and leaks from vehicles and equipment
- Contaminated soil areas; and
- Run-off from waste rock dumps

Potential closure phase pollution sources include:

- Contaminated pit lake water quality;
- Sedimentation from erosion; and
- Run-off from waste rock dumps.

At elevated concentrations contaminants can exceed the relevant surface water quality limits imposed by DWS and can be harmful to humans, livestock and biodiversity (Refer to the biodiversity section in this appendix for the potential biodiversity impacts. This impact will not be re-assessed in this section).

In the unmitigated scenario this is a high severity. In the mitigated scenario, where decommissioning activities are controlled according to the existing approved EMPr and the closure plan is effectively implemented, the severity reduces to low. It must be noted that this conclusion is drawn in the context of successfully achieving the stated end pit lake quality objective which is suitable for livestock watering and a functional biodiversity system but not for domestic use.

Duration

In the unmitigated scenario the sources of the contamination will extend beyond closure which is a high duration. With management actions, pollution can be prevented and/or managed and as such the impacts can be limited to the pre-closure phase. It must be noted that the pit lake water quality modelling extended to 200 years post closure.

Spatial scale / extent
In the unmitigated scenario contaminates could migrate off site, which is a medium spatial scale. In the mitigated scenario, all potential surface contamination sources will have been removed or mitigated preventing any possibility of offsite surface water contamination. This is a low spatial scale.
Consequence
In the unmitigated scenario the consequence is high and in the mitigated scenario it is low with management actions.

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

- Does contamination reach surface water resources;
- Will people and livestock utilise this contaminated water; and
- Is the contamination level harmful?

The first element is that contamination reaches the surface water resources. Due to the distance of the Tshipi Borwa Mine to the closest surface water resource (Vlermuisleegte River), which is located two kilometres west of the mine, it is unlikely that pollution sources will reach surface water resources. It should also be noted that the Vlermuisleegte is ephemeral in nature and therefore is associated with long periods of no flow. In the unmitigated scenario, the pit lake will become a surface water resource that is contaminated.

The second element is that third parties and/or livestock use this contaminated water for drinking purposes. In the unmitigated scenario this is a definite possibility because one of the stated end uses is grazing and use of the pit lake for livestock watering.

The third element in the unmitigated scenario, it is that it likely that some contaminants will be at a level which is harmful to humans and livestock. In the unmitigated scenario, this is possible particularly for the pit lake.

As a combination, the unmitigated probability is high, reducing to low with management actions.

Significance
In the unmitigated scenario, the significance of this potential impact is high. In the mitigated scenario, the significance is reduced to low.

It is however important to note that a potential latent impact could be associated with long term deterioration of pit lake water quality subject to the success of the ongoing floating wetland water treatment. If this latent impact manifests and cannot be mitigated through treatment adaptations then the use of/access to the pit lake will have to be reconsidered. The associated default management measure will be to fence and/or berm off access to the pit lake.

No cumulative impact has been identified.

Unmitigated and Mitigated – summary of the impact

Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
Unmitigated					
H	H	M	H	H	H
Mitigated/residual impact					
L	L	L	L	L	L

Project impact within the context of approved closure commitments

The impact associated with the contamination of surface water resources was assessed as part of the approved EMPr's (SLR, August 2017 and April 2019). In this regard, the significance of the impact was rated medium in the unmitigated scenario and reduced to low with mitigation. It is however important to note that the assessment focussed on the contamination of the Vlermuisleegte River only. The proposed project introduces issues associated with the pit lake which changes the assessment, particularly in the unmitigated scenario.

Summary of the impact significance rating in the context of the approved commitments

Management	Approved EMPr (August 2017)	Proposed project
Unmitigated	Medium	High
Mitigated	Low	Low

Management objective

The objective is to prevent pollution of surface water resources.

Management actions

Implement the following management actions:

- In order to address various potential pollution sources associated with decommissioning activities, Tshipi will implement the management actions for the decommissioning phase as outlined in the approved EMPr's (SLR, August 2017 and April 2019). These management actions focus on pollution prevention (collection, storage and disposal of hazardous waste), implement the stormwater management plan, regular inspection and maintenance of water management facilities and waste rock dumps and maintenance and servicing equipment and vehicles;
- *During operations, decommissioning and the initial part of the closure phase, surface water run-off and seepage paddocks will be installed and maintained around all waste rock dumps;*
- *Tshipi will implement the topography/topsoil and revegetation plans during the decommissioning phase. Once rehabilitated the final land forms are unlikely to erode and/or contribute to pollution run-off. Once this is confirmed, the run-off containment toe paddocks around the waste rock dumps can be removed and rehabilitated;*
- During the decommissioning phase *and the initial monitoring and aftercare part of the closure phase*, Tshipi will continue to implement a monitoring programme for surface water resources. This includes monitoring both up and downstream of the Vlermuisleegte when possible (the possibility of monitoring water in the Vlermuisleegte River may only arise during heavy periods of rain);
- *Once mining activities cease in the pit and sufficient water is available (during the closure phase), a floating wetland system will be implemented using a combination of vegetation types and surface area coverage that will enable the treatment of the pit lake water to meet DWS livestock watering objectives. Research, references and modelling indicate that this can be a successful treatment solution, but final design, maintenance requirements and related monitoring will be determined only on the basis of implementation on site. In this regard, final closure planning will be sufficiently flexible to allow for the following:*
    - *Ongoing optimisation and improvement of the floating wetland system;*
    - *Adaptation to changing circumstances that might require implementation of alternative and/or additional treatment technologies; and*
    - *Contingency planning in the event that water treatment becomes ineffective at some point in future and access to/use of the pit lake requires reconsideration.*
- *During the closure phase, monitoring the pit lake water quality will be undertaken. Details of the surface water monitoring programme;*
- During the decommissioning and the monitoring and aftercare part of the closure phases, should any surface water resource contamination be detected, the mine will immediately notify DWS. Tshipi, in consultation with DWS and an appropriately qualified person, will then notify potentially affected users (eg. farmers using the water for livestock watering), 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. Any related loss caused by Tshipi (in the short and long term) will be addressed through compensation, which may include an alternative water supply of equivalent quality and quantity; and

- Implement the emergency response procedure in the event of a potentially polluting discharge incident.

ISSUE: LOWERING OF GROUNDWATER LEVELS

Information in this section was sourced from the approved EMPr's (SLR, August 2017 and April 2019), the pit lake study compiled for the proposed project (SLR, June 2019).

Introduction

Dewatering of the open pit during operations has the potential to lower groundwater levels. Lowering of groundwater levels through dewatering may cause a loss in water supply to surrounding borehole users if they are in the impact zone. Once dewatering activities cease, groundwater levels will start to rebound.

Link to project specific activities/infrastructure

Activities associated with this impact include the cessation of dewatering.

Discussion

Prior to mining the natural depth of the water in surrounding boreholes ranged from 25 to 55 m below ground level. Groundwater level monitoring data currently shows water depths ranging from 41 to 75 m below ground level. At decommissioning, although dewatering activities will cease, the modelled cone of drawdown developed due to dewatering is predicted to be at a maximum extent of 5.5 km to the east and 8.3 km to the west of the Tshipi Borwa Mine. Third parties within the simulated cone of depression may therefore experience a drop in water levels. When mining and dewatering cease, groundwater levels will start to rebound and the water level in the pit will increase. Initially, inflows will be high, because the hydraulic gradient driving inflows from the aquifer into the pit would be at a maximum due to the water level being at base of the pit which will be approximately 250m below ground level. Over time, as the pit lake level rises inflows will diminish until a steady state level is reached. Due to evaporative loses and pit geometry; the partially filled pit will continue to be a hydraulic sink in perpetuity because the steady state pit lake level will remain approximately 6m below the natural groundwater level which is approximately 35 below ground level. The associated cone of depression hydraulic gradient will be significantly reduced (the depth to the base of the cone of depression reduces by 97%). It follows that groundwater levels at off-site third party boreholes are predicted to rebound to natural groundwater level. This impact has therefore not been assessed further and has been rated as being insignificant.

No additional latent impacts have been identified. If surrounding mining operations dewater it is possible that cumulative impacts on groundwater levels will be experienced.

Project impact within the context of approved closure commitments

The impact associated with the lowering of groundwater levels was not assessed at closure as part of the approved EMPr's (SLR, August 2017 and April 2019) given that it was assumed groundwater levels rebounded to natural ground level. The proposed project does not alter the impact finding.

Summary of the impact significance rating in the context of the approved commitments

Management	Approved EMPr (August 2017)	Proposed project
Unmitigated	Insignificant	Insignificant
Mitigated	Insignificant	Insignificant

Management objective

The objective is to prevent water losses to third party water users.

Management actions

Implement the following management actions:

- Tshipi will continue to monitor groundwater levels (refer to Section **Error! Reference source not found.** for the monitoring programme); and
- In the unlikely event that borehole users experience any additional post closure mine related water loss, Tshipi will provide compensation, which could include an alternative water supply of equivalent water quality and quantity. This will happen during the closure phase.

ISSUE: CONTAMINATION OF GROUNDWATER RESOURCES

Information in this section was sourced from the approved EMPr's (SLR, August 2017 and April 2019), the pit lake study compiled for the proposed project (SLR, June 2019) included in **Error! Reference source not found.**.

Introduction

The closure phase will present final land forms such as waste rock dumps remaining on surface and the waste rock backfilled into the open pit that may have the potential to pollute water resources through long term seepage and/or run-off.

Link to project specific activities/infrastructure

Post closure activities and infrastructure associated with the impact include:

- Waste rock backfilled into the open pit as part of in-pit dumping; and
- Waste rock dumps remaining on surface.

Rating of impacts

Severity/nature

Groundwater modelling undertaken for Tshipi makes provision for a worse case theoretical scenario which includes a completely backfilled open pit and all waste rock dumps remaining on surface. This allows for multiple pollution sources and re-establishment of close to normal groundwater flow. In reality, the proposed closure option will include the partially backfilled pit acting as a hydraulic sink with a draw down cone toward the pit lake in perpetuity. The reason for using the conservative theoretical modelling scenario is the precautionary principle which is relevant because of the importance of understanding groundwater risk in this particular arid region.

A chloride source concentration of 2200 mg/ℓ was simulated for the waste rock and simulated for 100 years. The worst case theoretical modelled results indicate that the pollution plume migrates off site but is unlikely to impact third party boreholes (Figure 14-1

). When applying these conservative results to the specific context of the proposed project, the extent of the pollution plume will reduce because the partially backfilled pit will act as a hydraulic sink and associated draw down cone will draw some of the pollution plume into the pit. No impact on any off-site third party boreholes is predicted. In both the mitigated and unmitigated scenarios the severity of the impact is low.

Duration

Groundwater contamination is long term in nature, occurring post closure in both the unmitigated and mitigated scenarios. This is a high duration in the unmitigated scenario. In the mitigated scenario, the contamination source will significantly reduce once the topsoiling and revegetation of the remaining waste rock dumps is complete because rainfall infiltration through the waste rock dump into the underlying ground will significantly reduce. This is a medium duration.

Spatial scale / extent

No impact on any off-site third party boreholes is predicted. In both the mitigated and unmitigated scenarios the spatial extent is low.

Consequence

The consequence is medium in the unmitigated scenario and reduces to low with mitigation.

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; and
- Is the contamination level harmful?

The first element is that contamination reaches the groundwater resources underneath or adjacent to the site. 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 boreholes located within the contaminant plume.

The third element is whether contamination is at concentrations which are harmful to users. Based on groundwater modelling predictions, potential contamination will be at low concentrations for a small area outside of the Tshipi Borwa Mine area.

As a combination, the unmitigated and mitigated probability is low.

Significance

The significance of this potential impact in both the unmitigated and mitigated scenarios is low.

No additional latent impacts have been identified. Modelling includes contributions from off-site sources in the context of current water quality. The predictive modelled results are therefore cumulative in nature.

Unmitigated and Mitigated – summary of the impact

Severity / nature	Duration	Spatial scale / extent	Consequence	Probability of Occurrence	Significance
Unmitigated					
L	H	L	M	L	L
Mitigated/Residual impact					
L	M	L	L	L	L

Project impact within the context of approved closure commitments

The impact associated with the contamination of groundwater resources was assessed as part of the approved EMPr's (SLR, August 2017 and April 2019). In this regard, the significance of the impact was rated low in the mitigated and unmitigated scenarios. The proposed project does not change the significant impact ratings, however the proposed project minimises the extent of the pollution plume because of the hydraulic sink associated with the partially backfilled pit.

Summary of the impact significance rating in the context of the approved commitments

Management	Approved EMPr (August 2017)	Proposed project
Unmitigated	Low	Low
Mitigated	Low	Low

Management objective

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

Management actions

Implement the following management actions:

- Tshipi will implement the management actions for the decommissioning phase as outlined in the approved EMPr's (SLR, August 2017 and April 2019). These management actions focus on implementing the stormwater management plan, pollution prevention through appropriate infrastructure design of waste rock dumps and updating the groundwater model;
- Post closure ground water monitoring will be undertaken until it is no longer deemed necessary. The post closure monitoring programme is included in Section **Error! Reference source not found.**; and
- If water users experience any Tshipi related contamination, Tshipi will provide compensation, which could include an alternative water supply of equivalent water quality. This commitment extends into the closure phase.

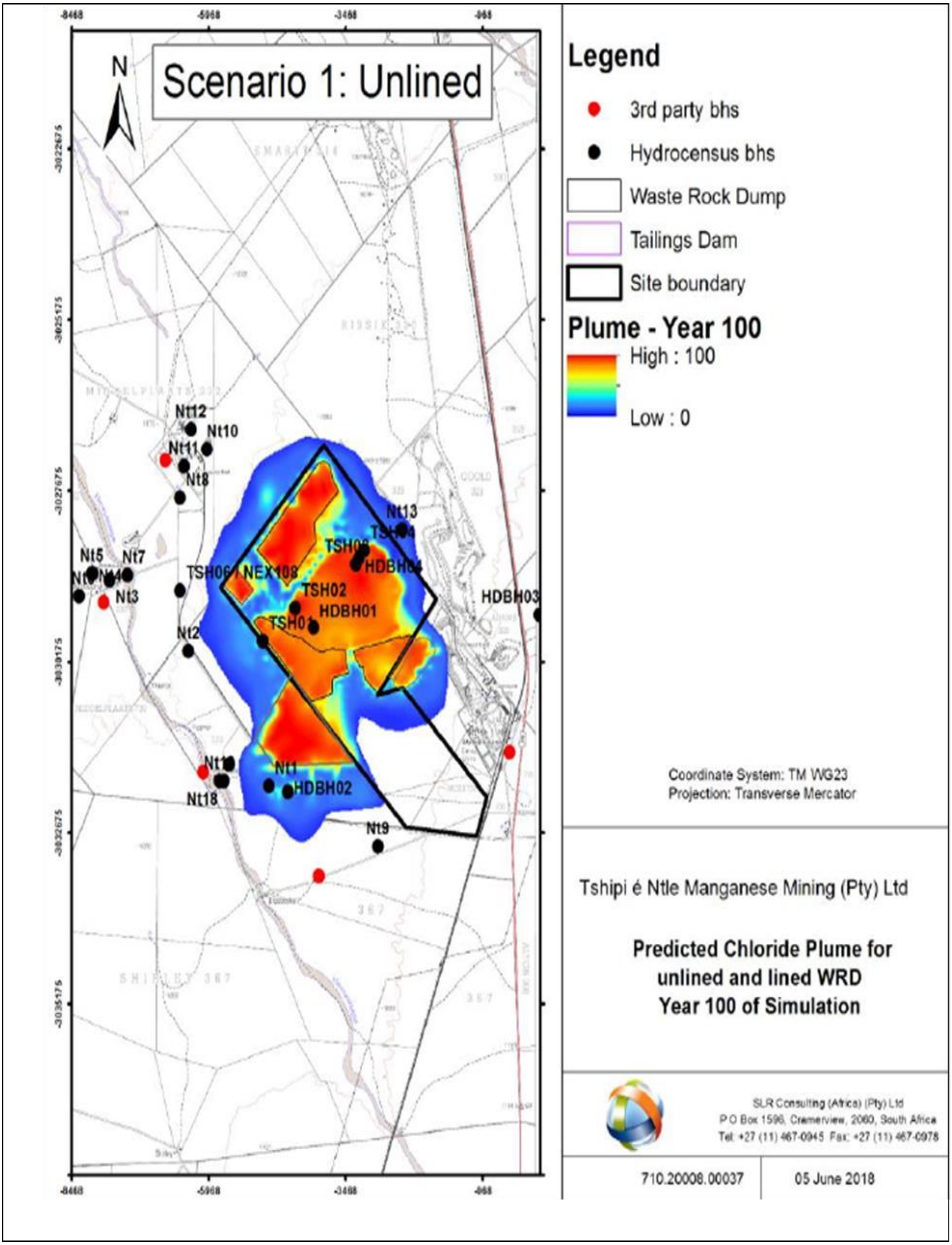


Figure 14-1: Predicted chloride plume – year 100 of simulation (SLR, 2018)

Monitoring requirements

<table>
<tr><th>Activity
Impacts requiring monitoring</th><th>Functional requirements for monitoring</th><th>Monitoring and reporting frequency and time period for management actions</th></tr>
<tr><td colspan="3">WATER ASPECTS</td></tr>
<tr><td rowspan="2">Contamination of surface water</td><td colspan="2">Ephemeral surface water courses and pit lake water quality</td></tr>
<tr><td>Monitoring of surface water quality will be undertaken in the event that surface water flow is present in the Vlermuisleegte River. In this regard, samples should be taken from both upstream and downstream of the Vlermuisleegte River. In addition to this, the sampling of the pit lake water quality must also be undertaken. Refer to Figure 15 for the location of the surface water monitoring points.

Water quality analyses results should be classified in terms of the SANS 241 (2015) Water Quality Standards and the DWAF Target Quality Range for Livestock Watering (1996), or whichever is applicable at the time. The monitoring results should be assessed by a suitably-qualified professional registered with the South African Council for Natural Scientific Professional (SACNASP). The parameters that need to be analysed are summarised in the table below.

<table>
<tr><td>pH</td><td>Surface water flow in the Vlermuisleegte
Pit lake</td></tr>
<tr><td>Conductivity in mS/m at 25 ° c</td><td>Surface water flow in the Vlermuisleegte
Pit lake</td></tr>
<tr><td>Temperature</td><td>Pit lake</td></tr>
<tr><td>Dissolved oxygen</td><td>Pit lake</td></tr>
<tr><td>Total dissolved solids (TDS) at 180 ° c</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Alkalinity as CaCO3</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Carbonate as CO3</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Bicarbonate as HCO3</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Boron as B</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Nitrate as N</td><td>Surface water flow in the Vlermuisleegte
Pit lake</td></tr>
</table>
</td><td>Monitoring will be undertaken when the Vlermuisleegte River is in flow.

Monitoring of the pit lake water quality will be undertaken for a minimum of 25 years. In this regard, quarterly monitoring will be required for the first 5 years, reducing to bi-annually for the next 10 years.

Monitoring reports need to be submitted to the DWS.</td></tr>
</table>

<table>
<tr><th>Activity
Impacts requiring monitoring</th><th>Functional requirements for monitoring</th><th>Monitoring and reporting frequency and time period for management actions</th></tr>
<tr><td></td><td>
<table>
<tr><td>Chloride as Cl</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Sulphate as SO4</td><td>Surface water flow in the Vlermuisleegte
Pit lake</td></tr>
<tr><td>Phosphate</td><td>Pit lake</td></tr>
<tr><td>Fluoride as F</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Sodium as Na</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Potassium as K</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Calcium as Ca</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Magnesium as Mg</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Manganese as Mn</td><td>Surface water flow in the Vlermuisleegte</td></tr>
<tr><td>Full metal scan - Inter Coupled Plasma Scan (ICP) (via Mass Spectrometry (MS)</td><td>Surface water flow in the Vlermuisleegte
Pit lake</td></tr>
</table>
</td><td></td></tr>
<tr><td></td><td colspan="2">Floating wetlands</td></tr>
<tr><td></td><td>Monitoring of the effectiveness of the floating wetland needs to be undertaken by a qualified specialist. Monitoring of the floating wetland is required for a minimum of 25 years because the floating wetland system takes time to establish and the size of the wetland needs to be appropriate to treat the pit lake water to meet DWS livestock watering objectives.</td><td>Monitoring should be undertaken for a minimum of 25 years.</td></tr>
<tr><td>Contamination of groundwater resources</td><td>Post closure groundwater quality monitoring will be undertaken. Refer to Figure 15 for the location of the groundwater monitoring points. It is recommended that after the first 5 years of monitoring is complete, a qualified specialist is contacted to determine the possibility of reducing the number of boreholes that are monitored.

Water quality analyses results should be classified in terms of the SANS 241 (2015) Water Quality Standards and the DWAF Target Quality Range for Livestock Watering (1996) or whichever is applicable at the time. The monitoring results should be assessed by a suitably-qualified professional registered with the South African Council for Natural Scientific Professional (SACNASP). The parameters</td><td>Groundwater quality must be monitored will be undertaken for a minimum of 10 years. In this regard, monitoring is bi-annually monitoring is required for the first 5 years, reducing to annually for the next 5 years.
Monitoring reports need to be submitted to the DWS on an annual basis.</td></tr>
</table>

Activity Impacts requiring monitoring	Functional requirements for monitoring	Monitoring and reporting frequency and time period for management actions
	that need to be analysed are summarised in the table below. pH Conductivity in mS/m at 25 ° c Total dissolved solids (TDS) at 180 ° c Alkalinity as CaCO3 Carbonate as CO3 Bicarbonate as HCO3 Boron as B Nitrate as N Chloride as Cl Sulphate as SO4 Fluoride as F Sodium as Na * Potassium as K * Calcium as Ca * Magnesium as Mg * Manganese as Mn * Full metal scan - Inter Coupled Plasma Scan (ICP) (via Mass Spectrometry (MS)	

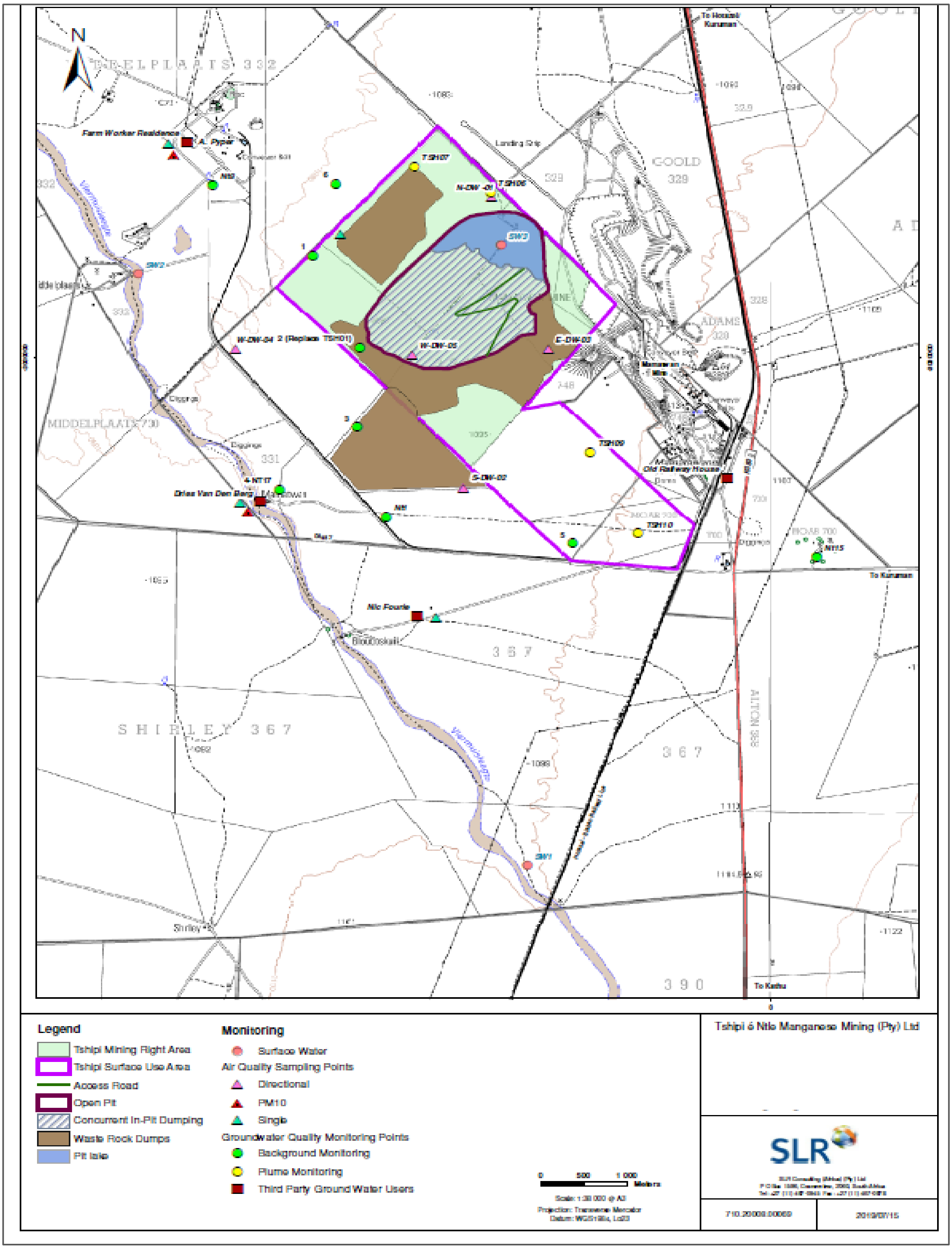


Figure 14-2: monitoring programme

APPENDIX 04: IAP COMMENT

A public consultation process was undertaken for the proposed project. In this regard, the public participation process was undertaken in accordance with the requirements of Chapter 6 of Regulations 982 of 4 December 2014 (EIA Regulations), as amended. In addition to this, consideration was also given to the public participation guideline in terms of the NEMA (2017). The purpose of the public participation process was to notify landowners, land users and other key stakeholders of the proposed project and to provide them with opportunity to raise any initial issues or concerns regarding the proposed project.

The details of the public participation process are outlined in the Basic Assessment Report compiled in support of the proposed project, however a summary of the comments raised during the public participation process of the proposed project coupled with the response is included in the table below.

Summary of Comments

Interested and affected party	Date comment received	Issues raised	Response provided
Fhatuwani Magonono	Comments raised at a focussed meeting held on 21 June 2019	The pit lake water will be contaminated because of the WRDs? It will end up infiltrating to the groundwater.	The waste rock has been subjected to leaching tests and these show results are comparable to the concentrations in the groundwater. The modelling has also shown however, that the amount of runoff that would enter the pit lake scenario is much lower than the volume of groundwater that will collect and therefore the influence from the waste rock runoff is very low compared to the groundwater chemistry. The selected options of the closure will mean that the pit lake will act as a sink and prevent the groundwater chemistry migrating beyond the pit lake boundary and therefore any influence on the surrounding groundwater quality is low. Should the pit be completely backfilled with waste rock – then the pit will not act as a sink and the groundwater will flow through and groundwater down gradient of the pit will be impacted. This is why option 3 is the preferred option.
		Will the pit spill?	The modelling has indicated the pit will never over top.
		The most critical part in terms of this application will be the geohydrological report, which must cover the modelling of the plume and the monitoring boreholes (post closure monitoring) both near and downstream.	This is explained below

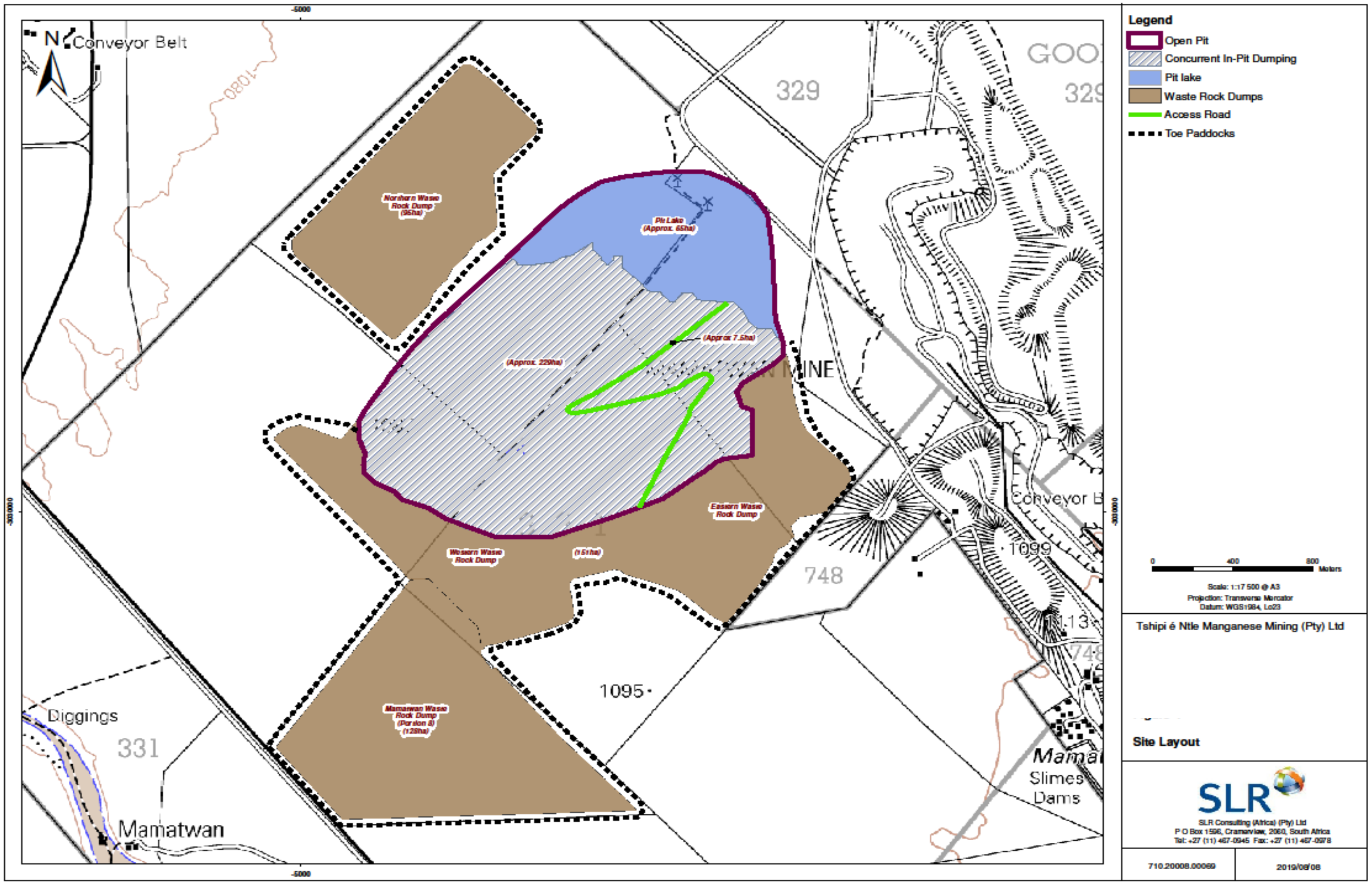
APPENDIX 05: NEMA TABLE

This specialist report was compiled taking into consideration the requirements for specialist reports as outlined in Appendix 6 of Regulations 982 of 4 December 2014 (EIA Regulations), as amended. The table below provides a summary of the requirements, with cross references to the report sections where these requirements have been addressed.

No.	Requirement	Section in report
a)	Details of -	
(i)	The specialist who prepared the report	Section 1.0
(ii)	The expertise of that specialist to compile a specialist report including a curriculum vitae	Section 1.0
b)	A declaration that the specialist is independent	Section 1.1
c)	An indication of the scope of, and the purpose for which, the report was prepared	Section 2.1
cA)	An indication of the quality and age of base data used for the specialist report	Section 5.0
cB)	A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change	Covered in other documents
d)	The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 5.6.3
e)	A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used	Section 4.0
f)	Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives	Appendix 03
g)	An identification of any areas to be avoided, including buffers	Covered in other documents
h)	A map superimposing the activity including the associated structure and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers	Appendix 06. Please note that there are no sensitive water courses located within the Tshipi surface use area and as such no buffers are applicable.
i)	A description of any assumption made and any uncertainties or gaps in knowledge	Section 10.2.1
j)	A description the findings and potential implication\s of such findings on the impact of the proposed activity, including identified alternatives on the environment or activities	Section 9.0
k)	Any mitigation measures for inclusion in the EMPr	Appendix 03
l)	Any conditions for inclusion in the environmental authorisation	Covered in other documents
m)	Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Appendix 03
n)	A reasoned opinion -	Section 13.0
(i)	As to whether the proposed activity, activities or portions thereof should be authorised	

No.	Requirement	Section in report
(iA)	Regarding the acceptability of the proposed activity or activities	Section 13.0
(ii)	If the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	
o)	A description of any consultation process that was undertaken during the course of preparing the specialist report	Appendix 04
p)	A summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	Appendix 04
q)	Any other information requested by the competent authority	Not applicable

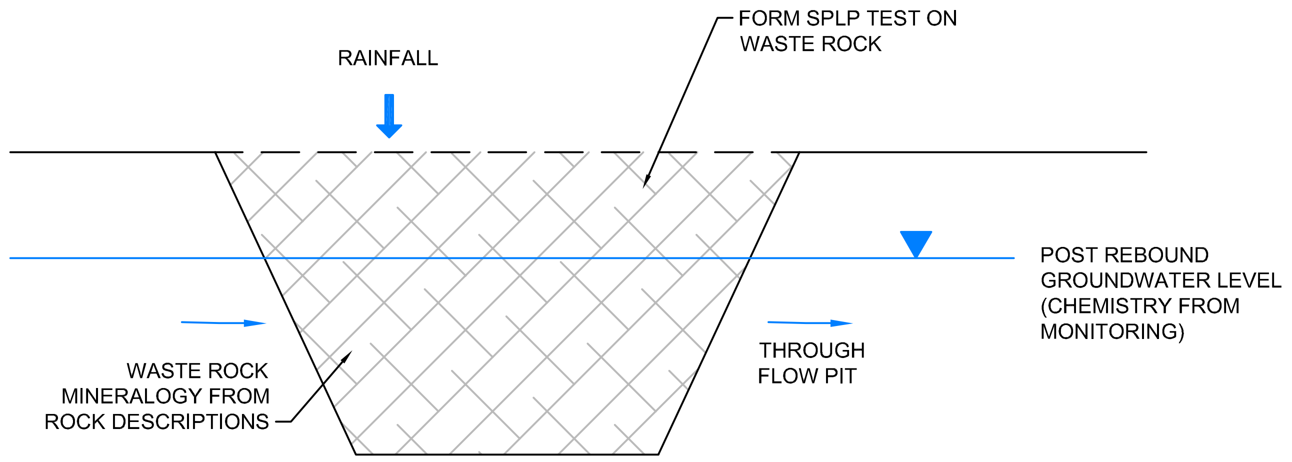
APPENDIX 06: PROPOSED SITE LAYOUT


-5000
N
Conveyor Belt
329
GOO
329
Norhern Wase Rock Dump (95ha)
Pit Lake (Approx. 65ha)
(Approx 7.5ha)
(Approx. 229ha)
MINE
Eastern Wase Rock Dump
Western Wase Rock Dump
(151ha)
Conveyor B
1099
748
1095
Mamatwan Waste Rock Dump (Portion 8) (128ha)
Diggings
331
Mamatwan
Mama
Slimes
Dams
-3030000
Legend
Open Pit
Concurrent In-Pit Dumping
Pit lake
Waste Rock Dumps
Access Road
Toe Paddocks
0
400
800
Meters
Scale: 1:17 500 @ A3
Projection: Transverse Mercator
Datum: WGS1984, Lo23
Tshipi é Ntle Manganese Mining (Pty) Ltd
Site Layout
SLR
SLR Consulting (Africa) (Pty) Ltd
P O Box 1596, Cramerview, 2060, South Africa
Tel: +27 (11) 467-0945 Fax: +27 (11) 467-0978
710.20008.00069
2019/08/08

DRAWINGS

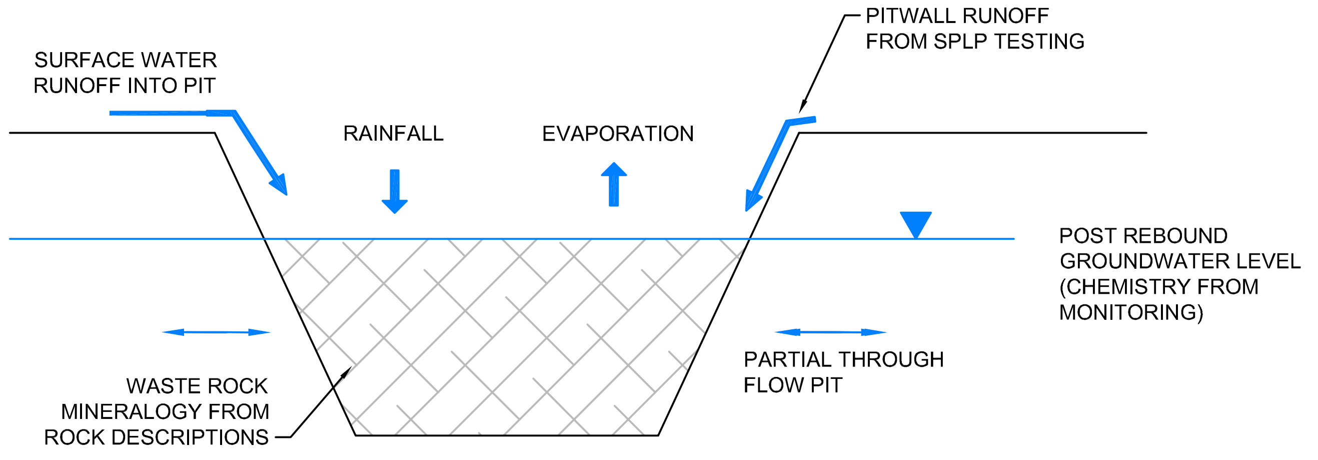
Drawing 01

1. COMPLETE BACKFILL



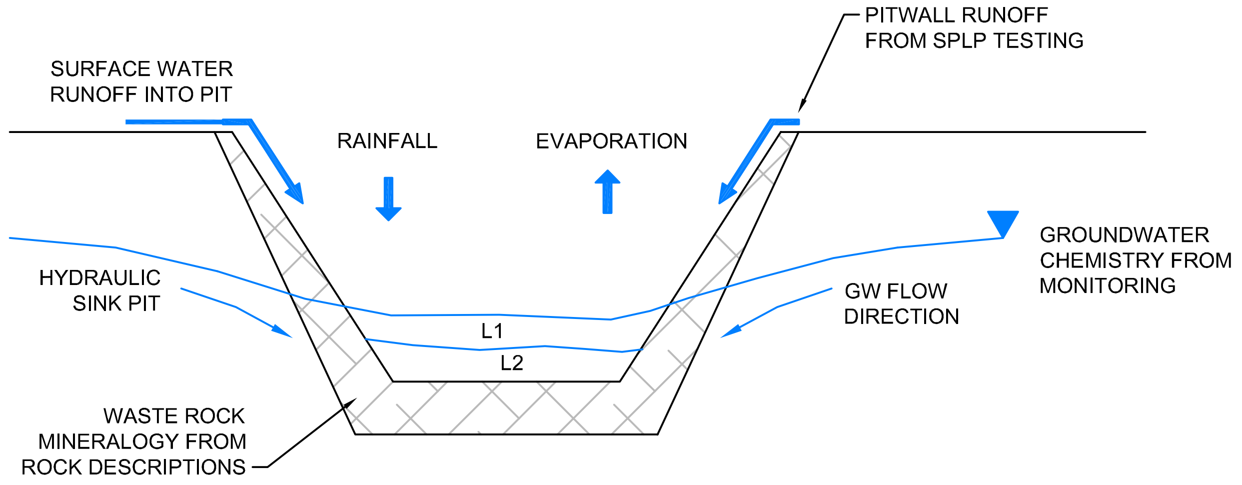
NOTES:
1. USE PHREEQ TO EQUILIBRATE GW CHEMISTRY WITH REACTIVE MINERALS IN WASTE ROCK
2. USE PHREEQ TO EQUILIBRATE SPLP LEACH DATA WITH MINERAK IN WASTE ROCK
3. USE GOLDSIM TO MIX CHEMISTRY FROM $\boxed{1}$ AND $\boxed{2}$

2. PARTIAL BACKFILL



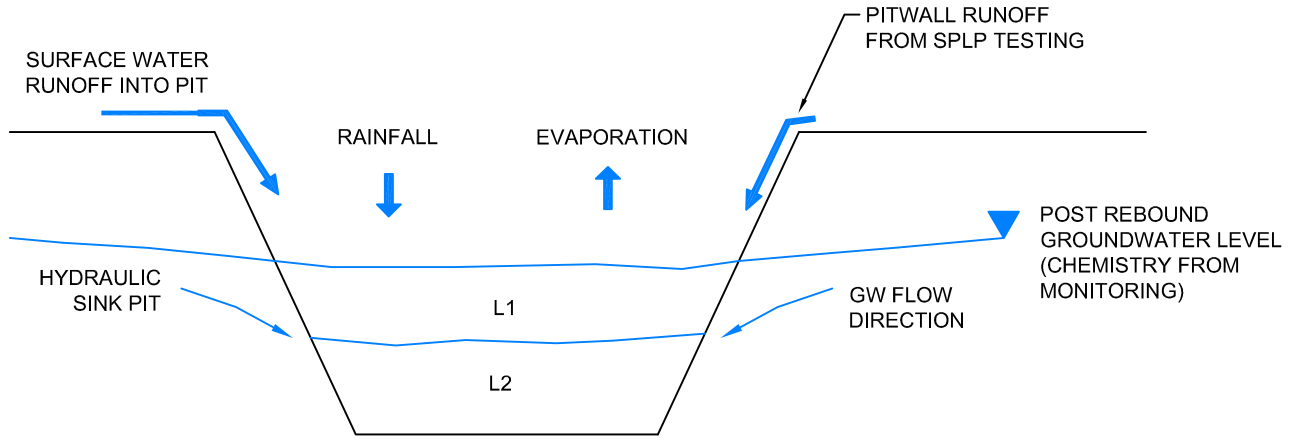
NOTES:
1. USE PHREEQ TO EQUILIBRATE GW CHEMISTRY WITH REACTIVE MINERALS IN WASTE ROCK
2. A SMALL COMPONENT OF THE SATURATED ROCK WILL HAVE RUNOFF - AMOUNT DEPENDS ON RISING GW RATE VS RUNOFF
3. IF APPLICABLE USE SPLP DATA TO MIX WITH EQUILATE GW DATA

3. CONCURRENT BACKFILL



NOTES:
1. USE PHREEQ TO EQUILIBRATE WASTE ROCK WITH GROUNDWATER
2. MIX WITH SPLP LEACH AS RUNOFF
3. MIX WITH RAINFALL CHEMISTRY
4. BULK MIXTURE FROM A AND EQUILIBRATE WITH O_2 AND CO_2 IN ATMOSPHERE. ALLOW PRECIPITATION OF MINERAL PHASES. THIS GENERATES LAYER 1 CHEMISTRY
5. THICKNESS OF LAYER 1 BASED ON PIT DIMENSIONS
6. THERMOCLINE THICKNESS BASED ON LAKE DIMENSIONS
7. LAYER 2 IS BULK CHEMISTRY WITH PRECIPITATION OF MAIN PHASES

4. NO BACKFILL



NOTES:
1. NO EQUILIBRATION OF GW AND SPLP BEFORE USING GOLDSIM
2. BULK CHEMISTRY FROM A (GOLDSIM) AND EQUILIBRATEWITH O_2 AND CO_2 IN ATMOSPHERE. ALLOW PRECIPITATION OF MINERAL PHASES
3. THICKNESS OF LAYER 1 BASED ON PIT DIMENSIONS - IF IT FORMS
4. THERMOCLINE THICKNESS BASED ON LAKE DIMENSIONS
5. LAYER 2 IS BULK CHEMISTRY WITH PRECIPITATION OF MAIN PHASES

LEGEND

▼	GROUNDWATER
▨	WASTE ROCK

D0	AB	JR	02.19	
Revision	By	Chk'd By	Date	Comments

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SPECIALIST HYDROLOGICAL AND GEOCHEMICAL EMP3 MODELLING

Drawing Title
CONCEPTUAL SITE MODEL FOR WATER QUALITY PREDICTION

Scale
NTS

Date
FEBRUARY 2019

Drawing Number
01

Revision
D0

DRAFT

405.03471.00039.18.01.D1 concept site model.dwg

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