# Grootegeluk Acid Mine Drainage (AMD) Strategy

exxaro
GROOTEGELUK | COAL

**TABLE OF CONTENT**


1 INTRODUCTION ..... 1
1.1 Location and background ..... 1
2 OBJECTIVES AND SCOPE ..... 1
2.1 Problem statement (acid mine drainage process) ..... 1
2.2 Objectives ..... 3
2.3 Scope of Acid Mine Drainage (AMD) strategy ..... 3
2.4 Test work ..... 4
3 REVIEW OF AVAILABLE INFORMATION ..... 5
3.1 Geology ..... 5
3.2 Hydrogeology and groundwater chemistry ..... 6
3.3 Surface-and pit-water chemistry ..... 7
3.4 Geochemistry ..... 10
3.4.1 Previous studies ..... 10
3.4.1.1 Golder 2007 ..... 10
3.4.1.2 Aphane 2014 ..... 12
3.4.1.3 GCS 2014 ..... 13
3.4.1.4 Schlumberger, December 2015 ..... 15
3.4.1.5 Digby Wells, September 2016 ..... 17
3.4.1.6 Exxaro 2016 ..... 19
3.4.1.7 Delta-H, September 2019 ..... 20
3.4.1.8 Summary of previous studies ..... 22
4 CONCEPTUAL MODEL ..... 26
4.1 Sources ..... 26
4.1.1 Mining (Open Pit) ..... 26
4.1.2 Backfilling ..... 27
4.1.3 Residue deposits ..... 28
4.1.4 Plant area and product stockpiles ..... 29
4.2 Pathways ..... 30
4.3 Receptors ..... 33
5 AMD RISK ASSESSMENT ..... 33
5.1 Introduction ..... 33
6 AMD MANAGEMENT STRATEGY ..... 34
6.1 Current AMD management at GGC. ..... 34
6.2 Gaps in Geochemical Data ..... 35
6.3 Groundwater Management Strategy ..... 35
6.4 Proposed further work ..... 36

**List of Tables**

Table 1. Average surface water qualities (pans) 2019/2020 ..... 8
Table 2. Sample selection for Golder 2007 study ..... 11
Table 3. Geochemical analyses done for the Golder 2007 study ..... 11
Table 4. Geochemical analyses done for the GCS 2014 study ..... 13
Table 5. Major and trace elements in fines and super fines ..... 13
Table 6. Sample selection for Schlumberger 2015 study ..... 15
Table 7. Geochemical analyses done for the Schlumberger 2015 study ..... 15
Table 8. Geochemical analyses done for the Digby Wells 2016 study ..... 17
Table 9. Major and trace elements in product samples ..... 18
Table 10. Sample selection for Delta-H 2019 study ..... 20
Table 11. Geochemical analyses done for the Delta-H 2019 study ..... 20
Table 12. Samples selected for kinetic testing, Delta-H ..... 22
Table 13. Summary of previous geochemical analytical work done at GGC. ..... 24
Table 14. Licensed abstraction boreholes at GGC ..... 32
Table 15. Typical acid and net neutralizing potential of material at GGC ..... 34
Table 16. Proposed schedule of further work ..... 37

**List of Figures**

Figure 1: Grootegeluk locality map ..... 1
Figure 2. Sources and Pathways of ARD, NMD, and SD in a Pit during Operation and Closure (www.gardguide.com) ..... 4
Figure 3: Grootegeluk lithology and bench definitions. ..... 6
Figure 4: Grootegeluk surface water runoff ..... 8
Figure 5: Grootegeluk pit 13 sump water quality trends ..... 9
Figure 6: Grootegeluk pit 11 sump water quality trends ..... 9
Figure 7: Grootegeluk Life of Mine plan (LOM). ..... 27
Figure 8: Backfill sealing compartments (north-south section) (Jones & Wagener, 2011) ..... 27
Figure 9: Backfill sealing compartments (east-west section) (Jones & Wagener, 2011) ..... 28
Figure 10: Main residue deposits at GGC. ..... 29
Figure 11: GGC plant area and product stock yards. ..... 30
Figure 12: GGC geological setting. ..... 31
Figure 13: Cross section showing the mining pit in relation to the plant area. ..... 31
Figure 14: Abstraction boreholes in the GGC plant area. ..... 33
Figure 15: Field trial barrels. ..... 35

## GLOSSARY OF TERMS

| | |
|---|---|
| ABA: | Acid-Base Accounting |
| AP: | Acid Potential |
| AMD: | Acid Mine Drainage |
| ARD: | Acid Rock Drainage |
| CSM: | Site Conceptual Model |
| NAF | Non- Acid Forming |
| NAG | Net Acid Generation |
| NMD: | Neutral Mine Drainage |
| NNP: | Net Neutralising Potential |
| NP: | Neutralisation Potential |
| NPR: | Neutralising Potential Ratio |
| MRD: | Mine Residue Dump |
| PAF: | Potentially Acid Forming |
| SD: | Saline Drainage |
| XRD: | X-ray Diffraction |
| XRF: | X-ray Fluorescence |

# 1 INTRODUCTION

## 1.1 Location and background

Exxaro's Grootegeluk Coal Mine is located approximately 20 km west of Lephalale (Figure 1) in the Limpopo Province. Grootegeluk is an opencast coal mine where mining activities started in 1980. The mining area consists of six (6) adjoining farms and amounts to a total area of 3 758 hectares (ha). The current depth of the opencast mining is approximately ~130 m and covers a surface area of ~850 ha. Grootegeluk Coal Mine produces approximately 36.8 million tonnes of Run of Mine (ROM) coal per annum. The coal is sold to Mittal Steel, the export market and to Eskom's Power Stations.

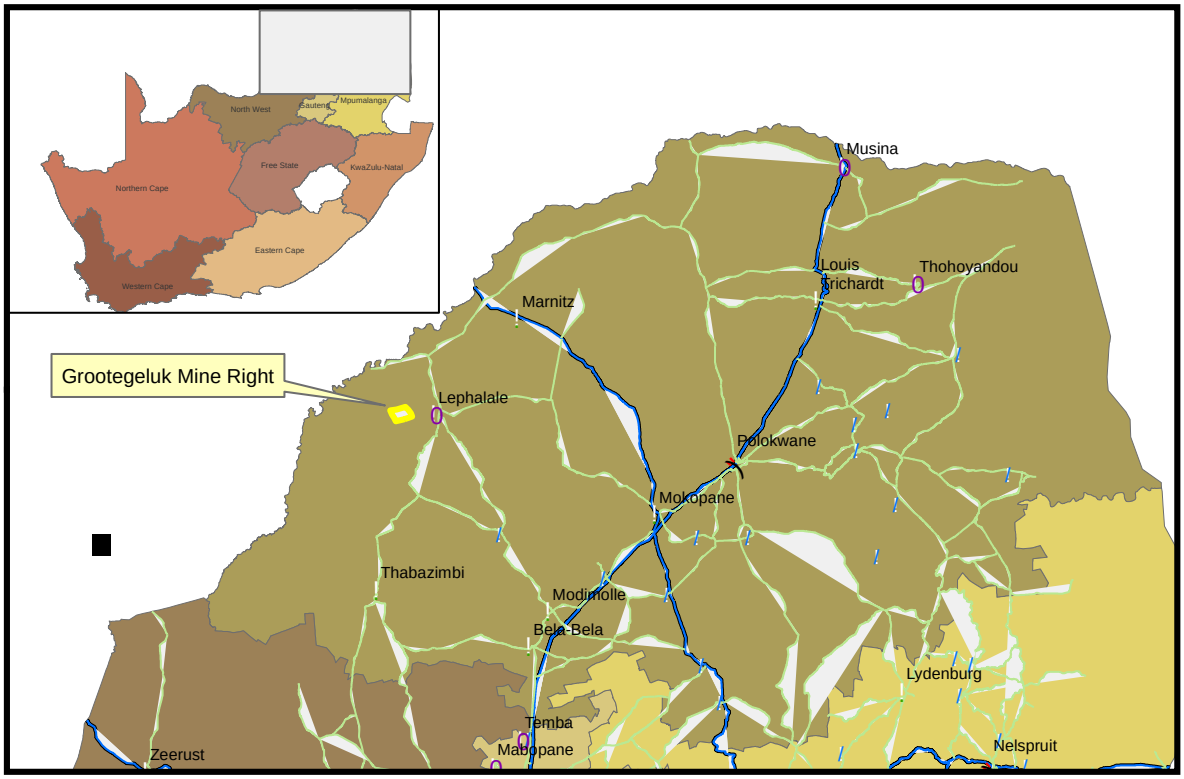


Figure 1: Grootegeluk locality map

# 2 OBJECTIVES AND SCOPE

## 2.1 Problem statement (acid mine drainage process)

The following section was taken from the Global Acid Rock Drainage guide (gardguide.com) and presents the problem statement for this document.

*Sulphide minerals in ore deposits are formed under reducing conditions in the absence of oxygen. When exposed to atmospheric oxygen or oxygenated waters due to mining, mineral processing, excavation, or other earthmoving processes, sulphide minerals can become unstable and oxidize.*

Pyrite is the most important sulphide mineral in coal mines such as GGC.

*The chemical reaction representing pyrite oxidation requires three basic ingredients: pyrite, oxygen, and water. The overall pyrite oxidation reaction generally is written as:*

$$FeS_2 + 7/2O_2 + H_2O = Fe^{2}+ + 2SO_4^{2}- + 2H^{+} \text{ [1]}$$

*This reaction can occur both abiotically or biotically (i.e., mediated through microorganisms). In addition to direct oxidation, pyrite can also be dissolved and then oxidized.*

*Under most circumstances, atmospheric oxygen acts as the oxidant. Oxygen dissolved in water can also result in pyrite oxidation but due to its limited solubility in water, this process is much less prominent. Aqueous ferric iron can oxidize pyrite as well according to the following reaction:*

$$FeS2 + 14Fe3+ + 8H2O = 15Fe2+ + 2SO42- + 16H+ \text{ [2]}$$

*This reaction is considerably faster (2 to 3 orders of magnitude) than the reaction with oxygen and generates substantially more acidity per mole of pyrite oxidized but it is limited to conditions in which significant amounts of dissolved ferric iron occur (i.e., acidic conditions). Therefore, pyrite oxidation is generally initiated through reaction [1] at circumneutral or higher pH, followed by reaction [2] when conditions have become sufficiently acidic (approximately pH 4.5 and lower). A third reaction is required to generate and replenish ferric iron, through oxidation of ferrous iron by oxygen as follows:*

$$Fe2+ + ¼O2 + H+ = Fe3+ +½H2O \text{ [3]}$$

*A common misunderstanding is that ferric iron can oxidize pyrite indefinitely in the absence of oxygen. As indicated by reaction [3], oxygen is required to generate ferric iron from ferrous iron. Also, the bacteria that may catalyze this reaction (primarily members of the Acidithiobacillus genus) are obligate aerobes (i.e., they require oxygen for aerobic cellular respiration). Therefore, some nominal amount of oxygen is needed for this process to be effective even when catalyzed by bacteria, although the oxygen requirement is less than for abiotic oxidation.*

*A process of environmental importance related to pyrite oxidation pertains to the fate of ferrous iron generated through reaction [1]. Ferrous iron can be removed from solution under slightly acidic to alkaline conditions through oxidation and subsequent hydrolysis and the formation of a relatively insoluble iron (hydr)oxide. Assuming the nominal composition of ferrihydrite [Fe(OH)3] for the latter phase, this reaction can be summarized as:*

$$Fe2+ + ¼O2 + 2½H2O = Fe(OH)3+ 2H+ \text{ [4]}$$

*When reactions [1] and [4] are combined, as is generally the case when conditions are not acidic (i.e., pH > 4.5), it can be seen that oxidation of pyrite generates double the amount of acidity relative to reaction [1] as follows:*

$$FeS2 + 15/4O2 + 7/2H2O = Fe(OH)3 + 2SO42- + 4H+ \text{ [5]}$$

## 2.2 Objectives

The key objectives of this document are:

- To present the current understanding of acid mine drainage (AMD) potential of the various geological units that have been disturbed by the mining operations at GGC. This includes the various waste rock facilities / mine residue deposits.

- To evaluate the current management strategies and operational practices to manage acid generating materials to reduce surface and groundwater pollution.

- To propose additional work to improve the knowledge base and management of AMD at the Grootegeluk Complex (GGC).

## 2.3 Scope of Acid Mine Drainage (AMD) strategy

Acid mine drainage (AMD) also known as acid rock drainage (ARD) is a well-defined process (see section 2.1) where sulphide minerals (mainly pyrite) are oxidized to produce acidic leachate.

In the natural environment this reaction takes place at a very slow rate and as a result naturalization almost always removes the acidity. Mining activities disturb the in-situ rocks and expose pyrite, which accelerates the oxidation reaction. In most of these environments the production of acid outweighs the neutralization capacity of the receiving environment and acidic leachate is produced.

An AMD management strategy is therefore required to manage acidic leachate and should consist of the following:

- **Development of a site specific conceptual model**. Figure 2 is a graphical presentation of the elements in a conceptual model. Such a model is dependent on the life cycle of the mine and describes the following:

    - Conceptualize the source – Identify all geological units that are disturbed during mining? Determine which of these units are potentially acid forming?

    - Conceptualize the pathway – What is the most likely pathway for contaminants to migrate off site and reach potential receptors (surface or groundwater)

    - Identify the receptors – identify all potential current and future receptors

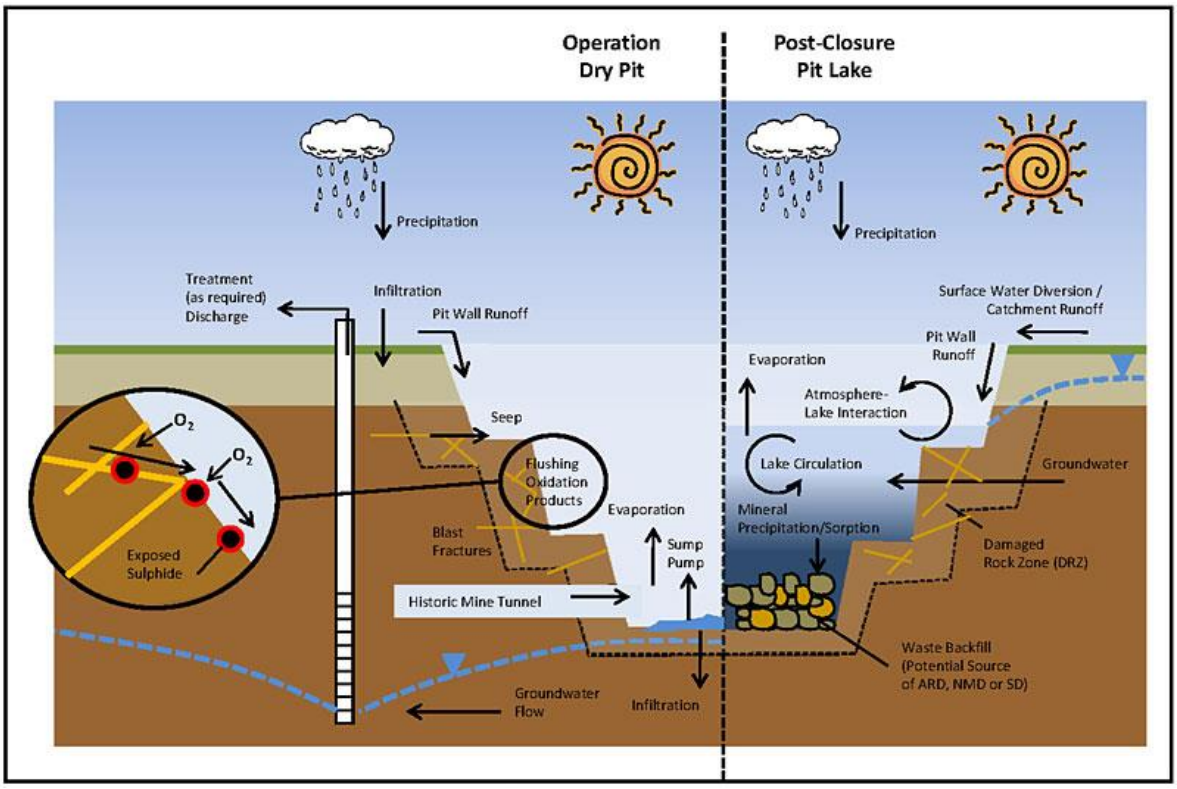


Figure 2. Sources and Pathways of ARD, NMD, and SD in a Pit during Operation and Closure (www.gardguide.com)

- **Sample selection**. Based on the conceptual model a sample plan should be developed to get information of the disturbed geological units (geochemical analyses) as well as the surface and groundwater quality. The sample plan will determine which materials and locations needs to be sampled.

- **Site characterization and Test work** (as described below)

- **Modelling and Risk Assessment**. Once the analytical information is available, geochemical and groundwater models should be constructed to predict the time, quality and volume of leachate that will be generated. Outcome of the models should be used to do a Source-Pathway-Receptor orientated risk assessment.

- **Development of mitigation/management measures**. Based on the outcome of the models and Risk Assessments, a mitigation/management plan should be developed.

The AMD Strategy is regarded as a working document, which will be updated and reviewed on a regular basis as projects are implemented and more information becomes available.

## 2.4 Test work

Geochemical test work to predict AMD consists of the following:

- **Static testing**, such as Acid Base Accounting (ABA). Static test gives an indication of the overall potential that a rock sample will generate acidic leachate. It determines the balance of acid generating and acid neutralizing capacity of a sample. This is a relatively low-cost procedure which can be done in a matter of hours to a few days.

- **Kinetic testing**, such as humidity cell tests attempt to predict the quality of the leachate over time. Rocks / samples with a net acid generating potential will be

subjected to kinetic test. Kinetic test is defined as a group of test work procedure wherein acid generation and metal mobilization from a sample is measured over time. These procedures could take up to 26 weeks to complete.

- **Field trails** are set up as large-scale column leach tests on the sites – under actual field conditions. Laboratory tests need to be converted to field conditions and the best way of "calibrating" the lab results are with field trails.

# 3 REVIEW OF AVAILABLE INFORMATION

## 3.1 Geology

Grootegeluk mine is situated in the Waterberg coal field which has an east-west striking length of approximately 88km, complemented by a north-south width of ± 40km within the Republic of South Africa. The Waterberg coal field also extends westward into Botswana.

The coal seams occur in the Ecca Group (Volksrust and Vryheid formations) of the Karoo sequence. The upper part of the coal deposit, the Volksrust formation (±60m thick), comprises intercalated mudstone or carbonaceous shale and bright coal layers. It displays such a well-developed repetition of coal-shale assemblages that it can be divided into seven discreet sedimentary cycles or zones (Figure 3 - Zone 11 – Zone 5). The terms "zone" and "sample" are used at Grootegeluk coal mine and on the Thabametsi project instead of "seam" and "ply" due to the site-specific intercalated nature of the coal and shale.

The Volksrust formation is classified as a Thick Interbedded Seam Deposit Type according to the South African guide to the systematic evaluation of coal resources and coal reserves (SANS 10320, 2004).

The Vryheid formation (± 55m thick) forms the lower part of the coal deposit and comprises carbonaceous shale and sandstone with interbedded dull coal seams varying in thickness from 1.5m to 9m. Due to its nature it is classified as a Multiple Seam Deposit Type according to the South African guide to the systematic evaluation of coal resources and coal reserves (SANS 10320, 2004). There are five coal zones in the Vryheid formation, predominantly dull coal, with some bright coal developed at the base of Zones 2, 3 and 4 (Figure 3).

All the coal and carbonaceous zones contain pyrite which oxidizes to form sulfuric acid, which is the main driver of acid mine drainage (AMD). Pyrite occur as small disseminated crystals in the Volksrust Formation, whereas larger nodules occur in the Vryheid Formation.

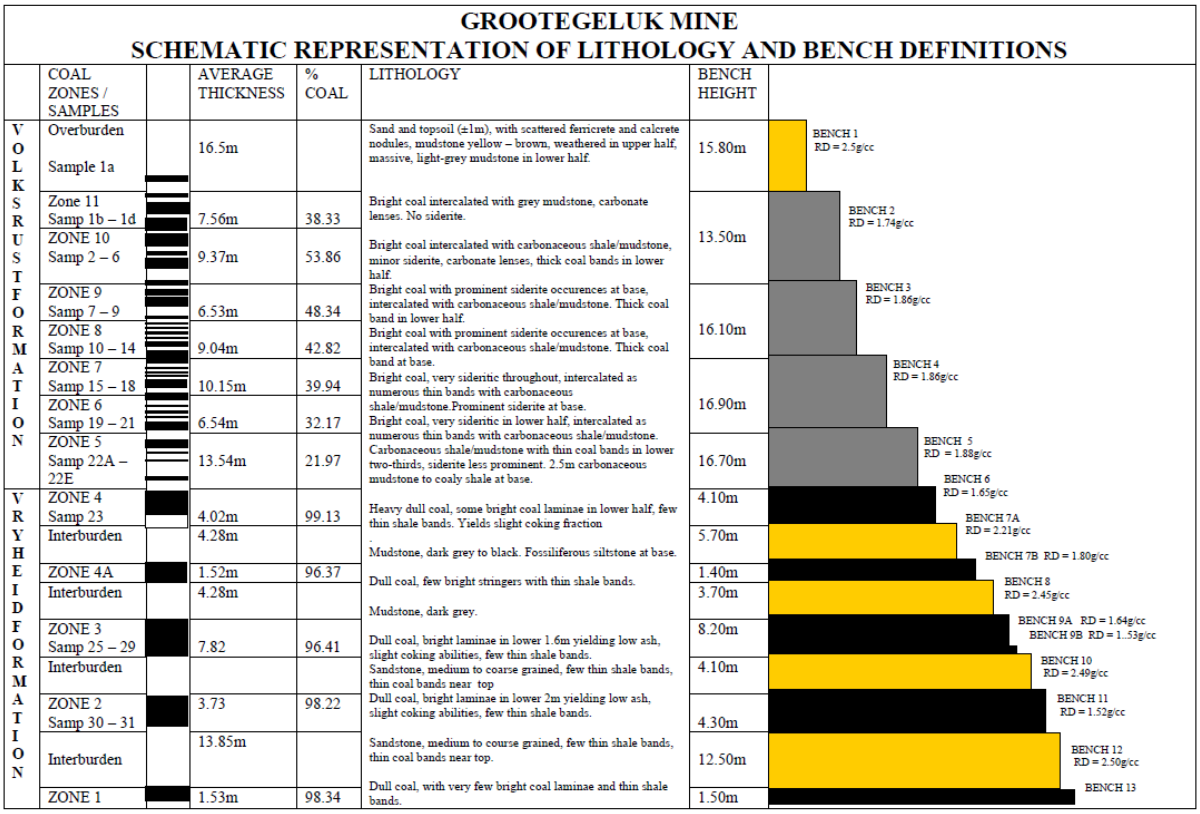


Figure 3: Grootegeluk lithology and bench definitions.

## 3.2 Hydrogeology and groundwater chemistry

The Karoo sequence, in the area, is situated in a graben structure which is defined by the Zoetfontein fault to the north and the Eenzaamheid fault to the south. The more recent Daarby fault cuts across the whole coalfield and intercepts the mining area between the open pit and plant area.

The aquifers of the Karoo Supergroup (mainly Ecca Group in the mining area) display characteristics of the intergranular and fractured regime. The Ecca Group is not known for the development of major aquifers, but occasional high-yielding boreholes may be present. The aquifers that occur in the area can in general be classified as minor aquifers (low yielding), but of high importance, as they are sometimes the only source of water for farming and rural communities.

The Eenzaamheid and the Daarby faults are impermeable as is evident by the difference in water levels on either side of the faults. Boreholes on the western side of the Daarby fault have deeper water levels than boreholes drilled on the eastern side of the fault. Two principal aquifers have been identified in the project area:

- A shallow aquifer formed in the weathered zone;
- A deeper aquifer formed by fracturing of the Karoo sediments (Ecca Group).

The groundwater chemistry around the Grootegeluk mine can be summarized as follows:

- Natural, mostly unaffected, groundwater varies from freshly recharged Ca/Mg Bicarbonate (Ca/Mg $(HCO_3)_2$) type to Ca/Mg Sulphate or Ca/Mg Cl (Ca/Mg$SO_4$ / Ca/Mg$Cl_2$) type. The shift in the chemical character is most probably due to long

residence times, allowing the exchange of ions between groundwater and aquifer material.

- The groundwater to the south of the mine and north of the Daarby fault has an evaporative signature with elevated Na and Cl.

- Groundwater in the plant area and close to mining activities show signs of $SO_4$ enrichment. They have a Calcium/Magnesium Sulphate or Calcium/Magnesium Chloride ($Ca/MgSO_4$ / $Ca/MgCl_2$) character.

- The sulphate enrichment in these samples, compared to the background chemistry, is most probably a result of mining related impacts on the groundwater regime where the anion $HCO_3$ was replaced by $SO_4$.

## 3.3 Surface-and pit-water chemistry

The Grootegeluk mine is situated approximately 2.4 km from a tributary of the Sandloop Spruit river in the east that drains to the Mokolo river. The Sandloop Spruit river which is 12km further to the east. These tributaries are mostly alluvial aquifer systems with very limited surface flow. (Figure *4***)**

The closest other watercourses are seasonal pans that occur within the area that forms part of the larger Exxaro owned landscape. These pans contain water for approximately 3 to 5 months of the year and is totally dependent on rainfall and are not directly linked to any neighbouring surface or groundwater sources within the area.

Any potential impact to these seasonal pans is licensed as a section 21 c&i water use under the National Water Act and are monitored monthly as part of the Exxaro surface water monitoring programme in the area. It is unlikely that the mining activities will impact the pans due to very limited runoff from the mining facilities to these systems.

A statistical summary of the water qualities for these pans are indicated in Table 1. The current qualities reflect the baseline qualities of these systems. Pan 21 is impacted by a haul road that undergoes dust suppression with mine impacted water and will be mined through in future. It should be noted that this haul road is the remnant of the original National Stockpoort road before it was relocated to its current position to make way for the mining activates in the late 80’s.

**Table 1. Average surface water qualities (pans) 2019/2020**

| Parameters | Pan 1 | Pan 2 | Pan 3 | Pan 4 | Pan 5 | Pan 6 | Pan 7 | Pan 8 | Pan 9 | Pan 10 | Pan 11 | Pan 12 | Pan 13 | Pan 14 | Pan 15 | Pan 16 | Pan 17 | Pan 18 | Pan 19 | Pan 20 | Pan 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH Value @ 20°C | 7.07 | 6.72 | 7.03 | | 7.49 | 6.90 | 7.56 | 7.11 | 6.97 | 7.54 | 7.58 | 7.23 | | 7.63 | 7.51 | 7.33 | 6.52 | 6.77 | 6.79 | 7.04 | 3.77 |
| Conductivity mS/m @ 25°C | 8.40 | 11.38 | 11.26 | | 19.57 | 6.39 | 16.69 | 7.06 | 5.56 | 11.86 | 11.00 | 11.87 | | 11.77 | 15.48 | 9.70 | 4.65 | 5.93 | 6.55 | 8.05 | 94.22 |
| Suspended Solids | 237.67 | 2689.00 | 1944.50 | | 375.33 | 449.00 | 267.58 | 39.00 | 402.50 | 283.00 | 150.00 | 1702.60 | | 301.80 | 868.20 | 140.00 | 157.75 | 317.00 | 548.40 | 276.86 | 33.17 |
| Total Alkalinity as $CaCO_3$ | 42.47 | 56.23 | 64.18 | | 94.00 | 31.35 | 75.39 | 30.40 | 47.75 | 57.85 | 47.70 | 54.90 | | 57.14 | 69.72 | 32.43 | 11.36 | 22.46 | 24.02 | 20.29 | 9.62 |
| Calcium, Ca | 5.52 | 4.78 | 8.84 | | 10.80 | 5.33 | 7.08 | 0.00 | 0.00 | 0.00 | 0.00 | 3.76 | | 11.50 | 5.83 | 4.52 | 1.18 | 1.28 | 2.55 | 3.03 | 138.00 |
| Sodium, Na | 1.08 | 2.04 | 1.81 | | 10.99 | 1.06 | 8.69 | 0.90 | 0.88 | 0.55 | 0.18 | 0.62 | | 0.83 | 0.83 | 0.54 | 0.49 | 0.69 | 0.69 | 0.74 | 1.14 |
| Chloride, Cl | 3.02 | 10.54 | 5.52 | | 10.60 | 3.24 | 12.97 | 2.96 | 4.40 | 2.23 | 3.32 | 3.68 | | 2.12 | 4.38 | 8.04 | 3.75 | 2.36 | 3.67 | 7.81 | 3.81 |
| Sulphate, $SO_4$ | 6.98 | 7.05 | 16.56 | | 6.52 | 7.29 | 9.57 | 4.26 | 15.15 | 3.12 | 5.96 | 6.47 | | 3.93 | 7.43 | 12.64 | 10.99 | 6.26 | 6.40 | 20.17 | 512.00 |
| Nitrate as N | 0.24 | 0.59 | 0.31 | | 0.31 | 0.33 | 0.43 | 0.21 | 0.15 | 0.10 | 0.20 | 0.23 | | 0.21 | 0.24 | 0.23 | 0.18 | 0.21 | 0.19 | 0.42 | 0.19 |
| Nitrate, $NO_3$ | 1.05 | 2.60 | 1.37 | Dry | 1.39 | 1.45 | 1.91 | 0.94 | 0.67 | 0.42 | 0.86 | 1.01 | Dry | 0.93 | 1.07 | 1.03 | 0.81 | 0.94 | 0.83 | 1.86 | 0.84 |
| Nitrite as N | 0.05 | 0.08 | 0.06 | | 0.07 | 0.07 | 0.07 | 0.07 | 0.05 | 0.05 | 0.07 | 0.05 | | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 | 0.08 | 0.05 |
| Nitrite, NO2 | 0.13 | 0.25 | 0.20 | | 0.24 | 0.24 | 0.22 | 0.23 | 0.17 | 0.16 | 0.22 | 0.16 | | 0.18 | 0.17 | 0.18 | 0.16 | 0.18 | 0.19 | 0.28 | 0.17 |
| Ammonium as N | 1.63 | 2.06 | 1.32 | | 0.70 | 0.52 | 0.77 | 0.21 | 0.67 | 1.69 | 0.34 | 1.74 | | 1.01 | 3.09 | 0.66 | 1.47 | 1.39 | 0.60 | 1.10 | 0.62 |
| Ammonia, NH3 | 0.01 | 0.01 | 0.01 | | 0.32 | 0.25 | 0.09 | <0.005 | <0.005 | <0.005 | 0.01 | 0.01 | | 0.01 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 0.08 | 0.11 |
| Aluminium, Al | 1.45 | 4.16 | 4.64 | | 1.15 | 1.29 | 2.20 | 1.25 | 7.13 | 0.50 | 0.98 | 1.67 | | 0.78 | 0.60 | 2.69 | 1.67 | 1.08 | 1.46 | 3.38 | 10.62 |
| Iron, Fe | 0.14 | 4.41 | 3.84 | | 0.97 | 4.79 | 1.88 | <0.004 | 0.01 | 0.01 | <0.004 | 0.76 | | 0.01 | 0.30 | 1.58 | 1.43 | 0.92 | 1.99 | 1.69 | 0.26 |
| Manganese, Mn | 0.13 | 0.42 | 0.31 | | 0.23 | 0.18 | 0.12 | 0.01 | 0.20 | 1.52 | 0.01 | 0.89 | | 0.54 | 0.81 | 0.02 | 0.28 | 0.36 | 0.18 | 0.06 | 7.05 |
| Dissolved Oxygen | 2.26 | 1.12 | 1.05 | | 2.25 | 1.89 | 2.31 | 2.03 | 1.65 | 1.83 | 2.14 | 1.67 | | 1.87 | 1.61 | 2.09 | 1.95 | 1.70 | 2.04 | 2.73 | 2.99 |
| Turbidity NTU | 260.00 | 2871.50 | 1767.25 | | 463.67 | 346.00 | 597.58 | 88.60 | 708.85 | 102.05 | 277.00 | 1561.60 | | 1173.37 | 1695.32 | 777.00 | 1131.50 | 1189.60 | 1119.78 | 1155.57 | 10.99 |

Further surface water sampling at Grootegeluk are all linked to the mines process water systems and pollution control facilities within the mining area. These facilities are also licensed as section 21g water uses under the National Water Act and the water quality results are submitted to the Department on a quarterly basis.

Figure 4: Grootegeluk surface water runoff

Figure 5 and Figure 6 below shows the water quality trends for Sump 13 and Sump 11 respectively.

Figure 5: Grootegeluk pit 13 sump water quality trends

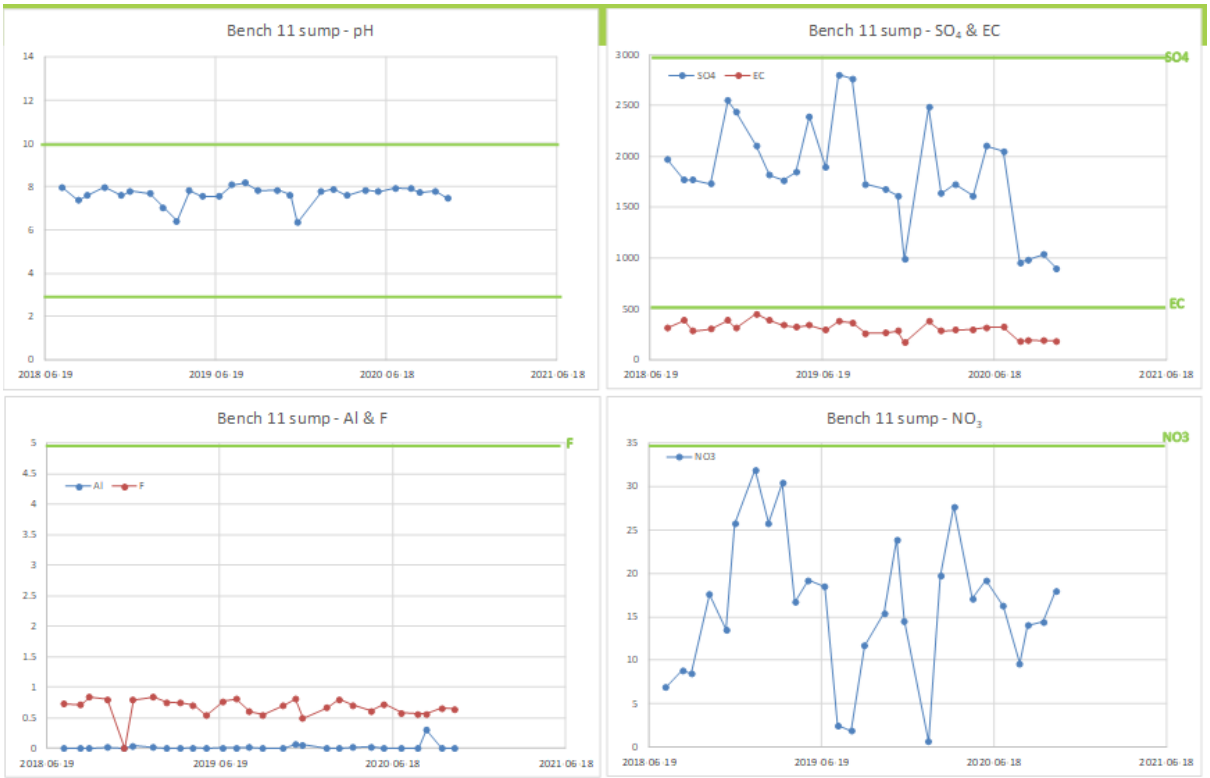


Figure 6: Grootegeluk pit 11 sump water quality trends

## 3.4 Geochemistry

### 3.4.1 Previous studies

Previous geochemistry work at the Grootegeluk Complex (GGC) and the wider Waterberg Coalfield were done for specific projects, theoretical studies as well as environmental authorizations. None of these studies had the objective to develop an overall AMD management strategy for GGC. They all, however, contain geochemical test work (static and/or kinetic), some studies included geochemical modelling and some even groundwater flow and transport modelling. All these studies contribute to the body of knowledge that currently exist around the geochemistry at the Grootegeluk Complex.

The following studies were reviewed and their key findings are summarized in this document:

- Feasibility study of the expected geochemical and geohydrological impacts related to the proposed backfilling of mixed mine discard and power station ash into the open cast void at Grootegeluk colliery, *Golder Associates, August 2007.*

- Evaluation of acid rock drainage potential in the Waterberg Coalfield, *Venessa Aphane, MSc Thesis, April 2014.*

- Grootegeluk Super Fines Tailings Disposal Facility: Hydrogeological Study: *GCS, August 2014.*

- Hydrogeological and geochemical investigations to refine the optimized long-term water management strategy: Grootegeluk Colliery, Limpopo, *Schlumberger, December 2015.*

- Grootegeluk Short-Term Stockpiles Amendment Project: Geochemistry Report: *Digby Wells Environmental, September 2016.*

- Exxaro sampling and testing*, Exxaro 2016*

- Grootegeluk Coal Mine: Geochemical Assessment, *Delta-H, September 2019.*

The section below summarizes the relevant geochemical information from the various studies.

#### 3.4.1.1 Golder 2007

**Study Objective**. "*The key objective of the project was to enable Grootegeluk Colliery to assess the groundwater quality impacts of various discard/ash backfill options relative to the Base Case (backfilling with discard), so as to select the option with the least potential for groundwater contamination in terms of the requirements of South African environmental legislation, or otherwise the option with the lowest overall environmental impact and cost"*

**Sample selection**. Table 2, below present a list and descriptions of the samples taken by Golder during their 2007 study. The samples consisted of twelve discard, six interburden and two overburden samples.

**Table 2. Sample selection for Golder 2007 study**

| Sample Name | Date | Description |
|---|---|---|
| Bench 7A interburden | 7-12-2006 | Interburden sample from blasted bench 7A material |
| Bench 8 interburden | 7-12-2006 | Interburden sample from blasted bench 8 material |
| Bench 10 | | interburden Interburden sample from blasted bench 10 material |
| Discard comp. | 8-12-2006 | Sample from Grootegeluk discard dump |
| Discard dump | 6.12.2006 | Sample from Grootegeluk discard dump |
| GG discard | 7-12-2006 | Sample from Grootegeluk discard dump |
| GG1 cyclone U/F discard | 7-12-2006 | Sample from GG1 wash plant cyclone underflow |
| GG1 drum discard | 07-12-2006 | Sample from GG1 wash plant drum separator |
| GG1 spiral discard | 07-12-2006 | Sample from GG1 spiral separator |
| GG2 Cyclone discard | 8-12-2006 | Sample from GG2 wash plant cyclone underflow |
| GG2 drum discard | 8.12.2006 | Sample from GG2 wash plant drum separator |
| GG4 cyclone discard | 7-12-2006 | Sample from GG4 wash plant cyclone underflow |
| GG4 drum discard | 7-12-2006 | Sample from GG4 wash plant drum separator |
| GG5 discard | 7-12-2006 | Composite discard from the GG5 plant |
| Coarse overburden | 22-02-2007 | Coarse grained type overburden from Grootegeluk |
| Fine overburden | 22-02-2007 | Fine grained type overburden from Grootegeluk |
| Bench 7A | 22-02-2007 | Interburden sample from blasted bench 7A material |
| Bench 8 | 22-02-2007 | Interburden sample from blasted bench 8 material |
| Bench 10 | 22-02-2007 | Interburden sample from blasted bench 10 material |
| Discard | 22-02-2007 | Discard sample from Kidney stockpile |

Table 3 lists the analyses that were performed on the samples.

**Table 3. Geochemical analyses done for the Golder 2007 study**

| | |
|---|---|
| X-ray Flourescence spectrometry (XRF) | Major element analyses |
| X-ray diffraction spectrometry (XRD) | Mineralogical analyses |
| ABA | Acid Base Accounting |
| NAG | Nett Acid Generation |
| Distilled water extraction | Determine leachability of salts |
| Acid Rain extraction | Determine leaching behaviour under extreme environmental conditions |
| Peroxide oxidation extractions | Detect the acidification potential and likely oxidation products generated by ARD processes |
| Sulphuric Acid extractions | Determine the leaching potential of non-acid producing materials under ARD conditions |
| Analyses of supernatants | Major and trace element analyses of leachate form cells |
| Kinetic geochemical testing | Twenty leaching cycles were conducted to assess whether Neutralisation Potential would be depleted over the 20-week test period |
| Analyses of supernatants | Major and trace element analyses of leachate form cells |

**Key Findings.** From the analytical results the following findings were made:

- XRF analyses indicated that the overburden materials contain relatively high concentrations of trace elements. For example, Fe, Mn, Co, V, Pb are all present at high concentrations relative to other materials, considering the weathered nature of this material

- The XRD results indicate that most minerals present in the discard material are un-reactive and will not contribute to ARD except as buffers under highly acid conditions. This conclusion is based on the presence of mostly high Al and Si minerals with low

concentrations of Ca, Mg, Na and K in their structures, as well as the low concentrations of Ca and Mg carbonate minerals (Calcite and Dolomite) in the samples.

- The ABA results indicated that the Acid Potential (AP) is much higher than the Neutralizing Potential (NP) for all materials. This implies that all backfill materials are likely to generate acid. Net Acid Generation (NAG) tests result in an acidic final pH and indicate a potential for acid generation should material be allowed to oxidise and weather.

- The analyses conducted on mixed discard materials from the discard dump and the Kidney stockpile indicate that pyrite is present at significant concentrations. Measurements of between 1% and 15% pyrite were recorded with a high degree of variability. This variability probably reflects variability in geology, plant operational parameters and/or sampling.

- Considering the spatial variability of S concentrations in coal, the likely average concentration of pyrite in discard is estimated at 5%. This assumes that:

    - Minimal S is present in Power Station coal due to concentration of sulphur in discard fraction;

    - A 50% discard yield is achieved from raw coal; and

    - No other sulphur (sulphide or sulphate) containing minerals are present

- Maximum elemental concentrations from the distilled water extractions were recorded for different materials as follows:

    - Overburden material – Al, Cu, Fe, Na, Pb, Si, Th and Zn;

    - Discard – K, Mg, U, Mn, Ni, Co and TDS

- Acid Rain extractions were conducted on overburden materials to determine leachability under acid rain conditions. Maximum leachability was as follows:

    - Overburden material – Al, Cr, Cu, Fe, K, Na, Pb, Rb, Si, Th, Zn

- The pH in the humidity cell with discard showed a continuous lowering over 9 weeks. This is an indication that the NP in the cell is becoming exhausted and that the cell is likely to become acidic over time

#### 3.4.1.2 Aphane 2014

**Study Objective**. This was a research study to fulfill the requirements of a MSc thesis. The study aims were:

- The acid-base potential of the coal-bearing, overburden and interburden of geological layers.
- The mineralogical and whole rock chemical analysis of the investigated geological layers.
- The effect that mining will have on the water resources and the environment

**Sample selection**. A total of 25 partially weathered overburden samples (carbonaceous mudstone) were collected and analysed. The samples were submitted for ABA analyses and kinetic testing.

**Key Findings.**

- The ABA test results showed that none of the overburden samples had a high risk of acid generation, 15% had medium risks of acid generation and 85% had a low risk of acid generation. Based on the ABA results, three samples were submitted for kinetic test work. The ABA results showed that the initial pH values, of the three samples, were between 7.71 and 8.62. One of the three samples turned acidic with a final pH of 4.82.

- The pH of the overburden samples remained high during the kinetic tests (20 weeks). All the samples had high sulphate production (and associated EC) at the beginning of the analysis; this may be due to soluble component from prior oxidation or weathering.

### 3.4.1.3 GCS 2014

**Study Objective**. The objective of this study was to conduct a hydrogeological investigation in support of the bankable feasibility study of the super fines Tailings Storage Facility (TSF) at Exxaro Grootegeluk Coal Mine. Although the was primarily a groundwater study a geochemical assessment of the fine material (Tailings) was done.

**Sample selection**. Two representative samples, one of the fine material and the other of the super fine material were submitted for geochemical analyses. Table 4 summarizes the analyses that were done:

**Table 4. Geochemical analyses done for the GCS 2014 study**

| | |
|---|---|
| X-ray Flourescence spectrometry (XRF) | Major element analyses |
| X-ray diffraction spectrometry (XRD) | Mineralogical analyses |
| ABA | Acid Base Accounting |
| NAG | Nett Acid Generation |
| Kinetic geochemical testing | Seven weeks kinetic testing in humidity cells |
| Analyses of supernatants | Major and trace element analyses of leachate form cells |

**Key Findings.** The following key findings were made based on the analytical results**:**

- The results of the XRF analyses is given in Table 5. Only the elements that were found in significant concentrations are presented here.

**Table 5. Major and trace elements in fines and super fines**

| **Major Elements** | **Major Element Concentration (wt %)** | |
|---|---|---|
| | Superfines | Fines |
| SiO2 | 25.89 | 21.22 |
| TiO2 | 0.48 | 0.49 |
| Al2O3 | 8.40 | 7.13 |
| Fe2O3 | 2.59 | 2.35 |
| CaO | 0.86 | 0.66 |
| **Trace Elements** | **Trace Element Concentration (ppm)** | |
| | Super fines | Fines |
| Ba | 76 | 80 |
| Ce | 12.9 | <5.00 |
| Co | <5.00 | 16.6 |
| Cu | 16.3 | 16.4 |
| Ga | 13.6 | 13 |
| La | 5.1 | 19.6 |

| | | |
|---|---|---|
| Nb | 11.9 | 12.2 |
| Nd | 22.3 | 17.4 |
| Ni | 29.9 | 29.3 |
| Pb | 16 | 12.3 |
| Rb | 27.7 | 22.1 |
| Sc | 6.8 | 7.3 |
| Sr | 67 | 68 |
| Th | 11.9 | 9.4 |
| V | 73 | 96 |
| Y | 24 | 21.1 |
| Zn | 103 | 75 |
| Zr | 142 | 170 |

- The XRD analyses returned the following major minerals in the samples:
    - Kaolinite, Graphite and Quartz are present as major to dominant minerals in both the samples that were submitted for XRD;
    - Dolomite, Magnetite Muscovite and Siderite were present in both samples as minor minerals;
    - Microcline was present as a minor to trace mineral in the samples;
    - Pyrite was present as a minor mineral in both the samples.
- From the ABA and NAG results the following observations were made:
    - Pyrite was the only sulphide containing mineral detected in the XRD analysis. Therefore it is assumed that the oxidation of pyrite is the only contributor to acidity. Both samples have a relatively high sulphide-S content (>0.3 %).
    - Both these samples have a low neutralization Potential (NP) compared to AP, with a no Net Neutralization Potential (NNP). From the mineralogy the only minerals present, that will initially buffer the system, is Siderite and Dolomite. No calcite was observed. This explains the relatively low neutralization potential of the samples.
    - Neutralising Potential Ratio (NPR) is lower than 1 for both samples, suggesting that acid drainage is likely.
    - The NAG pH results indicate that the super fine sample has a high risk to generate acid which correlates with the ABA results. The fine tailings sample has a lower acid drainage potential compared to the super fines sample. This is also reflected in the lower %S and AP values of the fine versus superfine material. However, considering the NAG value and ABA results, it is concluded that the fines, although having a slightly lower acid drainage potential compared to super fines, would generate acid leachate.
- It must be noted that the humidity cells were only run for 7 weeks during this study. Longer kinetic tests may be required to fully understand the geochemistry of these materials. The following was observed from the leach analysis data:
    - The leachate pH stayed neutral over the period of leaching. From the ABA it is expected that both the leachate from both the samples will turn acidic over time;
    - The sulphate and TDS concentration decreased exponentially from initially high values to stabilize at values lower than 100 mg/l. The high values in the first few weeks of the humidity leach tests may be attributed to secondary minerals

going into solution. Another factor is the decrease in reaction surface of pyrite due to oxidation;

- Elevated metal concentrations were observed in the leachate data in the first few weeks. This may be attributed to metals in the secondary minerals. Metals in the secondary minerals tend to be more mobile than those in the primary minerals.

### 3.4.1.4 Schlumberger, December 2015

**Study Objective**. The objective was to predict the temporal volume and chemistry change of water reporting to the Bench 13 Sump. Part of this study was a geochemical assessment of in-pit material

**Sample selection.** Composite rock samples were collected from each of the thirteen benches (1-COMP to 13-COMP) within the open pit. Samples were collected as surface grab samples from transects across each bench, with weights ranging from 1 to 1.5 kg in each instance. The samples collected are summarized in (Table 6). A total of 10 locations were sampled on each bench. These samples were then aggregated to produce the composites.

**Table 6. Sample selection for Schlumberger 2015 study**

| Sample ID | Sample Description | Weight (kg) |
|---|---|---|
| 1-COMP | Dry Coarse rock | 1.256 |
| 2-COMP | Dry Coarse rock | 0.988 |
| 3-COMP | Dry Coarse rock | 1.315 |
| 4-COMP | Dry Coarse rock | 1.5 |
| 5-COMP | Dry Coarse rock | 1.428 |
| 6-COMP | Dry Coarse rock | 1.22 |
| 7-COMP | Dry Coarse rock | 1.25 |
| 8-COMP | Dry Coarse rock | 1.628 |
| 9-COMP | Dry Coarse rock | 1.356 |
| 10-COMP | Dry Coarse rock | 1.18 |
| 11-COMP | Dry Coarse rock | 1.435 |
| 12-COMP | Dry Coarse rock | 1.544 |
| 13-COMP | Dry Coarse rock | 1.357 |

**Table 7. Geochemical analyses done for the Schlumberger 2015 study**

| | |
|---|---|
| Bulk geochemistry | Major and trace element analyses (ICP-MS) |
| X-ray diffraction spectrometry (XRD) | Mineralogical analyses |
| ABA | Acid Base Accounting |
| NAG | Nett Acid Generation |
| SPLP | Synthetic Precipitation Leaching Procedure (pH, EC, SO4, ICP-MS dissolved metals including Hg) |

**Key Findings.** The following key findings were made based on the analytical results**:**

- From the bulk geochemical analyses, the following can be deduced:
  - Elements which show significant enrichment relative to average crustal abundance include As, Bi, Hg, Pb, S, Se, and Te. Tellurium, sulphur, and selenium show the most significant enrichment with average enrichment

factors of 81, 26, and 6 times respectively those of continental crust. This is consistent with observations from numerous other coal deposits.

- Sulphur contents range from ~0.1% to 3.6% with highest sulphur concentrations found in samples from benches 3, 4, and 5.

- XRD data showed that all samples consist primarily of kaolinite (25 to 91.8%), with lesser amounts of quartz and accessory minerals that vary considerably between samples

    - Samples 2-COMP, 7-COMP, 9-COMP, 13-COMP contain the most reactive carbonate with total carbonate abundances ranging from 3.23 to 10.79% (as calcite, dolomite, and/or siderite).

    - Significant quantities of pyrite (>~1%) are present in samples 6-COMP, 7-COMP, 9-COMP, 11-COMP, and 13-COMP, with some samples containing particularly high quantities of pyrite (>5%; 9-COMP, 11-COMP, and 13-COMP).

    - Jarosite, a soluble sulphasalt which can contribute acidity upon dissolution, is present in decreasing quantities with depth from benches 2 and 3 (2-COMP and 3-COMP with 3.58 and 3.8 % abundance respectively) to bench 6 (1.16% in 6-COMP).

    - Gypsum occurrence broadly mirrors that of jarosite with high and decreasing concentrations from benches 2 and 3. Gypsum is also present, though in lower abundances (<2.5%) below bench 9. The occurrence of these soluble sulphate minerals likely reflects natural weathering and sulphate mobility profiles in the deposit.

- From the ABA and NAG results the following observations were made:

    - Paste pH ranges from pH 3.27 to 7.29.

    - Total S content ranges from <0.12% to 3.39% (average 1.25%), with relatively high values of 0.5- 3.39% in all samples except sample composites 1-COMP, 8-COMP, and 12-COMP.

    - Sample composites from benches 1, 7, 8, 9, 12 and 13 show a near 1:1 correlation between total Sulphur and sulphide sulphur. Samples with the most significant deviation from correlated total sulphur/sulphide sulphur are those with significant gypsum abundances. For these samples, as expected, a plot of total sulphur and sulphate sulphur indicates a strong correlation. Other slight deviations from a 1:1 correlation between total S and sulphate S or total S and sulphide S likely relate to organic sulphur. This organically bound sulphur will not leach from samples in the presence of acid and is unlikely to generate significant acid in the field setting. It is attributed to sulphide sulphur in the ABA method and therefore calculated acid generating potentials (AP) which are based on sulphide sulphur may include some degree of overestimation of AP.

    - Acid generation potential (AP) ranges from 1.9 to 52.2 kg $CaCO_3$/t (average 8.7 kg $CaCO_3$/t), with the highest values measured in samples 9-COMP and 11-COMP.

    - Neutralization potential (NP) ranges from –9.5 to 49.3 kg $CaCO_3$/t (average 10.9 kg $CaCO_3$/t), the highest value is found in sample 2-COMP.

- The neutralization potential ratio (NPR = NP/AP) for the samples ranges from -1.61 to 8.95. According to this criterion, only sample 1-COMP is strictly non-acid forming (NAF) (ie. its NPR is greater than 3). Samples 2-COMP, 5-COMP, and 7-COMP have an 'uncertain' acid forming potential (their NPRs lie between 1 and 3). The remaining nine samples are classified as potentially acid forming (PAF) according to this criterion, because their NPR is smaller than 1.

- NAG pH ranges from pH 2.54 in sample 13-COMP to pH 8.08 in sample 2-COMP.

- The NAG acidity to pH 7 ranges from zero to 67.7 kg $H_2SO_4$/t.

- According to the NNP and NAG pH values, samples 9-COMP, 13-COMP, and 11-COMP are clearly classified as PAF because their NNP are below –20 kg $CaCO_3$/t and NAG pH is <4.5. Only Sample 2-COMP is clearly classified as non-acid forming (NAF), while all other samples lie within a range of 'uncertain' potential for acid formation.

- The SPLP leach tests returned the following:

    - Six out of the thirteen samples (2-COMP, 3-COMP,4-COMP, 6-COMP, 10-COMP, 11-COMP) display acidic pH values. In general, these samples also leached elevated concentrations of sulphate, calcium and magnesium.

### 3.4.1.5 Digby Wells, September 2016

**Study Objective.** Perform a geochemical specialist study to provide additional information and motivation for the amendment of the environmental authorizations for the Grootegeluk Infrastructure Expansion Project that was undertaken in 2014. The focus of this study was the geochemistry of the temporary stockyards GG6/2, GG10A, GG10B and the Multi-product overflow stockyard.

**Sample selection**. Four samples were submitted for analyses (Table 8), two each from the product streams from GG1 to 6 and GG7 and 8 (GG7-8 A, GG7-8 B, GG1-6 A, GG1-6 B).

**Table 8. Geochemical analyses done for the Digby Wells 2016 study**

| | |
|---|---|
| X-ray Flourescence spectrometry (XRF) | Major element analyses |
| X-ray diffraction spectrometry (XRD) | Mineralogical analyses |
| ABA | Acid Base Accounting |
| NAG | Nett Acid Generation |
| Bulk geochemistry | Major and trace element analyses (ICP-MS) |
| Distilled water and SPLP | Synthetic Precipitation Leaching Procedure (pH, EC, SO4, ICP-MS dissolved metals including Hg) |

**Key Findings.** The following key findings were made based on the analytical results**:**

- The results of the XRF analyses is given in Table 9. From the results Cl, Ba, La, Zr, Cu, Sr, Zn and Ni are the dominant trace elements.

**Table 9. Major and trace elements in product samples**

| Major Oxides | Weight % | | | |
|---|---|---|---|---|
| | GG7-8 A | GG7-8 B | GG1-6 A | GG1-6 B |
| $SiO_2$ | 11.14 | 8.74 | 20.38 | 17.4 |
| $TiO_2$ | 0.35 | 0.39 | 0.36 | 0.35 |
| $Al_2O_3$ | 7.39 | 7.3 | 7.96 | 7.91 |
| $Fe_2O_3$ | 1.21 | 0.58 | 1.9 | 3.81 |
| MnO | 0 | 0 | 0.02 | 0.05 |
| MgO | 0.25 | 0.18 | 0.25 | 0.4 |
| CaO | 0.81 | 0.32 | 0.83 | 1.38 |
| Trace Elements Concentration (ppm) | | | | |
| As | 9.62 | 8.98 | 8.42 | 6.12 |
| Ba | 88.7 | 86.3 | 91.6 | 92.5 |
| Bi | 1.38 | 1.75 | 1.48 | 1.53 |
| Ce | <3.08 | <3.08 | 19.9 | 16.1 |
| Cl | 122 | 125 | 123 | 122 |
| Cs | 1.38 | 1.4 | 1.33 | 1.31 |
| Cu | 28.4 | 114 | 55.5 | 60.6 |
| Ga | 11.1 | 9.27 | 13.3 | 16.9 |
| Hf | 6.38 | 6.49 | 6.38 | 6.39 |
| La | 95 | 97.8 | 84.9 | 65.6 |
| Lu | 1.7 | 1.68 | 1.88 | 2.2 |
| Mo | 2.48 | 2.54 | 2.46 | 2.47 |
| Nd | 54 | 58.5 | 49.4 | 40.7 |
| Ni | 29.6 | 30.7 | 20.5 | 27.5 |
| Rb | 8.9 | 5.64 | 18.3 | 14 |
| Sc | 18.7 | 17.1 | 18.2 | 21.7 |
| Se | 0.83 | 1.12 | 0.5 | 0.62 |
| Sm | 9.32 | 7.8 | 10.4 | 14.9 |
| Sn | 4.57 | 3.72 | 4.91 | 7.06 |
| Sr | 68.6 | 60.5 | 57.9 | 66.3 |
| Ta | 1 | 0.76 | 1.05 | 1 |
| Te | 0.53 | <0.16 | 0.83 | 2.21 |
| Th | 5.34 | 5.97 | 4.39 | 3.37 |
| Tl | 2.33 | 2.31 | 2.22 | 2.18 |
| U | 2.39 | 2.48 | 2.35 | 2.46 |
| W | 6.86 | 6.86 | 6.87 | 6.91 |
| Y | 16 | 15.9 | 17.7 | 17.6 |
| Yb | 4.27 | 2.96 | 4.59 | 6.78 |
| Zn | 47 | 87.6 | 51.6 | 54 |
| Zr | 77.8 | 78.6 | 98 | 86.5 |

- Mineralogical analyses (XRD) showed that the main minerals are (in order of abundance) kaolinite, quartz, muscovite, dolomite, pyrite, siderite and calcite. Pyrite was present in all samples, ranging between 0.66 and 1.28 weight%.

- From the ABA and NAG test results the following can be concluded:

    - The paste pH in the ABA results shows that there was no acid generation prior to analysis. However, based on the paste pH from the NAG results (preparation pH of 4.5) samples GG7-8 A and B and sample GG1-6 A is acid generating with GG1-6 B being a slightly lower risk for acid generation.

    - From the ABA results the total sulphur (>0.3%), NNP (<0) and NPR (<1) shows that all 4 samples are potentially acid generating. This is due the pyrite content and low neutralizing potential.

    - All 4 samples are classified as acid generating.

- Both distilled water leachate and SPLP tests were performed on samples representing the two product streams (GG1 to 6 and GG7 and 8). The following can be concluded:

    - Concentrations of metals were below detection limits for both tests except for Ba, Ni and Mn. Ba and Ni are heavy metals commonly associated with the geology as trace elements. In both tests the leach concentrations were well below the guideline values. Mn concentrations were slightly elevated.

    - Sulphate ($SO_4$) concentrations ranged between a minimum detected in the distilled water leach of 134 mg/L and a maximum of 445 mg/L in the SPLP results. In both test methods applied the GG1-6 samples showed the highest $SO_4$ leachability.

    - The TDS values are mostly dominated by the sulphate concentrations, but does not pose a risk at the levels detected in all samples.

    - The elemental concentrations in the leachate of the distilled water tests and the SPLP tests returned similar results. Even though the SPLP is done at an acidic pH of 4.8.

    - The analytical results suggest that the metal leachability of the material is low.

#### 3.4.1.6 Exxaro 2016

**Study Objective** The aim of the sampling campaign was to determine the likelihood that the backfill material (discard and interburden) will produce acidic leachate

**Sample selection** Exxaro took five composite samples in 2016 and submitted them for static and kinetic testing. The samples were from:

- Discard from GG1

- Discard from GG2

- Discard from GG4 and GG5

- Composite sample from Bench 8 (interburden -mudstone)

- Composite sample from Bench 10 (interburden – sandstone).

**Key Findings** All the samples, except Bench 10 had Sulphur contents more than 1 %. All samples were classified as PAF.

### 3.4.1.7 Delta-H, September 2019

**Study Objective**. The objective was to assess the mine water geochemistry and operational chemical composition of mine water at the active Grootegeluk open cast coal mine

**Sample selection.** Table 10 lists the samples collected by Delta-H. Table 11 list the suite of analyses that were performed on the samples.

**Table 10. Sample selection for Delta-H 2019 study**

| Sample Name | Selection criteria |
|---|---|
| Discard @ Eastern Ramp | Characterisation of future backfill material, freshly stockpiled |
| Interburden1 @ Eastern Ramp | |
| Interburden2 @ Eastern Ramp | |
| Dump 6 | Characterisation of MRD |
| Silt Trap Pool Workshop | Characterisation of coal fines deposited on land surface as trapped at the Pool Workshop |
| Dump 4/5 North | Characterisation of MRD, old material |
| Dump 4/5 South | Characterisation of MRD, freshly deposited material |
| Dump 4/5 South B | |
| Product Stockpile | Characterisation of Stockpile |
| Slimes Dam 5 (listed as Tails SW in the laboratory certificates) | Characterisation of MRD |
| Slimes Dam 1 & 2 (listed as Tails Dam 5 in the laboratory certificates) | Characterisation of MRD |

**Table 11. Geochemical analyses done for the Delta-H 2019 study**

| | |
|---|---|
| X-ray diffraction spectrometry (XRD) | Mineralogical analyses |
| ABA | Acid Base Accounting |
| NAG | Nett Acid Generation |
| Total metals | Major and trace element analyses (Aqua regia digestion and ICP-MS) |
| Distilled water extraction | Determination of leachable concentrations |
| Kinetic geochemical testing | Kinetic testing with the aid of humidity cells according to the ASTM D5744 with 20 weeks of leaching |

**Key Findings.** The following key findings are based on the analytical results**:**

- The key features of the mineralogical analysis are as follows:
    - As expected from the depositional environment of the host rocks and coal seams, all samples show a prevalence of quartz and silicate minerals (kaolinite, muscovite).
    - The high organic carbon (coal) content of the samples Slimes Dam 5 and Slimes Dam 1 & 2 (56.45 and 36.89 wt-%, compared to 62.66 wt-% for the product stockpile sample) are noted
    - The Discard and Dump 4/5 samples show the highest (1.7 to 2.76 wt-%), and the interburden and Dump 6 samples the lowest (0 to 0.09 wt-%) pyrite contents.

- The elevated siderite contents in the Discard @ Eastern Ramp as well as Slimes Dam 1 & 2 samples reduce their effective neutralisation potential. Siderite contains reduced iron (ferrous iron), which remains in solution under reducing conditions (e.g. saturated backfill), but precipitates as iron oxy-hydroxide under oxidising conditions (e.g. decant) and then releases acidity. The effective neutralisation potential for these samples is therefore lower than determined in the laboratory ABA test under reducing (saturated) conditions, since the net neutralisation potential associated with siderite is zero under oxidising conditions. This implies that the samples have an even higher net potential to generate acid drainage than indicated by the ABA results.

- The prevalence of gypsum in numerous samples (especially Slimes Dam 5) indicates the occurrence of acid mine drainage conditions with subsequent precipitation of gypsum

- The ABA and NAG test results can be summarized as follows with regard to their acid generation potential:

  - All samples are potentially acid generating with measurable (>0.01%) total sulphur contents. Derived Acid Potentials (AP) range from 4.9 (Interburden2 @ Eastern Ramp) to 175 (Slimes Dam 5) kg/t H2SO4.

  - The limited sulphide sulphur content of the two interburden samples from the eastern ramp suggest a short term (life of mine) acid generation potential for the material.

  - The acid potential of sample Interburden1 @ Eastern Ramp exceeds its neutralisation potential, resulting in a likely net acidic leachate quality. Sample Interburden2 @ Eastern Ramp shows on the other hand a positive, albeit very limited net neutralisation potential of 3.3 kg $H_2SO_4$ / t, which is considered insufficient to reach a neutral leachate quality.

  - The highest acid generation potential is associated with the sample Slimes Dam 5 (188 kg/t), followed by Dump 4/5 South (85 kg/t), Slimes Dam 1 & 2 and Discard @ Eastern Ramp (both 49 kg/t) and the Product Stockpile (47 kg/t).

  - The Silt Trap Pool Workshop sample, which is indicative of fine material deposited on land surface and potentially leached by rain, suggests a net acidic leachate quality (30 kg/t).

  - The NAG test results had a support initial ABA assessment, with most samples being clearly classified as acid generating and the two interburden samples as uncertain.

- Results of the total metals in the samples highlighted Ba as the metal of concern with minor Pb and one elevated Cu concentration.

- The distilled water extraction produced mainly sulphate and, to a lesser extent nitrate and chloride. An elevated fluoride concentration was observed from the sample Interburden1@ Eastern Ramp. Manganese was the metal that returned the highest concentrations. Cadmium, cobalt and nickel leached from the Slimes Dam 5 sample.

- Three composite samples were selected for the kinetic tests (Table 12). The findings of the analytical results are discussed below.

**Table 12. Samples selected for kinetic testing, Delta-H**

| Sample | Motivation |
|---|---|
| Silt Trap Pool Workshop | To represent the future quality of surface runoff from the site due the ubiquitous dust (silt) deposition on hard and soft surfaces at the mine site |
| Composite of Interburden 2 and Discard at Eastern Ramp (1: 1.8 by weight) | To represent the future leachate quality from backfill material, the mixing ratio of 1:1.8 is based on the (arithmetic) average ratio (Jan-18 to Dec-19) as provided by the client (file name: LOM Waste dump report.xls) |
| Composite of Dump 4/5 South and South B (1: 1 by weight) | To represent the future seepage quality from the dump, Dump 4/5 North sample excluded as it represents already oxidised material |

  - Silt Trap Pool Workshop. The sample was classified as potentially acid generating according to the ABA assessment and as uncertain based on the combined evaluation of the NAG pH and NPR values. A kinetic leach test was conducted over a 20-week period to provide additional information on its acid generation potential. Both the sulphate production rate and carbonate NP consumption decreased exponentially, while the pH remained circum-neutral. This suggests the dissolution of soluble primary and precipitation of secondary sulphide and carbonate minerals in the sample. The neutral pH can be attributed to the carbonate NP consumption exceeding the sulphate production rate. However, the remaining NP depleted at a much faster rate compared to the remaining total sulphur concentration and if this trend is maintained over the long term, the material will potentially generate acidity once the available NP becomes less than the remaining total sulphur content. The kinetic leach test results therefore confirm the long-term acid generation potential of the silt sample identified in the static ABA tests.

  - The kinetic testing of the Discard and Interburden 2 Composite sample suggests an initial acidic leachate quality, which could turn in the long term into neutral draining. This correlates with the results of the ABA assessment, which suggested a short-term acid generation potential for the interburden sample and a long-term acid generating potential for the discard sample, with the mixing of the two samples prolonging the acid generating potential.

  - The kinetic leach tests of Dump 4/5 South sample support the long-term acid generating potential indicated by the ABA assessment. Once the limited neutralization potential is exhausted, the dump seepage is likely to become acidic

### 3.4.1.8 Summary of previous studies

Table 13 summarizes the analytical work that has been done on samples from GGC. The following key points are important:

- A total of 80 samples have been submitted for geochemical analyses.

- All major geological units, waste streams and residue deposits have been characterized.

- Most of the materials at GGC were classified as either potentially acid forming (PAF) or as intermediate.

- The geological units have insufficient neutralizing capacity to prevent long term acid generation.

Benches 9, 11 and 13 appears to have the highest acid potential (AP).

**Table 13. Summary of previous geochemical analytical work done at GGC.**

| Material Type | Samples | | Tests done | | | | | | Results | |
|---|---|---|---|---|---|---|---|---|---|---|
| | # | Source(#) | ABA | NAG | Bulk Chem | XRD | Kinetic | Leach | Rock Type | Notes |
| Bench 1 (Overburden) | 28 | a(2), b(25), d(1) | b(25), d(1) | d(1) | a(2), d(1) | a(2) | b(3) | a(2), b(25), d(1) | III(1) | Majority of samples were type III (b). Low risk of producing acidic leachate. |
| Bench 2 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | III(1) | One sample returned high Net Neutralizing Potential - sample had significant concentration of Calcite |
| Bench 3 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Bench 4 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Bench 5 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | II(1) | One sample with inconclusive results |
| Bench 6 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Bench 7A (interburden) | 2 | a(2) | a(2) | a(2) | a(2) | a(2) | | a(2) | II(2) | Two samples with inconclusive results |
| Bench 7B | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | II(1) | One sample with inconclusive results |
| Bench 8 (Interburden) | 4 | a(2), d(1), f(1) | a(2), d(1), f(1) | a(2), d(1) | a(2), d(1), f(1) | a(2) | f(1) | a(2), d(1), f(1) | III(1), I(3) | Most likely acid forming (PAF) |
| Bench 9 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Bench 10 (Interburden) | 4 | a(2) | a(2), f(1) | a(2) | a(2), f(1) | a(2) | f(1) | a(2), f(1) | II(3) | Inconclusive - possibly acid forming over long term |
| Bench 11 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | II(1) | Inconclusive - possibly acid forming over long term |
| Bench 12 (Interburden) | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Bench 13 | 1 | d(1) | d(1) | d(1) | d(1) | d(1) | | d(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Fresh Discard | 14 | a(11) | a(11), f(3) | a(11) | a(11), f(3) | a(11) | a(11), f(3) | a(11), f(3) | I(13), II(2) | pH declined from ~8 to ~7 over 20 wks in humidity cell (a) |
| Discard Unknown | 2 | a(1), g(1) | a(1), g(1) | a(1), g(1) | a(1), g(1) | a(1), g(1) | | a(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Interburden Unknown | 2 | g(2) | g(2) | g(2) | g(2) | g(2) | a(1) | g(2) | I(1), II(2) | No tendency for acidification in humidity cell (a), Short term acid generation of interburden (g) |
| Composite interburden & discard | | | | | | | g(1) | | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Slimes Dam 1/2 | 1 | g(1) | g(1) | g(1) | g(1) | g(1) | | g(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Slimes Dam 5 | 1 | g(1) | g(1) | g(1) | g(1) | g(1) | | g(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Fines | 2 | c(1), g(1) | c(1), g(1) | c(1), g(1) | c(1), g(1) | c(1), g(1) | c(1), g(1) | c(1), g(1) | I(2) | Two samples suggest that the material is potentially acid forming (PAF) |

| Material Type | Samples | | Tests done | | | | | | Results | |
|---|---|---|---|---|---|---|---|---|---|---|
| | # | Source(#) | ABA | NAG | Bulk Chem | XRD | Kinetic | Leach | Rock Type | Notes |
| Super Fines | 1 | c(1) | c(1) | c(1) | c(1) | c(1) | c(1) | c(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Dump 4&5 | 3 | g(3) | g(3) | g(3) | g(3) | g(3) | g(1) | g(3) | I(3) | Three samples suggest that the material is potentially acid forming (PAF) |
| Dump 6 | 1 | g(1) | g(1) | g(1) | g(1) | g(1) | | g(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Product Unknown | 1 | g(1) | g(1) | g(1) | g(1) | g(1) | | g(1) | I(1) | One sample suggest that the material is potentially acid forming (PAF) |
| Product GG1-6 | 2 | e(2) | e(2) | e(2) | e(2) | | | e(2) | I(2) | Two samples suggest that the material is potentially acid forming (PAF) |
| Product GG7&8 | 2 | e(2) | e(2) | e(2) | e(2) | | | e(2) | I(2) | Two samples suggest that the material is potentially acid forming (PAF) |

**Reference**

| | |
|---|---|
| Golder 2007 | a |
| Aphane 2014 | b |
| GCS 2014 | c |
| Schlumberger 2015 | d |
| Digby Wells 2016 | e |
| Exxaro 2016 | f |
| Delta-H 2019 | g |

**Rock Classification**

| | | |
|---|---|---|
| TYPE I | Potentially Acid Forming | Total S(%) > 0.25% and AP:NP ratio 1:1 or less |
| TYPE II | Intermediate | Total S(%) > 0.25% and AP:NP ratio 1:3 or less |
| TYPE III | Non-Acid Forming | Total S(%) < 0.25% and AP:NP ratio 1:3 or greater |

# 4 CONCEPTUAL MODEL

According to the International Network for Acid Prevention (INAP) in their Global Acid Rock Drainage guide (gardguide.com), "*A conceptual site model (CSM) describes what is known about the release, transport, and fate of contaminants at a mine site. As such, the model includes the following components:*

- *Sources*
- *Pathways*
- *Biological receptors*

*The CSM describes the sources of potential contaminants, the mechanisms of their release, the pathways for transport, and the potential for human and ecological exposure to these parameters. The most important potential sources of ARD at mine sites are the mine pit (walls, benches and floor), exposures in underground workings, waste rock, ore (including any low-grade stockpiles) and process residues (tailings and rejects)"*

In developing the SCM for GGC the source-pathway-receptor principal, as explained above was used.

## 4.1 Sources

### 4.1.1 Mining (Open Pit)

Mining processes exposes in-situ rock to oxygen and water. Any acid forming sulphides are therefore exposed to atmospheric oxygen, which accelerates oxidation and the formation of acidic leachate.

All the mining benches have been sampled and characterized (Table 13) and most are Type I material (PAF). Runoff water from the pit walls will be acidic (AMD) with elevated salt concentrations (SD). The portion of the run-off water that is captured in the in-pit sumps is transferred to the mine's dirty water system. Some of pit water remains trapped in the backfill material.

The Life of the Mine Plan until 2058 is presented in Figure 7. The pit will develop in three phases, as described by Zutari (October 2020):

- **Pit Mid** (Present-2030) - the mine currently consists of an open pit and a small section of unrehabilitated backfill. The pit will progressively move in a westward direction. Mining within this section of the pit is uphill, and therefore the sump collects water at the backfill face;
- **Pit North** (2030-2055) - By 2030 the mine face will reach its most westerly point, and mining will move to the northern section. Mining will then progress in an easterly direction. Mining within this section of the pit is in the majority downhill, and therefore the sump collects water at the mining face, and
- **Pit South** (2050-2057) - By 2050 the mining in the southern section will start in an easterly direction. The southern section will not be backfilled and will remain a large void.

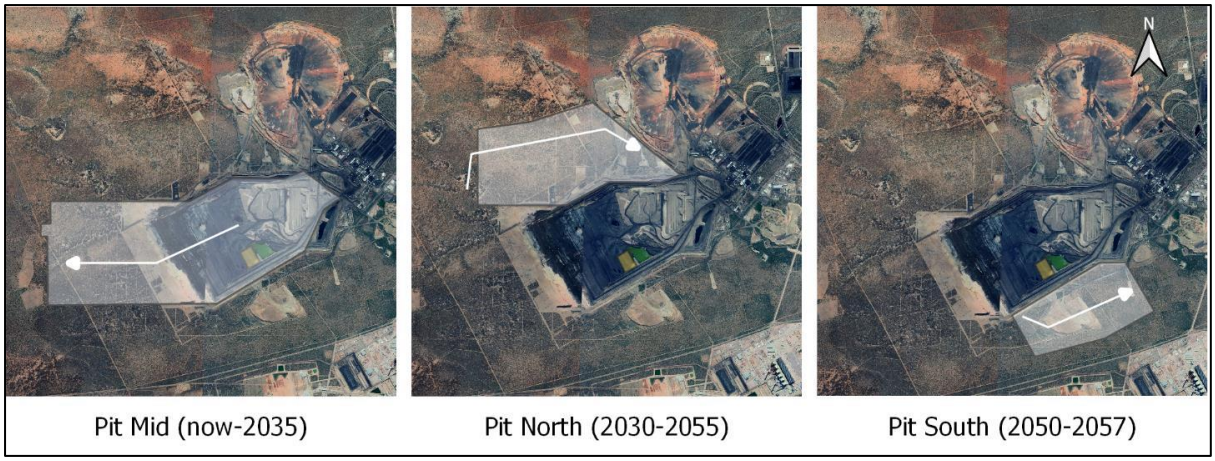


Figure 7: Grootegeluk Life of Mine plan (LOM).

### 4.1.2 Backfilling

The mine has developed and tested a method by which coal discard and interburden can be backfilled and sealed/isolated in compartments to prevent the discard and interburden from spontaneously combusting. Spontaneous combustion will be prevented by limiting oxygen ingress by a combination of the following (Jones & Wagener, 2011):

- Maintaining a sufficient advance rate of materials placement thereby limiting the time of exposure to the atmosphere; and

- Sealing the backfill in compartments at various intervals as backfilling takes place with available overburden material.

The backfill design (Figure 8 and Figure 9) of the mid and north pits (Figure 7) were done by Jones and Wagner in 2011.

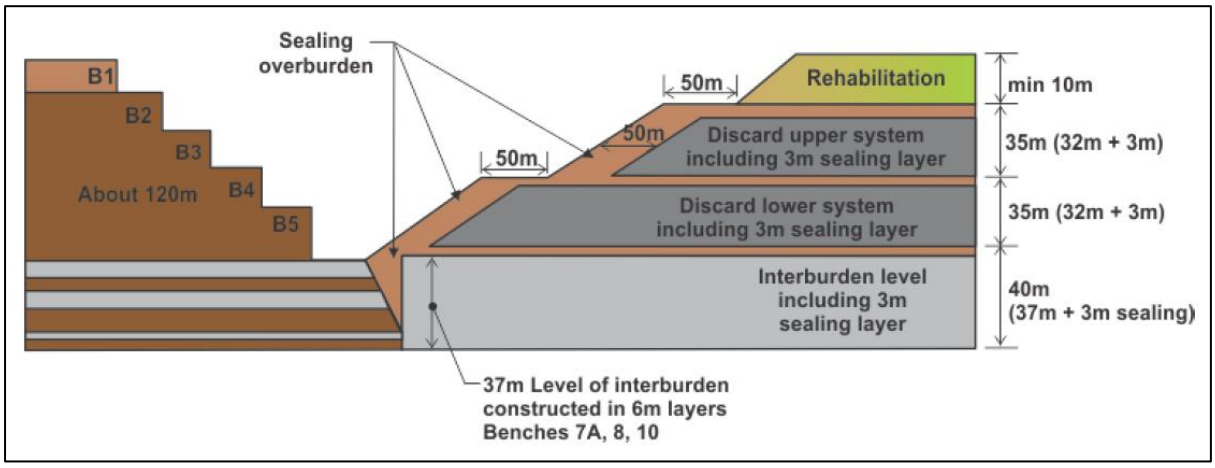


Figure 8: Backfill sealing compartments (north-south section) (Jones & Wagener, 2011)

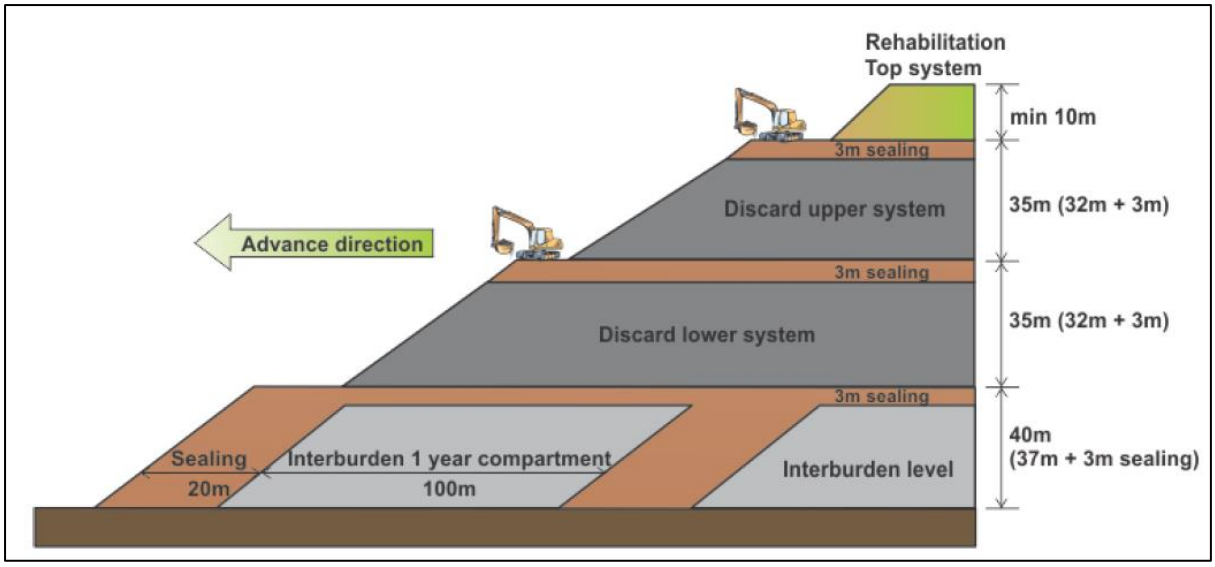


Figure 9: Backfill sealing compartments (east-west section) (Jones & Wagener, 2011)

Backfill material (internburden and discard) has been characterized through various studies (Table 13). Analytical results suggest that the discard and interburden is either PAF or has limited neutralizing capacity and therefore likely to produce acidic leachate. The analytical results are supported by the low pH in bench 13 sump.

### 4.1.3 Residue deposits

The main residue deposits are presented in Figure 10. These are all surface facilities which will have to be either removed (Renoster dump & Dump 6) or rehabilitated (Dumps 4 & 5, Slimes dams and cyclic ponds) after mine closure. Conceptually these facilities can be summarized as follows (refer to Table 13):

- Dump 4 & 5 – Discard and interburden, therefore likely to generate acidic leachate,
- Dump 6 – Mostly inert material, may produce saline drainage (SD),
- Renoster Dump – topsoil dump, unlikely produce poor quality leachate,
- Cyclic ponds (lined facility) – PAF material, likely to produce poor quality leachate. Seepage is captured in return water dams and returned into the mine's dirty water system for re-use, and
- Slimes Dams - PAF material, likely to produce poor quality leachate. Penstock water is transferred to Mamba Dam and returned into the mine's dirty water system for re-use

Figure 10: Main residue deposits at GGC.

### 4.1.4 Plant area and product stockpiles

All the product samples (Table 13) were classified as Type I material, or potentially acid forming (PAF). The stock yards (Figure 11) are lined and seepage water is directed into the mine's dirty water system. Some spillage from the plant area enters the Basalt aquifer and is recovered through abstraction boreholes (refer to section on groundwater management strategy).

Figure 11: GGC plant area and product stock yards.

## 4.2 Pathways

Surface water run-off from all the residue deposits and plant area reports into the mine's dirty water system (PCDs and channel to pit). Dirty water is re-cycled and re-used for mining and beneficiation. Surface water is therefore contained on site with limited impact on the receiving surface water environment.

Surface water was not considered as a pathway of concern for the off-site migration of mine related contaminants to receptors (surface water bodies).

Groundwater was identified as a pathway of concern for seepage from mining, plant and residue deposits. A conceptual discussion of this potential pathway necessitates a discussion of the underlying geological and hydrogeological conditions. The geological setting of GGC is presented in Figure 12. A north-south cross section through the major features is presented in Figure 13.

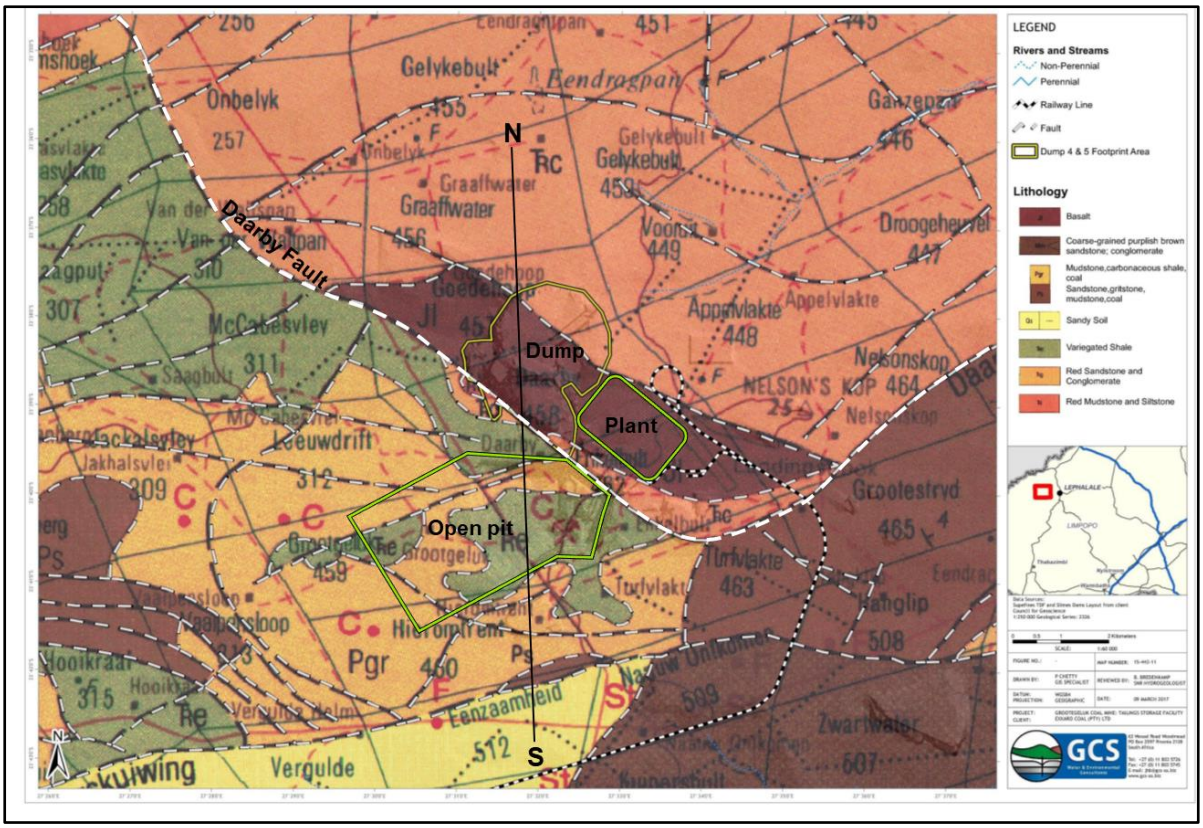


Figure 12: GGC geological setting.

The GGC open pit is situated to the south of the Daarby Fault, while the plant and residue deposits are situated to the north of the fault, mainly on a Basalt block (dark area on the map). The Daarby fault act as a groundwater flow barrier with two groundwater regimes either side of it.

Groundwater migration on the southern side of the Daarby is towards the open pit (Figure 13). The pit is a groundwater sink which captures contaminated water emanating from mining related activities to the south of the Daarby. The mine is licensed to take 1 606 689 $m^3$/annum from the pit for industrial use.

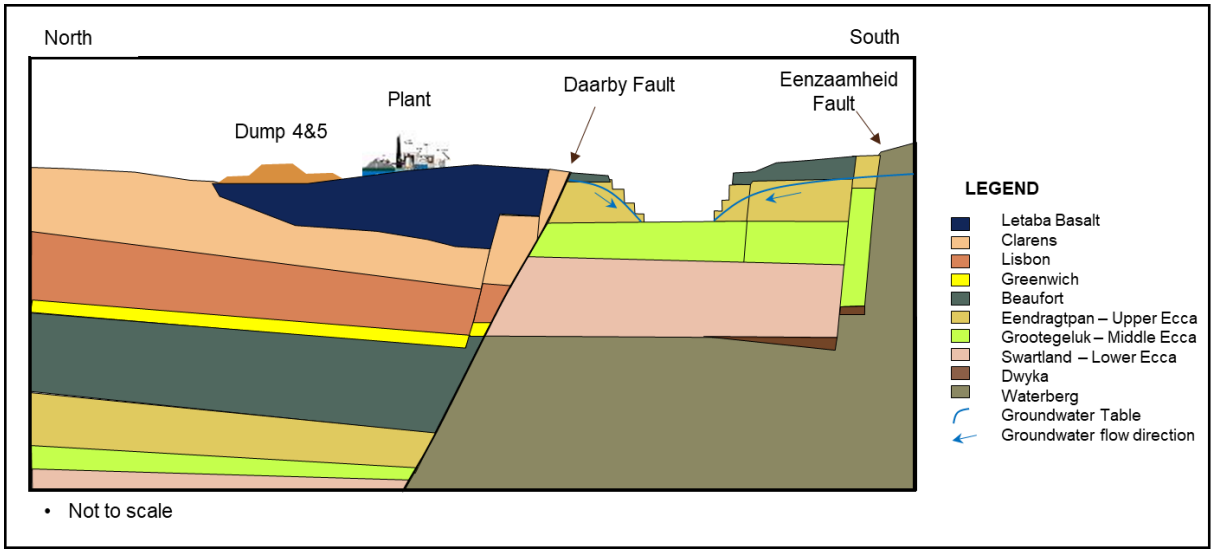


Figure 13: Cross section showing the mining pit in relation to the plant area.

Most of the infrastructure to the north of the Daarby, except the slimes dams and a section of Dump 4 & 5, are situated on the Basalt aquifer (Figure 12). The mine is licensed to abstract an average of 954 072 $m^3$/annum from the Basalt aquifer for industrial use. **Table 14** list the licensed abstraction boreholes at GGC. Through abstraction of groundwater from the Basalt aquifer, the water table is drawn down resulting in flow towards the abstraction areas. The positions of the active abstraction holes are presented in Figure 14.

For more information on the groundwater regime (conceptual model and flow analysis) the reader is referred to: Grootegeluk Mine Dump 4 and 5 waste facility: Contaminant Transport Modelling, GCS*, July 2019*

**Table 14. Licensed abstraction boreholes at GGC**

| Borehole Name | Longitude | Latitude | Status |
|---|---|---|---|
| WB 33 | 27.54896 | -23.6544 | Active pumping |
| WB 35 | 27.54501 | -23.6526 | Not being Pumped |
| WB 36A | 27.54053 | -23.65809 | Available |
| WB 38 | 27.5458 | -23.6615 | Active pumping |
| WB 39A | 27.55633 | -23.66761 | Active pumping |
| WB 41 | 27.56032 | -23.665 | Active pumping |
| WB 42 | 27.55522 | -23.6671 | Not being Pumped |
| WB 43 | 27.55869 | -23.6626 | Active pumping |
| WB 45 | 27.5647 | -23.6622 | Active pumping |
| WB 46 | 27.56463 | -23.6658 | Active pumping |
| WB 49 | 27.5608 | -23.6553 | Active pumping |
| WB 50 | 27.5636 | -23.6481 | Available |
| WB 51 | 27.56169 | -23.6579 | Not being Pumped |
| WB 52 | 27.55193 | -23.6654 | Active pumping |
| WB 53 | 27.55535 | -23.6619 | Active pumping |
| WB 54 | 27.56029 | -23.6651 | Active pumping |
| WB 55 | 27.56572 | -23.6587 | Not being Pumped |
| WB 56 | 27.55878 | -23.6573 | Available |
| WB 57 | 27.55041 | -23.6498 | Available |
| WB 59 | 27.55546 | -23.656 | Active pumping |

Figure 14: Abstraction boreholes in the GGC plant area.

### 4.3 Receptors

The following section describes the potential receptors around the Grootegeluk Complex (GGC).

- **Surface water**. All surface water runoff from mining and related infrastructure (including dumps) report to water management infrastructure and is either contained in pollution control dams or diverted to the pit. No surface water receptors were identified at GGC

- **Groundwater**. The groundwater resource is the only major receptor of poor quality leachate from the GGC. Grootegeluk abstract groundwater from the Basalt aquifer for industrial use and is therefore the main anthropogenic receptor. None of the adjacent landowners are near the mine or affected by poor quality groundwater because of mining activities. This has been confirmed through continuous monitoring as well as various hydro census studies around GGC

## 5 AMD RISK ASSESSMENT

### 5.1 Introduction

The risk of Acid Mine Drainage (AMD) is a function of three factors:

- The sulphide content of the rock and coal (or ore) being exposed, disturbed or dumped;

- The neutralising capacity of the rock and coal; and

- The availability of oxygen and water, which react with the sulphide minerals and oxidises them to sulphates, producing AMD – water is also the carrier for the AMD.

The AMD risks of the various sources are summarized in Table 15 below. There is a substantial risk of acid generation at GGC that needs to be managed.

**Table 15. Typical acid and net neutralizing potential of material at GGC**

| Source | Rock Type | Acid Potential kg/t | Net Neutralizing Potential kg/t | AMD Risk |
|---|---|---|---|---|
| Overburden | III | 1.9 | 15.1 | Low |
| Coal Benches | I | 23.7 | -12.3 | High |
| Interburden | II | 6.3 | -0.6 | Moderate |
| Discard | I | 67 | -49 | High |
| Product Stock Piles | I | 51.5 | -46.5 | High |
| Slimes | I | 125 | -118.5 | High |
| Dump 4&5 | I | 51 | -48.3 | High |
| Dump 6 | II | 11 | -12 | Moderate |

# 6 AMD MANAGEMENT STRATEGY

Various working procedures have been implemented at GGC to reduce the generation of Acid Mine Drainage and to manage the potential impact thereof. The section below describes the management processes and further proposed actions to finalize a comprehensive AMD management strategy.

## 6.1 Current AMD management at GGC.

To reduce the formation of ARD / AMD on site, various management practices have been introduced, these are:

- Encapsulation of discard in the pit with overburden. This process was developed to prevent spontaneous combustion by excluding oxygen from the discard material. It also inhibits the formation of AMD significantly by limiting oxidation of sulphides.
- Containment of contaminated water on site in Pollution Control Dams (PCDs) and the mine pit.
- In-Pit neutralization (lime dosing) of water for re-use for industrial use.
- Abstraction from the Basalt aquifer induces a groundwater sink in the plant area, which contains contaminated groundwater on-site.
- Construction and use of the cyclic ponds instead of the standard slimes dam facilities, to directly recover fines as product. This reduces the amount of potentially acid forming (PAF) material on site (reduction of source).
- A cut-off trench was installed to the north east of the cyclic ponds to intercept seepage from the unlined slimes dam. The water from this trench is returned to the mine's dirty water system for re-use.
- Field trials have been set up to gain a better understanding of acid generation under natural conditions.

Figure 15: Field trial barrels.

## 6.2 Gaps in Geochemical Data

Although numerous studies have been done on the geochemistry of the ore body, products and waste stream at GGC there is still a need to improve the knowledge base. Particularly with respect to the following:

- Limited kinetic testing (only 21 samples) have been done with no testing on the following:
    - Coal benches,
    - Slimes, and
    - Product.
- Limited field trials have been set up – theses should be expanded.
- Seepage water quality (toe seeps) from mine residue deposits are not individually available. This information can be used to calibrate future geochemical models.

## 6.3 Groundwater Management Strategy

As groundwater was identified as the pathway of concern the management thereof should be a priority. The current groundwater management strategy at GGC consist of the following:

- Groundwater monitoring as per approved network and schedule;
- Interpretation and reporting of monitoring data on an annual basis with emphasis around areas of concern;
- Continuous refinement of conceptual groundwater model with new information on an annual basis;

- Delineation of all potential sources of groundwater contamination (complete – Golder May 2020);

- Source characterisation to determine contaminants of concern (complete - – Golder May 2020);

- Update of current groundwater flow and transport model with source information has been completed (GCS; July 2019).

- Regular updates (annually) of the macro water balance to confirm relevance of closure scenarios;

- Report on the above in annual update of the IWWMP;

## 6.4 Proposed further work

Additional work to enhance the GGC AMD Management plan should consist of the following (see schedule in Table 16):

- Facility specific monitoring networks, will be implemented, where required, to verify success of mitigation/closure measures (in place for certain facilities i.e. cyclic ponds);

- The faults underlying contaminant sources should be further characterized to determine their hydrogeological characteristics (potential flow barriers/preferential flow paths). This includes the Eenzaamheid and Daarby faults;

- The calibrated flow and transport model must be used to assess (with aim to improve) current management practice of dewatering the basalt aquifer;

- Regular (annually) re-calibration of groundwater model to assess relevance of monitoring network should be conducted;

- Utilization of calibrated flow and transport model to assess closure scenarios on an annual basis;

- Included all mining activities in the flow model to provide the groundwater balances for the complex in future;

- The model will be used as a management tool to simulate potential future impacts and to scope additional intrusive work or data collection;

- Run What-if scenarios to design BAT (best available technology) mitigation options for areas of concern;

- Delineation of the proposed Tier zones in new RQOs will be done with the calibrated flow and transport model;

- Regular field pH and EC monitoring of toe seeps at all residue deposits and temporary stockpiles such as GG10A and B should be implemented and sampling conducted where anomalous readings are detected.

- Once the results of the field trials are available a geochemical report must be produced to make proposals for the handling and disposal of potentially acidic materials. This report will also inform closure scenario selections for the various mining voids.

- GGC should schedule a series of geochemical assessments, including geochemical models, for each of the major AMD sources on site.

- Provision for the implementation of the proposed work will form part of the Grootegeluk annual operational budget.

**Table 16. Proposed schedule of further work**

| **Work Item** | **Proposed date** |
|---|---|
| Updated Groundwater Model | Q3 2021 |
| Assess closure scenarios based on updated Groundwater Model | Q4 2021 |
| Re-assess and extend field trials | Q2 2021 |
| Inspection of toe seeps around discard dumps and stock piles | Annually - April and October |
| Delineation of Tier zones as per IWUL | Q3 2021 |
| Characterization of major geological faults (Daarby and Eenzaamheid) | 2022 – 2024 |
| Geochemical model based on field trials and other data | 2022 - 2023 |

## References


Feasibility study of the expected geochemical and geohydrological impacts related to the proposed backfilling of mixed mine discard and power station ash into the open cast void at Grootegeluk colliery, *Golder Associates, August 2007.*

Evaluation of acid rock drainage potential in the Waterberg Coalfield, *Venessa Aphane, MSc Thesis, April 2014.*

Grootegeluk Super Fines Tailings Disposal Facility: Hydrogeological Study: *GCS, August 2014.*

Hydrogeological and geochemical investigations to refine the optimized long-term water management strategy: Grootegeluk Colliery, Limpopo, *Schlumberger, December 2015.*

Grootegeluk Short-Term Stockpiles Amendment Project: Geochemistry Report: *Digby Wells Environmental, September 2016.*

Grootegeluk Coal Mine: Geochemical Assessment, *Delta-H, September 2019.*

Site Wide Rehabilitation Plan for Grootegeluk Coal Mine, *Golder Associates, May2014.*

www.gardguide.com, *INAP: The International Network for Acid Prevention*

Integrated Water and Salt Balance Baseline Model Report – Part 2, *Zutari, October 2020*

Grootegeluk Coal Mine Backfill Rehabilitation – Conceptual Design Aspects (report no. JW131/11/B791-Rev A), *Jones & Wagner, 2011*

Grootegeluk Mine Dump 4 and 5 waste facility: Contaminant Transport Modelling, *GCS, July 2019*

Pollution Source Term characterisation to support Groundwater model update at Grootegeluk - Preliminary Report, *Golder, May 2020*.