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The concession covering exploration licence areas 1032L, 1034L and 1035L is being explored and managed by Capitol Resources Limitada (CRL); a 100%-owned subsidiary company of Baobab. The Tete Pig Iron Ore and Ferro-Vanadium Project (Tenge Project) is focused on the Tenge Hill deposit located approximately 80 kilometres northeast of the town Tete, Tete Province, Mozambique; on the banks of the Revuboe River.

The Revuboe River flows from northeast towards the south and Tenge Hill is located within 100 metres of the Revuboe River. The Revuboe River is fed by several ephemeral tributaries and perennial streams including some which flow through the proposed mine infrastructure areas.

The mean annual precipitation for the project area is 624 mm, with the highest recorded rainfall measured during the month of January (based on 55 years of data from Chingodzi weather station, located approximately 45km southwest of the Tenge Project). The mean annual evaporation for the project area is 2 200 mm, and thus a negative water balance for open water sources is expected.

The regional geological setting of the area ranges from intrusive formations of the Tete Suite (formerly known as Tete Gabbro-Anorthosite Complex) to the sedimentary formations of the Karoo Supergroup. The contact between the Tete Complex and Karoo Supergroup is structurally controlled and is potentially associated with faults and fractures.

The dykes in the area are very elongate; continuous to sub-continuous bodies trending NE-SW. The dykes form swarms parallel, or in many cases are oblique or at right angles (perpendicular) to the magmatic banding. In instances where the dykes are perpendicular to magmatic banding, the margins are intensely sheared and the dykes are disrupted. Where they are intensely foliated and recrystallized, dykes are difficult to distinguish from the gabbroic country rocks (SRK, 2014).

**Current groundwater use and status**

Digby Wells carried out a hydrocensus (March 2014) within a 5km radius of the proposed Tenge Pit, that included the identification of groundwater use and groundwater recharge.

During the hydrocensus 10 water sites were identified consisting of six boreholes and four surface water sampling sites along the Revuboe River. From the six boreholes, four are exploration boreholes and two are currently used for domestic use.

In the project area groundwater use is very limited with the Revuboe River being the main source of water. The river flows throughout the year with the need for groundwater abstraction thus limited.

The groundwater elevation in the area ranges between 231 and 320 m amsl as recorded by SRK (2014 study, Appendix B). The depth to groundwater level is highly variable from 0.7 mbgl near the Revuboe River to 85 mbgl on top of Tenge Hill. The depth to the groundwater level increases with an increase in distance from the Revuboe River. Therefore the groundwater flow direction is towards the river, suggesting that the Revuboe River is a gaining stream.

In terms of the water quality the following were concluded:

- Most of the analysed parameters (groundwater samples) are within the stipulated World Health Organisation drinking water guidelines (Gorchev & Ozolins 2008), with the exception of total dissolved solids due to elevated alkalinity values;
- High alkalinity values might pose health risk to water users;
- The elevated concentrations for iron, manganese and selenium in the area is probably due
to underlying geological formations; thus natural concentrations;

- The analytical results show that the concentrations of several analysed parameters in groundwater is higher than the concentrations from Revuboe River, suggesting that there is interaction of rain water with the host rock and soils as it infiltrates the subsurface;
- The groundwater in the Karoo Supergroup is characterised by elevated concentrations of sodium and chloride; and
- The area is characterised by two groundwater types; shallow recently-recharged groundwater and deeper fractured groundwater. Both have similar isotopic compositions suggesting rainfall recharge for both.

The isotope assessment suggests that groundwater in the shallow and deeper aquifers are similar, indicating that the groundwater in the deeper and the shallow aquifer systems are connected and likely to be recharged by rainfall.

Two samples; one collected in October 2013 and another in April 2014 of the Revuboe River show very high variations in isotopic composition, from a depleted isotopic composition similar to groundwater in the wet season (April sample) to a highly enriched, evaporitic isotopic composition in the dry season (October sample).

Several isotope samples collected from borehole SRKGW01 were aimed at establishing whether during the pumping, river water was drawn into the aquifer system. The results indicate that the water before, during and at the end of pumping remain similar to the groundwater signature, suggesting that the deeper groundwater was drawn into the borehole during pumping not the Revuboe River water.

**Drilling Programme**

Seven boreholes were drilled and were positioned based on the results obtained from the geophysical survey. Five of the seven boreholes intercepted mainly gabbro and dolerite formations. Boreholes SRKGW11A and SRKGW9A were different and intercepted carbonaceous and schist formations respectively (Plan 7, Appendix A). Borehole SRKGW8B intercepted anorthosite and magnetite layers around 35 and 45 mbgl.

Dolerite intrusions were observed in all boreholes and might act as groundwater flow barriers, especially to vertical water or contamination migration.

Borehole yields are low, indicating no major aquifer system in the area. The highest yield was observed for boreholes SRKGW3A and SRKGW8B; 4 212 L/h and 792 L/h respectively. Both water strikes relate to fractured dolerite intrusions. The contact zones between the dolerite and surrounding formations and also between gabbro, carbonaceous formations and schist yielded only seepage water, but were mostly dry.

The depth of weathering (highly weathered) extended up to 20 mbgl based on the recent drilling programme results and slightly weathered material was encountered to depths of 40 mbgl.

The recorded groundwater levels vary between 4 and 25 mbgl. The shallower groundwater levels are associated with boreholes located close to the Revuboe River.

**Aquifer Testing**

Eight slug tests and five pump tests were performed by Digby Wells and SRK. The eight slug tests were performed on low yielding boreholes with the higher yielding boreholes being subjected to pumping tests.

The following is a summary of the test results:
The hydraulic conductivity calculated from the test pumping data indicates that the weathered and fractured zone has a low to intermediate hydraulic conductivity suggesting that the geological horizon between the Revuboe River and the proposed pit might leak water from the river into the pit;

The packer test results indicate that the ore body and the underlying fresh bed rock have very low hydraulic conductivity grading with depth to essentially impermeable;

The fractured zone is less permeable compared to the overlying weathered zone and this is because of poor interconnection between fractures;

The hydraulic conductivity in the area decrease with depth;

Lithological structure and dyke contacts within the Tete Complex are infilled with secondary minerals, further reducing the hydraulic conductivity of the rock; and

Isolated fractures can have high hydraulic conductivities; larger than 0.2m/d.

Geochemistry Assessment

Ore material assessment

The XRF results, indicating the oxide distribution within the mineralogy of the ore material, indicate high SiO$_2$ and Fe$_2$O$_3$ content as would be expected with the ore zone located in gabbro and anorthosite formations. MgO, CaO and Na$_2$O complete the oxide series for the ore material.

The oxides and various trace elements combine to form the mineralogy of the ore material. The ore material is dominated by ilmenite, magnetite and plagioclase, with chlorite, muscovite, enstatite and kaolinite making up the main accessory minerals of the ore zone.

From the three ore samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for sample B was below the 0.3% S margin, but for sample C it was above the margin with 0.4% sulphur. Sample F had a sulphur level of 0.3%;
- Samples B and F had positive NNP values, with sample C having a negative value;
- Sample B is classified as non-potentially acid generating;
- Sample C is potentially acid generating; and
- Sample F is marginal and inconclusive.

The ore material for environmental impact purpose is thus deemed to be potentially acid generating.

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water guideline values with only aluminium leaching out above the recommended 0.3 mg/L in samples B and F; and
- Although the leachate from the static tests is relatively clean, the long term acid producing potential and oxidation can lead to an increase in leachable elements. It is recommended that the ore material be submitted for long term kinetic tests.
**Waste rock assessment**

The XRF results, indicating the oxide distribution within the mineralogy of the waste material, indicate high SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ content as would be expected with the ore zone located in gabbro and anorthosite formations. MgO, CaO and Na$_2$O complete the oxide series for the ore material.

The oxides and various trace elements combine to form the mineralogy of the ore material. The ore material is dominated by various minerals with a wide range of silicates and clay minerals including actinolite, augite, biotite, chlorite, dolomite, enstatite, ilmenite, magnetite, plagioclase, quartz, smectite, spinel and talc.

From the four waste rock samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for samples A and E were below the 0.3% S margin and for samples D and G it was above the S margin;
- Sample E had a positive NNP value, but samples A, D and G had negative values;
- Samples A and E are classified as non-potentially acid generating;
- Samples D and G are potentially acid generating; and
- Based on sulphur content the results for the waste rock material analysis are inconclusive. However, due to the low neutralising potential also observed in the results, and the fact that the waste rock will be stored on the same WRD the overall outcome can be seen as potentially acid generating. Long term static tests are recommended with a bigger sample population and submitted for ABA and NAG to gain more certainty on the potential for AMD generation.

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water ranges with only aluminium leaching out above the recommended 0.3 mg/L in sample A; and
- Although the leachate from the static tests is relatively clean, the long term acid producing potential and oxidation can lead to an increase in leachable elements and thus it is recommended that the waste rock be submitted for long term kinetic tests.

**Numerical contamination model**

Various scenarios were simulated to quantify the impact on the groundwater reserve due to the proposed mining activities and related infrastructures. The open pit mine and its influence due to dewatering, as well as contaminant transport associated with the open pit, WRD, Slag dump and TSF were simulated. The following model scenarios were simulated:

- Scenario 1: Present day setup, water balance and flow conditions. This scenario was used to calibrate the flow model.
- Scenario 2: Operational transient mass transport. The transport model was simulated for the various possible pollution sources as supplied by the client.
- Scenario 3: Post operational mass transport – steady state.

**Scenario 1**

There is approximately 4 270 m$^3$/d flowing into the modelled groundwater system from recharge,
as calculated from MAP (624 mm/a). The resultant groundwater flow is due to a combination of inflow from recharge and losses to the drainage systems in the modelled area. The area modelled is such that no base flow is recorded. The resultant flow towards these drainage systems will be recorded as losses in the riparian zone due to evapotranspiration.

The 18 200 m³/d recharge on the 580 km² modelled catchment relate to an average of 6.24 mm/a of recharge that reaches the groundwater system. The topography is classified as fairly flat with undulating hills throughout the model domain. Elevation changes occur from approximately 410 m amsl at the highest point to 240 m amsl i.e. a maximum change of 170 m over a 250 km² area. The flow direction shows that the hydraulic gradient is from the topographical highs towards the confluence of the drainage systems. From there, the majority of groundwater flow is towards the southern outflow boundary i.e. towards the Zambesi River near Tete.

**Scenario 2**

The aim of the numerical modelling is to simulate the possible contaminant transport associated with various potential sources during Life of Mine (LoM) and post closure. Key sources of potential pollution include:

- The WRD/Pit;
- The TSF and Slag dump; and
- The Stockpiles/Plant area.

Analyses of the background values of iron indicated the average concentration in the groundwater is less than 1 mg/L. Conservative concentrations were chosen for iron to leach from the various facilities:

- The WRD/Pit – maximum of 178 mg/L;
- The TSF and Slag dump – maximum of 1 030 mg/L; and
- The Stockpiles/Plant area – maximum of 706 mg/L.

The concentrations chosen are conservative, and were sourced from the various geochemical tests done on the material during the project, with leachable and total concentrations taken into account.

A porosity value of 3% was used. Fluxes were assigned to TSF, slag dump, open pit and plant areas to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned.

Simulations of the WRD were done with no lining system installed i.e. a barrier that reduces the vertical hydraulic conductivity below these infrastructures to reduce seepage. A conservative approach was followed.

The open pit was included in the operational simulation. The open pit could act as a mitigatory measure due to the proximity of the open pit to various infrastructures. The groundwater flow in the vicinity of the open pit will change over time due to the mining.

The final pit at year 23 will be approximately 235m deep (from 405 m amsl to 170 m amsl) and 135m below the pit crest. The hydraulic gradient will change and the natural groundwater flow will be altered i.e. flow will occur towards the open pit and any possible contaminant within the Radius of Influence (ROI) of the open pit will migrate along the hydraulic gradient towards the pit.

The plumes associated with the plant area, the open pit, as well the slag dump indicate a distinct flow regime towards the open pit – simulated for 23 years operation.

The simulated plumes from the slag dump and plant area migrate a maximum of approximately
1 000 m before it reaches the open pit at concentrations ranging from 1 to 5 mg/L, which act as a natural mitigatory measure. The simulated plume associated with the TSF shows migration of Fe ranging from the north-west all the way to the south of the TSF. This is due to the distance of the TSF from the open pit (i.e. outside the possible ROI) and the proximity of the TSF to the main drainage in the model domain. The TSF is also situated on a topographical high, enabling migration to occur in various directions. Migrations during LoM are at a maximum in the western direction, measuring approximately 1 600 m during the 23 year LoM. Seepage capturing boreholes should be drilled south and west of the TSF to capture any possible seepage migrating towards the main river. The abstracted water should be used in the closed mine water circuit. Depending on the ground conditions and excavation possibility, a cut off trench should be installed around the TSF to capture toe seepage.

The aquifer thickness and porosity plays a vital role in the possible migration of the plumes associated with the simulated infrastructure. Monitoring should be conducted on a quarterly basis to ensure that proper mitigatory measures are implemented and adhered to.

No third party boreholes will be affected during the 23 years of mining, however a repeat of the hydrocensus should be conducted before construction starts to establish a decent baseline dataset of water levels and groundwater quality.

**Scenario 3**

The possibility exists that contamination may migrate from the slag dump and TSF and reach the local drainage connecting the model domain with the Zambesi River further downstream. The simulations clearly indicate that additional detailed mass transport simulations are required to address sensitivities associated with porosity values, aquifer thickness, and recharge on the facilities, as well as for mitigation measures such as capping or isolating the facilities.

**Scenario 4**

A simulation of the mass transport model was done with the inclusion of the mitigation option of lining the pollution sources (mainly the TSF) with a natural clay layer. Both the operational and post-closure option was simulated with transmissivity values of the top most layer (the liner below the sources) reduced to 0.0031 m²/d which is in line with literature values for compacted clay layers.

These values were assigned to the base of the potential contaminant facilities. The scenarios were simulated for life of mine as well as post closure for 50 years. Iron was used as the simulated contaminant for the various scenarios. Analyses of the background values of iron indicated the average concentration in the groundwater is less than 1 mg/ℓ. Conservative concentrations were chosen for iron to leach from the various facilities as in previous scenarios.

A porosity value of 3% was used. Fluxes were assigned to both TSF, slag dump, open pit and plant areas to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned.

The plumes associated with the plant area, the open pit as well the slag dump indicates a distinct direction of flow regime towards the open pit – simulated for 23 years operation (Figure 11). The simulated plumes from the slag dump and plant area migrate a maximum of approximately 1000 m before it reaches the open pit at concentrations ranging from 1 – 5 mg/ℓ, which act as a natural mitigatory measure. The simulated plume associated with the TSF shows migration of Fe ranging from the north-west all the way to the south of the TSF. This is due to the distance of the TSF from the open pit (i.e. outside the possible ROI) and the proximity of the TSF to the main drainage in the model domain. The TSF is also situated on a topographical high, enabling migration to occur in various directions. The migration of mass is less with the geoliner installed and simulated
compared to the unmitigated scenario i.e. up to 1000 m less migration.
The results obtained during the LoM simulation were used as initial conditions for the post operational simulation. The post operational simulations were done in steady state flow with transient transport for 50 years post closure.
As shown in Figure 11 and Figure 12, the results obtained and shown from the mitigated scenario differ from the unmitigated scenario, which reached the river to the west of the proposed TSF. The simulation indicates that a geoliner will assist in mitigating the potential flow of contaminants from the facilities. Nonetheless, a detailed monitoring plan should be implemented to measure and control any possible seepage.

**Potential Impacts on the Groundwater System**
The main potential impacts identified from the groundwater and geochemistry studies are:

- Potential for AMD from WRD, stockpiles and TSF facilities with a further potential for metal leachate reaching the groundwater reserves and depleting groundwater quality;
- Potential impact on local water supply and groundwater reserves due to dewatering; and
- Potential contamination of soils and groundwater through oil and gas spills on site.

If the local groundwater conditions and characteristics (section 5) are taken into consideration then the most suitable area for the construction and operation of a landfill site would be on the gabbro formation (Tete Complex):

- East of the Plant;
- Along the haul road running to the southeast; staying clear of the 1 in 50 year flood line of the northeast-southwest running un-named tributary; and
- Along the quarry road running to the northwest.

**Recommendations**

- A more extensive geochemical assessment on a wider range of samples should be undertaken (at least 50 waste and 50 ore samples for ABA, NAG and SPLP tests).
- Waste material and ore material samples should be sent for long term kinetic leachate tests (22 week tests).
- Monitoring of surface and groundwater should be done as discussed in section 8.
- The water monitoring network should be reviewed and amended every year as more results become available.
- If any infrastructure, especially tailings or waste rock facilities is placed on an existing water supply, monitoring or exploration borehole, the borehole should be adequately sealed before construction /disposal can commence.
- Detailed mapping should be done of the local faults and the influence thereof on the possible contaminant transport. No infrastructure such as the slag dump or TSF should be placed on a high permeable fault.
- Surface water features, process and domestic water should be monitored for chemical and micro-biological parameters at monthly intervals.
- Boreholes should be sampled on a quarterly basis.
■ Storm water management should be conducted in a way that surface water and groundwater is not contaminated with fine suspended material.

A detailed groundwater and geophysical assessment should be undertaken on the preferred landfill site.
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<td>Mtpa</td>
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<tr>
<td>m³</td>
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<tr>
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<td>Net Potential Ratio</td>
</tr>
<tr>
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<tr>
<td>SPLP</td>
<td>Synthetic Precipitation Leaching Procedure</td>
</tr>
<tr>
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<td>Standard Deviation</td>
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<tr>
<td>TDS</td>
<td>Total Dissolved Solids</td>
</tr>
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<td>Transmissivity</td>
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<td>World Health Organisation</td>
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<td>Waste Rock Dump</td>
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<tr>
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<td>X-ray Diffraction</td>
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<tr>
<td>XRF</td>
<td>X-ray Fluorescence</td>
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1. INTRODUCTION

Digby Wells Environmental (hereafter Digby Wells) has been requested by Coastal and Environmental Services (hereafter CES) to perform a groundwater and geochemical assessment for the proposed Tete Iron Project near Tete, Mozambique.

Baobab Resources (hereafter Baobab) is determining the feasibility of mining and processing iron ore from a concession located within the Tete Province of Mozambique. The concession, covering exploration licence 1035L is being explored and managed by Capitol Resources Limitada (CRL); a 100%-owned subsidiary company of Baobab. The Tete Pig Iron and Ferro-Vanadium Project (hereafter Tenge Project) is focused on the Tenge Hill deposit. The National Department of Mines (NDM), Mozambique has granted Baobab a 25 year mining concession for the Project renewable for a further 25 years.

The mining operation will comprise an open cast operation at Tenge Hill, waste rock and slag dumps, a processing plant, a tailings storage facility (TSF) and office and accommodation facilities. Coastal and Environmental Services (CES) is undertaking the Environmental Impact Assessment (EIA) for the project, while Digby Wells was appointed to compile the groundwater baseline and assess the impacts of the proposed mining activities on the local groundwater resources.

SRK Consulting was appointed by Baobab to assess the potential groundwater inflows into the proposed Tenge Pit and to provide pore pressure estimates for slope stability risk determination. Water management requirements for the effective operation of the pit would also be defined.

It was agreed that Digby wells will undertake the following tasks for the Tenge Project groundwater study:

- Hydrocensus within a 5 kilometre (km) radius of the proposed pit, including hydro-chemical sampling of accessible boreholes, rivers and springs. Collected water samples will be analysed for several determinants to define the current groundwater quality status and to ensure that the long term monitoring effectively measures all potential contaminants;
- Field investigations which included:
  - Geophysical surveys to delineate weathered zones and vertical to sub-vertical features underlying the proposed mine infrastructures;
  - Drilling of seven groundwater characterisation and monitoring boreholes around proposed tailings storage facility (TSF), processing plant, slag dump and waste rock dump; and
  - Aquifer testing of water-yielding boreholes;
- Develop a conceptual groundwater model jointly with SRK;
- Develop a contamination numerical model to evaluate the potential impacts of the proposed mine on the groundwater environment;
- Site assessment for the proposed landfill site;
- Groundwater impact assessment; and
- Groundwater monitoring network design.

A meeting was held with SRK Consulting on the 30th September 2013 to discuss the overlap in the groundwater study’s scope of work as proposed by both parties. A joint approach was discussed to ensure that duplication of the groundwater work is avoided.
SRK indicated that they will undertake the following:

- **Investigations to define pit water management requirements and to assess the potential groundwater inflows into the pit.** This included:
  - Drill stem tests such as packer testing and airlift recovery testing on exploration and geotechnical core holes;
  - Water sampling for hydro-chemical and isotope analysis;
  - Conceptual groundwater model;
- **Numerical groundwater flow modelling:**
  - Addressing the inflow, dewatering and if required, pore pressure predictions. Pit infilling on closure will also be included in simulations; and
- **Water management plan for pit dewatering, including:**
  - Conceptual dewatering and depressurisation plans together with CAPEX and OPEX estimates.

During July 2014, Baobab instructed SRK to stop their groundwater study investigations until the pilot scale metallurgical test results for the alternative production scenarios are available. SRK thus far had only completed their field surveys and their study was stopped before they could run the numerical flow model simulations. Details of the groundwater flow, pit inflow volumes and impacts on the Revuboe River were therefore not available. The contamination plume development and modelling was thus done under normal groundwater flow conditions. Further development of the SRK model can lead to increases in flow rates and changes in flow directions of the groundwater system due to the dewatering of the mine. This in turn can lead to the development of larger pollution plumes. It is recommended that this contaminant model given in this report be updated once the SRK model has been completed.

This report presents the results of the groundwater and geochemistry studies undertaken by Digby Wells to ultimately feed into the EIA and risk assessments.

### 1.1. **Deliverables**

The following deliverables form part of this study:

- A current groundwater use and status assessment;
- A field works programme – including a geophysical survey, and drilling and aquifer testing programmes around Tenge Pit and the TSF;
- Geochemical assessment of the ore body and host rock;
- Contamination plume modelling – TSF, as well as pit impacts; and
- A groundwater specialist report that includes an environmental risk assessment and mitigation measures.
2. SITE DESCRIPTION

2.1. Project Location

The concession, covering exploration licence 1035L, is being explored and managed by Capitol Resources Limitada (CRL); a 100%-owned subsidiary company of Baobab. The Tenge Project is focused on the Tenge Hill deposit located approximately 80km northeast of the town of Tete, Tete Province, Mozambique. The project area is located on the banks of the Revuboe River (Appendix A, Plan 1). The central coordinates for the study area are given in Table 1.

Table 1: Site coordinates

<table>
<thead>
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The mining operation will include an open cast mine at Tenge Hill, waste rock and slag dumps, a processing plant, a tailings storage facility (TSF) and office and accommodation facilities (Appendix A, Plan 2).

2.2. Topography and Drainage

The general slope and topography of the project area is undulating and dominated by small drainages and streams flowing into the Revuboe River (Appendix A, Plan 3). These smaller streams and drainages are usually dry, with flow only visible during the wet season. The weathered zone associated with these drainages is deep and steep slopes along these drainages are common. The general surface slope of the study area is towards the south, with topographical elevations 2km north of the proposed mining area at around 300 to 320 metres above mean sea level (mamsl), decreasing to 295 to 290 mamsl 2 km south of the mine. This equates to a general topographical gradient of 0.001 to 0.007, with an average of around 0.004 (SRK, 2014).

The four main topographical features dominating the landscape within the study area are (SRK, 2014):

- Tenge Hill east of the Revuboe River. The hill has a maximum elevation of approximately 405 mamsl with gradients of approximately 0.25 towards the surrounding plains. This hill forms part of the Tenge ore deposit and will be mined as an open pit, to a depth of 170 mamsl;
- Ruoni North Hill, west of the Revuboe River. The hill has a maximum elevation of 335 mamsl with slope gradients of 0.2 to 0.1. A portion of this hill is also formed by the magnetite ore deposit which could potentially be mined in future;
- Ruoni South Hill, west of the Revuboe River. The hill has a maximum topographical elevation of 340 mamsl with a gradient of approximately 0.1. The Ruoni Hills are also mineable ore deposits, but are not included in this Feasibility Study; and
- The Revuboe River that divides the Tenge and Ruoni Hills. The river drains the area and flows across the ore deposit from the northeast to the south. Tenge Hill is located within 100 metre (m) of the Revuboe River.

The surface hydrology of the Tenge Project area is defined by three major catchments, namely the Revuboe, Mussumbudze and Nhambia River catchments. The Tenge Project’s planned
infrastructure will be located in the Revuboe catchment. The Revuboe River is fed by several ephemeral tributaries and perennial streams including some which flow through the proposed mine infrastructure area (SRK, 2014).

2.3. Climate
The project area has a tropical climate, with the period between November and March experiencing the highest rainfall. Statistically the driest period is the month of September. The Mean Annual Precipitation (MAP) for the project area is 624 mm/a, with the highest recorded rainfall occurring during the month of January. This is based on data (55-year database) from Chingodzi weather station, located approximately 45km southwest of the Tenge Project (SRK 2014).

The Mean Annual Evaporation (MAE) for the project area is calculated at 2 200 mm/a. This might result in a negative water balance for the open water sources. The mean annual minimum temperature is 15ºC with a mean annual maximum of 34ºC.

2.4. Geology

2.4.1. Regional Geology
The regional geological setting of the area is relatively simple although locally diverse and ranges from intrusive formations of the Tete Suite, formerly known as Tete Gabbro-Anorthosite Complex, through to the sedimentary formations of the Karoo Supergroup. The contact between the Tete Complex and Karoo Supergroup is structurally controlled and is associated with faults and fractures. The general stratigraphic sequence of the area is presented in Plan 4 (Appendix A).

2.4.2. Tete Suite
The Tete Complex forms an elongate, sub-horizontal, sheet-like body with a surface area of approximately 6 000km². It stretches from near Estima in the west, across the Zambezi River north of Tete, to almost the border with Malawi in the east, a distance of over 150km.

The Tete mafic-ultramafic complex consists mostly of gabbro, with subordinate anorthosite and magnetite, and relatively minor occurrences of pyroxenite/websterite and troctolite (SRK, 2014). Rock fabrics are generally massive and medium to very coarse-grained or even pegmatitic. The widespread replacement of the original minerals and the imposition of planar fabrics occur in various places throughout the Complex, but are most common along the contact with the crystalline basement. These contact zones are characterised by ubiquitous and intense brittle and ductile shearing.

Dolerite Dykes
The Tete Complex is cut by numerous fine- to medium-grained intrusive dolerite dykes, composed essentially of pyroxene, plagioclase and Fe-Ti oxides, and commonly showing ophitic texture. The majority of the dykes are elongate, continuous to sub-continuous bodies trending NE-SW. The dyke swarms are parallel, or in many cases oblique or at right angles (perpendicular) to the magmatic banding. In instances where the dykes are perpendicular to magmatic banding, the margins are intensely sheared and the dykes are disrupted in places. Where they are intensely foliated and recrystallized, dykes are difficult to distinguish from the gabbroic country rocks (SRK, 2014).

In the mineralised zone the dykes occupy approximately 10 to 15% of the total area, whereas at other localities 20% of the volume of the rocks is composed of dykes. Because these dykes do not extend beyond the layered intrusions, they are supposedly co-magmatic and genetically related to the Tete Complex (SRK, 2014). Maier et al. (2001) conducted isotopic and mineralogy analysis on
8 samples from the Tete Suite and concluded the dolerite dykes, gabbro and pyroxenites could have originated from a common magmatic source. During intrusion the dolerite dykes followed zones of weakness in the host rock such as fractures and zones of continental divergence. The magma emplacement is either by dilation or forceful emplacement. This conclusion was reached because some dyke host rock contact zones are well deformed while others show no evidence of deformation. Drilling, mapping and trenching data have shown that the dykes are sub-vertical and dip steeply (75-80 degrees) to the southeast (SRK, 2014).

**Matinde Formation (Lower Karoo Supergroup)**

The eastern and southern portions of the Tenge Project area are underlain by the Matinde Formation of the Lower Karoo Supergroup. The Matinde Formation comprises a thick sequence of alternating fine-grained to gritty sandstone (PeT) and conglomeratic layers, with well-rounded vein quartz pebbles (PeTc). The conglomerate layers (PeTc) underlie the sandstone and coal layers, but are absent in the Tenge Project area (SRK, 2014).

**Quaternary Sediments**

In the eastern part of the Project area, the Matinde Formation is overlain by the Quaternary, semi-consolidated sediments dominated by sand. The entire thickness of these sediments is not known, but a 14m thickness was recorded in a borehole (VBH) drilled close to the Revuboe River.

2.4.3. **Local Geology**

The host rock and mineralised zones of the Tenge/Ruoni region are part of the Tete Complex and consist of a stacked series of gabbro, anorthosite and magnetite units. The lithological package of Tenge/Ruoni has been synformally folded, faulted and also intruded by numerous northeast-southwest trending dolerite dykes. SRK modelled the distribution and orientation of the dykes using traditional sectional interpretation based on the exploration drill information supplied by Baobab (SRK, 2014).

Drilling and mapping evidence have shown that the magnetite body is located between anorthosite and gabbro dominated layers, although the anorthosite itself contains substantial magnetite bands. SRK modelled the ore body, footwall and hanging wall as part of the Baobab Tenge mineral resources estimation (2014) using Leapfrog Geo explicit modelling.

**Hanging Wall (Anorthosite)**

Anorthosite occurs as pod shaped lensoid outcrops trending in the same direction - NNW-SSE - as the gabbro, and can be regarded as the host rock of magnetite. Anorthosite is interlayered with gabbro through crystal fractionation processes and cyclic injection of magma pulses throughout the suite. Magnetite rich magma was injected into an anorthosite crystal mush at the upper contact with the footwall gabbro layer. The most distinguishing characteristic of the feldspathic anorthosite is its coarse grained texture. The anorthosite occurs in low lying areas, as it is less resistant to weathering due to the presence of feldspars within its composition. The main rock outcrop occurs on the western side of Tenge Hill, on the banks of Revuboe River. Some outcrops are found on the northern side of Tenge Hill. Drilling results indicate that the anorthosite is shallow, dipping to the southwest on the northern limb and to the northwest on the southern limb.

**Ore Zone (Magnetite)**

Magnetite outcrops near the summit of Tenge Hill and on the western side of the hill where it forms the topographic high. The positive relief of the outcrops are mainly due to its resistance to weathering. It also outcrops at several positions along the northern and southern limbs of the fold. On the northern limb, the magnetite is trending NW-SE and dipping approximately 42° towards the southwest. However, some magnetite outcrops show a NNW-SSE strike (SRK, 2014).
The southern limb trends NE-SW and has possibly undergone more late stage structural
deformation with strong foliation and gneissic texture evident at the contact of the magnetite and
gabbro layers. This is possibly the result of layer parallel shearing and flexure during folding
events. Pulses of magnetite rich magma are interpreted to have been injected into the anorthosite
crystal mush above the gabbro contact forming magnetite layers by fractional crystallisation and
gravity settling processes.
Thick magnetite eluvium and colluvium deposits surround the magnetite outcrops.

**Foot Wall (Gabbro)**

Gabbro outcrops on the southern, eastern and north-eastern parts of Tenge Hill. It also occurs as
lensoid, pod shaped topographically low profiles with outcrops trending north-south; although a
NNE-SSW strike is common. Their low exposure is due to the fact that they are easily weathered.
Their general strike on the northern fold limb is approximately 340°, dipping approximately 50° to
the west.. The gabbros were the earliest layers to crystallize followed by the overlying anorthosites
and injected magnetite layers. The late stage dolerite dykes cross cut all these lithologies but
probably originated from the same parent magma (Maier, et al. 2001).

### 2.5. Methodology and Scope of Work

In order to complete the groundwater impact assessment there are a number of tasks that had to
be completed. These tasks are explained separately below.

#### 2.5.1. Desktop Study

The desktop study included a review of all available data including reports, data sheets and maps.
Documentation from a number of related studies that have been undertaken in the area was
included in the review (see Reference List – Section 12).

A review process was conducted and interpretations performed to establish a conceptual idea of
the groundwater occurrence and dynamics. This information was used to inform the field visits and
technical surveys (geophysical surveys, drilling and aquifer testing programmes).

#### 2.5.2. Hydrocensus

The hydrocensus concentrated on identifying existing boreholes and springs throughout the project
area to enhance the knowledge of the groundwater system and current groundwater use. This task
included the following:

- A hydrocensus within a 5km radius of the proposed pit area; and
- Hydrochemical sampling of accessible boreholes and surface water bodies. These water
  samples were submitted to a South African National Accreditation System (SANAS)-
  accredited laboratory in Johannesburg, South Africa.

The hydrocensus survey included visits to individual boreholes, measurement of water levels and
yields (if possible), as well as the selective collection of groundwater samples. Information
recorded on the field sheets include:

- Owner and property details;
- Borehole locality;
- Borehole depth;
- Rest water level;
- Borehole installation date;
Groundwater and Geochemistry Impact Assessment

- Borehole status and equipment;
- Groundwater abstraction rates;
- Primary groundwater usage; and
- Electrical conductivity, pH and groundwater sample details.

**Groundwater Sampling**

All water samples were taken in accordance with South Africa’s Department of Water Affairs and Forestry (DWAF); Department of Health (DoH); and Water Research Commission’s (WRC) Quality of Domestic Water Supplies: Volume 2: Sampling Guide (WRC 2000). These standards and procedures were used as no Mozambican standards were available. The South African standards are however in line with international guidelines. Samples were collected from boreholes across the project area to ensure a good representation of upstream and downstream water qualities, as well as different geological or aquifer units.

The pH and EC metres were calibrated daily using standard solutions obtained from the instrument supplier. Samples were submitted to M and L Laboratory Services in Johannesburg for chemical analysis of the following constituents:

- Total Dissolved Solids as TDS
- Nitrate and Nitrite as N
- Chlorides as Cl
- Total Alkalinity as CaCO₃
- Fluoride as F
- Sulphate as SO₄
- Total Hardness as CaCO₃
- Bicarbonate Alkalinity
- Carbonate Alkalinity
- Calcium as Ca
- Magnesium as Mg
- Sodium as Na
- Potassium as K
- Iron as Fe
- Manganese as Mn
- Electrical Conductivity in mS/m
- pH value
- Aluminium as Al
- Ammonium as NH₄
- Ortho Phosphate PO₄ as P
- Copper as Cu
- Nickel as Ni
- Cobalt as Co
- Cadmium as Cd
- Zinc as Zn
- Lead as Pb
- Total Chromium
- Arsenic as As
- Selenium as Se
- Boron as B

**Groundwater Level Measurements**

Water levels were measured by using a dip metre to measure the distance between the borehole
collar level on surface and the water table depth in the borehole. The height of the borehole collar was subtracted from the measured water level to determine a water level measured in metres below ground level (mbgl).

The mbgl measurement was subtracted from the borehole’s surface elevation to define metres above mean sea level (mamsl) for all measurements.

**Geosite Coordinates and Elevations**

All coordinates were taken with a hand-held Garmin GPS (Global Positioning System):

- Datum – WGS84 (UTM Zone 36 south)

All monitoring and future production boreholes will have to be surveyed with a differential GPS system to ensure accurate reporting of the groundwater levels and potential drawdown cone. Hand-held GPS systems have a coordinate accuracy variation of approximately 5m, whereas the differential GPS system records the coordinates with an accuracy variation of better than one centimetre.

**2.5.3. Geophysical Survey**

Ground geophysical surveys (magnetic and electromagnetic (EM) surveying) have been applied to delineate geological structures that may act as preferential groundwater flow pathways or barriers to groundwater flow and contaminant transport. The ground surveys have been used in conjunction with the available airborne geophysical maps, remote sensing images and geological maps to ensure an accurate and focussed drilling programme and geological structure characterisation.

The Tenge geophysical survey included 12 survey lines, each with a 10m station spacing to detect possible vertical to sub-vertical features. The line direction was chosen to intersect geological structures perpendicular to strike. Line and station coordinates were marked in the field using a handheld GPS.

**Magnetic Method**

Magnetic surveys were conducted to record spatial variations in the magnetic field and associated with the subsurface geological units. A one-man portable Geotron G5-magnetometer was employed to conduct the ground magnetic surveys.

The G5 instrument is a resonance, proton magnetometer and monitors the precession of atomic particles in an ambient magnetic field to provide an absolute measure of the earth’s total magnetic field intensity in nanoTeslas (nT).

Many geological formations, by virtue of their content of magnetic minerals will behave like “buried magnets”, and have a magnetic field associated with them. This very local magnetic field will be superimposed on the normal magnetic field of the earth. Measurements of the magnetic field taken in the vicinity of such geological formations will show departures from the undisturbed earth’s magnetic field. These changes - or anomalies, as they are called - could be larger or smaller and could be either an increase or a decrease of the earth’s field and will depend on the depth of burial, degree and direction of magnetisation and the attitude of formation in relation to the direction of the earth’s field.

**Electro-Magnetic Method**

The EM survey was conducted using the Geonics EM34-4 instrument. Since fault zones are often associated with weathered and fractured formations it result in contrasts in electrical conductivities, leading to detectable EM anomalies. Measurements are generally taken with two dipole orientations; horizontal dipole (HD) and vertical dipole (VD).
2.5.4. Drilling Programme

The drilling programme was performed by the Rotary Air Percussion method. Seven characterisation boreholes were proposed within the boundaries of the proposed mining infrastructure areas and will be used as monitoring boreholes for the mine during the operational and post-closure phases. The percussion drilling programme was used to assess the underlying geological horizons and their associated groundwater bearing (aquifer) properties. Borehole diameters of at least 6.5 inches (165mm) were required to allow for future aquifer testing of the boreholes and possible use as production or dewatering boreholes. Steel casing was used to secure the boreholes due to the risk that nearby blasting may cause damage to open or PVC cased boreholes. A maximum borehole depth of 60m was recommended for the environmental impact assessment.

Agua Terra Limitada (Agua Terra), a division of Geosearch International, was appointed by Baobab to undertake the drilling programme.

2.5.5. Aquifer Testing Programme

An aquifer testing programme was recommended to determine the following hydrogeological characteristics of the groundwater zone:

- Borehole drawdown and recovery response;
- Aquifer hydraulic parameters:
  - Transmissivity (T) - defined as the product of the average hydraulic conductivity (K) and the saturated aquifer thickness. It is a measure of the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer. The unit of measurement is m²/day.
  - Aquifer storage – either storativity (confined storage) or specific yield (unconfined storage). Storativity (S) is the volume of water released from storage per unit surface area, per unit change in head. It is a dimensionless quantity. Specific yield (S_{y}) is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table; and
- Characterisation of aquifer flow boundaries such as low permeable, no-flow or recharge boundaries. No-flow or low permeable boundaries refer to a lower transmissive structure (a mineralised fracture with a lower conductance or low permeable dyke, for example) or aquifer boundaries (limit of aquifer – no-flow boundary) that result in an increase in groundwater drawdown during borehole abstraction. Recharge boundaries often relates to leakage from surface water bodies or overlying aquifers.

The aquifer test programme was carried out in accordance with specifications provided by Digby Wells and included the following tests:

- **Step drawdown test (SDT).** During the SDT the borehole is pumped at a constant discharge rate for 60 minutes, whereafter the step is repeated at a progressively higher discharge rate. During the SDT the drawdown over time is recorded in pumping and observation boreholes (if available). The advantage of this test is that the pumping rate for any specific drawdown can easily be determined from the relationship between laminar and turbulent flow. After the test is stopped, residual drawdown is measured until 95% recovery of the water level has been reached. The discharge rate for the constant discharge test is calculated from the interpretation of the time drawdown data generated during the SDT.
The constant discharge test (CDT) follows after the SDT. During a constant discharge test (CDT) a borehole is pumped for a predetermined time at a constant rate. During the CDT test the drawdown over time is recorded in the pumping and observation boreholes (if available). Discharge measurements are taken at predetermined time intervals to ensure that the constant discharge rate is maintained throughout the test period. Any changes in discharge rate are accurately recorded and reported. The duration of CDT for most tests varies from 8 to 24 hours, depending on the yield of the borehole and future application. During CDT the aquifer needs to be stressed sufficiently to identify boundary effects that may impact on long-term aquifer utilization.

Recovery test (RT) follows directly after pump shut down at the end of the SDT and CDT. The residual drawdown over time (water level recovery) is measured in production and observation boreholes until 90% recovery is reached. Aquifer parameters and sustainable borehole yields can be derived from the time drawdown data of the CDT and recovery tests by application of a variety of analytical methods.

The aquifer test data was interpreted by using a number of analytical methods, such as Flow Characteristic; Cooper Jacob and Theis:

- The Flow Characteristic Method or FC Method, (Van Tonder et al, 2001) uses the first and second order derivatives interpreted from time drawdown data (during test pumping), available drawdown, boundary conditions and recharge to derive sustainable borehole yields. The method is suited for characterising fractured rock aquifers; and

- AquiferTest Pro. Internationally recognised test pumping analysis software, distributed by Waterloo Hydrogeologic. Theis-related analytical methods were used. The Theis method is a curve-fitting method developed for primary aquifers. However, in most cases it provides an acceptable first approximation of fractured aquifer hydraulic parameters.

Agua Terra Limitada (Agua Terra) was appointed by Baobab to undertake the aquifer testing programme.

2.5.6. Geochemistry Assessment

Drill core and other geological material samples were made available to Digby Wells to undertake geochemical testing. Seven samples from the ore body and host geology material were submitted for geochemical characterisation. The following characterisation tests were conducted:

- Representative samples of the ore (from cores) (fresh and weathered) were collected and submitted for standard static geochemical tests:
  - Synthetic Precipitation Leach Procedure (SPLP) tests;
  - Acid Base Accounting (ABA); and
  - Mineralogical and total elemental composition.

The sampling and laboratory test results were used as input parameters in the numerical contaminant transport modelling to determine the extent of potential contamination emanating from
the mine waste facilities.

2.5.7. Conceptual Model

The conceptual model was constructed by SRK with input from Digby Wells. The conceptual model aims to describe the groundwater environment in terms of the following:

- Aquifers - these are rock units or open faults and fractures within rock units that are sufficiently permeable (effectively porous) to allow water flow;
- Understanding of the chemical and physical processes involved in contaminant formation;
- Interconnections between aquifers;
- Boundaries that result in the change or interruption of groundwater flow;
- Hydro-stratigraphic units - these are formations, parts of formations, or a group of formations displaying similar hydrologic characteristics that allow for a grouping into aquifers and associated confining layers;
- The groundwater flow system;
- Precipitation, evapotranspiration;
- Runoff, groundwater head data, which yields groundwater flow;
- Hydraulic parameters;
- Recharge and discharge areas, exchange of groundwater and surface water; and
- Geochemical data including major ions.

2.5.8. Contamination Numerical Model

A numerical model was developed to evaluate the potential impacts of the proposed mine on the groundwater environment. Steady and transient state flow model simulations were conducted by SRK to estimate the groundwater flow direction and groundwater inflow rates into the pit area. Digby Wells was tasked to assess and model the size of the contamination plumes at various stages of the life of the mine. Impacts on the streams and boreholes over time (construction, operational, decommissioning and post-closure phases) were assessed. The contamination transport model will ultimately define the contamination plume extent and provide input to various scenarios relating to contamination risks from the TSF, waste rock dumps, the plant and pit impacts post closure.

2.5.9. Impact Assessment

The impact assessment methodology included the following:

- Identification of geohydrological impacts;
- Quantification of impacts through the numerical modelling scenarios;
- Impact risk rating; and
- Proposed mitigation and management measures.

The impact assessment approach adopted by CES was applied.

2.5.10. Monitoring Network Design

A groundwater monitoring network will be designed based on the information gathered during the hydrocensus, and drilling and aquifer testing programmes. Water quality parameter selection will
be a function of the results obtained from the laboratory analysis. Frequency of sampling and reporting will be a function of the life of mine and planned operations and its effect on the receiving environment.
3. RESULTS OF INVESTIGATIONS

3.1. Hydrocensus

Digby Wells carried out a hydrocensus, which included the identification of groundwater use and groundwater recharge during March 2014. The survey was undertaken within a 5km radius around the propose Tenge pit area. The identified hydrocensus locations are shown on Plan 5 (Appendix A).

During the hydrocensus a total of 10 water sites were surveyed consisting of six boreholes and four surface water sampling sites along the Revuboe River. From the six boreholes, four are exploration holes and two are for domestic use.

It was possible to measure groundwater levels from four boreholes as indicated in Table 2.

Table 2: Hydrocensus borehole summary

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<tr>
<td>TBH2</td>
<td>-15.72631</td>
<td>33.76664</td>
<td>Borehole</td>
<td>296</td>
<td>1.81</td>
<td>294.19</td>
<td>Inclined 45°</td>
</tr>
<tr>
<td>TBH3</td>
<td>-15.72537</td>
<td>33.76723</td>
<td>Borehole</td>
<td>308</td>
<td>2.42</td>
<td>305.58</td>
<td></td>
</tr>
<tr>
<td>TBH4</td>
<td>-15.72327</td>
<td>33.76835</td>
<td>Borehole</td>
<td>295</td>
<td>no level</td>
<td>-</td>
<td>Inclined 45°</td>
</tr>
<tr>
<td>TBH5</td>
<td>-15.71433</td>
<td>33.78066</td>
<td>Borehole</td>
<td>301</td>
<td>no access</td>
<td>-</td>
<td>Hand pump</td>
</tr>
<tr>
<td>TBH6</td>
<td>-15.71896</td>
<td>33.78018</td>
<td>Borehole</td>
<td>317</td>
<td>17.12</td>
<td>299.88</td>
<td>Electric pump</td>
</tr>
</tbody>
</table>

During the hydrocensus it was possible to sample six water sites, including four surface water samples from the Revuboe River. All samples were sent for macro and micro-chemical analysis to M and L Laboratory Services (Pty) Ltd; a SANAS-accredited laboratory in Johannesburg, South Africa. The interpretation of the results was done by SRK with details provided in their report; attached as Appendix B.

Groundwater use is limited in the project area, with the Revuboe River being the main source of water. The river flows throughout the year, thereby limiting the need for use of groundwater.

The groundwater elevation in the area ranges between 231 and 320 mamsl as recorded by SRK (2014 study, Appendix B). The depth to water level in the area is highly variable from 0.7 mbgl near the Revuboe River to 85 mbgl on top of Tenge Hill (SRK, 2014).

The depth to the groundwater level increases with an increase in distance from the Revuboe River. Therefore, the groundwater flow direction is towards the river, suggesting that the Revuboe River is a gaining stream. The overall groundwater flow broadly follows the surface topography of the area, with groundwater levels being very shallow near the river systems.

Groundwater flow direction in the vicinity of Tenge Hill is towards Revuboe River (westwards); whereas the groundwater flows at the TSF is southwards towards one of the Revuboe tributaries.

In terms of the water quality the following was concluded (SRK, 2014):

- Most of the analysed parameters are within the recommended World Health Organisation...
(WHO) drinking water guidelines, with the exception of total dissolved solids and alkalinity;

- The elevated iron, manganese and selenium concentrations in the area is probably associated with the underlying geology;

- Higher total dissolved solids due to alkalinity might pose health risk to water users;

- The analytical results show that the concentrations of several analysed parameters in groundwater is higher than the concentrations in the water from Revuboe River, suggesting that there are some interactions of rainfall water with host rock or soils as it infiltrates to groundwater;

- The groundwater in the Karoo Supergroup is characterised by elevated concentrations of sodium and chloride, if compared to groundwater in the Tete Complex;

- The area is characterised by two groundwater types; shallow recently recharged groundwater and deeper fractured groundwater. Both have similar isotopic compositions suggesting rainfall recharge for both; and

- The Revuboe River has a strong evaporitic signal during the dry season and has an isotopic composition close to rainfall water during the wet season.

3.2. Geophysical Survey

Twelve geophysical traverses were surveyed as indicated in Plan 6 (Appendix A). The large dyke swarm discussed in section 2.4.1 had an influence on the survey results and resulted in very ragged survey profiles in many instances.

The following traverses (Figure 1 to Figure 7) are associated with the areas that were ultimately targeted for drilling of the characterisation and monitoring boreholes.
3.2.1. Traverse 2

Traverse 2 (Figure 1) targeted the drainage line downstream of the plant area to serve as a monitoring borehole for any potential pollution from the plant activities (Plan 6). The magnetic data indicated a magnetic anomaly around station 230 and corresponds to anomalies also visible on the EM data. The traverse was surveyed across gabbro and anorthosite formations, with a potential geological feature located between stations 220 and 240. The EM data indicated high vertical and horizontal dipole readings in this area (high conductive formations) and borehole SRKGW2A was subsequently positioned on station 240 to target the area closest to the drainage line.

Figure 1: Traverse 2 data
3.2.2. Traverse 3

Traverse 3 (Error! Reference source not found.) was conducted from north to south across the contact between the gabbro and sandstone formations downstream of the proposed WRD. This traverse was targeting potential pathways that will allow groundwater to flow from the WRD towards the Revuboe River.

There was a good correlation between the magnetic data and the EM data between stations 310 and 360. At station 310 the vertical dipole readings increased with a decrease in horizontal readings, indicating a potential transition between two geological units with an increase in magnetic response also observed at this point. Borehole SRKGW3A was positioned at station 310.

The big change in conductivity data around station 250 relates to the contact zone between the gabbro and the sandstone – sedimentary versus igneous formations. This zone could also be associated with a potential fault zone, associated with the contact between the gabbro and sandstone that are associated with graben features with the Karoo sediments filling depressions in the gabbro.

![Figure 2: Traverse 3 data](image-url)
3.2.3. Traverse 8

Traverse 8 (Figure 3) targeted an area upstream of the proposed open pit where deeper weathering was mapped. No linear geological features could be identified from the geophysical data. A high vertical dipole reading correlated with a drop in magnetic response at station 470. This point was within the area of a drainage line upstream of the open pit and borehole SRKGW8B was positioned at this point to monitor upstream pit water qualities.

Figure 3: Traverse 8 data
3.2.4. Traverse 9

Traverse 9 (Figure 4) was surveyed from south to north across the contact between the gabbro and sandstone formations. It was surveyed to position a borehole targeting the north-western side of the proposed TSF. Only a magnetic survey was done on traverse 9 as it proved effective on previous traverses for the identification of the contact between the two formations. The contact was observed at station 250 as an increase in magnetic response. Borehole SRKGW9A was positioned at station 250.

Figure 4: Traverse 9 magnetic data
3.2.5. Traverse 10

Traverse 10 (Figure 5) targeted the contact between the sandstone and gabbro formations southwest of the proposed TSF. Only a magnetic survey was done with an anomaly observed between stations 130 and 180, indicating a potential dyke or sill, with a slow decrease in magnetic reading after a sharp increase. Borehole SRKGW10A was positioned at the toe of the potential sill feature (station 170).

Figure 5: Traverse 10 magnetic data
3.2.6. Traverse 11

Traverse 11 (Figure 6) targeted weathered zones close to drainage lines east of the proposed TSF. The magnetic survey data did not indicate any large anomalies or variations and borehole SRKGW11A was subsequently positioned based on geological data and observations close to the drainage line.

Figure 6: Traverse 11 magnetic data
3.2.7. **Traverse 12**

Traverse 12 (Figure 7) targeted the contact between the gabbro and sandstone formations south of the proposed TSF. The magnetic data correlated with the geological contact observed at station 120. Borehole SRKGW12A was positioned at station 140.

![Traverse 12 magnetic data](image)

**Figure 7: Traverse 12 magnetic data**
3.3. Drilling Programme

The seven boreholes (Table 3) were positioned based on the geophysical survey results (section 3.2). The locations of the new boreholes, as well as aquifer tested holes, are indicated on Plan 7 (Appendix A).

Table 3: Drilling summary

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>SRKGW 2A</th>
<th>SRKGW 3A</th>
<th>SRKGW 8B</th>
<th>SRKGW 9A</th>
<th>SRKGW 10A</th>
<th>SRKGW 11A</th>
<th>SRKGW 12A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>15.74259</td>
<td>15.73997</td>
<td>15.72093</td>
<td>15.75053</td>
<td>-15.7562</td>
<td>15.77102</td>
<td>15.77613</td>
</tr>
<tr>
<td>Longitude</td>
<td>33.78685</td>
<td>33.76558</td>
<td>33.77749</td>
<td>33.78162</td>
<td>33.77269</td>
<td>33.79281</td>
<td>33.7809</td>
</tr>
<tr>
<td>Z (mamsl)</td>
<td>318</td>
<td>302</td>
<td>313</td>
<td>309</td>
<td>304</td>
<td>273</td>
<td>292</td>
</tr>
<tr>
<td>Water Strike Depth (m below surface)</td>
<td>38</td>
<td>20, 44</td>
<td>14</td>
<td>11</td>
<td>36</td>
<td>8</td>
<td>29</td>
</tr>
<tr>
<td>Borehole Depth (m)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Blow Yield (L/h)</td>
<td>114</td>
<td>4212</td>
<td>792</td>
<td>720</td>
<td>Not enough water</td>
<td>Not enough water</td>
<td>288</td>
</tr>
<tr>
<td>Static Water Level (m below surface)</td>
<td>25.09</td>
<td>3.97</td>
<td>11.07</td>
<td>6.23</td>
<td>18.43</td>
<td>11.66</td>
<td>21.27</td>
</tr>
</tbody>
</table>

The following is a short description of the drilling results, with the borehole logs provided in Appendix C.

3.3.1. Borehole SRKGW2A

Borehole SRKGW2A was drilled to a depth of 60m below ground level (mbgl) for monitoring purposes. Gabbro was encountered throughout the borehole with dolerite intrusions observed between 20 and 22 mbgl, as well as 30 and 33 mbgl. The gabbro formation was completely weathered up to 15 mbgl with moderate weathering observed from 15 mbgl to 40 mbgl. A water strike with a blow yield of approximately 144 L/h was encountered at 38 mbgl, just above the contact with the fresh, un-weathered gabbro. Drilling penetration rates were fast through the weathered material with a definite decrease in rate from 40 mbgl where the fresh material was encountered. The final blow yield of the borehole was 114 L/h, with a static water level measured at 25.09 mbgl.

3.3.2. Borehole SRKGW3A

Borehole SRKGW3A was drilled to a final depth of 60 mbgl, with water strikes encountered at 20 and 44 mbgl. Soil was encountered up to a depth of 2 mbgl after which dolerite intrusions were encountered up to a depth of 44 mbgl. The first water strike at 20 mbgl (blow yield of 2 268 L/h) was encountered within the fractured dolerite, in the transition zone between the weathered and fresh dolerite formation. The second water strike was encountered at the contact between the dolerite intrusion and the underlying gabbro. The second water strike had a blow yield of 720 L/h. The gabbro was encountered to the end of the borehole. The final blow yield for the borehole was 4 212 L/h with a static water level measured at 3.97 mbgl. This borehole could potentially be recharged from the Revuboe River.

1 Blow yield: The volume of water per unit of time blown from the borehole during drilling. This yield gives an overestimation of the amount of water that can be abstracted and is usually 30 to 60% above the recommended sustainable yields calculated through scientific aquifer tests.
3.3.3. Borehole SRKGW8B
Borehole SRKGW8B was drilled to a depth of 60 mbgl with only one water strike encountered at 14 mbgl, with a blow yield of 561 L/h. The final blow yield measured for the borehole was 792 L/h with a static water level at 11.07 mbgl. Completely weathered overburden and gabbro was encountered up to a depth of 7 mbgl. Dolerite intrusions were encountered at 7 and 22 mbgl. The water strike correlated with fractured dolerite material. Weathered anorthosite was encountered from 33 mbgl to 49 mbgl. A magnetite layer was observed at 42 mbgl with a chlorite clay layer.

3.3.4. Borehole SRKGW9A
Borehole SRKGW9A was drilled to a depth of 60 mbgl with only one water strike within the weathered zone at 11 mbgl. The weathered aquifer is encountered from 0 to 19 mbgl. The geology had a schistose/sheared mineralogy with deformed dolerite intrusions. The final blow yield for the borehole was 720 L/h with a static water level measured at 6.23 mbgl.

3.3.5. Borehole SRKGW10A
Borehole SRKGW10A was drilled to a depth of 60 mbgl with one water strike encountered at 36 mbgl. The water strike relates to seepage water within the weathered dolerite at 36 mbgl. The main geological formation encountered throughout the borehole was gabbro. A static water level for the borehole was measured at 18.43 mbgl.

3.3.6. Borehole SRKGW11A
Borehole SRKGW11A was drilled within the vicinity of a drainage channel with quartz pebbles encountered up to a depth of 9 mbgl. A water strike was encountered at 8 mbgl at the base of the weathered unconfined aquifer. The final blow yield could not be measured due to its low yield. A static water level was measured at 11.66 mbgl; within the coal layers. Coal and carbonaceous shale was encountered from 9 mbgl up to the final depth of the borehole.

3.3.7. Borehole SRKGW12A
Borehole SRKGW12A was drilled to 60 mbgl with a water strike encountered at 29 mbgl. The water strike relates to fracturing and deep weathered gabbro. The intercepted geological formations varied between gabbro and dolerite intrusions. The final blow yield for the borehole was 288 L/h with a static water level at 21.27 mbgl.

3.3.8. Drilling Summary
- Seven boreholes were drilled within the proposed Tenge mining area. Five of the seven boreholes intercepted mainly gabbro and dolerite formations. Boreholes SRKGW11A and SRKGW9A intercepted carbonaceous and schist formations respectively. Borehole SRKGW8B intercepted anorthosite and magnetite around 35 and 45 mbgl.
- Dolerite intrusions were observed in all boreholes and could potentially act as groundwater flow barriers, especially to vertical seepage or contamination migration.
- Borehole yields are low, indicating no major aquifer system in the area. The highest blow yields were observed for boreholes SRKGW3A and SRKGW8B; 4 212 L/h and 792 L/h respectively. Both aquifer systems correspond to fractured dolerite intrusions. The contact zones between the dolerite and surrounding formations and also between gabbro, carbonaceous formations and schist yielded only seepage water.
- The depth of weathering (highly weathered) extended up to 20 mbgl (maximum) for the
recent drilled boreholes and slightly weathered material was encountered to depths of 40 mbgl.

- The recorded groundwater levels vary between 4 and 25 mbgl. The shallower groundwater levels were most often associated with boreholes located closer to the surface water resources.

3.4. **Aquifer Test Programme**

Eight slug tests – briefly described below - and five pump tests were performed by Digby Wells and SRK (Table 4 and Table 5).

The eight slug tests were performed on low yielding boreholes with the higher yielding boreholes subjected to pumping tests.

The following sub-sections describe the results of the tests as interpreted by Digby Wells and SRK.

### 3.4.1. Slug Tests

The slug tests involved positive displacement of the borehole water by dumping 50 litres of water into the borehole or core hole and recording the rate at which the groundwater level returns to its undisturbed state before injection. Slug tests are very basic hydraulic tests to determine the hydraulic conductivity of the formations intercepted by the borehole. The hydraulic conductivity values were determined using the Bouwer and Rice (Kruseman & de Ridder 1971) method.

Slug tests were performed on six newly drilled, low-yielding boreholes, as well as a new village water supply borehole (VNH) and on one existing core hole. A summary of the slug test data is presented in Table 4.

**Table 4: Slug test data**

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>Water level (mbgl)</th>
<th>T (m³/d)</th>
<th>K (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRKGW02</td>
<td>10.02</td>
<td>1.9x10^-1</td>
<td>2E10^-3</td>
</tr>
<tr>
<td>SRKGW2A</td>
<td>25.09</td>
<td>7x10^-2</td>
<td>2E10^-3</td>
</tr>
<tr>
<td>SRKGW8B</td>
<td>11.07</td>
<td>3.8x10^-1</td>
<td>8E10^-3</td>
</tr>
<tr>
<td>SRKGW10A</td>
<td>18.98</td>
<td>3x10^-2</td>
<td>9E10^-4</td>
</tr>
<tr>
<td>SRKGW11A</td>
<td>11.66</td>
<td>6x10^-2</td>
<td>1E10^-3</td>
</tr>
<tr>
<td>SRKGW12A</td>
<td>21.27</td>
<td>3x10^-2</td>
<td>9E10^-4</td>
</tr>
<tr>
<td>TGRC0041</td>
<td>32.99</td>
<td>5.8x10^-1</td>
<td>9E10^-3</td>
</tr>
<tr>
<td>VBH</td>
<td>12.45</td>
<td>1.34</td>
<td>6.7E10^-2</td>
</tr>
</tbody>
</table>

### 3.4.2. Pumping Tests

Baobab appointed Agua Terra to conduct the aquifer tests on pre-determined boreholes and under the supervision of Digby Wells and SRK. The test programme was based on the specifications compiled by SRK and it included the following activities:

- The **Step Drawdown Test (SDT)** comprised of up to 4 x 1 hour steps with the discharge at the subsequent step increased immediately after the completion of the previous step. Each step ranged between 60 and 100 minutes. Water level drawdown was recorded in each pumping hole during the SDT. After the completion of the last step of the SDT, water level recovery was recorded.

- The **Constant Discharge Test (CDT)** comprised pumping at a constant yield for extended periods of time. The duration of the CDTs run on the boreholes varied from 1 to 24 hours according to the borehole capacity. Water level drawdown was recorded in each pumping hole during the entire duration of CDT pumping. Recovery was recorded immediately after CDT pumping ceased.
A Recovery Test (RT) followed directly after pump shut down at the end of the SDT and CDT in the tested borehole. The residual drawdown over time (water level recovery) was measured in the tested borehole until 95% recovery was reached or up to the equivalent of the pumping time.

SRK supervised the test pumping of boreholes SRKGW01 and SRKGW02. The other boreholes were tested under supervision of Digby Wells and the computed hydraulic conductivity values and test data were made available to SRK to incorporate into their flow model and report.

Transmissivity (T) values have been determined using the Cooper Jacob (1946) method for Constant Discharge Tests (CDT) and Step Discharge Tests (STD). Hydraulic conductivity (K) values have been calculated from T-values based on estimated aquifer thicknesses.

### Table 5: Pump test summary

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>GPS Coordinates (WGS 84)</th>
<th>Borehole Depth</th>
<th>Assumed Aquifer thickness</th>
<th>T</th>
<th>K</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>m</td>
<td>m^2/d</td>
<td>m/d</td>
<td></td>
</tr>
<tr>
<td>SRKGW01</td>
<td>582 198</td>
<td>8 261 289</td>
<td>121</td>
<td>36</td>
<td>2.0 x 10^-1</td>
<td>4.3 x 10^-3</td>
</tr>
<tr>
<td>SRKGW02</td>
<td>582 630</td>
<td>8 261 850</td>
<td>121</td>
<td>37</td>
<td>2.0 x 10^-1</td>
<td>4.3 x 10^-3</td>
</tr>
<tr>
<td>SRKGW3A</td>
<td>582 017</td>
<td>8 259 678</td>
<td>60</td>
<td>23</td>
<td>3.55</td>
<td>1.5 x 10^-1</td>
</tr>
<tr>
<td>SRKGW8B</td>
<td>583 301</td>
<td>8 261 780</td>
<td>60</td>
<td>18</td>
<td>1</td>
<td>5.4 x 10^-2</td>
</tr>
<tr>
<td>SRKGW9A</td>
<td>583 731</td>
<td>8 258 507</td>
<td>60</td>
<td>34</td>
<td>1.0 x 10^-1</td>
<td>2.9 x 10^-3</td>
</tr>
</tbody>
</table>

Packer testing was also conducted by SRK to help characterise the local rock formations and aquifers. Major Drilling was appointed by Baobab to perform packer tests under the supervision of SRK. The packer tests were undertaken to determine hydraulic parameters of various horizons penetrated by the geotechnical and selected exploration core holes. The packer testing was carried out using drill rig wireline and using single and double packer assemblies. A double packer with 1m spacing or test interval was used.

A total of six core holes; two existing exploration and four newly-drilled geotechnical holes were packer tested. Due to the instability of the top weathered zone and risk of collapse during the test no packer test was conducted within this zone. Packer tests were only conducted in the underlying stable fractured zones and in the fresh rock. Potential permeable zones were selected for testing based on core inspection and geological logs, i.e. fractured and contact zones.

The aquifer test results from falling head test, slug test, pump testing and packer tests show that the permeability of the underlying geological formation decreases with increase in depth.

The weathered zone is highly permeable compared to the underlying fractured zone. The non-fractured and un-weathered zone, grades downwards to become essentially impermeable.

#### 3.4.3. Aquifer Test Summary

- The slug test results indicate that the weathered zone and upper portion of the fractured zone have low to intermediate hydraulic conductivities (SRK, 2014);
- The hydraulic conductivity calculated from the test pumping represent the bulk hydraulic
conductivity of the test horizon: that is, the weathered and fractured zone has a low to intermediate hydraulic conductivity suggesting that the geological horizon pillar between the Revuboe River and the proposed pit might leak water from the river into the proposed pit;

- The packer test results indicate that the ore body and the underlying fresh bed rock have very low hydraulic conductivity grading with depth to essentially impermeable;
- The fractured zone is less permeable compared to the overlying weathered zone and this is because of poor interconnection between fractures;
- The hydraulic conductivity in the area decrease with depth;
- Lithological structure and dyke contacts within the Tete Complex are in-filled with secondary minerals, further reducing the hydraulic conductivity of the rock; and
- Isolated fractures can have high hydraulic conductivities; larger than 0.2 m/d.
4. GEOCHEMISTRY ASSESSMENT

4.1. Sample Description

Seven rock samples were submitted for geochemical analysis at Waterlab (Pty) Ltd in South Africa. The samples were collected from two core holes and across their lithological extent to represent the waste rock and ore zone mineralogy. The two core holes include TGDH 11 and TGDH 23. The sample IDs and description of each sample are given in Table 6.

Table 6: Sample identification and description

<table>
<thead>
<tr>
<th>Report ID</th>
<th>Sample ID</th>
<th>Sample type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>TGDH 23, overburden, 7m-23m</td>
<td>Waste rock</td>
</tr>
<tr>
<td>B</td>
<td>TGDH 23, ORE, 29m</td>
<td>Ore</td>
</tr>
<tr>
<td>C</td>
<td>TGDH 23, ORE, 128m-271m</td>
<td>Ore</td>
</tr>
<tr>
<td>D</td>
<td>TGDH 23, 271m-278m</td>
<td>Waste rock</td>
</tr>
<tr>
<td>E</td>
<td>TGDH 11, 9m-60m</td>
<td>Waste rock</td>
</tr>
<tr>
<td>F</td>
<td>TGDH 11, ORE 60m-165m</td>
<td>Ore</td>
</tr>
<tr>
<td>G</td>
<td>TGDH 11, Footwall, under burden, 203m-212m</td>
<td>Waste rock</td>
</tr>
</tbody>
</table>

4.2. Laboratory Tests

The following laboratory tests were performed on each sample:

- **Synthetic Precipitation Leachate Procedure (SPLP)** tests are done to simulate the heavy metal and anion leachate potential of soils and waste material left in-situ under normal conditions with only rain water causing leaching to occur. These tests simulate and evaluate the potential of any heavy metal or ion contamination from the waste rock material and the ore that can potentially seep into the water table.

- The **Acid-base Accounting (ABA)** procedure measures the acid- and alkaline-producing potential of undisturbed soil and rock (overburden) in order to determine if, after disturbance, the waste material will produce acid and subsequently leach metals. This procedure includes **Nett Acid Generation (NAG)** tests that evaluate the nett acid generation and neutralising potential of the material.

- **X-Ray Diffraction (XRD)** allows for the measurement of the crystal structures within a sample to determine the mineralogical composition of the material.

- **X-Ray Fluorescence (XRF)** is an X-ray method used to determine the elemental composition of a material.

All laboratory results and certificates are presented in Appendix D.

4.3. Geochem Results

Table 7: Ideal mineral compositions

<table>
<thead>
<tr>
<th>Ideal Mineral compositions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>(SiO₂)</td>
</tr>
<tr>
<td>Pyrite</td>
<td>(FeS₂)</td>
</tr>
<tr>
<td>Muscovite</td>
<td>(KAl₂Si₃O₁₀(OH)₂)</td>
</tr>
<tr>
<td>Biotite</td>
<td>K(Mg,Fe)₃ ((OH)₂ Al Si₃ O₁₀)</td>
</tr>
<tr>
<td>Augite</td>
<td>Ca(Mg,Fe)Si₂O₆</td>
</tr>
</tbody>
</table>
4.3.1. Ore Material

Samples B, C and F were sampled from the ore zone, and the geochemical interpretations for the ore material are given in the next three sections.

**XRF and XRD**

The XRF results, indicating the oxide distribution within the mineralogy of the ore material, indicate high SiO$_2$ and Fe$_2$O$_3$ content, as would be expected with the ore zone located in gabbro and anorthosite formations. MgO, CaO and Na$_2$O complete the oxide series for the ore material.

The oxides and various trace elements indicated in the results (Appendix D) combine to form the mineralogy of the ore material. The ore material is dominated by ilmenite, magnetite and plagioclase, with chlorite, muscovite, enstatite and kaolinite making up the main accessory minerals of the ore zone.

**ABA and NAG**

From the three ore samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for sample B was below the 0.3% S margin, with sample C above the margin with 0.4% sulphur;
- Sample F had a sulphur level of 0.3%;
- Samples B and F had positive NNP values with sample C having a negative value;
- Sample B is classified as non-potentially acid generating, with sample C being potentially acid generating; and
- Sample F is however marginal and inconclusive.

The ore material for environmental impact purpose is thus deemed to be potentially acid generating.

**SPLP Tests**

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water guideline values with only aluminium leaching out above the recommended 0.3 mg/L in samples B and F; and
- Although the leachate from the static tests is relatively clean, the long term acid producing
potential and oxidation can lead to an increase in leachable elements. It is recommended that the ore material be submitted for long term kinetic tests.

4.3.2. Waste Rock Material

Samples A, D, E and G were sampled from the host formations (waste rock) and the geochemical interpretations for the waste material are given in the next three sections.

XRF and XRD

The XRF results, indicating the oxide distribution within the mineralogy of the waste material, indicate high SiO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3} and Fe\textsubscript{2}O\textsubscript{3} content, as would be expected with the ore zone located in gabbro and anorthosite. MgO, CaO and Na\textsubscript{2}O complete the oxide series for the ore material.

The oxides and various trace elements indicated in the results (Appendix D) combine to form the mineralogy of the ore material. The ore material is dominated by various minerals with a wide range of silicates and clay minerals including actinolite, augite, biotite, chlorite, dolomite, enstatite, ilmenite, magnetite, plagioclase, quartz, smectite, spinel and talc.

ABA and NAG

From the four waste rock samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for samples A and E were below the 0.3% S margin, with samples D and G plotting above the margin;
- Sample E had a positive NNP value, with samples A, D and G having negative values; and
- Samples A and E is classified as non-potentially acid generating with samples D and G being potentially acid generating.

Based on sulphur content the results for the waste rock material are inconclusive. However, due to the low neutralising potential also observed in the results and the fact that the waste rock will be stored on the same WRD the overall outcome can be seen as potentially acid generating. Long term static tests are recommended with a bigger sample population and submitted for ABA and NAG to gain more certainty on the potential for AMD generation.

SPLP Tests

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water guideline values, with only aluminium leaching out above the recommended 0.3 mg/L in sample A; and
- Although the leachate from the static tests is relatively clean, long term acid producing potential and oxidation can lead to an increase in leachable elements and thus it is recommended that the ore material be submitted for long term kinetic tests.
5. CONCEPTUAL GROUNDWATER MODEL

The Tenge Project conceptual model was prepared by SRK (2014) with input given by Digby Wells.

The conceptual hydrogeological model of the proposed Tenge Hill mine is shown in Figure 8 and describes the groundwater regime within the vicinity of Tenge Hill. It serves as input and basis for the numerical model. The components of the conceptual model are described below.

5.1. Hydrogeological Units

The identified hydrogeological units are presented in Table 8 and a brief description is presented below.

Table 8: Hydrogeological units

<table>
<thead>
<tr>
<th>Hydrostratigraphic Units</th>
<th>Depth (m)</th>
<th>Thickness (m)</th>
<th>Yield (L/h)</th>
<th>Depth to Water Strike (mbgl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils / overburden</td>
<td>0-5</td>
<td>0-5</td>
<td>Dry</td>
<td>None</td>
</tr>
<tr>
<td>Weathered zone</td>
<td>5-20</td>
<td>2-20</td>
<td>0.1-1.2</td>
<td>6-20</td>
</tr>
<tr>
<td>Fracture zone</td>
<td>20-60</td>
<td>20-40</td>
<td>0.01-0.2</td>
<td>20-60</td>
</tr>
<tr>
<td>Upper competent zone</td>
<td>60-140</td>
<td>40-100</td>
<td>0.1</td>
<td>60-100</td>
</tr>
<tr>
<td>Lower competent zone</td>
<td>From 140</td>
<td>80-140</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fault contact</td>
<td>From 20</td>
<td>10 m wide</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

5.1.1. Overburden/Vadose Zone

These are less pronounced, recent sediments comprised of alluvium and colluvium. The thickness ranges between 0.5 and 5m. These soils are highly permeable compared to the underlying weathered zones. In most cases these soil layers are located above the local water levels and are therefore unsaturated.

5.1.2. Weathered Zone

This is the main aquifer system in the area and it is laterally extensive, occurring between the alluvium and the fractured zone. The depth of this aquifer (as determined by the contact between weathered and the fractured zone) ranges between 5 and 20 mbgl. The weathered aquifer system is more permeable and yields more groundwater compared to the underlying fractured zone. This aquifer system stores and transports the bulk of the groundwater in the area. It is unconfined to semi-confined in places and is highly susceptible to surface induced activities and impacts. This zone is more permeable than the un-weathered rock formation. The borehole yields during the current investigations ranged between 360 and 4 320 L/h.

5.1.3. Fractured Zone

The shallow weathered aquifer system is underlain by a fractured rock aquifer system consisting of fractured rock, faults, joints and other lithological fabrics in the rock. The thickness of the fractured rock aquifer system ranges between 20 and 40m and its depth is between 20 and 60 mbgl. Most of the fractures are filled with secondary minerals reducing the permeability and connectivity of the fractured zone. As a result, this zone has limited storage capacity and is potentially low yielding.
The weathered and shallow fractured water bearing zones appeared to be hydraulically connected.

5.1.4. Un-weathered Zone

This zone is characterised by un-weathered and slightly fractured formations. The upper portion of the zone is slightly fractured and the thickness of fracturing ranges between 40 and 100m and mostly occurs below 60 mbgl. The hydraulic conductivity of this zone decreases with depth and grading from very low permeability to essentially impermeable.

5.1.5. Contact Zone

The contact between the intruded dolerite dykes and the host rock (Tete Complex) is tight, showing very little or no evidence of deformation of the host rock. The intrusion of dolerite dykes into the Tete Complex has not resulted in zones of increased hydraulic conductivity. Therefore, dolerite dyke contacts are not considered as preferential groundwater flow pathways.

Several faults were identified in the area and major faults are along the contacts between the Karoo and Tete Complexes. These faults and contact zones are reported to be steeply dipping, ranging between 75° and 80°. The influence of faults and fault contact zones and the existence of groundwater bearing zones within the hydrogeological aquifer system (HAS) has not been established.

Digby Wells and SRK have assumed that the contact fault zones are 10m wide and that the fault zones are more permeable than the host rocks.

5.1.6. Hydraulic Parameters

The hydraulic parameters of the area are principally related to the secondary structures and processes, such as weathering and fracturing, and not solely on lithological differences. Several hydraulic parameters were assigned to different hydraulic units/zones based on the findings of the field investigations. Based on the field experience and aquifer testing, the following assumptions were made in estimating the hydraulic parameters of different lithologies:

- In the Tete Complex, vertical hydraulic conductivity ($K_v$) is greater than the horizontal hydraulic conductivity ($K_h$), due to the near vertical jointing, faulting and fracturing of the lithologies;
- In the Matinde formation of the Lower Karoo Supergroup, vertical hydraulic conductivity ($K_v$) is less than the horizontal hydraulic conductivity ($K_h$) due to horizontal bedding; and
- In the quaternary sediments and fault zones, vertical hydraulic conductivity ($K_v$) is equal to the horizontal hydraulic conductivity ($K_h$).

5.2. Recharge

Precipitation is the main source of recharge in the area and the mean annual rainfall for the area is 624 mm per annum. The Chloride Mass Balance (CMB) method and isotope displacement were used by SRK during the 2014 investigations to estimate the recharge in the area. The CMB method estimated the recharge in the area to be above 2% of the annual rainfall. The isotope method estimated the recharge to be between 1 and 4% of the annual rainfall. Golder Associates estimated the recharge in Tete town for Moatize Coal mine (located 60 km south of Tenge Project) to be 1% of the annual rainfall.

For the purposes of this initial model SRK has used a recharge of 6.24 mm/year (approximately 1% of precipitation) and assumed that it is distributed uniformly throughout the entire HAS.
5.3. **Groundwater Quality**

Based on the analysis of the local groundwater and surface water resources the following were concluded:

- Two groundwater types are present – shallow, fresh, recently recharged groundwater and a deeper, fractured aquifer;
- The groundwater composition for the shallow aquifer is dominated by calcium-magnesium- and bicarbonate (Ca Mg HCO$_3$) suggesting a meteoric origin;
- Water from the core holes represent deeper groundwater that has undergone ion exchange of HCO$_3$ for Cl, as well as Mg/Ca for Na;
- Borehole SRKGW11A has the highest levels of Na and Cl (and thus TDS); typical of the coal and shale units of the Karoo Formation; and
- The water samples collected towards the end of pumping tests represent the deeper groundwater indicating a shift from shallow to deeper waters;
- The results indicate very low concentrations of metals in the groundwater and river samples. The exception is manganese and iron in borehole SRKGW02 (compared to WHO standards). The increased levels of manganese and iron are probably due to the intercepted geology; and
- Elevated concentrations of selenium were reported in three monitoring sites. Selenium concentrations in some samples are marginally higher than the WHO guideline limit and are probably due to the natural occurrence of selenium in the magmatic rocks of the Tete Complex.

5.3.1. **SRK Isotope Study**

The stable isotope (Oxygen-18 ($\sigma^{18}$O) and Deuterium ($\sigma^2$H)) composition of the waters in the Tenge Project were analysed to assess the possibility of direct recharge of the underlying aquifers by the Revuboe River. Water samples for isotope assessment were collected from existing exploration holes, boreholes in the area, rainfall and the Revuboe River.

Inclined core holes located between Tenge Hill and Revuboe River and that were drilled towards the River were purged before the samples were collected. Samples were collected before, during and towards the end of the aquifer test (borehole SRKGW01) to determine if there is any influence of the river seeping into the groundwater.

The isotope data suggests that groundwater in the shallow boreholes and deeper core holes are similar, indicating that the groundwater in the deeper and the shallow aquifer systems are connected and likely to be recharged by rainfall.

Two samples, one collected in October 2013 and another in April 2014, from the Revuboe River show very high variations in isotopic composition, from a depleted isotopic composition similar to groundwater in the wet season (April sample) to a highly enriched, evaporitic isotopic composition in the dry season (October sample).

Several samples collected from SRKGW01 were aimed at establishing whether, during the pumping, river water was drawn into the aquifer system. The results indicate that the water before, during and at the end of pumping remain similar to groundwater in the other deeper core holes, suggesting that the deeper groundwater was drawn into the borehole during pumping not the Revuboe River water.
Figure 8: Conceptual model
Source: SRK, 2014
6. NUMERICAL CONTAMINATION MODEL

Numerical modelling was undertaken by EXIGO\(^3\) with the full report provided in Appendix E. The purpose of this numerical model was to construct and simulate the contaminant transport and define the outcomes based on the proposed infrastructure that could influence the current and future status of the groundwater regime in terms of quality and quantity.

Proposed infrastructure that was simulated includes:
- The Waste Rock Dump (WRD) and Open Pit;
- The Tailings Storage Facility (TSF) and Slag dump; and
- The stockpiles and Plant area.

6.1. Modelling Objectives

The objective of the numerical contaminant transport model was:
- To construct and simulate a 2D numerical groundwater contaminant transport model, and provide feedback with regards to the anticipated groundwater impacts (if any) as a result of these proposed activities.

6.2. Model Assumptions

Modelling assumptions:
- Prior to development, the flow system is in equilibrium and therefore in steady state;
- The aquifer system is represented by a two dimensional system consisting of 7 hydraulic zones in 1 layer. The faults, dykes and drainage weathered zones were modelled discretely and form part of the total number of hydraulic zones;
- The modelling approach was based on the precautionary principle in areas where there were little or a lack of data. This means that the simulated impacts should be larger than they would be in the actual case. The real effect of the mining activities will only be quantified by additional site characterisation and monitoring that should be used to update the model before the implementation and on an on-going basis;
- The faults are 100m wide in their horizontal influence and are believed to be more than 100m deep. They are planar and vertical in orientation and are connected to smaller faults which were also assigned higher transmissivity parameters;
- The open cast mine is modelled as a drain, which takes water out of the system; and
- The accuracy and scale of the assessment will result in deviations at point e.g. individual boreholes.

6.3. Model Setup and Simulations

A basic groundwater flow model was constructed based on the parameters and dimensions supplied by SRK and detailed in the report Feasibility Study for the Tete Pig Iron and Ferro-Vanadium Project, Mozambique Interim Hydrogeological Report, Report Number 466974/Groundwater Interim, SRK, July 2014.

6.3.1. Model Objectives

The aim of the groundwater flow model is to simulate the groundwater system and determine the contaminant transport and the impact on the local environment. The aim of this model is to gain an
understanding of the groundwater flow dynamics and will be used to:

- Quantify expected groundwater flow rates in the vicinity of the mine and the significance of various hydrogeological factors in a groundwater flow balance; and
- Determine possible contaminant transport, taking into account temporal and spatial factors.

### 6.3.2. Model Setup

A numerical groundwater flow model was developed for the sub-catchment, using the modelling package Feflow 6.1. The groundwater model was developed using 123,615 elements and 63,364 nodes. The model was constructed with one layer, in two dimensions.

The model domain covers an area of 250 km² that was differentiated into a finite element network. The rivers were included explicitly to enhance simulation results and accuracy. Important modelling zones were delineated to simulate the impact on groundwater flow more accurately. Recharge coefficients were estimated for each identified zone.

### 6.3.3. Model Scale, Context and Accuracy

The regional model context and accuracy was based on existing 1:50,000 topographical GIS data, with 1:250,000 scale geological data. The field data included the hydrocensus data, drilling results and conducting falling head test data to evaluate hydraulic conductivity values. Historical data of the area were used to obtain representative parameters for the hydrogeological conditions of the local aquifer systems.

The groundwater flow model was simulated in steady state, as well as transient state to obtain calibration and initial simulated groundwater flow levels, velocities and flow directions. The numerical simulations are compared with the analytical interpolations for fit and correlation.

In steady state, unknown parameters are limited thus simplifying the calibration process i.e. to obtain calibrated water levels only transmissivity (or hydraulic conductivity) and recharge values (from precipitation) are used and adjusted to obtain an acceptable fit. In transient state the same parameters were used; however, time is limited and thus influences of boundary/contact transfers are limited and thus not dependent on infinite time.

The transient simulations were run for the initial 24 years, representing one year of no activity and 23 years of mining. This state of groundwater flow modelling takes storage and time into account. Operational dewatering and contaminant transport were simulated for the various proposed life of mine durations.

### 6.3.4. Model Boundary Conditions

Boundary conditions determine the reaction of the simulated environment, thus they represent natural conditions such as fluxes in or out of the model domain, as well as hydraulic heads. Application of these boundary conditions in various methods results in different solutions, thus ensuring correct application and assumptions through-out the modelling process.

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

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

The groundwater system within the area is recharged via precipitation which results in infiltration through the weathered zone. The drainages were assigned constant head boundary conditions along the non-perennial rivers to receive base flow from groundwater, if any. Values equal to
topographical elevations at the positions of the drainages were assigned as constant head values. The constant head boundary conditions allow groundwater to discharge, in this case from the model area at a rate dependent on the hydraulic conductivity and hydraulic gradient across the boundary. The constant head boundaries were constrained on all drainages so that water can only be removed from the system. A reversal of the hydraulic gradient back towards the aquifer from the surface system would therefore not allow water to enter the aquifer from the surface water system. This therefore represents a true “drain type” boundary condition.

The model boundaries were set equal to the model boundary selected as part of the SRK (2014) study (Table 9). The boundaries do not follow any outflow - river or drainage line, as well as no no-flow boundary - surface water shed or impermeable layer:

- Boreholes and drains were included as internal boundary conditions; and
- The initial boundary conditions, sources, sinks and aquifer parameters are specified in the steady state model, which is calibrated so that the flow model has the same behaviour as the actual system. Discrete features like the fault zones were included as line elements in the network.

The boundary constraints for the non-perennial rivers throughout the modelled boundary were constrained at heads 3 m below the provided DTM contours.

Table 9: Model boundary data

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Scale</th>
<th>Source, parameter or assumption description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography (DTM)</td>
<td>10 m contours obtained from the client.</td>
<td></td>
</tr>
<tr>
<td>Rivers, streams, drainages</td>
<td>1:50 000</td>
<td>Shape files received from the client.</td>
</tr>
<tr>
<td>Dams</td>
<td>1:50 000</td>
<td>Shape files received from the client.</td>
</tr>
<tr>
<td>Geology</td>
<td>1:250 000</td>
<td>Shape files received from the client.</td>
</tr>
<tr>
<td>Boreholes and pumping rates</td>
<td></td>
<td>Data received from the client. Hydrocensus and drilling conducted by the client as well as falling head tests/packer tests.</td>
</tr>
<tr>
<td>Rainfall (recharge)</td>
<td></td>
<td>Rainfall data was obtained from the client.</td>
</tr>
</tbody>
</table>

Steady State Modelling Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge</td>
<td>Recharge was set at 1% of MAP. The recharge values were calibrated to obtain acceptable flow equilibrium.</td>
</tr>
<tr>
<td>Transmissivity$^2$</td>
<td>Transmissivity parameters obtained from aquifer tests conducted on water supply and groundwater exploration boreholes.</td>
</tr>
<tr>
<td>Hydraulic Conductivity</td>
<td>Horizontal hydraulic conductivity calculated from transmissivity values and saturated aquifer thickness. Vertical hydraulic conductivity was assumed at 10% of horizontal hydraulic conductivity.</td>
</tr>
<tr>
<td>Aquifer thickness</td>
<td>The aquifer was modelled as a 2D model.</td>
</tr>
</tbody>
</table>

$^2$ Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer.
### Transient State Modelling Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Hydraulic Heads</td>
<td>Calibrated water levels obtained from steady state model calibration scenario used as initial hydraulic heads.</td>
</tr>
<tr>
<td>Specific Storage</td>
<td>The volume of water that a unit volume of aquifer releases from or takes into storage per unit change in head.</td>
</tr>
<tr>
<td>Specific Yield</td>
<td>The ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium. Assumed at approximately 10 times the value of Storativity.</td>
</tr>
<tr>
<td>Storativity / Storage Coefficient</td>
<td>The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Assumption of 0.001 to 0.005 for fractured aquifers and 0.01-0.05 for alluvial aquifer zones. No field test data were available for storativity values.</td>
</tr>
<tr>
<td>Effective Porosity</td>
<td>Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.</td>
</tr>
</tbody>
</table>

### 6.3.5. Scenario Modelling

Various scenarios were simulated to quantify the environmental impacts on the groundwater resource due to the proposed mining activities. These scenarios assist in the decision making process regarding the management of the groundwater resource and potential impacts in this area and neighbouring groundwater users.

Simulations varied with steady and transient state scenarios. Steady state refers to a scenario which is not influenced by time and storage. The transient simulations take into account time, storativity and time- dependent recharge. Both steady state and transient state calibration processes were followed to obtain the best possible correlation between measured and simulated heads.

The following model scenarios were simulated:

- **Scenario 1**: Present day setup, water balance and flow conditions. This scenario was used to calibrate the flow model.
- **Scenario 2**: Operational transient mass transport. The transport model was simulated for the various possible pollution sources as supplied by the client.
- **Scenario 3**: Post operational mass transport – steady state.
- **Scenario 4**: Operational and post operational mass transport with mitigation (clay liner)

The scenario outcomes are discussed in the following paragraphs and sub-sections, with the full report given in Appendix E.

**Scenario 1**

The steady state flow model was calibrated based on known geological, structural geology and piezometric head distribution data. Calibration was done by changing recharge and transmissivity values until an acceptable fit between the measured and simulated heads were obtained. A standard trial and error process is followed to calibrate the model.

The model was simulated with a total of 7 hydrogeological units spread over 1 layer in the model domain. The hydraulic values (Appendix E) were obtained from existing groundwater data, field tests and the model calibration process.
The conceptualized water balance components that are considered necessary were simulated in the numerical model using the available components of the Feflow software package. This included the “Inflow-Outflow from surface” package to simulate natural groundwater recharge and the constant head boundary condition Type I to simulate outflow from the internal model boundaries and in the mining area to represent the mining process. Mine dewatering was simulated using the drain boundary in the simulations without any dewatering boreholes.

The mining operations are the critical zone for calibration and recent static water levels recorded during the hydrocensus investigations were used in the calibration process.

The difference between the simulated and measured head was calculated for each borehole. Three methods were used to express the error in the calibration:

- **Mean Error (ME):**
  - Mean difference between the measured and simulated water levels.

- **Mean Absolute Error (MAE):**
  - Mean of the absolute value of the differences between the measured and simulated heads.

- **Root Mean Square Error (RMS):**
  - Average of the squared differences between the measured and simulated heads.

Negative and positive values and differences can cancel each other out. Thus, the ME is not necessarily a good indication of calibration. The MAE addresses this as the absolute values. In keeping with standard practice, the RMS error was evaluated as a ratio to the total water level change across the model domain. If the ratio is small, the errors are only a small part of the overall model response (Anderson and Woessner, 1992). The ME is -5.50, the MAE is 6.48 and the RMS is 20.69% of the range of water level change across the model. The RMS ideally should be below 10%; however, the ME and the MAE are less than 10% of the assumed aquifer thickness of 100m and are deemed acceptable for the purposes of the study. Once additional data becomes available the model should be recalibrated to obtain an RMS of less than 10%.

**Groundwater Balance**

There is approximately 4,270 m³/d flowing into the modelled groundwater system from recharge as calculated from MAP (624 mm/a). The resultant groundwater flow is due to a combination of inflow from recharge and losses to the drainage systems in the modelled area. The modelled area is such that no base flow is recorded. The resultant flow towards these drainage systems will be recorded as losses in the riparian zone due to evapotranspiration.

The 18,200 m³/d recharge on the 580km² modelled catchment relate to an average recharge of 6.24mm/a that reaches the groundwater system. The topography is classified as fairly flat with undulating hills throughout the model domain. Elevation changes occur from approximately 410 mamsl at the highest point to 240 mamsl; that is, a maximum change of 170m over a 250km² area (Table 10).

The flow direction shows that the hydraulic gradient is from the topographical highs towards the confluence of the drainage systems. From there, the majority of groundwater flow is towards the southern outflow boundary i.e. towards the Zambesi River near Tete.

The existing rivers or drainage systems balance the inflow and outflow components of the groundwater balance.
Table 10: Groundwater flow balance determined from the steady-state flow model

<table>
<thead>
<tr>
<th>Component</th>
<th>Inflow (m³/d)</th>
<th>Outflow (m³/d)</th>
<th>Balance (m³/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Recharge from precipitation</td>
<td>4270</td>
<td>0</td>
<td>4270</td>
</tr>
<tr>
<td>2 Abstraction from existing well field</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3 Losses to non-perennial drainages</td>
<td>0</td>
<td>-4270</td>
<td>-4270</td>
</tr>
<tr>
<td>Total</td>
<td>4270</td>
<td>-4270</td>
<td>0</td>
</tr>
</tbody>
</table>

Balance Error (%) 0.00%

**Scenario 2**

The aim of the study is to simulate the possible contaminant transport associated with various potential sources during Life of Mine (LoM) and post closure. The client provided key sources of potential pollution and these were incorporated into the transport model:

- The WRD/Pit;
- The TSF and Slag dump; and
- The Stockpiles/Plant area.

Various potential chemical attributes associated with potential leachate concentrations were supplied; that is, $\text{SO}_4$, TDS, Al and Fe concentrations. Due to the nature of the mine, iron was used as the possible contaminant source from the various facilities at various concentrations.

This scenario is only a simulation for management purposes; that is, advective transport was simulated on possible leaching concentrations of iron to show in which direction a possible plume could migrate and a maximum velocity. This will enable the client to install adequate monitoring points and provide mitigation measures to address this.

Analyses of the background values for iron indicate that the average concentration in the groundwater is less than 1 mg/L. Conservative concentrations were chosen for iron to leach from the various facilities:

- The WRD/Pit – maximum of 178 mg/L;
- The TSF and Slag dump – maximum of 1030 mg/L; and
- The Stockpiles/Plant area – maximum of 706 mg/L.

The concentrations chosen are conservative. The values were based on the total concentration and leachable concentration results obtained from the leachate tests discussed in section 4.3. These values represent the available concentration of metals and ions from the material that can potentially reach the groundwater system as indicated from the various tests performed on the waste and ore material.

A porosity value of 3% was used. Fluxes were assigned to TSF, slag dump, open pit and plant areas to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned.

The simulation of the WRD included in the groundwater flow model was simulated with no lining system below; that is, a barrier that reduces the vertical hydraulic conductivity below these infrastructures to reduce seepage. A conservative approach was followed.

The open pit was included in the operational simulation. The open pit could act as a mitigatory measure due to the proximity of the open pit to various infrastructures. The groundwater flow in the vicinity of the open pit will change over time due to the mining.

The final pit at year 23 of operation will be approximately 235m deep (from 405 mams to 170
mamsl) and 135m below the pit crest. The hydraulic gradient will change and the natural groundwater flow will be altered, i.e. flow will occur towards the open pit and any possible contaminant within the Radius of Influence (ROI) of the open pit will migrate along the hydraulic gradient towards the open pit.

The plumes associated with the plant area, the open pit, as well the slag dump indicate a distinct flow regime towards the open pit – simulated for 23 years operation (Figure 9).

The simulated plumes from the slag dump and plant area migrate a maximum of approximately 1000 m before it reaches the open pit at concentrations ranging from 1 to 5 mg/L, which act as a natural mitigatory measure.

The simulated plume associated with the TSF shows migration of iron from the northwest to the south of the TSF. This is due to the distance of the TSF from the open pit (outside the possible ROI) and the proximity of the TSF to the main drainage in the model domain. The TSF is also situated on a topographical high, enabling migration to occur in various directions. Migrations during life of mine (LoM) are at a maximum in a westerly direction, measuring approximately 1600 m away during the 23rd year (Figure 9). Seepage-capturing boreholes should be drilled south and west of the TSF to capture any possible seepage migrating towards the main drainage line. The water abstracted should be used in the closed mine water circuit. Depending on the ground conditions and excavation possibility, a cut-off trench should be installed around the TSF to capture toe seepage.

Aquifer thickness and porosity play a vital role in the possible migration of the plumes associated with the simulated infrastructure. Monitoring should be conducted on a quarterly basis to ensure that proper mitigatory measures are implemented and adhered to.

No third party boreholes are affected during the LOM. However, the hydrocensus should be repeated before construction starts to establish a decent baseline dataset of water levels and groundwater quality.

**Scenario 3**

The results obtained during the LoM simulations were used as initial conditions for the post operational simulations, which were done in steady state. Steady state is a conservative approach to the possible contaminant transport associated with the various facilities post closure. However, the steady state simulations assist in management of the local groundwater regime and implementing necessary precautions during LoM and closure.

The possibility exists that contamination may migrate from the slag dump and TSF and reach the local drainage, connecting the model domain with the Zambesi River further downstream (Figure 10). The simulations clearly indicate that additional detailed mass transport simulations are required to address sensitivities associated with porosity values, aquifer thickness and recharge on the facilities, as well as influences such as mitigation measures i.e. capping or isolating the facilities. Currently lining of the dams are being planned.

**Scenario 4**

A simulation of the mass transport model was done with the inclusion of the mitigation option of lining the pollution sources (mainly the TSF) with a natural clay layer. Both the operational and post-closure option was simulated with transmissivity values of the top most layer (the liner below the sources) reduced to 0.0031 m²/d which is in line with literature values for compacted clay layers.

These values were assigned to the base of the potential contaminant facilities. The scenarios were simulated for life of mine as well as post closure for 50 years. Iron was used as the simulated
contaminant for the various scenarios. Analyses of the background values of iron indicated the average concentration in the groundwater is less than 1 mg/l. Conservative concentrations was chosen for iron to leach from the various facilities as in previous scenarios.

A porosity value of 3% was used. Fluxes were assigned to both TSF, slag dump, open pit and plant areas to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned.

The plumes associated with the plant area, the open pit as well the slag dump indicates a distinct flow regime towards the open pit – simulated for 23 years operation (Figure 11). The simulated plumes from the slag dump and plant area migrate a maximum of approximately 1000 m before it reaches the open pit at concentrations ranging from 1 – 5 mg/l, which act as a natural mitigatory measure. The simulated plume associated with the TSF shows migration of Fe ranging from the north-west all the way to the south of the TSF. This is due to the distance of the TSF from the open pit (i.e. outside the possible ROI) and the proximity of the TSF to the main drainage in the model domain. The TSF is also situated on a topographical high, enabling migration to occur in various directions. The migration of mass is less with the geoliner installed and simulated compared to the unmitigated scenario i.e. up to 1000 m less migration.

The results obtained during the LoM simulation was used as initial conditions for the post operational simulation. The post operational simulations were done in steady state flow with transient transport for 50 years post closure.

As shown in Figure 11 and Figure 12, the results obtained and shown from the mitigated scenario differ from the unmitigated scenario which reached the river to the west of the proposed TSF. The simulation indicates that a geoliner will assist in mitigating the potential flow of contaminants from the facilities. Nonetheless, a detailed monitoring plan should be implemented to measure and control any possible seepage.
Figure 9: Mass
Figure 10: Post closure transport potential associated with the mine
Figure 11: LOM mass transport simulation with mitigation
Figure 12: Post operational mass transport simulation with mitigation
7. IMPACT ASSESSMENT

The impact methodology proposed by CES was followed.

7.1. Impact Assessment Methodology

Five factors need to be considered when assessing the significance of impacts, namely:

- Relationship of the impact to temporal scales - the temporal scale defines the significance of the impact at various time scales, as an indication of the duration of the impact.

- Relationship of the impact to spatial scales - the spatial scale defines the physical extent of the impact.

- The severity of the impact - the severity/beneficial scale is used in order to scientifically evaluate how severe negative impacts would be, or how beneficial positive impacts would be on a particular affected system (for ecological impacts) or a particular affected party.

- The severity of impacts can be evaluated with and without mitigation in order to demonstrate how serious the impact is when nothing is done about it. The word ‘mitigation’ means not just ‘compensation’, but includes concepts of containment and remedy. For beneficial impacts, optimization means anything that can enhance the benefits. However, mitigation or optimization must be practical, technically feasible and economically viable.

- The likelihood of the impact occurring - the likelihood of impacts taking place as a result of project actions differs between potential impacts. There is no doubt that some impacts would occur (e.g. loss of vegetation), but other impacts are not as likely to occur (e.g. vehicle accident), and may or may not result from the proposed development. Although some impacts may have a severe effect, the likelihood of them occurring may affect their overall significance.

Each criterion is ranked with scores assigned as presented in Table 11 to determine the overall significance of an activity. The criterion is then considered in two categories, viz. effect of the activity and the likelihood of the impact. The total scores recorded for the effect and likelihood are then read off the matrix presented in Table 12, to determine the overall significance of the impact. The overall significance is either negative or positive.

The environmental significance scale is an attempt to evaluate the importance of a particular impact. This evaluation needs to be undertaken in the relevant context, as an impact can either be ecological or social, or both. The evaluation of the significance of an impact relies heavily on the values of the person making the judgment. For this reason, impacts of especially a social nature need to reflect the values of the affected society.

7.2. Prioritising

The evaluation of the impacts, as described above is used to prioritise which impacts require mitigation measures.

Negative impacts that are ranked as being of “VERY HIGH” and “HIGH” significance will have to be investigated further (based on mine design and planning decisions made by the client leading from this investigation) to determine how the impact can be minimised or what alternative activities or mitigation measures can be implemented. These impacts may also assist decision makers i.e. numerous HIGH negative impacts may bring about a negative decision.

For impacts identified as having a negative impact of “MODERATE” significance, it is standard practice to investigate alternate activities and/or mitigation measures. The most effective and
practical mitigations measures will then be proposed.

For impacts ranked as “LOW” significance, no investigations or alternatives will be considered. Possible management measures will be investigated to ensure that the impacts remain of low significance.

**Table 11: Ranking of Evaluation Criteria**

<table>
<thead>
<tr>
<th>Temporal Scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term</td>
<td>1</td>
</tr>
<tr>
<td>Medium term</td>
<td>2</td>
</tr>
<tr>
<td>Long term</td>
<td>3</td>
</tr>
<tr>
<td>Permanent</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spatial Scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localised</td>
<td>1</td>
</tr>
<tr>
<td>Study Area</td>
<td>2</td>
</tr>
<tr>
<td>Regional</td>
<td>3</td>
</tr>
<tr>
<td>National</td>
<td>3</td>
</tr>
<tr>
<td>International</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>Severity</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight</td>
<td>Slight impacts on the affected system(s) or party(ies)</td>
<td>Slightly beneficial to the affected system(s) and party(ies)</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate impacts on the affected system(s) or party(ies)</td>
<td>Moderately beneficial to the affected system(s) and party(ies)</td>
</tr>
<tr>
<td>Severe/ Beneficial</td>
<td>Severe impacts on the affected system(s) or party(ies)</td>
<td>A substantial benefit to the affected system(s) and party(ies)</td>
</tr>
<tr>
<td>Very Severe/ Beneficial</td>
<td>Very severe change to the affected system(s) or party(ies)</td>
<td>A very substantial benefit to the affected system(s) and party(ies)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlikely</td>
<td>The likelihood of these impacts occurring is slight</td>
</tr>
<tr>
<td>May Occur</td>
<td>The likelihood of these impacts occurring is possible</td>
</tr>
<tr>
<td>Probable</td>
<td>The likelihood of these impacts occurring is probable</td>
</tr>
<tr>
<td>Definite</td>
<td>The likelihood is that this impact will definitely occur</td>
</tr>
</tbody>
</table>

* In certain cases it may not be possible to determine the severity of an impact thus it may be determined: Don’t know/ Can’t know.

**Table 12: Matrix used to determine the overall significance of the impact based on the likelihood and effect of the impact**

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 4 5 6 7 8 9 10 11 12 13 14 15 16</td>
</tr>
<tr>
<td>1</td>
<td>4 5 6 7 8 9 10 11 12 13 14 15 16 17</td>
</tr>
<tr>
<td>2</td>
<td>5 6 7 8 9 10 11 12 13 14 15 16 17 18</td>
</tr>
<tr>
<td>3</td>
<td>6 7 8 9 10 11 12 13 14 15 16 17 18 19</td>
</tr>
<tr>
<td>4</td>
<td>7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
</tr>
</tbody>
</table>
Table 13: Description of Environmental Significance Ratings and associated range of scores

<table>
<thead>
<tr>
<th>Significance Rate</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>An acceptable impact for which mitigation is desirable but not essential. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in either positive or negative medium to short term effects on the social and/or natural environment.</td>
<td>4-8</td>
</tr>
<tr>
<td>Moderate</td>
<td>An important impact which requires mitigation. The impact is insufficient by itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in either a positive or negative medium to long-term effect on the social and/or natural environment.</td>
<td>9-12</td>
</tr>
<tr>
<td>High</td>
<td>A serious impact, if not mitigated, may prevent the implementation of the project (if it is a negative impact). These impacts would be considered by society as constituting a major and usually a long-term change to the (natural &amp;/or social) environment and result in severe effects or beneficial effects.</td>
<td>13-16</td>
</tr>
<tr>
<td>Very High</td>
<td>A very serious impact which, if negative, may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts cannot be mitigated and usually result in very severe effects, or very beneficial effects.</td>
<td>17-20</td>
</tr>
</tbody>
</table>

7.3. Impact Assessment

This chapter details the impacts identified for the groundwater resource. For each issue identified, details are provided, followed by the mitigation measures required to minimise the negative impacts associated with the issue.

7.3.1. Construction Phase

This section presents the issues that may impact groundwater systems arising from the construction of the mine, including its associated infrastructure such as accommodation (which is minimal during normal operations), the haul road and the mineral concentration plant and associated infrastructure.

**Impact 1: Hydrocarbon Contamination of Groundwater through Oil Spills**

**Cause and comment**

Oil spills from construction activities can lead to infiltration of hydrocarbons into the receiving groundwater environment, through direct contact during drilling operations or through infiltration over a long period as part of natural recharge.

**Significance Statement**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Temporal Scale</td>
<td>Spatial Scale</td>
<td>Severity of Impact</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Short term</td>
<td>Localised</td>
<td>Slight</td>
</tr>
</tbody>
</table>
Mitigation and management

- Oil spill clean-up kits;
- Regular maintenance of vehicles and operational equipment;
- Proper storage of oil and fuel tanks on site in bunded / hard park areas; and
- Oil spill removal action plans.

7.3.2. Operational Phase

This section presents the issues that may impact groundwater systems arising from the operation of the mine, the haul road and the mineral concentration plant and associated infrastructure.

Impact 1: Hydrocarbon Contamination of Groundwater through Oil Spills

Cause and comment

Oil spills from construction operations can lead to infiltration of hydrocarbons into the receiving groundwater environment through direct contact during drilling operations or through infiltration over a long period as part of natural recharge.

Significance Statement

<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Long Term</td>
<td>May Occur</td>
<td>MODERATE</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Short term</td>
<td>Unlikely</td>
<td>LOW</td>
</tr>
</tbody>
</table>

Mitigation and management

- Oil spill clean-up kits;
- Regular maintenance of vehicles and operational equipment;
- Proper storage of oil and fuel tanks on site; and
- Oil spill removal action plans.

Impact 2: Depletion of Groundwater Reserves and Local Groundwater Supply

Cause and comment

Dewatering for mining purposes can potentially have an impact on the local groundwater resource and supply to communities. From the numerical groundwater flow models available at the time of reporting this impact is, however, small.

Significance Statement

<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Medium Term</td>
<td>May occur</td>
<td>LOW</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Short term</td>
<td>Unlikely</td>
<td>LOW</td>
</tr>
</tbody>
</table>
Mitigation and management

- Water supply to communities from treated water on site. This will be defined and included under the social infrastructure and resettlement programme; and
- Drilling of additional water supply boreholes.

Impact 3: Acid Mine Drainage and Potential Metal Leaching into the Groundwater System

Cause and comment

A moderate potential for AMD from WRD, TSF and stockpile facilities do exist based on the geochemical data. With the potential AMD formation metal leachate can reach the surface water and groundwater systems and deplete water quality.

Significance Statement

<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Long Term</td>
<td>Severe</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Study area</td>
<td>Probable</td>
<td>HIGH</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Medium Term</td>
<td>Localised</td>
<td>Slight</td>
</tr>
<tr>
<td></td>
<td>Study Area</td>
<td>May Occur</td>
<td>LOW</td>
</tr>
</tbody>
</table>

Mitigation and management

- Lining of TSF as currently planned and was simulated in the contaminant transport models;
- Storm water management and seepage capturing trenches to allow dirty water to be diverted and treated before discharge (being investigated as part of on-going studies);
- Monitoring of groundwater and surface water locations upstream and downstream of infrastructure to serve as early warning systems and seepage capturing boreholes; and
- Treatment of water before discharge.

7.3.3. Decommissioning Phase

A variety of impacts are likely to result from the decommissioning of the various components of the mine, these are discussed below.

Impact 1: Acid Mine Drainage and Potential Metal Leaching into the Groundwater System

Cause and comment

A moderate potential for AMD from WRD, TSF and stockpile facilities does exist based on the geochemical data. With the potential AMD formation metal leachate can reach the surface water and groundwater systems and degrade water quality.

Significance Statement

<table>
<thead>
<tr>
<th>Impact</th>
<th>Effect</th>
<th>Risk or Likelihood</th>
<th>Overall Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>Long Term</td>
<td>Severe</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Study area</td>
<td>Probable</td>
<td>HIGH</td>
</tr>
<tr>
<td>With Mitigation</td>
<td>Medium Term</td>
<td>Moderate</td>
<td>May Occur</td>
</tr>
</tbody>
</table>
 Mitigation and management

- Lining of TSF as currently planned;
- Storm water management and seepage capturing trenches to allow dirty water to be diverted and treated before discharge (being investigated as part of on-going studies);
- Monitoring of groundwater and surface water locations upstream and downstream of infrastructure to serve as early warning systems and seepage capturing boreholes;
- Treatment of water before discharge;
- Capping of WRD and TSF post closure to prevent oxidation to continue;
- Removal of all stockpiles and ore material; and
- Using waste rock material as backfill into the open pit to a point below the natural water table to prevent oxidation to continue.
8. LANDFILL SITE OPTION ANALYSIS

The objectives of the disposal site selection are:

■ To ensure that the site to be developed is environmentally acceptable and that it provides for simple, cost-effective design, which in turn provides for good operation; and

■ To ensure that, because it is environmentally acceptable, it is also socially acceptable.

This suggested approach would screen out options based on biophysical and social sensitivities and potential fatal flaws identified on site, and result in the identification of either one or more site options for detailed impact assessment. The intent is to ensure that site options which are environmentally viable are taken forward to the decision making phase.

8.1. Selection Criteria

The assessment of suitable sites was based on:

■ Criteria 1: Underlying geology – impacts on water movement and quality – the presence of deep weathered formations and aquifers; and fault and fold structures could have a major significance in terms of the movement of contamination off site or increasing water quality impacts of a major water resource;

■ Criteria 2: Catchment and aquifer boundaries – the locality of the proposed dumping sites in relation to the water management or catchment boundaries; and

■ Criteria 3: Water resources and users (receptors) – includes depth to water table.

The discharging of contaminated water into the local streams or aquifers could be a potential risk on groundwater quality. However, it is not expected that the volume of water discharged from the landfill site will increase the groundwater level significantly, so the driving head will not increase enough to greatly change local groundwater levels.

The water quality of the surface water streams will be a far greater consideration. The impacts to water quality primarily results from waste water or sludge directly discharging into the water resources. These discharges may result in the contamination of the Revuvoe River and its tributaries.

If the local groundwater conditions and characteristics (section 5) are taken into consideration then the most suitable area for the construction and operation of a landfill site would be on the gabbro formation (Tete Complex):

■ East of the Plant;

■ Along the haul road running to the southeast; staying clear of the 1 in 50 year flood line of the northeast-southwest running un-named tributary; and

■ Along the quarry road running to the northwest.

The Karoo Formations have higher horizontal conductivity values and contamination might migrate along the bedding planes towards local streams. The Tete Complex formations present lower horizontal conductivity values, but higher vertical conductivity. The area is intruded by numerous dolerite dykes and sills that will limit the vertical migration of contaminants.

No major linear geological features have been mapped in these areas. The contact between the gabbro and the Karoo formations is potentially linked to faults and fractures, but the recent drilling and aquifer testing programmes have indicated that these geological contacts yield little water and therefore movement of contaminants should also be limited. Once a suitable site is identified then it
would be best practice to do a fine grid geophysical survey across the landfill footprint to assess the presence of any linear geological features.

The natural groundwater levels in the three listed areas should be between 10 and 25 mbgl. Any landfill site option close to surface water sources should be avoided as the groundwater table is very close to surface in these areas.
9. MONITORING NETWORK

The proposed water monitoring locations listed in Table 14 and shown in Plan 8 (Appendix A) should be adopted as part of the environmental management plan for Tenge Mine. The monitoring frequency is also indicated, with quarterly monitoring during the construction and post-closure phases of the project and monthly monitoring during the operational phase.

The water quality parameters listed in Table 15 should be analysed monthly at the boreholes for the initial 24 months after which monitoring parameters and frequency can be reduced to quarterly intervals if no major problems are recorded.

### Table 14: Proposed water monitoring locations

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Coordinates</th>
<th>Site type</th>
<th>Construction phase</th>
<th>Operational phase</th>
<th>Post-operational phase</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRR1</td>
<td>-15.70103</td>
<td>33.82219</td>
<td>SW</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ</td>
</tr>
<tr>
<td>TRR2</td>
<td>-15.71499</td>
<td>33.77459</td>
<td>SW</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ</td>
</tr>
<tr>
<td>TRR3</td>
<td>-15.72317</td>
<td>33.7683</td>
<td>SW</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ</td>
</tr>
<tr>
<td>TRR4</td>
<td>-15.74516</td>
<td>33.76117</td>
<td>SW</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ</td>
</tr>
<tr>
<td>TBH1</td>
<td>-15.72686</td>
<td>33.7638</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>TBH2</td>
<td>-15.72631</td>
<td>33.76664</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>TBH3</td>
<td>-15.72537</td>
<td>33.76723</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>TBH4</td>
<td>-15.72327</td>
<td>33.76835</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>TBH5</td>
<td>-15.71433</td>
<td>33.78066</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>TBH6</td>
<td>-15.71896</td>
<td>33.78018</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W2A</td>
<td>-15.74259</td>
<td>33.78685</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W3A</td>
<td>-15.73997</td>
<td>33.78558</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W8B</td>
<td>-15.72093</td>
<td>33.77749</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W9A</td>
<td>-15.75053</td>
<td>33.78162</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W10A</td>
<td>-15.7562</td>
<td>33.77269</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W11A</td>
<td>-15.77102</td>
<td>33.79281</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
<tr>
<td>SRKG W12A</td>
<td>-15.77613</td>
<td>33.7809</td>
<td>BH</td>
<td>Quarterly</td>
<td>Monthly</td>
<td>WQ and WL</td>
</tr>
</tbody>
</table>

### Table 15: Monitoring parameters

<table>
<thead>
<tr>
<th>Chemical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl; SO$_4^-$; NO$_3^-$-N; NO$_2^-$ - N; PO$_4^3-$; NH$_3$+4; Fluoride</td>
</tr>
<tr>
<td>Al, Ca, Fe, K, Mg, Mn, Na, Cr, Cu, Ni, Cd, Co, Pb, Zn</td>
</tr>
<tr>
<td>pH &amp; Electrical Conductivity (EC)</td>
</tr>
<tr>
<td>Total Hardness</td>
</tr>
</tbody>
</table>

3 SW = Surface water, BH = Borehole
4 WQ = Water quality, WL = Water level
<table>
<thead>
<tr>
<th>Chemical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Alkalinity</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
</tr>
<tr>
<td>Dissolved oxygen (Alkalinity)</td>
</tr>
<tr>
<td>Bicarbonate as HCO$_3$ (Alkalinity)</td>
</tr>
<tr>
<td>Carbonate as CO$_3$ (Alkalinity)</td>
</tr>
<tr>
<td>Cr (III)</td>
</tr>
<tr>
<td>Pb</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>
10. CONCLUSIONS

10.1. Hydrocensus

Digby Wells carried out a hydrocensus (March 2014) within a 5km radius around the proposed Tenge Pit, that included the identification of current groundwater use and groundwater recharge. During the hydrocensus a total of 10 water sites were surveyed, consisting of six boreholes and four surface water sampling sites along the Revuboe River. From the six boreholes four are exploration holes and two are currently used for domestic use.

Groundwater use is very limited in the project area, with the Revuboe River being the main source of water. The river flows throughout the year, limiting the need of groundwater abstraction. The groundwater elevation in the area ranges between 231 and 320 mamsl as recorded by SRK (2014, Appendix B). The depth to the water level in the area is highly variable from 0.7 mbgl near the Revuboe River to 85 mbgl on top of Tenge Hill (SRK, 2014). The depth to the groundwater level increases with an increase in distance from the Revuboe River. Therefore the groundwater flow direction is towards the river, suggesting that the Revuboe River is a gaining stream. The overall groundwater flow broadly follows the surface topography of the area, with groundwater levels being very shallow near the river systems.

In terms of the water quality the following was concluded:

- Most of the analysed parameters are within the recommended WHO drinking water guidelines, with the exception of total dissolved solids and alkalinity;
  Higher total dissolved solids due to alkalinity might pose health risks to water users;
- The area is characterised by two groundwater types; a shallow, recently-recharged groundwater system and a deeper, fractured aquifer. Both have similar isotopic compositions, which suggests rainfall recharge for both;
- The groundwater composition for the shallow aquifer is dominated by calcium-magnesium- and bicarbonate (Ca Mg HCO₃), suggesting a meteoric origin;
- The elevated iron, manganese and selenium concentrations potentially relates to the underlying geology;
- The analytical results show that the concentrations of several parameters in groundwater is higher than the concentrations in the water from Revuboe River, suggesting that there are some interactions of rainfall water with the host rock or soil as it infiltrates;
- The groundwater in the Karoo Supergroup is characterised by elevated sodium and chloride concentrations;
- Borehole SRKGW11A has the highest levels of Na and Cl (and thus TDS); typical of the coal and shale units of the Karoo Formation;
- Water from the core holes represents deeper groundwater that has undergone ion exchange of HCO₃ for Cl, as well as Mg/Ca for Na;
- The water samples collected towards the end of the pumping tests represent the deeper groundwater, indicating a shift from shallow to deeper waters;
- The results indicate very low concentrations of metals in the groundwater and river samples. The exception is manganese and iron in borehole SRKGW02. The increased levels of manganese and iron are probably due to the intercepted geology; and
Elevated concentrations of selenium were reported in three monitoring sites. Selenium concentrations in some samples are marginally higher than the WHO guideline limit and are probably due to the natural occurrence of selenium in the magmatic rocks of the Tete Complex.

10.1.1. SRK Isotope Study

The isotope data suggests that groundwater in the shallow boreholes and deeper core holes are similar, indicating that the groundwater in the deeper and the shallow aquifer systems are connected and likely to be recharged by rainfall.

Two samples, one collected in October 2013 and another in April 2014, of the Revuboe River show very high variations in isotopic composition, from a depleted isotopic composition similar to groundwater in the wet season (April sample) to a highly enriched, evaporitic isotopic composition in the dry season (October sample).

The samples collected from SRKGW01 were aimed at establishing whether during the pumping, river water was drawn into the aquifer system. The results indicate that the water before, during and at the end of pumping remain similar to groundwater in the deeper core holes, suggesting that the deeper groundwater was drawn into the borehole during pumping, not the Revuboe River water.

10.2. Drilling Programme

Seven boreholes were drilled (Table 3) and were positioned based on the geophysical survey results. The location of the newly drilled and aquifer test boreholes are indicated on Plan 7.

Seven boreholes were drilled within the proposed Tenge mining area. Five of the seven boreholes intercepted predominant gabbro and dolerite formations. Boreholes SRKGW11A and SRKGW9A intercepted carbonaceous and schist formations respectively. Borehole SRKGW8B intercepted anorthosite and magnetite around 35 and 45 mbgl.

Dolerite intrusions were observed in all boreholes and can potentially influence groundwater flow and contaminant flow paths.

Borehole yields are low, indicating no major aquifer system in the area. The highest yield was observed for boreholes SRKGW3A and SRKGW8B; 4 212 L/h and 792 L/h respectively. These aquifer systems correspond to the fractured dolerite intrusions. The contact zones between the dolerite and surrounding formations and also between gabbro, carbonaceous formations and schist yielded only seepage water.

The depth of weathering extended up to 20 mbgl (maximum) for the recent drilled boreholes and slightly weathered material was encountered to depths of 40 mbgl.

The recorded groundwater levels varied between 4 and 25 mbgl.

10.3. Aquifer Testing

Eight slug tests and five pumping tests were performed by Digby Wells and SRK (Table 4 and Table 5).

The eight slug tests were performed on low yielding boreholes with the higher yielding boreholes being subjected to pumping tests.

The following is a summary of the aquifer test results:

- The slug test results indicate the weathered zone and upper portion of the fractured zone has a low to intermediate hydraulic conductivity;

- The hydraulic conductivity calculated from the test pumping represent the bulk hydraulic
conductivity of the test horizon i.e. the weathered and fractured zone has a low to intermediate hydraulic conductivity suggesting that the geological horizon pillar between the Revuboe River and the proposed pit might leak water from the river into the proposed pit;

- The packer test results indicate that the ore body and the underlying fresh bed rock have very low hydraulic conductivity grading with depth to essentially impermeable;
- The fractured zone is less permeable compared to the overlying weathered zone and this is because of poor interconnection between fractures;
- The hydraulic conductivity in the area decrease with depth;
- Lithological structures and dykes contacts within the Tete Complex are in-filled with secondary minerals further reducing the hydraulic conductivity of the rock; and
- Isolated fractures can have high hydraulic conductivities; larger than 0.2m/d.

10.4. Geochemistry Assessment

10.4.1. Ore Material Assessment

Samples B, C and F were sampled from the ore zone.

The XRF results, indicating the oxide distribution within the mineralogy of the ore material, indicate high SiO$_2$ and Fe$_2$O$_3$ content as would be expected with the ore zone in the gabbro and anorthosite formations. MgO, CaO and Na$_2$O complete the oxide series for the ore material.

The oxides and various trace elements indicated in the results (Appendix D) combine to form the mineralogy of the ore material. The ore material is dominated by ilmenite, magnetite and plagioclase, with chlorite, muscovite, enstatite and kaolinite making up the main accessory minerals of the ore zone.

From the three ore samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for sample B was below the 0.3% S margin, with sample C above the margin with 0.4% sulphur;
- Sample F had sulphur levels of 0.3%;
- Samples B and F had positive NNP values, with sample C having a negative value;
- Sample B is classified as non-potentially acid generating and sample C is potentially acid generating; and
- Sample F is however marginal and inconclusive.

The ore material for environmental impact purpose is thus deemed to be potentially acid generating.

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water guideline values with only aluminium leaching out above the recommended 0.3 mg/L in samples B and F; and
- Although the leachate from the static tests is relatively clean, a long term acid producing potential and oxidation can lead to an increase in leachable elements. It is recommended that the ore material be submitted for long term kinetic tests.
10.4.2. Waste Rock Material Assessment

Samples A, D, E and G were sampled from the host material – waste rock.

The XRF results, indicating the oxide distribution within the mineralogy of the waste material, indicate high SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ content as would be expected with the ore zone located in the gabbro and anorthosite formations. MgO, CaO and Na$_2$O complete the oxide series for the ore material.

The oxides and various trace elements indicated in the results (Appendix D) combine to form the mineralogy of the ore material. The ore material is dominated by various minerals with a wide range of silicates and clay minerals including actinolite, augite, biotite, chlorite, dolomite, enstatite, ilmenite, magnetite, plagioclase, quartz, smectite, spinel and talc.

From the four waste rock samples sent for ABA and NAG tests the following can be concluded:

- The paste pH for all samples were well above the recommended 5.5 level;
- The sulphur content for samples A and E were below the 0.3%S margin and for samples D and G it was above the margin;
- Sample E had a positive NNP value with samples A, D and G having a negative value;
- Samples A and E is classified as non-potentially acid generating with samples D and G being potentially acid generating; and
- Based on sulphur content the results for the waste rock material analysis are inconclusive. However, due to the low neutralising potential observed in the results, and the fact that the waste rock will be stored on the same WRD the overall outcome can be seen as potentially acid generating. Long term static tests are recommended with a bigger sample population and submitted for ABA and NAG to gain more certainty on the potential for AMD generation.

From the SPLP leachate results, compared to the SANS drinking water standards, the following can be concluded:

- All parameters are within the recommended drinking water ranges with only aluminium leaching out above the recommended 0.3 mg/L in sample A; and
- Although the leachate from the static tests is relatively clean, long term acid producing potential and oxidation can lead to an increase in leachable elements and thus it is recommended that the ore material be submitted for long term kinetic tests.

10.5. Numerical Contamination Model

Various scenarios were simulated to quantify the impact on the groundwater reserve due to the proposed mining activities and related infrastructure. The following model scenarios were simulated:

- Scenario 1: Present day setup, water balance and flow conditions. This scenario was used to calibrate the flow model.
- Scenario 2: Operational transient mass transport. The transport model was simulated for the various possible pollution sources as supplied by the client.
- Scenario 3: Post operational mass transport – steady state.

10.5.1. Scenario 1

There is approximately 4 270 m$^3$/d flowing into the modelled groundwater system from recharge as
calculated from MAP (624 mm/a). The resultant groundwater flow is due to a combination of inflow from recharge and losses to the drainage systems in the modelled area. The modelled area is such that no base flow is recorded. The resultant flow towards these drainage systems will be recorded as losses in the riparian zone due to evapotranspiration.

The 18200 m³/d recharge on the 580 km² modelled catchment relate to an average recharge of 6.24 mm/a that reaches the groundwater system. The topography is classified as fairly flat with undulating hills throughout the model domain. Elevation changes occur from approximately 410 m asl at the highest point to 240 m asl i.e. a maximum change of 170 m over a 250 km² area.

The flow direction shows that the hydraulic gradient is from the topographical highs towards the confluence of the drainage systems. From there, the majority of groundwater flow is towards the southern outflow boundary i.e. towards the Zambesi River near Tete.

10.5.2. Scenario 2

The aim of the study is to simulate the possible contaminant transport associated with various potential sources during Life of Mine (LoM) and post closure. Key sources of potential pollution include:

- The WRD/Pit;
- The TSF and Slag dump; and
- The Stockpiles/Plant area.

Various potential chemical attributes associated with potential leachate concentrations were supplied i.e. SO₄, TDS, Al and Fe concentrations. Due to the nature of the mine iron was used as the possible contaminant source from the various facilities at various concentrations.

This scenario is only a simulation for management purposes i.e. advective transport was simulated on possible leaching concentrations of iron to show in which direction a possible plume could migrate and a maximum velocity. This will enable the client to install adequate monitoring points and mitigation measures to address this possibility.

Analyses of the background values of iron indicate that the average concentration in the groundwater is less than 1 mg/L. Conservative concentrations were chosen for iron to leach from the various facilities:

- The WRD/Pit – maximum of 178 mg/L;
- The TSF and Slag dump – maximum of 1030 mg/L; and
- The Stockpiles/Plant area – maximum of 706 mg/L.

A porosity value of 3% was used. Fluxes were assigned to TSF, slag dump, open pit and plant areas to simulate the increased recharge on these facilities. A maximum recharge of 30% was assigned.

The simulation of the WRD’s included in the groundwater flow model was simulated with no lining system below i.e. a barrier that reduces the vertical hydraulic conductivity below these infrastructures to reduce seepage. A conservative approach was followed.

The open pit was included in the operational simulation. The open pit could act as a mitigatory measure due to the proximity of the open pit to various infrastructures. The groundwater flow in the vicinity of the open pit will change over time due to the mining.

The final pit after year 23 of operations will be approximately 190 m deep (from 350 m asl to 160 m asl). The hydraulic gradient will change and the natural groundwater flow will be altered i.e.
flow will occur towards the open pit and any possible contaminant within the Radius of Influence (ROI) of the open pit will migrate along the hydraulic gradient towards the pit.

The plumes associated with the plant area, the open pit, as well the slag dump indicate a distinct flow regime towards the open pit – simulated for 23 years operation.

The simulated plumes from the slag dump and plant area migrate a maximum of 1 000 m before it reaches the open pit at concentrations ranging from 1 to 5 mg/L, which act as a natural mitigatory measure. The simulated plume associated with the TSF shows migration of iron ranging from the northwest to the south of the TSF. This is due to the distance of the TSF from the open pit (i.e. outside the possible ROI) and the proximity of the TSF to the main drainage in the model domain. The TSF is also situated on a topographical high, enabling migration to occur in various directions. Migrations during LoM are at a maximum in the western direction, measuring approximately 1 600 m during the 23 year LoM. Seepage capturing boreholes should be drilled south and west of the TSF to capture any possible seepage migrating towards the main drainage line. The water abstracted should be used in the closed mine water circuit. Depending on the ground conditions and excavation possibility, a cut off trench should be installed around the TSF to capture toe seepage.

The aquifer thickness and porosity plays a vital role in the possible migration of the plumes associated with the simulated infrastructure. Monitoring should be conducted on a quarterly basis to ensure that proper mitigatory measures are implemented and adhered to.

No third party boreholes will be affected, however a repeat of the hydrocensus should be conducted before construction starts to establish a decent baseline dataset of water levels and groundwater quality.

10.5.3. Scenario 3

The results obtained during the LoM simulation was used as initial conditions for the post operational simulation. The post operational simulations were done in steady state. Steady state is a conservative approach to the possible contaminant transport associated with the various facilities post closure. However, the steady state simulations assist in management of the local groundwater regime and implementing necessary precautions during LoM and closure.

The possibility exist that contaminant may migrate from the slag dump and TSF and reach the local drainage connecting the model domain with the Zambesi River further downstream. The simulations clearly indicate that additional detailed mass transport simulations are required to address sensitivities associated with porosity values, aquifer thickness, and recharge on the facilities, as well as for mitigation measures such as capping or isolating the facilities.

10.5.4. Scenario 4

A simulation of the mass transport model was done with the inclusion of the mitigation option of lining the pollution sources (mainly the TSF) with a natural clay layer. Both the operational and post-closure option was simulated with transmissivity values of the top most layer (the liner below the sources) reduced to 0.0031 m²/d which is in line with literature values for compacted clay layers. In both cases () the mitigation option of lining the pollution sources drastically reduced the size and reach of the pollution plumes. In both the operational LOM and post-closure simulations the pollution plumes was reduced and mass transport of contaminants in the groundwater will only be limited to the immediate vicinity of the facilities.

10.5.5. Potential Impacts on the Groundwater System

The main potential impacts identified from the groundwater and geochemistry studies are:
Potential for AMD from the WRD, stockpiles and TSF facility with a further potential for metal leachate reaching the groundwater reserves and depleting groundwater quality;

Potential impact on local water supply and groundwater reserves due to dewatering; and

Potential contamination of soils and groundwater through oil and gas spills on site.

If the local groundwater conditions and characteristics are taken into consideration then the most suitable area for the construction and operation of a landfill site would be on the gabbro formation (Tete Complex):

- East of the Plant;
- Along the haul road running to the southeast; staying clear of the 1 in 50 year flood line of the northeast-southwest running un-named tributary; and
- Along the quarry road running to the northwest.
11. RECOMMENDATIONS

Based on the preceding study results Digby Wells recommends the following:

- Based on sulphur content the results for the waste rock material are inconclusive. However, due to the low neutralising potential also observed in the results and the fact that all waste rock will be stored on the same WRD the overall outcome can be seen as potentially acid generating. Thus, the current laboratory analysis (only 7 samples submitted from 2 holes) indicated a potential for AMD. Additional analyses and investigations are required post ESHIA/EMP work to more accurately assess the potential for AMD and associated risks. The following is recommended:
  - Long term static tests are recommended with a larger sample population and submitted for ABA and NAG analyses to gain more certainty on the potential for AMD generation;

- Groundwater monitoring has to continue (on a quarterly basis) during all phases of the mine operation to identify the impact on the groundwater environment over time and to allow for effective measures to be taken at an early stage before negative impacts to the environment occurs. The main objectives in positioning the monitoring boreholes are to:
  - Monitor the movement of polluted groundwater migrating away from the TSF, waste rock dump and the general mine area;
  - Monitor the lowering of the water table and the radius of influence; and
  - Monitor post closure groundwater recovery rates to assess the potential for decant and to define an approximate decant date (assessed as part on-going SRK of groundwater modelling).

- pH and heavy metal concentration trends should be studied during monitoring to ensure that ARD formation is identified early. As soon as pH levels decreases below a level of 5, management options of acid neutralisation through treatment with lime or calcite should be investigated and implemented, in the event that ARD is formed;

- Lining of the tailings, waste rock and slag dump facilities with natural clay is recommended to decrease seepage and to allow any contaminants to be captured in trenches before infiltration can occur;

- Monitoring of groundwater quality and water levels is recommended up gradient and down gradient of the TSF, waste rock dump and particularly down gradient of the mine site; with continuous refining and updating of the monitoring network based on the results obtained;

- Analyses of the following constituents are recommended for the first 2 years of the operational phase until the monitoring data demonstrate that element concentrations have not changed. The number and selection of parameters should be reviewed on an annual basis to optimise the monitoring programme:
  - EC, pH, TDS;
  - Macro Analysis i.e. Ca, Mg, Na, K, SO_4, NO_3, F, Cl; and
  - Heavy metals As, Al, Co, Cr, Zn, Cd, Cu, Fe, Ni, V, Mn, Se.

- Since oxidation in the post closure environment at the Tete Iron Ore Project is unavoidable, the most cost effective control would be to have a clay liner below the WRD and TSF, with cut-off drains leading to a return water dam;
A Storm Water Management Plan for the TSF and waste disposal facilities should be in place to capture contaminated water and potential ARD. This should be diverted to pollution control dams;

Seepage interception boreholes downstream of the TSF should be drilled to intercept and capture any possible seepage that may enter the groundwater system, if ongoing monitoring detects contaminated seepage. Any captured contaminated water should be pumped back onto the TSF or to pollution control dams;

Six sets of monitoring boreholes are recommended around the TSF to ensure effective monitoring of the groundwater environment. Two sets of monitoring boreholes are recommended around the waste rock dump. Each set is recommended to contain:
  o A borehole drilled to a maximum depth of 30 mbgl to monitor the water level and quality in the weathered aquifer; and
  o A deep borehole drilled to 60 m to monitor groundwater conditions in the upper fractured aquifer.

The conceptual and numerical models should be refined every six months in the first four years and thereafter every five years based on groundwater monitoring results.

Optional future studies to increase confidence levels on potential geochemistry and groundwater impacts include:

Evaluate the option of a permanent wetland on the TSF to cover the reactive materials in the post closure environment. Once the available oxygen in the water is consumed, the rate of reaction is reduced and the rate of oxygen replacement will be relatively slow. Reducing the availability of oxygen is a very effective inhibitor to sulphide oxidation;

Geochemical modelling is recommended to assess the various scenarios in terms of mixing of the various pollutants, rain water and groundwater. The static test results might proof inconclusive for acid generation, but when the leachate mixes with surface or groundwater the contaminants or metal concentrations might decrease significantly, resulting in a potential decrease in the risk of contamination downstream due to lower contamination levels away from the pollution source after initial reactions, adsorption and mixing with the receiving environment;

The current laboratory tests indicated a potential for AMD. Further analyses and investigations are required to more accurately assess the potential for AMD and associated risk. The following is recommended:
  o Long term static tests are recommended with a larger sample population (± 20 leachate tests and 50 static) and submitted for ABA and NAG analyses to gain more certainty on the potential for AMD generation;
12. REFERENCES

Coffey Mining Pty Ltd, May 2013. Pre-Feasibility Study. Tete Pig Iron and Ferro-Vanadium Project


SRK, 2014. Interim Hydrogeological Report Feasibility Study for the Tete Pig Iron and Baobab Resources,
APPENDIX B: SRK MODEL REPORT
APPENDIX C: BOREHOLE LOGS
APPENDIX D: LABORATORY CERTIFICATES
APPENDIX E: CONTAMINANT TRANSPORT MODELLING REPORT