TECHNICAL MEMORANDUM

DATE 5 March 2021

Project No. 19127735-612-01_E

TO [redacted] Department for Infrastructure

CC [redacted]

FROM [redacted]

EMAIL [redacted]

DALRADIAN PROPOSED CURRAGHINALT PROJECT PHREEQC MODELLING REVIEW

1.0 INTRODUCTION

Outlined in this memorandum are the findings of our review of reports and associated models regarding the modelling of contact water qualities from the proposed Curraghinalt project underground mine and associated infrastructure. This work was undertaken by SRK Consulting (UK) Limited (SRK) and presented in the report entitled “A Geochemical Characterisation Report for the Curraghinalt Gold Deposit, Northern Ireland” [1].

2.0 DATA PROVIDED

Contact water quality modelling is reported in the document “A Geochemical Characterisation Report for the Curraghinalt Gold Deposit, Northern Ireland”[1], which was submitted as Appendix C to the 2020 Mine Waste Management Plan (WMP)[2].

Four main geochemical models have been provided, comprising:

- “3_U7582_DSF_BaseCase_v1.9” (Base Case model for the Dry Stack Facility);
- “3_U7582_UG_LOM_BaseCase_v1.11 (Base Case model for the underground mine during Life of Mine);
- “3_U7582_UG_Closure_BaseCase_v1.6 (Base Case model for the underground mine after closure); and
- “3_U7582_UG-Adit_BaseCase_v1.11” (Base Case model for the adit after closure).

The geochemical models were implemented using PHREEQC software of the US Geological Survey, while the model input files were generated using Microsoft Excel. Model input files were provided in Excel file format for each model, along with an Adobe Acrobat (.pdf) printout of the PHREEQC model input (.pqi) file. Further to this, a number of sensitivity scenarios (12 for the DSF and 60 for the underground mine) were provided in Excel and .pdf file format.

The associated PHREEQC model input (.pqi), PHREEQC model output (.pqo), run log (phreeqc.log) and thermodynamic database (.dat) files were not provided.

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[1] SRK Consulting. 2020. A Geochemical Characterisation Report for the Curraghinalt Gold Deposit, Northern Ireland. Prepared for Dalradian Gold Limited. October 2020

[2] SRK Consulting. 2020. Waste Management Plan for the Curraghinalt Project, County Tyrone, Northern Ireland. Prepared for Dalradian Gold Limited. Appendix B3 to the FEI2 Volume 2 Second Addendum to the Environmental Statement. October 2020

Golder Associates (UK) Ltd
Cavendish House, Bourne End Business Park, Cores End Road,
Bourne End, Buckinghamshire, SL8 5AS, UK
Company Registered in England No.1125149
At Attenborough House, Browns Lane Business Park, Stanton-on-the-Wolds, Nottinghamshire NG12 5BL
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T: +44 0 1628 851851 F: +44 0 1628 851852

golder.com

3.0 SUMMARY OF REVIEW COMMENTS

3.1 Modelling software and objectives

The objectives of the geochemical characterisation and modelling programme are described as follows:

- To determine characteristics, implications and potential for Acid Rock Drainage and Metal Leaching (ARDML) from the waste materials from the development proposed under the FEI2 response; and,
- to provide a prediction of future water quality that would result from water contacting these materials.

The predictive geochemical modelling was undertaken using the United States Geological Survey (USGS) thermodynamic code PHREEQC (v3.6.2.15100; Parkhurst and Appelo, 2013)[3].

Golder comment

The contact water quality modelling objectives sufficiently address the requirements of the Environmental Statement[4].

PHREEQC is a standard tool used for source term water quality modelling. PHREEQC version 3 is capable of simulating the equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers, and sorption surfaces, and can also model kinetic reactions and one-dimensional transport. This tool is considered suitable to achieve the outlined modelling objectives.

Conclusion: The modelling software and objectives are considered appropriate.

3.2 Assessment of the Methodology Underpinning the Assessment of Acid Generating Rock and Changes in Water Chemistry

Is the methodology underpinning the assessment of acid generating rock and changes in water chemistry both above and below ground levels and at different phases of the project fit for purpose and representing best practice?

3.2.1 Overall Geochemical Modelling Approach

The approach which was adopted for the numerical calculations undertaken in order to predict contact water quality generated from the Dry Stack Facility (DSF) and underground mine both during mining and post-mining are outlined in Section 10.1 of the report “Geochemical Characterisation Report for the Curraghinalt Gold Deposit, Northern Ireland”[1]. The approach combines the following inputs:

- Geology (defined mass of each rock type);
- Mine design (physical parameters of the mine facilities, e.g. surface area, volume, footprint);
- Groundwater flow estimates (annualized volume of water entering and leaving the underground mine, providing chemical load in and out of the model and used in the definition of reactive mass);
- Groundwater rebound estimates (annualized level of the water table allowing for the definition of the portion of the mine above and below the water table, as well as an annualized interaction thickness of rising groundwater);

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[3] Parkhurst, D. L., & Appelo, C. A. J. (2013). Description of input and examples for PHREEQC version 3: a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations (No. 6-A43). US Geological Survey. https://pubs.er.usgs.gov/publication/tm6A43

[4] SRK Consulting. 2017. Environmental Statement for the Curraghinalt Project, County Tyrone, Northern Ireland. Volumes 1, 2 and 3.

- Surface water estimates (precipitation, runoff, infiltration and drain-down outputs from the mine water balance, used to calculate the reactive mass of material in the DSF);
- Baseline water chemistry (used to calculate groundwater chemical load);
- Rock weathering rates (based on the kinetic test program, used to calculate material release rates); and
- Attenuation (simulated using PHREEQC model with Dzombak and Morrel adsorption coefficients; solubility products for solids held within Minteq database).

Golder comment

- The outlined approach takes into account the different factors typically considered relevant to the generation of acid rock drainage and changes in water chemistry in a mine setting such as the proposed Curraghinalt Project.

Conclusion: The approach is considered appropriate to sufficiently address the requirements of the Environmental Statement[4] and WMP[5].

3.2.2 Assessment of Geochemical Mass Release Rates and Background Water Qualities used in the Models

Section 10.3 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] presents the mass release rates for Waste Rock, Underground Wall Rock, Ore Sorter Rejects and Tailings. It also presents the chemical composition of baseline groundwater and rainwater used in the models.

This section describes the methodology and rationale used to select the portions of kinetic test data which were used to describe chemical mass release from the different mine materials at different locations and stages of the project.

Golder comment

- The described methodology is considered appropriate to develop conservative source terms for the different materials.
- The differentiated treatment of mercury analytical results due to changing limits of detection achieved in the three separate geochemical characterisation studies (2013, 2016 and 2018/19) is considered adequate.
- The presented baseline groundwater and rainwater chemistries are considered appropriate.

Conclusion: The geochemical mass release rates and background water qualities used in the models are considered appropriate.

3.2.3 Assessment of the Thermodynamic Database used in the Models

Section 10.4 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] states that "a modified version of the Minteq.v4 thermodynamic database (Declercq et al 2016)" was used in the PHREEQC models.

Golder comment

- The modified thermodynamic database used in the simulations was not supplied with the model files.

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[5] SRK Consulting. 2020. Waste Management Plan for the Curraghinalt Project, County Tyrone, Northern Ireland. Prepared for Dalradian Gold Limited. Appendix B3 to the FEI2 Volume 2 Second Addendum to the Environmental Statement. October 2020

- The standard Minteq.v4 thermodynamic database is commonly used in mining geochemistry studies.
- Very little detail about the modifications of the Minteq.v4 thermodynamic database is presented in the 2020 Geochemical Characterisation Report. The report only states that "the database was modified to expand the number of mineralogical phases, include sorption data for manganese species together with corrections for weak and strong site adsorption of anions to hydrous ferric oxide".
- The Geochemical Characterisation Report submitted in 2017[6] describes the addition of three arsenic phases commonly occurring in mine sites reporting elevated arsenic content and the modification of the thermodynamic constant of another arsenic phase.
- No further details about the modifications relating to the modification of adsorption of anions to hydrous ferric oxide have been found in any of the submitted geochemistry reports.
- The impact of using a modified instead of a standard Minteq.v4 thermodynamic database in the geochemical models has been assessed in sections 3.4.4 and 3.5.4, differences in the modelling results have generally been found to be small.

Conclusion: The thermodynamic database used in the models is considered appropriate based on the results of the verification runs (see sections 3.4.4 and 3.5.4, below).

3.2.4 Assessment of Mineral and Gas Phase Equilibration used in the Models

Section 10.5 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] describes the mineral equilibrium phases that were allowed to precipitate if they become oversaturated, and the gas phases that interact with the liquid phase. Regarding the suite of minerals chosen, the report first states that it "was based on the geology and mineralisation of the deposit and an understanding of the types of minerals commonly observed in waste rock leachates", and subsequently that "these minerals were selected after preliminary geochemical calculations and/or from mineralogical analysis".

The geochemical model requires the definition of the saturation index above which the mineral phase will precipitate from solution, or below which the phase will dissolve if it is present as a solid in the system. SRK used the theoretical limit (SI = 0) or saturation indices of the secondary phases within the surrounding groundwater when they were above 0 to represent the site-specific conditions.

Equilibrium phases and saturation indices included in the DSF geochemical models are given in Table 10-10, those for the underground mine models are given in Table 10-11.

The report states that pCO_2 and pO_2 were maintained at 60% of the atmospheric values within the DSF and underground models to account for reduced gas flow through the facilities.

Golder comment

- The reasons for selection of the suite of minerals chosen are not presented in a unified manner in the report, but the suite of minerals which have been used is reasonable for the expected geochemical conditions in the simulated facilities.
- The saturation indices of the secondary phases for the DSF model in Table 10-10 and the underground mine in Table 10-11 display significant over-saturation of Manganese (Mn) and Iron (Fe) phases, which may indicate that the redox potential of groundwater assumed in the model calculations is more oxidising

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[6] SRK Consulting. 2017. A Geochemical Characterisation Report for the Curraghinalt Gold Deposit, Northern Ireland. Prepared for Dalradian Gold Limited. November 2017.

than field conditions. This could lead to under-estimation of mineral precipitation of these phases (more conservative results) if redox conditions in the modelled environment are oxidising.

- The postulated reduction of pO_2 and pCO_2 to 60% of atmospheric values was not implemented correctly in the PHREEQC model files (neither for the DSF nor the underground mine). The partial pressures in the DSF model file for O_2 (SI=-0.65, equivalent to a concentration of 22.4% vs. an atmospheric value of 21%) and CO_2 (SI=-2, equivalent to a concentration of 7940 ppm vs. an atmospheric value of 410 ppm) are higher than stated in the report and higher than atmospheric levels.
- Higher oxygen levels may lead to a higher proportion of the less mobile oxidised species for iron, manganese, arsenic and other redox-sensitive elements (less conservative results). However, even if oxygen levels would be reduced to 13% (0.6 times 21% as postulated in the report) in the simulation, conditions would still be oxic and differences in redox speciation are expected to be minor.
- On the other hand, higher CO_2 levels may cause more acidic conditions which may enhance mobility of metals (more conservative results).
- In the PHREEQC model file of the **DSF Base Case model** (tab “10_ToPhreeqc” in file “3_U7582_DSF_BaseCase_v1.9.xlsx”), the mineral equilibrium phases and saturation indices match the values given in Table 10-10, except for $Sn(OH)_4$ which is included in the PHREEQC model file with an SI of 0.6, but not shown in Table 10-10. It is unclear why this solid phase has been included.
- The equilibrium phases and saturation indices for the underground models given in Table 10-11 do not match the list in the **underground mine Base Case operational model** (tab “8_LOM_ToPhreeqc” in file “3_U7582_UG-Adit_BaseCase_v1.11.xlsx”). The list in the model file contains most mineral phases from Table 10-10, and some from Table 10-11, but all SI values are set to zero. No explanation is given for this discrepancy.
- For the **underground mine Base Case closure model** (tab “8_Closure_ToPhreeqc” in file “3_U7582_UG-Adit_BaseCase_v1.11.xlsx”) and the **underground mine Base Case Adit model** (tab “8_Adit_ToPhreeqc” in file “3_U7582_UG-Adit_BaseCase_v1.11.xlsx”), the list of equilibrium phases matches those given in Table 10-11, except for Anglesite ($PbSO_4$) which is listed in Table 10-11 but not used in the PHREEQC model (this omission leads to more conservative predictions). However, the saturation indices of several minerals with SI>0 do not match. No explanation is given for this discrepancy.

Conclusion: Despite the noted discrepancies between the mineral lists in the report tables and the actual PHREEQC model files, the minerals and saturation indices which have been used in the PHREEQC model files are considered reasonable for the simulated facilities.

3.2.5 Assessment of Adsorption Reactions Implemented in the Models

Section 10.6 of the 2020 “Geochemical Characterisation Report for the Curraghinalt Gold Deposit”[1] describes the adsorption reactions implemented in the PHREEQC models. The models assume that trace metals may be removed from solution via sorption onto freshly precipitated ferrihydrite.

Golder comment

- Adsorption of trace metals onto ferrihydrite is commonly observed in mining-impacted settings and inclusion into the geochemical models is considered appropriate.

Conclusion: The adsorption reactions implemented in the models are considered appropriate.

3.2.6 Assessment of Model Assumptions and Limitations

Section 10.6.1 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] describes the model assumptions and limitations.

Golder comment

- The model assumptions and limitations described in this section are considered appropriate for the conceptual settings of the Curraghinalt DSF and underground mine.

3.3 Assessment of Guidelines Considered

Section 10.7 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] summarises the set of water quality screening and target values developed by SRK against which the predicted source terms have been assessed. These are presented in Table 10-12 of the report for the following categories:

1) Screening level for protection of groundwater: Proposed Infrastructure Area during operations and following closure;
2) Screening level for protection of groundwater: Proposed Infrastructure Area including long-term liner degradation via stress crack development;
3) Groundwater Target: Proposed Mine Area;
4) Screening level for protection of groundwater: Proposed Mine Area during closure;
5) Drinking Water Standards;
6) Average Baseline Data Curraghinalt Burn (outliers removed); and
7) Screening Level for the Protection of Surface Water.

Golder comment

- The guidelines and methodologies applied to derive target values and screening levels are considered appropriate.

3.4 Validity of Key Assumptions and Conclusions – Dry Stack Facility

The validity of key assumptions and conclusions for each conceptual model and computer model associated with the DSF is discussed in each of the following sections.

3.4.1 Conceptual Model

The conceptual model for the DSF during life of mine (LOM) and post-closure are presented in Section 10.2.1 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1].

The conceptual model takes into account that the DSF will contain dry stacked tailings, non-acid generating waste rock and ore sorter rejects, and will be built in three consecutive cells which will be progressively rehabilitated throughout the mine life. The conceptual model presented provides a description of waste material masses, volumes and footprints; water flows which interact with the wastes and mobilise chemical mass; gas exchange and the effects of progressive rehabilitation.

Golder comment

- The descriptions provided for the conceptualisation are in line with what would be expected for the DSF setting and are considered adequate.

3.4.2 Numerical Model Development

Section 10.4.1 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] presents the overall approach applied to predicting the DSF seepage quality, particularly the scaling factors which were used to predict solute release rates at field scale (R_{field}) from laboratory kinetic test release rates (R_{lab}). The following scaling factors (from Kempton, 2012) were used:

$$R_{field} = R_{lab} \times SF_{size} \times SF_{moist} \times SF_{contact} \times SF_{Temp} \times SF_{O2}$$

where

- SFf_{size} represents grain size effects;
- SF_{moist} represents a reduction in oxidation in the case of a severe lack of water; this factor is not relevant in this setting and is set to 1;
- $SF_{contact}$ represents the amount of material in contact with water that can also be mobilised/flushed;
- SF_{Temp} is the temperature scaling factor; and
- SF_{O2} represents the reduction in the field oxidation rate caused by the limited O_2 availability in the pore gas.

Different scaling factors have been determined for tailings material, waste rock and ore sorter rejects, as well as depending on the absence (open conditions) or presence of a cover (closed conditions).

A summary of the individual scaling factors and resulting overall scaling factors for the different materials with and without a cover is presented in Table 10-9 of the Geochemical Characterisation Report.

Golder comment

- The approach described by Kempton (2012) is widely used in mine waste geochemistry for the prediction of mine contact water quality based on scaling of laboratory data to field conditions.
- The individual scaling factors for the different effects and materials are considered reasonable for the simulated settings.
- The combined scaling factors for open and closed waste rock, open and closed ore sorter rejects and open and closed tailings are considered appropriate.

Conclusion: The approach applied to predicting the DSF seepage quality is considered appropriate.

3.4.3 Assessment of associated levels of uncertainty and sensitivity analysis of the inputs and outputs

The 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] presents DSF modelling results of source term concentrations predicted for a "Base-Case" scenario (Section 11.1.1) and for ten sensitivity scenarios (Section 11.2). These are summarised in Table 1.

Table 1: Summary of base case scenario and sensitivity scenarios presented for the DSF

Results Table	Table Title
Table 11-5	Summary of the Base Case Results for the DSF Model
Table 11-8	Summary of the Case Results without Thermodynamic Calculations for the DSF Model
Table 11-11	Summary of the Results without Surface Complexation Calculations Case Results for the DSF Model

Results Table	Table Title
Table 11-18	Summary of the x 0.5 Scaling Factor Case Results for the DSF
Table 11-19	Summary of the x 2 Scaling Factor Case Results for the DSF
Table 11-30	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (Average All Results)
Table 11-31	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (Max Average Results)
Table 11-32	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (Max All Results)
Table 11-33	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (Ore Sorter Global Composite)
Table 11-34	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (Ore Sorter ROM Composite)
Table 11-35	Predicted Mine Water Composition for the DSF Obtained using the Variation in HCT Inputs (T17 Vein Tailings Sample)

The Summary section 11.2.6 of the sensitivity analysis highlights the following aspects:

- *“The predictions are resilient to change in scaling factors for both the underground mine and DSF*”.
- “*In terms of hydrogeological modelling, … light of the timescale considered … it appears that climate change impacts are minor against the predicted base case scenario.”*
- *“A more significant effect is the geochemical release rate inputs (HCT and MLT), especially in terms of mercury and chromium VI. This highlights the need for an ongoing waste characterisation programme…”*
- *“The particular focus is to ascertain if hazardous substances (As, Cr(VI), Hg and Pb) would be caused to exceed the proposed guideline values. As observed above, this is possible if there is significant deviation from the current base case scenario in terms of material reactivity and parameters contributing to the scaling factors definition (e.g. particle size distribution). Should variation of an order of magnitude or more be observed then the predictive modelling should be repeated to confirm compliance.”*

Golder comment

- A screening of the tabulated results suggests that generally, the lowest source term concentrations were obtained in the sensitivity scenario “x 0.5 Scaling Factor Case” (Table 11-18), and the highest source term concentrations in the sensitivity scenario “Variation in HCT Inputs (Max All Results)” (Table 11-32).

Conclusion: The scenarios and parameter variations which have been simulated are considered appropriate to assess the sensitivity of DSF model outcomes to variations in the input parameters.

3.4.4 Verification Runs

This section presents confirmation of which model runs were analysed/ re-run and opinion on how relevant/ adequate each model is or what their shortcomings/ limitations are.

The following Excel and PHREEQC model files of the DSF were opened and run for verification purposes:

- DSF Base Case (file 3_U7582_DSF_BaseCase_v1.9.xslx, tab "10_ToPhreeqc"), SRK results presented in Table 11-1 of the report.
- DSF Sensitivity Case without Surface Complexation Calculations (files 11_U7582_DSF_BaseCase_v1.9_NoSC.xslx and .pdf), SRK results presented in Table 11-11 of the report.
- DSF Sensitivity Case using x2 Scaling Factor (files 8_U7582_DSF_BaseCase_v1.9 - x2.xslx and .pdf), SRK results presented in Table 11-15 of the report.

Golder comment

- As the modified Minteq thermodynamic database was not provided, the models were run using the standard Minteq.v4 database which is included in the PHREEQC version 3 release. No significant discrepancies between the tabulated results and the verification runs were detected, despite the presumed differences between the thermodynamic databases.
- It is noted that for the Base Case DSF model, no ferrihydrite precipitation is predicted for any stage of mine development. Therefore, no surface complexation reactions can occur, because they would require the presence of ferrihydrite. Accordingly, the results of the Sensitivity Case without Surface Complexation Calculations (Table 11-11) should be the same as the Base Case (Table 11-5). Results for seepage are identical, but results for runoff are not. The reason for this discrepancy may relate to the application of different SI values for O_2 and CO_2 in the Sensitivity Case without Surface Complexation Calculations compared to the Base Case.
- For the Sensitivity Case using x2 Scaling Factor (file "8_U7582_DSF_BaseCase_v1.9 - x2.xlsx"), no significant discrepancies between the tabulated results and the verification runs were detected.

Conclusion: The verification runs are considered satisfactory.

3.4.5 Assessment of Key Model Reported Conclusions

The main conclusions regarding the DSF Base Case model are presented in Section 11.1.1 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1]. The Base Case source term chemistry results are shown in Table 11-1 of the report and are compared to the proposed screening values for the surface and groundwater:

- This comparison indicates that the runoff source term predictions are below the proposed screening values for surface water.
- For the infiltration source term, exceedances during LOM are predicted with respect to nitrate, arsenic, antimony and molybdenum. However, it is noted that water infiltrating the DSF will be captured by the liner and treated during LOM. For post closure, an exceedance of the Screening Level for the Protection of Surface Water is predicted for molybdenum.

Golder comment

- These key conclusions are valid for the values presented in the table.

Conclusion: These key conclusions are considered appropriate.

3.5 Validity of Key Assumptions and Conclusions – Underground Mine

This section describes each conceptual model and computer model summarising key assumptions and opinion on whether they are correct, incorrect or insufficient.

3.5.1 Conceptual Model

The conceptual model for the underground mine during life of mine (LOM) and post-closure are presented in Section 10.2.2 of the 2020 “Geochemical Characterisation Report for the Curraghinalt Gold Deposit”[1].

The conceptual model takes into account that the mine will be progressively backfilled as it develops. The backfilled material is composed of waste rock (including all PAG material), ore sorter rejects and cemented paste tailings (including all high sulphur material).

During LOM, the area will be dewatered and water infiltrating the underground mine will be pumped and treated. Post closure, the mine will be fully backfilled, and the dewatering will stop. Groundwater rebound to pre-mining level is estimated to take 15 years, but it is anticipated that some elements of the underground mine will lose hydrogeological containment between year 3 and year 7. At this stage, mine water will start discharging into the surrounding strata. As the groundwater rebounds, it will mobilise any unflushed available solutes generated in the interim between the end of mine life and the rebound.

The conceptual and numerical models differentiate between the portion above and below the level 168 m, because the adit at this level will remain open after closure. The portion of the mine above the level 168 will drain to the adit in perpetuity. This upper portion is considered to remain oxygenated and free draining. In the portion of the mine located below the level 168, mine water rebound will occur; this portion is considered not to be in equilibrium with atmospheric gases.

The conceptual and numerical models consider a first flush effect where soluble weathering salts are formed by the inflow of groundwater on the wall, paste backfill and backfilled waste rock, which are mobilised during the rebound phase post-closure.

Golder comment

- The descriptions provided for the conceptualisation take into account the key effects that are typically considered for underground mine settings such as the Curraghinalt project.

Conclusion: The conceptual model is considered appropriate.

3.5.2 Numerical Model Development

The numerical model simulates geochemical interactions between water entering the mine workings with the following reactive masses:

- the mine workings surface;
- the backfilled waste rock;
- the backfilled ore sorter rejects; and
- the cemented paste backfill.

The degree of reaction is dependent on the extent of water and oxygen penetration within the material. During operations, the mine workings surfaces have been exposed to oxygenated conditions and have weathered to form secondary minerals, including soluble salts. These soluble salts and other weathering products will dissolve into waters entering the mine workings, both during the remaining life of mine and post-closure.

To calculate mass release from the mine workings surfaces, the laboratory HCT data is scaled to reflect the mass release of solutes under field leaching conditions, based on estimates of the total mass of material available for leaching in the mine workings surfaces (exposed surface areas and proportion of each material type in the mine workings). This information is coupled with an estimate of the density and thickness of fracturing in the mine walls and a reactive rim or 'oxidized rind' of 0.012 m thickness, to calculate a mass of reactive rock.

The reactive mass of the paste backfill is defined as a reactive interface between the paste and the wall rock. The report states that for the Base Case, this reactive interface is estimated based on a reactive thickness of one centimetre over the surface area of the paste backfilled portions of the underground mine, a fracture density of 5%, and a paste density of 2,010 kg/m^3.

The scaling factor considered for the backfilled waste rock is the same as that considered for the waste rock within the surface facilities.

No information is given about the methodology applied to estimate solute mass release from ore sorter rejects.

Golder comment

- The implementation of the conceptual and numerical approach was reviewed based on the Base Case model (3_U7582_UG-Adit_BaseCase_v1.11.xlsx).
- In the calculation of mass release from the mine workings surfaces, the Excel spreadsheet (tab "01_Mine Design") appears to include only mass release from waste lithologies, not from veins that are exposed on the mine walls. The geochemical characteristics of vein material are not discussed in the report, but the average proportion of veins in the total waste tonnage is only about 4%. Therefore, the impact of this omission is expected to be small compared to the overall uncertainties in the upscaling process.
- The justification of the thickness of the reactive rim or 'oxidized rind' 0.012 m on the surfaces of rock fragments cites SRK (2008). This reference is missing in the final list, and has therefore not been verified. However, based on professional experience, this value is within the expected range of reaction depth, and the lack of a citation is not a major concern.
- The description provided for calculation of mass release from paste backfill suggests that this is based on the reactive mass of paste. However, tab "00_ReadMe" of the Excel file mentions that in Version 0.4 the calculations were updated to use surface area for paste instead of reactive mass. This approach is implemented on tab "01_Mine Design". The surface area of paste in the mine workings is calculated based on geometric CAD data, and then the reactive surface area of the paste is determined by applying a single scaling factor of 5% to account for fracture density, presumably fractures on the mine wall in contact with the paste. This approach is reasonable.
- In the underground mine Excel model, the temperature scaling factor has not been applied. The report does not explain why this effect has been excluded. This omission leads to more conservative modelling results (higher predicted concentrations).
- The other three scaling factors for backfilled waste rock and ore sorter rejects are similar to those applied to the DSF model.

Conclusion: Despite the minor observations highlighted above, the approach applied to predicting the underground mine water quality is considered appropriate.

3.5.3 Assessment of associated levels of uncertainty and sensitivity analysis of the inputs and outputs

For the underground mine below level 168, the 2020 “Geochemical Characterisation Report for the Curraghinalt Gold Deposit”[1] presents modelling results of source term concentrations predicted for the “Base-Case” scenario (Section 11.1.2) and for 17 sensitivity scenarios (Section 11.2). These are summarised in Table 2.

Table 2: Summary of base case scenario and sensitivity scenarios presented for the underground mine

Results Table	Table Title
Table 11-6	Summary of the Base Case Results for the Underground Mine Water Model
Table 11-9	Summary of the Results without Thermodynamic Calculations for the Underground Mine Water Model
Table 11-12	Summary of the Results without Surface Complexation Calculations Case Results for the Underground Mine Water Model
Table 11-14	Summary of the Results using the Low-end (P10) Hydrogeological Model Results for the Underground Mine Water Model
Table 11-16	Summary of the Results using the high end (P90) Hydrogeological Model Results for the Underground Mine Water Model
Table 11-20	Summary of the Different Scaling Factors for the Underground Mine Water Model (All)
Table 11-21	Summary of the Different Scaling Factors for the Underground Mine Water Model (Waste Rock and Ore Sorter Rejects)
Table 11-22	Summary of the Different Scaling Factors for the Underground Mine Water Model (Paste Backfill and Wall Rock)
Table 11-26	Summary of the Base Case Results with a Fracture Density of 1%
Table 11-28	Summary of the Results with a Fracture Density of 10%
Table 11-36	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in HCT Inputs (Average All Samples)
Table 11-37	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in HCT Inputs (Max All Samples)
Table 11-38	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in HCT Inputs (Max Average)
Table 11-39	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in MLT Inputs (Global Composite 1:1)
Table 11-40	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in MLT Inputs (Global Composite 2:1)

Results Table	Table Title
Table 11-41	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in MLT Inputs (Global Composite 3:1)
Table 11-42	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in MLT Inputs (Rougher yr 7+ : Scavenger yr 7+ at 2:1 ratio)
Table 11-43	Predicted Mine Water Composition for the Underground Mine Water Model Obtained using the Variation in MLT Inputs (Rougher yr 7+ : Scavenger yr 7+ at 3:1 Ratio)

For the underground mine adit, the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1] presents modelling results of source term concentrations predicted for the "Base-Case" scenario (Section 11.1.2) and for 17 sensitivity scenarios (Section 11.2). These are summarised in Table 3.

Table 3: Summary of base case scenario and sensitivity scenarios presented for the underground mine

Results Table	Table Title
Table 11-7	Summary of the Base Case Results for the Underground Mine Adit Model
Table 11-10	Summary of the Results without Thermodynamic Calculations for the Underground Mine Adit Model
Table 11-13	Summary of the Results without Surface Complexation Calculations Case Results for the Underground Mine Adit Model
Table 11-15	Summary of the Results using the Low-end (P10) Hydrogeological Model Results for the Underground Mine Adit Model
Table 11-17	Summary of the Results using the High End (P90) Hydrogeological Model Results for the Underground Mine Adit Model
Table 11-23	Summary of the Different Scaling Factors for the Underground Mine Adit Model (All)
Table 11-24	Summary of the Different Scaling Factors for the Underground Mine Adit Model (Waste Rock and Ore Sorter Rejects)
Table 11-25	Summary of the Different Scaling Factors for the Underground Mine Adit Model (Paste Backfill and Wall Rock)
Table 11-27	Summary of the Mine Adit Model Results with a Fracture Density of 1%
Table 11-29	Summary of the Mine Adit Model Results with a Fracture Density of 10%
Table 11-44	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in HCT Inputs (Average All Samples)
Table 11-45	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in HCT Inputs (Max All Samples)

Results Table	Table Title
Table 11-46	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in HCT Inputs (Max Average)
Table 11-47	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in MLT Inputs (Global Composite 1:1)
Table 11-48	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in MLT Inputs (Global Composite 2:1)
Table 11-49	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in MLT Inputs (Global Composite 3:1)
Table 11-50	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in MLT Inputs (Rougher yr 7+ : Scavenger yr 7+ at 2:1 ratio)
Table 11-51	Predicted Mine Water Composition for the Underground Mine Adit Model Obtained using the Variation in MLT Inputs (Rougher yr 7+ : Scavenger yr 7+ at 3:1 Ratio)

The Summary of the sensitivity analysis (Section 11.2.6 of the 2020 Geochemical Characterization Report) discussed above in Section 3.4.3 applies to both the underground mine and DSF and is not repeated here.

Golder comment

- A screening of the tabulated results suggests that generally, both for the mine below level 168 and the adit, the lowest source term concentrations were obtained in the sensitivity scenario “Fracture Density of 1%” (Table 11-27 and Table 11-28), and the highest source term concentrations in the sensitivity scenario “Variation in HCT Inputs (Max All Samples)” (Table 11-37 and Table 11-45).

  Conclusion: The scenarios and parameter variations which have been simulated are considered appropriate to assess the sensitivity of underground mine model outcomes to the input parameters.

3.5.4 Verification Runs

This section provides confirmation of which model runs were analysed/ re-run and opinion on how relevant/ adequate each model is or what their shortcomings/ limitations are.

The following Excel and PHREEQC model files of the underground mine were opened and run for verification purposes:

- Underground mine below level 168 Base Case for Life of Mine (files 3_U7582_UG-Adit_BaseCase_v1.11.xslx [tab 08_LOM_ToPhreeqc] and 3_U7582_UG_LOM_BaseCase_v1.11.pdf), full SRK results presented in Table 11-2 of the report;
- Underground mine below level 168 Base Case for Closure (files 3_U7582_UG-Adit_BaseCase_v1.11.xslx [tab 08_Closure_ToPhreeqc] and 3_U7582_UG_Clsoure_BaseCase_v1.11.pdf), full SRK results presented in Table 11-3 of the report;
- Underground mine adit Base Case for Closure (files 3_U7582_UG-Adit_BaseCase_v1.11.xslx [tab 08_Adit_ToPhreeqc] and 3_U7582_Adit_Clsoure_BaseCase_v1.11.pdf), full SRK results presented in Table 11-4 of the report; and

- Underground mine Adit Sensitivity Case with a Fracture Density of 1% (files 34_U7582_UG-Adit_BaseCase_v1.11-0.001FD.xslx and 34_U7582_Adit_Closure_BaseCase_v1.11-0.001FD.pdf), SRK results presented in Table 11-27 of the report.

Golder comment

- As the modified Minteq thermodynamic database was not provided, the models were run using the standard Minteq.v4 database which is included in the PHREEQC version 3 release. The following seven equilibrium phases had to be excluded from the model to be able to run the simulations: Cassiterite, Conichalcite, Dawsonite, Fluorapatite, Mg-Gypsum, Mn(OH)3, Pharmacolite;
- The largest relative differences in predicted concentrations between the values reported by SRK and those calculated using the standard Minteq.v4 database are observed (in decreasing order) for P, As, V, F, Sn.
- All other simulated parameters typically display differences of less than ±1% between the standard Minteq.v4 database and SRK's modified database.
- These differences indicate that the modifications to the thermodynamic database have a minor or negligible impact for most simulated elements. The elements with higher differences in predicted concentrations are not considered contaminants of major concern for the Curraghinalt deposit.
- For the Base Case underground mine model, ferrihydrite precipitation does occur. Therefore, surface complexation reactions can occur in the underground mine model, but as discussed in Section 11.2.2 of the report, the effect is very subtle compared to the effect of the precipitation of secondary mineral phases.
- The Sensitivity Case which is stated to represent a decrease of the fracture density from 5% to 1% in fact represents calculations for a fracture density of 0.1%. Even this decrease by two orders of magnitude decreases predicted solute concentrations by only a factor of about 3.

Conclusion: Despite the minor observations highlighted above, the verification runs are considered satisfactory.

3.5.5 Assessment of Key Conclusions

The main conclusions regarding the underground mine Base Case model are presented in Section 11.1.2 of the 2020 "Geochemical Characterisation Report for the Curraghinalt Gold Deposit"[1]. The Base Case source term chemistry results of the underground mine below level 168 are shown in Table 11-2 of the report for LOM and in Table 11-3 of the report for closure. Adit closure water quality draining from above the level 168m is given in Table 11-4. The simulated concentrations are compared to the proposed screening values for the surface and groundwater:

- The predicted mine water chemistry during the life of mine (LOM) exceeds groundwater screening values for several parameters including ammonia, nitrate, arsenic, chromium (IV), mercury, molybdenum, lead, antimony, thallium and uranium. During LOM, it is understood that the water will be pumped and treated.
- For the post closure simulations of the underground mine below level 168m, no exceedances with respect to hazardous substances are predicted. The predicted chemistry indicates exceedances with respect to the groundwater screening values for ammonia (until year 9), nitrate (year 6), molybdenum (year 2), and antimony (year 10). Exceedances with respect to the surface water screening values are expected for ammonia (7 years), nitrate (3 years), antimony (3 years) post closure and for manganese after year 19. As no water is expected to discharge from the underground mine below level 168m to surface until year 15 post-closure, only manganese will show exceedances with respect to surface water screening levels for all of the modelled years post closure.

- For the predicted adit chemistry post closure of water draining from above the level 168m, nitrate, molybdenum and antimony are predicted to exceed the surface water screening values until year 1, 7 and 12 respectively. After year 19, the rebounding water emanating from the adit causes a manganese exceedance with respect to surface water screening values.

Golder comment

- These key conclusions are valid for the values presented in the tables.

Conclusion: The key conclusions are considered appropriate.

4.0 ASSESSMENT OF COMPLIANCE OF THE PREDICTED OUTCOMES WITH REGULATION 9 & 10 AND THE EC DIRECTIVES REFERENCED WITHIN

DfI questions

Do the predicted outcomes resulting from the assessment of acid generating rock and changes in water chemistry both above and below ground levels, at different phases of the project, demonstrate compliance with regulation 9 & 10 and the EC Directives referenced within?

What do the outcomes from the models mean in terms of compliance with regulation 9 & 10 and the EC Directives referenced within it?

Golder comment

During mine operation, contamination risks for surface and groundwater will be managed by means of active water treatment. The Base Case simulations indicate that after closure, contact water from the underground mine may exceed surface water and/or groundwater screening values for ammonia, nitrate, molybdenum, antimony and manganese. Particularly manganese may require long-term management by active or passive treatment.

For DSF contact water, only molybdenum is predicted to exceed surface water screening values after closure in the Base Case simulations, and may require long-term management by active or passive treatment.

These considerations are addressed in more detail in the Surface and Groundwater Impact Assessment reports.

5.0 ASSESSMENT OF MODEL ASSUMPTIONS AND LIMITATIONS

DfI questions

What impact do the limitations of the model have on assessment of environmental impacts as per compliance with regulation 9 & 10 and the EC Directives referenced within?

Golder comment

A number of uncertainties are associated with the PHREEQC models, as with any model. These relate, inter alia, to the conceptualisation and parameterisation of the models. The range of predictions has been estimated using a number of sensitivity scenarios which cover a wide range of parameter uncertainties. The sensitivity runs demonstrate that other parameters than those mentioned in the previous sections may exceed the screening values under certain circumstances and may require management during or after mine operation.

6.0 SUITABILITY OF SOURCE TERM WATER QUALITY MODELS (FIT FOR PURPOSE)

DfI questions

Is the methodology underpinning the assessment of acid generating rock and changes in water chemistry both above and below ground levels at different phases of the project ***fit for purpose and represent best practice****?*

Are additional model scenarios/ other models recommended?

What additional information is required?

Is other modelling software recommended?

Which worse-case scenarios need to be assessed, if any?

Golder comment

Despite minor issues and discrepancies highlighted in the preceding sections, the methodology underpinning the assessment of acid generating rock and changes in water chemistry both above and below ground levels at different phases of the project is considered fit for purpose and to represent best practice.

7.0 CONCLUSION AND RECOMMENDATIONS

The methodology and results of the modelling of contact water qualities from the proposed Curraghinalt project underground mine and associated infrastructure as described in the 2020 Geochemical Characterization Report are considered appropriate for use in the water quality models and impact assessments for the proposed Curraghinalt project.

[redacted]

[redacted]

[redacted]