APPENDIX C
ARD ONSET AND TABLES

Model Sensitivity to ARD Lag Time

NRCan requested that Marathon "provide rationale for the methods used to determine the lag time to acidic conditions, and a discussion around the sensitivity of the water quality model to the assumptions related to this assumed lag time". In a call on (March 22, 2021), NRCan expressed concerns about estimates of lag time to acidic conditions without kinetic tests being conducted on several potentially acid generating (PAG) samples. The objectives of this memorandum are to:

- provide rationale for the methods used to determine the lag time to acidic conditions and estimate on the possible ranges of ARD onset lag time for exposed PAG materials
- assess and discuss sensitivity of the water quality model to ranges of ARD onset lag time

ARD Onset Time

The determination of the lag time to acidic conditions is based on Equations (1) and (2), which are consistent with MEND (2009).

Neutralization Potential (NP) Depletion Rate = Sulphate Leaching Rate*100.09/96.06 + Alkalinity Production Rate – Acidity Production Rate (1)

ARD onset time = (Carb. NP/ NP Depletion Rate) x 1000/(365.25/7) (2)

The following steps were used to derive conservative inputs from existing humidity cell tests (HCT) tests for use in Equations (1) and (2).

a. Leaching Rates Calculation

Sulphate leaching and alkalinity production rates are required for inputs into Equation 1. These rates are straight calculations from laboratory humidity cell testing results without any scaling to field conditions. The calculation of sulphate leaching rate for a specific week is shown as an example in Equation 3:

Sulphate Leaching Rate (mg/kg/week) = Sulphate Concentration (mg/L) x Leachate volume (L)/Samples mass (1kg)/Leaching time (1 week) (3)

The maximum concentrations from the first month (week 1 to 4) of testing were used as inputs to Equation 3 resulting in the highest rates listed in Table 1 (attached). The highest sulphate production and NP depletion rates using direct HCT data result in the shortest lag time estimates for ARD, which is a conservative approach.

b. Leaching Rate Regressions with Sulfur and NP

The next step was to evaluate the correlation between maxima sulphate and maxima alkalinity leaching rates with sulphur contents and NPs, respectively.

A linear regression for maximum sulphate leaching rates versus sulphur contents results in an good R^2 considered valid for general predictive use. Note that the reported R^2 was obtained after removal of one outlier, sample M MD (Figure 1). This sample showed an order of magnitude higher sulphate production rate likely due to over crushing of the sample resulting in higher reactive area. The regression equation (Equation 4) was used to estimate sulphate leaching rates from PAG samples with known sulphur content, which are provided in Table 2 (attached). A similar approach has been presented in Environmental Impact Statements (EISs) for other Canadian mine projects (e.g., SRK 2006, 2013).

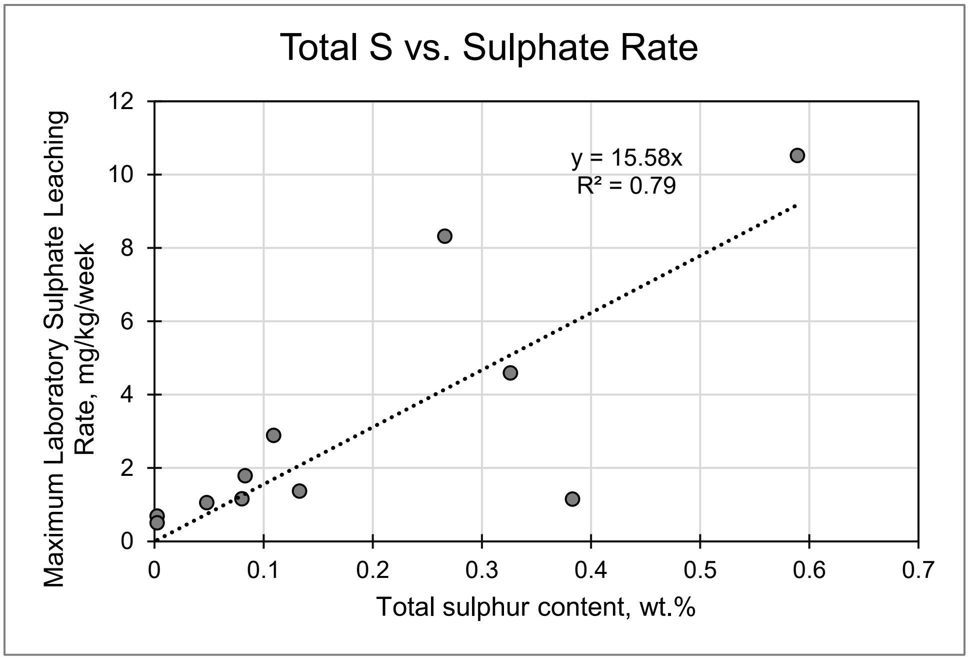

Figure 1 Regression of total sulphur vs. maximum sulphate leaching rate from laboratory humidity cells.

Sulphate Leaching Rate (mg/kg/week) = 15.6*Sulphur Content (wt%) (4)

Maximum alkalinity leaching rates do not show good correlation with NP even after removal of apparent outliers shown in red on Figure 2. Therefore, the 95th percentile of maximum alkalinity leaching rates (67.7 $mgCaCO_3$/kg/week) was conservatively selected for input into Equation 1 regardless of NP of a PAG sample.

The Acidity Production Rate was ignored in Equation 1 resulting in the shortening lag time estimates for ARD, which is a an additionally conservative assumption. Considering inputs and assumptions discussed above, the resulting calculation of NP depletion rate for each PAG sample was done using Equation 5.

NP Depletion Rate ($mgCaCO_3$/kg/week) = 15.6*Sulphur Content (wt%)*100.09/96.06 + 67.7 (5)

Examination of the sulphur inputs into this equation clearly shows than the first term of Equation 5 is an order of magnitude lower than the second term, alkalinity production rate. The second term is a constant and the NP Depletion Rate does not vary much between samples as shown in Table 2 (attached).

Therefore, the NP of a sample becomes the key factor determining ARD onset time in the sample per Equation 2.

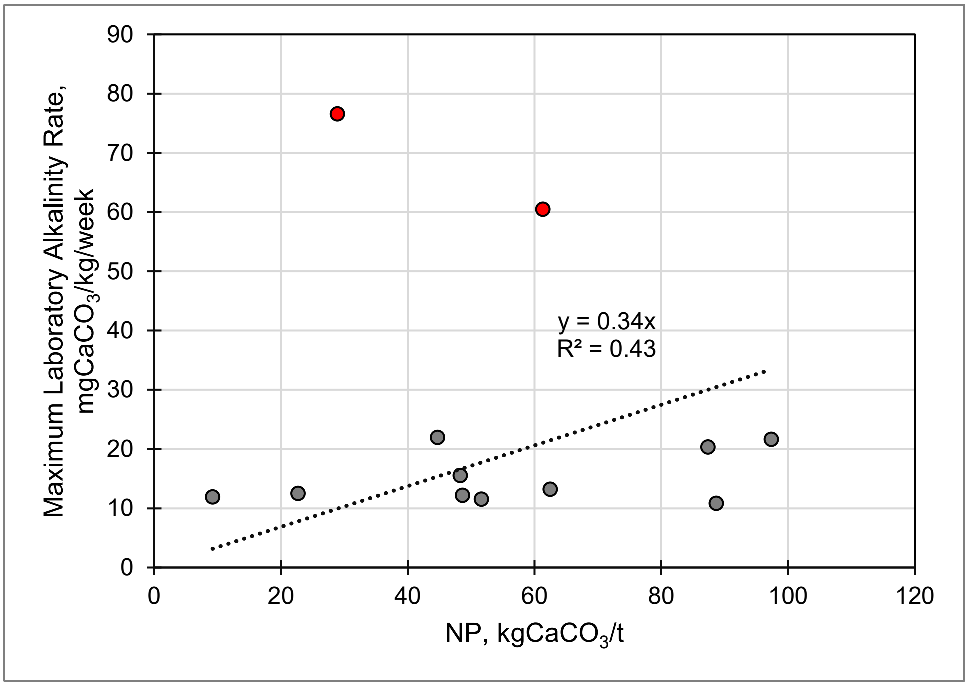

Figure 2 Regression of NP vs. maximum alkalinity rates from laboratory humidity cells.

c. Calculation of ARD Onset Time

Time to onset of ARD was calculated for all PAG samples from the Marathon deposit using Equation 2 (Table 1). Minimum, median, and maximum values are shown in Table 3 (attached) for the following three groups of samples:

- high grade ore
- low grade ore
- waste rock

The estimates of ARD onset time determined are conservative because the estimates are based on the laboratory rates. Laboratory derived rates are faster than the respective field rates, which, if field rates were applied, could result in a more realistic estimation of the ARD lag time. This is demonstrated in Table 1 (attached) by comparison of the recent field test results to the laboratory results for the same sample of low grade ore (MLGO-Met) with an uncertain ARD potential. Field based ARD onset time (200 years) is approximately 30x longer than the ARD onset time (6.3 years) calculated using laboratory-based inputs for this sample. Nevertheless, the conservative ranges of ARD onset time were used for sensitivity analysis of the water quality model.

Water Quality Model Sensitivity

ARD onset time lags were considered a probabilistic input parameter with triangular probability distributions in both the EIS (original) and sensitivity (models). In the original GoldSim model, one probability distribution was used to represent acidic rates in all mine components (Figure 3). In the sensitivity model for Marathon site, a separate probability distribution of ARD onset was assigned to ore, low grade ore and waste rock in accordance with statistics from Table 3 (attached).

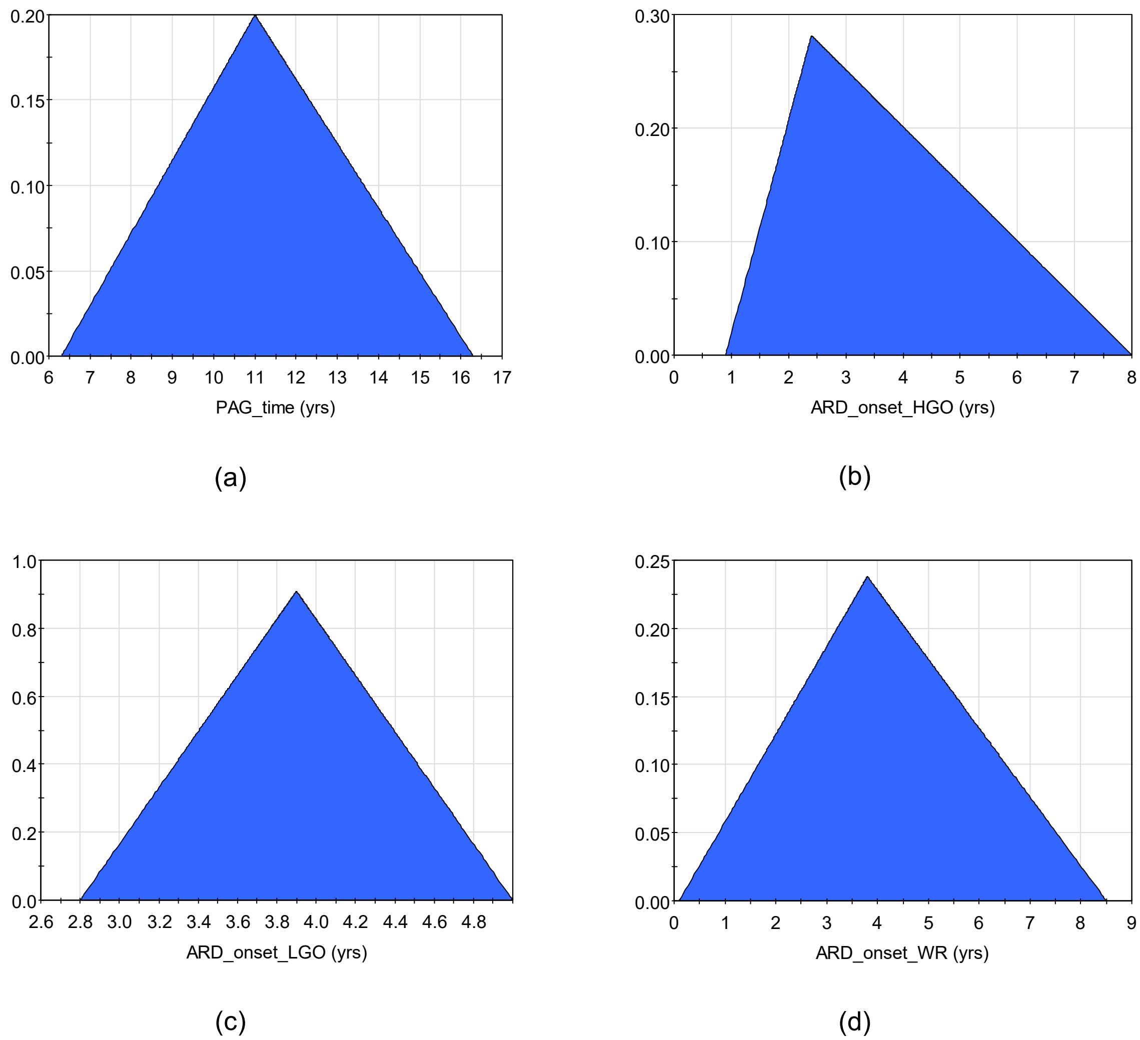

Figure 3 Probability distributions for ARD onset time in the EIS model for all materials (a) and the sensitivity model for ore (b), low grade ore (c), and waste rock (d).

The results obtained for the low-grade ore stockpile, waste rock, and open pit are provided in Tables 4 to 12 (attached). For each of these mine facilities, three tables are presented: 1) original results from the EIS model; 2) new results from the sensitivity model, and 3) ratios of new results to the original results. Ratios greater than 1.2 are highlighted in gray in the tables indicating a substantial increase from the original result. The key increases can be summarized as follows:

- In the LGO stockpile, up to 3.1x for Zn and 1.5x for Ni during operation. Concentrations of these metals were below MDMER limits at 95% confidence levels.
- In the waste rock stockpile, up to 1.4x for Zn and 1.3x for Ni during operation and up to 1.3x for Zn during closure. In both phases of the mine life cycle, concentrations of these metals were below MDMER limits at 95% confidence levels.
- In mine water from the pit, up to 2.4x for Ni, up to 2.2x for Zn, and 1.3x for Cd is predicted during operation. In the pit lake, an increase in concentration up to 1.21x for Zn during closure. In both phases of the mine life cycle, concentrations of Ni and Zn were below MDMER limits and Cd concentration was below the short-term Canadian Water Quality guideline at 95% confidence levels.

Overall model results show that faster ARD onset times result in an increase of average concentrations of Zn, Ni, and Cd generally during operation and less so in closure. Other parameters were less impacted because of lower or no multiplier for acidic leaching rates as noted in Section 5.3.1.1 in Appendix 7B of the EIS.

pH of LGO Seepage

The water quality GoldSim model probabilistically assumes that pH in the low grade ore stockpile will be between 7.5 and 8.5, based on pH measured in humidity cell M-LGO in first week (Figure 3). The validity of this assumption can be tested using alkalinity and acidity rates measured in LGO in normal (M-LGO) and carbonate depleted (M-LGO CNP DPL) humidity cells, respectively. The alkalinity rate is always greater than acidity rate over the testing period (Figure 3). On average, the alkalinity production rate (22.5 mg $CaCO_3$/kg/week) is almost 8x higher than the acidity production rate (2.9 mg $CaCO_3$/kg/week) between weeks 10 and 20, when rates had stabilized in both cells (Figure 3). This observation indicates that there is more than enough alkalinity produced from 50 percent of the non-PAG ore to neutralize acidity generated from 50% of the PAG material. Therefore, a reduction of pH below 6.5 in seepage from LGO stockpile is not expected.

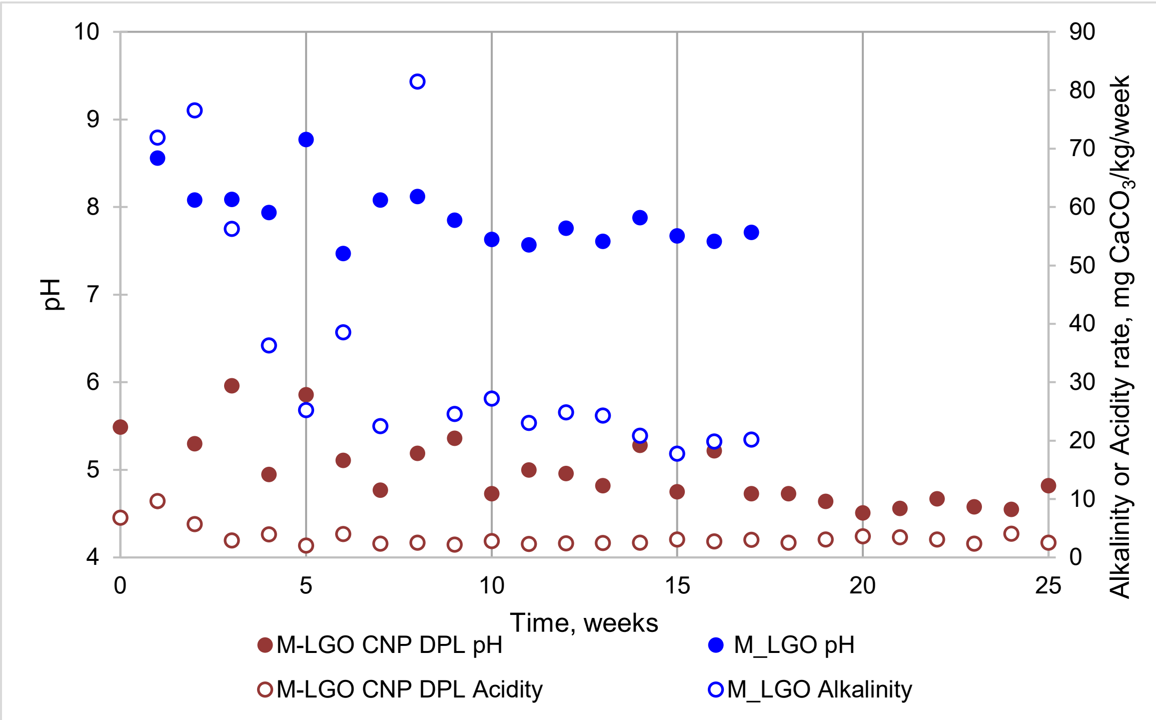

Figure 3 Alkalinity and acidity rates and pH from normal (M-LGO) and carbonate depleted (M-LGO CNP DPL) humidity cells

Summary

Conservative assumptions were made to calculate ARD onset time for PAG samples from the Marathon deposit. These calculations produced conservative (shorter) ARD onset time lags, which were used to address sensitivity of the water quality model predictions. Using a stochastic sampling of these inputs, the model predictions did not exceed the MDMER limits in discharges from the LGO stockpile, waste rock, and open pit over the life of the proposed mine. Therefore, treatment of these discharges is not warranted, which is similar to the conclusion presented in the EIS.

References:

Mine Environment Neutral Drainage Program (MEND), 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials, MEND Report 1.20.1, p. 1-579.

SRK Consulting. 2006. Galore Creek Project ML/ARD Characterization Report. Report prepared for Novagold Resources Inc. SRK Project. 1CR003.002. May 2006.

SRK 2013. Metal Leaching and Acid Rock Drainage Potential Characterization Sisson Project. August 2013.