Appendix E.4

DRAFT Beaver Dam Project: 2020 Kinetic Test Update (IR NSE 2-74) – June 11, 2020 as Completed for the Updated 2021 Beaver Dam Mine EIS

MEMORANDUM

To:	**James Millard**	**Date: June 11, 2020**
From:	**Timo Kirchner & Jennifer Stevenson**	**Project #: A458-7**
Subject:	**Beaver Dam Project: 2020 Kinetic Test Update (IR NSE 2-74) – DRAFT**	

1. Introduction

The Beaver Dam project is a proposed gold mine owned by Atlantic Mining Nova Scotia Corporation (AMNS) who has submitted a revised Environmental Impact Statement (EIS) to the Canadian Environmental Assessment Agency (CEAA) and Nova Scotia Environment (NSE). This memorandum is in response to one of the Round 2 Technical Review Requirements from NSE. Specifically, Information Request (IR) # NSE 2-74 states:

> *As part of the response to this information request, provide an update on the kinetic testing results to date, including discussion of potential acid generating material and metal leaching and if there are potential changes to predictions.*

At the time of the preparation of the Metal Leaching/Acid Rock Drainage (ML/ARD) Assessment Report (Lorax, 2018a) and geochemical source terms (Lorax, 2018b, 2019) in support of the revised EIS, the humidity cell kinetic tests had been running for 24 weeks. Additional data is now available for the humidity cells and is presented in the sections below. A brief summary of the static testing results that was included in Lorax (2018a) is provided in Section 2. Section 3 presents the updated kinetic testing results followed by conclusions based on the new results in Section 4.

2. Kinetic Test Sample Summary

Eight humidity cells were initiated in April 2018 using crushed drill core material and covering median and high sulphur content samples for each of the four lithologies – argillite (AR), argillite-greywacke (AG), greywacke-argillite (GA), and greywacke (GW). The objective of the program is to provide sulphide oxidation and metal leaching rates for a range of sulphide contents and material types under varying pH conditions to be used as input for the geochemical source term model. Six of the humidity cells were terminated in January 2019 after 39 weeks of testing, while HC4 and HC6 are currently ongoing. These two samples were selected since, at the time, they represent the most likely candidates to generate acidic leachate in the near future. This is an important information source for the prediction of long-term waste rock drainage chemistry. All samples used for humidity cell testing were initially characterized by acid-base accounting (ABA) (Table 2-1).

Table 2-1: Summary of acid-base accounting results for humidity cell samples

HC ID	Lithology	Rationale	Paste pH	Total S	Sulphate S	Sulphide S	Total C	CaNP	Modified NP	NPR
				%	%	%	%	kg $CaCO_3$/t	kg $CaCO_3$/t	ModNP/AP
HC1	Argillite	Median sulphur	8.9	0.02	0.02	0.02	*<0.05*	*<4.5*	6	9.6
HC2	Argillite	High sulphur	8.7	0.25	0.015	0.25	*<0.05*	*<4.5*	7.5	1.1
HC3	Argillite-Greywacke	Median sulphur	8.7	0.20	0.02	0.18	0.11	9.1	15	5.6
HC4	Argillite-Greywacke	High sulphur	8.2	0.77	0.015	0.76	*<0.05*	4.5	8	0.45
HC5	Greywacke-Argillite	Median sulphur	8.5	0.21	0.015	0.19	0.18	15	22	11
HC6	Greywacke-Argillite	High sulphur	8.6	0.39	0.015	0.39	*<0.05*	*<4.5*	5.5	0.47
HC7	Greywacke	Median sulphur	9.1	0.03	*<0.01*	0.03	0.2	15.9	23	25
HC8	Greywacke	High sulphur	9.3	0.36	0.03	0.35	0.05	4.5	8	0.74

Notes:

Values in grey italics are below the analytical detection limit. Values were set at the detection limit for calculation of NP, AP, and NPR values.
Sulphate S is calculated using the HCl method.
AP (acid potential) calculated using sulphide sulphur (% non-sulphate sulphur x 31.25).
CaNP (carbonate neutralization potential) calculated using total inorganic carbon (% TIC x (100.09/12.01) x 10).
Modified NP is obtained by the modified Sobek method.
NPR = neutralization potential ratio, calculated as Modified NP / AP.

The four high sulphur humidity cells are classified as potentially acid generating (PAG) based on a neutralization potential ratio (NPR) < 2, including the two tests that are currently ongoing (HC4 and HC6). The four median sulphur humidity cells are not potentially acid generating (NAG) with an NPR > 2. The humidity cell samples were also submitted for total solid-phase elemental analysis. These results were compared to the average upper continental crustal concentrations (AUCCC; Rudnick and Gao, 2014) to identify elements that are enriched in these samples. Elements above 3x the AUCCC include Ag (3 of 8 humidity cells), As (7 of 8), Cu (1 of 8), and Pb (1 of 8). The As content in the four high sulphur humidity cells (HC2, HC4, HC6, and HC8) is above 10x the AUCCC.

3. Updated Kinetic Test Results

Laboratory kinetic test procedures are designed to quantify weathering rates under standardized conditions. Following variable release rates in the initial cycles of testing, the exposed mineral surface will equilibrate, and stable reaction rates can be determined. Humidity cells often require several weeks to approach geochemical stability and reaction rates rarely remain constant on a week-to-week basis. At the time of reporting, HC4 and HC6 have been running for 107 weeks, while the remaining six humidity cells were terminated after 39 weeks.

The leachate pH from all humidity cells that were terminated after 39 weeks of operation has remained circum-neutral (Figure 3-1) falling between 7.1 and 8.6. In general, HC7, which exhibits the highest Modified NP and carbonate content of all samples (Table 2-1), shows the highest pH. HC4 and HC6 show a decreasing trend in pH as per the purpose of their continued operation. HC4 leachate, initially producing pH of ~7.5, has decreased to pH stabilizing just above 3.0 in the most recent weeks of testing. HC6 has decreased from pH 7.6 to values just below 4.0 (Figure 3-1). The alkalinity of these two humidity cells has also shown a decreasing trend to values below detection in recent weeks (Figure 3-1). The other humidity cells exhibit comparable or higher alkalinity relative to HC4 and HC6 up to kinetic test termination. HC1 in particular shows a decreasing, relatively low-alkalinity trend which can be explained by this cell being composed of oxidized material with very low NP and sulphur contents.

Leachate concentrations released by humidity cells are susceptible to changes in the volume of water added and collected at the end of each cycle and hence, concentration data do not provide a strictly quantitative estimate of drainage chemistry. To provide a more functional parameter which can be used to compare results between different humidity cells, sulphate and metal concentrations in mine rock leachate are normalized to the mass of sample in the humidity cell and the volume of leachate collected each week, producing weekly mass loadings ($mg_{solute}/kg_{sample/}wk$).

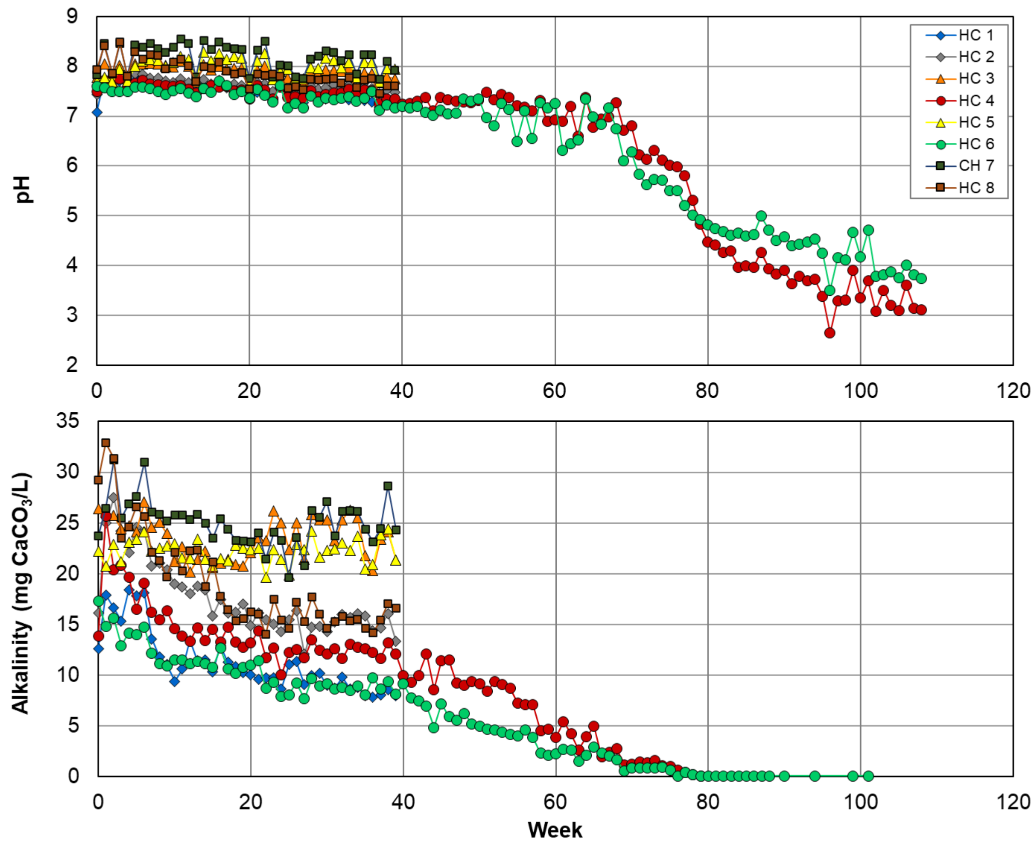

Figure 3-1: pH and total alkalinity in leachates from Beaver Dam humidity cells

All humidity cells show relatively high sulphate loading rates initially, likely due to the flushing of readily-soluble oxidation products or in response mineral liberation due to sample crushing. Sulphate loading rates stabilize by week 15 (Figure 3-2) in the majority of the humidity cells. HC1 and HC7 have the lowest stable sulphate loading rates (~0.4 to 2 mg/kg/wk), due to the low sulphide S content in these samples (0.02% and 0.03%, respectively). HC4, the sample with the highest sulphide S content, produces the highest sulphate loading rate throughout the kinetic test program, reaching values of >100 mg/kg/wk in the most recent test cycles. An increasing sulphate release rate is also evident for HC6, albeit not to the same extent. In both samples, the sulphate release rate is temporally correlated with the drop in pH indicating that sulphide oxidation rates are accelerating in response to the acidification of pore waters. The sulphate loading rates for both of these humidity cells have increased significantly since the original reporting (Lorax, 2018a).

Temporal trends of metal loading rates are provided in Figure 3-3 and Figure 3-4 for selected elements. Solid-phase As, Cu, and Pb (Figure 3-3) were found to exceed 3x the AUCCC, while Cd, Co and Ni (Figure 3-4) represent potential parameters of concern in the receiving environment. All of these species are known to be highly pH-sensitive in aqueous solutions.

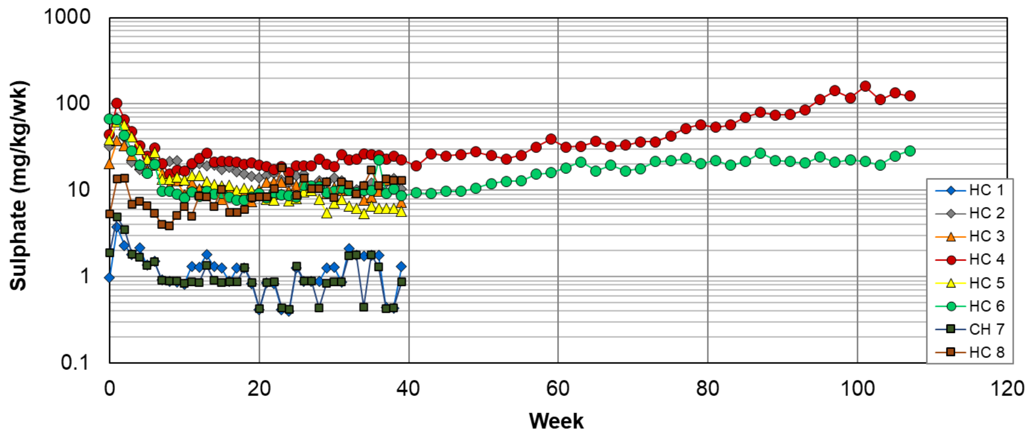

Figure 3-2: Sulphate loading rates for the Beaver Dam humidity cells

The six terminated humidity cells show a decrease in As loading rates over the duration of the experiments to values in the range of approximately 0.005 to 0.01 mg/kg/wk in the later test cycles. Under circum-neutral conditions, HC4 produces the lowest As loading rates of the eight humidity cells with As values remaining below 0.001 after week 19. Following the pH drop at around week 70, a marked increase of As loading rates is observed (Figure 3-3). Although the difference in As loading rates from neutral to acidic conditions in HC6 is less pronounced than for HC4, an increase in As release accompanying the acidification of the system is apparent with loading rates between 0.01 and 0.02 mg/kg/wk being produced. Under neutral conditions, the HC6 sample generated relatively low As leaching rates despite having the highest solid-phase As content (1,833 ppm; Lorax 2018a). These trends illustrate the major effect of pH on As mobility which appears to be at a minimum within a pH range of 6.5-7.5.

The Cu and Pb loading rates are low in all humidity cells (mostly < 0.005 mg/kg/wk) under circum-neutral conditions and do not display any notable trends. Both species see a spike in leaching rates associated with the drop in pH measured in leachates from both HC4 and HC6. HC4, which produces the slightly lower leachate pH in the most recent sampling cycles also currently displays higher Cu and Pb leaching rates than HC6 (Figure 3-3).

Although not identified as parameters of potential concern during static testing, Cd, Co, and Ni are known to be highly pH-sensitive and may pose and environmental concern in long-term Beaver Dam PAG rock drainage. The loading rates for these two parameters were generally low (<0.00001 mg/kg/wk for Cd; <0.0001 mg/kg/wk for Ni and Co) and stable in all humidity cell leachate under circum-neutral conditions (Figure 3-4). Following the depletion of NP and the drop in leachate pH, all three of these species display a gradual increase to values up four orders of magnitude higher than the corresponding neutral leaching rates. The highest loading rates are generally produced by HC4 which releases the lowest-pH leachate and had slightly higher Co and Ni solid-phase contents than the remaining samples

(Lorax, 2018a). It is notable that HC 4 also shows among the highest release rates for Cd, Co, and Ni under neutral conditions (Figure 3-4), while HC6 leaching rates for these species were relatively low during this test phase.

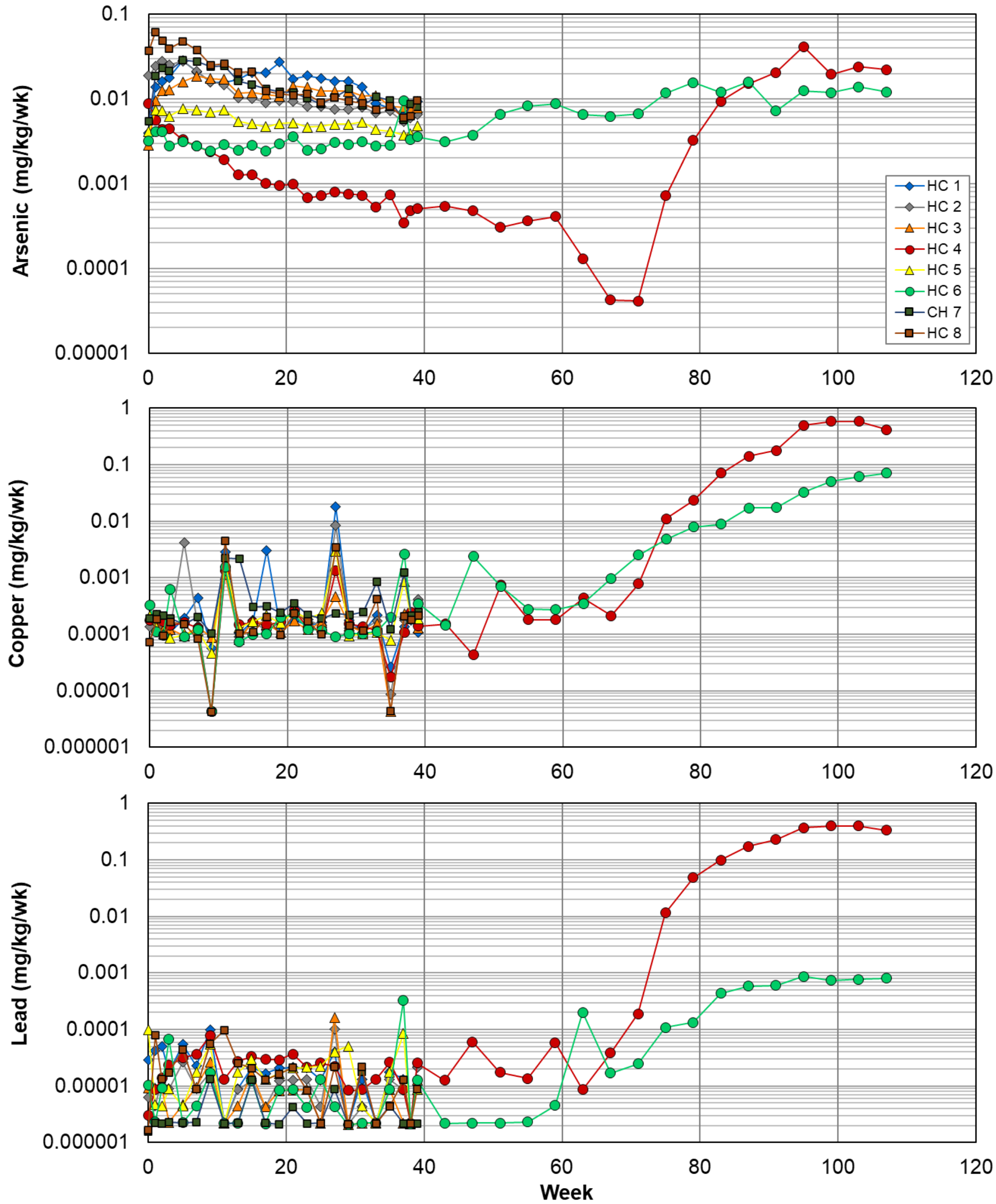

Figure 3-3: As, Cu, and Pb loading rates for the Beaver Dam humidity cells.

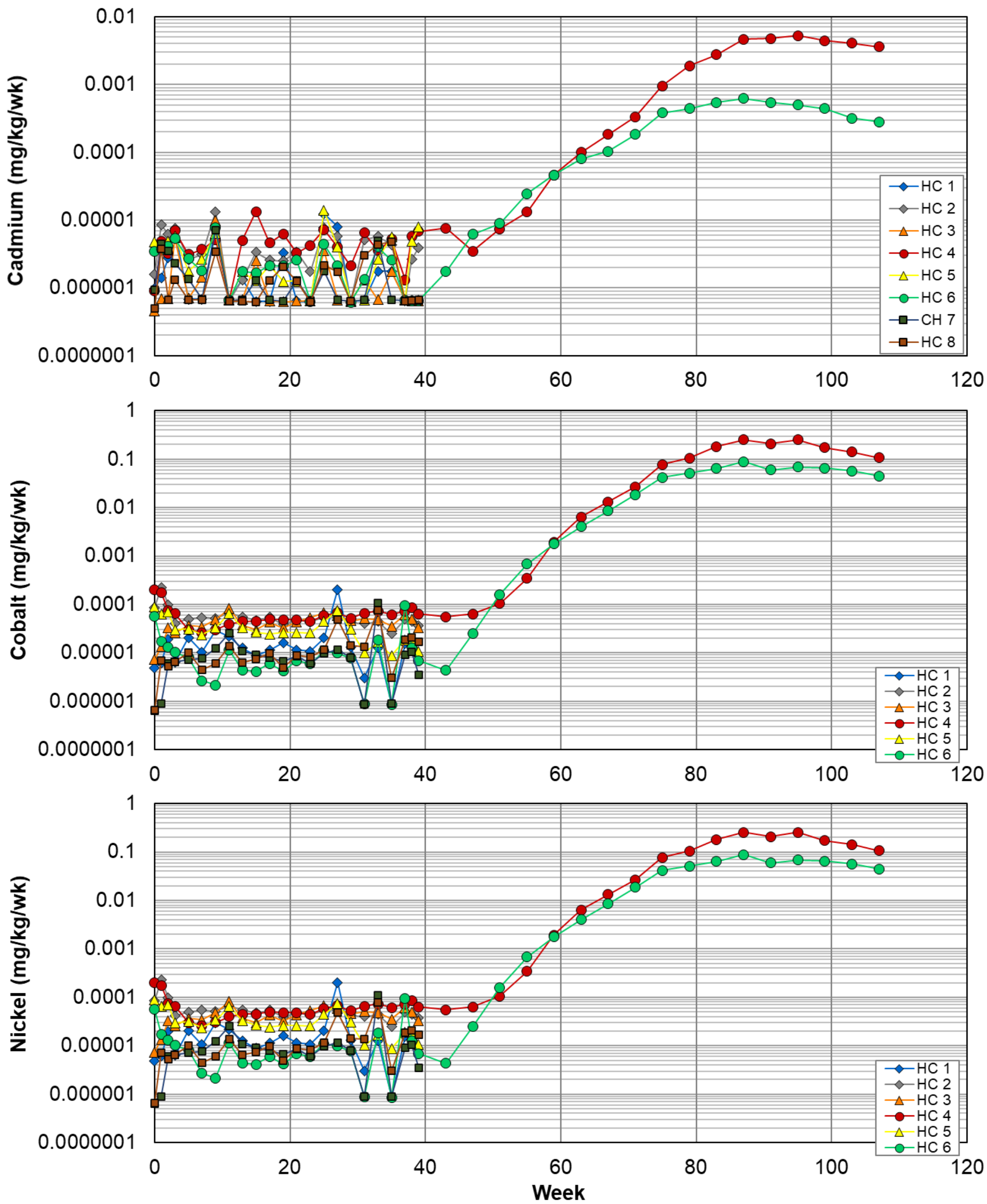

Figure 3-4: Cd, Co, and Ni loading rates for the Beaver Dam humidity cells

Average sulphate loading rates for the last five cycles of neutral leachate data for all humidity cells (week 33 to 39) show a strong positive correlation with the corresponding solid-phase sulphide S contents (Figure 3-5a). In contrast, the As load for the same period does not show a correlation with the solid-phase As content (Figure 3-5b). These results are comparable to the relationships, or lack thereof, observed at the time of the initial ML/ARD characterization (Lorax, 2018a). The phase association of As within the different humidity cell subsamples as well as pore water pH appear to have a stronger control over the respective leaching rates than solid-phase As abundance alone.

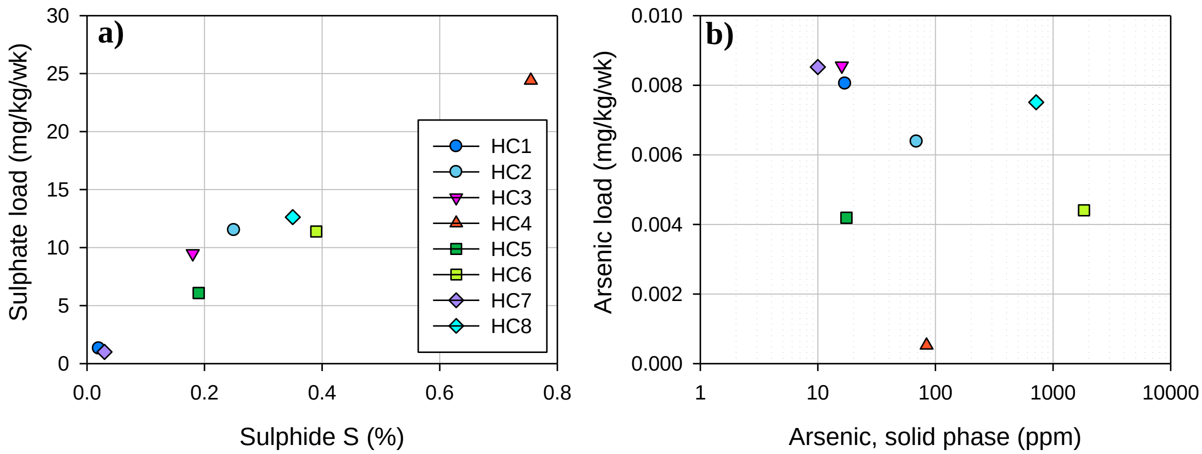

Figure 3-5: a) Sulphate load *vs* solid-phase sulphide S. b) As load *vs* solid-phase As. The loading rates are averaged for weeks 33 to 39.

4. Conclusions

- After >100 weeks of kinetic test operations, the two cells that were continued past 39 cycles have turned acidic with pH values currently falling between 3.0 and 4.0. This allows for the assessment of long-term metal loading rates for Beaver Dam specific PAG rock under acidic conditions. Due to the timing of the development of the geochemical source term model, acidic source term predictions currently still rely on the findings from Cochrane Hill (Lorax, 2018a, 2019). Future source terms will utilize Beaver Dam leachate chemistry directly, although a significant change in the predicted PAG drainage chemistry is not expected due to the generally consistent geochemical trends observed across the two mine sites.
- Arsenic leaching rates show a slightly decreasing trend in most of the humidity cells under neutral conditions. The acidification of contact water led to the increase in As leaching rates with a much more pronounced rise observed in HC4 which produced the lowest pH values (slightly above 3) in the most recent test cycles. The lowest As release rates are observed in leachates with 6.5< pH <7.5.
- Leaching rates of the base metals Cu, Pb, Cd, Co, and Ni are consistently low under circum-neutral conditions, with minor variations between the different material types. A drastic increase in loading rates, typically between three and four orders of magnitude, is associated with the drop in pH in HC4 and HC6.
- A strong correlation was observed for sulphide S content and sulphate release rates but not for As solid-phase content and As release rates under neutral conditions. The latter appears to be controlled more strongly by leachate pH rather than by solid-phase As content.

5. Closure

This memo has been prepared exclusively for AMNS in response to the Round 2 Information Requests from NSE. Please contact the undersigned should you require any additional information or clarification on the contents of this memo.

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References

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Lorax (2018b). Beaver Dam Project Geochemical Source Term Predictions for Waste Rock, Low-Grade Ore, Tailings and Overburden. Technical report prepared for Atlantic Mining NS Corp.; submitted December 20, 2018.

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