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Technical Memorandum

To:	Kathy Arnold	**From:**	Mark A. Williamson and Amy L. Hudson, REM
Company:	Rosemont Copper Company	**Date:**	April 12, 2011
Re:	Revised Heap Leach Facility Fate and Transport Modeling and Treatment Options Evaluation	**Doc #:**	087/11-320878-5.3
CC:	David Krizek, P.E. (Rosemont Copper)		

1.0 Introduction

This Technical Memorandum presents revised Fate and Transport modeling of the proposed Rosemont Copper Project (Project) Heap Leach Facility. The original modeling was presented in a memorandum dated January 14, 2010 (Tetra Tech, 2010a) and in the *Infiltration, Seepage, Fate and Transport Modeling Report – Revision 1* dated August 2010 (Tetra Tech, 2010b).

2.0 Summary of Previous Modeling

The previous modeling applied a simplified approach to the Fate and Transport simulations by including only mixing, oxidation-reduction reactions, and precipitation of oversaturated mineral phases. More complicated factors, such as adsorption, were not considered. The intention of this previous modeling effort was to provide relatively conservative results.

The heap leach materials are anticipated to be about 63% arkose, 21% quartz-monzonite porphyry (QMP), and 16% andesite. Starting solutions used in the geochemical model (PHREEQC) were derived from the Meteoric Water Mobility Procedure (MWMP) testing results. The arkose and QMP materials were represented by analytical results from MWMP testing performed on column leach material, i.e., both of these material types were leached with acid for metallurgical testing purposes prior to MWMP testing. However, the starting solution for the andesite material was an average of nine (9) waste rock samples (AR2001-01, AR2003-03, AR2009-01, AR2011-01, AR2036-01, AR2040-01, AR2041-01, UAGH-Arkose-1, VABH0609-01) tested using the MWMP method. These materials were unweathered and were not previously subjected to column leach solution.

The results of the original predictive modeling for the heap drain-down leachate solution quality, including the quality of the post-treatment effluents, are summarized in Table 1 below.

Treatment of the heap drain-down leachate included passive treatment using a limestone only system (limestone drain) and limestone with organic material (biological treatment).

Table 1 Summary of Originally Modeled Heap Drain-Down Leachate Quality

	AWQS	Heap Leachate	Passive Limestone Drain	Passive Biological Treatment
pH		3.23	6.84	6.24
Pe		17.4	13.8	-3.2
Total Alkalinity (mg/L $CaCO_3$)		-86.9	241	1215
Total Dissolved Solids, mg/L		970	1207	2185
Silver, mg/L		0.005	0.005	0.005
Aluminum, mg/L		16.0	0.6	1.2
Arsenic, mg/L	0.01	0.008	0.008	0.008
Barium, mg/L	2	0.015	0.015	0.015
Calcium, mg/L		149	249	149
Cadmium, mg/L	0.005	0.087	0.087	0.087
Chloride, mg/L		3.77	3.77	3.76
Chromium, mg/L	0.1	0.010	0.010	0.010
Copper, mg/L		30.2	30.2	30.2
Fluoride, mg/L		1.95	1.95	1.95
Iron, mg/L		0.300	0.003	0.300
Potassium, mg/L		5.93	5.93	5.93
Magnesium, mg/L		42.3	42.3	42.2
Manganese, mg/L		0.008	0.000	0.008
Molybdenum, mg/L		0.002	0.002	0.002
Sodium, mg/L		10.9	10.9	10.9
Nickel, mg/L	0.1	0.163	0.163	0.163
Nitrate, mg/L	10	0.035	0.035	0.035
Lead, mg/L	0.05	0.016	0.016	0.016
Sulfate, mg/L		704	704	235
Selenium, mg/L	0.05	0.056	0.056	0.056
Zinc, mg/L		4.97	4.97	4.97

The results showed that the untreated heap drain-down leachate would be acidic with cadmium, nickel, and selenium exceeding the Arizona Water Quality Standards (AWQS). For this reason, two (2) passive treatment options were considered, a limestone drain and a biological treatment system. The simulated treatment options resulted in improved pH and decrease of some constituents in solution; however, cadmium, nickel, and selenium remained above the AWQS.

3.0 Scope of Revised Modeling

After further review of the previous model, revisions were made to refine the original model assumptions and the source term data utilized. Some of the previous modeling constraints, such as not allowing absorption, were also revisited. Changes to the model included:

- An alternate chemical composition of the starting solution representing andesite, including the removal of added sulfuric acid solution; and
- Inclusion of a broader range of mineral phases that would likely precipitate from solution.

4.0 Model Revision

In the original modeling, the arkose and QMP starting solutions were derived from the results of MWMP testing on the acid-leached material samples. No samples of acid-leached andesite were available to perform MWMP testing. As indicated, the starting solution for andesite was therefore originally derived from the average of nine (9) MWMP testing results from the waste rock characterization program. These MWMP results also required the use of sulfuric acid solution to try and mimic the residual acid character of the metallurgical testing program, similar to that of arkose and QMP. However, the chemistry of the leached arkose and QMP materials is significantly different from that of just adding sulfuric acid to unleached and unweathered andesite material.

For the revised modeling, the original andesite starting solution was replaced with the leached arkose solution. The resulting new baseline leachate quality for the heap had a higher total dissolved solids load and lower pH. The arkose and andesite materials are sufficiently similar materials so that leached andesite material chemistry is expected to be more like leached arkose than the previous mix of nine (9) waste rock samples.

Additionally, the revised modeling provided for the inclusion of additional mineral phases that were allowed to precipitate from solution due to being oversaturated. The previous modeling used a limited list of common equilibrium phases and did not fully account for all potential precipitation reactions. The mineral phases used in the revised modeling were expanded to include a broad range of trace metal sulfides that would likely precipitate based on the anticipated treatment options.

4.1 Revised Model Results

The heap drain-down leachate quality, effluent quality from a passive limestone drain and effluent quality from a passive biological treatment system were reassessed, the results of which are presented in Table 2. As described above, the reassessment used a starting solution derived from previous leach column material (only arkose and QMP).

The passive treatment, limestone drain system was simulated as a reaction of the heap drain-down leachate with calcite resulting in neutralization of pH. In the biological treatment system, an organic carbon source was added along with the limestone, allowing the carbon to react which resulted in a near complete reduction of sulfate and associated increase in pH.

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Table 2 Summary of Revised Heap Drain-Down Leachate Quality

	AWQS	Heap Leachate	Passive Limestone Drain	Passive Biological Treatment
pH		3.04	6.59	6.31
Pe		17.6	14.0	-3.27
Total Alkalinity (mg/l $CaCO_3$)		-173	497	1905
Total Dissolved Solids (mg/L)		2848	2828	1717
Silver (mg/l)		0.005	0.005	0.005
Aluminum (mg/l)		57.7	0.0115	0.127
Arsenic (mg/l)	0.01	0.003	0.002	0.003
Barium (mg/l)	2	0.013	0.011	0.013
Calcium (mg/l)		442	649	237
Chloride (mg/l)		5.980	5.981	5.975
Cadmium (mg/l)	0.005	0.307	0.305	0.002
Chromium, total (mg/l)	0.1	0.034	0.034	0.009
Copper (mg/l)		62.2	0.49	0.002
Fluoride (mg/l)		5.23	1.96	2.64
Iron (mg/l)		4.844E-04	5.30E-09	4.84E-04
Potassium (mg/l)		8.21	8.21	8.20
Magnesium (mg/l)		150	150	105
Manganese (mg/l)		0.214	7.147E-04	0.214
Molybdenum (mg/l)		0.004	0.002	1.476E-29
Nitrate (mg/l)	10	0.107	0.107	0.107
Sodium (mg/l)		9.34	9.34	9.33
Nickel (mg/l)	0.1	0.592	0.593	8.39E-07
Lead (mg/l)	0.05	0.037	0.037	0.037
Sulfide (mg/l)		0.00E+00	0.00E+00	656
Sulfate (mg/l)		2089	1871	0.88
Selenium (mg/l)	0.05	0.099	0.099	7.60E-13
Zinc (mg/l)		17.6	17.6	0.3

The results of the revised modeling are similar to the previous modeling, although total dissolved solids are generally higher. As with the original evaluation, cadmium, nickel, and selenium exceed AWQS. However, the revised model representing the effluent from a passive biological treatment system produced results that showed all chemical constituents were below AWQS. This improved model performance is due specifically to the proper inclusion of additional potential mineral precipitates. The results of the passive biological system model suggest that this treatment method can result in water quality that meets all AWQS. The limestone treatment results in an improved pH and some constituents are decreased relative to the baseline heap leachate. However, the limestone only treatment method does not appear to lower the cadmium, nickel, and selenium to levels below the AWQS.

The performance of the modeled passive biological treatment system achieves both sulfate reduction and a reduction of all constituents below AWQS. Site-specific conditions at the time of drain-down will drive engineering designs and the performance of the treatment system. Thus, future bench and pilot scale studies performed during the initial three (3) year drain-down period of the heap will identify and constrain the critical design issues such as selection of suitable and appropriate organic amendments to support vigorous sulfate reduction. This will allow for system optimization prior to full scale construction and prior to covering the treatment ponds with waste rock.

REFERENCES

Tetra Tech, Hudson, A. (2010a). *Heap Leach Facility Infiltration, Seepage, and Fate and Transport Modeling/Treatment Options*. Technical Memorandum to Kathy Arnold (Rosemont Copper Company). Technical Memorandum Dated January 14, 2010.

Tetra Tech (2010b). *Infiltration, Seepage, and Fate and Transport Modeling Report – Revision 1*. Prepared for Rosemont Copper Company. Report Dated August 2010.