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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	April 30, 2010
cc:	Tom Furgason, SWCA File, SRK	**From:**	Mike Sieber, P.E, SRK Stephen Day, P.Geo. SRK Vladimir Ugorets, PhD, SRK
Subject:	Technical Review of *Infiltration, Seepage, Fate and Transport Modeling Report,* Tetra Tech, 2010, Prepared for Rosemont Copper Company	**Project #:**	183101

A technical review has been undertaken, and this Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a request for a Statement of Work dated February 17, 2010. Provided here are comments related to the review of the, *Infiltration Seepage, Fate and Transport Modeling Report*, prepared for the Rosemont Copper Company by Tetra Tech (2010b). These comments were prepared by Mike Sieber, Stephen Day, and Vladimir Ugorets of SRK Consulting, Inc. (SRK). Editorial review was completed by Cori Hoag and Larry Cope, also of SRK.

The seepage, fate and transport modeling report and supporting documents from Tetra Tech regarding the 2007 geochemical characterization (Tetra Tech, 2007a and Tetra Tech, 2007b) and the *Dry Stack Tailings Storage Facility Design Report* (AMEC, 2009, Appendix D) and the *Mine Plan of Operations* (WestLand Resources, 2007) were reviewed as part of this effort.

This memorandum is organized into two sections, corresponding to the two topics under review:

Section 1 - Infiltration and seepage modeling; and,

Section 2 - Fate and transport (geochemical) modeling.

The 2010 Tetra Tech report is well presented and well written, and as supported by the appendices, is in general comprehensive in scope. The GEO-SLOPE VADOSE/W code is industry standard infiltration-seepage modeling software. However, SRK requests clarifications and additional supporting data, as well as an explanation for several methodologies not clearly understood by the reviewers. The requests are indicated below in relevant sections. The models cannot be adequately judged as suitable and defensible without the requested information.

1 INFILTRATION AND SEEPAGE MODELING

1.1 Input Data

This section summarizes the review of the climatic data and the saturated and unsaturated material properties used for the infiltration models.

1.1.1 Site Climatic Data

The Nogales 6 N weather station was selected for the Waste Rock Storage Area and Heap Leach Facility infiltration models. The precipitation and maximum and minimum temperature data appear reasonable. However, the Santa Rita weather station is closer to the Rosemont Project area and is at an elevation closer to that of the project elevation than is the Nogales 6 N weather station. It is stated in Appendix B of the report that the Nogales 6 N pan evaporation data were adjusted to the Rosemont project site based on a linear extrapolation with each station's elevation. However, illustration 3.2 in the text does not appear to be a simple linear extrapolation. Section 4.1.4 states that a correlation was performed to translate the Nogales pan evaporation data to the Rosemont Project, please explain the method used. Three climate conditions were used for the transient model, average climate conditions, 24-hour, 100 year storm event, and multi-storm (approximately six inches of rain in seven days). What statistical method used to determine the 7-day storm event, it is not clear and cannot be understood form the description provided.

The report states that precipitation was applied in a "sinusoidal function that peaks at noon. The distribution pattern in the model allows for peak rainfall over a short period around noon." The transient log header in Appendix C states that average annual conditions are sinusoidal; however, the precipitation appears to be applied from 0 to 24 hours and nearly every day of the year. This does not appear to be average conditions in southern Arizona. A hydrograph of the simulated precipitation would aid in understanding the temporal distribution of precipitation.

1.1.2 Site Material-Soil Data

Section 5.3 of the report provides an explanation of unsaturated flow theory. Illustration 5.5 shows a generic soil water characteristic curve (SWCC) for two soils, however, an illustration of hydraulic conductivity as a function of capillary function or moisture content is not presented or discussed. Section 5.5.5 presents saturated hydraulic conductivity values for three waste rock materials, alluvium, and bedrock without providing either a range of values, or a source for the saturated hydraulic conductivity data.

The conceptual model for the Waste Rock Storage Area shows three layers of waste rock, benches-buttress, alluvial deposit, and bedrock, each with different properties. The model logs in Appendix C give a brief description of the material—Andesite—for unconsolidated waste rock and list the unsaturated properties. Section 5.5 state that laboratory and library parameters were used for unsaturated flow parameters. The laboratory work that was completed should include the data, laboratory name, and the ASTM methods that were used. The GEO-SLOPE library data should also be presented. SWCC and unsaturated hydraulic conductivity charts for the materials modeled should be presented in either the report or appendices. The charts in Figure 1 and Figure 2 below are examples of what is necessary to present a defensible infiltration-seepage model. In Appendix A, AMEC presented the SWCCs and a hydraulic conductivity function for the Dry Stack Tailings Storage Facility infiltration and seepage model.

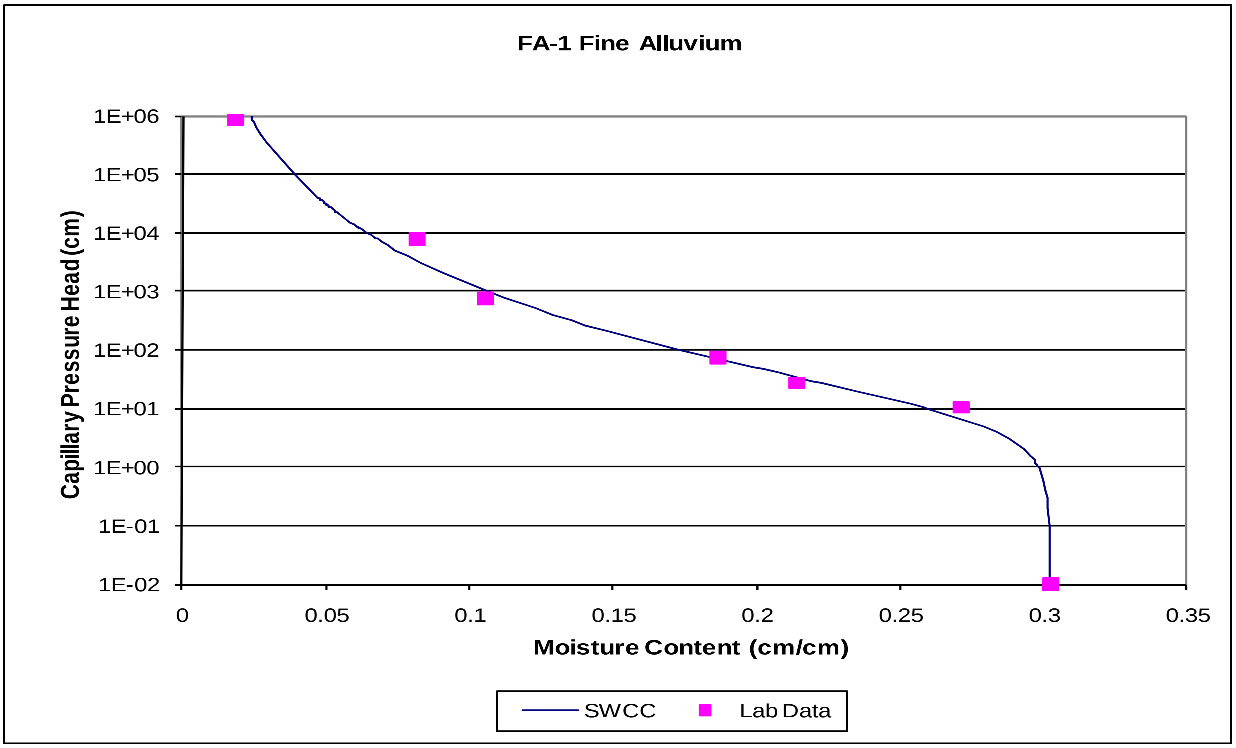

Figure 1 Example of soil water characteristic curve (SWCC)

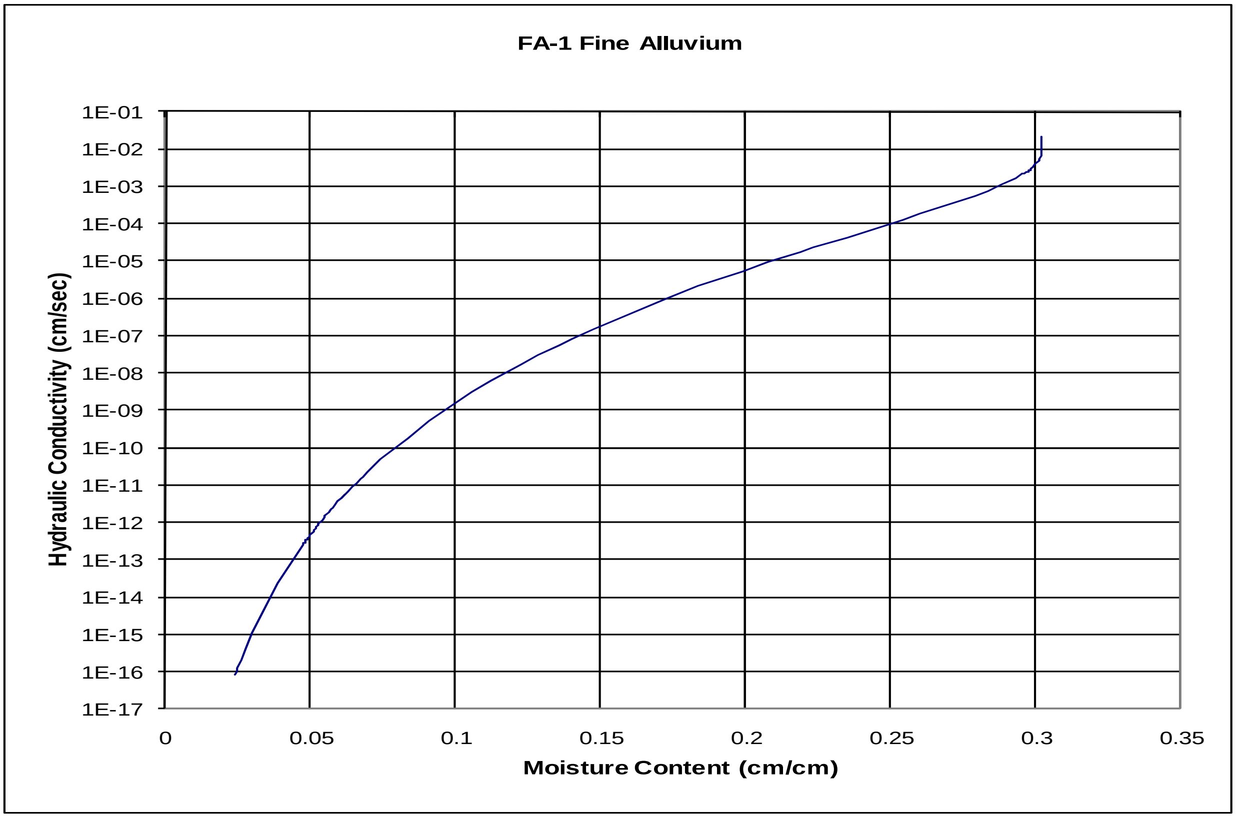

Figure 2 Example of unsaturated hydraulic conductivity function

1.2 Heap Leach Facility Conceptual Model

Infiltration-seepage modeling was completed to estimate the time required for draindown of the Heap Leach Facility (Heap) to drop to about 10 gpm. Appendix E describes the draindown modeling. Page 4 paragraph 4 of the report states, "The primary difference between the spent ore and the waste rock is the moisture content of the materials." Oxide ore placed on the heap is not the same material as waste rock in terms of mineral concentrations of copper-bearing minerals (oxide/carbonate/silicate/sulfide), associated gangue minerals like iron oxides/silicates/sulfides, clay, and calcite, and secondary minerals that will form in response to leaching. Although both the oxide ore and waste rock (bedrock) have been hydrothermally altered, the materials on the Heap will likely break into smaller size fractions owing to the intensity of alteration, and disaggregation that will occur during placement, exposure to raffinate, and ripping in the upper layer of each lift; the lifts within the Heap will also compact with burial depth. Raffinate leaching will cause the Heap material to break down to smaller particles and the leaching of the calcitic material will cause the formation of secondary sulfate minerals and gypsum. These reactions will likely significantly decrease saturated hydraulic conductivity. In addition, simulating the Heap Leach Facility materials as run-of-mine material may significantly under-estimate the duration for draindown. SRK experience with draindown of an 89 MT heap in Arizona (larger than the estimated 60 MT Rosemont heap) indicates a decrease in draindown to 20 gpm in 8 years. An estimate for the Rosemont Heap is that a decrease in draindown to about 10 gpm probably will take 8 to 10 years. During and after reclamation, the continued drainage from the Heap will have to be managed.

1.3 Waste Rock Storage Area

Based on the conceptual model text and the low-resolution figures SRK cannot ascertain the depth of the three simulated stages.

1.4 Steady-State and Transient Solutions

Section 5.7 states that the sequence of steady-state simulations were to "offer non-zero stating values for the subsequent transient modeling scenarios." We assume the non-zero refers to the moisture content of the material. The water balance illustrations presented in the report begin with the water content at zero. Can this be explained.

It is stated on Section 5.8, page 26 that, "Transient modeling provides a reasonable simulation of flow conditions within the Waste Rock Storage area, Heap Leach area, and the Dry Stack tailings facility." The transient simulations reported in this report are one in year duration using average climatic conditions. However, movement of moisture through such materials often takes many years, a reasonable approach would be to conduct the 50-year transient simulations utilizing the entire 50-year climatic data set from the Nogales 6 N weather station.

In addition, the averaging of daily climatic conditions into a single year likely miss-represents measured daily climate conditions. The apparent miss-representation may be evidenced in the simulated daily climate input data presented in Appendix C. Those data indicate that precipitation fell virtually every day of the year, the ranges in values for relative humidity are shown as broad and relatively invariable, and precipitation is shown to occur at all hours of the day for all days. Because of the muting of the data by the process of averaging, small amounts of precipitation (0.001 inch to 0.248 inches with a mean of 0.048) falls on 255 days of the year. With evaporation exceeding precipitation on most days, such small precipitation values might be evaporated before infiltrating to depth, resulting in an under-estimate of the flux of water through the material. In reality, a few heavy rains can fall on humid days producing a significant source of water for infiltration.

1.5 Illustrations and Tables

Illustrations 5.6, 5.7, 5.10, 5.12, and 5.13 of the waste rock and heap leach conceptual models and numerical model results are too small to read annotations and the horizontal and vertical scales. The values for moisture content and flux are often not legible. Illustration 5.22, presents the simulated volumetric moisture content distribution within the closed Heap, indicates upward flux from the base of the Heap. It is not clear to us how such a condition can exist, and we request that it be explained in text.

2 FATE AND TRANSPORT (GEOCHEMICAL) MODELING

2.1 General Comment

The overall approach to modeling the water chemistry for each facility (waste rock, heap leach, dry stack) is similar. The models combine understanding about the composition of the waste facilities with data on leaching behavior and water flow to predict pore water chemistry. Geochemical modeling was used in some cases to predict final water chemistry. The overall approach is consistent with general practice and the data used as a basis for the model are suitable for the intended purpose.

Details of each step in the geochemical method are reviewed below. SRK has identified concerns with the approach that are similar to those with the pit lake predictions (SRK, 2010b). The main factor that does not appear to have been addressed, however, is the degree to which the onset of acidic conditions in some components of the waste rock could affect overall water quality. In the following sections, a pre-amble review is provided, followed by specific bulleted items for follow-up.

2.2 Review of Modeling Steps

2.2.1 Waste Characteristics

Waste Rock

SRK (2010a) previously reviewed the overall geochemical database. Additional comments were provided by SRK (2010b). Acid-base accounting is used to acid rock drainage (ARD) potential while leachability was characterized using SPLP and MWMP. SRK (2010b) provided the following recommendations for the use of acid-base accounting data at the site:

- Calibration of the conventional ABA method to site mineralogy needs to be considered. A more detailed description of the relevant mineralogy including acid generating, acid neutralizing, and water-soluble minerals should be provided.
- The calculation of acid potential (AP) appears to have been based on sulfide sulfur though description of the method used to calculate this could not be located. It appears that soluble sulfur is an important component of the rock (Tetra Tech, 2007b, Illustration 3.1). The mineralogical form of soluble sulfur is important as it may be acid generating (e.g. jarosite) or non-acid generating (e.g. gypsum) and should be evaluated for its contribution to AP.
- The Sobek Neutralization Potential (NP) method can lead to over-statement of site-available NP if silicate minerals react in the test. To address this concern, the carbonate mineralogy of the site should be described (e.g. presence of iron carbonates), carbonate analytical data should be presented and compared with NP, and the effect of silicates on NP should be investigated by comparing carbonate and NP determinations.
- The possible effect of blasting on the release of mineral components to blast fines in the pit walls should be considered because the mineralization is described as “vein controlled.”
- Based on these considerations, the application of conventional ARD criteria may need to be re-considered for the site.

The bulk waste rock geochemical characteristics did not appear to be presented in the report. Table 6.2 provided the lithological composition of the waste rock while Tables 3.3 and 3.4 of Tetra Tech (2007) indicate the distribution of the ARD potential in waste rock. ARD potential is very low on the whole, but SRK notes that arkose is a major unit (44%) and 15% of samples from this unit were classified as potentially ARD generating (PAG) by ABA. This indicates that at least 7% of the rock could be composed of PAG rock.

To complement this work and support the subsequent development of source terms, the following additional information should be presented:

- Explanation of how the waste rock proportions were calculated.
- Presentation of the overall acid-base account of the waste rock (sulfur content, neutralization potential) based on the rock type characteristics and proportion of rock types.
- An evaluation of the timing of release of PAG materials because if the PAG materials are released at certain stages of the mine rather than being continuously mixed in with the non-PAG materials local acidification could occur.

Heap Leach Facility

No geochemical description of the heap leach materials could be located.

- Geochemical data for the heap leach materials should be presented.

Dry Stack Tailings

Tetra Tech (2007) provided geochemical data for the tailings. These data indicate that tailings have very low potential for ARD due to mostly low sulfide content. SRK noted that like waste rock, sulfate content was variable. It is assumed that sulfate occurs as gypsum rather than acidic salts.

- Discussion of how the tailings characteristics might change as mining progresses because some tailings have ARD potential.

2.2.2 Conceptual Geochemical Models

Section 6.1 of the report provided the “Conceptual Fate and Transport Model”; however, the description did not include geochemical processes.

- This section should be updated to include geochemical processes, for example, the role of sulfide mineral oxidation, gas partial pressures, temperature variations, and the precipitation and dissolution of secondary minerals.

2.2.3 Source Terms

Waste Rock

It is understood the waste rock source term was developed by developing source terms for individual waste rock types, combining the source terms according to the rock type proportions, and then equilibrating the resulting chemistry using PHREEQC. The details of the method were not provided and should include:

- Further discussion of the role of local acidification and the need for a source term to reflect acidic conditions. This may be unnecessary if it can be demonstrated that PAG rock becomes intimately mixed with non-PAG rock during mining.
- Explanation and discussion of justification for use of zero concentration in the source term for rocks with undetectable solid phase concentration (NA in Table 6.1). The description “not part of the rock’s composition” should be re-worded to indicate undetected. It is noted that arkose is shown as NA but in Illustration 3.4 in Tetra Tech (2007) arkose is shown as having an enrichment ratio of 10, which seems to indicate detection (as shown in Illustration 3.5).
- The methodology used to mix the waters.

- Which minerals were used to model the waste rock source term resulting in the concentrations in Table 6.6. This table indicates very high sulfur concentrations and extreme ion imbalance. It is assumed that this sulfate not sulfur.
- How the nitrate concentration was calculated. The concentrations seem very low given that explosives residuals will be present.

To perform a reality check on the concentrations, SRK compared them to compiled seepage chemistry data for calc-alkalic and alkalic porphyry deposits in British Columbia, Canada (Day and Rees 2006; Red Chris Development Company 2004) (Table 1). While it is acknowledged that Rosemont has some skarn characteristics, predictions for cadmium, copper, selenium and zinc seemed atypical. These elements are associated with sulphides which can occur in skarn deposits.

- Further discussion is needed about how the very dilute concentrations obtained from SPLP and MWMPs are scaled up to the much drier conditions at the site. A similar concern was raised for the pit wall source term during review of the geochemical pit lake model report (SRK 2010b).

Table 1. Statistics for Waste Rock Seepage from Porphyry Deposits

		pH<4				4<pH<6				pH>6			
Parameter	Unit	n	Max[1]	P_{95}[1]	P_{50}	n	Max[1]	P_{95}[1]	P_{50}	n	Max[1]	P_{95}[1]	P_{50}
Acidity	mg$CaCO_3$/L	58	25400	6412	1822	24	560	544	151	63	214	36	15
Alkalinity[1]	mg$CaCO_3$/L	4	0	0.15	1	32	1.2	2	5	262	1	7.525	43.6
SO_4[2]	mg/L	93	30910	7969	3220	46	2930	2440	1260	299	1896	1531	464
Al	mg/L	42	766	436	239	25	47	40	5	66	0.6	0.2	0
Sb	mg/L	8	0.13	0.09	0.020	0	-	-	-	40	0.09	0.08	0.010
As	mg/L	0	-	-	-	2	0.0006	0.0006	0.00	26	0.04	0.03	0.01
Cd[3]	mg/L	19	0.02	0.02	0.007	1	0.04	0.04	0.040	27	0.03	0.007	0.000
Ca	mg/L	54	804	748	532	39	832	793	361	147	964	727	247
Cu[4]	mg/L	42	655	512	249	25	370	340	66	107	1	0.14	0.02
Fe[5]	mg/L	42	1310	480	14	24	5	3	0.2	81	0.3	0.2	0
Hg[6]	mg/L	3	0.00110	0.0011	0.00070	1	0.0006	0.0006	0.00060	24	0.002	0.00043	0.00005
Pb[7]	mg/L	12	0.04	0.04	0.0155	7	0.02	0.02	0.012	27	0.01	0.0036	0.00007
Mg	mg/L	54	213	163	61	39	201	180	39	147	115	101	24
Mn	mg/L	37	56	41	4	26	31	26	9	113	6	4	1
Mo[8]	mg/L	3	0.009	0.009	0.006	15	0.03	0.03	0.0068	114	0.4	0.3	0.03
Ni	mg/L	31	2	2	0.8	12	1	1	0.4	48	0.4	0.21	0.006
K	mg/L	47	148	134	67	16	112	87	3	77	58	39	4
Se	mg/L	29	0.2	0.2	0.09	7	0.09	0.08	0.07	34	0.3	0.3	0.06
Ag[9]	mg/L	0	-	-	-	1	0.01	0.010	0.01	19	0.00001	0.00001	0.00001
Na	mg/L	54	204	91	20	35	64	49	14	127	126	54	11
Zn[3]	mg/L	35	6	5	2	18	4	4	2	84	1	0.8	0.03
pH[1]	s.u.	99	2.1	2.5	3.1	46	4.0	4.1	5.3	311	6.0	6.4	7.5

Annotations refer to footnotes about data sources for each of five sites in the compilation.

Heap Leach

The methodology used to develop the heap leach source term was unclear.

- Description of the input data and methodology is requested following the same format as the waste rock.

Comparison of the sources terms in Table 6.7 of the report with Table 1 (above) leads to similar observations as for waste rock. Concentrations of many parameters seem very low. For example, an iron concentration of 0.3 mg/L is predicted at pH 3.23. As iron is highly soluble at this pH, much higher iron concentrations would be expected from dissolution of silicates. In addition, the biological system is predicted to produce water with low Eh but this is not reflected in elevated iron concentrations in ferrous form.

- SRK recommends the source terms be re-visited and then used to re-assess the water treatment systems. The iron source term in particular will affect the performance of the water treatment systems.

Dry Stack Tailings

As with the other source terms:

- Further explanation of the modeling method and inputs is needed to address the scale-up of dilute leach tests to the full scale facility.
- The possible effect of timing of production of PAG tailings should be considered in the source term.

Concentrations reported in Table 6.8 do not appear to be consistent with equilibration with major minerals in the tailings, which would presumably include gypsum and calcite. Both minerals are probably present according to the acid-base accounting data. Concentrations of sulfate, alkalinity, and calcium would be expected to be comparable to the waste rock source term (Table 6.6).

3 Conclusions

For the infiltration and seepage component of the model report, SRK has the following recommendations:

- Results from the transient simulations do not indicate that a long-term solution has been reached at the end on one year. The transient simulations should be performed over the 50-year climatic data period of record, or at a minimum until the transient analysis demonstrates an asymptotic stabilization of results.
- Given the apparent need to extend the length of transient runs, the one year of averaged daily climate data may become mute. Actual climate data over the length of transient simulations should be applied as input.
- Present SWCC and unsaturated hydraulic conductivity functions on charts for all of the waste material and the alluvial deposit and bedrock.
- The Heap Leach Facility draindown model should use material typical of leached oxide ore. Alternatively, a review of actual draindown data from similar closed heap leach facilities could be considered.
- Several figures are difficult to read
- For the geochemical component of the model, SRK has recommended further explanation and/or re-visiting of source terms to address potential for local acidification in waste rock and tailings, and scale-up of laboratory leach tests to full scale.

4 REFERENCES

AMEC, 2009, Rosemont Copper Company, Dry stack tailings storage facility, Final design report: unpublished report prepared for Rosemont Copper Company, AMEC Project 842-1191, 54 p, 7 appendices.

Day, S. and Rees, B., 2006, *Geochemical controls on waste-rock dump seepage chemistry at several porphyry mines in the Canadian cordilleran*: paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502.

Red Chris Development Company Limited, 2004, *Application for Environmental Assessment Certificate for the Red Chris Porphyry Project* (October 2004). Volumes 1 to IV: unpublished report submitted to the British Columbia Environmental Assessment Office, October 2004.

SRK Consulting, 2010a, Technical review of *Baseline geochemical characterization* and *Geochemical characterization, Addendum:* unpublished technical memorandum prepared for SWCA reviewing a report prepared by Tetra Tech (2007) for Rosemont Copper Company, February 10, 2010, 12 p.

_____ 2010b, Technical review of *Geochemical pit lake predictive model*, *Rosemont Copper Project*: unpublished technical memorandum prepared for SWCA reviewing a report prepared by Tetra Tech (2010) for Rosemont Copper Company, April 16, 2010, 11 p.

Tetra Tech, 2007a, Baseline geochemical characterization, Rosemont Copper: Report prepared for Augusta Resource Corporation, Tetra Tech Project No. 320614, June 2007, 41 p., 2 appendices.

_____ 2007b, Geochemical characterization, Addendum I, Rosemont Copper: Report prepared for Rosemont Copper Company, Tetra Tech Project No. 320614.100.07, November 2007, 23 p., 2 appendices.

_____ 2010a, *Geochemical pit lake predictive model, Rosemont Copper Project*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320777, February 2010, 33 p., 6 appendices.

_____ 2010b, *Infiltration, seepage, fate and transport modeling report, Rosemont Copper*: unpublished report prepared for Augusta Resource Corporation, Tetra Tech Project No. 114-320794, February 2010, 68 p., 6 appendices.

5 REVIEWER QUALIFICATIONS

The Reviewer for hydrogeology, Mike Sieber, P.E. is a Hydrogeologist with SRK Consulting in Tucson, Arizona (resume attached). Mr. Sieber is a professional engineer with more than 20 years of experience in the preparing infiltration models to estimate infiltration through tailings impoundments and landfill covers, and numerical groundwater flow models to predict the formation of open pit lake loss of containment pit lake and underground workings. Mr. Sieber's review was under the supervision of Vladimir Ugorets, Ph.D., Principal Hydrogeologist with SRK Consulting in Denver, Colorado.

The Senior Reviewer for geochemistry, Stephen Day, P. Geol., is a Principal Geochemist with SRK Consulting in Vancouver, Canada (résumé attached). Mr. Day has more than 30 years of experience in geochemistry; in particular, he has more than 10 years of experience in the development of waste management plans to address acid rock drainage and leaching of mine wastes in general, as related to hard rock mining. One area of Mr. Day's expertise relevant to the present review is in the development of prediction methods for mine planning and modeling of leachate chemistry. Mr. Day was directly responsible for reviewing the geochemistry of the pit lake predictive model.