SRK Consulting (U.S.), Inc.
3275 West Ina Road, Suite 240
Tucson, Arizona
USA 85741

msieber@srk.com
www.srk.com

Tel: 520.544.3688
Fax: 520.544.9853

Memorandum - DRAFT

To:	Dale Ortman, P.E.	**Date:**	August 17, 2010
cc:	Tom Furgason, SWCA Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.S. Mike Sieber, P.E.
Subject:	Review of Tetra Tech Documents *Groundwater Flow Model Construction and Calibration* and *Steady-State Sensitivity Analyses*	**Project #:**	183101/2000

This memorandum provides a technical review of the two Technical Memoranda, *Groundwater Flow Model Construction and Calibration* dated July 26, 2010 (Tetra Tech, 2010a) and *Calibration* and *Steady-State Sensitivity Analyses* dated July 30, 2010 (Tetra Tech, 2010b). This review was undertaken, and our Memorandum prepared by Vladimir Ugorets, Larry Cope, and Mike Sieber of SRK Consulting (U.S.), Inc. (SRK), at the request of SWCA and the Coronado National Forest, as transmitted to SRK by Mr. Dale Ortman in email requests dated August 5 and August 9, 2010.

1 Description of Groundwater Flow Model Setup

Tetra Tech has a developed 3-D numerical regional groundwater flow model based on a framework model that was reviewed by SRK previously (SRK, 2010a). The geologic formations were grouped by Montgomery & Associates (2009a) into ten (10) hydrogeologic units on the basis of their age and material properties. The following four additional units were incorporated into the model by Tetra Tech (2010a):

1. Paleozoic units in the western side of the pit area (Zone 11 – Pz_Pit) that cover the Backbone Fault along the ridge of the Santa Maria Mountains,
2. Quaternary-Tertiary gravel in the Tucson Basin (Zone 15 – QTg_TB),
3. Quartz-Porphyry Dike (simulated as the HFB package in MODFLOW), and
4. Streambed material (simulated by the SFR package of MODFLOW).

The model domain and the external lateral model boundaries are the same as those applied by M&A (2009b).

The description of the model development in the reviewed document is detailed, comprehensive, and easy to follow. However, it should be noted that SRK did not find an explanation of modification of the western model boundary (assumed to be C-HEAD for the steady-state conditions) for transient mining and post-mining simulations.

2 Simulation of Recharge

Tetra Tech (2010a) methodology for building recharge into the model used a combination of Geographic Information System (GIS) analysis, empirical surface-runoff modeling, and water balance calculations. The model domain was divided into 21 sub-watersheds based on topography. The sub-watersheds were further divided into bedrock, alluvial fan, and valley floor. Precipitation distribution data obtained from the PRISM Group at Oregon State University were applied to each sub-basin using GIS methods. Precipitation data from the Santa Rita Experimental Range were used to simulate precipitation events and to develop runoff estimates for each sub-basin. Water balance calculations were performed to normalize the recharge rates for each sub-basin; the total recharge for all of the sub-basin was 10,100 acre-feet per year (ac-ft/yr), which is approximately 5.4 percent of annual precipitation. Six recharge zones were incorporated into the model with rates that varied from 0.33 inch per year (in/yr) to 1.31 in/yr. The total recharge calculated by the steady-state model was 9,909 ac-ft/yr.

The simulation of mining impacts and post-closure changed the recharge that was used in the steady-state calibration. SRK provides the following observations about these changes:

- Recharge from precipitation was not applied into the pit area during transient mining simulations assuming that all water will be captured by drain cells and removed from the model. SRK agrees that this is a valid approach to simulate water levels in the vicinity of the proposed pit; however, it is our opinion that this method would underestimate dewatering requirements.
- Post-closure recharge from the waste rock storage area and the heap leach facility is assumed to be zero, based on the Tetra Tech (2010c) report, *Infiltration, Seepage, and Fate and Transport Modeling Report.* It should be noted that the review of that report by SRK (2010b) indicated that zero recharge is likely unrealistic. However, the zero value was also applied by Tetra Tech. SRK is of the opinion that recharge through the facilities should be revised or otherwise explained.
- It is not clear from the reviewed Technical Memorandum why the recharge from the tailings is assumed to be a constant value for the entire duration of the post-closure simulation, given initial dewatering of the tailings following cessation of mining, followed by an asymptotic equilibration to average climatic conditions.

3 Simulation of Evapotranspiration

Tetra Tech simulated groundwater losses to evapotranspiration (ET) along the reaches of Cienega Creek and Davidson Canyon where riparian vegetation is present. ET was simulated with MODFLOW's evapo-transpiration (EVT) package. Maximum ET rates were assigned to each model cell, and simulated ET varied with groundwater level. The extinction depth was set to a constant depth of 16.4 ft (5 meters) below land surface. Simulated maximum evapotranspiration rates are shown in Figure 7 of the reviewed Technical Memorandum and vary from 10.9 in/yr to 39 in/yr. The bases for the following two model decisions are not clear to SRK:

- Assumption for extinction depth that was uniformly applied throughout the model domain (The Tetra Tech memorandum states that extinction depth varies with the types of the soil and vegetative cover, ranging from about 1.5 feet under bare conditions in sandy soil to about 27 feet under forest cover conditions in clayey soil). SRK requests an explanation of why a uniform extinction depth was applied.
- Distribution of maximum evapotranspiration rates along the reaches of Cienega Creek and Davidson Canyon. SRK suggests a better explanation for the basis in the data for the distribution.

4 Simulation of Groundwater—Stream Flow Interaction

Cienega Creek has two U.S. Geological Survey (USGS) stream gauges and there is one USGS gauge in Davidson Canyon with historical stream flow data between 1968 and 1981. Tetra Tech simulated the interaction between surface water and groundwater along Cienega Creek and Davidson Canyon with MODFLOW's Stream Flow Routing Package. Stream boundaries were assigned to model layers corresponding to the stream elevation. Stream flows were used as calibration targets in a qualitative manner due to the regional model scale that limits the accuracy of stream-channel aquifers.

5 Model Calibration and Simulated Groundwater Budget

Tetra Tech calibrated the groundwater model to measured steady-state pre-mining water levels by using a weighting approach. All water-level targets (377 wells, 12 piezometers, and 67 springs) were assigned calibration weights (ranging from 0 to 1) based on:

- Availability and completeness of well construction information;
- Well completion interval depth and screen length;
- Water level trends; and
- Period of water-level data.

Simulated groundwater budgets for the pre-mining steady-state conditions are shown in Table 1. The process of steady-state model calibration to the measured water levels is well described.

Table 1: Comparison of Component of Groundwater Budget Simulated by Tetra Tech (2010a) and M&A (2009b) Models.

Components of Groundwater Budget	M&A, 2009b Rate [ac-ft/yr]	Tetra Tech, 2010a Rate [ac-ft/yr]	Difference Rate [ac-ft/yr]
Recharge	7,010	9,909	2,899
Groundwater recharge from streams	2,172	8,344	6,172
Evapotranspiration	4,240	5,638	1,398
Groundwater discharge to streams	2,172	10,962	8,790
Net of boundary outflow	2,770	1,653	-1,117

SRK comments regarding the model calibration are:

1. It is not clear how the results of the interpretation of a 30-day pumping test by 2-D radial flow models (Tetra Tech, 2010d) were used for the model calibration. The comparison shown in Table 2 indicates that the hydraulic conductivity values calibrated and used in the model are less than those estimated from the 30-day pumping test data.

Table 2: Comparison of Hydraulic Conductivity Values for Lower Cretaceous Sedimentary Unit Used in Model and Derived from 30-Day Pumping Test.

Hydraulic Conductivity of Lower Cretaceous Sedimentary Unit	K_h (ft/d)	K_v (ft/d)
Used in Model	0.066	0.005
Estimated from PC-5 pumping test (piezometer PZ-5)	0.16	2.8
Estimated from PC-5 pumping test (piezometer PC-2)	0.1	0.006

2. Table 1 shows that the components of the groundwater budget simulated by the Tetra Tech (2010a) and M&A (2009b) numerical models both were calibrated to measured pre-mining water levels. Yet the components of the budget are substantially different. The differences in the components of the groundwater budget are as much as 2,900 ac-ft/yr for recharge and 8,800 ac-ft/yr in groundwater discharge into streams. Such differences indicate a non-unique calibration of the model to pre-mining only water levels.

3. The Tetra Tech Technical Memorandum indicates that the streambed hydraulic conductivity of 3.28 ft/day was increased by a factor of 2 during the steady-state calibration to better match data from stream flow gauges. However, SRK was not able to find a comparison of simulated stream flows (shown in Figure 40) to measured values.

4. Different pairs of values for recharge/vertical hydraulic conductivity can simulate the same distribution of the water levels, resulting in the same calibration to steady-state water levels. Calibrations of the model to steady-state fluxes (results have not been found) and transient conditions (not completed) are additionally required in SRK's opinion to decrease the non-uniqueness of the parameters used for the predictive simulations.

6 Models to Predict Mining and Post-Mining Conditions

Both models used for prediction of mining and post-mining conditions are very clearly described in the reviewed documents with the exceptions described below. SRK has the following observations and questions:

a) The specific storage parameter for bedrock units was assumed to be S_s=9.86 x 10^{-6} ft^{-1} based on the geometric mean of the values estimated from the radial flow modeling analysis of the 30-day pumping test. SRK is of the opinion that this number represents the high range of specific storage values and is not conservative enough to estimate the possible maximum extent of the cone of depression during mining and post-mining conditions. Storage parameters derived from the short stress tests tend to overestimate values. Based on SRK experience for low permeability bedrock units, a more realistic and conservative value could be S_s=1.0 x 10^{-6} ft^{-1}, which is recommended for use in a Best Case, or, as the value for the transient sensitivity analysis.
b) It is not clear how the values for conductance of the lake cells were assigned and how groundwater inflow to the pit was simulated by drain cells at the end of mining, as compared to the inflow by the lake cells at the beginning of pit lake infilling
c) It is not clear what boundary conditions are along the western model boundary for mining and pre-mining simulation. SRK requests an explanation of how the boundary conditions were constructed for mining and post-mining conditions.
d) It was assumed that the pit lake will reach a steady-state elevation 1,000 years after mining has ceased. This was estimated by extending the predicted post-mining conditions estimated in the 100-year prediction in M&A (2009b). It is not clear whether the assumption is appropriate and representative. SRK recommends completing an assessment of timing to reach steady-state post-mining conditions by using the Tetra Tech model, not M&A model.

7 Results of Model Calibration and Steady-State Sensitivity Analyses

Tetra Tech has completed a sensitivity analyses of model parameters to the steady-state pre-mining water levels by varying 13 parameters (recharge values in 6 model zones and horizontal/vertical hydraulic conductivity values in 6 hydrogeologic units), plus the horizontal flow barrier and streambed hydraulic conductivities values. Based on the completed analyses, Tetra Tech concluded that the steady-state calibration has a "nearly optimal parameter value for matching water level in the model." SRK agrees that mathematically this statement is correct. However, as mentioned above, the model should be calibrated to both water level and flow data. It should be noted that SRK did not find the results of the sensitivity analyses of model parameters to the data for groundwater/stream flow interaction.

8 References

Montgomery & Associates, Inc. (M&A), 2009a, *Results of Phase 2 Hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona*: unpublished report prepared for Rosemont Copper Company, February 26, 2009.

_____ 2009b, *Groundwater-flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper, October 28, 2009, 73 p.

SRK, 2010a, *Technical review of Tetra Tech (2010) Hydrgeologic framework model report*: Technical Memorandum prepared for SWCA, July 30, 2010, 2 p.

_____ 2010b, *Technical review of Tetra Tech (2010) Infiltration, seepage, fate and transport modeling report*: Technical Memorandum prepared for SWCA, April 30, 2010, 9 p.

Tetra Tech, 2010a, *Groundwater flow model construction and calibration*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 198-10-320874-5.3, July, 26 2010, 100 p, 2 attachments.

_____ 2010b, *Steady-state analysis report*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 202/10-320874-5.3, July 30, 2010, 12 p.

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

_____ 2010d, *Hydraulic-property estimates report*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 1741/10-320874-5.3, July, 9 2010, 25 p.