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Memorandum

To:	Dale Ortman, P.E.	**Date:**	July 18, 2012
Company:	Consultant	**From:**	Vladimir Ugorets, Ph.D. Larry Cope Mike Sieber
Copy to:	Chris Garrett, SWCA	**Project #:**	183100.020
Subject:	Responses to Comments provided in SWCA Memorandum of Feb. 17th, 2012, Request for Professional Opinion of Specific Groundwater Modeling Concerns		

1 Introduction

SRK reviewed Montgomery & Associates (M&A) and Tetra Tech (TT) groundwater modeling Technical Memoranda and draft and final reports, met at various times with the M&A modeling staff, and provided recommendations to M&A and TT on (1) geologic and hydrogeologic characterization, as such conditions are presently understood to exist at the Rosemont mine site and surrounding areas; (2) model conceptualization; and (3) model development. The reviews, meetings, and rendering of expert opinions and technical recommendations were undertaken at the request of the Coronado National Forest in accordance with specific Scopes of Work issued to SRK over a period of approximately 3 years.

SRK reviews began with the development of the conceptual model and carried through with discretization of geology and input parameters, calibration, sensitivity analyses, and predictive simulations. The work further included a review of the consistency between the values and approaches used in the models and reported in the documents, as well as a comparison of the M&A and TT models. SRK's expert opinions, discussions, and recommendations resulting from these reviews are documented in the various memoranda produced by SRK. The memoranda are provided as attachments to this document and are listed here for reference:

- Response to 1/15/09 Hydrologic Presentation by Montgomery & Associates, January 21, 2009
- Technical Review of M & A (2009c) Groundwater Flow Model Report Prepared for Rosemont Copper, February 9, 2010
- Technical Review of Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project (Tetra Tech, 2010a) and Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections, Rosemont Mine (Montgomery & Associates, 2010), May 11, 2010
- Review of Tetra Tech (2010) Hydraulic Property Estimates, August 2, 2010
- Technical Review of Hydrogeologic Framework Model (Tetra Tech, 2010), July 30, 2010
- Technical Review of Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project (Tetra Tech, 2010a), August 3, 2010
- Technical Review of Groundwater Flow Modeling sections 1-6 (M&A, 2010), August 17, 2010

- Review of Tetra Tech Documents Groundwater Flow Model Construction and Calibration and Steady-State Sensitivity Analyses, August 17, 2010
- Technical Review of Predictive Groundwater Modeling Results (TT, 2010a) and Rosemont Groundwater Flow Model Sensitivity Analyses (TT, 2010b), September 27, 2010
- Technical Review of Groundwater Flow Modeling Report (M&A, 2010b), October 22, 2010
- Technical Review of Tetra Tech (2010i) Report: Regional Ground-water Flow Model Rosemont Copper Project, January 13, 2011
- Technical Consistency Review of Tetra Tech and Montgomery & Associates Groundwater Models, April 6, 2011
- Technical Review to Compare the M&A (2010) and Tetra Tech (2010) Groundwater Flow Models for the Rosemont Project, April 25, 2011

SRK's principal criteria were to render professional opinions as to whether the groundwater models were constructed to standard industry practices and whether the results were reasonable. SRK was not task with, nor did we undertake an exhaustive inspection of input and output files, or running the models.

SRK undertook the work as a series of requests for review of specific aspects of the conceptualization and development of the models. The reviews relied on information provided by M&A and TT project and technical leaders and from reports and memoranda produced by those firms. The documents that SRK reviewed are summarized below:

- M&A, Results of drilling, construction, and testing of four pit characterization wells, September 6, 2007;
- M&A, Results of phase 2 hydrogeologic investigation, February 26, 2009;
- M&A, Analysis of long-term, multi-well aquifer tests, May 21, 2009;
- M&A, Groundwater flow modeling for simulation of proposed Rosemont pit dewatering and post-closure, October 28, 2009;
- M&A, Groundwater flow modeling for simulation of proposed Rosemont pit dewatering and post-closure, July 2010, Sections 1-6;
- M&A, Groundwater flow modeling for simulation of proposed Rosemont pit dewatering and post-closure, August 30, 2010;
- Tetra Tech, Technical memorandum, hydrogeologic framework model, July 3, 2010;
- Tetra Tech, Technical memorandum, hydraulic properties estimates, July 9, 2010;
- Tetra Tech, Groundwater flow model construction and calibration, July 26, 2010;
- Tetra Tech, Steady-state analysis report, July 30, 2010;
- Tetra Tech, Technical memorandum, Predictive groundwater modeling results, July 30, 2010;
- Tetra Tech, Technical memorandum, Steady-state sensitivity analysis,
- July 30, 2010;
- Tetra Tech, Technical memorandum, Predictive groundwater modeling results, August 17, 2010;
- Tetra Tech, Technical memorandum, Groundwater flow model sensitivity analysis, August17, 2010;
- Tetra Tech, Region groundwater flow model, November 2010; and
- Tetra Tech, Response to SRK's review comments on TT groundwater flow model, November 17, 2010.

The reviews, recommendations, and verification of M&A and TT's responses to the SRK recommendations were carried out as the models were constructed, with SRK providing the majority of input during early stages of conceptualization and data input. The bulk of the SRK effort is detailed in the SRK (2010) memorandum in which the principal recommendations for model improvements are summarized by the 12 bullet points on pages 2 and 3.

2 Responses to Comments

The comments below were provided in the SWCA Memorandum of February 17, 2012 titled "Request of Professional Opinion of Specific Groundwater Modeling Concerns," and are reproduced here verbatim. Each comment in italic font is followed by the SRK response.

Comment 1. *Both the Tetra Tech and Montgomery mine site models utilized constant-head or general-head boundaries at their margins, rather than using no-flow or specified flux boundaries aligned with basin boundaries/ ridgelines as is often done when modeling groundwater in the basin and range province. It is recognized that use of constant-head and general-head boundaries is a valid modeling technique and is used at the professional judgment of the modeler. However, there is concern that use of these boundaries allows an unlimited amount of water to flow into the model, which may be inappropriate for a region as dry as southern Arizona; and therefore leads to an invalid model that does not reasonably predict impacts to groundwater*.

a. Certain analyses or checks must be undertaken to ensure that constant-head or general-head boundaries are being used appropriately in a model. Did Tetra Tech and Montgomery appropriately analyze and check their constant-head and general head boundaries to determine whether unlimited inflow was affecting the results of the models, or had the potential to affect the results if hydraulic parameters should prove to be significantly different from what is currently believed?

Simulation of appropriate boundary conditions along the western model boundary is particularly important given the proximity of the proposed open pit. Hydrogeologists commonly use no-flow boundary conditions along a topographic divide and constant head boundary conditions where hydraulic heads stay unchanged (rivers, lakes, creeks). The proposed pit would be located adjacent to the crest (divide) of the Santa Rita Mountains, an area of groundwater recharge and higher water levels. Groundwater recharged along the divide outflows to the west and to the east. Values for hydraulic conductivity of the Precambrian basement rocks (pCb) to the west of the pit and Upper Cretaceous and Early Tertiary intrusive rocks (Kti) to the northwest are very low (2.38 x 10^{-3} ft/d and 1.31 x 10^{-3} ft/d, respectively) and significantly limit propagation of drawdown due to pit dewatering. The results of the model show that the west dipping (outward) gradient at the western boundary near the pit is lessened but not reversed by inflow to the pit.

SRK recommended (SRK, 2010) that the western boundary of the M&A model be changed from a constant head to general head boundary and be moved a distance from the ultimate extent of the proposed pit such that no changes in water levels would be expected during both mining and post-mining conditions. Those changes were made to the M&A model.

2.1 M&A Model

The western boundary of the M&A model (shown in Figure 80 of M&A, 2010) was simulated as a combination of:

- General head boundary conditions (GHB; a head-dependent flux boundary where flow across the boundary is dependent on variation in simulated groundwater level at boundary) with specified heads located one-half mile from model boundary, based on estimated equilibrium groundwater levels at these locations, and hydraulic conductivity of the model boundary;
- Constant head boundary conditions (CHEAD) based on estimates of equilibrium groundwater levels; and
- No flow boundary conditions.

GHBs were assigned in all saturated model layers across the boundary where the projected groundwater levels change from pit dewatering and specified water levels at a distance of 0.5 mile from the model domain. CHEAD were specified in all other model boundary cells, with the exception of the unsaturated Layer 1 and Layer 2 boundaries, which were specified as no-flow boundaries. A vertical gradient was not specified for the boundary conditions.

The steady-state model groundwater balance described in Section 7.7.3 of M&A (2010) does not specify groundwater inflow/outflow through the western boundary. The simulated steady-state water table and direction of groundwater flow as shown on Figure 96 of that report indicates that groundwater generally outflows through the western model boundary. The simulated water table at the end of mining is shown in Figure 107 indicating that the groundwater gradient from the western boundary would not be reversed and ground water will continue to outflow through the western model boundary in the proximity of the pit.

The M&A report does not show the predicted water table during post-mining conditions and simulated groundwater flow through the western boundary.

SRK asked the following questions in our technical review of M&A (2010) (SRK, 2010, page 5, items 4 through 7):

- Explain why a distance of ½ mile was used to assign GHBs along the western boundary of the model.
- Show simulated outflow from the western boundary of the model, modeled by GHBs at steady state conditions.
- Show a groundwater budget at the end of the life of mine containing the components of
- Predicted passive inflow to the pit, or otherwise state that all passive inflow would come from groundwater storage.
- Show a groundwater budget at long-term post-mining conditions (1,000 years after mine closure) and changes compared to pre-mining steady state condition. A table format is preferable and recommended.

SRK has not received documentation that demonstrates the above questions have been addressed.

2.2 Tetra Tech Model

The western boundary of the TT model was simulated as CHEAD (shown in Figure 6-2 of Tetra Tech, 2010) to reproduce groundwater outflow from this boundary. During the model review, SRK recommended replacing the CHEAD boundary with a GHB at different distances to evaluate the effect of the western boundary on results of the predicted mining and post mining conditions. As a result of this recommendation, Tetra Tech, as part of its sensitivity analysis, evaluated a scenario with GHB conditions along the western boundary with specified heads 0.5 mile west of the model boundary, which was itself, about 2 miles from the proposed pit.

As with the M&A model, the Tetra Tech (2010) report does not show the predicted water table at the end of mining and during post-mining conditions, nor does it show the simulated groundwater flow through the western boundary. The third paragraph of Section 8.4 of the TT report, Predictive Mass Balance, states:

> "High groundwater-level elevations along the crest of the Santa Rita Mountains and the Open Pit area resulted in outflows through the western boundary during all simulations. Outflows through the constant-head cells decreased 1,080 ac-ft/yr during the mining-phase. This is largely attributable to a 0.13 percent decrease in flow out of the western boundary. Drawdown in the Open Pit area decreased the hydraulic gradient toe the west."

In addition, page 85 of Tetra Tech (2010) indicates that model simulations using either CHEAD or GHB boundary conditions predict no groundwater inflow through the western model boundary. The results of sensitivity analysis completed by Tetra Tech show that replacing of CHEAD by GHB along the western boundary condition decreases groundwater outflow through this boundary by 0.04% by end of mining and 2.1% during post-mining conditions. These results show that boundary conditions (CHEAD vs. GHB) are not sensitive to the propagation of drawdown to the west due to the low permeability of Precambrian basement rocks (simulated *K*=2.38 x 10^{-3}ft/d) forming the core of the Santa Rita Mountains.

It should be noted that Tetra Tech also evaluated no-flow boundary conditions along the western model boundary and concluded that the model could not be calibrated to the measured water levels due to existing groundwater outflow along this model boundary.

SRK considers that the appropriate use of general head boundaries has not been sufficiently demonstrated by the information presented in the M&A and TT reports made available for our review. If not already performed, the following analyses would strengthen the models:

- Demonstration of the appropriateness of the 0.5 mile distance at which the GHBs were assigned for the pit lake infilling predictions;
- A map of the predicted water table at the end of mining and during post-mining conditions showing the direction of groundwater flow; and,
- Detailed groundwater budget showing all components of outflows and inflows from/through the constant-head and general head boundaries at the pre-mining, end of the mining, and during post mining conditions for each model boundary, including the western boundary).

b. *Describe in detail the level of review SRK conducted regarding head boundaries in both models. Did SRK conduct boundary flux analysis and evaluate the results? If so, what method was used and what were the results.*

SRK provided concepts and recommendations to M&A and TT based on the preliminary M&A model domain and the topographic and geologic realities within and adjacent to that domain. SRK recommended the western boundary be changed from a constant head to a general head boundary, and to move the boundary a significant distance westward from the mountain ridge line (and the planned extent of the pit) to eliminate the influence of pit dewatering and pit lake infilling on the boundary. SRK provided guidance through technical discussion during the development of the model, but did not run or otherwise evaluate the model results nor conduct a boundary flux analysis.

c. *Does use of these boundaries in the model invalidate the results of the models or render these models unacceptable for reasonably predicting future impacts?*

It is SRK's opinion that the use of general head (M&A) and constant head (Tetra Tech) boundary conditions along the western model boundary do not invalidate the model and reasonably predict the impacts because of the:

- Low permeability of the Precambrian basement rocks (estimated average hydraulic conductivity of K=2.38 x 10-3ft/d) forming the core of the Santa Rita Mountains and limiting propagation of drawdown to the west of the model boundary; and
- Existence of groundwater outflow through the western model boundary and absence of a reversal of the regional groundwater gradient in the predictions made by the M&A (2010) and Tetra Tech (2010) models.

However, SRK suggests that the defensibility of the models would be advanced by evaluating in more detail the boundary flux through the western boundary (as discussed above) by conducting additional sensitivity runs that would involve:

- Moving the GHB condition further away from the model domain to achieve no changes in groundwater outflow during mining and post-mining conditions; and,
- Replace CHEAD conditions used for pre-mining simulations by constant flux boundary conditions for the predictive simulations.

d. *Provide examples of mining projects, or similar, where general and or constant head boundaries have been utilized in an arid environment and or basin and range province. Describe the case studies, including rationale used, distance from pumping centers to boundaries and success of model results to monitoring results.*

Example 1 - San Manuel Mine Site, Arizona. A FEFLOW finite-difference groundwater flow model was run to simulate dewatering of the San Manuel underground mine and open pit and post-closure formation of a pit lake. The model domain had 14 layers and 74 square miles. Constant head (prescribed head) boundaries were assigned to layer 1 along the San Pedro River, 3 miles down gradient of the mine. C-Head boundaries were assigned to layer 3 for a short distance to simulate the San Pedro River alluvium. A constant head boundary was assigned to layer 2 at the up-gradient boundary above the town of Oracle, 8 miles up-gradient of the mine. The prescribed head of the 4,800 ft boundary was to simulate groundwater underflow, as this was not a groundwater divide. For all simulations the underflow from this boundary was 1.1 gpm (SRK, 2003)

Example 2 - San Manuel Plant Site, Arizona (5 copper tailing impoundments). A MODFLOW model was developed with 7 layers and a physical sub-watershed of 302 square miles. The groundwater boundaries are groundwater divides, and therefore, no flow boundaries. The San Pedro River flows southeast to northwest through the center of the model. Constant head boundaries were used on Layers 1, 3, 4, and 5 to simulate the river and alluvium. The tailings impoundments are 1600 ft to 240 ft up gradient of the San Pedro River (SRK Consulting, 2005).

e. *Did you examine the models from within the Groundwater Vistas preprocessor? An example of information not found in the text or without the use of the Vistas is all of the stream cells have a vertical hydraulic conductivity of 100 feet per day in the M&A model, and 6.6 feet per day for the Tetra Tech model (see attached). Do you believe this is appropriate? Do you believe the leakage from these stream cells is not excessive, based on these parameter values?*

SRK was tasked by CNF/SWCA to review the models within Groundwater Vistas preprocessor specifically to check the consistency of the models with the M&A model report (M&A, 2010) and the TT model report (Tetra Tech, 2010). Therefore, components of the numerical models that were not presented in the reports were not reviewed, i.e. the STR package input was not included in the reports. As mentioned, SRK was not tasked to run the models for verification.

f. *Dr. Roger Congdon, a Forest Service Hydrogeologist, ran the M&A model in steady state mode with a well pumping at 104 gallons per minute, simulating the pit lake evaporation. Comparing the output to the steady state output without any wells showed that 51% of the difference in mass flux came from the constant and general head boundaries. How can this model be relied upon to perform future predictions when over half the changes come from fictional water?*

SRK has not studied the analysis performed by Dr. Congdon, and cannot comment on it. For both the M&A and TT models, we are dealing with a minor decrease of groundwater outflow through the western model boundary. However, considering the sensitivity of the modeled boundary conditions along the western boundary, as stated, SRK is of the opinion that the defensibility of the model predictions would be improved if M&A and Tetra Tech were to evaluate the scenario witha steady-state CHEAD boundary flux used as a constant flux boundary for transient simulations as additional sensitivity run. The another sensitivity run might consider GHB conditions with specified head at the significantly larger distance than 0.5 mile (currently applied by M&A as Base Case and Tetra Tech for a sensitivity scenario) can be also evaluated but this would require re-doing steady-state calibration of the models.

<u>Comment 2</u>. *Tetra Tech and Montgomery both describe that fractured flow exists near the mine site, and both describe that farther afield in the Cienega Creek basin groundwater flow occurs through basin fill sediments. Both the Tetra Tech and Montgomery mine site models also utilize an equivalent porous media approach to modeling this hydrologic framework. There is concern that by using an*

equivalent porous media approach, impacts propagating from the mine site to perennial reaches of streams in the alluvial basin (i.e., Cienega Creek, Empire Gulch, and Gardner Canyon) may be underestimated.

a. *Is use of an equivalent porous media approach appropriate forth is hydrologic setting? Is there any groundwater modeling technique in standard use by groundwater professionals that would have been more appropriate forth is setting? For example, would it not be more appropriate to employ the Dual Domain transport module of MODFLOW-SURFACT, which is the engine used for both models?*

The groundwater system is simulated as an equivalent porous media (EPM) with explicit representation of the Backbone Fault, the Flat Fault, and the Davidson Canyon fault zones in the M&A model (M&A, 2010) and a quartz-porphyry dike in the TT model (Tetra Tech, 2010). The results from the long-term pumping test showed a multi-directional drawdown response in the observation wells, generally supporting the concept that the groundwater system can be considered to behave at a field scale as an EPM. In SRK's opinion, this is an acceptable, industry-standard methodology for simulating groundwater movement in faulted and fractured rock where the system is not strongly influenced by discrete flow conduits or by flow barriers that compartmentalize the flow system.

b. *Specifically, is there a groundwater modeling technique in standard use by groundwater professionals that would have been more appropriate for analyzing the impacts from mine pit drawdown on the distant perennial streams. For example, wouldn't a dual domain approach be appropriate since the porosity of the rocks is minimal and fractures may transport like open conduits?*

Use of an EPM groundwater flow model is a standard and commonly used method to model mining impacts to a groundwater system and to surface water. M&A has enhanced the technique by applying PEST during calibration to simulate variability in bedrock permeability. The technique resulted in continuously varying values for hydraulic conductivity within each hydrogeological zone. By employing a variable hydraulic conductivity parameter through the process of calibration, the model implicitly incorporates the geologic features that create varying water levels and discharges from test wells. This approach within a fractured system represented by an EPM is viewed in this case as more inclusive of reasonable fracture variability than would be an attempt to discretize fracture sets within large volumes of rock in light of the lack of identified individual large faults that clearly dominate the flow system at the site.

An additional point is that fractures, and in particular, large faults or fracture zones can carry large amounts of water, but the amounts of water they will convey over extended periods of time are limited by the recharge to those features. Without a constant source of recharge at the rate the fractures can potentially carry, the long-term flow through the features diminishes to the rate that equals recharge. If the source of recharge is a porous medium, the rate will equilibrate to the ability of that medium to drain into the feature. If the source is, for example, directly connected to a surface water body, the flow through the feature could stabilize at its potential capacity as an essentially free flowing conduit. At the project site, the sources of recharge to faults or fracture zones are local precipitation limited by infiltration of 15-20 inches per year of rainfall, and basin sediments controlled by their relatively moderate hydraulic conductivities.

SRK is aware of, but has not applied the fracture modeling software FracMan, which when combined with its complementary flow modeling software MAFIC, is designed to statistically generate a fracture field and simulate flow through the field as a double porosity flow system. In addition, SRK is aware of PMF and FRACTRAN, codes that serve as pre-processors to MODFLOW. They are stochastic fracture network generators that can be incorporated into MODFLOW to create a dual-domain model. SRK has used neither of those packages to model impacts at a regional scale. Defining fracture networks, either deterministically as discrete features or stochastically requires high density and extensive data collection specific to particular features that may or may not extrapolate to other non-tested features, and if statistically generated, can lead to greater uncertainty in model results. In SRK's opinion, fractured flow models are not practical at the regional scale, difficult to calibrate, may not represent actual fracture conditions, and do not yield better predictions compared to equivalent porous models that are well calibrated to steady-state and transient water levels and fluxes.

Comment 3. *Most of the hydrogeologic characterization (boreholes, pump tests) is located near the mine pit. The model extends much farther to the east.*

a. Is there a need for additional hydrologic characterization beyond the existing data set to validate the model?

It is SRK's opinion that the model can be validated only through permit-required updates as mining of the pit progresses.

There is a large amount of hydraulic test data that was generated for and applied to the models. In addition to the more recent testing conducted by M&A in the pit area, 30 short-term pumping tests were conducted for Anamax Mining Company in the area outside the current project area. M&A analyzed that data, which was included in the conceptual and numerical models and used in model calibration. Five of the Anamax pumping tests were completed in upper Cienega Creek; five tests were completed in the middle portion of Cienega Creek; and six tests were completed in lower Cienega Creek. Ten pumping tests were completed in Davidson Canyon. Four pumping tests were completed in the Tertiary basin-fill east of the project area.

The distribution of measured transmissivity and calculated average hydraulic conductivity data in space from performed hydrogeologic testing are shown in Figure 29 of M&A (2010). The locations of measured water levels within the model domain are shown in Figure 26 and 28 of M&A (2010). The M&A and TT models were calibrated using the early Anamax data and the later M&A data.

It is SRK's opinion that the hydrogeological data collected for this project are adequate to characterize the hydrogeology in the areas predicted by the model to be subject to impacts from pit dewatering. The data collected are sufficient, in our opinion, reasonable for the models developed and are consistent with standard industry practices, perhaps excepting the hydraulic properties of the porphyry dike included in the TT model, as explained in the following section.

b. If so, how could this affect the model results?

As described above in the response to Comment 3a, a large number of pumping tests were completed in Cienega Creek, Davidson Canyon, and Gardner Canyon and a significant amount of water level data were collected. It is SRK's opinion that the groundwater system has been adequately characterized to reasonably represent the groundwater flow system in the areas of expected maximum stress and the bulk properties of the rock and basin fill in, and around the area of the anticipated drawdown cone created by pit dewatering. One exception may be the quartz porphyry dike simulated in TT's model as a low permeability feature between the open pit and Davidson Canyon. The hydrogeological significance of this dike in unknown and a further assessment may be warranted by including this feature in the modeled Base Case prediction. SRK made this recommendation in a review memorandum (SRK, 2011) and recommended exclusion of this dike from the Base Case to conservatively simulate potential impact to the groundwater system and surface-water bodies in Davidson Canyon. SRK does not know whether the recommendation was followed.

c. Does the lack of additional hydrologic characterization affect the validity of the model with respect to Cienega Creek and other relatively distant stream/wetland areas? Why or why not?

The model is well calibrated to steady state (pre-mining) conditions. The aggregate pumping rates during the 30-day multiwell pumping test are within commonly accepted stresses with which to predict hydraulic stresses during future pit dewatering. The reasonable approach taken does not invalidate the model. As stated, the model can only be validated through comparison of model results to actual pit-induced drawdown, and recalibrated as required. The predicted maximum inflows to the proposed pit are 630 gpm and 510 gpm per the M&A and TT models, respectively. The total pumping rate from the 30-day multi-well pumping test was 200 gpm or 32 to 39 percent of the predicted stress. The M&A model was calibrated to the results of this multi-well pumping test with stress to the groundwater system 32 percent of the predicted pit inflow. In SRK's opinion, the current models are valid and provide reasonable predictions that will be updated with monitoring data collected during actual pit dewatering. As stated in several places in this response, SRK agrees with comments that the defensibility of the model can be improved.

Comment 4. The stream cells, which are all part of the SFR, or Stream Flow Routing package all have a vertical hydraulic conductivity of 100 ft/d in the M&A model, and 6.6 feet per day for the Tetra Tech model. This appears to be quite high as typical values range from 0.5 to 10 ft/day (one to two orders of magnitude). The issue is that of the elements in the mass balance section, this lessens the component of stream flow leakage in the model mass balance and increases the component from artificial boundaries.

a. Describe in detail the level of consistency review SRK conducted regarding vertical hydraulic conductivity of stream cells and the applicability of the values presented in the existing models.

SRK's scope of work in this regard was to review the groundwater flow model input/output files for consistency with the final model reports, with specific emphasis directed to:

- Steady-state and transient mining and pit lake infilling conditions;
- Areas of large drawdown, e.g. adjacent to the pit;
- Hydraulic parameters;
- Boundary conditions; and
- Other fundamental conditions.

Groundwater-surface water interaction of base flow in selected stream reaches within the model domain was simulated using the MODFLOW STR package. Two perennial reaches along Cienega Creek and one perennial reach along Davidson Canyon were incorporated into the M&A and TT models. The M&A model used a hydraulic conductivity value of 100 ft/day. The TT model used a hydraulic conductivity value of 6.6 ft/day. The TT model was calibrated to measured water levels and stream flow discharges using the different vertical hydraulic conductivity values for streams cells—6.6ft/d. The M&A model set the vertical hydraulic conductivity to 100 ft/d so as not to impede projected stream flow decreases due to pit dewatering. These relatively high values, compared to the range suggested by the CNF (0.5 ft/d to 10 ft/d), simulate relatively unrestricted hydraulic connection between the groundwater system and the modeled surface-water bodies. These parameters very often appear to be black-box values that are finalized during model calibration to measured water levels and stream flow data. SRK is of the opinion that the applied values for vertical hydraulic conductivity for the stream cells are conservative with respect to impacts to surface-water bodies from the pit.

Comment 5. The output file (SswithTriHs.out) supplied by Tetra Tech shows that it "failed to converge," which means that a solution was not reached (see attached printout). A discrepancy of 23% between outflow and inflow is reported. This is much larger than the less than 0.01% reported by Tetra Tech in the text of the modeling document.

a. Describe in detail the level of review SRK conducted regarding the various input and output files. Describe what the implications are of the results of the output file mentioned above.

TT and M&A provided SRK with numerical files for their steady-state models, mining models, and post-closure files to review using Groundwater Vistas version 5.5.1 software (Rumbaugh and Rumbaugh 2007). SRK used the software to review input files to check the consistency with what was described in their modeling reports (M&A, 2010 and TT, 2010). The models were checked for mesh discretization, stress period setup, hydraulic properties, boundary conditions, recharge, evaporation, groundwater/stream flow interaction, and boundary conditions.

Specifically, SRK has reviewed the TT output files:

- SS_33_Final (SSwithTrIHs.out),
- MiningJuly26 (MiningJuly26.out), and
- PostMineJuly26 (PostMineJuly26.out).

The TT steady-state model output file SSwithTrIHs.out shows that the numerical solution converged with 0.0 percent discrepancy (not 23.07% as indicated in the SWCA memorandum) and did not show any failure to converge, as stated by the CNF reviewer. The file MiningJuly26.out had a -0.02 percent discrepancy at the end of the simulation and the file PostMineJuly26.out had 0.00 percent discrepancy at the end of the simulation.

SRK has also reviewed the M&A output files for the steady-state model (file ss82.out), mining model (file trans82_DRN.out), and the post-closure model (file trans82_Lak_05a.out) for the Base Case scenario. The output file from the M&A steady-state model showed an acceptable discrepancy of 0.02 percent and an absence of a failure to converge.

<u>Comment 6</u>. *Please review the following scenario, regarding testing of head boundaries, and comment on its logic.*

a. Conduct a test of the head boundaries: To do this, run a steady state simulation. Then add a well to the steady state simulation (simulating the maximum rate of pit dewatering) and run it again. After the second run compare the two simulations and measure how much of the change to balance the added stress comes from the artificial boundaries. Results should be less than 10 percent. If less, test is complete. If more, then go to "b" below.

No response needed.

b. If the solution to "a" above is a fail, then conduct a transient simulation with the boundaries 'fixed' or "isolated" with the steady state flow rates. Change every constant head and general head boundary cell to a specified flux boundary, with the flux rate identical to the boundary fluxes in the steady state scenario; so that no additional fictional water can be introduced through the external boundaries. Then for the transient runs, these outer boundaries would be replaced with wells; each injecting or extracting water at the rate of the mass flux obtained from the steady state simulation. Therefore, no additional water would be produced at the boundary by virtue of a changed gradient. A cone of depression not influenced by an artificial influx of water may be produced in this manner.

The approach recommended by the CNF of replacing CHEAD conditions for constant flux boundary conditions during transient mining and post-mining simulations is a common technique used by groundwater modelers, and is a reasonable, and in many cases, a conservative approach. It is not an uncommon method to test boundary flux rates, and SRK agrees that it could be done this way.

3 Conclusions

SRK made recommendations throughout the process of development of the two models during meetings with the model authors and formalized in memoranda. In most cases M&A and TT incorporated the recommendations into their work, as described in the two model reports. However, an evaluation of the western boundary with sensitivity runs or with maps showing the potentiometric surface or flow vectors was not provided in the model reports nor provided as separate materials for SRK to review. As stated previously, SRK is of the opinion that reporting the results of such an evaluation would strengthen the defensibility of the models, and would us to provide a stronger opinion about the boundary. Specifically, the following should be provided:

- An explanation as to why the distance of ½ mile was used to assign GHBs along the western boundary of the model;
- A map or table that shows simulated outflow from the western boundary of the model;
- The predicted passive inflow to the pit to demonstrate that all inflow would come from groundwater storage; and,
- The groundwater budget at the end of the mine life and long-term post-mining conditions (1,000 years after mine closure) and changes compared to pre-mining steady state condition.

In addition SRK considers that the defensibility of the TT model could be improved by eliminating the porphyry dike in their base case predictive runs, so as to present a most conservative prediction with respect to water level impacts.

4 References

Montgomery & Associates, 2009, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., October 28, 2009, 51 p.

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SRK Consulting (U.S.), Inc., 2005, BHP Copper San Manuel Plant Site, Pinal County, Arizona, Groundwater Characterization Report: unpublished report prepared for BHP Copper Inc., San Manuel Operations, June 2005, 330 p. and nine appendices.

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Tetra Tech, 2010, *Regional Groundwater Flow Model Rosemont Copper Project*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320874, November 2010, 118p, 1 appendix.

5 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 33 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

Larry Cope, a Senior Hydrogeologist holds a Master of Science degree from Colorado State University with 25 years' experience consulting to the mining industry. He specializes in aquifer hydraulic testing and analysis, hydrogeologic characterization, mine water management, and environmental data management. For the mining industry, Mr Cope has collaborated with clients to evaluate and manage mine water inflow, develop mine water supply, conduct investigations for dewatering, design groundwater monitoring programs, and perform statistical evaluation of water chemistry data to meet regulatory reporting and internal client performance evaluations. Most recently, he has been the lead investigator for hydrogeologic investigations and mine water management at a number of operating underground and open pit mines.

The reviewer for hydrogeology, Mike Sieber, P.E., is a Hydrogeologist with SRK Consulting in Tucson. Mr. Sieber is a professional engineer with more than 17 years of hydrogeology experience including 15 years preparing infiltration and seepage models to estimate infiltration through tailings impoundments, waste rock storage and heap leach facilities, and landfill covers. He has more than 10 years' experience in the preparation of numerical groundwater flow models to predict the formation of pit lakes and potential loss of containment at open pit and under-ground mining operations.

Attachment: SRK Memoranda

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Memo

To:	Dale Ortman	**Date:**	January 21, 2009
cc:	Cori Hoag, SRK Consulting Ken Black, SRK Consulting Dawn Garcia, SRK Consulting	**From:**	Larry Cope, SRK Consulting Roger Howell, SRK Consulting Claudia Stone, SRK Consulting
Subject:	Response to 1/15/09 Hydrologic Presentation by Montgomery & Associates	**Project #:**	183101

Following are comments regarding the January 15, 2009 meeting held in Tucson with staff from Errol L. Montgomery & Associates (M&A) during which M&A hydrogeologists presented their hydrologic characterization and model development work done to date on the Rosemont Copper Project. The presentation was made for the benefit of the U.S. Forest Service and their consultant, SWCA. This memorandum was prepared jointly by L. Cope, R. Howell, and C. Stone of SRK Consulting, Inc., as requested by SWCA. The memorandum is intended to give the initial impressions of SRK attendees and does not constitute a thorough technical review.

1 Drilling

- M&A presented an overview of the wells that have been installed to characterize the groundwater of the proposed mine area. The data are from vertical wells intended to provide representative groundwater information. No data on angle or horizontal holes were presented to SRK, although some data may be available from Call & Nicholas or other consultants. Angled or horizontal holes, where appropriately located, provide information to characterize steeply dipping faults that may not otherwise be intersected in vertical holes. It would be helpful to the calibration and assessment of the hydrologic model to have drilled and tested angle holes or vertical holes into the west wall of the ultimate pit area where geologic mapping indicates the presence of numerous faults.

- There seems to be a paucity of flow and storage information governing the hydrologic characteristics of the Paleozoic formations, which form the crest of the Santa Rita Mountains, and the Continental granodiorite farther to the west. More definitive data derived from further hydraulic testing and core analysis would aid in evaluating the hydraulic properties of these units and establish better model boundary conditions…thereby enabling better model calibration and ultimately generating a more realistic model of flow through the porous and fractured rocks at and surrounding the ultimate pit area.

2 Model Development

- The no-flow boundary along the west side of the "model study area" should be changed. This type of model boundary presumes there is no flow across the western boundary of the model, which is represented by the rocks on the west side of the proposed pit and the west side of the mountain. A no-flow boundary juxtaposed to a groundwater divide may not allow drainage of water from the granodiorite to be accurately represented. The presence of transmissive faults or dikes would not be represented. Nor would the potential for westward expansion of the groundwater divide be accommodated. Data from the pumping tests and core analysis and further assessment of flow characteristics of the fractured or porous rock through further model calibration should provide a means to test the boundary conditions needed to adequately simulate the head changes and flow through the Paleozoic rocks on the west side of the pit.

- The constant-head boundary on the east side of the model domain also should be reconsidered. A fixed head is not conservative, as it will tend to minimize drawdown effects in this direction due to mining and/or dewatering for depressurizing and slope-stability control measures. Such a constant-head boundary should be demonstrably located beyond measurable drawdown.

3 Geological Representation

- The plan for the development of the groundwater numerical model in the M&A Technical Memorandum dated November 30, 2007 acknowledged that the initial plans were to represent the aquifer as an equivalent porous medium (EPM), and that if the results of the field investigation indicate otherwise, the modeling approach may need to be revised. Known significant faults and fracture zones should be discretized into the numerical groundwater-flow model. Although the assumption may be valid that the bedrock aquifer can be modeled as an EPM, structural barriers and conduits may exist that will affect the directions and amount of groundwater flow over durations longer than the anticipated short-term storage depletion of those structures. M&A concedes that they do not have hard data on the properties of the faults (especially distal to the pit). Nevertheless, the faults should be incorporated into the model grid even if the fault cells have to be assigned the parameters of the country rock. In this way, sensitivity analyses can be done to determine if the faults are hydrogeologically significant, and if additional characterization of their properties is needed.

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Technical Memorandum

To:	Tom Furgason, SWCA	**Date:**	February 9, 2010
cc:	Dale Ortman, P.E. Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.S. Michael Sieber, P.E.
Subject:	Technical Review of M & A (2009c) Groundwater Flow Model Report Prepared for Rosemont Copper	**Project #:**	183101

This review has been undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest. The memorandum provides comments related to a review of the report, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure,* (M & A, 2009c) prepared by Errol L. Montgomery & Associates, Inc. (M & A) for Rosemont Copper Company. These comments were prepared by Dr. Vladimir Ugorets, Mr. Larry Cope, and Mr. Michael Sieber of SRK Consulting (U.S.), Inc. (SRK). The groundwater modeling report and supporting documents from M & A regarding the 2008 field program (M & A, 2009a and M & A, 2009b) were reviewed as reference materials for preparing this memorandum.

The technical comments are grouped into four topics: (1) analysis and interpretation of field data, (2) model setup, (3) model calibration, and (4) predictive simulations. In general the comments are requests for: information that will clarify the use of measured data in the model, additional model calibration, and additional predictive simulations as part of the sensitivity analysis. Without the requested information and model outputs, SRK cannot adequately judge the model as suitable and defensible.

1 Analysis and Interpretation of Field Data

This section summarizes our review of the analysis and interpretation of field data. The field methods used in well construction and aquifer testing are considered acceptable and to standard industry practices.

Horizontal Hydraulic Conductivity

It is understood that most wells partially penetrated the geologic units that were pump tested. It appears that hydraulic conductivity was calculated from the aquifer test data using the saturated thicknesses of the unit being tested. It is unclear how those calculated values were incorporated into the model given that partial penetration effects could be significant at the pumped wells over 30 days of pumping. However, the effect of partial penetration diminishes with distance from a pumping well. Thus, the data that were used in creating the input data set to the model is unclear. A modification of the results tables in 2009b or in Table 4 of the reviewed report would help in assessing how the data were used.

Vertical Hydraulic Conductivity

The gaped, screened intervals of the pumping test wells and the multiple level standpipe and grouted-in piezometers as observation wells likely provide an opportunity for analysis of vertical hydraulic conductivity

(Kv). No values for Kv were provided, and as such there is no opportunity to verify the Kv assumptions used in the model. It is recommended that values for Kv be estimated, where possible, from the test data.

Hydraulic Influence of Faults

Analysis of the long-term pumping test data does not include an evaluation of the influence of faults on the values of hydraulic conductivity. The influence of faults on horizontal and vertical hydraulic conductivity appears to be implicit in the values applied to the model. Without the influence of the faults estimated from the test data, the representativeness of the modeled values for hydraulic conductivity cannot be verified.

2 Model Setup

The Rosemont model was constructed using the *MODFLOW-SURFACT* code (including the *LAK2* Package for simulation of the pit lake infilling and the graphical modeling interface, *Groundwater Vistas*). All of the programs are industry-accepted codes for groundwater modeling.

Grid Discretization

Grid discretization (203 rows, 168 columns, and 10 layers with a minimal lateral cell size of 200 ft by 200 ft) is generally adequate to simulate the proposed pit dewatering and post-mining conditions. However, the elevation of the layers (especially in the pit area), made flat for the convenience of the pit lake simulation, does not match the geological/hydrogeological units or zones. The bottom of the model is about 2,000 ft below the ultimate floor of the proposed open pit. The extent of the model and the model thickness are very reasonable to estimate both the horizontal and vertical components of groundwater inflow to the pit/pit lake and the possible impact of the mining operation on the groundwater system during mining and post-mining conditions.

Geological Representation

Ten hydrogeological units in the model area (page 12) are represented in the model by only three geological units (Section 8.3):

1. Quaternary and recent alluvium
2. Late Tertiary to Early Quaternary basin-fill deposits, and
3. Bedrock.

Each geological unit was subdivided by different numerical zones where hydraulic conductivity values were assigned using the PEST optimization subroutine (to be discussed below) during steady-state calibration of the model. In the reviewers' opinion, the simulated west-east modeled cross section shown on Figure 37 of the modeling report poorly matches the geological cross section A-A shown on Figure 4.

Simulation of Fault Zones

The groundwater flow model (M & A, 2009c) also does not include structural features that exist in the model domain. Page 18 of the report indicates that a fault zone through the Davidson Canyon area is a significant hydrogeological feature consisting of at least two major faults; the report states that the "potential hydraulic influence of this fault zone is evaluated as part of this investigation." It is not clear why this very important feature was not incorporated into the model. Even in the case of a lack of data, a sensitivity analysis could be applied for this zone.

Hydraulic Parameters Used in Model

It is not clear how hydraulic conductivity values (K) were assigned in the model. The **P**arameter **EST**imation (PEST) code was used for a model calibration to match water levels in individual monitoring points. However, without consideration of geological and structural features and without histograms or tabulations of the distribution of K by rock type and layer, the validity and accuracy of the results cannot be verified. As an example, it is not clear why the bedrock unit in layer 2 on Figure 37 (K=0.1 to 1 m/day, right part of cross section) is more permeable than it is in layers 1 and 3; or why bedrock in layer 3 on Figure 38 (with K=0.0001 - 0.001 m/day, right part of cross section also) is less permeable than it is in layers 2 and 4, above and below, respectively.

The report does not clearly indicate:

1. Modeled distribution of parameters within different hydrogeological zones,
2. The limits of K used for the PEST iterations, nor the criteria for selecting the limits, and
3. Measured values of K from hydrogeological tests conducted in the field (min, max, and average).

Table 4 does not provide information as to which hydrogeological units are screened, nor is it clear how the aquifer thickness was defined, i.e., is it a real aquifer thickness or the partial-penetrated screen interval? Figures 29 through 36 show simulated horizontal hydraulic conductivity values (zones where K values vary within one order of magnitude). Measured values interpreted from the field test data, are not shown on these figures, and it is difficult to judge how reasonable these distributions are of K values.

The following requests of information are to clarify how the geology and measured hydraulic conductivity/ transmissivity values correspond with the model parameters:

1. A table or tables that correlate model layers to rock type, and rock type to measured permeability values.
2. Addition of measured permeability values at the appropriate locations on the model layer cross sections of Figures 37 and 38.
3. Histograms of measured permeability values by rock type.

There is no assessment of vertical anisotropy in the report. M & A (2009c) used Kh:Kv = 10:1 for Qal and QTg units and Kh:Kv = 1:1 for bedrock. However, it is not clear how these ratios were confirmed by hydraulic test data.

Vertical hydraulic conductivities used in the model were assumed but not measured. Kv is a particularly important parameter in models where significant drawdown occurs next to an open pit. It is requested that values of Kv be calculated from available field test data to verify the adequacy of the assumptions of vertical anisotropy. The manner in which the individual screened zones of some pumping wells were isolated by packers and the completion geometry of a number of wells suggest that such an analysis is possible. A sensitivity analysis would show the relative importance of Kv (as well as the other input variables) in predictive simulations.

Storage parameters, generally, look reasonable. However, the values used do not cover the possible range of values. It is entirely possible that the simulated drawdown could be larger in extent than the prediction presented in the report.

Boundary Conditions

General head boundary (GHB) conditions, applied at the lateral model boundaries, are not clearly described. Section 8.1 of the report (M & A, 2009c) indicates that GHB conditions "were derived from estimates of equilibrium groundwater levels and hydraulic conductivity of the aquifer at model boundaries." However, it is not clear what parameters of the GHBs were used (specified head, distance, and transmissivity) nor how they were chosen. The choice of layers, where they were applied on Figure 26 (layers 1 and 2 in most areas, layers 2 and 3, 3 and 4 at the northwestern corner of the model), is not described in the text of the report. Description and assessment of the boundary conditions for the other layers are absent (by definition the *MODFLOW* code authors assumed them to be no-flow).

Recharge and Evapotranspiration

M & A (2009c) conducted thorough research for precipitation and evaporation data in the region of the Rosemont project. A conservative estimate of precipitation was used: 405,000 acre feet /year (ac-ft/yr). M & A's use of such units (ac-ft/yr) for precipitation, recharge, and evapotranspiration, however, makes it difficult for the reviewers to compare the model to precipitation, since precipitation typically is reported in inches per year (in/yr). The estimated precipitation of 405,000 ac-ft/yr converts to 16.62 in/yr, using the model area of 457 square miles (292,480 acres). The regional data indicate this is a reasonable estimate of annual precipitation. The applied recharge from precipitation is 7,016 ac-ft/yr, or about 1.73 percent of annual precipitation. This is a reasonable infiltration for southern Arizona.

It is stated in Section 8.4 of the report (last section of the first paragraph) that "A net inflow of 1,670 ac-ft/yr to upper Cienega Creek basin via the GHB boundaries is considered analogous to basin recharge…" This is not obvious and needs more explanation because the assignment of GHB conditions is not clearly described (see above). The inclusion of inflow from the GHB increases the recharge rate to 9,779 ac-ft/yr, 2.41 percent of the annual precipitation, which is considerably higher. The recharge is summarized at the bottom of page 52, Section 8.4, including the contribution from the upper and lower GHB boundaries. However, the steady-state water balance in Section 8.7.2 does not include the contribution to recharge from the upper and lower portions of the Cienega Creek basin via the GHB boundaries.

The applied evapotranspiration is reported as 4,240 ac-ft/yr. This appears to be reasonable, given the vegetation reported in Table 1 and for conditions in southern Arizona. But again, it is not clear whether this value was adjusted during model calibration.

Groundwater Interaction with Streams

Two perennial reaches along Cienega Creek were simulated. Extraction wells were used to simulate the two perennial, gaining reaches of the creek and injection wells were used to simulate the losing reaches at the downstream end of the creek. Simulating the stream reaches with flux-dependent boundaries does not allow for impacts from groundwater withdrawals during pit dewatering or for any potential production wells to affect the surface water flows in Cienega Creek. Cienega Creek should be simulated with either the *MODFLOW* River Package or Stream Routing Package. Both of these packages are head-dependent methods for simulating groundwater/surface water interactions, and will allow for the flow in Cienega Creek to be affected by the groundwater stresses due to the Rosemont project. Using extraction/injection wells with fixed rates to simulate interaction between groundwater and surface water systems during mining and post-mining conditions is a significant model limitation and needs to be corrected by using the appropriate *MODFLOW* package. It also is not clear why Davidson Creek was not incorporated into the model using the *MODFLOW* Stream Routing Package.

Springs

Five springs with sustained base flows, described on page 7 of the report, were not incorporated into the model, and spring discharge rates were not used for model calibration. If they had been incorporated in the model, this would have provided an additional calibration tool and would allow prediction of the long-term effect of the future pit dewatering on the springs.

3 Model Calibration

The model was calibrated only to water levels under steady state, pre-mining conditions. Although the quality line on Figure 41 looks reasonable, it is not clear how good the model reproduces the measured values of hydraulic conductivity (transmissivity) in the field and the measured discharges in the five springs having sustained base flow.

No transient calibration was completed. It is not clear why such a calibration was not completed using data from the long-term multi-well pumping test (30-day pumping test from five wells) in the Rosemont project area. In the reviewers' opinion, the predictive capability of this model is significantly limited by (1) the lack of a description of the results of the steady-state calibration (described above) and (2) the absence of a transient calibration of the model.

4 Predictive Simulations

Predictive simulations were completed to predict groundwater inflow to the proposed open pit, pit-lake infilling after mining ceases, and possible impacts to groundwater and surface water systems during both mining and post-mining conditions.

Simulation of Open Pit

The open pit excavation is a major stress to the groundwater system, and requires a detailed description of how it was incorporated into the model. The following data were not found in the M & A (2009c) report:

1. A drawing showing the ultimate pit plan.
2. A graph showing the ultimate pit bottom vs. time (this information also can be added to the existing Table 5).
3. The number of drain cells used for simulation of the pit excavation.
4. The number of pit plans incorporated into the model (32?).
5. The location of simulated drain cells in plan view.

It should be noted that the drain cells shown on the cross section on Figure 42 depict an ultimate pit-bottom elevation of 3,050 ft above mean sea level (amsl) after 22 years of mining. However, it is not clear whether the model cells above the drain cells shown on this figure also are specified as drain cells within the same column of cells. Figure 42 also does not show the simulated water table within the open pit on the cross section. Figure 45 shows a simulated water table in plan view at the end of mining; however, the water table elevation of 3,300 ft amsl is 250 feet above the ultimate pit-bottom elevation. This fact most likely indicates that all cells within the simulated pit were not completely drained and pit inflow was underestimated (either the conductivity of the drain cells was not large enough, or the entire column of cells above the pit bottom elevation were not specified as drain cells).

Results of Predictive Simulations

M & A's (2009c) model gives one set of solutions without a range of possible predictive values. A comprehensive sensitivity/uncertainty analysis (which has not been done) is required to define the possible ranges of pit inflows, pit-lake stages, and the extent of drawdown.

A steady-state post-mining prediction also is required to understand the permanent impacts of the proposed mining on the groundwater system.

A groundwater budget simulated by the model was presented only for pre-mining conditions. No budgets were presented for end-of-mining and post-mining conditions, so changes in flow from individual components due to mining could not be evaluated.

5 Conclusions

The descriptions of the model provided in the reviewed report do not allow SRK to determine the reliability of the predictions of possible impacts to the groundwater system from the proposed open pit excavation.

In the opinion of the SRK reviewers:

1. It is unclear whether the model sufficiently represents known geology and structures.
2. The assignment of parameters is unclear with respect to how representative the assigned values are of the field-determined test values and the geologic units/rock types.
3. Simulation of groundwater interaction with Cienega Creek by extraction/injection wells with fixed rates does not allow for the groundwater impacts from the Rosemont project to affect the flow system in Cienega Creek.
4. Full calibration of the model has not been completed due to the lack of a transient calibration to the long-term, multi-well pumping test. The model has a limited predictive capability due to the absence of a transient calibration.
5. Drain cells, representing the open pit excavation, most likely were not assigned properly and as result, the model under predicts inflow/drawdown propagation.
6. The model provides one set of solutions without a discussion of a range of possible predictive values. Due to existing uncertainties in hydrogeological parameters and boundary conditions, a sensitivity/ uncertainty analysis should be added to the predictive simulation to illustrate a range of possible impacts to the groundwater system from the proposed pit operation.

6 References

Montgomery & Associates, 2009a, Results of phase 2 hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona, Volumes I and II: unpublished report prepared for Rosemont Copper Company by Errol L. Montgomery & Associates, Inc., February 26, 2009, 45 p., 4 appendices.

Montgomery & Associates, 2009b, Analysis of long-term, multi-well aquifer test during the period November 2008 through January 2009, Rosemont Project, Pima County, Arizona: unpublished report prepared for Rosemont Copper Company by Errol L. Montgomery & Associates, Inc., May 21, 2009, 41 p., 2 appendices.

Montgomery & Associates, 2009c, Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure: unpublished report prepared for Rosemont Copper by Errol L. Montgomery & Associates, Inc., October 28, 2009, 73 p.

7 Reviewer Qualifications

Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado (résumé attached). Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines.

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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	May 11, 2010
cc:	Tom Furgason, SWCA File, SRK	**From:**	Vladimir Ugorets, PhD, SRK Michael Sieber, P.E., SRK Stephen J. Day, P.Geo., SRK
Subject:	Technical Review of *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project* (Tetra Tech, 2010a) and *Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections, Rosemont Mine* (Montgomery & Associates, 2010)	**Project #:**	183101/1700

A technical review was undertaken and this Technical Memorandum was prepared at the request of SWCA and the Coronado National Forest, in accordance with a statement of work from Mr. D. Ortman dated March 15, 2010. Provided here are comments related to the review of the following two reports:

(a) *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project* (Tetra Tech, 2010a), and

(b) *Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections, Rosemont Mine* (Montgomery &Associates, 2010)

These comments were prepared by Vladimir Ugorets, Michael Sieber, and Stephen Day of SRK Consulting, Inc. (SRK). Review was performed by Larry Cope, also of SRK.

This memorandum is organized into two sections, per the two reviewed documents listed above.

1 Davidson Canyon Hydrogeological Conceptual Model and Assessment of Spring Impacts

The report is relatively comprehensive, well presented, and well written. The report describes the most likely hydrologic dynamics and key physical processes that are governing groundwater-surface water interactions in Davidson Canyon. It includes a discussion of creeks and springs and their interface with the groundwater system (Tetra Tech, 2010a).

This document is a good compilation of available groundwater, surface water, local geology, and water chemistry data indicating that:

(a) The Rosemont Project will have some effect on Davidson Canyon due to the changes in the surface and groundwater flow patterns at the Project site.

(b) The estimated area affected by the Rosemont Project comprises about 16 percent of the Davidson Canyon watershed.

(c) In average annual conditions, Tetra Tech (2010a) estimated that most of the stormwater entering the flow-through drains will result in infiltration and likely will reduce flows to downstream receptors.

(d) The areas with the most for potential groundwater-surface water interactions are in topographically lower areas of Davidson Canyon (Reach 4), which are the furthest from the proposed Rosemont Project.

(e) Changes to baseline conditions in Davidson Canyon and Cienega Creek as a result of open pit dewatering operations will not occur unless the cone of depression extends to an aquifer that is hydraulically connected to surface water.

(f) Three springs (Questa, Rosemont, and Davidson) are potentially hydraulically connected with the regional bedrock groundwater system and might be impacted by in-pit dewatering, if drawdown propagates to their location. Other local (or perched-water) springs would be less likely to be affected by mine activities, unless they are proximate to the pit where the pit may alter the local flow system that is yielding water to the springs.

(g) The long term impacts to the water resources in Davidson Canyon and the larger Cienaga Creek basin will not exceed the predicted rate of pit inflow (300 to 400 gallons per minute (gpm) during mining, and will continuously decrease to 120 gpm after 100 years of pit lake infilling (M&A, 2009). This model is currently being revised and the impact on Davidson Canyon should be re-examined when the revisions are complete.

Mine Impacts

The mining operations that could potentially impact the Davidson Canyon and Cienaga Creek watersheds are the open pit dewatering (M&A, 2009 and Tetra Tech, 2010b) and seepage from the Dry Stack Tailings Storage Facility (TSF) (AMEC, 2009, Tetra Tech, 2010b), the Waste Rock storage area (waste rock), and Heap Leach facility (heap) (Tetra Tech, 2010b). The M&A numerical groundwater flow model is currently being revised and the impacts to Davidson Canyon from pit dewatering should be re-evaluated once the revisions are complete. Should the Infiltration and Seepage Model (Tetra Tech, 2010b) that was reviewed by SRK (2010) be revised, the impacts of seepage from the TSF, waste rock, and the heap also should be re-evaluated.

SRK found Tetra Tech’s conceptual model of Davidson Canyon and their conclusions regarding possible impacts from the mining operations to be reasonable. The isotopic interpretations they presented seem reasonable based on the information provided in the report. However, we feel that it should be considered preliminary due to limited available data and uncertainties in the groundwater modeling predictions (discussed in SRK (2010)). Our specific comments are:

(a) Figure 9: Local spring isolated from regional groundwater—groundwater flow lines are shown above the water table.

(b) Figure 15: Schematic cross section of Reach 2 spring development—what data are used for the unsaturated zone as shown between the alluvial and bedrock groundwater systems?

(c) The water quality data described in Section 7.6 need to be added in the spring comparison table, shown in Figure 8.

(d) There is reference to Stiff diagrams prepared by others. It would be helpful to include these in this report.

(e) A number of descriptors used in the report are relative but not quantified. Waters are described as “different,” “very similar,” and “dissimilar,” Inclusion of charts showing the data or more statistics would illustrate these differences.

(f) There are references to MC1 and MC2 differences being explained by the degree of rock alteration. Trace element characteristics could be included here as indicators. This would be a useful overall aspect to be added that could provide more in the geological context. A conclusions section should be included in the report.

Potential impacts to Davidson Canyon should be re-evaluated on the basis of the predictive simulations and sensitivity analyses of the 3-D numerical groundwater model currently being revised by M&A.

2 Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections, Rosemont Mine

This section presents the results of our review of the report on short-term and long-term groundwater fluctuations as compared to projected drawdown 100 years after closure of the proposed Rosemont mine (M&A, 2009). The document provides a thorough compilation of available groundwater level data that indicate that:

(a) Calculated short-term (2 to 3 years) groundwater level fluctuations measured in 52 wells range from 0.7 to 33 feet, with an averaged value of 7 feet.

(b) Calculated long-term (37 to 55 years) groundwater level fluctuations measured in 14 wells range from 0.7 to 69 feet, with an averaged value of about 20 feet.

(c) The projected drawdown at existing non-Rosemont wells east of the mine area, 100 years after closure of the proposed Rosemont mine, is generally of similar magnitude to the natural short-term fluctuation in groundwater levels observed during a 2- to 3-year period and is generally less than the long-term natural fluctuation in groundwater levels observed during the long-term 37- to 55-year period.

(d) The projected drawdown at existing non-Rosemont wells west of the Santa Rita ridge and at livestock wells in the immediate mine area, 100 years after closure of the proposed Rosemont mine, appears to exceed the natural short-term groundwater fluctuation (2-year period). No data are available concerning long-term groundwater fluctuation west of the Santa Rita ridge.

SRK has the following specific comments:

(1) It is not clear why the simulated drawdown of 100 years after closure was chosen for comparison with measured natural groundwater fluctuations. In SRK's opinion, the comparison should be made with the time of maximum drawdown (during the early or intermediate stage of pit-lake infilling) and at steady state, post-mining conditions, which will be significant after 100 years of pit lake infilling. The existing groundwater model (M&A, 2009) did not simulate full pit lake recovery and did not clearly indicate when maximum drawdown occurs at particular locations.

(2) Surface water bodies (such as creeks and springs) that show the propagation of drawdown need to be added to Figures 1 and 2.

(3) This comparison analysis should be repeated after existing numerical groundwater model is revised based on the transient calibration (recommendation by SRK (2010)) and to incorporate the revised model simulations.

3 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.

Montgomery & Associates, 2009, *Groundwater-flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Errol L. Montgomery & Associates, Inc., October 28, 2009, 73 p.

_____ 2010, *Comparison of natural fluctuation in groundwater level to provisional drawdown projections, Rosemont Mine*: Technical Memorandum prepared for Rosemont Copper by Errol L. Montgomery & Associates, Inc., March 1, 2010.

SRK, 2010, *Technical review of M & A (2009) groundwater flow model report prepared Rosemont Copper*: Technical Memorandum prepared for SWCA, February 9, 2010, 6 p.

Tetra Tech, 2010a, *Davidson Canyon Hydrogeologic Conceptual Model and assessment of Spring Impacts*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, April 2010, 72 p, 1 appendix.

_____ 2010b, *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.

4 QUALIFICATIONS OF KEY TECHNICAL REVIEWER

The Senior Reviewer for Hydrogeology, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado (résumé attached). Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets's areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines.

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Memorandum - DRAFT

To:	Dale Ortman, P.E.	**Date:**	August 2, 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 (2010) *Hydraulic Property Estimates*	**Project #:**	183101/1800

This memorandum provides a technical review of the Technical Memorandum, *Hydraulic Property Estimates* (Tetra Tech, 2010) dated July 9, 2010, hereafter referred to as the "Technical Memorandum." 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, and in accordance with a Statement of Work and Request for Cost Estimated from Mr. Dale Ortman dated July 18, 2010.

The comments in the present review are grouped into three topics: (1) short-term aquifer test analysis, (2) long-term pumping test analysis, and (3) hydraulic parameters used in the regional groundwater flow model. The Technical Memorandum is well written and the thinking of the authors can be followed in a straight forward manner. The comments presented below are, in general, requests for clarifications and additional detail related to the data applied and the configuration of the radial flow models.

1 Short-Term Aquifer Test Analysis

Tetra Tech re-evaluated the short-term aquifer tests completed by Montgomery & Associates (M&A) in 2007 and 2008 (M&A, 2007, 2009a, 2009b) by using standard straight-line solutions: Copper-Jacob or Theis Recovery. The results of this re-evaluation produced an arithmetic mean of all K values that was 90.9 percent of the M&A values calculated for the same subset of wells. Although there are some significant differences (by factors of up to 5) for several analyses, SRK considers the brief explanations in Attachment 1 (Tetra Tech, 2010) provide adequate rationale for the differences. With the 10 values of greater than a factor of two removed from the mean calculation, the Tetra Tech mean is 94.1 percent of the M&A mean. Given that the large differences do not have much impact on the mean of all the values, further refinement of the some values is not viewed here as warranted. It may be noteworthy that four of the 10 values with large differences used data from the multiple-level vibrating wire piezometers, which can be very interpretive given the difficulty in quantifying how the point pressure measurements relate to the larger (thicker) flow field.

To demonstrate that the re-analysis by Tetra Tech can be compared to the M&A analysis, SRK recommends that Attachment 1 include a column that refers the reader to the figures in the M&A report to show the particular analytical plots. Further, to make the comparisons fully defensible, it is recommended that the Tetra Tech analysis be provided as an additional attachment to the Technical Memorandum.

2 Long-Term Pumping Test Analysis

Tetra Tech completed re-evaluation of three long-term pumping tests (from wells PC-5, HC-1B, and HC-5A) using detailed 2-D radial numerical groundwater models. Their results are shown in their report Tables 1 through 4.

SRK agrees that a 2-D radial model is an appropriate way to evaluate vertical hydraulic conductivity values when pumping from one tested interval, and water levels are monitored in the same interval and in intervals below or above. However, no discussion is provided on the intervals pumped relative to the piezometers being monitored. Though the configuration is implied in Attachment 1, SRK recommends that the text include a description of the configuration and some detail on how the isolation packers were deployed and monitored (given the 60 plus day deployment of the packer, if used).

Figures 3 though8 show reasonably good agreement between observed and modeled drawdowns in the grouted-in piezometer PZ5 and the stand-pipes in PC2, HC-1A, and HC-5B. SRK would like to see a figure for that test cell similar to the Figure 2 cross section. The elevations of the screened intervals and piezometers, and the pumping rates should be listed in a text box on all plots. Tetra Tech should consider adding a right-hand Y-axis showing pumping rates over the duration of pumping. Also, the units on the time axis are not clear. They appear to be in units of “year decimal year,” which should be stated in the axis title. Actual dates may be a better presentation.

As pointed out in the Technical Memorandum, faults and discrete linear features are often difficult to represent in a radial model due to the possibility of their incorporation by using a cylindrical shape. It should be noted that such features as a fault and fault-truncated strata are present in the area of pumping well PC-5 and the contact with low permeable pre-Cambrian rocks is present in the vicinity of pumping well HC-1B. To present geological variation between PZ-5 and PC-2 (shown in Figure 2), it appears the model was run for scenarios with and without the Permian formations (Concha, Scherrer, and Epitaph/Colina). The estimated hydraulic parameters for both models are shown in Tables 1 and 2 (by using water level data from piezometers PZ-5 and PC-2, respectively). The results of the estimates for the Willow Canyon Formation (Ksd) are very different (K_h=0.16 feet per day (ft/day) and K_v=2.8 ft/day for piezometer PZ-5, and K_h=0.1 ft/day and K_v=0.006 ft/day for piezometer PC-2). The differences likely indicate the inapplicability of a 2-D radial flow analysis to simulate responses at PC-2 from the pumping of PC-5. To test the viability of the approach taken by Tetra Tech, SRK recommends a simplistic 3-D model (for the pumping area only) to re-evaluate the effects on the hydraulic parameters of the fault and truncated units for pumping test PC-5 and low permeable pre-Cambrian rock in pumping well HC-1B.

From the foregoing discussion, SRK’s specific requests are summarized as follows:

1. Include details to show how values for K_v and K_h varied with the placement of packers in pumping well PC-5.
2. List test parameters on Figures 3 through 8 (Q, packer/tested interval).
3. Include figures showing the numerical model grid used to simulate the cross section shown on Figure 2 and the pumping test from well HC-1B.
4. Complete an analysis of the pumping tests from wells PZ-5 and HC-1B by using a simplified 3-D numerical groundwater flow model.

3 Hydraulic Parameters Used in the Regional Groundwater Flow Model

The results of the interpretation of long-term pumping tests by using 2-D radial models indicate that:

a) Horizontal hydraulic conductivity varies from 0.00017 ft/day to 761 ft/day,

b) Vertical hydraulic conductivity varies from 0.0005 ft/day to 0.28 ft/day, and
c) Specific storage was estimated to range from $7x10^{-7}$ 1/ft to 0.0004 1/ft, with a geometric mean of 9x10-6 1/ft (this number was recommended to be applied to all bedrock units within a regional groundwater model).

It should be noted that no values for hydraulic conductivity were recommended as initial input to the regional groundwater model. Given that Tables 1 and 2 provide very different values for K_h and K_v, SRK is uncertain as to how the values will be applied. Part of our uncertainty comes from not clearly understanding the placement of the packer in PC-5, and the manner in which values for both the Concha Limestone and Scherrer Formation are provided in Table 1, even though they may have been producing at the same time from the same packer setting. Thus we are uncertain how vertical conductivities were calculated. Due to these uncertainties, SRK is not able to judge the applicability of a 2-D radial model to serve as input to, and provide transient calibration for a 3-D regional groundwater flow model.

4 References

Errol L. Montgomery & Associates, Inc. (M&A), 2007, Results of drilling, construction, and testing of four pit characterization wells, Rosemont Project, Rosemont Copper Company, Pima County, Arizona: report prepared for Rosemont Copper Company, September 6, 2007, 108 p., 2 appendices.

_____ 2009a, Results of Phase 2 hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona, Volume 2: Appendices: unpublished report prepared for Rosemont Copper Company, February 26, 2009, variously paginated.

_____ 2009b, Analysis of long-term, multi-well aquifer test, November 2008 through January 2009, Rosemont Project, Pima County, Arizona: unpublished report prepared for Rosemont Copper Company, May 21, 2009, 59 p, 2 appendices.

Tetra Tech, 2010, Technical Memorandum, Hydraulic property estimates, July 9, 2010, 12 p., 1 attachment.

5 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets’ areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for preparation of this memorandum. His resume has been provided to SWCA in prior submissions.

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Memorandum - DRAFT

To:	Dale Ortman, P.E.	**Date:**	July 30, 2010
cc:	Tom Furgason, SWCA Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.S. Mike Sieber, P.E.
Subject:	Technical Review of Hydrogeologic Framework Model (Tetra Tech, 2010)	**Project #:**	183101/1800

This memorandum provides a technical review of the Technical Memorandum, *Hydrogeologic Framework Model* (Tetra Tech, 2010) dated July 9, 2010. This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a Statement of Work and Request for Cost Estimate from Mr. Dale Ortman dated July 18, 2020. This memorandum was prepared by Vladimir Ugorets, Larry Cope, and Mike Sieber of SRK Consulting (U.S.), Inc. (SRK).

1 Description of Hydrogeologic Framework Model

The hydrogeologic framework model was constructed using Mining Visualization System and hydrogeologic data at 200-feet intervals between 5,400 and 2,400 feet above mean sea level (amsl). These horizontal slices, representing the subsurface hydrogeologic units, were developed by Montgomery & Associates (M&A, 2009) and were created from a combination of publically available surface geology maps, borehole lithology data, and cross sections. The geologic formations were grouped into ten (10) hydrogeologic units, based on their age and material properties as follows:

1. Quaternary and Recent alluvium (Qal)
2. Late Tertiary to Early Quaternary basin-fill deposits - higher permeability (QTg)
3. Late Tertiary to Early Quaternary basin-fill deposits - lower permeability (QTg1)
4. Late Tertiary to Early Quaternary basin-fill deposits - lowest permeability (QTg2)
5. Early to Mid-Tertiary sedimentary and volcanic units (Pantano Formation - Tsp)
6. Upper Cretaceous and Early Tertiary intrusive rocks (Kti)
7. Upper Cretaceous volcanic rocks (Kti)
8. Lower Cretaceous sedimentary units (Bisbee Group – Ksd)
9. Paleozoic sedimentary and metamorphic formations (Pz)
10. Precambrian igneous and metamorphic (pCb)

The process used by Tetra Tech to transform the two-dimensional data sets into the three-dimensional block model consisted of three steps: (1) data sampling, (2) hydrogeologic unit interpretation, and (3) consistency check. The steps are described in detail in their technical memorandum.

The developed regional groundwater flow model has a telescoping grid in plain view, with the grid ranging from a cell width of 800 feet at the model domain edges to a cell width of 200 feet in the vicinity of the pit. Vertically, the grid was constructed using a total of 20 horizontal model layers with consistent thicknesses. Flow model layers intersecting the pit were assigned a cell thickness of approximately 150 feet and model cells above and below the pit were assigned thicknesses between 200 and 430 feet. The uppermost elevation of the flow model was placed at an elevation of 5,500 feet amsl, and the base of the model was placed at an elevation of 1,000 feet amsl.

2 SRK Conclusions

SRK concludes that:

1. The geologically based approach used in the Hydrogeologic Framework Model by Tetra Tech is reasonable and is an accepted practice for groundwater modeling of mine dewatering projects. the geology incorporated into the numerical model matches the geology slice at 3,600 ft elevation (Figure 1) and cross sections A-A' and B-B' (Figures 5 and 6, respectively).

2. The 10 hydrogeologic zones with individual sets of hydraulic parameters look reasonable. It should be noted that SRK did not find a description of these parameters in the reviewed document. But in as much as it presents a concept for modeling, we expect the parameters will be described and defended in subsequent documents.

3. Proposed grid discretization (telescoping in plan view and detailed in cross section, shown in Figure 3) is considered adequate for the required predictive simulations and corresponds to standards in 3-D numerical groundwater modeling.

3 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	August 3, 2010
cc:	Tom Furgason, SWCA File, SRK	**From:**	Vladimir Ugorets, PhD, SRK Michael Sieber, P.E., SRK Larry Cope, SRK
Subject:	Technical Review of *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project* (Tetra Tech, 2010a)	**Project #:**	183101/1800(3)

A technical review was undertaken and this Technical Memorandum was prepared at the request of SWCA and the Coronado National Forest, in accordance with a statement of work from Mr. D. Ortman dated July 18, 2010. Provided here are comments related to the review of the following report:

(a) *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project* (Tetra Tech, 2010a)

These comments were prepared by Michael Sieber and Vladimir Ugorets of SRK Consulting, Inc. (SRK). Review was performed by Larry Cope, also of SRK.

The first draft of Davidson *Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Rosemont Copper Project*, April 2010 (Tetra Tech, 2010b) was reviewed by SRK (2010a) on May 11, 2010.

1 Davidson Canyon Hydrogeological Conceptual Model and Assessment of Spring Impacts

The report is relatively comprehensive, well presented, and well written. The report describes the most likely hydrologic dynamics and key physical processes that are governing groundwater-surface water interactions in Davidson Canyon. It includes a discussion of creeks and springs and their interface with the groundwater system (Tetra Tech, 2010b).

This document is a good compilation of available groundwater, surface water, local geology, and water chemistry data indicating that:

(a) The Rosemont Project will have some effect on Davidson Canyon due to the changes in the surface and groundwater flow patterns at the Project site.

(b) The estimated area affected by the Rosemont Project comprises about 16 percent of the Davidson Canyon watershed. Stormwater flow diversions will likely result in reduced flows to downstream receptors.

(c) In average annual conditions, Tetra Tech (2010a) estimated that most of the stormwater entering the flow-through drains will result in infiltration and likely will reduce flows to downstream receptors.

(d) The areas with the greatest potential for groundwater-surface water interactions are along the narrow riparian zones of Reaches 2 and 4, and potentially Reach 3.

(e) Changes to baseline conditions in Davidson Canyon and Cienega Creek as a result of open pit dewatering operations will not occur unless the cone of depression extends to an aquifer that is hydraulically connected to surface water, Reach 4.

(f) Three springs (Questa, Rosemont, and Helvetia) are potentially hydraulically connected with the regional bedrock groundwater system and might be impacted by in-pit dewatering, if drawdown propagates to their location. Other local (or perched-water) springs would be less likely to be affected by mine activities, unless they are proximate to the pit where the pit may alter the local flow system that is yielding water to the springs.

(g) The long term impacts to the water resources in Davidson Canyon and the larger Cienega Creek basin will not exceed the predicted rate of pit inflow (300 to 400 gallons per minute (gpm) during mining, and will continuously decrease to 120 gpm after 100 years of pit lake infilling (M&A, 2009). This model is currently being revised and the impact on Davidson Canyon should be re-examined when the revisions are complete.

(h) Tetra Tech is currently developing a regional groundwater model to simulate mining and post-mining conditions. The impacts on Davidson Canyon should be re-examined when this model is complete.

Mine Impacts

Open pit dewatering (M&A, 2009) and infiltration, seepage, and transport from the Waste Rock Storage area (waste rock), Heap Leach facility (heap), and the Dry Stack Tailings Storage Facility (TSF) (Tetra Tech, 2010c), and seepage from the TSF (AMEC, 2009, Tetra Tech, 2010c) are the mining operations that could potentially impact the Davidson Canyon and Cienega Creek watersheds. A large amount of work is currently being conducted by M&A and Tetra Tech. The M&A numerical groundwater flow model is being revised and Tetra Tech is currently developing a groundwater model. Once those works are complete and the final versions reviewed by SRK, the following will need to occur:

- Re-evaluation of the impacts to Davidson Canyon from pit dewatering once the M&A and Tetra Tech models are reviewed and complete.
- The Infiltration, Seepage, and Fate and Transport Modeling report (Tetra Tech, 2010c) was reviewed by SRK (2010c) and should be revised in light of the review comments.
- Re-evaluation of the impacts of seepage from the TSF, waste rock, and heap on Davidson Canyon.

SRK found Tetra Tech's conceptual model of Davidson Canyon and their conclusions regarding possible impacts from the mining operations to be defensible and supported by the data provided. The isotopic interpretations that were presented are also defensible and supported by the information provided in the report. However, we feel that it should be considered preliminary due to limited available data and uncertainties in the groundwater modeling predictions and infiltration and seepage modeling predictions (discussed in SRK (2010c)). Specifically, we consider a number of descriptors used in the report are relative and not quantified. Waters are described as "different," "very similar," and "dissimilar." Inclusion of charts showing the data or a more complete presentation of the data and summary statistics would illustrate the differences.

Potential impacts to Davidson Canyon should be re-evaluated on the basis of the predictive simulations and sensitivity analyses of the 3-D numerical groundwater model currently being revised by M&A and the completion of the Tetra Tech numerical groundwater flow model.

2 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.

Montgomery & Associates, 2009, *Groundwater-flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Errol L. Montgomery & Associates, Inc., October 28, 2009, 73 p.

SRK, 2010a, *Technical review of Tetra Tech (2010) Davidson Canyon hydrogeologic conceptual model and assessment of spring impacts*: Technical Memorandum prepared for SWCA, May 11 2010, 4 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.

_____ 2010c, *Technical review of M & A (2009) groundwater flow model report prepared Rosemont Copper*: Technical Memorandum prepared for SWCA, February 9, 2010, 6 p

Tetra Tech, 2010a, *Davidson Canyon hydrogeologic conceptual model and assessment of spring impacts*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, April 2010, 72 p, 1 appendix.

_____ 2010b, *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.

3 QUALIFICATIONS OF KEY TECHNICAL REVIEWER

The Senior Reviewer for Hydrogeology, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets's areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets's resume was submitted to SWCA previously.

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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:	Technical Review of Groundwater Flow Modeling sections 1-6 (M&A, 2010)	**Project #:**	183101/2000

This memorandum provides a technical review of Sections 1 through 6 of the report *Revised Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure Rosemont Project* dated July 2010 (Montgomery & Associates (M&A), 2010). This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a Statement of Work and Request for Cost Estimate from Mr. Dale Ortman dated July 27, 2010. This memorandum was prepared by Vladimir Ugorets, Larry Cope, and Mike Sieber of SRK Consulting (U.S.), Inc. (SRK).

This review will address the revisions made to the M&A July 2010 report relative to the *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure* (M&A, 2009) and the SRK (2009) review of (M&A, 2009).

1 Description of Sections 1 through 6 Revised Groundwater Model

The revised groundwater modeling report reviewed below consisted of the following sections:

1. Introduction
2. Location of Study Area
3. Hydrogeologic Framework
4. Groundwater Conditions
5. Hydraulic Parameters
6. Summary of Conceptual Groundwater Flow Model

In general this part of the revised report (Sections 1-6) (M&A, 2010) present a more detailed description of the 10 hydrogeologic units. Two cross-sections were prepared, a short one through the pit area and a longer section through the pit that extends further east. Each cross-section shows three sections; a geologic section, a hydrogeologic section, and a section showing the simulated hydraulic conductivity.

A description of three faults; steeply east dipping Backbone fault located in the west area of the pit; the Flat fault located in the central eastern part of the pit, a normal fault, at the base of the Willow Canyon formation; and the Davidson Canyon fault, northeast of the pit trending along Davidson Canyon. Results of hydraulic testing and measured groundwater levels were evaluated to determine whether faulting acts as a conduit or barrier to flow.

Information from the Tetra Tech *Davidson Canyon hydrogeologic conceptual model and assessment of impacts* (Tetra Tech, 2010) was included in a section of groundwater discharge to springs and stream flow in Davidson Canyon.

The short-term pumping tests (M&A, 2009b); packer testing (M&A, 2009b; and long-term pumping tests (M&A, 2009c) are presented in detail in this report (M&A, 2010). Table 5 was improved to incorporate the SRK comments (SRK, 2010).

2 SRK Conclusions

SRK concludes that:

Section 1 through section 6 (M&A, 2010) have incorporated SRK's comments (SRK, 2010) regarding these sections of the original model report (M&A, 2009a).

3 References

Montgomery & Associates, 2009a, *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., October 28, 2009, 73 p.

_____ 2009b, *Results of phase 2 hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona, Volumes I and II: unpublished report* prepared for Rosemont Copper Company by Montgomery & Associates, Inc., February 26, 2009, 45 p., 4 appendices.

_____ 2009c, *Analysis of long-term, multi-well aquifer test during the period November 2008 through January 2009*, Rosemont Project, Pima County, Arizona: unpublished report prepared for Rosemont Copper Company by Montgomery & Associates, Inc., May 21, 2009, 41 p., 2 appendices.

_____ 2010, *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., July 2010, 107 p, Sections 1-6.

SRK, 2010, *Technical review of M&A (2009) Groundwater Flow Model Report*: Technical Memorandum prepared for SWCA, February, 9 2010, 6 p.

Tetra Tech, 2010, *Davidson Canyon hydrogeologic conceptual model and assessment of impacts*: unpublished report prepared for Rosemont Copper by Tetra Tech, July 2010, 38 p., 1 ppendix.

4 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

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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 evapotranspiration (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	Tetra Tech, 2010a	Difference
	Rate [ac-ft/yr]	Rate [ac-ft/yr]	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.

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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	September 27, 2010
cc:	Tom Furgason, SWCA Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.S. Mike Sieber, P.E.
Subject:	Technical Review of *Predictive Groundwater Modeling Results* (TT, 2010a) and *Rosemont Groundwater Flow Model Sensitivity Analyses* (TT, 2010b)	**Project #:**	183101/2000

This memorandum provides a technical review of the two Technical Memorandums, *Predictive Groundwater Modeling Results* (Tetra Tech, 2010b) dated July 30, 2010 and *Rosemont Groundwater Flow Model Sensitivity Analyses* (Tetra Tech, 2010c) dated August 17, 2010. 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, and in accordance with the Statement of Work and Request for Cost Estimated from Mr. Dale Ortman dated July 28, 2010.

These two reviewed technical memoranda describe result of predictive simulation and sensitivity analyses for the Rosemont project by using a 3-D regional groundwater flow model developed by Tetra Tech as described in Tetra Tech (2010a). It should be noted that SRK reviewed the construction and calibration of the model and presented the results of that review in our Technical Memorandum dated August 17, 2010 (SRK, 2010). The conclusions and recommendations presented in that memorandum are related to model setup and calibration, and are not repeated in this document.

1 Results of Predictions

The predictions were conducted for mining and post-mining conditions using the model construction and calibration described in Tetra Tech (2010a).

1.1 Mining Conditions

Mining conditions were simulated by excavation of a proposed open pit using drain cells and parameters were predicted for the Base Case scenario in which the following were tracked over time:

a) Passive groundwater inflows to the pit during 22 years of mining;
b) Groundwater levels and drawdowns;
c) Groundwater discharge into the streams; and the,
d) Water balance during mining.

Predictions for the Base Case scenario are:

1) Passive inflow to the pit ranges from 400 to 500 gpm (about 400 gpm during last 10 years of pit expansion).
2) Maximum extent of drawdown of about 4-4.5 miles to the northeast. Cone of drawdown will not reach the Western boundary of the model, as simulated by Constant Head boundary conditions.
3) Significant impact to Rosemont Spring, which would be located within the 100-foot drawdown contour, and possible decrease in flow from Questa Spring, which would be within 10-foot drawdown contour.
4) No changes of stream flows in the Cienega Creek and Davidson Canyon. The 5-foot drawdown contour would not reach the vicinity of Cienega Creek or perennial reach of Davidson Canyon during the 22-year mining period.

The results of the predictions look reasonable and correspond to assumptions currently used in conceptual groundwater model.

SRK has one comment relative to the water balance simulations for pre-mining steady state conditions. The simulations were made using 3 models – pre-mining, mining, and post –mining. The results of the simulations are presented in Table 7 in Tetra Tech (2010a) and Tables 1 and 3 in Tetra Tech (2010b). The component of the pre-mining steady state water balance should be exactly the same in these three tables. However there is a difference up to 660 acre-ft/yr reported in Table 1 (Tetra Tech, 2010b) versus Table 7 (Tetra Tech, 2010a). About the same difference can be observed between Table 3 (Tetra Tech, 2010b) and Table 7 (Tetra Tech, 2010a). The difference needs to be understood and should be explained.

1.2 Post- Mining Conditions

Post-mining conditions were simulated by the inflow of groundwater to the open pit and corresponding changes to groundwater flow system using the LAK2 Package. Simulation of the creation of the pit lake included as output a detailed water balance.

The model predicts that a terminal hydraulic sink pit lake will equilibrate at 4,279 feet amsl after about 700 years of refilling . That elevation is approximately 700 feet below pre-mining water levels. The groundwater divide east of the open pit is predicted to occur at an elevation about 4,600 feet amsl. The predicted steady-state stage of the pit lake would thus need to rise about 320 feet before a flow-through condition would occur. Steady-state groundwater inflow to the terminal pit lake is predicted to be about 230 gpm, which by the interaction of groundwater gradient and formation permeabilities balances with the water lost by evaporation from the pit lake.

The 1,000 year model simulation predicts modest decreases to the base flows in Cienega Creek and Davidson Creek. A stream flow decrease of 0.09 cfs is predicted in the upper reach of the Cienega Creek, which is less than 3 percent of the base flow. In Davidson Canyon, base flow is predicted to decrease 0.01 cfs.

SRK comments related to the results to the prediction modeling are:

- Constant head (CHEAD) boundary condition at the Western boundary likely significantly limits propagation of drawdown to the east. SRK strongly recommends that the influence of the CHEAD boundary be investigated with a General Head Boundary (GHB) along the Western boundary of the model using a sensitivity analysis or post-mining conditions. The GHD utilizes a constant head at a defined distance that would be beyond the current western boundary, thereby mitigating the synthetic effect of a constant head so close to the pit.

- It is not clear why the extent of drawdown cone at steady-state post mining conditions (run by steady-state model) is smaller than the extent at 1000 years after mining ceased. An explanation is required. If the difference has a numerical origin (i.e., steady-state vs. transient simulations), SRK recommends that the transient model be run sufficiently long to demonstrate equilibration with steady-state results.

2 Results of Sensitivity Analyses

Tetra Tech conducted a comprehensive sensitivity analyses for pre-mining, mining, and post-mining conditions. The analysis investigated variations in key model parameters and their influence on the range of predictive results.

2.1 Steady state pre-mining conditions

Parameters that were varied:

- Horizontal hydraulic conductivity of QTg1, QTb_TB (± 30 percent),
- Horizontal hydraulic conductivity of Pz_Pit (-30, -50, -90 percent; +30 percent, +5x, +10x),
- Horizontal hydraulic conductivity of Basin Fill (± 30 percent),
- Horizontal hydraulic conductivity of Bedrock (-10 percent; +30 percent),
- Vertical hydraulic conductivity of Kv, Ksd, Pz, Pz_Pit (-30, -50, -90 percent; +30 percent, +5x, +10x),
- Vertical hydraulic conductivity of Basin Fill (± 30 percent),
- Vertical hydraulic conductivity of Bedrock (± 30 percent),
- Recharge (± 20 percent; ± 40 percent),
- Hydraulic conductivity of Quartz-Porphyry Dike (-90 percent; +10x), and
- Hydraulic conductivity of streambed sediments (-90 percent; +10x).

Evaluation of sensitivity of listed above parameters was limited to the effect on the sum of square weighted residuals (SOSWR), a measure of how closely the model matches target measured water levels.

2.2 Mining conditions

Parameters that were varied:

- Horizontal hydraulic conductivity of Basin Fill (± 30 percent),
- Horizontal hydraulic conductivity of Bedrock (-10 percent; +30 percent),
- Vertical hydraulic conductivity of Basin Fill (± 30 percent),
- Vertical hydraulic conductivity of Bedrock (-10 percent; +30 percent),
- Hydraulic conductivity of Quartz-Porphyry Dyke (± order of magnitude),
- Specific storage of all HGUs (± order of magnitude),
- Specific yield of Basin Fill (± 50 percent), and
- Specific yield of Bedrock (± factor of 2).

The report concluded that:

a) The most sensitive mining-phase parameters are specific storage and specific yield. Simulated variation in propagation of the drawdown is about 3 mi.
b) The low permeability the pCb unit and the constant-head boundary west of the open pit function to limit the propagation of drawdown propagation in the area immediately west of the pit.
c) Drawdown tends to propagate toward Davidson Canyon and southeast of the open pit.
d) Drawdown is not predicted to reach the quartz-porphyry dike to the northwest of the pit at end of mining.

2.3 Post-Mining conditions

Parameters that were varied:

- Pit lake precipitation (± 30 percent)
- Pit lake evaporation (± 20 percent)
- Pit runoff into pit lake (20 and 40 percent)
- Hydraulic conductivity of Quartz-Porphyry Dyke (± order of magnitude)
- Specific storage of all HGUs (± order of magnitude)
- Specific yield of Basin Fill (± 50 percent)
- Specific yield of Bedrock (± factor of 2)
- Horizontal hydraulic conductivity of Basin Fill (± 30 percent
- Horizontal hydraulic conductivity of Bedrock (-10 percent; +30 percent)
- Vertical hydraulic conductivity of Basin Fill (± 30 percent
- Vertical hydraulic conductivity of Bedrock (-10 percent; +30 percent)
- Recharge at facility area.

The report concluded that:

a) The extent and magnitude of drawdown in the post-closure model was sensitive to changes in storage parameters over the first 100 to 200 years post mining period. However, after 1,000 years, the groundwater system was close to steady-state and storage parameters were not significant.
b) The post-closure model is relatively sensitive to the hydraulic conductivity of the quartz-porphyry dike (simulated as an HFB). However, the extent of drawdown remained six miles or more from the perennial reaches in Davidson Canyon using the range of values for hydraulic conductivity.
c) The most sensitive parameters in the post-closure model are the 20% decrease in pit-lake evaporation and steady-state recharge distribution.
d) Drawdown tends to propagate toward Davidson Canyon and southeast of the open pit.

SRK concludes that Tetra Tech has completed comprehensive sensitivity analysis for pre-mining, mining, and post-mining conditions to evaluate the most sensitive key hydrogeological parameters used in the models (three models were used) and possible range of predictive characteristics (propagation of drawdown, pit lake stage, impact to the surface-water bodies).

3 Conclusions

From the review of the two documents, SRK recommends:

1) Include influence of the Western model boundary into the sensitivity analysis. The model predictions indicate that an assigned CHEAD boundary condition limits and, most likely, under-predict propagation of cone of drawdown (and at a minimum, deforms the cone) during post-mining conditions. It is recommended that GHB condition be applied at differing distances from the Western model boundary to evaluate its effect on predictive simulations, especially during post-mining conditions.

2) Though graphs and tables are present the results of the sensitivity analysis, SRK recommends that additional results be included as tables and/or graphs, showing:
   a) Predicted pit inflow in time (for mining phase, graphs);
   b) Pit-lake infilling curves in time (for post-mining, graphs);
   c) Drawdown propagation (for both mining and post-mining, table); and
   d) Impact to surface bodies – cumulative change in stream flow (for both mining and post-mining, table).

3) Explain the difference seen in Figure 23 between the drawdown contours from transient predictions at 1,000 years post mining, and for the steady-state post-mining conditions. Unless otherwise explained, it is SRK's opinion that steady-state contours of drawdown should not be closer to the pit than the 1,000-year contour generated by the transient predictive runs.

4) Add the extent of the steady-state post-closure drawdown to Figure 24 for purposes of comparison. The Figure currently compares drawdown contours at end of mining and after 150 and 1,000 years post closure. Adding the steady-state contour to the figure may shed insight into the differences mentioned in the previous bullet.

4 References

SRK, 2010, Review of Tetra Tech Documents *Groundwater Flow Model Construction and Calibration* and *Steady-State Sensitivity Analyses*: Technical Memorandum prepared for SWCA, August 17, 2010.

Tetra Tech, 2010a, *Groundwater Flow Model Construction and Calibration*: Technical memorandum submitted to Rosemont Copper Company on July 26, 2010.

Tetra Tech, 2010b, *Predictive Groundwater Modeling Results*: Technical memorandum submitted to Rosemont Copper Company on July 30, 2010.

Tetra Tech, 2010c, *Predictive Groundwater Modeling Results*: Technical memorandum submitted to Rosemont Copper Company on August 17, 2010.

5 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

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Memorandum

To:	Dale Ortman, P.E.	**Date:**	October 22, 2010
cc:	Tom Furgason, SWCA Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.S.
Subject:	Technical Review of Groundwater Flow Modeling Report (M&A, 2010b)	**Project #:**	183101/2000

This memorandum provides a technical review of the full version of the Montgomery & Associates (M&A) report, *Revised Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure Rosemont Project* (M&A, 2010b), dated August 30, 2010. This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a Statement of Work and Request for Cost Estimate from Mr. Dale Ortman dated July 18, 2010. This memorandum was prepared by Vladimir Ugorets and Larry Cope of SRK Consulting (U.S.), Inc. (SRK).

The review here addresses the revisions made by M&A to their initial report, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure* (M&A, 2009), which was reviewed by SRK in February 2010 (SRK, 2010a). The original review comments are incorporated by reference and are not replicated here.

The purpose for this second review is to confirm that the comments made in the first review have been addressed in the revised report. Several observations are presented that may be outside the scope of the confirmation, but are made to note additional insight that has been gained by the reviewers since the submittal of the first report.

1 Description of the Revised Groundwater Model

The revised groundwater modeling report was submitted in two volumes containing nine sections of text, 10 tables, and 119 figures. SRK has organized this review into two broad categories: (1) Hydrogeologic Conditions and Conceptual Model, and (2) Numerical Modeling and Model Results. Each is address in the following sections.

1.1 Hydrogeological Conditions and Conceptual Model (M&A Report Sections 1–6)

The first SRK review found the original report to be lacking in detailed descriptions of the 10 modeled hydrogeologic units and in the cross sections through the model domain. In addition, SRK found that the conceptual model needed elaboration; specifically text and graphics were needed to tie the geologic findings to the configuration of the model by showing in detail how geologic reality (to the extent understood by the field programs) was simulated by the model. SRK had requested that the geologic cross sections be annotated with the hydrogeologic data obtained from the field programs, and that they show how the geologic units were grouped into the modeled hydrostratigraphy. Further, SRK had requested certain modifications and additions to tables that assisted in understanding the groupings.

In this review of the revised report, SRK has found that M&A has adequately addressed those concerns. Two cross sections presented in the report both contain a geologic section, a hydrogeologic section of grouped hydrostratigraphy, and a section showing the digitized simulated hydraulic conductivity that relates the hydrostratigraphy to the model layers. SRK finds the graphics to be effective in conveying development of the conceptual model, which had been lacking in the initial report.

SRK had requested incorporation of faults into the model. The revised report provides a description of three faults incorporated into the conceptual and numerical models. The faults are:

1. Steeply east-dipping Backbone fault located in the west area of the pit;
2. A normal fault at the base of the Willow Canyon formation in the east-central portion of the pit named the Flat fault; and
3. Davidson Canyon fault, northeast of the pit trending along Davidson Canyon.

As requested, the results of hydraulic testing and measured groundwater levels were evaluated to determine the influence of faulting on the flow system. The acceptable calibration was achieved with the three faults included in the model.

M&A also enhanced its conceptual model by including information from the Tetra Tech report, *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Impacts* (Tetra Tech, 2010c), in a discussion of stream flow and groundwater discharge to springs in Davidson Canyon.

Also as requested, Table 5 was significantly improved to incorporate the SRK comments (SRK, 2010a). Descriptions of the short-term pumping tests (M&A, 2009b); packer testing (M&A, 2009b; and long-term pumping tests (M&A, 2009c) are presented in detail in the revised report (M&A, 2010b).

1.2 Numerical Groundwater Model and Modeling Results (Sections 7 and 8)

Section 7 of the revised report describes the formulation of the numerical groundwater flow model and the results of completed simulations. The detail and descriptions, as requested, clarify the approach taken and reported in the original report. The improvements adequately address the recommendations and comments made by SRK. Specific improvements are listed in the bullet items that follow.

- Proper boundary conditions were assigned at the lateral model boundaries. General head boundaries (GHB) were specified in all saturated model layers at boundary locations where drawdown by pit dewatering was projected to occur. Constant head boundaries were specified in all other model boundary cells, with the exception of unsaturated layer 1 and layer 2 boundaries, which were specified as no-flow. (The M&A (2009a) model boundary conditions had significant inconsistencies described in SRK (2010a)).
- Evapotranspiration was simulated for riparian areas along Cienega Creek and northern Davidson Canyon using the *MODFLOW EVT* package, which allowed evapotranspiration to vary in response to groundwater changes at discharging model cells (instead of using constant rate wells as modeled and reported in M&A (2009a).
- Groundwater interaction with streams was simulated using the *MODFLOW STR* package with head-dependent fluxes to simulate extraction and injection wells instead of using constant fluxes as applied and reported in M&A (2009a).
- Three fault zones—Backbone, Flat, and Davidson Canyon—were incorporated into the model in addition to the hydrogeological units used in the M&A (2009a) model.
- The model was calibrated to both steady-state and transient conditions (only steady-state calibration to water levels was provided in the original report). A transient-state calibration was completed to the long-term, multi-well, 30-day pumping test.

- Steady state calibration to measured water levels was completed to estimate recharge to the groundwater system, groundwater outflow from upper Cienega Creek basin, evapotranspiration, and hydraulic parameters for the flow system. A sensitivity analysis was added to estimate the sensitivity of hydraulic conductivity (horizontal and vertical) and recharge. Such sensitivity analysis was not completed for the M&A (2009a) model.
- Initially, hydraulic conductivity (*K*) values for model calibration to observed water levels were obtained by using the inverse parameter estimation code, PEST. Subsequently, *K* values were manually adjusted to calibrate the model to (1) measured groundwater responses to the 30-day aquifer test, (2) incorporate fault zones, (3) estimated evapotranspiration rates, and (4) estimated and observed perennial stream-flow rates and extent in Davidson Canyon and Cienega Creek. Matching the no-drawdown response observed in many wells during 30-day test was achieved during the transient calibration of the model.
- Model was modified to simulate pit excavation with properly assigned conductance values for drain cells, allowing the model to simulate the water table at the ultimate pit-bottom elevation at the end of mining (the model in the original report simulated the water table 250 feet above the bottom of the pit at the end of mining).
- Recharge was adjusted during post-mining conditions in the area of waste rock storage and tailing impoundments by using the AMEC and Tetra Tech studies completed in 2009 and 2010, respectively. (The M&A (2009a) model did not consider modification of recharge to account for land coverage by Rosemont project facilities, other than the pit.)
- Prediction of post-mining pit lake recovery (shown in Figure 108) was done with a proper incorporation of evaporation, precipitation, and runoff values.
- Pit lake recovery predictions were extended to 1,000 years to reach near steady-state post-mining conditions. The previous M&A (2009a) model predicted recovery only for 100 years and did not show steady-state impacts to the groundwater system and surface-water bodies.
- Comprehensive sensitivity analyses of post-mining transient conditions were completed to define the possible range of predicted parameters. The M&A (2009a) model produced a Base Case scenario only.

2 SRK Comments and Recommendations

Presented below are comments and recommendations related to the precipitation data used, the sensitivity analysis, and the report format.

2.1 Precipitation to the Pit Lake

It is noted that M&A applied precipitation to the pit lake during post-mining recovery that was based on data from the Santa Rita weather station, whereas the model constructed by Tetra Tech applies precipitation from the NOAA Nogales weather station. The differences in average annual precipitation between the two stations may be significant. The average precipitation measured at the Nogales station is 17.37 inches per year, and the average measured at the Santa Rita station is 22.19 inches per year.

2.2 Sensitivity Analysis

M&A completed a comprehensive sensitivity analysis of two types of predicted post-mining conditions by varying:

1. Hydraulic parameters (hydraulic conductivity, specific yield, and specific storage) of different hydrogeological units and fault zones (26 runs), by assuming Base Case pit lake parameters; and
2. Pit lake parameters (lake surface precipitation, lake evaporation, and precipitation runoff), by assuming Base Case distribution of hydraulic parameters.

Results of the first set of sensitivity analyses are summarized by SRK in Table 1 below.

Table 1 - Impact of Open Pit Operation at 1,000 Years after Mining Ceased Predicted by M&A

Predicted parameter		Base Case	Minimum	Maximum	Measured during Pre-Mining Conditions
Pit Lake Elevation, (feet, amsl)		4,097[1]	4,068	4,123	NA
Upper Cienega Creek	Change in Perennial Stream Reach Length (miles)	0.16	0.00	0.18	7.6
	Change in Base flow (cfs)	0.02[1]	0.01	0.04	2.0
	Change in ET (AF/yr)	51	28	72	3,100
Davidson Canyon Sub-Basin	Change in Perennial Stream Reach Length (miles)	0.29	0.00	0.29	0.70
	Change in Base flow (cfs)	0.04[1]	0.02	0.05	ND
	Change in ET (AF/yr)	22	12	40	115

Note 1: For the Base Case scenario, the Tetra Tech groundwater model predicts a pit lake elevation of 4,093feet amsl and changes in base flow in Upper Cienega Creek and Davidson Canyon of 0.09 cfs and 0.01 cfs, respectively (Tetra Tech, 2010b)

Results of the second set of sensitivity analyses indicate that the pit lake elevation is moderately sensitive to the varied lake parameters of lake precipitation, evaporation, and runoff. The simulated pit lake elevation after 1,000 years of recovery varied from 3,945 feet above mean sea level (amsl) to 4,264 feet amsl in the sensitivity runs compared to a lake elevation of 4,097 feet amsl for the Base Case prediction. The maximum difference in predicted pit lake elevations simulated in the second set of sensitivity analysis is about 319 feet, which significantly exceeds the difference in pit lake elevations under the first set of sensitivity analyses (only about 55 feet, as shown in Table 1) when only the hydraulic parameters were varied.

M&A calculated the potential impact to the Upper Cienega Creek and Davidson Canyon sub-basins for the first set of sensitivity analyses (shown in Table 1) and did not present the second set of sensitivity analyses in the report. It is from the second set of sensitivity analyses that potentially greater impact to surface-water bodies can be inferred. For example, the revised report indicates that increasing lake evaporation from 50 in/yr (Base Case) to 60 in/yr would lower the ultimate pit lake elevation by 152 feet. However, any decrease of groundwater discharge to surface water streams for that scenario is not presented in the report.

Additionally, the groundwater model predicts a Base Case scenario of:

- Decrease in groundwater outflow from the western boundary of 42 ac-ft/yr,
- Five identified perennial springs (MC-1, Deering, Rosemont, Questa, and Helvetia) and seeps to be within the area of the predicted 5-foot drawdown contour.

It is not clear to SRK from the revised report the magnitude of the potential impact to the decrease in groundwater outflow westward from the western model domain. No range in the outflow from a sensitivity analysis was presented. Also unclear is the range in potential impacts from that outflow to the five identified perennial springs and seeps for the sensitivity scenarios that were run. SRK recommends that these issues be clarified by presenting a summary table with the results of the second sensitivity analysis to the pit lake parameters in a format similar to that of Table 1 above. The new table should include the other predictive parameters of ultimate pit lake elevation, decrease in groundwater outflow from western boundary, and springs within area of projected 5-foot drawdown contour.

2.3 Reporting

SRK considers that though no additional analysis is warranted, the revised report could be improved and made more defensible in anticipation of future reviews by others by including the following in the document:

1. Add modeled cross section D-D’ (SRK was not able to find this modeled cross section in the report).
2. Add a grid on all modeled cross sections.
3. Add the location of the Davidson Canyon fault on appropriate maps.
4. Explain why a distance of ½ mile was used to assign GHBs along the western boundary of the model.
5. Show simulated outflow from the western boundary of the model, modeled by GHBs at steady state conditions.
6. Show a groundwater budget at the end of the life of mine containing the components of predicted passive inflow to the pit, or otherwise state that all passive inflow would come from groundwater storage.
7. Show a groundwater budget at long-term post-mining conditions (1,000 years after mine closure) and changes compared to pre-mining steady state condition. A table format is preferable and recommended.
8. Add the citation on Figure 94 to the Section 9 List of References that cites the location of a drain to a Tetra Tech document.

3 SRK Conclusions

Based on review of the revised model report, SRK concludes that:

- The groundwater model presented in the revised report addresses the comments and recommendations made by SRK in its review of the original report. SRK finds the revised model and report to represent hydrogeological conditions that are appropriate to the model that was developed and to the data that were available. The predictive model is based on a good steady-state calibration and a reasonable transient-state calibration.
- Model predictions for both mining and post-mining conditions are reasonable, are based on the results of a completed comprehensive analysis, and provide a possible range of potential impacts to the groundwater system and to surface-water bodies.
- The model was conceptualized, constructed, and presented to standard industry practices. Though there remain, and will always remain uncertainties with a simulation of complex natural systems, the revised model is judged to be sufficient in concept and execution such that the resulting predictions of impacts are reasonably supported and defended by the available data.

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.

Montgomery & Associates, 2009a, *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., October 28, 2009, 73 p.

_____ 2009b, *Results of phase 2 hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona, Volumes I and II*: unpublished report prepared for Rosemont Copper Company by Montgomery & Associates, Inc., February 26, 2009, 45 p., 4 appendices.

_____ 2009c, *Analysis of long-term, multi-well aquifer test during the period November 2008 through January 2009, Rosemont Project, Pima County, Arizona*: unpublished report prepared for Rosemont Copper Company by Montgomery & Associates, Inc., May 21, 2009, 41 p., 2 appendices.

_____ 2010a, *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., July 2010, 107 p, Sections 1-6.

_____ 2010b, *Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure*: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., August 30, 123 p, Full report in 2 volumes.

SRK, 2010a, Technical review of M&A (2009) Groundwater Flow Model Report: Technical Memorandum prepared for SWCA, February, 9 2010, 6 p.

_____ 2010b, Technical review of Groundwater Flow Modeling section 1-6 M&A (2010) Groundwater Flow Model Report: Technical Memorandum prepared for SWCA, August, 17 2010, 2 p.

Tetra Tech, 2009, Rosemont Copper Project Design Storm and Precipitation Data/Design Criteria: Technical Memorandum, April 2009.

_____ 2010a, Groundwater Flow Model Construction and Calibration: Technical memorandum submitted to Rosemont Copper Company on July 26, 2010.

_____ 2010b, Predictive Groundwater Modeling Results: Technical memorandum submitted to Rosemont Copper Company on July 30, 2010.

_____ 2010c, Davidson Canyon Hydrogeologic Conceptual Model and assessment of Spring Impacts: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, April 2010, 72 p, 1 appendix.

5 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground, and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

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Memorandum

To:	Dale Ortman, P.E.	**Date:**	January 13, 2011
From:	Vladimir Ugorets, Ph.D.	**cc:**	Tom Furgason, SWCA Cori Hoag, SRK File
Reviewed by:	Larry Cope, M.S.		
Subject:	Technical Review of Tetra Tech (2010i) Report: *Regional Ground-water Flow Model Rosemont Copper Project*	**Project #:**	183101/2300

This memorandum provides a technical review of the full version of the report *Regional Groundwater Flow Model Rosemont Copper Project* (Tetra Tech, 2010i) dated November 2010. This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a *Technical Review Scope of Work, Request for Cost Estimate and Schedule* from Mr. Dale Ortman dated December 2, 2010. This memorandum was prepared by Vladimir Ugorets and reviewed by Larry Cope of SRK Consulting (U.S.), Inc. (SRK).

1 Tetra Tech Responses to SRK Comments

Tetra Tech issued the initial sections of this report in the format of technical memoranda (Tetra Tech, 2010a through Tetra Tech 2010h). SRK's original review comments on the Tetra Tech memoranda are presented in SRK (2010a) through SRK (2010f) and are not replicated here. The correlation between the initial Tetra Tech documents and SRK's review memoranda is shown in Table 1.

Table 1: Correlation between Original Tetra Tech Report Sections and SRK Review Documents

Tetra Tech Report Sections	Tetra Tech Documents	SRK Review Documents
Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts	Tetra Tech, 2010a&b	SRK, 2010a&b
Hydrogeologic Framework Model	Tetra Tech, 2010c	SRK, 2010c
Hydraulic-Property Estimates	Tetra Tech, 2010d	SRK, 2010d
Predictive Groundwater Flow Model Construction and Calibration	Tetra Tech, 2010e	SRK, 2010e
Steady-State Sensitivity Analyses	Tetra Tech, 2010f	
Rosemont Groundwater Flow Model Sensitivity Analyses	Tetra Tech, 2010g	SRK, 2010f
Predictive Groundwater Flow Modeling Results	Tetra Tech, 2010h	

Tetra Tech's comprehensive responses to SRK's review comments are contained in Tetra Tech (2010j).

The purpose for this review is to confirm that the comments made in SRK's original reviews have been addressed in the final version of the report. SRK reviewed the Tetra Tech (2010j) response to SRK's comments and the final version of the report (Tetra Tech, 2010i) and confirms here that the pertinent issues in the SRK comments were addressed.

2 SRK Additional Comments and Recommendations

Several observations are presented below that may be outside the scope of this final review, but are made to provide insight that has been gained by the reviewers since the submittal of the individual sections of the report.

2.1 Simulation of Quartz-Porphyry Dike

The quartz-porphyry dike between the open pit and Davidson Canyon is a very important feature that restricts groundwater flow in the conceptual hydrogeological and numerical groundwater models.

Tetra Tech (2010i) states that "The quartz-porphyry dike strikes sub-perpendicular to groundwater flow in the Davidson Canyon area, is over four (4) miles long, and based on a field investigation, has a low fracture density and a thickness generally greater than 100 feet. The steep hydraulic gradient from the Open Pit area to Davidson Spring in Davidson Canyon is likely due, at least in part, to this quartz-porphyry dike. However, there has been no hydraulic testing of this dike to characterize its hydraulic properties and to confirm its influence on the groundwater system. The cross-cutting nature, width, and length of the dike, however, suggest that it restricts groundwater flow."

This dike was simulated (and finally calibrated to measured water levels) by using a Horizontal Flow Barrier (HFB) package with:

a) Hydraulic conductivity K=3.28x10^{-6} ft/day,
b) Width of 100 feet, and
c) Penetration within all model layers.

It should be noted that the calibrated K of the quartz-porphyry dike (simulated as a HFB) is more than three orders of magnitude lower than the horizontal hydraulic conductivity of the Upper Cretaceous and Early Tertiary intrusive rocks (KTi).

Tetra Tech concluded in their report that, *"Simulating a more permeable HFB resulted in the model under predicting water levels up-gradient of the HFB and over predicting water levels down-gradient of the HFB. The calibrated HFB hydraulic characteristic improved the match to water levels on the up- and down-gradient sides of the dike and improved the match to the observed hydraulic gradient in Davidson Canyon."* However, SRK did not find any technical discussion or data to support that conclusion in the text of the report. The maps of simulated pre-mining water levels shown on Figures 6-1, 6-2, and 6-29 do not show the location of the dike. Figures 6-4 through 6-23 depicting the hydraulic conductivity distribution of the simulated Hydrogeologic Units (HGU) also do not the show location of the simulated, almost impermeable dike. This makes it difficult to compare the hydraulic conductivity of the HFB with that of the surrounding HGU and to evaluate changes in the groundwater gradient to confirm the existence of such a hydrologic barrier.

The results of the predictive simulations during post-mining conditions as shown on Figures 9-8, 9-9, 9-16, and 9-27 through 9-73 in the report, suggest that the quartz-porphyry dike as modeled serves as a hydraulic barrier to groundwater flow that limits the propagation of drawdown into Davidson Canyon.

The completed sensitivity analysis of the hydraulic conductivity of the quartz-porphyry dike (increasing and decreasing the value of K by a factor of 10) showed that this parameter is:

a) Least sensitive to simulated pre-mining water levels (normalized composite scaled sensitivity is only 0.08 (see Table 9-2 of Tetra Tech (2010i), and

b) Very sensitive to the predict propagation into the Davidson Canyon area during post mining conditions.

This means that:

a) Because of the low sensitivity for the steady state condition (to which the groundwater model was calibrated), the calibrated value of the dike hydraulic conductivity is not very defensible and as a result, the predictive simulations are not likely to be conservative; and

b) A larger range of dike hydraulic conductivity is required for the predictive sensitivity analysis to more clearly evaluate possible ranges of impact to the groundwater system within Davidson Canyon.

It should be noted that Montgomery and Associates' groundwater flow model (M&A, 2010) does not simulate the quartz-porphyry dike. Instead, they modeled a zone of higher hydraulic conductivity in the area of the Davidson Canyon fault. They were able to obtain a steady state calibration as well. Given that a steady state calibration can be achieved from such differing approaches suggests that Tetra Tech consider further evaluation of the dike. SRK is of the opinion that the defensibility of the simulation of the dike is impacted by what is viewed as conclusions that are less than fully supported by the analyses and simulations. To improve defensibility, SRK suggests the following:

a) Run an additional sensitivity analysis scenario for the post-mining conditions without the quartz-porphyry dike as a HFB to cover all possible ranges of propagation of drawdown.

b) Prepare a better description of the data used to incorporate the quartz-porphyry dike into the hydrogeologic model as a groundwater barrier and use this dike as a very low conductive HGU for the Base Case predictive scenario.

c) Show the quartz-porphyry dike simulated as a HFB in all model layers that indicate the hydraulic conductivity distribution (Figures 6-4 through 6-23) for comparison of its hydraulic characteristics with the K values of the surrounding HGU.

d) Add the quartz-porphyry dike to the pre-mining water level on Figures 6-1, 6-2, and 6-29 and specify in which monitoring wells the measured water levels indicate that this dike is a hydraulic barrier.

2.2 Simulation of Pit Lake Stage-Volume Relationship by the Groundwater Flow Model

The range of simulated pit lake stage, shown on Figure 8-9, varies in elevation from 3,050 to about 4,350 feet above mean sea level (amsl). This range covers the majority of completed simulations, but not all of them. For example, the pit lake elevation was predicted to be 4,429 feet amsl at 1,000 years from a sensitivity run considering a decrease of lake evaporation by 20 percent. It is not clear to SRK whether Figure 8-9 needs to be revised or the stage-area relationship in the Lake Package (LAK2) should be revised and the sensitivity predictions re-run.

2.3 Precipitation to the Pit Lake

It is noted that Tetra Tech applied annual precipitation of 17.37 inches to the pit lake during post-mining recovery using data from the NOAA Nogales weather station. Montgomery and Associates (M&A) in a similar study (M&A2010) used the Santa Rita weather station, which reported an annual precipitation of 22.19 inches. The Santa Rita station is located at a higher elevation compared to the NOAA Nogales (4,300 feet amsl vs. 3,560 feet amsl) and is closer to the elevation of the Rosemont site (elevation about 5,300 feet amsl). SRK did not find an explanation in the model report of Tetra Tech's preference for the Nogales station vs. the Santa Rita station; however, use of the Nogales data, with lower annual precipitation, provides a more conservative assumption to evaluate the pit lake infilling and the impact to the groundwater system during post-mining conditions.

The justification for the use of the NOAA Nogales weather station data was explained in Rosemont Infiltration, Seepage, Fate and Transport Response to Comments (Tetra Tech, 2010k). The explanation for using the NOAA Nogales weather station data also should be in the *Regional Groundwater Flow Model Rosemont Copper Project* (Tetra Tech, 2010i).

3 SRK Conclusions

The groundwater model was not calibrated to the transient conditions induced by the 30-day pumping test, and there remain some uncertainties with a simulation of such a complex natural system. Specifically, SRK suggests that a better assessment of the hydrogeological role of the quartz-porphyry dike between the open pit and Davidson Canyon be performed via additional sensitivity simulations. At a minimum, SRK suggests that an additional sensitivity run should be performed without the dike to increase the defensibility of the model predictions and to cover the possible range of potential impacts to the groundwater system and to surface-water bodies in Davidson Canyon.

Despite those uncertainties, SRK concludes that the groundwater model presented in the final version of the report was conceptualized, constructed, and presented to standard industry practices. The model addresses the comments and recommendations made by SRK in its review of the individual sections of the report. Further, SRK finds that the model generally represents hydrogeological conditions that are appropriate to the available data, is robust, and well calibrated to the pre-mining steady-state conditions. Model predictions for both mining and post-mining conditions are reasonable, are based on the results of comprehensive sensitivity analyses, and provide a range of potential impacts to the groundwater system and to surface-water bodies.

4 References

Montgomery & Associates, 2010, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure*: unpublished report prepared for Rosemont Copper, August 30, 2 vol., 123 p.

SRK, 2010a, Technical Review of *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts Report* (Tetra Tech, 2010) and *Comparison of Natural Fluctuation in Groundwater Level to Provisional Drawdown Projections* (Montgomery & Associates, 2010): Technical Memorandum prepared for SWCA, May 11, 2010, 4 p.

____ 2010b, Technical Review of *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts—Final Version* (Tetra Tech, 2010a): Technical Memorandum prepared for SWCA, August 3, 2010, 3 p.

____ 2010c, Technical Review of Hydrogeologic Framework Model (Tetra Tech, 2010): Technical Memorandum prepared for SWCA, July 30, 2010, 2 p.

____ 2010d, *Review of (Tetra Tech, 2010) Hydraulic Property Estimates*: Technical Memorandum prepared for SWCA, August 2, 3 p.

____ 2010e, *Technical Review of Predictive Groundwater Flow Model Construction and Calibration* and *Steady-State Sensitivity Analyses*: Technical Memorandum prepared for SWCA, August 17, 2010, 5 p.

____ 2010f, *Review of Tetra Tech Documents Predictive Groundwater Modeling Results (Tetra Tech, 2010a) and Rosemont Groundwater Flow Model Sensitivity Analyses (Tetra Tech, 2010b)*: Memorandum prepared for SWCA, September 27, 2010, 5 p.

Tetra Tech, 2010a, *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, April 2010, 72 p., 1 appendix.

_____ 2010b, *Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts*: unpublished final version of report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, July 2010, 40 p., 1 appendix.

_____ 2010c, *Hydrogeologic Framework Model*: Technical memorandum submitted to Rosemont Copper Company on July 3, 2010, 13 p.

_____ 2010d, *Hydraulic-Property Estimates:* Technical memorandum submitted to Rosemont Copper Company on July 9, 2010, 21 p., 1 attachment.

____ 2010e, *Groundwater Flow Model Construction and Calibration*: Technical memorandum submitted to Rosemont Copper Company on July 26, 2010, 76 p., 2 attachments.

____ 2010f, *Steady-State Sensitivity Analysis*: Technical memorandum submitted to Rosemont Copper Company on July 30, 2010, 12 p.

____ 2010g, *Rosemont Groundwater Flow Model Sensitivity Analyses*: Technical memorandum submitted to Rosemont Copper Company on August 17, 2010, 93 p.

____ 2010h, *Predictive Groundwater Flow Modeling Results*: Technical memorandum submitted to Rosemont Copper Company on July 30, 2010, 28 p.

____ 2010i, *Regional Groundwater Flow Model, Rosemont Copper Project*: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320874, November 2010, 291 p, 3 appendices.

____ 2010j, *Responses to SRK's Technical Review Comments on Tetra Tech's Groundwater Flow Model Technical Memoranda*: Technical memorandum submitted to Rosemont Copper Company on November 17, 2010, 15 p., 5 attachments.

_____ 2010k, *Rosemont Infiltration, Seepage, Fate and Transport Response to Comments*: Technical Memorandum submitted to Rosemont Copper Company, Tetra Tech Project No. 268/10-320884-5.3, November 23, 2010, 24 p.

5 Reviewer Qualifications

Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the groundwater flow model. His resume has been provided to SWCA in prior submissions.

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Memo

To:	Dale Ortman, P.E.	**Date:**	April 6, 2011
From:	Mike Sieber, P.E.		
Copy to:	Tom Furgason, SWCA Cori Hoag, SRK File	**Project #:**	183101/2500
Subject:	Technical Consistency Review of Tetra Tech and Montgomery & Associates Groundwater Models		

This memorandum reviews the internal technical consistency of the:

- Tetra Tech numerical groundwater models (Steady-State, Mining Phase, and Post Closure models) and the Tetra Tech report Regional Groundwater Flow Model Rosemont Copper Project dated November 2010 (Tetra Tech, 2010); and the
- Montgomery & Associates (M&A) numerical groundwater model (Steady-State, Transient DRN, and Transient LAK models) and the M&A report Revised Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure Rosemont Project, dated August 30, 2010 (M&A, 2010).

The purpose for the review is to confirm that the digital input and output files created during the building of the models are consistent with the results of the steady-state and transient models presented by Tetra Tech (Tetra Tech, 2010) and M&A (M&A, 2010).

This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a Technical Review Scope of Work, Request for Cost Estimate and Schedule from Mr. Dale Ortman dated January 10, 2011. This memorandum was prepared by Mike Sieber, P.E. and reviewed by Vladimir Ugorets, Ph.D. Larry Cope of SRK Consulting (U.S.), Inc. (SRK).

1 Consistency Review of Tetra Tech Models and Tetra Tech (2010)

Tetra Tech provided SRK their final steady-state, mining phase, and post-closure numerical model files for SRK to review with Groundwater Vistas version 5.51 software, (Rumbaugh and Rumbaugh 2007). SRK opened the three models and checked the consistency with what was described in Tetra Tech (2010).

The steady-state model was checked for consistency of discretization; values for hydraulic conductivity on various layers, boundary conditions, recharge, evapotranspiration, groundwater/stream flow interaction parameters, the horizontal flow barrier hydraulic properties, and mass balance. The initial and calibrated groundwater elevation contours were compared to figures in the report (Tetra Tech, 2010). SRK's review of the steady-state model established that the steady-state model was consistent with what was presented in the report (Tetra Tech, 2010).

The transient mining phase model was checked for consistency for values of hydraulic conductivity, storage parameters (specific storage and specific yield), drain cell elevation and conductance values (used to simulate pit excavation), stress period set-up, passive inflow to the pit, and mass balance. SRK's review of the mining phase model established that it was consistent with what was presented the report (Tetra Tech, 2010).

The transient post-closure model was checked for consistency for hydraulic conductivity values, storage parameters (specific storage and specific yield), LAK2 package (Council, 1999) inputs (stage-area relationship) and output (precipitation to and evaporation from the pit lake, pit wall runoff, groundwater inflow, and pit lake elevation), stress period set-up, and mass balance. The post-closure model was consistent with the report (Tetra Tech, 2010). The LAK2 package was not incorporated into the post-closure model but was completed outside of the model. The drawdown contours presented in the report figures (Tetra Tech, 2010) were therefore not available to check for consistency. The figures showing the simulated drawdown shown on Figures 8-5, and 8-10 through 8-13 (Tetra Tech, 2010) were created with GIS using output from two models (personal communication with Grady O'Brien, Tetra Tech, March 16, 2011).

One additional comment on consistency is that Tetra Tech formulated their model using units of meters and days, whereas the report (Tetra Tech, 2010) was in feet and days. SRK checked the values and the unit conversions presented in the report were correct.

2 Consistency Review of M&A Models and M&A (2010)

M&A provided SRK with their final steady-state, mining, and closure numerical model files for SRK to review with Groundwater Vistas version 5.51 software (Rumbaugh and Rumbaugh 2007). SRK opened the three simulations and checked for consistency with what was described in the report (M&A, 2010).

The steady-state model was checked for consistency for discretization, values for hydraulic conductivity on various layers, boundary conditions, recharge, evapotranspiration, stream flow parameters and results, and mass balance. M&A utilized an inverse parameter estimation (PEST, Doherty, 2005) subroutine for evaluation of hydraulic conductivity and recharge during the steady-state calibration. The model files are much more complex than the equivalent figures in the report (M&A, 2010). However, the report figures have a range of values for each hydrogeologic unit that are consistent with the steady-state model input files for hydraulic conductivity values. The figure showing the simulated distribution of recharge has a range of recharge values for each recharge zone (M&A, 2010, Figure 93). This was consistent with the model recharge distribution that was generated using PEST. The steady-state model discretization and mass balance are also consistent with M&A (2010). The initial and calibrated groundwater elevation contours were consistent with the figures in the report (M&A, 2010).

It should be noted that the transient model used for calibration to the 30-day pumping test data was not available to SRK and was not reviewed.

The transient mining phase model was checked for consistency for values of hydraulic conductivity, storage parameters (specific storage and specific yield), drain cells parameters and fluxes (simulated pit inflows), and stress periods. SRK's review of the mining phase model established that it was consistent with the report (M&A, 2010). The mining phase model water level contours for the end of mining were consistent with the figure in the report (M&A, 2010).

The transient post closure model was checked for consistency for values of hydraulic conductivity, storage parameters (specific storage and specific yield), LAK2 setup (stage-area relationship) and output (precipitation to and evaporation from the pit lake, pit wall runoff, groundwater inflow, and pit lake elevation), and stress period set-up. The projected groundwater level drawdown for end of mining and at 1,000 years was reviewed. The M&A post-closure simulation is consistent with the report (M&A, 2010). M&A did not present mass balances in the report for their transient simulations, so these were not reviewed by SRK.

3 SRK Conclusions

SRK finds the Tetra Tech steady-state, mining phase, and post-closure numerical groundwater models to be consistent with their report (Tetra Tech, 2010).

SRK finds the M&A steady-state, mining phase, and post-closure numerical groundwater models to be consistent with their report (M&A, 2010).

4 References

Council, Gregory W. (1999), A Lake Package for MODFLOW (LAK2), Documentation and user's manual Version 2.2: software manual, 137 p.

Doherty, J. (2010), PEST: Model-Independent Parameter Estimation, version 12, Watermark Numerical Computing.

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Rumbaugh, J.O., and Rumbaugh, D.B., 2007, Groundwater Vistas (Version 5.16): software published by Environmental Simulations Inc., Reinholds, Pennsylvania.

Tetra Tech, 2010, Davidson Canyon hydrogeologic conceptual model and assessment of spring impacts: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320869, April 2010, 72 p., 1 appendix.

5 Reviewer Qualifications

The reviewer for hydrogeology, Mike Sieber, P.E., is a Hydrogeologist with SRK Consulting in Tucson. Mr. Sieber is a professional engineer with more than 17 years of hydrogeology experience including 15 years preparing infiltration and seepage models to estimate infiltration through tailings impoundments, waste rock storage and heap leach facilities, and landfill covers. He has more than 10 years experience in the preparation of numerical groundwater flow models to predict the formation of pit lakes and potential loss of containment at open pit and under-ground mining operations.

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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	April 25, 2011
Copy to:	Tom Furgason, SWCA Cori Hoag, SRK File	**From:**	Vladimir Ugorets, Ph.D. Larry Cope, M.Sc. Mike Sieber, P.E.
Subject:	Technical Review to Compare the M&A (2010) and Tetra Tech (2010) Groundwater Flow Models for the Rosemont Project	**Project #:**	183101/2600

1 Introduction

This memorandum provides a technical comparison review of the groundwater flow models developed by Montgomery and Associates (M&A, 2010) and Tetra Tech (2010) for the Rosemont Copper project and an evaluation of the reliability and accuracy of the model predictions. This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest, in accordance with a Statement of Work and Request for Cost Estimate from Mr. Dale Ortman dated February 22, 2011. This memorandum was prepared by Vladimir Ugorets, Larry Cope, and Mike Sieber of SRK Consulting (U.S.), Inc. (SRK). It should be noted that SRK previously reviewed the M&A and Tetra Tech groundwater flow modeling reports separately. The results of these separate reviews were presented in two Technical Memoranda (SRK, 2010 and SRK, 2011), respectively. This Technical Memorandum summarized the differences between the two groundwater models and the results of their simulations.

2 Differences between M&A (2010) and Tetra Tech (2010) Models

The differences in model setup, calibration, and predictions for both mining and post-mining conditions between M&A (2010) and Tetra Tech (2010) models are presented in detail in the attached Table 1.

3 SRK Conclusions

On the basis of the comparison between the M&A (2010) and Tetra Tech (2010) models performed by SRK, SRK concludes that:

1. The model predictions—made by both the M&A (2010) and Tetra Tech (2010) models (the Base Cases and Sensitivity Runs)—cover a range of possible impacts from the open pit excavation to the groundwater system and surface-water bodies.

2. The biggest differences between the two models are:

   (a) The M&A model uses enhanced values of hydraulic conductivity to simulate the inferred Davidson Canyon fault zone, but does not simulate the mapped quartz-porphyry dike; and,
   (b) The Tetra Tech model simulates the dike as an effectively impermeable barrier, but does not simulate the inferred fault zone along the axis of Davidson Canyon.

3. The M&A model uses continuously variable values of hydraulic conductivity (K) within each hydrogeological zone while the Tetra Tech model uses an averaged K for each zone. The M&A model is calibrated to the both steady-state and transient conditions; Tetra Tech model is calibrated only to steady-state conditions.

4. Other differences noted between the two models are that the Tetra Tech model:

   (a) Simulates more water flowing through the model domain;
   (b) Uses a higher recharge rate in the open pit area (by factor of 2.4) and a higher total recharge applied within model domain (by factor of 1.5); simulates increased recharge within the model domain during post-mining conditions (while the M&A model simulates decreasing of the recharge). These two factors limit the propagation of drawdown during post-mining conditions as compared to the M&A model;
   (c) Simulates larger groundwater discharge to the creeks;
   (d) Uses specific storage values 35 to 50 times higher than M&A model;
   (e) Predicts a higher ultimate pit lake elevation, pit lake evaporation (bigger size), and groundwater inflow to the pit lake than the M&A model;
   (f) Predicts a smaller extent of maximum drawdown and a smaller decrease in evapotranspiration during post-mining conditions;
   (g) Predicts more impact to Cienega Creek and less impact to Davidson Canyon; and,
   (h) Simulates the western boundary of the model as Constant Head (M&A uses General Head boundary), which limits propagation of drawdown to the west from pit lake.

5. The Tetra Tech model is less conservative in predicting impacts as compared to the M&A model with respect to Items 2 and 4 above.

6. SRK suggests that the hydrogeological role of the quartz-porphyry dike between the open pit and Davidson Canyon be assessed by conducting sensitivity simulations using the Tetra Tech model. The simulations should consider a broad range in the permeability of the dike. At a minimum an additional sensitivity run should be conducted wherein the dike is removed from the model to quantify the influence the dike could have on the groundwater system. By doing so, the defensibility of the Tetra Tech model would be improved by covering the possible range of potential impacts to the groundwater system and to surface water in Davidson Canyon.

4 Reliability and Accuracy of the Models

SRK considers model reliability as the ability of a model to reasonably simulate impacts across a range of inputs and environmental influences. Reliability is judged using sensitivity analyses that produce a range in model results from a reasonable range in model inputs. A model is said to be reliable (or robust) when it produces reasonable results across the ranges of input variables. Sensitivity analyses were conducted for both the M&A and Tetra Tech models. And the analyses yielded reasonable ranges in response to the models. As such, the models can be considered reliable with the following comments:

- The sensitivity analyses for the M&A model were more extensive than those for the Tetra Tech model. The number of variables and the ranges applied to the variables in the sensitivity analyses were greater in the M&A model.
- The Tetra Tech model did not conduct an adequate sensitivity analysis of the dike. The effect the dike has on the flow system was not assessed across a sufficiently broad range of dike hydraulic conductivities, nor did the model show predictions of impacts with and without the dike in place.

The accuracy of a model is considered the ability of a model to simulate conditions that compare to actual field data. Model calibration is the means by which a model is adjusted to produce results that are as similar as possible to measured water levels and flows. The impact on the groundwater flow system from dewatering an open pit mine is a dynamic transient condition that requires calibration to as similar a condition as possible. Clearly, the inflow to a large open pit cannot be fully simulated with field pumping tests. The multi-well 30-day pumping test conducted by M&A produced pumping rates and drawdowns of much smaller magnitude than those that would result from an open pit. The accuracy of the drawdown simulated by predictive runs of the models cannot be stated when the predicted drawdowns far exceed the extent of the pumping-test drawdown. M&A and Tetra Tech simulated the pumping tests as a step in model calibration (M&A simulated the 30-day pumping test by using a 3-D model during transient calibration. Tetra Tech did not complete transient calibration of 3-D model but used a simple axisymmetric model to interpret pumping-test results). In general, both methods simulated the drawdowns to a reasonable fit of the test data.

However, from those simulations, the accuracy of the model predictions over hundreds of years at large distances from the pit cannot be quantified. What can be stated is that the models predict a range of impacts that lie within the range established by the sensitivity analyses. Accuracy can be quantified via refinements to the models as the pit is advanced during mining operations.

5 References

Montgomery & Associates, 2010, Groundwater flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure: unpublished report prepared for Rosemont Copper by Montgomery & Associates, Inc., August 30, 123 p, Full report in 2 volumes.

SRK, 2011, Technical Review of (Tetra Tech, 2010) Report: Regional Groundwater Flow Model Rosemont Copper Project: Technical Memorandum prepared for SWCA, January 13, 2011, 5 p

SRK, 2010, Technical Review Groundwater Flow Modeling report Rosemont Copper Project: Technical Memorandum prepared for SWCA, October 22, 2010, 6 p

Tetra Tech, 2010, Regional Groundwater Flow Model Rosemont Copper Project: unpublished report prepared for Rosemont Copper, Tetra Tech Project No. 114-320874, November 2010, 118p, 1 appendix.

6 Reviewer Qualifications

The Senior Reviewer, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado. Dr. Ugorets has more than 32 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model. His resume has been provided to SWCA in prior submissions.

Table 1: Comparison of the M&A (2010) and Tetra Tech (2010) Groundwater Flow Models for Rosemont Project

Phase of Modeling	Model Element	M&A (2010)	Tetra Tech (2010)	SRK Comments
Model Setup	Vertical model discretization	10 numerical layers	20 model layers	Increasing of vertical discretization of Tetra Tech model does not increase predictability compared to M&A model.
	Hydraulic conductivity (K) values - grouped into ten hydrogeological zones determined from the geological mapping	Allowed K to vary within zone based on range of measured values and PEST calibration to measured water levels.	One K value for one hydrogeological zone, two additional zones used during calibration - for the Backbone fault and for basin fill in the Tucson basin.	M&A model uses continuously variable values for hydraulic conductivity within each hydrogeological zone while Tetra Tech model uses an averaged K for each zone. The biggest difference between two models: a) M&A model uses enhanced hydraulic conductivity values to simulate potential Davidson Canyon fault zone and ignores presence of quartz-porphyry dike, b) Tetra Tech model simulates this dike as almost "impermeable barrier" and ignores the possibility of presence a fault zone along the axis of Davidson Canyon.
	Important Geological Features (faults, dikes)	Backbone and Flat Faults were simulated as separate hydrogeological units with specific parameters. Potential Davidson Canyon fault zone was simulated indirectly by increasing hydraulic conductivity in a narrow zone (about 1,200 ft) within first 4 model layers with K ranging from 0.5 to 4 ft/d.	Backbone fault zone was simulated as additional hydrogeological unit. Additionally, a quartz-porphyry dike between open pit and Davidson Canyon was simulated as horizontal flow barrier (HFB) with extremely low hydraulic conductivity K=3.28 x10^{-6} ft/d, width of 100 ft, and penetration within all model layers.	
	Storage Parameters	Specific yield for alluvium varies from 0.1 to 0.15, for bedrock - 0.01 (0.025 for faults); specific storage values for alluvium and bedrock are 2x10^{-6} 1/ft and 2x10^{-7} 1/ft, respectively.	Specific yield for alluvium varies from 0.05 to 0.15, for bedrock - 0.01; specific storage values for alluvium and bedrock about 7x10^{-5} 1/ft and 1x10^{-5} 1/ft, respectively.	Tetra Tech model uses specific storage values 35-50 times higher than M&A model.
	Recharge from precipitation during pre-mining conditions	Recharge rate in pit area of about 0.55 in/yr.; total recharge applied to model domain is 6,500 AF/yr.	Recharge rate in pit area of about 1.31 in/yr.; total recharge applied to model domain is 9,900 AF/yr.	Tetra Tech model uses a higher recharge rate in the open pit area (by factor of 2.4) and total recharge applied within model domain (by factor of 1.5) than M&A model. This limits propagation of drawdown during mining and post-mining conditions compared to M&A model.
	Groundwater recharge during mining and post-mining conditions	Zero recharge from waste rock storage area and to open pit during excavation; total discharge from tailing seepage of 13.6 AF/yr. decreasing to 0 after 500 years; total discharge from drain infiltration within tailings of 7.5 AF/yr.	Recharge to model domain increased by 196 AF/yr. during post-mining conditions accounting increased infiltration due to the flow-through drains, containment pond PCA-2, and dry tailings drain down. No increase in additional recharge was simulated during sensitivity analysis.	Tetra Tech model simulates increased recharge within model domain during post-mining conditions while M&A model simulated decreaed recharge.
	Lateral boundary conditions	Constant head (CHEAD) and general head (GHB at the western and southwestern boundaries); model boundary inflow net is positive (227 AF/yr).	CHEAD only (GHB conditions ; model boundary inflow net is negative (-1,651 AF/yr).	Tetra Tech model simulates more water flowing through model domain than M&A; net of model boundary inflow indicates groundwater outflow since M&A model indicates that majority of groundwater inflow is through the model boundaries.
	Interaction with surface-water Bodies - simulated by MODFLOW STR package	Net of groundwater discharge to the creeks is positive (1,715AF/yr).	Simulated steady-state stream flows significantly exceed measured; net of groundwater discharge to the creeks is positive (2,616 AF/yr).	Tetra Tech model simulates groundwater discharge to the creeks significantly larger than measured and larger than simulated by M&A model.
	Evapotranspiration - simulated by MODFLOW EVT package	Simulated steady-state evapotranspiration is 5,007 AF/yr.	Simulated steady-state evapotranspiration is 5,633 AF/yr.	Tetra Tech model simulates slightly higher (by 11.7%) evapotranspiration within model domain than M&A model.
	Model inputs for pit lake simulations used for LAK2 package	Lake precipitation assumed to be 22.19 in/yr based on Santa Rita Station data and pitwall runoff assumed to be 6.66 in/yr (or 30% of precipitation).	Lake precipitation assumed to be 17.37 in/yr based on NOAA Nogales Station data and pitwall runoff assumed to be 5.21 in/yr (or 30% of precipitation).	Tetra Tech and M&A models use the different rainfall stations for their analysis. As result, Tetra Tech model uses less lake precipitation and pit wall runoff rates than M&A model
Model Calibration		Model calibrated to both steady-state (pre-mining water levels and measured stream baseflows) and transient (results of 30 day pumping test from 5 wells) conditions.	Model calibrated to steady-state (pre-mining water levels and measured stream baseflows) conditions only.	M&A model is better calibrated than Tetra Tech model to water levels measured in Davidson Canyon area and steam baseflow data. M&A model also reasonably reproduces results of 30-day pumping test from 5 wells.
Predictions of Mining Conditions	Passive inflow to proposed pit	Maximum predicted passive inflow is 630 gpm, at the end of mining - 552 gpm	Maximum predicted passive inflow is 510 gpm, at the end of mining - 400 gpm	M&A predicts passive inflow to the pit about 1.2-1.4 times higher than Tetra Tech model.
	Maximum extent of water tablechange (5 ft contour)	About 3.2 miles to the northeast but does not cover Questa spring	About 4.7 miles to the northeast and cover Questa spring (presented in model layer 17; Tetra Tech report does not show change in water table at end of mining).	Tetra Tech model simulates a more extensive maximum drawdown than does the M&A model.
Predictions of Post-Mining Conditions 1,000 years after End of operations	Ultimate pit lake stage	4,097 ft amsl for Base case (3,945 to 4,264 ft amsl for Sensitivity Analysis).	4,279 ft amsl (4,150 to 4,429 ft amsl for Sensitivity Analysis).	Tetra Tech model predicts higher ultimate pit lake elevation than M&A model. As result of this, Tetra Tech model predicts higher pit lake evaporation and groundwater inflow to pit lake than M&A model.
	Pit lake evaporation	410 gpm	552 gpm	
	Groundwater inflow to pit lake	104 gpm	230 gpm	
	Pit lake precipitation	161 gpm	191 gpm	
	Runoff into pit lake	145 gpm	131 gpm	
	Maximum extent of drawdown (5 ft contour)	About 11.5 miles to the northeast into Davidson Canyon.	About 7.4 miles to the east; quartz-porphyry dike significantly limits propagation of drawdown into the Davidson Canyon.	Tetra Tech model predicts less extent of maximum drawdown compared to M&A model
	Decrease in stream flows	0.02 cfs in Cienega Creek and 0.04 cfs in Davidson Canyon.	0.09 cfs in Cienega Creek and 0.01 cfs in Davidson Canyon.	Tetra Tech model predicts more impact to the Cienega Creek and less impact to the Davidson Canyon compared to M&A model.
	Decrease in evapotranspiration	51 AF/yr. in Cienega Creek and 22 AF/yr. in Davidson Canyon.	14 AF/yr. in Cienega Creek and in Davidson Canyon total.	M&A model predicts more decrease in evapotranspiration during post-mining conditions than Tetra Tech model.
Sensitivity Analysis		Comprehensive sensitivity analysis of all key model parameters.	Comprehensive sensitivity analysis of all key model parameters; however, range of variation of hydraulic conductivity for quartz porphyry dike is not enough to evaluate the most conservative predictions of potential impact to groundwater system and surface-water bodies.	Tetra Tech needs to conduct additional sensitivity run by removing of quartz-porphyry dike (re-calibration of the model might be required to use reasonable initial heads for this run).