

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 4,093 feet 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.