MWH

BUILDING A BETTER WORLD

TECHNICAL MEMORANDUM

TO: Tom Furgason
SWCA Environmental Consultants

DATE: August 09, 2010

FROM: Nathan W. Haws, MWH Americas, Inc.
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REFERENCE: 1005979

CC: Dale Ortman, Consultant
Stephen Taylor, MWH Americas, Inc.

SUBJECT: Technical Review of Response to Comments on Groundwater Flow Modeling Conducted for Rosemont Copper Company Mine Supply Pumping

At your request, MWH Americas, Inc. (MWH) has prepared this technical memorandum in support of the Environmental Impact Study (EIS) for Rosemont Copper Company (RCC). This memorandum was prepared to address the responses prepared by Montgomery & Associates (M&A, 2010)[1] to our comments (MWH, 2009)[2] on the report of groundwater flow modeling conducted for Rosemont Copper Company (RCC) mine supply pumping (M&A, 2009)[3]. The MWH (2009) memorandum reviewed the model development and simulation results as reported in M&A (2009). As stated in the MWH (2009) memorandum, MWH is of the professional opinion that the data, assumptions, and methods used to develop the numerical model are generally reasonable and in conformance with standard accepted industry practices. Some of the concerns noted in our 2009 memorandum have been satisfactorily resolved through M&A's response. The remaining concerns focus on properly demonstrating model calibration and appropriately communicating the model's capabilities and limitations. The resolution of these concerns may require only minor modifications to the model and may not result in significant changes to the conclusions drawn from the model simulations. Nevertheless, the resolution of these concerns will help validate the model construction and the simulation results and better define the appropriate uses and limitations of the model.

This memorandum first highlights unresolved topics of concern regarding the groundwater flow modeling conducted to evaluate the impacts of RCC mine supply pumping. Following this are our replies to the responses prepared by M&A.

Unresolved Topics

Unresolved topics of concern with the groundwater flow modeling as presented in the M&A (2009) modeling report are explained below. Included with each explanation are recommendations to address the concerns.

1. <u>The model is lacking quantitative calibration objectives and a formal calibration.</u>
   M&A states that the model "reasonably simulates average groundwater levels" and that the model is "acceptably" calibrated. While M&A may have accepted the match between simulated and measured groundwater levels, the terms "reasonably" and "acceptably" are subjective. No quantitative calibration

[1] Montgomery & Associates. 2010. Response to MWH October 23, 2009 Review of Groundwater Modeling Conducted for Rosemont Copper Company's Proposed Mine Supply Pumping. Technical memorandum submitted to Kathy Arnold, Rosemont Copper Company. February 9, 2010.
[2] MWH Americas, Inc. 2009. Review Comments of Rosemont Numerical Groundwater Model Update and Simulations; Rosemont EIS Support. Technical memorandum submitted to Tom Furgason, SWCA Environmental Consultants. October 23, 2009.
[3] Errol L. Montgomery & Associates, Inc. (M&A). 2009. Report: Groundwater Flow Modeling Conduction for Simulation of Rosemont Copper's Proposed Mine Supply Pumping, Sahuarita, Arizona. April 30, 2009.

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objectives have been established with which to judge the adequacy of the calibration. Further, no standard iterative calibration has been conducted to demonstrate whether an optimal set of parameter values has been selected.

- MWH recommends that a quantifiable set of calibration objectives be determined with which to judge whether the model simulations are reasonable. Model reviewers could then decide whether the objectives and the calibration are acceptable. The relationship between calibration objectives and simulation results will also aid in demonstrating the capabilities and limitations of the model predictions. The modeling report does discuss some limitations to the model's predictive capabilities. For example, the report explains that the model can only predict average groundwater levels and cannot simulate the large seasonal variations in groundwater levels. These limitations should be considered along with the intended use of the model's predictions to formalize quantifiable calibration objectives.

- MWH recommends that an iterative calibration be conducted to determine optimal parameter values. The modeling report documents that the updated model improves the match between measured and observed groundwater levels; however, the large residuals between simulated and measured values, and an apparent spatial bias in the distribution of residuals, suggests that further improvement may be possible. Because the RCC model was constructed from a larger regional model, calibrating every parameter may not be practical or necessary. MWH recommends that the calibration focus on the parameters that most affect groundwater levels within the RCC pumping influence. These parameters may include storage coefficients and specific yield (which were left unchanged from the original model despite changes to hydraulic conductivity and layer elevations) and hydraulic conductivity/transmissivity values (which were modified from the original model based on assumptions about how the results of recent aquifer pumping tests should be distributed across model layers).

- MWH recommends that the differences in simulation results between the original ADWR regional model and the updated model be illustrated with the differences and improvements to the original ADWR model clearly noted. Figure 26 of the modeling report compares "actual" groundwater levels with the results of the original and revised model for the 1940 steady-state simulation. A similar figure should to be created for the transient simulation for 1999 (last year of the original ADWR historical simulation). These figures (or separate figures) should zoom into the area surrounding the RCC property and show a higher resolution of groundwater contours.

2. <u>The capabilities and limitations of the model are not clearly delineated.</u>
The modeling report provides illustrations of groundwater level declines with and without RCC pumping, but the practical uses and limitations of these predictions are not clearly defined. For one example, the model is designed to predict groundwater levels that are spatial and temporal averages. The predicted groundwater levels are annual averages and cannot predict seasonal variations, which were shown to be between 10 and 100 feet. The model predictions are also spatial averages across a grid cell, which range from 100 feet by 100 feet (nearest the RCC pumping) to 0.5 miles by 0.5 miles. Given this construction, the model is capable of grossly predicting annual average groundwater levels, including impacts from RCC pumping. The model would not be suitable, however, for predicting maximum declines and impacts at an individual well. This could be an important distinction for owners of shallow wells.

   - MWH recommends that the appropriate uses and limitations of the groundwater model be clearly defined. Such a statement of limitations is often included in modeling reports. The statement of limitations does not necessarily change the validity of the model conclusions, but it will aid in the understanding of the appropriate uses of these conclusions.

3. <u>The uncertainties in the model are not clearly defined.</u>
Uncertainty is inherent in all model predictions. An important source of uncertainty in the RCC model predictions arises from unknowns in future aquifer stresses. The aquifer in the vicinity of RCC is highly

stressed from agricultural, industrial, and private water users. The actual locations and magnitude of the future aquifer stresses is uncertain. M&A's method of allocating future stresses based on committed pumping demands on file with the Arizona Department of Water Resources (ADWR) is reasonable, but the model report does not clearly document the uncertainties or potential deficiencies associated with these estimates or how these uncertainties affect model predictions.

- MWH recommends that the potential effects of the uncertainties should be considered, quantitatively if possible, but at least qualitatively. They could be considered quantitatively by conducting predictive simulations to test the sensitivity of the model predictions to a reasonable range of future groundwater stresses. This would help bound the range of model predictions due to uncertain future stresses. Two potential future aquifer stresses that should be included in such an analysis are the potential mitigation pumping for the Freeport-McMoRan Sierrita Mine and recharge of Central Arizona Project (CAP) water. Although these stresses may be difficult to characterize, they will, if implemented, have significant impacts on future groundwater levels in the Green Valley/Sahuarita area. Estimated timing and magnitudes of potential Sierrita mitigation pumping and CAP recharge are available. For example, Freeport-McMoRan Sierrita has posted the feasibility study and conceptual wellfield design for the sulfate mitigation on their website (www.fcx.com/sierrita/home.htm).

- MWH recommends that a figure be included in the modeling report that shows the additional drawdown caused by RCC pumping alone (neglecting other aquifer stresses). Such a figure could easily be created as the difference between the groundwater level declines with and without RCC pumping. This figure will better illustrate the groundwater level declines attributable exclusively to RCC and will nullify the effects of uncertainty associated with other groundwater stresses.

4. The plan view figures may be difficult to interpret.

    - MWH recommends that the modeling report include figures that show a profile view of groundwater levels and stratigraphy through sections that cross the maximum drawdown. These figures may be more readily interpreted than the plan view of groundwater levels to those unfamiliar with hydrogeology and groundwater modeling.

Reply to Responses

For convenience in referencing, the original comments and responses, as presented in the M&A response letter, are repeated here in italics and numbered. Our replies follow each response. Replies are made to only responses 1 through 11 because the remaining responses (12 though 17) were made to summary comments, which are addressed in the first 11 responses.

(1) *MWH Comment: The methodology for model predictions also follows good practice, with the exception that future pumping may be over-allocated (which would result in over prediction of groundwater level elevations) and some future source/sink terms may not be included (which would result in over-prediction in some locations and under-prediction in others).*

M&A Response No. 1: The RCC mine supply groundwater modeling study assumed future residential groundwater pumping in the area would increase at a rate determined from committed and existing groundwater withdrawals, as provided by Arizona Department of Water Resources (ADWR). Due to the recent economic downturn and the resulting substantial decrease in the area's residential growth, we agree that this approach will likely project more background groundwater level decline due to residential pumping than may actually occur. However, for purposes of the EIS study we did not speculate on how a reduced future residential pumping demand might occur. The future residential pumping simulated in the model is based on ADWR data and may result in conservatively larger background groundwater level declines (from residential pumping). The

conservatively larger projection of background groundwater level declines will have limited effect on the projected groundwater level decline due to proposed RCC pumping.

All future sinks and sources updated in the model by M&A are determined from existing permits or pending permits (supplied by ADWR), or are estimated based on past documented quantities of historic pumping or recharge. We did not add new future sinks or sources to the model which were not at the permit submittal stage and where quantities and/or schedules were not well defined.

Finally, the use of the term "over-prediction of groundwater level elevations" is confusing, since the term over-prediction implies neither groundwater levels being too high or too low; the concept is better described as: over-prediction of groundwater level declines.

MWH Reply: MWH agrees that M&A's approach to estimating future groundwater recharge and withdrawals is reasonable. The purpose of the comment was to note that, although the approach is reasonable, the estimates may over-allocate the future withdrawals. While the amount that future withdrawals have been over-allocated is difficult to quantify, the potential over-allocation should be noted. The other future sinks and sources noted in our original comment had reference to the possibility of CAP water recharge and Sierrita mitigation pumping. We also acknowledge that these future stresses are not well defined, though they may nonetheless have significant impacts on future groundwater levels in the Sahuarita/Green Valley area. Because the future aquifer stresses are highly uncertain, the sensitivity of the predictive simulations to this uncertainty should be evaluated and documented.

MWH also agrees that over- or under-prediction of future groundwater withdrawals or recharge will have limited impact on the projected groundwater level decline (drawdown) due to Rosemont Copper Company (RCC) pumping. An additional figure that shows the drawdown that is solely attributable to RCC pumping (i.e., additional drawdown caused by RCC pumping above the background groundwater level declines) could better illustrate RCC impacts while excluding most of the uncertainty associated with other groundwater stresses. Such a figure could easily be created as the difference between groundwater drawdown with Rosemont pumping and without Rosemont pumping (e.g., difference of Figure 31 and Figure 32).

The confusing phrase "over-prediction of groundwater level elevations" was misquoted. The actual phrase read, "under-prediction of groundwater elevations." By under-predict, we mean to predict groundwater levels that are lower than the actual groundwater levels. This is equivalent to "over-prediction of groundwater level declines" as suggested by M&A.

RESPONSES TO "(1) Major Review Findings – Updates to Historical Model"

(2) *MWH Comment: The major concern with the model updates is that no standard iterative recalibration of the aquifer parameters is performed.*

M&A Response No. 2: Accounting for the facts that most of the available observed groundwater level data are obtained during winter when agricultural pumping is not occurring, and simulated groundwater levels reflect annual average agricultural pumping simulated in the model, the updates to historical stresses in the study area resulted in a reasonable match of simulated groundwater levels and trends to observed data. The model is acceptably calibrated for purposes of simulating groundwater level decline due to proposed Rosemont pumping, although we agree it may over-predict future background groundwater level declines for reasons stated above. We believe further calibration is not required for this study.

MWH Reply: MWH understands the difficulty in determining calibration targets. The fact remains, however, that a recalibration of model parameters was not conducted, although layer elevations and hydraulic conductivities were revised in some portions of the model. At a minimum M&A should demonstrate that the model results meet quantifiable calibration objectives. Terms such as "reasonable match" and "acceptability calibrated" are subjective.

(3) *MWH Comment: It is possible that much of the error between measured and simulated groundwater levels, which can be several tens of feet and shows spatial bias in some areas, is partly a reflection of the model parameters being out of calibration.*

M&A Response No. 3: We believe the model is reasonably calibrated and the differences between simulated and observed groundwater levels are acceptable.

MWH Reply: See response to item (2)

(4) *MWH Comment: Another concern with the model updates is that no consideration is given for the Santa Cruz fault, which runs between the RCC wells and many of the other wells in the study area. Mason and Bota (2006) suspect the fault as a source of some of the large residuals (error between measured and simulated groundwater levels) in the ADWR model. M&A (2009b) documents the fault in the text and figures, but does not modify the model to account for the fault. The rationale for not explicitly accounting for the fault is not discussed in M&A (2009a, 2009b).*

M&A Response No. 4: The regional Santa Cruz fault is not considered to be a hydraulic barrier or conduit. In the area north from the proposed RCC well field Anderson (1987) (shown on ***Figure 6*** *of the EIS report) indicates vertical displacement along the fault resulted in a thicker deposition of the upper Tinaja beds on the east side of the fault relative to the west side of the fault. Knowledge of the Santa Cruz fault, including hydraulic conductivity data for the aquifer on both sides of the fault, has been previously incorporated into the ADWR model by the U.S. Geological Survey and ADWR. Mason and Bota do not indicate they suspect the Santa Cruz fault is the cause of large residuals in T.15S.,R.13 and 14.E., they simply point out that "residuals are in an area of suspected perched groundwater and near the Santa Cruz fault". The large residuals are predominantly indicating simulated groundwater levels are lower than observed. It has been M&A's experience simulating groundwater levels at the T.15S., R.13 and 14E location (for other groundwater investigations) that perched groundwater is a significant cause of simulated groundwater levels being lower than observed. Further, the area Mason and Bota describe as having high residuals is located approximately 12 miles north from the proposed RCC wellfield. The RCC wellfield is located in T.17S.,R.14E., where the residuals shown in Mason and Bota's 2006 report are relatively good (see page 72 and Figure 27 of the Mason and Bota report).*

MWH Reply: Because the Santa Cruz Fault separates the RCC wells and most of the other public and private well, M&A should clearly document what effects the fault has on water levels and how this is accounted for in the model. Otherwise, MWH finds M&A's response acceptable to resolve this concern.

RESPONSES TO "(1) Major Review Findings – Updates to Predictive Model"

(5) *MWH Comment: Other potential future groundwater sinks/sources not included in the model that may impact future groundwater levels within the study area are potential mitigation pumping near Freeport-McMoRan Sierrita Mine and delivery of underground storage of Central Arizona Project (CAP) water to the Sahuarita/Green Valley area.*

M&A Response No. 5: At the time of model construction the mitigation plan was still being developed and was not finalized or approved by Arizona Department of Environmental Quality. Sufficient information did not exist to justify including the potential mitigation pumping in the model. A CAP recharge site in the Green Valley area is under consideration, but has not been approved by regulatory agencies nor has a location for the site been selected; therefore, this potential recharge source was not included in the model. Potential CAP recharge in this area may mitigate drawdown impacts from the proposed RCC pumping.

MWH Reply: See response to item (1)

(6) *MWH Comment: An assumption of the predictive model, which may be incorrect, is that boundary conditions are static. This assumption is refuted by the continual groundwater level declines throughout the*

study area. The correctness of the assumption is only a minor concern as the boundary heads likely have relatively little influence on the groundwater levels within the study area.

M&A Response No. 6: As concluded by MWH, the southern constant head boundary located 14.5 miles south from the RCC wellfield and the much more distant model boundaries in Marana and Avra Valley are too distant to have impacts on projected groundwater level change due to RCC pumping.

MWH Reply: The conclusion that the model boundaries are too distant to have impacts on projected groundwater level changes due to RCC pumping should be tested and the results documented in the model report.

RESPONSES TO "(1) Major Review Findings – Model Predictions"

(7) *MWH Comment: As documented above, the confidence in the predictions of future groundwater levels in the numerical model is weakened by intrinsic model structural inaccuracies, calibration inaccuracies, and uncertainty and deficiencies in sinks/sources.*

M&A Response No. 7: We assume MWH's decription of structural inaccuracies is a reference to the Santa Cruz fault since no other structural issues are presented by MWH. Representation of the Santa Cruz fault is addressed in M&A Response No. 4. The model calibration is sufficiently accurate to project groundwater level declines due to proposed RCC pumping. All future sinks and sources updated in the model by M&A are determined from existing permits or pending permits (supplied by ADWR), or are estimated based on past documented quantities of historic pumping or recharge. This may result in a model which will project conservatively larger background groundwater level declines in the RCC wellfield area; however, it should have limited effect on the projected groundwater level decline due to proposed RCC pumping. We did not include potential Sierrita mitigation pumping or potential CAP recharge in the Green Valley area due to a lack of information regarding these potential sinks/sources.

MWH Reply: The Santa Cruz Fault is addressed in item (4) and model calibration is addressed in item (1)

(8) *MWH Comment: Seasonal variations and "calibration" errors are translated to predictive uncertainties that ranges from 10 to 100 feet due to seasonal variations and approximately a 25-foot under-prediction bias at RC-2.*

M&A Response No. 8: Recent continuous monitoring of groundwater levels at wells E-1 and RC-2 has resulted in documentation of seasonal variation of groundwater levels (ranging from 10 to 100 feet annually) at the proposed RCC wellfield. The purpose of the continuous monitoring was to remove uncertainty about seasonal variations from the model. Due to the continuous monitoring this variation is known and is not translated into predictive uncertainty. The match between simulated and observed groundwater level trends at well RC-2 is acceptable and correction of model projections for the 25-foot difference is consistent with standard modeling practice for predictive simulations. The 25-foot difference is not an uncertainty that is "translated" through to the predictive results.

MWH Reply: MWH acknowledges that a simulation with an annual stress period cannot resolve the large seasonal variations. The way that M&A accounts for the seasonal variations is reasonable without refining the stress periods. The question of whether the 25-foot bias at RC-2 is acceptable should be answered through the establishment of calibration objectives. If the bias at RC-2 meets these objectives, then the correction applied at RC-2 is a reasonable way to handle the model bias at this location.

(9) *MWH Comment: M&A (2009b) does not adequately document or quantify predictive uncertainties due to parameter uncertainties and due to uncertainties in the future groundwater recharge and withdrawal. These*

predictive uncertainties could be bounded by conducting a sensitivity analysis of model predictions to parameter and future source/sink variations. Sensitivity analyses are often a component of modeling studies.

M&A Response No. 9: *The substantial regional sinks and sources in the vicinity of the proposed RCC wellfield are the dominant factor in prediction of future groundwater levels. There is obvious uncertainty in these future stresses; however, quantification of uncertainties in rate of residential growth and future water demand in the area was not conducted as part of this study. For purposes of the EIS study, we have simulated stresses which may result in conservatively larger background groundwater level declines in the proposed RCC wellfield area than may occur.*

Although not typically conducted, statistical quantification of predictive model uncertainty can be determined through a rigorous aquifer parameter sensitivity analysis; however, many of the observation wells had only 1 data point (2005) obtained during the last 10 years and much of the data was affected by the substantial seasonal variation in groundwater levels. A rigorous aquifer parameter sensitivity analysis for purposes of statistically determining predictive uncertainty would have required substantial assumptions that would have rendered the statistical determinations more qualitative than quantitative. Further, as described above, predictive uncertainty determined from aquifer parameter sensitivity would be substantially less than uncertainty associated with future stresses. Ultimately we relied on the satisfactory match of simulated to observed groundwater level trends to determine confidence in the model's ability to predict future groundwater level change.

Finally, a sensitivity analysis where specific aquifer parameters are incrementally varied to determine sensitivity of the calibration to changes to those parameters was not conducted. This sensitivity analysis is used to determine aquifer parameters that the calibration is most sensitive to, which are the parameters requiring relatively more certainty in the accuracy of their simulated value in order to minimize predictive error. Aquifer parameters for the upper Santa Cruz basin hydrogeologic units encountered at the proposed RCC wellfield location have been extensively investigated and substantial aquifer parameter data have been collected for these units, including in the vicinity of the RCC wellfield; therefore, a sensitivity analysis was not considered to be beneficial. Note that aquifer parameters and layer thicknesses in the vicinity of the E-1 and RC-2 pumping tests were changed in the model to reflect results of test data; these modified parameters were not substantially different than original values in the model and the changes to simulated groundwater levels as a result of the modifications were minimal.

MWH Reply: The type of sensitivity analysis that is suggested by MWH is to determine the sensitivity of model predictions to parameter changes. M&A states that predictive uncertainty determined from aquifer parameter sensitivity would be substantially less than uncertainty associated with future stresses; however, no documentation exists that this statement has been tested. Further, if only the drawdown due to RCC pumping is considered (as suggested in the reply to item (1)), the aquifer parameters may have a large effect. M&A states that the aquifer parameters for the upper Santa Cruz basin hydrologic units encountered at the proposed RCC wellfield location have been extensively investigated. If so, a realistic range of these parameter values with which to test predictive sensitivity should be known. Whether or not a predictive sensitivity analysis is conducted, MWH recommends that the confidence in model predictions in relation to aquifer parameters be bounded, if possible.

(10) *MWH Comment: The confidence in the predicted groundwater levels will further decrease away from the RCC property as the grid coarsens and aquifer parameters and source/sinks become less defined.*

M&A Response No. 10: For purposes of determining groundwater level declines due to proposed RCC pumping, the confidence/accuracy of projected declines distant from the RCC property decrease negligibly due to the model grid becoming coarser. The grid is refined in the immediate area of pumping due to the substantial

groundwater level gradients in the immediate vicinity of the pumping wells. As these gradients decrease with distance from the pumping wells, grid cells can increase in size without decreasing confidence in the projected declines due to RCC pumping.

MWH Reply: This comment was made for completeness in discussing the model results. The way that M&A refined the model grid is appropriate and is consistent with standard practice. The decrease in model confidence/accuracy far away from the RCC property is not an important concern since the effects of RCC pumping will be minor in these outlying areas. Still, the model report needs to clearly document that the appropriate use of the model is to predict large-scale and annual average groundwater levels. For example, the model is not appropriate for prediction of instantaneous groundwater levels at individual wells and has less precision away from the RCC property as the grid coarsens.

(11) *MWH Comment: MWH evaluated the estimates of the drawdown levels due to RCC pumping reported in the M&A (2009b, Figures 35, 36) using a simple (Dupruit) solution to estimate steady-state drawdown. Although this solution cannot capture the complexity and transience of the model, it does provide a rough check on drawdown predictions. According to this check, the estimates of groundwater level drawdown due to RCC pumping reported in M&A (2009b) are reasonable.*

M&A Response No. 11: *As MWH has determined using their Dupuit analysis, the projected groundwater level declines due to proposed RCC pumping are reasonable. The model superimposes these simulated drawdowns on model projected background groundwater level declines. These projected background declines are likely conservatively larger than may occur (discussed previously); therefore, final projected groundwater level elevations at the end of the 20-year RCC pumping period may be conservatively lower than may occur.*

MWH Reply: The Dupuit analysis roughly confirms that the model results are reasonable given the model input; it does not provide a check on the model input parameters.