March 31, 2015

MEMORANDUM

TO: Jim Upchurch, Supervisor, Coronado National Forest
FROM: Joe Gurrieri and Roger Congdon, USFS Groundwater Program, WO

SUBJECT: Evaluation of Additional Groundwater Modelling Tasks Suggested by USGS for the Rosemont Mine Project

The WO Groundwater Team was asked to assist the Coronado NF in evaluating the efficacy of performing additional groundwater modeling tasks for the Rosemont Mine project as suggested by the USGS, Arizona Water Science Center. The USFS requested that the USGS review the documentation as part of Task 4: USGS Review of Boundary Condition Test Documentation, completing the following items:

(1) Evaluate if the tests were conducted in the manner suggested by the USGS;

(2) Evaluate if the results of these tests help reduce the uncertainty associated with the groundwater models by better describing the effects that boundary conditions have on model results.

On March 9, 2015, the USGS presented their results from Task 4 during a meeting with the Coronado National Forest, U.S. Fish and Wildlife Service, and SWCA Consultants. The USGS identified three topical areas that would substantively improve the groundwater models' capacity to simulate inherent uncertainty in the groundwater system:

1. Increase range of storage parameter values in uncertainty analyses
2. Employ Monte Carlo approach to improve prediction uncertainty
3. Use water-budget approach to evaluate effects to riparian areas

Our evaluation of these additional modeling tasks is presented below.

1. Storage Values

In regard to increasing the range of storage values used in the models, the USGS suggested that specific yield could be varied by an order of magnitude and specific storage by three orders of magnitude.

The model files supplied to USFS by Montgomery and Associates (M&A) include sensitivity runs which vary the storativity two orders of magnitude, from 10^{-8} to 10^{-6}. Kruseman and de Ridder (1994), page 23, state that storativity in confined aquifers ranges from 5×10^{-5} to 5×10^{-3}. Freeze and Cherry (1979) also give a range of 5×10^{-5} to 5×10^{-3} for storativity in confined aquifers (page 60). The presumption of these figures is that the aquifer behaves as porous media. Rutqvist and others (1998) reported storativities ranging from 9.1×10^{-9} to 3.3×10^{-7} in fractured granite aquifers of low transmissivity. It is not necessary to investigate lower storativities than the range used in the M&A model. Higher storativities are not justified as they would only serve to minimize the aerial extent of the cone of depression. In addition to the storage variation in the M&A and Tetra Tech models, the model designed by Dr. Tom Myers (2008) was included in the EIS. His storativities were on the order of 10^{-5} and with an impermeable western boundary, his cone of depression from mining was significantly smaller than either the M&A or the Tetra Tech models. As he states in his report, "If the storage coefficients of the aquifer were significantly less than modeled herein because aquifers are significantly less fractured and yield significantly less water than assumed, the effects of this project could be spread over a larger area more quickly." This is clearly demonstrated by the M&A and Tetra Tech models, which have significantly lower storativities; by one to three orders of magnitude.

The Specific yield values were not varied much, but are low for all scenarios, ranging from 0.1 to 0.01 in alluvium and Tertiary sediments, and 0.01 for most bedrock. Specific yield for Quaternary and Tertiary basin fill sediments was doubled and halved for sensitivity analysis. These are essentially the water table aquifers and are less sensitive to drawdown from a given amount of water withdrawal. There would be little gain from varying specific yield further. While storativity can vary by orders of magnitude, specific yield cannot.

There does not appear to be any significant gains in our knowledge of the effects on riparian areas from further varying storage parameters in the Rosemont models.

2. Monte Carlo Approach

In regard to employing the Monte Carlo approach to improve prediction uncertainty the USGS suggested that because the range of possible effects on surface features is uncertain, because of limited knowledge of the hydrologic system, a Monte Carlo analysis of model parameters could be used to generate a range of potential predictions that effectively identifies uncertainty in the groundwater system.

There are many approaches to evaluate prediction uncertainties. Refsgaard and others (2007) describe the Monte Carlo statistical method as one of fourteen potential methods. They give the advantages and disadvantages of each methodology. For the Monte Carlo method they state that "The advantage of Monte Carlo analysis is its general applicability . . . ," but also that "The key limitation is the large run times for computationally intensive models and the huge amount of outputs that are not always straightforward to analyze." Refsgaard and others (2007) also describe the method of Sensitivity Analysis (SA), for which they state that "The strength of SA is that it provides insight in the potential influence of all sorts of changes in input and helps discrimination across parameters according to their importance for the accuracy of the outcome. A limitation is the tendency of SA to yield an overload of information. Furthermore, SA most often takes the model structure and system boundaries for granted." They also include a table (Table 4, page 1553) that ranks the various methods of uncertainty analysis by their diagnostic abilities, and Monte Carlo and Sensitivity Analysis both rank in the same category of comprehensive analyses; i.e., they are treated as roughly equivalent.

The bottom line is that the method used in the Rosemont modeling; Sensitivity Analysis, is a rigorous and acceptable technique for evaluating uncertainty. There does not appear to be anything gained by performing further uncertainty analyses, including the Monte Carlo method. A Monte Carlo analysis is not a trivial task and the results probably would not change the overall conclusions that have already been established.

3. Water-Budget Approach

In regard to using a water-budget approach to evaluate effects to riparian areas USGS suggested that by examining water-budgets along with the current drawdown analysis and adding appropriate boundaries, the potential change in discharge to springs and streams can be represented.

Riparian areas are affected directly by changes in the position of the water table (Shafroth and others, 2000). They state that "The need for high water tables (often <1.5 m from the ground surface) for successful seedling establishment of woody riparian plants has been observed at numerous sites . . ." Groundwater fluxes are generally important, as indicated by the USGS, but for the purposes of evaluating effects to riparian vegetation, it is the vertical position of the water table and changes to it that are important with respect to root depth. Stromberg and others (1996) state clearly that water table declines in Arizona threaten riparian ecosystems. Although it would be difficult to use the model to make predictions of percentage effects to riparian environment, drawdown contours in the vicinity of riparian indicate that impacts are possible or likely. That may be as accurate as we can get. Adding groundwater flux information would not improve the prediction of impacts.

Other mining related modeling efforts have used stream depletion values to assess the effects of drawdown to streams, but have retreated from the quantitative use of results of this method due to the inherent uncertainties in the absolute values reported by the models. Recently the Rock Creek Mine in MT used this method however the conclusions by the modelers (Hydrometrics, Inc. 2014), third party experts (AquaResource 2014), and the SEIS writers was that the model output quantifying depletions from the tributary drainages could not be verified; therefore the data should not be used to quantify changes in base flow at specific locations. In addition, using the output data for quantifying stream depletion was deemed to be beyond the capabilities of the model. As a result the Rock Creek SEIS preparers used the modeled results to conduct a qualitative analysis at the sub-basin level of potential changes in water quantity from the proposed mine development. This qualitative analysis will then be used to help describe the potential impacts to aquatic resources. This approach is recommended by the modelers and supported by expert reviewers.

While the use of water budgets may have some value, it probably would not change the overall conclusions that have already been established or, significantly decrease the uncertainties inherent in this modeling effort.

References

AquaResource. 2014. Comments on Hydrometrics Rock Creek Modeling Report. March 6. 5 pp.

Freeze, R. A. and J. A. Cherry, 1979. Groundwater. Prentice Hall, 604 p.

Hydrometrics, Inc. 2014. Groundwater Modeling Assessment for the Rock Creek Project Sanders County, Montana. January 2014, revised October 2014. 148 pp.

Kruseman GP, de Ridder NA, 1994. Analysis and evaluation of pumping test data. ILRI, Nairobi, Kenya, 377 p.

Myers, Tom, 2008. Hydrogeology of the Santa Rita Rosemont Project Site Numerical Groundwater Modeling of the Conceptual Flow Model and Effects of the Construction of the Proposed Open Pit. Prepared for: Pima County Regional Flood Control District. 65 p.

Refsgaard, Jens Christian, Jeroen P. van der Sluijs, Anker Lajer Højberg, and Peter A. Vanrolleghem, 2007. Uncertainty in the environmental modelling process–a framework and guidance. Environmental Modelling & Software v. 22, n. 11, p. 1543-1556.

Rutqvist J, Tsang C-F, and O. Stephansson, 1998. Determination of fracture storativity in hard rocks using high pressure injection testing. Water Resources Research 34: p. 2551–2560.

Schweisinger, Todd, Erik J. Svenson, and Lawrence C. Murdoch, 2009. Introduction to hydromechanical well tests in fractured rock aquifers. Ground Water, v. 47, n. 1, p. 69-79.

Shafroth, Patrick B., Juliet C. Stromberg, and Duncan T. Patten, 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist, v. 60, n. 1, p. 66–76.

Stromberg, R. Tiller, J. C. and B. Richter, 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. Ecological Applications, v. 6, p. 113–131.