United States Department of the Interior

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Jim Upchurch, Forest Supervisor
Coronado National Forest
300 W. Congress St. 85701
Tucson, AZ

Dear Mr. Upchurch:

As requested by the U.S. Forest Service (USFS), the U.S. Geological Survey (USGS) has performed a peer review of the documentation of a series of tests on the possible effects of selected boundary conditions in two groundwater models for the Rosemont Copper project. These documents were requested and received by the USFS in 2012. The tests were suggested by the USGS in 2012 in comments to the U.S. Fish and Wildlife Service and during other discussions. 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.

This letter incudes USGS comments that address the items listed above. USGS comments are limited to the information and results provided in the documentation.

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

The USGS suggested that three tests could be conducted to evaluate potential effects of the selected boundary conditions on the model perimeter. The types of boundaries used in the model can affect the model results because constant-head and general-head boundaries can keep the hydraulic head at an artificially fixed level, which can result in artificial water being added to the model. The three tests are summarized below.

The first test was to replace any specified-head or general-head boundaries with a specified and constant flux boundary using transient, or time varying, runs. The fluxes that replaced the constant head or general-head boundary were to be computed from the pre-development steady-state model run. The amount of added artificial water through time could be calculated by differencing the computed fluxes along the original constant-head and general-head boundaries from the specified boundary flux. This test also can give insight into the difference that extreme artificial boundary conditions make in mine-induced drawdown and flow to streams, springs and phreatophytes. Constant-head and general-head boundaries can minimize possible effects, whereas a specified flux boundary can maximize possible effects.

The second test was to conduct a steady-state run with and without the mine pit using the original specified-head and general-head boundaries. The net flow rates from the two model runs can be compared to determine pumping-induced changes separately for artificial model boundaries and for real features. A comparison of the amount of mine water that comes from artificial boundaries indicates the ultimate impact of the artificial boundaries on the overall water budget.

The third test was to run two steady-state models with the mine pit, first using the original constant-head and general-head boundaries, and then with specified flux boundaries. This test can be used to identify the ultimate capture of water by the mine pit from natural stream, spring, and phreatophyte boundaries.

Our review of the documentation indicates that the first test appears to have been conducted for both the TetraTech and Montgomery models as suggested.

The documentation for the TetraTech model appears to indicate that the second and third tests were conducted as suggested. The documentation for the TetraTech model includes results at 1,000 years post mine closure that are close to steady state.

The documentation of the Montgomery model appears to indicate that the second and third tests were not completed or documented as suggested. After 900 years post mining, the flow rate from storage in the Montgomery model was 124 ac-ft/yr and the outflow to the pit lake was 168 ac-ft/yr. This indicates that the flow from storage is relatively large compared to the flow to the pit, and that the model has not reached steady state. The steady-state model with the mine pit may be been run, but the documentation does not include a water budget for this run.

(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.

The effects of the extraction on head-dependent boundaries representing actual features including perennial streams, springs, and phreatophytes should be much larger than effects of the extraction on artificial head-dependent boundaries on the perimeter of the model. The portion of the water supplied by the artificial boundaries should be small relative to the mine extraction because the water added by the boundary does not necessarily exist in the real system. For the purposes of looking at capture over large areas, Leake and Reeves (2008) suggested that the change in net flow to artificial boundaries divided by the pumping rate of the added well be less than 0.1 (10 percent of the extraction rate).

For the TetraTech model, the results of the first test indicate that the effects of extraction of water at the site of the mine are impacted by the chosen artificial boundaries. Table 1 provides results from this first test 20, 100, 300, and 1,000 years after the mine closure. The change in net flow is computed by differencing the modeled flow from constant head boundaries from the specified flow boundaries. A positive value means that more flow occurs to the model using a constant head boundary than with the specified flow boundary. Ideally, the amount of artificial water would be small relative to the extracted water so that the effect of the extraction on natural features can be evaluated. Because these models are distributed and transient, the effects of the mine are spread through space and time; that is to say that the effects of mine on the boundary are delayed in time. This means that the effects observed at the boundaries are related to earlier mine extractions. However, if we make the assumption that extractions and boundary responses are comparable at specific times, ratios between the change in net flow due to boundaries and the mine extraction are 0.64 after 20 years, 0.41 after 100 years, 0.29 after 300 years, and 0.28 after 1,000 years. In other words, the boundaries provide 64%, 41%, 29%, and 28% of the extracted water after these simulation periods—greater than the 10% level suggested by Leake and Reeves (2008). These results indicate that the model is likely underestimating the potential effect of the mine extraction on natural features because a large portion of the extracted water is delivered artificially.

For the Montgomery model, the results of the first test also suggest that the effects of mine extraction are impacted by the artificial boundaries. Results from the first test are included in Table 2 for 20, 100, 300, and 900 years after the mine closure. The ratios between the change in net flow due to boundaries and the extraction rate are 0, 0.02, 0.17, and 0.44.

Table 1 Table comparing the change in net flow to artificial boundaries to the flow to the pit lake in the TetraTech model. The change in net flow is computed by differencing the computed flow from constant head boundaries from the specified flow boundaries. A positive value means that more flow occurs to the model using a constant head boundary than with the specified flow boundary. The ratio between the changes in net flow rate to artificial boundaries to the extraction rate indicates the portion of extracted water that is supplied by the boundaries. These results are applied to the first and third tests.

Number of years post mine closure	Change in net flow rate to artificial boundaries, ac-ft/yr	Extraction (pit flow) rate, ac-ft/yr	Change in net flow rate to artificial boundaries / extraction rate
20 years	314	490	0.64
100 years	180	436	0.41
300 years	115	392	0.29
1000 years	104	372	0.28

Table 2 Table comparing the change in net flow to artificial boundaries to the flow to the pit lake in the Montgomery model. The values are computed the same as in Table 1.

Number of years post mine closure	change in net flow rate to artificial boundaries, ac-ft/yr	extraction (pit flow) rate, ac-ft/yr	change in net flow rate to artificial boundaries / extraction rate
20 years	0	403	0.00
100 years	5	250	0.02
300 years	34	197	0.17
900 years	75	169	0.44

The second test can be used to identify the portion of the water to the mine pit that ultimately comes from the artificial boundaries. This can be obtained by first computing the net change in flow at the boundaries from steady-state models with and without the pit. The net change in flow at the boundaries can then be compared to the flow to the mine pit. Table 3 includes the constant-head boundary flow rates for the steady-state models with and without the pit with values from Table 7 in the TetraTech report. The results of the second test for the TetraTech model indicate that approximately 32% of the final steady-state flow to the pit is supplied by the artificial boundaries. Ideally, all of the water to the pit should come from natural boundaries instead of the artificial boundaries. While net flow values for the entire model in Table 3 are two orders of magnitude larger than the flow to the pit, the effects of the pit may be important for local changes in nearby natural features.

Table 3 Table comparing change of flow from constant head boundaries in steady state simulations with and without a mine pit using the TetraTech model. These results are applied to the second test.

	steady state without pit	steady state with pit
In, constant head, ac-ft/year	24,465	23,824
Out, constant head, ac-ft/yr	26,116	25,348
net, ac-ft/yr (in-out)	-1,651	-1,524
Change in net flow rate, ac-ft/yr	127	
Flow to pit, ac-ft/yr	391	
Change in net flow rate / flow to pit	0.32	

The third test is similar to the first test but for a steady state-simulation. The TetraTech model approaches steady state conditions at the 1,000 year simulation. The Montgomery model does not provide the results at time when steady-state was achieved that can be evaluated for the third test. The 1,000 year results included in Table 1 for the TetraTech model can be applied to the third test. As in the first test, the change in net flow is computed by differencing the computed flow from constant-head boundaries from the specified-flow boundaries. At 1,000 years, 28% of the flow to the mine pit comes from artificial water from a constant head boundary.

The evaluation of the results from the tests indicates that the constant-head and general-head boundary conditions may generate a relatively large addition of artificial water on the simulations relative to the amount of water extracted for mining activities. The net effect of this addition will be to reduce projected impacts at natural boundaries such as springs and streams.

These evaluations have been limited in scope to the effect of the constant-head and general head boundaries in terms of water budgets. Other results in the documentation show comparisons of drawdowns and hydrographs. However, differences between drawdowns and hydrographs may be difficult to identify, quantify, and be resolved by the models. Further discussion between the USGS and USFS may further explore the use of water budgets rather than drawdowns and hydrographs to evaluate model results.

Model boundaries can introduce uncertainty because boundaries are a simplified representation of real-world features. The use of specified-flow boundaries maximizes the estimated effects on natural features such as streams and springs. On the other hand, the use of specified head and general head boundaries minimizes the estimated effects on natural features. The real physical system likely lies between these two end members. Further modeling work, such as parameter uncertainty analyses along with different configurations of constant head, general head, and constant flux boundaries, would provide a more robust estimate of the range of possible effects.

Sincerely,

References Cited:

Leake, S.A., and Reeves, H.W., 2008, Use of models to map potential capture of surface water by ground-water withdrawals: in MODFLOW and More 2008--Ground Water and Public Policy - Conference Proceedings, Poeter, Hill, and Zheng, eds, p. 204-208.