Technical Memorandum

To: Kathy Arnold  
From: Grady O’Brien, Project Manager  
Company: Rosemont Copper Company  
Date: July 30, 2010  
Re: Predictive Groundwater Flow Modeling Results  
Doc #: 201/10-320874-5.3  
CC: David Krizek, P.E. (Tetra Tech)

1.0 Introduction

This Technical Memorandum documents the results of the predictive groundwater flow models prepared by Tetra Tech for the proposed Rosemont Copper Project (Project) located on the east side of the Santa Rita Mountains, approximately 30 miles southeast of Tucson, Arizona in Pima County. The regional groundwater flow models prepared for the Project represent pre-mining steady state conditions, active mining conditions, and post-closure/post-mining conditions. In addition to these flow models, the following studies and/or tasks have also been performed: Davidson Canyon conceptual model, hydrogeologic framework model, recharge distribution, steady-state water levels and potentiometric surface, evaluation of aquifer testing and hydraulic properties, evapotranspiration distribution, and stream flow conditions. The model construction process and calibration results are presented in Tetra Tech (2010a). Sensitivity analyses on the predictive flow models will be documented in subsequent Technical Memoranda.

1.1 Project Objectives, Scope, and Approach

The objectives of this task are to predict the regional groundwater-flow system response to Open Pit dewatering and subsequent pit lake formation after closure. Dewatering of the Open Pit will continue throughout the 20-25 years of operation and cease at closure. When mining ceases and dewatering is discontinued, the pit will naturally refill with water from groundwater, surface-water, and precipitation contributions and a pit lake will form. It is expected that the pit will remain a perpetual hydraulic sink at a stabilized, equilibrium condition due to the high evaporation rate of the Rosemont area. This implies that groundwater will perpetually flow into the Open Pit, although at a much lower rate than during the active dewatering process.

Changes to regional groundwater levels and surface-water flows are evaluated at Cienega Creek, Davidson Canyon, and the regional springs. Groundwater inflows to the Open Pit are also estimated during the mining phase and post-mining phase. Changes in flows through the model’s lateral boundaries were also evaluated. Predictive simulations at the end of mining, 20 years, 50 years, 150 years, and 1,000 years post-mining, and steady state conditions are presented.

The scope of this analysis is limited to prediction of regional scale changes. Approximate magnitudes and timing of groundwater system changes is possible with a regional scale predictive flow model. Flow model grid size and available data constrain the resolution and accuracy of the predictions. Small changes in water levels and stream flows are inherently difficult for a regional model to accurately simulate, but the predictions are useful for assessing
Rosmont is pleased to transmit the following documents related to the groundwater modeling work that has been undertaken by Tetra Tech:

- Predictive Groundwater Flow Modeling Results, Tetra Tech, July 2010
- Steady-State Sensitivity Analyses, Tetra Tech, July 2010

Rosmont is providing three hardcopies and two disk copies for the Forest and two hardcopies and one disk copy for SWCA.
the potential range of impacts. Uncertainty in the predictions will be evaluated in companion Technical Memoranda that discuss the sensitivity analysis.

Predictive groundwater flow models simulating the mining phase and post-mining phase have been constructed and documented by Tetra Tech (2010a). These flow models simulate the regional groundwater flow system response to the Project activities and the Open Pit. The basis for these predictive models is the calibrated steady-state model, which is run in transient mode to create “base-case” conditions. The base-case model does not simulate the Open Pit or changes in recharge due to the Project facilities, but is otherwise identical to the predictive models. Predicted drawdown, which is the simulated water-level decline, and stream-flow changes are determined relative to the base-case model. Open Pit dewatering during active mining is simulated with drains (MODFLOW DRN package). Pit-lake formation is simulated with the LAK2 package, which simulates the pit lake water balance and stage that includes the effect of precipitation, evaporation, and runoff. Recharge conditions in the Project facilities area will be altered due to placement of the waste rock and dry stack tailings, which includes contributions from flow-through drains and draindown from the dry stack tailings facility (Tetra Tech, 2010b; Tetra Tech, 2010c; AMEC, 2009). These recharge conditions were incorporated into the post-mining phase flow model (Tetra Tech, 2010a). Details of model construction and calibration were provided in Tetra Tech (2010a).

2.0 Memorandum Organization
Predictive flow modeling results are presented for the mining phase and for the post-mining phase. During each phase, the water-level drawdown, stream flows, and pit inflows were evaluated and discussed, followed by a summary of the predictions.

3.0 Observation Locations
Drawdown and surface water flows were evaluated at several observation locations in the model domain. These locations were selected based on their proximity to important ecological areas. Simulated groundwater system changes in these areas provide a means for evaluating potential impacts. Declining water levels can result in decreased stream flow and loss of riparian vegetation. Drawdown was evaluated in Davidson Canyon, Cienega Creek, and at regional springs.

Davidson Canyon has a reach designated as a Unique Arizona Water (PAG, 2005). Simulated observation points (DC-1 and DC-2) are located upstream and downstream of this reach, identified as stream segment 15 on Figure 1. Simulated water-level and stream-flow changes were evaluated to assess the potential for impacts to this area.

Cienega Creek has several reaches with perennial stream flow and there are two (2) U.S. Geological Survey (USGS) stream gages that monitor flows (Figure 1). Changes in simulated stream flows for each stream segment were evaluated. Water levels at two (2) observation locations (C-1 and C-2) on Cienega Creek were also evaluated (Figure 1).

An assessment of spring data in the region identified Rosemont Spring and Questa Spring as the only springs fed by the regional groundwater system (Tetra Tech, 2010d; Figure 1). Other springs in the region have intermittent flows and characteristics that are indicative of shallow or perched-water sources that will not be impacted by regional water-level changes. Water levels at the regional springs were evaluated to determine impacts from the Project.
The simulated cone of depression, or outer zone of influence, is defined by the 5-foot drawdown contour in this document. The 5-foot contour is provided as a reference for comparing the drawdown extent at various times, but this small drawdown is within the flow model simulation error. Long-term water-level fluctuations from 0.7 to 69 feet have been observed in the flow model domain (Montgomery & Associates, 2010). Water-level declines resulting from Open Pit dewatering and pit-lake formation may be difficult to distinguish from these natural fluctuations.

4.0 Mining Phase Model Results

The mining-phase model simulates the advancement of the Open Pit over the 22-year mining period. A new Open Pit configuration is simulated every two (2) years, with the dewatering process initiated in advance of the actual excavation. The simulated Open Pit depths are illustrated on Figure 2. This creates step-wise changes in groundwater inflows as the pit is instantaneously advanced in the flow model. Simulated groundwater inflows to the Open Pit are removed via drains located beneath the pit floor. Drawdown and stream flows were predicted at the end of mining and compared to the base-case simulation.

4.1 Pit Inflows

Groundwater inflow rates into the Open Pit varied throughout the simulation period, primarily due to the increasing pit depth simulated every two (2) years (Figure 3). During operations, the increase in associated dewatering would be gradual as the pit is advanced. However, since the pit advance is simulated incrementally, and water is removed at the start of each new mine phase, dewatering rates are overestimated in the simulation.

As dewatering starts, groundwater inflow rapidly increases to approximately 475 gallons per minute (gpm), but then decreases over the initial 2-year stress period to less than 300 gpm as water is removed from aquifer storage and hydraulic gradients decrease. Further pit advancement results in the highest simulated groundwater inflow of approximately 509 gpm during operational year 4. Inflow rates also vary depending on the transmissivity of the geologic units being excavated as illustrated by the lower inflow peak and slower changes during operational years 5-7. As water is removed from storage, the peak inflows are attenuated even though the pit is increasing in depth (Figure 3). Groundwater inflow at the end of mining (operational year 22), when the excavation has reached a maximum depth of 3,050 feet above mean sea level (amsl), is approximately 400 gpm.

The range of groundwater inflow rates during dewatering operations is expected to range between 400 and 500 gpm. It is possible, however, that geologic complexities, including faults and fractures that are not discretely simulated in the flow model, can result in observed groundwater inflows that are higher or lower than this range. These dewatering rates represent groundwater inflows and do not include precipitation that reaches the pit bottom.

In practice, the groundwater inflow is likely to be less than simulated. There is evidence of aquifer compartmentalization that would tend to limit groundwater flow in the pit area (Tetra Tech, 2010d; Tetra Tech, 2010e). Variations in aquifer transmissivity and faults that could result in aquifer compartmentalization could not be explicitly simulated in the regional scale model. However, the influence of these hydrogeologic features was incorporated into the model’s effective hydraulic conductivity if they affected the calibration water-level targets. Water levels, however, are under predicted in the calibrated steady state model near the pit, which suggests that compartmentalization may have increased observed water levels near the pit. Assuming
reasonable ranges for hydraulic properties, and not simulating these hydrogeologic features, may have contributed to the inability to simulate the higher observed water levels in the pit area.

In general, groundwater inflow to open pits having low permeability rocks with relatively low fracture density and connectivity has shown that fractures can initially yield substantial volumes of water that decreases rapidly over time. The degree to which this occurs depends on how well connected the fracture network is over large areas. The equivalent porous media (EPM) flow model assumes that the fracture network is connected enough to be simulated as a porous media at the regional scale. This is likely not a valid assumption in the areas near the Open Pit. The predicted inflows are therefore averages that do not account for extreme high or low flows due to faults and fractures. However, on a regional scale the hydrogeology and groundwater system changes can be adequately simulated with the EPM flow model.

4.2 Groundwater Level Elevations and Drawdown

Dewatering of the Open Pit was simulated with drain cells that removed the water from the model when the water reached a specified drain elevation (Figure 4). Dewatering lowers the water table below the bottom of the pit and creates a cone of depression that extends away from the pit. Since drawdown propagation away from the Open Pit depends on the transmissivity and storage properties of the rock units, the cone of depression is not concentric around the pit. The furthest extent of the zone of influence at the end of the mining phase is predicted to be approximately 4 miles east and 4.5 miles to the northeast in Model Layer 17 (Figure 5). Drawdown expands in this direction partly due to the relatively low specific storage in the bedrock units. Additionally, the generally low hydraulic conductivity of the rocks near the pit creates a large hydraulic gradient towards the pit.

At the end of the mining phase, the cone of depression expands towards the upper reach of Davidson Canyon, but it has not yet reached the quartz-porphyry dike. Rosemont Spring is near the 100-foot drawdown contour and the large hydraulic gradient area (Figure 5). It is likely that Rosemont Spring flow will cease by the end of mining due to water-level declines and pit development. However, Rosemont Spring will be buried under waste rock during the mining phase. Questa Spring, located east of the Open Pit, is near the 10-foot drawdown contour. This is not a significant amount of drawdown, but it is possible that Questa Spring will have reduced flows or will stop flowing by the end of mining. Due to Questa Spring’s distance from the Open Pit, and the unknown origin of its source water, a definitive assessment of the potential impact from mining is not possible.

4.3 Predicted Surface-Water Flows

The simulated stream flow changes in Cienega Creek and Davidson Canyon were evaluated along specific stream segments (Figure 6). The 5-foot drawdown contour does not reach the vicinity of Cienega Creek or the perennial reach of Davidson Canyon during the 22-year mining period. Monitoring locations near Cienega Creek and Davidson Canyon also indicate that the water levels in these areas are generally stable during this time period (Figure 7). Since water levels have generally not declined, the simulated stream flows are unaffected (Figure 6). The global decrease in stream flow compared to the base-case simulation is less than 0.1 percent, which is within the model error.
4.4 Mining-Phase Water Balance

The flow model water balance at the end of mining indicates that the water being removed during dewatering is balanced by water from aquifer storage (Table 1). Other parameters indicate no change or negligible change relative to the base-case simulation with no Open Pit present. Groundwater flow out of the model through the constant head boundary is unchanged since the cone of depression has not reached the western model boundary. Evapotranspiration due to riparian vegetation in Davidson Canyon and Cienega Creek also remain unaffected by drawdown.

Table 1. Mining Phase Water-Balance Summary

<table>
<thead>
<tr>
<th>Source</th>
<th>Base Case (Cumulative) [acre-ft/yr]</th>
<th>Mining Phase (Cumulative) [acre-ft/yr]</th>
<th>Mining Phase (Final Time Step, 22 yrs) [acre-ft/yr]</th>
<th>Cumulative Difference from Base Case [acre-ft/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>42,075.6</td>
<td>42,899.0</td>
<td>42,660.8</td>
<td>-823.4</td>
</tr>
<tr>
<td>Storage</td>
<td>16.3</td>
<td>839.7</td>
<td>604.9</td>
<td>-823.4</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Recharge</td>
<td>9,900.3</td>
<td>9,900.3</td>
<td>9,900.3</td>
<td>0</td>
</tr>
<tr>
<td>Streams</td>
<td>8,336.4</td>
<td>8,336.3</td>
<td>8,334.8</td>
<td>0</td>
</tr>
<tr>
<td>Constant Head</td>
<td>23,822.7</td>
<td>23,822.7</td>
<td>23,820.7</td>
<td>0</td>
</tr>
<tr>
<td>Drains</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OUT</td>
<td>42,078.9</td>
<td>42,906.2</td>
<td>42,689.2</td>
<td>-827.3</td>
</tr>
<tr>
<td>Storage</td>
<td>454.8</td>
<td>473.9</td>
<td>362.1</td>
<td>-19.1</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>5,633.6</td>
<td>5,633.6</td>
<td>5,633.9</td>
<td>0</td>
</tr>
<tr>
<td>Recharge</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Streams</td>
<td>10,953.8</td>
<td>10,953.7</td>
<td>10,956.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Constant Head</td>
<td>25,236.6</td>
<td>25,035.9.1</td>
<td>25,087.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Drains</td>
<td>--</td>
<td>809.0</td>
<td>649.7</td>
<td>-809.0</td>
</tr>
<tr>
<td>IN – OUT</td>
<td>-3.2</td>
<td>-7.2</td>
<td>-0.8</td>
<td>--</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY</td>
<td>~0.00</td>
<td>~0.00</td>
<td>~0.00</td>
<td>--</td>
</tr>
</tbody>
</table>

5.0 Post-Mining phase Model Results

The post-mining model simulated the refilling of the dewatered Open Pit and the corresponding changes to the groundwater system. The pit lake water balance is schematically illustrated on Figure 8. Evaporation rates in the Project area are high and are expected to exceed the combined inflows to the pit lake. As long as the groundwater elevations around the pit form a hydraulic divide and never reach the pit-lake elevation all groundwater flow will be into the pit and there will be no outflow. This condition is called a terminal hydraulic sink. A groundwater divide, higher than the lake level, is predicted to form east of the Open Pit. Over the long-term, a
terminal-sink pit lake will continue to consume groundwater since there is a net loss of water due to evaporation, which is hydrologically equivalent to removing groundwater by production wells.

Pit lakes draw groundwater levels down most dramatically in the vicinity of the pit with decreasing drawdown at greater distances away from the pit. The magnitude and extent of the drawdown depends in part on the pit lake water balance, which determines the pit lake level and the groundwater inflows. This drawdown and the associated cone of depression can be advantageous by capturing process area contaminants and preventing their migration away from the pit. Drawdown in the regional groundwater flow system, however, can reduce base flows in streams and springs. Drawdown associated with the pit lake will continue to expand outwards until there is sufficient capture of water from other areas to create a new stable water table. This rate of water capture is equal to the groundwater inflow to the pit lake.

5.1 Pit Lake Formation

The post-mining flow model predicts that a terminal hydraulic sink will form after dewatering ceases. A steady-state lake stage of 4,279 feet amsl is predicted to occur after about 700 years of refilling. The groundwater divide east of the Open Pit creates the terminal hydraulic sink condition at an elevation of approximately 4,600 feet amsl. The pit lake stage would need to rise over 320 feet from the predicted steady-state stage of 4,279 feet amsl before a flow-through condition would occur. The predicted pit-lake water balance over a 1,000-year simulation is illustrated on Figure 9. The steady-state groundwater inflow to the pit is 230 gpm and represents the long-term water consumption rate due to the pit lake. The lake stage and groundwater inflow approximate steady-state conditions 700 years after the cessation of dewatering. At this time, the conditions reached are more than 99.5 percent of the 1,000-year simulation values.

The surface area of the steady-state pit lake is anticipated to be about 213 acres and have a volume of approximately 95,975 acre-feet. Components of the pit lake water balance at the end of the 1,000 year simulation period are summarized in Table 2.

Table 2. Simulated Pit Lake Water Balance 1,000 Years after End of Mining Operations (LAK2 Package)

<table>
<thead>
<tr>
<th>Inflows</th>
<th>Rate (gpm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Precipitation</td>
<td>191</td>
</tr>
<tr>
<td>Groundwater Inflow</td>
<td>230</td>
</tr>
<tr>
<td>Pit Wall Runoff</td>
<td>131</td>
</tr>
<tr>
<td>Upgradient Runoff</td>
<td>0</td>
</tr>
<tr>
<td>Total Inflow</td>
<td>552</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outflows</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>552</td>
</tr>
<tr>
<td>Groundwater Outflow</td>
<td>0</td>
</tr>
<tr>
<td>Total Outflow</td>
<td>552</td>
</tr>
<tr>
<td>Inflow - Outflow</td>
<td>0</td>
</tr>
</tbody>
</table>

*Average annual gallons per minute.
Groundwater inflow rates were expected to be highest immediately after the cessation of mine dewatering, then decreasing with time as the hydraulic gradient decreased. Theory predicts that groundwater inflow will decrease exponentially after the initial surge of inflow immediately after dewatering ends. The early time groundwater inflows, however, are lower than anticipated (Figure 9). This is largely explained by the methods used to simulate dewatering and pit refilling. The drain elevations in the mining-phase model were set as much as 65 feet below the pit-shell elevations in the deepest model layers. This drain configuration expands the footprint away from the pit shell and increases the volume of rock being dewatered. The LAK2 cells simulating the pit refilling, however, more closely approximate the pit shell. This simulated volume of rock is less than the volume that being dewatered at the end of the mining phase. During the transition from the mining-phase model to the post-mining phase model, the dewatered model cells around the pit cell must re-saturate before groundwater begins flowing into the pit. This results in the simulated delay.

The volume of dewatered cells to be filled and the hydraulic properties of the hydrogeologic units determine the lag time. For example, low hydraulic conductivity results in longer lag times. As the water levels initially recover around the pit, groundwater inflows increase. However, over the long term, the hydraulic gradient decreases and the inflow rate decreases to a steady-state rate of 230 gpm (Figure 9).

The highest groundwater inflow rate of 311 gpm occurs approximately 7.7 years after the end of mining. This is approximately 25 percent less than the groundwater inflows at the end of mining (400 gpm). This is due to the lower hydraulic gradient between the rock mass and the lake. In the dewatered condition the head difference is greater because the Open Pit is completely dewatered to an elevation of 3,050 feet amsl. Simulated groundwater inflow at steady state is >99.9 percent of inflows projected at 1,000 years, which indicates that the 230 gpm at 1,000 years represents the steady-state inflow.

5.2 Predicted Groundwater Elevation and Drawdown

The groundwater elevations near the pit start recovering after the end of the mining and dewatering phase. The pit lake stage has increased from a dewatered elevation of approximately 3,050 feet amsl to a simulated steady-state elevation of 4,279 feet amsl. Despite the recovery of groundwater elevations near the pit, the cone of depression associated with the Open Pit’s hydraulic sink continues to expand away from the pit. Drawdown propagation at 20 years, 50 years, and 150 years after mining ends is illustrated on Figures 10, 11, and 12. Drawdown elongates in the north-south direction, in part as a result of the bedrock’s higher hydraulic conductivity in this direction as compared to the east-west direction. This is also partly due to the drawdown reaching the western model domain boundary. After 150 years, the drawdown has not reached Cienega Creek or the perennial reach of Davidson Canyon (Figure 12).

The effect of the quartz-porphyry dike on drawdown propagation becomes relevant after 20 years (Figure 10). The low hydraulic conductivity of the dike hinders drawdown propagation into the lower reaches of Davidson Canyon. Due to this natural restriction in groundwater flow, the drawdown migrates laterally along the dike toward the northwest and southeast.

The extent of the predicted groundwater drawdown continues to expand between 150 years and 1,000 years (Figure 13). Drawdown near the Open Pit, however, is relatively stable as the 100-foot drawdown contour is nearly identical at 150 years and at 1,000 years. In contrast, the 5-foot drawdown contour has expanded to the east and north over this same time interval. The effects of groundwater inflow to the pit (hydraulic sink) take many years to materialize and stabilize at...
greater distances from the pit. The time to reach equilibrium, or steady-state conditions, depends on the hydraulic diffusivity (transmissivity divided by storativity) of the aquifer and the distance from the point of measurement to the pit lake. The relatively low bedrock transmissivity, therefore, requires hundreds of years to reach equilibrium.

A steady-state post-mining simulation indicates that the extent of the predicted equilibrium groundwater drawdown is less than the 1,000 year simulation (Figure 14). This suggests that the maximum drawdown has been achieved within 1,000 years and that the system is predicted to have some groundwater recovery after 1,000 years. The nearly two-fold decrease in groundwater inflow to the pit between the dewatered and steady-state pit-lake conditions creates a lagged response in the groundwater system to the lower steady-state inflow. The steady-state simulation indicates that the 1,000-year simulation represents the maximum predicted drawdown and that steady-state drawdown is somewhat less.

Simulated monitoring wells illustrate the predicted long-term drawdown near Davidson Canyon and Cienega Creek (Figure 7). The predicted stable drawdown at these locations, which are more than nine (9) miles from the Open Pit, also indicates that the maximum drawdown has been achieved within 1,000 years. Observation wells in Davidson Canyon predict a maximum drawdown of about 0.25 feet (DC-1 and DC-2 on Figure 7), which is likely less than the flow model's prediction accuracy. The greatest predicted drawdown of approximately one (1) foot is at observation location C-1 in upper Cienega Creek (Figure 7). Negligible drawdown is simulated in the lower reach of Cienega Creek (C-2, Figure 7). These minor drawdowns are anticipated to be indistinguishable from the natural groundwater-level variations (Montgomery & Associates, 2010).

The 10-foot drawdown contour west of the Open Pit reaches the model domain boundary, which is simulated with constant-head cells. The assigned heads at this boundary, which is on the edge of the basin-fill down slope of the Santa Rita Mountains, are lower than the water levels near the Open Pit. Under pre-mining, steady-state conditions, there is flow out of the model domain at this boundary. Drawdown at this boundary results in less water flowing out of the model through the constant-head cells. The flow out of this boundary is reduced by 52 gpm (84.5 ac-ft/yr) or approximately 3 percent of the total outflow between the post-mining phase model and the base-case model. This reduction in outflow is a form of capture by the Open Pit's hydraulic sink. The western model boundary will be simulated as a no-flow boundary as part of the sensitivity analysis to be discussed in companion Technical Memoranda.

**5.3 Predicted Surface-Water Flows**

The steady-state lake stage is approximately 700 feet below the pre-mining water levels. Therefore, drawdown extends away from the pit and towards Davidson Canyon and Cienega Creek. Some of the groundwater that would have discharged to these drainages is expected to be captured by the Open Pit. The predicted decreases in stream base flow was estimated by calculating the difference in stream flow simulated in the post-mining model and the base-case model, in which there is no Open Pit. The stream flow over each simulated stream segment was evaluated so the predicted base flow changes could be determined over the entire stream length (Figure 15).

Conceptually, the maximum possible steady-state impacts to Cienega Creek, Davidson Canyon, and regional springs within the zone of influence is the simulated steady-state groundwater inflow of 230 gpm or 0.51 cfs. This groundwater flow will be captured from various sources within the region. Sources of simulated water capture may include:
Increased flow into the model domain;
- Decrease in stream flow;
- Decrease in riparian vegetation evapotranspiration;
- Decrease in flow out of the model domain (e.g. western model boundary); and
- Increase in recharge resulting from post-mining conditions.

The total decrease in average annual base flow along Cienega Creek after 1,000 years is simulated as 0.09 cfs, which is less than 3 percent of the simulated base flow (Figure 15). The largest decreases in flow are predicted in the upper reaches of Cienega Creek (Segments 1 – 4, Figure 15). Stream flows are decreased due to less groundwater discharging to the stream channel. Stream-flow decreases of approximately 0.01 cfs are predicted in the downstream reaches of Cienega Creek (segments 8, 9, 10, Figure 15).

The flow model simulates low stream flows along the entire simulated stream length in Davidson Canyon. The predicted change in Davidson Canyon flow is 0.01 cfs in the upper most reach (Stream segment 11, Figure 15). A decrease in flow of 0.01 cfs is simulated over parts of Davidson Canyon, but no additional losses are simulated in the reach identified as a Unique Arizona Water (PAG, 2005; Stream segment 15, Figure 15). These small changes in stream flow are within the model error. The predicted cone of depression does not lower water levels enough to affect the simulated stream flows. Water-level declines also have a negligible effect on the riparian vegetated areas along Davidson Canyon and Cienega Creek. The simulated change in riparian vegetation evapotranspiration in Davidson Canyon and Cienega Creek is approximately 16 ac-ft/yr or 0.3 percent.

Water levels recover as the pit lake fills and less drawdown is predicted at the Rosemont Spring location in the 1,000-year simulation compared to the end of mining simulation (Figures 5 and 13). Additionally, Rosemont Spring is located underneath the Rosemont Ridge Landform.

Questa Spring is well within the 10-foot drawdown contour 1,000-years after the end of mining and is at the 10-foot drawdown contour at the end of mining. This increase in drawdown, compared to the end of mining, makes it more likely that Questa Spring will have reduced flows or will stop flowing over the simulation period. However, Questa Spring’s distance from the Open Pit prevents a definitive assessment of the potential impact.

5.4 Post-Mining Phase Water Balance

The flow model water balance 1,000 years after the end of mining indicates that the flow system is close to steady state conditions. There is a negligible change in storage during the final time step and the other inflows and outflows are stable (Table 3). Recharge is increased 195 ac-ft/yr in the post-mining simulation over the base case model due to the Project-area facilities. Flow-through drains and a stormwater retention pond contribute the majority of water that infiltrates and becomes recharge (Tetra Tech, 2010b). Drawdown due to the terminal pit lake results in a decrease of 16 ac-ft/yr in riparian vegetation evapotranspiration and 57 ac-ft/yr in stream flow (Table 3). Outflow through the constant-head boundaries decreased by 65 ac-ft/yr, largely due to the lower water levels in the pit area, which decrease groundwater flow to the western model boundary.
Table 3. Post-Mining Phase Water-Balance Summary

<table>
<thead>
<tr>
<th>Source</th>
<th>Base Case (Cumulative) [ac-ft/yr]</th>
<th>Post-Mining Phase (Cumulative) [ac-ft/yr]</th>
<th>Post-Mining Phase (Final Time Step, 1,000 yrs) [ac-ft/yr]</th>
<th>Cumulative Difference from Base Case [ac-ft/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>42,054.3</td>
<td>42,305.1</td>
<td>42,262.4</td>
<td>-250.8</td>
</tr>
<tr>
<td>Storage</td>
<td>0.9</td>
<td>44.8</td>
<td>2.0</td>
<td>-43.9</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Recharge</td>
<td>9,900.3</td>
<td>10,095.5</td>
<td>10,091.7</td>
<td>-195.2</td>
</tr>
<tr>
<td>Streams</td>
<td>8,341.2</td>
<td>8,340.8</td>
<td>8,342.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Constant Head</td>
<td>23,811.9</td>
<td>23,824.0</td>
<td>23,826.2</td>
<td>-12.1</td>
</tr>
<tr>
<td>Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OUT</td>
<td>42,053.9</td>
<td>42,307.0</td>
<td>42,261.3</td>
<td>-253.0</td>
</tr>
<tr>
<td>Storage</td>
<td>39.8</td>
<td>40.1</td>
<td>2.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>5,635.3</td>
<td>5618.9</td>
<td>5615.2</td>
<td>16.2</td>
</tr>
<tr>
<td>Recharge</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Streams</td>
<td>10,966.2</td>
<td>10,909.2</td>
<td>10,899.1</td>
<td>57.0</td>
</tr>
<tr>
<td>Constant Head</td>
<td>25,412.8</td>
<td>25,348.0</td>
<td>25,373.5</td>
<td>64.8</td>
</tr>
<tr>
<td>Lake</td>
<td>0</td>
<td>390.7</td>
<td>371.4</td>
<td>-390.7</td>
</tr>
<tr>
<td>IN – OUT</td>
<td>0.4</td>
<td>-1.8</td>
<td>0.0</td>
<td>--</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY</td>
<td>~0.00</td>
<td>~0.00</td>
<td>~0.00</td>
<td>--</td>
</tr>
</tbody>
</table>

6.0 Flow-Model Limitations

The regional-scale flow models used to simulate the groundwater system have limitations due to the simplifications necessary to represent the complexity of the natural system. Flow model grid size and available data constrain the resolution and accuracy of the predictions. Approximate magnitudes and timing of groundwater system changes is possible with regional scale predictive flow models. Small changes in water levels and stream flows are inherently difficult for a regional model to accurately simulate, but the predictions are useful for assessing the potential range of impacts.

The groundwater inflows to the Open Pit during mining and post-mining are quantified and the effects of this hydraulic stress on the system are quantified by predicting the groundwater level drawdown, changes in surface water flows in Davidson Canyon and Cienega Creek, and changes in flows through the model’s lateral boundary conditions. Some of these changes are small relative to the model scale, which limits the resolution of the predictions. The models are also constructed based on present-day conditions, but natural and anthropogenic changes should be expected over the simulation period. No attempt has been made to simulate possible future changes that could alter the groundwater system. As simulations extend further in time, the error associated with the predictions increases.
Groundwater inflows to the Open Pit and post-mining pit lake are likely to be lower than simulated. The necessary simplifying assumptions required to simulate the system at a regional scale as an equivalent porous media prevent simulation of the small-scale faults and fractures that could impact groundwater inflows. Lower groundwater inflow results in less water captured by the groundwater flow system, which can potentially lead to a smaller drawdown area near the pit.

The stream flows in Davidson Canyon and Cienega Creek are low (~1 cfs or less) and difficult to accurately simulate with a regional groundwater flow model. Relative changes in stream flow are evaluated to provide a useful comparison and indication of potential changes. Groundwater-surface water interactions in the flow models are largely influenced by the topography. The stream channel elevations were defined with a 10-meter resolution digital elevation model and model cell sizes are typically 800-feet by 800-feet. The large grid cells result in some numerical instability largely due to water flowing in and out of the stream package cells in areas with small horizontal and vertical gradients. These factors limit the precision and accuracy of the model predictions. However, the results presented here represent Tetra Tech’s best estimate of groundwater system changes associated with the Project. The uncertainty in these predictions will be evaluated as part of a sensitivity analysis.

7.0 Summary and Conclusions

The groundwater that flows to the pit during dewatering and to the post-closure/post-mining pit lake is captured from several sources within the groundwater flow system. These sources include lateral flow boundaries representing adjacent basins, changes in recharge near the pit, and stream flows in Davidson Canyon, Cienega Creek, and potentially springs within the cone of depression. Steady-state groundwater inflow to the terminal pit lake is approximately 230 gpm, which is captured from other areas and sources to balance the water lost due to evaporation associated with the pit lake.

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

Steady-state groundwater capture due to the terminal pit lake is accounted for from several sources. Approximately 49 percent of the groundwater inflow is derived from recharge increases due to flow-through drains. Approximately 23 percent of the capture comes from changes in flows through the lateral boundary conditions, of which 18 percent is due to reduced outflows, primarily along the western model boundary. Stream flow capture accounts for approximately 19 percent of the groundwater inflow. The post-mining phase model also predicts that changes to riparian vegetation evapotranspiration due to lower water-table elevations accounts for 5 percent of the groundwater flow to the pit lake. Overall, however, the simulated riparian vegetation evapotranspiration decreases by 0.3 percent relative to the base-case simulation.

The regional-model scale and equivalent porous media assumptions may contribute to over estimating the long-term groundwater inflow to the pit. This may result in a larger lateral extent of drawdown propagation and greater predicted groundwater capture. Uncertainty in these predictions will be assessed as part of the sensitivity analysis to be documented in companion Technical Memoranda.
8.0 References


FIGURE 1. OBSERVATION LOCATIONS FOR EVALUATING GROUNDWATER SYSTEM CHANGES
Simulated Groundwater Inflow During Mining Operations

Peaks represent instantaneous mining of new zones at the start of new stress periods.

As water is removed from storage over a larger area these spikes are attenuated despite deeper pit depths.

~400 gpm at the end of mining.

Dewatering begins.

Simulated Drain Flux (gallons per minute)

Years Since Start of Mining
Simulated Water Table along Row 105 – End of Mining
FIGURE 5. PREDICTED GROUNDWATER LEVEL DRAWDOWN AT THE END OF MINING OPERATIONS

Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
FIGURE 6. SIMULATED CHANGE IN STREAM FLOWS AT THE END OF MINING
FIGURE 7. PREDICTED GROUNDWATER-LEVEL DRAWDOWN AT SIMULATED OBSERVATION LOCATIONS

- Proposed Rosemont Open Pit
- Ephemeral Drainage
- Cienega Creek Watershed
- No Flow Cells
- Quartz Porphyry Dike
- Observation Location
- Perennial Stream
\[ \Delta \text{Pit Lake Volume} = I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}} + GW_{\text{inflow}} - E_{\text{pit}} - GW_{\text{outflow}} \]

Direct Precipitation \((I_{\text{precip}})\)

Pit Wall Runoff \((I_{\text{pit runoff}})\)

Evaporation \((E_{\text{pit}})\)

Upgradient Runoff \((I_{\text{runoff}})\)

Groundwater Inflow \((GW_{\text{inflow}})\)

\[ GW_{\text{outflow}} = 0 \]
Figure 9
Simulated Pit Lake Water Balance

EXPLANATION
- Groundwater Inflow
- Pit Wall Runoff
- Lake Precipitation
- Evaporation
- Lake Stage

Predicted Annual Average Rate (gallons per minute)

Lake Stage (ft amsl)

Elapsed Time Since End of Mining (years)
FIGURE 10. PREDICTED GROUNDWATER LEVEL DRAWDOWN 20 YEARS AFTER THE END OF MINING OPERATIONS

Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
FIGURE 13. PREDICTED GROUNDWATER LEVEL DRAWDOWN 1,000 YEARS AFTER THE END OF MINING OPERATIONS

Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
Note: The layer with the largest spatial extent of groundwater level drawdown is layer 17. The drawdown presented is from layer 17.
FIGURE 15. SIMULATED CHANGE IN STREAM FLOWS 1,000 YEARS AFTER THE END OF MINING