1.0 Introduction

Rosemont Copper Company (Rosemont) is planning the development of an open pit mining and mineral processing operation known as the Rosemont Copper Project (Project) on the east side of the Santa Rita Mountains, approximately 30 miles southeast of Tucson, Arizona in Pima County. As part of the mining operation, 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.

Rosemont has contracted Tetra Tech to develop regional groundwater flow models for the Project. These flow models will represent pre-mining steady state conditions, active mining conditions, and post-closure mining conditions. Tetra Tech has undertaken several tasks to support development of these groundwater flow models. These tasks include development of a 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 streamflow conditions. Upon completion of the groundwater flow models, Tetra Tech will document the model construction process, calibration results, flow model predictions, and sensitivity analyses.

This technical memorandum documents the tasks completed to evaluate existing aquifer test data and hydraulic properties. Results of these tasks will be incorporated into the regional groundwater flow models being developed by Tetra Tech.

1.1 Task Objectives, Scope, and Approach

The objective of this task is to provide hydraulic property estimates for constraining the simulated properties in Tetra Tech’s regional groundwater flow model. The scope is limited to
existing testing completed by M&A and test analysis evaluation documented in the following reports.

- Short-term aquifer tests performed from 5/15/2007 to 6/1/2007 (Results of Drilling, Construction, and Testing of Four Pit Characterization Wells, Rosemont Project, M&A, 8/7/2009);

- Short-term aquifer tests performed from 6/18/2008 to 10/23/2008 (Results of Phase 2 Hydrogeologic Investigations and Monitoring Program, M&A, 2/26/2009, Volume 2); and


No additional field investigation or hydraulic testing was completed as part of this task.

The approach was to conduct a quality-assurance evaluation of M&A’s aquifer test analyses, re-analysis of select short-term aquifer test data, and development of a method for analyzing the 30-day aquifer-test data. A range of parameter values for tested geologic formations and hydrogeologic units was then identified to allow comparison to simulated values in Tetra Tech’s groundwater flow models.

2.0 Geologic Units

The geologic units referenced in this technical memorandum are as follows (modified from Johnson and Ferguson, 2007):

Willow Canyon Formation (Lower Cretaceous): A succession of medium- to coarse-grained feldspathic to argillaceous sandstone with vuggy, silty mudstone. There is a volcaniclastic conglomerate interval near the middle of the unit below a sequence of mafic lava flows. This unit is up to 7,200 feet thick.

Glance Conglomerate (Upper Jurassic and/or Lower Cretaceous): A massive to very thick-bedded, clast-supported conglomerate containing pebble- to boulder-sized clasts reflecting the composition of underlying units (Proterozoic through Permian). The unit is at least 720 feet thick at the HC-1 well cluster and has only been mapped southwest of the pit.

Concha Limestone (Permian): A grey, medium- to thick-bedded, massive to planar-laminated, amalgamated, cherty limestone (locally dolomitic) with poorly formed chert nodules that locally form lenses. The Concha Limestone is mostly micritic and is about 650 to 820 feet thick.

Scherrer Formation (Permian): Generally light grey to pink, fine-grained, massive quartzose sandstone with rare laminations. The upper portion is locally differentiated as a transitional interval consisting of cream-colored, medium-bedded, dolomicrite with poorly preserved siltstone and argillaceous carbonate rocks. The unit is about 330-490 feet thick.

Epitaph Formation (Permian): A mixed siliciclastic-carbonate unit. The siliciclastic units are purple to reddish, thin- to medium-bedded siltstone and silty mudstone, and a fine-grained laminated sandstone. These units are often metamorphosed to a light orange-pink or greenish
hornfels. The carbonate units are light grey to pink micritic carbonates. The Epitaph Formation is about 250 to 390 feet thick.

**Colina Limestone** (Permian): A light grey to white, medium- to thick-bedded, amalgamated, commonly dolomitic, micritic carbonate and skeletal wackestone that is about 165 to 260 feet thick.

### 3.0 Short-Term Aquifer Test Analysis

The short-term aquifer tests were completed by M&A in 2007 and 2008 (M&A, 2007; M&A 2008). These constant-rate pumping tests were conducted for 12- or 24-hours. M&A analyzed these tests using the Cooper-Jacob (1946), Theis Recovery (1935), and the Theis (1935) type curve matching method. Tetra Tech re-analyzed a number of tests as a quality assurance measure to determine if differences in test interpretation would result in significant differences in parameter values.

Tetra Tech re-analyzed the short-term aquifer tests that were amenable to standard straight-line solutions. The tests analyzed were selected to meet the requirements of the Cooper-Jacob or Theis Recovery solutions as closely as possible. This constraint eliminated the observation well data, since the observation wells were not screened at the same depth intervals as the pumped wells. Results of Tetra Tech’s analyses for the pumped well data sets, and a comparison to the M&A results for the same pumped well data sets, are provided in Attachment 1.

In summary, the hydraulic conductivity values obtained from the re-analysis of the short-term aquifer test data using the Cooper-Jacob (1946) and Theis Recovery (1935) methods were similar to the results of M&A’s original analyses. The geometric mean of the original analysis (0.08 feet/day [ft/d]) and the re-analyzed data set (0.06 ft/d) are nearly identical. The hydraulic conductivity values M&A obtained ranged from 0.0004 to 761 ft/d and the re-analyzed results ranged from 0.0005 to 761 ft/d.

The pumped wells were selected for analysis were based on the following constraints:

- The pumped well was in the same portion of the aquifer or geologic formation as the observation well.
- The pumped well was not screened through multiple depth intervals.
- In cases where a packer was used in the pumped well, there was little or no drawdown above the packer. This indicates that the packer was effectively isolating the pumped interval.
- The measured drawdown was at least a few inches, and the water levels recovered when pumping was stopped. This indicates that the measured response was due to pumping and not due to other influences.
- If multiple pumping rates were used, only the drawdown for the first rate in the pumped well was analyzed, and recovery data were not analyzed. Multiple pumping rates were defined as persistent changes in rate that produced an obvious and sudden effect on the drawdown in the pumped well so that fitting a single straight line was not feasible. The recovery data were not analyzed since the aquifer was
affected by multiple pumping rates (not just the first or the last rate) in a potentially non-linear fashion.

- If multiple straight lines were observed in the data, Tetra Tech attempted to match to the one least likely to correspond to borehole storage (early-time data) or a possible boundary condition (very late-time data).
- Tests in which drawdown anomalies occurred near the end of the pumping period were analyzed using the earlier drawdown data only. The recovery data were not analyzed.

4.0 Long-Term Pumping Test

The long-term pumping test was conducted by M&A from November 2008 to January 2009 (Analysis of Long-Term, Multi-Well Aquifer Test November 2008 through January 2009, M&A, 5/21/2009). Five (5) wells (PC-5, RP-6, HC-1B, HC-5A, and RP-3B) were pumped simultaneously although there were staggered starting dates. The longest duration of pumping was 30 days. Average pumping rates varied from 27.8 to 47.2 gpm. Pumping in well RP-3B was terminated before the end of the test due to excessive drawdown at a pumping rate of 27.8 gpm.

The five (5) test wells were pumped simultaneously, so drawdown analysis at the observation wells was performed to determine if there was interference between the pumping wells. If a water-level response was observed, the pumped well inducing the response was identified. The pumping wells located closest together were HC-5A and PC-5, which are approximately 3,500 feet apart (Figure 1). The drawdown analysis indicated that neither of these wells, nor their nearby observation wells, hydraulically responded to another well's pumping. The other pumped wells for this test were at least one (1) mile from the next closest pumped well and no interference between the wells was observed. The drawdown analysis indicated that the observation wells only responded to the pumping of the closest pumped well, and that many observation wells did not respond to pumping at all (Figure 1). As a result of this analysis, each pumping well was considered to be a separate test for the subsequent analyses.

4.1 Analysis Methods

A purpose for analyzing the long-term pumping tests is to obtain hydraulic properties to constrain the regional flow models used to predict impacts due to the Open Pit. There are inherent scale issues between the tests (100's to 1,000's of feet) and the regional model (10's of miles). At the relatively small scale of the tests, there are numerous hydrogeologic complexities such as faults, fractures, dikes, and lithologic changes that control the responses. These small scale features cannot be simulated at a regional scale.

Analytical and numerical methods can be used for analyzing the long-term test data. Numerical models are better suited to the test conditions since they can better simulate the geologic and well configuration complexities. Numerical models can be constructed as 2-dimensional and 3-dimensional representations of the flow system.

Vertical, 2-dimensional models were considered for this analysis due to several positive attributes. A radial-flow model is an appropriate tool for simulating the geologic heterogeneities present within a borehole or a short distance between wells that either an analytical solution or a larger scale 3-dimensional groundwater flow model cannot model accurately. A 2-dimensional
radial-flow model assumes radial flow to the pumped well from all directions in an infinite aquifer. Vertical hydraulic gradients can be simulated in a radial model, which allows for vertical and horizontal hydraulic conductivity estimates.

The radial-flow assumption for these 2-dimensional models, however, does present limitations on the geology that can be accurately simulated. The geology in a radial-flow model section represents a cylinder around the borehole. Heterogeneities in this model section are theoretically present in a cylinder around the borehole. If the hydrogeologic features controlling flow toward the well are not present in this 360-degree cylinder around the borehole, the model results will be in error. A radial-flow model is capable of representing different rock layers if those layers are laterally extensive on all sides of the borehole. By contrast, a radial flow model would not appropriately represent flow barriers (e.g., vertical dike, fault, or intrusive body) present on one side of the borehole but not on the other.

A 3-dimensional numerical model could also be used to analyze the long-term test data. A refined horizontal and vertical grid, however, would be necessary to adequately represent the geologic complexity and the well configurations. The existing 3-dimensional regional model developed by M&A (2009) in MODFLOW for example, has 200 x 200 foot grid cells in the immediate pit area and 800 x 800 foot grid cells in the surrounding area and assumes an equivalent porous medium, not a fractured rock aquifer system. Most observation wells with a response to pumping are located within 800 feet of the pumped well. The regional model grid would therefore have the pumped well and observation well within the same model cell or in an adjacent cell. Although water levels can be interpolated to these observation wells, there would be numerical errors in the simulated drawdown amounts. Larger cell sizes and greater layer thicknesses in a regional model would result in an underestimation of drawdown and gross approximations of the hydrogeologic features that control the pumping responses. Additionally, relatively small-scale steeply-dipping and low-angle faults in the tested area cannot be accurately represented with a regional model grid in MODFLOW due to its equivalent porous medium assumption. These limitations decrease a regional-scale model’s simulation accuracy and reliability, which decreases the benefit of attempting to incorporate additional complexity.

More accurate results could possibly be obtained from a refined 3-dimensional model grid, but these results would need to be incorporated into a regional model grid to simulate the potential regional impacts of mining. It is unknown whether the hydrogeologic detail necessary to obtain a good calibration to the long-term pumping tests in a refined model could be directly transferred to a regional-scale model. It is necessary for regional-scale models to simplify the small-scale hydrogeologic features so that regional influences can be simulated.

Due to these conditions and complexities, 2-dimensional, numerical radial groundwater flow models were selected to analyze the long-term tests. The radial-model method can accommodate pumping and observation wells screened at different depth intervals in the same or different geologic formations. The simulated well completion and geologic complexity is greater than can be included in traditional analytical solutions. Another benefit of using a numerical model is that hydraulic properties can be optimized using parameter estimation (PEST; Doherty, 2010).

4.2 Radial Flow Model Development

The long-term pumping tests were analyzed using the MODFLOW-96 numerical model code in a 2-dimensional, radial coordinate system \((r-z)\) (radial distance – vertical distance). This analysis provides estimates of horizontal and vertical hydraulic conductivity \((K_h, K_v)\) and specific
storage ($S_a$). Estimation of these hydraulic parameters was used to guide development of the 3-dimensional groundwater flow models developed by Tetra Tech. The pumped well was located at the $r = 0$ boundary, incorporating the well construction information. Lithologic information was incorporated into the model grid with the lithologic layers assumed to be perpendicular to the well axis. The screened intervals of the production and monitoring wells were incorporated into the model grid based on their locations relative to the lithology and distance relative to the center of the pumping well. A zero-drawdown boundary condition was located at a large radial distance ($r$) beyond the expected zone of influence of the pumped well. Recharge was assumed to be zero.

Radial model construction, calibration, and results post processing required the use of several codes. The codes used for each step of the modeling process are described below.

1. **Radial Model Construction** - A USGS preprocessor (RADMOD) generated the model grid, conductances, and storage capacities for simulating cylindrical (axisymmetrical) flow to the pumping well (Reilly and Harbaugh, 1993). The input parameters for the preprocessor are 1) row spacings, 2) initial hydraulic conductivity in the r-direction, 3) initial hydraulic conductivity in the z-direction, and 4) specific storage or specific yield for the top of the model (i.e., row 1). The preprocessor generates the MODFLOW generalized finite-difference (GFD) package (Harbaugh, 1992). The GFD package takes the place of the Block Centered Flow (BCF) package since the conductances and storage capacities are calculated from the preprocessor. In essence, the radial model simulates a vertical cylinder of the pumped aquifers. The “rows” represent the vertical or z direction; the “columns” represent the distance away from the pumped well laterally ($r$).

2. **Pumping Distribution** - A Tetra Tech preprocessor (WELFLXMR) was used to determine the division of pumping within the well, which is represented by the model rows. Pumping is distributed according to the transmissivity of the model cell in a given row.

3. **Hydraulic Head Distribution** - A Tetra Tech preprocessor (FLAY) was used to determine the transmissivity-weighted head in the observation well(s), since the observation wells generally extended across multiple rows. Because pressure transducers were used to record thousands of data points for each observation well, representative data points were selected as water-level observations.

4. **Transient Model Simulation** - MODFLOW-96 was run in transient mode. Stress periods were specified for the duration of pumping test and recovery.

5. **Drawdown Calculation** - Tetra Tech post-processors OBHMOD and RESIDMD were used to calculate drawdown residuals based on the MODFLOW output. Transmissivity-weighted drawdown and temporal linear interpolation was used to calculate simulated drawdown, which was compared with observed drawdown.

6. **Parameter Optimization** – The parameter-estimation code PEST was used to assist in obtaining optimized vertical hydraulic conductivity, horizontal hydraulic conductivity, and specific storage values. PEST automatically adjusts these parameter values within user-provided ranges to determine the combination of parameter values that produces the best agreement between simulated and measured drawdown values. The user-specified parameter ranges were determined from the short-term aquifer testing results and literature values.
4.3 Long-Term Test Settings

Each of the five (5) pumped wells represents an individual long-term test with nearby observation wells. The setting for each of the individual pumped wells is summarized as follows:

- **Pumped well PC-5:** Water levels in wells PC-2, PC-6, PZ-7/PC-7, and PZ-5 (see Figure 1) responded to pumping in PC-5. Well PC-1 may also have responded, but the response is not clear since no recovery was observed when the pumping ceased. Available boring logs, geologic maps, and published and unpublished geologic sections provided by Rosemont and M&A were used to define the geology between PC-5 and each monitoring well that responded to pumping at PC-5. Each of the geologic sections between PC-5 and the observation wells are discussed below:
  - The geology of the section between PZ-5, PC-5, and PC-6 was based on Rosemont’s unpublished geologic maps. This section contains multiple faults, truncated near-vertically dipping geologic beds, and younger units overlain on top of the truncated geologic units. A radial model is suitable for representing hydraulic conductivity differences between laterally-homogeneous geologic layers, but it is not suitable for representing this significant level of lateral heterogeneity within a layer. This section was determined to be too geologically complex for representation and simulation in the radial-model analysis.
  - The geology between PC-5, PC-7, and PZ-7 crosses the proposed pit location, which has also been subjected to a high degree of faulting and alteration. This section was also determined to be too geologically complex for representation and simulation in the radial-model analysis.
  - The geology between PZ-5, PC-5, and PC-2 is illustrated on Figure 2. The section lies along strike, so the geologic units have no apparent dip along the section. However, the geologic units near PC-5 dip approximately 75-degrees based on geologic maps (Johnson and Ferguson, 2007). The units on either side of the steeply-dipping fault have the same dip and are part of the same hydrogeologic units, so it does not represent significant lateral heterogeneity. The geology present in this section is amenable to the simplifying assumptions and it was selected for analysis using the radial-model methodology.

- **Pumped well RP-6:** No observation wells responded to pumping in well RP-6, so this data set was not amenable to radial-model analysis. Hydraulic properties for this test have been estimated by M&A (2009b).

- **Pumped well HC-1B:** Observation well HC-1A is 30 feet from HC-1B and responded to pumping. These wells are completed in different zones of the same geologic formation with no faulting, so the data set could be analyzed using the radial-model analysis method.

- **Pumped well HC-5A:** Observation well HC-5B is 32 feet from HC-5A and responded to pumping. The static potentiometric surface changes by 50 feet over the 32 foot distance between these wells, which is a 60-degree angle. This is a very steep...
hydraulic gradient that would be difficult to accurately simulate with horizontal layers. However, the geologic units between these wells also have a 60-degree dip (Johnson and Ferguson, 2007). Setting the model layers parallel to the formation dip and the potentiometric surface allowed the response between HC-5A and HC-5B to be simulated with a radial model.

- **Pumped well RP-3B**: Well RP-3A appeared to respond to pumping in RP-3B. However, anomalous, post-test data adjustments were not reproducible, so the response was not considered reliable. This test was therefore not analyzed using a radial model.

Three (3) other locations, PZ-8/PC-8, HC-3 well cluster, and well 1445 (Figure 1), were identified by M&A (2009b) as having responses to the long-term pumping. These wells, however, were not analyzed using the radial-model method. The apparent 1-2 inches of response in the PC-8/PZ-8 well cluster is within the range of measurement error and non-pumping related influences. This questionable response was not sufficiently reliable to warrant further analysis. Well cluster HC-3 and well 1445 had less than one (1) foot of water-level change over the test duration. There was no water-level recovery when the pumping ceased, which indicates that the water-level changes were likely due to factors unrelated to the long-term pumping. The magnitude of water-level fluctuation during the test is much less than the ten (10) feet of change in well cluster HC-3 and well 1445 that was observed during non-pumping periods in 2008 (M&A, 2009a). The lack of response in these wells to pumping is probable since well cluster HC-3 is located about 3,600 feet from the nearest pumped well (PC-5), and well 1445 is located about 6,800 feet from the nearest pumping well (HC-1B).

5.0 Radial Model Construction and Calibration

Radial models were constructed and calibrated to obtain estimates of vertical hydraulic conductivity, horizontal hydraulic conductivity, and specific storage. The details of these models and their results are described in this section.

5.1 PC-5 Radial Model

The numerical model grid for this simulation consisted of 100 rows and 55 columns with the column spacing determined using a radial space multiplier of 1.25. The row, or vertical, spacing was based on lithologic picks and screened intervals from the lithologic logs of PZ-5, PC-5, and PC-2 as shown on the geologic cross-section (Figure 2). To represent the variations in PC-5's pumping rate from approximately 42 to 49 gallons per minute (gpm), seven (7) stress periods were used to represent the 30-day pumping phase of the test. A single stress period was used to represent the 30-day recovery phase for a total of eight (8) stress periods.

To represent the geologic variation between PZ-5 and PC-2, the model was run under two (2) scenarios. The radial model could have been used to represent the entire section simultaneously, but this would have resulted in a loss of the ability to resolve hydraulic properties of the three (3) Permian formations near PC-5 (Figure 2). The first scenario matched only to PZ-5 data to estimate the material properties of the Permian formations (Concha, Scherrrer, and Epitaph/Colina) separately. Figures 3 through 5 show the match between observed and simulated drawdown. The radial flow model underpredicts drawdown and overpredicts recovery, but the match is within one (1) foot for most observations and two (2) feet.
for all observations. The parameter values resulting from the first radial model scenario analysis of the PC-5 pumping test are provided in Table 1.

Table 1. Hydraulic-parameter estimates for PZ-5 from long-term pumping in well PC-5.

<table>
<thead>
<tr>
<th>Formation</th>
<th>$K_h$ (ft/d)</th>
<th>$K_v$ (ft/d)</th>
<th>$S_e$ (1/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Canyon (Ksd)</td>
<td>0.16</td>
<td>2.8</td>
<td>7.0E-07</td>
</tr>
<tr>
<td>Concha Limestone (Pz)</td>
<td>0.06</td>
<td>0.35</td>
<td>0.004</td>
</tr>
<tr>
<td>Scherrer Formation (Pz)</td>
<td>0.07</td>
<td>0.13</td>
<td>1.5E-07</td>
</tr>
<tr>
<td>Epitaph Limestone with Interfingered Colina Limestone (Pz)</td>
<td>0.00017</td>
<td>0.35</td>
<td>2.2E-06</td>
</tr>
</tbody>
</table>

The second scenario matched only to PC-2 data, and combined all the Permian formations as a single hydrogeologic unit. The Concha, Scherrer, and Epitaph/Colina formations were combined with the adjacent Epitaph formation near PC-2 as a single Permian unit. The match between observed and simulated drawdown in PC-2 is shown on Figure 6. The radial flow model matches the drawdown data values extremely well. The parameter values resulting from this analysis are presented in Table 2.

Table 2. Hydraulic-parameter estimates for PC-2 from long-term pumping in well PC-5.

<table>
<thead>
<tr>
<th>Formation</th>
<th>$K_h$ (ft/d)</th>
<th>$K_v$ (ft/d)</th>
<th>$S_e$ (1/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Canyon (Ksd)</td>
<td>0.1</td>
<td>0.006</td>
<td>0.0066</td>
</tr>
<tr>
<td>Permian Formations (combined, Pz)</td>
<td>0.57</td>
<td>0.0013</td>
<td>1.5E-07</td>
</tr>
</tbody>
</table>

Steeply dipping formations and faults are present in the western portion of the pit area based on unpublished Rosemont geologic maps and cross sections. The formations near PC-5 had higher estimated vertical hydraulic conductivity than horizontal (see Table 2), while the formations between PC-5 and PC-2 had overall higher estimated horizontal conductivity than vertical (see Table 3). Geologic units near PC-5 dip approximately 75-degrees based on geologic maps (Johnson and Ferguson, 2007). The direction of highest conductivity is expected to be nearly vertical near the pumped well and would be expected to intersect both the pumped well and the PZ-5 observation well due to their close proximity. The higher vertical conductivity estimated for well PZ-5 is therefore conceptually reasonable.

Faulting between PC-5 and PC-2 has truncated the bedding planes and offset the geologic units between these wells. This results in lateral heterogeneity that does not meet the radial-flow model assumptions regarding homogeneous and laterally extensive units. However, the radial-flow model results are representative of hydraulic properties in an equivalent porous media between PC-5 and PC-2, which is consistent with an underlying assumption of the 3-dimensional groundwater flow model. The vertical hydraulic conductivity estimates from the radial-flow model between PC-5 and PZ-5 however, more closely represent fractured rock properties due to nearly vertical bedding planes. Horizontal hydraulic conductivity values from the PC-5/PZ-5 model and both hydraulic conductivity values from the PC-5/PC-2 model represent rock matrix or porous media properties.
5.2 HC-1B Radial Model

The grid for the HC-1B radial model consisted of 24 rows and 45 columns with the column spacing determined using a radial space multiplier of 1.26. The row, or vertical, spacing was based on the screened intervals in HC-1A and HC-1B, since the lithology was consistent between the two (2) wells that are 30 feet apart. The pumping rate of HC-1B was fairly consistent at 43 gpm, so only one (1) stress period was used to represent the 25-day pumping phase of the test. A single stress period was used to represent the 32-day recovery phase, for a total of two (2) stress periods.

The match between observed and simulated drawdown data in HC-1A is illustrated on Figure 7. The model matches drawdown very well and overpredicts the recovery data by less than two (2) feet. Due to the secondary porosity effects inherent to fractured rock systems, it was not possible to precisely match the recovery data. The parameter values resulting from the radial flow model analysis of the HC-1B pumping test are presented in Table 3.

<table>
<thead>
<tr>
<th>Formation</th>
<th>$K_h$ (ft/d)</th>
<th>$K_v$ (ft/d)</th>
<th>$S_s$ (1/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glance Conglomerate</td>
<td>0.06</td>
<td>0.002</td>
<td>1.0E-06</td>
</tr>
</tbody>
</table>

5.3 HC-5A Radial Model

The grid for the HC-5A radial model consisted of 26 rows and 40 columns with the column spacing determined using a radial space multiplier of 1.25. The row, or vertical, spacing was based on lithology picks and the screened intervals of HC-5A and HC-5B. There is an approximate 60-degree dip of the beds between the two (2) wells, and a matching 60-degree slope of the potentiometric surface. The model was tilted 60-degrees to allow representation of a flat potentiometric surface and flat-lying geologic bedding planes. The distance between the wells was adjusted to be measured along dip. To represent the variations in HC-5A’s pumping rate from approximately 36 to 43 gpm, six (6) stress periods were used to represent the 23-day pumping phase of the test. A single stress period was used to represent the 32-day recovery phase, for a total of seven (7) stress periods.

The match between observed and simulated drawdown data in HC-5B is shown on Figure 8. The model slightly underpredicts drawdown and overpredicts recovery by 2 to 2.5 feet. Due to the secondary porosity effects inherent in fractured rock systems, it was not possible to precisely match the recovery data and a dual-porosity model would be required to represent these effects. However, since the material property values from the radial flow model are going to be used in a porous medium groundwater flow model (i.e., MODFLOW), their values are valid for that purpose.

The HC-5A/B lithologic logs indicate the presence of andesite and shale in the deeper portion of the predominately sandstone Willow Canyon Formation. Due to the dramatically different hydraulic properties within the Willow Canyon Formation, it was split into two (2) zones: Zone 1 (sandstones above 680 feet below ground surface [bgs]) and Zone 2 (andesite and shales below 680 feet bgs). Simulating the Willow Canyon Formation as two (2) material property zones in the radial-flow model made it possible to more closely match the observed drawdown
data at HC-5B. The parameter values resulting from the radial flow model analysis of the HC-5A pumping test are presented in Table 4.

### Table 4. Hydraulic parameter estimates for HC-5B from long-term pumping in well HC-5A.

<table>
<thead>
<tr>
<th>Formation</th>
<th>$K_h$ (ft/d)</th>
<th>$K_v$ (ft/d)</th>
<th>$S_s$ (1/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Canyon Zone 1 (Ksd)</td>
<td>0.25</td>
<td>0.55</td>
<td>3.3E-04</td>
</tr>
<tr>
<td>Willow Canyon Zone 2 (Andesite and Shale)</td>
<td>2.4E-04</td>
<td>5.0E-04</td>
<td>3.3E-04</td>
</tr>
<tr>
<td>Epitaph Limestone (Pz)</td>
<td>4.7E-03</td>
<td>4.7E-03</td>
<td>3.3E-04</td>
</tr>
</tbody>
</table>

The lower hydraulic conductivity values estimated for the Willow Canyon Zone 2 are due to the presence of low-conductivity shale and andesite. The upper portion (Zone 1) of the Willow Canyon is predominately sandstone and it has an overall higher hydraulic conductivity.

### 6.0 Summary

The results of hydraulic testing and 2-dimensional radial models provide a range of estimated hydraulic conductivity and specific storage values for groundwater flow modeling. The horizontal hydraulic conductivities ranged from 0.00017 ft/day to 761 ft/day. In addition, the 2-dimensional radial flow models indicated that vertical hydraulic conductivities ranged from 0.0005 ft/day to 0.28 ft/day. These ranges provided initial estimates of vertical and horizontal hydraulic conductivities for use in Tetra Tech’s 3-dimensional groundwater flow models.

The specific storage estimates obtained from the radial flow modeling ranged from 7x10^{-7} to 0.004 per foot, with a geometric mean of 9.8x10^{-4} per foot. The geometric mean from the multiple Willow Canyon specific storage values was obtained first to prevent over-representing that unit. The Willow Canyon’s geometric mean was used in the subsequent bulk geometric mean calculation. The specific storage (9.8x10^{-4} per foot) estimate was used for all bedrock units in Tetra Tech’s transient 3-dimensional groundwater flow modeling.

### 7.0 References


FIGURES
Figure 1
Location of Long-Term Tests
Considered for Radial Flow Modeling

LEGEND

- Analyzed with Radial Model
- Not Analyzed with Radial Model

Well Symbols
- Pit Characterization Well
- Multi-Level Piezometer
- Deep Characterization Well
- Intermediate Characterization Well
- Shallow Characterization Well
- Alluvium Characterization Well
- Other Water Well
- Other Piezometer
- Spring or Seep
- Mine Adit

Aquifer Test Symbols
- Pumped
- Observed
- No Measureable Response During Long-Term, Multi-Well Aquifer Test

Notes
1 in = 1,250 ft
Adapted from Figure 2, M&A, 5/21/2009
Radial Flow Model Geologic Section From PC-5 to PC-2
Figure 3
Simulated versus Observed Drawdown at PZ5-600 During Multi-Well Aquifer Test
Figure 4
Simulated versus Observed Drawdown at PZ5-1150
During Multi-Well Aquifer Test
Figure 5
Simulated versus Observed Drawdown at PZ5-1800
During Multi-Well Aquifer Test
Figure 6
Simulated versus Observed Drawdown at PC-2
During Multi-Well Aquifer Test
Project No: 114-320874

Figure 7
Simulated versus Observed Drawdown at HC-1A
During Multi-Well Aquifer Test
Figure 8
Simulated versus Observed Drawdown at HC-5B During Multi-Well Aquifer Test
ATTACHMENT 1
SHORT-TERM AQUIFER TEST ANALYSES
<table>
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<th>Test Start Date</th>
<th>Pumped interval (ft bgs)</th>
<th>Duration (minutes)</th>
<th>Initial WL (ft bgs)</th>
<th>Hydrogeologic Unit(s) Formation(s)</th>
<th>Screen Length (ft)</th>
<th>Cooper-Jacob T (gpd/ft)</th>
<th>Theis Recovery T (gpd/ft)</th>
<th>Average T (ft/day)</th>
<th>M&amp;A K (ft/d)</th>
<th>TI K (ft/d)</th>
<th>Figure #</th>
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Notes:
- ft bgs: feet below ground surface
- gpd: gallons per day
- gpm: gallons per minute
- K: hydraulic conductivity
- M&A: Montgomery and Associates
- Q: pumping rate
- s: drawdown
- s-s': residual drawdown
- T: transmissivity
- TI: Tetra Tech
- WL: Water level

* This value is calculated from the "Operative Transmissivity" in M&A's Table 4 in Results of Phase 2 Hydrogeologic Investigations and Monitoring Program Rosemont Project, Pima County, Arizona (February 26, 2009). Note that M&A sometimes used an average of the drawdown and recovery values, but sometimes selected one of the two values for the "Operative Transmissivity." The TI K value is always an average if both tests were analyzed. Hence, even when the M&A analyses were accepted without re-analysis, the TI and M&A values differ in some cases.

# Unless otherwise specified, figure numbers are taken from Results of Phase 2 Hydrogeologic Investigations and Monitoring Program Rosemont Project, Pima County, Arizona (February 26, 2009) Appendix D.
Memorandum

To: Beverly Everson
Cc: Tom Furgason
From: Kathy Arnold
Doc #: 025/10 – 15:3.2
Subject: Transmittal of Tetra Tech Groundwater Memoranda
Date: July 9, 2010

Rosemont is pleased to transmit the following technical memorandums related to the groundwater modeling work that has been undertaken by Tetra Tech:

- *Hydraulic Property Estimates*, Tetra Tech, July 2010
- *Hydrogeologic Framework Model*, Tetra Tech, July 2010

Rosemont is providing three hardcopies and two disk copies for the Forest and two hardcopies and one disk copy for SWCA.