Technical Memorandum

To: Kathy Arnold
From: Grady O’Brien and Michael Gabora
Company: Rosemont Copper Company (RCC)
Date: April 10, 2010
Re: Rosemont Backfill and Pit Lake Management Approaches
Doc #: 123/10-320869-5.3
CC: Jamie Sturgess (RCC); David Krizek, P.E. (Tetra Tech)

1.0 Introduction

Rosemont Copper Company (Rosemont) plans to develop an open pit mining operation on the east side of the Santa Rita Mountains, about 30 miles southeast of Tucson, Arizona in Pima County. This Technical Memorandum provides background information on how the post-closure conditions related to the Rosemont Copper Project (Project) might be affected by partial backfilling of the Open Pit.

The backfill approaches considered in this Technical Memorandum have been raised during development of the Environmental Impact Statement (EIS) associated with the Project. The physical processes related to pit lakes and how the backfill alternatives may affect the post-closure pit lake and the larger groundwater flow system are also discussed.

The comments expressed herein represent Tetra Tech’s current understanding of the Open Pit (pit) and the groundwater flow system. The basis for the comments is engineering judgment and experience: specific numerical simulations and analytical analyses related to the backfill approaches have not been completed. Therefore, discussions related to partial backfill of the proposed Open Pit developed herein are conceptual in nature and provide a basis for considering potential backfill approaches to address issues raised during project scoping.

The pre-mining condition where groundwater is flowing from the topographically high areas on the west side of the Project area to lower areas to the east is conceptually illustrated on Figure 1. Development of the Open Pit, located in the northern Santa Rita Mountains, will require dewatering during mining. Groundwater flow modeling completed by Montgomery & Associates (M&A) in 2009 indicates that the Open Pit will create a hydraulic sink and that a post-mining pit lake will develop (M&A, 2009).

Partial backfilling of the Open Pit is being considered to reduce the amount of drawdown associated with the maintenance of a perpetual pit lake. A terminal-sink (hydraulic sink) created by a pit lake results in drawdown of the groundwater flow system. Drawdown concerns have been identified as having the potential to impact other water resources in the area such as springs, wells, and riparian vegetation. Under some conditions, partial backfilling may reduce the potential for drawdown and associated impacts.
Memorandum

To: Beverly Everson
Cc: Tom Furgason
From: Kathy Arnold
Doc #: 017/10 - 15.3.1
Subject: Transmittal of Reclamation Concept Update Report
Date: April 13, 2010

Rosemont is pleased to transmit the following reports/technical memoranda:

- Davidson Canyon Hydrogeologic Conceptual Model and Assessment of Spring Impacts, Tetra Tech, April 2010 – This is a discussion of the Davidson Canyon area and its hydrogeology and geology associated with groundwater. This also contains the Springs discussion that Rosemont had originally planned to submit as a separate document.
- Rosemont Backfill and Pit Lake Management Approaches, Tetra Tech, April 2010 – This is a discussion of the various partial backfill options available for the Rosemont project.

These reports constitute four of the reports (two were combined) that were scheduled for delivery on Friday, April 8 but were held up in document production over the weekend. The remaining reports (Site Water Management, the 404(b)1 Alternatives and Talus Snails) are going through those same processes right now and will be submitted by Friday April 15.

We are providing two hardcopies and two disk copies to the Forest and one hardcopy and one disk copy to SWCA.
There are benefits and risks associated with pit backfilling. By understanding the physical processes related to pit lakes and backfilling, these benefits and risks can be compared. In addition to partial backfilling, there are other pit backfill and management methods available that may reduce groundwater drawdown effects.

Four (4) backfill or pit lake management approaches are evaluated herein that have potential application at Rosemont:

- Backfill above the pre-mining groundwater elevations;
- Partial backfill below the pre-mining groundwater elevations;
- A Quick-Fill option; and
- A managed stormwater inflow option.

The general hydrogeologic conditions related to pit lakes are briefly discussed in Section 2.0. The post-mining pit lake water level and post-mining equilibrium groundwater conditions are driven by the system water balance, which is an accounting of water entering and leaving the pit lake. At equilibrium or steady state, the inflows equal the outflows. How the water balance is altered due to the four (4) backfill options listed above is then discussed.

### 2.0 Hydrogeologic conditions

As indicated above, the water balance of a pit lake describes how water flows into and out of the lake. Depending on the relative magnitudes of these flows, a pit lake will form or the pit could remain dry. For the following discussion, it is assumed conditions are favorable for the formation of a post-mining pit lake. The pit lake level and the rate at which the pit fills are controlled by the post-closure water balance. The post-closure water balance can be expressed as:

$$\Delta_{\text{pit lake volume}} = I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}} + G W_{\text{inflow}} - E_{\text{pit}} - G W_{\text{outflow}}$$ (Equation 1)

Where:

- $\Delta_{\text{pit lake volume}}$ is the change in pit lake volume;
- $I_{\text{precip}}$ is the inflow from direct precipitation falling on the lake surface;
- $I_{\text{runoff}}$ is the inflow from runoff from upgradient drainages;
- $I_{\text{pit runoff}}$ is the inflow from pit wall runoff (the fraction of precipitation falling on the pit walls that ultimately reaches the pit lake);
- $G W_{\text{inflow}}$ is the groundwater inflow to the pit lake;
- $E_{\text{pit}}$ is the open water evaporation from the pit lake surface based on a modified pan evaporation rate; and
- $G W_{\text{outflow}}$ is the outflow of groundwater from the pit lake.

The interaction between these parameters for a terminal-sink pit, which has no groundwater outflow ($G W_{\text{outflow}} = 0$), is presented schematically on Figure 2.

There are two (2) types of pit lakes: terminal-sink and flow-through. A terminal-sink pit lake has no groundwater leaving the pit (Equation 1: $G W_{\text{outflow}} = 0$). A flow-through pit has a component of
groundwater leaving the pit (Equation 1: \(GW_{\text{outflow}} > 0\)). Evaporation must be greater than sum of precipitation, runoff, and groundwater inflow for a terminal-sink pit lake to form.

At steady-state conditions, evaporation is expected to exceed the other individual components of the water balance at the Rosemont Project. Due to the steep walls of the proposed Open Pit (roughly cone shaped), the surface area of the pit lake is initially small, but increases as the lake stage rises. Therefore, evaporation losses increase as the surface area increases. The lake level will stabilize when the evaporation rate equals the sum of the inflow components. A terminal-sink pit lake will create a cone-of-depression or water-level declines (also termed drawdown) around the Open Pit as a result of groundwater inflow (Figure 3). As long as the groundwater elevations around the pit never become low enough to reach the pit lake elevation, groundwater will flow toward the pit. A hydraulic sink is created when the elevation of the groundwater divide is greater than the lake level (Figure 3). Over the long-term there would be a net loss of water due to evaporation in a terminal-sink pit lake.

Drawdown of groundwater levels occurs most dramatically in the vicinity of the Open Pit, with decreasing drawdown at greater distances from the pit. The magnitude and extent of the drawdown depends on the pit lake water balance (Equation 1) and the hydraulic properties of the surrounding rocks. The water balance determines the pit lake level, which in turn determines the magnitude of the drawdown. This drawdown can be advantageous by capturing process area contaminates and preventing their migration away from the pit. Drawdown in a regional groundwater flow system, however, can reduce flows and stages in streams, springs, and lakes. Over time, the 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.

Conversely, a flow-through pit lake has groundwater elevations that reach the lake level over a portion of the lake, allowing groundwater to flow out of the pit (Figure 4). If the pit lake water quality is poor, undesirable down-gradient consequences could occur. However, flow-through conditions created by backfilling the pit above the pre-mining water level results in no long-term evaporative losses, thus allowing the flow system to return to approximate pre-mining conditions (Figure 5).

### 3.0 Backfill Objectives

In general, there are several considerations related to backfilling an open pit after the cessation of active mining. The most important consideration is whether a flow-through pit or a terminal-sink pit is desired. Additionally, the backfill level will depend on the desired post-mining hydrologic condition and the backfilling objective. The following are some of the objectives for backfilling an open pit:

- Cover acid rock drainage (ARD) generating rock located in the pit;
- Create a free draining surface;
- Eliminate the pit lake or reduce the lake’s depth;
- Restore aesthetics (i.e. move material back into the pit from waste piles); and
- Decrease drawdown.

With respect to the Rosemont Project, the only practical backfill consideration would be a partial backfill approach with the goal of reducing the amount of drawdown associated with the
anticipated presence of a perpetual pit lake. By raising the lake stage, the hydraulic gradient is reduced and groundwater inflow into the pit is minimized.

The reduction in groundwater consumption depends on how much groundwater inflow (GW_{inflow}) to the pit is reduced due to the higher pit lake stage. In this sense, the level of backfill in the pit can be used as a management tool for creating the desired post-mining conditions. However, there is the risk of backfilling too high and inadvertently creating a flow-through condition. This outcome could have unintended consequences if the quality of the pit lake water was poor or if the sink was being used for passive containment for the operations areas. Even though potential seepage from the remaining major facilities at the Rosemont Project is expected to be at or slightly above Arizona Aquifer Water Quality Standards (AWQS), the pit is still expected to be used for passive containment of these facilities at closure.

4.0 Management Options

As indicated in Section 1.0, four (4) backfill or pit lake management approaches are reviewed herein for the Rosemont Open Pit:

- Backfill above the pre-mining groundwater elevations;
- Partial backfill below the pre-mining groundwater elevations;
- Quick-Fill option; and
- A managed stormwater inflow option.

4.1 Backfilling Above Pre-Mining Groundwater Elevations

Creating a flow-through pit from a terminal-sink condition requires backfilling to a level above the groundwater elevations of the surrounding aquifer, which over the long-term would be similar to pre-mining water levels (Figure 5).

Due to the size of the excavated pit, it could take hundreds of years for the water table to re-equilibrate to near pre-mining levels assuming groundwater inflow and recharge rates were low. Backfilling the pit would accelerate the rate at which the pit would refill with groundwater. Less inflow would be required since the backfill material would take up most of the empty space. For example, typical backfill might have a porosity of 25%. As a result, only 25% of the volume of water would be necessary to fill the pit to a particular level. Also, because the backfill would be placed higher than the water level in the pit, there would be minimal evaporation. This would effectively accelerate the rate of groundwater level recovery.

An important negative component of this approach is that potentially impacted water can migrate out of the pit as a result of creating a flow-through condition. In the case of the Rosemont Project, existing studies have been performed predicting the pit lake water quality. After 200 years of simulation, modeling has indicated the pit lake water quality would resemble that of local groundwater (Tetra Tech, 2010a). Infiltration, Seepage, and Fate and Transport modeling has also been performed on the waste rock, dry stack tailings, and spent ore pile associated with the Heap Leach Facility (Tetra Tech, 2010b). The results of this analysis indicated that any potential seepage from these facilities would have measured constituents mostly below the AWQS.
4.2 Partial Backfill Below Pre-Mining Groundwater Elevations

Backfill can be used to manage the pit lake level when a terminal-sink condition is desired. Water levels in the backfill will rise until the inflows are balanced by evaporation. When the water-level depths are significantly below the backfill, groundwater inflow and infiltration into the backfill (from pit wall runoff, upgradient runoff, and precipitation) are occurring but open water evaporation is not. Shallow, seasonal water ponding on the backfill would occur if the pit lake levels were just below the backfill level and evaporation losses were closely matched to the pit inflows (Figure 6). This backfill scenario would maintain a hydraulic sink, but with less drawdown than a no-backfill scenario.

If backfill is determined beneficial to achieve a specific goal, the optimum level depends on the specific project objectives and the site specific hydrogeologic conditions. The optimum level is achieved when a terminal-sink is maintained, drawdown is minimized, and the desired factor of safety is maintained. The critical issue is ensuring that the pit lake level is sufficiently low to maintain a terminal-sink condition. A groundwater divide must be maintained between the pit and the down-gradient areas. The distance from the pit lake level to the top of the groundwater divide is termed the “factor of safety” (Figure 6). The larger the factor of safety, the more likely it is that a terminal-sink condition will be maintained if the hydrogeologic conditions change or if they are not accurately known.

Partially backfilling a pit to reduce drawdown effects, however, is not a common practice since it does not result in significantly different groundwater levels. After active dewatering ceases, drawdown will continue to propagate down-gradient through the groundwater flow system, even while water levels in the pit area are recovering.

Over the long-term (hundreds of years), a higher pit-lake stage (as a result of backfilling above the predicted, non-backfilled, steady-state lake stage) will reduce the steady-state groundwater inflow into the pit. This decrease in inflow is due to smaller hydraulic gradients between the lake level and the surrounding groundwater table. In turn, the smaller gradients and lower inflows reduce the steady-state drawdown associated with the hydraulic sink of the pit lake.

4.3 Quick-Fill Option

Adding an external source of water to the pit after the end of dewatering would accelerate the water-level rise within an open or backfilled pit. This has been termed the Quick-Fill option. Adding large volumes of external water to the pit could also potentially shorten the time to reach equilibrium conditions in the areas near the pit. Although the Quick-Fill option results in less water being removed from storage in the aquifer, drawdown would not be significantly affected. Drawdown in the aquifer continues to propagate outwards after dewatering ceases and is not immediately influenced by the near pit water levels. Furthermore, the steady-state pit lake elevation would be unchanged, as would the long-term groundwater inflow to the pit (Figure 7).

The Quick-Fill option could be used in conjunction with backfilling to increase water inflows and decrease the effects of evaporation temporarily, thus increasing the rate at which water levels in the immediate vicinity of the pit would rise (Figure 7). Quick-Filling would have to be closely managed to ensure that a temporary flow-through condition is not created. Adding too much water, too quickly could raise the pit lake level above the groundwater elevations in the surrounding aquifer. This situation could temporarily result in pit lake water flowing down-gradient. This condition could reverse and a terminal–sink condition could reestablish itself once the external water source is stopped and equilibrium is restored.
4.4 Managed Stormwater Inflow Option

Managing the volume of surface runoff into the pit is a variation on the Quick-Fill option. The Rosemont Landform (tailings and waste rock piles) and/or mine operations areas could be graded to direct stormwater runoff into the pit (Figure 8). This would provide a long-term, perpetual source of water to the pit lake, whereas the Quick-Fill option would typically supply external water for one (1) to three (3) years. The addition of stormwater runoff could offset water lost to evaporation, which may reduce the long-term groundwater inflows into the pit lake. Reducing long-term groundwater inflows to the pit would also reduce the long-term drawdown due to the pit.

5.0 Potential Applications

A complete or near complete backfilling of the proposed Open Pit to above pre-mining water levels would create a flow-through condition. This would result in pit lake water and/or water interacting with pit walls and waste rock to flow down-gradient away from the Project site. In this scenario, there would be no pit lake formation and no perpetual consumption of groundwater by evaporation. As a result, the groundwater flow system would be expected to eventually recover to a flow condition similar to what persisted prior to mine development (Figure 5). However, the water flowing out of the system after adding waste rock backfill to the pit may or may not result in a quality resembling pre-mining conditions. Also, there would also be no passive containment of the major facilities provided by the Open Pit.

As discussed in Section 4.0, there are three (3) potential options that could reduce the long-term drawdown and consumption of groundwater while maintaining a terminal-sink pit lake condition:

- Partial backfill to an optimized level;
- Partial backfill with Quick-Fill option; and
- Managed Stormwater Inflow option.

Results of the M&A groundwater flow model (M&A, 2009) frame the discussion on how the partial backfill alternatives could be applied to the proposed Rosemont Open Pit. The pre-mining water level is approximately (~) 5,000 feet above mean sea level (amsl) in the pit area. The predicted pit lake elevation, with no backfill and after 100 years of model simulation, results in ~1,000 feet of drawdown or a water level of ~4,000 feet amsl. Groundwater elevations on the east side, or down-gradient side, of the pit are expected to be ~4,500 feet amsl.

After about 100 years following the cessation of mining, the relative difference in the predicted pit lake elevation (~4,000 feet amsl) and the groundwater elevation (~4,500 feet amsl) on the east side of the pit is therefore ~500 feet. Accounting for a factor of safety for maintaining a pit lake, with no backfill, at the predicted equilibrium elevation of ~4,000 feet amsl, is therefore ~500 feet.

Where the groundwater levels on the down-gradient side of the pit ultimately equilibrate is dependant on the water balance, the hydrogeologic properties of the rocks, and the final lake stage. Pit backfill can be used in an attempt to mange the final lake stage and the factor of safety.

In order to maintain a terminal-sink pit lake in combination with a partially backfilled pit, the maximum backfill elevation would need to be determined above the predicted lake stage of
~4,000 feet amsl. The backfill level would be something less than 500 feet above the predicted lake stage. Maintaining a high safety factor would entail a backfill level closer to an elevation of ~4,000 feet amsl. The safety factor diminishes as the backfill elevation approaches ~4,500 feet amsl. The highest factor of safety against creating a flow-through condition is achieved by not adding any backfill to the pit.

Assuming a factor of safety of 300 feet (pit backfill to ~4,300 feet amsl) may be appropriate based on the level of uncertainty in the analysis and the potential for short or long-term changes in climate. In this case, the drawdown at the pit would be approximately 20% (200 feet) less (800 feet vs. 1000 feet) than the no-backfill scenario. This reduction in drawdown would decrease groundwater inflow, but comparatively increase evaporation losses, so the net reduction in groundwater consumption would be less than 20%.

In the Quick-Fill option, less water will be withdrawn from aquifer storage and equilibrium conditions could be obtained in less time. This option, however, is unlikely to significantly affect the drawdown magnitude and the long-term water consumption associated with the pit lake.

The Managed Stormwater Inflow option is a variation of the Quick-Fill option and has the potential to further accelerate refilling of the pit lake. Inflows need to be managed to avoid creating a flow-through condition or over-flow condition. Stormwater inflows greater than that lost to evaporation will raise pit lake levels. The unpredictable timing and magnitude of stormwater runoff events would need to be considered in this option. Temporary flow-through conditions could be created if the rate of inflow creates a lake level higher than the groundwater divide (Figure 5). The use of managed stormwater inflow will require calibration in order to maintain an adequate safety factor against developing flow-through conditions.

6.0 Summary

The most important consideration when managing a post-mining pit lake is whether a flow-through pit or a terminal-sink is desired. In the case of the Rosemont Project, maintaining a terminal-sink pit lake condition is desired.

Based on groundwater modeling results (M&A, 2009), a terminal-sink pit lake is expected to form. Even though geochemical modeling has indicated that the pit lake water quality would resemble that of local groundwater (Tetra Tech, 2010a) and that any potential seepage from the other major facilities would have measured constituents mostly below Arizona Aquifer Quality Standards, maintaining a terminal-sink condition is desired. Maintaining a terminal-sink condition provides tertiary containment of these major facilities at closure. Additionally, pit lake predictive geochemical modeling has not been performed assuming any pit backfill scenarios. The desire to maintain the Rosemont Open Pit as a hydraulic sink eliminates backfilling above or close to the pre-mining groundwater elevations.

In terms of partial backfill or other pit lake management approaches, the following options are available:

- Partial backfill;
- Quick-Fill; and
- Managed stormwater inflows.
Partially backfilling the pit is not expected to result in significantly different groundwater levels. After active dewatering ceases, drawdown will continue to propagate down-gradient through the groundwater flow system, even while water levels in the pit area are recovering. Depending on the final partial backfill elevation, a 20% reduction in the equilibrated drawdown elevations around the pit may be achieved. A reduction in short-term groundwater inflows would also be achieved by the partial backfill option.

Quick-Fill may result in reaching equilibrium conditions sooner than the other approaches, but it would not significantly impact the long-term drawdown impacts.

Depending on actual precipitation and inflow conditions, the Managed Stormwater Inflow option could be used to reduce groundwater inflow to the pit. This alternative would require grading the post-closure mine area so that the desired surface area contributes a predictable and manageable volume of stormwater runoff into the pit.

In all partial backfill and pit lake management approaches, an appropriate factor of safety is the key to maintaining a terminal-sink condition. The factor of safety refers to the difference between the pit lake water surface elevation and the elevation of the down-gradient groundwater divide. Considering all the partial backfill and other management alternatives, the Managed Stormwater Inflow option has the greatest potential for variability in terms of affecting the pit lake elevation, and thus the highest chance for flow-through conditions to occur. Selection of the stormwater management area is therefore critical to this option.

7.0 Conclusions

Backfilling above or close to the pre-mining groundwater elevation does not allow Rosemont to maintain the desired condition of having a terminal-sink pit lake and maintaining tertiary containment of the post-mining facilities. Additionally, partially backfilling the pit is not anticipated to have a large effect on the overall groundwater drawdown conditions since a sufficient vertical distance or safety factor must be maintained between the pit lake elevation and the down-gradient groundwater divide.

Assuming a limited application period, the Quick-Fill option has the opportunity to reduce short-term groundwater inflows to the pit until equilibrium conditions are achieved. This option, however, does not significantly effect the overall groundwater drawdown.

The Managed Stormwater Inflow option has the opportunity to replace water lost to evaporation for a longer period than the Quick-Fill option. Over the long-term the Managed Stormwater Inflow option may reduce groundwater inflows to the pit. As with the partial backfill and Quick-Fill scenarios, a large reduction in the overall groundwater drawdown is not anticipated. In this scenario, however, managing stormwater inflows to the pit is a key design component in order to maintain an appropriate safety factor or elevation difference between the maximum anticipated pit lake elevation and the elevation of the groundwater divide.

8.0 References


Figure 1:
Conceptual View of Rosemont
Pre-mining Conditions
\[ \Delta \text{Pit Lake Volume} = l_{\text{precip}} + l_{\text{runoff}} + l_{\text{pit runoff}} + GW_{\text{inflow}} - E_{\text{pit}} - GW_{\text{outflow}} \]

- Direct Precipitation ($l_{\text{precip}}$)
- Pit Wall Runoff ($l_{\text{pit runoff}}$)
- Upgradient Runoff ($l_{\text{runoff}}$)
- Evaporation ($E_{\text{pit}}$)
- Groundwater Inflow ($GW_{\text{inflow}}$)

$GW_{\text{outflow}} = 0$

Figure 2: Conceptual Hydrologic Model for a Terminal Pit Lake
\[ E_{\text{pit}} + G W_{\text{outflow}} = G W_{\text{inflow}} + I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}} \]

**Figure 4:**
Flow-through Pit Lake, No Backfill
$E_{\text{pit}} + G W_{\text{outflow}} = G W_{\text{inflow}} + I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}}$
\[ E_{\text{pit}} \approx G W_{\text{inflow}} + I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}} \]

\[ G W_{\text{outflow}} = 0 \]

**Figure 6:**
Pit Lake Levels Near Partial Backfill Level
\[ E_{\text{pit}} > G W_{\text{inflow}} + I_{\text{precip}} + I_{\text{runoff}} + I_{\text{pit runoff}} + \text{Quick-fill water} \]

\[ G W_{\text{outflow}} = 0 \]

Figure 7:
End of Mining Quick-fill Alternative
$E_{pit} > GW_{inflow} + I_{precip} + I_{runoff} + I_{pit\ runoff} + \text{Quick-fill water}$

$GW_{outflow} = 0$

**Legend**:

- $I_{runoff}$ = Runoff
- $I_{precip}$ = Precipitation
- $E_{pit}$ = Evaporation
- $I_{pit\ runoff}$ = Pit wall runoff
- $= \text{Groundwater inflow}$
- $= \text{Groundwater flow}$
- $= \text{Groundwater table}$
- $= \text{Saturated pit backfill}$
- $= \text{Pit backfill}$

*Figure 8: Managed Surface Inflow Option*