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Technical Memorandum

To:	Kathy Arnold	**From:**	Grady O'Brien (EA) & Paul Ridlen (Tt)
Company:	Rosemont Copper Company	**Date:**	May 18, 2011
Re:	Additional Rosemont Response to FS/BLM Comment ES-1 on Tetra Tech Groundwater Model	**Doc #:**	114/11-320878-5.3
CC:	David Krizek, P.E. (Rosemont Copper)		

1.0 Introduction

Rosemont Copper Company (Rosemont) received review comments on both the Montgomery & Associates (M&A) and Tetra Tech groundwater flow models in a letter titled "Groundwater Modeling for the Rosemont Copper Project Environmental Impacts Analysis", dated April 5, 2011 (Attachment 1). This letter was the follow-up to a meeting held in February 2011 between Rosemont's groundwater modeling consultants, the United States Forest Service (FS), the Bureau of Land Management (BLM), and their contractors.

Rosemont provided responses to the April 5, 2011 comment letter on May 6, 2011. The FS has requested additional responses to comment ES-1. This Technical Memorandum attempts to respond to our understanding of the verbal FS request.

The original ES-1 comment provided in the FS Letter is restated in Section 2.0 and followed by an expanded response.

2.0 Forest Service ES-1 Comment with Expanded Tetra Tech Response

ES-1 Comment. FS: *Describe in detail why constant and/or general head boundaries are employed on the model periphery, why the results of the model are not affected or minimized by them, and why basin boundaries were not utilized rather than the rectangular configuration in the current models. Please provide examples and references of any other projects which have handled boundaries in a similar manner. If it is necessary to show flux out of the model boundary on the west, and it is deemed that the best way to represent this is with a general head or constant head boundary, then the use of these boundary types should be limited to the region of outflow, rather than generally applied to the model periphery.*

ES-1 Response. The Tetra Tech groundwater flow model domain was consistent with the previously established M&A groundwater flow model domain (M&A, 2009; M&A, 2010). The model study area boundary was established by M&A to encompass the Project area and to extend past areas that could potentially be impacted by the Project. Changing the external model boundary locations was not feasible for the Tetra Tech model since the foundational geologic data was limited to the M&A model domain.

As the reviewers suggest, topographic basin boundaries are commonly used to define groundwater model boundaries. These basin boundaries are used as a convenience and can represent no-flow conditions or flow conditions where water enters and leaves the model. There are numerous modeling methods for simulating these inflows and outflows and the most appropriate method depends on the specific application. In all modeling cases the intent is to minimize the influence of the model boundaries on the model predictions and to appropriately simulate changes in flow at the boundaries. The reviewers also suggest that the external model boundaries should be simulated as no-flow boundaries or should only allow outflow from the model. The following discussion provides the basis for using flow boundaries rather than no-flow boundaries or only allowing outflow.

In arid and semi-arid basins like those found in the western United States, topographic divides that define surface-water drainages may or may not define the underlying groundwater basins. Numerous groundwater flow models have used topographic surface-water basin boundaries and these boundaries are often simulated as flow boundaries, not as no-flow boundaries. The Death Valley Regional Flow System Model (D'Agnese and others, 2002, pages 36-39, 49-50); Belcher and Sweetkind, 2010, pages 99-100, 114-116, 128-129, 258, 275, 319-324, 333-337) and the Albuquerque Basin model (Kernodle and others, 1995, pages 11-13, 16-17; Thorn and others, 1993, pages 80-86, 90-93) are major groundwater studies that simulated groundwater flow into and out of the model along basin boundaries using head-dependent boundaries.

The Rosemont model domain consists, in general, of low permeability fractured bedrock and basin-fill deposits. Although the bedrock has low permeability and in some projects could be simulated as a no-flow boundary, this was not appropriate due to the Rosemont model objectives that required simulation of impacts due to pit dewatering. Reilly (2001, page 9) states that "no earth material is completely impervious to water. Many earth materials, however, have very low hydraulic conductivities and thus contribute relatively small amounts of water to adjacent permeable ground-water systems." No-flow boundary conditions may be appropriate to simulate groundwater divides under steady-state conditions with no applied stresses. However, no-flow boundaries do not allow the groundwater divide to move in response to a stress (Reilly, 2001, page 13). Furthermore, ASTM (2002, page 3) states that "the locations of ground-water divides depend upon hydrologic conditions in the sense that they can move or disappear in response to stress on the system. For these reasons, ground-water divides are not physical boundaries of the flow system." The predicted extent of drawdown due to pit dewatering was unknown at the start of the Rosemont regional modeling project, Tetra Tech determined that using flow boundaries was an appropriate approach for simulating the variable physical conditions represented by the M&A boundary locations.

In the same manner as the Death Valley and Albuquerque Basin models, inter-basin flow and potential changes at the external model boundaries were simulated using constant-head cells to account for flow into and out of the model domain under steady-state and transient conditions. Tetra Tech's modeling approach followed that suggested by Reilly (2001, page 2), which states "During the simulation process, the extent of the model, the conceptualization of the flow system, and mathematical representation of the boundaries is continually checked and evaluated to ensure the representation of the system captures the essence of the actual ground-water system." Ultimately, the simulations and sensitivity analysis (as described below) indicated that the use of constant-head cells for the external model boundary did not result in underestimation of potential impacts. The essence of the flow system was captured even though basin boundaries were not used.

The low permeability and low storage granodiorite along the western boundary limits groundwater capture west of the pit and results in drawdown propagating to the east. A no-flow model boundary along the Santa Rita Mountain topographic divide is inappropriate due to its proximity to the pit, which will result in migration of the steady-state groundwater divide during mining and post-closure simulations (Reilly, 2001, page 13). Simulating the western model boundary as a specified-head condition (general head or constant head) allows the Santa Rita Mountain groundwater divide to be lowered and to migrate west in response to pit dewatering. Simulating the western boundary further to the west into the Santa Cruz basin would not remove the hydrogeologic influence of the Santa Rita Mountain's low permeability granodiorite that limits drawdown propagation to the west.

The steady-state potentiometric surface was used to define the hydraulic head elevations at the model boundaries. The potentiometric surface was contoured inside and outside of the model domain so that the natural hydraulic gradients and flow directions would be maintained within the model boundary cells. The majority of the boundary reaches and particularly the reaches near sensitive areas have water leaving the model domain. Flow rates through some of the constant-head cells reaches decreased during the mining and post-closure simulations, but flow direction did not reverse for any reaches or simulations. Changes in inflow to the model domain were negligible during all simulations. Flow rates and directions for constant-head cell reaches for steady-state, mining, and post-closure conditions are provided in response to comment ES-3. These results indicate that the constant-head cells did not reduce the predicted impacts.

Sensitivity analyses were also performed to determine whether the constant-head cells on the western model boundary were inappropriately influencing the predicted impacts, which is an accepted modeling protocol (ASTM, 2002, page 3). First, the western model boundary was simulated as a no-flow boundary, but the model would not converge due to very high simulated hydraulic heads along this boundary. As Reilly (2001, page 9) states, true no-flow conditions do not exist in nature, particularly in this area with large hydraulic gradients. This simulation confirmed that groundwater flow out of the western model boundary is required to have a stable numerical simulation.

The western model boundary was also simulated with general head cells with a conductance term based on extending the boundary ½-mile to the west. Predicted drawdown and western model boundary fluxes were virtually unchanged between the constant-head and general-head boundary conditions. Based on the results of this sensitivity analysis, it was determined that the use of constant-head cells was adequate.

Simulation results with the general head (GHB) and constant head boundaries (CHB) were similar since both mathematical representations are head-dependent flow boundaries. Conceptually, the GHB represents a "leaky" boundary with a layer of material that provides resistance to flow between the interior model cells and the specified head at the boundary. In the Rosemont model case, the GHB conductance term was used to simulate basin-fill deposits occurring to the west of the bedrock unit. Conceptually, this approach extends the model domain to the west and away from the pit, but there is a limitation on how far to extend the boundary since the basin fill's hydraulic gradient is much smaller and water levels lower than within the bedrock located at the model boundary.

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REFERENCES

ASTM (2002). Standard Guide for Defining Boundary Conditions in Ground-Water Flow Modeling. Designation: D 5609-94 (Reapproved 2002).

Belcher, W. R. and Sweetkind, D.S. eds., (2010). Death Valley regional ground-water flow system, Nevada and California -- Hydrogeologic framework and transient groundwater flow model: U.S. Geological Survey Professional Paper 1711, 398 p.

D'Agnese, Frank A.; O'Brien, G. M.; Faunt, C. C.; Belcher, W. R.; San Juan, C. (2002). A three-dimensional numerical model of predevelopment conditions. in the Death Valley regional ground-water flow system, Nevada and California. U.S.Geological Survey Water-Resources Investigations Report 2002-4102.

Kernodle, J.M., McAda, D.P., and Thorn, C.R. (1995). Simulation of ground-water flow in the Albuquerque Basin, central New Mexico, 1901-1994, with projections to 2020: U.S. Geological Survey Water-Resources Investigations Report 94-4251, 114 p.

Reilly (2001). System and Boundary Conceptualization in Ground-Water Flow Simulation. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Application of Hydraulics, Chapter B8. 29 p.

Thorn, C.R., McAda, D.P., and Kernodle, J.M. (1993). Geohydrologic framework and hydrologic conditions in the Albuquerque Basin, central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 93-4149, 106 p.

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Memorandum

To:	Beverly Everson
Cc:	Chris Garrett
From:	Kathy Arnold
Doc #:	062/11 – 15.3.2
Subject:	**Transmittal of Technical Memoranda**
Date:	May 19, 2011

Rosemont Copper is transmitting the attached memoranda responding to questions raised at our meeting on May 13.

- *Second Response to April 5, 2011 Selected Comments Provided by U.S Forest Service Regarding Groundwater Flow Modeling Conducted for the Rosemont Project*, Montgomery and Associates memorandum dated May 17, 2011
- *Additional Rosemont Response to FS/BLM Comments ES-1 on Tetra Tech Groundwater Model,* Tetra Tech memorandum dated May 18, 2011

These memoranda are being transmitted in electronic form via email only. Please let me know if you require additional hardcopy versions of these documents.

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Memorandum

To: Bev Everson
Cc: Chris Garrett
From: Kathy Arnold
Doc #: 090/11-15.3.2
Subject: **Transmittal of Technical Data in Hard Copy and CD Format**
Date: 6 September 2011

Rosemont Copper Company is having delivered by courier, the following materials in hard copy and cd format as were previously submitted electronically:

- *Second Response to April 5, 2011 Selected Comments Provided by U.S. Forest Service Regarding Groundwater Flow Modeling Conducted for the Rosemont Project,* Montgomery & Associates, May 17, 2011
- *Equipment Emissions*, Summary, Empire CAT, June 27, 2011
- *Rosemont Pit Backfill Simulation*, Montgomery & Associates, August 18, 2011
- *Pit Backfill Simulation,* Engineering Analytics, Inc., Technical Memorandum, August 17, 2011
- *Predicted Groundwater Level Drawdown 20 Years after End of Operations (Layer 17),* Engineering Analytics, Inc., Maps, August 2011
- *Comments Regarding Memorandum Safety Bench Alternatives for Rosemont Pit Walls on Face of Santa Rita Mountains,* Call & Nicholas, Inc., Memorandum, July 8, 2011
- *Response to Golder Commments on Drop Chutes – Site Water Management Update Report,* Rosemont Copper Company, Memorandum, June 8, 2011
- *Response to SRK Pit Lake Comments,* Rosemont Copper Company, Memorandum, May 13, 2011
- *Predicted Regulatory (100-Yr) Hydrology and Average-Annual Runoff Downstream of the Rosemont Copper Project,* Tetra Tech, Technical Memorandum, July 21, 2011
- *Rosemont Facility Infiltration and Seepage Response to Comments,* Tetra Tech, Technical Memorandum, April 22, 2011
- *Response to Comments – Infiltration, Seepage, Fate and Transport Modeling,* Tetra Tech, Technical Memorandum, June 9, 2011
- *Additional Rosemont Response to FS/BLM Comments ES-1 on Tetra Tech Groundwater Model,* Tetra Tech Technical Memorandum, May 18, 2011
- *Response to PCRFCD Comments Regarding Hydrology,* Tetra Tech, Technical Memorandum, August 18, 2011

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- *Rosemont Facility Fate and Transport Modeling Response to Comments,* Tetra Tech, Technical Memorandum, May 16, 2011
- *Pima Pineapple Cactus Survey for the Rosemont Mine Southern Utility Line Alternative, East of Sahuarita, Pima County, Arizona,* WestLand Resources, Inc., August 13, 2010
- *AERMOD Modeling Analyses for the Alternatives to the Proposed Action for the Rosemont Copper Project,* Applied Environmental Consultants, August 15, 2011
- *Response to Golder Comments,* Rosemont Copper Company, Technical Memorandum, May 6, 2011
- *Misc. Docs. Submitted via Email,* Rosemont, September 2011 CD

Please do not hesitate to contact me should you require anything further.