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C.H. HUCKELBERRY
County Administrator

March 9, 2011

Jim Upchurch, Forest Supervisor
Coronado National Forest
300 W. Congress Street
Tucson, Arizona 85701

Re **Groundwater Impacts of the Proposed Rosemont Mine**

Dear Mr. Upchurch:

Pursuant to our Cooperator status, the Pima County Regional Flood Control District engaged the services of a qualified expert, Dr. Tom Myers, in reviewing recently revised groundwater models for impacts that would be caused by open-pit copper mining on the flank of the Santa Rita Mountains. Dr. Myers' technical memorandum (Attachment 1) was transmitted to your staff on February 17, 2011 for use in your deliberations regarding the water resource impacts.

There are now three different models representing the potential outcome of the mining activity on the aquifer conditions in the vicinity of the mine. Two of the models were prepared by Rosemont Copper, and one was prepared by Dr. Myers himself. All three models show that open-pit mining would cause profound lowering of the aquifer and reversals of the direction of groundwater movement near the pit and that these impacts would continue to spread outward, expanding in geographic extent for many human lifetimes after the mining and pumping would cease.

The models differ in some fundamental ways, however. Rosemont Copper's models limit impacts to groundwater-dependent ecosystems on Las Cienegas National Conservation Area, and to Davidson Canyon with several assumptions. Both of Rosemont's models assume the pit impacts would extend across the crest of the mountains, in effect diverting groundwater from the Tucson basin toward the pit's cone of depression (see attached map of 50-year projection). If this were true, not only could springs, wells and streams near

Helvetia and Sycamore Canyons be affected, but the mine could also affect the fundamental processes of natural recharge, reducing one component of the water budget to the Tucson Active Management Area for many generations to come.

Another difference is that the model proposed by Rosemont's consultant Tetra Tech assumes a dike crossing Davidson Canyon will limit the impacts of the mine on well owners down gradient of the dike (Attachment 2). In over 30 years of groundwater studies of the area, no previous groundwater consultant has proposed such a barrier to groundwater movement.

Obviously, the three models show there are some very large uncertainties associated with the potential impacts of the mine. Additional work is needed to determine if the assumptions made by Rosemont's consultants can be supported. As stewards of various water-related resources, the federal agencies have the duty to understand the potential impacts. The Forest Service has been entrusted with the care of spring-fed wetlands, streamside vegetation and caves on Forest land as described in your organic act and subsequent federal legislation and as codified.

Pima County supports the recommendations for additional research contained in the attached report. We have also asked for an opportunity to discuss the information at a future meeting of the Cooperators.

Sincerely,

C.H. Huckelberry
County Administrator

CHH/mjk
Attachments

c: The Honorable Chairman and Members, Pima County Board of Supervisors
Tom Dabbs, Gila District Manager, Bureau of Land Management
Marjorie Blaine, US Army Corps of Engineers
Jason Douglas, Fish and Wildlife Biologist, US Fish & Wildlife Service Tucson Office
Michael Fulton, Water Quality Division Director, Arizona Department of Environmental Quality
Suzanne Shields, Director, Regional Flood Control District
Nicole Fyffe, Executive Assistant to the County Administrator
Julia Fonseca, Environmental Planning Manager
Diana Durazo, Staff Assistant to the County Administrator

ATTACHMENT 1

Technical Memorandum

Review of the Proposed Rosemont Ranch Mine

Groundwater Models

Prepared for Pima County and Pima County Regional Flood Control District

January 29, 2011

Prepared by:
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The mining company, Rosemont Copper, has recently revised its numerical groundwater model completed by Errol L. Montgomery and Associates (M&A) and has also had Tetra Tech, complete a new groundwater model in support its environmental analysis for its proposed mine. This technical memorandum reviews these model reports:

- Montgomery and Associates, 2010. Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure Volume 1: Text and Tables, Rosemont Project, Pima County, Arizona, Revised Report, August 30, 2010. Montgomery and Associates, Tucson AZ – M&A (2010)
- Tetra Tech, 2010. Regional Groundwater Flow Model, Rosemont Copper Project. November, 2010. Tetra Tech, Denver, CO. – Tetra Tech (2010a)

In addition, this technical memorandum contrasts these groundwater flow model reports with previous groundwater assessments and reviews completed by this author, as follows:

Myers, T., 2010c. Technical Memorandum, Updated Groundwater Modeling Report, Proposed Rosemont Open Pit Mining Project. Prepared for Pima County and Pima County Regional Flood Control District. April 21, 2010.

Myers, T., 2008. Hydrogeology of the Santa Rita Rosemont Project Site, Numerical Groundwater Modeling of the Conceptual Flow Model and Effects of the Construction of the Proposed Open Pit. Prepared for Pima County Regional Flood Control District, April 2008.

Myers, T. 2007. Hydrogeology of the Santa Rita Rosemont Project Site, Conceptual Flow Model and Water Balance, Prepared for: Pima County Board of Supervisors, August 8, 2007.

This technical memorandum is organized as follows:

1.0 Summary and Comparison of Models
2.0 Montgomery and Associates Model
  2.1 Model Structure, Domain, and Boundaries
  2.2 Recharge
  2.3 Transient Calibration
  2.4 Parameter Zones
3.0 Tetra Tech Model
  3.1 Conceptual Model
  3.2 Groundwater Model Development
  3.3 Calibration
  3.4. Prediction of Drawdown and Long-term Pit Lake Development
4.0 References

1.0 SUMMARY AND COMPARISON OF MODELS

This section summarizes the differences between and shortcomings of the Tetra Tech (2010a) and M&A (2010) models. It also refers to and compares with similar features in the Myers (2010c, 2008) model.

The M&A and Tetra Tech models have similarities and differences. Some of the differences in models result in major differences in the predictions made with these models. Most of the differences result in the Tetra Tech model simulating less extensive impacts due to dewatering the proposed pit than were simulated with the M&A model.

- The Tetra Tech model includes a horizontal flow barrier (HFB) simulating the quartz-porphyry dike damming off the groundwater flow from the upper reaches of Davidson Canyon to the lower parts. Neither M&A nor Myers included this feature and it is not supported by the data. Comparisons of drawdown figures show that it limits the extent that drawdown reaches down Davidson Canyon.
  - *Without specific data showing the hydraulic effect of this feature, Tetra Tech has not justified its use; at present, the model is a good interpretative model of what would occur <u>if there were</u> an impervious and horizontally and vertically continuous dike at that location. Specific data could include cores of the dike, geophysical tests, or aquifer tests with monitoring wells up- and downgradient of the dike.*

- The M&A model directly simulated the new Backbone and Flat Faults with specific parameter zones to simulate these features. The primary difference between the conceptualization of these parameter zones with the other zones in the model was in

anisotropy – M&A allowed for a higher north-south and vertical conductivity. The vertical conductivity allowed recharge to circulate more deeply, which is supported by the idea that the Questa Spring has 1000-year old water. Both Tetra Tech and Myers had conductive zones on the west side of the proposed pit, but neither specifically analyzed this as a feature; nor did they consider the Flat Fault.

- *Simulating these features is justified by the data; its effect on the long-range predictions is unclear.*

- Tetra Tech's model allows much more groundwater inflow through its boundaries than did M&A, although each model had boundaries in the same locations.
  - *Tetra Tech did not appropriately constrain its calibration with flow data which allows this additional groundwater inflow. The simulation of this excess groundwater inflow is not supported by any data or geologic mapping.*
  - *The inflow should be constrained by an estimate of recharge that would have occurred between the model domain boundary and the basin boundary.*
  - *The excess groundwater inflow in the Tetra Tech model may limit the expansion of drawdown into the Cienega Basin.*

- Tetra Tech has much more steady state recharge near and above the pit than does M&A. They simulated in excess of 0.53 in/y all along the crest; they essentially forced water into non-receptive bedrock. M&A had simulated similar rates over the Backbone fault but near-zero rates over the granodiorite (pCb) outcrops along the crest of the Santa Rita Mountains. Myers' rates were high near the fault zone but very low south along the ridge near the granodiorite outcrops.
  - *The extra recharge as simulated by Tetra Tech provides more water nearer to the proposed pit. This extra water entering the pit area from the west would limit help to fill the groundwater deficit created by dewatering and pit development. It may limit the extent that drawdown moves downgradient into Davidson Canyon.*

- The simulation of recharge near and through the mine facilities is a large difference between Tetra Tech's and M&A's model. Tetra Tech has reasoned there would be about 75 af/y more recharge after mining than before mining; M&A has reasoned that recharge will decrease by a similar amount.
  - *Both estimates are inaccurate, but Tetra Tech's estimate provides additional water that helps to satisfy the pit lake deficit which decreases the predicted impacts due to pit lake development downstream in Davidson Canyon.*

- The Tetra Tech and M&A models used the same rectangular domain with head-controlled flux boundaries on most sides.

- *Most modeling guidance suggests that the boundaries of a model should be at a point where conditions are known; usually this means the boundaries coincide with a topographic divide or significant change in formation. The ideal is for the boundaries to be a flow line, except for specified inflow and outflow reaches at locations where the flow is constrained.*
- *M&A and Rosemont should implement a much more extensive analysis of the intrusive rock formations west of the pit to determine whether impacts will extent westward, or not, and whether the model boundary should be on the topographic divide.*
- *Myers had modeled the region between the topographic divides, and this would have been preferable for both Tetra Tech and M&A because it is preferable to simulate boundaries at locations where conditions are known.*

- Both models used the same grid discretization, however 200-foot spacing near the pit may be more detailed than the understanding of the hydrogeology justifies. Smaller grid spacing should not be interpreted as providing more accurate or more precise model results.

- M&A used ten and Tetra Tech used twenty model layers. The only advantage Tetra Tech gained would be improved mathematical solution near the pit whether the gradients are steep.
  - *It is not likely they know the details of the formations accurately enough to justify the vertical precision added by the additional layering. Even if they did know the formation depths and thicknesses perfectly, they assumed the same parameter values applied to the entire formation, so they did not take advantage of the additional precision obtained by detailed geologic mapping.*

- Both the Tetra Tech and M&A models are run for 1000 years after which time the pit lake is close to equilibrium. Myers (2010) ran his model for 7500 years after which the pit lake level is essentially stable at a level about 300 feet lower than the other two models. Myers' water level is lower because he simulated more volume at depth in the pit lake.

- Each model based their parameter zones on the ten hydrogeological units determined from the geologic mapping. Tetra Tech determined just one parameter zone for each unit, adding just two during calibration – for the Backbone fault and for basin fill in the Tucson basin. M&A allowed the parameter values to vary within a zone.
  - *Because there are sufficient monitoring wells to justify this and to achieve an adequate solution to the solver, this is preferable and gives a more accurate representation. Myers divided his original zones into 36 units.*

- *The following table suggests that Myers's steady state solution was more accurate, based on the absolute value of the standard deviation. The percent that standard deviation was of the range was not as low for Myers because his simulation did not include the low elevation areas in the Tucson basin, so the range was just 1100 feet.*

Statistic	M&A (2010)	M&A (2009)	Tetra Tech (2010a) *	Myers (2008)
Residual Mean (feet)	26.2	11.3	-1.18	-4.8
Absolute Res. Mean (feet)	58.0	61.0	97.7	
Standard Deviation (feet)	80.6	90.3	133.1	49.7
Std. Dev./Range of Obs Data (%)	2.8	2.8	4.6	4.5
* - unweighted calibration				

- The Myers model is most unique because it was constrained for flow into and out of the domain. The other two models could have had the same calibration statistics with different flows because the inflow was not constrained.

The predicted drawdown cones for mine dewatering and pit lake development provide a vivid example of how the differences between the models affect the simulation results.

- Tetra Tech Figures 8-5, -10, -11, -12, and -13 show the 100-, 10-, and 5-foot drawdown contours for the end of mine and 20, 50, 150, and 1000 years after mining. M&A Figures 110, 111, 112 and 113 show drawdown contours at the end of mining, and 20, 150, and 1000 years after mining ceased.

- At the end of mining, the Tetra Tech model had predicted the 5-foot drawdown had expanded further than had the M&A model. Tetra Tech's 5-foot drawdown contour approached the dike and contained the Questa Spring. However, the M&A 100-foot drawdown contour had extended further north along the ridge than had the Tetra Tech 100-foot drawdown contour.

- Twenty years after mining had ceased, the Tetra Tech drawdown, defined by the 5-foot drawdown, continues to be more expansive than in the M&A model. It has reached the quartz-porphyry dike. However, the M&A 100-foot drawdown contour covers a larger area.

- After 50 and 150 years, the quartz-porphyry dike defines the downstream location of the five-foot drawdown in the Tetra Tech model while in the M&A model the five-foot drawdown has extended about three miles further downstream.

- After a thousand years, the Tetra Tech five-foot drawdown is about a mile past the dike while in the M&A model it is about five miles further downstream, within a mile of Interstate 10. Even after 1000 years, the Tetra Tech 100-foot drawdown is only about half as extensive as is the M&A 100-foot drawdown.

- The drawdown cone is much more circular in the Tetra Tech model for all time periods. This reflects its simpler parameterization with just one conductivity value for each hydrogeologic unit. Tetra Tech did not consider heterogeneity within the parameter zones. M&A drawdown contours are more convoluted, following the different parameter zone values. The M&A results show the drawdown may be more complicated than expected from the simple conceptualization modeled by Tetra Tech.

- Drawdown in both the Tetra Tech and M&A models extends west of the Santa Rita ridge crest. Both the Tetra Tech and M&A models had conceptualized a connection with the west side, even though the granodiorite has low conductivity and the deeply dipping Paleozoic rock in which the pit is constructed may not be connected in a significant way to the formations on the west.
    - Allowing this connection allows the dewatering and pit lake development to draw water from areas west of the ridge that may not in reality be connected to the pit. This extra water provided to the pit introduces a bias in both models and limits the distance the drawdown extends down Davidson Canyon. If the models had not included this connection, the drawdown in Davidson Canyon may have been larger.
    - Myers' model did not simulate this connection because it had set a boundary at the ridgeline based on the geology and topography.

- Myers' model simulated drawdown in Davidson Canyon to about the same distance as did the Montgomery model. His model simulated drawdown further into the Cienega basin than did either of the other models because he simulated more connection between the bedrock and basin fill in that basin; he also constrained the flows through that basin based on the flows through the Narrows – Tetra Tech did not. Because there are no hydraulic data showing no connection – the pump tests were much too short – impacts into Cienega basin could occur.

1.1 Recommendations

Throughout the summary above and the detailed review below, there are many comments and criticisms of the two models prepared for the proposed Rosemont project. The modelers should use these comments in a reconceptualization and reworking of their respective model. There are

three field investigations which Rosement should complete, with their consultants, before finalizing these models.

- The granodiorite intrusive rock west of the pit should be drilled to conceptualize the extent of fracturing. This would verify whether this area should be treated an impervious boundary or as a source of water to the model. Without such investigation, the model boundary west of the pit should be the ridgeline and should be no flow.
- Rosemont should conduct test of the quartz-porphyry dike that crosses Davidson Canyon. This should include several boreholes to assess its density and thickness. The tests should include long-term pump tests with multilevel pumping on one side and multilevel monitoring on the others; the design could be similar to the long-term pump test completed near the pit. This test would help determine at what levels the dike is a flow barrier, if any.
- The long-term pump test should be redone, possibly in multiple stages. The wells should be pumped from specific layers, not over all of the screened lengths and different geologic formations at the same time.

2.0 MONTGOMERY AND ASSOCIATES MODEL

M&A's report (M&A, 2010) is revised from their 2009 model report (M&A, 2009b). The new report and model is much more extensively documented than their 2009 report (279 pages v. 147 pages). Myers (2010b) reviewed the M&A (2009b) model and model report. M&A implemented some of the recommendations from that review into the revised model and report, as noted herein. This section reviews the revised model providing new comments and considerations without substantially repeating the previous review except by comparison to the original model.

In this section, Myers refers to Myers (2010b) and M&A refers to M&A (2010).

M&A does not explain why they revised their original model. In fact, a glaring omission from this report is even a reference to the earlier report, other than that the title includes "Revised". The reference list includes M&A (2009a) and M&A (2009c), but not the original model report, to which this report (M&A) is compared.

2.1 Model Structure, Domain, and Boundaries

The model grid and layers have not changed. The primary grid spacing is 800 feet by 800 feet which telescopes to 200 by 200 feet near the proposed pit. M&A used ten layers with thickness varying from 71 to 2600 feet, but most of the layers were 300 feet (layers 2 through 6) or variable to 700 feet below that. The bottom elevation of layer 10 is approximately 2000 feet below the pit bottom. Layer 1 is both the thinnest and thickest layer because of the substantial relief. The layers slope so that the layer bottom does not intersect the ground surface. Myers had recommended M&A combine the bottom layers but instead they increased the conductivity zones in those layers, which is an acceptable alternative.

The model domain continues to be much too large, as noted by Myers. M&A (p. 4) appears to respond by stating the area is "substantially larger than the Rosemont Project area to enable a better understanding and representation of the hydraulic connection between the fracture bedrock flow system in and around the Rosemont Project area and the surrounding regional groundwater flow system". This reasoning is flawed because the model will reproduce the conceptualization that the modeler implements into it, so the "understanding" they obtain is what they input to the model.

The large domain is mostly rectangular so groundwater may flow through boundaries without control; they used constant head (CHB) or general head boundaries (GHB). *It is preferable to set boundaries at points of estimated flow, such as the Narrows on Cienega Creek (Myers, 2008). The estimated flow through boundaries can and should be a target for calibration, but not the way that M&A modeled it because their boundaries do not constrain the flow. They did not specify a vertical gradient at the boundaries (M&A, p. 65) which means they assume away the observed vertical gradients indicating discharge to surface layers or recharge.*

2.2 Recharge

Recharge is a specified flux boundary which allows the modeler to control the amount and distribution of inflow to the model. The amount applied to a basin or a model is usually determined independent from the model calibration based on various empiric or water balance methods.

M&A (p. 29) estimated that recharge for their model study area equals 10,100 af/y based on the Anderson (1995) method. They also noted that use of the method predicted 10,426 af/y recharge for the Cienega Creek basin. *Myers (2010) explained why that methodology is inappropriate for this site; specifically it was derived for entire basins, not subbasins as it was used here.*

The model study area does not include the entire Cienega Creek basin, but does include parts of the Tucson basin, as can be observed on M&A Figure 2. An entire basin includes the mountain, mountain front, and alluvial basins which have different recharge mechanisms. *Estimating recharge is an additional reason the model domain should coincide with a specific basin.*

M&A states that even though the "model domain does not cover the entire Cienega Creek basin" (M&A, p. 29), it can be assumed that the entire basin recharge will be inflow to the model domain. *M&A should clarify how much of this recharge is in addition to the predicted amount for the model study area , which includes additional area outside of the Cienega Creek basin.*

M&A claimed their model "could not transmit this quantity of flow" (M&A, p. 75) referring to the entire estimate of recharge. *This statement requires much more explanation.* As a result, M&A reduced the estimated recharge by one-third but supposedly maintained the original spatial distribution (M&A, p. 75). The resulting recharge in the revised M&A model is 6500 af/y, a 500 af/y reduction from the 2009 model.

They supposedly distributed the total recharge based on geology, which contradicts the statement that they maintained the original spatial distribution. *M&A should better explain the final distribution.* Distribution of recharge is usually estimated based on precipitation distribution, geology, and soils around the basin. Some precipitation recharges where it falls (distributed recharge) and some as recharge into channel bottoms. Recharge in this study area depends more on geology than on the distribution of precipitation because the geology is highly variable, especially between intrusive and sedimentary rock. Areas along the ridgeline which receive more precipitation are steep and have little recharge capacity. More precipitation at high elevations does not mean more recharge will occur there. M&A reduced the rates to 0.19 and 0.22 in/y (M&A, p. 75). The Backbone Fault zone would allow recharge wherever fractures intersect the surface or the shallow soils on the surface. M&A's Figure 93 shows a narrow zone with higher recharge, 1.36 in/y, just east of the crest but intersecting the west side of the proposed pit. Just east of that fault in the pit area, the recharge is 0.33 in/y. The figure shows the zone through the mine having relatively high recharge decreasing to the east. *It would be better for the recharge to be concentrated in the washes (Myers, 2008) with some of it extending further east even to lower Davidson Canyon.* This would be more "simulated mountain front recharge" which M&A included in the Cienega basin and the Tucson Basin (M&A, p. 61 and 75). *However, the M&A recharge distribution does not obviously bias the result or diminish the predicted impacts.*

Inflow to the model domain through GHBs is additional recharge from within the Cienega basin but outside the model domain. This brings the total recharge to 9009 af/y (M&A, p. 76). There is a large difference in the amount of streamflow that recharges the groundwater; this would be negative flow at stream boundaries. Because the streamflow had resulted from groundwater discharge to the streams, the *percolation of streamflow is secondary recharge which should not be counted as part of the estimated recharge to the basin. The 2009 model simulated 2172 af/y of flow from the streams to the groundwater but this version simulated no flow to the groundwater. This major change in model output should be explained.*

M&A (2010a) Figure 94 (Figure 1) shows the simulated recharge during mining. *Comparison with M&A Figure 93 suggests some significant problems.* If the pit and waste rock area is simulated as having zero recharge, the total recharge in the project area would decrease substantially due to mining; M&A states there is about a 75 af/y decrease to recharge through the mine facilities. At least during mining, there would be recharge through the pit walls. During pit lake formation, recharge would occur through the pit wall above the lake. Simulating no recharge through the waste rock dump implies that the reclamation shuts off seepage. If the rock is placed dry, some years may be required until recharge commences, but recharge would eventually return to pre-mine rates[1].

[1] This review did not include any analyses of seepage through the waste rock. My experience is that modeling of seepage through waste rock has yielded positive estimates of recharge in areas with much less precipitation.

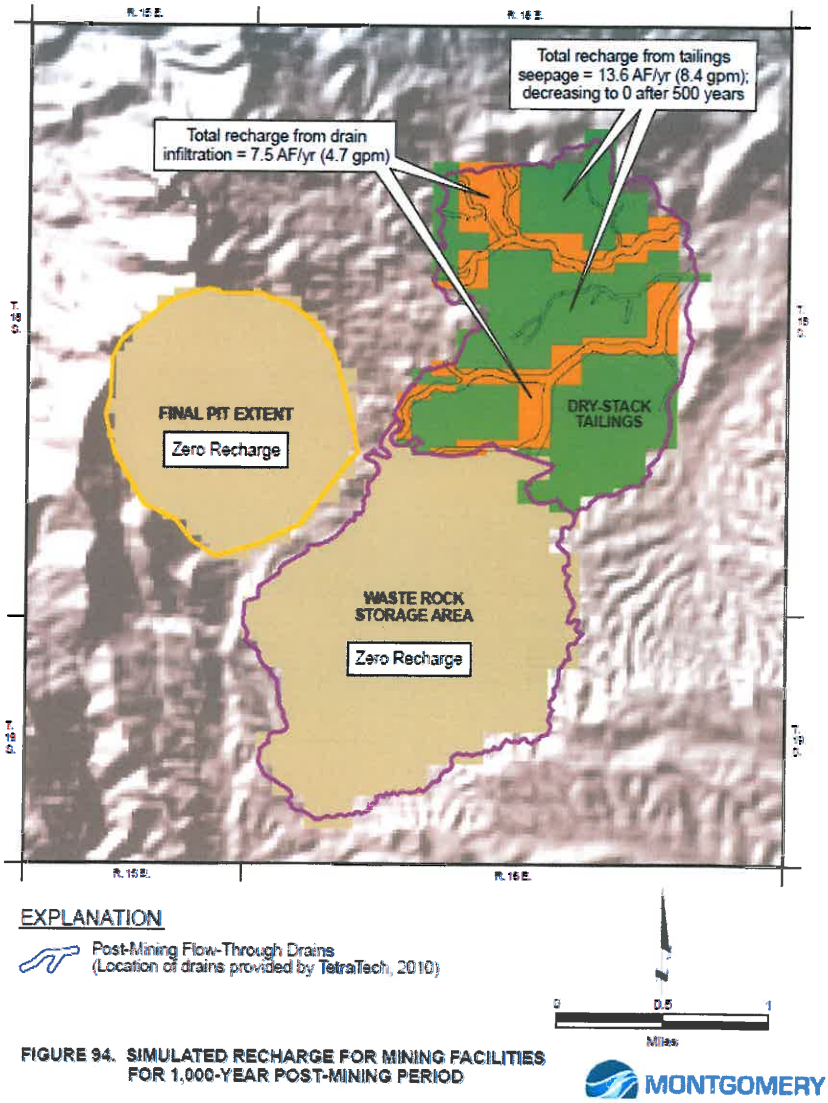

Figure 1: Snapshot of M&A Figure 94 showing recharge through the mine facilities during the post-mining period.

2.3 Transient Calibration

M&A did transient calibration to the multi-well pumping test to set the storage parameters, but had not done so in the 2009 model for which they had used literature values. Myers had recommended they use the long-term pump test for calibration.

They also used the pump tests to refine their conceptual model, which the transient calibration tends to verify. M&A (p. 4 and 9) continued to argue that "long-term hydraulic testing indicates limited hydraulic connectivity". *The long-term pump tests (M&A, 2009a) do not stress the aquifer sufficiently (pumping rate too low) or sufficiently long to make these claims, and there is no other supporting data.* Although I disagree with their lack of consideration of the pump tests for other reasons, Tetra Tech (2010) did not use these pump tests at all for this very reason, as discussed below.

Another problem with the long-term pump tests is the pumped wells are screened in multiple layers. Without knowing the amount of water pumped from a given formation, it becomes difficult to assess the results. *It is also simply not appropriate to conclude based on this test data that drawdown cannot propagate to Cienega Creek or lower Davidson Canyon because the pumping rate was too low and the pumping time too short (M&A, p. 46). The claim that drawdown at PC-6 is equal due to pumping from each well PC-5 and HC-5A (M&A, p. 48) is also inappropriate because the wells pumped at the same time.*

M&A did increase the use of the pump test data, especially incorporating the findings regarding anisotropy as recommended by Myers (2010a). They also used the pump tests for transient calibration, as recommended.

2.4 Parameter Zones

M&A made several important changes in the hydrogeologic units between the 2009 and 2010 model. They used the same ten units as in 2009, but appropriately added two new fault zones as parameter zones, the Backbone and Flat Faults (these names appear to have been created by Rosemont). These zones coincide with recommendations by Myers to consider anisotropic conditions around the pit as caused by faulting. The Backbone Fault is an area of fractured Paleozoic rock west of and in the west half of the pit area; it has significant north-south anisotropy and significant vertical conductivity due to the tilt of the fractured formations (M&A, 2010a, p. 18). The general properties are correctly interpreted (M&A, 2010a, p. 48) with the final conductivity estimate in the model. The Flat Fault is low angled sloping gently to the east. M&A (2010a) simulated these fault zones as parameters in the model that intersect (Figure 2).

The Backbone Fault Zone has conductivity from 0.01 to 0.001 ft/d, about an order of magnitude higher than the surrounding bedrock. A more important difference is that Kx and Ky differ which allows for north-south flow and that Kz is higher allowing for vertical flow. The Flat Fault has much higher conductivity which allows recharge near the ridgeline to flow eastward toward Davidson Canyon. This fault underlies the Willow Canyon formation which performs as a "confining unit" (M&A, p. 19). The fault zone also decreases in conductivity to the east, as it dips beneath the Willow Canyon formation which controls the flow east of the pit and into Davidson Canyon (see all of the M&A geologic cross-sections, Figures 5 through 7) (Figure 1). M&A's (p. 19-20) interpretations of the fault seem correct and are supported by the artesian pressure in PC-2 and PC-5. The statement that the Flat Fault is not a drain is acceptable; if it were a drain it would drain groundwater very deeply beneath the Willow Canyon formation. The presence of relatively high flowing springs would support the concept that it drains flow, and they simply do not exist. Considering that it appears to be dammed on three sides, east, north, and south, there is likely little flow through the zone. M&A's sensitivity analysis (p. 83-86) tested the Flat Fault parameters but found them not to be sensitive to changes, unlike most other parameter zones.

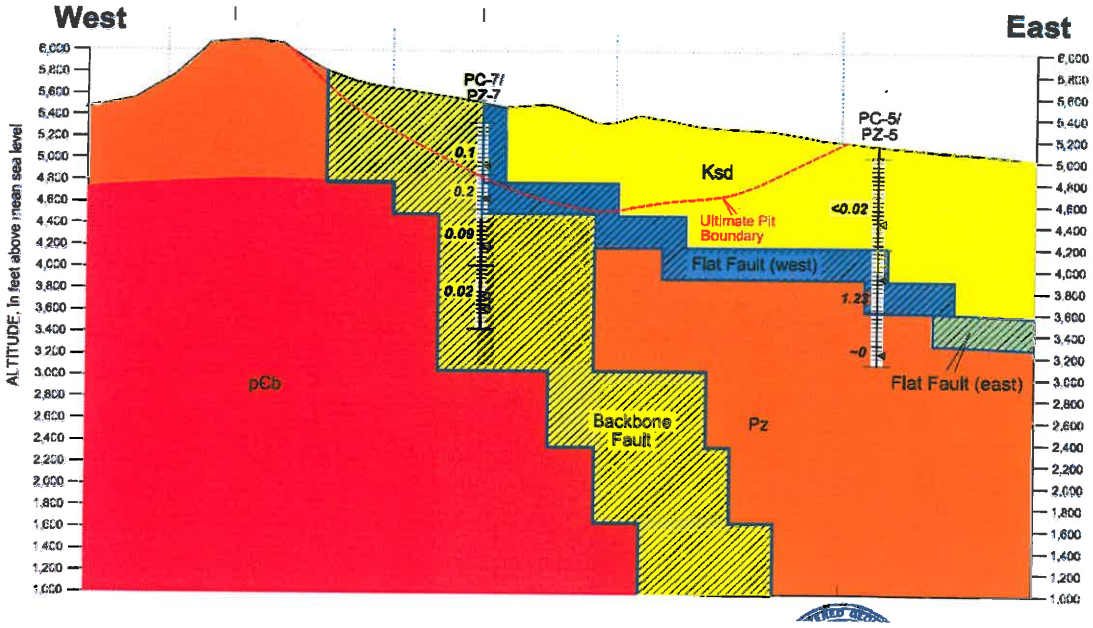

Figure 2: Snapshot of model cross-section from M&A (2010a) Figure 5.

M&A does not simulate the quartz-porphyry dike as Tetra Tech does, and as discussed below in the section regarding the Tetra Tech modeling effort. Ultimately in this model, the Ksd and Kv formations control flow to Davidson Canyon and because their calibrated conductivity is low, the impacts move slowly in that direction. The calibrated conductivity east and northeast of the pit is 0.01 to 0.001 ft/d in the higher elevations and 0.001 to 0.0001 ft/d in the lower model layers. This revised model however does not surround the pit zone with bedrock having conductivity less than 0.0001 ft/d, as criticized by Myers (2010). The Davidson Canyon fault zone is modeled with much higher conductivity in the top four layers (M&A, 2010a, Figures 81-85). The thickness depends on geologic mapping; low conductivity bedrock underlies the fault zone.

The previous discussion partly relied on the artesian pressure noted at depth in some of the wells near the pit. *Yet, M&A did fail to accept the recommendation (Myers, 2010a) that potentiometric maps be prepared for aquifer different layers (M&A, p. 26) as was done by Myers (2007). In other words, to assess vertical gradient and possible flow in different directions with depth, M&A should prepare potentiometric surface maps based on wells screened at different depths.*

Aquifer tests continue to show that conductivity varies throughout the domain (M&A, 2010, p. 15). *Unfortunately, the method of treating conductivity as a parameter that varies evenly over the domain fails to capture the small-scale variability that likely controls flow through the entire project area.*

The Continental Granodiorite rock is a Precambrian rock that outcrops on the ridge and western slopes of the Santa Rita Mountains near the proposed pit. It forms the western edge of the model and certainly has a much lower conductivity than other more fractured rocks. M&A (2010a, p. 17) considers the granodiorite rock to be a flow barrier "except where fractured or faulted". The

extent of faulting is very important to this project and to the model. It controls whether the project will affect flows on the west side of the ridge. M&A found the model results highly sensitive to the conductivity values for this parameter (p. 83-86). *M&A and Rosemont should implement a much more extensive analysis of this rock formation to determine whether impacts will extent westward, or not.*

M&A changed the calibrated hydraulic conductivity values substantially from the 2009 model to the 2010 model; compare Figures 81-90 in the 2010 report with Figures 27 to 36 in M&A (2009). Calibrated hydraulic conductivity has changed significantly in the model bottom layers, as Myers had recommended; that review noted that the bottom four layers in M&A had very low conductivity and very little flow circulating through them.

3.0 TETRA TECH MODEL

The Tetra Tech model has similarities to the M&A model, but also some substantial differences. The two were compared in section 1.0. A couple of obvious similarities include use of the hydrogeologic units, recharge estimate, and grid layout. That is where the similarities end.

Tetra Tech (2010a) describes the conceptual model including components as general hydrogeology, groundwater/surface water interactions, groundwater model boundaries, recharge, ET, groundwater pumping, and groundwater and surface-water fluctuations. They had previously documented the development of the model in a series of technical memoranda.

- Tetra Tech, 2010. Technical Memorandum, Groundwater Flow Model Construction and Calibration. July 26, 2010.
- Tetra Tech, 2010. Technical Memorandum, Hydraulic-Property Estimates. July 9, 2010.
- Tetra Tech, 2010. Technical Memorandum, Hydrogeologic Framework Model. July 9, 2010.
- Tetra Tech, 2010. Technical Memorandum, Predictive Groundwater Flow Modeling Results. July 30, 2010.
- Tetra Tech, 2010. Technical Memorandum, Rosemont Groundwater Flow Model Sensitivity Analyses. August 17, 2010.
- Tetra Tech, 2010. Technical Memorandum, Steady-State Sensitivity Analyses. July 30, 2010.

This section reviews these components primarily as presented by Tetra Tech (2010a), with some reference to these technical memoranda when they provide additional information. *Interestingly, Tetra Tech refers to the M&A (2009a) model, but does not reference the revised version reviewed in section 2.0. It is also interesting that most of the data used by Tetra Tech is from various M&A reports and analyses.*

Throughout this section, I refer to Tetra Tech (2010a) simply as Tetra Tech.

3.1 Conceptual Model

3.11 Hydrogeological Units

Tetra Tech (p. 26-30) essentially copied the hydrogeologic units from the M&A (2009b) model, but not the changes made by M&A to include the Backbone Fault or Flat Fault (which M&A simulated with conductivity parameters because they are zones of enhanced horizontal anisotropy, not a flow barrier) in their revised model.

As part of the discussion concerning bedrock, Tetra Tech (p. 12) notes that upward hydraulic gradients in the pit area "are likely monitoring localized conditions…that are not representative of the overall regional flow system." *This is an incorrect interpretation because the higher heads are likely due to recharge in the Backbone Fault area west of the pit at higher elevations than the pit area.* They do correctly interpret downward gradients east of the pit as representing recharging conditions.

Tetra Tech included the Backbone Fault as a subdivision of the Pz HGU.

3.12 Faults/Fracturing

Tetra Tech describes the Davidson Canyon fault zone as highly conductive but limited in water supply by being separated from the upper parts of Davidson Canyon and the pit. Tetra Tech uses a HFB to represent a porphyry quartz dike in Davidson Canyon about five miles downstream from the proposed pit. The inclusion of this dike in the model is the primary addition to the hydrogeologic domain made by Tetra Tech (p. 6 and 45). The following passage from Tetra Tech (2010a) describes how they viewed the dike.

> Numerous quartz-porphyry dikes have formed in the Empire Mountains (Ferguson, C.A., 2009) and Mount Fagan areas (Ferguson et. al., 2001). Some of these dikes appear to have been formed by intrusion into existing faults (Drewes, 1972). These dikes are younger than the surrounding bedrock and therefore cut through the older bedrock. There is the potential that these dikes may create barriers to groundwater flow. A northwest-striking quartz-porphyry dike has been mapped on the Mount Fagan and Empire Ranch 7.5' quadrangles (Ferguson, 2009; Ferguson et al., 2001).
>
> One of the longest and most continuous of these dikes intersects perpendicular to Davidson Canyon approximately 3,000 feet northeast of monitoring well RP-7 (Appendix A, Figure 6). This Tertiary age geologic feature is described in Ferguson (2009) as "*felsic porphyry containing 10-30% quartz and feldspar phenocrysts (1-3 mm) and sparse biotite in a fine-grained light-colored matrix, locally flow-foliated. Forms dikes and sills, and a plug-like stock in the northwest corner of the map area.*"
>
> This quartz-porphyry dike strikes sub-perpendicular to groundwater flow in the Davidson Canyon area, is over four (4) miles long, and based on a field investigation, has a low fracture density and a thickness generally greater than 100 feet. The steep hydraulic gradient from the Open Pit area to Davidson Spring in Davidson Canyon is likely due, at least in part, to this quartz-porphyry dike. However, there has been no hydraulic testing of this dike to characterize its hydraulic properties and to confirm its influence on the groundwater flow system. The crosscutting nature, width, and length of this dike, however, suggest that it restricts groundwater flow. (Tetra Tech, 2010a, p. 13)

This passage describes the dike as a flow barrier, but there is really no data provided to support this conceptualization. In fact the maps of the dike (Figures 3 and 4) show that the quartz-porphyry dike is not continuous across Davidson Canyon. It has been faulted and offset so that there could be flow paths through the dike.

There are no field observations of the fracture density, thickness of the dike, or it hydraulic properties. If the dike were a barrier, water would dam on the upgradient side and be lower on the downgradient side; this would form a step in the contours. None of the groundwater contour maps (M&A, 2010; Myers, 2007) show such a step and no pairs of wells, up- and down-gradient of the dike, demonstrate it. There would be significant major springs along it if it were as effective as described herein; the very low flow springs observed in the area do not qualify as proof of its imperviousness. *Tetra Tech acknowledges "there has been no hydraulic testing", therefore before using it as a major barrier in the modeling they should verify it. The conceptualization and parameterization of this dike in the model is not supported by available data.*

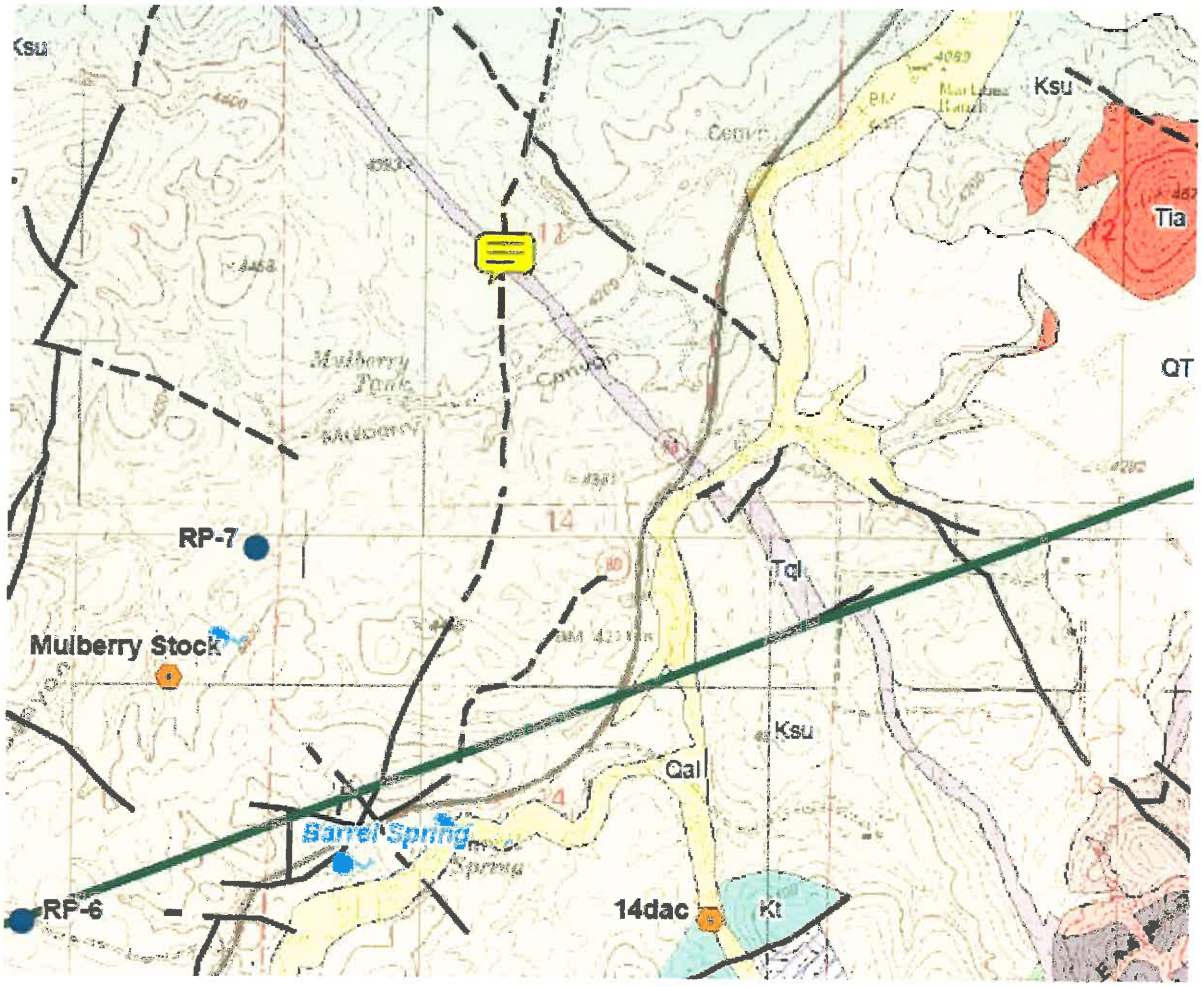

Figure 3: Snapshot from M&A (2010a) Figure 3 showing Tql, the quartz-porphyry dike.

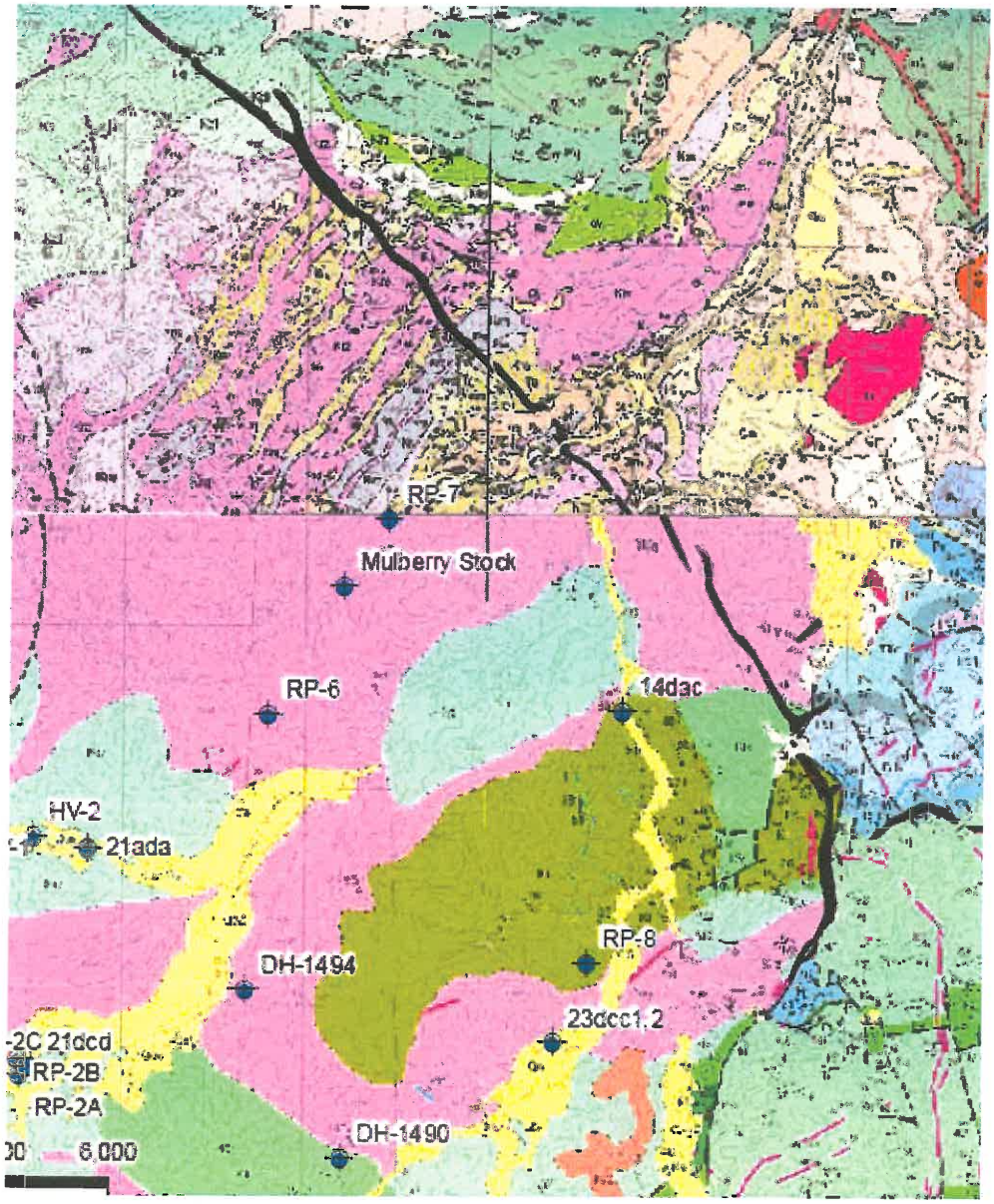

Figure 4: Snapshot of Tetra Tech (2010a) Figure 5-9 quartz-porphyry dike (in black).

3.13 Groundwater Discharge

There are two forms of groundwater discharge – to stream baseflow and to riparian/wetland vegetation in the lowlands of a basin where the groundwater table is close to the surface. Tetra Tech argues that within this basin neither Davidson Canyon nor Cienega Creek are perennial streams (Tetra Tech, 2010a, p. 14). They argue this based on the lack of water during a field visit in stream channel previously reported to be perennial. Even if the stream does occasionally dry, the groundwater levels are shallow. There is definitely regional groundwater discharge to the stream and to the hyporheic zone under this channel. Steady conditions may not occur due to

the seasonal changes near the channels. Also, bedrock constrictions may cause short-range reaches to have water more often than not (Tetra Tech, 2010a, section 2.3.1.1).

Tetra Tech interpreted three springs as being perennial - Helvetia, Rosemont, and Questa - although their flow rates are too small to model at the scale used for this model. However, carbon-14 data suggests that Questa Spring could be fed by water that "is possibly thousands of years old" (Tetra Tech, 2010a, p. 16). This indicates the recharge circulates deeply, but neither Tetra Tech nor M&A have presented a conceptual model that accounts for this type of deep circulation. *Tetra Tech (and M&A) should present a conceptual model that explains the flow paths that would require such long travel time. Both models should incorporate a conceptualization informed by this data.*

They used the same ET rates as developed by M&A for this study.

3.14 Long-term Pump Test Analysis

Tetra Tech chose not analyze to the long-term pump test results with a transient calibration within their model because the regional-scale model grid is too coarse, they argue (Tetra Tech, 2010a, p. 36). They also argued that a telescoped model could not be used in MODFLOW-SURFACT because it would not be possible to import the new grid. *Both of these arguments are fallacious. The regional model has a given scale, discussed in the next section, and the results of the analysis would fit directly into the model. Alternatively, the results of a telescoped model could be combined by weighted averaging and assigned to the model cells near the pump test.*

Instead, Tetra Tech completed a two-dimensional radial flow model to simulate the long-term pump test for each pumped well and relevant monitoring wells. This model is essentially a profile model (Anderson and Woessner, 1992) with a cross-section being the simulated two-dimensional space. A profile model can generally be used to simulate a flow pathway. With radial flow to a well, the flow paths are converging so that any cross-section with a constant thickness would have groundwater converging within it. For this reason, the profile model would have a variable thickness. They relegated the description of this to a memorandum, Tetra Tech (2010c). They simply list a series of pre-processor which they used to construct the model grid and distribute pumping and transmissivity among layers. The method is reasonable, but they simply used the simulations as a means of estimating conductivity and storage properties for different formations. To this end, they typically fit just one parameter zone, except for instances with more than one screen (and water level). *It simply seems like a lot of effort to make an estimate of a formation hydraulic parameter value.*

3.2 Groundwater Model Development

3.2.1 Model Code

Tetra Tech used MODFLOW-SURFACT as did M&A. It was an appropriate choice.

3.2.2 Model Grid and Layers

Tetra Tech uses the same domain with essentially the same boundaries as M&A. They also used constant head and general head boundaries, as did M&A. In this circumstance CHB and GHB boundaries are essentially the same thing because the layer thickness and conductivity define the conductance for a CHB while the user inputs conductance into the GHB. *Tetra Tech's calibration allowed much more water to flow through the domain, however, as will be discussed below.*

Both the M&A and TT models consider the same domain and have the same grid spacing, with 800 foot square cells telescoping to 200 foot square cells near the proposed pit. They use different layer thickness however.

Tetra Tech used 20 layers, consisting of ten 150-foot thick layers through the proposed pit area and ten more layers with thickness increasing to 430 feet down to layer 20, which is approximately 1600 feet below the pit bottom. The top layer thickness also varies with the ground surface. Tetra Tech's layers are flat and they intersect the ground surface; they use no flow boundaries for the portions of the layer that are above the ground surface, a common and acceptable practice.

Tetra Tech's representation of the grid and layering is more detailed than M&A's, but that does not necessarily make it better. Thinner layers around the pit may improve the convergence during steady state solution and may improve the computational accuracy near steep drawdown cones; this decreases the potential water balance error near the pit as compared to thicker cells. However, *more model layers do not imply a better representation of the geology because the accuracy of the geologic model is the limiting factor.*

3.2.3 Parameter Values

Tetra Tech simulated parameter values for each of the ten units without allowing variation within the units. During calibration, they added the Pz Pit zone to represent the Backbone fault zone west of the pit, which they suggest "may enhance north-south groundwater flow" (Tetra Tech, p. 53). The new zone had higher Ky (north-south) and Kv (vertical) conductivity than it did Kx. Although they imply the new zone was to provide higher conductivity, the values were actually lower than the surrounding Pz (Pz_Pit, Kx=3.28e-4, Ky=3.28e-3, Kv=3.28e-3; Pz, Kxy=2.23e-2, Kz=1.08e-2). With the values, the Backbone fault in the Tetra Tech model is more like a barrier. They also added a higher conductivity alluvial zone in the Tucson Basin, but this is much less important.

Tetra Tech missed an opportunity to improve their model by not allowing the conductivity to vary within parameter zones, probably by establishing sub-zones, as did M&A who allowed for more realistic distribution of conductivity. There are clearly enough well observations to calibrate to.

3.2.3.1 Faults

Tetra Tech simulated the quartz-porphyry dike with a HFB having conductance based on a 100-ft thickness with a conductivity of 3.28×10^{-3} ft/d. They simulated it as continuous through all model layers. *There is no data, as discussed above, to support its inclusion through all layers, over 3000 feet of model thickness.* Tetra Tech's overall calibration depended on this dike, as can be seen in the sensitivity analysis which showed that increasing the conductance of the dike lowered the water levels upgradient of the dike. This just means that the water level in this portion of the model depends on the dike rather than the conductivity of bedrock.

Tetra Tech has relied heavily on a structural feature whose hydraulic properties have not been studied. As will be discussed below, the HBF controls the simulated extent of drawdown in Davidson Canyon. M&A did not simulate this feature, but did not explain why it did not. The geologic maps (Figures 2 and 3) show that the dike may be broken across Davidson Canyon, but there were no breaks in the HFB to simulate any of these breaks.

3.2.4 Groundwater Recharge

Tetra Tech (2010a, p. 49) used the M&A recharge estimate of 10,100 af/y within their model domain. *They suggest they distributed the recharge using a GIS and hydrologic soil group classification, but provide no details.* Their resulting Figure 5-4 shows that their initial recharge varies from 0.34 to 0.66 in/y around the model domain (Figure 5). The ranges shown on the figure are due to them initially using 58 recharge zones. The distribution obviously does not include any mountain front recharge. *It appears to primarily depend on elevation, with high elevation areas having the highest recharge. There are high recharge rates along the crest in the areas of granodiorite geology, which M&A had properly set as having very low recharge rates. Tetra Tech apparently forced recharge into non-receptive bedrock and ignored the runoff that recharges at the mountain front; their initial conceptual model of recharge in the area is incorrect.*

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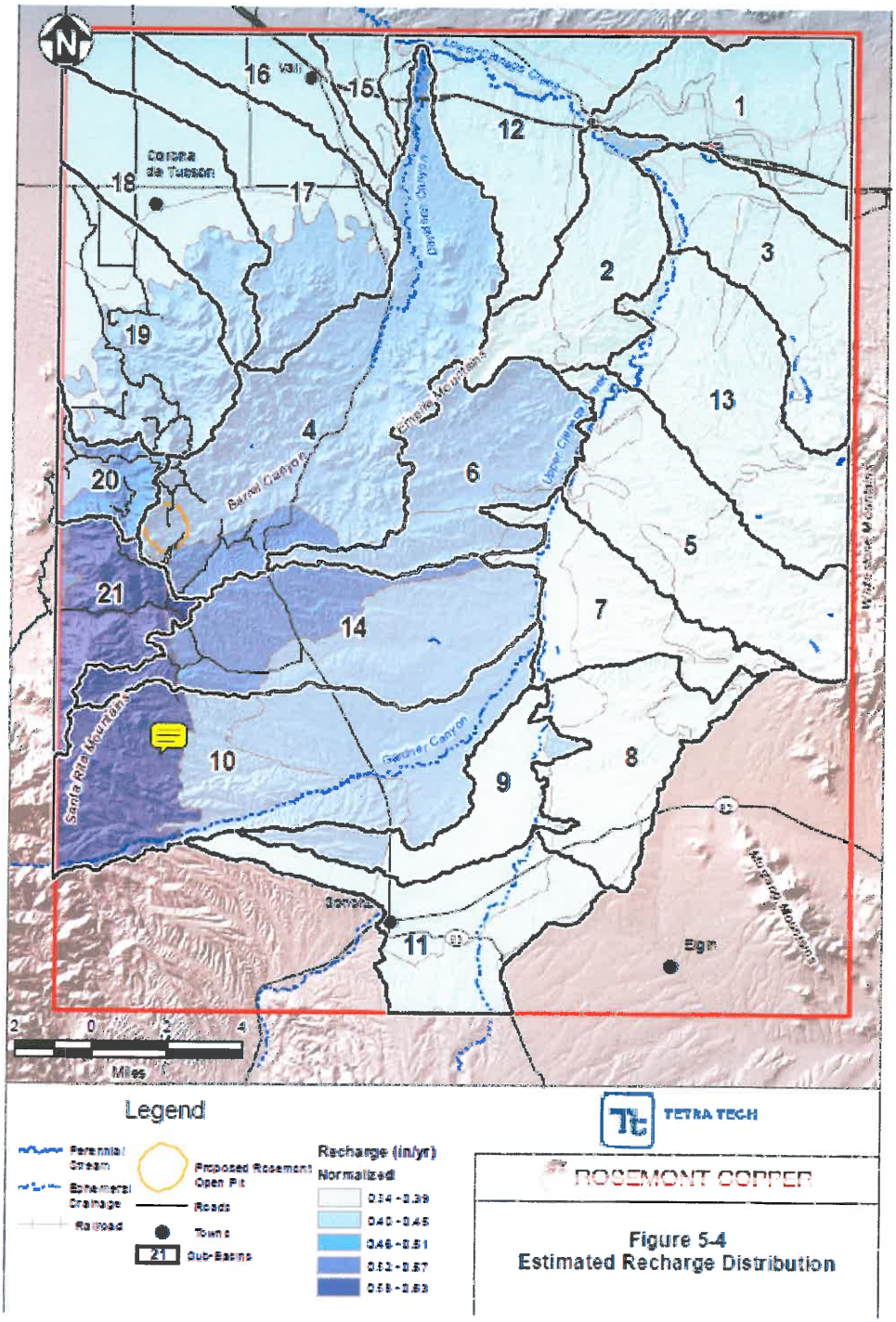

Figure 5: Snapshot of Tetra TEch Figure 5-4 showing initial recharge distribution.

Tetra Tech (p. 60) modified the recharge distribution during calibration. They do not specify the reason for changing the recharge distribution other than to "maintain a reasonable balance with simulated hydraulic conductivity values" (*Id.*). The total recharge in the calibrated steady-state model supposedly was 9,900 af/y which is less than the initial estimate 10,100 af/y (*Id.*). Figure

6 shows the calibrated distribution. *The primary change appears to have increased recharge in the Backbone Fault zone significantly with small reductions over all the Cienega Basin. There is still too much recharge in the granodiorite regions along the mountain crest.*

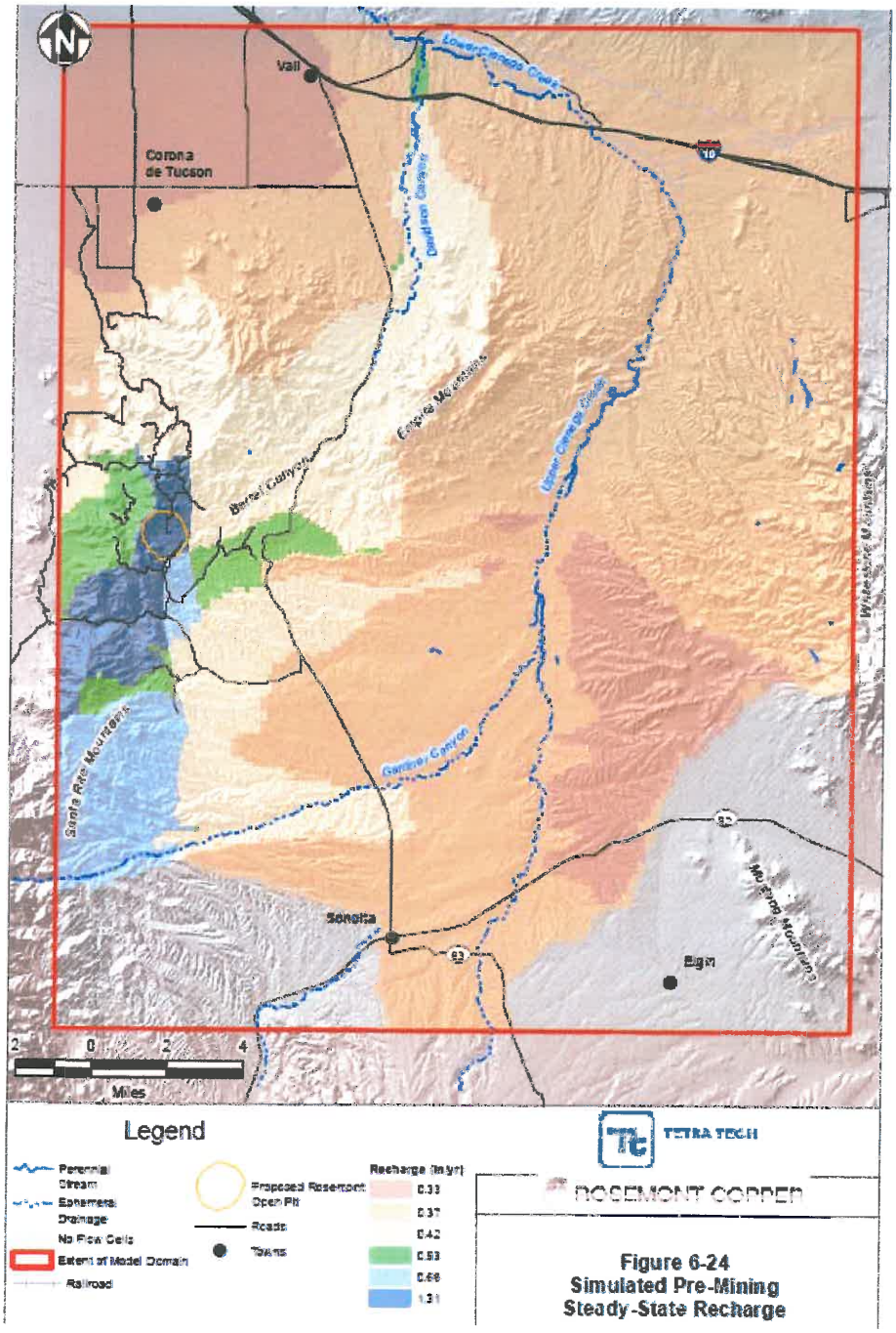

Figure 6: Snapshot of Tetra Tech Figure 6-24 showing the calibrated steady state recharge distribution.

The report describes both mining-phase and post-closure recharge, and how it changes from before pre-mining steady state, but the descriptions are very confusing and there is no figure. The first statement is that "recharge distribution remained unchanged from the pre-mining, steady-state model" (Tetra Tech, p. 49). This means that recharge continues within the pit, and the drain cells may immediately remove it. This is more accurate than the M&A method. However, it is incorrect to not consider the changes in recharge due to "changing facility layouts" because liners will eliminate recharge.

Dry stack tailings should not initially cause recharge because they will be unsaturated and the water they contain will evaporate or move only slowly. They should actually stop the natural recharge until precipitation onto the tails can reestablish seepage through the tails. Once reclaimed, the tails could seep less water into the groundwater. Tetra Tech (p. 50) indicates that draindown from the tailings will decrease from 8.4 gpm to 0 gpm within 500 years[2]; this is how they model it and use five 100-year stress periods to do so. This appears to be new recharge to the mine process facilities' area.

They simulate recharge through the "network of flow-through drains" that is planned beneath the waste rock and dry stack tailings areas. These drains will move stormwater along the base of these waste storage facilities. They claim the drains will cause "recharge to the groundwater" (Tetra Tech, p. 50). They imply this will increase recharge from pre-mining conditions. Presumably, these drains will simply connect existing surface drainage channels from above the facilities to below them; these channels would have had recharge from them in the pre-mine condition.

Overall, they estimate that post-closure recharge in the Project facilities will be 81 to 95 af/y greater than pre-mine conditions (Tetra Tech, p. 50). This appears to be due to the tailings draindown and seepage from the stormwater drains. *As explained in the previous paragraphs, this appears to be new recharge within the pit lake capture zone. This new recharge would go to fill the pit lake and minimize the effects of filling the pit lake on the regional groundwater table. The additional recharge simulated in the Tetra Tech model during the post-mining phase biases the model in a way that decreases the extent of drawdown simulated due to the mine.*

[2] It is unlikely that draindown will reach zero, although the residual tails fluid may become depleted. Usually, the draindown decreases but percolating meteoric water reaches steady state so that the total seepage through the tails stabilizes at a non-zero value. This statement is based on experience at many other mines but I did not review the tailings report as part of this or any other review.

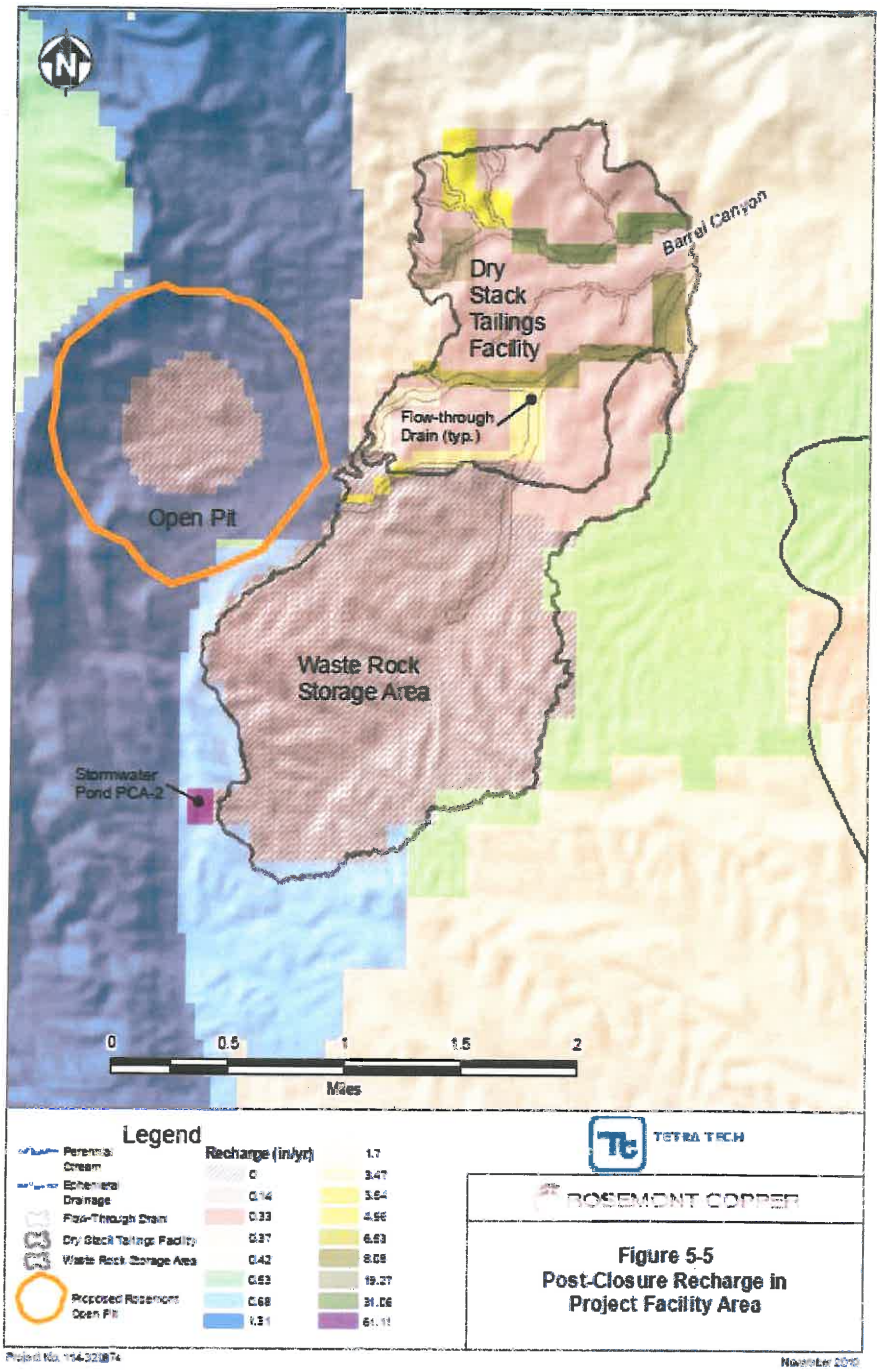

Figure 7: Snapshot from Tetra Tech Figure 5-5 showing Tetra Tech's simulated post-closure recharge in the project facility area.

3.3 Calibration

Tetra Tech used groundwater levels and baseflow estimates as targets, an improvement over the calibration done by M&A. *However, there are problems with each type of target.*

3.3.1 Baseflow

The baseflow target was estimated incorrectly. The problem is the flow rate Tetra Tech used as the target. They used the median flow value for the USGS gages (Table 5-2, Tetra Tech), not the baseflow. It would be more reasonable to use the median flow from the low flow month, which is June. If ET were not being simulated, it would be appropriate to use the median value from the low flow month with the least ET. The target values used herein were too high.

3.3.2 Water Level Observations

Tetra Tech weighted the water level observations for automated calibration. *If done properly, this is a good practice and had been recommended by Myers (2010b), although Myers (2010c) was not successful in using weights. Tetra Tech explains the weighting criteria are explained in Table 6-1, but there are apparently some problems with it. The most accurate observations are given the highest weight, 1, with other observations being weighted less due to their uncertainty. The method used by Tetra Tech may have effectively increased the number of observations available from a given number of wells; it may have also minimized vertical gradients.*

They grouped the wells and springs into fourteen different groups and gave them a different weight, as explained here:

- Group 1 pertained to wells intended to pertain to just one model layer; these were weighted highest, 1.
- Group 2 included wells intended to represent two layers, so they used the observation as a target in each layer with a 0.9 weight. *Because the sum of the weights exceeds 1.0, these observations appear to be weighted more than a group 1 observation.*
- Group 3 does the same for wells screened in three layers, so they used the observation as a target in each layer with 0.8 weight. *Because the sum of the weights exceeds 1.0, these observations appear to be weighted more than a group 1 observation.*
- Group 5 does the same for wells intended to represent four layers, they used the observation as a target in each layer with 0.4 weight. *Because the sum of the weights exceeds 1.0, these observations appear to be weighted more than a group 1 observation.*
- Group 4 also includes "screened interval unknown and total depth and water level span three or more model layers". It is unclear whether the target would be used in each layer spanned, but in the fractured rock in this project area, the water level could easily be above the screened interval; this is known as artesian pressure. *Group 4 targets appear to ignore artesian pressure.*
- Group 6 sets a target, with weight 0.2, for wells with unknown screen and depth in the layer the water level occur in. *This also ignores potential artesian pressure. These observations should not be used or effectively weighted 0.0.*
- Groups 7 through 9, 11, 12, and 14 are effectively weighted 0, or discounted. Based on the criteria, these observations represent highly variable water levels and may be rejected.
- Groups 10 and 13 reduce the weight by half for wells with data prior to 1980 or if a flowing well. This is also acceptable.

3.3.3 Calibration Statistics

Tetra Tech used automated parameter estimation, with head observations weighted as discussed above. The statistics are not unreasonable, but they acknowledge a bias in underpredicting water levels near the pit where several wells have measured water levels above the ground surface. However, the calibration statistics are not as good those by M&A or Myers, as discussed in section 1.0.

3.3.4 Water Balance

The major problem with Tetra Tech's calibration is the water balance. They show that 60% of the water budget is flow in and out of the external model boundaries. *There had been no pre-simulation estimate or target for this flow, so it is completely unrestrained.* They present no figure that shows where the flow enters and exits, but from contours (Tetra Tech, 2010a, Figure 6-29), the inflow is from the Whetstone Mountains and the outflow is north and northwest to the Tucson Basin and west from the Santa Rita Crest. *This flow should have been constrained with a recharge estimate for the area between the model boundary and the Cienega basin boundary.* The contours do not show that flow would reach Davidson Canyon, so it does not appear this excessive throughflow limits the impacts to that canyon. *However, there is apparently a large flow through the Cienega Basin which could limit the extent of project impacts to the southeast into the Cienega Basin.*

3.3.5 Transient Calibration

Tetra Tech performed no transient calibration. They chose not to calibrate to the long-term pump test, as M&A did and as I had recommended (Myers, 2010). The storage coefficients used in this model was from the radial modeling of the pump test, discussed above.

3.4. Prediction of Drawdown and Long-term Pit Lake Development

3.4.1 Pit Dewatering

Tetra Tech simulated dewatering with 12 stress periods for 22 years and used drain cells to lower the water table below the target pit level. The method is acceptable. *However, they may have lowered the water table faster than necessary.* They set conductance so that groundwater could enter the pit without "flow restriction" (Tetra Tech, p. 68). A better way would be to calibrate the conductance so that the groundwater level reaches the bottom of the pit at the end of the stress period, presumably the time that it would do so during actual mining (Myers, 2010c).

They also simulated the physical removal of the rocks by increasing the hydraulic conductivity of the rock within the pit zone to 6.6 ft/d (Tetra Tech, p. 68). *They did this because the water drained from the rock too slowly, although they should explain what this means*. MODFLOW does not allow transient conductivity parameters, therefore they would have set the new conductivity at the beginning of the simulation. *This would affect the flow in the pit area even without the dewatering. Tetra Tech should discuss this.*

Simulated dewatering rates fluctuate substantially from less than 300 to greater than 500 gpm during the first ten years of mining; this is due to the stepped nature of lowering the targeted level. After 10 years the flow rate equilibrates at about 400 gpm. Recharge has continued within the pit, so this adds directly to drain flow; the amount does not include runoff which may accumulate in the pit (although that runoff may cause increased recharge through the pit walls).

3.4.2 Pit Lake Formation

Tetra Tech used the LAK2 package to simulate pit lake formation. *They made assumptions that are not fully justified.* First, they assume that 30% of precipitation becomes runoff to the pit lake. They also note that the actual rate changes as the pit level rises because more precipitation will fall directly onto the forming lake. *There is no reference for this value and details of the pit lake suggest it is too low. The pit walls are very steep and made of bedrock with essentially no soil. It is reasonable that much more precipitation runs off.* Also, more recharge likely occurs because the exposed rock will have been fractured by blasting and excavation. Otherwise, they are simulating that about 11 in/y evaporates from the pit walls (17in/y precipitation – 5 in/y runoff – 1 in/y recharge).

Tetra Tech properly accounts for additional precipitation (beyond the 30%) reaching the pit lake due to it falling directly on the lake. They do this by simulating pit lake evaporation, which is calculated directly from the pit lake area, as a net value with 70% of the actual precipitation reduced from the evaporation rate.

They simulated post-closure conditions (pit lake formation) for 1000 years, using six stress periods to simulate the transient recharge they allege would occur due to the tailings draindown (see the discussion above regarding with-project recharge in section 3.2.4).

3.4.3 Extent of Drawdown

Tetra Tech provides dozens of maps and figures showing predicted drawdown with time. Section 1.0 compared the predicted drawdown with that from the M&A model. It is in the predictions that the true effect of the quartz-porphyry dike becomes apparent. About 20 years after dewatering ended (Tetra Tech, p. 73), the drawdown abuts the HFB which represents the dike; drawdown contours after this time period also butt into the dike, which limits its expansion downstream in Davidson Canyon. The dike limits the drawdown down Davidson Canyon simulated into the future by the Tetra Tech model.

3.4.4 Simulation to Equilibrium

The Tetra Tech model approaches equilibrium after 1000 years, but their simulation was not run to equilibrium or a point at which the water level effectively ceased to increase. A simple water balance of several fluxes at the beginning and end of mining and the beginning of pit lake formation and equilibrium (Tetra Tech, 2010a, Table 8-3) shows how water initially draws from storage and eventually from discharge. The table is poorly explained, but "Cumulative" apparently means an average over the periods, 22 years for mining and 1000 years for post closure and the "final time step" apparently means the values at the end of the period.

The recharge increases from mining to post-closure due to increases in recharge under the waste rock and tailings discussed above. Discharge to and from the streams effectively remains the same, as does evapotranspiration. Both of these fluxes are in the Cienega Basin or far downstream on Davidson Canyon. The high inflow from the boundaries may control the ET and streamflow discharges.

Several significant changes from steady state to mining to post-closure are apparent.

1. There is inflow to the model domain from storage at rates near 840 af/y during mining; this is just a little higher than the amount removed by the drains which indicates that mine dewatering captures water stored near the pit and lowers the water table.
2. *Both inflow and outflow from constant head boundaries change substantially from the steady state simulation to mining. This indicates that something changed in the boundary because flow should continue as a steady state for areas not experiencing model stress.* The CH boundaries move water from the Whetstone Mountains to the Tucson Basin and lower Davidson Canyon, areas not significantly affected as just observed in the lack of change in stream discharge and ET. There is a small change in flow west of the mine, but not the magnitudes simulated here. *Tetra Tech should explain this anomaly in the transient water balance.*
3. The water balance for the pit lake is a subset of the overall water balance. In other words, it is contained within that water balance. *The pit lake water balance does not start where the dewatering stopped which suggests a problem with the parameterization of the LAK2 package or in it conceptualization.* The dewatering rate had equilibrated at about 400 gpm (see above), but the pit lake inflow rate began very low, near zero (Tetra Tech, 2010a, p. 78) and increased to just over 300 gpm within a year (Tetra Tech, 2010a, Figure 8-16). Tetra Tech explains this is due to their dewatering drying out a larger shell near the pit (Tetra Tech, 2010a, p. 79) – a reasonable explanation.

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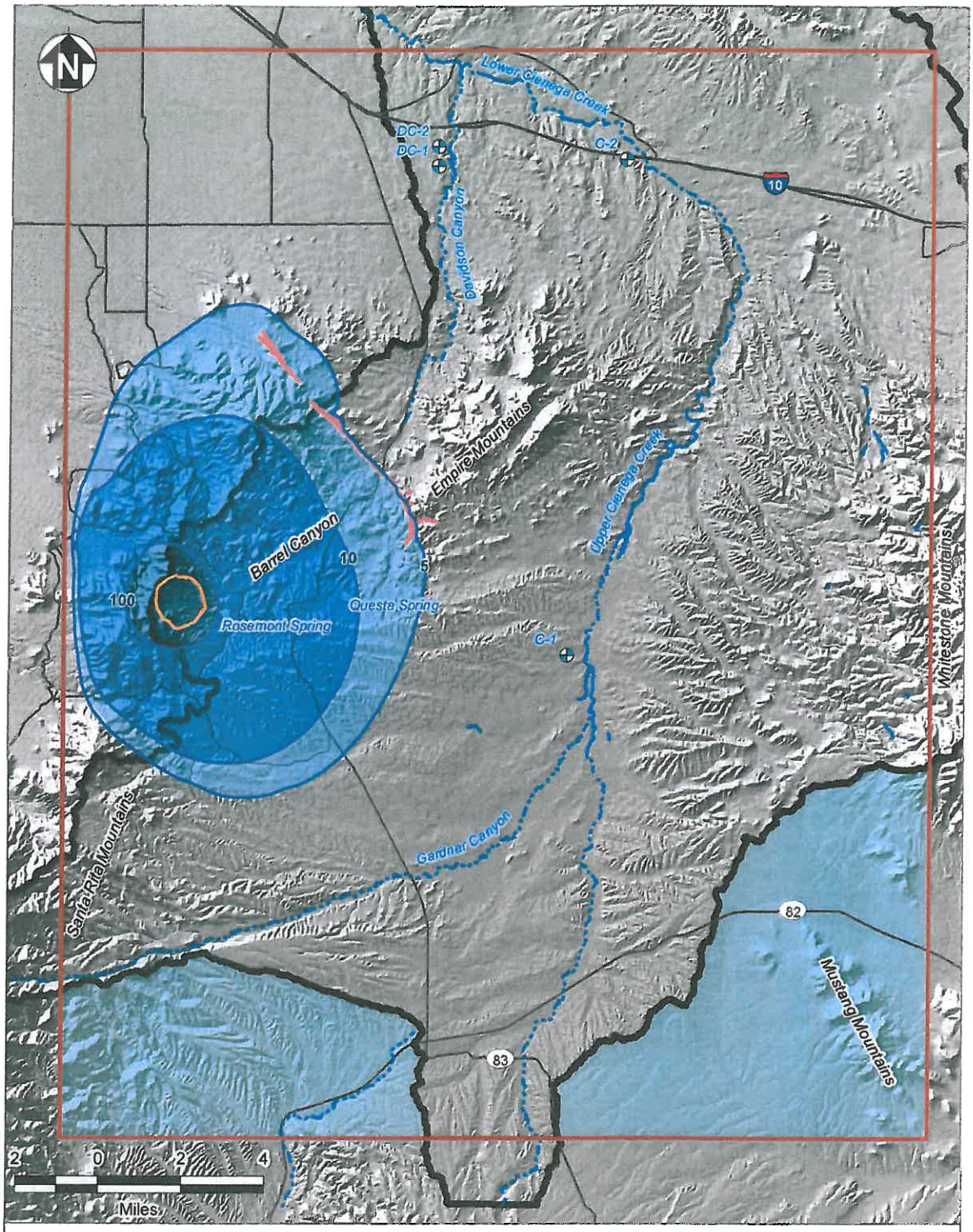
ATTACHMENT 2



100 Groundwater Level Drawdown Contour (Feet)

Proposed Rosemont Open Pit

Cienega Creek Watershed

Model Domain

Quartz Porphyry Dike

Observation Location

Perennial Stream

Ephemeral Drainage

No Flow Cells

Regional Spring

ROSEMONT COPPER

FIGURE 11. PREDICTED GROUNDWATER LEVEL DRAWDOWN 50 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.