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Memorandum

To:	Chris Garrett, P.HGW.	**Date:**	August 8, 2012
Company:	SWCA	**From:**	Vladimir Ugorets, Ph.D.
			Larry Cope, M.S.
			Corolla Hoag, R.G.
Copy to:	Dale Ortman, P.E.	**Project #:**	183100.020/Task 600
Subject:	Pt. 3 SWCA Questions 1 through 3 - Professional Opinions to Assess Impacts to Distant Surface Waters and Modeling Certainty		

This review was undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest (CNF), in accordance with a Statement of Work (SOW) and Request for Cost Estimate from Mr. Chris Garrett, SWCA, dated June 14, 2012. The purpose of this memo is to provide professional opinions on action items generated during a specialist panel discussion with CNF held May 3, 2012 related to surface waters located at some distance from the proposed Rosemont Copper Company (Rosemont) operation. Additional action items from the panel discussions focused on assessing potential impacts to caves (both known and currently unknown) in the Santa Rita mountains. SWCA also asked SRK to address three miscellaneous public comments.

SRK will provide opinions on potential impacts to distant surface waters in this memorandum (SWCA Questions 1 through 3). This memorandum was prepared by the SRK personnel listed in Table 1. SRK has already provided opinions on the potential impacts to caves (SWCA Questions 4 through 6) (SRK, 2012a) and the miscellaneous public comments (SWCA Questions 7 through 10) (SRK, 2012b).

References for the cited documents are provided in Section 5. The complete text of the SWCA questions are presented in blue italicized text and the original numbering scheme is retained for clarity.

Table 1 List of key personnel

SRK Team Member	**Responsibilities for Each SWCA Question**
Vladimir Ugorets, Ph.D., Principal Consultant (Hydrogeology)	Prepared responses to Sections 1–3 (Questions 1-3)
Larry Cope, M.S., Senior Consultant (Hydrogeology)	Prepared responses to Sections 1–3 (Questions 1–3)
Corolla Hoag, R.G., Principal Consultant (Geology)	Input to and technical reviewer of all responses.

1 Question 1 – Source of Water for Springs in Lower Davidson Canyon

The Outstanding Arizona Water reach of Lower Davidson Canyon is supported by several springs located within the stream channel, specifically Reach 2 Spring and Escondido Spring. These springs could arise from the regional bedrock aquifer of the Cienega Basin, a more local shallow bedrock/colluvial/alluvial system associated with the north flank of the Empire and Santa Rita mountains, or from a shallow alluvial system within the Davidson Canyon drainage channel

a) Based on all lines of evidence available to SRK, what is the most likely source or sources of water for these springs?

The question of whether the springs in Lower Davidson Canyon derive their water from the crystalline bedrock aquifer or from the alluvial aquifer in the canyon is central to whether the groundwater flow model is relevant as a means to predict impacts to the springs. If the water levels in the bedrock occur below the bottom of the alluvium, there is no direct hydraulic connection between the alluvium and bedrock. The springs that occur in

the alluvium are, therefore, influenced by surface water flow in the alluvium that is fed by precipitation, and are not influenced locally by fluctuations in the bedrock water table.

At the Reach 2 Spring the lines of evidence suggesting a lack of hydraulic connection with groundwater include:

- The water level in Pima County Well, the sole bedrock well in the general Lower Davidson Canyon area, is 7-14 feet below the top of bedrock at that location indicating there is no physical connection between the surface flow and the bedrock aquifer [see hydrograph in Figure 5 of Tetra Tech's report (2010a)];

- The Reach 2 Spring was observed on a site visit in May 2012 by SRK[1] and Golder Associates[2] staff to be two small pools (puddles), with adjacent alluvium outside the banks that was dry. The alluvium in the area of the spring was observed about one month earlier by Golder Associates to be moist and the pools to be noticeably larger. This change suggests there was a rapid decrease in the presence of water and soil moisture with the onset of late spring heat and dry conditions. A spring fed by groundwater would be expected to retain both water flow volumes and soil moisture in the area immediately adjacent to the pools despite short-term changes in local precipitation and evaporative conditions.

- Tetra Tech has documented that wells and springs in the upper reaches in Davidson Canyon have isotopic values indicating winter recharge from precipitation is a significant source of water (Tetra Tech, 2010a). Water samples taken for Reach 2 Spring in Lower Davidson Canyon have a geochemical signature that indicates the spring water is primarily influenced by summer rain; this suggests that bedrock groundwater is not a significant component of the Reach 2 Spring.

b) Are there lines of evidence that point to contradictory conclusions or are inconclusive?

The evidence outlined in response to Question 1(a) above is limited to the hydrograph data of a single well located several miles downstream of the Reach 2 Spring and to the water quality samples taken from selected springs. In addition, there are no water level data to show seasonal variations in the alluvium, nor the relationship of the degree of alluvial saturation with intense summer monsoonal precipitation events. The summer storm events typically produce flash flooding and rapid recharge to the alluvium. Winter rains would be expected to produce saturated alluvial flow conditions that might be more prolonged in duration, although not as dramatic in response. Data have been not yet been collected to demonstrate the type of response relationship to precipitation events in Davidson Canyon.

Finally, there are no wells at the Reach 2 Spring that document the bedrock and alluvial water levels. Although the physical, observational evidence presented in the response to Question 1a is reasonable, it is anecdotal and thus uncertain.

c) What methods of additional data collection would be recommended to provide more conclusive evidence as to the origin of these springs?

An Alluvial/Bedrock well pair at the Reach 2 Spring and at two additional places in Davidson Canyon should provide sufficient demonstration of the hydraulic communication (or lack thereof) between the saturated alluvium and bedrock water table. The additional two locations should be upstream and downstream of the Reach 2 Spring to confirm or otherwise refine the conceptual model presented by Tetra Tech (2010a). If the elevation of the water levels in the paired devices is the same to similar, a connection between bedrock and alluvium would be demonstrated. On the other hand, if water level elevations in the two devices are disparate, the two aquifers are not connected.

Drive-point piezometers are the recommended alluvial installations at each pair location. An example of this type of piezometer is shown in Figure 1. An additional three alluvial piezometers are also recommended that there would be six piezometers along the length of Lower Davidson Canyon. Each would be fitted with a water level data logger for frequent monitoring (on the order of a reading taken and digitally stored every 4 hours). Each of the three bedrock wells would also be fitted with dedicated electronic data loggers. Locations would likely need to be carefully selected to minimize theft, vandalism, or potential disturbance by recreational visitors. A reconnaissance of the canyon length would be recommended before selecting this method to ensure that a drill rig is able to access the sites.

[1] Dr. Vladimir Ugorets, Larry Cope, Stephen Day, Corolla Hoag, Michael Sieber
[2] Dr. George Annandale, Jennifer Patterson

SRK recommends that photographic documentation of the Reach 2 Spring be taken on a monthly schedule, and during and immediately following intense rain events to the best and safest extent practicable. Alternatively, a wildlife monitoring camera could be set on a timer to take a daily time-lapse photo to document spring flow conditions. The photos could be downloaded monthly and uploaded to a common shared site. Wildlife cameras (see for example the Covert MP6: www.dlccovert.com) are very small and battery operated; typically they are disguised with a camouflage design and are easy to hide in the brush or in a tree, which would help avoid detection, theft, or vandalism.

d)   What would be the approximate time frames and costs needed to collect this additional information?

The recommended monitoring period would be approximately one year to measure water levels that document the potential seasonal variation. If the well and piezometer installation could be completed in the early Fall months of 2012, for example, the water levels would be monitored for approximately one year through the end of summer rains of 2013.

The bedrock wells would be drilled to a depth of 75-200 feet depending on the depth to groundwater. Blank and slotted PVC casing (2-inch diameter) would be installed in the well with the screened interval set to straddle the water table. A hydraulic seal would be installed in the annulus above the screen to isolate the bedrock water table from potential leakage from above via the annulus. Each well would be fitted with a data logger and the wellhead protected with a locked steel cover. The installation cost is estimated to be a maximum of $12,000 per bedrock well and $2,500 per alluvial drive-point piezometer, which includes dedicated dataloggers. Consulting fees of a groundwater consultant to supervise the project would also likely be required.
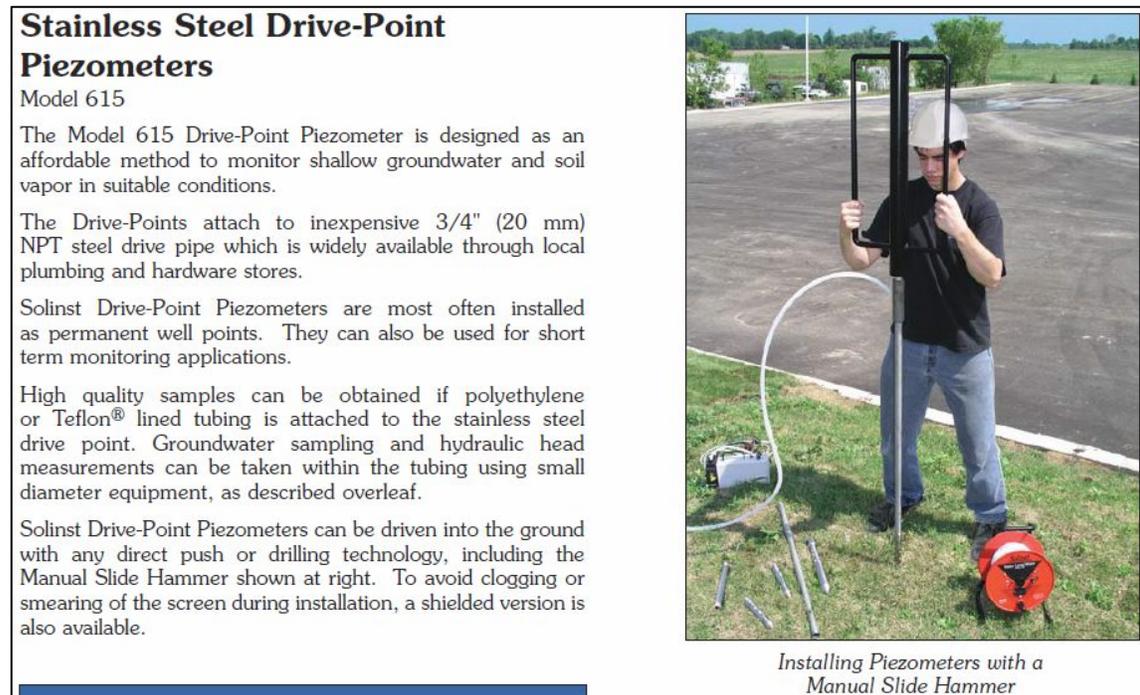
Figure 1 Example of a drive-point piezometer (from Solinst website)

2   Question 2 – Ability of Existing Regional Groundwater Models to Predict Effects on Streamflow

During the May 3 panel discussion, several specialists reflected on the uncertainty associated with the existing groundwater flow models. Specifically, there was the opinion that the accuracy of the modeling technique was not sufficient to predict impacts at certain surface water locations relatively distant from the mine site.

a)   Cienega Creek is modeled to experience these impacts (at gaging station 09484550): Montgomery model (0.01 feet of drawdown after 1,000 years), Myers model (0.2 feet of drawdown after 1,000 years). Based on these drawdowns, the Montgomery model predicts a 0.02 cfs reduction in baseflow, and the Tetra Tech model predicts a 0.09 cfs reduction in baseflow. In SRK's professional opinion are the existing

groundwater flow models, including the groundwater-surface water interaction models, capable of predicting these impacts to the accuracy implied by the reported values?

b) *Empire Gulch is modeled to experience these impacts (at the springs, near headquarters): Montgomery model (3.3 feet of drawdown after 1,000 years), Tetra Tech model (6 feet of drawdown after 1,000 years), Myers model (4.3 feet of drawdown after 1,000 years). In SRK's professional opinion are the existing groundwater flow models, including the groundwater-surface water interaction models, capable of predicting these impacts to the accuracy implied by the reported values?*

c) *Gardner Canyon is modeled to experience these impacts (at confluence with Cienega): Montgomery model (no drawdown), Tetra Tech model (1 foot of drawdown after 1,000 years), Myers model (2.2 feet of drawdown after 1,000 years). In SRK's professional opinion are the existing groundwater flow models, including the groundwater-surface water interaction models, capable of predicting these impacts to the accuracy implied by the reported values?*

d) *If connected to the regional bedrock aquifer that will be impacted by the mine, Lower Davidson Canyon is modeled to experience these impacts: Montgomery model (1 foot of drawdown after 1,000 years), Tetra Tech model (<1 foot of drawdown after 1,000 years). Based on these drawdowns, the Montgomery model predicts a 0.04 cfs reduction in baseflow. In SRK's professional opinion are the existing groundwater flow models, including the groundwater-surface water interaction models, capable of predicting these impacts to the accuracy implied by the reported values?*

SWCA Questions 2a through 2d address the results from three numerical flow models predicting drawdown expected in four drainages distal to the proposed project area 1,000 years after closure of the proposed mining operation. The models were prepared by Montgomery & Associates (2010), Tetra Tech (2010a; 2010b), and an independent consultant, Dr. Tom Myers of Reno, Nevada (2007, 2008[3]). The distal drainages include Cienega Creek, Empire Gulch, and Lower Davidson Canyon located east and north-east of the project area. Gardner Canyon is located approximately 8.5 miles south of the project area. Although the model results for each area are different, the questions and response about each of the drainage areas are similar. SRK will address all four areas with a single opinion, using Cienega Creek as a representative example.

The prediction of the lateral extension of drawdown toward Cienega Creek (and the other distal drainages) due to excavation of an open pit 10-12 miles away from the creek depends on the following:

- Depth of pit excavation below the water table (or the pit lake elevation during post-mining conditions),
- Hydraulic conductivity of the rock between the pit and the creek(s),
- Groundwater storage parameters,
- Distance between the pit and the creek(s), and
- Length of time into the future for which the predictions are calculated.

Prediction of the changes in creek flow depends additionally on the hydraulic connection of the groundwater system with the creek. If there is no connection to the groundwater system, drawdown might propagate below the creek(s) without any changes in flow.

If a numerical model is calibrated to a groundwater stress (usually withdrawal) similar or several times less than expected during pit dewatering, the model can reliably simulate pit inflow and drawdown in the vicinity of the pit. The ability to reliably predict the propagation of drawdown away from the pit is fair to poor, however, at large distances and great lengths of time due to the asymptotic nature of the response to groundwater withdrawals at large distances and times,[4] especially if the groundwater system exists within low permeable rock. If the rock is of low permeability, the groundwater system may not be able to be stressed enough during pre-mining testing, and the model could not be calibrated to represent impacts to the larger stresses during mining. Calibration of a model to only steady-state parameters (i.e. water levels, groundwater discharges to the creek) results in less certain predictions during the transient conditions with significant changes in water levels that exist during mining and post-mining periods.

Both of the models reviewed by SRK are reasonably well calibrated to pre-mining steady state conditions with very limited transient calibration for the M&A model and none for the Tetra Tech model. These models show

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[3] The models prepared by Tom Myers, Ph.D., were not reviewed by SRK Consulting.
[4] A groundwater model predicts decreasing drawdown with distance from a pit as source of hydrogeological stress, but it never reaches an absolute zero value. As a result, the uncertainty of propagation of drawdown between 0.01 ft and 0.1 ft is very large.

the predicted 5-ft contour of drawdown (Figure 2 and Figure 3, respectively) with a range of possible variation of the contours based on sensitivity analysis (M&A model only).

It is SRK's opinion, that the 5-ft and 10-ft drawdown contours represent the precision of regional groundwater models that can be most relied upon. That is, the models can reliably predict impacts down to perhaps 5 feet of change. Uncertainty in results increases with predictions less than these contour intervals. Thus, after addressing problems with boundary conditions along the western model boundary (both models, as described in SRK, 2012a) and simulation of the quartz latite porphyry dike (in the Tetra Tech model), the groundwater models would be reasonably able to predict changes in water levels and flows of surface-water bodies inside the 5-ft to 10-ft drawdown contours.

Based on this and existing uncertainties in parameters such as hydraulic connection between groundwater and Cienega Creek (M&A and Tetra Tech), SRK's professional opinion is that the existing groundwater flow models or any other mathematical models are not capable of predicting these impacts to the accuracy implied by the reported values.

In addition to the inherent uncertainty of long-term numerical flow model predictions, whether surface water or groundwater, climate variability adds another level of uncertainty to flow predictions. Likewise the ability to accurately predict groundwater and surface water flows is severely limited by uncertainties related to the extent of future groundwater withdrawals needed to satisfy growing demands by increased populations and/or other potential industrial or agricultural users, all of which may cause low river flows and/or declining groundwater levels independent of withdrawals related to the proposed mining project.

2.1 Qualitative Level of Certainty

e) In SRK's professional opinion what is the qualitative level of certainty for the existing models to make such predictions? In SRK's professional opinion what is the qualitative level of certainty for modeling in general to make such predictions?

In SRK's professional opinion, the qualitative level of certainty for the existing models to make predictions listed in Item 2 above is low. These models were designed to (and are suitable to) predict inflow to the proposed open pit and pit lake infilling with an acceptable level of certainty. This can be done after addressing the problems with boundary conditions along the western model boundary (both models, as described in SRK, 2012a) and simulation of the dike (Tetra Tech model only).

In addition to the constraints and limitations found in any numerical model, other factors not included in the models will likely have an influence on conditions 1,000 years from closure. Numerous, unknown future factors and conditions have the potential to produce drawdown impacts much greater than the reported 0.1-0.2 ft. These unknown factors include the density of local population growth and groundwater pumping related to new subdivisions, geologic erosion (localized sedimentation or scouring), global climate change, and local weather conditions such as extended periods of wet or drought.

f) Quantitatively, is there an approximate distance from the mine pit, approximate time period, or approximate amount of drawdown predicted by the models, within which predicted model results can be reasonably relied upon to predict impacts to accuracy similar to that stated in item 2 above?

SRK's opinion is that both models (again, after addressing the problems mentioned above) would reasonably be able to predict changes in groundwater levels 1,000 years after mining only within the current simulated extent of the 5ft or 10ft drawdown contours. Thus, the predicted impacts to the surface water sources cannot be considered reliable with the accuracy stated in Item 2 above.

3 Question 3 – Other Approaches to Predict Effects on Stream Flow

Given that the existing groundwater flow models may not be an appropriate tool to analyze potential impacts to Cienega Creek or other relatively distant surface water sources, is there a different method that could be used to reasonably estimate impacts to these water sources?

There are two principal methods to predict changes in groundwater levels (and associated changes in stream flow). Those are analytical methods and numerical methods. An analytical method will not work for the Rosemont project owing to the hydrogeological complexity and the three-dimensional (3-D) character of the groundwater flow model. A numerical method is the common approach to predict impacts to groundwater systems and surface water sources and was used by M&A and Tetra Tech, as well as Dr. Tom Meyers.

A numerical method, however, does not allow a reliable estimate of potential impact to surface water sources that can address all uncertainty because of the:

- Distant location of the surface water sources from the proposed pit/pit-lake;

- Significant length of prediction time period after mining ceases when the cone of drawdown could potentially reach these surface water sources;

- Low hydraulic conductivity of rock in the vicinity of the proposed pit and the resulting inability to create adequate stress on the groundwater system to calibrate the model to transient conditions similar to those that would exist during pit excavation and pit lake infilling; and

- Lack of incorporation of other realistic (but unknown in intensity) potential stresses that may impact the results such as climate change, local weather conditions such as drought, or the influences of future groundwater withdrawals related to population growth and increased industrial and agricultural uses.

SRK does not know of any better approach than 3-D numerical groundwater modeling to predict effects of mining on stream flow and believes that both the M&A and Tetra Tech models would be able to predict mining impact (or no impact) to Cienega Creek after calibration to the transient data (pit discharge, changes in water levels in monitoring wells) collected during the initial phase of pit excavation. An observational approach in which a numerical model is a "living" simulation that adjusts as mining proceeds allows calibration to actual conditions that lessens uncertainty as the model evolves.

4   References

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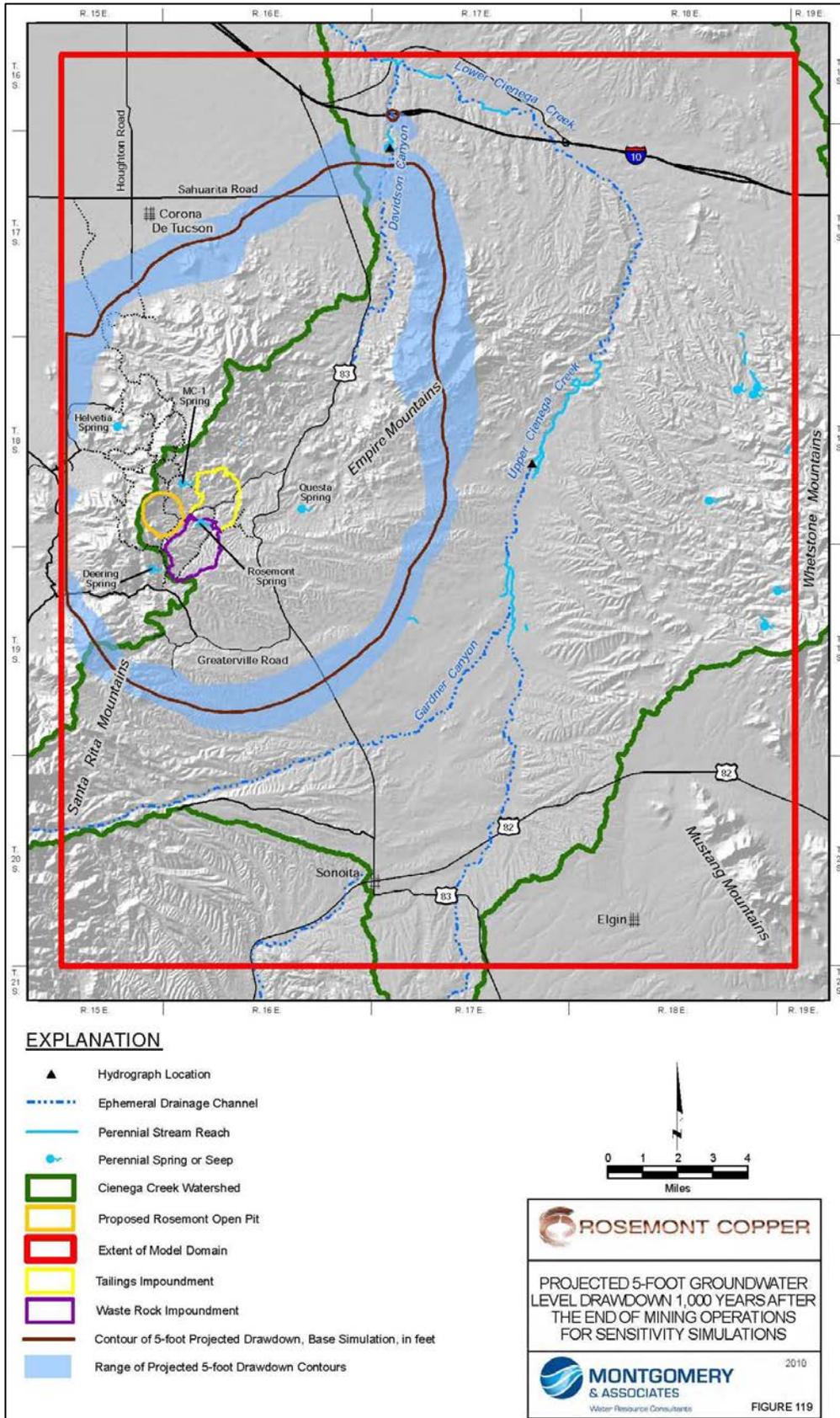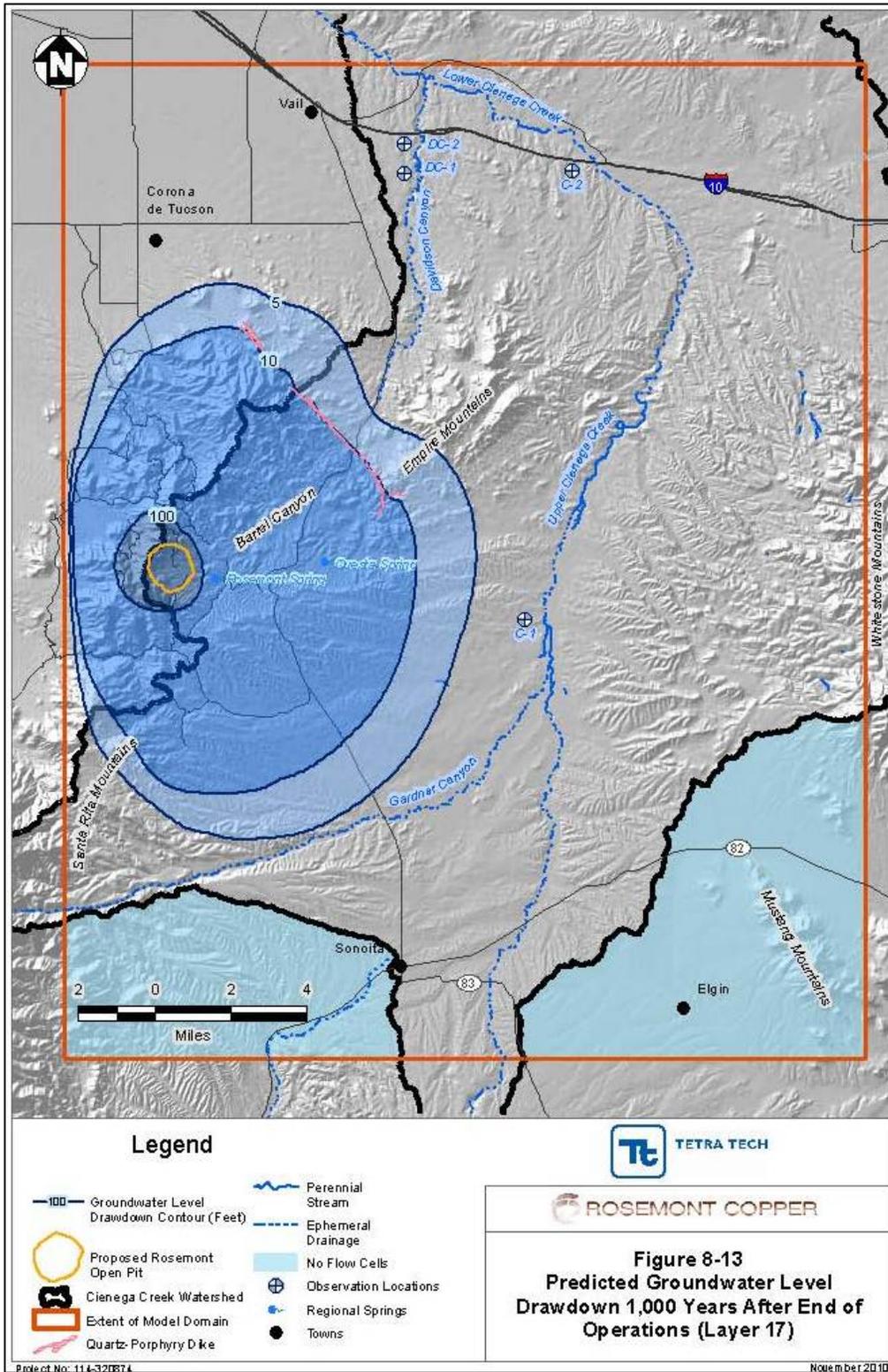
Figure 2 Predicted drawdown 1,000 years after end of mining operation by M&A model [Base Case scenario with results of sensitivity analyses (Source: Figure 119 in M&A, 2010)].

Figure 3 Predicted drawdown 1,000 years after end of mining operation by Tetra Tech model [Base Case scenario (Source: Figure 8-13 of Tetra Tech (2010)].