BRIEF HISTORY OF FEIS GROUNDWATER/STREAMFLOW ANALYSIS

Overview of Groundwater Modeling Process

- From mid-2007 through mid-2009, Rosemont Copper was collecting and submitting hydrologic data to support the upcoming groundwater modeling process.

- In November 2007, the first documents related to the Montgomery model were submitted. Meetings of the east side hydrologic team (Forest Service, SWCA, SRK, and Montgomery & Associates) began in January 2009. Montgomery submitted the first draft of the east side model in October 2009. SRK provided peer review on the Montgomery modeling reports.

- Hydrologic team meetings continued through 2010. In August 2010, Montgomery submitted a revised east side model.

- Tetra Tech was contracted by Rosemont Copper to prepare a second, independent groundwater model and joined the hydrologic team meetings in April 2010. Tetra Tech prepared a series of six tech memos in July/August 2010 describing different parts of their modeling process, culminating in submittal of a combined synthesis report in November 2010. SRK provided peer review on the Tetra Tech modeling reports.

- Throughout this time period, Dr. Tom Myers was under contract to Pima County and was also providing review comments on the Montgomery and Tetra Tech reports, as well as providing his own modeling reports in April 2008 and April 2010. All three modeling efforts (Montgomery, Tetra Tech, Myers) were used in the FEIS analysis.

- Peer review and data requests continued through August 2011, at which time the models were deemed sufficient for use in the Draft EIS. The Draft EIS was published in October 2011.

- Numerous public comments were received on the groundwater analysis. Beginning in December 2011, additional data requests were submitted and expert opinions were obtained in order to respond to specific public comments. Specific topics included cave/karst issues and riparian impact assessment.

- Key “all-hands” meetings were held in April, May, and October 2012. These meetings were meant to allow direct discussions between contracted experts (SRK), Forest Service specialists, line officers including the responsible official for this project, experts from other cooperating and Federal agencies, and in some cases, contractors from Rosemont Copper.

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1 Full details can be found in the project record #047366, Process Memorandum to File, Overview of Water Resource Process, December 6, 2013.
• Final documentation on the models was submitted in November 2012. Based on the October 2012 meeting and subsequent documentation the Forest Service determined that the models were still considered the best available science, and were appropriate and acceptable for use in the FEIS analysis. Key findings include:
  
  o Selected boundary conditions on the west side of the Santa Rita Mountains begin to potentially affect the modeling results after about 300 years.
  
  o “…both models...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.”

• The period from October 2012 through posting of the Final EIS in November 2013 was occupied with development of mitigation and monitoring measures, and refinement of how the groundwater models are used to analyze impacts to sensitive riparian resources (discussed further below).

Overview of Refinement of Riparian/Streamflow Impacts

• Substantial concerns were raised during public comments on the DEIS regarding how impacts to riparian areas were assessed. The Forest Service convened a meeting of interested cooperating agencies in June 2012 to discuss alternative approaches to riparian impact assessment.

• A Preliminary Administrative FEIS (PAFEIS) was released to cooperating agencies for review in July 2013. Based on the results of the groundwater modeling discussions, the analysis made use of the groundwater modeling results (from all three models) but consisted largely of qualitative statements to assess impacts to perennial streams.

• Two general principles were taken from the cooperating agency review and used to refine the analysis of impacts to perennial streams:
  
  o A “risk assessment” approach would be useful, in order to weigh probabilities of outcomes and the impacts of those outcomes.
  
  o That the uncertainty associated with the groundwater models should not preclude analyzing what the effects could be if the aquifer behaved as the models predict it will.

• The riparian impact analysis was further refined during the period from August to November 2013. Most of this refinement involved direct collaboration with the EPA.

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2 SRK, July 31, 2012. Memorandum: Pt. 3 SWCA Questions 1 through 3 - Professional Opinions to Assess Impacts to Distant Surface Waters and Modeling Certainty

3 See project record #047009, Memorandum: Process followed for Developing Hydrologic Monitoring Requirements, December 27, 2013.
- Post-publication of response to FEIS streamflow analysis:
  - CEQ
  - Objection process
FLOW OF WATER OUT OF AN AQUIFER

The flow of water out of an aquifer and into a stream is governed by Darcy’s law:

\[ Q = K \times A \times \frac{dh}{dl} \]

Where:

- \( Q \): flow
- \( K \): hydraulic conductivity
- \( A \): cross-sectional area of aquifer intersecting stream
- \( \frac{dh}{dl} \): hydraulic gradient

Flow out of the aquifer is therefore proportional to hydraulic gradient, which will change as aquifer water levels change. Hydraulic gradient can be broken down even further:

\[ \frac{dh}{dl} = \frac{(h_a - h_s)}{dl} \]

Where:

- \( h_a \): the water level elevation in the aquifer
- \( h_s \): the water level elevation at the stream surface
- \( dl \): the horizontal distance between \( h_a \) and \( h_s \)

Conclusion: a decrease in water level elevation in the aquifer will in turn decrease the hydraulic gradient, which in turn will decrease the flow of water from the aquifer into the channel.

FLOW OF WATER IN THE STREAM CHANNEL

Once the water leaving the aquifer is in the stream channel, its movement is described by Manning’s equation:

\[ Q = A \times R^{2/3} \times s^{1/2} / n \]

Where:

- \( Q \): flow
- \( A \): cross-sectional area of stream
- \( R \): hydraulic radius of stream = \( A/P \), where \( P \) = wetted perimeter of stream
- \( s \): slope of stream channel
- \( n \): Manning’s roughness coefficient

\[ ^1 \text{Note that in this discussion, units are intentionally left out of the discussion for the most part, as the intent is to focus on the proportional relationships between aquifer drawdown and depth of water in the stream.} \]
Manning's equation is often rearranged to solve for channel geometry, including depth of water, which is our interest:

\[ A \cdot R^{2/3} = Q \cdot n / s^{1/2} \]

For a theoretical rectangular channel, stream depth can be entered into the formula as well:

\[ A = d \cdot w \]
\[ R = A / P = d \cdot w / [2d + w] \]

Where:
- \( d \) = depth of water
- \( w \) = width of stream

Therefore Manning's equation becomes:

\[ d \cdot w \cdot (d \cdot w / [2d + w])^{2/3} = Q \cdot n / s^{1/2} \]

Conclusion: while it is clear that depth of water in the stream is proportional to flow, it is not possible to solve directly for depth, \( d \), so most solutions require an iterative process.

*Theoretical interaction of groundwater and surface water*

From the above, we can see that these equations are complex and interrelated. A decrease in aquifer water level elevation decreases the hydraulic gradient, which in turn decreases outflow from the aquifer into the stream. A decrease in flow in the stream in turn leads to a decrease in depth—which in turn changes the hydraulic gradient.

An iterative solution for a hypothetical scenario is attached, with the results graphed below. The actual values involved in this scenario are not necessarily realistic for any real-world stream, but they allow us to graph the theoretical relationship between \( h_a \) (elevation of water in aquifer) and \( d \) (stream depth).
### Darcy's Law

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<th>Hs (elev)</th>
<th>Ha (elev)</th>
<th>dl (feet)</th>
<th>dh/dl</th>
<th>K (ft/day)</th>
<th>A (ft²)</th>
<th>Q (cfs)</th>
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Hs = Water level elevation of stream surface (feet amsl)
Ha = Water level elevation of aquifer (feet amsl)
dl = horizontal distance between Hs and Ha (feet)
dh/dl = calculated hydraulic gradient
K = hydraulic conductivity of close-stream aquifer material (ft/day)
A = cross-sectional area of aquifer feeding stream (ft²)
Q = calculated flow into stream (cfs)

### Manning's Equation

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<th>s</th>
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<th>w (ft)</th>
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<th>P (ft)</th>
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s = slope of stream bottom
n = Manning's roughness coefficient
d = stream depth (feet), iteratively changed until Q matches that from Darcy calculations
w = stream width (feet)
A = calculated flow area = d * w (ft²)
P = calculated wetted perimeter = 2d + w (feet)
R = calculated hydraulic radius = A/P (feet)
Q = calculated flow in stream (cfs)
FEIS Analysis – 1:1 Stream/Aquifer Drawdown

Sensitivity Analysis – 1:5 Stream/Aquifer Drawdown

Sensitivity Analysis – 1:10 Stream/Aquifer Drawdown
Depth of Water in Cienega Creek, 2001-2013

Depth of Water Converted from Daily Average Streamflow using USGS Rating Curve

Average percent time with no flow = 0.7%

Predicted Water Level in Cienega Creek with 0.5 ft Modeled Drawdown

Modeled drawdown of 0.5 feet superimposed on depth of water measurements

Percent of time with no flow = 77.5%