Technical Memorandum

Review of Surface Water/Groundwater Relations Memoranda in the Cienega Creek Watershed

June 25, 2014

Prepared by: Tom Myers PhD, Hydrologic Consultant, Reno, NV

The Forest Service used analyses by SWCA (2013) to complete a risk analysis of the potential for drawdown to increase the length of dry stream in the upper Cienega Creek basin. Rosemont Mining (2014) presented an alternative analysis in objection to the SWCA risk analysis. SWCA responded with a sensitivity analysis (SWCA 2014). This memorandum reviews these three memoranda and recommends a new method for estimating the effect of drawdown on the Cienega, primarily because neither of the methods reviewed have much basis in hydrologic reality. Additionally, this memorandum reviews Westland (2012), which estimates changes in wetted stream length for the lower Cienega Creek, and recommends an alternative means of estimating changes in that stream reach.

Review of SWCA 2013

SWCA prepared a risk assessment to address riparian impacts, assessing the range of potential drawdown and the impacts that could be caused by that drawdown. They gathered a series of detailed stage and daily flow measurements for the USGS gage on Cienega Creek near Sonoita (#09484550). The gage is a v-notch weir embedded in a concrete wall. There had been a period of zero flow during May/June 2010. Zero flow means no flow passing the gage, but others have observed that pools and the channel above the gage may have water; the photo of the gage in SWCA (2013) shows the v-notch to be above the channel thalweg and that the weir causes a pool to form above the location. Also, the gage is near a bedrock constriction so that groundwater flowing along the alluvium beneath the stream is forced to the surface. They also had 27 depth and flow measurements collected at various locations in the upper Cienega Creek area.

SWCA used the rating curve to convert flows at the gage to the "depth of water" at the gage. Importantly, the depth at the gage controls the depth in the channel only to nearest upstream riffle, where the flow passes through critical depth. Backwater from the weir only affects flow depth to that point.

SWCA compares the 29 point depth measurements throughout the watershed to the "median monthly water depth" at the gage. The point of that comparison is unclear, especially since many of the spot measurements are from the 1990s before the data used to determine the gage station median. Ostensibly the comparison of point flow depths with the gaged depth in Table 2 provides information about how the depth at a few locations compares to the gaged depth.

The comparison of spot measurement depth with median monthly depth at the gage in Figure 4 is completely meaningless because, as specified by SWCA, "channel geometry and flow characteristics are highly variable, even with short distances". Flow depth along the profile probably varies over several feet along a stream profile, and the reason for having a depth measurement at a given location is not provided - the choice and resulting depth seems to be random. Yet, SWCA states that "use of the stream gage as a surrogate for all of Upper Cienega Creek seems reasonable as an approximation of typical conditions along Upper Cienega Creek", even though they also recognize that **"actual impacts … would depend on the specific channel geometry, hydraulic connection with the regional aquifer, and riparian vegetation characteristics at a specific location".** These characteristics would likely cause the water level at random reaches through the watershed to vary much more than behind the v-notch weir, which are very controlled conditions.

Flow at the gage is an indicator of conditions in the watershed, meaning basically whether the watershed is wet or dry, but there is too much variability to glean any information from a perceived relationship of gage depth with spot depths through the watershed.   This includes generalizing the potential impacts. The use of the gage for tributary impacts is even more dubious.

SWCA estimated the effects of tributaries Empire Gulch and Gardner Canyon by considering that a drawdown at these tributaries of 0.3 feet will cause those tributaries to go dry and stop contributing flow – essentially an on/off switch that eliminates 11 or 26% of the flow in Cienega Creek. The 0.3 feet is based on the median flow depth at the gage during the critical May/June period. They provide no analysis but merely assume this relationship which is ultimately meaningless. Even if there was a 1:1 correspondence between drawdown and flow depth (there is not), no explanation was made of why 0.3 feet of drawdown will eliminate that flow. No tributary flow measurements relate to the gage. Additionally, their assumption assumes that no underflow would discharge from the watershed, again without justification.

The details of the calculation are not reviewed because the concept illustrated in Figures 6 and 7 shows the basic calculation to be flawed. It assumes that a drawdown in the regional groundwater table, as determined from the model, can be translated 1:1 to drawdown of stream depth. This is incorrect for several reasons.

- Flow in Cienega Creek depends on conditions throughout the watershed above the point, not simply on the slope of the water table from the bank to the stream. For example, if the flow in the creek at a point is x cfs, and the reach near that point contributes y to that flow, lowering the slope controlling y will decrease that discharge. At the limit, the streamflow becomes x-y (if the bank slope reaches 0, yielding no discharge). The depth of water in the creek will be that corresponding to x-y. The effect that eliminating y from the flow will have depends on the magnitude of y in relation to x.

- It is average head in the stream that controls groundwater discharge to the creek. The stream depth changes along the profile but the head "seen" by the groundwater would be an average of that profile.
- Darcy's Law does not explain the flow into the stream from the banks in an unconfined aquifer. Rather, it is the Dupuit-Forcheimer discharge formula which ultimately described the discharge to the creek and describes a parabolic water surface to the creek. Discharge from the banks cannot be described based on a simple value of slope from some point on the banks to the creek. (This does not preclude a regression yielding a meaningful relation, but the parabolic shape of the water table renders the regression not useful beyond the range of the regression.)

Review of Rosemont 2014

Rosemont used length of wet stream data collected by BLM that SWCA apparently did not use. BLM collected the wetted stream length data during the dry season so that surface runoff should not have had an influence on the data (Rosemont 2014).

Rosemont fitted the wetted stream length data to various probability distributions so that they could use probability modeling to determine the probability of the stream being dry, or in probabilistic terms, the wetted stream length going to zero. There were just eight data points used, and the shortest wetted stream length is 4.7 miles, recorded in June 2013. Rosemont Table 12 presents results of a fit test showing that even the lowest test statistic, supposedly meaning the distribution that best fits the data, is not significant. Rosemont chose the log-normal and normal distributions because the test statistics were lowest. The following figures are from Rosemont (2014) and show the cumulative probability and the probability density for each of the chosen distributions. Their Figure 3 shows that the one percent cumulative probability is about 3.5 and 3.9 for the normal and lognormal distributions, respectively. That means that if the distributions accurately describe the wetted stream length, the return interval is 100 years for wetted stream length being less than 3.5 or 3.9 miles (probability of 0.01 corresponds to return interval if the wetted stream length can be considered an annual value, in this case the shortest length for the year). Rosemont Figure 4 shows that the probability of a wetted stream length being less than about 2.5 miles is much less than 1%.

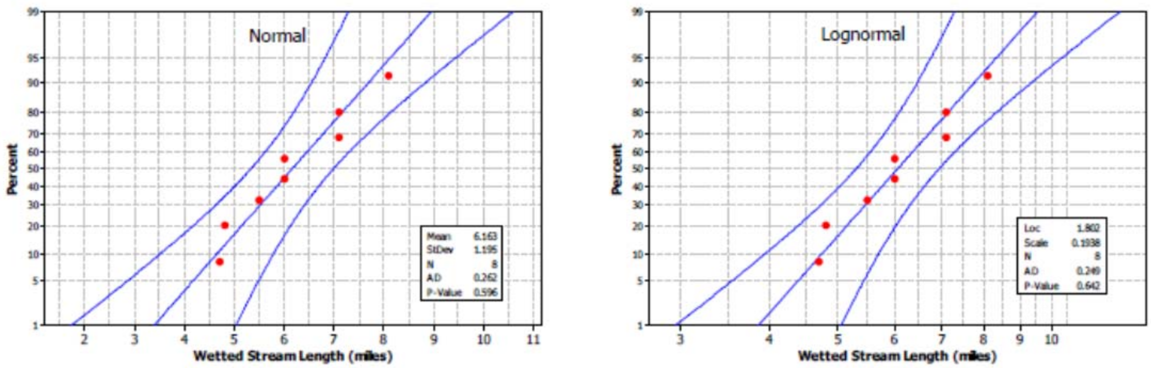

Figure 3. Probability plots with 95% confidence limits for normal and lognormal distributions.

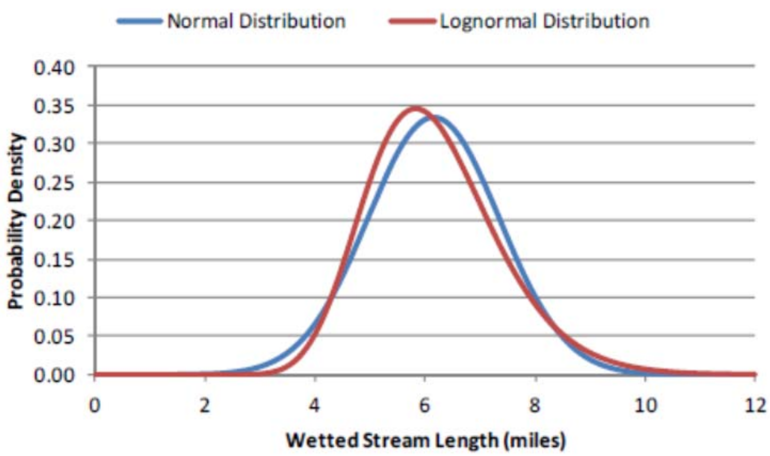

Figure 4. Probability density distribution for the normal and lognormal distributions fit to the BLM stream length data.

It is apparent that Rosemont used probability distributions far beyond their population of data (the population being the measured wetted stream lengths). **No results using such a distribution can be considered credible because it is far beyond the realm of model calibration**.

As part of their consideration of the Tetra-Tech model of decreased streamflow, Rosemont correlated flow of various metrics with the wetted stream length. As the following figure, snipped from Rosemont (2014) shows, the average of the gaged flow for the previous 170 days correlated the best, meaning that wetted stream length depends most on the previous six months climatology rather than short-term flows. The correlation was non-parametric and the linear regression completed to obtain 4.35 miles of stream length lost for a 1 cfs change in flow is inappropriate because linear regression assumes normality. **The R^2 is low and non-significant, therefore it is inappropriate and incorrect to claim that a 0.08 cfs predicted reduction in flow can translate into a 0.334 mile reduction in wetted stream length**. Additionally their Table 11 shows that the range in wetted stream length is from 4.7 to 8.1

miles which is a significant scatter in their regression (there is no scatter plot of the wetted stream length to any of the flow metrics). Finally, it is inappropriate because Tetra Tech's simulated flow rate would be base flow, not the 170-day flow preceding the wetted stream length measure as used in the equation.

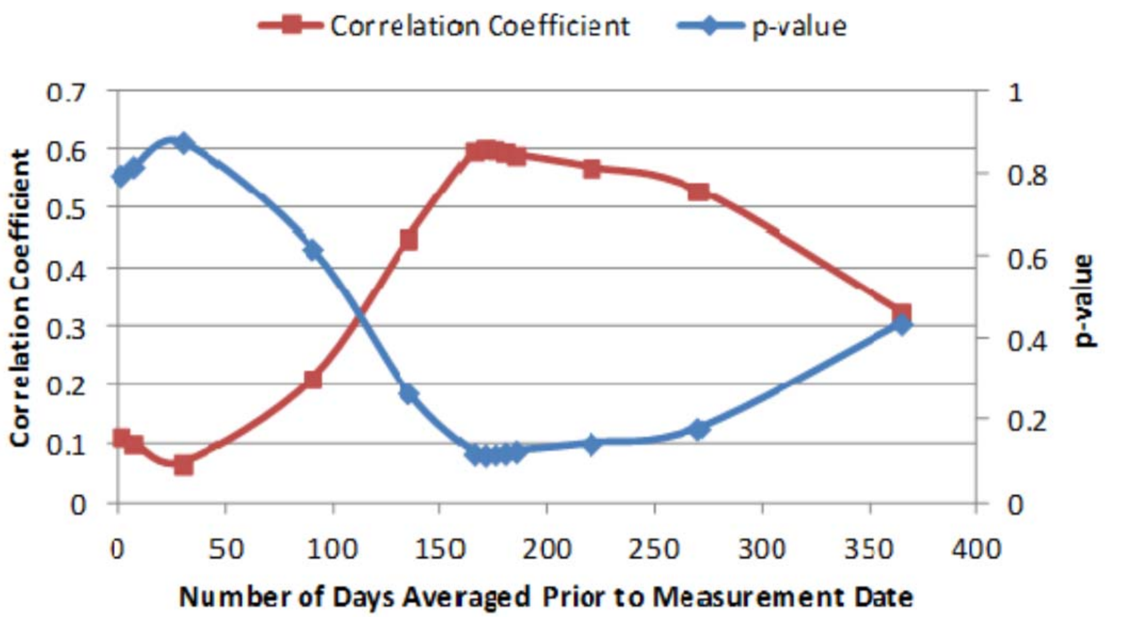

Figure 7. Correlation between flow and wetted stream length as a function of averaging period.

Simply, Rosemont used inappropriate flows and inappropriate probability distributions to estimate the probability of a dry stream. Their finding that even adding the drawdown causes essentially no chance of a dry stream is meaningless because it **is based on stretching empirical data far beyond their range**. The discussion of climate change effects simply adds one more bit of speculation to the calculation because they have to translate an annual streamflow reduction into an annual hydrograph when the effect in reality will vary through the year.

Considering the length of wetted stream length even during the driest period is 4.7 miles, it seems very unlikely that it would ever go dry under natural conditions. Because it is the primary discharge point for recharge within that watershed, it will continue to receive a discharge of groundwater until literally all of the recharge diverts toward the mine. This would require a drawdown sufficient to change the groundwater divide between the Cienega watershed and the proposed mine. The models all predicted drawdown through the watershed of less than 10 feet up to 1000 years from the end of mining. Thus, discharge to Upper Cienega Creek will be reduced because the gradient to the creek will be reduced.

The wetted stream length depends on both regional and local conditions and it is possible that drawdown will prevent regional groundwater discharge along some reaches. **The stream wetted length relates to gage data only if that the gage reflects watershed conditions**.

Summary

In summary, Rosemont claims the analysis depends on two major assumptions (Rosemont 2014, p 30), both of which are bad. The wetted stream length does not follow a distribution that allows estimates at the extreme. The scatter and low correlation of stream flow at the gage is poorly related to wetted stream length. No useful result appears to be gained from this analysis**. The only way to estimate the effect of drawdown on streamflow reductions and the length of wetted stream is to collect detailed empirical data and calibrate a local groundwater model of the surface/groundwater relations in the Cienega Creek, as described below.**

Review of SWCA 2014

This memorandum performs a sensitivity analysis of one key assumption in their 2013 streamflow analysis – the relationship of change in bank water level to the change in stream depth. They test the difference that a 1:5 and a 1:10 ratio of change in stream depth to bank ground level difference would make in the estimate of flow in the stream.

SWCA lists many assumptions that went into the original analysis. Several are problematic, such as the assumption of a 1:1 linear relationship between drawdown and loss of water depth as described above. Another very problematic assumption is that flow contribution from Empire Gulch and Gardner Canyon is binary, meaning that if flow at the mouth is zero then the contribution goes to zero. **This is incorrect because the contribution includes surface and underflow. Flow through the groundwater beneath the streambed will also contribute to flow in Cienega Creek because it may surface at some point downstream**.

It is also incorrect to assume that flow impacts, other than changes in flow rate, will migrate downstream to Lower Cienega Creek because there is a bedrock constriction at the gage. The contribution of the upper basin to the lower depends on the stream flow; the effect on groundwater in the Lower Cienega depends on how much recharges the alluvial aquifer, an amount which cannot be affected by drawdown because of the bedrock.

It is correct to state that “dry” conditions may occur while there are isolated pools with no surface flow between them. There could be subsurface flow.

Based on the above, there is not a simple linear relation of any ratio that can explain the change in discharge to the stream due to drawdown. Not infrequently, an iterative process using Darcy's Law and Manning's equation is used to estimate the change, but there are inherent inaccuracies due to the relation actually being nonlinear. So, based on the above, the sensitivity analysis completed by SWCA is meaningless.

Review of Westland (2012)

This analysis attempts to relate the wetted stream length of three different intermittent reaches of Lower Cienega Creek with the depth to water in various overbank wells. Ostensibly there is nothing wrong with the concept that the amount of flow in the creek relates to the depth to water in the wells. The regression lines explain from about 43 to 73% of the variance, so they have merit. The scatter plots do not suggest the correlation is spurious, although they indicate there is a huge scatter in the results. The scatter covers as much as 7000 feet for a two-foot change in depth to water; **obviously other factors affect the wetted stream length.** The confidence in the results of the regression analysis is very low, especially considering the prediction is for a drawdown in the overbank wells of about 0.1 feet. The predicted changes due the drawdown are two orders of magnitude less than the natural scatter in the data and should be given little credence.

The analysis in the second section concerning the potential effects due to surface water impoundment suffers from an error in concept. The estimate is that annual flow at the confluence of Cienega Creek and Davidson Canyon reduces by 12% of average flows[1]. This is likely to occur during large storm flows. Westland recognizes that the contribution of storm flows is to infiltration into the stream bank for later discharge to the stream. They assume that the contribution of Davidson Canyon annual flows to Cienega Creek is 24 percent but provide no basis for that assumption.

The regression of wetted stream length to flow rate at the confluence shows two different relations (Westland Figure 5), which Westland does not account for. At flows higher than 0.6 cfs, the relation appears linear. Below that point there is a huge scatter with wetted stream length ranging from less than 1000 to about 6000 feet. The data above 0.6 cfs controls the slope which due to the scatter is meaningless at 0.35 cfs, the assumed baseflow rate. They estimate the flow rate change due to the mine to be 12% of the 24% of the average 0.35 cfs baseflow, or 0.12x0.24*.35 = 0.01 cfs. This very low flow rate yields a very small estimated change in wetted stream length as the estimated reduction due to the mine.

The conceptual error is that the estimated flow reduction is of annual average flow and is not a reduction applied uniformly through the year. Changing storm flow changes the recharge characteristics in the floodplain aquifer, which could be a change in the dynamics of the aquifer that supports Lower Cienega baseflow. Total recharge could likely be much decreased as could

---

[1] **It is assumed this means flow in Cienega Creek, not just Davidson Canyon.**

the distribution of recharge along the stream reach. The changed dynamic render the regression equation even more unrepresentative of the stream than it had been previously.

Recommendation

Several alternative analyses could be done to improve the risk assessment, but each requires the collection of significant amounts of data. **It is simply not possible to use existing data provide a meaningful estimate of the risk to Cienega Creek from long-term drawdown.**

During baseflow conditions, those most likely to be affected by drawdown, surface water flow rates on Cienega Creek vary along the profile according where water flows into the stream and where it flows from the stream. Flow directions can reverse in very short distances based on the cross-sectional area and conductivity of the alluvial aquifer beneath the stream; there are likely reaches with no flow, the length of which depends on the depth of wet reaches up and downstream. Flow data along the entire reach can be related to the gage if accurate data on flows, gaining and losing reaches, and the length of dry reaches can be obtained.

Detailed synoptic surveys of the flow along the creek should be obtained over at least two baseflow periods (two to consider variability). Flow measurements should be obtained at the up- and downstream ends of each gaining reach, to allow an assessment of the amount of flow that enters and leaves the stream. Gaining and losing reaches may be estimated by measuring temperature change in the flow and in the substrate and by installing piezometers near the stream and in the substrate under the stream to assess small-scale gradients (see the USGS study of eastern Nevada for information on completing such a survey, http://nevada.usgs.gov/water/studyareas/springsnake.htm). In conjunction with these surveys, there should be piezometers installed in the stream bank to assess how the changes in channel depth or wetted stream length related to changes in water level in the banks. Piezometers would be needed on each side of the creek at spacing depending on the canyon characteristics. Two piezometers would partially explain changes in a reach, but the length of that reach depend on the alluvial aquifer characteristics being homogeneous.

Collected over a period of at least two years, this data could be related to gaging station depth record to extend the record and complete a risk assessment. As part of the synoptic survey, detailed cross-section would be measured. Using these and the changes in flow rate, a water surface profile model such as HEC-RAS or HEC-2 could be used to estimate new flows and velocities. Or, the USFWS model PHABSIM (Physical Habitat Simulation) model could be used to assess changes caused by drawdown.

It would also be possible use this data to calibrate a detailed local-scale groundwater model of the alluvial aquifer and the stream depth. This model should include data relating it to the regional aquifer. Once calibrated, the results of the regional models could be imposed to determine the frequency and length of stream that goes dry due to mine development.

The potential changes to flow in Lower Cienega Creek are much greater due to the change in runoff from Davidson Canyon. The first step to understanding these changes is to apply runoff changes to the annual runoff hydrograph and assess how the recharge to the alluvial aquifer will change. A simple numerical model could be developed to assess seasonal changes in the floodplain aquifer; calibration could be done with the existing wells. Decreased recharge due to runoff changes could then be applied to the model to assess changes in wetted stream length.

References

Rosemont Copper Co (2014) Review of USFS Model and an Alternative Approach to Inform the Effects of Groundwater Drawdown on Cienega Creek.

SWCA (2014) Memorandum: Sensitivity Analysis for FEIS Streamflow Impact Assessment.

SWCA (2013) Memorandum: Review of Available Depth of Flow Information on Cienega Creek and Empire Gulch and Protocol for Estimating Impacts to Streamflow. October 30, 2013.

Westland Resources (2012) Rosemont Copper Project: Potential Effects of the Rosemont Project on Lower Cienega Creek.