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Technical Memorandum

Review of Underground Injection Control Permit and Application

Gunnison Copper Project

January 6, 2017

Dragoon, Arizona

Summary and Conclusions

Excelsior Mining Arizona proposes to construct an in-situ leach and recovery copper mine near Dragoon, Arizona. This technical memorandum reviews the draft Underground Injection Control Permit (UIC) and application materials for the Gunnison Copper Project.

The regional aquifer under consideration extends from the Little Dragoon Mountains in the west to the Gunnison Hills in the east and Dragoon Mountains on the south. Groundwater generally flows from recharge areas near the Little Dragoon Mountains and within ephemeral channels in the west almost directly eastward across the site to gaps in the mountains north and south of the Gunnison Hills. Groundwater would flow through these gaps eastward to the broader Willcox Valley.

The aquifer properties are highly heterogeneous and oriented according to the dip of faults and fracturing that occurs naturally in the area. However, the analysis presented in the UIC application averages the hydrologic properties so that heterogeneity is not well considered and the importance of preferential flow paths is minimized. Fracture intensity and porosity modeling shows substantial variability that the application tends to present as averages. Even though the pump tests indicate that properties vary by direction, with a tendency for the northwest to southeast direction to have higher conductivity, the analysis in the application does not account for this. Averaging and failure to consider directional differences causes the application to not adequately consider preferential flow paths caused by fracturing and through which much more groundwater, and injected fluid, would flow.

Regional groundwater contour mapping shows a west to east gradient, and a groundwater divide near the south edge of the project that Excelsior considers as a separation between its project and the aquifer further south. This is likely untrue and the divide, if it actually exists, would not prevent contaminants released from the proposed project from transporting south.

Mapping is based on a paucity of wells, and is likely inaccurate so that the location of the divide could easily be further north placing part of the project site south of the divide. Mapping groundwater contours assumes the horizontal flow direction is exactly the same regardless of depth. This assumption also ignores the likelihood of preferential flow paths which could connect areas south and north of the regional divide.

Three things could change the location of the divide and cause more flow in a southerly direction. First, pressure from injection at the project site could cause southerly flow, especially if a recovery well is not located in a connected fracture zone. Second, pumping in wells near Dragoon could increase the southerly component of the gradient, especially through preferential pathways. Third, drought could decrease recharge west of the site and lower the contours thereby changing gradients and the location of the divide.

The project is an in-situ leach and recovery project for copper (Cu) in the bedrock formations underlying the basin fill at the site. The project involves injecting an acid solution into the groundwater of the bedrock aquifers so that it can leach Cu which would then be recovered in capture or collection wells. The well layout would have four collection wells surrounding each injection well, but a map of the pattern suggests that each collection well would be part of the four collection wells surrounding other injection wells. The injection rate would vary with time throughout the project life, with the total injection increasing from 5300 to 25,600 gallons per minute with over the project life. The injection/collection process would collect more water than is injected, which should cause a general groundwater level drawdown within the well field. A line of hydraulic control wells would surround the well field and be designed to withdraw water and create a trough in the potentiometric surface intended to prevent fluid from escaping from the wellfield. Predicted drawdown from hydraulic control wells would extend to the east of the well field by 1200 to 1500 feet from the control wells at maximum pumping based on modeling. There is no guarantee that these wells would intercept flow in each preferential flow path, due to the heterogeneities described above.

The processing of copper would allow most other metals to remain in solution, and be circulated back through the system, so that the water would have concentrations of metals and some anions that are multiple times their water quality standards. Concentrations of cadmium, lead, selenium, nickel, thallium, zinc, and fluoride, among others, would be orders of magnitude higher than background levels and most water quality standards. The incredibly poor water quality of the leach solution exemplifies why preventing any of it escaping the system is critical.

The application argues this site is favorable for “maintaining control of the leach solution” because there is limestone within and downgradient of the wellfield, which would provide a large attenuation and neutralizing capacity. The claim regarding downgradient attenuating formations is too broad because there has been no consideration how much neutralizing carbonate rock would actually contact any acid escaping the well field. If escaping acidic fluid flows through preferential pathways so that only a small portion of limestone is contacted, some may escape unattenuated. The limestone should not be relied on to neutralize acid that reaches it, unless there is an accounting for the effective neutralizing capacity of in situ limestone.

Groundwater model simulation of the ISL project is too coarse, meaning it was completed without sufficient detail, and too unrealistic, to provide much confidence in the results. Only the hydraulic control wells were simulated. The ISL system was simulated by simply placing contaminant particles in the model at the edge of the interior wells fields, but not under pressure as they will be during operations. High injection rates and heterogeneities in the well field could easily cause flow paths not captured by collection wells. Without simulating the injection/collection wells, this model does not provide reliable information regarding the effect of the injection/recovery system on local or regional flow paths.

The model is too coarse because the pathways are, at a minimum, 50-feet wide (model cell sizes) which means the hydrologic properties are averaged over an area that wide. It completely misses the potential narrow pathways that could preferentially allow particles to exit the system. Simulation of mining should be improved by simulating the actual injection/recovery wells, with injection rates depending on the localized conductivity and pressures that would be acceptable for operations. The model should be discretized into much smaller cells at the mine so that injection/recovery can be simulated more accurately. The geology/fracture intensity model should be used at a smaller scale to provide more detail of flow paths through the well field.

The monitoring plan proposed for the project area is insufficient to protect downgradient water resources. Although there are several rings of monitoring wells, they would be insufficient. The spacing does not account for aquifer heterogeneity, in both the horizontal and vertical direction. In a highly fractured aquifer, contaminants would follow the most transmissive pathway, but there is no certainty these pathways would be monitored. This is especially problematic with respect to the potential for flow southward through fractures perpendicular to the regional gradient. The monitoring would not detect excursions through the southern project boundary.

There are far too few point of compliance (POC) wells and the design could allow contaminant plumes to escape the well field undetected. The POC wells also have screens, or open intervals, that are far too wide that will allow the contaminants to be diluted by clean flow either above or below the pathway transporting the contaminants. POC wells should be redesigned according to results from modeling dispersion with the more-detailed model. The POC wells should have multiple screens so that individual productive flow zones can be sampled without dilution from above or below.

The following sections provide much more detail regarding the application, and the factors of it that should be improved to make the UIC application more protective of the environment. This is especially true for the groundwater modeling and the POC wells.

Introduction

This technical memorandum is a review of the draft Underground Injection Control (UIC) Permit and supporting documents for the Gunnison Copper Project proposed by Excelsior Mining Arizona. References herein are to the draft permit or its appendices, as well as to CCA (2016), the application for the Arizona Aquifer Protection Permit (APP), because it provides a good discussion of how some aspects of the project tie together. Many of the documents are the same for each permit, but have different names.

Regional Hydrogeology

Surface formations at the site and around the valley from the Little Dragoon Mountains to the Gunnison Hills are basin fill except near the mountains where there are bedrock outcrops. Basin fill is generally eroded material from nearby mountains that has settled into a valley and has been minimally sorted by rivers and streams. The basin fill near the proposed wellfield is saturated only in one area near the project site. East of the project site and near Dragoon, the basin fill approaches 1000 feet in thickness in a deep north-south trending trough.

Groundwater generally flows from recharge areas near the Little Dragoon Mountains and within ephemeral channels on the west side of the valley through bedrock to deep basin fill almost directly eastward across the site. Groundwater recharge is precipitation that percolates through the soil and rock to reach the groundwater table. Depth to water ranges from 244 to 655 feet, with most water levels below the top of bedrock except for a north-south swath across the western third of the site where the water levels indicate the aquifer is confined (CCA 2016, p 5-9). Confined aquifers are those in which the water pressure causes water level in the wells to rise above the top of the aquifer, the confining layer that separates the aquifer from overlying formations.

Groundwater flowing in bedrock fractures to the east would reach the basin fill in the deep trough east of the site. Groundwater likely discharges to saturated fill in the deep trough. Residence time, or the average time for water to cycle through the aquifer, in the fill is likely very long, on the order of at least centuries if there is mixing. If mixing is limited, the residence time for some of the water could be much shorter. East of the proposed wellfield, groundwater either flows south to a gap between the Gunnison Hills and Dragoon Mountains or north of the Gunnison Hills.

The regional potentiometric surface slopes steeply east until reaching the saturated basin fill east of the project site where the slope flattens greatly (Figure 1). Flow in the bedrock is mostly east toward the saturated basin fill. In the fill, the slope is much flatter but to the south and the discharge point east to the Willcox Playa area. Hydraulic gradient, slope measured in feet per foot, is significantly flatter through the area of the deposit, and proposed wellfield, about 0.01 or lower than in bedrock to the west (CCA 2016, p 5-11). The application claims it is due to more fracturing and higher permeability associated with skarn mineralization but the gradient flattening could also be due to flatter topography and geologic structure downgradient, such as impervious faults on the west face of the Gunnison Hills damming or diverting the flow.

Figure 2, showing more detailed localized groundwater contours, does not replicate the regional divide. Figure 2 contours demonstrate the complexity of groundwater flow through the site.

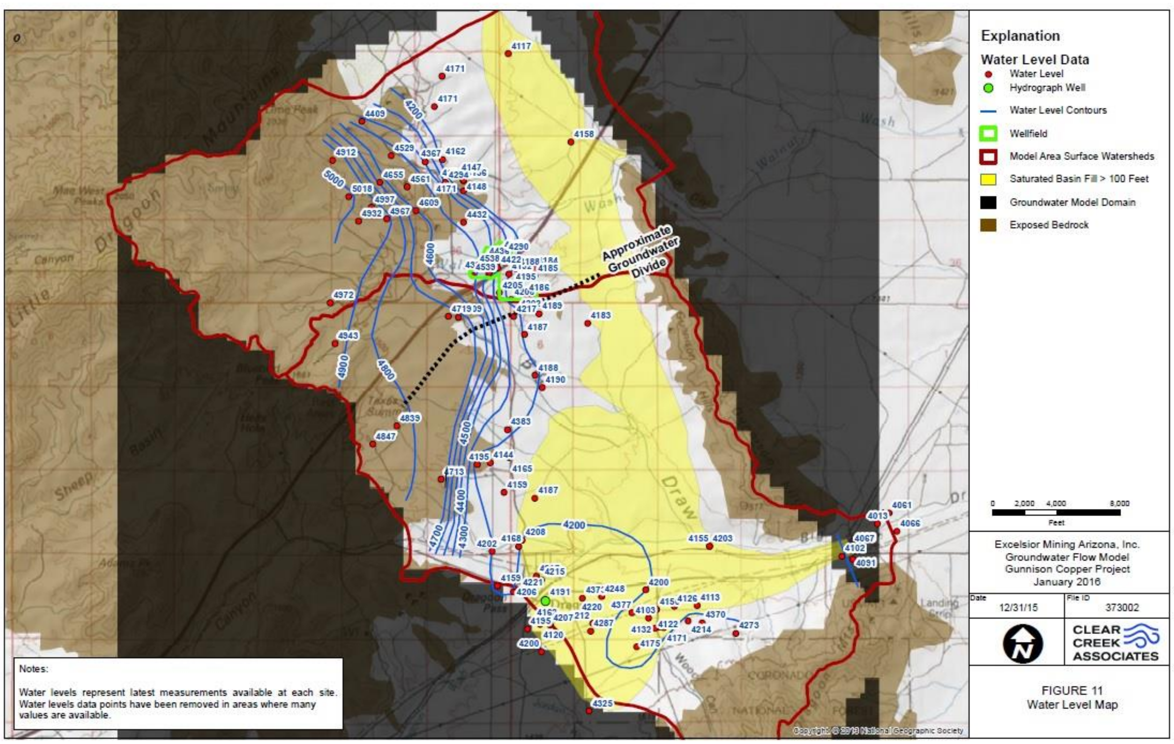

Figure 1: Figure 11 from Attachment A-2 showing the regional potentiometric surface. The red boundary line is the bounds of the regional groundwater model.

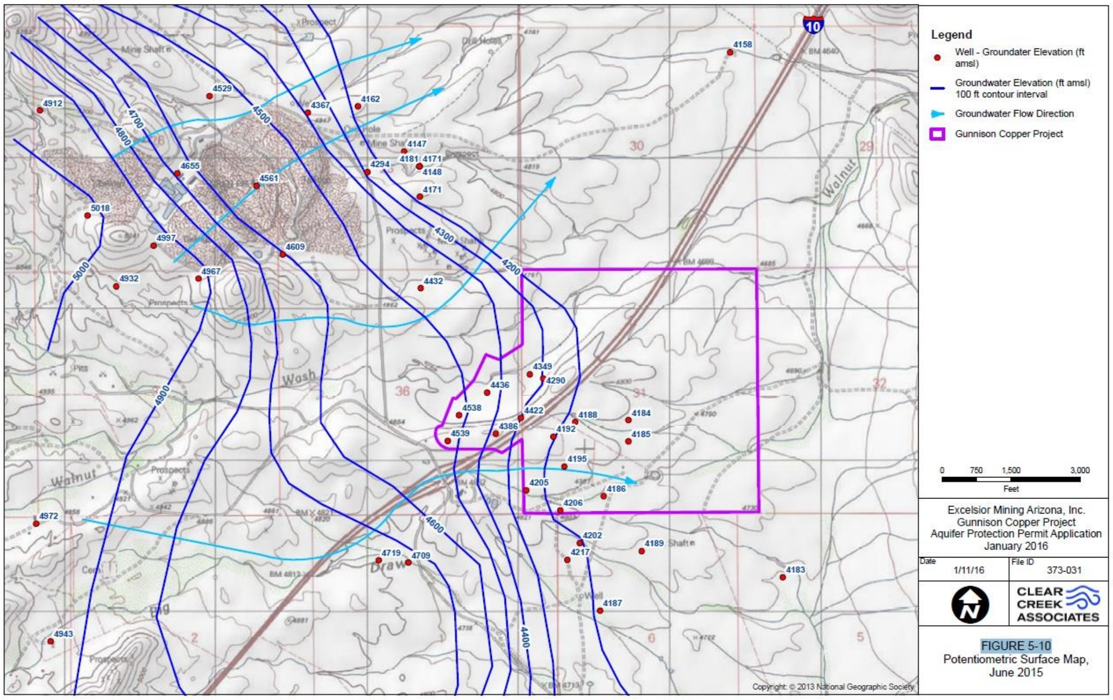

Figure 2: Figure 5-10 from Clear Creek Associates (2016) showing the potentiometric surface at the site and to the west and northwest.

CCA (2016) does not present a natural water balance for the aquifer. A water balance would be an estimate of recharge and discharge from the aquifer. The Application describes recharge properly in that it occurs from precipitation at higher elevations or from runoff through washes at low elevations, estimating that about 3% of the average 12.5 in/y precipitation becomes recharge across the basin.

- The hydrogeology discussion should present a water balance for the regional aquifer system, with an estimate of recharge and an estimate of groundwater flow leaving the basin through the two gaps on the east.

Geologic formations beneath the basin fill are in order of increasing depth are Me (Escabrosa Limestone), Dm (Martin Formation), Cau (Upper Abrigo), Cam (Middle Abrigo), Cal (Lower Abrigo), and Cb (Bolsa Quartzite) with pCu (PreCambrian Undivided) underlying these formations. These formations dip about 20 to 40 degrees to the east, and there are several near-vertical faults that offset the formations. Mineralization occurs in most of these with the base of the well field expected to be in the Cal formation (CCA 2016, Figures 3-5, -6, and -7). The bedrock surface is highly variable, which makes the basin fill thickness vary substantially. Bedrock elevation contours show significant variability over short distances, including drops of as much as 300 feet (CCA 2016, Figure 5-13).

Local Hydrogeology

There are 202 known wells within ½ mile of the project, although these are mostly mine exploration drill holes including those of Excelsior (CCA 2016, p 5-1). Most are owned by mining companies. Excelsior constructed 32 total wells through basin fill into the bedrock (Figure 3). The deepest wells, greater than 1400 feet, are in the south-central and southwest portions of the project area (Figure 3). There were additional coreholes drilled, to as deep as 2500 feet (CCA 2016, p 5-4).

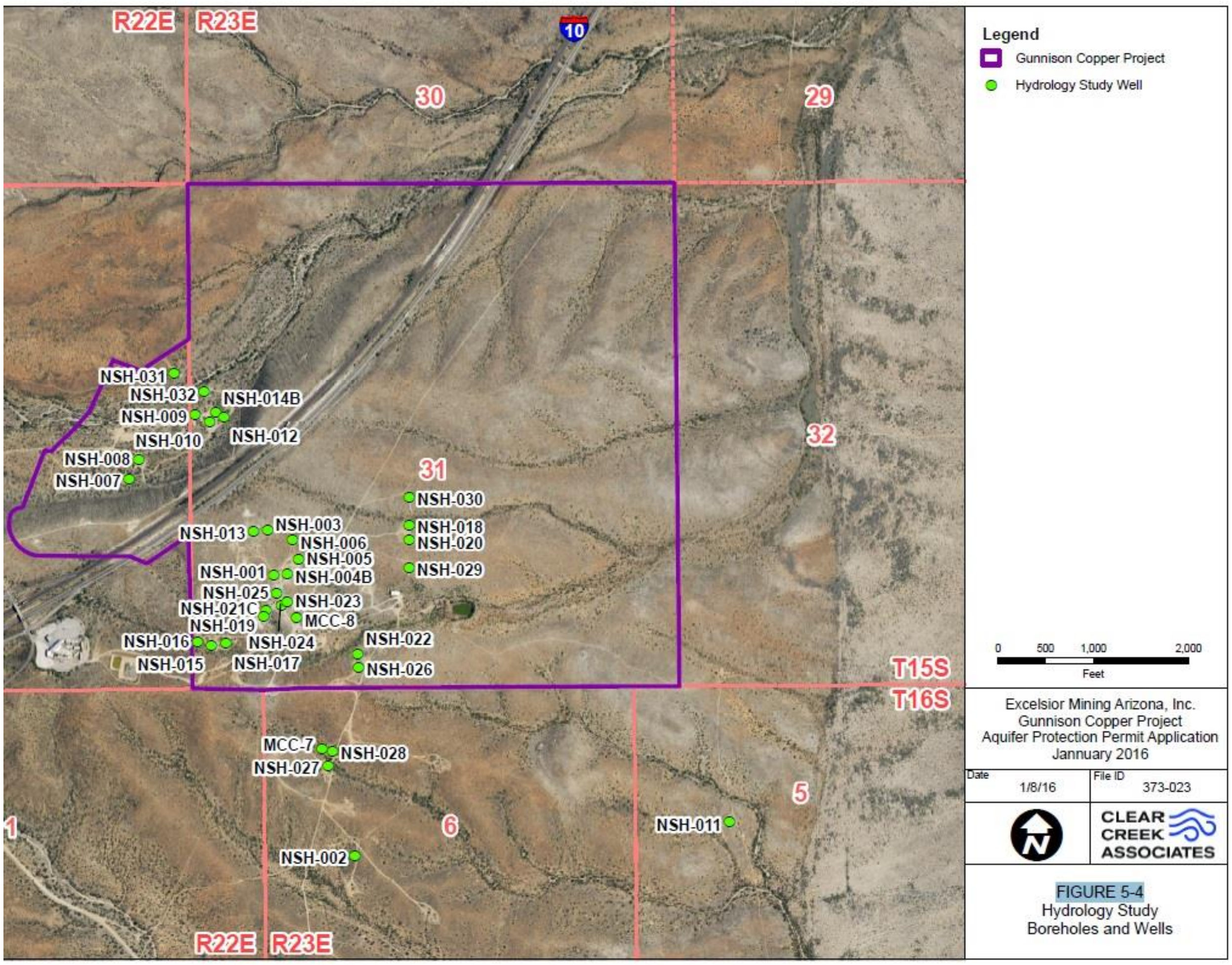

Figure 3: Figure 5-4 from CCA (2016) showing the boreholes and wells installed by Excelsior on and near the project site.

Aquifer Properties and Pump Tests

Excelsior (Attachment A-3) estimated most material properties using pump tests and geophysical techniques to estimate fracturing the various wells. Pump tests were completed with four two-hour steps followed by five days of steady state pumping and with three days of recovery monitoring. Drawdown in observation wells was monitored so there is an indication that properties in one direction is different from properties considered in a different direction, which may be the effect of fractures.

Attachment A-3 Table 1 summarizes estimate transmissivity (T), maximum pumping rate (Qmax), and drawdown (Hmax) for each pump test. Transmissivity is the product of conductivity (K) and aquifer thickness. Conductivity K is the ease with which groundwater flows through a formation. The pump tests show a very large variability in T, more than three orders of magnitude, with values from 2 to 4000 ft^2/d (K varies from 0.01 to 9.8 ft/d based on thickness equal to pumping screen thickness, Attachment A-3, Table 3) and maximum pumping rates from 2 to 170 gpm. Lower pumping rates generally coincided with a low T. The author indicates that the variability "is to be expected as some wells were completed in highly fractured rocks while others were in unfractured or solid rock" (Attachment A-3, p 6). Because the formations dip, it is likely that most wells intersected fracture zones so that T probably is related to the fracture density rather than simply the presence of fractures. The large range in K around the site indicates the site is highly heterogeneous. It is very likely that some layers intersected by the wells are the primary producing layers and that others produce very little, as demonstrated by the variability in pumping rates among the wells. The weighted averaging inherent in the estimated material properties does not account for this variability.

Attachment A-3 improperly claims there is no horizontal anisotropy, which for K the horizontal anisotropy is the ratio of K in one direction to K in a different direction, usually perpendicular to the first. Observation well drawdown often varied depending on whether the observation well is screened in the same fracture zone as the pumping well (Attachment A-3, p 7). A plot of K and the azimuth between the pumping and observation wells shows a significant dependence on direction (Figure 4). The description of drawdown at well NSH-08 due to pumping at NSH-07 found that the significant drawdown at the pumping well compared to the observation well indicated flow to the pumping well likely came from a direction different than a direct pathway between the wells (Attachment A-3, p 8).

The pump test for well NSH-005, which is completed in bedrock, caused a larger drawdown in basin fill well NSH-006 than did the pump test directly in well NSH-006 (1.8 ft v 0.4 ft). Both wells are completed near the Forty Mile Fault structure (Attachment A-3, p 15). Well NSH-006 has about 30 feet of saturated fill so it is in the primary unconfined aquifer at the site. This substantial response indicates the fault connects the bedrock with the basin fill so that stresses in the bedrock that affect the fault will also affect the water in the basin fill. This observed connection suggests that injected water (lixiviant) near this location could be forced upward into the unconfined aquifer. Pump testing at NSH-006 caused only 0.4 feet of drawdown but the pumping rate was very low; small drawdowns were observed at two bedrock wells (Figure

3) confirming the connection. It would have been useful to pump this well at a higher rate to better test the connections to the bedrock aquifers.

Attachment A-3 presents a directional plot of conductivity with azimuth (Figure 4). Rather than showing “that the hydraulic conductivities are relatively evenly distributed with little prevalent direction” (Attachment A-3, p 31), Figure 4 shows a substantial correlation with direction. This is especially true for a direction from midway between north and northeast and between south and southwest, where the K exceed 4.0 ft/d, and for a roughly perpendicular direction along which K is just over 3.0 ft/d. Additionally, between those transverse K trends, there is another line of about 3.2 ft/d trending from between north and northwest to between south and southeast. K in other directions is less than half as much. The trends show a perpendicular fracture pattern, but do not demonstrate that “the fracture patterns intersect sufficiently at the well spacing of 100 feet to smooth out, for the purpose of hydraulics, discrete fracture spacing which is on the order of one foot” (Attachment A-3, p 31). There is nothing in the Appendix, or anywhere in the Application, that indicates the spacing of the intersection of fracture patterns or of one-foot discrete fracture spacing.

Figure 123. Compilation of K-values from the Gunnison ore body by azimuth and magnitude

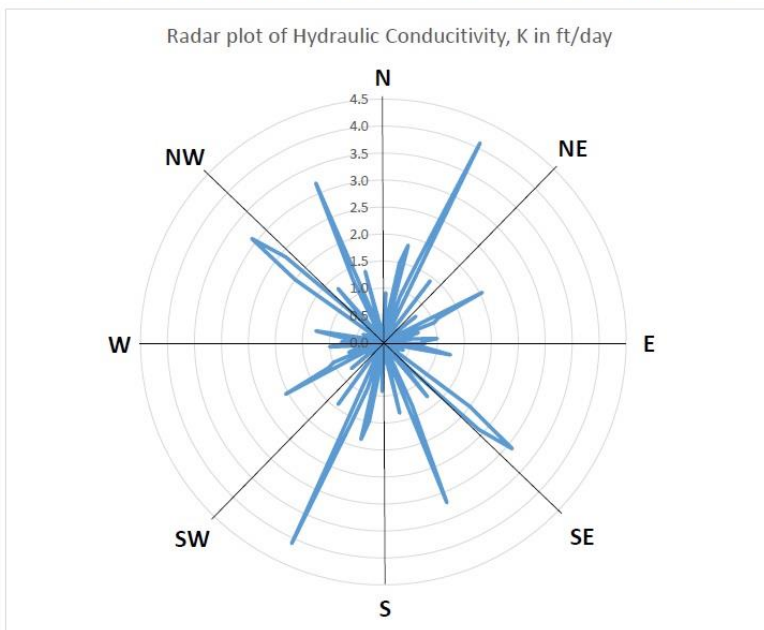

Figure 4: Figure 123 from CCA (2016) Attachment A-3 showing the relation of hydraulic conductivity with azimuth between pumping and observation wells.

The property data identified in Attachment A-3 was used “to populate and calibrate the hydrogeological flow model” (Attachment A-3, p 32), but they ignore heterogeneity and directional tendencies.

The application claims that even "the low-yield wells demonstrated long-distance hydraulic connectivity with observation wells" (Attachment A-3, p 37), based on responses even when the wells were not screened in the same fracture zone. In a confined aquifer, a stress in one location will propagate as a pressure response in all directions; Excelsior properly references this response as indicating the aquifer is confined. However, Excelsior may be implying that this means that groundwater (and contaminants, or lixiviant) will flow from one point to the other. As noted in the pump test analysis, due to the directional tendency of the fractures, much of the flow may be parallel. Pressure responses occur in all directions in a confined aquifer, and may not represent proof of flow between the two points. This interpretation is important because of the need for the injection/collection system to capture flow from all points of the system.

Attachment A-2 notes that in bedrock the model treated K as equal in all directions except for the basin fill. By not considering anisotropy the Application (most importantly in the modeling) ignores preferential flow either on the horizontal plane or vertically. Fractures trend from northwest to southeast which suggests the K along that direction should be considered higher than in other directions. The formations dip to the east which also suggests that K is higher parallel to the dip than in other directions. The Application ignores these issues even though geologic figures presented within the application provides the relevant evidence regarding the dip. For example, drawdown from pump tests in an observation well more than 1000 feet from pumping wells indicates "good connectivity" (Id.) in a prevailing direction between the pumping and observation wells.

- Excelsior should consider horizontal anisotropy in its modeling and project design. The effects of not considering this are better considered below in the discussion of modeling.

Excelsior also did not interpret the pump tests accounting for vertical connectivity or use available core holes to determine connectivity of wells within the proposed well field and formation beneath well field. As noted, coreholes had been completed to as much as 2400 feet bgs. During the pump test, Excelsior missed an opportunity by not recording the response within those deep wells. The application presents no information or evidence regarding the potential for pumping the injection/collection wells on groundwater beneath the site. This could be important because the formations and groundwater at depth are sulfide.

- Excelsior should complete at least one longer term pump test using the higher producing wells and monitoring their wells both within the well field, outside the well field, and beneath the well field. This would provide improved evidence regarding connectivity throughout the aquifers near the project site.

Most of the storage coefficients from tests near the proposed well field indicate confined conditions, although there are exceptions usually on one or more of the observation wells for a given test. Storage coefficients indicate how much water would be released from storage due to a change in pressure within the aquifer. The values vary over six orders of magnitude which indicates great variability and that no average value should be applied over the entire model domain. Storativity probably varies among bedrock type and among the fracture density, thus no estimate will be accurate for the entire domain. This is a critical problem for the modeling because storativity controls the amount of water that would be released for a given change in potentiometric surface.

Estimated porosity values from pump tests are minimum because drawdown at the observation wells had not come to equilibrium (Attachment A-3, p 29). Excelsior also used gamma-gamma logs to estimate porosity for each 0.1 feet down the wellbore (CCA 2016), but presented only a weighted average for seven wells and determines only an overall estimated porosity of 2.7% (Attachment A-3, p 29). Values for the wells vary from .0133 to .0577, a substantial range which demonstrates significant variability across the site. It is also likely the vertical distribution of porosity along a given well would be much more variable as the well bore intersects fractures and intact bedrock. Presenting graphs of how porosity varies vertically along the wells would illustrate the vertical variability and the potential for preferential flow. The more variable a formation is in the vertical direction, the more potential there is for vertical flow paths and the less potential there is for a hydraulic barrier formed by pumping wells to prevent water from escaping the well field.

Summary

The hydrogeology of the area shows a very heterogeneous, anisotropic aquifer, with variability being maximum at the proposed well field. Figure 1 shows a groundwater divide that Excelsior considers would separate its project from the aquifer further south. However, there are four reasons this is likely untrue and the divide, if it even exists, would not prevent contaminants released from the proposed project from transporting south.

Mapping of the groundwater contours is based on a paucity of wells, and is likely inaccurate in areas. The location of the divide could easily be further north placing part of the project site south of the divide.

Mapping of the groundwater contours also assumes there is vertical homogeneity through the site in the potentiometric surface. This means the mapping assumes there is no vertical gradient, and the horizontal flow direction is the same regardless of depth. This assumption also ignores the likelihood of preferential flow paths which could connect areas south and north of the regional divide.

The groundwater divide is very flat, and just south of the divide the regional gradient is more south and southeasterly than north of the divide. This would direct contaminants that cross the divide towards Dragoon.

Three things could change the location of the divide and cause more flow in a southerly direction. First, pressure from injection at the project site could cause southerly flow, especially if a recovery well is not located in a connected fracture zone. Second, pumping in wells near Dragoon could increase the southerly component of the gradient, especially through preferential pathways. Third, drought could decrease recharge west of the site and lower the contours thereby changing gradients and the location of the divide.

Excelsior modeled the regional hydrogeology using a groundwater flow model based on the MODFLOW code. The model was reviewed, and the review is included as the bottom section of this document.

Water Chemistry

The groundwater is generally a calcium-sodium-magnesium-bicarbonate type with TDS varying from 210 to 420 mg/l, with some high fluoride concentrations. Samples from the sulfide zone are sodium-carbonate-bicarbonate or sodium-bicarbonate-chloride-sulfate with higher TDS (p 5-6). Metals are generally low but there were some hits of volatile organics.

Excelsior reported petroleum products in the groundwater on the project site. The following discussion of petroleum contamination is based on the discussion in the UIC application (CCA 2016), because no discussion of petroleum contamination was found in the UIC documents. Coreholes CS-10 and CS-14 had free petroleum product in the groundwater, which means there is LNAPL (light, non-aqueous phase liquid) floating on the surface of the water (Figure 5). After pumping it from the corehole, it reappeared and was 0.25 feet thick in about ten days (CCA 2016, p 5-8). That indicates there is a significant source of LNAPL near the site. The clustering of wells with different hydrocarbons, as seen by the distribution of hydrocarbons in Figure 5, may reflect different transport and attenuation rates for the different products within the fracture zone affected by the source. The intermixed wells without any hits may be screened in different fracture zones.

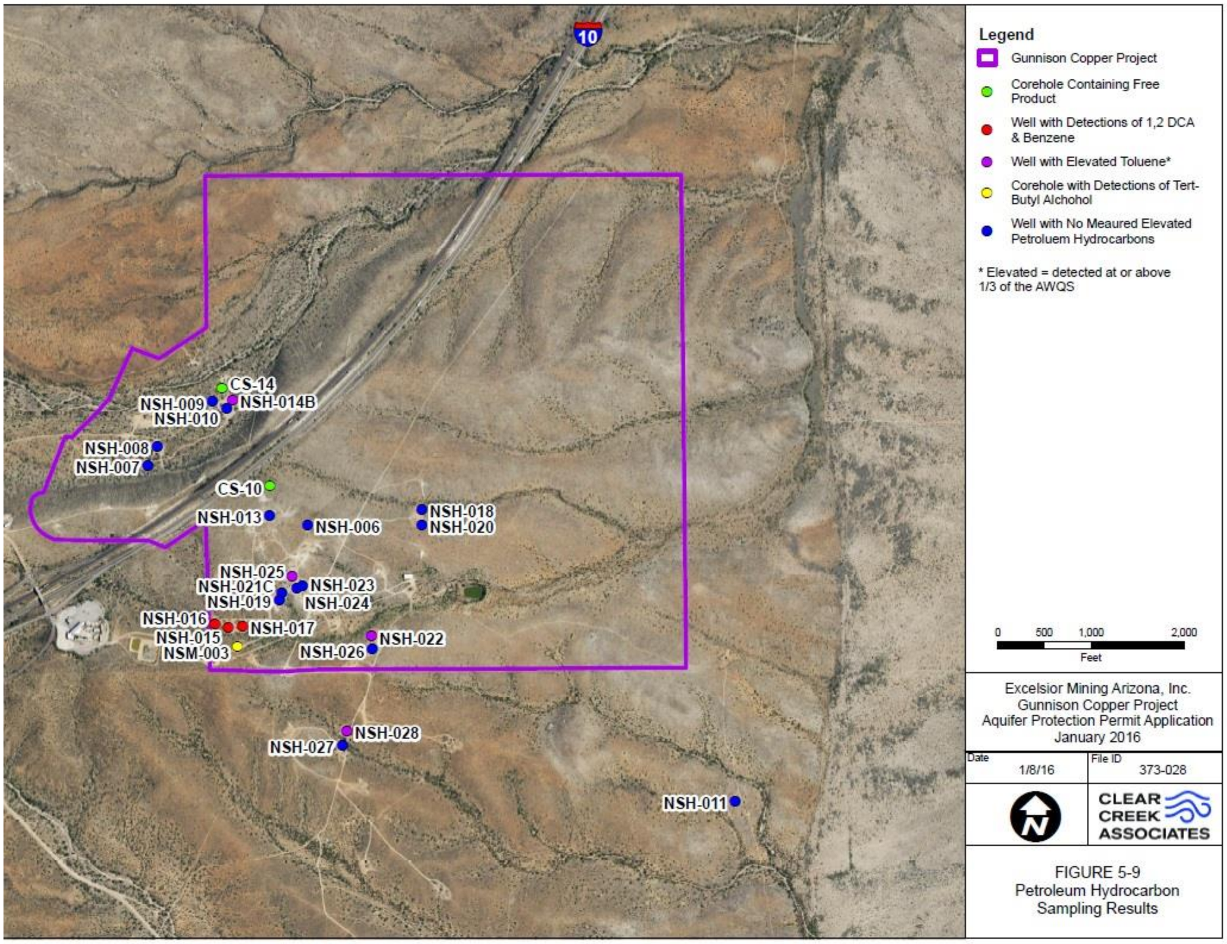

Figure 5: Figure 5-9 from Clear Creek Associates (2017a) showing the wells and coreholes with petroleum hydrocarbon hits.

Excelsior explains the potential sources are The Thing gas station and the Johnson Camp Mine, although the mine may not have stored petroleum products (CCA 2016, p 5-9). The Thing site had underground storage tanks removed in 1996 because there had been contamination detected in the soil. ADEQ closed the case files investigating the contamination between the substantial depth to groundwater (hundreds of feet) and the presence of bedrock just two feet below the tanks. Most of the detections (Figure 5) are potentially downgradient of the Thing site (Figure 2). If indeed The Thing is the source, there has been substantial transport and lack of attenuation, which could be a significant source of contamination to the project.

As noted, the mine apparently did not use gasoline, so Excelsior seems convinced that it could not be a source (CCA 2016, p 5-9). They also point to the gradients of the potentiometric surface which suggest that groundwater flow from the mine would be to the northeast and would miss the project site by a mile or more. The potentiometric surface (Figure 2) appears to drop steeply northeast of the mine and appears to form a ridge on the west side of the project site.

- Due to the importance of understanding the source of petroleum products, Excelsior should reconsider the potentiometric surface map to consider whether the water levels used for mapping all represent the same aquifer level. In a fractured rock aquifer, it is not often appropriate to assume there are no vertical gradients. The map with water level with respect to the top of the bedrock (Figure 5-12, CCA 2016a) shows significant variability in small areas, suggesting that it is possible the water levels represent different bedrock levels. It is possible that groundwater flows southeast from the mine at certain levels. For this reason, the mine cannot be ruled out as a source.
- Hydrocarbons in the groundwater could affect the chemistry of the project. Excelsior must complete a larger survey of the LNAPL contamination and assess whether and how it could affect ISL operations.

Copper Mining Project

The project is an in-situ leach and recovery project for copper in the bedrock formations underlying the basin fill at the site. The project involves injecting an acid solution into the groundwater of the bedrock aquifers so that it can leach Cu which would then be recovered in capture or collection wells. The project involves the construction of various ponds and a solvent-extraction electrowinning plant (SX-EW plant). The SX-EW plant would be at the Johnson Camp mine during phase 1 and then just east of the mine in phases 2 and 3 (the second ten years of the 20-year project life) (Fact Sheet, Clear Creek Associates 2016, p 1-4). The site plan (Figure 6) only shows the SX-EW plant at the mine site.

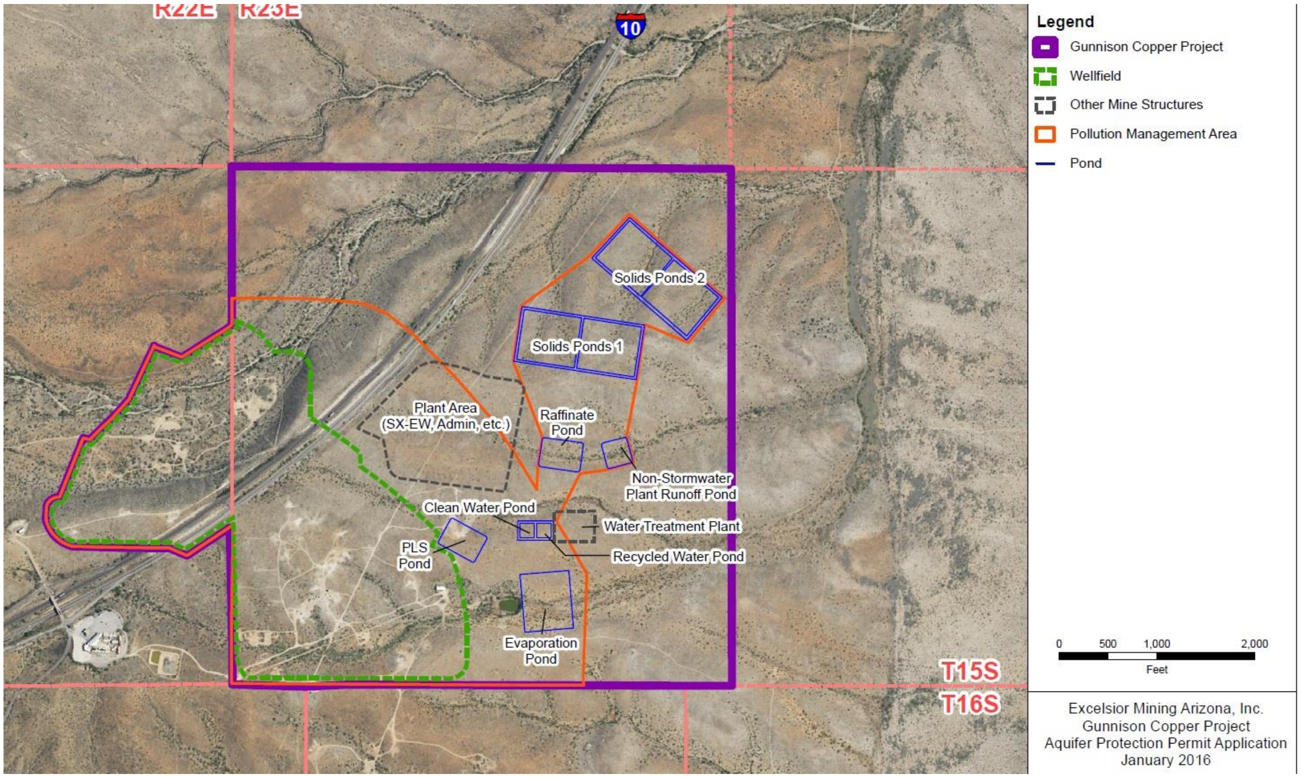

Figure 6: Facility site plan, from Figure 1-2 (Clear Creek Associates 2016)

The well layout would have four collection wells surrounding each injection wells. However, the map of the well field (App I, Figure 44, shown below in the review of groundwater modeling as Figure 18) shows a 5-spot well pattern that shows that each collection well would be part of the four collection wells for at least four injection wells. The development blocks (App I, Figure 45) indicate that sections of the well field would be developed such that 5-spot patterns would overlap with adjacent 5-spot patterns which would cause the 4:1 collection to injection well ratio to not hold throughout the project life.

The injection rate would vary with time throughout the project life (Attachment K). Total rates range from 5300 to 25,600 gpm with the lower rate for the first ten years (Draft Permit, p 16). They also propose to limit pressure applied according to the formation type, with a 0.9 factor of safety (Draft Permit, p 21). The actual injection rate would depend on the pressure, but there is no discussion of that. Pressure is limited to avoid fracturing the rock. However, the pressure necessary to fracture a formation is likely very variable, and there is a possibility that the factor of safety would be insufficient in some areas. Fracturing could connect previously unconnected fractures and preferential flow zones allowing lixiviant to escape the project area through unmonitored fracture zones.

The injection/collection process would collect more water than is injected, which should cause a general drawdown within the well field. A line of collection wells, known as hydraulic control (HC) wells, would surround the well field and be designed to withdraw water and create a trough in the potentiometric surface intended to prevent water from within the wellfield from escaping from the wellfield. Predicted drawdown from HC wells would extend to the east of the well field by 1200 to 1500 feet from the control wells at maximum pumping based on modeling (Application, p 5-15). Also, modeling suggests drawdown would never exceed 50 feet (Id.). There is no guarantee that these wells would intercept flow in each preferential flow path. As described below in the groundwater modeling section, the model uses model cells with averaged material properties, so estimated drawdown is an average for the cells that does not account for preferential flow paths. The model does not consider the potential for fractures to transmit flow and contaminants from the well field. The modeling includes MODPATH simulations which are described below in the Groundwater Modeling section. The use of HC wells as monitor wells is discussed further in the monitoring well section below.

The system works by injecting acid-rich barren solution into the ore-bearing aquifer. The low pH leachate would dissolve copper, and other metals from the ore. The processing of the pregnant solution would remove copper, after which the solution would be recycled to be used for leaching again. Acid would be added to lower the pH once again before being reinjected into the ore body. The processing of copper would allow most other metals to remain in solution, so that the water being circulated through the system would have concentrations of metals and some anions that are multiple times their water quality standards. Concentrations of cadmium, lead, selenium, nickel, thallium, zinc, and fluoride, among others, would be orders of magnitude higher than background levels and most water quality standards (CCA 2016, Table 6-1, Appendix J-3). The incredibly poor water quality of the leach solution exemplifies why preventing any of it escaping the system is critical.

Excelsior argues this site is favorable for “maintaining control of the leach solution” (Application, p 7-2) because there are no drinking water aquifers, or underground sources of drinking water (USDW) above or below the zone of injection, and there is limestone within and downgradient of the wellfield which would provide a large attenuation capacity. The well field would be sandwiched between mostly unsaturated basin fill and a mostly low permeability sulfide zone below. The application presents evidence that the potentiometric surface is above the base of the alluvium in some areas which would confirm the target zone is a confined aquifer, which means pumping it would have little effect on water levels in any saturated layers above the target zone. The underlying sulfide zone has low conductivity, as confirmed with two pump tests which at 1 and 4 gpm caused substantial drawdown.

Excelsior's claim regarding downgradient attenuating formations is too broad with respect to the downgradient Escabrosa and Horquilla limestone because they fail to consider how much of the amount of neutralizing carbonate rock would actually contact any acid escaping the well field. If acid escapes and contacts the limestone much of it could be neutralized, but only if the acid solution actually contacts the limestone. If the acid solution preferentially flows through fractures in the limestone, it may use much of the carbonate within the fractures so that the remaining acid would flow through without actually contacting the neutralizing limestone. Analyses that simply show the limestone has sufficient neutralizing capacity, such as Appendix J-1, but do not assess the flowpaths through the limestone, cannot prove the downgradient formations are an adequate buffer. The limestone should not be relied on to neutralize acid that reaches it unless there is an accounting for the effective neutralizing capacity of in situ limestone.

- Excelsior should provide a realistic assessment of attenuation capacity considering the amount of limestone that escaping acid solution would contact.

The injection/collection well fields would be rinsed after the copper has been removed to flush the contaminants from the aquifer and the groundwater. The plan includes rinsing with three pore volumes of freshwater (Stage 1), followed by rest for one year (Stage 2), followed by rinsing with two more pore volumes (Stage 3) (Draft permit, p 39). The rest period allows the latent solution to reside in the pores where ongoing neutralization would occur. They estimate this would require a year. The injection/collection wells no longer being used would be abandoned and closed. The standards for determining when rinsing is done are water quality standards in random samples (Draft permit, p 40). The pore volumes have been estimated assuming 3% porosity. This should be considered a minimum, because average porosity at the site is slightly less than 3%, but Excelsior should estimate porosity for the ore body for each well as it is constructed and logged. As noted above, porosity in some of the wells exceeded 5%. If porosity is higher than 3%, the amount of rinsing should be increased accordingly.

- Rather than specifying a number of pore volumes of rinsing, the requirement should be to rinse until a given contaminant concentration is reached. The rest period is appropriate. Rinsing appropriately is complete when sampling after rinsing has ceased for a period and concentrations have not risen.

The draft permit calls for a five-year post-rinsing monitoring period, but there is no description of the goals of that period. Most wells would be abandoned, so it is not clear what could be done. The draft permit should outline a strategy for remediation during the post rinsing period.

Monitoring Wells

If the well field operates properly and there are no fractures connected to injection but not recovery wells, the project would not contaminate offsite groundwater. However, even if monitoring wells show a 1% inward gradient, it is possible for fluids to escape hydraulic control through preferential flow pathways.

Groundwater monitoring wells are necessary to verify that the project is operating properly, since a significant change in gradient around the site or changes in specific conductivity or other contaminant would identify the problem. For this reason, the monitoring well layout is of utmost importance. Also, the monitoring wells must be designed to protect potential incursions offsite to groundwater users in the area. The draft permit (p 6) claims there will be 30 HC wells, 22 observation wells (OW), 30 intermediate monitoring wells (IMW), and five point-of-compliance (POC) wells. POC wells would be constructed along an outer ring, so they would be the last monitoring wells to detect contaminants leaving the project site. There will also be up to 120 rinse-verification monitoring wells (RVW) (Id.). These will monitor up to 1400 Class III injection and recovery wells constructed through the project site (Id.).

Figure 7, Figure A-7 from the draft permit, shows the HC, IMW, and POC wells for the site. The OW wells show as green circles without labeling; some of them plot underneath the yellow squares showing HC wells, so the figure is not perfectly clear. There are three pairs of OW wells and seven HC wells across the southern boundary of the well field, or about 2000 feet. Most remaining HC wells spread along the east and northeast boundary of the site, about 4000 feet, with two HC wells on the west. There are seven pairs of OW wells on the east and one pair on the west (Figure 7). Not all wells would operate simultaneously, however. Draft permit, Appendix A, Figures A-7a, A-8, and A-13 through A-16, show the monitoring wells as operated for given time periods. The draft permit does not show the monitoring well layout after year 13 (Figure A-16), which is the end of mining stage 2. This is a concern because it is after year 13 that mining stage 3 begins, during which most of the project area is being mined at the same time. With over 25,000 gpm being injected, this would seem to be the most important time period for extensive monitoring.

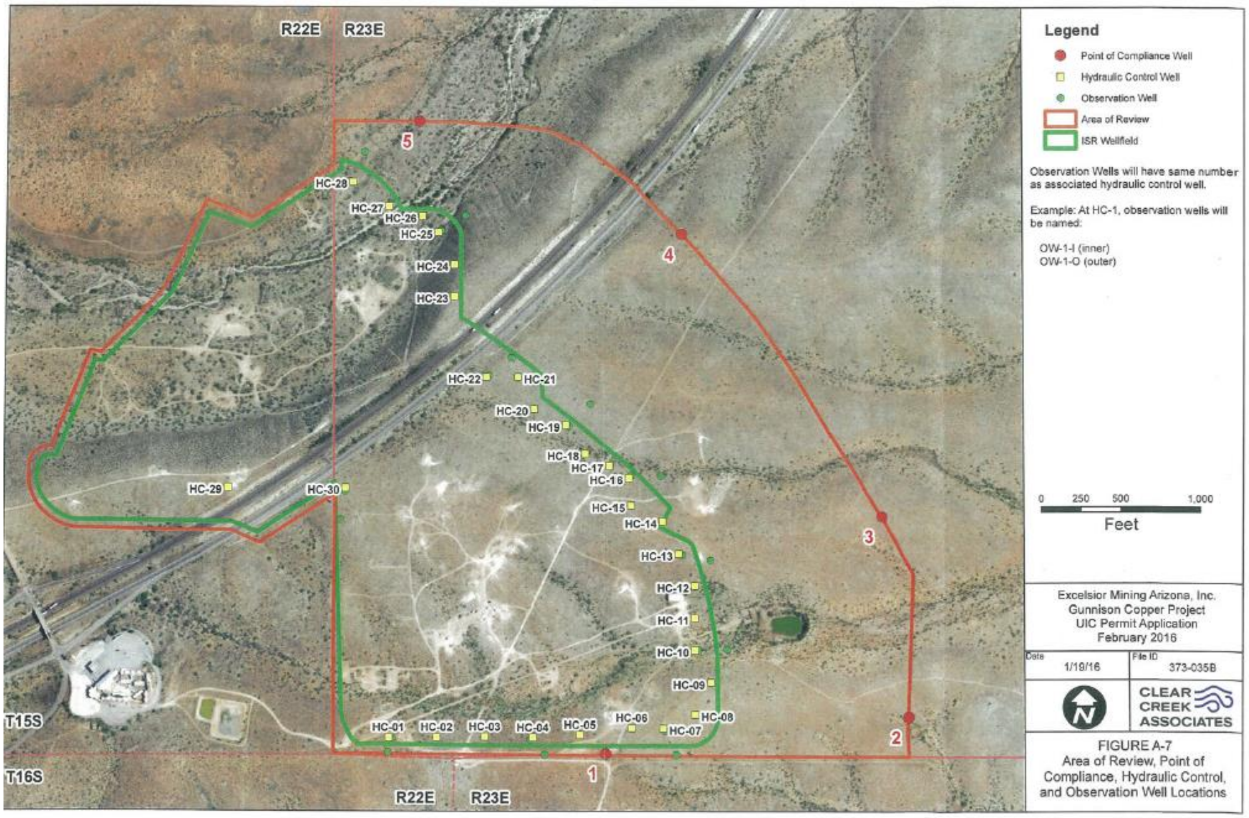

Figure 7: Figure A-7 from the draft permit, Appendix A, showing the project area and location of hydraulic control wells, observation wells, and point-of-compliance wells.

As described above, there are multiple pathways and scenarios which could lead to contaminants escaping the hydraulic control of the site. The monitoring well scenario described within the draft permit is insufficient to protect offsite resources, including wells near Dragoon. This violates requirements for monitoring wells outlined in 40 CFR 146.32(h), which requires spacing based on an assessment of geology.

HW and OW wells surround the immediate project site, as shown in Figure 7. HC wells would surround the project site and are pumped to create a trough in the water table to capture any water escaping the project and to assure that flow is toward the project. There would be up to 30 such wells, although not all would operate at the same time, with operations based on which sections of the project are being processed at any given time. The amount of water pumped from them would cause total project recovery to exceed total injection by 1%. Fluids pumped from the HC wells would be monitored for SC, so if these wells capture any project lixiviant, SC would spike. Twenty-two paired OW wells (11 pairs) would monitor the gradient, which is intended to be inward, with inward meaning that groundwater levels outside the project would exceed those inside the project. The OW well pairs must demonstrate a 1% gradient toward the well field.

The gradient measured by the OW wells as designed could meet the standard but there could be zones within the monitored rock with gradients away from the project. The water level in an OW well would rise to a transmissivity-weighted average of all productive zones within the well. Each productive zone could have its own gradient which could be masked within the OW well. Flow could leave the mine site undetected. The only way to prevent this is to monitor each productive zone separately, which can be accomplished by using the geophysical logging to identify layers in the formations.

- Each OW well should be assessed to determine whether there are different productive zones. If there are substantial differences in fractures or other indicators of differing permeability down the well bore, the permittee should isolate each zone for separate monitoring, including groundwater level and water quality. This is the only way the OW well pairs can adequately monitor the gradient around the site and assure no flow will likely leave the site.
- HC wells should also be considered as to whether they control some flow zones better than others. Pumping wells that span more than one productive zones will withdraw water according to the transmissivity of the various zones. If those zones do not coincide with the well field production zones, the HC wells may not provide the necessary control. The HC wells should have the ability to produce from all productive zones they intersect.

The Draft Permit establishes special consideration for three HC wells established on the southern project boundary prior to year 1 (Draft Permit, p 25). The consideration includes daily monitoring of SC, even though the development is at least 700 feet north of the boundary. This indicates the EPA recognizes the potential for southward flow, but their response is inadequate because the wells would be spaced too widely. Figure A-13 shows the wells fields and IMW wells at year 1 (partially reproduced here as Figure 8), including at least six faults trending NW-SE. Any of these faults could provide a pathway for contaminants to escape the project site, especially with a pressure boost from injection. The monitoring of this potential threat is grossly insufficient.

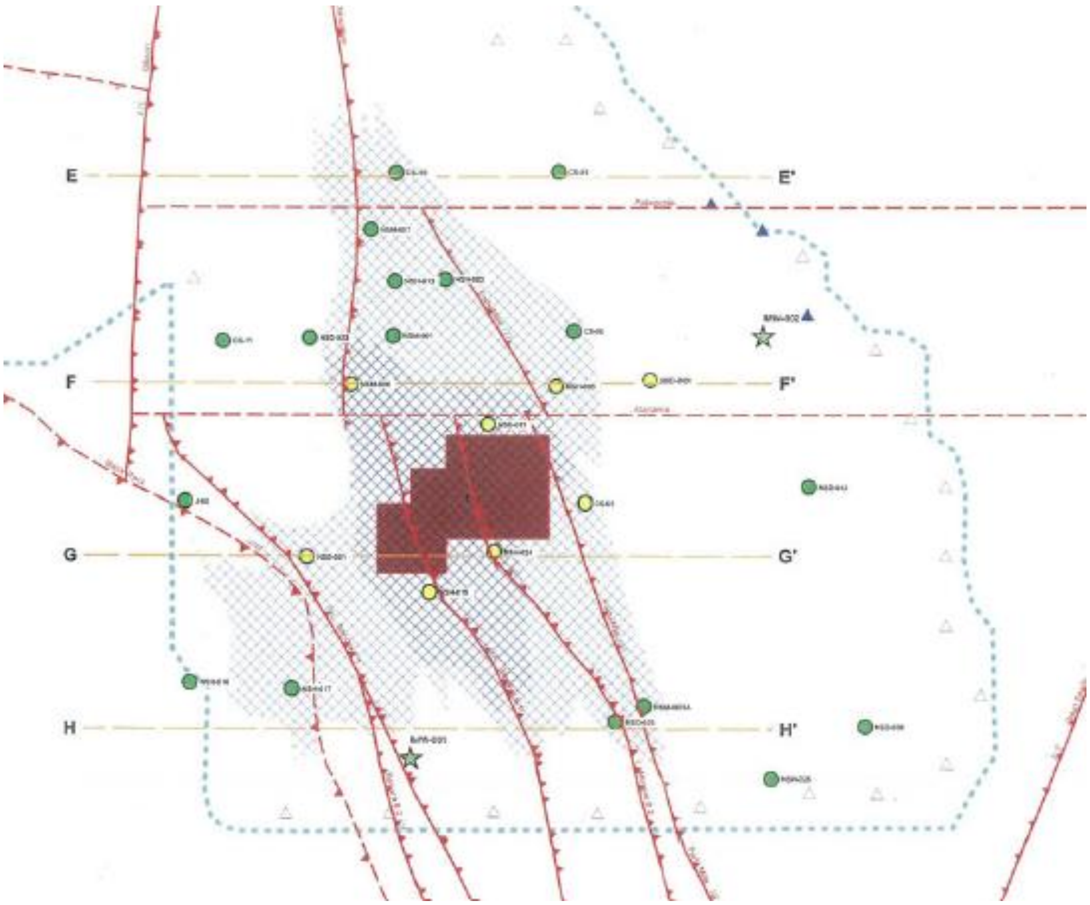

Figure 8: Portion of Draft Permit, Appendix A, Figure A-13 showing the intermediate and HC monitoring well layout for year 1. the green circuls are IMW wells, the trianges are inactive HC wells. The figure shows faults and the project boundary (blue dashed line.

There would be POC wells to detect whether contaminants are moving off the wellfield. Excelsior proposed five POC wells located outside the area of review (AOR) (Figure 7). The AOR is roughly the hydraulic barrier created by the hydraulic control wells. The five POC wells are grossly insufficient for two reasons. First, the wells would be "screened in bedrock, with the top and bottom of the screen set at approximately the same elevations over which the injection wells are open". This would ultimately be a screen over hundreds of feet, which is grossly insufficient to detect contaminants moving off of the site. Contaminants escaping the site would follow preferential flow pathways, so even if the screened intervals intercept the flow paths, the contaminants would be highly diluted by mixing with groundwater higher and lower than in the aquifer.

Second, five wells spaced along the perimeter (Figure 7) is grossly insufficient spacing. Large contaminant plumes could flow between the wells undetected.

- The number and spacing of POC wells should be determined by modeling of contaminants being released either within the well field or the ponds accounting for horizontal dispersion. Well-spacing should be less that the width of simulated plumes at the line of POC wells.
- The POC wells downgradient from the well field should monitor different vertical preferential flow paths separately. That means that at each POC well location, the wells should monitor each potential flow zone. Either nested wells or multiple opening wells could be used. Multiple screened openings along the bore hole no more than 20 feet long would be preferable so that the depth of the contaminant could be determined.

The obvious concern for contaminant excursions across the southern boundary indicates additional importance for monitoring the southern boundary of the site. This is the boundary that separates the project from Dragoon, and as discussions above have shown, there is a substantial potential for flow to vary from the regional contours and head south. The UIC should monitor for this by considering the following:

- The HC wells should be fully installed and active at the beginning of mining. This would create a trough in the water table that would prevent excursions, if the pathways are connected to the regional water table.
- HC wells should be installed in fracture zones associated with the faults.
- The faults should be more fully monitored, with IMW wells situated along each of them.
- POC wells on the south boundary should be outside the boundary created by the HC wells. This is necessary to monitor for contaminants not captured by the HC wells. The POC wells should be about 300 feet south of the HC wells, and be associated with fractures and pathways associated with the faults.

POC wells are the only monitoring beyond the HC wells on the east side of the project. There are just four of them, spaced at over 1200 feet and up to 2000 feet. If a plume does escape the HC wells, the POC wells would not reliably detect it. EPA should require modeling of leaks from the project, without the HC wells operating, to estimate the likely plume that would develop, including dispersion, to determine the needed spacing. EPA should require POC wells spaced according to the update plume modeling.

IMW wells appear to be the primary operational water quality control wells. There would be two rings of IMW wells between the operating mine area and the HC and OW wells (Draft permit, Appendix I, p 8). The inner ring is for operator control and results would not be reported. The outer ring would be monitored for SC to detect movement of fluids away from the mine area. If SC increases beyond certain limits, there would be mandatory change in operations to prevent further excursions of fluids from the mining area (Id.). Draft permit, Appendix I (p 9) claims the "general principle" is to locate IMWs along "more conductive fluid pathways". it also claims that "aquifer test results show that all the structures are hydrologically well connected", so as long as an IMW intersects a structure or bedding feature, the IMW should "respond to and detect potential migrations outside the active mining area in that direction" (Id.).

- The premise of locating the IMW wells along a pathway is correct, but the claim is that pump tests show interconnectivity is incorrect, as discussed above. Also, the claim that interconnectivity would allow an IMW to show contaminant excursions would require that the contaminants disperse through all of the interconnected pathways. This has not been shown and is highly unlikely because contaminant migration will follow gradients and disperse unequally through a pathway. The permit should require monitoring of pH in addition to SC at the IMWs; that could provide good early warning of a loss of hydraulic control through pathways.

POC and outer OW wells would be used for water quality monitoring of the perimeter of the project. The Draft permit does not establish concentration limits, but notes they are TBD (to be determined) (Draft Permit, Table 2). First, many of the parameters would only be monitored with alert limits set for fluoride, nitrate+nitrite, antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, thallium, adjusted gross alpha, radium 226+228, benzene, toluene, ethylbenzene, and total xylenes. The draft permit would require only monitoring for various other parameters; some monitor-only parameters, including total dissolved solids (TDS), specific conductivity (SC), and pH (Draft Permit, Table 4.1-5B), are the best indicators of a problem with the well field. There is a series of intermediate monitoring wells (IMWs) at which SC would be monitored daily.

The method for setting the alert level would be based on the method used by Arizona DEQ (Draft Permit, Appendix I, p 6), using observed ambient conditions, with AL=M+KS with M being mean, S being standard deviation, K being the one-sided normal tolerance interval with a 95% confidence limit is standard. The concentration values would account for dilution if the screens are too large, as described above.

- The alert limits and aquifer quality limits should be set and enforced for each POC, by screened interval, to set limits and commence mitigation based on preferential pathways.

- The concentration limits specified for POC wells should account for dilution. This would account for the fact that standards could be exceeded over a portion of the water column but not all of it. Failing to acknowledge that can lead to downgradient resources being affected if they depend only on a small thickness of the aquifer.

The draft permit specifies various actions that will be taken if alert levels are exceeded, but they are in the longer term insufficient. The draft permit must indicate that if exceedances last for more than six months, the facility, or at least the specific section of the well field responsible for the exceedance, must cease operations and commence rinsing. This is because the exceedance is an indicator that the hydraulic control has been lost. Exceedances lasting more than six months indicate that other steps taken have not worked. The only way to protect downgradient aquifers would be to cease operations.

Excelsior proposed the POC wells be monitored for four quarters after rinsing is complete (CCA 2016, p 7-13). These wells are downgradient of the entire well site, so this presumably means the monitoring would continue for just one year beyond the end of rinsing. The length of the monitoring period is insufficient because it is not long enough for contaminants residing within the well field, but not neutralized, to flow from the well field through the POC wells. Particle tracking in the groundwater modeling (Attachment A-2) shows that particles have not yet reached the edge of the mine within years, so there would be substantial time for residual particles to reach the POC wells.

- Monitoring beyond the end of rinsing should continue as long as the estimated travel time for particles from the most distant part of the well field to reach the POC line, plus at least 50% for a safety factor.

Review of Groundwater Modeling Report -Attachment A-2

Clear Creek Associates modeled the regional hydrogeology using the MODFLOW computer code (CCA 2016, Attachment A-2). MODFLOW is a program that solves the equations of groundwater flow by completing a water balance among model cells. A model cell is a three-dimensional rectangular volume in which various properties of the geology are described. Those properties usually are an average of properties that could vary at scales much smaller than simulated with the cells. The modeler inputs the model domain structure, material properties, and known groundwater flow inputs to the model which solves the equations specifying the water level or pressure over the model domain and the groundwater discharges to various points. The model domain is the aquifer volume being modeled.

Excelsior relied on the numerical groundwater model to show that their project will control the hydraulic gradients and prevent contaminants from escaping to the surrounding aquifer. This section reviews the model and shows that it is not sufficient evidence to show there will be no escape of contaminants.

Model Structure

Solving the equations completes a water balance among model cells that describe parts of the domain. For this site, the cells range from 300 feet to 75 feet square, with the finest discretization in the well field (Figure 9), which allows for more detailed calculations. The model domain extends from the Little Dragoon Mountains in the northwest to the Dragoon Mountains in the southeast (Figure 9).

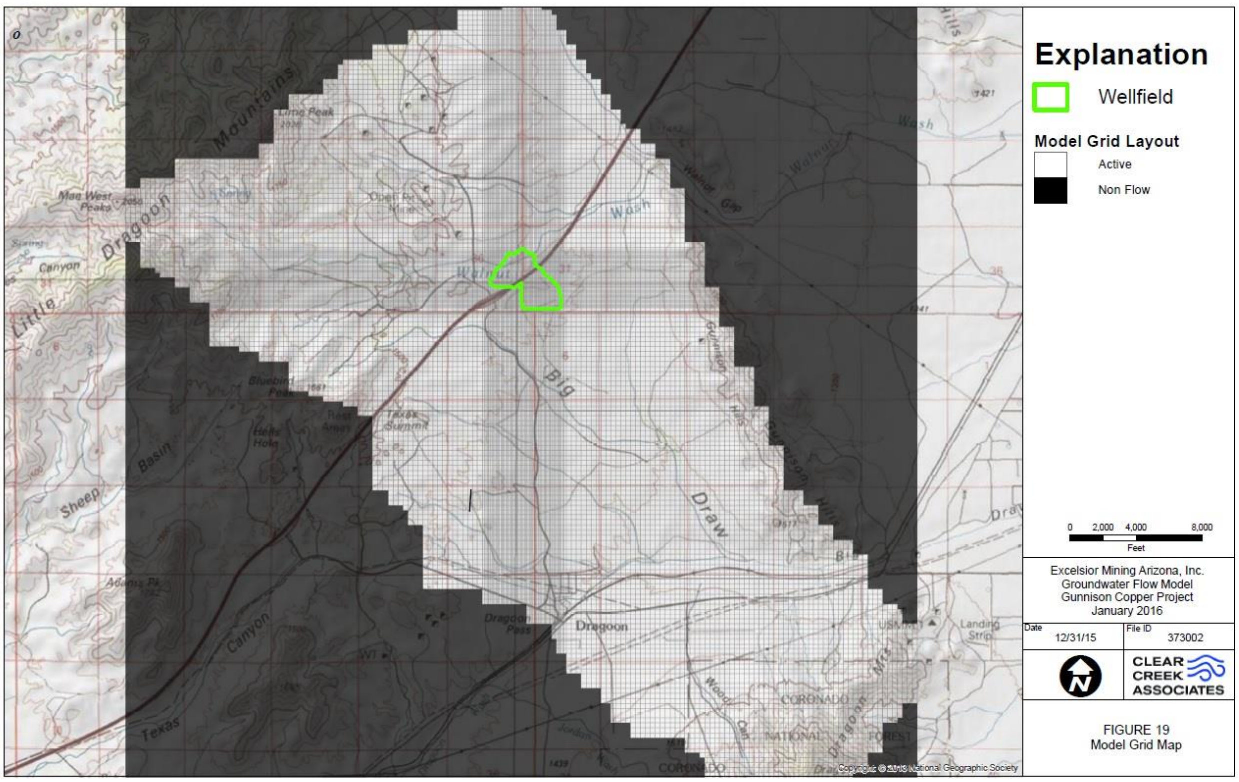

Figure 9: Figure 19 from CCA (2016) Attachment A-2 showing the groundwater model grid.

Vertically, the geologic formations are divided into seven layers. Layer 1 varies from 85 to 1648 feet thick, while layers 2 through 5 are 300 feet thick, and layers 6 and 7 are 400 feet thick (Figure 10). All layers are bedrock in the west where bedrock outcrops in mountains and layer 1 is basin fill everywhere other than at the outcrops (p 18). Layers 2 through 4 have decreasing amounts of saturated alluvium corresponding with the deep fill east of the project. The lower portion of all layers is horizontal, meaning that formations dip through the layers (Figure 10). Layer 1 is unconfined, layers 4 through 7 are confined, and layers 2 and 3 are convertible, meaning the model would treat them as either aquifer type depending on the simulated water level. The layers are much too thick to accurately simulate the flow around the injection/collection wells which would depend on fracture zones.

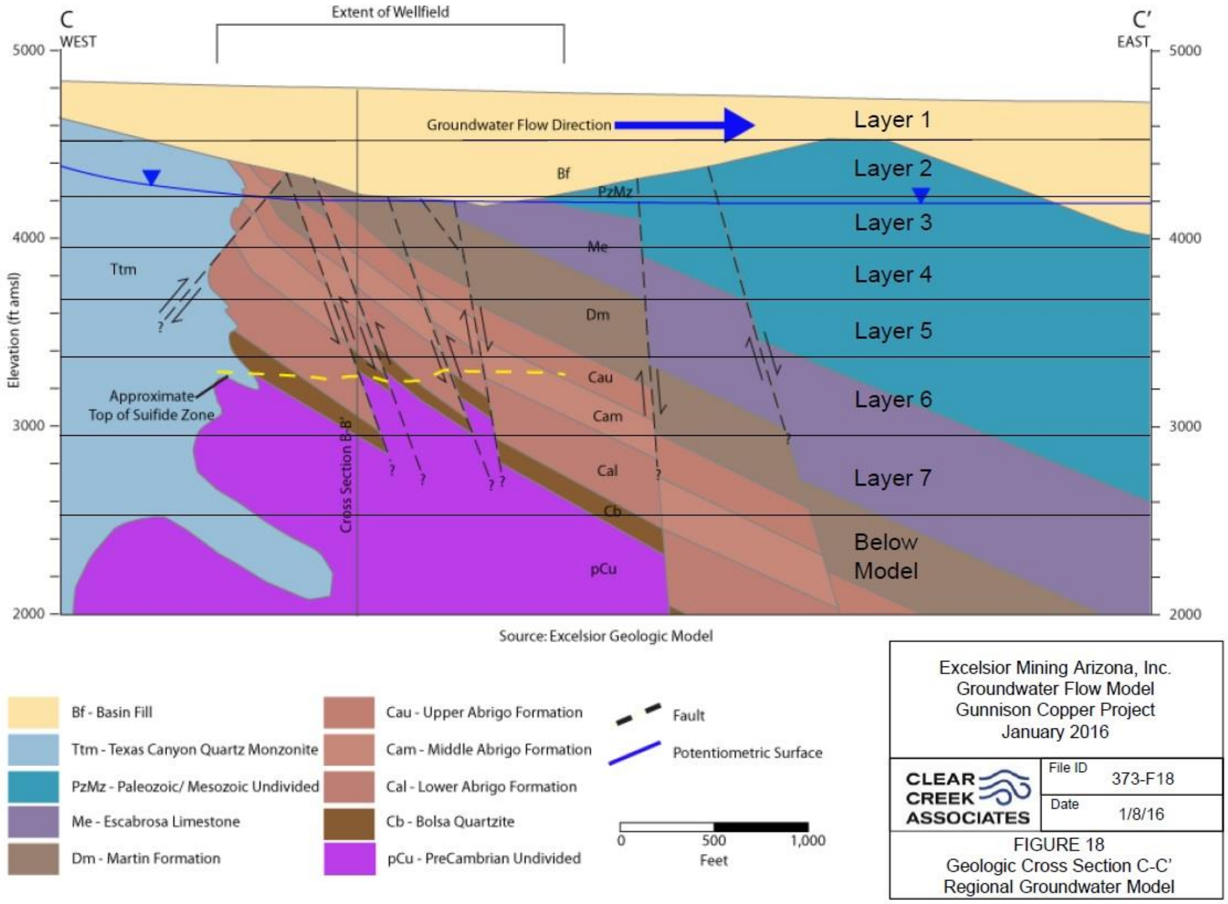

Figure 10: Figure 18 from CCA (2016) showing the model layers and geologic formations dipping east through them.

The model includes neither horizontal anisotropy or an orientation of grids to align with the fracture orientation, which would facilitate simulation of horizontal anisotropy (Attachment A-2, p 18). This is a failure to consider the preferential flow potential parallel to the fracture orientation (see the discussion above regarding horizontal anisotropy).

Boundary Conditions

The water balance and flow equations require boundary conditions where either the water level, a groundwater flow, or both are specified. There are no flow boundaries on the north, west and south bounds of the model domain which generally coincide with a topographic and expected groundwater divide, as is appropriate. A no flow boundary is one through which groundwater does not flow and generally means that groundwater flow is parallel to the boundary. Recharge is the boundary in this model which provides the flow through the aquifer system. The estimated total recharge was 738.2 af/y for the entire model domain after calibration, which the modelers divided into Walnut Wash and Big Draw areas (CCA 2016, Attachment A-2, Table 4). This is discussed in more detail below.

Attachment A-2 Figure 30 shows constant head boundaries for flow to the east. There is one to the north where Walnut Wash leave the domain and one the south through the gap where Big Draw leaves the domain. Because the boundary on the north is much longer than the boundary on the south, there may be a tendency for flow to go north, although the conceptual flow model does not justify this. The outflows are with constant head boundaries through layers 2 through 7, with the same head in each layer (p 20). This means the modeling does not impose any vertical gradient at the model boundary. Because the report does not provide water balance data, it is not possible to assess the reasonableness of the constant head boundaries through which groundwater flow leaves the model domain.

Modeled Material Properties

The model includes material properties, which are generally set by calibration guided by prior knowledge of the formation properties. The prior information was the pump tests and transmissivity estimates discussed above. This section discusses the modeled material properties. The modelers establish hydrologic parameters using the parameter zone method, meaning that a given geologic formation was assigned a series of parameter values. Excelsior assigned the parameter blocks and values based on their combined geologic/fracture intensity model, as critiqued below.

The final parameter values were set by calibration, described below, and the Initial values used for calibration were based on correlation between fracture intensity and hydraulic conductivity. Excelsior estimated fracture-intensity for 100 by 50 by 25 feet thick blocks within and near the ore body. The geologic model was incorporated into finite difference model cells. Outside the ore body, material properties were based on mapped geologic units. Each modeled material was divided into five property zones to specify K for the formations in the model, based on the conductivity/fracture intensity relationship (CCA 2016, Attachment A-2, p 19). Outside the ore body, a sixth property zone was used to simulate properties that were not as fractured as within the ore body. The fracture intensity was assumed lower away from the ore body, which resulted in a lower simulated conductivity away from the ore body. This has the effect of containing the simulated effects of mining to the project site.

The fracture intensity is much higher in the areas with significant faults, as shown on Figure 11. Faults trends just west of north through the domain south of the project site and curve to a more northwest trend near the site. The yellows and reds on the fracture intensity model is the area of higher fracture intensity. Fracture intensity is much lower west and east of the project area. A model fit shows that conductivity ranges from 1 to about 10 ft/d for the higher fracture intensity (Attachment A-2, Figure 16).

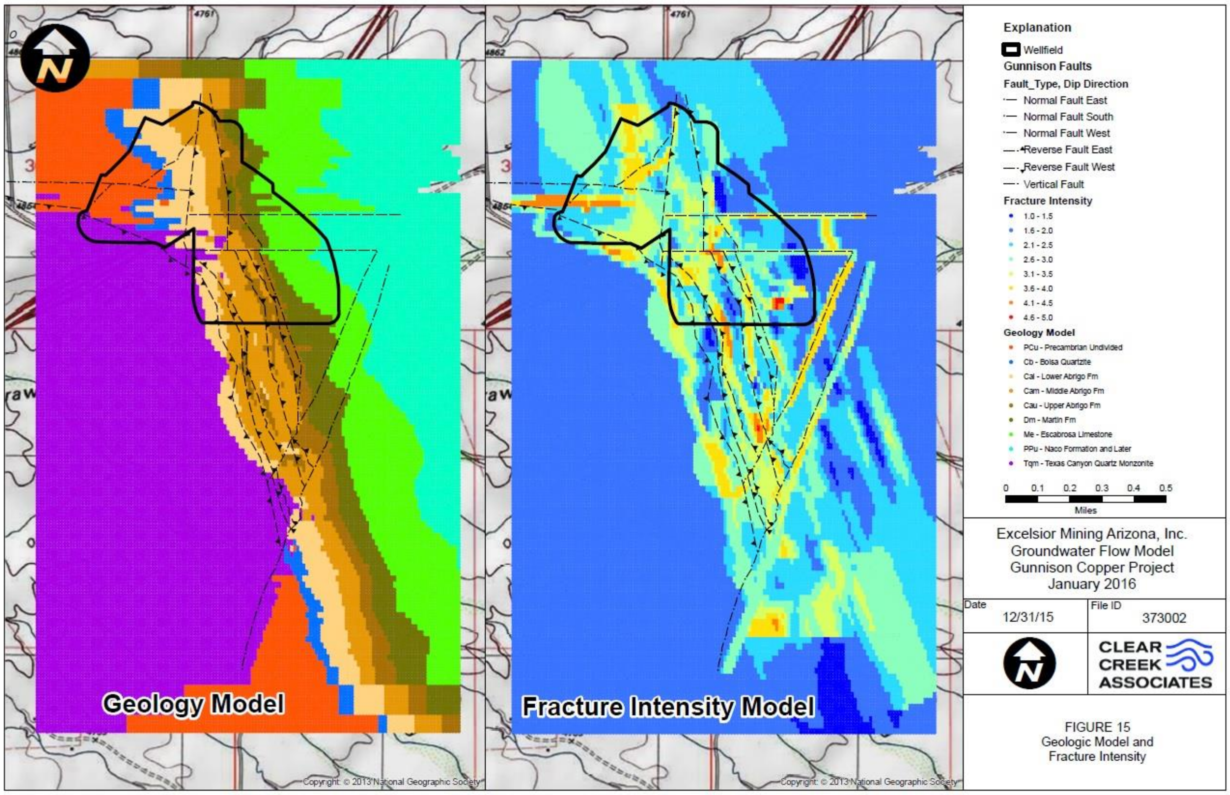

Figure 11: Figure 15 from CCA (2016) Attachment A-2 showing the geologic and fracture intensity model.

Attachment A-2, Table 9 summarizes the hydraulic conductivity values by formation type and fracture density. Fracture density is rated from 1 to 5 with increasing density corresponding to increasing values. A 0 was used for formations away from the areas with fracture intensity measurements. There are at least three major problems with the way the model handles conductivity based on the presentation in this table.

1. Permeability, and therefore conductivity, should increase with fracture density, but Attachment A-2, Table 9 has many exceptions which are not logical. Most formations have an example of higher fracture density coinciding with lower conductivity.
2. With the exception of basin fill, there is no simulated difference among Kx, Ky, and Kz. This means the model would treat conductivity in all directions for all bedrock formations equally. The very nature of fractures is they tend to be more prominent in a primary direction, so this table violates that precept. Due to bedding in sedimentary

rock (most of the formations), there is also tendency for flow along the dip rather than perpendicular to it. Both would cause Kx≠Ky≠Kz.

3. The conductivity values are commonly the same depending on fracture intensity rather than formation type. For example, for fracture intensity 4 and 5, K = 10 and 65 ft/d, respectively. There are other examples. This suggests there have been too few aquifer tests to justify discretizing among so many formation types. It also means there are no differences among geologic formation types.
4. There are six zones for each geologic formation. The text claims the formation outside of the ore body is not mapped with respect to fracture intensity, represented by zone 0 for each formation on the table. They claim that "fracture intensity appears to be strongest in the area of the ore body" (Attachment A-2, p 19), therefore the conductivity outside the ore body is usually lower than within the ore body. However, they did not sample outside the ore body (Id.), so it is no data or evidence to support this claim. Table 9 does not confirm this statement because there are examples of the intensity 0 (outside the ore body), having a higher conductivity than within. If the model has higher K within the ore body, it would simulate less head drop and easier flow through the ore body than around it.
5. Attachment A-2, Table 11 purportedly includes calibrated K values, but shows values as high as 65 ft/d, whereas the figures showing calibrated K zones with values (App I, Figures 21-27) do not show any values greater than 10 ft/d. This is a substantial error in the presentation of the model parameters.

The conductivity values for each material zone (App I, Figures 21-27) are the result of the steady state calibration, details of which are described below. Values for layer 1 show the meeting of the bedrock outcrops on the west with the basin fill on the east, with low values, less than 0.01 ft/d matching with higher values, 1 to 10 ft/d for the fill (Figure 11). The low K for bedrock under the outcrop extends down through all seven layers (App I, Figures 21-27). This low K area causes the steep groundwater contours west of the well field. The high values for basin fill, 1 to 10 ft/d, shown in red running north-south through the valley east of the project, extend to layer 5 to represent the full thickness of the fill (Attachment A-2, Figures 21-25), primarily causes the flat groundwater contours seen in this area. At depth, bedrock K is low, with K less than 0.01 ft across the southeast portion. At shallower layers, higher K from 0.5 to 1.0 ft/d provides a conduit for flow to reach the boundary outlet from the domain in the southeast.

Because of the fracture intensity modeling, the model has very detailed parameter zone models within the ore bodies, as can be seen from detailed observation of the ore body on the parameter zone maps for each model layer (App I, Figures 21 -27). Most of the well field area has K equal to 0.5 to 1.0 ft/d, with some intermittent higher and lower cells that resulted from the detailed fracture intensity modeling. The west half of the ore body has the most detailed parameter zones, as may be seen in the magnified portion of App I Figure 22 shown in Figure 12 for layer 2. The complicated fracture intensity model may represent the fractures associated with faulting, as shown in Figure 11.

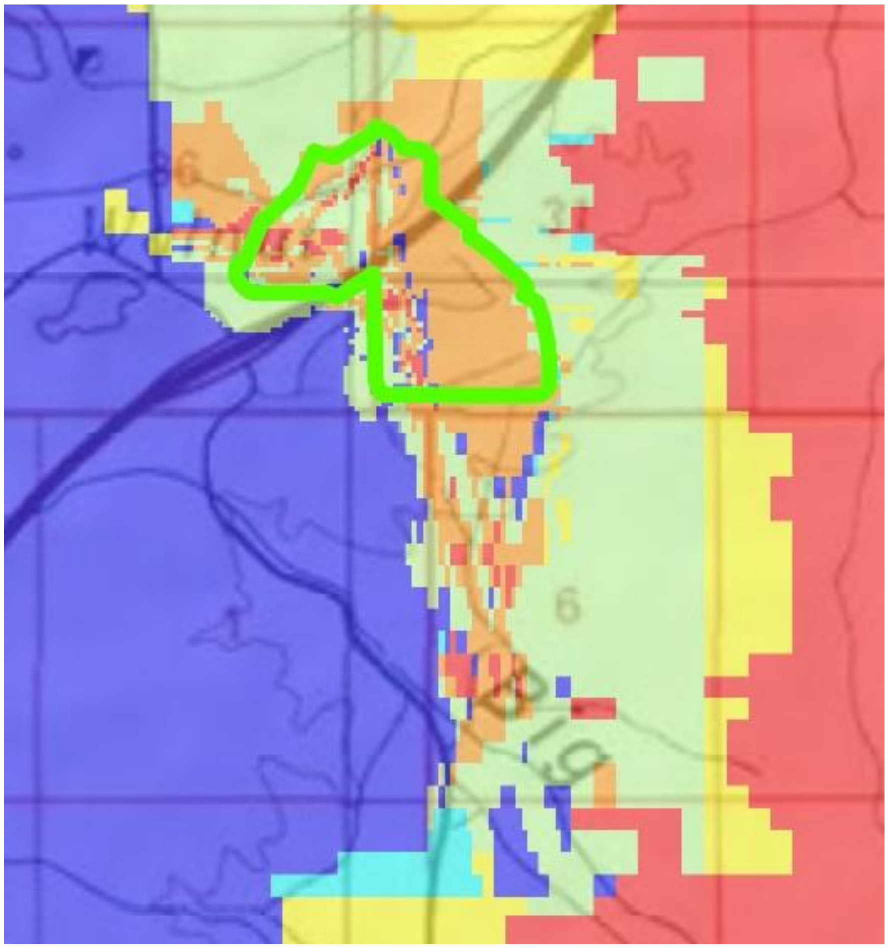

Figure 12: Magnified portion of Attachment A-2, Figure 22 showing the details of the parameter zones on the west side of the ore body, and to its south.

Recharge is a specified flux boundary to the model, meaning the modeler sets a constant value that is forced to enter the model at a given point. It is the boundary that inputs water to the model. Recharge is distributed around the model domain jointly with the setting of hydraulic conductivity, because the conductivity controls groundwater flow through the model domain and sets the observed water levels. The modelers assumed an average 12.5 inches of precipitation with 3% becoming recharge, “based on other similar modeling studies” (Attachment A-2, p 12). The report does not reference those other modeling studies or provide any support to the use of 3% in this area. The modelers adjusted the recharge percentage to 2.8% of annual precipitation, presumably due to an inability to force the recharge into the model without using unreasonably high conductivity values. Conductivity controls the ease with which recharge enters the model domain, and during a steady state model simulation, the model would establish the groundwater level at that necessary to create the gradient necessary to force the water into the domain. If the water level is unreasonably high, the modeler has the choice of changing the amount of water being forced into the domain or changing the conductivity to ease the entry of the flow.

Higher flow rates require higher conductivity values for the simulated head values to equal the observed values. Model calibration would establish the conductivity along these flow paths, all else being equal, to be higher to allow a larger amount of water to flow through. If the recharge amount is either too high or too concentrated in one area, the conductivity would therefore also be artificially too high.

As part of calibration, the modelers distributed the total recharge around the model domain (Figure 13). The noncolored area on Figure 13, which is most of the domain away from the mountains and washes, represents recharge less than 0.012 in/y.

The concentrated recharge may significantly bias the model results. The large zone in orange, west of the project site in the Little Dragoon Mountains, is recharge from 1.2 to 2.4 in/y (Figure 13). Recharge would enter the groundwater in this mountain block only if the geology is highly fractured at the surface, otherwise the area should mostly generate runoff. Much of those mountains have the second highest conductivity values (Figure 14), possibly due to the calibration.

Walnut Wash is a substantial drainage which flows east from these mountains, which indicates there is substantial runoff from the mountains. The model simulates from 0.55 to 6.6 in/y near Walnut Wash west of and within and north of the north quarter of the wellfield. The area is almost 2000 feet wide and over 6000 feet long. The recharge rate into the model domain through the Walnut Wash area is very high, the product of the rate and area shown in red. Most other areas that represent washes are simulated with recharge from 0.12 to 0.5 in/y (green).

Only the smallest recharge rate is used for recharge in the Dragoon Mountains in the southeast. Even if the geology is not conducive to distributed recharge, there should be runoff that leads to mountain-front recharge.

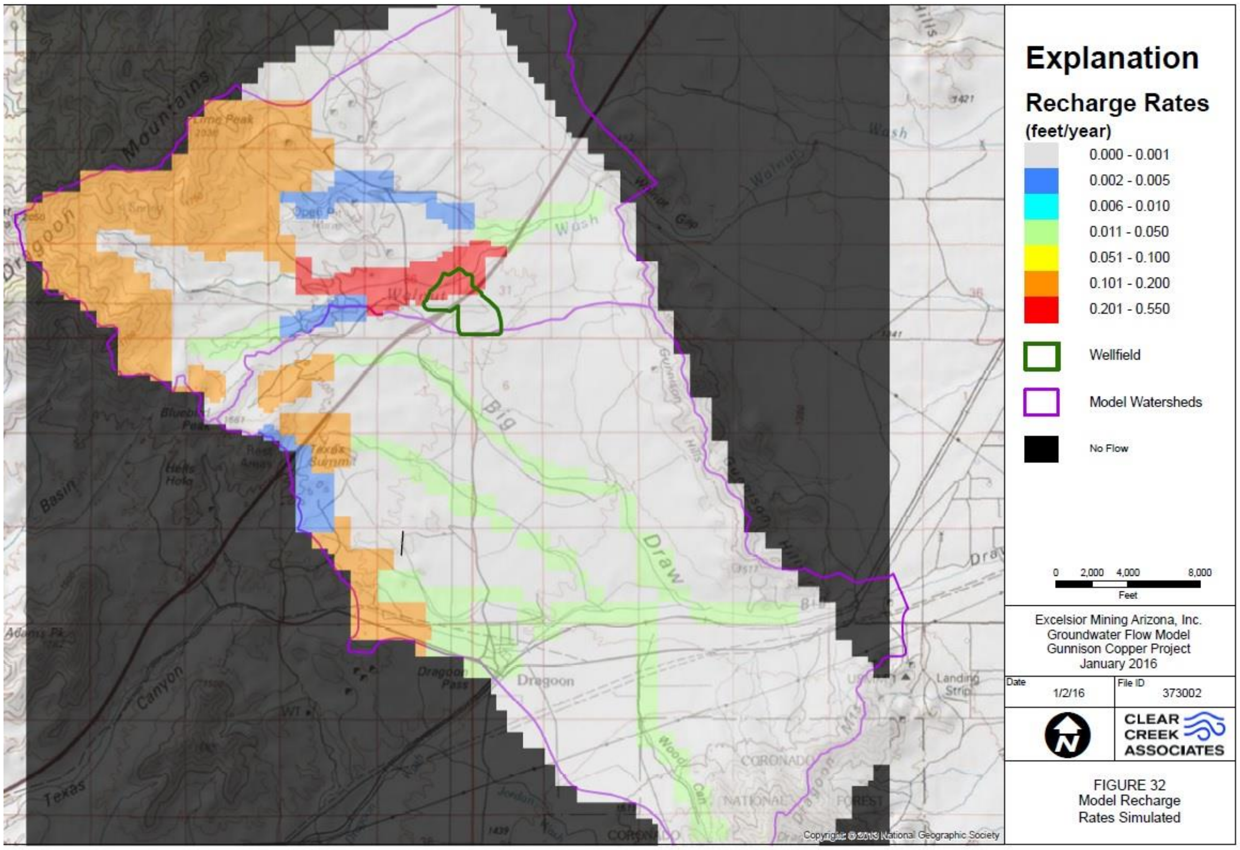

Figure 13: Figure 32 from CCA (2016) Attachment A-2 showing the calibrated steady state recharge rates around the model domain.

As a result, the calibrated conductivity near the wellfield could be artificially too high. This would cause simulated flow through the area, both regional flow and injected flow to be channeled through large preferential flow areas which would prevent it from flowing away from the well field. Essentially this recharge distribution could channel flow away from Dragoon and other areas, thereby causing the model to not estimate impacts to groundwater users near Dragoon.

The recharge distribution used by the modelers forces most of the recharge for the entire domain into the ground in the mountains just west of the project site or along the wash just west and north of the project site. This recharge distribution would cause much higher flows to emanate from that area to the outflow points. Some of the area under the wash has some of the lowest conductivity values, which may be due to the high groundwater elevations west of the site. It also may cause some of the recharge to flow initially to the north where the conductivity is lower.

The low K in model layer 1 west of the well field (Figure 14) coincides with the high recharge in the Walnut Wash (Figure 13). This causes the higher groundwater ridge and steep slopes seen in the modeled steady state contours (Figure 15). Much of the remainder of the high recharge zones west of the project coincides with higher conductivity material in layer 1.

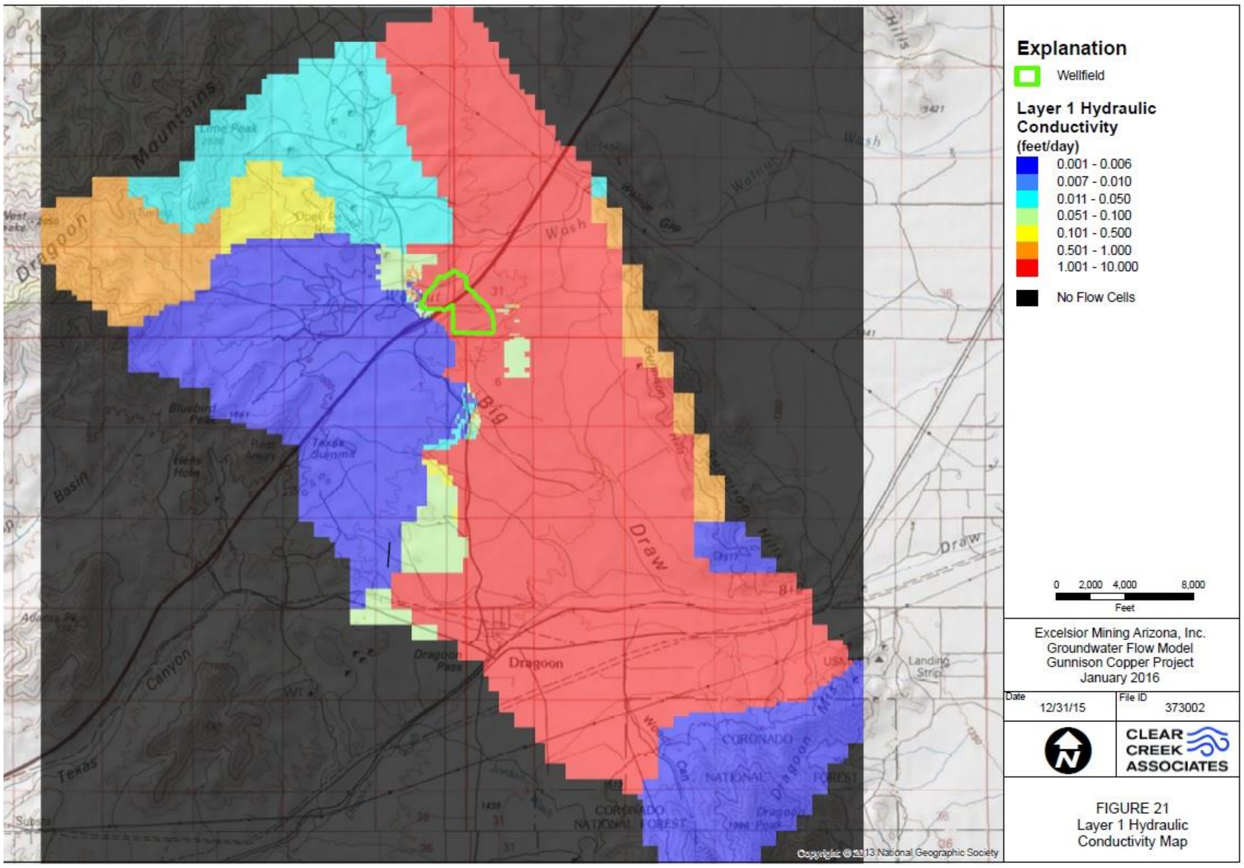

Figure 14: Figure 21 from CCA (2016) Attachment A-2 showing conductivity in model layer 1, the uppermost layer in the model.

Vertical K equals horizontal K for all bedrock, so there is no resistance to deep groundwater flow. There is no discussion of vertical circulation as part of the conceptual model, meaning the modelers had no expected natural vertical circulation of groundwater flow. It is likely that the numerical modeling allows an unrealistic amount of water to flow at depth through the domain because of vertical K equaling horizontal K, especially at depths below layer 1. Attachment A-2 does not provide water balance data, either for the entire model or for individual layers, as is customary for the presentation of groundwater model results (Anderson and Woessner 1992). This limits the ability of the reviewer to assess how realistic is the simulated groundwater flow.

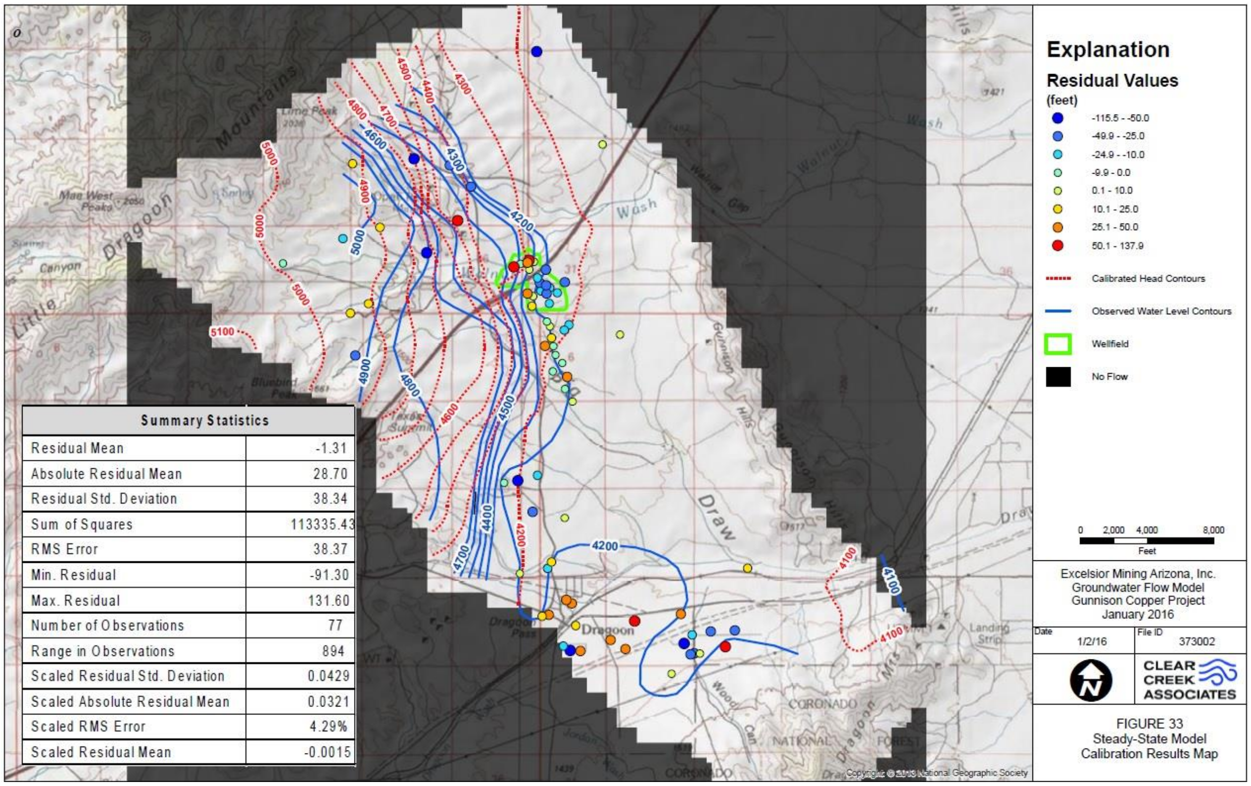

Figure 15: Figure 33 from Attachment A-2 showing groundwater elevation contours, residuals at observation wells, and residual statistics.

Storage properties of the material control how much water is released for a unit change in pressure or head. It effectively controls how fast the aquifers release groundwater to pumping. Specific storage was set equal to 0.00001/ft, which ignores the vast variability in values found during the pump tests.

Faults and fractures play a large role controlling the flow through the model (CCA (2016), Attachment A-2, p 15). The model uses a horizontal flow barrier (HFB) through the middle of the wellfield area to simulate a large head difference observed in the wells (Figure 16). The head is variable throughout the area, and there is a lot of variability even within blocks as defined by the faults or HFB. For example, the difference between NSD-028 (4437) and NSM-013 and NSD-027 (4391 and 4376) suggest significant vertical gradients within the block, which suggests the model uses an HFB in appropriate areas. A NW to SE HFB would seem more reasonable to separate NSD-026 (4423), NSH-007 (4427), NSH-008 (4425), and NSD-032 (4437) from NSH-010 (4189), NSH-031 (4198), NSH-032 (4190), NSD-037 (4296); NSH-012 is labeled 4747 but its color code suggests it should be 4147. The distance between these groups is generally around 1000 feet.

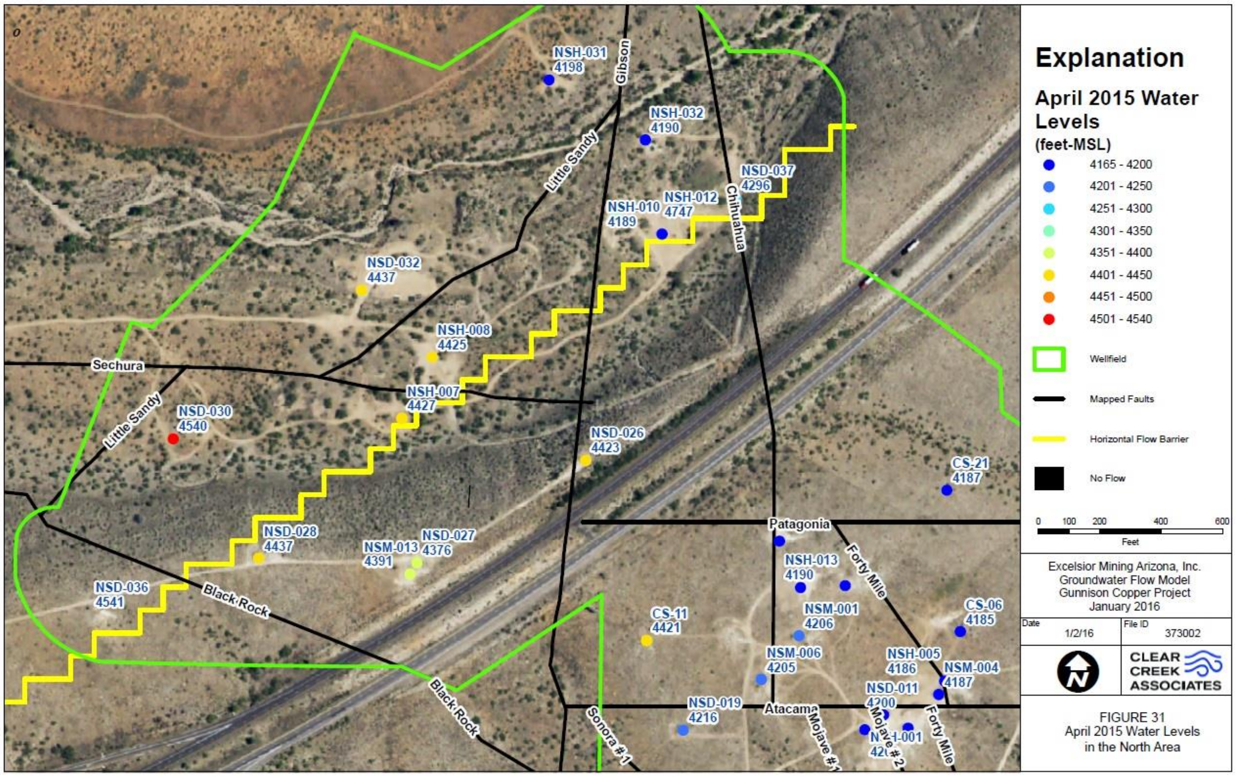

Figure 16: Figure 31 from CCA (206) Attachment A-2 showing the horizontal flow barrier and April 2015 water levels near the barrier.

Model Calibration

Calibration is the process of matching simulated and observed head levels by adjusting the material properties to adjust the simulated heads. Calibration also involves matching simulated and observed groundwater flow rates, if there are observed rates available. Steady state calibration occurs assuming the system is at steady state. Because there is little stress in the aquifers near the proposed project, the system currently is close to being in steady state so matching average water levels would be considered steady state calibration.

The description of matching simulated with observed heads (Attachment A-2, p 21) suggests the simulated heads were the water table values from the simulation. This means it is the water level in the uppermost active layers. Model layers for which the bottom of the layer is above the water table are inactive. Because the model allowed layers 2 and 3 to be convertible with respect to being simulated as confined or unconfined, the uppermost aquifer could not be confined because once pressure in one layer goes above the top of the layer, the layer above becomes an unconfined layer. Thus, the calibration appears to have compared simulated unconfined conditions in the uppermost active layer in the model with either the water table of an observed unconfined aquifer or the pressure level of a confined aquifer. In other words, the model simulates saturated conditions above a confining layer, which is inappropriate. In areas where the flow is known to be confined, the layer with the flow should be set as confined so the head in the layer may be higher than the top of the layer without flow entering the layer above.

Figure 15 shows simulated and observed groundwater contours and residuals resulting from the final calibration. A residual is the difference between simulated and observed values. The simulated heads have a much more consistent gradient and resemble a surface much more than the observed heads. This probably reflects how the model layers represent average values over several fracture zones whereas the observation wells are monitoring different fracture zones. Simulated contour 4200 ft lies a couple thousand feet east of the observed 4200 ft contour which means the simulation results in a potentiometric surface above the observed.

The residuals through the wellfield area transition from high positive values, 50.1 to 137.9 with red circles to high negative values, -115.5 to -50.0 with blue circles over a short distance. The simulated potentiometric surface resembles an eastward dipping plane through a water table that is both far above and far below the plane. This could be the result of a flow barrier that causes the actual water levels to drop but is not included in the model or trying to match observed water levels from aquifers that are not connected. The rapid change in residuals across the site indicate the conceptual model for the area is inaccurate. It could assume connectivity among formations that does not exist, not considering horizontal anisotropy which would cause flow to trend in a certain direction and drop faster in other directions, or assuming more recharge which causes conductivity values that are generally too high. If the fractures trend NW-SE, as noted above, simulated east to west flow would be at an angle to the preferred direction based on fractures.

There is little data for transient calibration, which would attempt to match observed water level changes due to a stress applied to the aquifer by changing storage coefficients. The modelers calibrated to data for a pump test at NSH-015, which included a series of four short-term pumping rates followed by a several-day period of constant pumping at 85 gpm. Drawdown at NSH-019 had been predicted to be 4.89 feet but the model simulated just 0.01 feet (Figure 17). This is due to the fracture-dominated flow system and that drawdown depends on the observation well being developed in the same fracture system as the pumping well.

These results demonstrate future problems that will occur with the system. Injection of leachate into a fracture zone that does not have a collection well or a control well will allow flow to exit the system. Figure 17 shows however that there is likely an inappropriate model flow barrier between NSH-015 and NSH-019 since the observed drawdown, as noted 4.89 feet, occurs about 500 feet east of the simulated 1-ft drawdown contour. The simulated material properties may not connect high K values to create an actual zone. The model cells are much larger than any fracture zone and the fracture intensity would depend on the observed fractures within the cell.

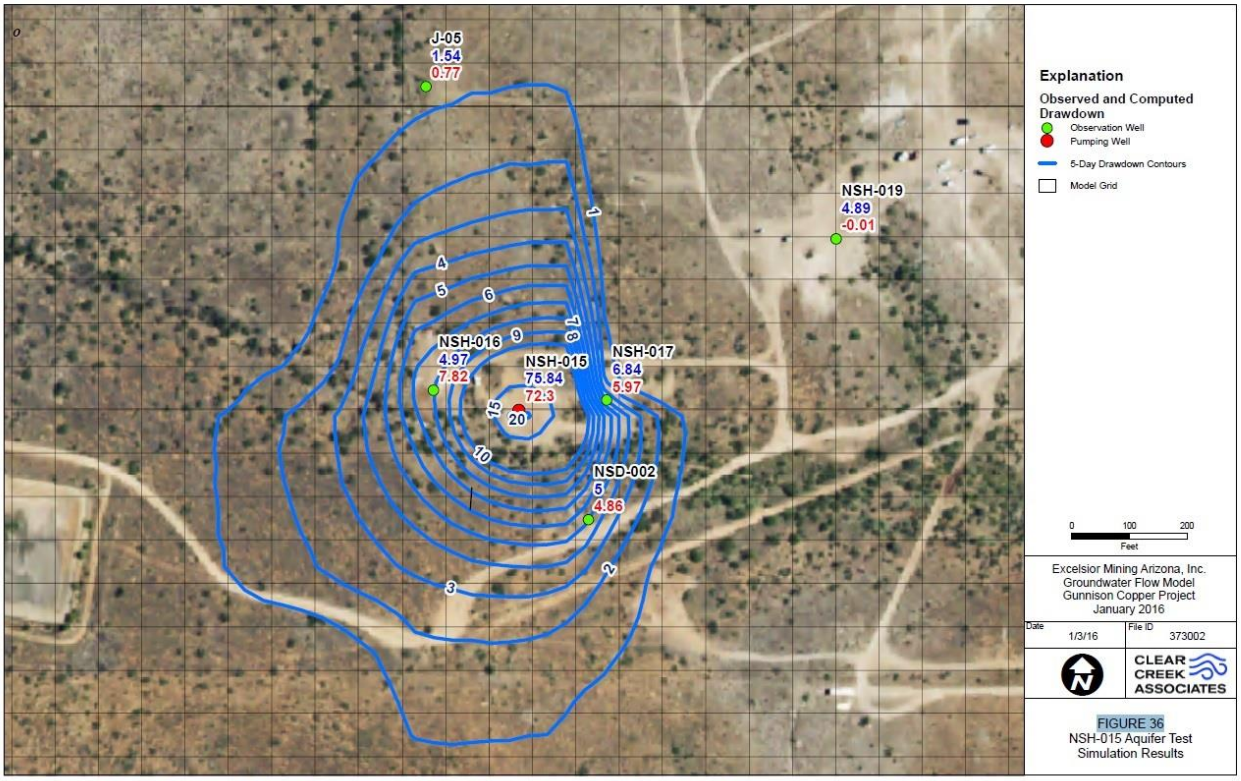

Figure 17: Figure 36 from Attachment A-2 showing the drawdown from the pump test at well NSH-015.

As critiqued above, the calibration involved adjusting recharge as well as material properties. This would result in a nonunique model, meaning there are an infinite number of combinations of material properties and recharge that could result in the same simulated head values (the only observed values being matched for calibration). This may be seen from Darcy's Law, which relates flow rate to conductivity and gradient. For a given gradient (defined by the head values), K would vary as flow rate (flux) varies. If flux changes, K changes as well. If the K value is known in advance, the flux can be determined using Darcy's Law. If both K and Q can be adjusted, there are an infinite number of solutions to yield a measured gradient. By adjusting material properties and flux within a groundwater model, the resulting model is nonunique because there are an infinite number of property values than can match the observed heads. Based on the information regarding calibration of recharge and material properties at the same time in Attachment A-2, the Gunnison model is nonunique. It is accurate only if the recharge estimates are accurate but there are no measurements of recharge.

The problems with the model being nonunique are that the parameters values may be grossly wrong. This could affect the predicted results of the project simulations and lead to inappropriate assumptions about the operations of the model, especially on a regional basis. By this, I mean that even during operations, Excelsior will adjust injection and collection rates to meet the needs within the well field; elsewhere, the model predictions could be very inaccurate due to inaccurate parameters.

Model Recommendations

The previous sections provided comments on numerous aspects of the model, but there are two overriding recommendations which would improve the model and improve most of these comments.

- The model should be improved with a better conceptual flow model, that better accounts for the fracture system near the well field due to the faults. It should better simulate horizontal anisotropy as caused by the fracturing. It should have more layers to better simulate the steps in the observed water table.
- The conceptual model should also include estimates of discharge from the model domain. these estimates should be targets in the calibration, which would make the model more unique.

Simulation of the ISL System

The ISL system involves injection and recovery of acidic solutions within the ore body, using four collection wells for each injection well. However, collection wells will be used with adjacent wells, as shown in Figure 18. Injection/recovery rates will vary and may be as high as 100 gpm from individual wells (Attachment A-2, p 25). Overall, the simulated injection is several thousand gpm for the first ten years and more than 20,000 gpm during the last seven years. most of the water would be recirculated, so this does not represent an ongoing consumptive used.

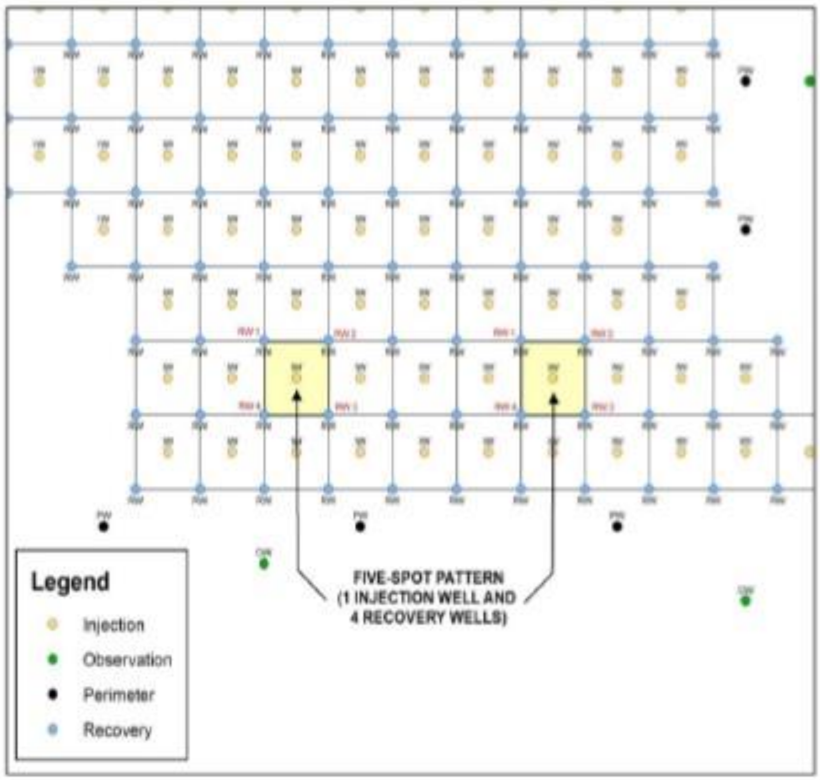

Figure 18: Portion of Figure 44, Attachment A-2, showing the five-spot pattern for injection/recovery wells.

The model simulates pumping the hydraulic control wells that surround the well field, but does not simulate the 5-spot injection/collection regime within the well field (Figure 19). The hydraulic control well pumping was imposed on the steady state flow simulated in the calibration. Simulations ran for 23 years, simulating each year as a new stress as new blocks of injection/collection wells come on line (Figure 19). Pumping rates extend to only about 190 gpm total. Only hydraulic collection wells downgradient from operating injection/collection wells were operated during any given year. As may be seen from the annual drawdown maps (Attachment A-2, Figures 48 – 56), drawdown centers on the hydraulic collection wells and the model simulated no groundwater level changes near the area being mined.

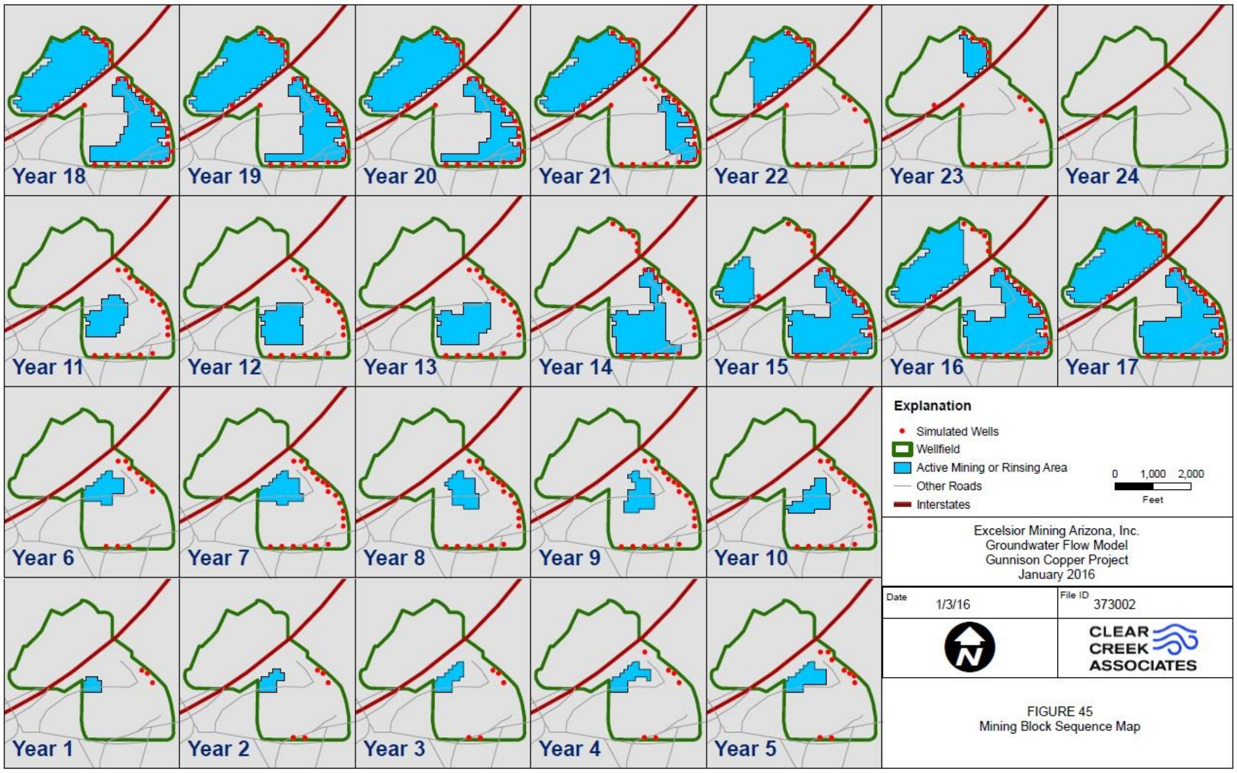

Figure 19: Figure 46 from Attachment A-2 showing the progression of mining, in blue, and simulated hydraulic control wells.

The model simulated the transport of contaminants from the mining areas using particle tracking as implemented by the MODPATH model within MODFLOW. The modelers released contaminant particles into the model at the edge of the mining areas (Figure 20) at various times based on the progression of mining. Figure 20 also shows the simulated hydraulic control wells. Being downgradient from the particle release points, the model simulates all released particles that are captured by the hydraulic control wells (Attachment A-2, Figures 57 – 59).

Particle track modeling shows that released contaminants would not escape the well field, but the modeling provides little confidence in the results. The particles follow the simulated flow paths, which are average flow paths that do not account for preferential flow paths through fracture zones.

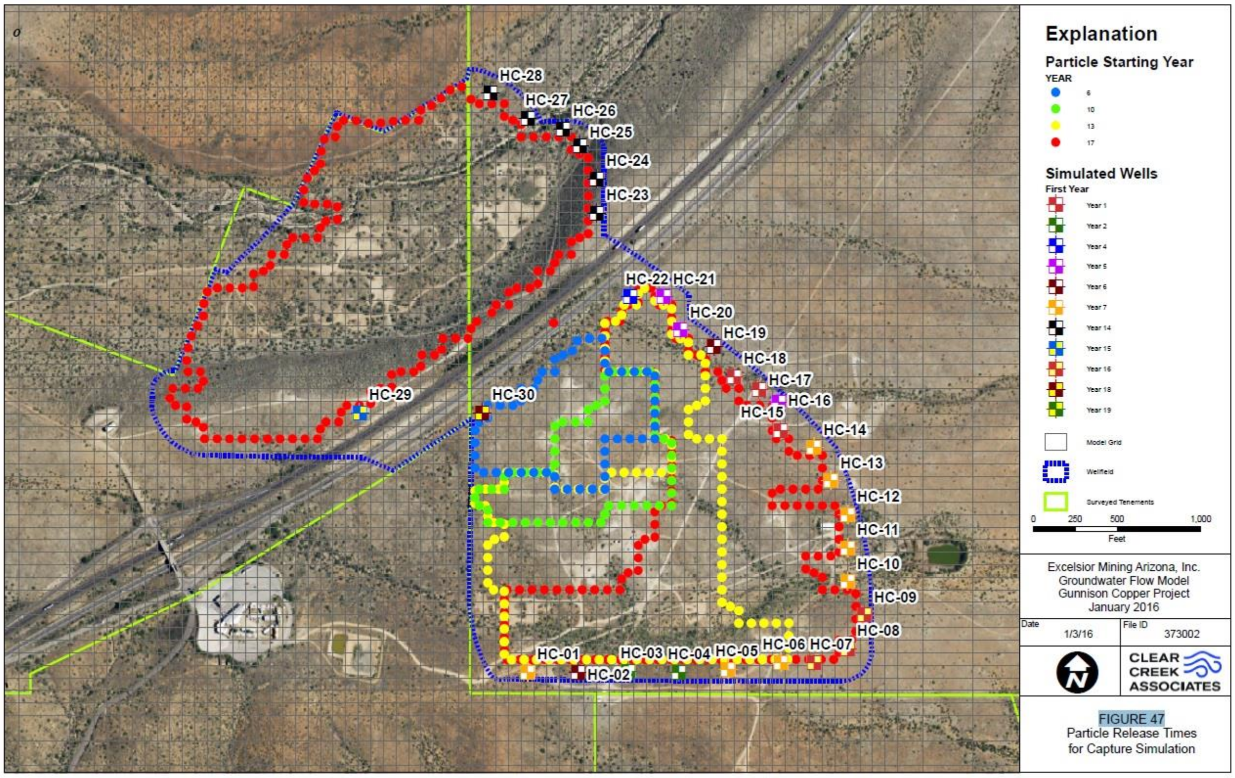

Figure 20: Figure 47 from Attachment A-2 showing the location and times that contaminant particles are released for simulation.

The report presents the results in a time series of drawdown maps and particle tracking for contaminants released at various points within the well field. The drawdown maps show the entire well field would eventually have drawdown. This drawdown represents an amount of water that has been removed from storage and would be the difference between injection collection. Drawdown due to the project is the difference between the simulated groundwater level at any given time in the future and the baseline, the steady state water level.

Not all areas within a drawdown cone are areas in which the groundwater flow is toward the middle of the cone. If the baseline groundwater contours dip steeply in one direction, a drawdown may just be a change in slope and the flow may still be away from the cone. Figure 21 shows groundwater velocity vectors (arrows showing direction with the length of the arrow proportional to the speed of groundwater flow) and the groundwater contours (not drawdown) for year 21 (not accounting for injection/collection wells). On the north, west, and south, the groundwater contours naturally slope steeply toward the well field, but in the east and southeast the contours define a relatively flat surface. The surface is so flat that small changes would could cause directional changes in the velocity vectors. The contours in Figure 21 are based on the average head for a specific cell. There is a 4170 contour around the southeast corner of the wellfield delineates a trough in the contours, meaning that simulated flow is to the center of the trough. Based on the estimated capture zone line, the yellow line on Figure 21 which shows the position of the groundwater divide, the water level is relatively flat throughout the southeast quarter of the wellfield.   The mound in the water table represented by the capture zone line is only a few feet higher than the water table in the southeast corner of the project. The pressure at different levels in the groundwater, from the water table surface to a point below the well field, could easily vary from that estimated by consideration only of the water table due to different transmissivity flow paths. Contaminants could escape from the hydraulic control through preferential flow paths through the mapped divide because the average heads in the model cells may not represent actual heads in the fracture zones.

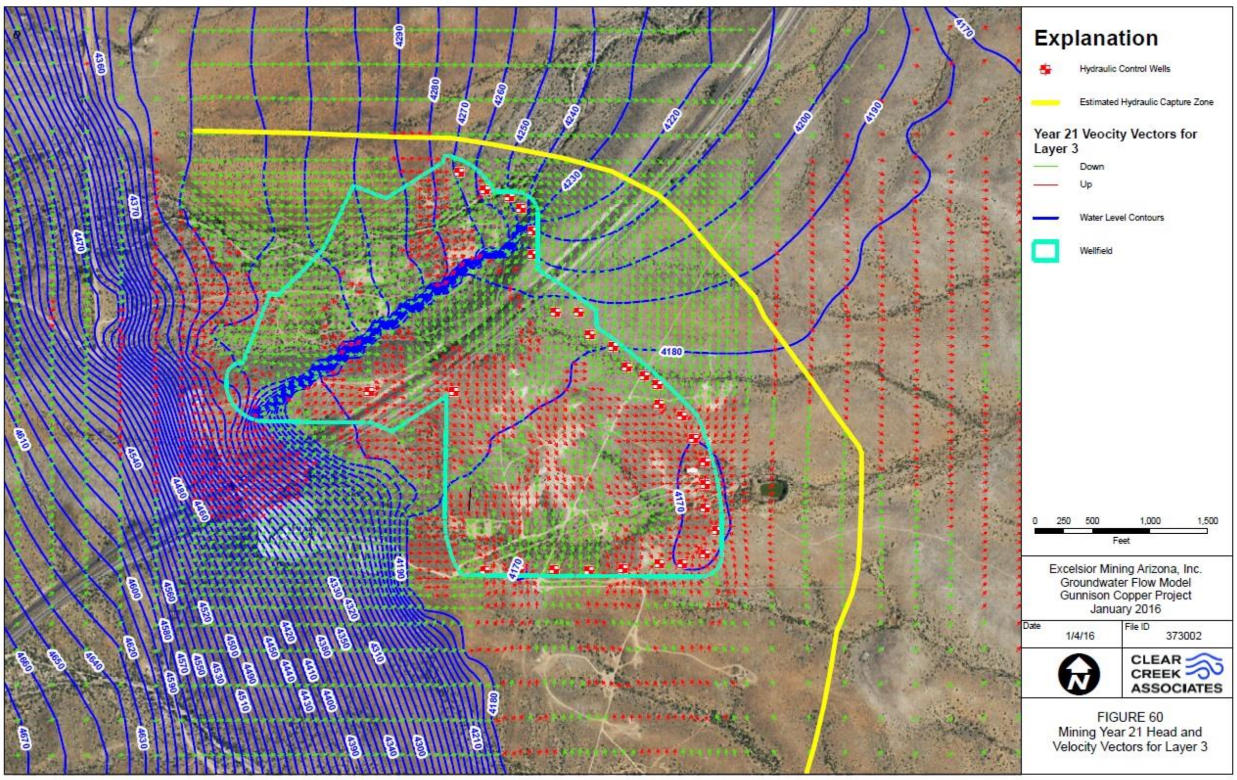

Figure 21: Figure 60 from Attachment A-2 showing the simulated groundwater contours and groundwater velocity vectors for model layer 3, year 21, the end of Stage 3 mining.

The simulation of particle capture and release is not an accurate area, for the following reasons:

- Drawdown throughout the mining area caused by pumping only the hydraulic control wells is unrealistic. The injection wells would be injecting much more fluid into the system than the hydraulic control wells removed. Of course, the collections wells also remove more, but due to the high injection rates and heterogeneities in the well field, there could easily be high pressure injection into flow paths not otherwise captured by collection wells. The combination of injection and recovery wells would create a combination of local mounding and drawdown. Due to the volumes and gradients resulting from the injection/collection wells, the hydraulic control well pumping could be overwhelmed. Without simulating the injection/collection wells, this model does not provide reliable information regarding the effect of the injection/recovery system on local or regional flow paths.

- Contaminants in the model would be released at the edge of the interior well fields (Figures 19 and 20), but they would not be under pressure as they will be during operations. During operations, the particles would be released at the beginning of a pressurized stream that would cause the particle to move faster than simply being placed at given levels in the aquifer.
- The model simulates pathways that are at a minimum 50-feet wide (model cell sizes) which means the properties are effectively an average over an area that wide. It completely misses the potential narrow pathways that could preferentially allow particles to exit the system.

Simulation of mining should be improved by doing the following:

- The actual injection/recovery wells should be simulated, with injection rates depending on the localized conductivity and pressures that would be acceptable for operations.
- The model should be discretized into much smaller cells at the mine so that injection/recovery can be simulated more accurately. This could include telescoping the regional model into a much more detailed model at the well field.
- The geology/fracture intensity model should be used at a smaller scale to provide more detail of flow paths through the well field.
- The POC wells should be redesigned according to results from the modeling. The flow model should be used with MT3DMS to simulate transport from the well field to the POC wells. Assuming sources emanating from various positions through the well field, the model could simulate a plume that POC wells should be positioned to detect.

Clear Creek should provide figures similar to Figure 21 for other time periods and for other model layers. Simply maintaining a drawdown is insufficient; it is necessary to maintain a hydraulic low point wherein no flow from the well field can escape into the regional flow field.

References

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Clear Creek Associates (CCA) (2016) Aquifer Protection Permit Application, Gunnison Copper Project, Cochise County, Arizona, Prepared for Excelsior Mining Arizona, Inc. Scottsdale AZ