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June 12, 2008

Via Certified Mail # 7006 2150 0004 3661 3196
Return Receipt Requested

Ms. Cynthia S. Campbell
Manager, Water Quality Compliance Section
Arizona Department of Environmental Quality
1110 West Washington Street
Phoenix, Arizona 85007-2935

Re: Mitigation Order on Consent No. P-50-06
Response to Arizona Department of Environmental Quality Comments on the Aquifer Characterization Report

Dear Ms. Campbell:

Freeport-McMoRan Sierrita Inc. (Sierrita) provides the following responses to the Arizona Department of Environmental Quality's (ADEQ) comment letter dated April 24, 2008[1] and received by Sierrita on May 1, 2008. ADEQ's comments pertained to the Aquifer Characterization Report (ACR) prepared and submitted on December 28, 2008 pursuant to the Work Plan[2] and schedule developed for the Mitigation Order.

ADEQ and Sierrita met twice to discuss ADEQ's April 24, 2008 comments. The first meeting was May 14, 2008 at which ADEQ comments were generally reviewed. It was determined that a second meeting was needed to specifically discuss the development and use of the numerical model reported in the ACR. The second meeting took place on May 28, 2008. Sierrita thanks ADEQ for attending the meetings as they were very productive and, we hope, provided both answers to many of the questions asked in ADEQ's comment letter and the context for use of the numerical model to develop and evaluate mitigation alternatives.

ADEQ's letter of April 24, 2008 describes three main concerns regarding the ACR. These concerns can be paraphrased as:

1) The vertical characterization of the plume may be incomplete because wells were not installed in bedrock. ADEQ is concerned that bedrock is a conduit for sulfate from the tailing impoundment to the basin fill.

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[1] ADEQ. 2008. Correspondence from Cynthia Campbell, ADEQ, to E.L. (Ned) Hall, Freeport McMoRan Sierrita Operation, Regarding: Mitigation Order, Docket No: P-50-06 – Review of Aquifer Characterization Report. April 24, 2008.
[2] Hydro Geo Chem, Inc. 2006. Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment, Pima County, Arizona. August 11, 2006 and Revised October 31, 2006.

2) Measured heads and sulfate concentrations vary through the basin fill aquifer and are not always matched by values calculated by the calibrated numerical model. ADEQ is concerned about the accuracy of the model in predicting future plume movement.

3) The model underestimates sulfate concentrations in the vicinity of the MO-2007-5 monitoring wells, where ADEQ is concerned that the sulfate plume may be migrating toward water supply well CW-10. ADEQ recommends a monitoring well be installed in vicinity of CW-10 to define the lateral boundary of the plume in this area and to monitor for encroachment of sulfate towards CW-10.

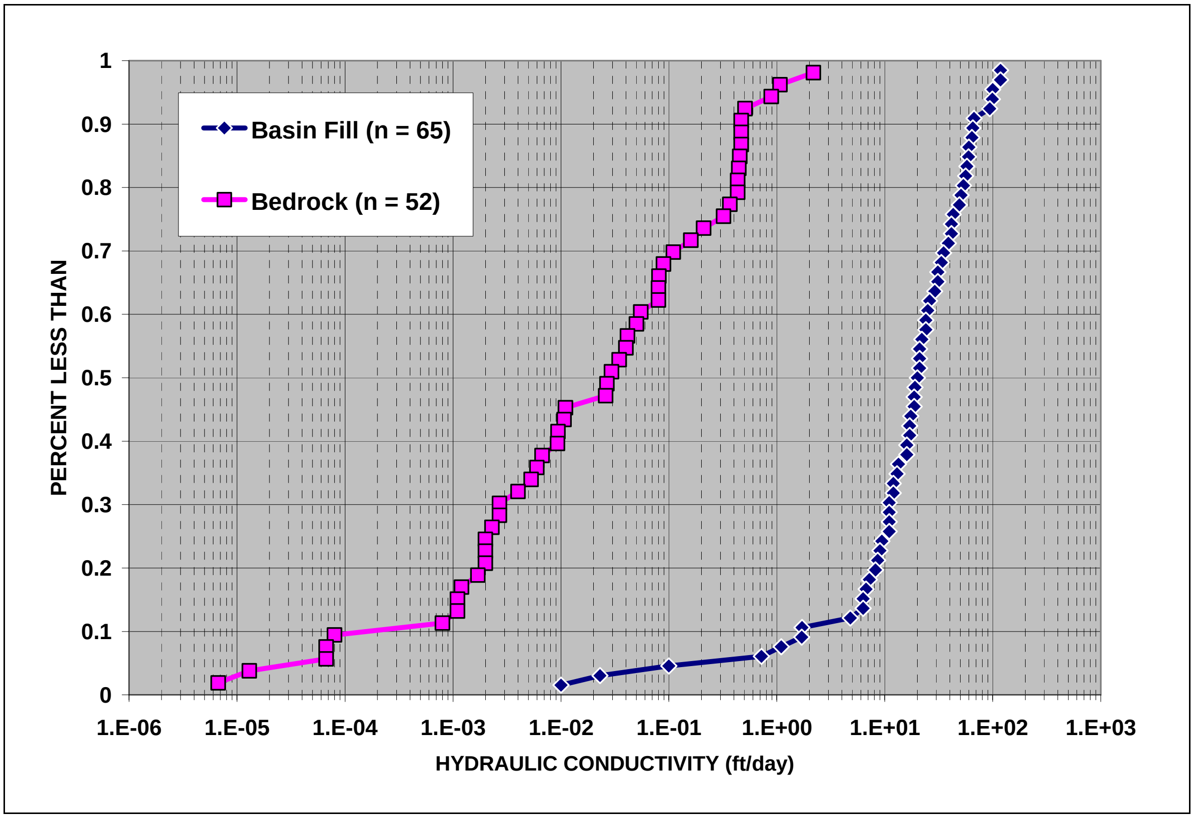
ADEQ's concerns raise important questions that all environmental characterization projects ask about what level of data collection is needed in sub-areas of a site to answer the larger questions presented by the entire site; and what level of resolution to uncertainty is technically feasible or necessary to identify, evaluate and select mitigation actions. ADEQ's three main concerns are discussed below because they address global issues with respect to the Mitigation Order work and represent the most significant of ADEQ's comments. Responses to ADEQ's general and specific comments on the ACR are provided in Attachment 1.

1. Vertical Characterization of Sulfate Plume and the Potential Presence of Sulfate in Bedrock

The bedrock permeability is extremely low in comparison to that of the overlying basin fill aquifer. Therefore, bedrock is not believed to yield significant groundwater flow or sulfate mass and bedrock flow pathways (if they exist) will not be a significant mechanism for sulfate transport. This conclusion is consistent with ADEQ's assessment of potential sulfate sources from shallow bedrock to the basin fill discussed in comment 12, which states "Hence, the sulfate mass flux from the bedrock to the basin fill would be minimal".

Evaluation of the potential presence or migration of elevated sulfate in the bedrock was not proposed in the Work Plan for several reasons including:

a) Hydraulic tests of existing shallow bedrock wells at the Sierrita Mine indicate that bedrock hydraulic conductivities are typically one to more than four orders of magnitude lower than for the basin fill. This is shown by the figure below which is a frequency distribution of hydraulic conductivity for basin fill and bedrock wells based on data in Appendix B of the Work Plan or by review of ACR Tables A.3 (basin fill wells) and A.4 (bedrock wells). The highest hydraulic conductivities estimated from tests in bedrock wells are typically less than 1 ft/day, and range to as low as about 0.00001 ft/day. In contrast, basin fill hydraulic conductivities have a mean of 20 ft/day and range up to 120 ft/day. The majority of basin fill hydraulic conductivities (88 percent) exceed 5 ft/day.



While bedrock conductivity must depend to some extent on lithology, the large range in bedrock conductivities is likely due primarily to the degree of fracturing, with the largest conductivities probably representative of more highly fractured rock. Because even the highest bedrock conductivity estimates, presumably representative of more fractured rock, are significantly lower than typical basin fill conductivities, the bedrock cannot be a significant source of or conduit for sulfate migration to the basin fill even if elevated concentrations of sulfate are present.

b) Bedrock conductivities in areas underlying the basin fill aquifer are likely to be even lower than shown in Table A.4 due to the larger lithostatic pressures resulting from greater depths. Fractured rock at depths of 1000 feet may have conductivities that are two to three orders of magnitude lower than those for more shallow zones typical of the data shown in Table A.4. The reduction in conductivity is primarily due to closing of the fracture apertures. For this reason, bedrock underlying the basin fill aquifer is even less likely to be a significant source of or conduit for sulfate regardless of the bedrock lithology.

c) ADEQ noted elevated sulfate concentrations in well MH-25D (screened in bedrock) as evidence that bedrock needs to be characterized with respect to sulfate transport. The sulfate concentration in MH-25D is likely not representative of bedrock because the well is screened within, but probably not sealed within, bedrock. Well construction and lithologic logs for the well show that the bentonite seal starts exactly at the top of the bedrock surface. Therefore, during purging, the well likely takes in water from the overlying basin fill. Because the well may not be properly sealed within the bedrock, the water quality data from the well do not necessarily indicate elevated sulfate concentrations in the bedrock.

In summary, the low permeability of bedrock, the large contrast between basin fill and bedrock hydraulic conductivities, and the reduction in bedrock conductivities with depth due to lithostatic pressure mean that bedrock is unlikely to be a significant source of groundwater recharge or sulfate mass loading even if elevated concentrations of sulfate are present. Therefore, with regard to the evaluation of potential mitigation actions, consideration of any elevated sulfate that may be present in bedrock is unnecessary.

2. Groundwater Flow and Sulfate Transport Model

A regional-scale groundwater flow and sulfate transport model was developed for the vicinity of the sulfate plume and reported in the ACR. It is important to review the objective and intended use of the model as these are the measures against which model adequacy needs to be evaluated.

- The objective of the model is to predict future hydraulic head and sulfate distributions for purposes of comparing the potential effectiveness of different mitigation alternatives under expected long-term conditions, such as water supply pumping.

- The intended use of the model is for evaluation of the effectiveness and preliminary design of mitigation actions using groundwater pumping or recharge. Specifically, the model is used to evaluate potential groundwater pumping strategies by simulating the aquifer and plume response to various well arrays and pumping rate regimes or recharge rates over time.

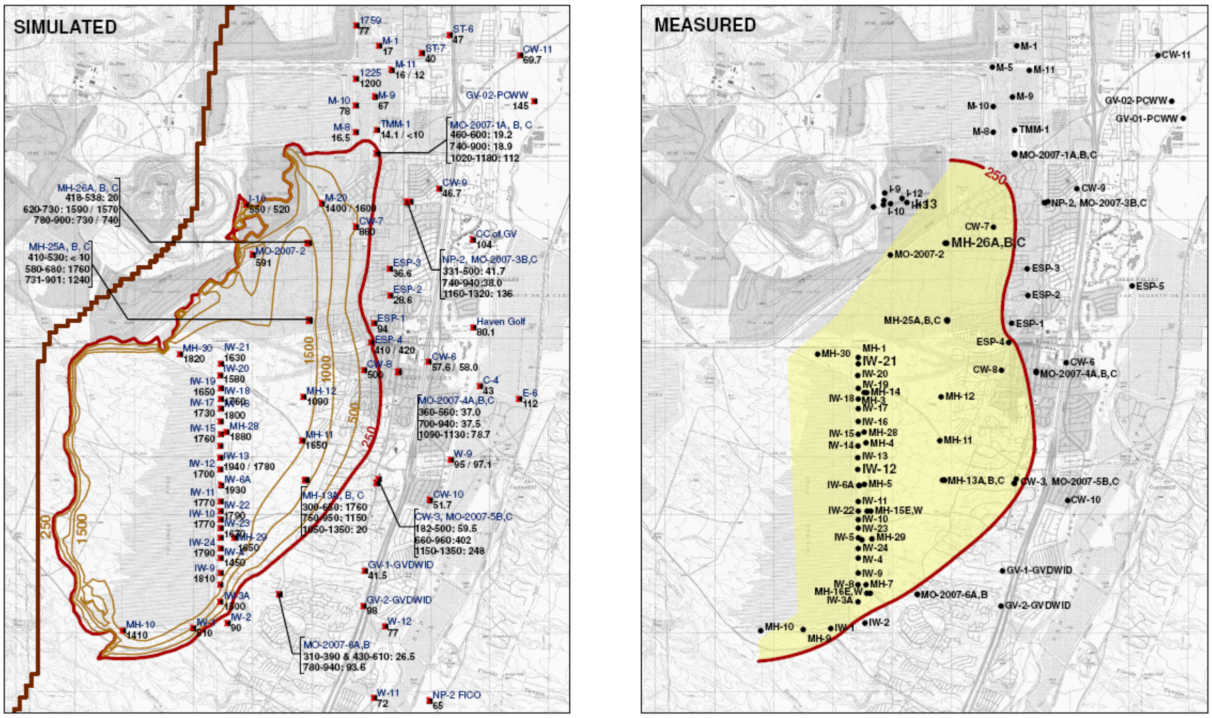
To accomplish the objective, the model must approximate 1) the geometric and the potentiometric features of the aquifer and 2) the general temporal and spatial distribution of sulfate. The model is ambitious in that it is constructed and calibrated to simulate a large range of hydrologic processes over a 66-year record of groundwater pumping and a 47-year record of tailing emplacement. By standards usually employed in modeling, the calibration data approximate available measurement data fairly well.

Admittedly, the model portrays a simplistic conceptualization of a very complex natural system (this is inherent in all models). Still, the model is a valuable tool for decision making with regard to evaluating and comparing the effectiveness of mitigation alternatives, and along with performance monitoring and adaptive management (including model recalibration as needed), will aid in successful mitigation of the sulfate plume.

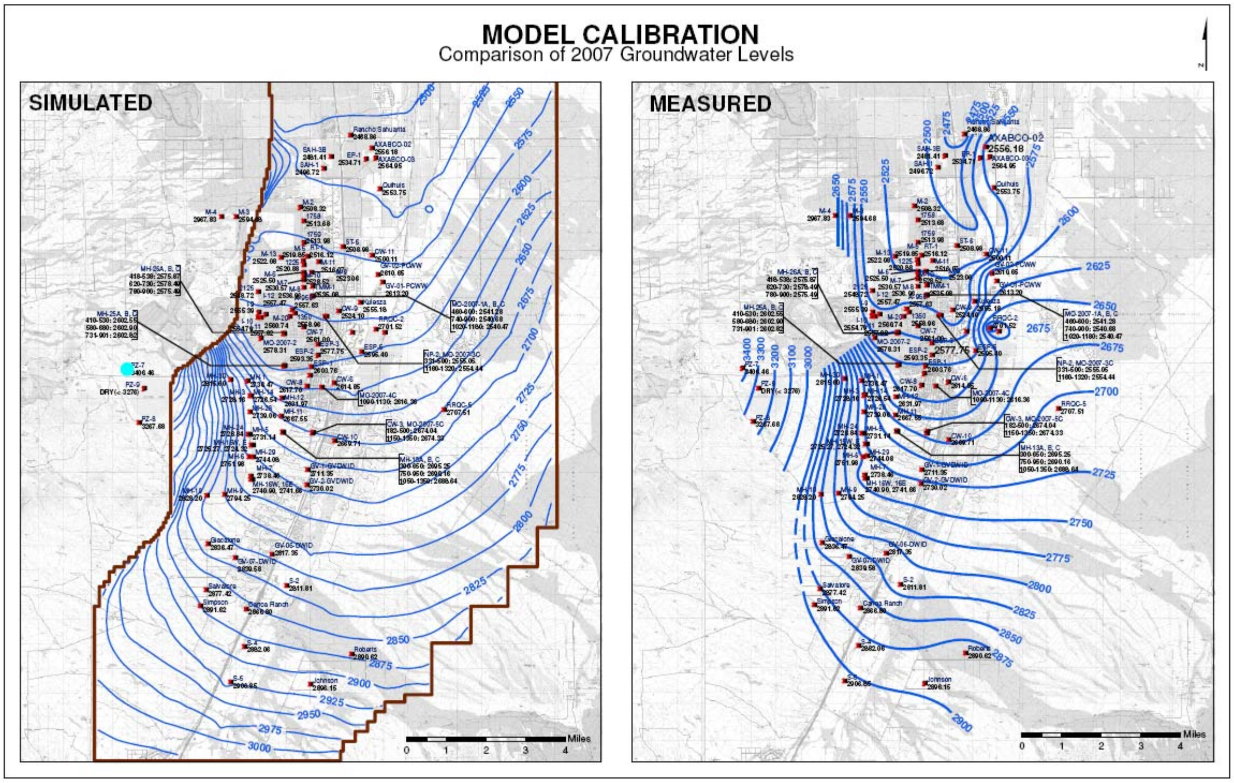
Groundwater flow and transport models never exactly match all aspects of systems they are designed to simulate because models are by necessity generalizations of more complex environmental systems. Appendix I of the ACR details the basis for model construction and calibration, and it discusses the strengths, limitations, and appropriate uses of the model. By replicating the geometry of the basin fill aquifer and water levels over time, the model must, by definition, be an adequate representation of the groundwater flow system. The ability of the model to match the arrival time and general magnitude of sulfate over time in various wells indicates that the large scale features of sulfate transport are captured. The model is not expected to match all well data exactly all the time because the well data represent various averaging scales (e.g., water quality data are for wells with different length screens completed with different levels of penetration in the aquifer) that differ from the averaging scale of the model and because of simplifications inherent in model development. As stated by Bear and Verruijt (1987) in *Modeling Groundwater Flow and Pollution*, *"a model may be defined as a simplified version or the real (here groundwater) system that approximately simulates the excitation-response relations of the latter. The real system is very complicated and there is no need to elaborate on the need to simplify it for the purpose of planning and management decisions. The simplification is introduced in the form of a set of assumptions that express our understanding of the nature of the system and its behavior".*

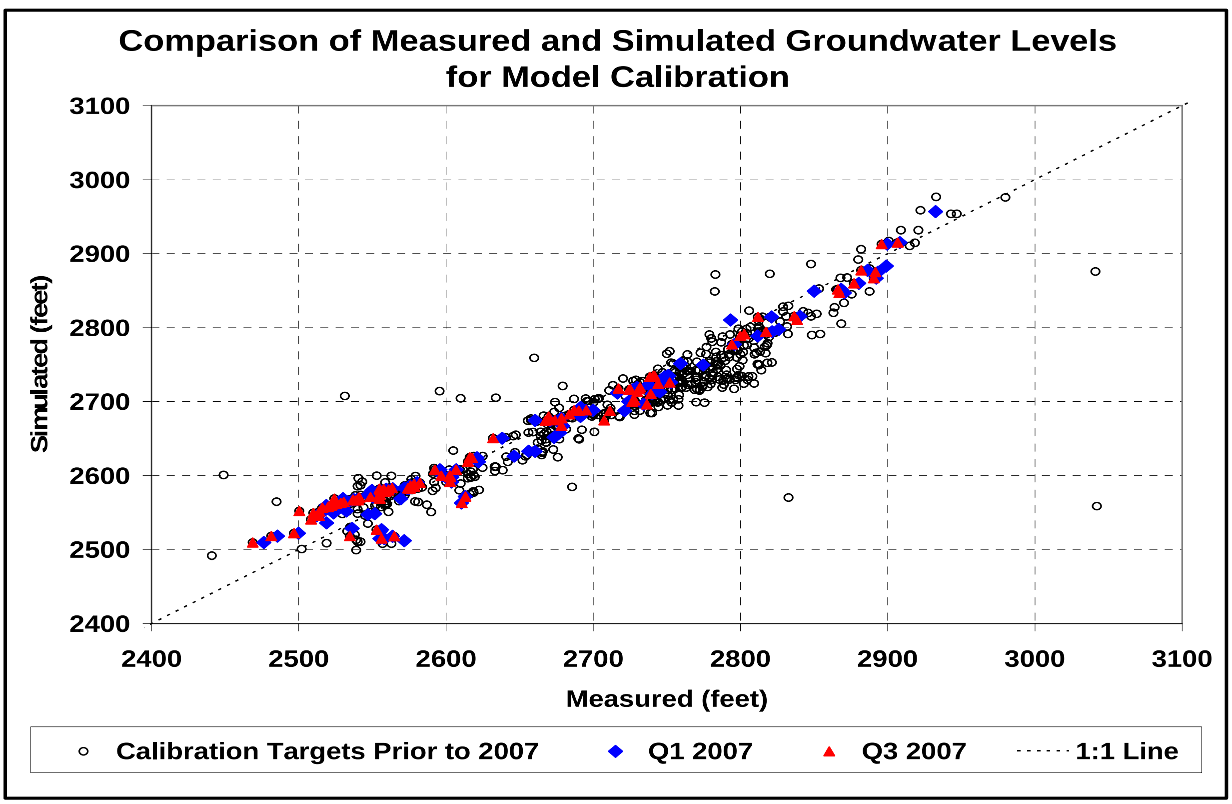
ADEQ states that "the model may be a poor predictor of sulfate plume fate and transport, especially with regard to estimating the timing of the plume migration." This statement neglects the success of the model in predicting the approximate locations of the measured plume after simulation of 66 years of groundwater pumping in the vicinity of the plume and 47 years of seepage from three tailing impoundments (see figure below comparing simulated and measured sulfate concentrations). The statement also neglects the data in Appendix I.3 showing agreement between measured and predicted sulfate concentration over time at key wells within the plume. Agreed, the approximation of observed concentrations over time is not exact in all cases, but it is good in that the timing of sulfate increases and the relative magnitude of sulfate are generally well replicated. These data indicate the simulated sulfate migration in time and space more than adequately approximate observations at a level sufficient to meet the model objective.

MODEL CALIBRATION
Comparison of 2007 Sulfate Concentration Levels



The validity of the model as a tool for predicting the hydraulic response of the aquifer and plume movement under various mitigation pumping strategies is not negated by the relatively minor discrepancies between the observations and the corresponding simulated values. All models have such discrepancies because calibration is a process of obtaining acceptable matches to many different parameters; no one parameter is matched perfectly but all need to be matched reasonably well. Furthermore, the quality of the hydraulic calibration was enhanced by the calibration to sulfate concentrations. During the process of calibrating to sulfate concentrations, the hydraulic calibration was adjusted and improved to meet the additional constraints imposed by the sulfate, which, in a sense, acted as a tracer. The results of the hydraulic simulation are illustrated in the two figures below.


MODEL CALIBRATION
Comparison of 2007 Groundwater Levels
SIMULATED
MEASURED
Miles
0
1
2
3
4


Comparison of Measured and Simulated Groundwater Levels
for Model Calibration
Simulated (feet)
Measured (feet)
2400
2500
2600
2700
2800
2900
3000
3100
Calibration Targets Prior to 2007
Q1 2007
Q3 2007
1:1 Line

The calibrated model approximates the present distribution of head and sulfate in the basin fill close enough for adequate simulation of groundwater capture and mitigation planning. Groundwater capture of sulfate by groundwater pumping is a hydrodynamic process that is approximated by simulation of ambient groundwater flow conditions and groundwater flow to wells. Groundwater pumping strategies will need to evaluate hydraulic capture from fully penetrating wells in most cases because sulfate is distributed through the entire saturated thickness of the basin fill in most cases. Given the hydrodynamic nature of potential mitigation actions, the ability to simulate sulfate capture by mitigation actions is dependant primarily on the transmissivity, the head distribution, and the location of wells with respect to the plume. Inasmuch as 1) simulated water levels approximate the observed potentiometric surface, 2) simulated sulfate concentrations approximate the current measured plume boundaries, 3) the best information available was used for model calibration, and 4) boundary conditions are reasonable, the model should give reasonable approximations of future sulfate transport under various mitigation actions.

As a final statement regarding the model, ADEQ states “Moreover, the model may be flawed as a tool for planning interim or final mitigation actions for drinking water sources”. Sierrita disagrees with this statement. As we discussed at the May 14, 2008 meeting, ADEQ’s statement was based on a different expectation regarding the use of the model. Also discussed and agreed with ADEQ was that the model may be refined in the future as more information is collected. Performance monitoring of a mitigation action based on predictive simulation is a necessary component of evaluating the accuracy of the prediction. Performance monitoring data may be used for recalibration of the model to improve the simulation or in the context of adaptive management for modification of mitigation actions.

3. Conditions in the Vicinity of MO-2007-5

Wells MO-2007-5B and MO-2007-5C were installed from July to October 2007 near pre-existing well CW-3 at the southeast portion of the sulfate plume. Together, these wells monitor different depths in the aquifer with CW-3 being the most shallow well and MO-2007-5C the deepest. Sulfate concentrations in the MO-2007-5 wells are at or exceed the 250 milligram per liter (mg/L) action level for sulfate, whereas the sulfate concentration in CW-3 is about 50 to 60 mg/L. The identification of elevated sulfate at the MO-2007-5 wells should not be interpreted as recent eastward movement of the plume or sulfate migration that is “more aggressive than other nearby zones.” Instead, the sulfate detected at MO-2007-5A and MO-2007-5B was likely present but unknown until the new monitor wells were installed as suggested by the rise in sulfate concentrations at CW-3 in the late 1980s. The sulfate concentration at CW-3 has declined since the early 1990s, but the installation of the MO-2007-5 wells identified elevated sulfate at depth. Furthermore, plume monitoring over seven quarters has not observed an “aggressive” plume migration.

ADEQ correctly points out the risk that drinking water supply well CW-10, about 3,000 feet east-southeast of the MO-2007-5 and CW-3 wells, could be impacted if the plume were moving in the direction of CW-10. However, groundwater level contours show a strong northward to north-northeastward hydraulic gradient in the vicinity of CW-3, meaning that bulk sulfate transport will be northward, not easterly toward CW-10. Additionally, measurements of static groundwater elevations collected since the ACR was submitted indicate that the groundwater elevation in CW-10 is higher than those in the MO-2007-5 and CW-3 wells, indicating that groundwater at the MO-2007-5 and CW-3 wells would not flow toward CW-10 unless influenced by pumping at CW-10. Regardless of hydrodynamic data suggesting a low potential for impacts at CW-10, because migration of sulfate toward CW-10 has important consequences, Sierrita agrees that this potential migration pathway should be monitored by installation and sampling of an additional well between MO-2007-5 and CW-10.

The simulation of the sulfate plume using the calibrated model shows the plume (as defined by the 250 mg/L contour) extending eastward, but approximately 1500 feet short of the MO-2007-5 and the inferred plume edge. The model does predict a sulfate concentration of about 170 mg/L at the location of the MO-2007-5. Simulating the eastward extent of sulfate in the vicinity of the MO-2007-5 and CW-3 wells, what ADEQ calls the “bulge”, is difficult because of the complexity of the groundwater gradients in this area where flow changes from eastward to northward.

The underestimation of sulfate concentrations at the plume’s southeastern margin does not make the model unfit for evaluating mitigation alternatives because the model replicates the overall large-scale shape and migration patterns of the plume which are of greater importance for the evaluation of the effectiveness and conceptual design of potential mitigation actions. Also, simulation of sulfate transport in this portion of the plume where spreading lateral to the direction of groundwater flow dominates was not as high a priority for mitigation action evaluation as simulation of sulfate advance at the northern leading edge of plume. The portion of the plume at the ‘bulge’ is a small portion of the model that does not represent a significant fraction of flow or sulfate mass. Nonetheless, installation of an additional well in this area will allow monitoring of the future distribution of sulfate between MO-2007-5 and CW-10.

In summary,

- There is no need to characterize conditions in the bedrock because, as ADEQ has recognized, the low permeability of bedrock makes it an unlikely source of significant groundwater flow or sulfate mass.
- The groundwater flow and transport model satisfies its objective of simulating the large-scale sulfate plume for purposes of evaluating the relative effectiveness of potential mitigation actions. The simulation of future plume movement for mitigation planning will be conducted considering the potential limitations of the model with respect to the spatial and temporal accuracy of

model predictions. Thus, the ultimate mitigation action will use safety factors for design, and include performance monitoring and adaptive management.

- The numerical model underpredicts sulfate concentrations in the southeastern portion of the sulfate plume near MO-2007-5 and CW-10. An additional monitoring well will be installed to monitor quality in the vicinity of CW-10.

Please contact me at (520) 648-8857 if you have any questions regarding these responses.

Sincerely,

Chad D Fretz for

E. L. (Ned) Hall
Chief Environmental Engineer

ELH:ms
Attachment
20080612-001

xc: Joan Card, Arizona Department of Environmental Quality
Robert Casey, Arizona Department of Environmental Quality
John Broderick, Sierrita
Chad Fretz, Sierrita
Ray Lazuk, Freeport-McMoRan Copper & Gold Inc.
Stuart Brown, Bridgewater Group, Inc.
Jim Norris, Hydro Geo Chem, Inc.

ATTACHMENT 1

RESPONSE TO GENERAL AND SPECIFIC COMMENTS

In the following response to comments by Arizona Department of Environmental Quality (ADEQ), ADEQ's original comment is reproduced in normal font and the Freeport-McMoRan Sierrita Inc. (Sierrita) response is provided in bold italics.

<u>GENERAL COMMENTS</u>

1. The Aquifer Characterization Report (ACR) is the final report of field activities involving several months of site investigations, groundwater monitoring and computer modeling of the hydrology and water quality of the sulfate plume located downgradient of the Phelps Dodge Sierrita Tailing Impoundment (PDSTI). The objectives of the report are to characterize the sulfate plume and collect data for a feasibility study. The scope of the report includes the findings of the following tasks:

   - Completion of a well inventory to identify drinking water wells that could be impacted by the sulfate plume.
   - Determination of the lateral and vertical extent of the sulfate plume.
   - Evaluation of the fate and transport of the sulfate plume.
   - Evaluation of the effectiveness of the current interceptor wellfield.

   Several interim reports were submitted during the period of investigations, and the final ACR briefly summarizes and references the results of the previously reported work.

SIERRITA RESPONSE:

No response necessary.

2. ADEQ believes that the ACR does not adequately summarize or integrate all the relevant information obtained from background data, five quarters of groundwater monitoring and field work results from newly installed wells in characterizing the sulfate plume. The first sentence on Page 4, Section 1.2 "*Scope of the Aquifer Characterization Report*," states, "*For completeness, this report summarizes the results of previously reported work conducted under the Aquifer Characterization Plan, but will not reproduce previously submitted reports*." The ACR should be a "*stand alone*" document that allows reasonable conclusions to be made on the adequacy of the plume characterization. It would be helpful if Freeport would

revise the text of the ACR to provide full documentation as to all work that was conducted, and integrate the information/data with previously known information/data. At a minimum, Freeport should include CD copies of all of all previous major reports as part of the ACR.

SIERRITA RESPONSE:

Section III.C of the Mitigation Order defines the ACR requirements as follows: "In accordance with the schedule in the approved Work Plan, PDSI shall submit to ADEQ an Aquifer Characterization Report (ACR) that provides detailed findings pertaining to sulfate concentrations down gradient of PDSM. At a minimum PDSI shall address in the ACR, the following:

1. ***Current sulfate plume delineation;***
2. ***Sulfate plume fate and transport***
3. ***Identification of all existing registered private drinking water wells and public drinking water system wells identified by the well inventory required by Section III.A.4; and ;***
4. ***An analysis of the effectiveness of PDSI's current groundwater sulfate control system."***

Section 2.2.2.2 of the ACR describes the plume delineation at the time of the report. Sulfate plume fate and transport is addressed in Section 3 which describes the conceptual model for the groundwater sulfate plume and in Section 4 and Appendix I which discusses the numerical groundwater flow and sulfate transport model. All existing drinking water supply wells identified by the well inventory are shown on Figure 2 of the ACR and discussed on Section 2.1. Section 2.3 provides the results of the evaluation of the groundwater sulfate control system. Thus, the content of the ACR meets the specifications of the Mitigation Order. Furthermore, Section 3.6 of the Work plan discusses how the ACR was to be composed of task specific reports provided to ADEQ as the tasks were completed so that the agency could review them as the investigation progressed. This is the ACR structure that ADEQ agreed to when they approved the Work Plan.

The ACR does rely on Appendices and reference to previously submitted reports. Previous reports prepared for the ACR are referenced in Section 1.2 along with a website address where the report could be downloaded for review. Sierrita believes this organization is efficient and best provides for the needs of a wide readership, including regulators, technical consultants, and the lay public. However, the ACR will be modified to address this comment by adding a CD containing reports submitted to ADEQ pursuant to the Mitigation Order prior to the ACR submittal.

3. Appendices: The main part of the report is followed by Appendix A which describes "*Data Compilation and Evaluation of Bedrock Elevation*" and then by Appendix B which contains a "*Summary of Water Quality Data*." For easy reference, Freeport should reverse the sequence of these two appendices. Other Appendices could be rearranged to facilitate easy flow of information.

SIERRITA RESPONSE:

Sierrita respectfully disagrees with this comment. The order of the appendices is based on the order in which they are cited in the text. Because the ACR is organized by work plan task, the discussion of the data compilation for Task 2.1 precedes the discussion of groundwater monitoring for Task 2.2. Thus, the appendix referenced in the discussion of Task 2.1 precedes the appendix referenced in the discussion of Task 2.2. This is a standard report format.

4. Background Sulfate Concentration: During the development of the Work Plan, it was discussed that, at the end of the aquifer characterization, adequate water quality data would be generated to establish a background sulfate concentration in groundwater for the basin fill sediments and bedrock respectively, using new and existing data sources from locations upgradient and outside the areas affected by the plume. This issue has not been addressed in the ACR, although there were references to the value of "50 ppm" to separate sulfate sources near the Santa Cruz River.

   The sulfate background value should be determined and used in defining areas impacted by the PDSTI sulfate plume.

SIERRITA RESPONSE:

ADEQ seems to suggest in its comment that there is a single background value. This is an overly simplified notion given the diversity of source regions for groundwater in the vicinity of the plume and the amount of mixing that occurs in the central portion of the basin. In reality, background concentrations vary as a function of position in the basin depending on the groundwater flow paths at that location.

The sulfate concentration in groundwater for the basin fill upgradient and cross gradient of the plume was determined by sampling and analysis conducted for groundwater monitoring under Task 2.2. The distribution of sulfate concentrations is discussed in Section 2.2.2.2. and displayed on Figure 4 which shows sulfate concentrations around the sulfate plume. The sulfate data depicted on Figure 4 illustrate concentrations in the vicinity of the plume; including locations upgradient, cross gradient, and downgradient of the plume.

Wells immediately south of the Sierrita Tailing Impoundment in the cross gradient direction had the lowest sulfate concentrations measured, typically less than 10 mg/L. The low concentration flow from south of the tailing impoundment mixes with flow along the axis of the basin containing between approximately 60 and 130 mg/L sulfate. Wells on the westernmost side of the basin typically have sulfate concentrations ranging from approximately 20 to 80 mg/L. As discussed in Section 3.1, sulfate concentrations of approximately 300 to 450 mg/L occur in bedrock immediately upgradient to the west of the Sierrita Tailing Impoundment.

5. In Section 4, "*Numerical Model of Groundwater Flow and Transport*," Freeport should provide a more detailed summary of the groundwater model including model specifics, (i.e., grid spacing, layers, hydraulic conductivities, calibration, sensitivity analysis, etc.).

SIERRITA RESPONSE:

Section 4 of the ACR references the reader to Appendix I for a detailed discussion of all the modeling specifics requested by ADEQ. This detailed discussion includes nearly 50 pages of text, numerous tables and figures, and three appendices. For the interested reader, Appendix I is conveniently bound with the main text for easy reference. This organization best provides for the needs of a wide readership, including regulators, technical consultants, and the lay public. Nonetheless, additional discussion of the model will be added to Section 4.

6. In Appendix I,"*Numerical Model for Simulation of Groundwater Flow and Sulfate Transport,*" Freeport should include a section that summarizes the Conceptual Site Model.

SIERRITA RESPONSE:

The conceptual site model is discussed in Section 3 of the ACR and referenced in Section 3 of Appendix I. Appendix I will be revised to add a summary of the conceptual site model.

7. In general, all sections of Appendix I should include additional documentation to provide the rationale as to the starting input conditions for the numerical model.

SIERRITA RESPONSE:

Regarding the rationale of the starting input conditions, the rationale for the initial conditions of the model are discussed in Section 3.1 and 3.5, and documentation for the starting values of the input parameters is provided in Table I.1.

8. It would be helpful if Freeport would provide additional information, and rationale regarding these areas:

    - Appropriateness of hydraulic data;

SIERRITA RESPONSE:

The appropriateness of the historic hydraulic data is discussed in Section 3.5 of Appendix A. Section 4 of Appendix E discusses hydraulic data collected pursuant to the Work Plan. In general, a check of the historical data found that most estimates were made with appropriate methods and that the estimated hydraulic conductivities could be duplicated. Hydraulic properties estimated under the Work Plan were consistent with the range of previous values determined for similar materials.

- Appropriateness of contouring the highest sulfate concentration data regardless of the depth from which the sample was collected;

SIERRITA RESPONSE:

When more than one concentration was available for samples from co-located wells, the maximum sulfate concentration was used for preparing concentration contour maps. This is appropriate because (1) the majority of the sulfate concentration data are for wells that are screened over large sections of aquifer and do not provide depth specific data and (2) the extent of the sulfate plume is conservatively estimated. The estimation of plume extent is conservative in that the use of the maximum concentration at co-located wells yields the largest potential extent of the plume. The assumption of the highest concentration as the basis for contouring is stated in Section 2.2.2.2 of the ACR.

- Description of the ranges of groundwater elevation;

SIERRITA RESPONSE:

Groundwater elevations were measured using standard methods identified in the QAPP. As discussed in Section 2.2.2 of the ACR, the groundwater elevation measurements made for the ACR showed consistent magnitudes and spatial distribution from quarter to quarter and were consistent with groundwater elevation patterns displayed data sets from 2005/2006 and 1993/1994.

- Description of how depth specific sampling was conducted;

SIERRITA RESPONSE:

The methods used to collect and evaluate depth-specific samples are provided in Section 2 of Appendix C.

- Discussion of any potential data gaps that may exist;

SIERRITA RESPONSE:

Based on discussion with ADEQ and the discussion in these responses to comments, a new monitoring well will be installed between CW-10 and the MO-2007-5 wells to address the water quality monitoring data gap in that area.

- Rationale regarding the choice of screen intervals for the newly installed monitoring wells;

SIERRITA RESPONSE:

The rationale for the choice of screen intervals for the newly installed monitoring wells is provided in detail in Section 3 of Appendix D, pages D-11 to D-27.

- Description of the usefulness of step-drawdown aquifer tests and whether constant-discharge aquifer tests should be conducted;

SIERRITA RESPONSE:

A step drawdown test as described in the ACR is better suited for characterizing hydraulic properties than a single rate pumping test. The first two steps of the step test are typically short (60 to 90 minutes) whereas the last step is long (6 to 8 hours) and serves the purpose of a constant rate test. The time series drawdown data collected by the step tests are interpreted using analytical solutions that account for well efficiency and drawdown

throughout the entire test period employing the principal of superposition (see, for example, Bear, J. 1979. The Hydraulics of Groundwater. McGraw-Hill Inc.). Information regarding well efficiency and aquifer hydraulic properties can be obtained from all three steps. Well efficiency and its impact on drawdown cannot be easily interpreted from a constant rate pumping test. Thus, step-tests allow a greater diagnostic analysis of pumping test data than do constant rate tests because the time-varying pumping and drawdown require a unique solution to match observations throughout the entire test

- Re-evaluating sulfate loading of the lower basin fill aquifer as the data presented in the Attachments seems to indicate;

SIERRITA RESPONSE:

ADEQ's attachments infer sulfate concentrations in the bedrock at certain locations. Sierrita does not agree with ADEQ's inferred sulfate distribution. However, as discussed in the cover letter to these responses, even if elevated concentrations of sulfate are present in bedrock the bedrock cannot be a significant source of or conduit for sulfate migration to the basin fill because even the highest bedrock conductivity estimates are significantly lower than typical basin fill conductivities.

- Additional well installation into bedrock to fully characterize the horizontal and vertical,sulfate concentrations;

SIERRITA RESPONSE:

There are no water supply wells in the bedrock and the hydraulic conductivities in bedrock materials are much lower than that of the basin fill aquifer, as presented in Appendix A of the ACR. Therefore, the contribution of sulfate to the bedrock, movement of sulfate in the bedrock, and movement of sulfate from the bedrock to the basin fill are considered to be minor relative to sulfate transport in the basin fill, as stated in Section 3.2.1 of the ACR and as indicated by ADEQ in Specific Comment 12.a and discussed in the cover letter to these responses.

- Groundwater and transport modeling.

SIERRITA RESPONSE:

Issues related to the groundwater flow and transport model are discussed in the cover letter to these responses and in subsequent responses to comments regarding the model.

SPECIFIC COMMENTS

1. Section 2.1: Task 1 – Well Inventory

   The results of the well inventory are well summarized in this section of the report. However, Freeport should provide the sulfate concentrations in the 10 active drinking water wells on the map (Figure 2) showing the locations of these drinking water wells. Also, it is relevant to indicate if the sulfate concentrations at these wells have changed over time during the period of groundwater monitoring. For example, the sulfate concentrations in the Green Valley drinking water well GV-2, showed increasing concentrations of sulfate - 48 ppm, 85ppm, 103 ppm and 106 ppm during four quarters of consecutive groundwater monitoring. Well CW-10 may be showing a similar pattern of increasing sulfate concentrations. These wells are all located near the southeastern edge of the plume where a former drinking water well CW-3 has been "impacted" by the plume. ADEQ notes evidence of an aggressive subsurface plume migration along this edge of the plume boundary where the sulfate distribution shows a prominent protrusion ("bulge" shape) (see Fig 1 of the ACR). It is important for Freeport to include this observation in the ACR and explain or rationalize the plume's behavior.

SIERRITA RESPONSE:

Sulfate concentrations determined for the drinking water supply wells are presented in Table B.1 of the ACR which lists results by the ADWR well registry numbers shown on Figure 2. To address this comment, the third quarter 2007 sulfate concentrations of the 10 active drinking water wells will be added to Figure 2, except for the Gatterer well where the concentration is from October 2006. Sierrita will also include a discussion on changes in sulfate concentrations over time in drinking water supply wells in Section 2.1 of the ACR.

In general, most of the 10 drinking water supply wells have a flat sulfate concentration trend with the exception of ESP-1 which is decreasing. The data ADEQ cites for well GV-2 are incomplete. Table B.2 lists the sulfate concentrations for GV-2 as 48.6, 95.3, 103, 106, and 98 mg/L for samples between August 2006 and July 2007. Wells CW-10 and GV-2 had sulfate concentrations of 37.2 mg/L in December 2006 and 48.6 mg/L in August 2006, respectively. However, sulfate concentrations reported for the subsequent consecutive quarters indicate a relatively flat concentration trend ranging from 48.6 to 52.8 mg/l in CW-10 and 95.3 to 106 mg/l in GV-2. Therefore data suggest that the initial concentrations in CW-10 and GV-2 may be outliers. ADEQ is incorrect in stating that the groundwater monitoring results support an increasing trend in sulfate concentrations over the period of monitoring for the Mitigation Order.

For discussion of "evidence of an aggressive subsurface plume behavior" see the response to Specific Comment 3, below.

2. Section 2.2.1: Task 2.1 - Data Compilation and Evaluation

   In this section Freeport states that all data evaluation was conducted in Appendix A, and the last sentence reads, "*The hydraulic properties data reported in the Work Plan were determined to be suitable for use in aquifer characterization*." The body of the ACR should provide, at a minimum, the results of the evaluation to justify the statement that the data provided in the work plan is suitable.

   Specifically, the vertical extent of the sulfate plume is not defined. Freeport should include a summary of the hydraulic properties of the bedrock in the vicinity of the PDSTI based on the accumulated data. In Appendix A, Freeport describes how the data was compiled, but provides no significant analysis or discussion. The conclusions reached in the report do not appear to consider the data compiled in the tables. The extent of fracturing of the bedrock is not fully explored. It is possible that the fractured bedrock has an impact on hydraulic conductivity, which in turn, might indicate the sulfate is migrating deeper through the fractured bedrock. These issues should be more fully explained.

   Within the sulfate plume, none of the monitor wells are screened solely within bedrock, with the exception of MH 25D which contains 600 ppm of sulfate as compared to 1400 ppm of sulfate in the overlying basin fill. The possible correlation between the elevated sulfate content in the basin fill and the hydraulic characteristics of the underlying bedrock is not explained. The characterization of the hydraulic properties and sulfate distribution in bedrock underlying the plume is currently poorly understood, and requires a more rigorous evaluation of its potential impact on sulfate migration. There is a probability that, if the underlying bedrock is not adequately characterized, it may affect future mitigation actions.

SIERRITA RESPONSE:

Task 2.1 of the Work Plan included 1) definition of the bedrock surface underlying the basin fill aquifer, 2) verification of existing hydraulic property estimates at existing wells that included basin fill wells and also bedrock wells located generally west of the limits of the basin fill aquifer, and 3) water quality of area wells.

Definition of the bedrock surface and verification of hydraulic property estimates are discussed in Section 2.2.1 and Appendix A. Tables A.3 and A.4 compare the

ranges of hydraulic conductivities estimated as part of the verification with those reported in the Work Plan. Water quality of area wells and evaluation of sulfate distribution are provided in Section 2.2.2.2 and Appendix B. Evaluation of the potential presence or migration of elevated sulfate in the bedrock was not proposed in the Work Plan for several reasons including:

a. Hydraulic tests of existing shallow bedrock wells indicate that bedrock hydraulic conductivities are typically one to more than four orders of magnitude lower than for the basin fill, as can be seen by comparing Tables A.3 (basin fill wells) and A.4 (bedrock wells). An exception is MH-13C, screened in deep basin fill that has conductivity more typical of a bedrock well. The highest conductivities estimated from tests in bedrock wells (Table A.4) are typically less than 1 ft/day, and range to as low as about 0.00001 ft/day. While bedrock conductivity must depend to some extent on lithology, the large range in bedrock conductivities is likely due primarily to the degree of fracturing, with the largest conductivities likely representative of more highly fractured rock. Because even the highest bedrock conductivity estimates, presumably representative of more fractured rock, are significantly lower than typical basin fill conductivities, the bedrock cannot be a significant source of or conduit for sulfate to the basin fill even if elevated concentrations are present.

b. Bedrock conductivities in areas underlying the basin fill aquifer are likely to be even lower than as shown in Table A.4 due to the larger lithostatic pressures resulting from greater depths. Fractured rock at depths of 1000 feet may have conductivities that are two to three orders of magnitude lower than those for more shallow zones typical of the data shown in Table A.4. The reduction in conductivity is primarily due to closing of the fracture apertures. For this reason, bedrock underlying the basin fill aquifer is even less likely to be a significant source of or conduit for sulfate regardless of the bedrock lithology.

c. ADEQ is incorrect in assuming that well MH-25D is screened entirely in the bedrock. The sulfate concentration in MH-25D is likely not representative of bedrock because the well is screened within bedrock it is probably not sealed within bedrock. Well construction and lithologic logs for the well show that the bentonite seal starts exactly at the top of the bedrock surface. Therefore, during purging, the well likely takes in significant water from the overlying basin fill. Because the well may not be properly sealed within the bedrock, the water quality data from the well do not necessarily indicate elevated sulfate concentrations in the bedrock.

Overall, because of the large contrast between basin fill and bedrock hydraulic conductivities, and the reduction in bedrock conductivities with depth due to lithostatic pressure, the bedrock underlying the basin fill aquifer is unlikely to be a significant source of sulfate to the basin fill even if elevated concentrations are present. This is consistent with ADEQ's assessment of potential sulfate sources from shallow bedrock to the basin fill discussed in comment 12, which states

"Hence, the sulfate mass flux from the bedrock to the basin fill would be minimal." Therefore, Sierrita does not believe that additional characterization of the hydraulic properties or sulfate distribution in the bedrock is needed to support the identification and evaluation of potential mitigation actions.

3. Section 2.2.2: Task 2.2 – Groundwater Monitoring

   A comparison of the lateral extent of the sulfate plume in October 2007 and April 2006 shows that the plume has expanded in the southeastern margin based on data from Wells MO 2007-5B and 5C. This plume migration may threaten newly-installed drinking water wells CW-10, GV-1 and GV-2. ADEQ has concerns as to whether the plume's southern boundary west of well GV-1 has been well defined. ADEQ suggests sampling existing wells or installation of a new monitoring well to serve as a "sentinel well" for the drinking water wells in this area, especially CW-10. A well in this general location was originally proposed in the Work Plan, but was moved approximately 3000 feet to the southwest.

   Another location where ADEQ recommends that Freeport perform additional monitoring is midway between the MO-2007-4 and MO-2007-5 series of monitoring wells, because of the need to better define the boundary and monitor the migration of the plume along this edge of the plume.

SIERRITA RESPONSE:

ADEQ is incorrect in stating that the plume expanded between April 2006 and October 2007. The difference between the April 2006 and October 2007 sulfate maps is that the October 2007 plume map shows data available from newly installed wells MO-2007-5A and MO-2007-5B, which did not exist in April 2006. This difference was discussed at the October 9, 2007 CAG meeting and in the quarterly groundwater monitoring reports for the third and fourth quarters of 2007. Thus, ADEQ is incorrect when it states in Specific Comment 1 that there is "evidence of an aggressive subsurface plume migration." Instead, the sulfate detected at MO-2007-5A and MO-2007-5B was likely present in April 2006 but unknown until the new monitor wells were installed. The change in sulfate plume configuration from April 2006 to October 2007 is a result of incorporating data from newly constructed monitor wells and not necessarily from plume migration. The plume may, in fact, be retreating in this area (See response to Specific Comment 20 b.)

Groundwater elevation maps (Figures 5 and B.2) indicate that the groundwater flow direction is north to northeasterly in the vicinity of wells CW-10, GV-1 and GV-2. Figure 4 shows that sulfate concentrations are less than 100 mg/L at MO-2006-6A and MO-2006-6B, located between the source and GV-1 and GV-2

indicating that the bounding edge of the plume is west of the MO-2007-6 wells and flowing northeasterly rather than toward GV-1 and GV-2. With respect to the east boundary of the plume in the vicinity of CW-3 and the MO-2007-5 wells, Sierrita agrees that plume boundary is between those wells and CW-10. However, the groundwater flow direction indicated by groundwater levels is northeasterly from the MO-2007-5 wells rather than toward CW-10. However, as discussed in the cover letter to these comments, Sierrita agrees that this potential migration pathway should be monitored by installation and sampling of an additional well between MO-2007-5 and CW-10. Tracking the location of the plume over time is the objective of quarterly groundwater monitoring implemented for Task 2.2 of the Aquifer Characterization Plan.

Deviation from the Work Plan regarding the proposed location of Site 6 (MO-2007-6A and B) was necessary because several months of access negotiations with land owners at the original proposed location were unsuccessful. As stated in Section 3.3.4 of the Work Plan, "The exact locations of the proposed wells are provisional subject to successful negotiation of site access". As it turned out, Sierrita assumed additional risk by locating these wells closer to the source. MO-2007-6A and -6B are on or east of edge of the sulfate plume and between the source and GV-1 and GV-2. Thus, MO-2007-6A and -6B are able to provide an indication of potential impact should the plume move eastward toward GV-1 and GV-2. Sierrita believes that the ultimate location of MO-2007-6A and -6B is in the best interests of all parties and is a very beneficial deviation from the Work Plan necessitated by site access considerations.

Sierrita respectfully disagrees that another well is needed between MO-2007-4 and MO-2007-5 because the sulfate plume edge is constrained by the MO-2007-4 wells.

4. Section 2.2.2.2 Sulfate Distribution

   Freeport states in the last sentence of the first paragraph "*The contours on Figures 1 and 4 were developed using the highest measured sulfate concentrations at co-located wells*," but the report does not provide a rationale as to why the highest concentration of sulfate was used. ADEQ believes it would be more informative to contour the sulfate data per potential hydrostratigraphic units. Freeport also should discuss the vertical distribution of sulfate within the basin fill aquifer, and include cross-sections that post and contour the sulfate data (See Attachments).

SIERRITA RESPONSE:

When more than one concentration was available for samples from co-located wells, the maximum sulfate concentration was used for preparing concentration

contour maps. This is appropriate because (1) the majority of the sulfate concentration data are for wells that are screened over large sections of aquifer and do not provide depth specific data and (2) the extent of the sulfate plume is conservatively estimated. The estimation of plume extent is conservative in that the use of the maximum concentration at co-located wells yields the largest potential extent of the plume. The assumption of the highest concentration as the basis for contouring is stated in Section 2.2.2.2 of the ACR.

The vertical distribution of sulfate is discussed in Sections 2.2.3, 2.2.4, and 3.2.2; and depicted in Figure 4 and Figures H.2 through H.10 (cross sections that post sulfate concentrations). Cross sections shown on Figures H.2 through H.10 depict measurements of sulfate as a function of depth where co-located wells exist. The cross sections were not contoured to avoid an overly subjective interpretation of the data and because wells with long screened intervals provide data at a different scale and across different hydrostratigraphic units than do co-located wells.

The contours provided by ADEQ in its "Attachments" are only generally constrained by existing data. Attempts made during the compilation of the ACR to formulate vertical profiles of concentration with depth were omitted from the report because of their subjectivity and because they did not provide unique information that could not be obtained from Figure 4 and Figures H.2 through H.10. Nests of wells installed as described in Appendix D are adequate to monitor the encroachment of the plume in any specific depth interval near the margins of the plume.

5. Section 2.2.2.3 Groundwater Elevation

   Freeport should describe the ranges of groundwater elevations for the sampling events, a discussion of changes of groundwater elevation over time, especially from wells that have been monitored prior to the mitigation order, and a discussion of horizontal and vertical hydraulic gradients. The ACR should also include cross-sections that include groundwater elevation contours.

SIERRITA RESPONSE:

The ranges of measured groundwater elevation are depicted on groundwater elevation maps for January and February 2007 (Figure B.2) and July through October 2007 (Figure 5). Figures B.2 and 5 also depict groundwater elevation at different depths at co-located wells. Data on water elevation over time in the vicinity of the plume are presented in Appendix 1.2 which includes time series water level data at 12 wells. Differences in groundwater elevation vertically at co-located wells are discussed in Section 2.2.4.3. Sierrita believes the water

elevation map is the best means of describing hydraulic gradients because hydraulic gradients vary in direction and magnitude as a function of location. Sierrita respectfully disagrees with the request for cross sections showing groundwater elevation contours. Cross sections showing groundwater elevation contours cannot be constructed because most of the existing wells are screened over long sections of the aquifer and provide no vertical information beyond the water table surface plotted on Figures H.2 through H.10 or the water levels depicted on Figures 5 and B.2.

6. Section 2.2.3 <u>Task 2.3 Depth-Specific Sampling</u>

   a. ADEQ agrees that a vertical zonation of sulfate probably exists in the middle aquifer in association with a high permeability zone, although there are still some data gaps. The observation in the report about vertical uniformity in sulfate concentrations in wells MH-11 and MH-12 may be best attributed to the limited penetration of these wells as shown in the hydrogeologic cross sections.

SIERRITA RESPONSE:

ADEQ is incorrect. The cited wells are fully penetrating, as shown in cross-section B-B'.

   b. Freeport should include a description of how depth-specific groundwater samples were collected from long-screened groundwater monitoring wells MW-11 and MW-12, and provide a description of depth-specific sampling and flow velocity profiling that conducted at ESP-2 and ESP-4.

SIERRITA RESPONSE:

Description of the methods used to collect depth-specific groundwater samples and flow velocity profiling are provided in Section 2 of Appendix C. An entire appendix to the ACR is devoted to this topic. Section 2.2.3 provides a summary discussion.

   c. The last bullet on page 15 states "*Sulfate concentrations in samples from MH-11 (screened from 300 to 800 feet below ground surface (ft bgs) and sampled from 450 to 750 ft bgs) and MH-12 (screened from 280 to 800 ft bgs and sampled from 470 to 700 ft bgs) are consistent from top to bottom of the intervals samples*. Freeport should provide depth to water measurements from MH-11 and MH-12 during depth specific sampling, and explain why depth specific samples were not collected at the water table**.**

SIERRITA RESPONSE:

Depth to water is approximately 370 feet in MH-11 and 420 feet in MH-12. The sampling technique requires at least 50 feet of submergence to acquire a usable sample. There is no particular relevance of depth-specific samples collected at the water table to evaluation of sulfate zonation with depth in the basin fill aquifer.

d. The last sentence in Section 2.2.3 states "*The uniformity and continuity of the high permeability zones is uncertain given the large distances between wells*." Freeport should provide a discussion on whether that is a data gap that should be addressed with additional investigation or at least considered in evaluating mitigation options. If these high permeability zones are continuous, the lateral extent of the sulfate plume may be much further down-gradient than currently determined. This scenario would place down-gradient production wells at risk of impact by the sulfate plume, as sulfate concentrations would rapidly increase with little lead time to implement the chosen mitigation action.

SIERRITA RESPONSE:

The zones of increased permeability observed in depth specific sampling ranged from about 50 to 150 feet thick in a portion of the basin fill aquifer with saturated thicknesses between 500 and 600 feet. The difference in permeability could not be quantified and is only known relative to materials above and below the intervals. Both depth specific sampling and observations of geology during drilling were unable to project features laterally due to lack of well defined layering the basin fill as demonstrated by the inability to define anything more than highly generalized hydrostratigraphic units in the basin fill. It is unlikely that a continuous preferential pathway exists in the basin fill because of the relative uniformity observed in material type and the limited range of hydraulic properties. Also, the results of hydraulic testing and water quality sampling at multiple completion wells at the MO-2007-3 and MO-2007-4 sites in the proximity of ESP-2 and ESP-4 did not suggest the presence of a preferential pathway (see Figure H.8b of the ACR). Given these conditions, the downgradient extent of the plume is established by wells NP-2, MO-2007-3B, MO-2007-3C, MO-2007-1A, MO-2007-1B, and MO-2007-1C which monitor large portions of the basin fill aquifer. Ongoing groundwater monitoring at these wells for Task 2.2 is the best means of detecting the movement of the plume in the vicinity of drinking water supply wells. Sierrita recognizes that there are natural variations in hydraulic conductivity vertically and laterally within the basin fill. The observations at ESP-2 and ESP4 are not surprising but are important to keep in mind during mitigation planning. The observations at ESP-2 and ESP4 are not considered to be a data gap that requires

attention at this time because multi-level groundwater monitoring wells are in place to monitor the plume front.

e. It appears from the report that most of the evaluation of the depth specific data was focused on the middle and northern half of the impacted area around MH 11, MH 12 and ESP 2 & 4. In the southeastern part of the plume, the data obtained from nested wells MH-13A, B and C were not discussed in the same detail particularly to determine if there is any correlation with data obtained along the eastern edge of the plume in nested wells MO-007-5A, 5B & 5C.

SIERRITA RESPONSE:

As stated in the Work Plan, depth-specific sampling in the ESP-series wells, CW-7, MH-11, and MH-12 was conducted because the depth-specific information were not available for those wells as compared to the depth-specific information available from well nests such as those at MH-13 and subsequently installed at MO-2007-5. Section 2.2.4.3 describes the depth-specific sampling results at the MO-series wells. Section 3.2.1, in conjunction with cross sections in Appendices G and H, provides an analysis of general correlations between geologic, hydraulic conductivity, and water quality data based on data from existing wells, newly installed wells, groundwater monitoring, depth specific sampling, and hydraulic testing. Section 3.2.1 of the ACR will be modified to include additional discussion of the vertical zoning of sulfate as determined from depth-specific samples.

7. Section 2.2.4.1 Well Drilling and Installation:

   a. The first sentence of the second Paragraph under Appendix D, Section 2.3 states, "*Deminimus General Permits were obtained for the release of development water into nearby washes for each with the exception of MO-2007-4C, where water was stored in a 20,000-gallon tank and later hauled away for disposal*." Freeport should provide an explanation as to why development water from this particular well was hauled away for disposal.

SIERRITA RESPONSE:

Development water from MO-2007-4C was hauled away because there was no nearby wash to which the water could be discharged.

   b. Freeport should provide the rationale for the location and screen intervals selected for the MO-2007-series monitoring wells that were installed.

SIERRITA RESPONSE:

The rationale for the location of each screened interval is provided in Section 3 of Appendix D, pages D-11 to D-27.

c. Well MO-2007-6 was supposed to serve as a sentinel well to drinking water wells GV-1 and GV-2 along the southeastern edge of the plume. Instead, it was installed several thousand feet to the southwest. Freeport should explain why this well was constructed at a different location from that in the Work Plan, potentially creating a gap in the monitoring of the southeast edge of the sulfate plume. A replacement monitoring point or new well may be necessary.

SIERRITA RESPONSE:

MO-2007-6A and -6B were installed at their present location because property owners in the proposed location would not provide access, requiring relocation of these wells. Deviation from the Work Plan regarding the proposed location of Site 6 (MO-2007-6A and B) was necessary because several months of access negotiations to install wells at the original proposed location were unsuccessful. As stated in Section 3.3.4 of the Work Plan, "The exact locations of the proposed wells are provisional subject to successful negotiation of site access". As it turned out, Sierrita assumed additional risk by locating these wells closer to the source. MO-2007-6A and -6B are on or east of edge of the sulfate plume and between the source and GV-1 and GV-2. Thus, MO-2007-6A and -6B are able to provide an indication of potential impact should the plume move eastward toward GV-1 and GV-2. Sierrita believes that the alternate location of MO-2007-6A and -6B is in the best interests of all parties. The alternate location demonstrates that the plume edge is further west of GV-1 and GV-2 than originally expected. Given the results for this well and the northerly to northeasterly groundwater flow direction between the plume and the GV wells, Sierrita does not believe there is a need for another well in this area.

8. Section 2.2.4.3 <u>Initial Sampling of MO-2007 Wells</u>

a. In the second paragraph of this section, Freeport states that the water quality data for the newly-installed nested monitoring wells "*indicate that sulfate concentrations tend to be higher in the lowermost screened intervals than in screened intervals at more shallow depths,*" and further hypothesizes in this same paragraph, "*A possible explanation for the observed distribution of sulfate is that the naturally occurring background sulfate concentration is higher in the lower basin fill, possibly due to the presence of hydrothermal alteration in the underlying bedrock as observed in MO-2007-2 and MO-2007-3*." While sulfate concentrations do increase closer to the bedrock, Freeport has not provided any data to support that the source of the increase is bedrock. However, in Section 3.1, "*Sulfate Sources*," the second sentence of the second paragraph on Page 28 reads, "*However, the contribution of sulfate by bedrock recharge is likely very minor compared to the tailing seepage because the low permeability of bedrock would limit the sulfate mass flux from the upgradient area*." This is a clear contradiction of the earlier stated hypothesis. The report should clarify which hypothesis is correct. Furthermore, considering the fact that the underlying bedrock is indurated arkosic sandstone, if hydrothermal alteration occurred, one would expect some connection with igneous/volcanic activity. However, in Well MO-2007-6C where the basin fill overlies bedrock of felsic volcanics where hydrothermal alteration is more likely, the sulfate concentration is relatively low.

At paragraph 3 of this section where Freeport discusses water level measurements at co-located MO-2007 wells, the last sentence reads, "*A possible explanation for the large vertical downward hydraulic gradients at sites MO-2007-5 and MO-2007-6 may be groundwater pumping at nearby wells*." This explanation raises some questions considering the distance between these wells and the pumping water supply wells. Nevertheless, a probable implication of the strong vertical hydraulic gradients at these wells is the likelihood that they may promote the vertical migration of sulfate-rich water into fractured underlying bedrock or indurated lower basin fill. This may partly explain the elevated sulfate in sedimentary bedrock.

SIERRITA RESPONSE:

The "higher" concentrations in the lowermost zones described in Section 2.2.4.3 are in the range 18 mg/L to 136 mg/L and can be classified as "elevated" with respect to the concentrations from samples obtained higher in the aquifer. The data to support a potential source in the bedrock or lower basin fill is presented on pages D-15 and D-18 where hydrothermal alteration is reported in the form of oxidized pyrite, which can result in elevated sulfate concentrations. There is no contradiction between the presence of elevated sulfate from oxidizing pyrite and the conclusion that seepage from the bedrock is not a significant source of mass flux to the basin fill as a contributor to the 250 mg/L sulfate plume. The arkosic bedrock was present during the copper mineralizing event and hosts documented hydrothermal alteration, whereas the volcanic rocks in question are post-mineral and not known to exhibit hydrothermal alteration of the type that would produce elevated sulfate concentrations.

With regard to downward vertical hydraulic gradients, large production water supply wells completed deep within the basin fill could induce downward

hydraulic gradients within the basin fill especially if fine-grained, semi-confining layers are present. However, because production wells are completed within the basin fill and not the low permeability bedrock, any vertical hydraulic gradients induced within the bedrock by pumping would likely be upward, toward the shallower source of the pumping. Therefore, downward migration of sulfate into the bedrock as a result of basin fill pumping is highly unlikely.

A possible explanation for the high sulfate concentrations within the lower basin fill aquifer may be that sulfate has been transported through fractures in bedrock due to mass loading from mining operations and/or mass loading into bedrock and deep basin fill from the PDSTI, which is contributing to elevated concentrations at lower depths. (See Attachment, Modified Cross-Section B-B'). In order to fully address this issue, ADEQ recommends further vertical characterization involving the installation of monitor wells screened exclusively in bedrock.

SIERRITA RESPONSE:

See cover letter discussion on bedrock permeability and response to Specific Comment 2.

b. In the first sentence of the third paragraph of this section, Freeport states, "*The sulfate concentration data from initial water sampling at the MO-2007 wells better define the eastern and northern limits of the sulfate plume and provide monitoring facilities capable of depth-specific sampling in areas between the sulfate plume and drinking water supply wells*." The sulfate data does not support this statement. Based upon data presented from MO-2007-2 and M-20, sulfate concentrations at these northern monitoring wells are 591 mg/L and 1400 mg/L, respectively. Therefore, there may be additional sources of sulfate other than just the PDSTI. If Freeport intends to determine the full lateral extent of sulfate contamination in the northern portion of the plume, ADEQ recommends installation of additional groundwater monitoring wells.

SIERRITA RESPONSE:

Sulfate data from the MO-2007-1 wells in conjunction with data from wells TMM-1, M-8, M-9, and M-10 constrain the northern limit of the plume in the vicinity of the Twin Buttes property. Data from MO-2007-2 and the I-series wells indicate that the plume extends west to the edge of the basin fill aquifer.

11. Section 2.3 Task 3- Evaluation of PDSI Groundwater Control System

In this section Freeport provides a brief discussion on the effectiveness of the interceptor well field focusing on the previously identified challenges of the northern portion of the wellfield. However, based upon sulfate concentration data, it is clear that the wellfield has not contained sulfate contamination in the central and south-central portions. In evaluating locations for a second well field to contain the sulfate plume, this information should be provided in the report. Additionally, when evaluating capture in the future, Freeport should use the following guidance:

a. A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report, 2008 (EPA/600/R-08/003);
b. Methods for Monitoring Pump-and-Treat Performance, 1994 (EPA/600/R-94/123); and,
c. Elements for Effective Management of Operating Pump and Treat Systems, 2002 (EPA/542-R-0-2-009).

SIERRITA RESPONSE:

Sierrita believes that evaluation of a second wellfield to contain the sulfate plume is outside the scope of the ACR. As is stated in the Work Plan, the evaluation of mitigation alternatives, such as a second wellfield, is part of the FS. This is consistent with ADEQ's comments on the Focused Feasibility Study which indicated that the evaluation of the second wellfield should be part of the overall Feasibility Study. The guidance identified by ADEQ will be considered during the Feasibility Study.

12. Section 3 Conceptual Model For The Groundwater Sulfate Plume

a. ADEQ finds the three hydrostratigraphic units identified by Freeport in the geologic logs to be reasonable. They can be used as a three layer working model for the sulfate transport modeling. The major sources of sulfate were sufficiently identified. However, it appears that undue prominence may have been given to upgradient bedrock as a potential source of sulfate for the plume. Freeport should state that the bedrock upgradient of the PDSTI is composed of low permeability indurated or crystalline rocks that are not likely to contribute much sulfate to the plume although the concentrations of sulfate in groundwater from the two piezometers in upgradient bedrock (360 - 450 ppm) are relatively high. This should be attributed to the fact that the igneous bedrock is most probably mineralized with sulfides, and the elevated levels may not be typical of groundwater sulfate in regional bedrock, comprised mostly of arkosic sandstones. Hence, the sulfate mass flux from the bedrock to basin fill would be minimal.

SIERRITA RESPONSE:

Sierrita agrees with ADEQ's conclusion that sulfate mass flux from the bedrock to the basin fill is minimal. However, there was no particular "prominence" ascribed to bedrock as a sulfate source upgradient of the plume. Section 3.1 which discusses the data for upgradient bedrock wells states "the contribution of sulfate by bedrock recharge is likely very minor compared to the tailing seepage because the low permeability of bedrock would limit the sulfate mass flux from the upgradient area".

b. This section Freeport should discuss potential receptors and include a "cartoon" block diagram.

SIERRITA RESPONSE:

Section 3.2.3 will be modified to address this comment. Drinking water supply wells east and north of the Sierrita Tailing Impoundment will be identified as the potential receptors of sulfate-impacted groundwater. A schematic cross section showing the source, migration pathway, and potential receptors will be added to Section 3.

13. Section 4 <u>Numerical Model of Groundwater Flow and Transport</u>

Though ADEQ agrees that some correlation exists between simulated goundwater elevation contours and measured values, ADEQ has serious reservations about the ability of the model to simulate sulfate concentrations. The boundary conditions are not well defined. There appears to be problems with the calibration of the model due to parameters that are not well understood and/or for which there are data gaps. A comparison of the simulated and measured sulfate in specific wells shows mismatches. If Freeport intends to use this sulfate transport model in evaluating the impact of mitigation actions, a more rigorous evaluation of the sources of the mismatches should be undertaken at various scales, including regional, local and specific wells.

SIERRITA RESPONSE:

ADEQ's reservations seem to be three-fold: (1) boundary conditions are that not well defined, (2) problems with calibration of parameters that are not well understood, (3) mismatches between simulated and measured sulfate concentrations at some wells. The model boundary conditions are described in Section 3.3 of Appendix I. Two main types of boundary conditions were used: no-flow and specified head. No flow boundary conditions were specified along the mountain fronts where the basin fill aquifer pinches out against the rising

mountain ranges. These boundaries reflect a natural feature of the basin hydrogeology (see response to comment 16b). The other type of boundary condition, specified head, is used in areas where no natural boundary may exist but where needed to limit the size of the model domain for practical reasons. For example, the southern specified head boundary of the model coincided approximately with the southern specified head boundary in the previously calibrated and published ADWR model and was placed there for the same reasons in both models.

As explained in Section 3.3.2 of Appendix I, care was taken to locate and specify the heads at the specified head boundaries so as to minimize any potential discontinuities between the model domain and the regional hydrogeologic system. This included starting the model calibration using heads from the previously calibrated ADWR model at locations and/or times were there were no measured data and extrapolating measured hydraulic gradients to the model boundaries. Furthermore, the model domain was much larger than the primary area of interest (the area surrounding the sulfate plume) in order to minimize any potential effects of imposed boundary conditions. These approaches to determining the model domain and boundary conditions are common to most groundwater flow and transport models (for example the ADWR model) and are not unique to the PDSIRM.

ADEQ's concerns about the calibration of parameters that are not well understood are ambiguous. Is ADEQ concerned about the calibration methodology or the final value of the calibrated parameter(s)? What parameter(s) in particular is ADEQ concerned with? Uncertainties in flow and transport model parameters can never be completely resolved. For example, estimates of mountain front recharge and evapotranspiration vary significantly depending on the investigator. There are also uncertainties with the estimation of the PDSI seepage rates and concentrations. Simulated sulfate plume concentrations are particularly sensitive to these parameters (see Table I.3). Uncertainties with these parameters exist because they can neither be measured directly, nor can variations in their temporal and spatial distributions be fully ascertained. However, the parameter values used in the PDSIRM are based on sound rationale. For example, seepage concentrations are based on the average sulfate concentration measured in water samples from the reclaim pond. While there may be justification for using a higher or lower value, values lower than those used in the model weaken the model calibration, and values higher than those used are not justified because they approach or exceed the probable solubility limit for sulfate under site conditions. When calibrating the model, the initial seepage rates were based on an independent estimation of tailing seepage as reported in ELMA (2007b). Rates were then adjusted upwards to improve model calibration. It is possible that the need to increase the seepage rates above the estimates of ELMA (2007b) during calibration was due to a data gap in the

PDSIRM or in the ELMA (2007b) seepage model; however, such a data gap – and how it would be revealed – is not apparent. Furthermore, the problem of parameter uncertainty is not unique to the PDSIRM, but is common to groundwater flow models, which are all simplifications of real systems. The PDSIRM represents a large spatial and temporal extent with multiple groundwater and sulfate sources and sinks in a heterogeneous alluvial aquifer. In spite of these complications, the model provides a satisfactory constraint on uncertainty to give a reasonable representation of the hydrologic system

ADEQ's final reservation regards mismatches between simulated and measured concentrations at specific wells. There are always discrepancies between measured and simulated water levels and solute concentrations in flow and transport models. For example, differences between simulated and measured water levels in the ADWR model are of similar magnitude to those in the PDSIRM. Discrepancies are related not only to model predictions but to errors in groundwater level and solute concentration measurements. Due to the large scale and complexity of the PDSIRM, and the inherent uncertainties common to all flow and transport models, it is not possible to precisely match every measurement at every well at every time, even if all error in the measured data could somehow be eliminated. The goal of the PDSIRM is to adequately represent the average behavior of the hydrogeologic system and to acceptably minimize discrepancies. Consistent with this goal, the PDSIRM has the ability to represent important aspects of the sulfate plume at regional and local scales and at individual wells. For example, at the regional scale, the general shape of the plume, including the broad base near the tailing impoundment and the thinner leading edge, is adequately represented. Furthermore, at more local scales, the model adequately represents the plume's arrival and the rapid rise in sulfate concentrations at "sentinel" wells along the northeastern edge of the plume (i.e., ESP-4 and CW-7). Discrepancies that exist along the northern edge of the plume are generally consistent with a more conservative representation of the plume than measurements would indicate (the simulated plume extends farther downgradient). Likewise, time series plots for specific wells (Appendix I.3) show simulated chemographs that, in most cases, capture the general trends of sulfate measurements or are more conservative (overpredict) measured concentrations. ADEQ's concern about the mismatch in the southeastern "bulge" is addressed in the response to comment 20b. In general, the discrepancies between measured and simulated concentrations are on the conservative side and will provide a safety factor when using the model to simulate potential mitigation actions.

14. Appendix I, Section 3.1 <u>Spatial and Temporal Extents</u>

    In this section Freeport provides the areal extent of the active portion of the PDSI Regional-Scale Model (PDSIRM) to be approximately 100 square miles (260 square kilometers), and states the "*active model region extends from just above*

West Arivaca Road on the south (Universal Transverse Mercator [UTM] 3510500) to just below Pima Mine Road on the north (UTM 3540000). From the PDSTI this region extends east about 8.5 miles (13.5 km).” However, Freeport does not provide similar areal information for the area of primary emphasis for the PDSIRM, only stating, “*the area of primary emphasis for the PDSIRM is the area in the vicinity of PDSTI, including the areas surrounding tangle the current extent of the sulfate plume. This area of primary interest is depicted as the rectangle within the lateral model boundaries shown in Figure b1.2*.” Freeport should provide areal information for the area of primary emphasis and state whether the lateral boundaries of the rectangle correspond to the 250 mg/l sulfate contour east of the interceptor well field.

SIERRITA RESPONSE:

The statement that the area of primary emphasis “include[es] the areas surrounding the current extent of the sulfate plume” means that the area of primary emphasis circumscribes the 250 mg/L contour because this is how the extent of the sulfate plume is defined (Section 1 of Appendix I). Furthermore, the rectangle in Figure I.2 clearly illustrates the spatial location and extent of the area of primary emphasis. The rectangle extends east of I-19, which is well outside of the current 250 mg/L sulfate contour. Appendix I text will be revised to state that the area of primary emphasis extents from approximately UTM 3519700 on the south to approximately UTM 3531900 on the north and from the no flow boundary on the west to approximately UTM 503700 on the east. Figure I.2 will also be revised to show the 250 mg/L contour.

15. Appendix I, Section 3.2 <u>Discretization</u>

In this section Freeport explains that the PDSIRM was discretized into three layers to represent the upper, middle, and lower zones of the basin fill aquifer. ADEQ concurs with this delineation. However, having stated that the PDSIRM is divided into 25 rows and 162 columns, Freeport did not provide a rational for this discretization. This information should be included in this section.

SIERRITA RESPONSE:

We are pleased that ADEQ concurs with the vertical discretization. Regarding the horizontal discretization, ADEQ is mistaken regarding the number of rows. The text states that the model domain was divided into 215 (not 25) rows and 162 columns. Regarding the horizontal discretization, the total number of number of rows and columns is not as important as the distance between rows and columns which defines the grid spacing. Section 3.2 of Appendix I states, “Grid cell widths and lengths range from 100 meters [m] to 400 m. The coarsest grid cell spacing occurs in the southern, northern, and eastern positions of the model

domain, peripheral to the area of emphasis (which, as discussed above, encompasses the entire area of the sulfate plume including a generous margin). The finest grid cell spacing (100 m) is centered in the area of emphasis surrounding the PDSTI (Figure I.2)." (Note: the reference to Figure I.2 will be changed to Figure I.3.). The rationale for the discretization was based on a balance between computational requirements and accuracy. The following statement can be added to the text: "Larger grid cell spacings decrease model computational requirements, but at the expense of accuracy and resolution. By placing the largest grid cells in the periphery of the model domain and decreasing the grid cell spacing within the area of emphasis, model computational requirements could be reduced without compromising spatial resolution within the area of emphasis. The 100 m by 100 m spacing within the area of emphasis provides for sufficient model accuracy and resolution in this area without dramatically increasing the computational burden." By comparison, the grid cell spacing in the ADWR model was 0.5 mile, or approximately 805 m. Therefore the area of the ADWR grid cells was approximately 64 times as large as the cell areas specified within the area of emphasis in the PDSIRM.

16. Appendix I, Section 3.3.1 No Flow Boundaries

    a. Freeport should provide a discussion as to why no flow conditions in the PDSIRM are assigned along the model boundary at locations that represent the outer edges of the basin fill aquifer, Figure 1.4, corresponding to the Sierrita Mountains to the west and the Santa Rita Mountains to the southeast. At Table I, "*Initial and Calibrated Model Parameters, Final Value or Range*" Freeport provides flow values of 7,700 acre feet/year for Western Mountain Front Recharge, and 2,600 acre feet /year for Southeastern Mountain Front Recharge, respectively.

SIERRITA RESPONSE:

No flow boundaries were specified where the basin fill aquifer pinches out against the bedrock. Mountain front recharge, a well known source of recharge to aquifers was assigned to the basin fill aquifer immediately inside the no-flow boundaries, consistent with common modeling practice. For example, a similar methodology was employed in the ADWR model and other models of the PDSTI vicinity (Travers and Mock, 1984; Hansen and Benedict, 1994; ELMA 1994, 2007a). This practice allows all mountain front recharge to enter the aquifer and prevents groundwater and sulfate from entering or exiting the aquifer boundary.

    b. In the final paragraph of this section Freeport states, "*For the purpose of model stability, the total thickness of each layer of the PDSIRM was kept to a minimum of 30 meters (98 feet)*." Freeport should state whether these thicknesses correspond to the measured thickness of the respective basin fill layers, and if not, discuss their impact on the data generated by the PDSIRM.

SIERRITA RESPONSE:

The minimum layer thickness of 30 meters was necessary to prevent model instability. These types of adjustments are often necessary when working with flow and transport codes such as MODFLOW. As stated in Section 3.3.1, "This stipulation required depressing the estimated bedrock elevation along portions on the model boundaries". This statement could be embellished by adding that "depressing bedrock elevations was required only along the portions of the model boundaries where the basin fill aquifer pinched out against the rise of the mountain fronts". The one area that this stipulation may have had important consequences is along the interceptor wellfield; however, as stated in Section 3.3.1, "it did not affect the estimated bedrock elevations under the IW wellfield." In other areas where the bedrock was lowered, a thicker-than-actual aquifer representation was likely compensated by adjustments to the hydraulic conductivity made during model calibration. Further, because the minimum 30 meter stipulation only affected portions of the outer model domain where flow was minimal, it likely had little effect on flow and transport domain. Still, because a simulation could not be successfully conducted without the stipulation, a rigorous evaluation of the effect of the stipulation cannot be made.

17. Appendix I, Section 3.4.2 <u>River and Agricultural Recharge</u>

In the final paragraph of this section Freeport states, "The ADWR model runs only through 1999. The value of river and agricultural recharge in the PDSIRM after 1999 was set at about 15,400 ac-ft/yr, which is near the recharge volumes in the mid 1990's." Based on Figure 1.7, ADEQ believes the amount of Agricultural Recharge should be determined over a wider time period and recommends at least a value of 18,500 ac-ft/yr.

SIERRITA RESPONSE:

An important distinction made in Section 3.4.2 is that river and agricultural recharge are specified as a lumped parameter. While it may be a reasonable assumption that river recharge by itself is ergodic – thus justifying the use of a longer-term average – agricultural recharge has decreased over time. Figure I.7 shows a decrease in the river + agricultural recharge with time until about 1990. Thus using the river + agricultural recharge values from the 1990's to approximate the river + agricultural recharge from 2000 to 2006 is more appropriate than using a longer-term average, which would likely overestimate recharge.

18. Appendix I, Section 3.4.3.1 Phelps Dodge Sierrita Tailing Impoundment

Freeport states that the "total estimated seepage volume through 2006 is 252,406 ac-ft." ADEQ questions this quantity, because it apparently neither takes into account the 38,294 ac-ft of seepage from the Esperanza Tailing Impoundment shown in Table I, nor includes the estimated seepage value from the Twin Buttes Mine.

SIERRITA RESPONSE:

As implied by the title of this section, the stated seepage value refers to the Sierrita Tailing Impoundment only. The sentence will be made more precise by stating the "total seepage volume through the Sierrita Tailing Impoundment is estimated to be 252,406 ac-ft at the end of 2006." Table I.2 shows clearly that the volume of 252,406 ac-ft refers only to the Sierrita Tailing Impoundment.

19. Appendix I, Section 3.4.5 Pumping

The first sentence in this section states, "*Groundwater withdrawal by pumping is the major groundwater sink in the PDSTI region*." Freeport then acknowledges that few pumping records are available for the period 1940 through at least 1979, and the available pumping estimates are of questionable accuracy. Freeport should provide a discussion on how this may affect data generated by the PDSIRM.

SIERRITA RESPONSE:

The uncertainty in the pumping rates was discussed in the text to enhance an accurate understanding of the strengths and limitations of the model. ADWR began tracking and recording groundwater withdrawals in the Active Management Areas (AMAs) in 1984. Thus, any model within an AMA that includes years prior to 1984 will have uncertainties in pumping rates. The ADWR model includes what are probably the best regional-scale estimates of pumping prior to 1984, and these estimates are used in the PDSIRM. It is unlikely that the uncertainties in these early pumping rate estimates will significantly affect model results at the present time. It would be possible to test the effects of uncertainties in the pre-1984 pumping by conducting a sensitivity analysis on pumping rates for this period. However, doing so would reduce these early pumping rate estimates to an additional calibration parameter. This is undesirable because of the additional non-uniqueness that would be added to the model calibration. Furthermore, while the degree of uncertainty in the early-time pumping rates is not known, they are likely more certain than hydrologic parameters, particularly outside the area of aquifer characterization. Unless

ADEQ has a more reliable method for estimating these early pumping rates, using the ADWR estimates is considered appropriate for the PDSIRM.

20. Appendix I, Section 4.3.2 Sulfate Concentration calibration

   a. In this section Freeport discusses Chemographs based on the average simulated sulfate concentrations over the upper two layers of the model and "*measured sulfate concentrations at several key locations.*" Freeport should define "*key locations,*" and prepare Chemographs based on simulated sulfate concentrations at each individual layer of the model and measured sulfate concentrations at corresponding layers in the basin fill aquifer. This approach should provide a more rigorous test of the model's capabilities.

SIERRITA RESPONSE:

Key locations include wells near the edge and within the interior of the plume where a time series of sulfate concentrations data are available and/or where significant changes in sulfate concentrations have occurred. For example, chemographs for wells ESP-4 and CW-7 represent the northeast edge of the plume and are locations that experienced an unexpected and rapid rise in sulfate concentrations; chemographs for wells I-12 and M-20 are indicative of the calibration at the northern edge of the plume; and chemographs for wells MH-11, MH-12, and MH-13 are representative of the model's ability to simulate the plume interior.

We disagree that comparing simulated and measured chemographs on a layer-by-layer basis would provide a more rigorous test of the model's capabilities. Measured chemographs are based on water quality samples that are taken from wells that are typically screened over multiple layers and, therefore, represent flow- and screen- weighted averages. Consequently, using layer averages better approximates the measured values used in the chemographs. The exceptions to this would be nested wells; however, because the nested wells have only been recently installed (many as part of the Aquifer Characterization Plan), measured data are insufficient from these wells to construct a chemograph.

   b. In the third paragraph Freeport states, "*The model simulation suggests that the high sulfate concentrations measured in MO-2007-5 may represent residual concentrations from a retreating plume rather than an advancing plume.*" Freeport should describe how this was determined. The measured data does not show this phenomenon. Freeport should discuss this discrepancy.

SIERRITA RESPONSE:

The hypothesis of the retreating plume is based on: (1) historic measurements at CW-3 that show a peak in sulfate concentrations in 1988, followed by a slight decline, (2) the determination that the southern portion of the Interceptor Wellfield is now operating effectively to cut off the primary sulfate source to the south-eastern portion of the plume (ELMA, 2007b) and (3) the model simulations that show the southeastern edge of the plume expand and then contract over time – presumably indicative of the effectiveness of the southern portion of the Interceptor Wellfield and the northerly hydraulic gradient. The available data are is insufficient to confirm this hypothesis because a time-series of measurements are is not available from newly installed wells MO-2007-5 and CW-10. Thus the discrepancy is related to the model's ability to fully recreate the "bulge" in the southeastern portion of the plume and not necessarily to the hypothesis of the direction that the bulge is moving. Still, we acknowledge that this hypothesis needs to be evaluated through continued monitoring.

c. In the fourth paragraph Freeport broadly discusses the model's inability to match the sharpness of the plume front and concentrations at certain point locations, concluding that this may be due to "*aquifer heterogenities that cannot be adequately captured in the model*." Freeport should provide a more detailed discussion on this matter pointing out the specific aquifer heterogenities in question.

SIERRITA RESPONSE:

The heterogeneities alluded to include heterogeneities inherent to natural alluvial aquifers and dynamic aquifer systems: abrupt and localized contrasts in permeability and porosity and anisotropies in aquifer properties; and "processes that vary at spatial and temporal scales finer than the model discretization" (Section 4.3.2). These heterogeneities cannot reasonably be detected using the available aquifer characterization methods, nor can they be simulated by a large-scale numerical model constructed with spatial zone-wise homogeneity and isotropy and temporal period-wise uniformity. Mason and Bota (2006, p. 107) states that model error "usually reflects small-scale heterogeneities within an aquifer that are difficult for a model to simulate due to cell-size or data limitations." The only situation in which a model may be able to predict movement of a plume front with high accuracy would be for an artificial aquifer constructed in the laboratory using uniform grains (for example glass beads) and under highly controlled flow and plume development conditions. These practical limits to any model's predictive ability within natural systems are shared by the PDSIRM. Section 6 of Appendix I discusses model limitations in detail.

21. Appendix I, Section 6 Summary and Conclusions

ADEQ agrees with the summary of strengths and limitations presented in the ACR. However, based on the limitations of the model, and particularly on the uncertainty regarding the assumptions made by Freeport, ADEQ has serious doubts regarding Freeport's conclusion at Section 6.3 that "*The PDSIRM is capable of meeting objectives identified in the Work Plan (HGC, 2006)*."

SIERRITA RESPONSE:

The strengths and limitations of the model are clearly defined so that the reader understands the appropriate and inappropriate applications of the model. The model is not appropriate for such uses as long-term, regional-scale water resources planning or point- and time-specific prediction of fluctuations in groundwater elevations and sulfate concentrations (especially outside the area of emphasis). Similar limitations are inherent in all large-scale models of natural systems (Mason and Bota, 2006, p. 106). The model has demonstrated, however, the ability to simulate important spatial and temporal characteristics of the sulfate plume. It is this ability that makes the PDSIRM capable of meeting the objectives identified in the Work Plan. We are unsure which specific assumptions that ADEQ refers to in their comment. The assumptions used in the model are based on the best information available and are often shared by other groundwater flow and/or transport models of the Green Valley area (for example, the ADWR model).

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