FREEPORT-McMoRAN
COPPER & GOLD
Sierrita Operations

December 28, 2007

Via Certified Mail #7006 2150 004 3614 0807
Return Receipt Requested

Mr. Robert Casey
Arizona Department of Environmental Quality
Water Quality Enforcement Unit
1110 West Washington Street
Phoenix, Arizona 85007-2935

Re: Final Aquifer Characterization Report
Phelps Dodge Sierrita, Inc. – Mitigation Order on Consent, Docket No. P-50-06

Dear Mr. Casey:

Phelps Dodge Sierrita, Inc., operating as Freeport McMoRan Copper & Gold, Sierrita Operations ("Sierrita"), submits three copies of the attached Aquifer Characterization Report. This document was prepared by Hydro Geo Chem, Inc. as described in Section 3.6 (Task 5) of the Work Plan.

Please do not hesitate to contact Mr. Stuart Brown at (503) 675-5252 or myself at (520) 648-8857 if you have any question regarding this submittal.

Very truly yours,

Ned Hall

E. L. (Ned) Hall
Chief Environmental Engineer

ELH:ms
Attachment
20071228-003

xc: John Broderick, Sierrita Operations
Chad Fretz, Sierrita Operations
Ray Lazuk, Freeport McMoRan Copper & Gold Inc.
Stuart Brown, Bridgewater Group, Inc.

AQUIFER CHARACTERIZATION REPORT

TASK 5 OF AQUIFER CHARACTERIZATION PLAN
MITIGATION ORDER ON CONSENT DOCKET NO. P-50-06
PIMA COUNTY, ARIZONA

Prepared for:

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December 28, 2007

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PIMA COUNTY, ARIZONA

Prepared for:

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Green Valley, Arizona 85614

Approved by:

James R. Norris
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December 28, 2007

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1. INTRODUCTION

In June 2006, Phelps Dodge Sierrita, Inc. (PDSI) and Arizona Department of Environmental Quality (ADEQ) entered into Mitigation Order on Consent Docket No. P-50-06. The Mitigation Order requires PDSI to characterize the extent of a groundwater sulfate plume (defined as sulfate concentrations in excess of 250 milligrams per liter (mg/L)) originating from the Phelps Dodge Sierrita Tailing Impoundment (PDSTI) (Figure 1) and to develop a Mitigation Plan for impacted drinking water supplies attributable to the PDSTI.

Pursuant to the Mitigation Order, PDSI submitted to ADEQ the *Work Plan to Characterize and Mitigate Sulfate in Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment* (Work Plan) (Hydro Geo Chem, Inc. (HGC), 2006a). ADEQ approved the Work Plan in a letter dated November 15, 2006 (ADEQ, 2006), initiating its implementation by PDSI. The Aquifer Characterization Plan is a component of the Work Plan that specifies work to better characterize the hydrogeology and water quality of the sulfate plume. The Work Plan also provides for a Feasibility Study to evaluate potential mitigation actions for a Mitigation Plan.

1.1 Purpose of the Aquifer Characterization Report

The Aquifer Characterization Report is a requirement of Section III.C of the Mitigation Order and presents the results of hydrologic investigations conducted from November 2006 through December 2007 as prescribed by the Aquifer Characterization Plan contained in the

Work Plan. As described in the Work Plan, the results of the Aquifer Characterization Plan provide information needed to complete the Feasibility Study and Mitigation Plan for sulfate-impacted drinking water supplies. HGC prepared the Work Plan, conducted Aquifer Characterization Plan investigations identified in the Work Plan, and prepared this report under contract to PDSI.

1.2 Scope of the Aquifer Characterization Report

As stated in the Work Plan, the objectives of the Aquifer Characterization Plan are to address the Mitigation Order requirements to characterize the sulfate plume and to collect data to complete the Feasibility Study. Specifically, the objectives included the following requirements of Sections III.A and III.C of the Mitigation Order:

- Complete a well inventory to identify drinking water wells within one mile downgradient and cross-gradient of the outer edge of the sulfate plume.
- Determine the vertical and horizontal extent of the sulfate plume.
- Evaluate the fate and transport of the outer edge of the sulfate plume.
- Evaluate the effectiveness of the interceptor wellfield as a groundwater sulfate control system.

Based on an analysis of Mitigation Order requirements and data needs, the Aquifer Characterization Plan includes five tasks as follows:

- Task 1 – Well Inventory
- Task 2 – Plume Characterization

  - Task 2.1 Data Compilation and Evaluation
  - Task 2.2 Groundwater Monitoring
  - Task 2.3 Depth-Specific Groundwater Sampling at Existing Wells
  - Task 2.4 Offsite Well Installation and Testing

- Task 3 – Evaluation of PDSI's Sulfate Control System

- Task 4 – Sulfate Fate and Transport Evaluation

- Task 5 – Preparation of the Aquifer Characterization Report

The Work Plan detailed the scope, methods, and reporting schedule for these tasks, which include field and office activities conducted by HGC and others. Reports for Tasks 1, 2.2, and 3 have been previously reported to ADEQ in the following submittals:

- Well Inventory Report for Task 1 of Aquifer Characterization Plan for Mitigation Order on Consent No. P-50-06 dated December 20, 2006 by HGC (HGC, 2006b).

- Groundwater Monitoring Report, Fourth Quarter 2006, Tasks 2.2 and 2.3 of Aquifer Characterization Plan, Mitigation Order on Consent No. P-50-06 dated December 29, 2006 by HGC (HGC, 2006d).

- Evaluation of the Current Effectiveness of the Sierrita Interceptor Wellfield, Phelps Dodge Sierrita Mine, Pima County, Arizona dated February 26, 2007 by Errol L. Montgomery & Associates, Inc. (M&A) (M&A, 2007a).

- First Quarter 2007 Groundwater Monitoring Report, Tasks 2.2 and 2.3 of Aquifer Characterization Plan, Mitigation Order on Consent No. P-50-06 dated March 30, 2007 by HGC (HGC, 2007a).

- Second Quarter 2007 Groundwater Monitoring Report, Tasks 2.2 and 2.3 of Aquifer Characterization Plan, Mitigation Order on Consent No. P-50-06 dated June 28, 2007 by HGC (HGC, 2007b).

- Third Quarter 2007 Groundwater Monitoring Report, Tasks 2.2, 2.3, and 2.4 of Aquifer Characterization Plan, Mitigation Order on Consent No. P-50-06 dated September 26, 2007 by HGC (HGC, 2007c).

- Revised Report: Evaluation of the Current Effectiveness of the Sierrita Interceptor Wellfield, Phelps Dodge Sierrita Mine, Pima County, Arizona dated November 14, 2007 by M&A (M&A, 2007b).

For completeness, this report summarizes the results of previously reported work conducted under the Aquifer Characterization Plan, but will not reproduce previously submitted reports. Previously submitted reports are available at the information repository at the Joyner-Green Valley Branch Library or from the PDSI document library website (http://www.phelpsdodge.com/caglibrary). This report does provide complete task reports for the previously unreported Tasks 2.1, 2.3, 2.4, and 4. The Aquifer Characterization Report itself is the deliverable for Task 5.

Background information on the Mitigation Order, the nature of the sulfate plume, the hydrogeology and water quality of the sulfate plume, and mitigation activities at the interceptor wellfield are available from the Work Plan and will not be repeated here except as needed to report work results or to describe the conceptual model for the sulfate plume. The Work Plan contained a preliminary conceptual model of the sulfate plume which was updated based on information from investigations conducted pursuant to the Aquifer Characterization Plan.

1.3 Organization of Report

Section 2 summarizes the results of Tasks 1, 2, and 3, namely, the well inventory, plume characterization, and evaluation of the interceptor wellfield. Section 3 discusses the revised conceptual model based on these results. Section 4 presents the results of numerical modeling of the sulfate plume conducted for Task 4. Section 5 summarizes the accomplishments of work conducted under the Aquifer Characterization Plan.

The Appendices contain individual task reports for Tasks 2.1, 2.3, 2.4, and 4 as follows:

- Appendix A - Data Compilation and Evaluation of Bedrock Elevations and Hydraulic Tests for Numerical Model Development in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment, Task 2.1 of Aquifer Characterization Plan

- Appendix B - Summary of Water Quality and Water Level Data Collected for Task 2.2 of Aquifer Characterization Plan

- Appendix C - Depth-Specific Water Sampling and Inflow Profiling at Existing Wells in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment, Task 2.3 of Aquifer Characterization Plan

- Appendix D - Results of Monitoring Well Installation, Task 2.4 of Aquifer Characterization Plan

- Appendix E - Evaluation of Hydraulic Tests at MO-2007-Series Wells, Task 2.4 of Aquifer Characterization Plan

- Appendix F - Results of Initial Water Quality Sampling at Off-Site Monitoring Wells Installed for Task 2.4 of Aquifer Characterization Plan

- Appendix G - Geologic Cross Sections

- Appendix H - Cross Sections Showing Water Quality and Hydraulic Conductivity Data

- Appendix I - Numerical Model for Simulation of Groundwater Flow and Sulfate Transport in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment, Task 4 of Aquifer Characterization Plan

2. RESULTS OF AQUIFER CHARACTERIZATION PLAN TASKS 1, 2, AND 3

Aquifer Characterization Plan Tasks 1, 2, and 3 include the well inventory, plume characterization activities, and the evaluation of the effectiveness of the interceptor wellfield operated by PDSI to mitigate the sulfate plume.

2.1 Task 1 - Well Inventory

The objective of the well inventory was to identify and sample drinking water supply wells within one mile of the downgradient and crossgradient edge of the sulfate plume from the PDSTI (Figure 2). The well inventory also evaluated the presence of drinking water wells within the footprint of the plume. The results of the well inventory were reported by HGC (2006b).

The well inventory identified 165 wells within one mile of the sulfate plume of which 10 were active drinking water supply wells (Figure 2). The drinking water supply wells were identified using the following steps:

- Compilation and review of data for wells registered with the Arizona Department of Water Resources (ADWR).
- Cross checking of the registered wells with information from databases for ADWR water providers and ADEQ public water systems.
- Compilation and review of ADWR imaged records for potential drinking water supply wells.
- Field checking of potential drinking water supply wells.
- Contacting the owners/operators of potential drinking water supply wells.

Of the 10 active drinking water supply wells, one was a private domestic supply well and nine were public supply wells. A water quality sample was collected from the private domestic well which was subsequently determined to be outside the inventory area based on its location determined by a global positioning system. Water quality data for the nine wells serving as public supply wells were provided by the owners or operators. Samples from the 10 drinking water supply wells had sulfate concentrations less than the limit of 250 mg/L set by the Mitigation Order except for well ESP-1, which had a sulfate concentration of 262 mg/L in a sample collected on December 4, 2006. At the time of the well inventory, water from ESP-1 was blended with water from ESP-2 and ESP-3 in a storage tank to reduce the concentration of the blended water to less than 250 mg/L prior to distribution for use. Wells ESP-1, ESP-2, and ESP-3 were used as drinking water supply only temporarily while additional wells were being developed by Community Water Company (CWC). Use of wells ESP-1, ESP-2, and ESP-3 to provide drinking water was discontinued in 2007 after CWC placed wells CW-10 and CW-11 into service. Ongoing sampling of public drinking water supply wells was conducted quarterly under Task 2.2 (Section 2.2.2).

In conjunction with the well inventory and pursuant to the Work Plan, a technical memorandum (HGC, 2006c) was submitted to ADEQ describing the potential interim actions PDSI would take if a drinking water supply was found to be impacted due to the PDSTI. The memorandum describes a monitoring program implemented for sulfate in drinking water supplies, sulfate levels that would trigger an interim action, and the process to be followed to select and implement any needed potential interim action.

2.2 Task 2 - Plume Characterization

Plume characterization activities for Task 2 consisted of data compilation and evaluation activities as well as field investigations. The data compilation and evaluation activities focused on assembling and evaluating existing data that would be used to characterize the structure and hydraulic properties of the basin fill aquifer containing the plume. The field investigations focused on characterizing current water level and water quality conditions in the regional aquifer, installing monitoring wells to determine the vertical and lateral distribution of the sulfate plume, and testing monitoring wells to estimate aquifer hydraulic properties.

2.2.1 Task 2.1 - Data Compilation and Evaluation

An evaluation of available bedrock elevation data and hydraulic test results was performed under Task 2.1. The purpose of the evaluation was to compile, evaluate, and verify data on the depth and hydraulic properties of the basin fill aquifer. These data are needed to develop and calibrate a numerical groundwater flow model for the site. The results of the data compilation and evaluation are detailed in Appendix A.

The purpose of the bedrock evaluation was to develop a bedrock elevation database for the southern portion of the Tucson basin using well and borehole data and to construct a bedrock elevation contour map. Figure 3 is a contour map of subsurface bedrock elevations based on a geostatistical interpretation of bedrock depth data from wells and boreholes.

Hydraulic test data were compiled and evaluated to verify the hydraulic properties of the basin fill and bedrock in the vicinity of the PDSTI. As reported in Appendix A, pumping test and slug test data were obtained from the reports of various hydrologic studies conducted in the PDSTI and Green Valley area. HGC analyzed data from pumping tests and slug tests to verify aquifer hydraulic properties including transmissivity and hydraulic conductivity data reported in the Work Plan. Appendix A contains summary tables with the results of the hydraulic test analyses. The hydraulic properties data reported in the Work Plan were determined to be suitable for use in aquifer characterization.

2.2.2 Task 2.2 - Groundwater Monitoring

Groundwater monitoring for Task 2.2 consisted of groundwater sample collection and water elevation measurement from wells in the vicinity of the PDSTI. Data for the fourth quarter of 2006 (HGC, 2006d) and the first (HGC, 2007a), second (HGC, 2007b), and third (HGC, 2007c) quarters of 2007 were collected and reported under the groundwater monitoring program. Appendix B contains tables summarizing water quality and water level measurements for Task 2.2 from fourth quarter 2006 through third quarter 2007.

2.2.2.1 Overview of Groundwater Monitoring Program

The Work Plan identified two purposes for the groundwater monitoring program for Task 2.2, namely, plume monitoring and regional monitoring. Plume monitoring was conducted quarterly at wells near the boundary of the sulfate plume to track its location. Regional monitoring was conducted twice, in the first and third quarters of 2007, to characterize regional hydrologic and water quality conditions during high (summer) and low (winter) seasonal pumping periods.

PDSI and HGC conducted the majority of the groundwater monitoring pursuant to Task 2.2. Groundwater sampling and analysis methods used by PDSI and HGC are described in the Quality Assurance Project Plan (Appendix E of HGC, 2006a). Some groundwater monitoring data were reported to PDSI by other parties that may have used different, but comparable, sampling protocols. Data verification reports were prepared for each quarterly report for quality assurance and quality control purposes. As determined by the analytical data verification review, all groundwater monitoring data collected for Task 2.2 are of acceptable quality for use in the aquifer characterization program.

Plume monitoring for Task 2.2 is ongoing. Monitoring wells installed under Task 2.4 (Section 2.2.4) were added to the plume monitoring program as soon as they were completed. Water quality sampling at the new wells has helped to define the eastern extent of the sulfate plume and the vertical distribution of sulfate. The results of the two regional monitoring events in the first and third quarters of 2007 provided water level and water quality data sets with broad geographic coverage. For example, in the third quarter of 2007, water level measurements were collected at 134 wells and water quality samples were collected from 108 wells covering an area of 50 square miles.

The results of individual monitoring events are presented and discussed in the quarterly groundwater monitoring reports (HGC, 2006d, 2007a, 2007b, and 2007c). The results of regional monitoring in the third quarter 2007 are used to illustrate sulfate concentration and water elevation trends because they are the most complete and exhibit the same general trends observed in the previous monitoring events. Figures 4 and 5 show sulfate concentration and groundwater elevation data for the third quarter of 2007 (HGC, 2007c) augmented with data for newly installed wells (Section 2.2.4). Sulfate concentration and water elevation maps for the first quarter of 2007 (HGC, 2007a and 2007b) are contained in Appendix B for comparison.

2.2.2.2 Sulfate Distribution

Figure 4 shows the regional distribution of sulfate concentrations in samples collected from wells in the basin fill aquifer. The concentration contours shown in Figure 4 are inferred assuming that sulfate concentrations in the aquifer are spatially related, although a strict linear interpolation was not applied. The contours on Figures 1 and 4 were developed using the highest measured sulfate concentrations at co-located wells.

The sulfate concentration data for third quarter 2007 provide the most complete description of the sulfate plume associated with the PDSTI available to date. Groundwater sample results indicate that the northern extent of the plume is north of Duval Mine Road and west of La Canada Drive, as indicated on Figure 4, which is consistent with the extent of the plume shown in previous reports (HGC, 2006a, 2006d, 2007a, and 2007b). The initial sulfate analyses from reconditioned wells TMM-1, NP-2, and CW-3, and newly installed wells

MO-2007-1A, -1B, -1C, -2, -3B, -3C, -4A, -4B, -4C, -5B, -5C, -6A, and -6B provide a better definition of the northern and eastern edges of the plume than previously available. The initial sulfate concentrations detected in samples collected from the newly installed wells will be confirmed by subsequent monitoring.

Groundwater samples with sulfate concentrations less than 50 mg/L sulfate define a north-south zone approximately 6 miles long and ranging from 1,400 to 6,000 feet wide east of the sulfate plume. This zone of low sulfate groundwater is centered on Green Valley and extends north of Duval Mine Road along Interstate 19. Sulfate concentrations less than 10 mg/L are contained in groundwater samples from wells south of the PDSTI and west of Interstate 19. Samples from wells along the channel of the Santa Cruz River east of Interstate 19 had sulfate concentrations ranging between approximately 60 mg/L and 160 mg/L. Sulfate concentrations are generally less than 100 mg/L in samples collected from wells on the alluvial fan from the Santa Rita Mountains east of the Santa Cruz River channel. Groundwater samples collected from wells farthest east on the alluvial fan of the Santa Rita Mountains had sulfate concentrations less than 50 mg/L.

2.2.2.3 Groundwater Elevation

Groundwater elevations are shown on Figure 5. Appendix B contains maps of depth to water and basin fill saturated thickness for the third quarter of 2007 (Figures B.3 and B.4, respectively). Groundwater elevations decrease eastward from the immediate vicinity of PDSTI, from south to north across the central portion of the study area near Green Valley, and from east to west on the alluvial fan east of the Santa Cruz River. Based on the groundwater elevation contours, groundwater flows from the flanks of the Santa Rita on the east and Sierrita Mountains on the west toward the central axis of the basin, and then northerly. This overall pattern of groundwater flow is consistent with expected regional groundwater flow patterns in the southern portion of the Tucson groundwater basin. The groundwater elevations and consequent flow directions indicated in the vicinity of the PDSTI are generally consistent with data for 2005/2006 (HGC, 2006a) and 1993/1994 (M&A and Dames & Moore, 1994).

Comparison of the third quarter 2007 water elevations with those shown in the Work Plan for 2005/2006 and with those in the groundwater monitoring reports for the fourth quarter 2006 (HGC, 2006d), first quarter 2007 (HGC, 2007a), and second quarter 2007 (HGC, 2007b*)* indicates no substantive difference in groundwater elevations and consequent flow directions over this time range.

2.2.3 Task 2.3 - Depth-Specific Sampling

Depth-specific sampling and flow velocity profiling at existing wells in the vicinity of PDSTI were conducted between November 9, 2006 and June 7, 2007. The purpose of the depth-specific sampling and flow velocity profiling was to delineate aquifer characteristics, including water quality variations and changes in relative permeability with depth.

Depth-specific sampling was conducted at long-screened monitoring wells MH-11 and MH-12 in accordance with the Work Plan. Depth-specific sampling and flow velocity profiling were completed at wells ESP-2 and ESP-4. Attempts to conduct sampling and profiling at wells CW-7, CW-8, ESP-1, and ESP-3 were unsuccessful due to the inability of the sampling tool to access the entire depth of the wells as a result of the configuration of existing equipment in the pumps and riser piping in the wells.

The results and interpretation of sampling for Task 2.3 are presented in Appendix C. The salient findings of sampling for Task 2.3 are:

- A zone of relatively high permeability at ESP-2 appears to be present at depths between 650 and 700 feet.
- A zone of relatively high permeability in the vicinity of ESP-4 appears to be present at depths from about 650 feet to about 800 feet.
- ESP-4 lies within the zone of sulfate impact, and the most elevated sulfate concentrations are centered between depths of 750 and 800 feet, corresponding to the zone of higher apparent permeability.
- 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.

The general implications of these findings is that there can be zones of higher relative permeability at depth in the basin fill aquifer that impart heterogeneity to the basin fill. A strong vertical zoning of sulfate was evident at ESP-4 where the high permeability zone was associated with an order of magnitude increase in sulfate concentrations. The uniformity and continuity of the high permeability zones is uncertain given the large distances between wells.

2.2.4 Task 2.4 - Offsite Well Installation and Testing

Pursuant to Task 2.4, HGC conducted drilling, construction, and testing of thirteen water quality monitoring wells in areas east and northeast of the PDSTI in and near the community of Green Valley, Arizona. Monitor wells were installed to:

- Further define the lateral extent of the sulfate plume.
- Define the vertical zoning of sulfate.
- Provide installations for long term monitoring of water levels and water quality.
- Characterize aquifer materials and hydraulic properties in the basin fill aquifer.
- Determine depth to bedrock and thickness of the basin fill at each location.

Monitoring wells were installed at six locations, MO-2007-1 through MO-2007-6, located east and northeast of the PDSTI (Figures 1, 4, and 5). The sites were selected to provide additional definition of the plume limits at their respective locations. Table 1 summarizes the well construction of the MO-2007-series wells.

2.2.4.1 Well Drilling and Installation

Monitor well installation was focused at the northern and eastern portions of the plume because groundwater flow downgradient from the PDSTI is to the east and then north, and because these areas had the greatest uncertainty regarding the distribution of sulfate and are of concern with respect to future plume migration. Some of the well sites were selected so that the wells can serve as sentinel wells for water supply wells near the current plume margin.

Appendix D details the drilling, construction, and development of the MO-2007-series monitoring wells and provides a summary of the geology, the rationale for well screen selection, drilling logs, well construction diagrams, and well development information.

Nests of two to three wells were installed at all sites except MO-2007-2 to assess vertical differences in hydraulic properties and sulfate distribution in the basin fill aquifer. Only one well was installed at MO-2007-2 because the saturated thickness of the basin fill is insufficient to warrant multiple screened intervals. The well nests allow sampling and hydrologic testing of specific vertical intervals within the basin fill. Selection of screened intervals for the monitor well nests was based on two primary criteria. First, the screened intervals were positioned to monitor the top, middle, and bottom of the basin fill with the shallow (“A”), middle (“B”), and deep (“C”), respectively, to follow the pattern that had been established for some MH-series monitor wells. Second, lithological and water quality information provided by pilot boreholes drilled from the surface to bedrock at each site was used to select specific hydrostratigraphic zones to include or avoid in the screened intervals in a particular well. Access to pre-existing shallow wells NP-2 and CW-3 was obtained at sites MO-2007-3 and MO-2007-5, respectively, eliminating the need to install shallow wells at these locations.

Pilot boreholes drilled at the MO-2007 sites intercepted Quaternary- to Tertiary-aged basin fill deposits overlying Cretaceous clastic sedimentary and volcanic bedrock. The basin fill is composed of unconsolidated to moderately consolidated sand, silt, gravel, and clay. Basin fill thicknesses encountered in the pilot boreholes drilled to bedrock ranged from a minimum of 687 feet in MO-2007-2 to a maximum of 1,442 feet in MO-2007-3C. Depth to bedrock and bedrock lithology encountered in the MO-2007 pilot boreholes are summarized in Table D.1 (Appendix D).

Identification of stratigraphy in the basin fill was an objective of Task 2.4 because the physical characteristics of the basin fill, such as the presence or absence of consistent layering or laterally extensive zones of fine- or coarse-grained materials can be controls on the hydraulic properties of basin fill and influence the movement of groundwater and solutes. Appendix D contains a generalized stratigraphic section for each MO-2007 pilot borehole. The stratigraphic sections were developed by grouping together the predominant material types and interpreting transition breaks between the groups. The generalized stratigraphic sections are meant to show only the general tendencies of the basin fill at the well sites because the grouping of materials can be somewhat subjective due to the discontinuous and disrupted nature of samples collected, the generally coarse-grained character of the deposits, and the gradational and sporadic transition between interpreted groups of materials.

Five of the MO-2007-series well sites are located along the northeastern and eastern margin of the sulfate plume (e.g., MO-2007-1, -3, -4, -5, and -6) and one site, MO-2007-2, is located in the northwestern portion of the plume. Geologic data for wells along the northeastern and eastern margin of the plume were amenable to interpretation of generalized stratigraphic units in the basin fill.

A consistent aspect of the basin fill observed in the MO-2007-series well sites is that the uppermost 200 to 450 feet contained a significant fraction of silt and clay. This was not observed in MO-2007-2 on the northwest side of the plume. The upper zone of basin fill is composed of mixed sand, gravel, silt, and clay, but has a greater occurrence of silt or clay layers intermixed with layers of silty sand or gravel compared to the underlying material. Within the interpreted upper zone there are lateral variations such as at MO-2007-5 which has less silt and clay than observed at the other MO-2007 wells on the east side of the plume. The upper zone of basin fill typically extends from the surface to the vicinity of the water table. The upper portion of the basin fill at MO-2007-2 was sand that lacked the higher content of fines observed at the other MO-2007 wells. For this reason, the upper zone of the basin fill may not extend to MO-2007-2.

Below the upper zone, a middle zone of the basin fill consists of predominantly coarse-grained sediments containing various sand and gravel mixtures. In general, the middle zone is characterized by higher percentages of sand and gravel compared to overlying and underlying materials. Silt is a subsidiary component of the middle zone and increases from north to south based on the observation that layers of sand with silt or silty sand occur more commonly at sites MO-2007-4, -5, and -6 than at sites MO-2007-1 and -3.

A lower zone of the basin fill can be inferred on the basis of sediment characteristics and drilling characteristics, although the lateral consistency of the lower unit is more variable than the overlying units. One characteristic of the lower zone is a general lack of gravel. At sites MO-2007-1, -5, and -6, a lower zone of silty sand and sand with silt underlies the coarse-grained middle zone. The lower portions of MO-2007-3 and 4 were sand that contrasted with overlying material due to the lack of gravel and the relative uniformity of the sand. Other characteristics of the lower unit are 1) the materials in it, whether silty or sandy, were periodically associated with slow drilling conditions (e.g., a "hard formation" penetration rate of less than 5 feet per hour for a continuous period of 2 hours); 2) sediment is moderately indurated in places (e.g., sites MO-2007-4 and -5); and 3) greater calcium carbonate relative to overlying material (e.g., sites MO-2007-1, -3, and -4) as determined by testing with hydrochloric acid. Although there are enough apparent features to differentiate the lower zone from the overlying material at each well site, the lower zone appears to vary laterally in its silt and clay content and degree of induration.

In general, site MO-2007-3 on the northeast margin of the plume contains the thickest assemblage of sand and sand with gravel, whereas site MO-2007-6, southeast of the plume, contains the least amount of clean sand and gravel. In Section 3.2.1, the stratigraphy of the MO-2007-series well sites is discussed in the context of previously collected geologic information.

2.2.4.2 Hydraulic Testing of MO-2007 Monitor Wells

Aquifer testing was conducted at each of the MO-2007 monitor wells following their development. The purpose of the tests was to evaluate basin fill aquifer hydraulic properties, including transmissivity, vertical hydraulic conductivity, and storage coefficient in the vicinity of each well nest. Appendix E reports the results of the aquifer testing program in detail, including discussion of the test methods, presentation of drawdown graphs, and interpretation of the results of tests. Table 2 summarizes the results of hydraulic testing.

The hydraulic conductivities estimated for the MO-2007 wells range from approximately 0.7 feet per day (ft/day) to 120 ft/day, with the majority of estimates between about 10 and 30 ft/day. This magnitude and range of hydraulic conductivities are comparable to previously reported values for the basin fill (HGC, 2006a and Appendix A). The low end of the range of estimated hydraulic conductivities were for tests in the deepest monitoring wells (i.e., MO-2007-6B, -5C, -4C, -3C, and -1C), which are screened in the lower zone of the basin fill. Hydraulic conductivity estimates for lower zone monitoring wells ranged from 0.7 ft/day to 11 ft/day. Hydraulic conductivity estimates for wells in the middle zone ranged from 9 ft/day to 31 ft/day. The highest hydraulic conductivity estimate of 118 ft/day was from the test at MO-2007-2 in the northwest part of the study area where the saturated basin fill is predominantly sand and sand with gravel. The upper zone of the basin fill is mostly unsaturated.

2.2.4.3 Initial Sampling of MO-2007 Monitor Wells

Initial water quality samples were collected from the MO-2007 wells to document their water quality. The initial water sampling was conducted after well development and during aquifer testing conducted at each well. Appendix F describes the methods and provides the results of the initial water sampling. The results of the initial water quality sampling have been included in the quarterly groundwater monitoring reports as they became available.

All of the water samples had near-neutral pH, ranging from 7.05 to 7.93. Of the 13 monitoring wells installed for Task 2.4, only wells MO-2007-2, MO-2007-5B, and MO-2007-5C had sulfate concentrations at or in excess of the action level of 250 mg/L

(Figure 4). The water sample from shallow well CW-3 near MO-2007-5B and -5C contained 57.9 mg/L sulfate, indicating vertical zoning in sulfate at that location. Water sampling results for wells at sites MO-2007-1, -3, -4, and -6 ranged in sulfate concentration from 18.9 mg/L to 136 mg/L. The water quality results for the co-located wells at sites MO-2007-1, -3, -4, and -6 indicate that sulfate concentrations tend to be higher in the lowermost screened interval than in screened intervals at more shallow depths at the same location. The observation of higher sulfate in the deeper basin fill, which is generally less permeable than the overlying basin fill, is perplexing because there does not appear to be a source of sulfate other than the lowermost basin fill itself. For example, if sulfate in the deepest wells was attributable the sulfate plume, higher concentrations of sulfate would be expected in the more permeable overlying portion of the basin fill where sulfate transport would be fastest. 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 (Appendix D).

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 results of the initial water quality sampling from the newly installed wells will be verified by subsequent monitoring conducted by the ongoing groundwater monitoring program pursuant to Task 2.2.

Water level measurements at co-located MO-2007 wells indicate slight differences (less than 4 feet) in water elevation between the upper, middle, and lower well screens at MO-2007-1, -3, and -4 (Figure 5). Water level differences of approximately 19.7 feet and 16.1 feet are observed at co-located wells at sites MO-2007-5 and MO-2007-6, respectively. The lowest water levels at sites MO-2007-5 and MO-2007-6 occur in the lowest screened intervals, MO-2007-5C and MO-2007-6B. The screen in MO-2007-6B is below a thick clay bed which may act as a confining layer between the lower screen and the overlying screened interval. There is no similar low permeability layer above MO-2007-5C, although there are several thin clayey beds within the screened interval. 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.

2.3 Task 3 - Evaluation of PDSI Groundwater Control System

The interceptor wellfield is a system of 23 wells (the IW-series wells) that pump sulfate-impacted groundwater at the east edge of the PDSTI (Figures 1 and 4). Groundwater pumped at the interceptor wellfield is used at the Sierrita Mine. The objective of the interceptor wellfield is to capture sulfate-impacted seepage at the east edge of the PDSTI before it flows eastward to the regional basin fill aquifer.

An evaluation of the effectiveness of the interceptor wellfield was included in the Aquifer Characterization Plan and was conducted to address the requirement of Section III.C.4 of the Mitigation Order. The evaluation reviewed the development and operation of the PDSTI and the interceptor wellfield, including estimated seepage and sulfate mass capture over time. The effectiveness of the interceptor wellfield was evaluated based on analysis of water level and water quality data for the wellfield and the results of numerical simulation of wellfield capture (M&A, 2007a and 2007b). The evaluation determined that current groundwater pumping effectively captures sulfate-impacted seepage in the southern portion of the interceptor wellfield, but not the northern portion from approximately well IW-6A northward (Figures 1 and 4).

Seepage capture at the northern portion of the interceptor wellfield is currently ineffective because the small saturated thickness of the basin fill aquifer prevents sufficient pumping to develop an effective hydraulic barrier given the current number of wells. In contrast to the north half of the interceptor wellfield, the south portion of the wellfield has a greater saturated thickness that allows the high pumping rates needed to establish effective capture of sulfate-impacted seepage.

In response to the findings of the interceptor wellfield evaluation, PDSI conducted a focused feasibility study (FFS) to evaluate potential mitigation alternatives for improving the effectiveness of the north portion of the interceptor wellfield (HGC, 2007d). The FFS identified and screened the potential mitigation actions and technologies that could be used to improve the effectiveness of the northern interceptor wellfield. Mitigation alternatives were developed from mitigation actions and technologies retained by the screening. The mitigation alternatives included:

- a new and larger wellfield on PDSI property in the vicinity of the existing northern interceptor wellfield,

- new wellfields east of PDSI property where the basin fill saturated thickness is larger, and

- groundwater recharge via injection wells on PDSI property at the northern interceptor wellfield to enhance seepage recovery.

The mitigation alternatives were evaluated for their implementability, effectiveness, and cost using the methodology described in the Work Plan.

3. CONCEPTUAL MODEL FOR THE GROUNDWATER SULFATE PLUME

A preliminary conceptual model describing known and potential sources of sulfate and the movement of sulfate-bearing groundwater in the vicinity of the PDSTI was presented in the Work Plan. The conceptual model provides a framework for summarizing information regarding the source of the sulfate plume and the factors that influence its migration in the environment. The conceptual model is updated here based on information gathered for the Aquifer Characterization Plan.

3.1 Sulfate Sources

The primary known source of sulfate is seepage from the PDSTI to the underling basin fill aquifer. The seepage is due to the gravity drainage of the pore water from the PDSTI. The pore water consists of water from the tailing slurry delivered to the impoundment, precipitation that falls on the PDSTI, and surface water discharged to the PDSTI. Seepage from the PDSTI in 2006 was estimated at approximately 7,470 acre feet (M&A, 2007b). Sulfate in the tailing slurry water results from reagents used in milling, the dissolution of sulfate salts and the oxidation of sulfide minerals during milling and flotation, and the use of sulfate-bearing water from the interceptor wellfield in the mill circuit. Sulfate in the reclaim pond results from collection of tailing slurry water and surface water discharges from the mill.

The drainable moisture content of the tailing impoundment represents a finite source of sulfate-bearing solution that will diminish following the end of mining and mineral processing, when tailing is no longer deposited and residual moisture drains from the tailing material.

Groundwater in the bedrock upgradient of the tailing impoundment is a second potential source of sulfate to the basin fill beneath the impoundment. Groundwater samples collected at piezometers PZ-7 and PZ-8 upgradient of the PDSTI had sulfate concentrations of 360 mg/L and 450 mg/L, respectively, in the third quarter of 2007 (Figure 4 and Appendix B). 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.

Other potential sources of sulfate may occur outside the PDSTI. Studies by the Pima Association of Governments (PAG) (1983a and 1983b) identified tailing impoundments at other mines as potential sources. Groundwater sampling results indicate that groundwater in the vicinity of the Twin Buttes Mine, at the north end of the sulfate plume, contains localized zones of sulfate in excess of 250 mg/L (Figures 4 and Appendix B).

Another potential source of sulfate is groundwater in the vicinity of the Santa Cruz River. As documented by Laney (1972) and PAG (1983a), groundwater in the vicinity of the Santa Cruz River in this part of the Tucson basin can contain greater than 250 mg/L sulfate (Plate 5 in PAG 1983a). Laney (1972) attributed the sulfate to groundwater derived from gypsiferous sediment east of the Santa Cruz fault, but irrigation return flow may also add dissolved solids including sulfate. Work conducted for the Aquifer Characterization Plan did not yield additional information on these potential sources.

Monitoring conducted for Task 2.2 identified a zone of sulfate in excess of 100 mg/L along the Santa Cruz River channel. The groundwater sampling results indicate that the sulfate plume from the PDSTI is west of the Santa Cruz River channel and separated from Santa Cruz River area by a zone of relatively low sulfate (less than 50 mg/L) groundwater (Figure 4 and Appendix B). At this time, there no apparent interaction between the plume and sulfate-bearing water along the Santa Cruz River channel.

The results of initial water sampling at sites MO-2007-1, -3, -4, and -6 indicate that slightly elevated concentrations of sulfate (approximately 75 mg/L to 140 mg/L) are observed in wells screened in the deeper portions of the basin fill (Figure 4 and Appendix F). The origin of the sulfate in these deeper wells is uncertain because the locations are outside the area of the plume and the wells are in sediment with generally lower permeabilities than the overlying basin fill which has lower sulfate concentrations (Section 2.2.4.3). A possible source of the sulfate in the deeper basin fill is pyritic and hydrothermally altered bedrock underlying the basin fill, which may have been incorporated as detritus in the deeper basin fill. It is also possible that the slightly elevated concentrations of sulfate in these wells are background concentrations for the deeper basin fill.

3.2 Sulfate Migration

Once introduced to the basin fill aquifer, sulfate is transported at the average groundwater flow velocity because it is a conservative ion and does not attenuate through adsorption or precipitation at the concentrations and conditions observed in the study area. The direction and velocity of groundwater flow and sulfate transport are determined by the prevailing hydraulic gradients and hydraulic properties of the basin fill aquifer.

3.2.1 Hydrostratigraphy of the Basin Fill Aquifer

The Work Plan summarized previous descriptions of the basin fill aquifer in the study area, including data compiled from wells in the vicinity of the sulfate plume and a hydrostratigraphic model based on a regional analysis of the Tucson Basin. As noted in the Work Plan, Davidson (1973) identified three stratigraphic units in the southern Tucson Basin: Fort Lowell Formation, Tinaja Beds, and Pantano Formation. However, basin fill descriptions in the Green Valley area typically do not identify these units with the exception of the Pantano Formation. Geologic data for the MO-2007 wells and previous geologic logging of existing wells could not be associated confidently with the regional hydrostratigraphic units of Davidson (1973). Instead, stratigraphic relationships were interpreted based on classification and comparison of material types intercepted in boreholes.

The hydrostratigraphy and hydraulic properties of the MO-2007-series wells are discussed in Sections 2.2.4.1 and 2.2.4.2. Appendix G contains geologic cross-sections based on geologic logs for the MO-2007 wells and borehole data previously reported in the Work Plan.

In general terms, the basin fill consists of coarse-grained sediment, primarily sand and gravel. However, the geologic cross-sections (Appendix G) indicate that in detail there is a considerable amount of variation in material types with depth and laterally in the basin fill. In the vicinity of the sulfate plume, a generalized stratigraphic sequence was inferred based on data from the MO-2007 wells. The stratigraphic sequence identified at the MO-2007 wells (Section 2.2.4.1) can be generally interpreted through the plume area, although it is not necessarily identifiable at all locations. Appendix G contains cross-sections showing interpreted stratagraphic correlations based on the MO-2007 well data and previously reported geologic data (HGC, 2006a) . The generalized stratigraphy is described below.

The upper zone of basin fill contains sand and gravel with a high proportion of silt and clay either as discrete layers or as mixtures with the sand and gravel. This zone is between 200 and 600 feet thick in the study area.

Sand and gravel are the predominant material in the middle zone of the basin fill. Although silt and clay are locally present, they do not form a significant percentage of the middle zone. The middle zone locally extends to bedrock and elsewhere is underlain by a lower zone of basin fill.

Geologic logging at the MO-2007 wells identified a lower zone of basin fill that varied from the overlying middle zone by containing one or more of the following: greater amounts of silt and clay, the lack of gravel, zones of moderate induration, and increased calcium carbonate based on reaction with hydrochloric acid. Correlation of the lower zone of basin fill from well to well in the vicinity of the plume is difficult on the basis of pre-existing well logs, but some general observations can be made. Where identified in the MO-2007 wells, the elevation of the top of the lower zone appears to correlate laterally either in elevation or stratigraphic position with material previously identified as Pantano Formation (e.g., between MH-13 and MO-2007-5 on Cross-Section F-F', at ESP-1 through ESP-4 between MO-2007-5 and MO-2007-1 on Cross-Section C-C', see Appendix G). Although they share the apparent correlation of depth and position beneath the middle zone, there are distinct differences between projected lower unit materials. For example, the lower zone identified as weakly to moderately lithified Pantano Formation at MH-13 is a gravel, whereas the lower zone at MO-2007-5 and 4 is unconsolidated to moderately indurated silty sand to sand with silt. Projecting the lower zone north from MO-2007-5, the lower zone is described as a variably indurated sand at MO-2007-4, poorly consolidated to cemented, variably calcareous conglomerate and quartzose sandstone of the Helmet Peak Fanglomerate (equivalent to the Pantano Formation) at ESP-1, -2, -3, and -4, uniform sand at MO-2007-3, and silty sand at MO-2007-1. There is insufficient information to extrapolate the lower basin fill unit east of the plume. A lower unit of basin fill can be projected west of MH-13 to wells IW-12, IW-14, and IW-15, where Pantano Formation is identified beneath sand and gravel at the interceptor wellfield (Cross-Section A-A', Appendix G).

The geologic data for wells in the vicinity of the plume were interpreted in terms of an informal hydrostratigraphy consisting of an upper zone of sand-containing zones or layers of silt and clay, a middle zone of sand and gravel, and a lower zone of unconsolidated to moderately consolidated sand to silty and clayey sand to gravel. Based on this interpretation, the upper stratigraphic zone of basin fill is largely unsaturated and the basin fill aquifer is comprised primarily of the saturated middle and lower stratigraphic zones.

The stratigraphic interpretation provided here is provisional because of the inherent uncertainties in projecting units based on the available data. First, stratigraphic interpretation is difficult in sequences of coarse-grained fluvial sediments such as the basin fill because the differences between units can be subtle and gradational, based on relatively minor variations in the percentages of different materials. Second, the processes that deposit coarse fluvial sediment can result in lateral and vertical facies changes that limit the extent and complicate the pattern of occurrence of different stratigraphic units. Third, the use of previously reported geologic data for drill cuttings sampled by different techniques and logged by numerous individuals for different purposes over time, complicates stratigraphic interpretation because the data are not always comparable.

Hydraulic conductivity estimates for wells in the vicinity of the plume are plotted on cross-sections in Appendix H based on data previously presented in the Work Plan and verified for Task 2.1 (Appendix A). In general, most of the estimated hydraulic conductivities shown on the cross-sections range between 5 and 50 ft/day. With the exception of wells in the lowermost basin fill, hydraulic conductivity estimates for wells screened both over the entire saturated thickness of the basin fill and wells with shorter screened intervals range about an order of magnitude and are generally about several tens of feet per day. The cross-sections show that there is a tendency for lower hydraulic conductivities in the lower unit of basin fill, although there is not always a significant difference between the hydraulic conductivities of the middle and lower zones of the basin fill (e.g., sites MO-2007-3 and MO-2007-4). There is also a general tendency for hydraulic conductivity to increase slightly from south to north, with the highest hydraulic conductivities in the northern portion of the plume (e.g., CW-7 and MO-2007-2).

As discussed in the Work Plan, the bedrock is significantly less permeable than the overlying basin fill aquifer based on the results of hydraulic testing of bedrock at MH-25 within the plume and elsewhere in the vicinity of the PDSTI. For this reason, the bedrock aquifer is not considered to have significant groundwater flow or the potential to transport sulfate relative to the basin fill aquifer.

The information from pre-existing boreholes and drilling conducted for this study is consistent with a hydrostratigraphic model of a continuous, unconfined basin fill aquifer consisting of well-sorted, coarse-grained sediment possessing a generalized three-layer stratigraphy. Although there are variations in the hydraulic conductivity of the basin fill aquifer indicating the middle zone has a higher permeability than the deep zone (e.g., low permeability in the deep screened intervals at MH-13 and the MO-2007 wells and high inflows suggesting high permeability in the middle zone at ESP-2 and ESP-4), large-scale features with significant (two orders of magnitude or more) hydraulic conductivity contrasts have not been identified in the basin fill aquifer. Thus, there is no evidence of regionally extensive heterogeneities that can cause preferential flow paths, such as laterally extensive aquitards or high permeability units, although variations in the velocity of groundwater flow and sulfate transport may occur due to local scale differences in hydraulic properties.

3.2.2 Sulfate Distribution in the Basin Fill Aquifer

The lateral distribution of sulfate in the basin fill aquifer is shown on Figure 4. The extent of the sulfate plume as defined by the 250 mg/L contour is shown on Figure 1. Within the plume, elevated sulfate occurs throughout the thickness of the saturated basin fill aquifer with the exception of the uppermost portions of the basin fill aquifer at MH-25A, MH-26A, and in the lower most part of the aquifer at MH-13C (Figure 4 and Appendix B). On the eastern margin of the plume, elevated sulfate is observed in an apparent permeable zone at a depth of approximately 650 and 800 feet in well ESP-4 (Section 2.2.3) and at wells MO-2007-5B (screened from 660 to 960 ft bgs) and MO-2007-5C (screened from 1,150 to 1,350 ft bgs) (Section 2.2.4.3). The lateral and vertical distributions of sulfate on the margins of the plume can be influenced by local-scale aquifer heterogeneities and hydraulic conditions.

3.2.3 Sulfate Transport

Sulfate-bearing seepage from the tailing impoundment infiltrates into the underlying basin fill, mixes with groundwater recharge by surface infiltration and groundwater inflow from the upgradient bedrock, and flows eastward. Sulfate-bearing seepage is intercepted through groundwater pumping within the interceptor wellfield. Current pumping at the southern portion of the interceptor wellfield effectively captures most of the sulfate-bearing seepage in the area. Capture of sulfate-bearing seepage by the northern portion of the interceptor wellfield is currently incomplete (M&A, 2007), an issue that is being addressed by the FFS (HGC, 2007d). Impacted groundwater that is not intercepted at the wellfield or that has already moved downgradient of the interceptor wellfield flows north-northeasterly as it enters the northerly flowing regional groundwater system in the basin fill aquifer near Green Valley (Section 2.2.2.3, Figure 5). The sharp north-south orientation of the eastern plume boundary (Figure 4) is due to the northward groundwater flow that occurs as the hydraulic gradient becomes northerly and groundwater from the PDSTI area mixes with regional groundwater flow in the central part of the basin.

In addition to regional hydrologic conditions, groundwater flow and sulfate transport can be influenced by local sites of groundwater pumping and recharge. For example, pumping at a well in the immediate vicinity of the plume margin can induce hydraulic gradients that cause the plume to migrate toward the well. This can be seen in sulfate concentration data for well ESP-1, which increased when the well was pumped for several months and decreased when pumping ceased (see data for ESP-1 Table B.2 in Appendix B, pumping at ESP-1 was reduced in the second quarter of 2007 and stopped in the third quarter 2007). Collectively, groundwater pumping at wells outside of the plume and recharge along the Santa Cruz River due to stream channel infiltration or groundwater recharge projects can influence the migration and location of the sulfate plume, but the degree of influence will depend on the location, magnitude, and duration of pumping or recharge.

4. NUMERICAL MODEL OF GROUNDWATER FLOW AND TRANSPORT

A numerical model of groundwater flow and sulfate transport was developed for Task 4 of the Aquifer Characterization Plan. The model and the results of its calibration to current conditions are generally discussed in this section. Appendix I reports the scope, construction, calibration, and sensitivity of the model.

The model is regional in scale, but was developed to focus on the area of the sulfate plume for the purpose of evaluating mitigation alternatives. The model was calibrated to past and present measured hydraulic heads and sulfate concentrations to provide a reasonable approximation of the groundwater flow system and the sulfate plume. The model is intended for use as a predictive tool to simulate the fate and transport of sulfate in the vicinity of the PDSTI under various potential mitigation actions such as groundwater pumping. Groundwater flow and transport simulations with the model will be used to provide conceptual design bases for potential mitigation actions considered in the Feasibility Study. Any use of the model outside the area of the sulfate plume may require additional aquifer characterization and model refinement.

The model is calibrated on simulation of conditions from 1940 through 2006 including groundwater pumping at wells in the vicinity of the PDSTI and seepage from the PDSTI. The results of the calibrated model are presented as contour maps comparing measured and simulated water level elevations and sulfate concentrations. Figures 6 and 7 show the water elevation and sulfate concentration predictions of the calibrated model. Appendix I contains illustrations of the transient simulation of time series water level and sulfate concentration data. In viewing and interpreting the results of the calibrated model, it is important to understand that a regional model of groundwater flow and sulfate transport for a system such as the sulfate plume from the PDSTI cannot match every detail of the observed system. The model is necessarily a generalized representation of the aquifer because data on the spatial distribution of material types and hydraulic properties are incomplete, as are data on the temporal and spatial distribution of sources and sinks. Therefore, the objective of calibration was to match groundwater elevations and sulfate concentrations in the vicinity of the plume, and the overall temporal development of the plume. Because the majority of available hydrologic data are for the immediate vicinity of the plume, prediction in areas far from the plume may have greater uncertainty because of the lack of site-specific information for those areas.

Comparison of Figures 5 and 6 shows the calibrated model matches the current water level elevations and potentiometric configuration fairly well. The measured and predicted distribution of sulfate is also good based on comparison of Figures 4 and 7. The model is considered suitable for the purpose of simulating plume behavior under potential mitigation actions, although the model does have limitations in areas outside of the plume.

As discussed in the Work Plan, the calibrated model will be used in the Feasibility Study to develop and evaluate potential plume mitigation actions. Simulations of potential mitigation actions will be conducted to predict future conditions of hydraulic head and sulfate distribution over time as a basis for evaluating effectiveness. Simulations of future conditions for the

Feasibility Study will consider future pumping and water supply development described by water system plans.

5. CONCLUSIONS

Hydrologic investigations required by the Aquifer Characterization Plan were implemented and completed between November 2006 and December 2007 in accordance with the Work Plan schedule approved by ADEQ. This Aquifer Characterization Report is the final task required for the Aquifer Characterization Plan, although groundwater monitoring for Task 2.2 will be ongoing until it is superseded by the recommendations of the Mitigation Plan. Additional requirements of the Work Plan that are currently in development are the Feasibility Study due April 30, 2008 and the Mitigation Plan due June 30, 2008.

The results of the Aquifer Characterization Plan have accomplished the objectives stated in the Work Plan (Section 1.2). Specific accomplishments include:

- A well inventory of drinking water supply wells within one-mile downgradient and crossgradient of the sulfate plume was completed, including sampling drinking water supplies to identify any impacted wells. No active drinking water supplies were found to be impacted by sulfate from the PDSTI. An interim action plan was put in place to identify and implement mitigation actions in the event a drinking water supply becomes impacted. Prior to entering the Mitigation Order, PDSI replaced two CWC drinking water supply wells.

- The vertical and lateral extent of the sulfate plume was determined by the installation and water quality sampling of 13 new monitoring wells at six locations along the margin of the plume, rehabilitation and sampling of three previously inactive wells (TMM-1, NP-2, and CW-3) on the margin of the plume, completion of four quarters of plume monitoring and two regional monitoring events to determine the extent of the plume and characterize regional water quality, and depth-specific sampling at four wells to evaluate vertical trends. PDSI collected and analyzed more than 350 water quality samples to evaluate the extent of sulfate.

- The effectiveness of the interceptor wellfield was evaluated based on a thorough review of its construction and operational history, including estimation of seepage and sulfate mass capture. When the northern portion of the interceptor wellfield was found to be ineffective, PDSI initiated the FFS to identify a more effective control strategy.

- A numerical model of groundwater flow and sulfate transport was developed to evaluate the fate and transport of the sulfate plume. The model is conditioned on site-specific information for the basin fill aquifer and the results of calibration to a 66-year record of groundwater pumping and a 47-year record of tailing emplacement. The model will be used in the Feasibility Study to evaluate the effectiveness of mitigation actions on control of the sulfate plume.

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7. LIMITATIONS STATEMENT

The opinions and recommendations presented in this report are based upon the scope of services and information obtained through the performance of the services, as agreed upon by HGC and the party for whom this report was originally prepared. Results of any investigations, tests, or findings presented in this report apply solely to conditions existing at the time HGC's investigative work was performed and are inherently based on and limited to the available data and the extent of the investigation activities. No representation, warranty, or guarantee, express or implied, is intended or given. HGC makes no representation as to the accuracy or completeness of any information provided by other parties not under contract to HGC to the extent that HGC relied upon that information. This report is expressly for the sole and exclusive use of the party for whom this report was originally prepared and for the particular purpose that it was intended. Reuse of this report, or any portion thereof, for other than its intended purpose, or if modified, or if used by third parties, shall be at the sole risk of the user.

TABLES

TABLE 1
Summary of MO-2007-Series Wells

WELL NAME	ADWR WELL REGISTRY NUMBER	UTM NORTHING (NAD 83, meters)	UTM EASTING (NAD 83, meters)	DRILLED DEPTH (ft bls)	CASING DEPTH (feet)	CASING DIAMETER (inch)	DEPTH TO TOP OF SCREEN (ft bls)	DEPTH TO BOTTOM OF SCREEN (ft bls)	SCREEN LENGTH (feet)	MEASURING POINT ELEVATION (NAVD 88, ft amsl)	DATE MEASURED	DEPTH TO WATER BELOW MEASURING POINT (feet)	STATIC WATER LEVEL ELEVATION (ft amsl)
MO-2007-1A	907342	3529331.380	500016.947	620	610	5	460	600	140	2967.15	07/30/07	425.87	2541.28
MO-2007-1B	907210	3529325.119	500021.574	920	910	5	740	900	160	2966.35	07/30/07	425.67	2540.68
MO-2007-1C	907209	3529328.959	500013.405	1260	1190	5	1020	1180	160	2964.34	07/30/07	423.87	2540.47
MO-2007-2	906765	3527621.102	497912.410	740	685	5	520	680	160	3153.61	08/09/07	575.30	2578.31
MO-2007-3B	906816	3528508.801	500522.491	960	950	5	740	940	200	2910.75	09/10/07	359.38	2551.37
MO-2007-3C	906817	3528508.743	500529.713	1430	1330	5	1160	1320	160	2910.09	07/05/07	356.30	2553.79
MO-2007-4A	907213	3525634.956	500383.682	580	570	5	360	560	200	2923.47	10/09/07	307.67	2615.80
MO-2007-4B	907212	3525613.952	500380.947	960	950	5	700	940	240	2923.22	10/11/07	308.72	2614.50
MO-2007-4C	907211	3525624.484	500382.217	1153	1140	5	1090	1130	40	2923.49	08/12/07	307.13	2616.36
MO-2007-5B	907456	3523743.376	500013.850	980	970	5	660	960	300	2943.42	10/12/07	268.27	2675.15
MO-2007-5C	907457	3523736.459	500014.152	1370	1360	5	1150	1350	200	2944.33	08/23/07	294.04	2650.29
MO-2007-6A	907607	3521842.050	498367.161	630	620	5	310	390	80	3042.49	10/02/07	303.60	2738.89
							430	610	180				
MO-2007-6B	907606	3521849.495	498367.887	1060	950	5	780	940	160	3041.95	10/04/07	319.17	2722.78
Existing Wells at MO-2007 Sites													
CW-3	627483	3523809.985	500047.663	501	500	16	182	500	318	2941.44	06/06/07	265.35	2676.09
NP-2	605898	3528517.116	500582.904	515	515	12	331	515 [1]	184[1]	2907.05	06/04/07	351.50	2555.55

Notes:
ADWR = Arizona Department of Water Resources
UTM = Universal Transverse Mercator (Zone 12)
NAD 83, meters = North American Datum of 1983
NAVD 88 = North American Vertical Datum of 1988
ft amsl = feet above mean sea level
ft bls = feet below land surface

[1] depth to bottom of screen and screen length are not provided in the ADWR well registry and therefore estimated

TABLE 2
Summary of Hydraulic Parameters for MO-2007-Series Wells

Well	T (ft^2/day)	S	b (ft)	Kh (ft/day)
MO-2007-1A	20,000	0.001	815	25
MO-2007-1B	25,000	0.001	815	31
MO-2007-1C	7,000	0.001	815	8.6
MO-2007-2	13,000	0.001	110	118
MO-2007-3B	17,700	0.001	1,060	17
MO-2007-3C	10,100 - 11,600	0.00016 - 0.001	1,060	9.5 - 11
MO-2007-4A	7,500	0.005	835	9
MO-2007-4B	10,000 - 20,000	0.005 - 0.1	835	12 - 24
MO-2007-4C	8,680 - 9,000	0.001	835	10-11
MO-2007-5B	31,200	0.001- 0.1	1085	29
MO-2007-5C	785	0.001	1085	0.72
MO-2007-6A	4,150 - 17,000	0.0057	325 - 655	12 - 31
MO-2007-6B	210-750	0.001	190 - 655	1.1

Notes:

T = Transmissivity

S = Storage coefficient

b = Assumed aquifer thickness

Kh = horizontal hydraulic conductivity calculated as T/b

ft/day = feet per day

ft^2/day = feet squared per day

TABLE 3
Water Quality Data for Initial Sampling of MO-2007-Series Wells

Well Name	ADWR 55 Well Registry Number	Sample Date	Field pH (SU)	Field EC (µS/cm)	Field Temp (deg C)	Sulfate, total	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Nitrate as N, dissolved	Nitrite as N, dissolved	Nitrate/Nitrite as N, dissolved	Calcium, dissolved	Magnesium, dissolved
MO-2007-1A	**907342**	**08/08/07**	7.17	370	29.0	19.2	19.2	8.4	0.4	0.54	< 0.01	0.54	40.4	6.4
MO-2007-1B	**907210**	**08/02/07**	7.41	321	30.7	18.9	18.9	12.4	0.6	0.71	< 0.01	0.71	32.4	4.3
MO-2007-1C	**907209**	**07/31/07**	7.35	523	27.9	114	112	22.4	0.5	0.82	< 0.01	0.82	57.5	9.3
MO-2007-2	**906765**	**06/14/07**	7.05	1372	32.2	596	591	28.3	0.3	0.94	< 0.01	0.94	196.0	35.5
NP-2 [1]	**605898**	**06/04/07**	7.20	411	25.9	41.3	41.2	9.1	0.2	0.34	< 0.01	0.34	50.3	10.9
MO-2007-3B	**906816**	**09/10/07**	7.53	373	28.7	38	38	7.0	0.5	0.33	< 0.01	0.33	31.5	2.8
MO-2007-3C	**906817**	**06/28/07**	7.93	570	32.2	136	136	11.4	3.1	0.30	< 0.01	0.30	28.2	1.4
MO-2007-4A	**907213**	**10/09/07**	7.46	412	27.5	37.2	37	10.2	0.3	0.93	< 0.01	0.93	42.8	6.2
MO-2007-4B	**907212**	**10/11/07**	7.93	376	26.4	37.5	37.6	9.1	0.6	0.77	< 0.01	0.77	41.6	4.3
MO-2007-4C	**907211**	**08/16/07**	7.62	472	35.2	78.6	78.7	11.8	5.0	0.48	< 0.01	0.48	13.0	0.3
CW-3 [1]	**627483**	**06/06/07**	7.74	449	25.3	58.7	57.9	17.7	0.3	2.92	< 0.01	2.92	56.1	10.9
MO-2007-5B	**907456**	**10/12/07**	7.63	1150	29.9	392	402	44.5	1.2	1.97	0.01	1.98	84.8	3.7
MO-2007-5C	**907457**	**08/23/07**	7.46	780	31.4	252	248	12.0	2.1	0.13	0.02	0.15	30.0	1.4
MO-2007-6A	**907607**	**10/02/07**	7.52	405	28.5	27	26.5	10.5	0.3	0.99	< 0.01	0.99	36.3	5.4
MO-2007-6A [DUP]	**907607**	**10/02/07**	7.52	405	28.5	26.5	26.5	10.5	0.3	0.98	< 0.01	0.98	36.4	5.4
MO-2007-6B	**907606**	**10/04/07**	7.70	483	33.1	93.5	93.6	10.9	0.5	0.67	0.02	0.69	28.1	2.9

Notes:

All units are in milligrams per liter (mg/L) unless otherwise noted

1 = Existing well designated as monitoring well for sampling the shallow zone of the basin fill aquifer
ADWR = Arizona Department of Water Resources
SU = Standard Units
µS/cm = microsiemens per centimeter
deg C = degrees Celsius
TDS = Total Dissolved Solids
meq/L = milliequivalent per liter
DUP = Duplicate Sample

TABLE 3
Water Quality Data for Initial Sampling of MO-2007-Series Wells

Well Name	ADWR 55 Well Registry Number	Sample Date	Potassium, dissolved	Sodium, dissolved	Total Alkalinity	Bicarbonate as CaCO3	Carbonate as CaCO3	Hydroxide as CaCO3	Residue, Filterable (TDS) @ 180ºC	TDS (calculated)	TDS Ratio (measured/ calculated)	Sum of Anions (meq/L)	Sum of Cations (meq/L)	Cation-Anion Balance (%)
MO-2007-1A	**907342**	**08/08/07**	3.0	30.4	164	164	< 2	< 2	250	209	1.20	3.9	3.9	0.0
MO-2007-1B	**907210**	**08/02/07**	3.2	40.5	140	140	< 2	< 2	220	199	1.11	3.6	3.8	2.7
MO-2007-1C	**907209**	**07/31/07**	4.8	49.3	124	124	< 2	< 2	380	334	1.14	5.5	5.9	3.5
MO-2007-2	**906765**	**06/14/07**	7.7	73.5	108	108	< 2	< 2	1060	1000	1.06	15.4	16.1	2.2
NP-2 [1]	**605898**	**06/04/07**	3.9	31.7	169	169	< 2	< 2	280	250	1.12	4.5	4.9	4.3
MO-2007-3B	**906816**	**09/10/07**	3.1	44.1	134	134	< 2	< 2	250	209	1.20	3.7	3.8	1.3
MO-2007-3C	**906817**	**06/28/07**	3.3	93.4	103	103	< 2	< 2	380	340	1.12	5.4	5.7	2.7
MO-2007-4A	**907213**	**10/09/07**	3.3	37.1	160	155	5	< 2	270	239	1.13	4.3	4.3	0.0
MO-2007-4B	**907212**	**10/11/07**	2.9	35.7	143	143	< 2	< 2	230	221	1.04	3.9	4.0	1.3
MO-2007-4C	**907211**	**08/16/07**	1.9	80.8	103	101	2	< 2	310	256	1.21	4.3	4.2	-1.2
CW-3 [1]	**627483**	**06/06/07**	3.0	30.5	140	140	< 2	< 2	300	273	1.10	4.7	5.1	4.1
MO-2007-5B	**907456**	**10/12/07**	5.5	164.0	95	95	< 2	< 2	780	771	1.01	11.8	11.9	0.4
MO-2007-5C	**907457**	**08/23/07**	7.1	129.0	71	71	< 2	< 2	540	473	1.14	7.0	7.4	2.8
MO-2007-6A	**907607**	**10/02/07**	3.8	39.8	164	164	< 2	< 2	920	225	4.09	4.2	4.1	-1.2
MO-2007-6A [DUP]	**907607**	**10/02/07**	3.8	40.0	163	163	< 2	< 2	260	225	1.16	4.2	4.1	-1.2
MO-2007-6B	**907606**	**10/04/07**	11.3	60.6	125	119	5	< 2	400	287	1.39	4.8	4.6	-2.1

Notes:

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