FREEPORT-MCMORAN COPPER & GOLD

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PO Box 527
Green Valley, Arizona 85622-0527

February 2, 2009

Via Certified Mail # 7008 1140 0000 4223 1191
Return Receipt Requested

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

Re: Revised Aquifer Characterization Report
Mitigation Order on Consent Docket No. P-50-06

Dear Ms. Campbell:

Freeport-McMoRan Sierrita Inc. submits three copies of the enclosed Revised Aquifer Characterization Report (ACR) for Mitigation Order on Consent Docket No. P-50-06. The revised ACR addresses comments and requirements from Arizona Department of Environmental Quality's review of the ACR in 2008.

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.

Sincerely,

Ned Hall

E. L. (Ned) Hall
Chief Environmental Engineer

ELH:ms
20090202_001
Attachments

xc: Joan Card, Arizona Department of Environmental Quality, without attachments
John Broderick, Sierrita
Chad Fretz, Sierrita
Stuart Brown, Bridgewater Group, Inc.
Jim Norris, Hydro Geo Chem, Inc.

REVISION 1

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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January 30, 2009

REVISION 1

AQUIFER CHARACTERIZATION REPORT

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MITIGATION ORDER ON CONSENT DOCKET NO. P-50-06
PIMA COUNTY, ARIZONA

Prepared for:

FREEPORT-MCMORAN SIERRITA INC
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Approved by:

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James R. Norris
Arizona Registered Geologist No. 30842

January 30, 2009

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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. In April 2008, PDSI changed its name to Freeport-McMoRan Sierrita Inc. Because this report was originally submitted in the name of PDSI, and to avoid confusion and unnecessary revisions, the references to PDSI have been retained.

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.

The initial version of this report was submitted to ADEQ on December 28, 2007. Revision 1 of the Aquifer Characterization Report (ACR) was developed in response to written comments (ADEQ, 2008) and discussions with ADEQ. Report components changed for Revision 1 were portions of the main text and figures, and Appendices A, D, and I. To avoid unnecessary revisions, the dates and footers of the report were only changed on components that were revised. Formal written responses to ADEQ's comments were also submitted by Freeport-McMoRan Sierrita Inc. to ADEQ in June 2008 (Hall, 2008).

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
  - o Task 2.1 Data Compilation and Evaluation
  - o Task 2.2 Groundwater Monitoring
  - o Task 2.3 Depth-Specific Groundwater Sampling at Existing Wells
  - o 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).

The well inventory report presented the results of work to identify and sample drinking water supply wells within one mile of the sulfate plume. Section 2.1 reviews the results of the well inventory. The results of water quality and water level measurements collected during the investigation of the sulfate plume were reported in quarterly groundwater monitoring reports as the data became available. The results of the quarterly groundwater monitoring events are compiled and described in Section 2.2.2. The interceptor wellfield evaluation report assessed the effectiveness of the interceptor wellfield at capturing sulfate-impacted seepage from the PDSTI. As described in Section 2.3, the interceptor wellfield evaluation used pumping and water quality information over time to estimate the sulfate mass capture of the wellfield. Because these reports were submitted to ADEQ as the work was completed, the results of that work are only summarized by this report. For completeness, electronic copies of previously submitted reports are included in a compact disc located at the end of Section 6. Previously submitted reports are also available at the information repository at the Joyner-Green Valley Branch Library or from the PDSI document library website (http://www.fcx.com/sierrita/home.html). This report provides 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 cross gradient 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 at the time of the well inventory in the fourth quarter of 2006 (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 within on mile of the plume at the time of the well inventory, one was a private domestic supply well and nine were public supply wells. A water quality sample was collected from the Gatterer 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 (Figure 2). 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 wells 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 the well inventory was completed and 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 and Appendix B). Sulfate concentrations of samples collected in the third quarter 2007 are shown in Figure 2. The results of the quarterly sampling indicate that, in general, the drinking water supply wells show no temporal trends in sulfate concentrations

(Table B.2, Appendix B)[1]. One exception to this general observation is at ESP-1, where sulfate concentrations consistently decreased overtime after pumping at the well ceased.

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.

[1] ADEQ (2008) hypothesized that sulfate concentrations were increasing in drinking water supply wells GV-2 and CW-10. The sulfate concentration data in Table B.2 do not support the hypothesis that concentrations increased at GV-2 and CW-10. Additionally sulfate concentration data collected subsequently at GV-2 and CW-10 through the fourth quarter 2008 show that sulfate concentrations have been steady over time. ADEQ (2008) also hypothesized "aggressive subsurface plume migration" in the vicinity of GV-2 and CW-10 based on data at the MO-2007-5 wells. Conditions at the MO-2007-5 wells are discussed in Section 2.2.2.2.

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. HGC's review of the hydraulic data found that most estimate were made using appropriate methods, could be replicated, and were consistent with the range of values previously determined for similar materials. Tables A.3 and A.4 of Appendix A compare the results of the hydraulic test analyses conducted under Task 2.1 and hydraulic conductivity estimates reported by the Work Plan (Table A.5). These comparisons show that the hydraulic properties data reported in the Work Plan are suitable for use in aquifer characterization. The hydraulic properties of the basin fill and bedrock are described further in Section 3.2.3 which discusses sulfate transport.

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). Data from the newly installed wells (Section 2.2.4) allows the extent of the sulfate plume and the details of groundwater elevations to be better defined than they were for previous sampling events. 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 extent of the sulfate plume shown on Figure 1 and the sulfate concentration contours shown on Figure 4 were developed using sulfate concentrations measured in wells with different screened intervals, including some co-located wells. The majority of sulfate concentration data are for wells screened over large sections of the aquifer so the data do not provide depth-specific sulfate concentration information. Consequently, sulfate concentration contours and plume extent inferred from measurements taken in these wells represent vertically averaged concentrations. In contrast, co-located wells do provide information on the vertical distribution of sulfate in the aquifer because the co-located wells allow water samples to be collected from discrete depth intervals in the basin fill aquifer. For co-located well sites, the highest measured sulfate concentrations were used in constructing the concentration contours rather than an average concentration of the discrete depth intervals at a particular site. Using the highest measured sulfate concentrations at co-located wells is the most conservative method of plume delineation because it estimates the largest potential extent of the sulfate plume.

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. In particular, the sulfate concentrations measured in the M0-2007-5 wells delineate a more eastward plume extent than inferred from previous sampling events. This can be seen by comparing the sulfate concentration contours in the third quarter of 2007 (Figure 4) with those for the first quarter of 2007 (Figure B.1). The additional data from the MO-2007-5 wells do not suggest eastward plume migration between the third quarter 2007 and previous sampling events. Instead, the sulfate detected at the MO-2007-5 wells was likely present but unknown until the MO-2007-5 wells were installed. Thus, the difference in the inferred eastward plume extent is due to incorporation of data from the newly constructed MO-2007-5 wells which had not been installed as of the first quarter of 2007. This conclusion is substantiated by groundwater level contours in the vicinity of the MO-2007-5 wells that show a northeast to northward hydraulic gradient (Figure 5), indicating that sulfate migration eastward from the MO-2007-5 wells is unlikely.

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, whereas sulfate concentrations of approximately 300 to 450 mg/L occur in bedrock immediately west and upgradient of the PDSTI. 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. The distribution of sulfate vertically within the basin fill aquifer is discussed in Sections 2.2.4.3, 2.3, 3.1, and 3.2.2 which report and evaluate the results of depth-specific sampling.

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. Groundwater elevations range from about 2900 feet above mean sea level (ft amsl) at the southern end of the Canoa Ranch wellfield to about 2500 ft amsl north of the Twin Buttes Tailing Impoundment (Figure 5). Based on the inferred groundwater elevation contours shown in Figure 5, groundwater flows from the flanks of the Santa Rita Mountains on the east and Sierrita Mountains on the west toward the central axis of the basin, and then northerly. The greatest regional hydraulic gradients, inferred from the groundwater contours in Figure 5 range from about 0.015 to 0.025 eastward from the PDSTI. Regional hydraulic gradients in the central aquifer range from about 0.006 to about 0.008 northward. This overall pattern of water levels and groundwater flow is consistent with expected regional groundwater flow patterns in the southern portion of the Tucson groundwater basin (e.g., Pima Association of Governments (PAG), 1983b, and Mason and Bota, 2006). 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). Potential vertical hydraulic gradients are discussed in Section 2.2.4.3 which presents the results of initial sampling at monitoring wells installed under the Work Plan.

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,, although groundwater elevations at specific wells are observed to vary seasonally, with elevations being lowest in the late summer (e.g., compare Figure 5 and Figure B.2). Of the 90 wells for which depth to water was measured in both the first and third quarters of 2007 (i.e., winter and summer), approximately 78 percent of water elevations declined in the summer and 22 percent increased. Water elevation declines in the summer typically ranged from less than a foot to 8 feet.

2.2.3 Task 2.3 - Depth-Specific Sampling

Depth-specific sampling and inflow 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 using the Hydro Booster technique and inflow velocity profiling was conducted using the Dye Tracer technique (BESST, Inc.). The Hydro Booster technique uses pressurized tubing to retrieve groundwater samples from wells at discrete well depths. The Dye Tracer technique compares travel times of a fluorescent dye tracer injected at different depths in a pumping well to infer groundwater inflow at discrete well depth intervals. Both techniques allow for depth-specific sampling at wells without the removal of pumps or pump housing. Sampling and inflow profiling was conducted at intervals of 50 feet within the screened portion of the well to a minimum depth of 50 feet below the water table (the Hydro Booster sampler required about 50 feet of submergence for sample retrieval. A more detailed discussion of depth-specific sampling techniques is provided in Appendix C.

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 (sampled from 450 to 750 ft bgs) and MH-12 (sampled from 470 to 700 ft bgs) are relatively consistent. The depth to water in MH-11 and MH-12 was approximately 370 ft bgs and 420 ft bgs, respectively. At the time of depth-specific sampling, water samples were not collected at the water table because the sampling technique required at least 50 feet of submergence of the sampling device.

The general implication 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. From these tests, the uniformity and continuity of the high permeability zones is uncertain given the large distances between wells. Offsite well installation and testing conducted as part of Task 2.4 was unable to identify any well-defined preferential pathways or continuous hydrostratigraphic units.

The zones of increased permeability observed in depth-specific sampling ranged from about 50 to 150 feet thick in portions of the basin fill aquifer where saturated thicknesses are 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. Neither depth-specific sampling or observations of geology during drilling (Sections 2.2.4.1 and 3.2.1) were able to project features laterally due to lack of well-defined continuous layering 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 (Sections 2.2.4.2 and 3.2.1). 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 (Sections 2.2.4.3 and 3.2). Given these conditions, the northern and eastern extents of the plume are established by wells at sites, MO-2007-1, MO-2007-3, MO-2007-4, and MO-2007-6 (Section 2.2.2.2).

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. In general, new monitoring wells were located as proposed in the Work Plan, subject to the successful negotiation of site access. In the case of the MO-2007-6 wells, site access negotiations were conducted with several parties over a period of six months, but were unsuccessful in gaining access to the location proposed in the Work Plan. As a result, the MO-2007-6 wells were placed approximately 1,800 feet southwest of the location proposed in the Work Plan, where site access could be obtained and where the wells could still monitor any eastward plume migration. 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. Descriptions of the rationale for screened interval selection for each well are provided in Appendix D.

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. Aquifer testing consisted of step-rate pumping tests that used two 60- to 90-minute pumping periods followed by a 6- to 8-hour pumping period. The pumping rate was increased in each successive pumping period. The time series drawdown data collected by the aquifer tests were interpreted with analytical solutions that use the principal of superposition to account for drawdown due to well efficiency and pumping. Appendix E includes 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, as further discussed in Appendix D. Sections 3.1 and 3.2.3 discusses the permeability of bedrock and the potential role of bedrock as a source of sulfate to the sulfate plume.

The sulfate concentration data from initial water sampling at the MO-2007 wells along with data from existing 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. Additional discussion of plume boundaries is in Section 3.2.2.

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 production wells, particularly if fine-grained, semi-confirm layers are present. Because the production wells are within basin fill and not the deeper low permeability bedrock, any vertical gradients induced within the bedrock would likely be upward and downward migration of sulfate into the bedrock would be unlikely. The potential for sulfate transport within bedrock is discussed further in Section 3.2.

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). As discussed in Section 3.2.3, 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 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.

As discussed in Section 2.2.2.2, 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 stratigraphic 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. Figure 6 is a graph showing the frequency distributions of hydraulic conductivity estimates for basin fill and bedrock based on the data in Table A.5. The bedrock permeability is low compared to basin fill. Ninety (90) percent of bedrock hydraulic conductivities are less than 0.5 ft/day, whereas 90 percent of basin fill hydraulic conductivities are greater than 2 ft/day. The mean hydraulic conductivity for bedrock (50 percent) is nearly three orders of magnitude less than that of basin fill. Because of its low permeability compared to basin fill, the bedrock aquifer is not considered to have significant groundwater flow or the potential to transport sulfate relative to the basin fill aquifer. The low permeability of bedrock would also limit the potential for sulfate migration into bedrock from basin fill.

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

3.2.2.1 Lateral Distribution

The lateral distribution of sulfate in the basin fill aquifer is shown on Figure 4 and cross-sections showing the vertical distribution of sulfate are provided in Appendix H. The extent of the sulfate plume as defined by the 250 mg/L contour is shown on Figure 1. Wells immediately south of PDSTI in the cross gradient direction had the lowest sulfate concentrations measured, typically less than 10 mg/L. The low concentration groundwater 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 PDSTI.

3.2.2.2 Vertical Distribution

The vertical distribution of sulfate in the basin fill is known from water sampling at co-located well nests with screens completed at different elevations and from depth-specific sampling from wells with long screened intervals conducted for Task 2.3. Most older (pre-2006) monitoring and production wells do not provide depth-specific data because they were constructed with long screen intervals, typically penetrating the full extent of the basin fill aquifer. Because sampling from wells with long screened intervals is typically conducted from pump discharge that draws groundwater from the entire screened interval and mixes it in proportion to the proximity to the pump intake and hydraulic conductivity of the formation at any given depth, variations in concentration with depth are indistinguishable using this sampling protocol.

The following discussion of sulfate concentrations is based on data collected from July through October 2007 (Figure 4 and Appendix H). There are two sets of co-located wells useful for evaluating the vertical distribution of sulfate. The one set consists of co-located wells MH-13, MH-25, and MH-26 which are within the sulfate plume. The other set of co-located wells are those at the MO-2007-1, -3, -4, and -6 sites outside of the plume.

Co-located wells MH-13, MH-25, MH-26, and MO-2007-5 within the plume (Figures H.3a, H.3b, H.6, and H.7) display different sulfate concentration patterns. Sulfate concentrations at MH-13 in the southern portion of the plume were between 1150 and 1760 mg/L in the upper and middle screened intervals and at 20 mg/L in the lowermost screened interval in Pantano Formation. Sulfate concentrations in MH-25 and MH-26 in the northern portion of the plume and at MO-2007-5 in the southeast portion of the plume exhibited concentrations of sulfate less than 60 mg/L in their upper screened intervals and elevated concentrations of sulfate in their middle and lower screened intervals. Sulfate concentrations between 730 and 1760 mg/L occurred in the middle and lower screened intervals of MH-25 and MH-26 whereas lower sulfate concentrations between 248 and 402 mg/L occurred in the lower and middle screened intervals of MO-2007-5. In general, the sulfate concentration was elevated at or above concentrations of 250 mg/L over most of the saturated basin fill at MH-13, MH-25, MH-26, and MO-2007-5 with the greatest concentration differences related to low concentrations of sulfate in the Pantano Formation at MH-13 and a zone of low sulfate concentrations in the upper several hundred feet of saturated basin fill at MH-25, MH-26, and MO-2007-5.

Co-located wells MO-2007-1, -3, -4, and -6 outside of the plume (Figures H.3a, H.4a, H.4b, H.5, H.6, H.7, H.8a, H.8b, H.9, and H.10) had sulfate concentrations less than 136 mg/L in the third quarter of 2007. The sulfate concentrations were highest in the lower screened intervals of MO-2007-1, -3, -4, and -6 corresponding to the lower zone of the basin fill and ranged from 78.7 mg/L to 136 mg/L (Section 3.2.1). Sulfate concentrations in samples collected from screened intervals in the middle and upper units of the basin fill at wells MO-2007-1, -3, -4, and -6 ranged from 18.9 mg/L to 41.7 mg/L. As discussed in Sections 2.2.4.3, the observation of higher sulfate in the deeper basin fill at co-located wells outside the plume, 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. Thus, it is hypothesized that the sulfate in the deeper basin fill may be naturally occurring background concentrations.

In summary, 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 higher 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. This, along with the strong northward hydraulic gradient of the basin fill aquifer near Green Valley, has limited the eastward migration of the southeast portion of the sulfate plume. In contrast, 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 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.

Bedrock is not a significant groundwater flow or sulfate transport mechanism. This conclusion is based on the extremely low permeability of the bedrock in comparison to the permeability of the overlying basin fill aquifer. This conclusion is based on the results of hydraulic tests of existing shallow bedrock wells at PDSI that indicate that bedrock hydraulic conductivities are significantly lower than basin fill hydraulic conductivities (Section 3.1, Figure

6; and Tables A.3, A.4, and A.5 of Appendix A). Because even the highest measured bedrock hydraulic conductivities, presumably representing bedrock fractures, are significantly lower than typical basin fill hydraulic conductivities, the bedrock is not an important conduit for sulfate migration to the basin fill even if elevated sulfate concentrations of sulfate are present in the bedrock.

In summary, the conceptual model of sulfate transport is that sulfate-sulfate bearing seepage from the PDSTI infiltrates and mixes with groundwater in the basin fill. Some of the sulfate-laden water bypasses the northern interceptor wellfield and enters the northerly flowing regional aquifer system. Sulfate-laden water moves conservatively with the regional hydraulic gradients and/or locally-induced gradients caused by pumping towards drinking water supply wells, which are the potential receptors. Figure 7 illustrates the source-pathway-receptor conceptual model.

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.

4.1 Model Extents

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 active portion of the model domain covers an area of approximately 100 square miles (260 square kilometers [km^2]), extending 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) (Figure I.2). From the PDSTI this region extends east about 8.5 miles (13.5 km). The area of primary emphasis for the model is the vicinity of PDSTI and includes the current extent of the sulfate plume as defined by the 250 mg/L concentration contour.

4.2 Model Construction

MODFLOW-SURFACT version 3.0 (HydroGeologic, Inc., 1996) is the numerical code used for the groundwater flow and transport simulations. MODFLOW-SURFACT is a finite-difference model based on the widely used United States Geological Survey modeling program

MODFLOW (McDonald and Harbaugh, 1998). The model domain is discretized into 215 rows, 162 columns, and 3 layers. The coarsest grid cell spacing (400 meters by 400 meters) occurs in the southern, northern, and eastern positions of the model domain, peripheral to the area of emphasis. The finest grid cell spacing (100 meters by 100 meters) is centered in the area of primary emphasis (Figure I.3). Placing the largest grid cells in the periphery of the model domain and decreasing the grid cell size within the area of primary interest reduced computation requirements without compromising spatial resolution within the area of primary interest. The temporal domain of the model is divided into three simulation periods: steady-state (1940), historic (1941 – 2007), and predictive (2007 and beyond).

Boundary conditions, groundwater and sulfate sources and sinks, and initial hydraulic parameters were specified based on previous modeling efforts, previous field investigations, and aquifer characterization studies performed for this Aquifer Characterization Report, and calibration to measured groundwater levels and sulfate concentrations. Boundary conditions include no-flow boundaries where the basin fill aquifer pinches out against mountain fronts and specified head boundaries at the south and north ends of the model domain. Natural recharge along the mountain fronts was accounted for by specifying mountain front recharge immediately interior to the no-flow boundaries. The hydrologic processes included in the model are river recharge, mountain front recharge, and artificial recharge, seepage from tailing impoundments, evapotranspiration, and groundwater pumping. Aquifer properties controlling groundwater flow and sulfate transport include saturated hydraulic conductivity, storage coefficient, specific yield, effective porosity, and dispersivity. Aquifer properties were spatially variable. The details of how boundary conditions, hydrologic properties and aquifer property zones and values were specified are given in Appendix I.

4.3 Model Calibration

The initial aquifer and sulfate transport properties were adjusted within reasonable ranges during model calibration. The model calibration was an iterative process that considered both measured groundwater levels and measured sulfate concentrations. The historic measurements of groundwater levels and sulfate concentrations that were used for model calibration were taken from the PDSI database, reports of groundwater monitoring investigations, and previous numerical models. Groundwater monitoring data collected during the first and third quarters of 2007 as part of this Aquifer Characterization report was used to calibrate the model for the end of 2006. The adjustments made to model parameters during calibration improved the match between measured and simulated groundwater levels and sulfate concentrations and were consistent with the conceptual model and field measurements. Details of the model adjustments made during calibration are included in Appendix I, and the ranges of initial and final model parameters are listed in Table I.1.

The results of the calibrated model are presented as contour maps comparing measured and simulated water level elevations and sulfate concentrations. Figures 8 and 9 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 8 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 9. The model is considered suitable for the purpose of simulating plume behavior under potential mitigation actions, although the model's ability to simulate certain portions of the sulfate plume are limited. In particular, the model simulation for the year 2006 is unable to simulate the full southeastern extent of the sulfate plume (as defined by the 250 mg/L concentration contour). This may lead to under prediction of the future southeastern extent of the plume, although the strong northward gradient of the regional aquifer will likely restrain any rapid eastward migration of the plume. The model also slightly over predicts the northern extent of the plume. The over prediction of the plume's northern extent results from the model's difficulty in simulating the sharpness of the sulfate plume at the down gradient end, where sulfate concentrations rapidly decrease from about 1,400 mg/L at M-20 to 100 mg/L and less at MO-2007-1 which is approximately 4,000 feet to the northeast. This may lead to a conservative prediction (i.e., earlier arrival of predicted than measured) at the northern extent of the plume. These areas of discrepancies, while minor compared to the overall sulfate plume, illustrate localized limitations of the model and highlight the need to couple model simulations with a field monitoring program in an adaptive management approach.

4.4 Strengths and Limitations

The numerical model has been constructed and calibrated specifically for use in the Feasibility Study 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. Particular strengths of the model in meeting this objective include the following:

- Large spatial extents of the model domain that reduce the influence of boundary conditions within the area of the plume.
- Long temporal extent, beginning in 1940 when the aquifer is considered to be in "dynamic equilibrium", minimizes the influence of initial aquifer conditions on future simulations.
- Integration of the most comprehensive datasets on aquifer characteristics (e.g., Ksat values and bedrock elevations).
- Calibration to both groundwater level and sulfate concentration measurements, including measurements taken as part of the Aquifer Characterization Plan.

These strengths make the model well suited for providing conceptual design bases for potential mitigation actions considered in the Feasibility Study. Equally important to understand, are the limitations of the model.

Numerical models are by necessity generalizations of more complex systems. The generalizations put practical limits on the applicability and predictive ability of the model. For example, 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 the model spatial and temporal discretization does not allow for sub-grid (or sub-stress period) resolution of point values. Also, because information on aquifer characteristics and groundwater levels used for conceptual model development and model calibration decreases away from the area of emphasis, the confidence in model predictions decreases away from the area immediately down gradient of the PDSTI. For similar reasons, the model's predictive ability is expected to decrease the farther forward in time that projections are made.

In conclusion, when the appropriate applications and limitations of the numerical model are respected, it can be an effective tool to evaluate the various mitigation actions to be considered in the Feasibility Study. Any use of the model outside the area of the sulfate plume or outside the scope of the Feasibility Study may require additional aquifer characterization and model refinement. In addition, performance monitoring of a mitigation action based on predictive simulations 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.

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. At the time of this report there are no active drinking water supplies 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 that had become impacted by sulfate exceeding the 250 mg/L threshold.

- 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:

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