Safford Mine

2012 – 2013 Groundwater Monitoring Report

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Project 00010

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1.0 Introduction

This report summarizes and presents an evaluation of the Model, Monitor, and Mitigate (3M) Program for the Dos Pobres/San Juan Project (Safford Mine) for the 2012-2013 evaluation period. This is the sixth annual 3M evaluation. This evaluation was done in accordance with the Dos Pobres/San Juan Project Clean Water Act Section 404 Mitigation and Monitoring Plan (MMP), described in the Dos Pobres/San Juan Project Final Environmental Impact Statement (FEIS) (Section 3 of Appendix F of the FEIS; BLM, 2003). The U. S. Geological Survey (USGS), a stakeholder identified in the MMP, provides technical review of the annual 3M Program reports, performs biennial sampling of wells for water chemistry analyses, and hosts the 3M Program website. This report was prepared for Freeport-McMoRan Safford Inc. (FMSI) by AquaGeo, Ltd., with technical assistance from Clear Creek Associates and Dr. Robert Mac Nish.

The 3M Program was devised to assist in evaluating effects of groundwater pumping at the Safford Mine and the adequacy of ongoing measures implemented to mitigate such effects. The 3M Program involves the use of statistical measures in a series of tests using water level data from specified groundwater monitoring locations. Each statistical measure (3M Statistic) is evaluated against a set of criteria (3M Criteria).

A component of the 3M Program is a three-dimensional computer model of groundwater flow (URS Corporation, 2002), known as the 2002 FEIS Model. The 2002 FEIS model is based on "MODFLOW-96" published by the U. S. Geological Survey (USGS) (Harbaugh and McDonald 1996). The 2002 FEIS model was slightly modified, as discussed in Section 5.0, to allow it to perform the appropriate simulations for the current 2012-2013 3M evaluation. The model used in the current 2012-2013 3M evaluation is called the 2013 3M model. The purpose of the model is to predict future changes of the current and planned mining operations on the aquifer system near the mine, and ultimately show how these predicted changes may influence groundwater conditions, either directly or indirectly, tens of miles from the mine. Therefore, the model is ultimately used to predict potential impacts, if any, to the Gila River, Bonita Creek and the San Carlos Apache Reservation. The model is calibrated in both steady-state and transient modes to observed hydrogeologic conditions. Water level data obtained from numerous monitor wells in and around the Safford Mine (**Figure 1**) are used in the 3M Program to compare simulated results with measurements.

The sets of 3M Criteria establish bounds for each statistical test, and depending on whether a statistic value falls in or out of the range of specified bounds, a predetermined decision is identified regarding the next step to be performed. Based on the overall evaluation result of the 3M Program, one of two possible actions will be implemented:

- Recalibrate the model, run the mining period prediction, and adjust the mitigation as necessary, or
- Wait one year and re-evaluate.

There are five groups of monitoring wells included in the 3M Program. The 48 wells, with Group numbers, are shown on **Figure 2**. The wells are grouped geographically and hydrogeologically based on their locations relative to the mining and production well pumping areas, or relative to the Gila River, which is located approximately eight miles to the south of the mine.

- Group 1 wells are located between the mining operation and the Gila River and are a critical component of the 3M Program. The primary purpose of the Group 1 wells is to evaluate potential aquifer changes in the Lower Basin Fill (LBF). Four wells (LBF-01, LBF-02, LBF-03 and LBF-04) are screened in the LBF, and two wells (LBF-01d and LBF-02d) are screened in bedrock beneath the LBF. Although LBF-01d and LBF-02d are in Group 1, they are not included in the evaluation tests of the 3M Program because they are not screened in the LBF (see Section 6).

- Group 2 wells are located similar to Group 1 wells, but occupy a larger geographical area. The intent of these wells is to monitor water levels in either the LBF or bedrock.

- Group 3 wells are located northeast of the Butte Fault. These wells are included in the 3M Program for general hydrogeological information. However, Group 3 wells are not included in the 3M decision process because they are not required for evaluating whether or not to recalibrate the model (see the MMP). All wells in this group are screened in bedrock.

- Group 4 wells are located northwest of the geologic structure known as a graben, which is a distinguishing feature in the vicinity of the Safford Mine. The Graben was formed by and is situated between the Butte Fault and the Valley Fault (**Figure 2**). Wells in this group are screened in bedrock. The production wells that provide water for the mining operation are located in the Graben structure to the southeast of the Group 4 wells[1].

- Group 5 wells are located between the mining operation and the San Carlos Apache Reservation boundary to the northwest and Bonita Creek to the northeast. Wells in this group also are screened predominately in bedrock.

Table 1 provides a summary of the following for wells in the 3M Program: group number, well name, coordinates, altitude of land surface, depth of open intervals, corresponding model layer and water level measured prior to when mining commenced. In addition, **Table 1** also provides summary information for wells from which water samples were collected for laboratory analysis (Section 4.3).

2.0 Purpose and Scope

The purpose of this 3M evaluation is to monitor the performance of the current 3M model in simulating the effects of actual pumpage on an annual basis. The 2013 3M model is a revised version of the original 2002 FEIS Model (see Section 5.0 below). The 3M evaluation relies on water level measurements obtained from wells in the vicinity of the Safford Mine. The results of this evaluation are used to assess whether or not the current 2013 model requires recalibration to bring the model projections into closer agreement with the water level conditions observed in the field. The model is used to predict potential future effects on the regional groundwater system and to guide the implementation of mitigation measures consisting of a farmland-fallowing program to offset the effects of mine pumping on the flow of the Gila River.

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[1] Shaft 1 produces groundwater, most of which comes from the Graben structure, as discussed in Section 5.

August 2007 through June 2013 is called the “evaluation period” for the current 2012-2013 3M evaluation (see Section 4 below for additional detail). The scope of this report includes presentation of the available water level data for the 37 wells (Groups 1, 2, 4 and 5) for the evaluation period[2]. The compiled water-level data have been used to calculate differences between model-projected water levels and gradients with those collected by, or estimated from, measurements obtained from the 3M monitoring program. Information developed from the four well groups and the 3M model are used in a decision process illustrated in **Figure A1 of Attachment 1**, titled “Schematic Flow Chart of the Groundwater Model, Monitor, and Mitigate Process”. Note that **Figure A1 of Attachment 1** is equivalent to Figure 11 of the MMP except that it has been annotated in red to identify test numbers described in Section 6.0.

3.0 Background

The Safford Land Exchange between Phelps Dodge Corporation (now Freeport Minerals Corporation) and the Bureau of Land Management (BLM) was completed in September 2005. Following receipt of the remaining environmental permits, Phelps Dodge Safford, Inc., now FMSI, began construction of the Safford Mine in August 2006. Mining operations in the Dos Pobres pit began in August 2007.

During 2006, groundwater pumping for construction water was accomplished by installing relatively small horsepower (HP), temporary pumps in two of the production wells, GI-P1 and GI-P4 (**Figure 2**). A larger HP pump was also installed in Shaft 1 in the spring of 2007. By the fourth quarter of 2007, permanent pumps with greater HP were installed in production wells GI-P1, GI-P2, and GI-P4. Also during the fourth quarter of 2007, water was used to pre-wet the crushed/screened over-liner fill and run-of-mine rock layers on top of the leach pad liner in advance of leaching activities. Crushed ore agglomerated with water and acid was placed on the leach pad for the first time near the end of November 2007. Shortly thereafter, water and acid were applied to the mined ore materials by drip lines. Prior to this time, most of the water produced at the mine was used for dust control and, to a lesser extent, other construction-related work, such as moisture conditioning of the leach pad under-liner materials. The first production of copper cathode from the electrowinning tank house occurred on December 26, 2007.

Implementation of the Alternate Year Fallowing Plan to mitigate impacts to the Gila River (see Section 3.3.3 of Appendix F of the FEIS) commenced in January 2008, with the fallowing of 200 acres of farmland near the Gila River in the Sanchez area. The amount of acreage fallowed every year is the same but the fields that are fallowed change each year. Fields fallowed as part of this plan during 2013 are listed in **Attachment 2** of this report.

4.0 Data Summary

This section provides a summary of the data available for the 2012-2013 3M evaluation. The evaluation includes groundwater production rates and groundwater levels from July 2012 through June 2013.

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[2] Water level data are presented for LBF-01d and LBF-02d, but are not used in any of the 3M tests (see Section 6).

4.1 Groundwater Production Rates

Prior to December 2007, the average monthly groundwater production rate was estimated based on periodic meter readings of pumped volumes. The values listed are average rates for each month, starting December 2007. They are based on automatically recorded pumping rates that were digitally recorded at regular intervals by FMSI. The average pumping rates were derived from the pumping records by calculating the total volume pumped, in gallons, for each month and dividing the value by the total number of minutes in the corresponding month.

Figure 3 shows the monthly average pumping rate for each production well over time since March 2006, when site preparations began. Groundwater pumping through November 2007 was relatively small, typically ranging from 40 to 680 gpm. Mining commenced in August 2007 followed by leaching operations in December 2007 resulting in an increase in pumping. Since that time, average monthly pumping has ranged from a low of about 740 gpm in February 2010 to a peak of just over 3,370 gpm in October 2011. In general, fluctuations in pumping rates correlate closely with seasons, with larger pumping rates occurring during the summer months and smaller pumping occurring during winter months. This seasonal variation in rates is due to the amount of precipitation and evaporation occurring at the site.

The average pumping rate for the 2012-2013 evaluation (sixth year of mining) was approximately 1,800 gpm, which is 49% of the anticipated pumping rate simulated in the 2002 FEIS Model for the same year of mining. From the time when mining commenced in August 2007 to the end of June 2013, the total volume of water pumped was approximately 19,300 acre-ft. This volume is approximately 37% less than the anticipated volume of approximately 30,800 acre-ft simulated in the 2002 FEIS Model for the first six years of mining due to an overly conservative estimate of water demand.

4.2 Water Levels

The equipment used to monitor water levels at wells in each of the five well groups of the 3M Program are owned and operated by FMSI[3]. Most water-level data are collected by Allen Pump Company (APC) of Safford, Arizona, who is subcontracted by FSMI for this activity. APC submits the water-level data on behalf of FMSI to the USGS, who reviews and then posts the data on their National Water Information System (NWIS) website: http://nwis.waterdata.usgs.gov/nwis

The water level data can also be accessed from the USGS project website that is linked to the NWIS: http://az.water.usgs.gov/projects/9671-BGJ/samap-gmap.html. Water–level data for this report were obtained from the USGS NWIS. Water level hydrographs for wells in each of the five well groups of the 3M Program are shown in **Figures 4** to **14**.

The hydrographs show that measured water levels fluctuate over time in every well of the 3M Program. These fluctuations generally occur over durations of less than a day to several months. For example,

[3] USGS provides periodic oversight and makes confirmatory measurements biannually.

during the month of June 2005, daily to weekly water-level fluctuations in LBF-01 (a Group 1 well[4]) ranged in magnitude from approximately 0.02 to 0.15 feet; whereas, longer-term, monthly fluctuations at the same location ranged in magnitude from approximately 0.05 to 0.1 feet in 2007. These fluctuations can hide or mask small changes in hydraulic gradients and drawdown caused by pumping.

There are 44 wells in the 3M Program with data on which to assess water-level trends. **Table 2** summarizes the short-duration water-level changes and the water-level change for the evaluation period for each of the 44[5] wells in each of the 3M well groups. The following sections describe water-level trends in four areas: 1) the Graben (where most of the pumping occurs), 2) the area south and southwest of the Graben, 3) the area north and east of the Graben, and 4) other areas. This section also describes water-level changes since mining began and the area most likely affected by pumping for mine operations.

Graben

Water levels in the Graben area started declining shortly after 2006, when pumping began for mine construction and subsequent operation. Wells AP-11, AP-12, DPW-01/GI-T21, GI-T18 and GI-T34 monitor water levels in the Graben area that are influenced by pumping. These wells show an early phase in which the water level declined linearly a small amount prior to pumping for current mine operations. This period is followed by a trend of increasing decline with time that started around the time pumping began, which is then followed by a period of linear decline with time. The hydrograph for AP-11 on **Figure 9** best exemplifies this behavior.

South and Southwest of the Graben

Water-level trends in several wells completed in bedrock just south and southwest of the Graben have declines that are also likely influenced by mine pumping. The wells exhibiting this response include AP-22, AP-34, and DPW-03. The hydrograph for DPW-03 (**Figure 8**) exemplifies this type of hydrologic behavior. Water-level declines in these wells started in mid-2007. It must be noted that the current 2013 3M model (Section 5.0) does not represent these declines sufficiently well.

The influence of mine pumping on wells farther to the south and southwest of AP-22, AP-34, and DPW-03 is less apparent in the water-level data. It appears that mine pumping may not be the sole cause of water-level decline in wells farther south and southwest of these wells. Unlike wells in the Graben, the start of water-level decline occurs at approximately the same time in several of the wells (mid-2011) and approximately 4 years after declines began in AP-22, AP-34, and DPW-03. Additionally, the overall frequency and longer-term amplitude of water-level fluctuations amongst the wells is similar. An example of this behavior is seen by comparing DPW-07 (near to the Graben where pumping occurs) and DPW-13 (far from the Graben in the direction of the Gila River; for locations see **Figure 2**). The hydrographs of these two wells (**Figures 5 and 6**) show strong similarities in both the magnitude and

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[4] The Group 1 wells have pressure transducers and dataloggers that record water levels on a daily basis. Most other wells are measured manually on a quarterly basis.

[5] Three wells in the 3M Program, AP-01, AP-3A and AP-21 have unusual water-level fluctuations or have no data available for evaluating long-duration trends; thus, 44 wells are evaluated with regard to long-duration trends. Well GI-T21 replaces DPW-01; this pair of wells has been treated as one location.

longer-term timing of water level changes despite the fact that DPW-07 is approximately 2 miles from the Graben and DPW-13 is approximately 3.5 miles from the Graben in the general direction of groundwater flow. With few exceptions, these types of similarities occur regardless of the distance of a well from the Graben where pumping occurs. If mine pumping were the sole cause of the declines, it is likely that some attenuation of the influence of pumping on water levels with distance from the Graben would be measured and noted in the hydrographs.

The influence of several processes on groundwater flow, including mine pumping and natural variations in groundwater recharge result in the observed water-level fluctuations and trends. The primary effect of groundwater pumping on groundwater levels results from the capture of groundwater that would have flowed toward wells downgradient of the Graben. Natural variations in recharge are caused by spatial and temporal variations in precipitation and other factors.

North and East of the Graben

In this area, a number of monitor wells completed in bedrock exhibited declining water levels 4 to 5 years before the start of mine pumping. This area includes DPW-06, AP-10, GI-T20, GI-T38, G5-01A and G5-01B. This suggests that at least in some bedrock areas, groundwater levels may have been declining because of reduced recharge related to the current drought, which began locally in the late 1990's (see AP-10 on **Figure 11** and AP-20 on **Figure 8**). The most dramatic response of this type was observed in well G5-01A (**Figure 14**) where the water level declined from at least August 2003 until mid-2011, then stabilized at approximately 4,879 ft and has remained relatively constant since then. The total water decline prior to the commencement of mine pumping was approximately 12 feet. Well G5-01A is located several miles north and upgradient of the mine, far from mine activity.

Well RB-1 is located at Pima Gap, near the boundary of the San Carlos Apache Reservation, and is completed in bedrock. For the period from August 2003 through June 2013 (excluding the measurements in June and September of 2008), the average water-level elevation in RB-1 was 4,858.19 ft (**Figure 14**). The minimum and maximum water-level elevations for this period were 4,857.96 ft and 4,858.67 respectively. The annual average water level in this well has declined no more than approximately 0.1 ft since 2003, which is much smaller than the range of water-level fluctuations in the well of approximately 0.7 ft. The water level in G5-02, which is completed in bedrock on the north side of Lone Star Mountain, while continuing to rise a small amount, seems to be stabilizing at approximately 3,843 ft. Both of these wells are far from the Safford mining operations, and the water-level trends and fluctuations in these wells probably reflect natural variations in the groundwater system.

Other Areas

Between November 3 and November 12, 2011, pumping tests were performed at well WW-2 to obtain estimates of aquifer hydraulic parameters for the LBF aquifer. This well is located approximately 2 miles southwest of the Graben (1,450 feet south and slightly east of LBF-01 and 3,130 feet northeast of LBF-02, see **Figure 2**). During the pumping tests, the well was pumped at a rate of up to approximately 1,100 gpm. Water levels in LBF-01, LBF-01d, LBF-02 and LBF-02d reflect hydraulic responses to the pumping stress (**Figure 4**). Hydrologic responses in other wells may also have been caused by the WW-2 pumping test. Data from the pumping tests will be used in future efforts to improve the groundwater model for the 3M Program.

Water level measurements taken at the Group 1 wells indicate that natural water-level fluctuations and trends occur at approximately the same time and magnitude in both the LBF (LBF-01 and LBF-02) and the deeper bedrock (LBF-01d and LBF-02d) (**Figure 4**). This suggests that a significant hydraulic connection exists between bedrock and LBF in the zones monitored by these wells.

Since early 2013, an anomalous water level rise of approximately 40 feet has been recorded at AP-24 (**Figure 9**), which is located south of the San Juan Pit. A smaller rise of approximately 10 feet was also recorded in late January 2008. The 2008 rise may have been a delayed response to infiltration of 5.6 inches of precipitation and subsequent runoff during July and August of 2007. Two unlined stormwater retention ponds constructed after 2008 are nearby this well. The larger 2013 rise may have caused by infiltration of stormwater generated from approximately 0.58 inches of precipitation during December 2012 that was accumulated and retained by the ponds.

Another well with an abrupt water level rise is well GI-T25 (Group 4), which is located adjacent to the Butte Fault, approximately 2 miles northwest of the Dos Pobres pit. The hydrograph for GI-T25 on **Figure 13** indicates a water-level rise of nearly 14 feet between June and September 2007. This well is located approximately 50 feet north of one of the mine's stormwater diversion ditches that were constructed in 2006. The ditch near the well channels stormwater runoff. The cumulative precipitation recorded at Safford Airport for June, July and August of 2007 was 4.3 inches (based on data obtained from the National Climate Data Center) compared to the long-term average (1987 to 2001) of 3.46 inches for the same three months. The 2007 water-level rise in GI-T25 appears to be in response to increased recharge from infiltration of runoff under and adjacent to the newly constructed diversion ditch when there was apparently enough precipitation to cause water to flow into the diversion ditch. Smaller water-level rises in GI-T25 were also detected in 2008 and 2010; however, no rise was detected in 2009, coincident with less precipitation (approximately 2.2 inches for June-August 2009). The annual pulses of recharge from the ditch appear to mask, but do not completely overwhelm, the longer-term trend of declining water levels in the well. Despite the anthropogenically-enhanced recharge in the vicinity of GI-T25, its water-level trend remains reasonably consistent with other nearby wells such as GI-T20 (**Figure 13**) where water levels were declining before the current mining began. Because of the consistency with other nearby wells, monitoring of GI-T25 will continue as part of the 3M evaluation. Since there are no other monitor wells in this area, an attempt will be made to separate out the effect of local infiltration from pumping influences.

Since mid-2007, the water level in GI-T18, which is located in the Graben, has declined 103 feet (**Figure 13)**. The total magnitude of the water-level decline in GI-T18 is much larger than declines observed in other surrounding wells such as GI-T20, GI-T25, GI-T38, and G5-01B. The water level decline in GI-T18 began in early 2007, soon after mine construction began, and then increased abruptly in January 2008. Because of the consistent rate of decline in the surrounding wells (**Figures 13 and 14**), it appears that GI-T18 is more hydraulically connected to the pumping center in the Graben, or to the mine dewatering system, than the surrounding wells, perhaps through fracture zones sub-parallel to the Butte Fault located north of GI-T18. Given that nearby well GI-T34 also shows substantial water level decline (just under 40 feet), it appears that drawdown from pumping in the Graben structure is focused by the Butte and

Valley Faults towards the northwest, possibly by cross-faults and fracture zones. As discussed with the USGS for concurrence in August 2013, GI-T18 is not being included in the current 2012-2013 3M evaluation because routine statistical screening of the Group 4 water-level data indicates that GI-T18 is an outlier[6] as compared with other Group 4 wells, whose inclusion would introduce bias in the 3M evaluation. The purpose of the 3M statistical screening is to assess the need for model recalibration by comparing observed and predicted drawdown. Since water level measurements taken in GI-T18 and GI-T34 indicate localized drawdown within the bedrock fracture systems, recalibration of the entire model does not appear warranted at this time based only on observed drawdown in GI-T18. If at least one other nearby well provides confirmatory observations, GI-T18 will be restored as a Group 4 well in the 3M Program.

Net Water-Level Change

For each well in the 3M Program, an estimate of the net change in water level between July 2007 (prior to pumping for mine operations) and June 2013 has been calculated as shown in **Table 2** and on **Figure 15**. Net change is defined as the overall change in water levels over that period, despite any trends or fluctuations in water levels established prior to the onset of the pumping. The area with groundwater declines solely or mostly due to mine pumping is also shown on **Figure 15**. In general and as expected, net water-level changes are greatest in the vicinity of the Graben where mine pumping has occurred. Areas outside of the Graben may also exhibit a smaller influence from mine pumping.

4.3 Water Chemistry

Water chemistry samples were collected from wells in the area of the Safford Mine at locations shown on **Figure 16** to monitor conditions prior to and during mining operations. Samples were collected from 11 wells in November 2012 using procedures based on the USGS field manual (USGS 2010). Sampling of spring water was discontinued after the 2009-2010 evaluation period because evaluation of the data collected up to that time showed that spring water and regional groundwater were derived from different sources and are not hydraulically connected (AquaGeo, 2011c). After July 2012, well DPW-01 could no longer be sampled due to an insufficient amount of water in the well, so it was eliminated from the sampling program. The water chemistry data for this report were downloaded from the USGS NWIS website (see Section 4.2). A summary of the water chemistry data is provided below and the data are contained in Appendix A.

Anions and Cations

Anion and cation concentrations from the November 2012 sampling event are plotted on a piper diagram (**Figure 17**) and as stiff diagrams (**Figure 18**). Four general water types have been identified based on the stiff diagrams:

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[6] The Dixon Extreme Value Test (Singh, Maichle and Armbya, 2010) was used to identify outliers in the calculated change in water levels of Group 4 (water-level changes were computed using the methods of Test 2A, Section 6.3). The water-level change computed for GI-T18, 102.7 feet, was identified as an outlier at a significance level of between 5% and 10%.

- Water Type 1 contains relatively more Na+K and Cl, and was present at AP-26, AP-27, and AP-29 in the mountain-front pediment area and at AP-01 near the northern FMSI property boundary.

- Water Type 2 contains relatively more Na+K and HCO_3, and was present at AP-01, AP-09 and AP-11. AP-09 also exhibits relatively higher concentrations of chloride.

- Water Type 3 contains relatively more Ca+Mg and HCO_3, was present at AP-22, GI-P1 and GI-P2. AP-22 also exhibits relatively higher concentrations of Na+K.

- Water Type 4 contains relatively more Na+K and SO_4, and was present at AP-21, which is located east of the San Juan pit, and at DPW-06, which is located north of the San Juan pit.

Stable and Radioactive Isotopes

Groundwater samples collected for the 3M Program were analyzed between 2005 and 2012 for the stable isotopes carbon-13, oxygen-18, and deuterium, as wells as the radioactive isotopes carbon-14 and tritium.

The groundwater samples generally have more carbon-13 than typically found in modern organic matter (biological systems tend to concentrate carbon-12 and omit carbon-13). This suggests that a source of inorganic carbon, derived from carbonates in soil or rock, has contributed to the concentration of this isotope in the samples. Similarly, the carbon-14 concentrations in water samples have likely been influenced by sources of inorganic carbon, which may also contain carbon-14. Water concentrations of carbon-14 may be enhanced by dissolution of carbon-14 bearing carbonate minerals.

Delta oxygen-18[7] and delta deuterium[8], as plotted on **Figure 19**, lie below the global meteoric water line[9], suggesting that a strong evaporative effect has concentrated the heavier isotopes. This evaporative effect is consistent with the semi-arid environment of the Safford region.

5.0 Groundwater Model for 3M Program

The 3M plan requires that long-term effects from mine pumping on the groundwater system be prepared using predictions from a numerical groundwater model. To test the model's ability to make representative long-term projections, the model is annually updated with pumping information to make short-term predictions for comparison to water-level data measured from the monitoring network for the 3M Program. For the first 3M evaluation (2007-2008), the groundwater model developed for the FEIS (URS Corporation 2002), known as the 2002 FEIS model, was slightly modified to allow it to perform the appropriate simulations for the 2007-2008 evaluation period. Modifications to the 2002 FEIS model are described in detail in the 2007-2008 3M report (AquaGeo, 2011a). The modified 2002 FEIS model is referred to as the 2008 3M model. For the current 2012-2013 3M evaluation, a copy of the 2008 3M

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7 "Delta Oxygen-18" is a measure of how much oxygen-18 there is in a sample relative to a standard amount, and is a function of ratios of the two isotopes, oxygen-16 and oxygen-18.

8 "Delta Deuterium" is a measure of how much deuterium (hydrogen-2) there is in a sample relative to a standard amount, and is a function of ratios of the two isotopes, hydrogen-2 and hydrogen-1.

9 A meteoric water line represents typical conditions for precipitation for a certain area.

model was further modified as described in this section. The model used in the current 2012-2013 3M evaluation is called the 2013 3M model.

The current 2013 3M model was developed using the following modifications that were made to the 2008 3M model:

- The newest groundwater pumping well, GI-P07, was added to the model. The location of the pumping well in the model is slightly different from its actual location due to limitations of the model grid layout that was developed for the 2002 FEIS Model.

- Three simulations were prepared using the 2013 3M model.

    1. A steady-state simulation of pre-mining conditions was first conducted in which pumping related to the mine was excluded. This simulation is essentially a re-run of the 2002 FEIS Model to obtain initial hydraulic-head conditions for conducting the subsequent transient simulations. Because the 2002 FEIS Model was calibrated to steady-state conditions, characterized by water levels available through June 1996, all transient simulations start in June 1996.

    2. The second simulation was a transient prediction for the period of time from June 1, 1996 to June 30, 2013. This period of time includes pre-mining groundwater pumping conducted for the purposes of large-scale testing or to supply construction water, as well as full-scale pumping for the mining operation that began in 2007.

    3. The third simulation was a transient prediction for the same period of time as the second, except that no pumping for mining operations was included. This third simulation provides the hydraulic head data for the groundwater system without mine-related pumping stresses. This dataset is used for calculating the predicted drawdown due to mining. This was accomplished by subtracting predicted water levels with mine pumping from those without pumping.[10] The second and third predictive simulations are referred to as "pumping" and "non-pumping" simulations, respectively.

- The transient simulations are based on stress periods of one month in length. The total number of stress periods is 205. Each stress period is simulated using five time steps of varying length (shortest at the beginning of the month).

- For each monthly stress period, the average monthly rate of pumping was specified at each pumping well in the model based on FMSI records. Section 4.1 provides a discussion of pumping rates and their estimation.

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[10] It is likely that if pumping from the pre-mining period were included in the model-predicted drawdown and subsequently used in 3M Tests, the conclusions of the overall 3M Program would not change. The method of computing predicted drawdown in a large three-dimensional transient model with varying hydraulic conductivity and hydraulic stress by comparing two transient simulations is a commonly accepted method that improves the precision of the calculated drawdown.

Except as noted above, no recalibration was performed and no other changes were made to the 2008 3M model to develop the current 2013 3M model used for this report. After running the transient pumping and non-pumping simulations, predicted drawdown was calculated for subsequent 3M calculations. The total amount of water pumped in the model was checked to confirm that it was the same as the actual recorded pumping.

6.0 Implementation of the 2012-2013 3M Evaluation

Evaluation of the 3M Criteria using statistical tests requires comparisons of observed and modeled elevations of groundwater at specified monitor wells. These wells, along with the 3M group numbers, are shown on **Figure 2**. Each 3M statistic to be estimated from the water-level data is described in Section 3.3.1.3, "Data Analysis" of the MMP. The evaluation of the program is achieved through a decision process that is comprised of a series of tests. The specific tests, along with numerical values of the 3M Criteria, are described in Figure 11 of the MMP (**Figure A1**, **Attachment 1**).

The influences on measured water levels from both groundwater pumping for mining purposes and natural background fluctuations are incorporated into both the measurement-based estimates of changes in water levels and in the measurement-based hydraulic gradients generated for each of the 3M tests. For monitoring locations where the natural water-level fluctuations and trends are significant, the influence of mine pumping may be a small component of the measurement-based estimates of change. In fact, the component related to the pumping may not be discernible at all from the direct measurements, especially in areas distant from where the pumping occurs. The difficulty in assessing these small groundwater pumping effects on the aquifer system is one benefit of utilizing the 3M model.

The 3M Program (BLM, 2003) uses the Group 1 wells to assess potential impacts to the LBF aquifer, the most permeable and widespread aquifer southwest of the mine. The program also uses the deep wells LBF-01d and LBF-02d to monitor water-level conditions in the bedrock beneath the LBF for model calibration purposes (particularly the vertical gradient between the bedrock and overlying LBF). According to well logs and well construction information, LBF-01d and LBF-02d are completed in bedrock just below the LBF. The monitoring intervals of these wells are sealed off from the LBF, so that water-level measurements taken in these two wells are representative of the bedrock groundwater system immediately beneath the LBF. In addition, due to the substantially smaller permeability of the bedrock relative to that of the LBF, any hydraulic influence from the mine pumping in the LBF should be transmitted to the deep Group 1 wells through the overlying LBF. Therefore, wells LBF-01d and LBF-02d are not included in the 3M calculations.

Each test of the 3M Program corresponds to a specific test in the flowchart shown in Figure 11 of Appendix F of the FEIS (**Figure A1**, **Attachment 1**). Boxes on the left side of the flow chart are numbered Test 1 and Test 2, whereas corresponding boxes on the right side are numbered 1A and 2A. Diamond shapes on the figure indicate the established 3M Criteria against which each test is evaluated. Each of the applicable tests for the 2012-2013 evaluation period is discussed in detail in the following subsections.

6.1 Description and Results of 3M Test 1

Test 1, which only applies to Group 1 wells, focuses on water-level changes in the LBF between the mine and the Gila River. Test 1 is intended to evaluate the difference between two values for each Group 1 well, with each value representing an estimate of the influence of mine pumping on site groundwater levels. The first value is calculated from measured groundwater levels, whereas the second value is a simulated water level obtained from the 2013 3M model for the same location. Both values represent a change in water level between pre-mining conditions and mining conditions at the end of the evaluation period. For each well, the calculated difference between the two values is the statistical measure of Test 1. To meet the statistical requirements of Test 1, the difference between the modeled and measurement-based values must be 5 feet or less. The 3M Program allows for an adjustment of the measurement-based value that may account for variations in water levels that are not related to mine pumping, as discussed below.

An adjustment for natural fluctuation in water levels is critical to properly applying the statistical evaluation of Test 1. Depending on which period of time is used to calculate the amount of natural water-level variation from measured water levels, the resulting estimate of drawdown attributed to the mine pumping may not be realistic. A one-year period of time just prior to mine startup (August 1, 2006 to July 31, 2007) is used for calculations related to pre-mining conditions. For the current 2012-2013 3M evaluation, available water-level data for Group 1 wells were used for calculating the average pre-mining water level and the pre-mining range of natural water-level fluctuation for each well during this period. The natural-fluctuation range is calculated by subtracting the minimum measured pre-mining water level from the maximum measured pre-mining water level for the one-year period.

A one-month period of time, from June 1, 2013 to June 30, 2013 (the end of the evaluation period) is used for calculations related to mining conditions as called for in the 3M Program.[11] Therefore, available water-level measurements for Group 1 wells for this one-month period were used for calculating the average water level during the time period associated with mine pumping.

Estimated water-level changes based on model predictions were calculated from the pumping and non-pumping simulations (Section 5.0). To calculate the model-projected magnitude of change due to mine-related pumping, the water level at the end of June 2013 for the pumping simulation was subtracted from the water level at the end of June 2013 for the non-pumping simulation.

For the current 2012-2013 3M evaluation, results of Test 1 (**Table 3**) indicate that, for each Group 1 well, the difference between the two values representing the estimated influence of mine-related pumping on the groundwater system is within the permissible criterion established by the 3M Program. This is because the model predicts very little drawdown at the LBF wells (less than 0.01 ft). Essentially all of the calculated difference between the values estimated by the model and the values computed from water-level data is associated with variation in the measured water levels. In the first four years of the 3M evaluation (2007 to 2011), the difference in these two values increased from zero as the drawdown calculated from water-level data became increasingly nonzero (net water-level differences exceeded the pre-mining water-level fluctuation). Then, as measured water levels decreased over the last two years

[11] See Section 3, Exhibit 3, Appendix F of the FEIS; BLM, 2003

(2012 and 2013), drawdown calculated from the water-level data decreased and has been obscured by the much larger pre-mining fluctuation (as it was in the first year of evaluation). Hence, the 2013 values shown in **Table 3** are all zero after rounding.

According to the MMP, if the difference between these two values is less than the pre-mining range of water-level fluctuations, the criterion for the test is presumed to be satisfied. Based on the successful results of Test 1 for this evaluation period, the decision analysis of the 3M process proceeds to the next step, Test 1A.

6.2 Description and Results of 3M Test 1A

Test 1A is intended to evaluate the difference between two values representing changes in horizontal hydraulic gradients due to the influence of groundwater pumping for mining purposes. The first value is calculated from measured groundwater levels, whereas the second value is calculated based on modeling results from the transient simulation. For this test, the change in hydraulic gradient over time is expressed as a percentage. For the model to pass the Test 1A criterion, the difference between the two percentages must be 25% or less. The 3M Program does not allow for an adjustment of the measurement-based value representing the magnitude of change in hydraulic gradient that could account for natural water-level variations.

Because the hydraulic gradients are a composite response to numerous factors, including fluctuations of the natural system and groundwater pumping for mining purposes, the computed gradients represent a composite measurement-based value for assessing the magnitude of overall change across the area of interest. Prior to installation of the Group 1 wells, there were no data available on the transient variability of water levels in the Group 1 area. For Test 1A, hydraulic gradients based on measured water-level data are computed for two pairs of wells: LBF-01 and LBF-02, and LBF-03 and LBF-04. The computed hydraulic gradients based on measured water levels are much smaller than anticipated when the 3M Program was originally conceived. This has resulted in a situation where small natural water-level fluctuations cause gradient changes that exceed the range of the gradient criterion specified in the 3M Program.

Test 1A only applies to the following two pairs of wells in Group 1 (see Section 6.0 regarding the exclusion of wells LBF-01d and LBF-02d):

- LBF-01 and LBF-02
- LBF-03 and LBF-04

A straight line connecting each well pair, oriented northeast to southwest and approximately in the direction of the anticipated pre-mining water-level hydraulic gradient, was used for computing hydraulic gradients. For each well pair, the measurement-based values of hydraulic gradients were calculated as follows. In accordance with the 3M Program, the pre-mining average water level from Test 1 for the southwestern well (LBF-02 or LBF-04) was subtracted from the pre-mining average water level from Test 1 for the northeastern well (LBF-01 or LBF-03). This water-level difference is then divided by the distance in feet between the two wells in the well-pair under evaluation to provide a gradient value. A positive hydraulic gradient indicates an overall groundwater flow direction to the southwest. The hydraulic gradient value for the mining period is calculated using the same procedure used for the pre-mining period, except that the average water levels for the mining period are used. Estimated hydraulic gradients based on model predictions were calculated similar to the measurement-based estimates using model-based average water levels at the model cells corresponding to each well location.

The percent change in hydraulic gradient over time is then computed for each well pair from the estimates of hydraulic gradient for the pre-mining and mining periods[12]. This calculation is performed for both measurement-based values and model-based estimates of hydraulic gradient. The difference between the measurement-based and model-based change in hydraulic gradient, expressed in percent, is then computed and compared to the criterion of Test 1A.

The results of Test 1A for the current 2012-2013 3M evaluation period indicate that the difference between the model- and measurement-based values of hydraulic gradient change over time are unacceptable according to the 3M Program for the LBF-03/LBF-04 well pair (**Table 4)**. Under normal conditions, the results of Test 1A would indicate that the decision analysis of the 3M process should proceed to Test 2. However, the analysis of hydraulic gradient changes has been complicated by widespread rising water levels occurring before 2011 followed by widespread water-level declines from 2011 to 2013. As a result, any impact from mine pumping is obscured by these widespread regional changes. As indicated in the hydrographs of Group 1 wells shown on **Figure 4**, groundwater levels near the mine were in fact higher in June 2013 than they were at the beginning of mining in 2007. Furthermore, the 3M Program, as originally conceived, did not anticipate a period of water-level rise, even during mining operations, which has led to the current situation and has rendered Test 1A inconclusive. Therefore, it is recommended that the results of Test 1A be considered inconclusive and that another year's worth of water-level data be collected and analyzed with the intent of having the updated model ready for the next 3M evaluation. Additional data and modeling may clarify both the causes of the declines and the nature of the hydraulic connections between the LBF wells and the Graben.

Assuming that the inconclusive nature of Test 1A is acceptable, instead of proceeding to Test 2, the decision analysis of the 3M process proceeds to Test 2A, which focuses on the Group 4 and 5 wells that are closer to the mine pumping.

6.3 Description and Results of 3M Test 2A

The intent of Test 2A is similar to that of Test 1, except Test 2A applies to wells in Groups 4 and 5. The numerical criterion for Test 2A is 10 feet of water elevation difference for the current 2012-2013 3M evaluation. Unlike Test 1, the 3M Program for Test 2A does not allow for an adjustment of the measurement-based values of water-level change that may account for transient variation in water levels that are not related to mine operations.

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[12] Percent change in gradient is computed by subtracting the June 2013 gradient from the June 2007 gradient, then dividing that difference by the June 2007 gradient, and then multiplying the result by 100 (Section 3, Exhibit 3, Appendix F of the FEIS; BLM, 2003). A positive percentage indicates a decrease in the gradient toward the southwest.

For Test 2A, water levels measured immediately prior to the start of mining are considered representative of pre-mining conditions. Similarly, conditions during mining operations are assessed using the water levels measured nearest the end of the evaluation period (June 2013). For conducting the comparison to model prediction results, the simulated water level closest in time to the measured water level is used to represent pre-mining (i.e. non-pumping) and mining (i.e., pumping) conditions for each well and time period. To calculate the water-level change, the selected water levels during the mining period are subtracted from the selected pre-mining water levels.

To implement the test, the absolute value of the difference between the measurement-based change and the model-based change for each well of Group 4 and 5 is calculated. The mean value of change for each group of wells is then calculated for comparison to the test criterion.

For the current 2012-2013 3M evaluation period, the results of Test 2A indicate an acceptable difference between the modeled estimates of water-level change and the change in water level based on measurements for wells in Groups 4 and 5. **Table 5** provides a summary of results for Test 2A, which indicates that the statistical measures for the test comply with the mean value criterion of 10 feet for each well group. This outcome for Test 2A is reasonable considering the trends indicated by measured water levels for all wells of Groups 4 and 5. With the elimination of an evaluation of Test 2 and the successful outcome of Test 2A, the decision analysis of the 3M process terminates at the conclusion of Test 2A. According to the 3M Program, monitoring will continue for one year before a re-evaluation is conducted to assess possible further actions. Given the likely outcome that an additional one-year of monitoring will not substantially change the outcome of the 3M tests, it is recommended that an update to the 3M model be completed for the next 3M Program evaluation. In addition, given some of the difficulties encountered in implementing the 3M Program, it is further recommended that other statistical methods and criteria be explored for a potential modified 3M Program.

6.4 Summary of 3M Evaluation

An evaluation of the 3M Program for the 2012-2013 evaluation period has been conducted utilizing the 2013 3M model to represent groundwater conditions and simulated responses to induced stresses. The results of the 3M evaluation for the 2012-2013 period are summarized in **Table 6**. Although one 3M test was deemed inconclusive (Test 1A), recalibration of the existing model is not recommended at this time based on the results of the current 3M evaluation. Instead, it is recommended that an update to the 3M model be completed for the next 3M Program evaluation based on the inability of the model to adequately represent water-level declines in Group 2 wells AP-22, AP-34 and DPW-03.

7.0 Summary and Conclusions

The sixth annual evaluation of the 3M Program for the Safford Mine has been conducted. The purpose of the 3M evaluation is to monitor the performance of improved versions of the 2002 FEIS 3M model with regard to its ability to simulate properly the changes in water levels and hydraulic gradients over time as mining proceeds. The performance of the model is evaluated using a series of statistical tests that compare differences between measurement-based values and model-based estimates of hydrogeologic conditions. The measurement-based values are calculated from water-level data obtained from five groups of wells monitored for the 3M Program. The model-based estimates are obtained from a version of the 2002 FEIS Model that has been modified to simulate water-level responses based on actual monthly average pumping rates for the mine. The 2013 3M model is the most recent improved version of the model and the 2002 FEIS Model represents the most recent calibration of the model.

The intent of the 3M Program is to provide a representative groundwater model that can reliably predict future effects of mine pumping on the groundwater system. The available data indicate that stresses from mine pumping remain relatively localized within and near the Graben and have not had wider impacts on other regional aquifers.

Well GI-T18 was not included in this year's 3M Program evaluation due to a localized water-level decline observed in the well that is a statistical outlier compared to other nearby wells. GI-T18 will be added back to the 3M evaluation process when additional wells indicate that the influence of mine pumping has spread over a larger area than is suggested by just this one well.

Eleven wells were sampled in November 2012, for analysis of water chemistry. Results of these analyses show that the groundwater chemistry is stable and that there are no discernable effects from the mining operation.

Review of the water-level data from the five groups of 3M wells indicates that significant water level trends were established long before the commencement of mining. Of particular interest, increases in the water level elevations have been observed in all of the Group 1 wells, and many of the Group 2 wells located closest to the Gila River. The increase in water levels at these locations began more than two and a half years before groundwater pumping commenced at mine production wells GI-P1, GI-P2, GI-P4 and Shaft 1. This trend of increasing water levels may be obscuring any effect on the groundwater system from localized mine pumping and has made interpretation of water level changes more challenging than had been envisioned for the 3M Program.

Actual pumping rates for the Safford Mine, both during the construction period and through the mining period that have been included in this analysis, are substantially less than the original estimated water demand rates used in the FEIS (Section 2.1.2.2.1 of the FEIS). These water demand rates were used in the 2002 FEIS Model for developing model-simulated effects of mine development and operation. However, given the actual water demand for the Safford Mine thus far, and the current operating plans, the pumping rates for the foreseeable future are expected to be significantly less than the rates originally used in the model to predict potential effects to the regional groundwater system, including potential effects to surface flows of the Gila River.

Water levels in many of the wells in Groups 1 and 2 began declining in 2011 after a long period of water level increases. The magnitudes of water-level declines since 2011 are smaller than the overall increases that occurred prior to 2011. Water levels in numerous Group 2 wells appear to have stopped declining and some wells again show a slight water-level rise although this observation is only based on a few recent water level measurements. Preliminary review of the water-level data suggests that the water-level declines (or rises) could be due to variable recharge from changes in precipitation, due to mine pumping, or due to a combination of both. Water level changes in and near the Graben also suggest that drawdown surrounding the mine's wellfield is more complex due to hydrogeologic conditions than originally envisioned when the FEIS was being prepared. Additional data and modeling will support efforts to better understand the aquifer system, and the system's response to mine pumping and to natural variations in recharge. The recorded data indicates that the regional groundwater system is in a dynamic state that started well before the current mining operations and continues to the present. The influence of several processes on groundwater flow, including mine pumping and natural variations in groundwater recharge, result in the observed water-level fluctuations and trends.

Considerable data has been collected since the inception of the 3M Program. Incorporating this new information in the model should lead to improvements in our understanding of groundwater conditions in the area being monitored and should improve the ability of the model to simulate observed conditions. Although the result of the current 2012-2013 evaluation of the 3M Program is that the model apparently does not need to be recalibrated at this time, an update of the model using more advanced software technology, and evaluation of the updated model based on the accumulated monitoring data is in progress, and will be incorporated into the next 3M Program report. The result should be an improvement in the ability to predict hydraulic response of the groundwater system to pumping for mine operations and to adjust the mitigation, as necessary. In addition, proposed modifications to the 3M Program will be discussed with the USGS.

8.0 Selected References

AquaGeo, 2011a, 2007–2008 Groundwater Monitoring Report, Dos Pobres / San Juan Project.

AquaGeo, 2011b, 2008–2009 Groundwater Monitoring Report, Dos Pobres / San Juan Project.

AquaGeo, 2012, 2009–2010 Groundwater Monitoring Report, Dos Pobres / San Juan Project.

AquaGeo, 2013, 2010–2011 Groundwater Monitoring Report, Dos Pobres / San Juan Project.

Bureau of Land Management, 2003, Final Environmental Impact Statement, Dos Pobres / San Juan Project; 2 volumes.

Environmental Simulations Inc, 2007, Groundwater Vistas, Version 5. Available from www. groundwatermodels.com

Harbaugh, A.W. and McDonald, M.G., 1996, User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model; U.S. Geological Survey Open-File 96-485; 56 p.

Singh, A., Maichle, R. and Armbya, N., 2010, ProUCL Version 4.1 User Guide (Draft), Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations, U.S. Environmental Protection Agency, EPA/600/R-07/041.

URS Corporation, 2002, Documentation of a Regional Ground-Water Flow Model of the Dos Pobres/San Juan Project and Vicinity, Near Safford, Arizona; September 26, 2002.

U.S. Geological Survey, 2010, National Field Manual for the Collection of Water-Quality Data, U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapters A1-A9, variously dated, http://pubs.water.usgs.gov/twri9A.

TABLES

FIGURES

APPENDIX 1

ATTACHMENT 1

ATTACHMENT 2