FEASIBILITY STUDY AND MITIGATION PLAN FOR DRINKING WATER SUPPLIES AFFECTED BY SULFATE

MITIGATION ORDER ON CONSENT DOCKET NO. P-121-07

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March 28, 2012

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1. INTRODUCTION

1.1 Overview of the Feasibility Study and Mitigation Plan for Affected Drinking Water Supplies

The Feasibility Study (FS) and Mitigation Plan for affected drinking water supplies (i.e., supplies that currently have sulfate concentrations greater than 250 milligrams per liter [mg/L]) identifies mitigation actions that were evaluated by Freeport-McMoRan Corporation Copper Queen Branch (CQB) for existing drinking water supplies that contain sulfate due to the Concentrator Tailing Storage Area (CTSA) located at CQB south of Bisbee, Arizona (Figures 1 and 2). The Mitigation Plan for affected drinking water supplies describes the steps that are underway to implement mitigation actions, and proposed to monitor and ultimately terminate mitigation actions.

On November 14, 2007, CQB and Arizona Department of Environmental Quality (ADEQ) entered into Mitigation Order on Consent Docket No. P-121-07 (Mitigation Order) to address drinking water supplies affected by the sulfate plume from the CTSA. Groundwater investigations conducted to address Mitigation Order requirements in the vicinity of the CTSA have identified a groundwater sulfate plume which is defined as consisting of groundwater with sulfate concentrations in excess of 250 mg/L sulfate. The sulfate plume extends southwesterly and southerly from the CTSA toward Naco and Bisbee Junction as shown on Figure 3. The FS and Mitigation Plan for affected wells were prepared pursuant to the Mitigation Order.

The Mitigation Order requires CQB to characterize the hydrogeology in the vicinity of the sulfate plume and to develop a Mitigation Plan to practically and cost effectively provide a drinking water supply to the owner/operator of an existing drinking water supply affected by sulfate attributable to the CTSA. Characterization was conducted in accordance with the ADEQ-approved *Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Concentrator Tailing Storage Area* (Work Plan) (Hydro Geo Chem, Inc., 2008). The results of investigations completed to characterize the hydrogeology and water quality of the sulfate plume are reported in the *Revision 1 Aquifer Characterization Report* (ACR) (Clear Creek Associates, 2010).

The Work Plan specified that a FS would be conducted to identify and evaluate potential mitigation actions for affected drinking water supplies. The Work Plan describes the following FS components:

- Identification and screening of potentially applicable response actions, control technologies, and process options
- Development and screening of mitigation alternatives
- Detailed analysis of mitigation alternatives
- Recommendation of a preferred mitigation alternative

The Work Plan originally envisioned one FS and one Mitigation Plan to address issues related to drinking water supplies affected by the sulfate plume. To accelerate implementation of mitigation actions for existing affected drinking water supplies, CQB undertook work to identify and evaluate potential mitigation actions while additional hydrogeologic characterization work was being completed and the revised ACR was being reviewed by ADEQ. As a result of this work, and with notice to ADEQ, some of the mitigation actions were commenced. Another result of the work was that the identification and evaluation of mitigation actions for affected domestic and public drinking water supply wells was relatively advanced when ADEQ approved the ACR in October 2011 (ADEQ, 2011).

Progress on the identification and evaluation of mitigation alternatives was reviewed with ADEQ at meetings on April 27, 2011, September 28, 2011, and November 29, 2011. CQB met with ADEQ to present and discuss CQB's evaluation of potential mitigation actions for the affected drinking water supplies, CQB's intention to work with the well owners to provide a final mitigation action for their wells, and the selection of the preferred actions by affected well owners. Technical memoranda on well replacement (Appendix A) and the migration rate of the sulfate plume (Appendix B) were also submitted to ADEQ in November 2011 and January 2012, respectively, as a result of the progress reviews of mitigation actions.

In January 2012 as follow up to a November 2011 meeting, CQB also proposed that ADEQ allow CQB to document the steps taken to develop mitigation actions for affected wells in a combined FS and Mitigation Plan that would be submitted in March 2012 (CQB, 2012). CQB also proposed a separate FS to be submitted in 2013 to address drinking water supplies that might be affected in the future. Drinking water supplies that may be affected in the future include unaffected supplies such as those in the path of or proximal to the sulfate plume. The Mitigation Plan for water supplies that may be affected in the future would be submitted 60 days after ADEQ approval of the FS for water supplies that may be impacted in the future. The two track FS process was proposed so that the Mitigation Plan for currently affected drinking water supplies could be submitted to ADEQ without waiting for the completion of additional studies needed for the analysis of mitigation alternatives for drinking water supplies that may be affected in the future.

There are 15 drinking water supply wells that contain sulfate in excess of 250 mg/L (Table 1). The "affected wells" are clustered in three areas: the Naco Highway/Purdy Lane (9 wells – 1 public supply well and 8 private domestic supply wells), the San Jose (3 private domestic wells), and the Bisbee Junction/Airport (3 private domestic wells) areas as illustrated on Figure 4. The FS identifies potential mitigation actions for the affected wells based on site-specific data including well location, groundwater chemistry, hydrogeologic conditions, the location of existing public water supplies, and discussions with owners of affected wells. The mitigation actions were evaluated based on their effectiveness, implementability, and cost. A range of potentially applicable mitigation actions were reviewed with ADEQ and the owners of affected wells. The mitigation alternative being implemented consists of actions that are not only effective at providing a reliable, long-term water supply, but are also preferred by the owners of affected water supplies.

1.2 Feasibility Study Approach

Section III.E of the Mitigation Order stipulates:

> *"PD shall submit a Mitigation Plan to ADEQ for review and approval, which identifies and evaluates alternatives (e.g., containment, collection and discharge*

with or without treatment, institutional controls, alternative water supplies (including, but not limited to a new supply well, use of an existing drinking water supply well, modifying the screened interval of an existing drinking water supply well, connection to an existing public drinking water supply system, and bottled water), mixing or blending, technically practicable treatment, and no action) to practically and cost effectively provide a drinking water supply that meets applicable drinking water quality standards and with sulfate concentrations less than 250 mg/L to the owner(s)/operator(s) of existing drinking water supplies determined from the characterization described in Section III.C of this Order and verified by sampling and analysis to have an average sulfate concentration in excess of 250 mg/L (or other legally enforceable numeric concentration for sulfate which is enacted by statue or rule after the effective date of this Consent Order) as a result of the sulfate plume originating from the PDCTSA".

Based on Section III.E, drinking water supply mitigation actions are measures that can be taken to provide an existing affected drinking water supply with a source of drinking water with less than 250 mg/L sulfate at the point of use. To accomplish the requirements of Section III.E, the FS identifies potential mitigation actions that are consistent with Arizona Revised Statue (ARS) § 49-286 pertaining to mitigation of non-hazardous releases such as sulfate.

ARS § 49-286.A states that a party may be ordered "*to perform one or more of the following mitigation measures as:*

1. *Providing an alternative water supply.*
2. *Mixing or blending if economically practicable.*
3. *Economically and technically practicable treatment before ingesting water.*
4. *Such other mutually agreeable mitigation measures as are necessary to achieve the purposes of this section.*"

The mitigation measures of ARS § 49-286.A are included as potential mitigation actions evaluated in the FS.

ARS § 49-286.B states "The director's selection of mitigation measures shall balance the short-term and long-term public benefits of mitigation with the cost of each alternative measure. The director may only require the least costly alternative if more than one alternative may render water usable as a drinking water source."

1.3 Report Organization

The remainder of the FS is organized as follows:

- Section 2 provides the site background including descriptions of the hydrogeology; the sulfate plume, and affected wells
- Section 3 identifies and screens potentially applicable response actions, technologies, and process options
- Section 4 identifies and screens mitigation alternatives
- Section 5 is a detailed analysis of the mitigation alternatives
- Section 6 identifies the preferred mitigation alternative
- Section 7 is the Mitigation Plan for implementing actions at affected water supplies

2. SITE BACKGROUND

The CTSA is approximately 3.5 miles southeast of Bisbee, four miles northeast of Naco, and one mile south of Warren (Figure 1). As defined in the Mitigation Order, the CTSA consists of two inactive tailing impoundments (the North Tailing Impoundment and the South Tailing Impoundment), a former evaporation pond, and a stormwater impoundment known as Horseshoe Pond (Figure 2). The North and South Tailing Impoundments and former evaporation pond cover an area of approximately 1,000 acres in Sections 27, 33, and 34, Range 24 East, Township 23 South, and Sections 3 and 4 in Range 24 East, Township 24 South. Comprehensive reviews of the site history, hydrogeology, and water quality in the vicinity of the plume are provided in the Work Plan and ACR, which are the sources of the following summary.

2.1 Site History

The CTSA facilities were used variably from 1905 through 1987 for the storage and evaporation of excess mine water, the placement of tailing and mine materials, and containment of stormwater. The CTSA facilities are currently inactive and receive no process solids or liquids.

The North and South Tailing Impoundments are inactive facilities that last received tailing in 1974. The impoundments are unlined and currently being reclaimed voluntarily by CQB by regrading, capping with local soil, and installation of engineered surface water management facilities. The soil capping will restrict rainfall from infiltrating to the tailing below the cap. The surface regrading and engineered surface water management facilities will shed, collect, and route rainfall from the impoundments without allowing infiltration to the tailing. The collected surface water will be used or recharged.

The former evaporation pond was an unlined pond of approximately 350 acres. Excess mine water was sent to the former evaporation pond from 1908 to 1987. Surface sediments from the bottom of the former evaporation pond were excavated and placed on the south slope of the South Tailing Impoundment between 1989 and 1990.

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Horseshoe Pond is an unlined stormwater impoundment of approximately six acres, constructed in 1990 in the footprint of the former evaporation pond. Horseshoe Pond periodically collects incident rainfall and stormwater runoff from the North and South Tailing Impoundments and areas north of the CTSA (Phelps Dodge Corporation [PD], 2004). Water that currently collects in the pond is pumped to the Lavender Pit for evaporation. Horseshoe pond will ultimately be reclaimed by grading to shed surface water to an engineered surface water management facility as part of the tailing impoundment reclamation.

Historically, water was pumped from the various shafts of the Warren Mining District to dewater underground workings during underground mining (PD, 1990 and 2004; Water Management Consultants, 2006). Dewatering ceased in 1987 with the end of underground mining. The estimated volume of groundwater pumped from underground workings from 1906 through 1987 is approximately 168.6 billion gallons (Water Management Consultants, 2006). Water from underground workings was used in mining and excess mine water was discharged to the former evaporation pond or used at the former Warren Ranch irrigation area (Figure 2).

As described in the ACR, the sulfate plume developed over 80 years primarily due to the infiltration of excess mine water historically discharged to the former evaporation pond and, to a lesser degree, mine water used for irrigation of crops at the former Warren Ranch irrigation area (PD, 1990; Savci Environmental Technologies, Inc., 1998). The potential for the CTSA and former mining facilities in the vicinity of the CTSA to be current or future sources of sulfate is considered negligible because the facilities have been inactive for many years, only temporarily receive rainfall or stormwater, are managed to minimize potential infiltration, and are being reclaimed. Based on the data available, including data collected from groundwater monitoring wells and reported in the ACR, there are no significant ongoing sources of sulfate to the plume.

2.2 Hydrogeologic Setting

The CTSA is in the northeastern portion of the Bisbee-Naco physiographic basin south of the Mule Mountains (Figures 1 and 2). The Mule Mountains, Cerro La Muela, and Sierra San Jose, form the northern, eastern, and southern margins of the basin, respectively. Approximately one-half of the physiographic basin lies in Mexico. The mountains surrounding the basin are composed of bedrock materials, and the basin area consists of clastic sediment, called basin fill, which is underlain by bedrock. Surface runoff from the Bisbee-Naco watershed drains into Greenbush Draw, which flows to the west to the Upper San Pedro River (Figure 1).

Groundwater occurs in two hydrostratigraphic units in the vicinity of the sulfate plume: basin fill and bedrock of the Bisbee Group. Figure 5 is a geologic map of the area in the vicinity of the sulfate plume. Basin fill is relatively permeable and consists of poorly to moderately cemented sand and gravel deposits that form alluvial fans from the mountains. The thickness of the basin fill increases from zero at the mountain fronts to approximately 635 feet in the central portion of the basin north of Naco. The Bisbee Group underlies the basin fill and consists of (from younger to older) the Cintura Formation, Mural Limestone, Morita Formation, and Glance Conglomerate. As described in the ACR, the Cintura Formation, Mural Limestone, and Morita Formation are called the “undifferentiated Bisbee Group” because the shale, siltstone, and sandstone beds of the Cintura and Morita Formations units are difficult to tell apart in drill cuttings unless contacts with the Mural Limestone or Glance Conglomerate are present. The undifferentiated Bisbee Group has a low to moderate permeability compared to basin fill, although massive portions of the Mural Limestone may be relatively impermeable. The Glance Conglomerate has a sandy to silty matrix and a low permeability compared to basin fill.

The structural geology in the vicinity of the CTSA is complex and appears to have a significant influence on groundwater flow. Four major fault zones are identified in the CTSA area: the Bisbee West-Gold Hill fault, the Abrigo fault, the Black Gap fault, and the Ninety-One Hills fault (Figure 5). The Bisbee West-Gold Hill and Abrigo faults are west-northwest trending, south-dipping high angle faults with normal offset. The Black Gap fault trends north-northeast and dips steeply to the west. The Ninety-One Hills fault is a west-northwest and west trending, north dipping complex of normal faults paralleling the Abrigo and Bisbee West faults.

The basin fill is saturated south of the Abrigo fault and west of the Black Gap fault, and is the primary drinking water supply in the area due to its high permeability and reliable productivity compared to bedrock. Public drinking water supply wells that draw supply from the basin fill are operated by Arizona Water Company (AWC) and Naco Water Company (NWC) to supply water to Bisbee and Naco, respectively. Domestic wells completed in the basin fill supply water to rural properties in San Jose and around Naco; although there is only a thin saturated zone in the basin fill at San Jose. The undifferentiated Bisbee Group underlying basin fill west of the Black Gap fault is also water-bearing and provides supply to a few wells. North of the Abrigo fault and east of the Black Gap fault the basin fill is typically unsaturated. East of the Black Gap fault the Morita Formation and Glance Conglomerate are the primary water-bearing formations for wells in the Bisbee Junction and near the airport east of the former evaporation pond.

Wells in the undifferentiated Bisbee Group and Glance Conglomerate are not as productive as wells in basin fill due to the lower permeability of bedrock as compared to basin fill. However, the productivity of bedrock wells is sufficient for domestic supply at private properties, although bedrock wells east of the Black Gap Fault are susceptible to drying out in response to prolonged pumping. NWC operates a public supply well in bedrock at Bisbee Junction.

Groundwater elevations in the fourth quarter of 2011 are shown on Figure 6. Groundwater elevations in bedrock wells east of the Black Gap fault and in basin fill and bedrock west of the Black Gap fault decrease from east to west, indicating westerly groundwater flow.

Sulfate concentration data in the vicinity of the plume have been collected quarterly since January 2008 for groundwater quality monitoring to define lateral and vertical extent of sulfate. Figure 3 is a contour map showing the areal distribution of sulfate in the fourth quarter of 2011. The sulfate concentration contours are inferred based on the maximum sulfate concentration at locations where closely spaced wells display different concentrations. The distribution of sulfate can appear complex on plan maps because the sulfate plume is three dimensional and plume water can be underlain or overlain by groundwater with lower sulfate concentrations depending on location.

The sulfate plume extends southwest and south from the vicinity of the former evaporation pond to the vicinity of Naco and Bisbee Junction. The sulfate plume is contained primarily in the basin fill and undifferentiated Bisbee Group except near the former evaporation pond where wells in the Glance Conglomerate have sulfate concentrations greater than 250 mg/L. West of the Black Gap fault the sulfate plume is contained primarily within the basin fill, although elevated sulfate concentrations do extend into the underlying undifferentiated Bisbee Group in the central and northern portions of the plume (e.g., BMO-2008-8M and BMO-2008-13M on Figure 5). East of the Black Gap fault the sulfate plume is within Morita Formation and Glance Conglomerate.

The sulfate plume extends from the water table to varying depths depending on location. Groundwater monitoring data presented and discussed in the ACR indicate that sulfate in excess of 250 mg/L extends to approximately 400 feet below the water table in monitoring wells in Glance Conglomerate and undifferentiated Bisbee Group east of the Black Gap fault, although deeper levels of penetration (at least 500 feet below the water table) are observed at BMO-2008-10GL in the footprint of the former evaporation pond. In the central to northern portions of the plume west of the Black Gap fault sulfate in excess of 250 mg/L occurs throughout the basin fill and into undifferentiated Bisbee Group to approximately 600 feet below the water table. In the southwestern portion of the plume west of the Black Gap fault, sulfate exceeding 250 mg/L is restricted to the basin fill and extends less than 300 feet below the water table such that elevated sulfate concentrations do not extend into the lowermost portion of the basin fill or the underlying bedrock. The water-bearing characteristics of the aquifer and spatial distribution of sulfate in the vicinity of affected wells are important factors constraining the implementability of potential mitigation actions.

As described in the ACR, the sulfate plume was caused by the historical infiltration of sulfate-bearing water from the former evaporation pond. The sulfate-bearing infiltration water migrated down to the water table and mixed with ambient groundwater in the basin fill and bedrock, creating a groundwater mound below the pond. The sulfate-affected groundwater then flowed away from the CTSA under the prevailing hydraulic gradients caused by the groundwater mound, which has dissipated since discharge to the pond was discontinued in 1987. The current hydraulic gradient and direction of groundwater movement is westerly in the vicinity of the former evaporation pond and throughout the area of the sulfate plume. Water quality monitoring data support the interpretation that expansion of the plume is halted in the upgradient eastern portion of the plume near the Bisbee Junction/Airport area. West of the Black Gap fault the plume is primarily within basin fill with westerly groundwater flow, although bedrock beneath the basin fill is affected by sulfate in the central and northern portion of the plume. Under the currently existing conditions, the sulfate plume in the basin fill will continue to migrate to the west. Groundwater flow velocities in the basin fill at the leading edge of the sulfate plume are estimated to be on the order of 47 to 115 feet per year under current conditions (Appendix B).

2.3 Affected Drinking Water Supply Wells

Drinking water supplies affected by sulfate are those having sulfate concentrations that exceed 250 mg/L. Affected water supplies have been identified by the well inventory and groundwater monitoring programs implemented for the Mitigation Order and reported in the ACR. The ongoing well inventory and groundwater monitoring programs and CQB's community outreach activities are the continuing means of identifying affected drinking water supply wells. When an affected well is identified, the users of the water supply are provided bottled drinking water as an interim mitigation action and an interim action report for the water supply well is filed with ADEQ as required by the Mitigation Order.

Figure 4 shows existing affected drinking water supply wells and their locations within the sulfate plume. Table 1 lists well construction data for the affected wells. Affected wells are clustered in three areas in different parts of the sulfate plume: the Naco Highway/Purdy Lane, San Jose, and Bisbee Junction/Airport areas. The Naco Highway/Purdy Lane area has eight domestic wells and one public water supply well affected by the southwest portion of the plume. The San Jose area has three domestic wells affected in the northern part of the plume. The Bisbee Junction/Airport area is on the east side of the plume and consists of one affected domestic well near Bisbee Junction and two affected domestic wells at the north end of the Bisbee International Airport. The affected wells are domestic drinking water supply wells with the exception of well NWC-03, which is a public water supply well in the Naco Highway/Purdy Lane area. The domestic wells service one to two households, except for one well that services four households. NWC-03 has 11 service connections in a small development north of Greenbush Draw and east of the Turquoise Valley Golf Course.

The water use rate at domestic wells is estimated at approximately 530 gallons per day per residence or 0.37 gpm per residence, assuming three persons per residence and the Tucson, Arizona average per capita residential use rate of 177 gallons per day. The water use rate for the 11 service connections of NWC-03 is approximately 123 gallons per day per residence or 0.09 gpm per residence based on a total of 495,000 gallons sold in 2010 (Arizona Corporation Commission, 2011) and assuming full time occupancy at the service connections.

3. INDENTIFICATION AND SCREENING OF POTENTIALLY APPLICABLE RESPONSE ACTIONS, TECHNOLOGIES, AND PROCESS OPTIONS

This section describes the mitigation action objective and identification and screening of potentially applicable mitigation actions for affected drinking water supplies. Potentially applicable mitigation actions were identified and screened using the following hierarchy: response actions, technologies, and process options. Response actions are generic categories of actions that can be taken to accomplish the mitigation action objective. For example, alternate water supply, water treatment, and blending are response actions that can be used for drinking water supply mitigation consistent with ARS § 49-286. Response actions can include a range of technologies. In the case of water treatment, one treatment technology that could be used is membrane treatment. Technologies can include a range of process options. For example, different process options for membrane water treatment are reverse osmosis, nanofiltration, and electrodialysis reversal. The purpose of mitigation action identification and screening is to identify actions that can be assembled into a range of potential mitigation alternatives.

Response actions, technologies, and process options potentially applicable to drinking water supply mitigation are screened for effectiveness, implementability, and cost. Effectiveness refers to the ability and reliability of the mitigation action to meet the mitigation objective over both short- and long-term time horizons, and whether the measure is proven and reliable with respect to site conditions. Implementability is defined in terms of technical and administrative factors. Technical implementability is an assessment of the ability to construct, operate, and maintain a mitigation action given site conditions. Administrative implementability refers to the ability to meet regulatory permitting requirements and project timelines given the general site conditions. Since most of the actions considered require the cooperation of well owners, their preferences also were given strong consideration. Effectiveness, implementability, and cost are the screening criteria used. The identification and screening of mitigation actions for the domestic wells and NWC-03 was relatively straight forward because there are only a limited number of actions that can be employed.

3.1 Mitigation Action Objective

The mitigation action objective is a qualitative or quantitative statement of the mitigation goal. Per Section III.E of the Mitigation Order, the mitigation objective is to:

- Provide the owner(s)/operator(s) of an existing drinking water supply affected by the sulfate plume from the CTSA with a drinking water supply having sulfate concentrations less than 250 mg/L at the point of use

There is no Arizona numeric aquifer water quality standard for sulfate to use as a quantitative mitigation objective. The Mitigation Order adopted a sulfate limit of 250 mg/L for drinking water supplies. Thus, potential mitigation actions will use the Mitigation Order sulfate limit of 250 mg/L as a numeric limit for the acceptable sulfate concentration at the point of use in an existing drinking water supply.

3.2 Response Actions

Response actions for drinking water supply mitigation are measures that can provide existing affected drinking water supplies with a drinking water source meeting the 250 mg/L mitigation action objective. Response actions evaluated for drinking water supply mitigation are listed below and in Table 2.

- **Alternate water supply** – measures that would modify an affected supply well to meet the mitigation objective or replace an affected supply well with a new supply that meets the 250 mg/L sulfate limit
- **Water treatment –** measures that would treat water from the affected water supply to reduce the sulfate concentration to meet the 250 mg/L sulfate limit
- **Blending** – measures that would mix sulfate-bearing water from an affected water supply with a source of dilute water such that the concentration of the mixture meets the 250 mg/L sulfate limit

3.3 Technologies and Process Options

The technologies and process options for response actions are described below along with a summary of effectiveness, implementability, and relative cost. The rationale for retaining or eliminating technologies and process options is also described. The results of the screening are summarized in Table 2.

3.3.1 Alternate Water Supply

A.R.S. § 49-286 identifies providing an alternate water supply as a potentially applicable response action for meeting the mitigation objective. Alternate water supply refers to different ways of developing or providing a new source of drinking water for an affected supply. The alternate water supply response action contains four technologies: well modification, well replacement, connection to public water supply, and bottled water.

3.3.1.1 Well Modification

Well modification would retrofit an affected drinking water supply well to exclude zones that produce sulfate-bearing water. Depending on site-specific hydrogeology, water quality, and well construction, well modification could consist of sealing off sections of well screen to exclude sulfate-bearing water, deepening a well by drilling through the existing casing to access deep water-bearing zones, or both.

Sealing off Sulfate-Bearing Water - Sealing off sulfate-bearing water from an existing well would require determining the vertical distribution of sulfate in the well to establish whether there is a section that contributes low sulfate water. If a low sulfate zone exists, a casing liner or some other method might be capable of sealing off the portion of the well screen in sulfate-bearing water so that it no longer contributes flow to the well.

Sealing off sulfate-bearing water would be potentially effective at meeting the mitigation objective if it could be reliably implemented. Sealing off sulfate-bearing water is not expected to be technically implementable for the affected wells for a variety of reasons. First, most of the affected wells are unlikely to intersect low-sulfate groundwater because they have limited saturated thickness (Table 1) and are in areas where sulfate occurs to depths greater than the depth of the well Second, there is only limited technical certainty in the long-term reliability of well modifications to effectively seal off a sulfate bearing zone and prevent sulfate-bearing water from migrating along the annulus of the wells. Finally, there is high potential to damage the wells during the modifications given the age, materials, and diameters of the wells. Attempting to seal off sulfate-bearing water would require depth specific characterization of water quality and a specialist in well modification.

Sealing off sulfate-bearing inflow to wells is judged to not be implementable for domestic wells because of the technical challenges presented by small saturated thicknesses, the age and small casing diameters of the wells which increase the potential for damaging the well, and the potential inability to completely seal off sulfate bearing water from the well. Additionally, the potential for sealing off sulfate-bearing water is low because it is unlikely that a zone of low sulfate water exists in the screened portions of the affected water supply wells. Sealing off sulfate-bearing water is administratively implementable in that there are no regulatory restrictions against trying to modify a well. An Arizona Department of Water Resources (ADWR) permit would be required. The cost of sealing-off sulfate bearing water would be highly site specific, but would probably be less than drilling a new well because less equipment and crew are required. Sealing off sulfate-bearing water is rejected from further consideration because it is not implementable.

Well Deepening - Well deepening would require drilling through the bottom of the existing well to access a deeper part of the aquifer that is below the sulfate plume. If low sulfate water is found at depth, a new screen and casing of a smaller diameter than the existing well could potentially be installed. The new well screen would need to be sealed off from the overlying existing screen to prevent the incursion of sulfate-bearing water. Well deepening may be possible with some wells, but is not expected to be a generally implementable way of obtaining a supply meeting the mitigation objective due to technical and hydrogeologic factors.

There are technical difficulties associated with implementing well deepening. Well deepening always has a risk that drilling may damage the existing well, but the risk of damage increases with well age. Seven of 15 affected wells have steel casings that are 30 year old or more (Table 1). The steel in the existing casings could be fatigued through corrosion and may not withstand the stress of drilling. The casing diameters of most domestic wells are 6 inches or less, making them difficult to drill in. The small casing diameters require that even smaller drill bits and casing be used for the deepened well. The small diameter of the new casing would make placing a seal between the old and new casings a technically challenging and potentially infeasible task. The small diameter of the new casing may also limit the production of the modified well or make equipping with a small diameter submersible pump difficult or infeasible. Finally, well deepening has the potential of creating a vertical pathway for sulfate affected water to impact deeper zones if the annular space is poorly sealed or a there is a faulty seal between the casings.

Well deepening may not be implementable for hydrogeologic reasons in the areas of affected wells. It is uncertain whether drilling deeper would encounter a water-bearing zone of sufficient quantity or quality to supply domestic needs in the San Jose and Bisbee Junction/Airport areas. As discussed in Section 2.2, groundwater with sulfate concentrations greater than 250 mg/L extends throughout the basin fill and at depth in bedrock in the central and northern portions of the plume, such as near San Jose and the airport area. Additionally, the productivity of bedrock in the San Jose and Bisbee Junction/Airport areas is highly variable because groundwater flow is controlled by fractures that are not uniformly distributed throughout the bedrock. Thus, deepening a well in these areas may not intersect enough fractures to produce sufficient water for a domestic supply. The southwest portion of the plume near Naco is the only area where well deepening may be implementable because low sulfate water is known to be laterally extensive in basin fill and bedrock below the plume at that location.

Well deepening is judged to have poor technical implementability because of the technical difficulties presented by well age, the small casing diameters of the wells, and the uncertainty of placing and maintaining a seal between the old and new portions of the well. Well deepening is also likely not to be implementable in the San Jose and Bisbee Junction/Airport areas because a reliable quantity and quality of water at depth cannot be guaranteed. Well deepening is administratively implementable in that there are no regulatory restrictions against it. An ADWR permit would be required. The cost of well deepening would depend on site-specific conditions, but might equal or exceed the cost of drilling a new well because the equipment, crew, and effort would be of a similar scale. Well deepening is rejected from further consideration because of poor implementability and a cost comparable to or greater than well replacement.

3.3.1.2 Well Replacement

Well replacement would consist of replacing an affected well with a new well drilled to and screened in an unaffected portion of the basin fill or bedrock. The replacement well would be connected to the existing water distribution system and the affected well disconnected from it. The affected well could still be used by the owner for non-drinking water purposes. To be effective, well replacement requires that there be a deeper aquifer identified with appropriate water quality and sufficient, reliable productivity to target with a replacement well. A replacement well would also need to be in a hydrogeologic setting that is far enough from the plume (vertically) that the new well does not pull in sulfate-affected groundwater.

As discussed in Section 2.2, the only area of affected wells known to be underlain by basin fill and bedrock with groundwater sulfate concentrations less than 250 mg/L is the Naco Highway/Purdy Lane area at the southwestern portion of the plume. Although low-sulfate water is documented in basin fill at the Naco Highway/Purdy Lane area, it is recommended that any replacement well be constructed in the bedrock to provide a safety factor separating the replacement well from the plume. In the San Jose and Bisbee Junction/Airport areas groundwater occurs in bedrock with uncertain water quality. Data presented in the ACR for the drilling and sampling of wells BMO-2008-8M and BMO-2008-13M (Figure 5) in bedrock east and south of San Jose indicate that affected groundwater occurs to depths of 1,000 feet below ground surface (ft bgs) or more and that water productivity varies considerably with depth in the bedrock. In the Bisbee Junction/Airport area, data for wells BMO-2008-10GL and BMO-2010-2M west of the airport indicate sulfate-affected water to depths greater than 800 ft bgs, while pumping tests during drilling showed large differences in bedrock productivity as a function of depth. Data for BMO-2010-1M north of Bisbee Junction indicate complex potentiometric conditions in the bedrock aquifer, with affected water perched over a regional water table showing sulfate-affected water to a depth of approximately 300 ft bgs. The hydrogeologic conditions in the San Jose and Bisbee Junction/Airport areas make the success of well replacement uncertain because there is potential that the water quality or the water productivity of a replacement well would not provide a long-term, reliable domestic supply.

A well in the bedrock can potentially produce sufficient flow to meet domestic supply needs if a sufficient number of fractures are intersected by the well screen. In the Naco Highway/Purdy Lane area bedrock productivity is sufficient to supply an existing domestic well (GARNER 635) in the bedrock and provide a portion of the supply in public supply well AWC-05 which is screened in both basin fill and bedrock. The productivity of the bedrock in this area may be due in part to the presence of the overlying saturated basin fill. In contrast, the productivity of bedrock of the San Jose and Bisbee Junction/Airport areas is uncertain. A potential reason for the erratic productivity of bedrock in the San Jose and Bisbee Junction/Airport areas is that saturated basin fill is either thin or absent in those areas.

Based on site-specific hydrogeologic conditions, well replacement is judged to have good effectiveness and technical implementability in the Naco Highway/Purdy Lane area where aquifer materials contain water with low sulfate concentrations at relatively shallow depths (approximately 350 ft bgs) below the plume. Well replacement has poor technical implementability in the San Jose and Bisbee Junction/Airport areas where the water quality and quantity in the deep bedrock are unreliable.

The administrative implementability of replacement wells is good. Domestic well replacement requires a drilling permit from ADWR and connection of the new well to the existing household plumbing. Well replacement for a public water supply well would also require review by ADEQ and the Arizona Corporation Commission.

The drilling and construction of a replacement well in bedrock in the Naco Highway/Purdy Lane area has an estimated cost of $100,000 per well. Costs for a domestic replacement well in the San Jose and Bisbee Junction/Airport areas are difficult to estimate because the depth of a well cannot be determined in advance of drilling, but would be expected to be greater than in the Naco Highway/Purdy Lane area because of the greater depth of affected groundwater. Additionally, there would be only limited probability of successfully developing a long-term, reliable drinking water well in the San Jose and Bisbee Junction/Airport areas.

Well replacement is technically implementable to provide a water supply that meets the sulfate action level in areas with appropriate hydrogeological conditions, such as at Naco Highway/Purdy Land. Well replacement was retained for use in this area, but was considered to be not implementable in the San Jose and Bisbee Junction/Airport areas.

3.3.1.3 Connection to Alternate Public Water Supply

Connection to alternate water supply would provide service to the affected water supply from an unaffected supply public water supply and would discontinue use of the affected well for drinking water purposes. The affected well could still be used for non-drinking water purposes. Connection to a public water system may be practicable in some cases.

AWC and NWC are existing public water supplies with distribution systems in the vicinity of the affected water supplies. Figure 4 shows extent of the AWC and NWC supply pipelines and service areas. The AWC service area includes San Jose. NWC has three separate service areas: Naco Township (NWC-02 and NWC-06), Naco Highway north of Greenbush Draw (NWC-03) and Bisbee Junction (NWC-04).

In the Naco Highway/Purdy Lane area NWC-03 is the only public water supply well affected by the sulfate plume. The service connections of NWC-03 could be connected to the Naco

Township system if a pipeline is constructed between the locations. Connection of affected domestic wells in the Naco Highway/Purdy Lane area to NWC service could be possible depending on the adequacy of supply wells, the size of the infrastructure supplying water to NWC-03, and the viability of constructing a pipeline along Naco Highway and Purdy Lane. CQB discussed with NWC the possibility of connecting NWC-03 to the Naco Township system. NWC confirmed that there is sufficient supply in the Naco Township system and that the project would be acceptable to them.

Affected water supplies in the San Jose area could be connected to AWC service by running new distribution pipelines from AWC's existing pipelines to the affected properties. The existing pipelines are within 1,500 feet of the affected properties. CQB discussed with AWC the possibility of connecting the San Jose properties to the AWC supply system. AWC confirmed that there is sufficient supply in the AWC system and that the project would be acceptable to them.

Affected wells in the Bisbee Junction/Airport area are close to the public water supply system supplied by NWC-04. Historically, NWC-04 has had problems with adequate production during the summer when water use is high and the possibility of increasing productivity is limited because the low productivity of the bedrock tapped by NWC-04. In addition, connection to NWC-04 would require adding new distribution piping to the existing system. The existing infrastructure limits expansion because the pipelines farthest from NWC-04 are small diameter (2-inch) pipes that do not carry the quantity of flow or sustain sufficient pressure for a reliable supply.

Connection to alternate public water supply is implementable with the acceptance of the appropriate water utility. A connection to alternate public water supply would need to comply with Cochise County, ADEQ, Arizona Corporation Commission, and any other applicable regulations pertaining to the construction and operation of a public water supply.

The cost of connection to an alternate public water supply is expected to be significantly greater than the cost of drilling new wells because of the need for engineering studies and the cost of materials and construction.

Connection to an alternate public drinking water supply would effectively provide the owner/operator of an affected drinking water supply with a long-term, reliable supply meeting the sulfate action level. An alternate water supply is potentially implementable in the San Jose and Naco Highway/Purdy Lane areas due to their proximity to existing AWC and NWC infrastructure. Limited water supply and existing infrastructure in the Bisbee Junction/Airport area make the implementability of connection to an alternate public water supply poor in the absence of a major engineering and construction project. Connection to alternate water supply is retained as an effective and implementable technology for drinking water supply mitigation in the San Jose and Naco Highway/Purdy Lane areas, but not the Bisbee Junction/Airport area.

3.3.1.4 Bottled Water

Bottled water would provide affected water supplies with bottled water for drinking water purposes. A commercial service in Sierra Vista currently provides bottled water delivery to the affected water supplies as an interim action. The bottled water interim action has been successful in meeting the needs of affected water supplies based on the general satisfaction with the program by affected owners.

Bottled water is an effective way to provide the owner/operator of an affected water supply with a drinking water meeting the sulfate action level. The implementability of bottled water is good because commercial services are available to provide service and the number of affected parties is small enough to make bottled water practical. In the short term the cost of bottled water is low compared to well replacement, but over time the cost of bottled water can be significant. Bottled water was retained because of its effectiveness, implementability, and cost.

3.3.2 Water Treatment

A.R.S. § 49-286 identifies economically and technically practicable water treatment prior to ingestion as a potential response action. Water treatment would treat sulfate-bearing water to meet the sulfate action level for use as drinking water supply. The most common water treatment process technology for sulfate removal from drinking water supplies is the reverse osmosis (RO) membrane treatment process that separates dissolved solids from water. RO treatment produces two streams: a low total dissolved solids permeate and a high dissolved solids brine or reject. The permeate is available for ingestion, while the brine is disposed in the sewer or septic system.

Other treatment processes exist for sulfate removal, such as ion exchange, or wellhead treatment by RO, nanofiltration, or electrodialysis reversal membrane processes, but these technologies are only available as industrial-scale water treatment systems capable of treating flows (tens of gpm or more) greater than those needed for the affected wells and needing specialized equipment, service, and operators. These other sulfate treatment technologies are not implementable as small capacity systems with the ease of operation appropriate for the type and size of the affected wells, and were not considered further.

The water treatment process options considered for the affected domestic wells are full house RO and point of use RO treatment, which can be implemented as household water treatment systems producing less than a gallon per minute. The NWC-03 well has a larger water production requirement than do the domestic wells and must meet ADEQ water quality and operations requirements for a public drinking water system. Full house RO and point of use RO treatment could be implemented as household treatment systems at the service connections of NWC-03. However, installation and operation of a centralized RO treatment system at the NWC-03 well is considered nonimplementable at the product water flow needed (about 1 gpm on average without accounting for peaking factors) and the level of technical support available for this small public drinking water supply.

3.3.2.1 Full House RO

Full house RO would treat all water from an affected supply at a point of entry into a residence to meet all indoor household demands. In this option, water from the affected well would be treated prior to distribution into the residential supply system for use. The RO system would need to be sized to treat and supply all indoor household uses including shower, toilet, and laundry.

A full house RO system would likely need to be installed in a garage or shed near the where the well water supply enters the residence. A water softener may also need to be installed to remove calcium to extend the life of the RO system. A full house RO treatment system would be installed by a trained technician from a commercial water treatment company. Water softeners and RO systems require regular maintenance. A service contract with the water treatment company would be established for this purpose. A full house RO system could have a capacity of up to 500 gallons per day.

Full house RO systems only recover 50 to 60 percent treated water. Thus, approximately 830 to 1,000 gallons per day would need to be pumped to produce 500 gallons per day of treated water for use. On the same basis, 330 to 500 gallons per day of brine would be created. The amount of additional water needed for full house RO is significant because of the large volume of water being treated compared to point of use RO. The additional water requirement could limit the application of full house RO on some wells. Septic systems would also need to be evaluated for their ability to handle the additional load of wastewater. To conserve water, the system could be configured so that untreated water is used for exterior applications such as landscape irrigation.

Full house RO would be effective at providing an affected drinking water supply a source of drinking water meeting the mitigation objective of 250 mg/L sulfate. Full house RO would exceed the mitigation objective because it would also treat household water that is not used as potable supply. Full house RO would waste water because of the large amount of brine production. A potential problem associated with full house RO for houses with a septic system is that a relatively large volume of reject brine would be released to the septic system and could potentially migrate to the aquifer.

The technical implementability of full house RO is good in that the RO treatment is reliable if properly maintained and commercial services are available for installation and ongoing maintenance. Some affected water supplies may not be suitable for full house RO if the well is unable to produce adequate supply or the septic is unable to receive the volume of brine waste. There are no special regulatory requirements for installation of a full house RO treatment system. The purchase and installation of a full house RO system would cost approximately $12,000 per home. Annual maintenance costs are estimated to be about $1,000 per home for supplies and service fees.

Although full house RO has disadvantages in terms of water conservation and brine management, full house RO is judged to have good effectiveness and implementability for developing reliable, long-term drinking water supply mitigation. Full house RO treatment is retained as a process option.

3.3.2.2 Point of Use RO

Point of use RO systems are designed to provide treated water in the user's kitchen. Point of use RO systems are typically installed beneath the kitchen sink with a second faucet to provide low sulfate water for drinking and cooking purposes, while untreated water would be used for toilets, bathing, laundry, irrigation, and other non-potable uses. Depending on source water chemistry, a water softener may also need to be installed to remove calcium to extend the life of the RO system. A point of use RO treatment system would be installed by a trained technician from a commercial water treatment company. Water softeners and RO systems require periodic maintenance. A service contract with the water treatment company would be established for this purpose. A typical system will produce 10 gallons per day of drinking water.

Point of use RO systems only recover 50 to 60 percent treated water. Thus, for every 10 gallons of drinking water, 17 to 20 gallons of water must be pumped while 7 to 10 gallons of brine is discharged to the drain. The amount of additional well water that would need to be pumped to make up for the wastage of a point of use RO system would be minimal given the low volume of water treated. The additional load of water to septic system would also be minimal.

Point of use RO would be effective at providing an affected drinking water supply a source of drinking water meeting the mitigation objective of 250 mg/L sulfate. The technical implementability of point of use treatment is good in that it is a reliable technology if properly maintained and commercial services are available for installation and ongoing maintenance. Point of use RO would not cause a significant increase in pumping or septic flow. There are no special regulatory requirements for installation of a full house RO treatment system. A water softener and point of use RO system can be purchased and installed for approximately $3,400 per unit based on information from Culligan of Tucson. The annual service fee and materials for system maintenance is estimated to be $730 per unit. Point of use RO treatment is retained as a process option.

3.3.3 Blending

A.R.S. § 49-286 identifies blending as a potentially applicable process option for meeting the sulfate action level. Blending would mix waters of high and low sulfate concentrations to produce a mixed water meeting the sulfate action level prior to the point of distribution to the water system.

Opportunities for blending will be highly site-specific depending on the availability of low sulfate water, infrastructure, and operations experience. For example, there is little opportunity for blending for a single private well whereas blending may be applicable for a public water system with trained operators and multiple supply wells feeding a common storage tank. In addition to a source of low sulfate water, blending also requires storage tanks, valves, piping, and pumps to build and operate a mixing system given the design constraints of the particular water supply. Blending also requires knowledge of the sulfate concentrations in the waters being mixed so their proportions could be designed to reliably produce a blended water meeting the sulfate action level.

Blending could be effective at meeting the mitigation objective assuming the availability of a source of low sulfate water for mixing, and the infrastructure and operator knowledge needed for implementation. Although the equipment and knowledge needed to implement blending are readily available, the technical implementability of blending is poor because sources of low sulfate water are not available in the vicinity of affected domestic and public water supplies. With respect to affected domestic wells, the level of knowledge needed to reliably operate a blending system is outside the experience of most owners and there are no commercial services available for a system such as a domestic well. The cost of blending for small quantities of water would probably be less than well replacement and development of an alternate water supply. Blending was not retained for domestic water supplies or NWC-03 because of poor implementability.

3.3.4 Summary of Drinking Water Supply Mitigation Process Options

The evaluation considered nine technologies/process options for drinking water supply mitigation. The five technologies/process options retained for drinking water supply mitigation are:

- Alternate Supply:
    - Well Replacement in the Naco Highway/Purdy Lane area
    - Connection to Alternate Public Water Supply in the San Jose and Naco Highway/Purdy Lane areas
    - Bottled Water

- Water Treatment:
    - Full House RO
    - Point of Use RO

The drinking water supply mitigation process options retained for alternatives development can be used to provide a drinking water supply meeting the sulfate action level to the owner/operator of an existing drinking water supply affected by the CTSA as required by Section III.E of the Mitigation Order. However, the process options are not uniformly applicable to all affected wells because the wells are in different geographic areas that have site-specific infrastructure and hydrogeologic conditions that constrain the use of some options. For this reason, the mitigation action(s) appropriate for a particular affected well will depend on site-specific conditions. CQB has worked with the owners of affected water supply wells to determine the most appropriate mitigation action based on the location of the well.

The technologies/process options retained for drinking water supply mitigation provide a variety of techniques for accomplishing the mitigation objective and include the mitigation measures identified in ARS § 49-286. The potentially applicable technologies/process options allow a range of mitigation alternatives to be developed in the context of site-specific conditions consistent with Section III.D of the Mitigation Order. Section 4 of the FS describes the application of the retained technologies/process options in development of mitigation alternatives.

4. DEVELOPMENT AND SCREENING OF MITIGATION ALTERNATIVES

Mitigation alternatives are combinations of response actions, technologies, and process options that can potentially meet the mitigation objective. This section formulates and describes mitigation alternatives consisting of the response actions, technologies, and process options retained by the screening evaluation described in Section 3.

4.1 Development of Mitigation Alternatives

Although a range of response actions, technologies, and process options may meet the mitigation objective, the specific mitigation alternatives applicable to an affected well depends on its location. Therefore, potential mitigation alternatives were developed separately for the three areas of affected wells: the Naco Highway/Purdy Lane, San Jose, and Bisbee Junction/Airport areas. Because all of the technologies/process options retained by the screening are generally effective and implementable, any of them will provide a drinking water supply that meets the mitigation objective consistent with ARS § 49-286. Thus, a range of potential mitigation alternatives were developed for evaluation consistent with Section III.D of the Mitigation Order. Table 3 lists the mitigation alternatives that were developed for affected wells in the three, defined areas.

4.1.1 Naco Highway/Purdy Lane Area

Mitigation alternatives for the Naco Highway/Purdy Lane area were developed separately for the NWC-03 public water supply and the private domestic water supplies because the two types of affected supplies have different regulatory and service requirements.

4.1.1.1 NWC-03 Public Water Supply

The possibility of connecting residents served by NWC-03 to the alternate public water supply at Naco Township was discussed by NWC and CQB. The Naco Township system is supplied by two wells: NWC-02 and NWC-06. Based on past pumping, the capacity of the Naco Township wells is adequate to supply the NWC-03 service connections if a pipeline were constructed northward from Naco Township. The concept of extending the Naco Township water supply northward to NWC-03 has been accepted by NWC and a conceptual design was developed to identify the infrastructure requirements of the line extension and verify project constructability. CQB will pay for NWC to design and construct the pipeline extension.

The Naco Township wells are believed to be long term sources of low sulfate water because of their location in the regional groundwater flow system. Figure 7 shows ground elevation contours in October 2008 in the vicinity of Naco Township as reported in the ACR. Groundwater flow is from high to low elevation and perpendicular to the water level contours as depicted by the arrows on Figure 7. These groundwater elevation data and water quality data support the interpretation that groundwater pumped from the Naco Township wells is derived from groundwater flow from Mexico and that the sulfate plume, which is migrating westerly, will remain north of Naco Township.

4.1.1.2 Domestic Water Supplies

Five mitigation alternatives were developed for domestic water supplies in the Naco Highway/Purdy Lane area:

- Well Replacement
- Connection to Alternate Public Water Supply
- Full House RO
- Point of Use RO
- Bottled Water

All of these mitigation alternatives are applicable to domestic water supplies in the Naco Highway/Purdy Lane area because the area has favorable hydrogeology for installation of replacement wells and is close to the NWC-03 service area which would be a source of alternate public water supply when it is connected to the Naco Township system. Point of use RO, full house RO, and bottled water are generally applicable to affected wells regardless of location.

A potential concern with well replacement is that pumping from deeper wells could draw the sulfate plume into the deeper aquifer over time. An assessment was conducted to evaluate the potential that pumping from replacement wells in the Naco Highway/Purdy Lane area would draw the sulfate plume downward. The assessment used the numerical model for groundwater flow to evaluate the impact on the plume of pumping from replacement wells for the affected domestic wells. The results of the assessment are described in a technical memorandum that was submitted to ADEQ (Appendix A). A preliminary design for replacement wells was developed assuming that the wells would be constructed to draw water from the bedrock beneath the low sulfate portion of the basin fill and that the wells would be sealed off from the basin fill. The numerical model simulated the movement of sulfate in different scenarios in which replacement wells pumped for a 100-year period under a range of pumping rate assumptions. The assessment concluded that sulfate is not predicted to migrate vertically in response to pumping at the replacement wells. Sulfate does not migrate downward because the drawdown caused by pumping from the replacement wells in bedrock is insufficient to induce downward vertical flow in the basin fill aquifer. The results of the assessment indicate that well replacements are feasible in the Naco Highway/Purdy Lane area without jeopardizing the water quality of the deep aquifer. Thus, sulfate concentrations will meet the mitigation objective over the long term. The viability of well replacement is demonstrated by a replacement well installed along Purdy Lane in 2001 (well GARNER 635). After 10 years of continuous operation, GARNER 635 has produced an adequate quantity for domestic purposes and the sulfate concentration in the well remains between the baseline concentrations of 30 and 40 mg/L measured when the well was first installed.

NWC's agreement to extend Naco Township service to NWC-03 makes it possible to consider extending a water supply pipeline north and east from NWC-03 to service the affected domestic wells along Naco Highway and Purdy Lane. This possibility was discussed by NWC and CQB. NWC agreed to the concept of extending service to the Naco Highway/Purdy Lane domestic wells and believes the Naco Township system has adequate supply to service both the NWC-03 service connections and the Naco Highway/Purdy Lane domestic wells. A conceptual design was developed to identify the infrastructure requirements of potential line extensions and verify the project constructability. CQB would pay for NWC to design and construct the pipeline extension. As discussed above, the Naco Township wells are believed to be long term sources of low sulfate water.

4.1.2 San Jose Area

The range of potential mitigation alternatives available for the San Jose area includes:

- Connection to Alternate Public Water Supply
- Full House RO
- Point of Use RO
- Bottled Water

Connection to an alternate public water supply was identified as a mitigation alternative for affected wells in the San Jose area because it is within the AWC service area, near their distribution system, and adequate supply is available to service the three affected water supplies. Point of use RO, full house RO, and bottled water are generally applicable to the affected wells regardless of location. Well replacement is not a potential alternative for the San Jose area because of the uncertainty of being able to develop a water supply of adequate quality and quantity in the bedrock aquifer at the location of the affected supplies.

CQB discussed with AWC the possibility of extending service to the affected supplies in San Jose. AWC indicated that a pipeline extension and addition of three new service connections are feasible. The pipeline extension was accepted by AWC and a process for installation of the new service connections was identified with AWC responsible for design, construction, and permitting of the project. CQB will pay AWC for the pipeline extension and contract plumbing services to complete the water supply connection on the affected properties.

4.1.3 Bisbee Junction/Airport Area

Fewer potential mitigation alternatives are available for affected wells in the Bisbee Junction/Airport area:

- Full House RO
- Point of Use RO
- Bottled Water

Well replacement is not a potential alternative for the Bisbee Junction/Airport area because of the uncertainty of being able to develop a water supply of adequate quality and quantity in the bedrock aquifer at the locations of the affected supplies. Connection to an alternate drinking water supply is also not an option for the affected supplies because the water quantity at NWC-04 is limited and the water distribution system from NWC-04 is inadequate to service the affected supplies. NWC-04 has historically had difficulty meeting the total system demand during the summer, necessitating water importation to meet demand. Additionally, the existing 2-inch pipelines extending service from NWC-04 are inadequate to sustain the flow and pressure needed for a long-term reliable supply.

5. DETAILED ANALYSIS OF MITIGATION ALTERNATIVES

The detailed analysis of mitigation alternatives evaluates the effectiveness, implementability, and cost of the potential mitigation alternatives. The mitigation alternatives identified for each area of affected water supplies are all effective and implementable based on the previous screening analysis (Sections 3 and 4). The cost of the mitigation alternatives was not a factor weighted as heavily as effectiveness and implementability, except in cases for which a large construction project would be needed to implement the alternative. Cost was a key consideration for alternatives requiring large construction projects because there is a minimum threshold of affected parties that would be needed to make the alternative cost-effective.

The acceptability of the mitigation alternatives by ADEQ and the affected parties were key considerations for this FS. Discussions with ADEQ indicated that it preferred mitigation actions that would offer reliable, long-term mitigation for affected supplies and that actions such as providing bottled water may not be acceptable as a final mitigation action. The acceptability of a mitigation alternative by the affected parties was weighted heavily so that any actions taken would have the support of those they are intended to benefit. For this reason, the affected parties were provided the opportunity to select their preferred mitigation alternative from the range of potentially applicable alternatives.

5.1 Analysis of Mitigation Alternatives by Affected Area

5.1.1 Naco Highway/Purdy Lane Area

The Naco Highway/Purdy Lane area contains one public supply well (NWC-03) and eight domestic wells currently affected by the sulfate plume. Mitigation alternatives for the NWC-03 public water supply and domestic water supplies were developed separately.

5.1.1.1 NWC-03 Public Water Supply

In 2011, NWC and CQB agreed to upgrades of the NWC-03 water supply system. The upgrades will supply water from Naco Township to the NWC-03 service area and include:

- Development of 4,500 feet of 6-inch pipeline between the Naco Township wells and the NWC-03 distribution system
- Additional water storage and pumping capabilities, and
- Abandonment of NWC-03.

Figure 9 is a schematic of the proposed NWC-03 upgrades. The Naco Township wells are expected to provide a reliable, long-term water supply to the NWC-03 service area. The water system upgrades will also provide the benefit of increasing NWC's water supply for firefighting purposes. The connection to an alternate public water supply is a reliable, long-term mitigation for NWC-03.

5.1.1.2 Domestic Water Supplies

Mitigation alternatives available for domestic wells in the Naco Highway/Purdy Lane area are:

- Well Replacement
- Connection to Alternate Public Water Supply
- Full House RO
- Point of Use RO
- Bottled Water

Well Replacement

Well replacement consists of CQB contracting services for the permitting, drilling, construction, equipping, and connection of a new domestic well. Figure 8 shows a preliminary schematic of a replacement well suitable for the Naco Highway/Purdy Lane area. The well would be installed in a borehole advanced 150 feet below the basin fill/bedrock contact. The new well would contain 100 feet of well screen open to the bedrock aquifer. The annular space around the well screen would be surrounded by a filter pack of coarse sand or gravel and overlain by a bentonite clay grout seal to prevent migration of water along the annulus of the well. A new submersible pump would be installed in the well and connected to a new pressure tank. The supply line from the pressure tank would be plumbed into the point of entry to the residence to replace the affected well. Plumbing and electrical work would be completed to make the new well operational. As part of a private agreement with the well owner, CQB would pay for the well replacement and connection to the household point of entry and would offer to abandon the affected well at no cost to the owner. Alternately, the affected wells could be used only for outdoor application. The replacement well alternative is a reliable, long-term mitigation alternative for affected supplies.

Connection to Alternate Public Water Supply

The NWC-03 upgrades will connect the NWC-03 service area to the Naco Township water supply. NWC agreed to consider connecting the affected domestic wells in the Naco Highway/Purdy Lane area to the upgraded NWC water supply. Connection of the affected domestic water supplies to NWC service requires installing new water distribution lines north along Naco Highway and east along Purdy Lane. Approximately 6,200 feet of new 4-inch pipeline and additional water storage and pumping facilities would be required to provide a reliable, long term water supply to the affected domestic wells. NWC would be responsible for design, construction, and operation of the pipeline and water supply. As part of an agreement with NWC,,CQB would pay for the pipeline extension. As part of a private agreement with the well owner, CQB would contract plumbing services to connect the affected domestic supplies to the NWC water line, and pay the water bill for the affected drinking water supply for 10 years. The affected well would be disconnected from the household and CQB would offer to abandon the affected well at no cost to the owner. Alternately, the affected wells could be used only for outdoor applications.

Connection of the eight affected domestic water supplies to NWC service would be a costly construction project that would not be cost-effective for only one or two affected supplies even if the NWC-03 upgrades are implemented. Acceptance by at least 75 percent of the affected supplies would be required for this project to be less expensive on a per household basis than well replacement. The mitigation alternative of connection to alternate public supply is a reliable, long-term mitigation alternative for affected domestic water supplies.

Full House RO

Full house RO could be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system of sufficient throughput to supply the indoor household needs of the affected water supply. The details of the RO treatment system and the household connections would be dependent on site-specific conditions at the affected supplies. CQB would contract and pay for the purchase and installation of the RO treatment system and plumbing/electrical services needed to make the system operational. As part of a private agreement with the well owner, CQB would contract a commercial vendor to provide regular maintenance for the RO units and pay for 10 years of operation and maintenance. The full house RO alternative is a reliable, long-term mitigation alternative for affected domestic water supplies.

Point of Use RO

Point of use RO would be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system suitable throughput to supply the drinking water needs of the affected water supply. The details of the RO system and the household connections would be dependent on site-specific conditions at the affected supplies. As part of a private agreement with the well owner, CQB would contract and pay for the purchase and installation of the RO system. CQB would contract a commercial vendor to provide regular maintenance for the RO system and pay for 10 years of operation and maintenance. Although ADEQ has expressed a preference for full house RO, the point of use RO alternative would be a reliable, long-term mitigation alternative for affected domestic water supplies if it is preferred by the owner due to site specific concerns such as water availability, water conservation, or septic capacity.

Bottled Water

Bottled water would consist of providing the users of affected supplies with bottled water and water dispensers. A Sparkletts vender in Sierra Vista currently provides bottled water to the users of affected supplies. To implement this alternative CQB would maintain a service contract with a commercial provider of bottled water to provide and/or continue water delivery to the affected supply. Although ADEQ has stated that it has questions about the use of bottled water as a reliable, long term solution for affected supplies, the bottled water alternative may be acceptable if it is preferred by the owner due to site specific circumstances such as water availability, water conservation, or septic capacity.

5.1.2 San Jose Area

The San Jose area contains three domestic wells affected by the sulfate plume. Mitigation alternatives available for the San Jose area are:

- Connection to Alternate Public Water Supply
- Full House RO
- Point of Use RO
- Bottled Water

5.1.2.1 Connection to Alternate Water Supply

Connection to alternate public water supply is available for affected wells in the San Jose because they are within the AQC service area, near AWC's existing distribution system, and adequate supply is available to service the three affected water supplies. AWC is agreeable with the concept of connecting the affected water supplies to AWC supply. Approximately 1,000 feet of new water line (6-inch ductile iron pipe) is needed to extend the existing AWC pipeline and provide service to the affected supplies. The design and construction of the extension will be managed by AWC and paid for by CQB under an agreement with AWC. The extension would bring water service to the property line of the affected supply where AWC would install a water meter. As part of a private agreement with the well owner, CQB would pay for contract plumbing services to connect the affected supply to the new AWC system (including installation of a certified backflow preventer), and, pay the water bill for the affected supply for 10 years. The affected well would be disconnected from the household and CQB would offer to abandon the affected well at no cost to the owner. Alternately, the affected well could be use only for outdoor applications. Connection to AWC service is a reliable, long-term mitigation alternative for affected domestic water supplies.

5.1.2.2 Full House RO

Full house RO could be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system of sufficient throughput to supply the indoor household needs of the affected water supply. The details of the RO treatment system and the household connections would be dependent on site-specific conditions at the affected supplies. As part of its private agreement with the well owner, CQB would contract and pay for the purchase and installation of the RO treatment system. CQB would contract a commercial vendor to provide regular maintenance for the RO units and pay for 10 years of operation and maintenance. The full house RO alternative is a reliable, long-term mitigation alternative for affected domestic water supplies.

5.1.2.3 Point of Use RO

Point of use RO could be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system suitable throughput to supply the drinking water needs of the affected water supply. The details of the RO system and the household connections would be dependent on site-specific conditions at the affected supplies. As part of its private agreement with the well owner, CQB would contract and pay for the purchase and installation of the RO system. CQB would contract a commercial vendor to provide regular maintenance for the RO system and pay for 10 years of operation and maintenance. Although ADEQ has expressed a preference for full house RO, the point of use RO would be a reliable, long-term mitigation alternative for affected domestic water supplies if it is preferred by the owner due to site specific concerns such as water availability, water conservation, or septic capacity.

5.1.2.4 Bottled Water

Bottled water would consist of providing the users of affected supplies with bottled water and water dispensers. A Sparkletts vender in Sierra Vista currently provides bottled water to the users of affected supplies. To implement this alternative CQB would maintain a service contract with a commercial provider of bottled water to provide and/or continue water delivery to the affected supply. Although ADEQ has stated that it has questions about the use of bottled water as a reliable, long term solution for affected supplies, the bottled water alternative may be acceptable if it is preferred by the owner due to site specific circumstances such as water availability, water conservation, or septic capacity.

<u>5.1.3 Bisbee Junction/Airport Area</u>

The Bisbee Junction/Airport area contains three domestic wells affected by the sulfate plume. Mitigation alternatives available for the Bisbee Junction/Airport area are:

- Full House RO
- Point of Use RO
- Bottled Water

5.1.3.1 Full House RO

Full house RO could be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system of sufficient throughput to supply the indoor household needs of the affected water supply. The details of the RO treatment system and the household connections would be dependent on site-specific conditions at the affected supplies. As part of its private agreement with the well owner, CQB would contract and pay for the purchase and installation of the RO treatment. CQB would contract a commercial vendor to provide regular maintenance for the RO units and pay for 10 years of operation and maintenance. The full house RO alternative is a reliable, long-term mitigation alternative for affected domestic water supplies.

5.1.3.2 Point of Use RO

Point of use RO could be implemented by installation and operation of an RO and water softening (dependant on site-specific water chemistry) treatment system suitable throughput to supply the drinking water needs of the affected water supply. The details of the RO system and the household connections would be dependent on site-specific conditions at the affected supplies. As part of its private agreement with the well owner, CQB would contract and pay for the purchase and installation of the RO system. CQB would contract a commercial vendor to provide regular maintenance for the RO system and pay for 10 years of operation and maintenance. Although ADEQ has expressed a preference for full house RO, the point of use RO alternative would be a reliable, long-term mitigation alternative for affected domestic water supplies if it is preferred by the owner due to site specific concerns such as water availability, water conservation, or septic capacity.

5.1.3.3 Bottled Water

Bottled water would consist of providing the users of affected supplies with bottled water and water dispensers. A Sparkletts vender in Sierra Vista currently provides bottled water to the users of affected supplies. To implement this alternative CQB would maintain a service contract with a commercial provider of bottled water to provide and/or continue water delivery to the affected supply. Although ADEQ has stated that it has questions about the use of bottled water as a reliable, long term solution for affected supplies, the bottled water alternative may be acceptable if it is preferred by the owner due to site specific circumstances such as water availability, water conservation, or septic capacity.

5.2 Acceptability of Mitigation Alternatives to Affected Parties

The mitigation alternatives identified for the different areas of affected water supplies are all generally effective and implementable. The primary criterion used to differentiate between the alternatives is their acceptability to the affected parties.

In 2010 and 2011, CQB met with NWC to discuss mitigation actions for NWC-03 and an agreement between CQB and NWC was executed in June 2011. The agreement stipulated that the NWC-03 service area would be connected to the alternate water supply of the Naco Township as described in Section 5.1.1.2.

In 2011, CQB and AWC began discussions to establish the acceptability to AWC of providing water supply to affected arties in the San Jose area. AWC indicated that extending the existing water supply in the San Jose area to the affected parties was feasible and acceptable to AWC. CQB and AWC executed a Main Extension Agreement for the project in October 2011.

On July 16, 2011, CQB met with the owners of affected domestic water supplies. CQB presented the owners with an overview of the process by which mitigation alternatives were developed for each area and described the alternatives available to them as described in Section 5.1. The attendees received information packets describing the mitigation alternatives available to them and containing a document that they could use to select a preferred alternative. A process was established whereby the owner would communicate their preferred alternative to CQB. All owners of affected domestic wells were invited to the meeting and only two owners did not attend. CQB subsequently arranged a meeting with the two owners that could not attend the July presentation to describe the mitigation alternatives and seek their preference.

The results of the owner selection of preferred alternative are:

- Naco Highway/Purdy Lane Area: Seven of eight owners of affected domestic wells selected well replacement as the preferred alternative. One well owner selected either of the connection to an alternate water supply or well replacement.
- San Jose Area: All three owners of affected wells selected the alternative of connection to an alternate water supply. In San Jose the alternate water supply is AWC.
- Bisbee Junction/Airport Area: One of the three owners of affected wells selected full house RO. Two of the well owners remain undecided.

6. SELECTED MITIGATION ALTERNATIVE

Table 4 compares the effectiveness, implementability, and acceptability of mitigation alternatives for the three areas of affected wells. The mitigation alternatives are reliable, long term actions that all meet the mitigation objective of providing a drinking water supply with sulfate concentrations less than 250 mg/L. The selection of a mitigation alternative was made by the affected parties. The mitigation alternatives evaluated by the affected parties are consistent with ARS § 49-286.

Based on their acceptability and selection by affected owners, the following mitigation actions constitute the mitigation alternative for existing drinking water supplies affected by sulfate.

- Naco Highway/Purdy Lane Area
  - NWC-03 Public Supply Well – Connection to Alternate Public Supply. Connect the NWC-03 service area to an alternate water supply provided by NWC's Naco Township public water system. CQB has established an agreement with NWC for the design and construction of the NWC-03 upgrades described in Section 5.1.1.2.
  - Domestic Wells – Well replacement. Domestic wells will be replaced by drilling, constructing, equipping, and connecting new domestic wells screened in the bedrock aquifer below the sulfate plume as described in Section 5.1.1.1. Technical hydrogeologic analysis indicates that replacement wells in the bedrock aquifer in the Naco Highway/Purdy Lane area will not cause the plume to migrate vertically downward if the well is properly constructed and when pumped at levels sufficient for domestic supply.
- San Jose Area
  - Domestic Wells – Connection to Alternate Public Supply. Affected domestic water supplies will be connected to an alternate water supply provided by the AWC public water system. CQB has established an agreement with AWC for the design and construction of new pipeline facilities needed to convey public water supply to the affected water supplies as described in Section 5.1.2.1.
- Bisbee Junction/Airport Area
  - Domestic Wells – Full House RO. CQB will implement full house RO water treatment (with water softening as needed) at one affected domestic well. CQB will identify and contract a service provider for the installation and 10-year operation of an RO system capable of supplying indoor water needs.

- Undecided Well Owners. The owners of two affected domestic water supplies remain undecided about a preferred mitigation alternative. CQB will continue providing bottled water to the undecided water supplies until such time that they select a preferred alternative.

7. MITIGATION PLAN FOR EXISTING DRINKING WATER SUPPLIES AFFECTED BY SULFATE

The Mitigation Plan describes the process to implement, monitor, terminate, and report the selected mitigation alternative described in Section 6.

7.1 Mitigation Implementation

Steps that have been or will be taken by CQB to implement the selected mitigation alternative are described by area. Bottled water delivery to affected owners will be continued through the implementation of the mitigation actions until the new source of water is installed and properly operating.

7.1.1 Naco Highway/Purdy Lane Area

7.1.1.1 NWC-03 Upgrades

NWC is currently proceeding with the design and construction of upgrades to the water system that will provide an alternate public water supply to the service area of NWC-03. Work is proceeding under a June 2011 agreement between NWC and CQB. Pursuant to the agreement, NWC is responsible for the design, construction, and operation of the upgrades, which will be paid for by CQB. In general, implementation of the upgrades consists of the following steps.

- Design of upgrades to the piping, pumping, and storage system
- Submittal of designs to ADEQ for Approval to Construct
- Procurement of Cochise County approvals, rights-of-way, and access agreements, as needed
- Procurement of Arizona Corporation Commission approvals as needed
- Development of bid specifications, project bidding, and contractor selection
- Construction of upgrades

- Submittal of Approval of Construction to ADEQ
- System startup

The project will be executed in two phases. The first phase will consist of design, permitting, and construction of improvements to well sites NWC-03 and NWC-06. The second phase will design, permit, and construct the pipeline interconnection between the Naco Township system and the NWC-03 service area. The NWC-03 well will be abandoned once the system upgrades are complete and water service is being provided from the Naco Township wells. The design, ADEQ Approval to Construct, and Cochise County approvals have already been completed for the first phase of work. The design for the second phase of work is in preparation.

The connection of the NWC-03 service area to the Naco Township water supply is being implemented by NWC. The project duration is not yet known, but is expected to take approximately 18 months or until the third quarter of 2013 to complete if there are no unforeseen delays. CQB will report project progress to ADEQ in the quarterly status reports and periodic Community Advisory Group meetings required by the Mitigation Order.

7.1.1.2 Domestic Well Replacement

The domestic well replacements are being implemented by CQB. Technical specifications for the well replacement program were developed in December 2011 and submitted to five Arizona-licensed drilling companies for bid. Based on a review of the bids, CQB contracted Yellow Jacket Drilling Services (Yellow Jacket) for the project in January 2012. Yellow Jacket will be responsible for drilling, constructing, and developing the wells, installation of submersible pumps, and wellhead completion. CQB contracted a Bisbee-area licensed contractor for electrical and plumbing services needed to energize the wells, install new pressure tanks, and connect the system to the point of entry at the residence. The affected wells will be disconnected from the point of entry at the residence, but well owners did not elect abandonment of the affected wells. Clear Creek Associates was contracted for hydrogeologic support, project oversight, and water quality sampling services on the project.

Yellow Jacket mobilized to the first well site in February 2012 and drilling is currently in progress. The replacement well drilling will be conducted using a single dual rotary drilling rig and crew on a 10 days on and 4 days off basis. Each replacement well is expected to take about 20 days to install. The eight replacement wells will be installed consecutively and are expected to be completed in eight to nine months or in the fourth quarter of 2012. CQB will report progress on the replacement wells to ADEQ in the quarterly status reports and periodic Community Advisory Group meetings required by the Mitigation Order.

7.1.2 San Jose Area

AWC is currently proceeding with the design and construction of pipeline extensions that will provide an alternate water supply to the affected domestic wells. CQB entered into a Main Extension Agreement with AWC in October 2011. Pursuant to the agreement, AWC is responsible for the design and construction of the pipeline extensions. In general, connection of the affected wells to AWC service consists of the following steps.

- Design of piping extension
- Submittal of designs to ADEQ for Approval to Construct
- Procurement of Cochise County approvals, rights-of-way, and access agreements as needed
- Procurement of Arizona Corporation Commission approvals as needed
- Development of bid specifications, project bidding, and contractor selection
- Construction of pipeline
- Submittal of Approval of Construction to ADEQ
- Connection of domestic water supplies to AWC service

AWC has completed the extension design and ADEQ has issued its Approval to Construct the extension. The Arizona Corporation Commission has reviewed and approved the Main Extension Agreement. AWC solicited bids for construction services and selected a qualified contractor. Construction is expected to start in March 2012. CQB will contract with a Bisbee-area licensed contractor to provide services needed to disconnect the affected well from the domestic water supply and connect the domestic supply to AWC service. This includes the installation and certification of a backflow preventer by a licensed inspector. Well owners did not elect abandonment of the affected wells. AWC service is expected to be available to the users of affected water supplies by the third quarter of 2012.

7.1.3 Bisbee Junction/Airport Area

7.1.3.1 Full House RO

CQB will contract with a provider of home water treatment systems for the design (if needed), purchase, installation, and 10-year servicing of an RO and water softening (dependant on site-specific water chemistry) treatment system. A home water treatment service provider has not yet been selected.

CQB will take the following implementation steps for full house RO.

- Meet well owners to verify property ownership, inspect and document existing infrastructure, and explain the process for identifying and contracting a service provider.
- Identify and evaluate licensed and bonded providers of home water treatment systems capable of turn key design, purchase, installation, and servicing of an RO treatment system to be placed between the existing well and the water distribution system with the exception of exterior faucets.
- Obtain proposals and cost estimates from at least three potential service providers, if possible. Review proposals and select contractor.
- Conduct a site examination with the successful service provider so that a design and cost estimate can be developed.
- Oversee system installation to monitor progress and verify operation. The service provider would be responsible for utility clearance using a private utility clearance contractor in the event excavation is required.

A schedule is not yet developed for installation of the full house RO treatment. It is expected that it will take nine months to identify, procure, and install a water treatment system. Implementation is expected to be complete by the fourth quarter of 2012.

7.1.3.2 Undecided Well Owners

CQB will continue to provide the two undecided well owners with bottled water until such time that a mitigation action is selected and implemented or the well meets the criterion for discontinuing mitigation. CQB will continue to provide information to the undecided owners when requested. If the undecided well owners select a mitigation action, CQB would work to implement it in a timely manner consistent with the other mitigation actions.

7.2 Monitoring Mitigation Actions at Affected Drinking Water Supplies

CQB will conduct water quality testing for sulfate at the replacement wells and wells with full house RO or point of use RO systems, if any. No water quality tests will be conducted for drinking water supplies provided by the NWC or AWC public drinking water systems because they are tested pursuant to ADEQ regulations.

CQB will monitor groundwater sulfate concentrations during and after mitigation action implementation pursuant to a groundwater monitoring plan approved by ADEQ. The current ADEQ-approved groundwater monitoring plan will be continued through the implementation of mitigation actions for impacted drinking water supplies. The Naco Highway/Purdy Lane replacement wells will be added to the groundwater monitoring schedule for quarterly sampling and sulfate analysis when they are completed and become operational. Quarterly sampling and sulfate analysis is the same sampling frequency currently used to document the sulfate concentration in private and public drinking water supplies in the vicinity of the plume, including the wells providing supply to the NWC and AWC water systems. Groundwater samples will also be collected annually from wells with RO treatment units in order to determine when sulfate concentrations reach levels that allow termination of the mitigation action. Samples of RO-treated water will not be collected by CQB after the system is operational because it will be the responsibility of the water treatment service provider retained to maintain the treatment system to test and ensure proper system operation.

CQB will periodically review the groundwater monitoring plan and recommend modifications to improve the plan, if needed, based on site-specific data for sulfate and the uses of the data collected. The groundwater monitoring plan also may be revised pursuant to the conclusions of the FS and recommendations of the Mitigation Plan to be submitted for drinking water supplies that may be affected in the future.

If it is determined that a mitigation action implemented under this Mitigation Plan is ineffective (e.g., sulfate concentrations do not meet the mitigation objective initially or increase over time) or if additional affected wells are identified, CQB will implement additional mitigation actions to address the situation pursuant to the Mitigation Order. This FS describes the range of potential mitigation actions for affected wells. Any potential additional mitigation action that may be required for an affected well would be selected from the mitigation actions described in this FS.

7.3 Termination of Mitigation Actions

The results of water supply monitoring for sulfate would provide the basis for continuing or terminating a mitigation action as described in Section 4 of the Work Plan. Water quality sampling to determine the average sulfate concentration would be conducted at water supply wells receiving RO treatment as mitigation. The average sulfate concentration will be calculated as the arithmetic mean of the three most recent discrete and valid water sampling results from the well. As described in the ADEQ-approved Work Plan, a mitigation action will be terminated when monitoring results indicate that the average sulfate concentration of the drinking water supply well is less than the sulfate mitigation level of 250 mg/L based on at least three quarters of monitoring.

7.4 Mitigation Reporting

The progress of mitigation actions will be reported to ADEQ through the periodic Community Advisory Group meetings and quarterly status reports required by Sections III.I and V.A of the Mitigation Order. The results of ongoing water quality monitoring will be reported to ADEQ according to a schedule identified in the groundwater monitoring plan approved by ADEQ.

8. REFERENCES

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Clear Creek Associates. 2010. Revision I Aquifer Characterization Report, Task 4 of the Aquifer Characterization Plan, Mitigation Order on Consent Docket No. P-121-07. December 15, 2010.

Clear Creek Associates. 2012. Fourth Quarter 2011 Groundwater Monitoring Report, Tasks 1.0 and 2.2 of Aquifer Characterization Plan, Mitigation Order on Consent Docket No. P-121-07. January 19, 2012.

Copper Queen Branch (CQB). 2012. Correspondence from Rebecca A. Sawyer, CQB, to Mindi Cross, ADEQ, Re: Mitigation Order on Consent No. P-121-07. January 24, 2012.

Hydro Geo Chem, Inc. (HGC). 2008. Revision 1, Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Concentrator Tailing Storage Area, Cochise County, Arizona. July 3, 2008.

Phelps Dodge Corporation (PD). 1990. Aquifer Protection Permit Application, Copper Queen Branch CTSA, Cochise County, Arizona. August 14, 1990.

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Savci Environmental Technologies, Inc. 1998. Hydrologic Assessment of Tailing Impoundments CTSA APP Project Area, Bisbee, Arizona. Prepared for Phelps Dodge Mining Company. May 12, 1998.

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TABLES

TABLE 1
Construction Data for Affected Wells

WELL NAME	AREA	ADWR REGISTRY NUMBER	YEAR DRILLED[1]	WELL DEPTH[1] (feet)	CASING MATERIAL[1]	CASING DEPTH[1] (feet)	CASING DIAMETER[1] (inches)	MEASURING POINT ELEVATION[2] (ft amsl)	DEPTH TO TOP OF SCREEN[1] (feet)	DEPTH TO BOTTOM OF SCREEN[1] (feet)	REPORTED DEPTH TO WATER WHEN DRILLED OR MODIFIED WITH DATE OF MEAUREMENT[1] (feet below surface)	MOST RECENT DEPTH TO WATER AND DATE OF MEASUREMENT (feet below measuring point)	APPARENT THICKNESS OF SCREENED SATURATED ZONE IN WELL (feet)
ANDERSON	Naco Hwy/Purdy Ln	55-613396	1954	236	Steel	110	8	4588.51	Unknown	Unknown	126	150.2 (10/11/2011)	86
BIMA	Bisbee Jct/Airport	55-577927	2000, deepened in 2004	465	PVC	465	6 (10-255), 4.5 (350-465)	4802.05	350	465	320 (1999)[3], 341 (2004)	395.2 (4/4/2011)	70
COOPER C	Naco Hwy/Purdy Ln	55-637069	1966	220	Steel	220	6	4599.14	Unknown	Unknown	165	159.8 (10/13/2011)	60
DURAZO	San Jose	None	Unknown	Unknown	Unknown	Unknown	Unknown	ND	Unknown	Unknown	Unknown	Unknown	Unknown
FRANCO	Naco Hwy/Purdy Ln	55-500101	1981	200	PVC	200	6	ND	180	200	160	Unknown	40
HOWARD	Naco Hwy/Purdy Ln	None	Unknown	Unknown	Unknown	Unknown	Unknown	4593.91	Unknown	Unknown	Unknown	155.02 (10/11/2011)	Unknown
MARCELL	Naco Hwy/Purdy Ln	None	2011	220	Unknown	Unknown	Unknown	ND	Unknown	Unknown	Unknown	Unknown	Unknown
MCCONNEL 265	Naco Hwy/Purdy Ln	55-539265	1993	216	Steel	216	6	4600.7	174	216	130	161.2 (10/11/2011)	55
METZLER	San Jose	35-71891	1979	351	Steel	351	6	4728.53	245	345	238	290.5 (10/12/2011)	55
NOTEMAN	Bisbee Jct/Airport	55-212483	2006 (?)[4]	400	PVC	400	5.5	4800.68	Unknown	Unknown	Unknown	327.5 (2/25/2009)	72
NWC-03	Naco Hwy/Purdy Ln	55-203321	2004	312	Steel	312	6.625	4572.82	252	312	140	134.7 (10/13/2011)	177
PANAGAKOS	Bisbee Jct/Airport	35-76413	1957	205	Steel	205	6.625	4691.4	141	200	131	172.9 (8/25/2011)	27
PARRA	San Jose	55-576415	1999	355	Steel and PVC	355	6 (1-120), 4.5 (115-355)	4727.21	255	355	263	281 (7/20/2009)	92
PIONKE	Naco Hwy/Purdy Ln	55-613395	1964	300	Steel	300	6	4592.13	Unknown	Unknown	Unknown	153.9 (10/11/2011)	146
WEISKOPF	Naco Hwy/Purdy Ln	55-641802	"prior to 1960"	200	Steel	200	6	4586.89	Unknown	Unknown	Unknown	148.3 (10/13/2011)	52

[1] Information ADWR Imaged Records
[2] Information from Clear Creek Associates (2012)
[3] Pump installation report predates well driller report
[4] Information based on NOI data only, no drillers report filed
ADWR = Arizona Department of Water Resources
ft amsl = feet above mean sea level
ND = No Data

TABLE 2
Response Actions, Technologies, and Process Options Evaluated for Mitigation of Affected Drinking Water Supplies

RESPONSE ACTION	TECHNOLOGY	PROCESS OPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST	EVALUATION
DRINKING WATER SUPPLY MITIGATION						
Alternate Water Supply	Well Modification to Eliminate Pumping from Sulfate Zone	Casing Liner to Exclude Sulfate-Bearing Inflow	Potentially effective if it could be reliably implemented.	Nonimplementable due to difficulty of retrofitting existing wells, high risk of damage to well, difficulty of ensuring and maintaining adequate seal, and low probability of low sulfate zone in the screened interval of affected wells. Administratively implementable.	Medium	Reject due to lack of technical implementability
		Well Deepening to Draw from Low Sulfate Aquifer at Depth	Potentially effective if it could be reliably implemented.	Overall poor technical implementability due to difficulty of retrofitting existing wells, high risk of damage to well, difficulty of ensuring and maintaining adequate seal. Not implementable at San Jose and Bisbee Junction/Airport areas due to lack of reliable water quantity and quality in bedrock at those locations. Potentially implementable at Naco Highway/Purdy Lane area due to low sulfate groundwater at depth in basin fill and bedrock. Administratively implementable.	Medium	Reject due to poor technical implementability
	Well Replacement		Effective at meeting mitigation objective where low sulfate groundwater is present at depth and can be targeted for replacement well.	Good technical implementability in Naco Highway/Purdy Lane area due to low sulfate groundwater in basin fill and bedrock below the sulfate plume. Not implementable in San Jose and Bisbee Junction/Airport areas due to lack of reliable water quantity and quality in bedrock at those locations. Administratively implementable.	Medium	Retain for Naco Highway/Purdy Lane area
	Connection to Alternate Public Water Supply		Effective at meeting mitigation objective by providing public water supply monitored by ADEQ.	Good technical implementability in the Naco Highway/Purdy Lane and San Jose areas where the public water supplies of NWC and AWC are proximal to affected wells. Poor technical implementability in Bisbee Junction/Airport area where public water supply has inadequate supply and infrastructure. Administratively implementable with ADEQ, Cochise County, and Arizona Corporation Commission review.	Medium	Retain for Naco Highway/Purdy Lane and San Jose areas
	Bottled Water		Effective at meeting mitigation objective by providing bottled drinking water.	Implementable with commercial drinking water providers. Administratively implementable	Low	Retain for all areas
Water Treatment	Wellhead Treatment	Install reverse osmosis or other membrane treatment at wellhead	Potentially effective if it could be reliably implemented.	Nonimplementable due to lack of commercial treatment systems small enough and simple to operate and maintain for application to the affected wells; household RO systems are used for treatment of small flows.	Medium	Reject due to lack of technical implementability
	Full-House Reverse Osmosis	Install reverse osmosis system for all household demands	Effective at meeting mitigation objective through water treatment at point of entry to home	Technically implementable as household treatment systems are an existing and reliable technology, but high water waste is associated with large volume of treatment. Implementability may be limited by site specific factors such as limited well production or septic capacity. Administratively implementable.	Medium	Retain for all areas
	Point-of-Use Reverse Osmosis	Install reverse osmosis system for kitchen use only	Effective at meeting mitigation objective through water treatment at point of use in the kitchen.	Technically implementable as household treatment systems are an existing and reliable technology. Because of low treatment volume, implementability should not be limited by well production or septic capacity. Administratively implementable.	Medium	Retain for all areas
Blending	Mix Impacted Well Water with Water from Other Sources to Meet Sulfate Action Level		Potentially effective if it could be reliably implemented.	Poor technical implementability due to lack of sources of low sulfate water for blending and because a high level of operating oversight is impracticable for affected water supplies	Medium	Reject due to poor technical implementability

Shading indicates process option retained for alternatives analysis

TABLE 3
Mitigation Alternatives for Affected Drinking Water Supplies

Naco Highway/Purdy Lane Area
1. Well Replacement
2. Connection to Alternate Water Supply (Naco Water Company)
3. Full House Reverse Osmosis (RO)
4. Point of Use RO
5. Bottled Water
San Jose Area
1. Connection to Alternate Water Supply (Arizona Water Company)
2. Full House RO
3. Point of Use RO
4. Bottled Water
Bisbee Junction/Airport Area
1. Full House RO
2. Point of Use RO
3. Bottled Water

TABLE 4
Analysis of Mitigation Alternatives for Affected Drinking Water Supplies

MITIGATION ALTERNATIVE	EFECTIVENESS	IMPLEMENTABILITY	ADEQ ACCEPTABILITY	ACCEPTABILITY BY AFFECTED PARTIES
Naco Highway/Purdy Lane Area				
Well Replacement	Effective	Implementable	Acceptable	Preferred alternative by all eight owners of affected domestic water supplies
Connection to Alternate Water Supply (Naco Water Company)	Effective	Implementable for NWC-03, implementable for domestic wells if greater than 75% of affected owners select (or 7 of 9 owners)	Acceptable	Preferred alternative by NWC for mitigation of NWC-03
Full House Reverse Osmosis (RO)	Effective	Implementable	Acceptable	Not selected by owners of affected water supplies
Point of Use RO	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies
Bottled Water	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies
San Jose Area				
Connection to Alternate Water Supply (Arizona Water Company)	Effective	Implementable	Acceptable	Preferred alternative by all three owners of affected domestic water supplies
Full House RO	Effective	Implementable	Acceptable	Not selected by owners of affected water supplies
Point of Use RO	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies
Bottled Water	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies
Bisbee Junction/Airport Area				
Full House RO	Effective	Implementable	Acceptable	Preferred alternative by one of three owners of affected supplies; two owners are undecided
Point of Use RO	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies
Bottled Water	Effective	Implementable	May be Acceptable Based on Site-Specific Factors	Not selected by owners of affected water supplies

FIGURES

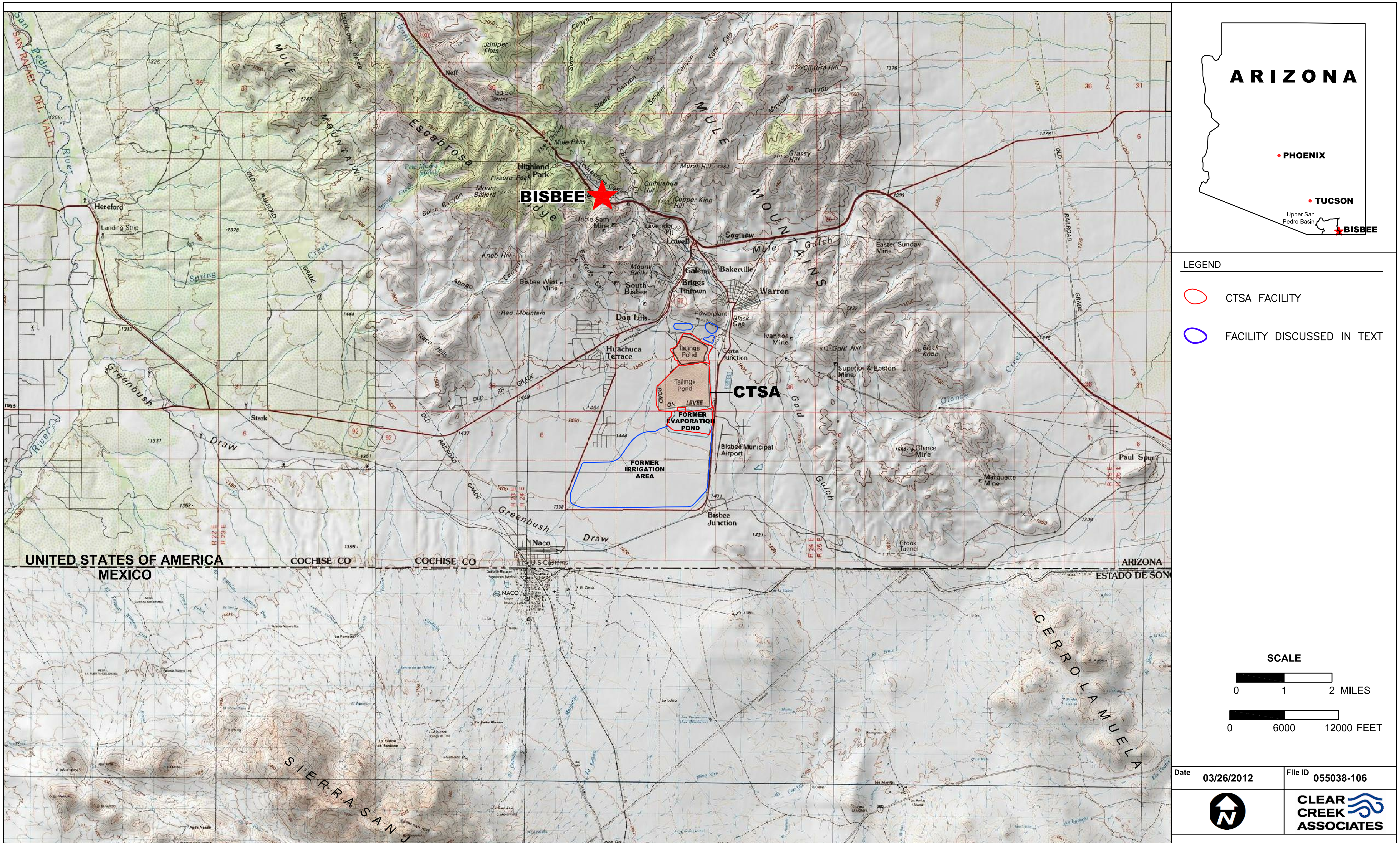
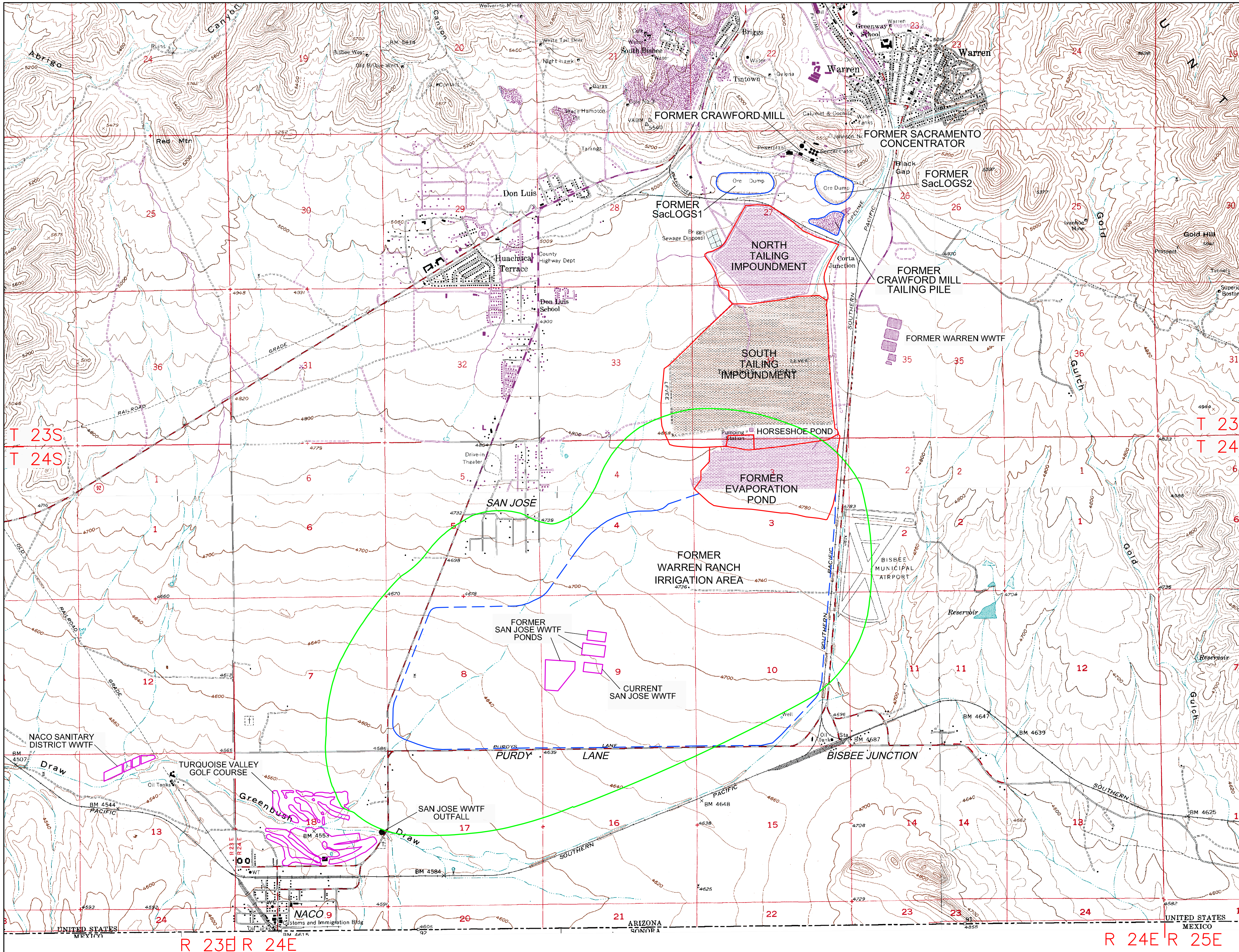


FIGURE 1
LOCATION MAP
BISBEE - NACO AREA



LEGEND

CTSA FACILITY

FACILITY DISCUSSED IN TEXT

250 mg/L SULFATE ISOLINE (BASED ON FOURTH QUARTER 2011 DATA)

SCALE (FEET)

0 1000 2000

MAP SOURCE: USGS 7.5 MIN QUADS: BISBEE, BISBEE NE, BISBEE SE, AND NACO, ARIZONA. NAD 27 ZONE 12 CENTRAL, METERS

Date 03/26/2012	File ID 055038-107

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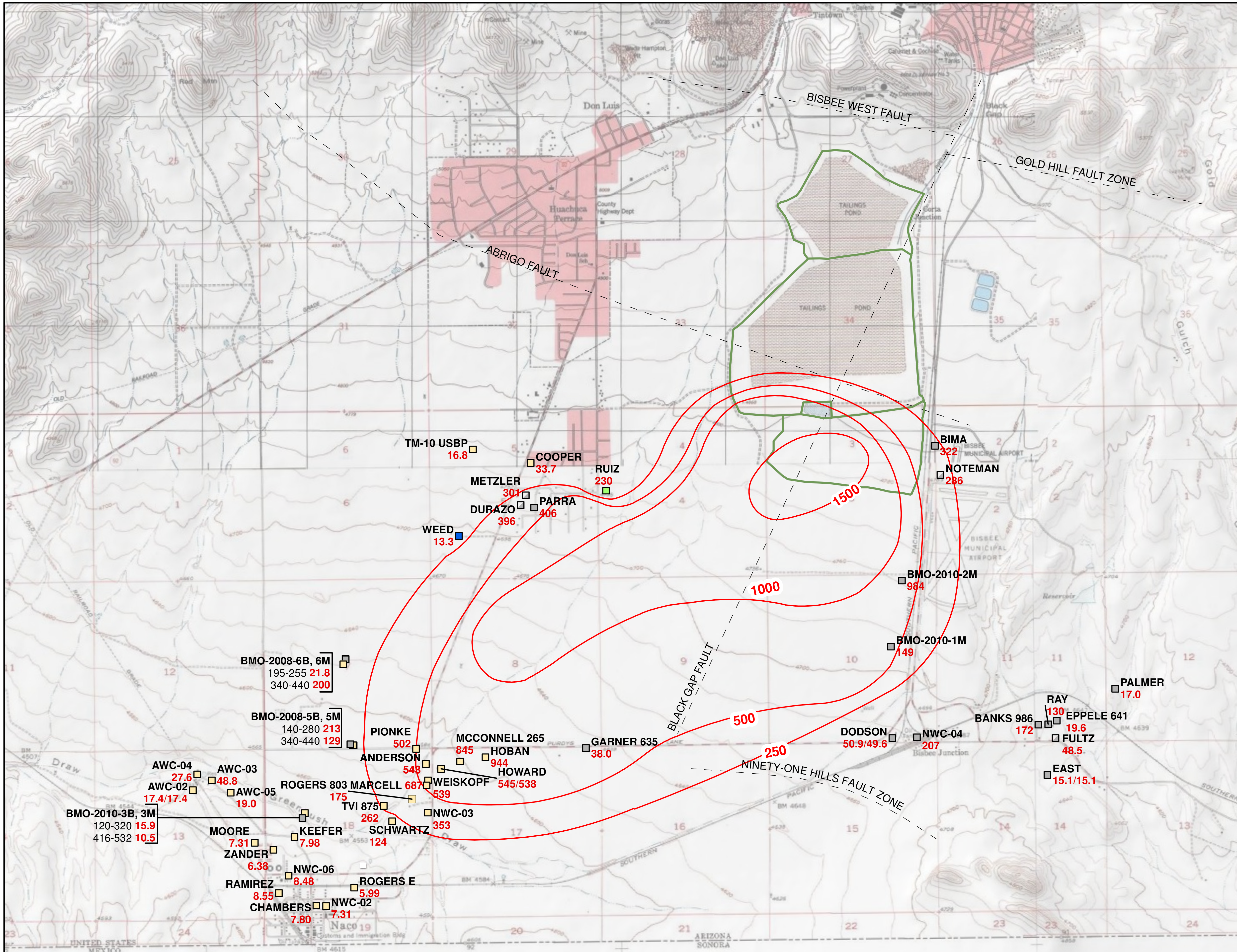
FIGURE 2
FACILITIES IN THE VICINITY OF THE CONCENTRATOR TAILING STORAGE AREA



Legend

POOL	Well ID
115	Sulfate Concentration (mg/L)
(red line)	Sulfate Concentration Contour (mg/L)
(dashed line)	Faults (inferred)
(green line)	CTSA Facility

Co-located Wells
Well ID
Screen (ft bls): SO4 Concentration (mg/L)

Screened Formation
- Basin Fill
- Basin Fill and Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group - Estimated
- Undifferentiated Bisbee Group and Glance Conglomerate
- Glance Conglomerate
- Glance Conglomerate-Estimated

Undifferentiated Bisbee Group: Cintura, Mural Limestone, and Morita Formations

Scale (Feet)
0 3,000 6,000

Notes:
Projection: UTM Zone 12N NAD83
GARNER635, BMO-2010-1M, AND ROGERS not used for contouring. Sulfate concentration contours are based on third quarter 2011 data and adjusted for current data.

Date 03/26/2012
File ID 055038-179

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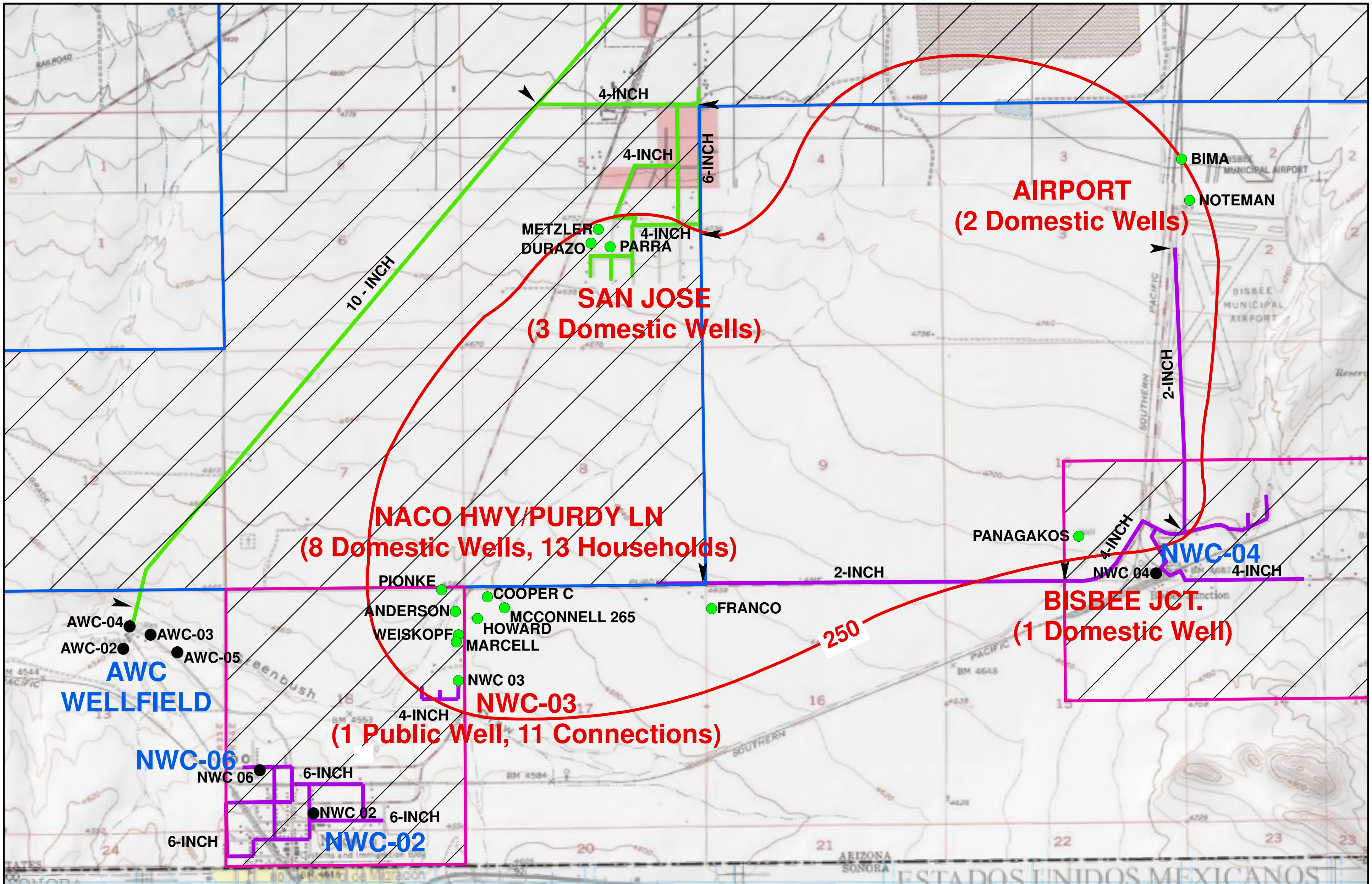
FIGURE 3
SULFATE CONCENTRATIONS IN GROUNDWATER FOR FOURTH QUARTER 2011



Legend

- Affected Drinking Water Supply Well
- Drinking Water Supply Well with Sulfate <250mg/L
- NWC Pipeline (Existing)
- Arizona Water Company Bisbee Service Area
- Naco Water Company Service Area
- AWC Pipeline (Existing)

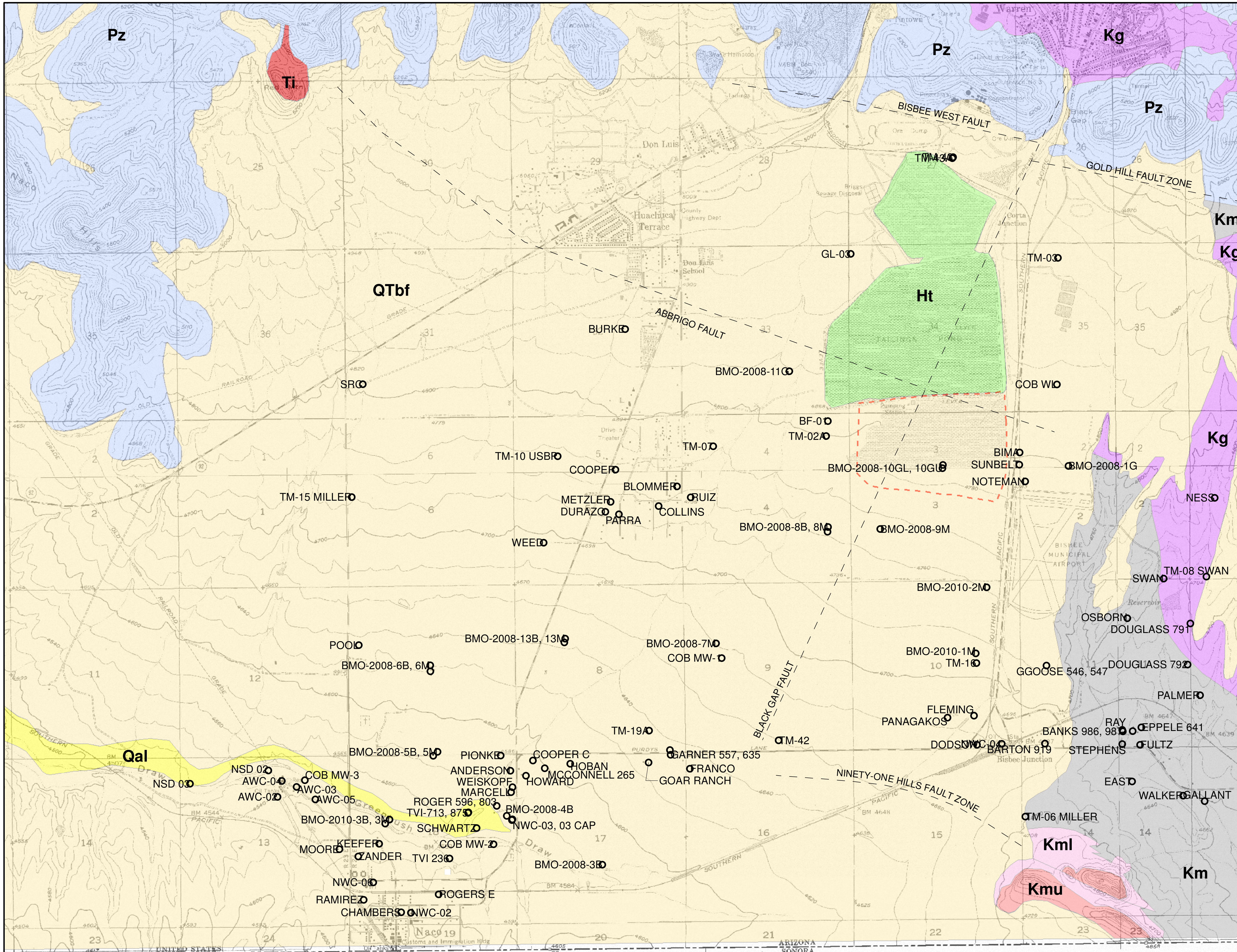
0 1500 3000
Feet

CLEAR CREEK ASSOCIATES

Date 03/26/2012

File ID 055038-178

FIGURE 4
LOCATION OF
AFFECTED WELLS



Legend

- Sampling / Water Level Location

  Not all wells shown are currently sampled. Current sampling locations are based on the Revised Monitoring Program approved by ADEQ in 2010.

- Former Evaporation Ponds

Geologic Unit

- Ht - Holocene Tailings
- Qal - Quaternary Alluvium
- QTbf - Quaternary-Tertiary Basin Fill
- Ti - Tertiary Intrusive
- Kc - Cintura Formation
- Kmu - Upper Mural Limestone
- Kml - Lower Mural Limestone
- Km - Morita Formation
- Kg - Glance Conglomerate
- Pz - Paleozoic Sedimentary Formations

Undifferentiated Bisbee Group (Kc, Kmu, Kml, Km)

Scale

0 1,500 3,000 6,000 Feet

Notes:
Projection: UTM Zone 12N NAD83

Date	File ID
02/23/2012	055038-180

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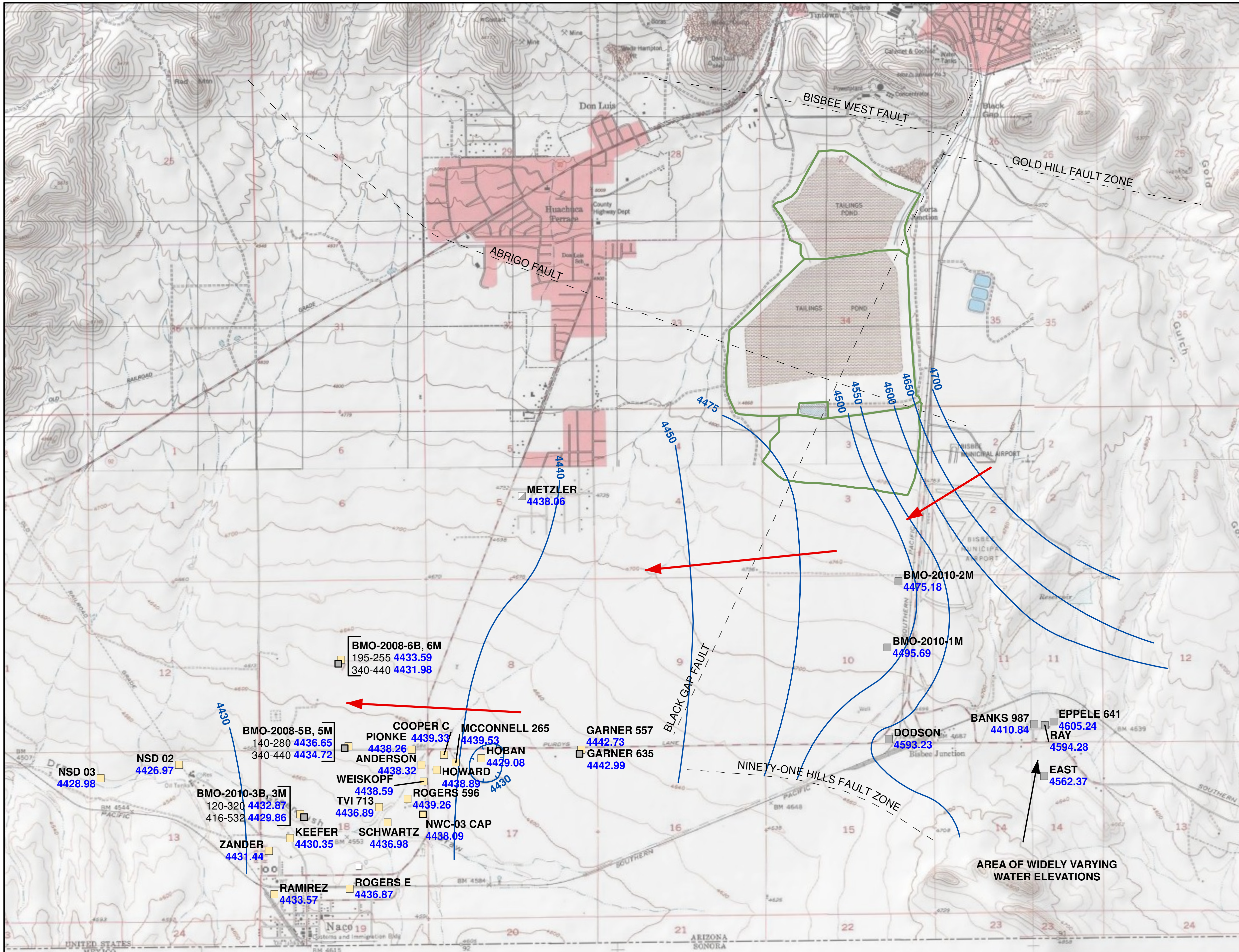
FIGURE 5
GENERALIZED GEOLOGY AND WELL LOCATIONS

DRAFT - PRIVILEGED AND CONFIDENTIAL
Prepared at the Direction of Legal Counsel



Legend

POOL — Well ID

4432.35 — Groundwater Elevation (ft amsl)

Groundwater Elevation Contours (dashed where inferred)

Groundwater Depression

Faults (inferred)

CTSA Facility

Co-located Wells

Well ID

Screen (ft bgs): Water Elevation (ft amsl)

Screened Formation

- Basin Fill
- Basin Fill and Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group - Estimated
- Undifferentiated Bisbee Group and Glance Conglomerate
- Glance Conglomerate
- Glance Conglomerate-Estimated

Undifferentiated Bisbee Group: Cintura, Mural Limestone, and Morita Formations

BANKS 987 and EPPELE 641 not used for contouring. Groundwater elevation contours are based on third quarter 2011 data and adjusted based on current data.

Direction of Groundwater Flow

Scale (Feet)

0 3,000 6,000

Notes:

Projection: UTM Zone 12N NAD83

Date	File ID
03/26/2012	055038-181

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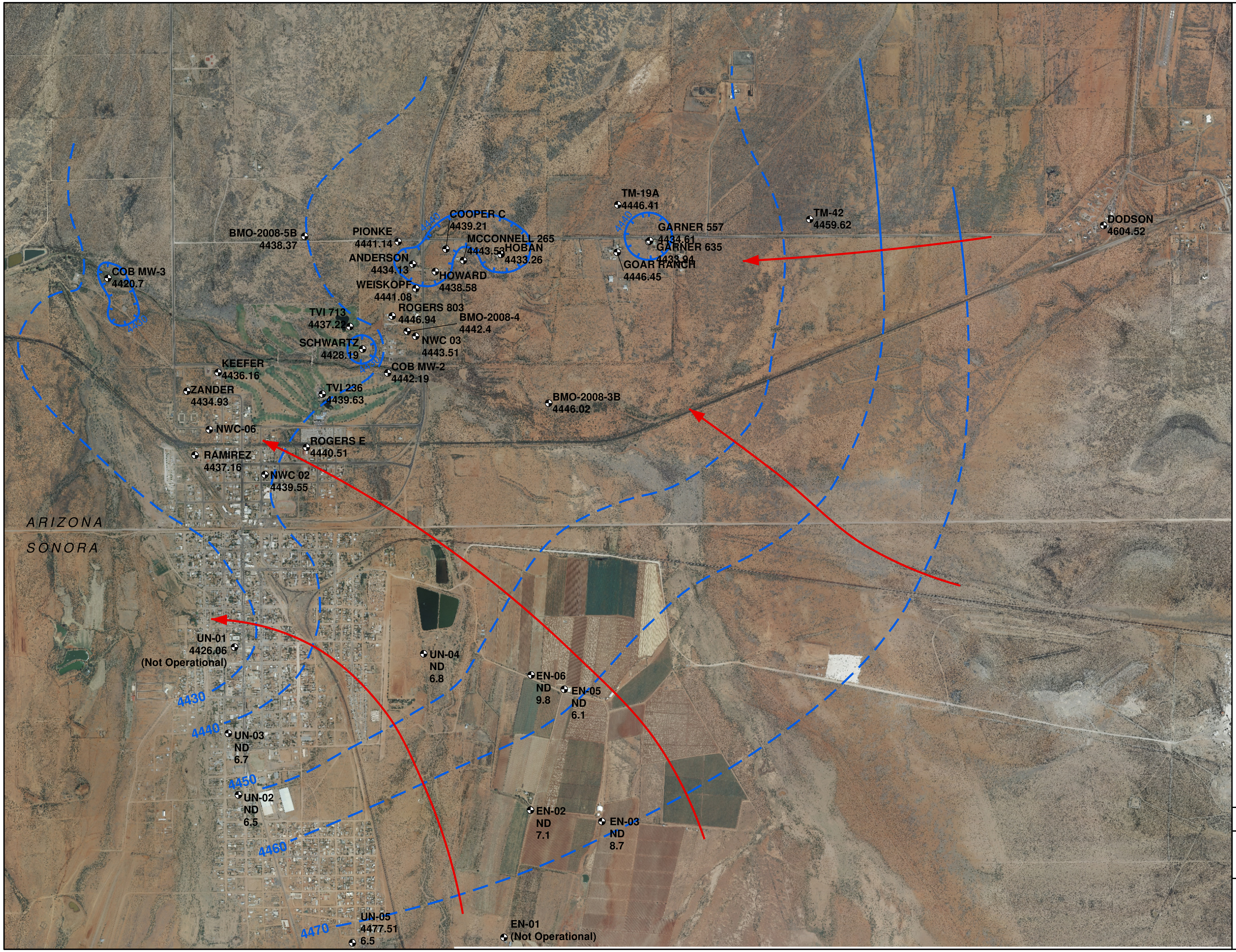
FIGURE 6
GROUNDWATER ELEVATIONS FOR FOURTH QUARTER 2011



Legend

- TVI-713 — Well ID
- 4440.92 — Groundwater Elevation (ft amsl)
- 10 — Sulfate Concentration (mg/L)
- Groundwater Contours (dashed where inferred)
- Groundwater Depression

ND = No Data, no sounding tube
EN = Ejido Naco
UN = Urbano Naco

Direction of Groundwater Flow

Scale (Feet)
0 2,000 4,000

Notes:
Projection: UTM Zone 12N NAD83

FIGURE FROM HGC (2009c)

Date	File ID
03/26/2012	055038-182

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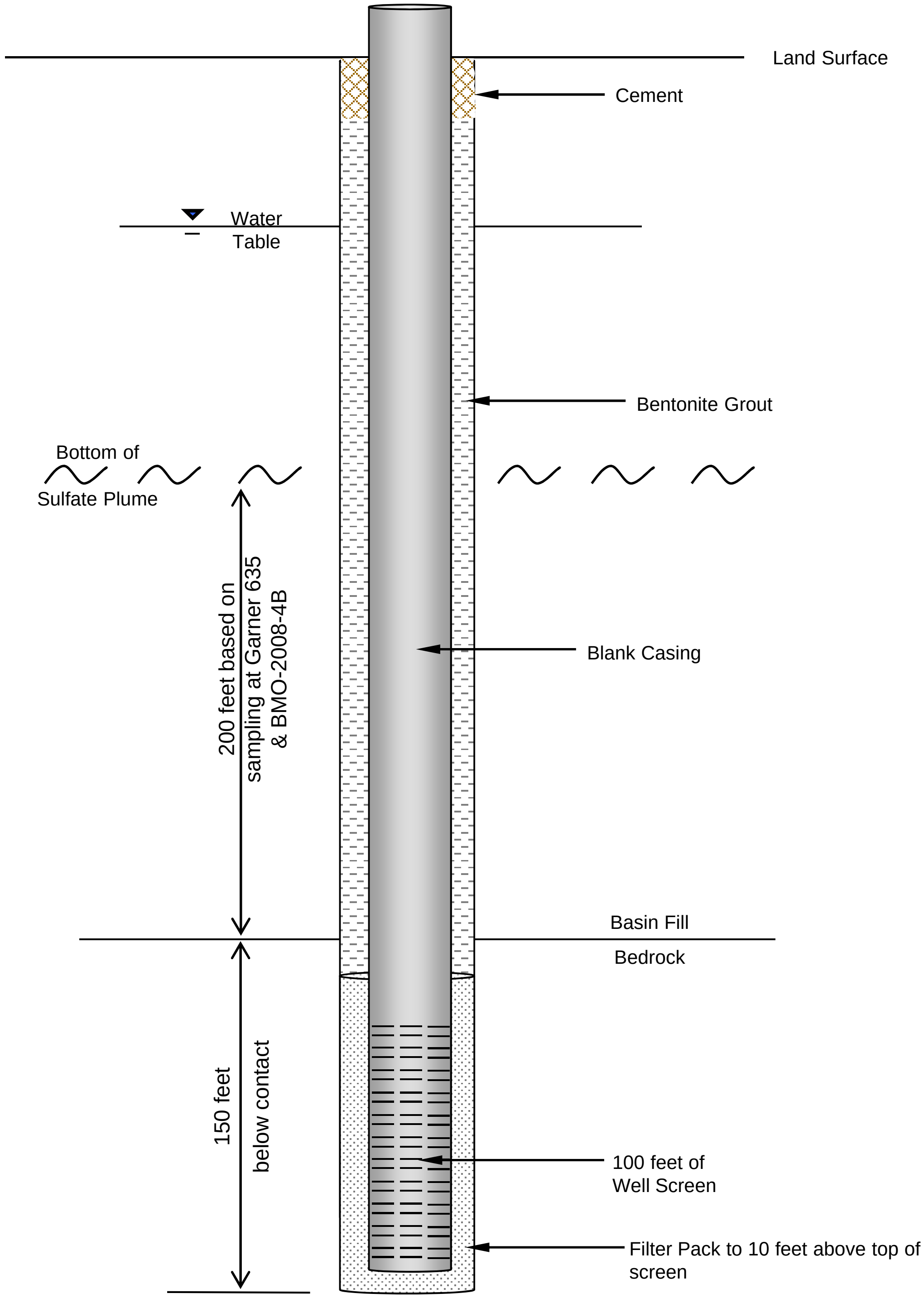
FIGURE 7
SULFATE CONCENTRATIONS AND GROUNDWATER ELEVATIONS FOR NACO, SONORA OCTOBER 2008

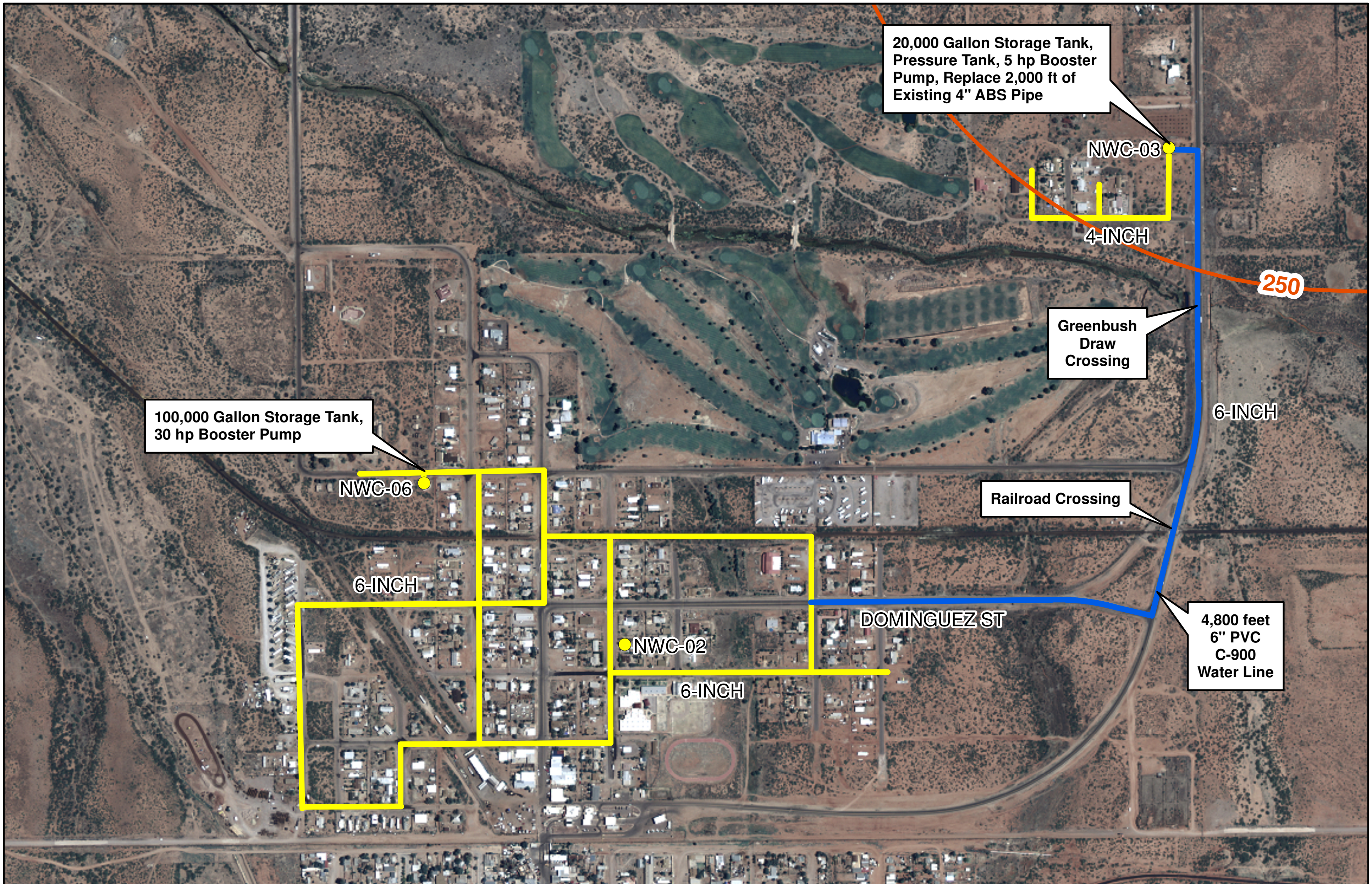


Not To Scale

CLEAR CREEK ASSOCIATES

Date 03/28/2012	File ID 055038-184

FIGURE 8
CONCEPTUAL WELL DESIGN FOR REPLACEMENT WELLS



Legend

- Production Well
- Existing Naco Water Company Pipeline
- Proposed Pipeline
- 250 mg/L SO4 Contour

0 400 800
Feet

CLEAR CREEK ASSOCIATES

Date 03/26/2012

File ID 055038-183

FIGURE 9
SCHEMATIC OF
NWC-03 UPGRADES

APPENDIX A

EVALUATION OF SULFATE MIGRATION IN RESPONSE TO PROPOSED INSTALLATION OF REPLACEMENT WELLS IN THE NACO HIGHWAY/PURDY LANE AREA

CLEAR CREEK ASSOCIATES

TECHNICAL MEMORANDUM

To: Mindi Cross and David Haag, Arizona Department of Environmental Quality

From: Paul Plato, R.G. and James Norris, R.G., Clear Creek Associates

Subject: Evaluation of Sulfate Migration in Response to Proposed Installation of Replacement Wells in the Naco Highway/Purdy Lane Area
Mitigation Order on Consent Docket No. P-121-07

Date: November 22, 2011

REGISTERED GEOLOGIST CERTIFICATE NO. 30842 JAMES R. NORRIS Date Signed 11/22/11 ARIZONA U.S.A. Expires 12/31/11

REGISTERED GEOLOGIST CERTIFICATE NO. 29376 PAUL R PLATO Date Signed November 22, 2011 ARIZONA, U.S.A. Expires September 30, 2013

1 INTRODUCTION

This memorandum presents the results of numerical groundwater flow and sulfate transport modeling to evaluate the installation of deep domestic water production wells as a mitigation measure in the Naco Highway/Purdy Lane area, north of Naco, Arizona (Figure 1). The purpose of modeling was to evaluate whether wells drilled deeper into the basin fill and bedrock would be adequately isolated from shallow groundwater containing sulfate at concentrations greater than 250 milligrams per liter (mg/l). Freeport-McMoRan Corporation Copper Queen Branch has proposed, as one mitigation measure and where feasible for certain well owners, to deepen wells in the Naco Highway/Purdy Lane area into the underlying bedrock which does not contain elevated sulfate concentrations at this location. To evaluate the influence of installing deeper wells on the future distribution of sulfate in groundwater, groundwater pumping and sulfate transport in the vicinity of the proposed replacement wells were simulated for a 100-year period using several different assumptions for hydraulic conductivity and pumping rate.

2 WELLS EVALUATED

Figure 2 illustrates the wells considered for replacement in the area. These wells are currently shallow wells completed in the upper portion of the basin fill aquifer. Table 1 lists the well construction and average sulfate concentrations for wells proposed for replacement. Average sulfate concentrations range from 362 to 909 mg/l.

Table 1 – Wells Proposed for Replacement

Well Name	East	North	Cadastral	Well Depth (feet)	Casing Depth (feet)	Casing Diameter (inches)	Elevation (feet-MSL)	Depth to Top of Screen (feet)	Depth to Bottom of Screen (feet)	Average Sulfate Since 2008 (mg/l)
ANDERSON	601135	3468816	D24024018AAA	236	110	8	4580.34	100	236	511
COOPER C	601350	3468913	D24024017BBB	220	220	6	4595.06	100	220	909
FRANCO	602850	3468836	D24024016BBB	200	200	6	4636.00	180	200	635
HOWARD	601282	3468769	D24024017BBC	600	4	6	4589.70	150	300	362
MCCONNELL 265	601463	3468840	D24024017BBB	216	216	8	4600.70	174	216	716
PIONKE	600936	3468837	D24024018AAA	300	300	6	4592.13	100	300	431
WEISKOPF	601155	3468659	D24024018AAD	200	200	6	4586.89	100	200	520

Elevations are feet above mean sea level. Depths are feet below land surface.

Figure 3 illustrates geologic Cross-Section C-C' (see Figure 1 for location of cross section) from the Aquifer Characterization Report (ACR) (Clear Creek Associates, 2010) overlain by a groundwater model cross-section showing the layers of the original numerical model. Layer 1 represents basin fill, Layers 2 and 3 are undifferentiated Bisbee Group bedrock, and Layer 4 is Glance Conglomerate bedrock. This section also shows wells in the Purdy Lane area. The domestic water supply wells are generally completed in the shallow portion of the basin fill aquifer (Layer 1).

Based on sampling data collected in 2001 and 2008, sulfate concentrations greater than 250 mg/l are limited to the upper portion of the basin fill aquifer. During 2001, a well at the Garner property was replaced with a deeper well (GARNER 635) drilled to bedrock. Samples collected from temporary wells during drilling of the GARNER 635 (GW-47 samples on Table 2) indicated that sulfate in excess of 250 mg/l did not extend below a depth of 350 feet below land surface, and that the lower basin fill and underlying bedrock contained sulfate concentrations in the range of 25 to 50 mg/l. GARNER 635 was constructed with approximately 100 feet of screen in the upper portion of the bedrock. After 10 years of continuous operation, the sulfate concentration at GARNER 635 remains in the 30 to 40 mg/l range (Clear Creek Associates, 2011); demonstrating that in the Naco Highway/Purdy Lane area well replacement in the bedrock aquifer is an effective mitigation option for obtaining drinking water with sulfate concentrations below 250 mg/l. In 2008, the installation of monitor well BMO-2008-4B provided depth specific sampling results indicating that the lower portion of the basin fill deeper than 450 feet below land surface had sulfate concentrations in the 10 to 20 mg/l range (Clear Creek Associates, 2010). Figure 4 is an east-west cross section along Purdy Lane illustrating the sulfate results for samples collected during drilling of the GARNER 635 and BMO-2008-4B wells and groundwater sampling at private wells.

Table 2 – Depth-Specific Sample Results from GARNER 635

Site ID	Depth Interval	Sample No.	Concentration (mg/l)	Type of Aquifer Material
GW-47	250-280	5	632	QTbf
GW-47	345-375	4	25.8	QTbf
GW-47	455-485	3	16.7	QTbf
GW-47	545-575	2	39.8	Km
GW-47	630-670	1	54.2	Km

These sampling results indicate that the lower portion of the basin fill (designated as QTbf on Figures 3 and 4) and the underlying bedrock (Km, Kml, Kmu, and Kc on Figures 3 and 4) in the Naco Highway/Purdy Lane area do not contain sulfate concentrations exceeding 250 mg/l. Concentrations are slightly higher in samples from the bedrock than in the deeper basin fill, but this is likely due to groundwater age and natural geochemical conditions, rather than transport from the shallow sulfate plume.

3 MODEL SIMULATION APPROACH

One consideration regarding the installation of deep wells beneath the sulfate plume is that the low hydraulic conductivity of the bedrock could result in significant well drawdowns during pumping, which may cause vertically downward hydraulic gradients and deeper migration of the shallow sulfate. To evaluate the potential to draw groundwater with elevated sulfate concentrations to the deepened wells, model simulations were executed using the groundwater flow and sulfate transport model developed to simulate the sulfate plume for the ACR (Clear Creek Associates, 2010). Using the Groundwater Vistas™ telescopic mesh refinement (TMR) feature, a sub-model focused on the area around the Naco Highway/Purdy Lane wells was constructed from the larger original calibrated model (Figure 5). The TMR utility uses the original model to setup a sub-model domain, setting boundary conditions based upon the original model. The TMR model boundaries were designated as constant heads, and were set to the values from the end of the model calibration (end of 2008) as calculated in the model simulation. The resulting model used uniform model cells approximately 141 feet by 157.5 feet in size[1]. Other stresses, such as recharge, are assigned to the TMR model based on specifications in the original model.

In addition to the horizontal refinement of the model domain using TMR, the model was divided into additional layers to allow for better definition of the groundwater zone containing sulfate in excess of 250 mg/l. The basin fill aquifer layer (original model layer 1) was divided into 5 TMR model layers, each approximately 98 feet thick with the exception of the uppermost TMR layer which was partially saturated and varied in thickness. Original model Layer 2 (bedrock) was also split into 2 layers, such that the undifferentiated Bisbee Group is represented by 3 TMR model layers (2 new layers, plus former Layer 3). Figure 6 displays a cross-section along model row 28 of the TMR model, illustrating several potential replacement wells extending into the uppermost bedrock.

Using the information from depth specific sampling, high sulfate concentrations were generally restricted to TMR model Layers 1 through 4, which were set to an initial concentration of 800 mg/l (Figure 6). Each constant head boundary cell for TMR Layers 3 and 4 was also set to a constant concentration of 800 mg/l (TMR Layers 1 and 2 are unsaturated at the boundaries). TMR Layer 5 representing the low-sulfate zone in the basin fill was set to 20 mg/l. Constant head cells for TMR Layers 6, 7, 8, and 9 representing bedrock were set to 40, 45, 30, and 20 mg/l, respectively.

It should be noted that the simulation of an initial constant sulfate concentration of 800 mg/l in the shallow basin fill layers (TMR Layers 1 through 4) is a simplification of the system assumed to conveniently simulate the vertical extent of the sulfate plume. This assumption of a uniform, high sulfate concentration in the basin fill does not simulate the observed extent and concentration of the sulfate plume, which is less laterally extensive and has lower concentrations at the plume margin than was assumed for the TMR model (i.e., the TMR model does not represent the leading edge of the plume but, instead, assumes the plume is laterally continuous across the entire TMR model domain). Simulation of a more laterally continuous plume than the actual plume is conservative in that it overestimates the extent and, in places, the concentration of the plume; which allowed the simulations to focus on determining whether sulfate concentrations would spread vertically in response to pumping.

Each of the proposed replacement wells was initially simulated assuming continuous pumping at a rate of 0.35 gallons per minute (gpm) per well or 518 gallons per day (gpd). The replacement wells were simulated as being screened in TMR Layer 7 at the top of the bedrock. The initial simulation used the

[1] The TMR procedure allows interactive on-screen selection of a sub-model domain, which led to uniform model cells with odd dimensions.

same horizontal to vertical hydraulic conductivity ratios used in the calibrated model (approximately 8:1 in basin fill and 20:1 in bedrock). The horizontal to vertical hydraulic conductivity ratio was also tested in a simulation at 1:1 which allows the maximum opportunity for the vertical transport of sulfate.

3.1 Initial Model Simulation Results

Figure 7 displays the simulated sulfate concentrations in TMR model Layer 5, the lowermost basin fill layer, after 100 years (2109) of pumping from the proposed replacement well. The simulation results illustrate that sulfate concentrations are predicted to rise from the initial (2009) Layer 5 concentration of 20 mg/l to as much as 30 mg/l on the west side of the model domain in 2109. This indicates that vertical transport of sulfate is minimal over the 100 year period simulated and that bedrock would be unaffected by sulfate because concentrations in the overlying basin fill do not rise significantly.

Figure 8 shows the predicted concentrations in basin fill Layer 5 and bedrock Layers 6 and 7 (the proposed completion depth of replacement wells) at Observation Point 1 over the simulation. The proposed wells are simulated as pumping from Layer 7 (bedrock aquifer) at a rate of 0.36 gpm (518 gpd). The results indicate little change in the predicted sulfate concentrations in Layers 5, 6, and 7 over 100 years. The simulation results predict that pumping from the proposed bedrock replacement wells does not cause sulfate to migrate downward from the sulfate plume to the deeper basin fill or bedrock.

3.2 Vertical Hydraulic Conductivity

The initial simulation was run using the model horizontal to vertical hydraulic conductivity ratios from the calibrated model (approximately 8:1 in basin fill and 20:1 in bedrock). The ratio of horizontal to vertical hydraulic conductivity in the basin fill varies from approximately 9:1 to 7:1 in the model area. This ratio naturally limits the ability of contamination to migrate vertically in the basin fill to a deepened well because flow occurs more easily in the horizontal direction than the vertical direction. To test the sensitivity of the initial simulation to the assumed hydraulic conductivity ratios, the groundwater model was run with the hypothetical condition that the horizontal to vertical hydraulic conductivity are the same value, for both the bedrock and basin fill layers. A simulation of the horizontal to vertical hydraulic conductivity ratio set to 1:1 would tend to overestimate the vertical migration of sulfate compared to the initial simulation because it removes the naturally occurring resistance to vertical flow imparted by the lower vertical hydraulic conductivity. Figure 9 shows the results of the simulation with a 1:1 hydraulic conductivity ratio, which were nearly identical to the first simulation using the original ratios. Figure 10 shows that concentrations at Observation Point 2 in TMR model Layer 5 representing the lower basin fill are predicted to rise from the initial (2009) concentration of 20 mg/l to about 30 mg/l over the 100 year period. As in the initial simulation, the wells are pumping from TMR model Layer 7 at a rate of 0.36 gpm (518 gallons per day). Concentrations in TMR model Layer 7 are nearly constant over the course of the 100 year simulation.

3.3 Wells in Lower Basin Fill

As an additional test, a groundwater simulation was completed with the replacement wells moved to TMR model Layer 5, which is the layer of basin fill immediately below the zone of elevated sulfate in the shallow aquifer. This simulation used the same pumping rates as the previous two simulations and a 1:1 ratio of horizontal to vertical hydraulic conductivity. Figure 11 illustrates these results, with sulfate concentrations rising from 20 to 28 mg/l over the 100-year period in TMR model Layer 5 at Observation Point 2. Based on these results, sulfate is not predicted to migrate vertically downward to the lower basin fill in response to pumping 518 gallons per day (0.36 gpm) from each of the proposed replacement wells if they were located in the lower basin fill. The conclusion is that the hydraulic stresses from the proposed domestic wells are not adequate to cause significant changes in the existing groundwater flow and transport conditions.

3.4 Pumping Rates Raised to 10 GPM

To evaluate the possibility for sulfate migration under a scenario of relatively high pumping, a simulation was conducted in which each of the proposed replacement wells was pumped from TMR model Layer 7 (bedrock) steadily at 10 gpm (14,400 gpd) for the entire 100 year projection period. These results are nearly identical to those in the previous simulation (see Figure 11). Concentrations in TMR model Layer 5 are predicted rise from the initial (2009) concentration of 20 mg/l to 28 mg/l over the 100-year period.

4 CONCLUSION

The groundwater model reported here simulates flow and transport using porous media assumptions. These standard modeling assumptions should accurately simulate flow through an aquifer not dominated by preferential flow paths, such as conductive fractures or layers more discrete than the scale of the layers or model cells. The conclusion of these simulations is that pumping from the replacement wells proposed for construction in the bedrock is not predicted to result in sufficient drawdown to cause the plume to move downward into the bedrock under the simulation assumptions used. The lack of significant vertical migration of sulfate predicted for continuous groundwater pumping at 10 gpm at the seven proposed replacement wells indicates that no impact would be predicted for the installation of several additional replacement wells pumping at rates expected for domestic supply wells (i.e., approximately 0.36 gpm).

The proper placement of annular seals in the proposed wells will be a significant factor in preventing sulfate migration down the borehole. Figure 12 is a proposed conceptual design for the replacement wells. The depth of bedrock in the vicinity of Purdy Lane ranges from 535 feet at TM-19A to 636 feet at BMO-2008-4B. The conceptual design includes drilling 150 feet into the bedrock and installation of 100 feet of screen from the bottom of the borehole to approximately 50 feet below the basin fill. Filter pack would be placed in the well annulus from the bottom of the borehole to 10 feet over the top of the screen. A bentonite seal would be placed above the filter pack to approximately 20 feet below land surface, with the remainder of the annulus consisting of a cement surface seal. The well screen and casing would be 5-inch (nominal) Schedule 80 polyvinylchloride.

References

Clear Creek Associates, 2010. *Revision 1 Aquifer Characterization Report – Task 4 of the Aquifer Characterization Workplan – Mitigation Order on Consent Docket No. P-121-07, Cochise County, Arizona.* December 15, 2011.

Clear Creek Associates, 2011. *Third Quarter 2011 Groundwater Monitoring Report.* October 7, 2011.

Environmental Simulations, Inc., 2010. Groundwater Vistas™ software, version 5.

Attachments

- Figure 1 – Mitigation Order Model Area
- Figure 2 – Wells Considered for Replacement
- Figure 3 – Model Cross Section in Purdy Lane Area
- Figure 4 – Depth Specific Sampling for Sulfate, Garner 635 and BMO-2008-4 Wells
- Figure 5 – TMR Model Domain
- Figure 6 - TMR Model Cross-Section Along Row 28
- Figure 7 – TMR Model Layer 5 Sulfate Concentrations in 2109 (Kv:Kh ratio from original model)
- Figure 8 – Projected Sulfate Concentration by TMR Model Layer, Observation Point 1 - 2009 to 2109
- Figure 9 – TMR Model Layer 5 Sulfate Concentrations in 2109 (Kv:Kh ratio 1:1)
- Figure 10 – Projected Sulfate Concentration by TMR Model Layer, Observation Point 2 - 2009 to 2109
- Figure 11 – Projected Sulfate Concentration by TMR Model Layer, Observation Point 2 - 2009 to 2109
- Figure 12 – Conceptual Design for Replacement Wells

- Table 1 – Wells to be Deepened (**in text**)
- Table 2 – Depth-Specific Sample Results from GARNER 635 (**in text**)

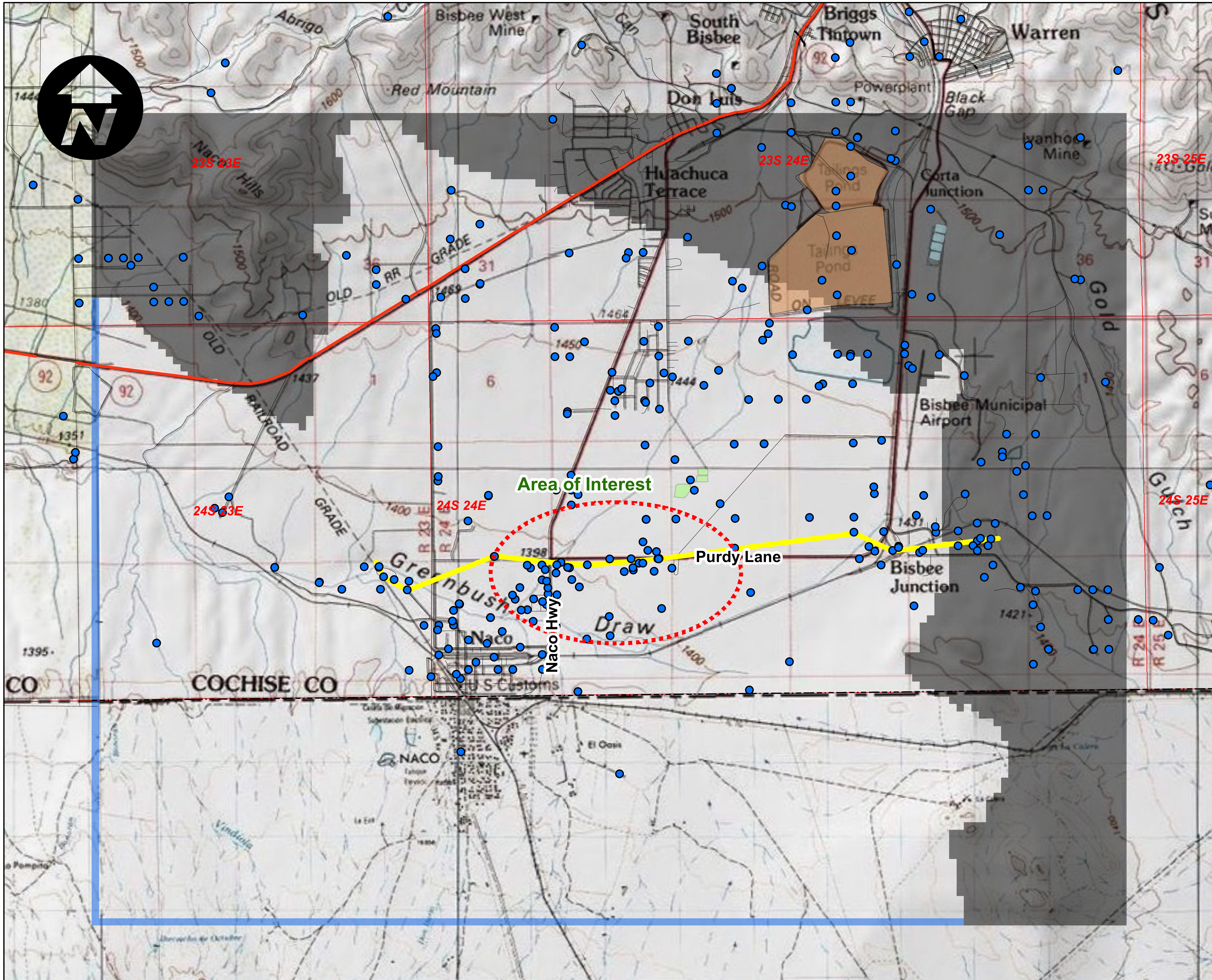
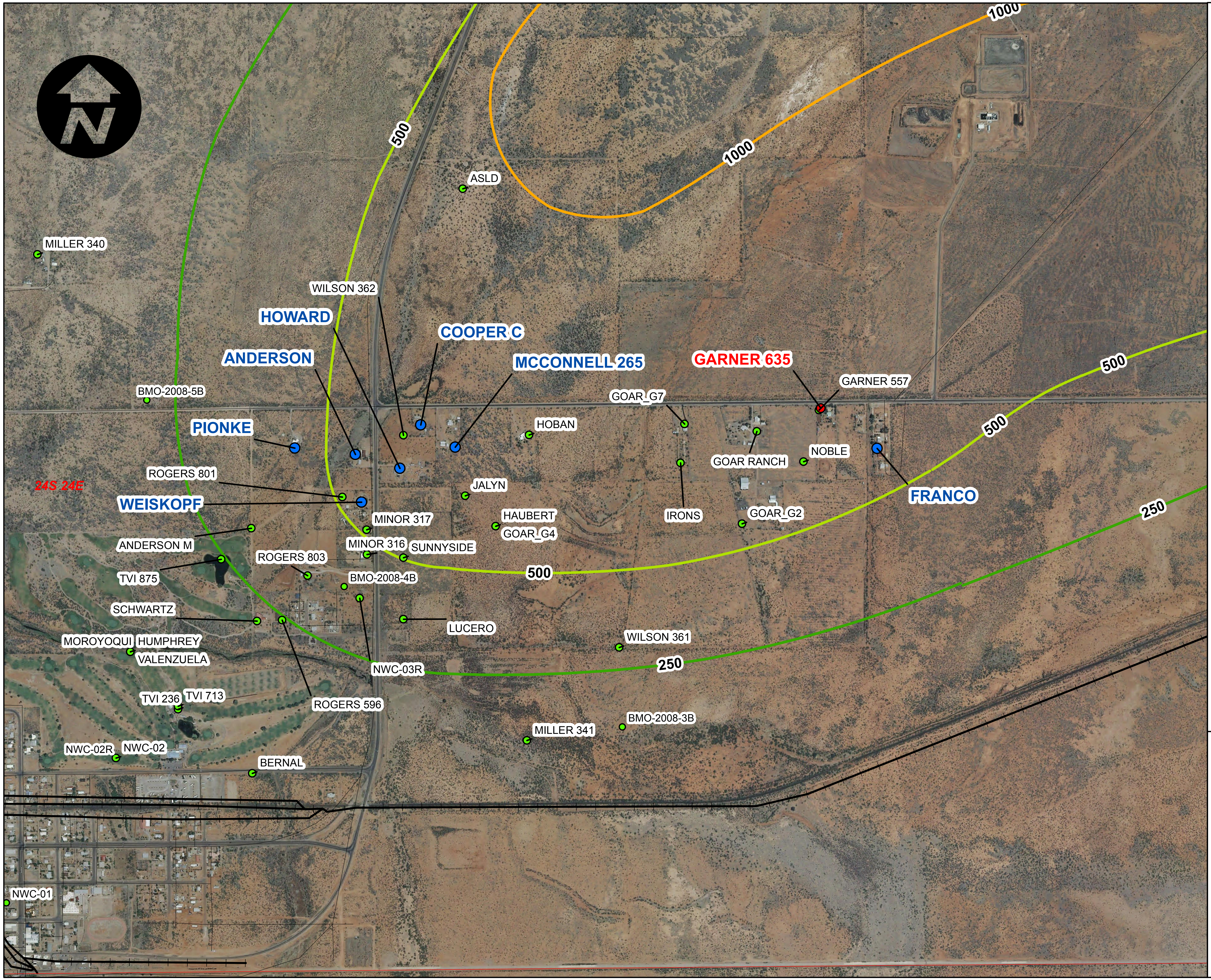


Figure 1

Mitigation Order Model Area

CLEAR CREEK ASSOCIATES

October 2011



Legend

Wells Along Purdy Lane

Well Type

- Potential Well to be Replaced
- Garner Well (previously replaced)
- Other Wells

3rd Quarter 2011 SO4 Contours

Sulfate Concentration Contour (mg/l)

- 250
- 500
- 1000
- 1500

Railroads

- Railroad

0 250 500 1,000 1,500 2,000
Feet

Figure 2

Wells Considered for Replacement

CLEAR CREEK ASSOCIATES

October 2011

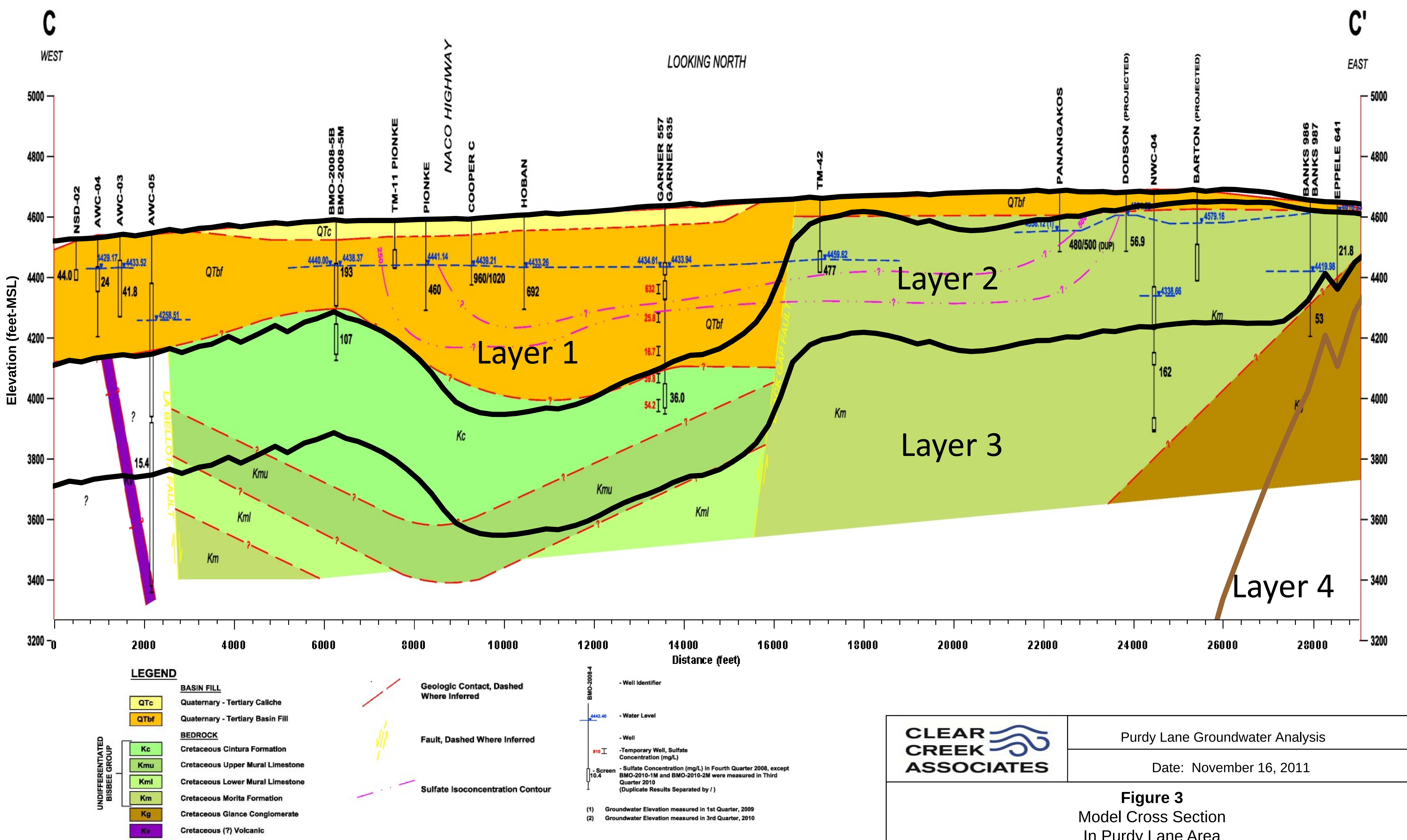


Figure 3
Model Cross Section
In Purdy Lane Area

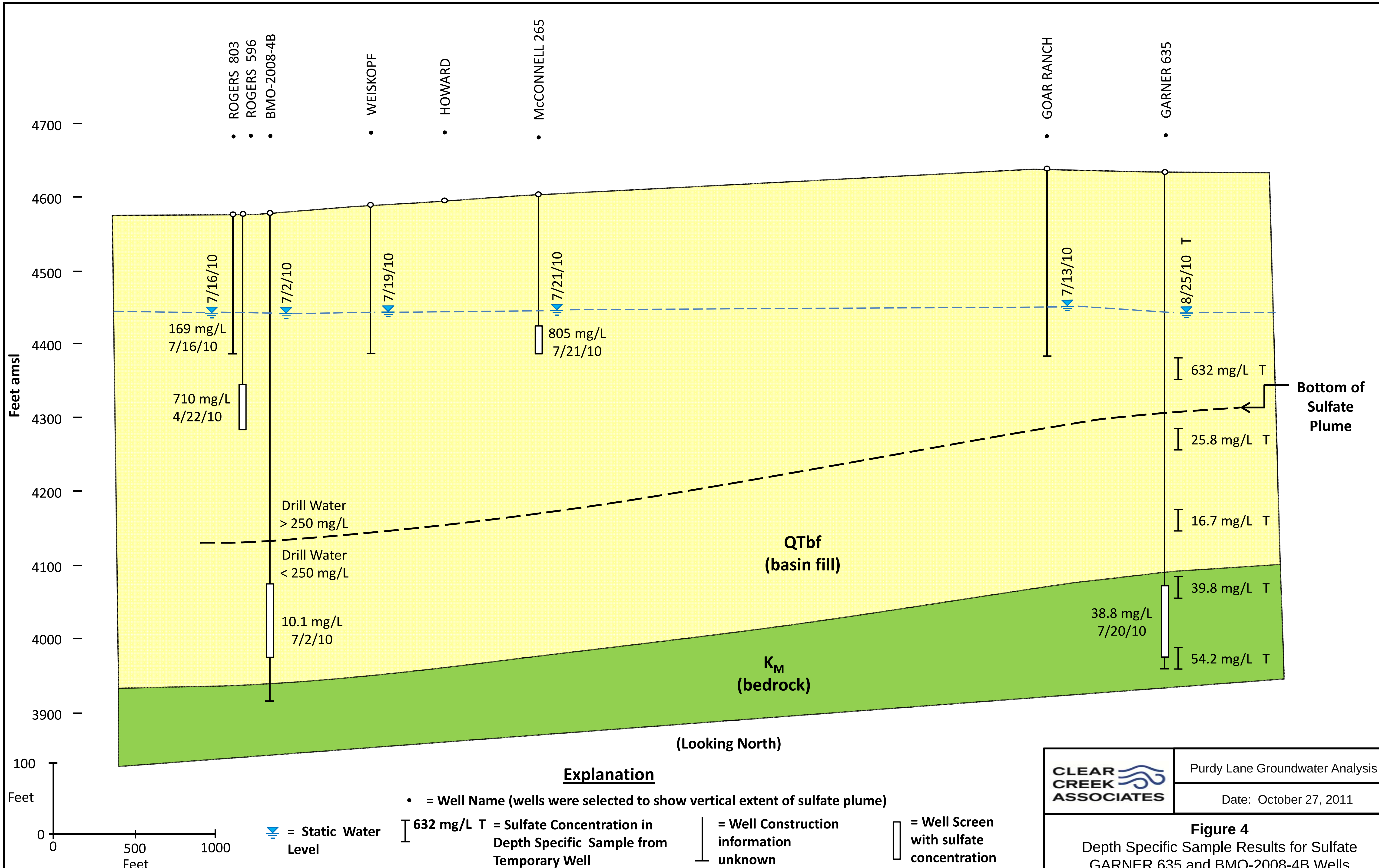
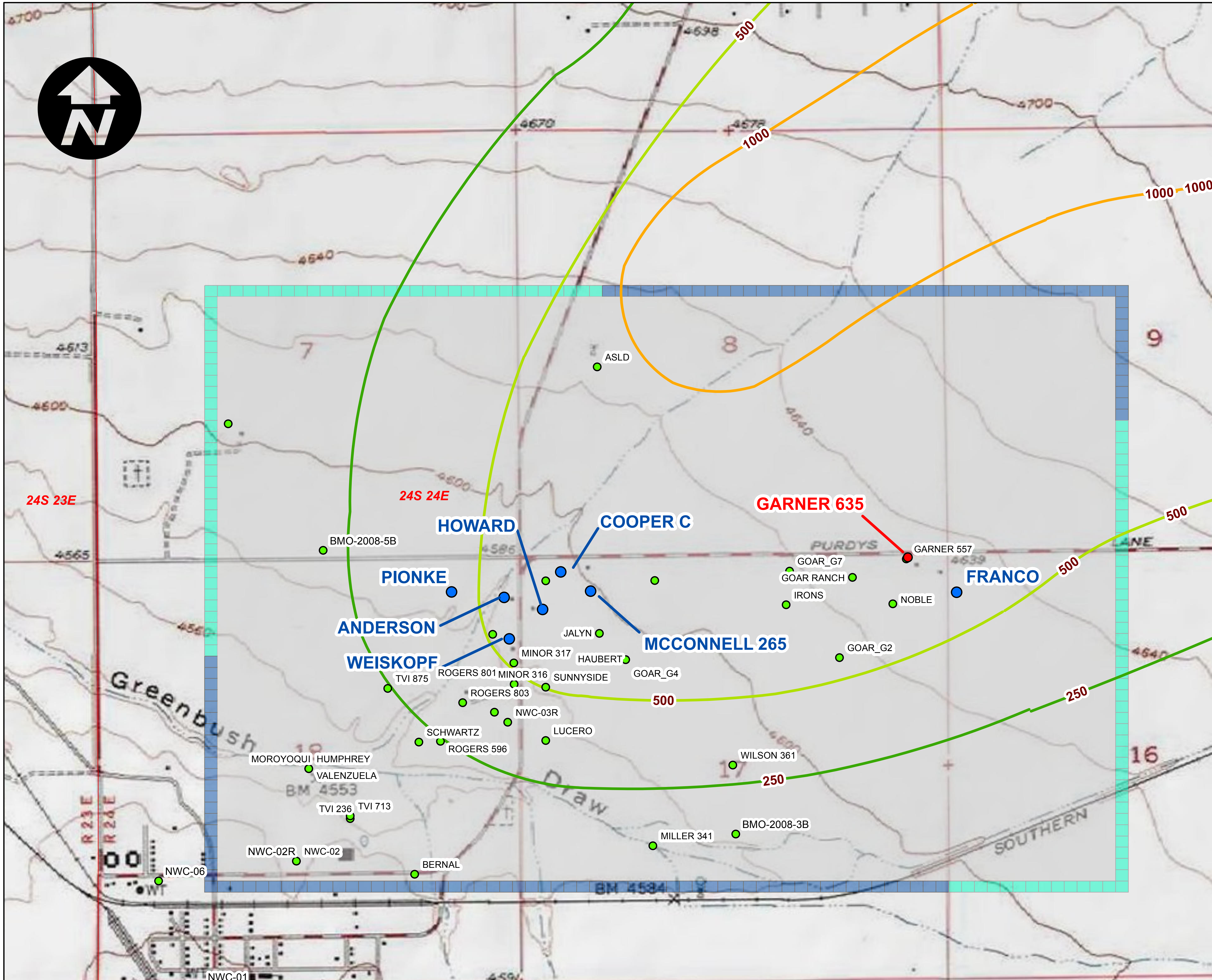


Figure 4
Depth Specific Sample Results for Sulfate
GARNER 635 and BMO-2008-4B Wells



Legend

Domestic Wells Along Purdy Lane

Well Type

- Potential Domestic Well to be Deepened
- Garner Well (previously deepened)
- Other Wells

3rd Quarter 2011 SO4 Contours for Basin Fill Aquifer

Contour (mg/l)

- 250
- 500
- 1000
- 1500

TMR Model Domain

Layers and Cells

- Active Model Cell: All Layers
- Constant Head: Layers 3-9
- Constant Head: Layers 4-9

NOTES:
Layers 1 and 2 are not saturated at the boundaries, so constant heads were not assigned.

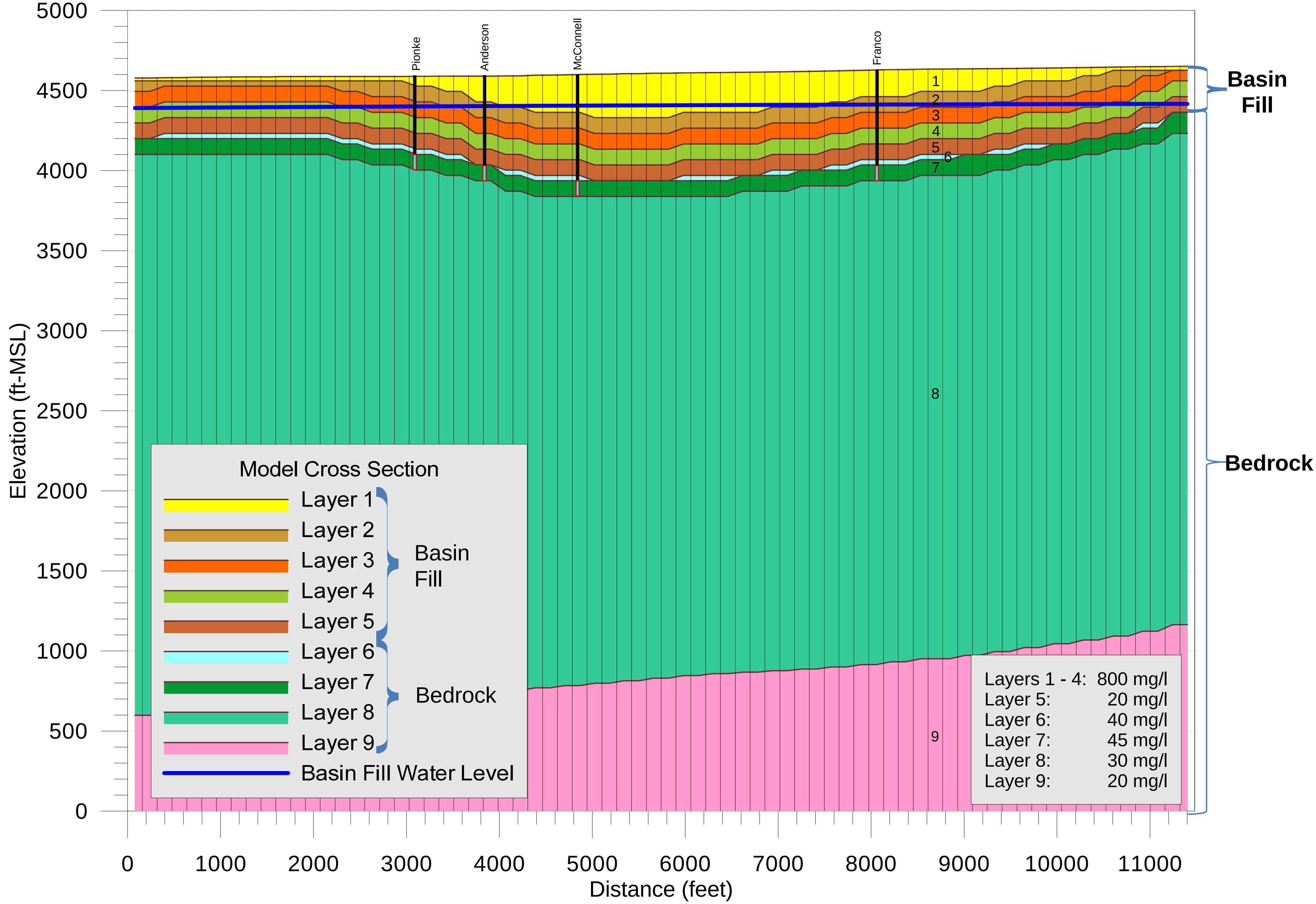
0 250 500 1,000 1,500 2,000 2,500 3,000 Feet

Figure 5

TMR Model Domain

CLEAR CREEK ASSOCIATES

October 2011



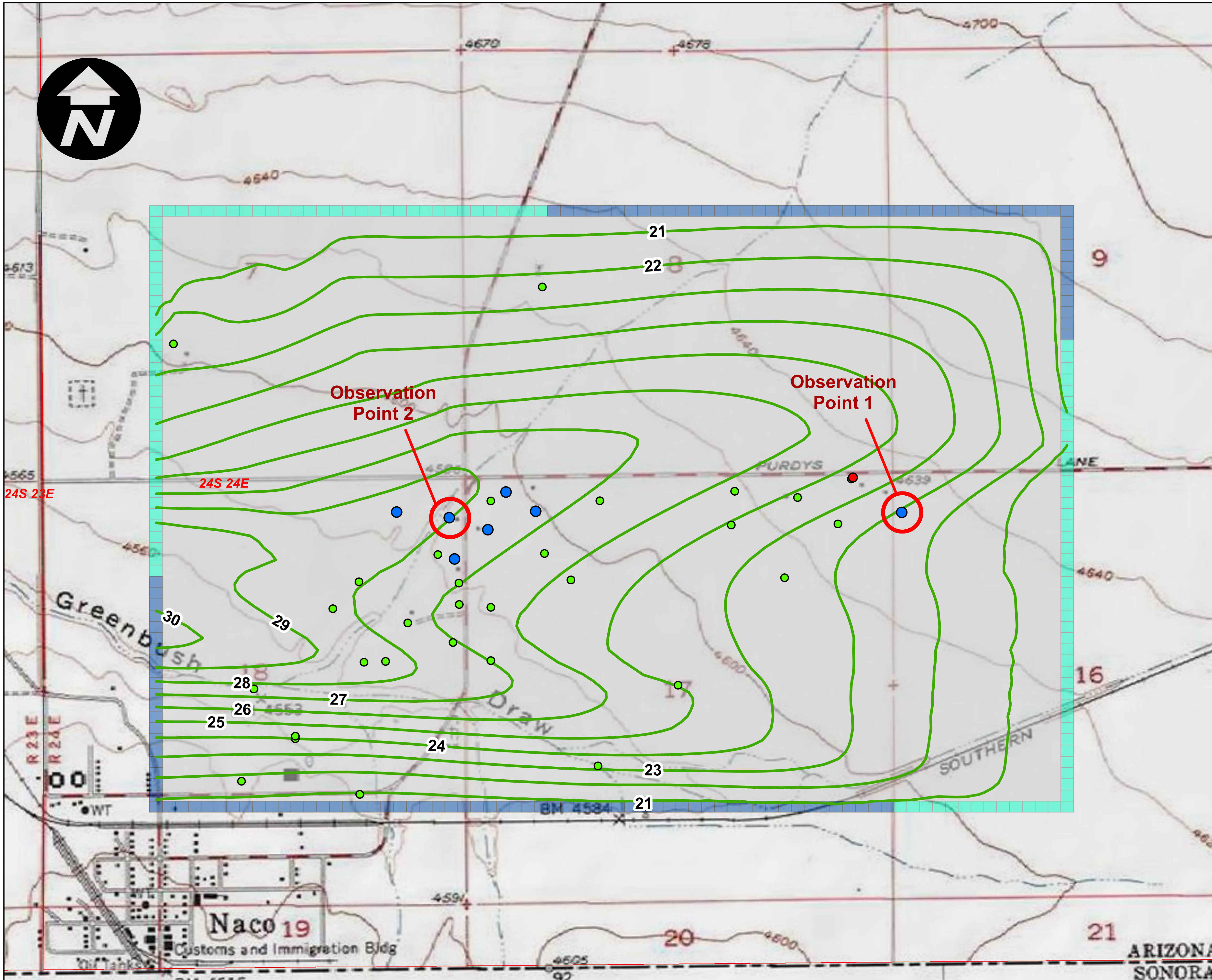
CLEAR CREEK ASSOCIATES

6155 East Indian School Road
Suite 200
Scottsdale, Arizona 85251
(480) 659-7131

October 20, 2011

Model Cross-Section along Row 28
TMR Model

Figure
6



Legend

Wells Along Purdy Lane

Well Type

- PotentialWell to be Replaced
- Garner Well (previously deepened)
- Other Wells
- 2109 Sulfate Concentraions in Layer 5

TMR Model Domain

Layers and Cells

- Active Model Cell: All Layers
- Constant Head: Layers 3-9
- Constant Head: Layers 4-9

0 250 500 1,000 1,500 2,000 2,500 Feet

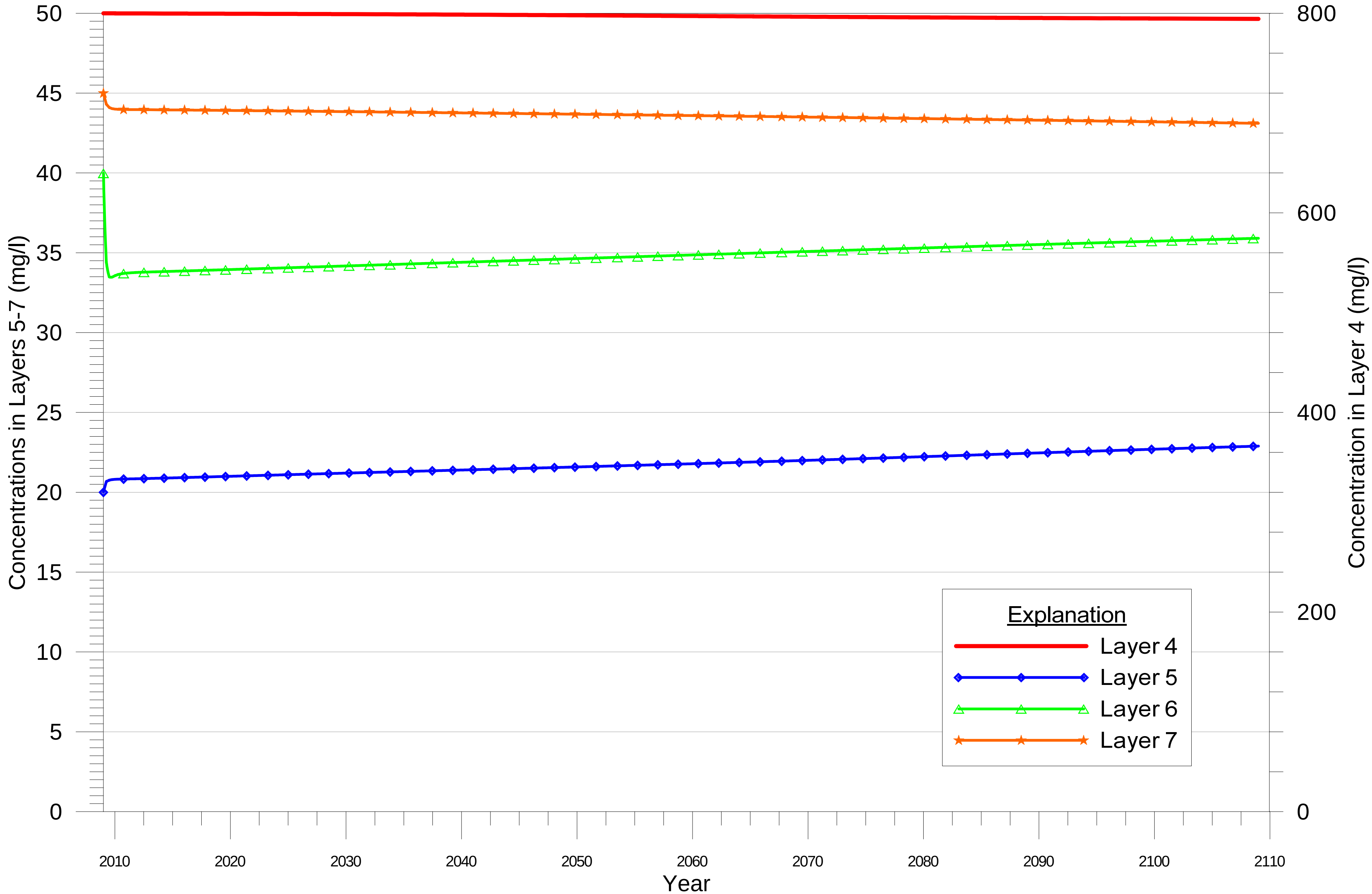
Figure 7

TMR Model Layer 5
2109 Sulfate Concentrations

(Kv:Kh Ratio from Original Model)

CLEAR CREEK ASSOCIATES

October 2011



Note: Pumping Rate at each well = 0.36 gpm or 518 gpd; K_V/K_H = Same as Original Model

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Projected Sulfate Concentration
TMR Model Layers
Observation Point 1 - 2009 to 2109

Figure 8

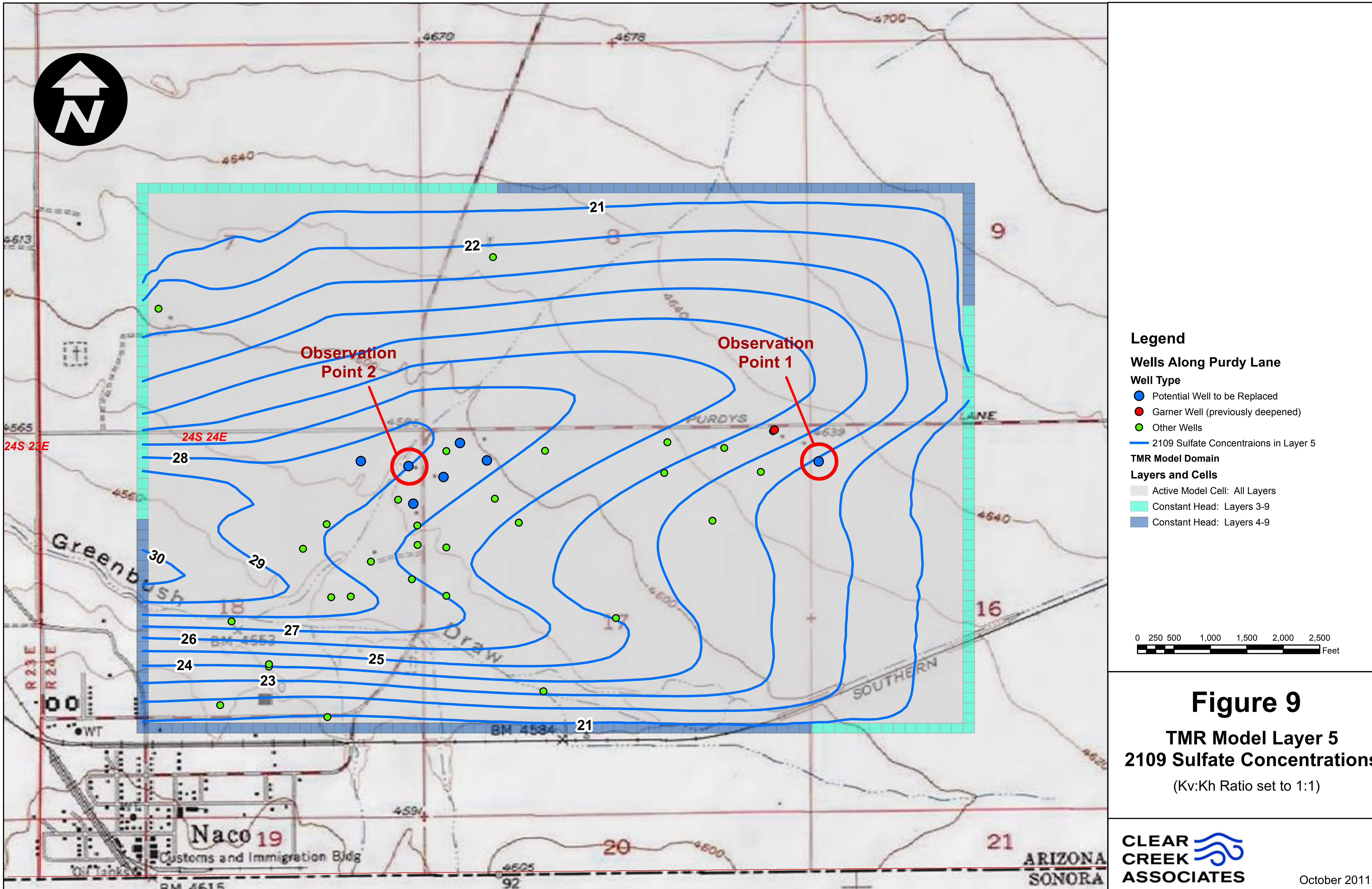


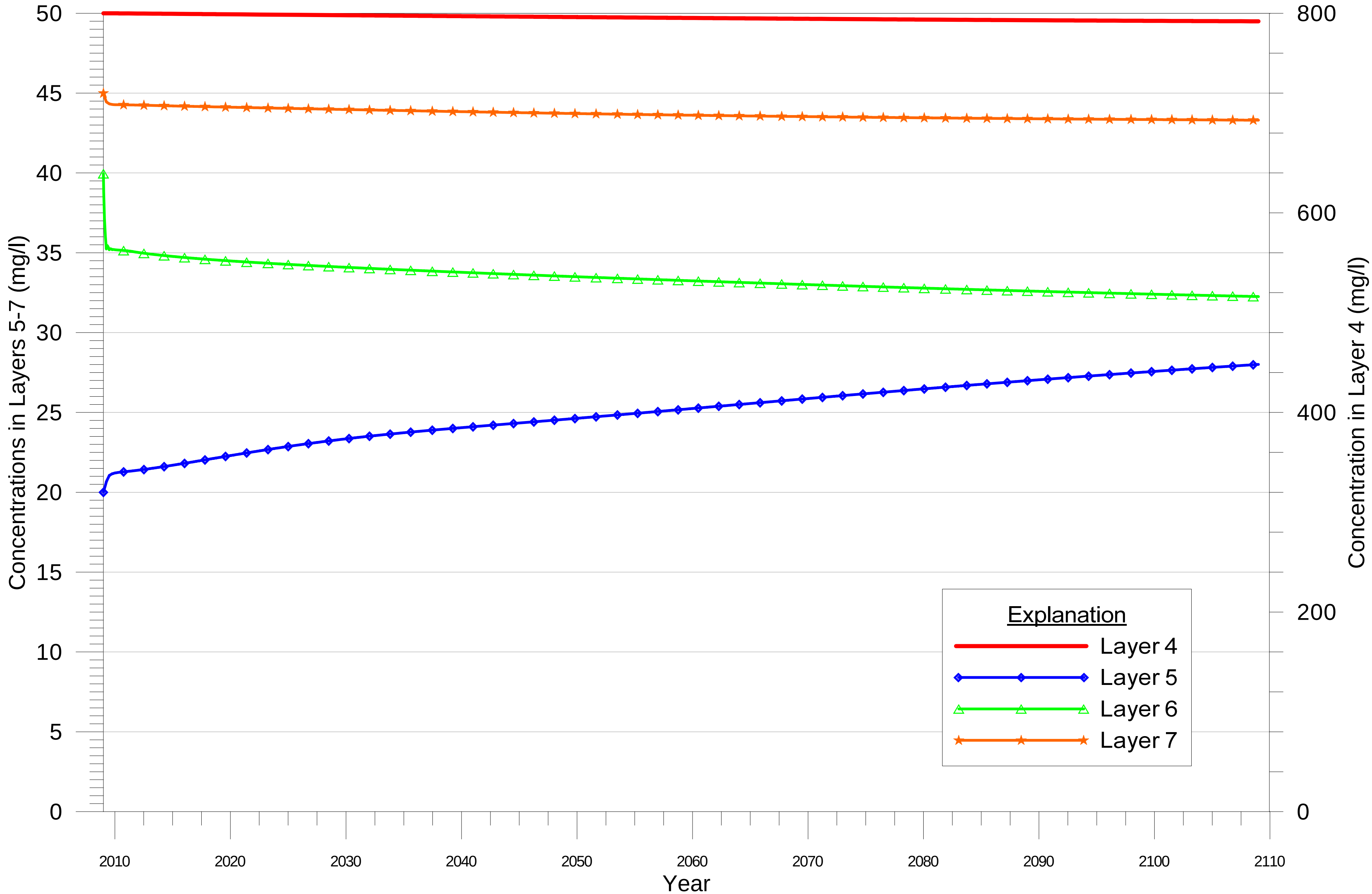
Figure 9

TMR Model Layer 5
2109 Sulfate Concentrations

(Kv:Kh Ratio set to 1:1)

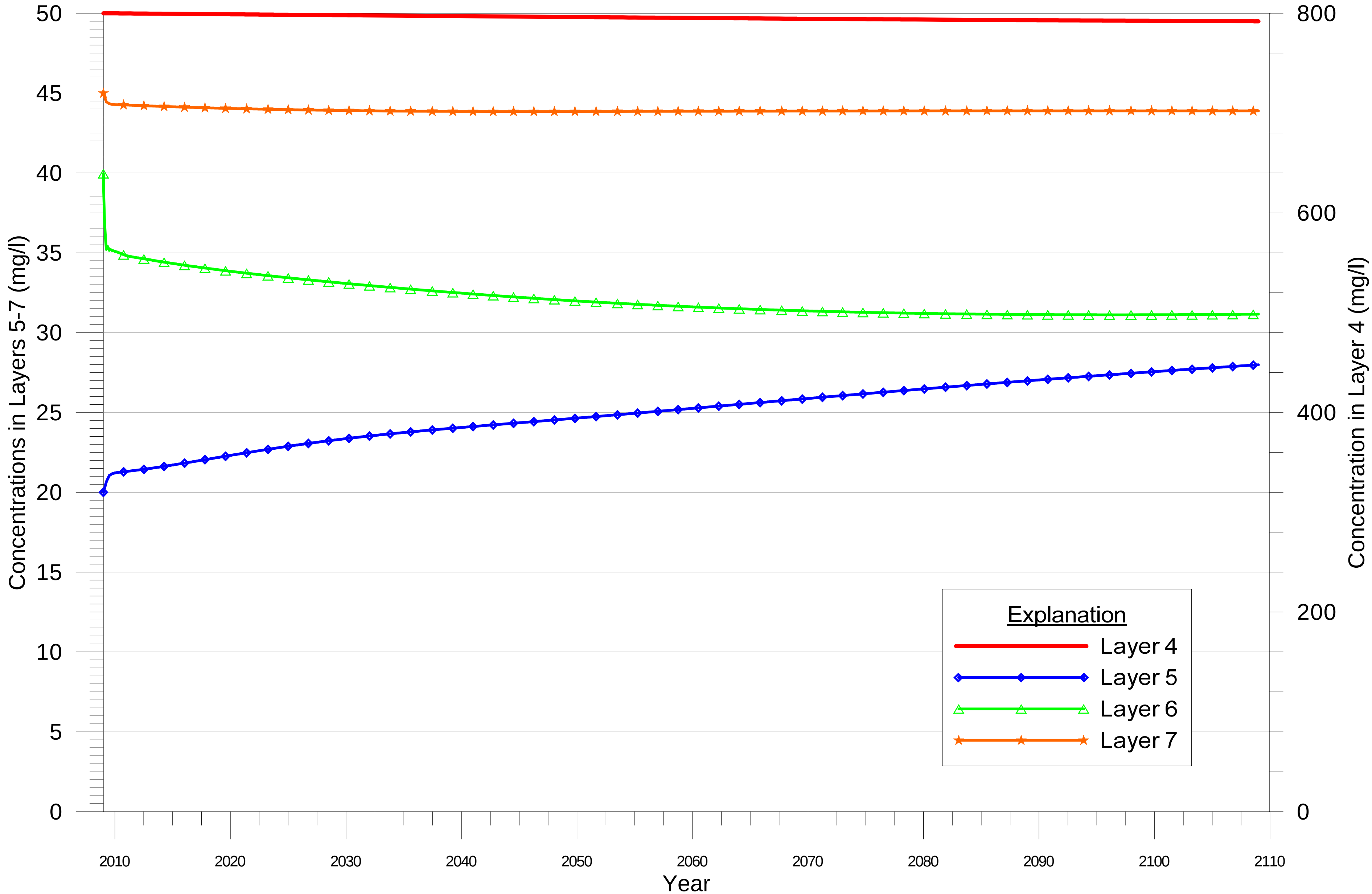
CLEAR CREEK ASSOCIATES

October 2011



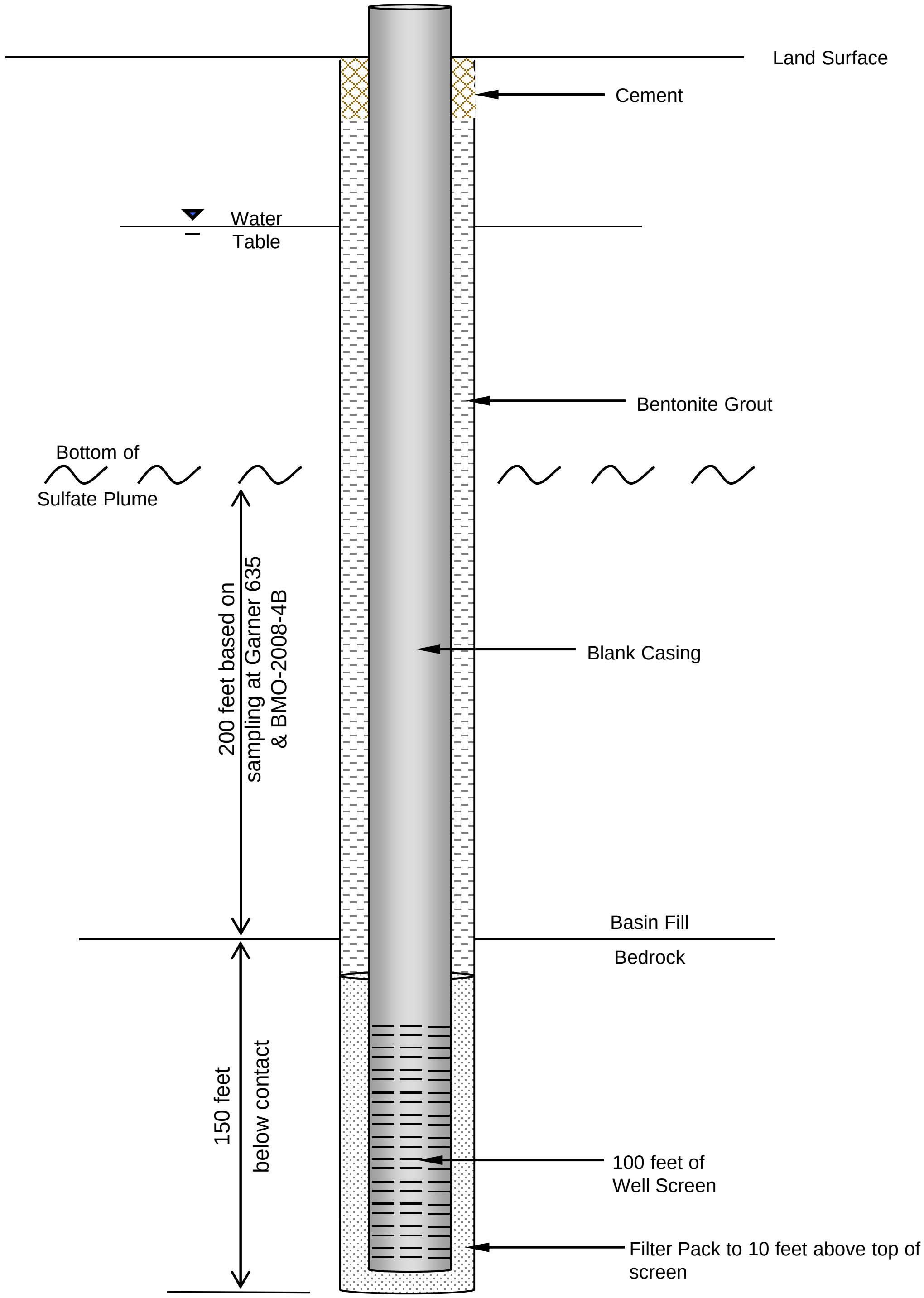
Note: Pumping Rate at each well = 0.36 gpm or 518 gpd; $K_V/K_H = 1$

CLEAR CREEK ASSOCIATES	6155 E Indian School Road Suite 200 Scottsdale, Arizona 85251 (480) 659-7131	**Projected Sulfate Concentration** **TMR Model Layers** **Observation Point 2 - 2009 to 2109**	**Figure** **10**



Note: Pumping Rate at each well = 10 gpm or 14400 gpd; $K_V/K_H = 1$

CLEAR CREEK ASSOCIATES	6155 E Indian School Road Suite 200 Scottsdale, Arizona 85251 (480) 659-7131	**Projected Sulfate Concentration TMR Model Layers Observation Point 2 - 2009 to 2109**	**Figure 11**



Not To Scale

CLEAR CREEK ASSOCIATES

Purdy Lane Groundwater Analysis

Date: October 27, 2011

Figure 12
Conceptual Well Design for
Replacement Wells

APPENDIX B

TRAVEL TIME ANALYSIS FOR LEADING EDGE OF THE SULFATE PLUME

CLEAR CREEK ASSOCIATES

TECHNICAL MEMORANDUM

To: Rebecca Sawyer, Freeport-McMoRan Corporation, Copper Queen Branch
From: James Norris, R.G., Clear Creek Associates
Subject: Travel Time Analysis for Leading Edge of the Sulfate Plume
Mitigation Order on Consent No. P-121-07
Date: January 16, 2012

REGISTERED GEOLOGIST CERTIFICATE NO. 30842 JAMES R. NORRIS Date Signed 1/16/12 ARIZONA U.S.A. Expires 12/31/14

1 INTRODUCTION

This memorandum contains migration rate estimates for the leading edge of the sulfate plume[1] based on site-specific water level and hydraulic properties data. The purpose of the analysis is to evaluate the timeframe over which the sulfate plume could potentially migrate from its current location to the Arizona Water Company (AWC) wellfield west of the plume.

A more detailed analysis of the direction and migration rate of the sulfate plume will be conducted using the groundwater flow and sulfate transport model presented in the *Aquifer Characterization Report* (Clear Creek Associates, 2010). The numerical modeling results will be used to determine whether the sulfate plume would migrate to the AWC wellfield and, if so, in what timeframe. The modeling results will be reported as part of the Feasibility Study for drinking water supply wells that might be impacted in the future.

2 BACKGROUND AND PROCEDURE

Figures 1 and 2 are maps showing sulfate concentrations and water levels, respectively, in the vicinity of the sulfate plume in the third quarter of 2011. Figure 3 shows wells completed in the basin fill aquifer at the leading edge of the sulfate plume.

The basin fill aquifer consists of unconsolidated sand and gravel deposits that contain the leading edge of the sulfate plume. This analysis focused on the basin fill aquifer because it is the only aquifer containing sulfate in excess of 250 mg/L at the front of the sulfate plume. The hydrology, nature, and extent of the westward-migrating sulfate plume are detailed in the *Aquifer Characterization Report* (Clear Creek Associates, 2010) submitted to Arizona Department of Environmental Quality. The water level and water quality data presented in this analysis are collected and reported quarterly to ADEQ (e.g., Clear Creek Associates, 2011) pursuant to Mitigation Order on Consent P-121-07 (Mitigation Order).

[1] The sulfate plume is defined as the zone of groundwater with sulfate concentrations exceeding 250 milligrams per liter due to the Concentrator Tailing Storage Area.

Darcy's Law calculations were used to estimate the rate of plume movement and potential travel times to the AWC wellfield, assuming that the amount of groundwater pumping at the front of the plume would remain at current levels into the future. Water levels in basin fill wells at the leading edge of the plume were used to calculate the hydraulic gradient that constitutes the driving force for groundwater flow. Hydraulic conductivity and porosity estimates for basin fill were used with the calculated hydraulic gradient to calculate the average groundwater flow velocity. The flow velocity and distance between the plume and points of interest were used to calculate the travel time assuming sulfate is transported at the same velocity as the average groundwater velocity (i.e., sulfate migration is not retarded by chemical processes). The following equations were used for this analysis.

Average Groundwater Flow Velocity = ((Hydraulic Conductivity) (Hydraulic Gradient))/Porosity (1)

Travel Time = Distance/Average Groundwater Flow Velocity (2)

3 WATER LEVELS, GROUNDWATER FLOW DIRECTION, AND HYDRAULIC GRADIENTS

Figure 2 illustrates groundwater elevations measured during the third quarter of 2011. Groundwater flow is perpendicular to equipotential lines such as the water elevation contours shown on Figure 2. Thus, groundwater in the region between the plume and the AWC wellfield flows westerly. The velocity of groundwater flow is directly proportional to the hydraulic gradient which is calculated as the water elevation difference between two measurement points divided by the distance separating them. Water level data for basin fill wells at the front of the plume were compiled and the distances between wells were determined to calculate the hydraulic gradient.

Wells selected for water level analysis and hydraulic gradient calculations are monitoring wells BMO-2008-4B, BMO-2008-5B, and BMO-2008-6B at the leading edge of the plume, BMO-2008-13B which is upgradient of BMO-2008-6B, BMO-2010-3B along Greenbush Draw between the plume edge and the AWC wellfield, wells at the AWC wellfield (extraction wells AWC-02, AWC-03, AWC-04, and AWC-05 and monitoring well COB MW-3), and monitoring wells NSD-02 and NSD-03 downgradient of the AWC wellfield (Figures 1, 2, and 3). Water level data for these wells are tabulated on Table 1. Figure 4 is a graph of water elevations over time at the wells.

The water level data on Figure 4 show contrasting behaviors in wells at and in front of the leading edge of the plume. Water elevations in wells distant to the AWC wellfield (e.g., BMO-2008-4B, BMO-2008-5B, and BMO-2008-6B, BMO-2010-3B, and NSD-03) vary less over time than do water elevations in wells within or peripheral to the wellfield (i.e., AWC-02, AWC-03, AWC-04, AWC-05[2], COB MW-3, and NSD-02). The large variation in water elevations in wells within or close to the wellfield is due to water level drawdown caused by pumping at the wellfield. The large fluctuations in water levels at the AWC wells are likely due to residual drawdown in the wells (i.e., incomplete recovery of the water levels at the time of measurement). In COB MW-03 and NSD-02 the fluctuations are likely due to drawdown which can vary over time due to changes in the rates and locations of pumping. The effect of the wellfield diminishes with distance from it such that NSD-03 which is farther from the wellfield has higher water level elevations and less water level fluctuation than NSD-02.

The regional hydraulic gradient is the driving force for movement of the sulfate plume. Static (non-pumping) groundwater elevations are the most representative data on which to base regional hydraulic gradient calculations. The water elevations at AWC-02, AWC-03, AWC-04, AWC-05, COB MW-03, and NSD-02 appear to be influenced by wellfield operations and do not represent water levels characteristic of regional conditions. Localized hydraulic gradients that occur in the vicinity of an individual pumping well or a wellfield can also influence sulfate movement, but only when the sulfate plume has moved within the capture zone of the wellfield. Localized hydraulic gradients caused by pumping wells may result in the capture of sulfate if the plume impinges on the wellfield, but do not control the large scale movement of the plume at a distance from the wellfield.

Water level data for wells near the front of the plume were used to characterize the water elevation in the upgradient area. With respect to the AWC wellfield, the upgradient area is the area from which sulfate-bearing groundwater is flowing. Water level data for the downgradient area, the direction in which sulfate–bearing groundwater is flowing, are provided by wells near and west of the AWC wellfield. However, water level data representing the regional hydraulic gradient are limited because many downgradient monitoring points are influenced by the AWC wellfield. Wells influenced by wellfield drawdown have lower water elevations than wells outside the influence of the wellfield. For example, the water elevations at NSD-03 are higher than those at COB MW-3 even though NSD-03 is downgradient of the wellfield with respect to the regional groundwater flow system. The use of water elevations influenced by drawdown would bias travel time calculations by yielding higher hydraulic gradients and flow velocities, and shorter travel times (Equations 1 and 2) than would the use of water elevations from wells outside the influence of the wellfield.

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[2] Water level elevations at AWC-05 are not shown on Figure 4 because they are almost 200 feet lower than in other AWC wells with the exception of a measurement in June 2009 (Table 2). It is uncertain whether the lower water elevations were measured while the well was pumping, but the June 2009 measurement is comparable to pseudostatic water levels in the other AWC wells.

Water levels at NSD-03 are the downgradient data most representative of the regional hydraulic gradient influencing migration of the sulfate plume. Although water levels at NSD-02 are influenced by wellfield pumping, they are more representative of the regional hydraulic gradient than water levels at COB MW-3 which are anomalously low compared to NSD-02, NSD-03, and the AWC wells. For this reason, hydraulic gradient calculations were conducted using data for NSD-02 to represent a downgradient water level condition between those at COB MW-3 and NSD-03.

The following well pairs were used to estimate the hydraulic gradient between the front of the plume and the AWC wellfield:

- BMO-2010-3B and BMO-2008-4B: characterizes potential flow path between the plume and BMO-2010-3B
- NSD-02 and BMO-2010-3B: characterizes potential flow path between BMO-2010-3B and AWC wellfield
- NSD-02 and BMO-2008-5B: characterizes potential flow path between BMO-2008 and AWC wellfield
- BMO-2008-6B and BMO-2008-13B: characterizes flow path north of the AWC wellfield

Table 2 contains water level differences for measurements collected at approximately the same time, distances between the well pairs, and the calculated apparent hydraulic gradients over time. The term "apparent" is used here to indicate that the hydraulic gradients are approximate in that they are calculated along lines between existing points that may not be orthogonal to the potentiometric field. The apparent hydraulic gradients at the well pairs range from 0.0012 feet per foot (ft/ft) to 0.0040 ft/ft.

4 HYDRAULIC CONDUCTIVITY

The hydraulic conductivity of basin fill has been estimated by interpretation of pumping tests conducted at various locations in the vicinity of the sulfate plume. The pumping test data and their interpretation are described in the *Aquifer Characterization Report* (Clear Creek Associates, 2010). Table 3 lists hydraulic conductivity estimates for basin fill, including the arithmetic and geometric means for the data set. Basin fill hydraulic conductivities range from 2.3 feet/day (ft/day) to 100.9 ft/day and have arithemetic and geometric means of 39.5 ft/day and 29.7 ft/day, respectively. Figure 5 is a cumulative frequency plot of the basin fill hydraulic conductivity estimates.

Hydraulic conductivity estimates for wells BMO-2008-4B, BMO-2008-5B, BMO-2008-6B, and BMO-2010-3B at the leading edge of the sulfate plume are 39.5 ft/day, 55 ft/day, 2.3 ft/day, and 15.5 ft/day, respectively (Figure 5). The arithmetic and geometric mean hydraulic conductivities of wells at the leading edge of the plume are 28.1 ft/day and 16.6 ft/day, respectively. The arithmetic mean of hydraulic conductivity (28.1 ft/day) was used as the best estimate of local conditions with which to calculate groundwater flow velocities.

5 GROUNDWATER FLOW VELOCITY AND TRAVEL TIME CALCULATIONS

Groundwater flow velocities were calculated using the apparent hydraulic gradients (Table 2), the average hydraulic conductivity of 28.1 ft/day, and an assumed average porosity of 25%. Travel time calculations for the edge of the sulfate plume to move to the east edge of the AWC wellfield were conducted by dividing the shortest distance between AWC-05 and plume edge depicted on Figure 1 (4,100 feet) by the calculated groundwater velocities. The other AWC wells range from 4,600 feet to 5,200 feet from the plume and would have longer travel times. Flow from BMO-2008-6B to AWC-05 was not considered likely given the westward trajectory of the plume.

Table 4 summarizes the groundwater flow velocity and travel time calculations. Calculated groundwater velocities ranged between 47 and 115 feet per year (ft/yr) for hydraulic gradients calculated between well pairs BMO-2010-3B and BMO-2008-4B, NSD-02 and BMO-2010-3B, NSD-02 and BMO-2008-5B, and BMO-2008-6B and BMO-2008-13B. The fastest velocities were calculated from hydraulic gradients that used the July 2011 water elevation at NSD-02 which was about 6 feet lower than previous measurements (Figure 4) and may be anomalously low. The calculated travel times for the plume edge to migrate to the AWC wellfield ranged from 36 years to 86 years.

6 TRAVEL TIME SENSITIVITY ANALYSIS

A sensitivity analysis was conducted by varying the assumptions used for calculations in two scenarios. The first scenario increases the hydraulic conductivity to 55 ft/day, the maximum value measured at the leading edge of the plume while maintaining the hydraulic gradients measured to NSD-02. The second scenario is that of high hydraulic gradients and a high hydraulic conductivity. The second scenario used the apparent hydraulic gradients between a well influenced by the AWC wellfield, COB MW-3, and upgradient wells BMO-2008-4B, BMO-2008-5B, and BMO-2010-3B, and assumed a hydraulic conductivity of 55 ft/day. Travel times in both scenarios represented the time to travel the shortest distance (4,100 feet) between the plume edge and AWC-05. The results of sensitivity calculations are provided on Table 5.

The first scenario resulted in flow velocities and travel times ranging from 93 ft/yr to 225 ft/yr and 18 years to 44 years, respectively. The first scenario is conservative in that it may overestimate flow velocities and underestimate travel times by using the highest hydraulic conductivity measured at the front of the plume (55 ft/day) which is almost double the arithmetic mean hydraulic conductivity (28 ft/day) measured at the front of the plume and 38% greater than the arithmetic mean of all hydraulic conductivity data (40 ft/day).

The second scenario resulted in flow velocities and travel times ranging from 93 ft/yr to 742 ft/year and 6 years to 44 years, respectively. Results for the second scenario indicate that travel times under 10 years could occur in the unlikely circumstances that the plume is moving under the high hydraulic gradients calculated with COB MW-3 which is clearly impacted by drawdown from the AWC wellfield and the same high hydraulic conductivity as the first scenario.

The sensitivity analysis results illustrate how the calculated flow velocities and travel times are highly sensitive to the assumed hydraulic gradients and hydraulic conductivity. The results of the first scenario are conservative because they are calculated with a high estimate of hydraulic conductivity. The second scenario results in unrealistically high velocities and short travel times because the hydraulic gradients are based on a well in the zone of drawdown of the AWC wellfield and a high hydraulic conductivity. Although the conditions of the second scenario may be appropriate in close proximity to the AWC wellfield, they do not control the migration of the plume at its current location.

7 CONCLUSION REGARDING TRAVEL TIME CALCULATIONS

The actual migration of the plume from NWC-03 provides a point of comparison for the calculated migration rates. The first measured sulfate concentration in a sample from NWC-03 (Figures 1 and 2) was 460 mg/L in October 2005 based on data in the *Aquifer Characterization Report* (Clear Creek Associates, 2010). The edge of the sulfate plume in the third quarter of 2011 was no farther west than wells TVI-875 and SCHWARTZ (Figure 1). If the plume had just arrived at NWC-03 in October 2005, it has moved no more than the distance to TVI-875 (1,400 feet) and SCHWARTZ (1,200 feet) in 6 years indicating a maximum velocity of 200 ft/yr to 233 ft/yr. At a velocity of 233 ft/yr, the travel time for the plume to migrate 4,100 feet to the AWC wellfield is 18 years. The actual velocity and travel time are likely slower than this estimate because the plume had arrived at NWC-03 prior to October 2005. If migration rates were faster than 200 ft/yr to 233 ft/yr, such as most of those calculated for the second sensitivity scenario, the plume would have already arrived at TVI-875 and SCHWARTZ, which is not observed.

Based on the foregoing Darcy's Law calculations using the average hydraulic conductivity at the front of the plume and hydraulic gradient calculated for NSD-02, our best estimate of the travel time from the current plume edge to the AWC wellfield is 36 years or more (Table 4). If the actual plume migration rate is closer to those calculated for the first sensitivity scenario (maximum hydraulic conductivity at front of plume) and the apparent plume migration rate at NWC-03 (considered an overestimate), the travel time would be 18 years or more (Table 5). The second sensitivity scenario (maximum hydraulic conductivity at front of plume and maximum hydraulic gradient) is considered to yield unrealistically short travel times that do not agree with the apparent migration rate from NWC-03. The question of whether the AWC wellfield will capture the sulfate plume in the future is being addressed by numerical modeling of groundwater flow and sulfate transport.

8 SULFATE CONCENTRATION DATA AND GROUNDWATER MONITORING

Sulfate concentration data for basin fill aquifer wells downgradient of the leading edge of the sulfate plume are listed in Table 6. Figure 6 shows sulfate concentrations from 2008 through 2011 at the BMO-2008-5B, BMO-2008-6B, BMO-2010-3B, COB MW-3, AWC-02, AWC-03, AWC-04, and AWC-05. Sulfate concentrations at these wells are generally less than 50 mg/L except for BMO-2008-5B and COB MW-3. The sulfate concentration at BMO-2008-5B has ranged between 175 mg/L and 203 mg/L. Sulfate concentration data for COB MW-3 show two peaks of 102 mg/L and 112 mg/L against a background of approximately 50 mg/L. The cause of the concentration peaks at COB MW-3 is uncertain, but both occurred in winter suggesting a possible relation to a seasonal variable.

The position of the sulfate plume is monitored at wells upgradient of the AWC wellfield. It is unlikely that the arrival of the sulfate plume at BMO-2008-6B would threaten the AWC wellfield given the westerly direction of groundwater flow. However, the arrival of the plume at BMO-2008-5B or BMO-2010-3B could indicate a potential for migration to the wellfield.

AWC-05 is 2,408 feet from BMO-2010-3B and 4,110 feet from BMO-2008-5B. The sulfate plume would take 21 years to migrate from BMO-2010-3B to AWC-05 and 35 years to migrate from BMO-2008-5B to AWC-05 at the fastest a plume migration rate (115 ft/yr) calculated for our best estimate of average conditions, The sulfate plume would take 10 years to migrate to AWC-05 from BMO-2010-3B and 18 years from BMO-2008-5B at the maximum apparent migration rate based on NWC-03 data (233 ft/yr), but the apparent travel time is probably underestimated because the timing of plume arrival at NWC-03 is uncertain. Ongoing quarterly groundwater sampling at BMO-2008-5B and BMO-2010-3B will be used to monitor the movement of the sulfate plume for refinement of the travel time calculations.

9 REFERENCES

Clear Creek Associates. 2010. Revision 1 Aquifer Characterization Report. December 15, 2010.

Clear Creek Associates. 2011. Third Quarter 2011 Groundwater Monitoring Report. October 7, 2011

TABLE 1
Groundwater Elevation Data

Well Name	ADWR 55 Registry No.	UTM East (meters)	UTM North (meters)	Measuring Point Elevation[1] (ft amsl)	Date	Depth To Water (feet)	Groundwater Elevation (ft amsl)
AWC-02	616586	598907.911	3468549.357	4547.64	4/8/08	116	4431.64
					8/27/08	121.12	4426.52
					10/23/08	115	4432.64
					4/22/09	118	4429.64
					10/9/09	117	4430.64
					4/23/10	119	4428.64
AWC-03	616585	599090.322	3468681.898	4539.52	4/8/08	112	4427.52
					8/27/08	119.40	4420.12
					10/23/08	106	4433.52
					4/22/09	114	4425.52
					10/9/09	116	4423.52
					4/23/10	116	4423.52
AWC-04	616584	598949.929	3468717.084	4540.48	4/8/08	108	4432.48
					8/18/08	112.56	4427.92
					10/23/08	111.31	4429.17
					4/22/09	110	4430.48
					10/9/09	110	4430.48
					4/23/10	109	4431.48
AWC-05	590620	599269.904	3468541.692	4542.51	4/8/08	284	4258.51
					8/27/08	299.65	4242.86
					10/23/08	284	4258.51
					4/22/09	286	4256.51
					6/3/09	125	4417.51
					10/9/09	289	4253.51
					4/23/10	278	4264.51
BMO-2008-4B	910096	601099.405	3468383.430	4573.17	12/11/08	130.77	4442.40
					2/18/09	130.58	4442.59
					4/30/09	131.24	4441.93
					8/6/09	131.96	4441.21
					10/27/09	132.04	4441.13
					2/24/10	131.82	4441.35
					4/16/10	132.65	4440.52
					7/2/10	133.20	4439.97
					2/15/11	133.78	4439.39
					7/22/11	134.80	4438.37
BMO-2008-5B	909653	600438.159	3468994.715	4585.10	9/30/08	145.10	4440.00
					2/18/09	144.35	4440.75
					4/27/09	144.78	4440.32
					8/4/09	145.36	4439.74
					10/29/09	145.88	4439.22
					2/15/10	145.42	4439.68
					4/15/10	145.80	4439.30
					7/7/10	146.59	4438.51
					10/5/10	147.00	4438.10
					2/14/11	147.56	4437.54
					5/12/11	148.04	4437.06
					7/13/11	148.31	4436.79
BMO-2008-6B	909146	600366.523	3469820.644	4627.44	7/16/08	190.13	4437.31
					11/4/08	190.23	4437.21
					2/19/09	189.71	4437.73
					4/27/09	189.99	4437.45
					8/4/09	190.80	4436.64
					10/26/09	191.04	4436.40
					2/15/10	190.82	4436.62
					4/15/10	190.75	4436.69
					7/1/10	191.43	4436.01
					10/5/10	192.50	4434.94
					2/14/11	192.19	4435.25
					5/12/11	192.70	4434.74
					7/12/11	193.30	4434.14

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TABLE 1
Groundwater Elevation Data

Well Name	ADWR 55 Registry No.	UTM East (meters)	UTM North (meters)	Measuring Point Elevation[1] (ft amsl)	Date	Depth To Water (feet)	Groundwater Elevation (ft amsl)
BMO-2008-13B	909551	601657.612	3470076.358	4649.21	10/3/08	206.42	4442.79
					2/17/09	206.11	4443.10
					5/6/09	206.32	4442.89
					8/5/09	206.79	4442.42
					10/28/09	207.08	4442.13
					2/16/10	207.26	4441.95
					4/14/10	207.27	4441.94
					7/6/10	207.68	4441.53
					2/10/11	208.51	4440.70
					5/13/11	208.95	4440.26
					7/15/11	209.36	4439.85
BMO-2010-3B	219970	599977.962	3468347.363	4550.59	7/28/10	115.38	4435.21
					11/10/10	115.80	4434.79
					1/20/11	115.46	4435.13
					4/7/11	116.11	4434.48
					7/13/11	117.30	4433.29
					10/13/11	117.72	4432.87
COB MW-3	906823	599169.225	3468726.000	4538.63	2/28/08	120.84	4417.79
					5/20/08	125.00	4413.63
					7/30/08	118.50	4420.13
					10/23/08	117.93	4420.70
					2/12/09	110.91	4427.72
					4/23/09	125.13	4413.50
					7/22/09	124.09	4414.54
					10/22/09	118.03	4420.60
					3/3/10	120.14	4418.49
					4/26/10	123.12	4415.51
					7/13/10	128.6	4410.03
					7/14/11	132.41	4406.22
NSD-02	527587	598820.051	3468821.474	4531.38	10/7/09	101.17	4430.21
					3/16/10	99.43	4431.95
					5/25/10	101.63	4429.75
					8/25/10	102.38	4429.00
					3/17/11	102.68	4428.70
					6/17/11	109.29	4422.09
NSD-03	527586	598070.538	3468694.259	4518.28	10/7/09	85.62	4432.66
					3/16/10	83.51	4434.77
					5/25/10	84.49	4433.79
					8/25/10	85.70	4432.58
					3/17/11	86.76	4431.52
					6/17/11	88.76	4429.52

ADWR = Arizona Department of Water Resources; UTM = Universal Transverse Mercator Zone 12, North American Datum 1983 (NAD83);

ft amsl = feet above mean sea level; NR = No Record

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TABLE 2
Water Levels and Apparent Hydraulic Gradient Calculations

Well	Date	Water Elevation (ft amsl)	Well	Date	Water Elevation (ft amsl)	Water Elevation Difference (ft)	Distance Between Wells (ft)	Apparent Hydraulic Gradient (ft/ft)
BMO-2010-3B	07/28/10	4435.21	BMO-2008-4B	07/02/10	4439.97	4.76	3680	0.0013
	01/20/11	4435.13		02/15/11	4439.39	4.26		0.0012
	07/13/11	4433.29		07/22/11	4438.37	5.08		0.0014
NSD-02	08/25/10	4429	BMO-2010-3B	07/28/10	4435.210	6.21	4104	0.0015
	03/17/11	4428.7		04/07/11	4434.480	5.78		0.0014
	06/17/11	4422.09		07/13/11	4433.290	11.2		0.0027
NSD-02	10/07/09	4430.21	BMO-2008-4B	10/27/09	4441.13	10.92	7613	0.0014
	03/16/10	4431.95		02/24/10	4441.35	9.4		0.0012
	05/25/10	4429.75		04/16/10	4440.52	10.77		0.0014
	08/25/10	4429		07/02/10	4439.97	10.97		0.0014
	03/17/11	4428.7		02/15/11	4439.39	10.69		0.0014
	06/17/11	4422.09		07/22/11	4438.37	16.28		0.0021
NSD-02	10/07/09	4430.21	BMO-2008-5B	10/29/09	4439.220	9.01	5338	0.0017
	03/16/10	4431.95		02/15/10	4439.680	7.73		0.0014
	05/25/10	4429.75		04/15/10	4439.300	9.55		0.0018
	08/25/10	4429		07/07/10	4438.510	9.51		0.0018
	03/17/11	4428.7		02/14/11	4437.540	8.84		0.0017
	06/17/11	4422.09		05/12/11	4437.060	14.97		0.0028
BMO-2008-6B	11/04/08	4437.21	BMO-2008-13B	10/3/08	4442.79	5.58	4317	0.0013
	02/19/09	4437.73		2/17/09	4443.10	5.37		0.0012
	04/27/09	4437.45		5/6/09	4442.89	5.44		0.0013
	08/04/09	4436.64		8/5/09	4442.42	5.78		0.0013
	10/26/09	4436.4		10/28/09	4442.13	5.73		0.0013
	02/15/10	4436.62		2/16/10	4441.95	5.33		0.0012
	04/15/10	4436.69		4/14/10	4441.94	5.25		0.0012
	07/01/10	4436.01		7/6/10	4441.53	5.52		0.0013
	02/14/11	4435.25		2/10/11	4440.70	5.45		0.0013
	05/12/11	4434.74		5/13/11	4440.26	5.52		0.0013
	07/12/11	4434.14		7/15/11	4439.85	5.71		0.0013

ft amsl = feet above mean sea level; ft = feet; ft/ft = feet per foot

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TABLE 3
Basin Fill Hydraulic Conductivity Estimates

Well	Hydraulic Conductivity (ft/day)
COB MW-1	100.9
TM-13	59.0
BMO-2008-5B	55.0
TVI 875	49.3
NWC-03	41.6
BMO-2008-4B	39.5
TM-11	39.0
BMO-2008-3B	30.8
BMO-2008-13B	24.0
BMO-2008-8B	17.8
BMO-2010-3B	15.5
BMO-2008-6B	2.3
Arithmetic Mean	39.5
Geometric Mean	29.7

ft/day = feet per day

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TABLE 4
Groundwater Flow Velocities and Travel Times

Well	Date	Well	Date	Apparent Hydraulic Gradient (ft/ft)	Hydraulic Conductivity (ft/day)	Porosity	Velocity (ft/day)	Velocity (ft/yr)	Distance (ft)		Travel Time (yr)
BMO-2010-3B	07/28/10	BMO-2008-4B	07/02/10	0.0013	28.1	0.25	0.15	53	Shortest Distance Between Plume Edge and AWC-05	4100	77
	01/20/11		02/15/11	0.0012			0.13	47			86
	07/13/11		07/22/11	0.0014			0.16	57			72
NSD-02	08/25/10	BMO-2010-3B	07/28/10	0.0015			0.17	62			66
	03/17/11		04/07/11	0.0014			0.16	58			71
	06/17/11		07/13/11	0.0027			0.31	112			37
NSD-02	10/07/09	BMO-2008-4B	10/27/09	0.0014			0.16	59			70
	03/16/10		02/24/10	0.0012			0.14	51			81
	05/25/10		04/16/10	0.0014			0.16	58			71
	08/25/10		07/02/10	0.0014			0.16	59			69
	03/17/11		02/15/11	0.0014			0.16	58			71
	06/17/11		07/22/11	0.0021			0.24	88			47
NSD-02	10/07/09	BMO-2008-5B	10/29/09	0.0017			0.19	69			59
	03/16/10		02/15/10	0.0014			0.16	59			69
	05/25/10		04/15/10	0.0018			0.20	73			56
	08/25/10		07/07/10	0.0018			0.20	73			56
	03/17/11		02/14/11	0.0017			0.19	68			60
	06/17/11		05/12/11	0.0028			0.32	115			36

ft/ft = feet per foot; ft/day = feet per day; ft/yr = feet per year; ft = feet; yr = year

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TABLE 5
Results of Sensitivity Calculations

Well	Date	Water Elevation (ft amsl)	Well	Date	Water Elevation (ft amsl)	Water Elevation Difference (ft)	Distance Between Wells (ft)	Apparent Hydraulic Gradient (ft/ft)			Velocity (ft/day)	Velocity (ft/yr)	Distance (ft)		Travel Time (yr)
First Scenario: Sensitivity Calculation with Regional Hydraulic Gradient and High Hydraulic Conductivity															
BMO-2010-3B	07/28/10	4435.21	BMO-2008-4B	07/02/10	4439.97	4.76	3680	0.0013	55	0.25	0.28	104	Shortest Distance Between Plume Edge and AWC-05	4100	39
	01/20/11	4435.13		02/15/11	4439.39	4.26		0.0012			0.25	93			44
	07/13/11	4433.29		07/22/11	4438.37	5.08		0.0014			0.30	111			37
NSD-02	08/25/10	4429	BMO-2010-3B	07/28/10	4435.210	6.21	4104	0.0015			0.33	122			34
	03/17/11	4428.7		04/07/11	4434.480	5.78		0.0014			0.31	113			36
	06/17/11	4422.09		07/13/11	4433.290	11.2		0.0027			0.60	219			19
NSD-02	10/07/09	4430.21	BMO-2008-4B	10/27/09	4441.13	10.92	7613	0.0014			0.32	115			36
	03/16/10	4431.95		02/24/10	4441.35	9.4		0.0012			0.27	99			41
	05/25/10	4429.75		04/16/10	4440.52	10.77		0.0014			0.31	114			36
	08/25/10	4429		07/02/10	4439.97	10.97		0.0014			0.32	116			35
	03/17/11	4428.7		02/15/11	4439.39	10.69		0.0014			0.31	113			36
	06/17/11	4422.09		07/22/11	4438.37	16.28		0.0021			0.47	172			24
NSD-02	10/07/09	4430.21	BMO-2008-5B	10/29/09	4439.220	9.01	5338	0.0017			0.37	136			30
	03/16/10	4431.95		02/15/10	4439.680	7.73		0.0014			0.32	116			35
	05/25/10	4429.75		04/15/10	4439.300	9.55		0.0018			0.39	144			29
	08/25/10	4429		07/07/10	4438.510	9.51		0.0018			0.39	143			29
	03/17/11	4428.7		02/14/11	4437.540	8.84		0.0017			0.36	133			31
	06/17/11	4422.09		05/12/11	4437.060	14.97		0.0028			0.62	225			18
Second Scenario: Sensitivity Calculation with High Hydraulic Gradient and High Hydraulic Conductivity															
BMO-2010-3B	07/28/10	4435.21	BMO-2008-4B	07/02/10	4439.97	4.76	3680	0.0013	55	0.25	0.28	104	Shortest Distance Between Plume Edge and AWC-05	4100	39
	01/20/11	4435.13		02/15/11	4439.39	4.26		0.0012			0.25	93			44
	07/13/11	4433.29		07/22/11	4438.37	5.08		0.0014			0.30	111			37
COB MW-3	07/13/10	4410.03	BMO-2010-3B	07/28/10	4435.21	25.18	2929	0.0086			1.89	690			6
	07/14/11	4406.22		07/13/11	4433.29	27.07		0.0092			2.03	742			6
COB MW-3	02/12/09	4427.72	BMO-2008-4B	02/18/09	4442.59	14.87	6430	0.0023			0.51	186			22
	04/23/09	4413.5		04/30/09	4441.93	28.43		0.0044			0.97	355			12
	07/22/09	4414.54		08/06/09	4441.21	26.67		0.0041			0.91	333			12
	10/22/09	4420.6		10/27/09	4441.13	20.53		0.0032			0.70	256			16
	03/03/10	4418.49		02/24/10	4441.35	22.86		0.0036			0.78	285			14
	04/26/10	4415.51		04/16/10	4440.52	25.01		0.0039			0.86	312			13
	07/13/10	4410.03		07/02/10	4439.97	29.94		0.0047			1.02	374			11
	07/14/11	4406.22		07/22/11	4438.37	32.15		0.0050			1.10	402			10
COB MW-3	10/23/08	4420.7	BMO-2008-5B	09/30/08	4440	19.3	4254	0.0045			1.00	364			11
	02/12/09	4427.72		02/18/09	4440.75	13.03		0.0031			0.67	246			17
	04/23/09	4413.5		04/27/09	4440.32	26.82		0.0063			1.39	506			8
	07/22/09	4414.54		08/04/09	4439.74	25.2		0.0059			1.30	476			9
	10/22/09	4420.6		10/29/09	4439.22	18.62		0.0044			0.96	351			12
	03/03/10	4418.49		02/15/10	4439.68	21.19		0.0050			1.10	400			10
	04/26/10	4415.51		04/15/10	4439.3	23.79		0.0056			1.23	449			9
	07/13/10	4410.03		07/07/10	4438.51	28.48		0.0067			1.47	538			8
	07/14/11	4406.22		07/13/11	4436.79	30.57		0.0072			1.58	577			7

ft amsl = feet above mean sea level; ft = feet; ft/ft = feet per foot; ft/day = feet per day; ft/yr = feet per year

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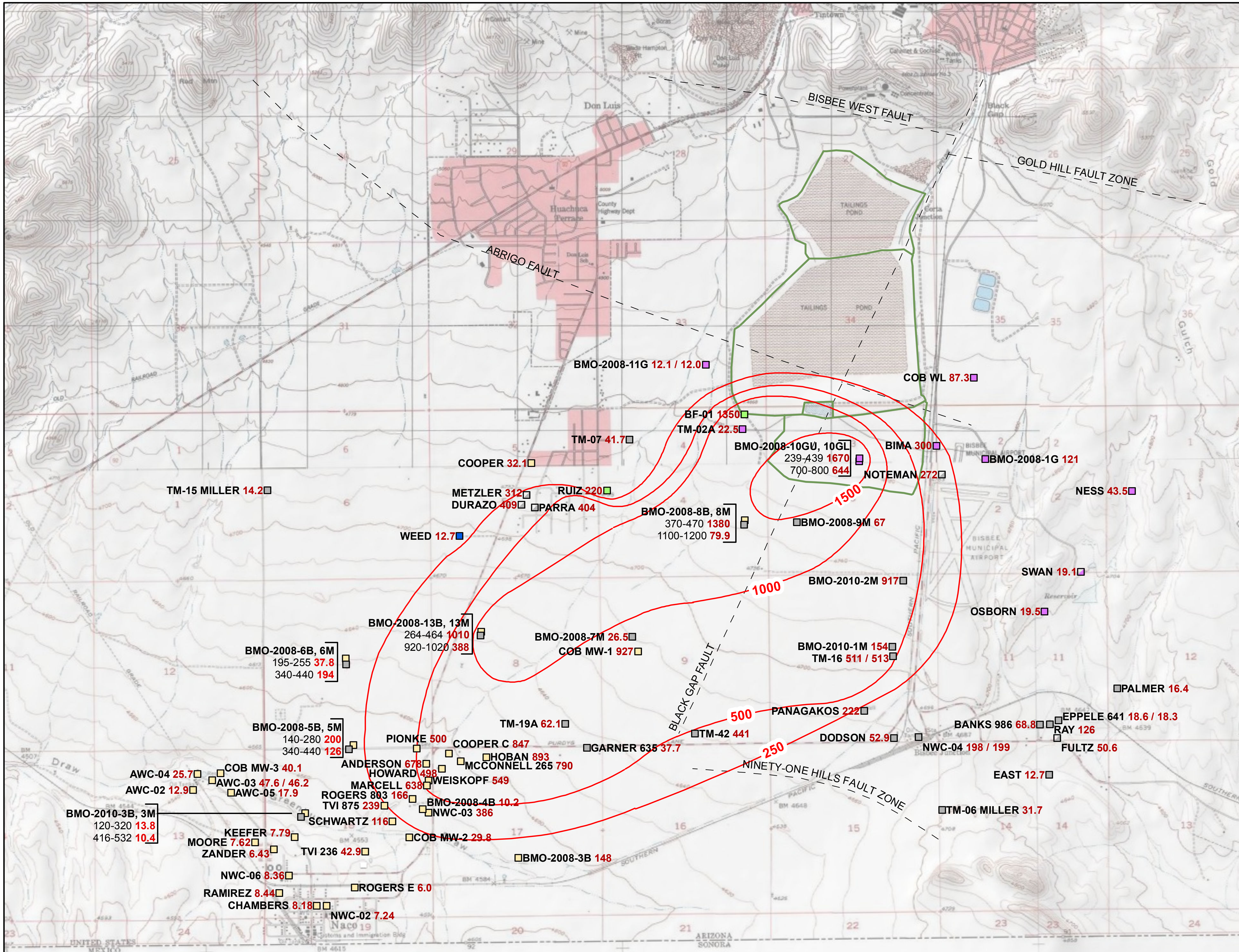
Table 6
Sulfate Concentrations at Wells Downgradient of the Sulfate Plume

Well Name	ADWR 55 Registry No.	Sample Date	Sulfate, dissolved (mg/L)
AWC-02	616586	1/7/08	14
		3/3/08	16
		5/5/08	13.3
		8/12/08	14.3
		10/23/08	15.9
		3/11/09	15.5
		4/22/09	14.7
		7/22/09	14.2
		10/21/09	16.8
		2/3/10	18.6
		4/23/10	18.3
		7/20/10	18.2
		11/4/10	18.8
		1/19/11	18.4
		4/7/11	17.3
		7/13/11	12.9
AWC-03	616585	1/7/08	41
		3/3/08	38
		5/5/08	37.3
		8/12/08	38.8
		10/23/08	41.8
		3/11/09	64.2
		4/22/09	42.4
		7/22/09	41.8
		10/21/09	50.5
		2/3/10	42.0
		4/23/10	44.4
		7/20/10	46.7
		11/4/10	46.3
		1/19/11	49
		4/7/11	46.8
		7/13/11	47.6
		7/13/11	46.2
AWC-04	616584	2/4/08	18
		4/7/08	18
		6/2/08	14.3
		8/12/08	21.6
		10/23/08	24
		3/11/09	27.2
		4/22/09	26.1
		7/22/09	26.2
		10/21/09	25.7
		2/3/10	16.3
		4/23/10	27.4
		7/20/10	26.6
		11/4/10	24
		1/19/11	26.2
		4/7/11	25.8
		7/13/11	25.7

Table 6
Sulfate Concentrations at Wells Downgradient of the Sulfate Plume

Well Name	ADWR 55 Registry No.	Sample Date	Sulfate, dissolved (mg/L)
AWC-05	590620	2/4/08	13
		4/7/08	14
		6/2/08	14.3
		8/12/08	14.9
		10/23/08	15.4
		3/11/09	16.5
		6/3/09	12.1
		7/22/09	14.1
		10/21/09	16.5
		2/3/10	16.3
		4/23/10	17.6
		7/20/10	19.1
		11/4/10	18.4
		1/19/11	17
		4/7/11	17.6
		7/13/11	17.9
BMO-2008-5B	909653	9/30/08	193
		2/18/09	192
		4/27/09	177
		8/4/09	174
		10/29/09	181
		10/29/09	185
		2/15/10	185
		4/15/10	194
		7/7/10	183
		10/5/10	201
		2/14/11	203
		5/12/11	195
		7/13/11	200
BMO-2008-6B	909146	7/16/08	53.3
		11/4/08	60.3
		2/19/09	54.3
		4/27/09	52.7
		8/4/09	48.5
		10/26/09	48.7
		2/15/10	33.5
		4/15/10	37.0
		7/1/10	40.1
		10/5/10	37.2
		2/14/11	40.2
		5/12/11	35.0
		7/12/11	37.8
COB MW-3	906823	2/28/08	57.8
		3/27/08	57.7
		4/30/08	37
		5/20/08	35.8
		7/24/08	64.9
		7/30/08	67.3
		10/9/08	52.5
		10/23/08	76.6
		2/12/09	112
		4/23/09	43.7
		7/22/09	52.3
		10/22/09	74.2
		10/22/09	73.9
		3/3/10	102
		4/26/10	77.6
		7/13/10	46.5
		7/14/11	40.1

mg/L = milligrams per liter



Legend

POOL	Well ID
114	Sulfate Concentration (mg/L)
(red line)	Sulfate Concentration Contour (mg/L)
(dashed line)	Faults (inferred)
(green line)	CTSA Facility

Co-located Wells
Well ID
Screen (ft bls): SO4 Concentration (mg/L)

Screened Formation
- Basin Fill
- Basin Fill and Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group - Estimated
- Undifferentiated Bisbee Group and Glance Conglomerate
- Glance Conglomerate
- Glance Conglomerate-Estimated

Undifferentiated Bisbee Group: Cintura, Mural Limestone, and Morita Formations

Scale (Feet)
0 3,000 6,000

Notes:

Projection: UTM Zone 12N NAD83

Date	File ID
9/20/11	055038-146

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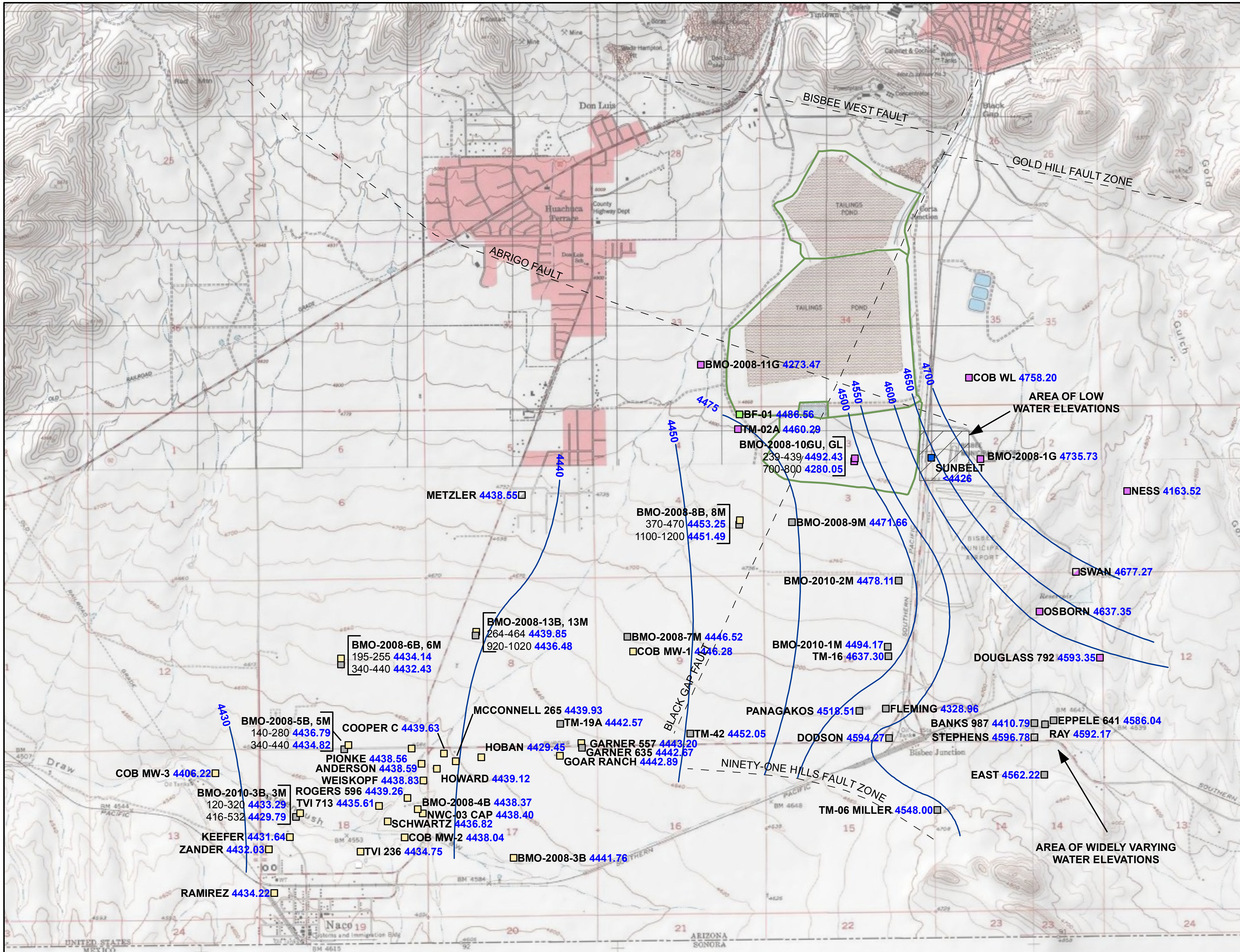
Figure 1
Sulfate Concentrations in Groundwater
Third Quarter 2011



Legend

BIMA — Well ID
4406.83 — Groundwater Elevation (ft amsl)
Groundwater Elevation Contours (dashed where inferred)
Faults (inferred)
CTSA Facility

Co-located Wells
Well ID
Screen (ft bls): Water Elevation (ft amsl)

Screened Formation
- Basin Fill
- Basin Fill and Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group
- Undifferentiated Bisbee Group - Estimated
- Undifferentiated Bisbee Group and Glance Conglomerate
- Glance Conglomerate
- Glance Conglomerate-Estimated

Undifferentiated Bisbee Group: Cintura, Mural Limestone, and Morita Formations

Scale (Feet)
0 3,000 6,000

Notes:
Projection: UTM Zone 12N NAD83

Date	File ID
9/20/11	055038-145

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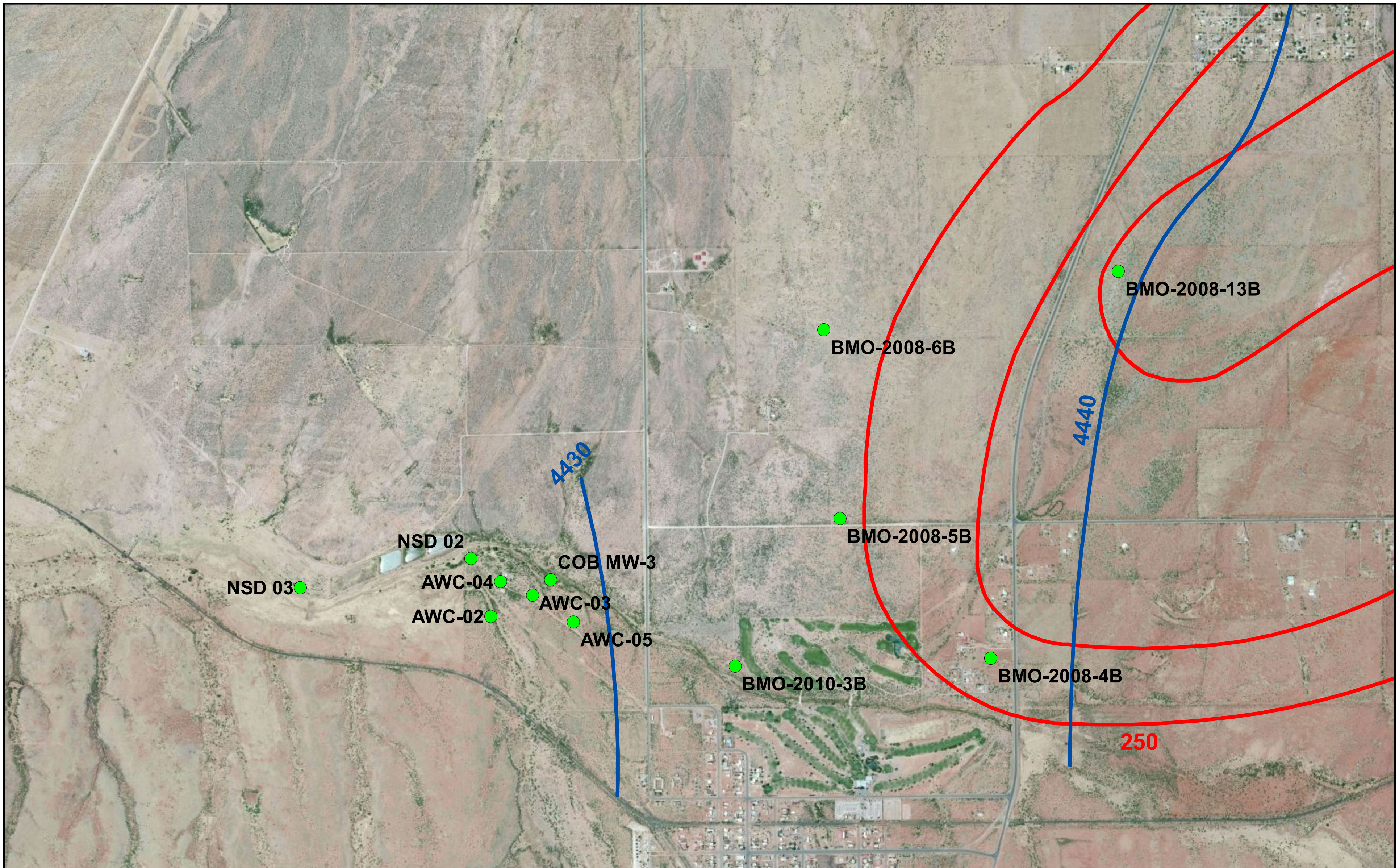
Figure 2
Groundwater Elevations
Third Quarter 2011



Legend

- Well Location
- Sulfate Concentration Contour Third Quarter 2011 (mg/L)
- Groundwater Elevation Contour Third Quarter 2011 (ft amsl)

0 1,000 2,000
Feet

N

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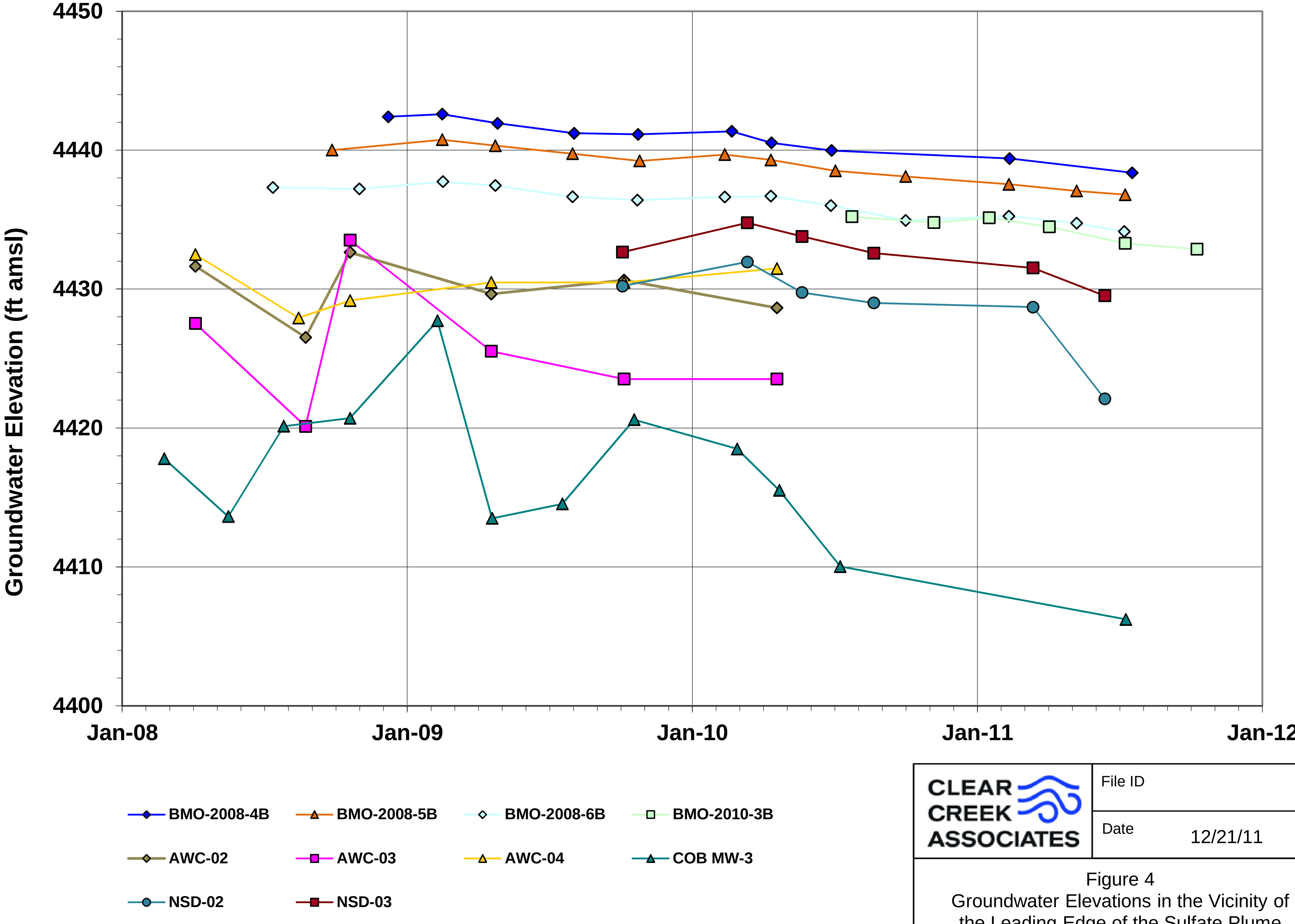
File ID 055038-167

Date 12/22/11

Figure 3
Basin Fill Wells
in the Vicinity of the Leading
Edge of the Sulfate Plume



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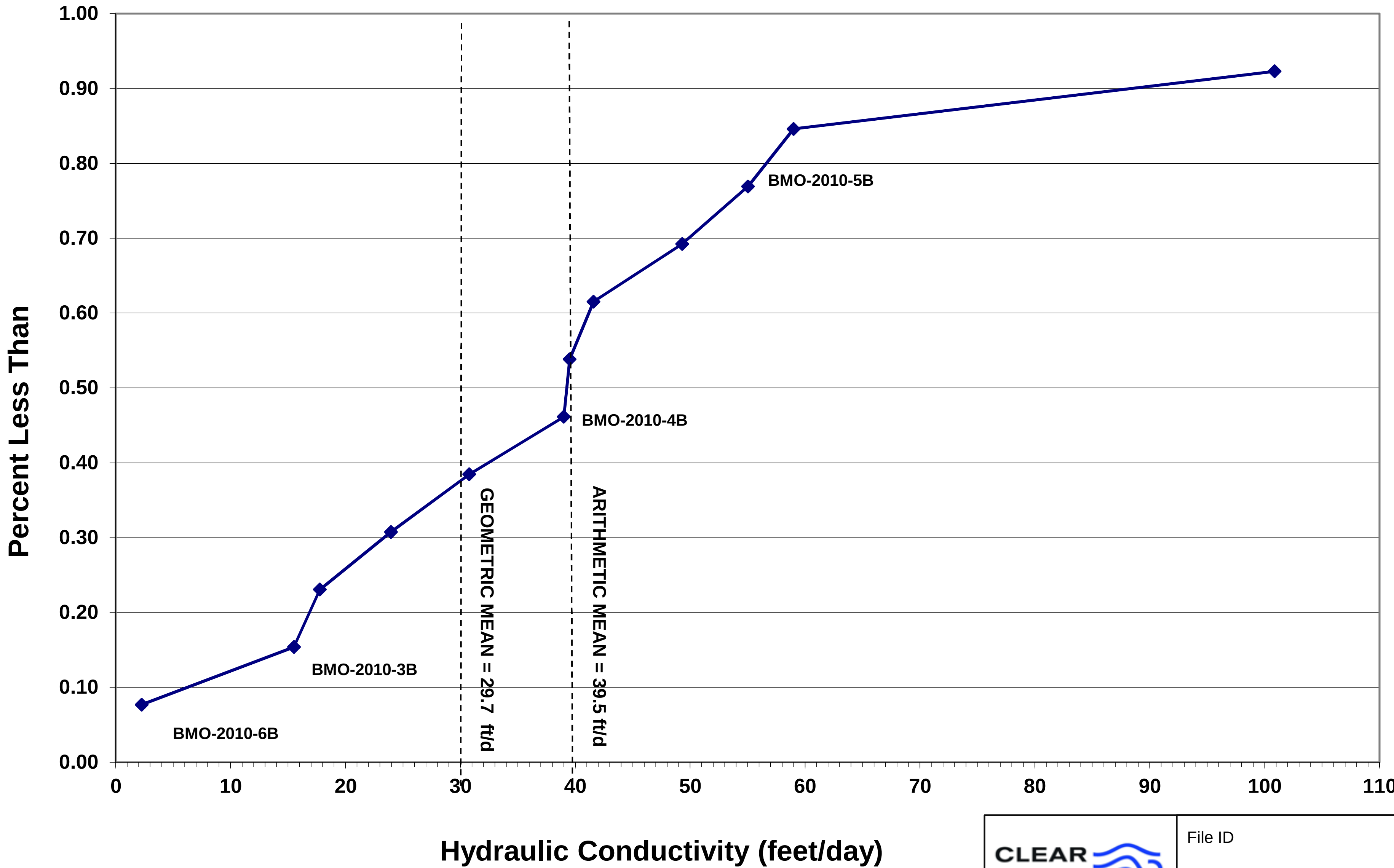
File ID	
Date	12/21/11

Figure 4
Groundwater Elevations in the Vicinity of the Leading Edge of the Sulfate Plume



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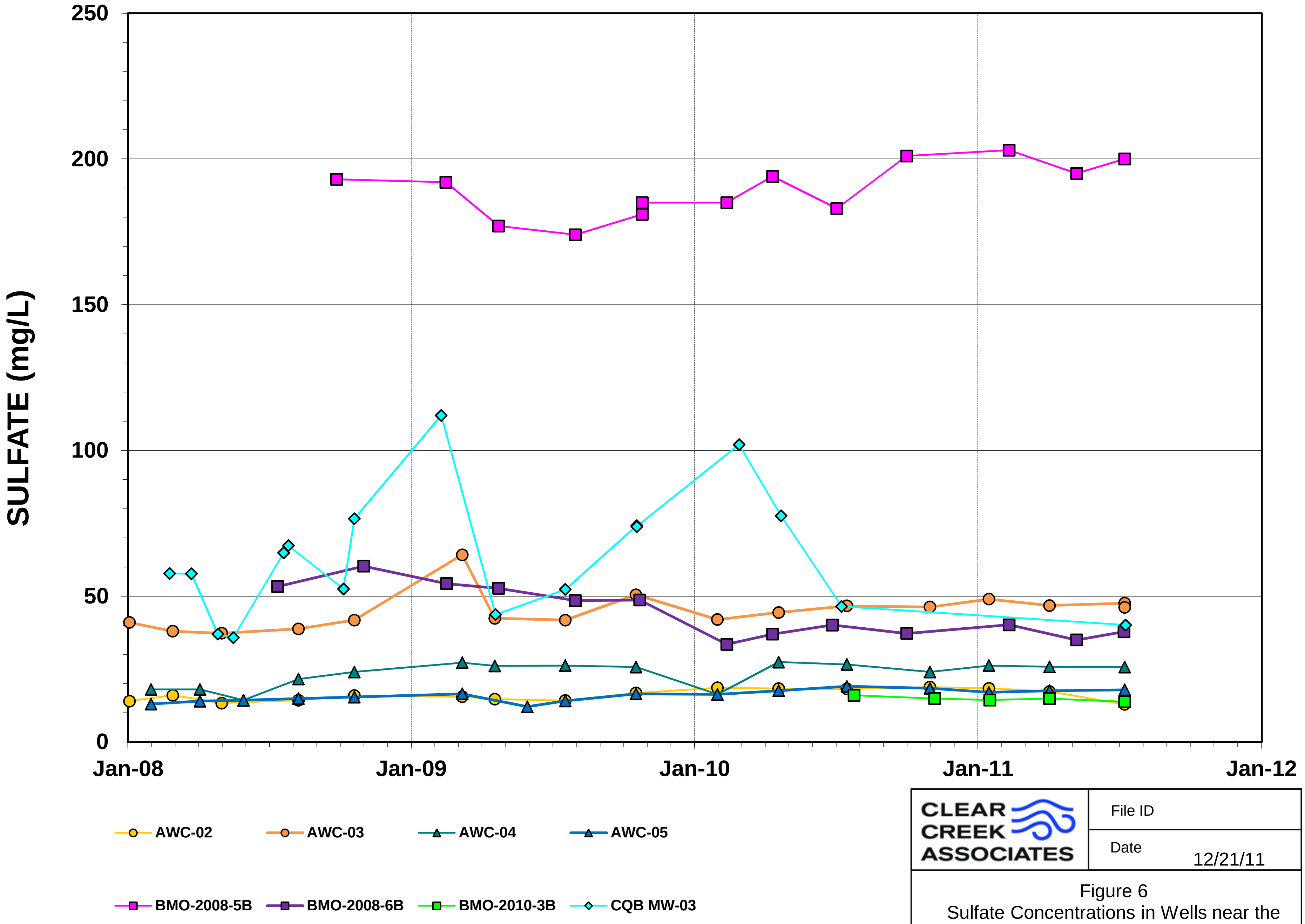
File ID

Date 12/21/11

Figure 5
Basin Fill Hydraulic Conductivities



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File ID	
Date	12/21/11

Figure 6
Sulfate Concentrations in Wells near the Front of the Sulfate Plume