APPENDIX F

DEVELOPMENT OF NUMERICAL MODEL FOR PREDICTIVE SIMULATIONS AND EVALUATION OF MITIGATION ALTERNATIVES

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Prepared for:

FREEPORT-MCMORAN SIERRITA INC.
6200 West Duval Mine Road
Green Valley, Arizona 85614

Prepared by:

HYDRO GEO CHEM, INC.
51 West Wetmore Road, Suite 101
Tucson, Arizona 85705-1678
(520) 293-1500

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1. INTRODUCTION

Hydro Geo Chem (HGC) developed a numerical groundwater flow and sulfate transport model for Task 5 of the *Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment* (Work Plan) (HGC, 2006). The purpose of the numerical model is to evaluate potential mitigation actions being considered in the Feasibility Study (FS). The numerical model was constructed to represent the hydrogeologic conditions of the basin-fill aquifer in the vicinity of the Sierrita Tailing Impoundment (STI) using information from several hydrogeologic investigations, including work conducted for the Aquifer Characterization Report (ACR) (HGC, 2007); previous numerical models; and information provided by local water users. Hydrogeologic processes represented in the numerical model include groundwater recharge sources (e.g., river, agricultural, mountain front, tailing seepage, and artificial recharge) and withdrawal sources (e.g., pumping wells and evapotranspiration). The numerical model was calibrated to groundwater level measurements dating from the year 1940 through 2006 and to sulfate concentrations in regional wells either measured as part of the work conducted for the ACR (HGC, 2007) or assembled from historical data. Numerical code selection, model construction, parameterization, and calibration of the model are described in Appendix I of the ACR (HGC, 2007). The calibrated numerical model as explained in Appendix I of the ACR simulates historical groundwater flow and transport of the sulfate plume through the year 2006.

The report below describes how the calibrated numerical model (historical model) was prepared to be used to simulate future groundwater flow and sulfate transport in the vicinity of the STI as a tool to evaluate mitigation alternatives (predictive model). Section 2 describes the estimation of future pumping rates; Section 3 discusses future evapotranspiration and aquifer recharge; Section 4 explains the estimation of future seepage from the STI; Section 5 discusses boundary conditions; Section 6 explains adjustments made to the numerical model for predictive simulations; and Section 7 describes uses and limitations of the predictive model. HGC conducted this work under contract to Freeport-McMoRan Sierrita Inc. (Sierrita).

2. FUTURE PUMPING RATES

Table F.1 provides a summary of anticipated annual future pumping rates and well locations used in the predictive model and Figure F.1 maps the locations of existing wells and the locations of future (i.e., not currently existing) wells used in the predictive model. The estimations of the future pumping rates were based on the following resources:

- Water use projections for the southern Tucson Active Management Area (TAMA) prepared by the Upper Santa Cruz Providers and Users Group (PUG) (Hedden et al., 2008)
- Water system plans submitted by water companies to the Arizona Department of Water Resources (ADWR)
- Information provided to HGC by water companies or groundwater right holders
- Historical pumping rates found in ADWR and Sierrita databases
- Pumping projections used in the ADWR groundwater flow model for the TAMA (Mason and Bota, 2006)

The PUG report (Hedden et al., 2008) served as the primary resource for the estimation of future pumping rates. Projected pumping rates for most water providers were specified in the predictive model to be consistent with the estimates given in the PUG report, with a few exceptions where updated information was provided to Sierrita. The rationale for allocating future pumping rates and locating future wells for the various water providers and users is summarized in Table F.1 and described in detail below for the agricultural water providers, municipal water providers, metal mining, golf courses, and other users.

2.1 Agricultural Water Providers

Irrigation water for the agricultural sector within the model domain is primarily supplied by Farmers Investment Co. (FICO). Historical groundwater pumping in FICO wells has been fairly constant, but the PUG report estimates that water usage by FICO will begin to decrease some time after 2010, a probable consequence of the conversion of agricultural lands to residential subdivisions. FICO shares water usage for irrigation with water usage by Farmers Water Co. (FWC) for municipal supply; therefore, the annual withdrawals for these two suppliers are combined in Table F.1. FICO/FWC withdrawals were kept consistent with the PUG report estimates for 2010, 2020, and 2030 and linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. The annual withdrawals were allocated among the various FICO/FWC wells based on historical pumping rates and on relative pumping rate projections reported in the water system plans for FWC. Pumping rates were constant within a given year.

2.2 Municipal Water Providers

Large municipal water providers include the following:

- FWC
- Green Valley Domestic Water Improvement District (GVDWID)
- Community Water Company of Green Valley (CWC)
- Sahuarita Water Company (SWC)
- Las Quintas Serenas Water Company (LQS)
- Quail Creek Water Company (QCWC)

The allocation of future pumping rates for each of these suppliers is explained below.

2.2.1 Farmers Water Co.

Future pumping from FWC wells was set to be consistent with the estimates given in the PUG report. The PUG report projects an increase from 915 acre-feet to 1,625 acre-feet in FWC annual withdrawals between 2006 (base year) and 2030. The annual withdrawals projected for FICO are combined with those for FWC in Table F.1. Pumping rates among the various FICO/FWC wells were based on historical pumping rates and the water system plan for FWC. FICO/FWC withdrawals were kept consistent with the PUG report estimates for 2010, 2020, and 2030 and linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year.

2.2.2 Green Valley Domestic Water Improvement District

Future pumping from GVDWID wells was set to be consistent with the estimates given in the PUG report. The PUG report projects an increase from 1,075 acre-feet to 1,530 acre-feet in GVDWID annual withdrawals for municipal supply between 2006 and 2030. GVDWID also services several golf courses: Desert Hills, Canoa Hills, San Ignacio, and Canoa Ranch. Therefore, total annual withdrawals from GVDWID wells were the estimated withdrawals for municipal supply given in the PUG report combined with the estimated groundwater usage given in the PUG report for the golf courses serviced by GVDWID. GVDWID withdrawals specified in the predictive model were kept consistent with the PUG report estimates for 2010, 2020, and

2030 and linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year.

2.2.3 Community Water Company of Green Valley

CWC provided updated water usage projections to Sierrita after the publication of the PUG report (Gabaldón, 2008a and 2008b). Therefore, future pumping from CWC wells was taken from the estimates provided by CWC. CWC estimates that annual groundwater withdrawals will increase from 4,259 acre-feet in 2010 to 6,192 acre-feet in 2030. (These estimates are greater than the estimates given in the PUG report). CWC further projects that wells CW-6 and CW-9 will need to be replaced by 2010 and that two additional wells, CW-11 and CW-12, will be in operation by 2010 and 2015, respectively. CWC withdrawal estimates were provided for years 2010, 2020, and 2030, and withdrawal estimates were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year.

2.2.4 Sahuarita Water Company

Future pumping from SWC wells was set to be consistent with the estimates given in the PUG report (SWC is listed as Rancho Sahuarita in the PUG report). The PUG report projects an increase from 1,150 acre-feet to 4,220 acre-feet in SWC annual withdrawals between 2006 and 2030. The SWC wells are also anticipated to supply water to the proposed Mission Peaks Development (Section 2.6.1). The large expected increase in production will likely necessitate that several additional wells be put into operation: two additional wells by 2010, a third additional well by 2020, and a fourth additional well by 2030 (Seamons, 2008). The locations of the additional wells have not been determined. The assumption was made in the predictive model that the additional wells would be spaced approximately equidistant within the SWC service area. The PUG report provides withdrawal estimates for 2010, 2020, and 2030 and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year.

2.2.5 Las Quintas Serenas Water Company

Future pumping from LQS wells was set to be consistent with the estimates given in the PUG report. The PUG report projects a small increase from 590 acre-feet to 685 acre-feet in LQS annual withdrawals between 2006 and 2030. The PUG report provides withdrawal estimates for 2010, 2020, and 2030 and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year. The allocation of the total groundwater withdrawals among the three LQS wells was based on the relative pumping rates given in the water system plan for LQS.

2.2.6 Quail Creek Water Company

Future pumping from QCWC wells was set to be consistent with the estimates given in the PUG report. The PUG reports projects an increase from 415 acre-feet to 1,050 acre-feet in

QCWC annual withdrawals for municipal supply between 2006 and 2030. The PUG report provides withdrawal estimates for 2010, 2020, and 2030 and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030. Pumping rates were constant within a given year. The allocation of the total groundwater withdrawals among the three LQS wells was based on the relative pumping rates given in the water system plan for LQS.

2.3 Metal Mining

The PUG report identifies three mining operations: Pima Mission Mine (listed as ASARCO in the PUG report), Sierrita (listed as Phelps Dodge in the PUG report), and Rosemont Copper Company (RCC). Pumping wells for the Pima Mission Mine are located outside of the model domain and were therefore not included in the predictive model. The allocation of future pumping from Sierrita and RCC wells is described below.

<u>2.3.1 Sierrita</u>

Determining the future pumping requirements from the Sierrita wells within the model domain, including the FS wells, was the objective of the predictive simulations. Initially the pumping rates for wells in the Interceptor Well (IW) wellfield and Canoa Ranch wellfield were set to their average pumping rates for years 2006 and 2007. For the different FS mitigation alternatives, pumping rates in the IW and FS wells were adjusted as needed to achieve the objective of the mitigation alternatives. Pumping rates in the Canoa Ranch wells were adjusted accordingly to keep total groundwater withdrawals from Sierrita wells within Sierrita's projected water use of 28,000 acre-feet per year.

2.3.2 Rosemont Copper Company

Future pumping from RCC wells was set to be consistent with the estimates given in the PUG report. The PUG report estimates that RCC wells will be in operation by the year 2020 and pump at a constant rate of 6,000 acre-feet per year. The water supply plan for the Rosemont Mine anticipates that four or five wells will be required to meet the production demand (Westland Resources Inc., [WRI], 2007). One well has already been constructed on a 53-acre parcel located southeast of Sahuarita Road and Santa Rita Road, and the water supply plan anticipates that the other wells will be constructed on, or in the vicinity, of the 53-acre parcel. Accordingly, the predictive model included four RCC wells located within the 53-acre parcel. Each well pumps at a constant rate of 1,500 acre-feet per year beginning in the year 2020. The modeled screen intervals for the wells were patterned after the well construction diagram for the newly-installed RCC well (Errol L. Montgomery and Associates [M&A], 2007a).

2.4 Golf Courses

Groundwater withdrawal for golf courses was assumed to be constant over time, as estimated in the PUG report. GVDWID supplies water for Desert Hills, Torres Blancas, Canoa Hills, San Ignacio, and Canoa Ranch golf courses. Water for Quail Creek, Country Club of Green Valley, and Haven golf courses is supplied by wells owned by the respective golf course.

Groundwater withdrawals for golf courses were assumed to be constant in time, as estimated in the PUG report.

2.5 Sand and Gravel

The PUG report identifies two sand and gravel operations (Rinker and CEMEX). The pumping wells for these operations lie outside the model domain and, consequently, were not included in the predictive model.

2.6 Other Users

Other water users included in the predictive model were the proposed Mission Peaks Development, the proposed Twin Buttes Properties, potential residential development on Arizona State Land Department (ASLD) property, and other existing miscellaneous users.

2.6.1 Mission Peaks Development

The Mission Peaks Development is a 4,200 acre master-planned community being planned immediately west of the Town of Sahuarita (American Nevada Company, 2008). The PUG report estimates that the Mission Peaks Development will begin using groundwater by 2010 and that usage will increase to 4,690 acre-feet per year by 2030. SWC likely will be the water provider for the development (Franchine, 2007), and, the estimated pumping requirements for the Mission Peaks Development were assumed to be allocated evenly among the SWC wells in the predictive model. The PUG report provides water usage estimates for the years 2010, 2020, and 2030, and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030.

2.6.2 Twin Buttes Properties

Twin Buttes Properties is planning a residential development east of the Twin Buttes Mine tailing impoundment. The PUG report estimates that the development will begin using water by the year 2010 and that demand will increase to 1,500 acre-feet per year by the year 2030. Water demand for the development will likely be met with the installation of a new well. The location of the new well was assumed in the predictive model to be east of the Twin Buttes Mine tailing impoundment, near the intersection of La Canada Drive and Anamax Mine Road. The PUG report provides water usage estimates for the years 2010, 2020, and 2030, and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030.

2.6.3 Development on Arizona State Land Department Property

The PUG report recognizes the possible use of what is currently ASLD property for future residential development. The report estimates that groundwater withdrawal for development on ASLD property will begin by the year 2020 and increase to 1,325 acre-feet per year by the year 2030. Although when, and where, ASLD property will be converted to residential development is only speculative, an ASLD parcel located near the intersection of East

Dawson Road and South Santa Rita Road has been identified as a good candidate for future development (Hedden, 2008a). A well was placed at this location in the predictive model. Pumping rates in the well are consistent with the estimates given in the PUG report. The PUG report provides water usage estimates for the years 2010, 2020, and 2030, and withdrawals were linearly interpolated for intermediate years. Post 2030, the annual withdrawals were set equal to the withdrawal for 2030.

2.6.4 Existing Miscellaneous Users

Existing miscellaneous users include private residences, small community water providers, government entities (e.g., parks and schools), and businesses with water supply wells. Future pumping rates for each of these users were estimated using historical pumping rates and predicted pumping rates used in the ADWR model (Mason and Bota, 2006). Withdrawals by these existing users were understood to account for the Individual Homeowners category of the PUG report.

3. EVAPOTRANSPIRATION AND AQUIFER RECHARGE

Evapotranspiration and aquifer recharge applied in the predictive model included the following:

- Santa Cruz Basin evapotranspiration
- Sierrita and Santa Rita mountain front recharge
- Santa Cruz River recharge
- Recharge from the Robson Ranch/Quail Creek Recharge Facility
- Recharge from the Sahuarita Waste Water Treatment Plant (WWTP)
- Recharge from golf courses
- Seepage from the STI
- Recharge of Central Arizona Project (CAP) water

Figure F.1 maps where the recharge sources were specified in the predictive model. The estimates of future evapotranspiration or recharge rates, with the exception of seepage from the STI, are described below. Seepage from the STI is discussed in Section 4.

3.1 Evapotranspiration

The predictive model included the same evapotranspiration zones and potential evapotranspiration rates as the historical model. The potential evapotranspiration rates range from 0.0023 feet per day to 0.03 feet per day and have an extinction depth of 25 feet.

3.2 Mountain Front Recharge

Future recharge along the Sierrita and Santa Rita mountain fronts was assumed to remain at the constant value applied in the historical simulation (approximately 200 gallons per minute per mile) (HGC, 2007).

3.3 Santa Cruz River Recharge

The historical simulation lumped recharge from the Santa Cruz River with agricultural recharge. For the predictive simulations, river recharge was assumed to be constant at the rate used for the last year of the historical model (year 2006), but agricultural recharge was assumed to decrease as a result of the conversion of agricultural lands to residential development. The PUG report estimates that agricultural recharge will decrease by 2,250 acre-feet per year between 2010 and 2030. The expected decrease in agricultural recharge was applied in the predictive model by uniformly reducing the river/agricultural recharge rates to be consistent with the decreases given in the PUG report.

3.4 Robson Ranch/Quail Creek Recharge

The Robson Ranch/Quail Creek Recharge Facility is permitted to store up to 2,240 acre-feet per year, and in 2006, with nine of the twelve basins operational, the facility recharged 1,619 acre-feet (ADWR, 2006). The assumption in the predictive model is that by the year 2010, all twelve basins are in use and that the facility is recharging its full allotment of 2,240 acre-feet per year. The numerical code used for the model simulations (MODFLOW-SURFACT;

Hydrogeologic, Inc., 1996) applies recharge instantaneously to the groundwater table. A "lag time" (time difference between when actual recharge begins and when it is specified in the model) was specified to account for the travel time for recharge water to reach the groundwater table. Although the ADWR model of the TAMA (Mason and Bota, 2006) specified a lag time of 10 years, studies indicate that the aquifer response to recharge is much shorter:

- A stable isotope study in monitoring wells located near the Pima Mine Road Recharge Facility used ratios of stable oxygen isotopes as source water identifiers to estimate arrival times of CAP recharge water between three months and two years for monitoring wells located 700 feet to 1500 feet from the recharge site. Arrival times were not correlated with the location of the well (Pima Association of Governments and University of Arizona, 2001).

- Measurements of CAP water arrival and groundwater level responses in monitoring wells near recharge facilities operation by Tucson Water indicate travel times from approximately 10 days at the Sweetwater Recharge Facilities (depth to groundwater approximately 125 feet) to four to five months at the Southern Avra Valley Storage and Recovery Project facility (depth to groundwater approximately 325 feet) to about one year at the Central Avra Valley Storage and Recovery Project facility (depth to groundwater approximately 425 feet). Water level rises were observed prior to the detection of CAP water in groundwater. The early responses are believed to be resident interstitial water that was pushed downward by the recharged CAP water. (Marra, 2008).

Given the relatively short travel times suggested by the above studies, a lag time of only one year was specified in the predictive model. Therefore, recharge of 2,240 acre-feet per year that was assumed to begin in 2010 was applied in the predictive model in 2011. A concentration of 50 mg/L was used for the sulfate concentration in the recharged effluent.

3.5 Sahuarita Wastewater Treatment Plant Recharge

The Sahuarita WWTP was permitted to recharge up to 896 acre-feet per year beginning on November 30, 2007. The predictive simulations assumed that the facility began recharging its full allotment in 2008 and that the travel time to the aquifer (lag time) is 1 year (see Section 3.4). A sulfate concentration of 50 mg/L was used for the recharge effluent. (The Sahuarita WWTP was included in the predictive model because it lies within the model domain. Model results are insensitive to recharge from the WWTP because the facility lies on the northern boundary of the model.)

3.6 Golf Courses Recharge

Recharge rates used in the predictive model for the eight golf courses in the Green Valley area were consistent with the estimates given in the PUG report. The recharge was applied to the approximate area of the golf courses, as determined by satellite imagery. The sulfate concentration in the recharge from golf courses was specified as 110 mg/L, which is the approximate sulfate concentration in the wells at Haven Golf Course, Country Club of Green Valley Golf Course, and Quail Creek Golf Course (HGC, 2007). Potential increases in sulfate concentration of golf course recharge caused by evaporation were not considered in the predictive model.

3.7 Central Arizona Project Water Recharge

As part of its Mine Plan of Operations, the RCC has committed to offset 105 percent of its total pumping volume with recharge of CAP water (WRI, 2007). The PUG report estimates that during RCC mine operation, 7,000 acre-feet per year will be recharged at a new recharge facility. A public memorandum issued by the Bureau of Reclamation has identified that a portion of the 7,000 acre-feet per year will come from CWC's CAP water allocation as part of an agreement between RCC and CWC. The memo further identifies the proposed site for the new recharge as a 20-acre parcel in Section 29, Township 17 South, Range 14 East, approximately 1.5 miles east of Old Nogales Highway along the extended alignment of El Corto Road (Erwin, 2008). Recharge at the new facility is expected to begin sometime around the year 2012 (Hedden, 2008b) and continue for approximately 15 years (WRI, 2007; Erwin, 2008). The predictive model included the CAP water recharge beginning in the year 2013 (one year lag period; see Section 3.4) at the proposed recharge location and continuing at 7,000 acre-feet per year for 15 years. The sulfate concentration in the CAP recharge water was specified as 266 mg/L, which is equal to the 24-month average (August 2006 to July 2008) sulfate concentration measured in CAP water at the San Xavier pump plant (Table F.2; CAP, 2008). Equating the CAP recharge concentration with the concentrations measured at the pump plant inherently assumes that evaporation effects on sulfate concentrations are negligible.

4. SEEPAGE FROM THE SIERRITA TAILING IMPOUNDMENT

The estimation of future seepage for the STI was conducted using three steps:

1. Estimation of water available for seepage under future conditions

2. Estimation of transient decrease in seepage (drain down) due to termination of tailing slurry application in the years 2016 (new tailing impoundment option) and 2043 (end of mine life).

3. Estimation of transient increase in seepage due to increases in water delivery to the STI beginning in 2010

Each of these steps is discussed in the subsections that follow.

4.1 Water Available for Future Seepage

The estimation of water available for seepage in the STI under future conditions was made using the water balance approach described in M&A (2007b) for estimation of the historical seepage in the STI. This approach computes annual seepage as the difference between the sum of all water inputs to the STI and the sum of all water outflows from, and water retained in, the STI. Water inputs include water delivered to the STI, precipitation, and surface water discharges to the STI. Water outflows include water reclaimed from the STI, evaporation, and water retained in the tailing material.

Table F.3 gives the average value used for each component in the water balance. With the exception of water deliveries to, and water reclaimed from, the STI, estimates of each of the water balance components were based on the 10-year average (1997 through 2006) of each component using the information compiled in M&A (2007b). Water delivered to, and reclaimed from, the STI was estimated by accounting for current mine operations and the anticipated increase in ore milling. For the year 2007, the annual volumes of water delivered and reclaimed were estimated as the average of the 2005 and 2006 volumes. The volumes of water delivered and reclaimed for 2008 and 2009 assumed a five percent increase per year in ore milled at the mine, resulting in five percent increases annually in both water delivered and reclaimed. For the years 2010 to end of tailing slurry application to the STI (2016 or 2043, depending on the assumptions of the mitigation alternatives described in the FS), an increase in ore milling of 22 percent over 2007 values was assumed, resulting in a 22 percent increase in water delivered and reclaimed. The water delivery was assumed to be zero starting the year after the end of tailing slurry application to the STI (2016 or 2043). Seepage during the post-application period was estimated from drain down simulations (Section 4.2).

4.2 Drain Down Estimation

Estimation of the drain down of seepage from the STI at the end of slurry application was made using MODFLOW-SURFACT, a numerical model capable of simulating water movement and retention in variably saturated media (Hydrogeologic, Inc., 1996). Details of drain down model construction, initial parameterization, calibration, and predictive simulations are provided below.

4.2.1 Drain Down Model Construction

For the drain down model, the STI was represented as a one-dimensional vertical column. The total height of the column represented the average thickness of the STI and the underlying native alluvium to the groundwater table, which was assumed to be located 50 feet below the bottom of the STI. The average thicknesses of the STI for the years 2016 and 2043 were estimated by (1) determining the current (2007) average thickness of the STI, (2) computing the total volume of tailing expected to be applied by the target date (2016 or 2043), and (3) relating the estimate tailing application volume to a future average STI thickness.

The current thickness of the STI was estimated by dividing the current volume of the STI by the surface area of the STI. The volume between the current surface of the STI and the pre-mining ground surface was computed using the Civil 3D package in AutoCAD (Autodesk, Inc.). The current surface was based on contour maps from aerial photos taken in 2007 and the pre-mining ground surface was estimated from digitized contours of pre-mining topographic maps prepared by Duval Sierrita Corporation in 1978. Using this approach, the current average thickness of the STI was determined to be 170 feet (range from 20 feet to 301 feet).

The total mass of tailing applied to the STI between 2007 and the target date was estimated assuming that 39.1 million tons of ore was milled in 2007 and that this amount will increase to 47.5 million tons by 2010. After 2010, the milling rate was assumed constant at 47.5 million tons per year. The tailing fraction of the ore milled was taken to be 0.98745 (M&A, 2007b). Under these assumptions, the mass of new tailing applied to the STI was computed to be 448 millions tons by 2016 and 1,667 million tons by the year 2043. Using a tailing dry density of 100 pounds per cubic foot (URS Corporation [URS], 2007) the volume of new tailing added was estimated as 332 million cubic yards (2016) and 1235 million cubic yards (2043).

From the estimated tailing volume added to the STI, the future average thickness of the STI was projected using two methods. In the first method, the volume of new tailing was divided by the STI surface area. The resulting height was then added to the current average STI thickness. In the second method, the volume of new tailing was converted to a new STI surface elevation using mass-volume-elevation relationships developed for the STI (URS, 2007). The future average thickness was then computed with the AutoCAD Civil 3D package as explained previously using the future STI elevation and the pre-mining topography. The two methods gave estimates within 10 percent of each other, and the averages of the two methods (230 feet for 2016 and 450 feet for 2043) were used as the future STI elevations for the drain down simulations.

Three drain down model domains were constructed, one for the current average STI thickness, one for the estimated average thickness in 2016, and one for the future average thickness in 2043. The vertical grid cell spacings were 2 feet in the simulation of the current average STI thickness, 3 feet in the simulation of the 2016 thickness, and 5 feet in the simulation of the 2043 thickness. Constant head boundary conditions were used to control the pressure and water saturations in the model domain. A constant head of zero was specified on the lowermost grid cell to represent the water table. For steady-state simulations (used for drain down model calibration and to establish initial conditions), a constant head was specified for the uppermost cell. The constant head for this cell was specified to produce a water saturation of 80 percent within that portion of the drain down model domain corresponding to the STI. A saturation of 80 percent is equivalent to the approximate average tailing saturation measured in STI soil core samples (M&A, 2007b). The transient simulations (used for estimation of the drain down time series) used a no-flow top boundary condition rather than a specificied head boundary at the upper grid cell.

4.2.2 Initial Parameterization

Parameters that affect drainage in the STI include the following:

- Saturated hydraulic conductivity (*Ks*)
- Tailing porosity (θ_s)
- Initial tailing saturation
- Residual tailing water content (θ_r)
- Moisture retention parameters (α and *n* [van Genuchten, 1980])

Parameter calibration for the STI drain down model was constrained to be within the range of the measured or estimated parameters from STI material samples. Over 90 STI material samples were collected by M&A in 2007. The samples were taken from depths ranging from three to 180 feet in boring locations ranging from the interior STI to the STI face. GeoSytems Analysis, Inc. (GSA) conducted soil properties measurements on the tailing samples. Measured properties included porosity, *Ks* (30 samples), θ_s (27 samples), and water content (91 samples). GSA also conducted moisture retention tests on 27 tailing material samples using seven suction values from 0.1 centimeters (cm) to 1000 cm (1 bar). Values of α and n were estimated by curve fitting to the measured data from the moisture retention tests.

An uncertainty in the curve fitting was the value of θ_r. The curve fitting was conducted twice using different assumptions for the value of θ_r. For the first fitting (Estimate A in Table F.4), the values of θ_r were estimated from using the Rosetta neural network database model (Schaap, 1999). The θ_r values from this database model were low, between 0.02 and 0.05, and suggest a highly drainable material, which is counter to the expected behavior for tailing material. A second curve fitting (Estimate B in Table F.4) was conducted with the θ_r set equal to the tailing water content at the 1 bar suction measurement (θ_r between 0.06 and 0.18). The two curve fitting methods yielded slightly different averages for the α and n values (Table F.4).

4.2.3 Drain Down Model Calibration

Drain down model calibration was conducted using a steady-state model with the current average thickness of the STI (170 feet). The calibration goal was to match the current seepage rate of approximately 7,500 acre-feet per year when the one dimensional model was upscaled assuming an infiltration surface area of 4.7 square miles.

The steady-state model calibration was conducted by varying *Ks*, α, and n within the range of measured and estimated values until a good match to the steady-state seepage rate was obtained. Although drainage from the STI also will be influenced by the initial and residual saturations, these parameters were not adjusted during model calibration. The initial saturation was specified as 80 percent and the residual saturation was specified as 25 percent. The initial saturation was chosen as the average saturation measured by GSA for the tailing samples (although saturation values varied over a wide range). The residual saturation was derived by assuming a θr value between the average values from the two curve fitting approaches (Section 4.2.2). The calibrated values of *Ks* and *n* were on the high end of the range of measured and estimated values (Table F.4), implying that the coarser-grained fraction of tailing dominates the drainage response.

The steady-state model was insensitive to the value of α; therefore, a rigorous calibration of this parameter could not be performed. The value of α does, however, affect the transient (drain down) simulations. To understand the sensitivity of the drain down to the value of α, preliminary drain down simulations were run using different values of α to estimate a range of possible drain down profiles due to the uncertainty in α. The value of α selected for use in the predictive model was 0.01 cm^{-1}, which is a reasonably conservative value (i.e., producing a longer drain down period) within the ranges of values estimates for α.

4.2.4 Drain Down Simulations

Following parameter calibration, transient simulations were run to predict the annual seepage from the STI assuming cessation of tailing deposition in 2016 or 2043. Figure F.2 shows relative seepage fluxes for the two simulations. The seepage rates initially decrease rapidly with time and the rates of decrease slow with time as the tailing desaturates and the remaining pore water is held more tightly by capillary forces. Times to achieve the same level of drain down increase for the greater tailing thicknesses as a result of the greater amount of water in storage and the longer drainage distances. The drain down profile for a tailing thickness of 230 feet predicts that seepage will decrease to 50 percent of its original rate in 8 years after the start of drain down and that it will decrease to 10 percent of its starting rate in 32 years. The drain down profile for a tailing thickness of 450 feet takes 16 years to decrease to 50 percent and 61 years to decrease to 10 percent of the starting rate.

4.3 Estimation of Seepage Increases

Increases in the seepage rate resulting from the anticipated increase in water delivery to the STI were estimated using the one-dimensional drain down model developed for the current average tailing thickness (170 feet). Initial conditions for the simulation were established by specifying a constant flux boundary condition for the top model cell. The constant flux was set to establish a uniform saturation within the STI of 80 percent at steady state. After steady-state conditions were established within the model domain, the specified flux through the upper boundary was increased to correspond to the estimated seepage increases for years 2008 through 2010. The simulations predict a lag time of about four years before the seepage through the bottom of the STI is equivalent to the increased seepage input.

4.4 Modeled Seepage for Predictive Simulations

The estimates of the future increase and drain down in relative seepage rates were used to specify the transient seepage volumetric rates from the STI in the predictive model. During the calibration of the historical model, the volumetric seepage rates in the STI were increased over the values estimated in the water budget reported in M&A (2007b). The increase was necessary to better match sulfate concentrations and groundwater levels down-gradient of the STI (Appendix I of HGC, 2007). The predictive model accounted for the higher seepage rates needed to calibrate the historical model. The initial seepage rate (stress period 1) used in the predictive model was the average of the 2005 and 2006 seepage rates used in the historical model (7,838 acre-feet per year). The projected increases in seepage rates after the year 2008 were then added to the initial value of 7,838 acre-feet per year. The maximum seepage rate applied in the predictive model is 11,000 acre-feet per year beginning in the year 2014. This maximum rate was multiplied by the relative drain down curves (Figure F.2) to give the seepage rates during drain down in the predictive model. Figure F.3 and Table F.5 provide the seepage rates applied in the predictive model.

5. BOUNDARY CONDITIONS

All boundary conditions for the predictive model were specified to be the same as the boundary conditions at the end of the historical model (year 2006) and were assumed to be constant with time. Historically, water levels have declined over time within the TAMA. The rate of decline, however, has slowed in recent years, and groundwater recharge at the Pima Mine Road Recharge Facility located immediately north of the northern model boundary may cause groundwater levels to rise in the area near the northern model boundary. The ambiguity about the future trends in groundwater levels at the model boundaries provided no justification for changing boundary conditions with time in the predictive model. The uncertainty in the future trends of groundwater level limits the model's predictive abilities near the model boundaries where the specified head boundary conditions are used.

6. ADJUSTMENTS TO PREDICTIVE MODEL

Several adjustments were made to the historical model in construction of the predictive model. These adjustments generally were made in order to improve computational stability, and they do not significantly alter the model calibration. The additional adjustments include the following:

- Lowering the bedrock elevation at the basin margins
- Modifying layer thicknesses
- Modifying hydraulic conductivities
- Terminating the groundwater sink near the Twin Buttes Mine pit

6.1 Lowering Bedrock Elevations

In the initial development of the historical model, the minimum thickness of each of the model layers was constrained to be 30 meters. The 30-meter thickness constraint was imposed to improve computational stability and required lowering the bedrock elevation at locations near the western basin margins. To improve the computational stability of the predictive model, the minimum layer thickness was increased from 30 to 50 meters. The increased minimum layer thickness artificially lowers the bedrock elevation under most of the STI, but does not impact with the bedrock elevation beneath the IW wellfield.

6.2 Modifying Layer Thicknesses

The thicknesses of the model layers were redistributed to decrease the thickness of the upper layer (Layer 1) throughout most of the model domain (the total model thicknesses at each location remained the same). Decreasing the thickness of Layer 1 improved model stability. Prior to reducing the thickness of Layer 1, the water table would fluctuate near the lower boundary of Layer 1, which would cause problems with model convergence.

6.3 Modifying Hydraulic Conductivities

The modifications to the model layer thicknesses resulted in the need for a minor recalibration of hydraulic conductivities in the predictive model at locations where the hydraulic conductivities were different in each of the model layers. The recalibration was limited to varying hydraulic conductivities in localized areas. The changes to the original hydraulic conductivities were about 20 percent or less.

6.4 Terminating the Sink at the Twin Buttes Mine Pit

During calibration of the historical model, a groundwater sink of 200 gallons per minute was specified near the Twin Buttes Mine tailing impoundment to represent a possible groundwater sink toward the Twin Buttes Mine pit. The presence of the sink near the model boundary often caused convergence problems when groundwater levels in the area were depressed under certain pumping conditions in the FS alternatives. For this reason, the Twin

Buttes Mine pit sink was terminated when water levels in the area were reduced enough to cause convergence problems.

7. USES AND LIMITATIONS

The predictive model accounts for estimated future groundwater withdrawals, recharge sources, and changes in seepage rates from the STI. Adjustments were also made in preparing the predictive model to improve computational stability. These adaptations make the predictive model suitable for simulating the flow of groundwater and the migration and attenuation of the sulfate plume in the vicinity of the STI under the different mitigation alternatives considered for the FS.

The accuracy of predictive model simulations is dependent on the validity of the information used for model construction, including information on aquifer characterization collected by, or provided to, HGC; prediction of mining operations that influence water delivery to the STI; and estimation of future withdrawal and recharge rates and locations. The predictive model is constructed using the most current information available. Deviations from the assumed regional water and land use patterns may result in important differences between predicted and actual groundwater flow and sulfate transport. Uncertainties in future conditions at the model boundaries also weaken the model's predictive ability away from the primary area of interest (i.e., area of the current sulfate plume) and approaching the model boundaries (Section 5). Likewise, the overall predictive ability of the model likely becomes less certain the farther forward in time simulations are projected due to the increasing uncertainty of projections of aquifer conditions with time.

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TABLES

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	Annual Withdrawal (acre-feet) 2010	2020	2030	2040	Basis for Estimate
Agriculture								
Farmers Investment Co. and Farmers Water Co.[1]								
C1	624008	503353	3529320	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
C4	624010	501760	3525384	1472	1330	1057	1057	PUG report. Allocation based on system water plan and/or historical pumping
E10A	086931	502452	3523995	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
E11A	624018	502092	3527822	537	485	386	386	PUG report. Allocation based on system water plan and/or historical pumping
E12	624019	500635	3520347	378	342	272	272	PUG report. Allocation based on system water plan and/or historical pumping
E13	624020	503122	3526403	1092	987	785	785	PUG report. Allocation based on system water plan and/or historical pumping
E15	624022	500333	3518794	586	530	421	421	PUG report. Allocation based on system water plan and/or historical pumping
E16	624023	503328	3525727	726	656	522	522	PUG report. Allocation based on system water plan and/or historical pumping
E3A	624011	502198	3523933	936	1005	874	874	PUG report. Allocation based on system water plan and/or historical pumping
E5A	624012	502184	3524332	514	626	577	577	PUG report. Allocation based on system water plan and/or historical pumping
E6	624013	502425	3525169	530	479	381	381	PUG report. Allocation based on system water plan and/or historical pumping
E7	624014	503086	3525553	7	7	6	5	PUG report. Allocation based on system water plan and/or historical pumping
E8	624015	502374	3525166	314	284	225	225	PUG report. Allocation based on system water plan and/or historical pumping
E9	624016	500862	3521222	286	259	206	206	PUG report. Allocation based on system water plan and/or historical pumping
NP2	624028	500929	3519541	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
W11	624025	499969	3520085	359	487	468	468	PUG report. Allocation based on system water plan and/or historical pumping
W12	624026	500156	3521299	1001	905	719	719	PUG report. Allocation based on system water plan and/or historical pumping
W9	624024	501271	3524132	956	863	686	686	PUG report. Allocation based on system water plan and/or historical pumping
FICO623990	623990	505931	3536661	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
S12	623981	505183	3535660	1137	1186	1015	1015	PUG report. Allocation based on system water plan and/or historical pumping
S19	623982	504841	3532023	1369	1237	983	983	PUG report. Allocation based on system water plan and/or historical pumping
S22	623983	503660	3531621	563	509	405	405	PUG report. Allocation based on system water plan and/or historical pumping
S25	623985	503037	3533248	1261	1139	906	906	PUG report. Allocation based on system water plan and/or historical pumping
S29	623986	503806	3535671	496	448	357	357	PUG report. Allocation based on system water plan and/or historical pumping
S31	623987	505995	3537476	356	322	256	256	PUG report. Allocation based on system water plan and/or historical pumping
S33	623988	503859	3532226	585	529	420	420	PUG report. Allocation based on system water plan and/or historical pumping
S40	623991	505004	3534851	1318	1191	947	947	PUG report. Allocation based on system water plan and/or historical pumping
S43	623993	503813	3537068	852	770	612	612	PUG report. Allocation based on system water plan and/or historical pumping
S44	623994	503859	3530811	1593	1439	1144	1144	PUG report. Allocation based on system water plan and/or historical pumping
S45	623995	504834	3532831	1769	1598	1271	1271	PUG report. Allocation based on system water plan and/or historical pumping
S46	623996	502647	3532239	1047	946	752	752	PUG report. Allocation based on system water plan and/or historical pumping
S48	623997	504987	3537067	688	622	494	494	PUG report. Allocation based on system water plan and/or historical pumping
S49	623998	504793	3538083	477	431	343	343	PUG report. Allocation based on system water plan and/or historical pumping
S50	623999	504991	3538695	38	35	28	28	PUG report. Allocation based on system water plan and/or historical pumping

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
				Annual Withdrawal (acre-feet)				
S51	624000	503017	3535471	1268	1146	911	911	PUG report. Allocation based on system water plan and/or historical pumping
S52	624001	504790	3535663	540	649	595	595	PUG report. Allocation based on system water plan and/or historical pumping
S52A	534992	504806	3534853	107	259	289	289	PUG report. Allocation based on system water plan and/or historical pumping
S53	624002	503453	3532635	1650	1491	1185	1185	PUG report. Allocation based on system water plan and/or historical pumping
S54	624003	503069	3531047	1321	1194	949	949	PUG report. Allocation based on system water plan and/or historical pumping
S55	624004	502062	3531858	1904	1721	1368	1368	PUG report. Allocation based on system water plan and/or historical pumping
S56	624005	505213	3534443	455	411	327	327	PUG report. Allocation based on system water plan and/or historical pumping
201058	201058	506980	3532009	10	10	10	10	PUG report. Allocation based on system water plan and/or historical pumping
FICO543409	543409	500252	3521313	520	470	374	374	PUG report. Allocation based on system water plan and/or historical pumping
FICO624008	624008	500844	3522312	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
FICO624017	624017	502434	3523937	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
FICO624042	624042	502790	3531624	0	0	0	0	PUG report. Allocation based on system water plan and/or historical pumping
			Model Total	**31,021**	**28,999**	**23,523**	**23,522**	
			PUG Total	**31,020**	**28,995**	**23,510**	**--**	

Municipal Water Providers

Community Water Company of Green Valley

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
CW3	627483	500048	3523810	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW5	627484	501234	3522497	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW6	627485	500891	3525794	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW7	502546	499660	3528094	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW8	543600	499799	3525661	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW9	588121	501072	3528741	0	0	0	0	Rates and allocation estimates provided by Community Water Company
CW10	207982	500975	3523255	1349	1540	1724	1724	Rates and allocation estimates provided by Community Water Company
CW11	608518	502442	3530984	1349	1540	1724	1724	Rates and allocation estimates provided by Community Water Company
CW6r	future	501123	3526046	781	876	981	981	Rates and allocation estimates provided by Community Water Company
CW9r	future	501233	3528673	781	876	981	981	Rates and allocation estimates provided by Community Water Company
CW12	future	500249	3523080	0	697	781	781	Rates and allocation estimates provided by Community Water Company
			Model Total	**4,259**	**5,529**	**6,191**	**6,191**	
			PUG Total	**3,200**	**3,500**	**3,900**	**--**	

Green Valley Domestic Water Improvement District

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
GV1	603428	499813	3522254	1455	1548	1597	1597	PUG report (including water supplied to golf courses[2]). Allocation based on system water plan.
GV2	603429	499786	3521654	1660	1767	1823	1823	PUG report (including water supplied to golf courses[2]). Allocation based on system water plan.
			Model Total	**3,115**	**3,315**	**3,420**	**3,420**	
			PUG Total	**3,115**	**3,315**	**3,420**	**--**	

Las Quintas Serenas Water Company

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
ST5	608531	500619	3531941	90	102	102	102	PUG report. Allocation based on system water plan.

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	Annual Withdrawal (acre-feet) 2010	2020	2030	2040	Basis for Estimate
ST6	608530	501248	3531353	203	228	228	228	PUG report. Allocation based on system water plan.
ST7	566940	500778	3531036	316	355	355	355	PUG report. Allocation based on system water plan.
			Model Total	**610**	**685**	**685**	**685**	
			PUG Total	**610**	**685**	**685**	**--**	

Quail Creek Water Company[2]

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
AN-2(RRQC2)	608519	503457	3529250	0	0	0	0	PUG report. Allocation of rates based on historic rates and system water plan.
AN-4(RRQC1)	608521	503457	3527990	460	460	460	460	PUG report. Allocation of rates based on historic rates and system water plan.
QCWC_No11	608597	505964	3526918	0	0	0	0	PUG report. Allocation of rates based on historic rates and system water plan.
QCWC_No13	608522	504788	3528380	510	746	1046	1046	PUG report. Allocation of rates based on historic rates and system water plan.
QCWC_No16	608598	506962	3526858	0	4	4	4	PUG report. Allocation of rates based on historic rates and system water plan.
			Model Total	**970**	**1,210**	**1,510**	**1,510**	
			PUG Total	**970**	**1,210**	**1,510**	**--**	

Sahuarita Water Company[3,4]

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
SWC_1	611144	502752	3537471	2210	2583	2583	2583	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company.
SWC_2	562962	501558	3535872	0	0	0	0	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company.
SWC_3	future	501134	3537343	50	1614	1614	1614	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company. Locations of future wells uncertain
SWC_4	future	501983	3534401	0	1144	1571	1571	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company. Locations of future wells uncertain
SWC_5	future	501134	3534401	0	1144	1571	1571	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company. Locations of future wells uncertain
SWC_6	future	501558	3537343	0	0	1571	1571	PUG report. Allocation of rates based on historic rates and estimates provided by Sahuarita Water Company. Locations of future wells uncertain
			Model Total	**2,260**	**6,485**	**8,910**	**8,910**	
			PUG Total	**2,260**	**6,485**	**8,910**	**--**	

Metal Mining

Freeport-McMoRan Sierrita

Well ID	ADWR Reg.	UTM East	UTM North	2010	2020	2030	2040	Basis for Estimate
IW1	623129	496905.9	3521277.779	558	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW10	508237	497370.4	3523122.199	491	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW11	508235	497371.4	3523428.954	537	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW12	545555	497364.9	3523969.869	242	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	Annual Withdrawal (acre-feet) 2010	2020	2030	2040	Basis for Estimate
IW13	545556	497363.8	3524166.673	0	0	0	0	No anticipated use
IW14	545557	497367.1	3524373.123	144	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW15	545558	497372.9	3524567.261	70	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW16	545559	497370.7	3524782.868	0	0	0	0	No anticipated use
IW17	545560	497373.7	3525002.869	0	0	0	0	No anticipated use
IW18	545561	497374.1	3525169.771	0	0	0	0	No anticipated use
IW19	545562	497373.6	3525343.392	271	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW2	623130	497485.5	3521360.552	861	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW20	545563	497364.7	3525568.77	225	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW21	545564	497374.6	3525773.267	255	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW22	200554	497369.6	3523273.592	644	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW23	200555	497369.2	3522970.788	327	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW24	200556	497371.7	3522633.594	397	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW3	623131	497366.2	3521722.609	0	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW3A	201732	497366	3521723	923	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW4	623132	497372	3522466	371	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW5	623133	497370	3522815	186	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW6A	545565	497381	3523709	206	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW7	623135	496428	3521307	0	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
IW8	508238	497368	3522021	729	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	Annual Withdrawal (acre-feet) 2010	2020	2030	2040	Basis for Estimate
IW9	508236	497370	3522208	409	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S1	623111	499931	3518793	2335	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S2	623112	499133	3517459	2169	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S3	623113	498136	3516037	2779	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S4	623114	497344	3514807	3623	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S5	623115	496561	3513401	4416	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
S6	623116	496371	3511992	4005	TBD	TBD	TBD	Pumping for 2010 is average of 2006-2007 pumping. Pumping for others years to be determined in Feasibility Study
ESP1	623102	499970	3526449	0	0	0	0	No anticipated use
ESP2	623103	500242	3526925	0	0	0	0	No anticipated use
ESP3	623104	500234	3527377	0	0	0	0	No anticipated use
ESP4	623105	499917	3526133	0	0	0	0	No anticipated use
			Model Total	**27,173**	**TBD**	**TBD**	**TBD**	
			PUG Total	**28,000**	**28,000**	**28,000**	**--**	
Rosemont Copper Company								
Rosemont1	214277	508428	3533489	0	1500	1500	1500	PUG report
Rosemont2	future	507818	3533390	0	1500	1500	1500	PUG report
Rosemont3	future	507818	3533590	0	1500	1500	1500	PUG report
Rosemont4	future	508123	3533490	0	1500	1500	1500	PUG report
			Model Total	**0**	**6,000**	**6,000**	**6,000**	
			PUG Total	**0**	**6,000**	**6,000**	**--**	
Golf Courses[2]								
Haven	515867	501609	3526344	765	765	765	765	PUG report
TorresBlancas	543409	502409	3521313	560	560	560	560	PUG report
CCofGV	501760	501635	3527876	700	700	700	700	PUG report
			Model Total	**2,025**	**2,025**	**2,025**	**2,025**	
			PUG Total	**2,025**	**2,025**	**2,025**	**--**	

TABLE F.1
Pumping Wells and Rates

Well ID	ADWR Reg.	UTM East	UTM North	Annual Withdrawal (acre-feet) 2010	2020	2030	2040	Basis for Estimate
Other Users								
TwinButtes	future	500455	3530824	150	500	1500	1500	PUG report
StateLand	future	506015	3533579	0	500	1325	1325	PUG report
			Model Total	**150**	**1,000**	**2,825**	**2,825**	
			PUG Total	**150**	**1,000**	**2,825**	**--**	
ContSD39	601769	504049	3522942	4	4	4	4	Average pumping rate
Cox	604432	508795	3534015	3	3	3	3	Average pumping rate
Grant	801401	496059	3518416	2	2	2	2	Average pumping rate
GVINV_625711	625711	501568	3526181	370	370	370	370	Average rate from 1990 -2007
GVINV_625712	625712	501600	3526400	301	301	301	301	Average rate from 1990 -2007
Lamb	628534	505340	3535044	4	4	4	4	10-yr average rate
LosArboles	524178	502573	3533448	53	53	53	53	10-yr average rate
OcotilloCommunity	801309	498963	3511412	17	17	17	17	Pumping rate for 2001
Olivas	801154	503396	3531213	1	1	1	1	Average pumping rate
			Model Total	**755**	**755**	**755**	**755**	
			PUG Total	**--**	**--**	**--**	**--**	

Notes:

[1] *Includes groundwater withdrawal for both municipal and agricultural uses by Farmers Investment Co. and Farmers Water Co.*

[2] *Withdrawals for Desert Hills, Canoa Hills, San Ignacio golf courses included in pumping from Green Valley Water Improvement District Wells*
Withdrawals for Quail Creek Golf Course included in pumping from Robson Ranch/Quail Creek wells

[3] *Listed as Rancho Sahuarita Water Company in PUG report*

[4] *Withdrawals for the proposed Mission Peaks development including in pumping from Sahuarita Water Company wells*

TBD = To be determined as part of the Feasibility Study

TABLE F.2
Sulfate Concentration in CAP Water at the San Xavier Pump Plant

Sample Date	Sulfate Concentration (mg/L)
7/8/2008	270
6/17/2008	280
5/13/2008	270
4/2/2008	270
3/6/2008	270
2/6/2008	260
1/9/2008	270
12/6/2007	250
11/7/2007	270
10/4/2007	270
9/6/2007	260
8/9/2007	250
7/2/2007	270
6/6/2007	270
5/1/2007	270
4/3/2007	280
3/6/2007	280
2/7/2007	280
1/9/2007	280
12/6/2006	250
11/8/2006	290
10/23/2006	280
9/13/2006	250
8/2/2006	200
Average	**266**

Notes:
mg/L = milligrams per Liter

TABLE F.3
Water Budget Components for Seepage Estimation

Year(s)	Ore Milled (million tons/year)	Water Delivered to Impoundment (ac-ft/yr)	Reclaimed Water[1] (ac-ft/yr)	Surface Water Discharge[2] (ac-ft/yr)	Precipitation[2] (ac-ft/yr)	Evaporation[2] (ac-ft/yr)	Retained in Impoundment[2] (ac-ft/yr)	Available Seepage Water[3] (ac-ft/yr)
2007	39.06	26,196	6,222	296	3,507	12,156	5,364	6,258
2008	40.88	27,417	6,512	296	3,507	12,156	5,614	6,939
2009	40.88	27,417	6,512	296	3,507	12,156	5,614	6,939
2010 - 2032	47.5	31,857	7,566	296	3,507	12,156	6,523	9,415
2033 - future	0	0	0	na	na	na	na	0

Notes:
1. *Value for 2007 based on average value for 2005 and 2006 (M&A, 2007)*
2. *Values based on average value for 1997 - 2006 (M&A, 2007)*
3. *Derived from water budget*

ac-ft/yr = acre-feet per year
na = not applicable

TABLE F.4
Summary of Parameter Estimates

Summary	Ks [1] (cm/s)	Unsaturated Parameters[2]			
		θ_s	θ_r	α (cm^{-1})	n
		Estimate A[5]			
Average[3]		0.36	0.03	0.087	1.350
Median		0.29	0.02	0.016	1.284
Min		0.29	0.02	0.002	1.054
Max		0.44	0.05	0.575	2.570
Std Dev[4]		0.04	0.01	0.153	0.325
		Estimate B[6]			
Average[3]	7.70E-06	0.37	0.23	0.061	1.59
Median	5.90E-06	0.37	0.18	0.026	1.60
Min	1.50E-06	0.28	0.06	0.003	1.09
Max	1.20E-03	0.45	0.64	0.380	2.51
Std Dev[4]	4.76	0.04	0.18	0.083	0.35
		Calibrated			
	2.30E-05	0.36	0.09	0.01	2.03

Notes:

1. *Measured by Geosystems Analysis, Inc.*
2. *Estimated via curve fitting using unsaturated measurements made by Geosystems Analysis, Inc.*
3. *Average for Ks is geometric average. All others averages are arithmetic averages*
4. *Standard deviation for Ks is reverse transform of the standard deviation of the natural log transformed data*
5. *Parameters estimated by using database values for* θ_r
6. *Parameters estimated by using* θ_r *equal to* θ *at 1000 cm suction*

Ks = Saturated hydraulic conductivity
θ_s *= saturated water content (porosity)*
θ_r *= residual water content*
α*,* n *= van Gentuchten (1980) equation constants*

TABLE F.5
Seepage Rates Applied in Predictive Simulations

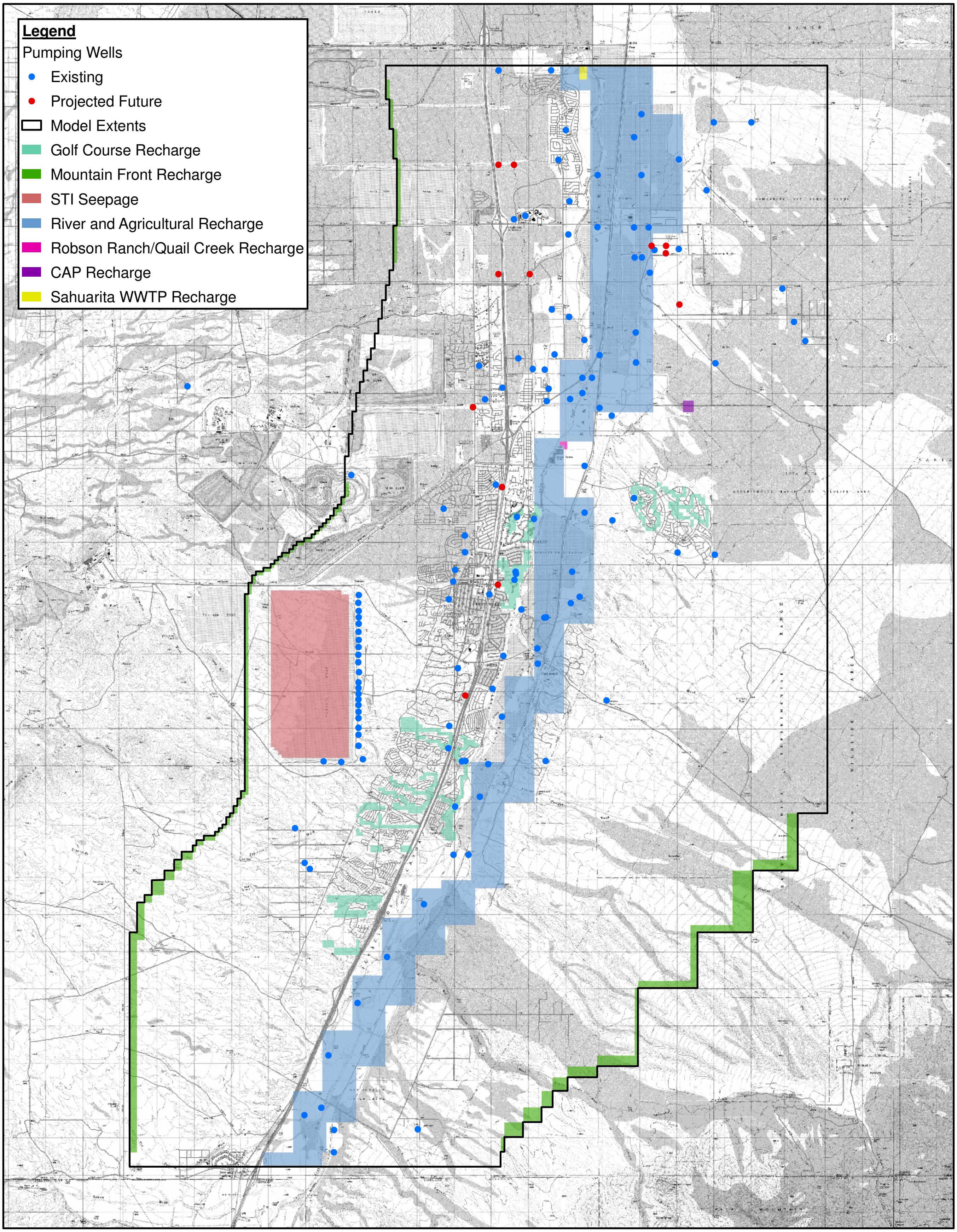
Year	2016 Scenario[1] (ac-ft/yr)	2042 Scenario[2] (ac-ft/yr)
2007	7,843	7,843
2008	7,843	7,843
2009	7,843	7,843
2010	7,853	7,853
2011	7,986	7,986
2012	8,414	8,414
2013	9,640	9,640
2014	11,002	11,002
2015	11,002	11,002
2016	11,002	11,002
2017	11,001	11,002
2018	10,952	11,002
2019	10,534	11,002
2020	9,550	11,002
2021	8,331	11,002
2022	7,191	11,002
2023	6,230	11,002
2024	5,446	11,002
2025	4,809	11,002
2026	4,288	11,002
2027	3,856	11,002
2028	3,495	11,002
2029	3,190	11,002
2030	2,929	11,002
2031	2,703	11,002
2032	2,507	11,002
2033	2,335	11,002
2034	2,183	11,002
2035	2,048	11,002
2036	1,927	11,002
2037	1,819	11,002
2038	1,721	11,002
2039	1,632	11,002
2040	1,552	11,002
2041	1,478	11,002
2042	1,410	11,002
2043	1,348	10,997
2044	1,290	11,002
2045	1,237	11,002
2046	1,188	10,991
2047	1,142	10,920
2048	1,099	10,689
2049	1,059	10,239
2050	1,022	9,618
2051	987	8,919
2052	954	8,222
2053	923	7,567
2054	894	6,973
2055	866	6,441
2056	840	5,969
2057	816	5,549
2058	792	5,177
2059	770	4,844
2060	749	4,547
2061	729	4,280

TABLE F.5
Seepage Rates Applied in Predictive Simulations

Year	2016 Scenario[1] (ac-ft/yr)	2042 Scenario[2] (ac-ft/yr)
2062	710	4,039
2063	692	3,821
2064	675	3,623
2065	658	3,443
2066	642	3,277
2067	627	3,126
2068	612	2,986
2069	599	2,858
2070	585	2,738
2071	572	2,628
2072	560	2,525

Note:
ac-ft/yr = acre-feet per year
[1] Tailing impoundment drain down begins in the year 2016
[2] Tailing impoundment drain down begins in the year 2042

FIGURES



0 6,000 12,000 Feet

PROJECTION:
UTM Zone 12N NAD83

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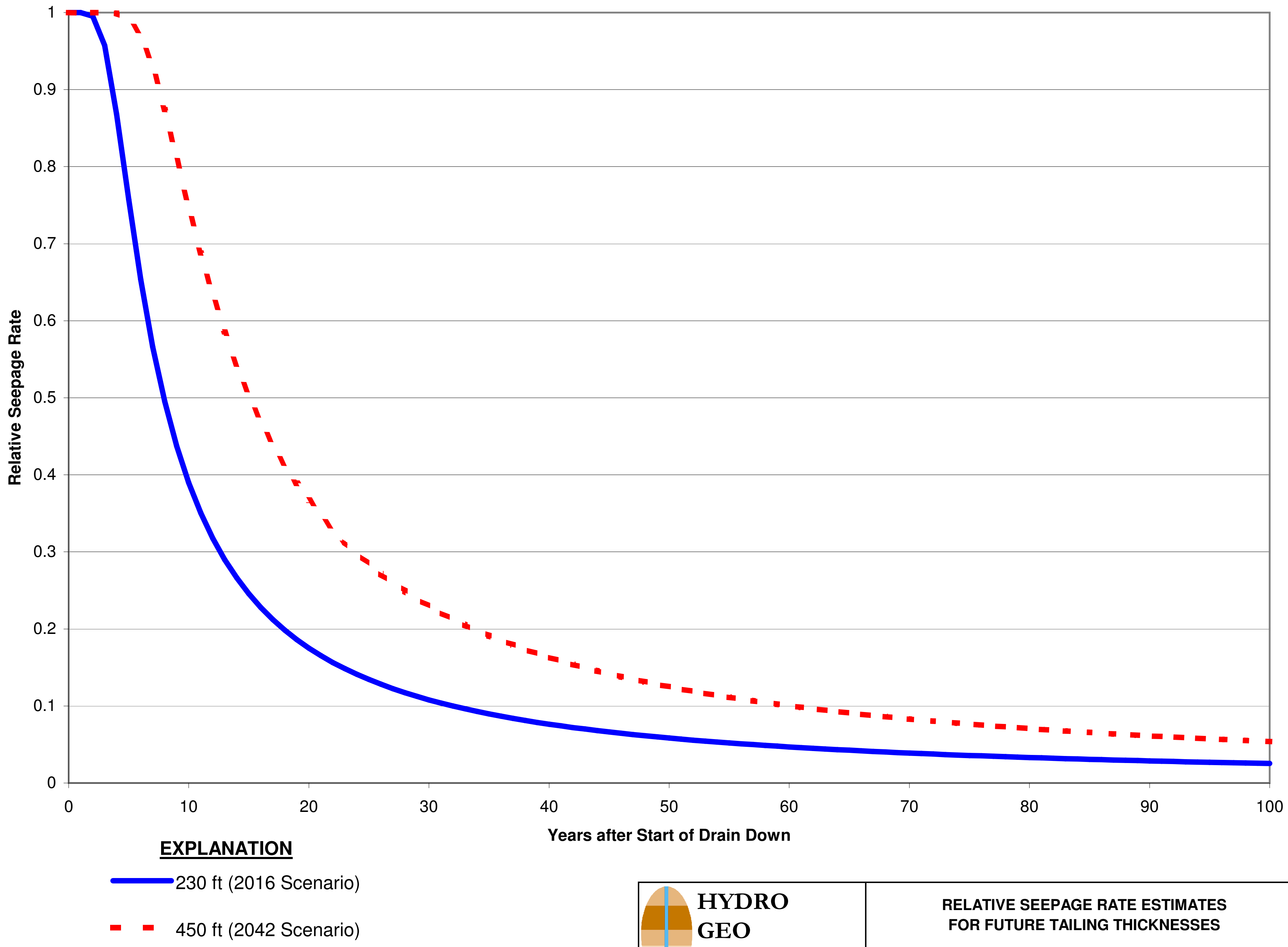
HYDRO GEO CHEM, INC.

PUMPING WELLS AND RECHARGE SOURCES IN THE NUMERICAL MODEL

Approved	Date	Author	Date	File Name	Figure
NWH	10/02/08	RAM	10/02/08	7831108G	F.1



HYDRO GEO CHEM, INC.

RELATIVE SEEPAGE RATE ESTIMATES FOR FUTURE TAILING THICKNESSES					
Approved NWH	Date 8/12/08	Author NWH	Date 8/12/08	File Name F2 QREL	Figure F.2

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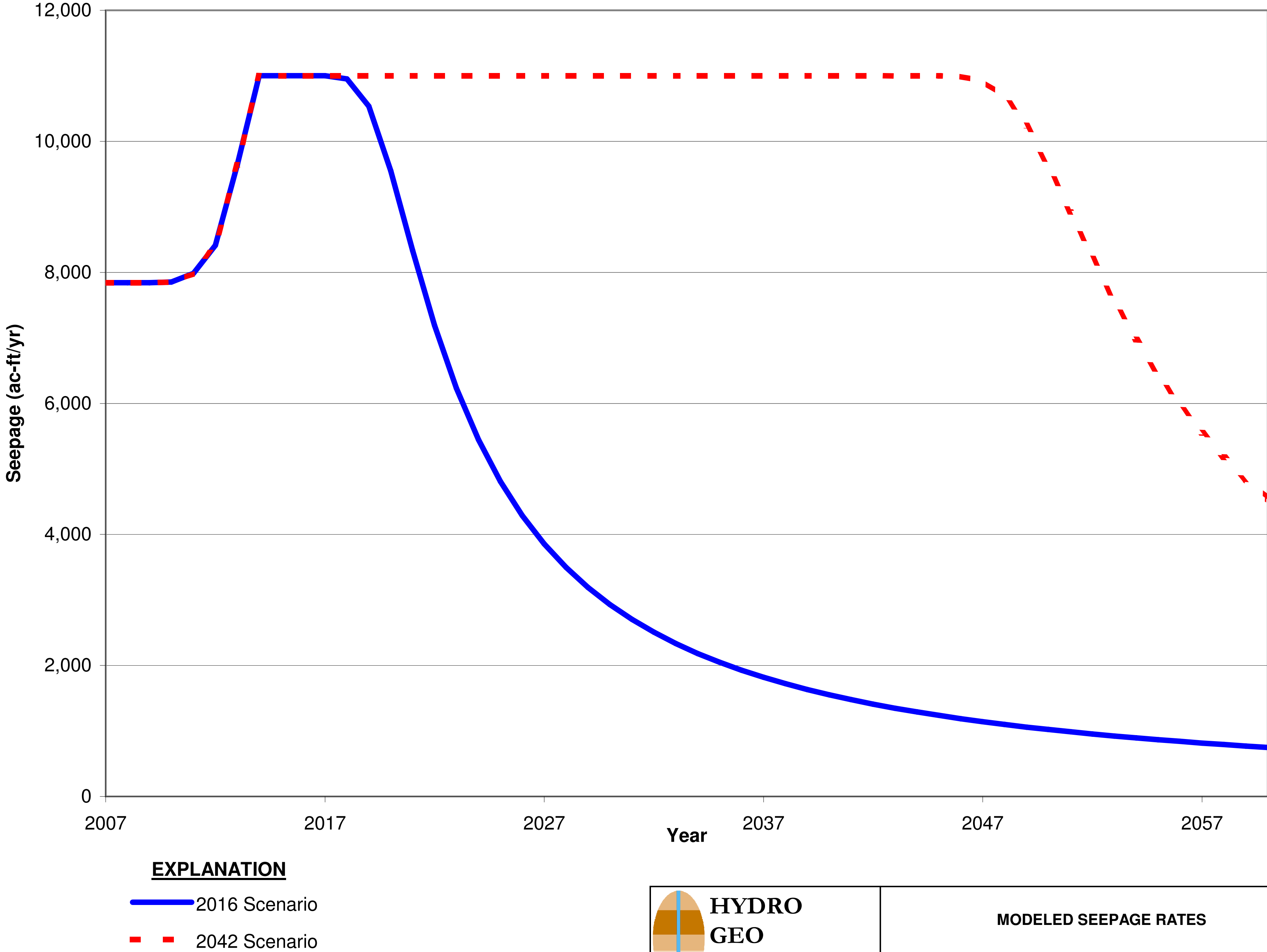

HYDRO GEO CHEM, INC.	MODELED SEEPAGE RATES					
	Approved NWH	Date 8/12/08	Author NWH	Date 8/12/08	File Name F3 seepage	Figure F.3

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