APPENDIX E

DESCRIPTION AND SUMMARY OF WATER BALANCE CALCULATIONS FOR SIERRITA PIT

TECHNICAL MEMORANDUM

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DATE: October 13, 2008

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SUBJECT: Description and Summary of Water Balance Calculations for Sierrita Pit (Mitigation Alternatives 3 and 5)

SUMMARY

- A water balance model was used to assess whether the pit at the end of mine life had sufficient volumetric capacity to maintain passive hydrologic containment if either groundwater from the inceptor well field directly or reverse osmosis plant reject were discharged to the pit.
- Long-term mitigation groundwater plume pumping estimates for Alternatives 3 and 5 were evaluated.
- The sensitivity pit water level elevation to different discharge scenarios of natural upgradient groundwater to the pit was assessed.
- The results demonstrate that the pit at the end of mine life has sufficient volumetric capacity to receive either reverse osmosis reject or direct discharge of sulfate plume groundwater and still maintain passive hydrologic containment.

INTRODUCTION

This letter report provides a description of water balance calculations made to support the evaluation of potential mitigation alternatives as required by the Arizona Department of Environmental Quality (ADEQ) Mitigation Order (MO) Docket No. P-50-06. The purpose of the calculations is to determine whether there is sufficient volumetric capacity in the Sierrita pit to store water from groundwater extraction and water treatment plant operations (RO Plant Reject), in addition to the natural inflows that would enter the pit due to cessation of dewatering systems following mine closure. The scenarios for adding water from groundwater extraction and water treatment plant operations to the pit are defined by different potential mitigation alternatives being evaluated in the Feasibility Study. The modeling results described here are specific to Alternatives 3 and 5 which bracket the range of potential flows to the pit. The pumping scenarios for these two alternatives are described below.

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WATER BALANCE MODEL STRUCTURE AND FORMULATIONS

Model Structure. The water balance model for the Sierrita pit lake is developed on the GoldSim modeling platform (v. 9.60-SP4). The model has a very simple structure that accounts for the balance between water inflows and outflows according to the following general equation:

$$\text{Pit Volume} = \text{Inflows} - \text{Outflows} \qquad (1)$$

The inflows in the model are:

- Precipitation that falls directly on the lake surface (P_{direct})
- Precipitation that falls on the catchment, comprising surface runoff to the lake (P_{runoff})
- Groundwater inflow (G_w)
- Added water for the different mitigation alternatives ($A_{mitigation}$)

The single outflow is:

- Evaporation (E) from the pit lake surface

The substitution of these variables into Eq. (1), yields a more detailed water balance equation for the lake:

$$\text{Pit Volume} = P_{direct} + P_{runoff} + A_{mitigation} + G_w - E \qquad (2)$$

Formulations. The calculation methods for the variables in Eq. (2) are as follows.

- The rate of inflow from direct precipitation is calculated by:

  $$P_{direct} = \text{Precipitation Rate (in/month)*Lake Surface Area (acres)} \qquad (3)$$

  In Eq. (3), the lake surface area is obtained from an area-volume relationship calculated for the pit shape and dimensions and provided by FCX (Figure 1).

- The rate of inflow from precipitation runoff (P_{runoff}) is calculated by:

  $$P_{runoff} = \text{Precipitation Rate (in/month)*Catchment Area (acres)*Runoff Coefficient} \qquad (4)$$

  where the catchment area is 1102 acres. The runoff coefficient is estimated to be 0.2.

- The rate of water added to the pit lake for different mitigation scenarios ($A_{mitigation}$) is described in more detail below (see Table 2).

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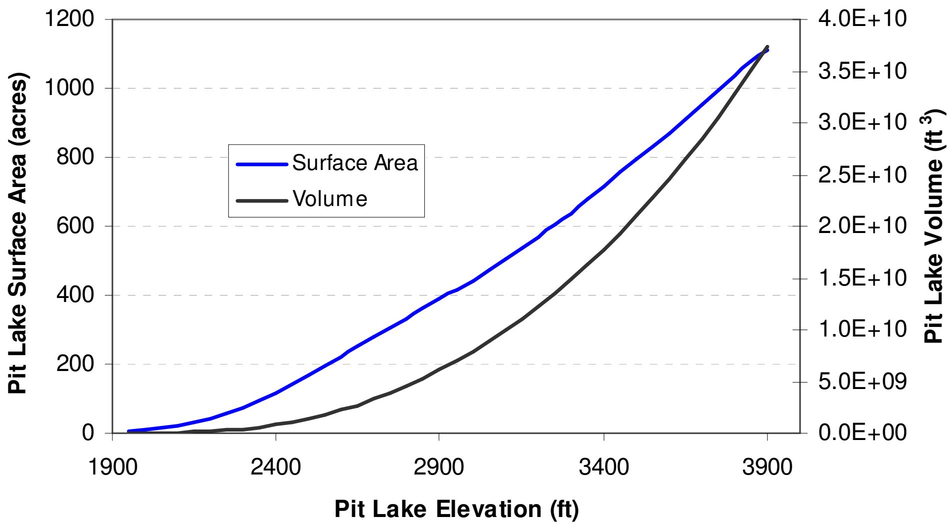

Figure 1. Surface area-elevation and volume-elevation curves for the Sierrita pit lake.

- The rate of evaporation from the pit lake surface (E) is calculated by:

  E = Pit Lake Area(acres)*Pan Evaporation Rate (in/month)*Pan Factor (5)

  In Eq. (5), the lake surface area is obtained from an area-volume relationship calculated for the pit shape and dimensions (see Figure 1). The pan evaporation rates are monthly averages and are provided in Table 1. The Pan Factor is estimated to be 0.8.

- The rate of natural inflow of groundwater (G_w) from the surrounding hydrologic system is calculated using the following equation from Lewis[1](1999):

$$G_w = \frac{2Kbi(r_p + r_b)}{Cos\beta} \qquad (6)$$

  The variables in Eq. (6) are:

K = Aquifer hydraulic conductivity (0.03 ft/day) (from Appendix A by Errol Montgomery Assoc. in MWH, 2005, Supplement to the APP Application BADCT Demonstration Addendum, March 2005)

[1] Lewis, R.L., 1999. Predicting the steady-state water quality of pit lakes. Mining Eng., Oct., 54-58.

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b = Aquifer thickness (1200 ft) from Appendix A by Errol Montgomery Assoc. in MWH, 2005, Supplement to the APP Application BADCT Demonstration Addendum, March 2005)

i = Regional hydraulic gradient (dimensionless). It is calculated from the difference between the regional groundwater elevation, assumed to be 3800 ft, and the lake elevation at any time in a simulation.

$\mathbf{r_b}$ = Radius of the pit lake bottom (236 ft)

$\mathbf{r_p}$ = Radius of the pit lake surface (ft): It is calculated as a function of time in the simulation from the lake area-elevation curve assuming a circular shape for the pit lake.

$\boldsymbol{\beta}$ = Compliment of the pit slope angle [$\cos(90^\circ - 37^\circ) = 0.6018$]

The application of Eq. (6) to the Sierrita pit results in the rates of groundwater inflow as a function of lake elevation shown in Figure 2. The curve in Figure 2 is the result of two competing parameters in Eq. (6); lake radius and hydrologic gradient. Initially, the groundwater inflow low rate is low because the lake radius is small. As the lake fills and the radius increases, the rate of groundwater inflow increases up to a lake elevation of 2700 ft. At that point, the hydrologic gradient becomes the more important parameter. Hence, as the lake continues to increase past 2700 ft, the hydrologic gradient decreases enough that groundwater inflow rate decreases proportionately. At an elevation of 3800 ft, the hydrologic gradient is zero and the groundwater inflow rate is 0 gpm. It is assumed that the 3800 ft level is the point at which the lake becomes a source to the groundwater system rather than a sink.

However, it is not clear that this predicted behavior for groundwater inflow is completely correct for the Sierrita pit because inflows are currently thought to be approximately 500 gpm while the lake elevation is low (GW Base Case). Thus, the model was also run with an initial groundwater inflow rate of 500 gpm that decreases with lake elevation at elevation greater than 2700 ft (GW Case 2) and for a constant inflow rate of 500 gpm (GW Case 3) for all lake elevations. These other groundwater inflow cases are also shown in Figure 2. The results from simulations with these different groundwater inflow curves are discussed below in the section on sensitivity analysis for Alternative 3.

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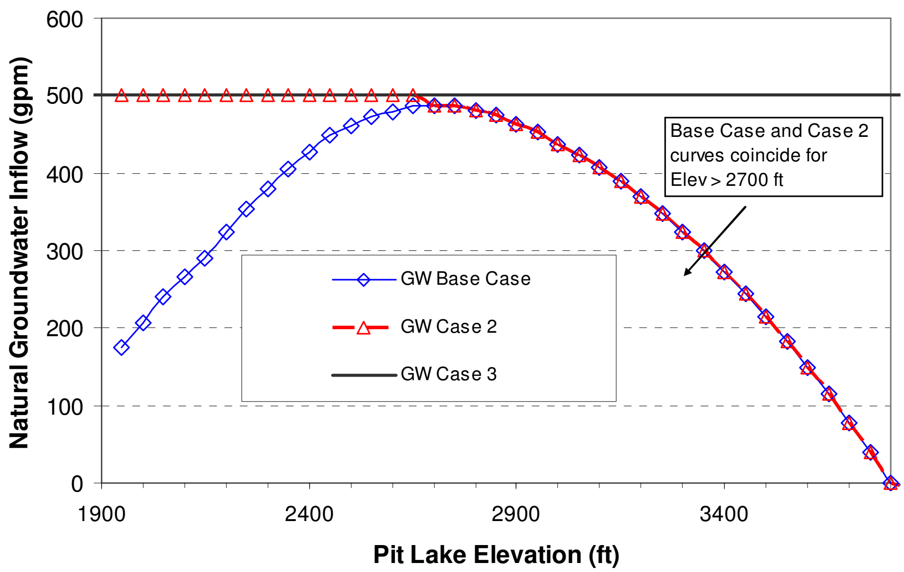

Figure 2. Rates of groundwater inflow used in model simulations.

INPUT DATA

Meteorology. The precipitation and evaporation rates used in the model are based on average meteorological conditions (Table 1). These monthly values are used repeatedly for each simulation year.

Lake Area and Volume. The lake elevation and lake surface area are determined from the curves shown in Figure 1, which are based on the pit shape and dimensions. These data were provided by FCX.

Table 1. Monthly average precipitation and evaporation rates.

Month	Precipitation (in)	Pan Evaporation (in)
Jan	0.6	2.8
Feb	0.8	3.5
Mar	0.6	6.0
Apr	0.2	8.4
May	0.1	7.3
Jun	1.1	13.2
Jul	2.8	8.8
Aug	1.9	5.2
Sep	1.2	6.6
Oct	1.4	4.7
Nov	0.6	3.8
Dec	1.2	2.9
Total	12.6	73.2

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Alternatives 3 and 5. The schedules of rates of water pumping to the pit lake for Alternatives 3 and 5 are summarized in Table 2. For each alternative, two variations are possible, resulting in a total of 4 different scenarios. These are:

- Alternative 3a. Starting in 2043, 100% of the water from the groundwater extraction system is discharged directly to the pit without treatment. The rate of water addition declines with time as shown in Table 2.
- Alternative 3b. Starting in 2043, water from the groundwater extraction system is treated and only the RO reject water from the water treatment plant is discharged to the pit. The rate of addition is assumed to be 25% of the groundwater extraction system influent to the water treatment system under Alternative 3a (Table 2).
- Alternative 5a. Starting in 2043, 100% of the water from the groundwater extraction system without treatment is discharged directly to the pit at a lower rate than for Alternative 3. The rate of water addition declines with time as shown in Table 2.
- Alternative 5b. Starting in 2043, water from the groundwater extraction system is treated and the RO reject water from the water treatment plant is discharged to the pit. The rate of addition is assumed to be 25% of the groundwater extraction system influent to the water treatment system under Alternative 5a (Table 2).

Simulation Parameters. The GoldSim model is run in deterministic mode (no stochastic variables) on a monthly time-step for 250 years.

Table 2. Schedule of water pumping ($A_{mitigation}$) to the Sierrita pit for Alternatives 3 and 5. Data provided by FCX.

Start Year	End Year	Pumping Rate to Pit (gpm)	Pumping Rate to Pit (gpm)
		Alt 3a-Groundwater Extraction	Alt 3b-RO Reject*
2043	2050	9,361	2340
2051	2080	8,111	2028
2081	2090	4,482	1120
2090	2116	2,605	651
		Alt 5a-Groundwater Extraction	Alt 5b-RO Reject
2043	2080	2,555	639
2081	2116	2,455	614

*RO Reject rate = 25% of Groundwater Extraction rate

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MODEL RESULTS

Base Case (no additional water from pumping alternatives). The rate of filling of the pit is shown in Figure 3 for the three estimates of natural groundwater inflow rate portrayed graphically in Figure 2, i.e.:

- GW Base Case: Analytical expression (Eq. 6)
- GW Case 2: 500 gpm initially, decreasing according to Eq. (6)
- GW Case 3: Constant rate of 500 gpm

The pit filling curves for each case are similar with GW Case 3 (constant rate of 500 gpm) resulting in a slightly more rapid rate of increase in elevation with time (Figure 3). The final pit elevation for all cases is about 2690 ft after 300 years. For each case, groundwater comprises from 63 to 65% of the total cumulative volume of water entering the pit lake over 250 years.

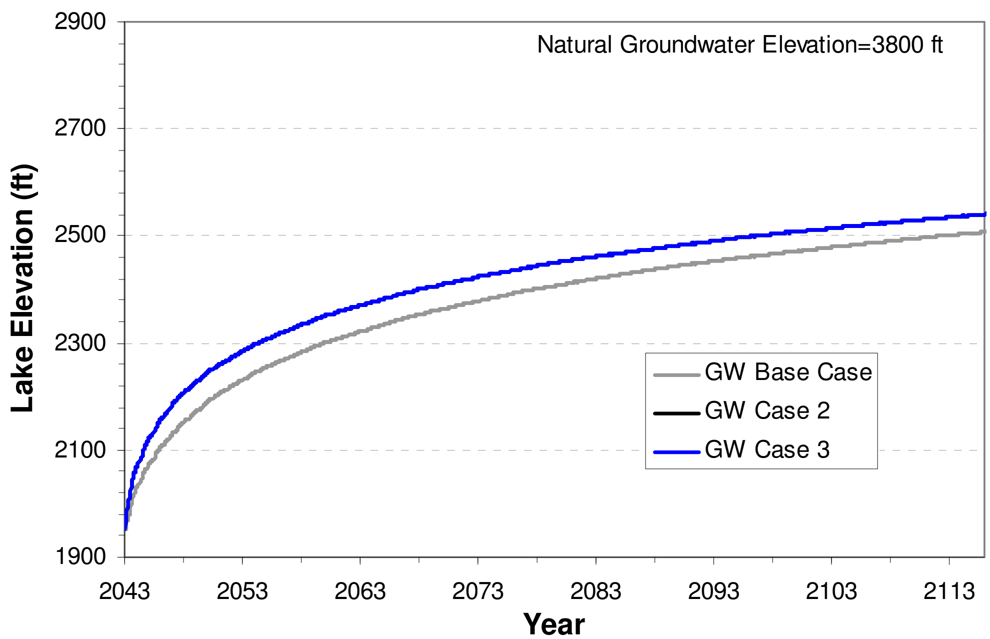

Figure 3. Based case predicted rates of filling of the Sierrita pit lake by natural inflows (no alternative pumping) for three representations of natural groundwater inflow. (Data for GW Case 2 and GW Case 3 are nearly equivalent so only one line is shown.)

Alternative 3. The rate of filling of the pit is shown in Figure 4 for the Alternatives 3a and 3b. The schedules of water added to the pit for each alternative are provided in Table 2. The rate of pit filling for the GW Base Case where only natural inflow to the pit occurs is shown for comparison to the results for the alternatives. The high rate of water added for Alternative 3a

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causes the pit to come closest to the estimated elevation for natural groundwater of 3800 ft of any of the alternatives simulated. The highest lake elevation is reached at 3591 ft in years 2116-2117 according to the simulations. For Alternative 3b, the highest lake elevation is reached at 2936 ft in years 2116-2117. After reaching maximum elevations, the lake levels for both alternatives decrease toward that predicted for the GW Base Case in response to the end of additional pumping of water under Alternatives 3a and 3b.

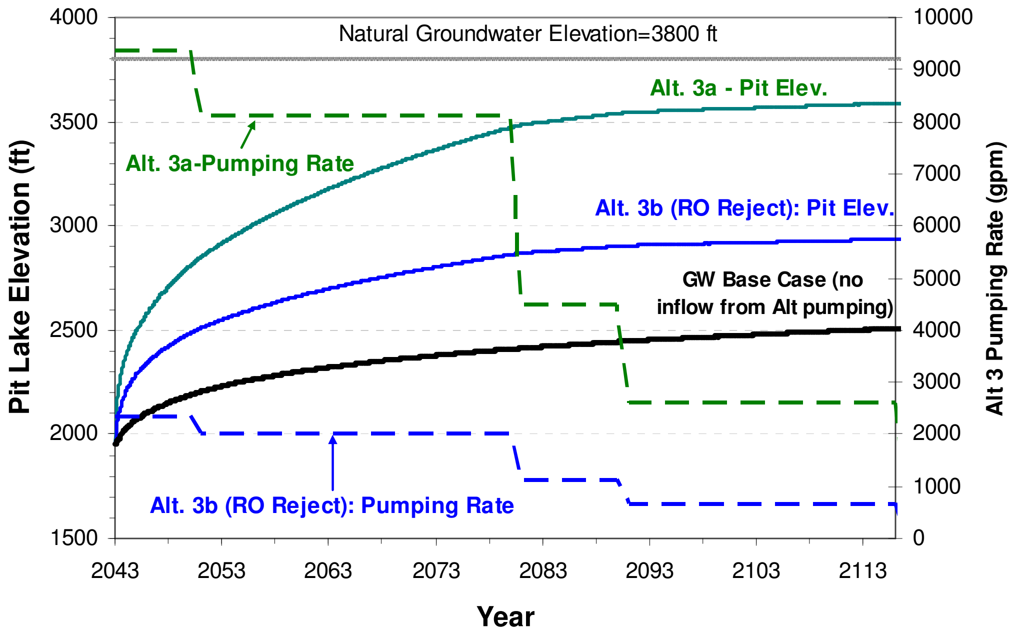

Figure 4. Alternative 3 predicted rates of filling of the Sierrita pit lake. Dashed lines show the rate of groundwater pumping into the pit according to the schedules in Table 2 for Alternative 3a and Alternative 3b. The filling rate for the GW Base Case is shown for comparison.

Alternative 5. The rate of filling of the pit is shown in Figure 5 for the Alternatives 5a and 5b. The schedules of water added to the pit for each alternative is provided in Table 2. The rate of pit filling for the GW Base Case where only natural inflow to the pit occurs is shown for comparison to the results for the alternatives. The additional water added for Alternative 5a causes the pit to approach the estimated elevation for natural groundwater of 3800 ft. The highest lake elevation is reached at 3168 ft in year 2117 according to the simulations. For Alternative 5b, the highest lake elevation is reached at 2747 ft in year 2117. After reaching maximum elevations, the lake levels for both alternatives decrease toward that predicted for the GW Base Case in response to the end of additional pumping of water under Alternatives 5a and 5b.

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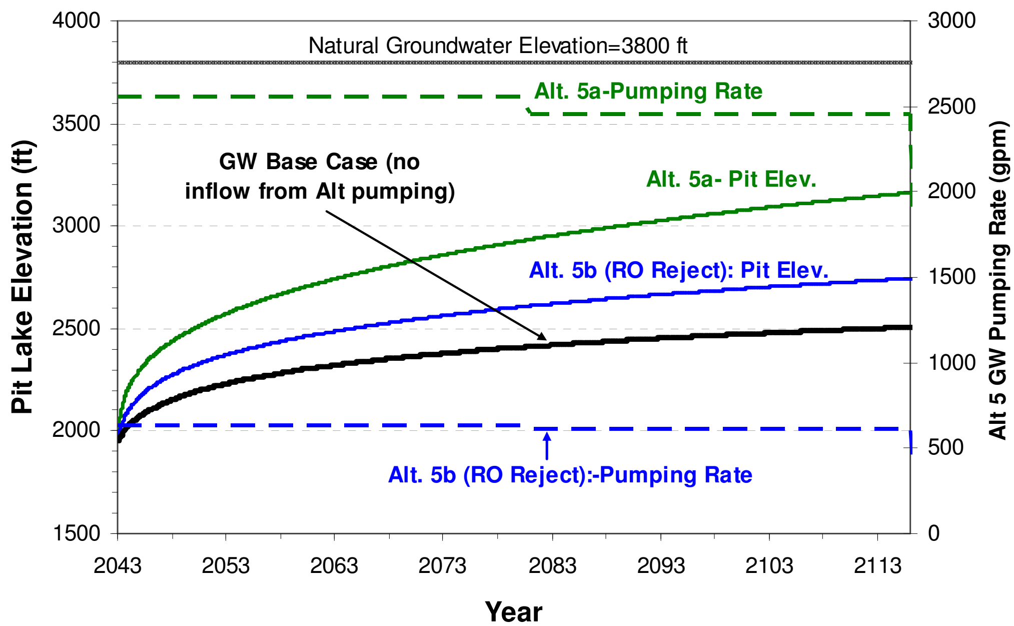

Figure 5 Alternative 5 predicted rates of filling of the Sierrita pit lake. Dashed lines show the rate of groundwater pumping into the pit according to the schedules in Table 2 for Alternative 5a and Alternative 5b. The filling rate for the GW Base Case is shown for comparison.

Sensitivity Analysis for Alternative 3. The rate of natural groundwater inflow is an uncertain parameter in the model. Thus, simulations were run to examine the sensitivity of the pit lake elevation to the groundwater inflow rate for the mitigation pumping scenario of Alternative 3a, which is the alternative that results in the high lake levels. The results of the sensitivity simulations are shown in Figure 6. They indicate that the rate pit elevation is not sensitive to the three different methods of calculating rates of groundwater inflow (e.g., GW Base Case, GW Case 2, and GW Case 3). The reason for this lack of sensitivity is that groundwater inflow rate comprises only a small percentage of the total water entering the pit lake compared to the pumped-in water under the Alternative 3a scenario (Figure 7). Natural groundwater makes up only about 5% of the cumulative inflow volume to the pit lake at the start of filling compared to 93% from the Alternative 3a pumped-in water. The percentage of natural groundwater starts to increase in response to the decreasing rate of Alternative 3a pumping and but only reaches about 7% after 100 years (Figure 7).

An additional set of simulations was run to determine how high the natural groundwater inflow rate would have to be for the pit lake to reach the 3800-ft level. The results are:

- A constant rate of approximately 2000 gpm or more is needed to reach 3800 ft and maintain that level (Figure 6).

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- Alternatively, if the hydraulic conductivity (K) used for Eq. (6) of 0.03 ft /day is in error by a factor of ten and should be 0.3 ft/day, then the resulting increase in natural groundwater inflow is enough to cause the lake elevation to reach 3800 ft (Figure 6).

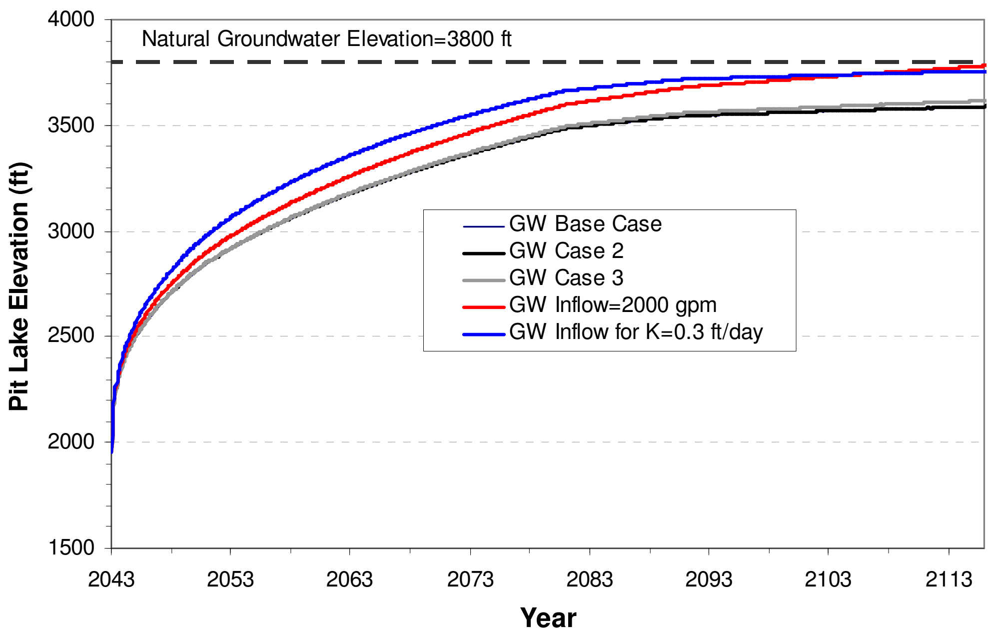

Figure 6. Sensitivity of the rate of pit lake filling to different methods of calculating natural groundwater inflow rates for the Alternative 3a mitigation pumping scenario. Data for GW Base Case and GW Case 2 overlap so only one line is shown.

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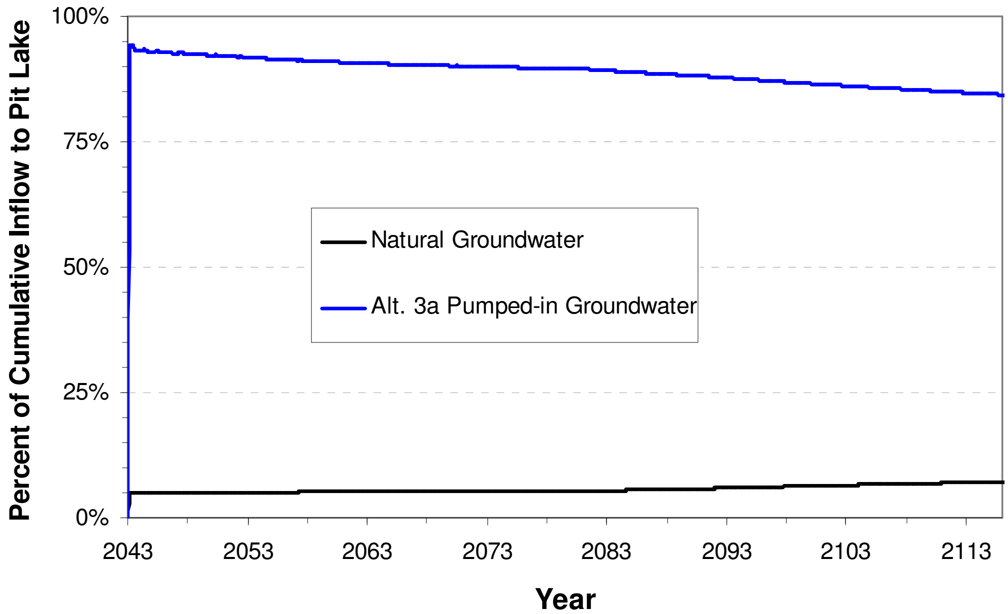

Figure 7. Percentages of cumulative water volume in the pit lake from natural groundwater inflow and Alternative 3a pumped-in water.

Water Balance at the 3800-ft Level. An analysis of the annual water balance for the hypothetical condition of the pit lake at elevation 3800 ft provides a convenient way to check the robustness of the above simulations. The 3800-ft level is assumed to be the maximum elevation for the pit lake. Above 3800 ft, the pit lake becomes a source of water to the groundwater system instead of a sink. From Eq. (2), the water balance is a function of the difference between the inflows and outflows. At the 3800-ft elevation, the yearly average inflows are (see Table 3 below for calculations of flow rates):

- P_{direct} = 675 gpm
- P_{runoff} = 143 gpm
- G_w = 0 gpm
- $A_{mitigation}$ = 0 gpm (no pumped-in water for this steady state analysis)

The only outflow is evaporation:

- E = 3139 gpm

The net balance from the difference between the sum of the inflows and outflows (evaporation) is -2320 gpm, meaning that an additional inflow of 2330 gpm would be needed to maintain the pit lake at an elevation of 3800 ft. This rate of 2330 gpm is close to the estimate of a 2000 gpm

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determined from the simulations as the amount of extra groundwater inflow needed for the lake to approach and stay near an elevation of 3800 ft (see Figure 6). The high rate of evaporation is due to the large size of the pit lake of 1037.5 acres at the 3800-ft level which, when multiplied by an annual evaporation rate of 6.1 ft and pan evaporation factor of 0.8, results in a high rate of water loss (Table 3).

Table 3. Yearly water balance for the Sierrita pit lake for a lake elevation of 3800 ft.

	Lake Area at Elev=3800 ft (acres)	**Lake Area at Elev=3800 ft (ft^2)**	**Yearly Ave. Evap (in)**	**Yearly Ave. Evap (ft)**	**Evap Rate (ft^3/yr)**	**Evap Rate (gal/yr)**	**Evap Rate (gpm)**
Evaporation from pit lake	1037.5	45193500	73.2	6.1	220544280	1649671214	3139
Pan Evap Factor=	0.8						
	Lake Area at Elev=3800 ft (acres)	**Lake Area at Elev=3800 ft (ft^2)**	**Yearly Ave Precip (in)**	**Yearly Ave Precip. (ft)**	**Precip. Rate (ft^3/yr)**	**Precip. Rate (gal/yr)**	**Precip. Rate (gpm)**
Rainfall directly to pit lake	1037.5	45193500	12.6	1.05	47453175	354949749	675
Runoff coefficient=	0.2						
	Catchment Area (acres)	**Catchment Area (ft^2)**	**Yearly Rain (in)**	**Yearly Rain (ft)**	**Catchment runoff rate (ft^3/yr)**	**Catchment runoff rate (gal/yr)**	**Catchment runoff rate (gpm)**
Catchment runoff	1102	48003120	12.6	1.05	10080655	75403300	143
							GW Inflow (gpm)
Natural Groundwater Inflow							0
						Balance (gpm)	**-2320**

CONCLUSIONS

The results demonstrate that the pit at the end of mine life has sufficient volumetric capacity to receive either reverse osmosis reject or direct discharge of sulfate plume groundwater and still maintain passive hydrologic containment, because of the large volume of the pit and high rates of evaporative losses. These results also indicate that the passive hydrologic containment created by evaporation from the pit surface would not be lost over a reasonable range of natural groundwater inflows to the pit.

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