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BUILDING A BETTER WORLD

MEMORANDUM

TO:	Stuart Brown (Bridgewater Group, Inc)	DATE:	October 14, 2008
FROM:	Ed Cryer (MWH)	REFERENCE:	1005720.011801
SUBJECT:	Sierrita Mine Groundwater Treatment Alternative Evaluation		

1.0 INTRODUCTION

The Sierrita Mine is operated by Freeport-McMoRan Sierrita Inc. (Sierrita). The mine is located in Southern Arizona 25 miles south of Tucson and mines and processes primarily copper and molybdenum ores. The milling process incorporates a tailing impoundment to contain milling residuals. As part of the impoundment management, Sierrita maintains a groundwater interceptor wellfield to collect seepage from the tailing. At present, the water collected in the wellfield is reused in the mining/milling process.

The objective of this study is to develop potential conceptual treatment options for groundwater containing sulfate that may be pumped down gradient of the tailing impoundment for source control and plume management purposes, and provide capital and operation and maintenance (O&M) costs for the feasible options considered.

The memorandum evaluates water treatment technologies that could be implemented as part of an overall mitigation alternative to meet the 250 mg/l sulfate mitigation level established by the Arizona Department of Environmental Quality (ADEQ) in Mitigation Order on Consent (MO) Docket No. P-50-06. The memorandum presents conceptual water treatment option(s) that are used to: 1) develop conceptual design criteria, schematic layout and sizing of equipment and facilities, and capital and operational costs, and 2) evaluate issues related to operability, risk in terms of cost and reliability, and implementability.

The memorandum does not address the interceptor wellfield, the interceptor wellfield conveyance system, potential uses of final treated water, land acquisition requirements and costs for water supply and conveyance facilities, the availability of the necessary infrastructure (e.g., power) or closure of these facilities. Those aspects are beyond the scope of the study.

2.0 GROUNDWATER QUANTITY AND CHARACTERISTICS

For this study, Sierrita requested that three influent groundwater flow rates be evaluated: 2,000 gpm, 4,000 gpm and 6,000 gpm. The evaluation addressed treatment of these influent flow rates. as well as management of any residual brine, solids or other materials that would result from treatment. Treated water (i.e., effluent) management and disposal options were not evaluated. The finished water must satisfy the 250 mg/L sulfate concentration established by the MO.

Existing water quality information for groundwater downgradient of the tailing impoundment was provided by Sierrita (Hydro Geo Chem Inc. 2007). This information was used to establish the potential water treatment plant influent water quality for treatment (see Table 1). The potential influent water quality would be characterized as having moderate alkalinity (100 mg/l) and total dissolved solids (2,670 mg/l). The raw water (influent) sulfate concentration is approximately 1,570 mg/l; the calcium concentration is approximately 513 mg/l. From a water treatability standpoint, the only issues may be the calcium (513 mg/l) and silica (55 mg/l) concentrations in regard to scale formation potential and the necessity to pretreat the water to remove calcium and silica prior to sulfate treatment. The iron and manganese are both reasonably low and the water temperature is warm, approximately 80°F (27°C).

TABLE 1

SIERRITA GROUNDWATER CHEMISTRY

Parameter	Unit	Value
Calcium	mg/l	513
Magnesium	mg/l	111
Sodium	mg/l	98
Potassium	mg/l	12
Barium	mg/l	0.08
Alkalinity as $CaCO_3$ equivalents	mg/l	100
Sulfate	mg/l	1,570
Chloride	mg/l	121
Fluoride	mg/l	0.1
Nitrate, as N	mg/l	3.2
Aluminum	mg/l	<0.06
Phosphorus	mg/l	N/A
Silica	mg/l	55
Boron	mg/l	0.12
Iron	mg/l	0.1
Manganese	mg/l	0
pH	s.u.	7.7
TDS	mg/l	2,670
Temperature	°C	27.1

Table Footnote: N/A = not available

Based upon Table 1, 87 percent (%) sulfate removal would be required to meet the 250 mg/L sulfate concentration established by the MO.

3.0 PRIMARY TREATMENT PROCESSES CONSIDERED AND SCREENED

There are a variety of chemical, physical and biological processes that have been proposed for the removal or sequestering of sulfate. For the purpose of this memorandum, the treatment process technologies must be sufficiently developed to permit the process to be implemented at the scale required to treat the flow rates being evaluated without additional technology development or pilot-scale testing. A number of these processes are relatively experimental or require conditions and operational involvement beyond the practical consideration for a large scale treatment facility. Of the sulfate treatment methods typically cited in the literature, the following will be discussed:

- Chemical Precipitation
- Ion Exchange
- Membrane Separation
- Biological Treatment
- Distillation/Evaporation

Sulfate reducing bacteria (SRB) using an ex situ reactor is a biological process that converts sulfate to a sulfide (reduction) where the sulfide is then precipitated as a metal complex or elemental sulfur. Typically the biochemical reaction requires the addition of a biologically usable carbon source. Although this process has been used for acid mine drainage and other water treatment applications, these were relatively low flow (less than 50 gpm) systems. Designing and constructing a biological treatment system capable of treating the flow rates evaluated in this memorandum would require considerable pilot-scale testing. Because of the additional technology development and pilot-scale testing, the biological treatment alternative was not evaluated further

Chemical precipitation with lime or caustic could not reduce the sulfate level below 1,000 – 1,500 mg/l (co-precipitation dependent). Additional chemical precipitation with barium salts can be used to further reduce the sulfate concentration but the process would be costly to operate and somewhat difficult to control. As can be seen from the reaction formula, this process will not significantly reduce total dissolved solids (TDS). The reported sulfate removal limit, using barium salts, is approximately 200 mg/l.

$$Na_2SO_4 + BaCl_2 \longrightarrow 2\ NaCl + BaSO_4$$

Ion exchange is an option that could be considered. The use of selective sulfate exchange resins (non-anionic resins) will effectively adsorb sulfate. However, if the raw water has a significant amount of calcium, that would compete for adsorption sites on the exchange resin, it may require pretreatment using a two-stage ion exchange and/or lime softening to reduce the calcium ions. While this system could be designed to remove sulfate below 250 mg/l it would not be expected to remove significant amounts of TDS due to the ionic exchange phenomenon. Ion exchange also has a residual issue (regeneration brine) that must be considered and disposed of by a separate mechanism. While ion exchange for sulfate removal is not uncommon, it would require additional technology development and pilot-scale testing. Consequently ion exchange was not considered further.

Distillation and thermal evaporation could be considered as a method to produce a high quality and low TDS finished water. Distillation will remove essentially all of the sulfate and most of the TDS, but it is a very energy intensive process. Distillation evaporation systems are used to produce potable water world-wide from brackish or saline sources, however, for this application the expenditure of the amount of energy required (±100,000 kWH/acre foot) is not a reasonable alternative given the large volumes (2.9 – 8.5 million gallons per day (mgd), or 8.9 to 26 acre feet per day) being considered. Even if only a portion of the water was thermally distilled and blended back with the raw water, the energy cost could be prohibitive.

The only option that would appear to be both technically conventional and economically feasible is membrane filtration. Electrodialysis (ED), electrodialysis reversal (EDR) and reverse osmosis (RO) could be considered for this application.

3.1 Electrodialysis Treatment

ED and EDR employ electrical current and a semipermeable membrane to separate ions from water. Flat sheet membranes are stacked with flow channel between each of the membranes. Cathode and anode electrodes are installed on either side of a stack of membranes. The electrical charge draws the opposite charge ions through the membrane providing a low total dissolved solids (TDS) separate product water and a high TDS concentrate water (brine).

The efficiency of electrodialysis is dependent upon the ionic solids and fouling potential from organics and particles in the feed water, the temperature, the flow rate, system size and required electrical current. Organics and weakly-charged inorganics are not removed by ED. Recent developments have improved the efficiency of ED by periodically reversing the polarity of the electrodes. This is referred to as EDR and has reduced the scaling and fouling problems common to ED.

Reverse osmosis is a pressurized membrane process. The process will remove both dissolved organics and ionic salts. The pressure membrane process is more common than EDR and has been developed for a number of applications including waste treatment, potable water supply and industrial manufacturing.

3.2 Reverse Osmosis Treatment

The use of reverse osmosis to provide low ion concentration water is a well understood and commercially accepted method to provide fresh industrial and potable water for a variety of uses. The technology involves the use of a fine porous membrane process to separate the very fine suspended and dissolved ions (salts) from the fresh water. The higher the total dissolved solids in the water to be treated, the more restrictive (tighter) the membrane porosity must be and, as a consequence, the higher the pressure required to maintain an acceptable product water (fresh) flow rate. The product water flow (flux rate) and quality of the product water are, in part, a function of the feed water TDS (dissolved solids concentration). Brackish water, with a lower TDS concentration (10,000 – 15,000 mg/l), can have a higher flux rate and produce better quality water at a lower membrane feed pressure (energy cost) than sea water (TDS typically in the 32,000 to 38,000 mg/l). In order to maintain the flux rate at higher TDS concentrations, the pressure across a desalination membrane must be increased. Sea water RO systems operate at 800 – 1,200+ psi while brackish water and membrane water softening systems are typically in the 300 – 600 psi range. Due to the higher pressures required to maintain a reasonable flux rate, desalination of ocean water has a higher capital cost and will require higher energy use than lower brackish water sources.

3.2.1 Treatment Alternative Summary

EDR while useful in producing a high quality water source from higher TDS water, it would not be as effective in reducing the TDS concentration for meeting the sulfate concentration requirement as RO. However, EDR is not impacted by higher silica concentrations that can, in some applications, impact RO membrane longevity.

The reported success in providing reliable sulfate reduction, in high sulfate water, using EDR is marginal. For meeting the 250 mg/l finished water concentration objective this option will not be considered further for this application. Reverse osmosis will be considered the primary candidate for treatment of the Sierrita groundwater in this report.

3.3 Reverse Osmosis Treatment Criteria Discussion

The preliminary operational design criteria for the RO process is provided on Table 2 for the three flow options. We are assuming that a series of wells can be developed that will provide in excess of 2,000, 4,000 and 6,000 gpm of clean (low total suspended solids - TSS) groundwater. The need for chemical addition (precipitation/flocculation/settling) and prefiltration has not been included in this analysis but may be required based upon pilot analysis and further testing. The addition of this level of pretreatment would significantly increase capital and operating costs of the proposed system. The well water would be pumped to a storage head tank prior to treatment. We have assumed (without additional testing) that no form of pretreatment other than slight acidification (to pH = 6.5), the addition of antiscalent, and 10µm and 5µm cartridge filtration will be required using the well water supply.

TABLE 2

PRELIMINARY OPERATIONAL DESIGN CRITERIA
Preliminary Conceptual Assessment for Well Water Treatment Plant

		2,000 gpm	**4,000 gpm**	**6,000 gpm**
Individual RO Unit	**Unit**	**Value**	**Value**	**Value**
RO Permeate Flow, Each Unit (est. Design)	USGPM	750	750	750
Number of Units (including one standby)	No.	3	5	7
RO Permeate Flow, Total* (2 units)	USMGD	2.1	2.9	4.3
Water Recovery (assumed Design No.)	%	75	75	75
RO Feedwater Flow, Total*	USMGD	2.88	5.76	8.64
Reject (Concentrate) Flow, Total*	USMGD	0.68	1.37	2.05
Feedwater Flow, per Train (Unit)*	USMGD	1.37	2.74	2.74
Reject (Concentrate) Flow, per Train (Unit)*	USMGD	0.34	0.67	1.02

*Commercial units @ 95% operating factor average year

For initial planning purposes, we have assumed the use of multiple 1,000 gpm (feed water) commercially available RO units that would process the required influent water flow with one unit (redundant) out of service in cleaning or maintenance mode. This configuration will insure uninterrupted full service operation at design flow. The 1,000 gpm units are considered large for a standard design. The manufacturers contacted were reluctant to provide a budget price for larger, custom units without more design information. Larger units would be custom designed and site constructed, but total cost would be within the range generally used in this estimate. Assuming a 30± and 10± minute operating detention time, both raw and treated water storage reservoirs would be included as part of the treatment system. We have typically experienced a 90-95 percent plus operating factor for commercial RO units of good quality (major manufacturers). Normal down time is related to scheduled membrane cleaning and preventative maintenance. Figure 1 provides a typical schematic diagram of the system proposed. Each alternative flow would have a multiple of 1,000 gpm RO units as shown on Table 2. This approach assumes that the system could be staged and increased in 2,000 gpm units.

Significant electrical power for the treatment equipment and ancillary facilities will be required. We have assumed that reliable commercial power is available. No study has been undertaken to confirm this assumption at the mine site.

Figure 1 provides a conceptual plan of the proposed treatment facility. Groundwater would be pumped from wells to a head tank where the pH would be adjusted to 6.5±. If the total suspended solids (TSS) were low in the feed water (<5 mg/l) no additional pretreatment would be required. Filtration by pressure

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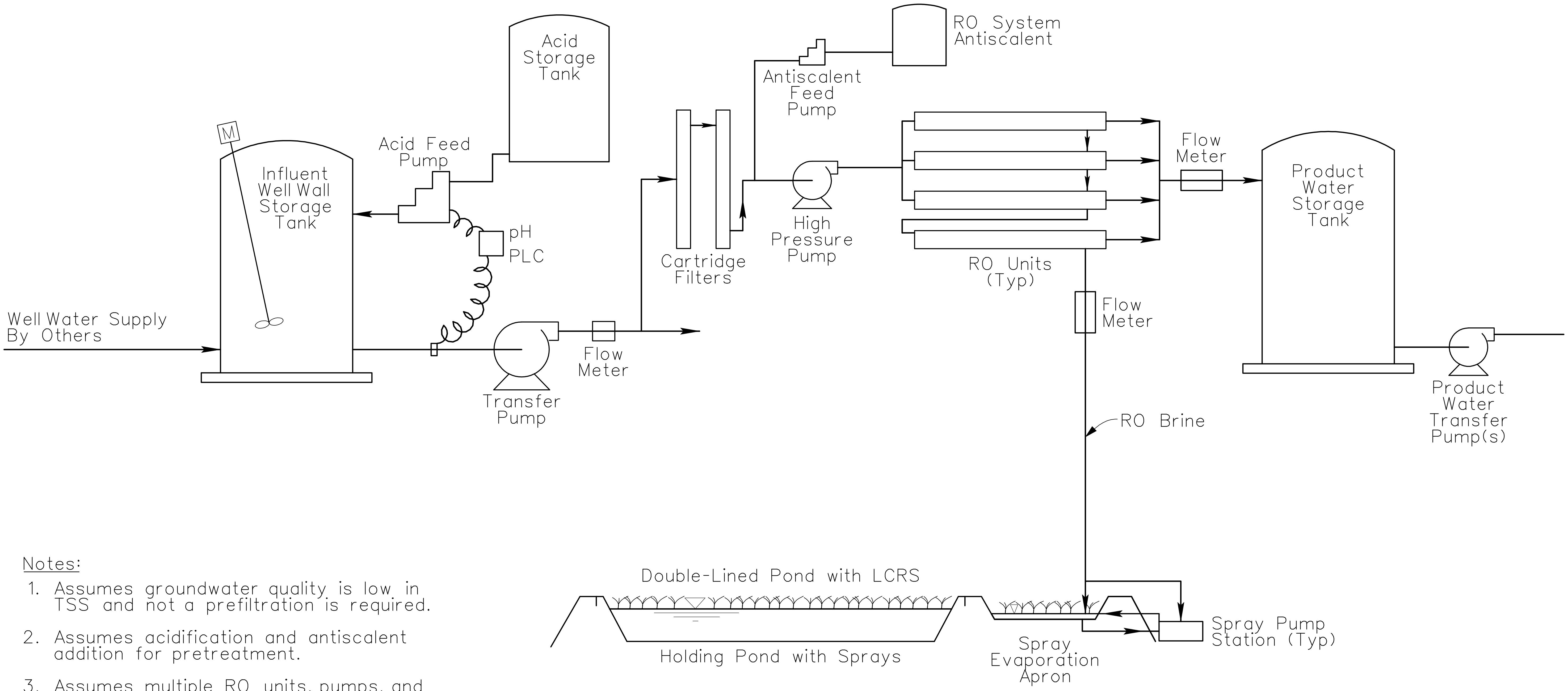

Enhanced Evaporation Pond Cell (Typ)

Notes:

1. Assumes groundwater quality is low in TSS and not a prefiltration is required.
2. Assumes acidification and antiscalent addition for pretreatment.
3. Assumes multiple RO units, pumps, and evaporation cells.
4. Assumes no product water pH adjustment required.

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Sierrita Mine Ground Water
Treatment Project
Schematic Diagram
Figure 1

media filters using FRP filter units would be recommended if TSS treatment of the well water is required prior to RO.

The pH adjusted water would be pumped to the individual RO systems by booster pump. Each 1,000 gpm feed water unit would be sized to provide approximately 750 gpm of product water. The anticipated product recovery is in the 70-80 percent range. This will need to be confirmed by empirical testing. The feed water would pass through fine cartridge filter(s) (5-10µ) and an antiscalent solution will be added to reduce salt accumulation (scale) on the brine side of the membrane units. This will prolong membrane life and reduce the necessity for frequent cleaning of the membranes. Specialized antiscalents are available for higher calcium sulfate water to reduce scaling. Additional analysis and bench and possibly pilot scale testing would need to be completed to assess the need for and value of additional pretreatment.

The feed pressure in the RO units is boosted by the high pressure RO pump and water is forced through the membranes separating fine particulate and the dissolved ions (salts) into a concentrated brine and a high quality product (fresh) water. The brine will require final disposal. The RO filtration process involves several (2 to 3) separate internal separation steps that are designed to maximize recovered water flow (flux), provide a high quality (low salt concentration) water and save energy. The balance between flow (membrane flux rate) and quality is a critical factor in the development of an effective membrane separation system.

The product water (fresh water) can be neutralized with caustic or lime slurry in a permeate storage tank if it is necessary to raise the pH to neutral conditions prior to discharge. Post treatment costs were not included in our estimates.

4.0 RESIDUAL MANAGEMENT OPTIONS CONSIDERED AND SCREENED

The major concern with most membrane separation treatment facilities involves not only the operation of the RO equipment and production of a final, high quality, product water but the disposal of the concentrated brine. Typically desalination (sea water treatment) brine can be discharged back to the ocean or to an estuarine location. Inland treatment facilities pose much more complicated problems both in reducing the volume of brine and its final disposal.

There are several methods for brine disposal. These include:

- Pond Solar Evaluation and Pond and Spray Solar Evaporation
- Thermal/Mechanical Evaporation
- Deep Well Injection
- Evaporation in Existing Mine Pit After Mining is Completed

Generally in the United States, deep well injection of brines and other high TDS fluids will not be accepted if it adversely affects the capacity or quality of the aquifer. Typically an aquifer with a TDS greater than 10,000 mg/l might be permitted and acceptable for disposal of brine in some instances (no beneficial use or in coastal environments). However, in some states, a disposal aquifer may need to have high TDS concentrations between (20,000 and 25,000 mg/l) before it would be considered for disposal based upon state and federal regulations. Basically the aquifer must have little or no municipal, agricultural or industrial beneficial use. It would warrant further investigation as to the acceptability of the local deep aquifers to determine if any injection program would be permittable. This could significantly reduce capital and operation cost. This level of investigation was beyond the scope of this study.

We have no specific information regarding water quality in deep aquifers in the Sierrita Mine area. As a result, this option will not be considered further herein.

Brine from water treatment could be discharged to the existing mine pit after mining is completed. The potential for the mine pit to continue to be a hydraulic sink even after the discharge of brine from a potential water treatment system is evaluated separately in Appendix E to the Feasibility Study.

The other options involve the evaporation of the brine concentrate. We would, at this point, not consider any additional chemical or physical treatment for this flow to harvest salts or further concentrate the brine.

Evaporation of water requires that energy be applied to the water in an amount which equals or exceeds the enthalpy of vaporization of the water at a given pressure. Application of this energy goes first to raising the temperature of the water toward the boiling point and second to converting the liquid to a saturated vapor. Pond evaporation provides a passive solar method to vaporize water. Utilizing a spray system enhances this process by adding mechanical and solar energy. Various techniques including dryers and falling- or rising-film evaporators and active solar heating also can be employed for transferring energy directly to the water (i.e., heating). Due to process inefficiencies, the amount of energy required by these techniques will typically exceed the theoretical amount of energy needed to convert water to vapor.

Several issues must be examined in the selection of evaporation system. The composition of the water is a concern due to scaling and corrosion problems which can develop as water is evaporated and the solubility limits of salts are exceeded. These problems can be avoided by specifying the proper materials of construction and/or keeping the solution strength of the evaporated stream below the solubility limits of the salts in solution. For example, evaporating 100 gpm of a 112 gpm stream at a concentration of 5,000 ppm (0.5% solids) would produce a discharge stream of 12 gpm at a concentration of 50,000 ppm (5% solids). The corrosiveness or scaling potential of the actual evaporated (concentrated) solution would require characterization. If corrosion and/or scaling can be avoided, this will allow for capital costs of evaporation equipment to be based on less expensive materials of construction.

Additional considerations in the selection of evaporation equipment include efficiency and energy consumption, reliability, turn-down, and maintenance. With respect to efficiency and energy consumption, falling/rising film evaporators could be expected to require much less energy than dryers due to better heat transfer capabilities. One manufacturer indicated that dryers would require from ten to fifteen times more energy than falling film or other types of evaporators to remove the same amount of water. Given the volume of water and power cost at the Sierrita site, dryers (crystalizers) do not appear to be a feasible alternative due to the extremely high energy use. With respect to the remaining options, falling/rising film evaporators or variation of this type of mechanical heat transfer equipment can accommodate a wide range of flows and are considered reasonably reliable (per statement by manufacturers). Maintenance, however, could be an issue as these units would require an annual servicing and monitoring on a daily basis.

Both falling- and rising-film evaporators operate by passing films of water through tubes that are in contact with saturated steam on the other side. Steam can be maintained in the evaporator via a boiler system or mechanical vapor re-compression. In the absence of an available steam supply, mechanical vapor re-compression is the preferred method due to lower capital and operating costs. This method requires an initial source of steam but substitutes the need for a boiler and associated equipment with a positive displacement compressor and equipment. Additional components of this system typically include a recirculation pump, a heat exchanger, a deaerator, controls, and piping.

4.1 Active Brine Evaporation

We evaluated several methods of improved RO brine residual water management. Of the systems considered the following were given consideration:

- Solar heating of one or more ponds to improve evaporation
- Mechanical/combustion evaporators
- Cogeneration of electricity collection of waste heat to an enhanced spray pond evaporation

None of these options can realistically result in the complete elimination of the RO concentrate or final drying out of storage ponds except for mechanical thermal evaporation (crystallization). They can however, reduce the volumes and provide a more managed water balance and work in concert with the natural evaporation rates. While there are numerous approaches to using heat to reduce water volume for this initial preliminary assessment, we considered only these limited options.

A brief analysis of the potential to use active solar technology (enhanced solar collectors) for essentially heating of an evaporation pond(s) was prepared by a third party proposing to market their technology for brine evaporation. Their initial analysis was for a relatively small unit capable of heating brine/pond water and evaporating 100 gpm on an annualized basis. They indicated that the capital cost would be in excess of $2,800,000 and the operating expense would be on the order of $150,000 per year (including pumping and solar collector panel maintenance). Scaling these costs up would indicate the following for the Sierrita options.

Options	Capital Cost	Operation and Maintenance Cost
2,000 gpm	$14,000,000	$750,000
4,000 gpm	$28,000,000	$1,500,000
6,000 gpm	$42,000,000	$2,250,000

This appears to be very costly and while the technology is relatively simple (solar panels) and the reliance on the sun, as the energy source, makes this an interesting approach.

A similar exercise (100 gpm evaporation) prepared by a manufacturer of mechanical/thermal evaporators indicates that the capital installed cost for this system would be approximately $3,200,000. Estimates of the power requirements for 100 gpm evaporators ranged from 150 hp (112 kilowatts (kW)) to 180 hp (135 kW). Assuming a power cost of $0.10 per kW-hour, the yearly power cost of the 100 gpm evaporators could range up to $1,260,000. The costs for evaporation are based on the assumption of production at 24 hours per day for 365 days per year.

For the Sierrita options, the scaled-up cost for thermal/mechanical evaporation would be on the order of the following.

Options	Capital Cost	Operation and Maintenance Cost
2,000 gpm	$16,000,000	$6,300,000
4,000 gpm	$32,000,000	$12,600,000
6,000 gpm	$48,000,000	$18,900,000

While these costs were based upon smaller units and scaled up to evaluate the Sierrita project, these are representative of the typical costs for equipment for these systems without installation, site engineering, etc. The very high operations cost of the thermal/mechanical system would indicate that this is impractical at this scale of project, unless a waste heat source were available (unlikely), or if there were a byproduct (salts) to recover. We will not consider this option further. Enhanced solar evaporation does appear to be a potential for brine management and could be considered in more detail if this project were to be taken to the next level of planning.

4.2 Passive Brine Evaporation

We would, however, consider the use of shallow ponds to provide passive solar evaporation with and without surface aeration (sprays). For example, at an evaporation rate of 47.1 gallons per year per square foot of pond surface (75% of a class A evaporative pan rate of 100 inches per year for Sierrita area), a 130 acre pond would be required for every 500 gpm (2,000 gpm Sierrita Option) of brine produced. If aeration (sprays) were included, the evaporation rate may be as high as 140 gallons per year per square foot (45 acres/500 gpm). The capital cost of a 500 gpm passive solar pond would be approximately \$20,000,000 (@ \$3.10 ft^2 for double-lined pond construction) and the annual operation cost and liner maintenance would be about \$90,000. The spray pond option for 500 gpm would have a capital cost of approximately \$10,800,000 (45 acres at \$5.50 ft^2) and the annual operation cost (pumping and pond maintenance) would be on the order of \$800,000 - \$1,000,000 at \$0.10 kWH. These are order of magnitude cost that will be refined in a later section of this document.

4.3 Cogeneration Waste Heat Evaporation Option

Another option we investigated was cogeneration. Electrical power would be produced using micro turbine technology. The waste heat from the turbines would be used to raise the water temperature of the brine to increase the evaporation rate. Based upon turbine manufacturer's claim, a 60 kW turbine generator will generate enough waste heat to raise the temperature of 40 gpm of water approximately 40°F (efficiencies not included). For example, to raise the temperature of say 150 gpm of brine 40°F (50°F to 90°F) would require approximately four to five 60 kW turbine units. This system would produce approximately 240 - 300 kW which is approximately enough to partially run only one of the proposed RO units. The effect on evaporation by spraying this heated water would vary with the ambient temperature and other climate conditions. Literature value indicates an increase of 10 times ambient (approximately 2%) pan evaporation can be expected from a 50°F to 90°F increase in water temperature. The actual water evaporative loss expected would require more evaluation but an even 25% or greater increase in total evaporative loss would begin to reclaim a significant pond volume. The actual rate of enhanced evaporation loss would have to be modeled in more detail.

The micro turbine systems are commercially available in factory assembled units with integral heat exchangers. A four-unit turbine array with a single heat exchanger (15 to 200 gpm of water flow) would have an installed capital cost of approximately \$900,000. The annual operating cost using natural gas in the Sierrita area would be approximately \$140,000 (assume \$0.35 therm). This operating would be offset by the production of approximately 5,800 kWH/day or \$210,000 (@\$0.10 kWH) of electrical power.

A 12 turbine unit array (720 kW) capable of heating 500 gpm would have capital cost of approximately \$2,000,000 and a natural gas cost of approximately \$330,000 per year. The offset electrical generation value would be approximately \$630,000 which could keep supply the energy requirements of the entire water treatment plant. However, this option would only increase the pond evaporation rate and the evaporation pond would still be required.

We have reviewed the micro turbine option for several similar projects where power generation was necessary and concluded that the system is very energy intensive, requires a significant natural gas supply and has a number of mechanical operability (maintenance and replacement) and reliability concerns. It will therefore not be considered further.

4.4 RO Residual Management Summary

In addition to brine disposal in the mine pit, pond evaporation and spray assisted pond evaporation with a spray system is the most likely and cost-effective candidate for brine management and disposal given the large amount of brine expected. While it may be possible to improve the membrane recovery of product water to as much as 80 percent, it would still result in a significant production of brine concentrate flow for all of the three inflow options.

5.0 PROPOSED CONCEPTUAL WATER TREATMENT SYSTEM

5.1 Treatment Using RO Membrane Separation

Based upon the foregoing information, the following water treatment option appears to be the best apparent option for treating groundwater downgradient of the tailing impoundment.

- Chemical pH adjustment, cartridge filtration and antiscalent addition
- Ultrafiltration using low pressure RO membranes
- Brine management through discharge to the mine pit, or
- Pond evaporation with and without mechanical sprays and/or other passive heat collecting systems

This assumes that the groundwater is low in suspended solids (particulates) and that prefiltration is not required and that calcium and sulfate scaling can be controlled by acidification and antiscalent addition. Bench and pilot scale testing will be required to determine potential recovery rates (product flux rates), scaling factors and membrane cleaning effectiveness. If suspended solids or scaling are problematic, then additional pretreatment prior to membrane filtration will be warranted.

For conceptual design purposes, we have selected a low pressure (brackish water) membrane system. For estimating purposes, a basic 1,000 gpm feed flow RO unit was used to develop the three options. Each option will have the capacity to treat the required influent flow (2,000, 4,000 or 6,000 gpm) and have one additional unit in standby to accommodate periodic cleaning without diminishing the total system capacity. The treatment system may not require this level of redundancy but for comparative purposes, all alternatives have been treated similarly. The approach we have selected would accommodate an implementation of the project on a phased development schedule that would allow expansion from 2,000 gpm to 6,000 gpm.

The treatment system will include a raw well water storage tank, pH adjustment at the tank, multiple low pressure RO units that includes a cartridge filter, antiscalent injection, high pressure pump 300 – 400 psi, a two-stage membrane array and a product water tank.

The membrane treatment system itself is generally straight forward and would include a 3, 5 or 7 separate RO skid units of 1,000 gpm each. In actual design, this may be modified if a 6,000 gpm system (ultimate) design were installed initially. For example four 2,000 gpm custom onsite built units may have a cost advantage over seven standardized 1,000 gpm units.

The 1,000 gpm unit would include 318 first-stage and 207 second-stage pressure vessel (approximately 530 RO elements. The cartridge filter array would consist of 3 – 4 separate units using 5 – 10 µ filter elements. Prior to the high pressure pump intake antiscalent would be injected to prevent calcium and iron scale formation on the concentrate side of the membranes. In high calcium sulfate waters this can be a problem. Gypsum ($CaSO_4$-$2H_2O$) formation can be very difficult to remove and can blind the membranes in such a manner that cleaning becomes very ineffective. The use of acid (pH 6.5±) and antiscalent addition would be expected to prolong membrane efficiency, but for a project of this size pilot testing on the actual water source is warranted in order to develop accurate design criteria and better understand operational issues. If calcium fouling was to prove to be a problem the influent water would need to be softened to remove the calcium using caustic or lime, settled to separate the calcium carbonate settable solids and filtered to remove the nonsettleable solids. This level of pretreatment would significantly increase not only the capital cost but would involve long-term operating costs for chemical consumption and solid/sludge disposal.

The question of when pretreatment is best used will depend upon the chemistry of the water. In a similar groundwater project the pilot study indicated that the high calcium and sulfate concentrations (230 – 2,300 mg/l, respectively) may not significantly impact membrane cleaning, but it was decided to remove the calcium (lime softening) in order to prolong operating periods, membrane life and reduce cleaning frequency. This project has been in operation over eight years and has been able to achieve much longer than originally projected membrane life by diligent pretreatment (5± years). However, on another recent project with higher calcium and sulfate concentration (350 and 2,600 mg/l, respectively), the membrane system has appeared to operate effectively using acidification and antiscalent alone for over 12 months. The long-term operation is still an issue that needs to be better defined.

We would assume that this project may need to be operated for an extended period of time. Since longevity is important, we will assume that the building to house the treatment system will be durable. Masonry or concrete construction will have a longer functional life than a pre-engineered metal structure. The difference in cost between a steel joist metal roof concrete/masonry construction and a metal building will be on the order of $\$50/\mathrm{ft}^2$. The estimate building sizes for the three options using cement masonry units (CMU) construction with a metal joist and roof would be as shown below using $\$170/\mathrm{ft}^2$.

2,000 gpm	$\$680,000$ @ 4,000 ft^2
4,000 gpm	$\$1,360,000$ @ 8,000 ft^2
6,000 gpm	$\$2,040,000$ @ 12,000 ft^2

These are the installation costs of slab on grade CMU building construction alone without electrical, heating ventilation and air conditioning (HVAC) or contractor mark-up, engineering and contingencies.

The treatment system will require significant electrical power. Based upon the conceptual design, the power requirements will include the RO high pressure pump, the building demands (lights, chemical pumping, etc.) and miscellaneous power requirements. We have assumed that a new primary voltage transformer would be required for primary service. No cost for primary power lines has been included. However, if required, a new primary electrical service for this type of system will be on the order of $750,000 – $1,000,000 per mile depending on terrain.

We would also include a final product storage tank (10 minutes hydraulic detention time) as the location for the finished water prior to discharge. Table 3 presents the conceptual treatment design criteria for the three flow options. Figure 1 provides a conceptual schematic diagram.

TABLE 3

SIERRITA WATER TREATMENT
CONCEPTUAL DESIGN CRITERIA

Parameter	Unit	Option (gpm) 2,000	 4,000	 6,000
Influent Storage Total (30 min.)	Gallon	60,000	120,000	18,000
Construction	Type	Poly or Steel	Steel/Conc.	Conc./Steel
Transfer Pumps				
Number	No.	3	5	7
Flow (ea)	gpm	1,000	1,000	1,000
HP (ea)	HP	75	75	75
Cartridge Filter Unit				
Number (each RO unit)	No.	2 - 3	2 - 3	2 - 3
Size	µm	5 – 10	5 – 10	5 – 10
RO Units				
Size Influent	gpm	1,000	1,000	2,000
Number	No.	3	5	7
HP Pumping (ea)	HP	200	200	200
VFD*	Yes/No	Yes	Yes	Yes
Antiscalent Unit (ea)	No.	1	1+	1+
Product Water Storage	Gallon	15,000	30,000	45,000
Construction	Type	Poly/FRP	FRP/Steel	Steel/Conc.

* Variable frequency driver

5.2 Brine Disposal

The disposal of concentrated brine in an inland location can be a difficult issue for providing a reliable engineered solution. As discussed, mechanical or thermal evaporation of brine at the scale and volume being considered for this project will be very expensive from both a capital and operations and maintenances (O&M) prospective. It would not appear to be practical to attempt to operate or maintain a thermal evaporation system to dispose of 720,000 to 2,160,000 mgd of brine to dryness at an estimated energy cost alone of almost $24.00 per 1,000 gallons ($24,000 per mgd) at today's energy prices. The future cost of energy is expected to continue to increase.

Brine could be cost effectively managed through discharge to the pit or through pond evaporation. Pond evaporation can be operated as static shallow ponds that rely on pan evaporation or as spray assisted evaporation ponds. Spray ponds can use a variety of mechanical means to increase the surface area of the water by forming droplets to attempt to accelerate solar and wind evaporation. This can be accomplished with surface mechanical aerators/agitators, surface spray systems using pumps and a network of nozzles and systems that combine high volume fans or compressed air and pump and nozzle arrangement (a.k.a. snow-making equipment). We have assumed that all facilities would be located on the mine site where there is sufficient land area, electrical power and company infrastructure to provide effective operations.

During the operation of an evaporation spray pond only a small fraction of the sprayed water is actually evaporated. In theory, only approximately 1% of the spray water can be evaporated for each 10°F drop in water temperature. In spray evaporation ponds, specifically designed for evaporating water, the same water is continually resprayed until the bulk of the water has been evaporated, leaving behind a concentrated brine high solids sludge. In theory, an acceptable evaporation rate is dependent on maintaining a significant difference between the pond water temperature and the wet bulb temperature of the environment. The actual efficiency of the evaporation pond hinges on a proper pond location and layout, wet bulb temperature, prevailing wind conditions, pond construction, spray nozzles, spraying pressure, and water temperature.

Any water spraying operation produces cooler water temperatures in the spray: continuous respraying of the same water will result in a cooled pond water temperature that can eventually approach the wet bulb temperature; and evaporation rates will be reduced significantly. At this point, if evaporation is to continue, the heat for evaporation must come from the water individual spray droplets and the ambient air temperature gain, which can supply only minimal amount of heat. Therefore, in spray evaporation ponds, external heat applied by solar radiation or other sources to the water, is necessary in order to maintain an actual water temperature higher than the wet bulb temperature. To enhance the solar heating effect, the pond should be shallow (to provide a larger heat loading water surface area) and have a layer of black, heat absorbing material coating the bottom of the pond. Adding a dark dye to the water to enhance adsorption of solar radiation (heat) has also been advocated.

As discussed earlier, increasing the water temperature with external heat exchanger equipment, possibly using hot wastewater from a fuel fired electrical generator or other salvage heat sources would also have a constructive effect on increasing the evaporation rate. We have not assumed that any auxiliary source of thermal heat is available.

It is difficult to generalize on the expected performance characteristics of an evaporative spray pond because the continuous respraying increases the solids concentration in the water which can affect the flow and the efficiency of the spray characteristics of the system. Each application would have its individual cooling/evaporation process characteristics which depend on atmospheric conditions, location, and the design and operation of the spray system and the operation of the system.

Since the purposes of the spraying is to obtain a maximum evaporative effect, factors such as smaller spray droplet sizes (by using smaller capacity nozzles and/or higher pressures), and longer spray droplet dwell (air suspension) times (by using higher pressure and/or by positioning the nozzles higher above the pond level), can also improve the evaporation rate.

It takes a considerable amount of heat to evaporate water. To evaporate one pound of water it requires 1,000 lbs. of water losing 1°F or 100 pounds of water losing 10°F. Evaporating 1% of the total inventory water being sprayed can cool the spray water by 10°F.

As discussed, continued respraying of the same water would eventually bring the pond water temperature down to a point that approaches the wet bulb temperature. Under these conditions the necessary heat for evaporation must come from the environment or other sources (artificial or natural). Since, in reality, the surrounding air environment can supply very little instantaneous heat to the droplets, external sources such as solar heat, or heat transfer equipment, would be desirable to maintain a relatively warm water temperature in the pond.

Most current spray evaporation systems rely on relatively deep (10 ft±) storage-style ponds, that have marginal to poor spray efficiency and little actual ambient daily heat gain. Increasing spray water temperature is the only parameter that will significantly improve actual evaporation. For example, in theory if the water being sprayed is continually heated to 20°F above the spray-cooled water temperature, to provide a 2% evaporation rate, it would take about 115 spray cycles to evaporate 90% of the water. If an 80°F water temperature difference (spray vs. pond) could be maintained, to provide an 8% actual evaporation rate, only about 30 spray cycles would be required to evaporate 90% of the water.

To aid this water evaporation process, it is useful to remove the vapors efficiently by providing for air replacement using the prevailing wind to best advantage. Therefore, the long side of the spray pond should be perpendicular to the prevailing wind direction. Most current systems in use at mines are designed primarily for water storage, not evaporation, and are typically square and not wind effective. However, significant wind drift loss of water (no evaporation) does occur which is often evidenced by the surrounding building of salts on the ground.

While it is possible to theoretically estimate evaporative loss for a spray pond it is an imprecise calculation. For example, it is theoretically possible to evaporate 200 gpm if the following southwest conditions were assumed:

1. Wet bulb temperature (summer average) 75°F
2. Dry bulb temperature (summer average) 85°F
3. Difference 10°F
4. 70% cooling efficiency (10°F) x 0.7 = 7°F
5. 1.0% evaporative loss per 10°F (0.001 rate/1 F° drop) 7°F x 0.001 = 0.007% of water sprayed
6. Therefore to evaporate 200 gpm under these conditions over 28,500 gpm of water would have to be continually pumped.

   200 gpm loss = 28,751 gpm
   (0.007 loss factor)

In theory at a spray pressure of 40 psi, this would require an installed pumping horsepower of over 95 hp. However, this is a theoretical calculation and most systems we have seen do much better for a variety of reasons. For example, a system in central New Mexico (similar to Sierrita) can dispose of 200 gpm (annualized) using approximately 400 hp (including pan losses).

Based upon U.S. Geological Survey (USGS) historic information, the general Tucson area annual pan evaporation rate is approximately 110 inches a year (23 years of record) while the annual mean precipitation rate is 11.2 inches a year (11 years or record). This provides approximately 100 inches/year of total net evaporation. Assuming the 100 inches/year is a suitable pan evaporation rate, this equates to approximately 5.17 gpm/acre on an annualized basis.

The following pond surface area would be required to meet the pan evaporation requirements of the RO brine disregarding ionic concentration effects (total evaporation is impractical), wind drift and other factors.

RO Option Flow	Projected* Brine Flow (gpm)	Pond Area Requirements (acres)
2,000 gpm	500	96.7
4,000 gpm	1,000	193.4
6,000 gpm	1,500	290.1

*@75% recovery

The addition of a spray system could reduce that area significantly.

Using the theoretical spray loss formula above, the following total evaporative loss (impractical as indicated) can be derived to evaporate the full brine flow produced by the three options.

RO Option	Project Brine	Spray* Pond Rate (gpm)	HP Required @ 40** psi (92.3 ft)
2,000 gpm	500	71,428	2,380
4,000 gpm	1,000	142,854	4,761
6,000 gpm	1,500	214,286	7,140

*Derived from example 0.007 loss factor
**Assumes ±20% friction losses – 111 ft head and 75% pump efficiency

Assuming $0.10 kWH, the following energy cost would be associated with the theoretical evaporation of the total brine flow for the three options.

RO Option	Projected kWH/day	$* Cost/Day	$* Cost/Year
2,000 gpm	42,840	$4,284	$1,563,660
4,000 gpm	85,680	$8,568	$3,127,320
6,000 gpm	12,852	$12,852	$4,690,980

*$0.10/KWH – 24 hr/7-day

While these are all very theoretical values and would be subject to actual field conditions, they are used to demonstrate the significance of the operating cost on a project of this magnitude and the necessity to balance the use of available pond (pan) evaporation rates with enhanced spray effects. A combination of the two methods that can take advantage of specific site condition (significant wet bulb/dry bulb differences, site climatic conditions, design, etc.) would be the most cost effective method to manage brine inventory in a pond.

The cost of shallow (heat gaining) holding/evaporation ponds for this type of system are typically not inexpensive. We would assume that a double membrane lined (flexible polyethylene membrane liner or similar) pond with a leach collection and recovery systems (LCRS) will be required by the regulators. Estimating the balance between having a large evaporation pond and installing a spray system is not an intuitive exercise. Weather conditions can change and enough storage needs to be provided to insure that the treatment system can continue to operate under less than ideal evaporation conditions. For planning purposes we have assumed that 60 percent of the evaporation can be achieved from pond (pan) evaporation and 40 percent is derived from a spray system. The systems would be separate (an intensive spray area and a deeper pond) but connected to prevent the intensive spray system from interfering with the pond system solar evaporation. We have also assumed that the ponds will need to contain storage for at least 3 - 6 months of RO brine if no evaporation were to occur, and that the pond would have a spray system over the entire surface to take advantage of warmer air temperatures. The validity of this assumption needs to be discussed.

Table 4 provides an evaluation of the brine evaporation balance for the RO brine for each of the options.

TABLE 4

RO BRINE EVAPORATION BALANCE POND SURFACE AREA/SPRAY
Sierrita Mine

Option (gpm)	**2,000**	**4,000**	**6,000**
Total Brine (gpm)	500	1,000	1,500
Pond Evaporation (gpm)	300	600	900
Spray evaporation (gpm)	200	400	600
Pond Surface Area (acres)	58	116	174
Spray (HP)**	1,068	2,137	3,206
Pond volume @ 8'* (million gallons)	151	302	453
3-Month RO Storage required (million gallons)	134	268	402

*8-ft depth is assumed
**Based on calculation

Table 5 presents an evaluation of the proposed enhanced pond evaporation on a monthly basis, assuming the pan evaporation rates are shown from the USGS data for the area (net evaporation – precipitation – evaporation). As shown, the 60:40 split between pan and spray evaporation are about balanced (4 – 5 million gallons annual excess) and any excess would be taken up by the enhanced spray.

Table 6 provides the monthly storage information and pond sizes for a passive solar evaporation pond designed to satisfy the three flow options.

TABLE 5

ENHANCED POND EVAPORATION WITH SPRAY SYSTEM

Evaluation of Evaporation Rates vs. Pond Size

Assume 300 GPM To Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/ 58 Acres Gal/Month	58 acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	58 acres Evap-Waste Gal/Month
January	3.42	2.08	5,389,659	92,925	300	13,392,000	-8,002,341
February	4.27	2.60	6,077,982	104,793	300	13,392,000	-7,314,018
March	6.78	4.13	10,684,763	184,220	300	13,392,000	-2,707,237
April	10.34	6.29	15,769,405	271,886	300	13,392,000	2,377,405
May	14.04	8.55	22,125,970	381,482	300	13,392,000	8,733,970
June	16.23	9.88	24,752,171	426,762	300	13,392,000	11,360,171
July	13.1	7.97	20,644,602	355,941	300	13,392,000	7,252,602
August	9.57	5.82	15,081,591	260,027	300	13,392,000	1,689,591
September	9.5	5.78	14,488,332	249,799	300	13,392,000	1,096,332
October	6.87	4.18	10,826,597	186,665	300	13,392,000	-2,565,403
November	4.1	2.50	6,252,859	107,808	300	13,392,000	-7,139,141
December	2.31	1.41	3,640,384	62,765	300	13,392,000	-9,751,616
YEARLY	100.53	5.20	155,734,315			160,704,000	-4,969,685

Assume 600 GPM To Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/116 Acres Gal/Month	116 acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	116 acres Evap-Waste Gal/Month
January	3.42	2.08	10,779,319	92,925	600	26,784,000	-16,004,681
February	4.27	2.60	13,458,389	116,021	600	26,784,000	-13,325,611
March	6.78	4.13	21,369,527	184,220	600	26,784,000	-5,414,473
April	10.34	6.29	32,590,104	280,949	600	26,784,000	5,806,104
May	14.04	8.55	44,251,940	381,482	600	26,784,000	17,467,940
June	16.23	9.88	51,154,487	440,987	600	26,784,000	24,370,487
July	13.1	7.97	41,289,204	355,941	600	26,784,000	14,505,204
August	9.57	5.82	30,163,182	260,027	600	26,784,000	3,379,182
September	9.5	5.78	29,942,552	258,125	600	26,784,000	3,158,552
October	6.87	4.18	21,653,193	186,665	600	26,784,000	-5,130,807
November	4.1	2.50	12,922,575	111,402	600	26,784,000	-13,861,425
December	2.31	1.41	7,280,768	62,765	600	26,784,000	-19,503,232
YEARLY	100.53	5.20	316,855,239			321,408,000	-4,552,761

Assume 900 GPM To Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/ 175 Acres Gal/Month	175acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	175 acres Evap-Waste Gal/Month
January	3.42	2.08	16,261,903	92,925	900	40,176,000	-23,914,097
February	4.27	2.60	20,303,604	116,021	900	40,176,000	-19,872,396
March	6.78	4.13	32,238,510	184,220	900	40,176,000	-7,937,490
April	10.34	6.29	49,166,105	280,949	900	40,176,000	8,990,105
May	14.04	8.55	66,759,393	381,482	900	40,176,000	26,583,393
June	16.23	9.88	77,172,717	440,987	900	40,176,000	36,996,717
July	13.1	7.97	62,289,747	355,941	900	40,176,000	22,113,747
August	9.57	5.82	45,504,800	260,027	900	40,176,000	5,328,800
September	9.5	5.78	45,171,954	258,125	900	40,176,000	4,995,954
October	6.87	4.18	32,666,455	186,665	900	40,176,000	-7,509,545
November	4.1	2.50	19,495,264	111,402	900	40,176,000	-20,680,736
December	2.31	1.41	10,983,917	62,765	900	40,176,000	-29,192,083
YEARLY	100.53	5.15	478,014,370			482,112,000	-4,097,630

TABLE 6

PASSIVE POND EVAPORATION
Evaluation of Evaporation Rates vs. Pond Size

Assumes 500 GPM to Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/ 100 Acres Gal/Month	100 acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	100 acres Evap-Waste Gal/Month
January	3.42	2.08	9,292,516	92,925	500	22,320,000	-13,027,484
February	4.27	2.60	11,602,060	116,021	500	22,320,000	-10,717,940
March	6.78	4.13	18,422,006	184,220	500	22,320,000	-3,897,994
April	10.34	6.29	28,094,917	280,949	500	22,320,000	5,774,917
May	14.04	8.55	38,148,224	381,482	500	22,320,000	15,828,224
June	16.23	9.88	44,098,695	440,987	500	22,320,000	21,778,695
July	13.1	7.97	35,594,141	355,941	500	22,320,000	13,274,141
August	9.57	5.82	26,002,743	260,027	500	22,320,000	3,682,743
September	9.5	5.78	25,812,545	258,125	500	22,320,000	3,492,545
October	6.87	4.18	18,666,546	186,665	500	22,320,000	-3,653,454
November	4.1	2.50	11,140,151	111,402	500	22,320,000	-11,179,849
December	2.31	1.41	6,276,524	62,765	500	22,320,000	-16,043,476
YEARLY	100.53	5.20	273,151,068			267,840,000	5,311,068

Assume 1000 GPM To Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/ 200 Acres Gal/Month	200 acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	200 acres Evap-Waste Gal/Month
January	3.42	2.08	18,585,032	92,925	1000	44,640,000	-26,054,968
February	4.27	2.60	23,204,119	116,021	1000	44,640,000	-21,435,881
March	6.78	4.13	36,844,012	184,220	1000	44,640,000	-7,795,988
April	10.34	6.29	56,189,835	280,949	1000	44,640,000	11,549,835
May	14.04	8.55	76,296,449	381,482	1000	44,640,000	31,656,449
June	16.23	9.88	88,197,391	440,987	1000	44,640,000	43,557,391
July	13.1	7.97	71,188,282	355,941	1000	44,640,000	26,548,282
August	9.57	5.82	52,005,485	260,027	1000	44,640,000	7,365,485
September	9.5	5.78	51,625,090	258,125	1000	44,640,000	6,985,090
October	6.87	4.18	37,333,091	186,665	1000	44,640,000	-7,306,909
November	4.1	2.50	22,280,302	111,402	1000	44,640,000	-22,359,698
December	2.31	1.41	12,553,048	62,765	1000	44,640,000	-32,086,952
YEARLY	100.53	5.20	546,302,137			535,680,000	10,622,137

Assume 1500 GPM To Evaporation

Month	EvapRate Inches	Evap Rate Ac GPM/Acre	Evap w/ 300 Acres Gal/Month	300acres Gal/Acre/Mo.	Waste to Evap. GPM	Waste Gal/Month	300 acres Evap-Waste Gal/Month
January	3.42	2.08	27,877,549	92,925	1500	66,960,000	-39,082,451
February	4.27	2.60	34,806,179	116,021	1500	66,960,000	-32,153,821
March	6.78	4.13	55,266,017	184,220	1500	66,960,000	-11,693,983
April	10.34	6.29	84,284,752	280,949	1500	66,960,000	17,324,752
May	14.04	8.55	114,444,673	381,482	1500	66,960,000	47,484,673
June	16.23	9.88	132,296,086	440,987	1500	66,960,000	65,336,086
July	13.1	7.97	106,782,423	355,941	1500	66,960,000	39,822,423
August	9.57	5.82	78,008,228	260,027	1500	66,960,000	11,048,228
September	9.5	5.78	77,437,635	258,125	1500	66,960,000	10,477,635
October	6.87	4.18	55,999,637	186,665	1500	66,960,000	-10,960,363
November	4.1	2.50	33,420,453	111,402	1500	66,960,000	-33,539,547
December	2.31	1.41	18,829,572	62,765	1500	66,960,000	-48,130,428
YEARLY	100.53	5.15	819,453,205			803,520,000	15,933,205

Figure 1 provides a schematic diagram of the general treatment process proposed. Figure 2 provides a plan view and general dimensions of a typical water treatment building and ancillary facilities for the 2,000 gpm option and the layout space for expanding to 4,000 and 6,000 gpm by adding additional building units to the long side of the building.

Figures 3 and 4 provide one concept of a typical design for a high efficiency, enhanced evaporation pond. Multiple units of this concept would be used to meet the total demand.

6.0 OPINION OF PROBABLE CONCEPTUAL PROJECT COST

The cost estimate for the proposed treatment system has been divided into two sections. Section one includes our opinion of capital cost for the water treatment facilities and the enhanced brine storage pond and enhanced evaporation system. The second section will discuss the estimated annual operation maintenance cost for the systems proposed.

Cost estimates for equipment and material are based on recent US quotes and other projects completed by MWH. Labor and civil-work were assumed to be similar to typical historic southwestern United States projects. All costs assume a second quarter 2008 base year. No cost for test or production well drilling or exploration, transportation and freight, spare parts, licenses, permitting, right-of-ways, legal or land costs were included in these conceptual costs. The availability and actual purchase price for commercial electrical power needs to be confirmed. Given that power is a very significant cost (capital and O&M) for the project, determination of the actual power system requirements and purchase price will require careful additional investigation. Accuracy of this opinion of capital and operation costs should be assumed at ±40 percent at this conceptual level of study. The estimated costs can be refined with further design and specific site information.

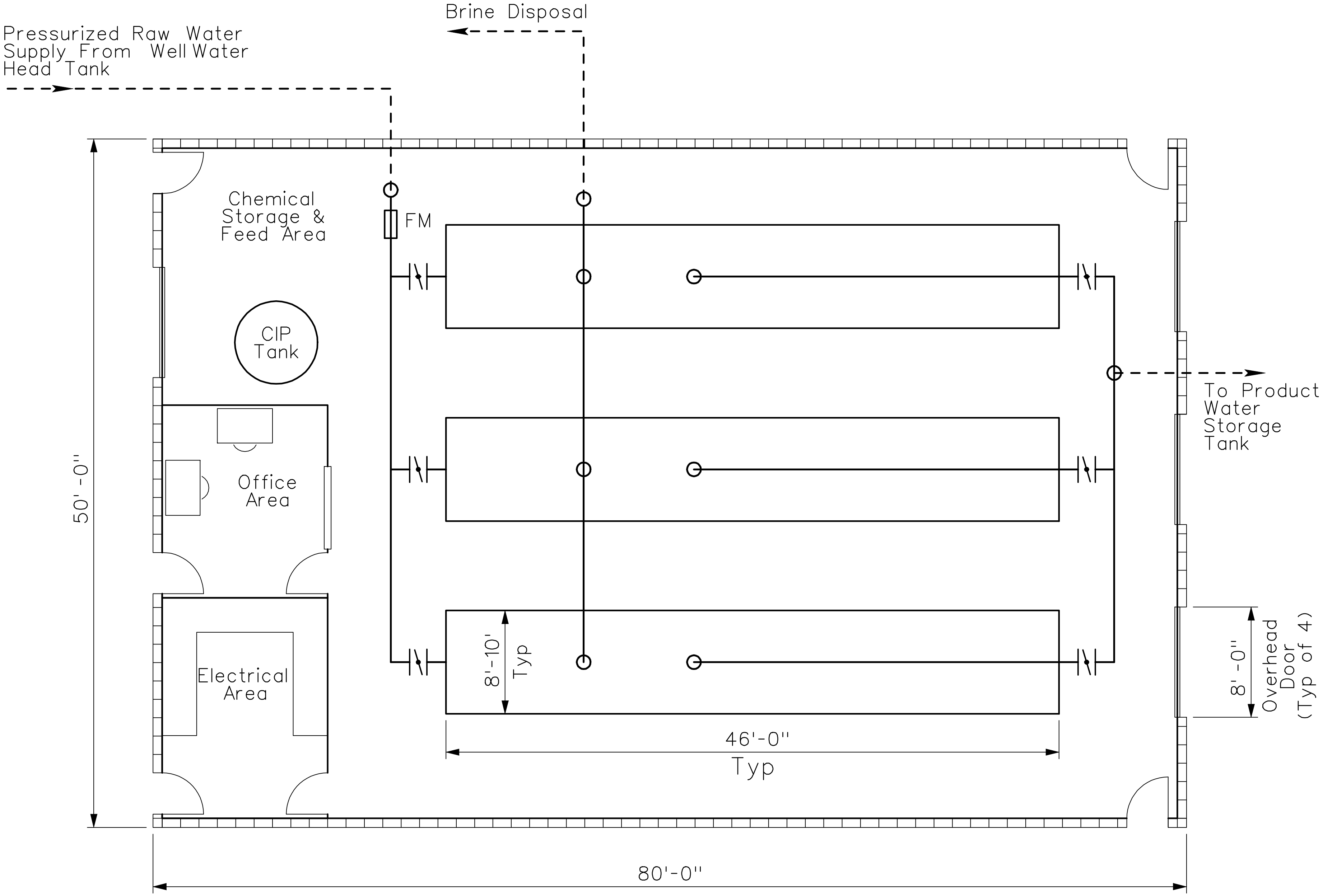
Figure 2 provides a typical building plan layout of the desalination building (80 ft x 50 ft) with three 1,000 gpm (feed) water RO units. This would be typical for the 2,000 gpm influent option. The building (concrete block or metal) would include an electrical room, operators area, and a space for chemical feed and storage. All water and major chemical storage tanks will be located outside the building and be constructed of polypropylene fiberglass reinforced plastic (FRP), concrete, or steel. We have not, at this point, assumed the need for other support buildings, maintenance facilities, residences or ancillary facilities. We have assumed that these facilities will be located at the existing mill site. A new substation/transformer would be located onsite to provide power for the water treatment and primary pumping and a medium voltage supply line will be installed from available commercial line. The building would be expanded in stages or at the initiation of the project to accommodate the 4,000 gpm and 6,000 gpm options.

6.1 Sierrita Mine Groundwater Treatment Opinion of Cost Analysis

Tables 7, 8 and 9 provide our 2008 (fourth quarter) capital cost estimate for the membrane treatment facilities for the three flow options considered.

Tables 10, 11 and 12 present our opinion of operational and maintenance cost for the three flow alternatives.

We have assumed that a new evaporation pond would be required to be built to hazardous material type standards. The use of double containment (2 layers of FML) with a leak detection and containment/recovery system would represent an assumed level required for those facilities have that a hydraulic head in excess of 36 inches (i.e., deeper pond area). A 40-mil underliner (bottom) and an 80



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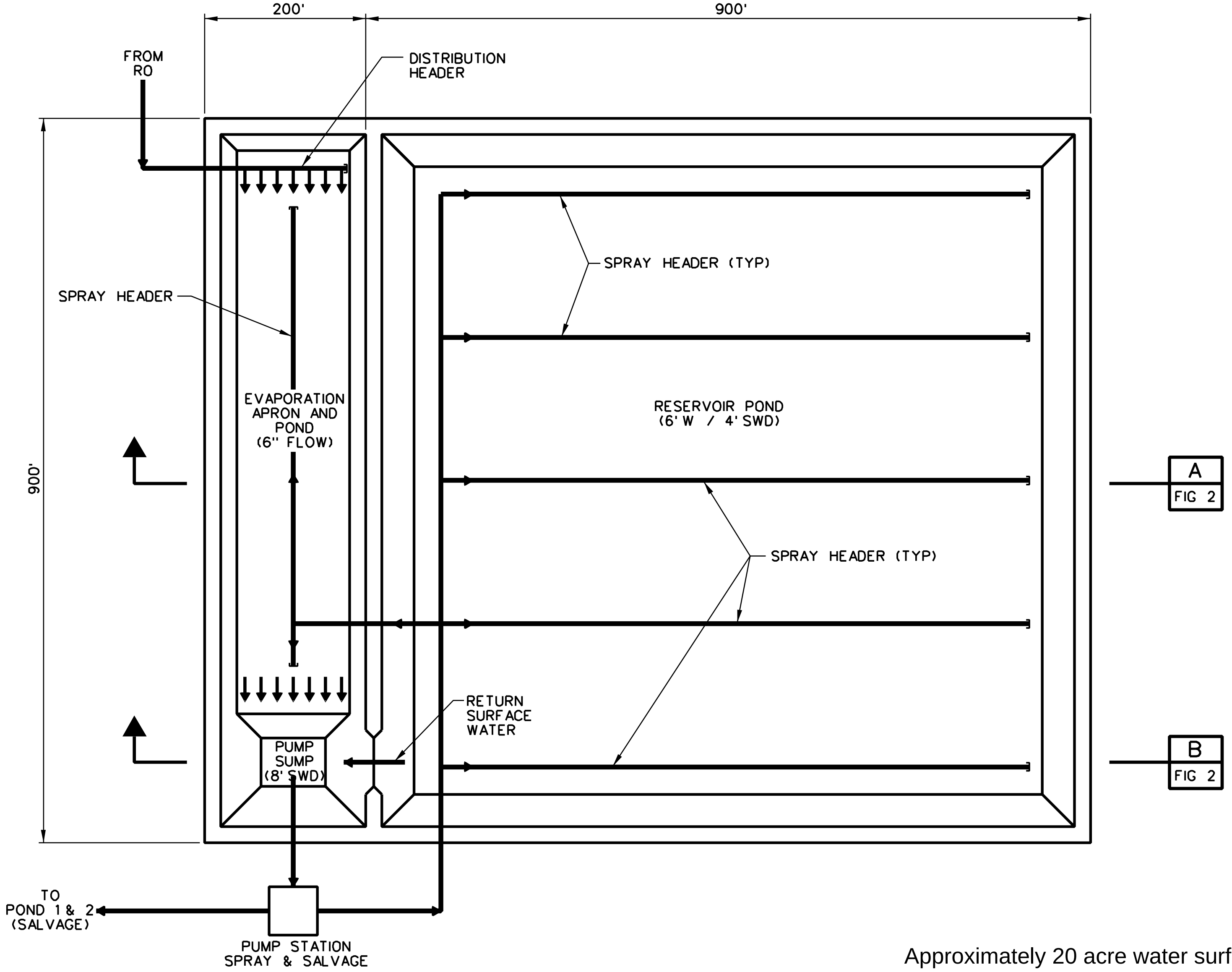
Conceptual Layout 2000 gpm Feed RO Treatment Facility

Figure 2



Approximately 20 acre water surface area unit

MWH

Schematic Layout - Sierrita Enhanced Evaporation Pond System

Figure 3

TABLE 7

ESTIMATED CONCEPTUAL CAPITAL COST OPINION FOR WATER TREATMENT SYSTEM
2,000 gpm Option

	Description	Units	$ Unit Cost	$ Cost
1)	Site Civil Preparation (roads, paving, etc.)	1	LS	$200,000
2)	Raw Water Storage with Mixing (30 min. HDT)	3	60,000	180,000
3)	Acid Storage and Mixing (poly) and Feed Pumps (2)	1	85,000	85,000
4)	Booster Pumping	3	35,000	105,000
5)	Antiscalent Storage and Mixing (2 pumps)	1	40,000	40,000
6)	RO Units, complete (1,000 gpm feed) w/piping, pumps, etc.	3	867,000	2,601,000
7)	Building Piping	LS	80,000	80,000
8)	Permeate Storage with 10 min. HDT	1	60,000	60,000
9)	Brine Disposal Pipeline (off-site treatment plant 1,000 ft)	1	LS	75,000
10)	RO Building (4,000 ft^2) CMU	1	170 ft^2	680,000
11)	CIP System, complete with heater and piping/valves	1	LS	50,000
12)	Yard Piping and Valves (influent to WTP from holding tank)	1	LS	100,000
13)	Site Electrical*	1	LS	516,000
14)	Controls & Instrumentation	1	LS	150,000
15)	Electrical Service**	1	LS	516,000
16)	Miscellaneous	1	LS	100,000
	Subtotal			**$5,538,000**
17)	Contractor OH&P (32%)			1,772,000
18)	Engineering & Admin. (15%)			831,000
	Subtotal			**$8,141,000**
19)	Contingencies (25%)			2,035,000
TOTAL				**$10,176,000**

*Secondary electrical supply estimate
**Site electrical and I&C estimate

TABLE 8

ESTIMATED CONCEPTUAL CAPITAL COST OPINION FOR WATER TREATMENT SYSTEM
4,000 gpm Option

	Description	Units	$ Unit Cost	$ Cost
1)	Site Civil Preparation (roads, paving, etc.)	1	LS	$250,000
2)	Raw Water Storage with Mixing (30 min. HDT)	1	300,000	300,000
3)	Acid Storage and Mixing (poly) and Feed Pumps (2)	1	85,000	85,000
4)	Booster Pumping	5	35,000	175,000
5)	Antiscalent Storage and Mixing	2	40,000	80,000
6)	RO Units, complete (1,000 gpm feed) w/piping, pump, etc.	5	867,000	4,335,000
7)	Building Piping	LS	150,000	150,000
8)	Permeate Storage with 10 min. HDT	1	100,000	100,000
9)	Brine Disposal Pipeline (off-site treatment plant 1,000 ft)	1	LS	95,000
10)	RO Building (8,000 ft^2) CMU	1	170 ft^2	1,360,000
11)	CIP System, complete with heater and piping and valves	1	50,000	50,000
12)	Yard Piping and Valves (influent to WTP from holding tank)	1	LS	100,000
13)	Site Electrical*	1	LS	895,000
14)	Controls & Instrumentation	1	LS	200,000
15)	Electrical Service**	1	LS	895,000
16)	Miscellaneous	1	LS	150,000
	Subtotal			**$9,200,000**
17)	Contractor OH&P (32%)			2,944,000
18)	Engineering & Admin. (15%)			1,380,000
	Subtotal			**$13,524,000**
19)	Contingencies (25%)			3,381,000
TOTAL				**$16,905,000**

*Secondary electrical supply estimate
**Site electrical and I&C estimate

TABLE 9

ESTIMATED CONCEPTUAL CAPITAL COST OPINION FOR WATER TREATMENT SYSTEM
6,000 gpm Option

Description	Units	$ Unit Cost	$ Cost
1) Site Civil Preparation (roads, paving, etc.)	1	LS	$325,000
2) Raw Water Storage with Mixing (30 min. HDT)	1	500,000	500,000
3) Acid Storage and Mixing (poly) and Feed Pumps (2)	1	100,000	100,000
4) Booster Pumping	7	35,000	245,000
5) Antiscalent Storage and Mixing	3	40,000	120,000
6) RO Units, complete (1,000 gpm feed) w/piping, pumps, etc.	7	867,000	6,069,000
7) Building Piping	LS	200,000	200,000
8) Permeate Storage with 10 min. HDT	1	150,000	150,000
9) Brine Disposal Pipeline (off-site to ponds 1,000 ft)	1	LS	115,000
10) RO Building (12,000 ft^2) CMU	1	170 ft^2	2,040,000
11) CIP System, complete with heater and piping and valves	1	50,000	50,000
12) Yard Piping and Valves (influent to WTP from holding tank)	1	LS	150,000
13) Site Electrical*	1	LS	1,269,000
14) Controls & Instrumentation	1	LS	250,000
15) Electrical Service**	1	LS	1,269,000
16) Miscellaneous	1	LS	200,000
Subtotal			**$13,052,000**
17) Contractor OH&P (32%)			4,177,000
18) Engineering & Admin. (15%)			1,958,000
Subtotal			**$19,187,000**
19) Contingencies (25%)			4,767,000
TOTAL			**$23,954,000**

*Secondary electrical supply estimate
**Site electrical and I&C estimate

TABLE 10

ESTIMATE OF ANNUAL OPERATING AND MAINTENANCE COST OPINION FOR GROUNDWATER TREATMENT 2,000 GPM OF RAW WATER OPTION

Description	Units	Unit Price	Cost ($)
Power Cost Utility Power (Treatment)*		$0.10 kWh	
1) Booster Pumping (2 x 100 Hp)	1,248,000 kWh		
2) RO Pumping (2 x 200 Hp)	2,500,000 kWh		
3) Miscellaneous Chemicals	50,000 kWh		
4) CIP	50,000 kWh		
5) Building	26,000 kWh		
Utility Electrical Power Subtotal	3,874,000 kWh		**$387,000**
Chemical (delivery not included)			
6) Acid	42,000 lbs	$0.112/lb	$4,700
7) Antiscalent	25,000 lbs	$0.85/lb	$21,300
Chemical Subtotal			**$26,000**
Membrane Filter Replacement			
8) 42 months Replacement of 540 Membranes @ $600 unit (assumed replacement accrual at 155 units each year)			$93,000
9) Cartridge Filter Replacement 12 x year (57 x 12 x 2)		$6.00/ea	$8,200
			$101,000
Labor			
10) 5 FTUs @$65.00 hour (burdened)			**$676,000**
Miscellaneous			
11) Admin, Laboratory, Engineering, Misc., etc.			**$300,000**
TOTAL			**$1,490,000**

*Assumes 95% operation year-round.

TABLE 11

ESTIMATE OF ANNUAL OPERATING AND MAINTENANCE COST OPINION FOR GROUNDWATER TREATMENT 4,000 GPM OF RAW WATER OPTION

Description	Units	Unit Price	Cost ($)
Power Cost Utility Power (Treatment)*		$0.10 kWh	
1) Booster Pumping (4 x 100 Hp)	2,497,000 kWh		
2) RO Pumping (4 x 200 Hp)	4,993,000 kWh		
3) Miscellaneous Chemicals	75,000 kWh		
4) CIP	75,000 kWh		
5) Building	50,000 kWh		
Utility Electrical Power Subtotal	7,690,000 kWh		**$769,000**
Chemical (delivery not included)			
6) Acid	84,000 lbs	$0.112/lb	$9,400
7) Antiscalent	50,000 lbs	$0.85/lb	$43,000
Chemical Subtotal			**$52,000**
Membrane Replacement			
8) 42 months Replacement of 1,080 Membranes @ $600 unit (assumed replacement accrual at 309 units each year)			$186,000
9) Cartridge Filter Replacement 12 x year (57 x 12 x 4)		$6.00/ea	$16,000
			$202,000
Labor			
10) 5 FTUs @$65.00 hour (burdened)			**$676,000**
Miscellaneous			
11) Admin, Laboratory, Engineering, Misc., etc.			**$350,000**
TOTAL			**$2,049,000**

*Assumes 95% operation year-round.

TABLE 12

ESTIMATE OF ANNUAL OPERATING AND MAINTENANCE COST OPINION FOR GROUNDWATER TREATMENT 6,000 GPM OF RAW WATER OPTION

Description	Units	Unit Price	Cost ($)
Power Cost Utility Power (Treatment)*		$0.10 kWh	
1) Booster Pumping (6 x 100 Hp)	3,745,000 kWh		
2) RO Pumping (6 x 200 Hp)	7,490,000 kWh		
3) Miscellaneous Chemicals	100,000 kWh		
4) CIP	100,000 kWh		
5) Building	75,000 kWh		
Utility Electrical Power Subtotal	11,510,000 kWh		**$1,151,000**
Chemical (delivery not included)			
6) Acid	126,000 lbs	$0.112/lb	$14,000
7) Antiscalent	75,000 lbs	$0.85/lb	$64,000
Chemical Subtotal			**$78,000**
Membrane Replacement			
8) 42 months Replacement of 1,620 Membranes @ $600 unit (assumes replacement accrual at 464 units each year)			$279,000
9) Cartridge Filter Replacement 12 x year (57 x 12 x 6)		$6.00/ea	$25,000
			$304,000
Labor			
10) 5 FTUs @$65.00 hour (burdened)			**$676,000**
Miscellaneous			
11) Admin, Laboratory, Engineering, Misc., etc.			**$375,000**
TOTAL			**$2,584,000**

*Assumes 95% operation year-round.

mil top flexible membrane liner was assumed for costing purposes. A HDPE “Geonet” type leak collection material would be sandwiched between the two liners. The liner would be connected (bonded) on 50-ft. centers and soil anchors installed to prevent wind movement. The maximum average pond operating depth should be maintained below five (5) feet.

The use of enhanced evaporation depends on adding solar or other heat sources to the water to allow more rapid vaporization to occur. Significant heat gain by solar radiation is possible for a thin film flow in the project area. We have proposed a two element pond for the new evaporation system. This would include 1) a heat gaining apron area with intensive spray system including a catchment sump, and 2) a larger shallow storage pond with a pump pack and some spray capability. Water would be sprayed over the apron area and allowed to flow slowly over the apron. This would allow time for solar heat accumulation and surface evaporation. Additional sprays would be added at the end of the apron to take advantage of heat gain. Water that did not evaporate by the end of the apron would be collected in a sump and pumped to a spray system installed in the shallow pond. The actual pond would be designed for 5 foot operating depth with 2 feet of freeboard (more could be added for emergency storage). The shallow depth and a pressurized spray system would encourage evaporation (See Figures 4 and 5). The effectiveness of this system would depend largely upon the weather and climate (daytime temperature, precipitation, cloud cover, and wind) in the area, and the final size and design.

Solids buildup on the apron liner could be a concern but should be controlled (resuspended) by surface flow during cooler operating periods when precipitation is depressed and by occasional cleaning with pressurized water, and scale sloughing. In a similar operation, solids sloughing has occurred, however, some regular maintenance should be anticipated in order to maintain the spray system for effective evaporation. The option to add dye to the water to aid in solar heat gain has been recommended by some authors, but we have had no direct experience in implementing this option and addition research would be required. The sump would be interconnected to the pond via an adjustable weir. If the pond water elevation were to reach a point higher than the weir, the water would flow back into the pump sump and be resprayed either over the apron or the pond. By using a flow control weir this system should be somewhat self-regulating. Both the holding pond and apron would have separate spray pumping systems.

Using the pond evaporation information developed in Table 13, the cost for the three brine evaporation/storage pond was estimated.

Based upon our experience and recent costs for similar systems, we have estimated that the unit cost (cost/ft^2) of the double-lined pond section would be as shown on Table 13.

TABLE 13

IN PLACE DOUBLE LINER COST FOR EVAPORATION PONDS

Item	Unit Cost/ft^2
Grubbing	0.10
Over excavation	0.20
Base material & berms	0.50
80-mil FML - Top Liner	0.80
Geonet and LCRS	0.60
40-mil FML – Bottom Liner	0.70
Soil anchors/restraints	0.20
	$3.10

The estimated area of coverage includes:

	Option (gpm)		
Component	**2,000**	**4,000**	**6,000**
Apron	185,000 ft^2	370,000 ft^2	555,000 ft^2
Sump	35,000 ft^2	70,000 ft^2	105,000 ft^2
Pond	2,338,000 ft^2	4,676,000 ft^2	7,014,000 ft^2

The installed capital cost of the brine management system for the three options are presented on Table 14. This includes the estimated cost for the enhanced evaporation spray system, piping and pump station(s), electrical services (secondary) and ancillary facilities.

Table 15 provides our opinion of potential year-one operating cost (second quarter 2008). These costs do not include ultimate disposal of salts and residual from the evaporation pond system, but it would be assumed, that upon final reclamation, the pond(s) with dry solids would be encapsulated within the existing membrane liner system and would be buried on the mine site in a dedicated facility. Alternatively, the encapsulated material could be disposed of offsite at a commercial waste handling location.

Note that the capital and operating and maintenance costs shown in Tables 13, 14 and 15 would be avoided if brine were managed through discharge to the pit.

TABLE 14

ENHANCED RO BRINE EVAPORATION SYSTEM
OPINION OF CAPITAL COST

Option	2,000 gpm	4,000 gpm	6,000 gpm
Pond Area (ft^2) (total)	58 acres	116 acres	174 acres
Lined Pond Unit Cost ($/$ft^2$)	$3.10	$3.10	$3.10
Spray System Size (HP)	1,068	2,137	3,206
Unit Cost ($) Spray System ($ft^2$) – total distribution area	$0.77	$0.77	$0.77
Total Pond cost ($)	$7,821,000	$15,642,000	$23,464,000
Pump Cost ($) (est. as several pump stations)	$534,000	$1,068,000	$1,603,000
Total Spray System Cost ($)	$1,955,000	$3,911,000	$5,866,000
Total System Cost ($)	**$10,310,000**	**$20,621,000**	**$30,933,000**
Cost per ft^2 Total	**$4.08**	**$4.08**	**$4.08**

TABLE 15

ENHANCED RO BRINE EVAPORATION SYSTEM
OPINION OF ANNUAL OPERATIONS & MAINTENANCE COST
(2,000 gpm Option)

Description	Units	Unit Price(s)	Total Annual Cost ($)
1) Annual Power Cost**	7.1 million kWH	$0.10 kWH	$702,000
2) Spray System Maintenance	5% Capital*	LS	$98,000
3) Liner Maintenance	0.5% Capital*	LS	$39,000
4) Annual Labor	FTE	$40,000	$120,000
5) Pump Station Maintenance	5% Capital	$27,000	$27,000
6) Management & Administration	0.5 FTF	$80,000	$40,000
7) Miscellaneous	LS	$50,000	$50,000
TOTAL ANNUAL			**$1,076,000**

*Capital Accrual
**Assumes 24/7 full operation

The O&M cost for the 4,000 and 6,000 gpm brine management system would be multiples (i.e., 2X, 3X) of the 2,000 gpm option ($2,152,000 (4,000 gpm) and $3,228,000 (6,000 gpm)) less the minor savings in labor and administrative cost.

6.2 SUMMARY

The summarized capital and O&M costs for a water treatment system, if one needs to be implemented as part of a mitigation alternative, are provided in Table 16. Based upon these estimates, the resulting total operating unit cost for ground water treatment (raw water treatment and brine disposal) would be as follows for all options. Note that the brine disposal component of the these costs would be avoided if the brine were discharged to the pit.

$/1,000 gallons*	$/acft*
$2.15	$701.43

*95% operability

TABLE 16

SUMMARY OF CAPITAL AND FIRST YEAR* ANNUAL O&M COST
SIERRITA MINING PROJECT GROUNDWATER TREATMENT

	RO Treatment Components		**Brine Disposal Component**	
Option	**Capital**	**O&M**	**Capital****	**O&M**
2,000 gpm	$10,176,000	$1,490,000	$18,042,000	$1,076,000
4,000 gpm	$16,905,000	$2,049,000	$36,087,000	$2,152,000
6,000 gpm	$23,954,000	$2,584,000	$54,133,000	$3,228,000

*Based Year 2008
**Includes 15% engineering and 25% contingencies from Table 14

REFERENCES

Hydro Geo Chen, Inc. 2007
Aquifer Characterization Report
Task 5 of Aquifer Characterization Plan
Mitigation Order on Consent Docket No. P-50-06, Pima County Arizona