

# **Water Consumption at Copper Mines in Arizona**

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## **WATER CONSUMPTION AT COPPER MINES IN ARIZONA**

Arizona has the best copper deposits in the United States, and produces more of the red metal than most countries except Chile and Peru. All mining needs water for mining and processing and copper mining is no exception. Arizona is mostly desert and, therefore, short of water. This scarcity has been exacerbated because of the rapid growth of population in the state and the resulting enhanced demands for the resource. This has also attracted the attention of the general public to the use of water for mining.

Most water is used in flotation beneficiation, smelting, and electro-refining. Small amounts are used for domestic purposes (drinking, bathing, and such). It is also used for wetting roads to suppress dust. Factors affecting dust suppression include annual precipitation, natural vegetation, land morphology, and other factors. The amount of water used for wetting may vary between 0% and 15% of the total water used at the mine, depending on conditions. The water source may be from underground aquifers, Central Arizona (CAP), surface streams, precipitation, or a combination.

Copper minerals generally occur as oxides or sulfides. These require different treatments for extraction of the metal. The oxides are exposed to acid in a heap leach; this liberates the copper ions and the resulting solution is then sent to the solvent extraction (SX) process followed by electrowinning (EW) of the copper. The sulfides are subjected to crushing, grinding, and then flotation and the resultant concentrates then transported to smelters, where the sulfur is oxidized to sulfur oxides. The copper is then electro-refined.

### **Hydrometallurgical (Leaching) Process**

Leaching, solvent extraction (SX) and electro-winning (EW) have been used for producing copper from oxide ores since the 1960s and since the 1980s some secondary sulfide ores, such as chalcocite, can also be treated in this manner. Figure 1 shows one possible flowsheet for the leaching process.

The process can involve crushing the ore and then binding it, or the ore can be directly placed on the heap or leach dump, where the lixiviating solution percolates through the ore to release the copper ions into solution. If agglomeration is used the sulfuric acid starts to dissolve the copper from the minerals. At the end of agglomeration, the moisture content is nearly 10%. It is then placed on heaps, 5 to 30 feet high, and irrigated with sulfuric acid. The process can be accelerated with the addition of oxidizing agents such as ferrous ions or bacteria. The heaps, or leach dumps, are built so that the solution can be collected for the next stage, without impact to the surrounding environment. The solution recovered from the heaps contains 0.008 to 0.25 lb of copper/gallon. This concentration is increased during the solvent extraction (SX) process.

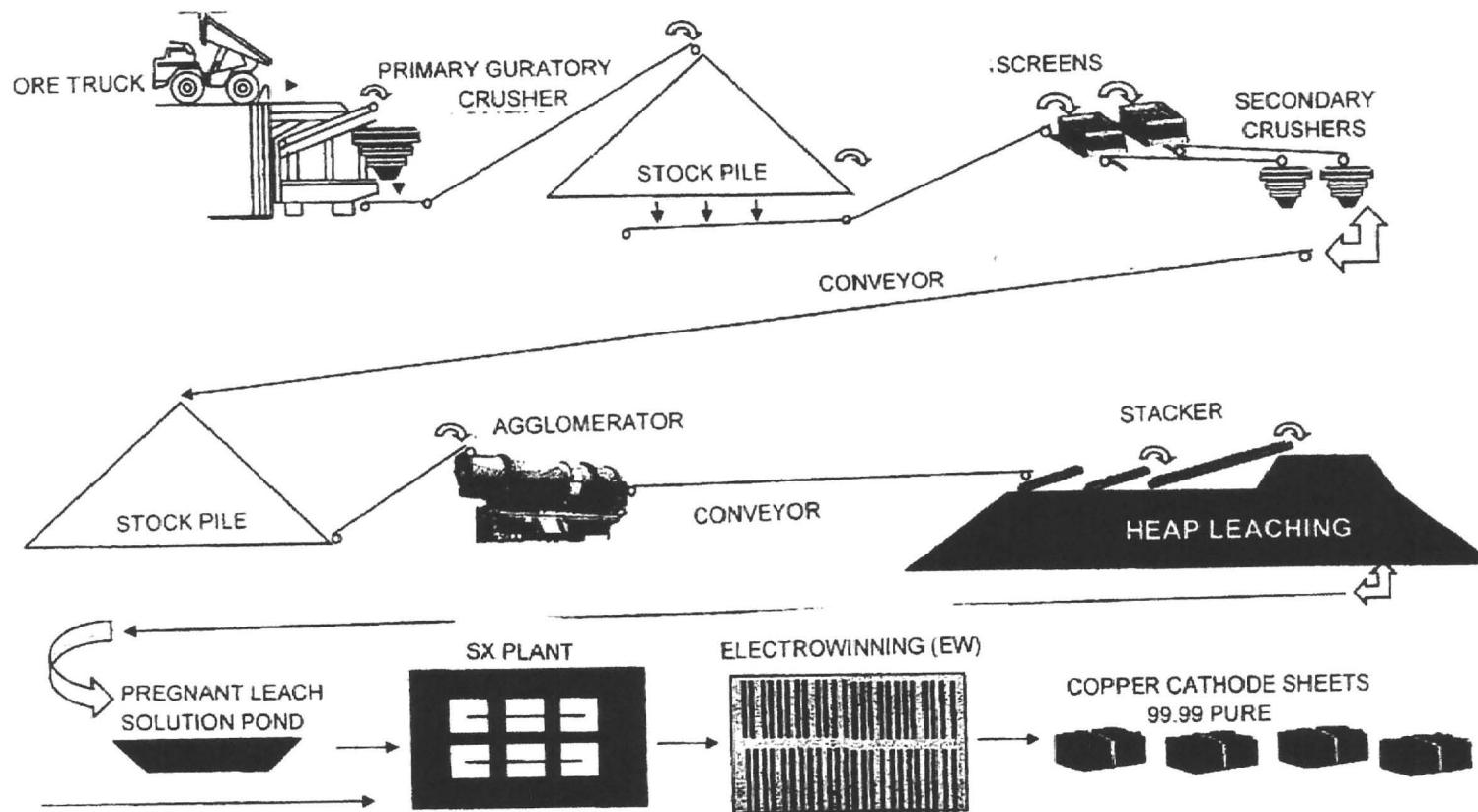


Figure 1 – Typical Flowsheet for the Hydrometallurgical (Leaching) Process

SX involves extracting the copper into an organic phase and then stripping it into a new aqueous phase. This brings the amount of copper in solution to approximately 0.3 lb/gallon, and is referred to as the electrolyte or “loaded electrolyte.” The leaching solution, after the copper is removed in the SX process, is recirculated for heap leach irrigation.

The electrolyte from the SX process is filtered to remove solids and then sent to the electro-winning (EW) plant. The EW plant operates like a large battery where metallic copper is electro-plated on to cathode starter sheets using a direct current (DC) and lead anodes.

Water losses in this process occur due to:

- Evaporation from the leach heaps.
- Evaporation from ponds.
- Organic phase washing.

### **Sulfide Concentration and Smelting Process**

Sulfur containing ore is crushed and ground, and then subjected to flotation, classification, and thickening. Water is used for the grinding and flotation processes, and will ultimately end up being recirculated in the process; in the concentrates (8% moisture) and shipped off site; or with the tailings material (50% solids). Figure 2 depicts a flowsheet for the sulfide concentration and smelting process.

Flotation employs physical processes which causes the hydrophobic mineral to attach to an air bubble. The process requires the addition of water and some reagents. During flotation there is an excess of water and the medium is alkaline (pH 10 or 11). This is accomplished by adding a reagent like lime to increase the pH from 7 (natural water) to 10 or 11. The resulting product contains about 20% to 40% copper, depending on the minerals involved. The flotation process is conducted with a solids concentration of between 25% and 40%. The overall water requirements, which include recirculated water, vary between 800 and 400 gallons/ton of ore.

Water from flotation is also used to transport tailings to the tailings dams. A significant portion of the water is in the tailings, where thickeners are used to extract much of the water, which is recirculated to the mill. The solids content in the tailings after thickening is approximately 55%. The tailings are then discharged into impoundments. These serve to settle the sediments and allow the clear water at the surface to be collected and recirculated to the flotation plant.

Modern tailing impoundments are built so that the bottom is sealed with either a geosynthetic or natural material with the starting dike and can incorporate drains.

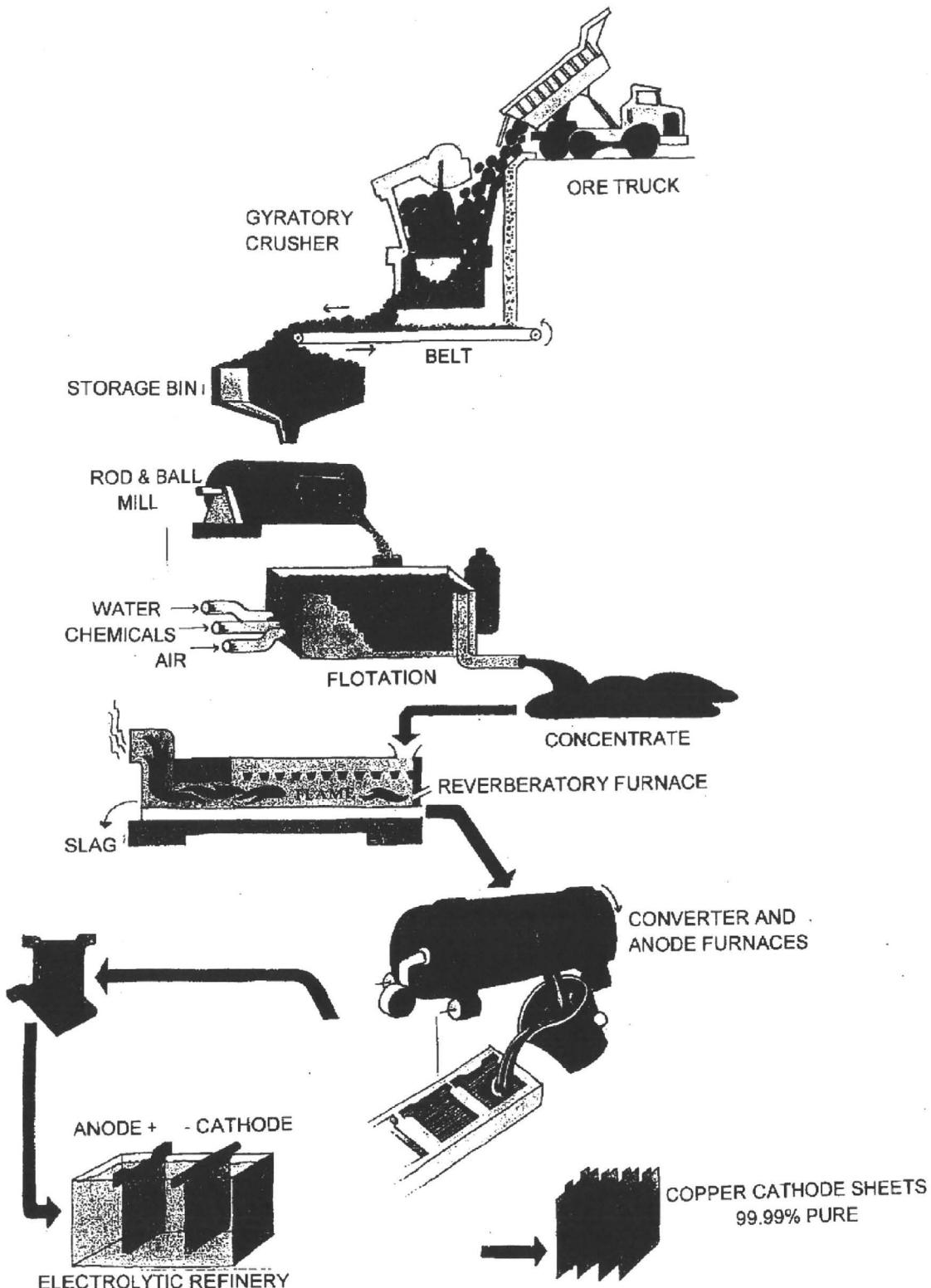


Figure 2 – Typical Flowsheet for the Pyrometallurgical (Smelting) Process

Fresh water consumption at the concentrator plant is around 200 gallons/ton of ore. If recirculation is maximized, leaks are avoided, and evaporation is reduced, the water use may be optimized to about 90 gallons/ton of material, as has been shown to be possible in some plants in Chile.

Causes of water losses include:

- The concentrate filtering process.
- Evaporation, especially from tailing ponds and thickeners.
- Retention in the tailings materials.
- Infiltration losses.

Transportation of concentrates or minerals may be by truck or train. At the smelter, blister (anode) copper is produced in a two-stage process – fusion and conversion.

The anodes still contain about 0.01% to 0.3% impurities, mostly metallic. During electrolytic refining, which is very similar to the EW process, the pure copper is deposited on the cathodes. Loss of water results from evaporation and solution disposal. Evaporation occurs in the cells, which are at a temperature of about 140°F. Sometimes small plastic spheres are floated on the surface to reduce evaporation. When the solution contains a high quantity of impurities, such as arsenic and antimony, this can no longer be recycled for refining and must be discarded, otherwise the water is recovered for re-use.

### **Water Consumption Rates**

All companies that are mining copper in Arizona are cognizant of their responsibility towards sustainable development and the need to conserve water. They are continually trying to reduce water consumption and recirculate as much of the process water as possible. The following table presents the data for the 5-year period of 2004 through 2008 for the major mining operations (1 acre-foot = 325,851 U.S. gallons):

### Water Usage in Major Copper Mines in Arizona in Acre-Feet

Mine	Affected GW Basin	Water Type	2004	2005	2006	2007	2008	Average Use
Bagdad <sup>1</sup>	Big Sandy	Groundwater	16,200	14,700	11,900	14,800	16,600	<b>14,840</b>
Miami <sup>2</sup>	Salt River	Groundwater	3,850	4,050	3,900	3,800	3,800	<b>3,880</b>
Mission <sup>3</sup>	Tucson AMA	Groundwater	4,520	4,270	7,069	7,929	10,130	<b>6,784</b>
		Central Arizona Project	0	0	0	1,028	2,460	<b>1,744</b>
Morenci <sup>4</sup>	Morenci	Groundwater	6,400	6,000	8,400	14,100	9,900	<b>8,960</b>
	Salt River	Surface Water	5,200	5,400	5,000	300	4,900	<b>4,160</b>
Ray <sup>2</sup>	Lower San Pedro	Groundwater	13,700	13,000	16,500	13,100	16,000	<b>14,460</b>
Sierrita <sup>3</sup>	Tucson AMA	Groundwater	26,480	28,490	26,690	26,710	27,180	<b>27,110</b>
Silver Bell <sup>3</sup>	Tucson AMA	Groundwater	1,156	928	1,034	905	820	<b>969</b>
<b>Total Use</b>								<b>55,659</b>
<b>Projected Water Use</b>								
Rosemont <sup>5</sup>								<b>5,000</b>
Safford (Dos Pobres) <sup>5</sup>								<b>5,500</b>

1-Data from ADWR estimates  
 2-Data from USGS Arizona Water Science Center  
 3-Data from ADWR 2009 Data Files  
 4-Data from USGS Files/Gila Water Commissioner Annual Reports  
 5-Data from Environmental Impact Statement (EIS)

The average amount of water used per pound of copper mined varies from mine to mine and from year to year, as mining and processing rates change and as market prices fluctuate, but for the years above these figures were:

### Water Use (Gallons) per Pound of Copper

Mine	2004	2005	2006	2007	2008	Average
Bagdad <sup>1</sup>	24.0	23.8	23.4	23.9	23.8	<b>23.8</b>
Miami <sup>2</sup>	64.0	53.6	66.9	61.9	65.2	<b>62.3</b>
Mission <sup>3</sup>	27.3	36.4	24.1	24.1	26.8	<b>25.0</b>
Morenci <sup>4</sup>	4.5	4.6	5.3	5.8	6.5	<b>5.4</b>
Ray <sup>2</sup>	18.5	18.8	23.1	18.6	24.0	<b>20.6</b>
Sierrita <sup>3</sup>	55.7	58.5	53.8	58.0	47.1	<b>54.6</b>
Silver Bell <sup>3</sup>	7.9	6.3	7.2	6.3	5.6	<b>6.7</b>
<b>Projected Use</b>						
Rosemont <sup>5</sup>						<b>7.4</b>
Safford (Dos Pobres) <sup>5</sup>						<b>7.5</b>

Production data for the above are taken from DMMR files.

It is projected that the Rosemont mine will use 5,000 acre-feet of water per year with a production of 220 million pounds of copper. This gives 7.4 gallons of water/pound of copper, which is at the low end.

The decrease in water usage by mines is better illustrated by exploring the data from specific mines.

The Morenci Mine was the second largest open-pit copper mine in North America in 2009, and one of the largest in the world. The property covers nearly 60,000 acres and includes five pits, of which three are currently in operation. There is also a solution extraction/electrowinning (SX-EW) facility at the site. Freeport-McMoRan (formerly Phelps Dodge) has a 50-year lease agreement with the San Carlos Apache Tribe pursuant to the San Carlos Apache Tribe Water Rights Settlement Act of 1992, as amended in 1997, to lease up to 14,000 acre-feet per annum (AFA) of its allocation of Central Arizona Project (CAP) water by means of an exchange at the Black River. The company is also entitled to 250,000 acre-feet (AF) of water from the Black River under the 1944 Horseshoe Exchange Agreement (according to ADWR). Water use in acre-feet by Morenci is as follows:

	1991-1995	1996-2000	2001-2005
Surface Water	2,425	2,105	1,141
Groundwater	13,700	17,800	8,100

Morenci has a \$9-million water recovery and control system that keeps the water on the mine property. There are a series of monitor wells that are used to check on the downstream water quality. It takes about 500 gallons of water to treat a ton of copper (0.25 gallons/lb of Cu) in the concentrators, but only 85 gallons (0.0425 gallons/lb) of this is fresh make-up water. The rest of it is recycled water; on average the water is recycled three times.

The water for the Bagdad Mine is pumped from wells along a 10-mile reach of the Big Sandy River north of Wikieup, in the Big Sandy Basin, and delivered by pipeline to the mine site. The water used at the mine is considered proprietary, but the following is estimated from mine production and processing by the Arizona Department of Water Resources (ADWR):

	1991-1995	1996-2000	2001-2005
Groundwater	16,200	16,800	15,800

A small quantity of surface water from Francis Creek springs and wells is used for the town of Bagdad and/or the mine. This is probably less than 500 AFA.

A water balance diagram for the Mission Complex for the year 2008 is shown in Figure 3.

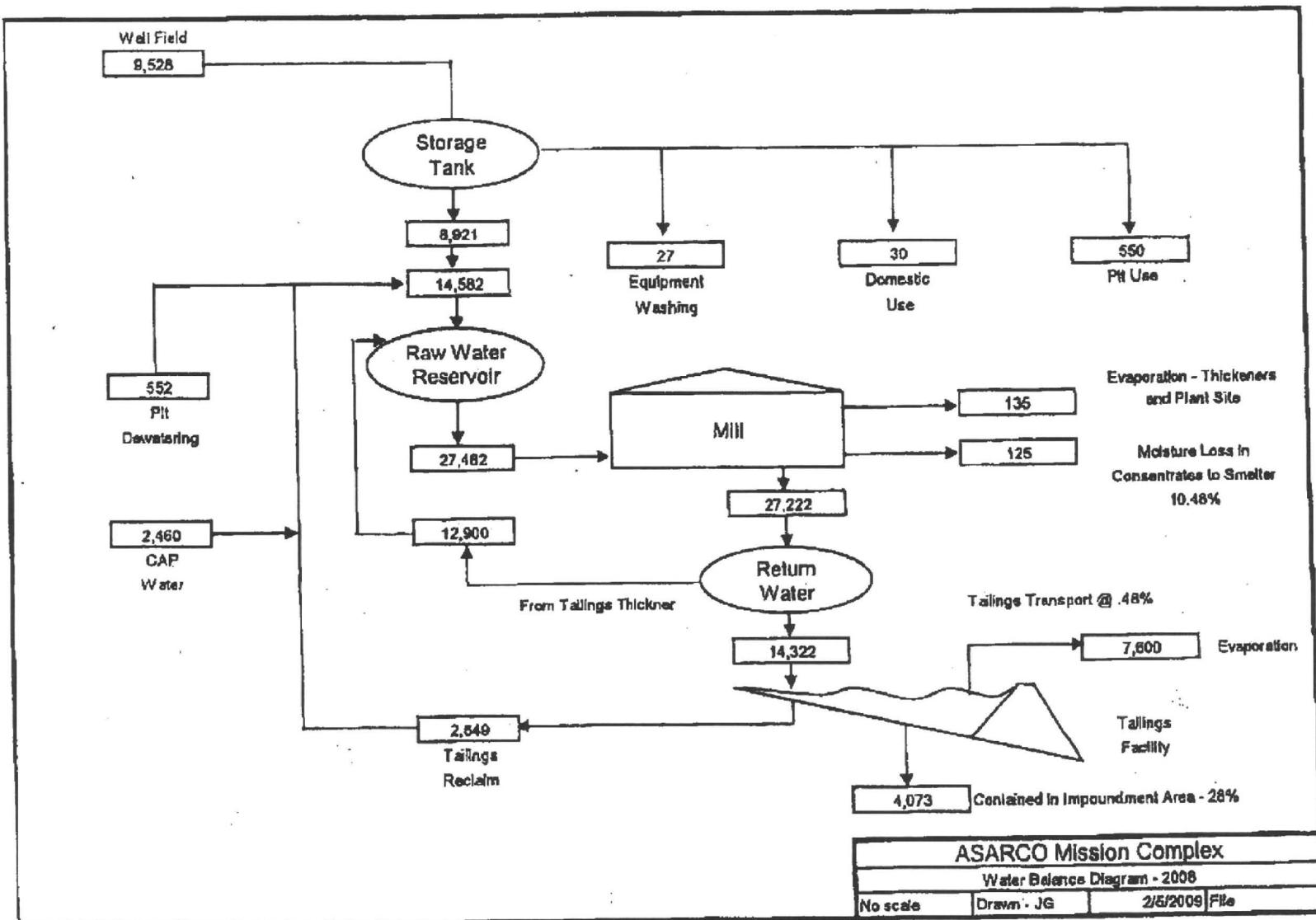


Figure 3 – Water Balance Diagram  
(Figures are in acre-feet per annum)

Courtesy ASARCO

## **Water Resources Management Practices**

Management of water resources implies reducing the amount of water used, efficient use of the water resources available, and sustainable management of the aquifers and ecosystems affected.

This is achieved by performing a complete water balance study so that the current situation can be assessed, and corrective action taken so that water usage is reduced. This information should be incorporated into all future plans. The steps entailed may involve:

- Installing accurate instrumentation for measuring volumes of water used.
- Creating indicators to monitor the water used in key operations.
- Control of water rights that are available.

Some options for optimizing water conservation could include:

- Recycling as much water as is feasible; this may mean using water from concentrate thickeners, tailings thickeners, tailings impoundments (perhaps by constructing appropriate drainage), transportation (if slurries are used), and any other sources that contain reusable water.
- Regularly reviewing available alternatives.
- Re-routing natural water away from tailings and other industrial waters so that there is total separation; generally this is being done.
- Constructing facilities so that they are leak-proof and the maximum amount of water can be captured and recirculated.
- Monitoring the quality of natural waters to ensure that they are not impacted by operations.
- Maintaining a measuring system so that the water used in each process is methodically monitored.
- Devising process consumption indices and evaluating these as they evolve.
- Using local water sources that are lower quality than groundwater, if it is feasible to use them.
- Assessing the effectiveness of all actions that are taken.

Total water consumption, total make-up water consumption, and recirculation rates could serve as efficiency indicators. Initial goals can be established by comparison with other mining operations with similar characteristics and processes. Other sustainability indices might be set which embrace water resource management principles.

### Activities Resulting in Efficient Water Management

Many of these activities are required by the Aquifer Protection Permit (APP) issued by the Arizona Department of Environmental Quality (ADEQ). The APP “regulates new and existing facilities that dispose pollutants to the land surface, underlying soil, or groundwater, in order to prevent groundwater contamination, where there is a reasonable probability that the pollutants would otherwise reach groundwater.” “The most critical requirements specified in the APP regulations are that the applicant must show that the Best Available Demonstrated Control Technology (BADCT) will be utilized by the facility, that aquifer water quality standards will not be violated in the aquifer at a point of compliance as a result of discharge, and finally, the applicant must demonstrate financial and technical capability.”

Measurement is indispensable for good water resource management; operations must be continually monitored and controlled. This might include, or are already in place:

- Monitoring sources of supply such as wells and basins. This may entail keeping electronic records throughout the life of the operation and observing the quality and volumes of the water extracted.
- Checking on the level of solution ponds to avoid spills, infiltration of water, or other water losses (as required by the Aquifer Protection Permit).
- Testing the quality of underground water sources, to ensure that leakages are not occurring from tailing dams, leach heaps, or other sources (as required by the Aquifer Protection Permit).
- Monitoring the levels of aquifers from which the water is extracted by readings in observation wells, sampling the water, and by modeling aquifer operations (as required by the Aquifer Protection Permit and the Department of Water Resources).
- Noting the inputs and outputs of treatment plants (if any); this information can be used internally and for final disposal (as required by the Aquifer Protection Permit).
- Supervision of basin slopes, if applicable (as required by the Aquifer Protection Permit).
- Checking on the seismic stability of tailings dams, and other features that could be affected by earthquakes (as required by the Aquifer Protection Permit, the State Mine Inspector, and the Mine Safety and Health Administration, MSHA).

The Aquifer Protection Permit program requires that baseline data be collected for water systems so that it can be used when designing closure plans (water balancing, normal and flood volumes, projected flooding, impoundment stability, and long-term risk assessment). Immediate corrective action against negative impacts, if necessary, is always better than retroactive steps.

In desert areas the effective management of water resources becomes extremely important.

- Hydrogeological models provide insight into impacts; these can aid in developing mitigation procedures that could be used, if necessary.
- Keep the surrounding community informed of changes and work with them as much as possible.

The following commonly-used steps may be helpful during effective water withdrawal, transportation, storage and distribution, which are also applicable to mines:

- Water can be lost through evaporation and leaks due to damaged pipes; appropriate and well-timed preventive maintenance on the system decreases the chance of mishaps.
- Install instrumentation to detect the occurrence of leaks in a timely manner.
- Flows in distribution lines should be monitored and recorded regularly for both quality and volume.
- Avoid situations that may lead to emergencies, such as water shortage, by installing storage of adequate capacity and monitoring the water level.

Some measures that help to reduce water consumption:

- Analysis of historical water consumption records to see where water usage has increased and why, as well as where further reductions are possible.
- Inspect to see if there are losses in any lines in the system and institute possible improvements.
- Review current procedures to see if improvements (e.g. use of different equipment) can be made.
- Check water recirculation circuits and make changes as appropriate.
- Analyze water use for miscellaneous purposes, such as road maintenance and dust suppression, use in offices, or in green areas.

Good practices for general control of water usage:

- Recover water wherever possible; this could be done at any number of points in the system.
- Cooling water from various locations, such as equipment, acid plants, laboratories, thermoelectric plants, and others, should be recirculated – after treatment if necessary.
- Whenever possible efficiencies should be introduced at concentrators, by installing high density thickeners and pressure filters.
- Recirculation from tailings impoundments can be improved by designing to get better recovery (largest losses occur because of evaporation, infiltration and retention), covering the bottom of the impoundments with a geosynthetic liner or other fine material to decrease its permeability, installing a basin drain (to reduce filtration), and filtering the tailings.
- Heap leach construction may be enhanced by using drip irrigation to reduce evaporation, and constructing drains (basal, intermediate, and pipes).
- Process solution ponds should be covered where practicable to minimize evaporation.
- As required, use proper procedure to avoid spills, especially when loading tank trucks or tanks.
- Watering roads as specified in the air quality permits; at least half the road should get watered in one pass.
- Using asphalt or chemical stabilizers on roads to reduce water use.
- The landscape should be xeroscape.
- Conserve water in offices and other buildings.

Water use improvements are also aided by implementing new technologies that provide greater control over various processes. This requires a commitment on the part of all employees and perhaps a change in the culture of the operators. The use of an intelligent controller in the thickening circuit allows the system to be fully automated. This controls all aspects of the system, including the water used. The discharge concentration can be increased by 2 to 3% as compared to manual controls. The controller can be installed in currently operating systems, but requires complex maintenance. The water flow through each process of the mine system should be monitored with flow meters incorporated in each part of the operation. This could help save up to 2% of the water usage at the site. In addition it gives the community the confidence that optimum use of the water is being made, at relatively low cost. Even thickened tailings have a considerable amount of water that can be reduced by filtering. Construction of thickeners at heights greater than normal by about 45 to 60 feet, results in pulp that is of higher density (65 to 75%), which increases the concentration in the weight of the tailings by about 8%, as compared to conventional high efficiency thickeners (which typically save 15% water).

## **Arizona Department of Water Resources Requirements**

The Arizona Department of Water Resources (ADWR) has developed requirements for conservation, monitoring, and reporting for metal mines in the state. All mines in Arizona are required to and do comply with these requirements:

- Transport tailings at an average density of 48 percent solids by weight over a three-year running average for pre-1985 mines and an average annual density of 50 percent at facilities built after 1984.
- Decrease water loss from tailings impoundments by placing the tailings up slope from the free water surface in the impoundments to minimize seepage; alternatively, at pre-1985 mines, interceptor wells should be installed down gradient of the impoundments to capture seepage.
- “Preslime” i.e. place fine-grained tailings at the bottom of the tailings impoundment for a thickness of at least 12 inches, or drill interceptor wells downgradient from the impoundment to intercept seepage water.
- Create stilling basins so that their surface area is minimized to reduce water loss by evaporation. Stilling basins are areas of free-standing water that are formed in tailings impoundments when the tailings are deposited and settle out.
  - This should be accomplished so that the rate of decant water recovery is increased.
  - Decant towers, barge pumps, or sump pumps may be used to recycle the water back to the mill concentrator.
  - Increase the capacity of the decant towers or barge pumps to enhance the recycling of the reclaimed water.
  - Maximize the use of water from the tailings impoundment so that use of new groundwater is decreased.
- Reclaim tailings impoundment water and recycle it.
- Cover or cap abandoned tailings impoundments to reduce water for dust control.
- Minimize water used for leaching, consistent with reasonable economic return.
- Adopt at least three of the following eight conservation measures:
  - Utilize drought-tolerant plants when revegetating abandoned mine land.
  - Build multiple decant towers for a single impoundment to augment the decant rate.
  - Use high density polyethylene (HDPE) pipe so that the higher density tailings can be transported.
  - Reuse runoff storm water that has been harvested on site.
  - Water from pit dewatering should be used.

- In addition to stilling basins, evaporation from any other standing water should be reduced.
- Dust control water should be minimized by reducing the length and number of haul trips, using road binders, changing to conveyors from trucks, and any other means that reduce water use.
- If possible, replace sprinklers for heap or dump leaching with alternative methods of delivery, if these use less water.

If there is some reason why the above-listed requirements cannot be met or need to be changed, a request for a modification should be submitted to the director of ADWR detailing the changes and rationale for the same.

At least three months prior to the start of a new operation, a long-range water conservation plan needs to be submitted to ADWR for approval. This must include the design, construction, and operation of the facility. It should provide the ore type, mining method, and processing involved. The latest available technology should be evaluated in light of a reasonable economic return. Attention should be paid to:

- Use of an alternative source of water other than groundwater, and where this other water is to be obtained.
- Minimizing evaporation losses from tailings impoundments, using the latest technology and adopting good management practices.
- Dust control procedures on haul roads so as to reduce water usage. Use of binders, paved roads, conveyors, and other procedures should be considered.
- Increasing tailings densities to at least 55% solids by weight.

Any other conservation techniques that can be used should be discussed. The dates at which these practices are to be implemented should be given.

Reports required in accordance with Arizona Revised Statutes (A.R.S.) 43-632 are submitted annually and contain the following information:

- The amount of water used for dust control, tailings revegetation, domestic use, and transportation of tailings to the impoundments. The water quantities for dust suppression and revegetation should be measured and reported separately. The measuring devices used should conform to Arizona Administrative Code (A.A.C.) R12-15-901 *et seq.* Water for domestic use and transportation of tailings may be estimated.
- The quantity of water, including effluent, used for equipment washing, leaching, and milling should be measured separately using a device that is in accordance with A.A.C. R12-15-901 *et seq.*

- The volume of water, including effluent, obtained from tailing impoundments and pit dewatering. The device used to measure these should also comply with A.A.C. R12-15-901 *et seq.* and reported separately.
- Tons of ore milled.
- Tons of ore stacked to heap and/or dump leach.
- Tons of ore vat leached.
- Tons of material mined.
- Tons of mineral produced from mill and leach circuits.
- Average gallons of water consumed per ton of mineral produced.
- Average percentage of solids by weight in tailings transported to impoundments for that year and each of the two previous years.
- Average annual depth of water at the deepest portion of the stilling basin(s).
- Copies of aerial photos of tailing impoundments with scale indicated, to determine the wetted surface area of the tailings impoundments.
- Description of additional conservation techniques that were used at the facility.

If there are contiguous mining operations owned by the same proprietor, and some are pre-1985 and others post-1984, these could be reported together in one document.

### **Conclusions**

Rosemont Copper has been permitted by the Arizona Department of Water Resources (ADWR) to pump up to 6,000 acre-feet of water per year. The Sierrita mine (Freeport-McMoRan) pumped 27,180 acre-feet and the Mission mine (ASARCO) used a combination of CAP and pumped groundwater totaling 12,590 acre-feet in 2008, giving a total of 39,770 acre-feet. These are the two large copper mines in the vicinity of Green Valley in the Tucson Active Management Area (AMA). Sieritta has pumped between 18,299 and 28,492 acre-feet from 2000 to 2008; the corresponding figures for Mission are 4,270 to 10,130 acre-feet. Rosemont is pumping water from the Central Arizona Project (CAP) into the aquifer even though mining has not started, as already noted above. ASARCO started purchasing some CAP water in 2007, while Freeport-McMoRan has not taken any such action to date.

In comparison, the Farmers Investment Company (FICO) pumped 30,541 acre-feet of groundwater in 2008 and has pumped between 25,624 to 31,696 acre-feet between 2000 and 2008, based on ADWR figures. This is five times the amount planned to be pumped by Rosemont and exceeds the amount used by the operating mines. FICO has not taken any steps in this regard, because farm use of groundwater is exempt from any replenishment requirements under current state law. FICO draws the water for growing pecans, which it has done for decades.

Water for municipal use pumped by the utilities serving Sahuarita and Green Valley was 6,993 acre-feet in 2008. The golf courses in the area consumed 4,250 acre-feet that year.

Good water resource management practice implies that the mine operator take a proactive position and direct its efforts for economy and sustainability. Mineral deposits must be mined where they occur. In desert areas, such as Arizona, water is a scarce commodity that requires conservation. With the adoption of many of the practices that are discussed above the amount of water consumed can be managed effectively. This is the goal of the mining industry in the state.

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