

US EPA ARCHIVE DOCUMENT

1.5 WASTES AND OTHER MATERIALS ASSOCIATED WITH COPPER EXTRACTION AND BENEFICIATION

This section describes several of the wastes and materials that are generated and/or managed at copper extraction and beneficiation operations and the means by which they are managed. As is noted in the previous section, a variety of wastes and other materials are generated and managed by copper mining operations.

Some, such as waste rock and tailings, are generally considered to be wastes and are managed as such, typically in on-site management units. Even these materials, however, may be used for various purposes (either on- or off-site) in lieu of disposal. Some quantities of waste rock and tailings, for example, may be used as construction or foundation materials at times during a mine's life. Many other materials that are generated and/or used at mine sites may only occasionally or periodically be managed as wastes. These include mine water removed from underground workings or open pits, which usually is recirculated for on-site use (e.g., as mill/leaching makeup water) but at times can be discharged to surface waters. As another example, leaching solutions are typically regenerated and reused continuously for extended periods. On occasion, however, such during temporary or permanent closure, the solutions are disposed as wastes via land application or other means. Finally, some materials are not considered wastes at all until a particular time in their life cycles. These include spent ore at dump leaching operations: here, only when active leaching for copper recovery ends is the spent ore that comprises the dump considered a waste.

The issue of whether a particular material is a waste clearly depends on the specific circumstances surrounding its generation and management at the time. In addition, some materials that are wastes within the plain meaning of the word are not "solid wastes" as defined under RCRA and thus are not subject to regulation under RCRA. These include, for example, mine water or process wastewater that is discharged pursuant to an NPDES permit. It is emphasized that any questions as to whether a particular material is a waste at a given time should be directed to the appropriate EPA Regional office.

The first subsection below describes several of the more important wastes (as defined under RCRA or otherwise) and nonwastes alike, since either can have important implications for environmental performance of a facility. The next subsection describes the major types of waste units and mine structures that are of most environmental concern during and after the active life of an operation. Figure 1-16

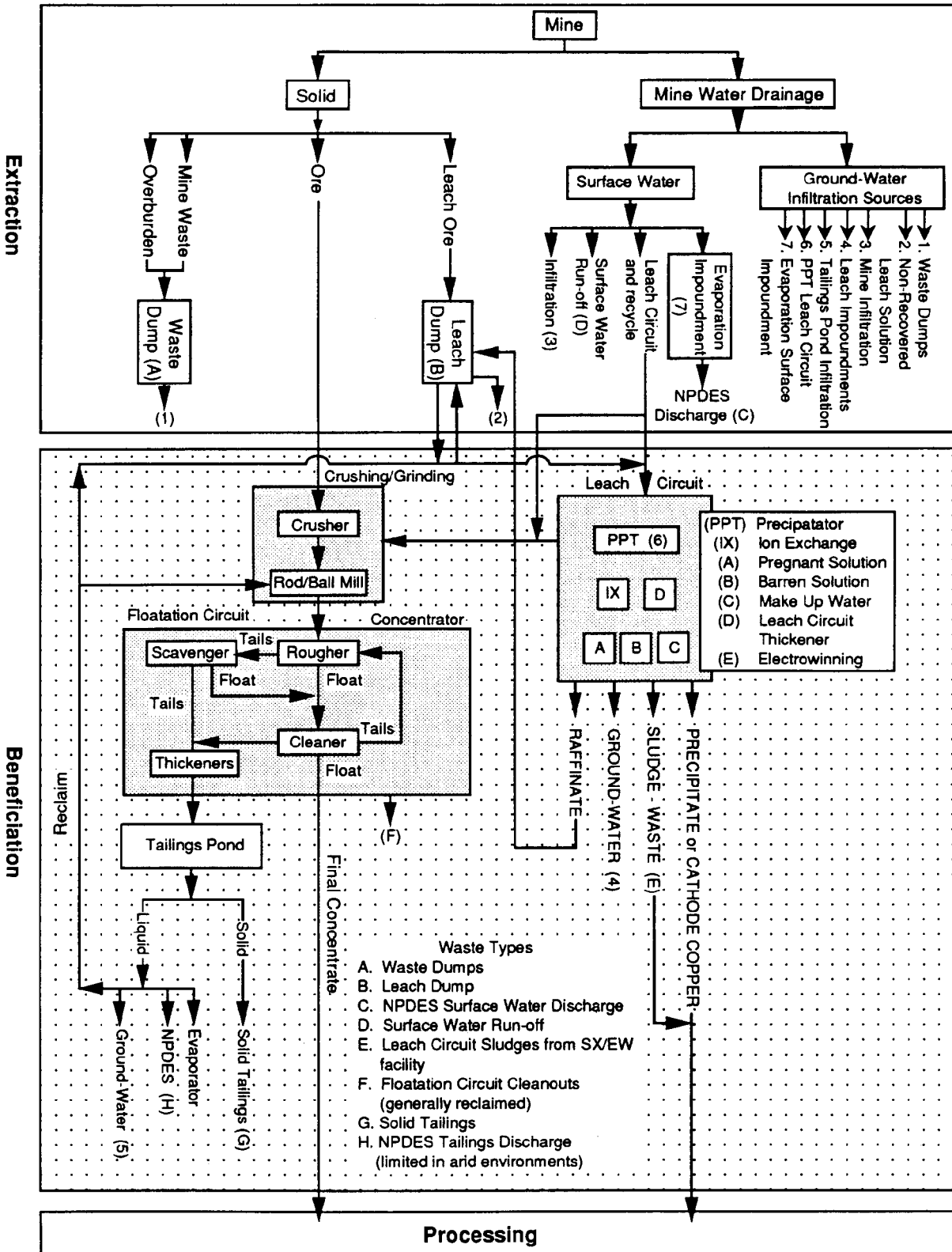


Figure 1-16. Schematic of Typical Copper Mining Extraction and Beneficiation Wastestreams

(Source: Modified from U.S. EPA 1985a)

identifies many of the typical wastes and materials and management practices employed by the copper industry.

1.5.1 Extraction and Beneficiation Wastes and Materials

The subsections below describe many of the wastes and materials generated and managed at copper sites. Notwithstanding the status of a particular waste or material, it should be noted that a number of

factors determine whether that waste or material poses any risk to human health or the environment. Perhaps the most important are the inherent nature of the material (which is generally determined by its origin and the processes by which it is generated), the manner in which the material is managed, and the environment in which it is managed and to which it could be released. As noted above, questions concerning the actual status of any particular material or waste should be directed to the appropriate EPA Region.

1.5.1.1 RCRA Wastes

Waste Rock

For this discussion, waste rock is defined as all overburden and mine development rock moved during mining. These materials contain little or no recoverable mineral values. Industry uses the term "overburden" to refer to nonmineralized soils and rock that are above (over) an ore body. Similarly, mine development rock refers to material removed from underground mines to access the ore body. Waste rock is used by industry to refer to poor or nonmineralized rock that is within or surrounding the ore body at surface mines.

Waste rock and ore are relative terms in the context of copper porphyry ore bodies since few distinct boundaries exist. Usually, contacts between mineralization zones are gradational; there is a gradual increase in mineralization from nonmineralized areas to quality ore areas. Therefore, waste rock may contain some values. (U.S. DOI, Bureau of Mines 1965a).

Waste rock is typically hauled from the mine site to waste dumps for disposal. Waste rock piles may have high permeability to both air and water. Oxygen and sulfide minerals may be contained in the dump. The quantity and composition of waste rock generated at mines vary greatly by site. This material can be classified as either oxide or sulfide, with varying solubilities, depending on the composition of the ore body. Sulfur-bearing minerals, such as pyrite and pyrrhotite, can oxidize to form sulfuric acid. Factors that influence acid generation by sulfide wastes include: (1) the amount and frequency of precipitation, (2) the design of the disposal unit, and (3) the neutralization potential of the rock. Constituents of concern for waste rock include sulfur-bearing minerals that may generate acid and leach metals contained in the ore body and surrounding rock.

Tailings

Tailings are generated during flotation. Tailings are made up of very fine host rock (i.e., gangue) and nonmetallic minerals separated from the values during beneficiation. The physical and chemical nature of tailings varies according to the ore characteristics and the beneficiation techniques used. Tailings are a slurry of fine-grained rock material and process water. Liquid is removed from the tailings slurry in thickeners and the thickened tailings are discharged to the tailings impoundment. Water is usually reclaimed from the thickeners and recirculated to the mill to be used in beneficiation and dust control (U.S. DOI, Bureau of Mines 1965a).

In the arid southwest, where evaporation rates exceed precipitation, the mine-mill water balance usually requires that water recovered in the tailings pond be recycled to the mill as process water. At copper mines in the central United States (such as White Pine in Michigan) the reverse situation exists; precipitation exceeds evaporation rates and excess mine-related water must be discharged to the environment (U.S. DOI, Bureau of Mines 1965a).

In 1985, 195 million tons of copper and copper-molybdenum ores were treated by flotation concentration, resulting in the production of 5.8 million tons of concentrate using 97 million gallons of water and 0.32 million tons of reagents. More than 97 percent (189 million tons) of ore tonnage processed in 1985 was disposed of as tailings (U.S. DOI, Bureau of Mines 1987a).

Spent Ore from Heap, Dump, and Vat Leaching

Spent ore consists of the material remaining in either dump or heap leach piles when leaching ceases. Spent ore from heap, dump, and vat leaching may contain residual lixiviant and other constituents of the ore. Some operations may refer to wastes from vat leaching operations as tailings.

1.5.1.2 Materials

Mine Water

Mine water is generated when water collects in mine workings, both surface and underground, as a result of inflow from rain or surface water and from ground water seepage. During the active life of the mine, water is pumped out to keep the mine relatively dry and to allow access to the ore body for extraction. At surface mines, mine water may be pumped from sumps within the mine pit. Surface water is controlled using engineering techniques to prevent water from flowing into the mine. Pumped water may be used in extraction and beneficiation activities (including dust control), pumped to tailings impoundments, or discharged as a waste through an NPDES permit. Because mine water at copper mines is often rich in dissolved copper and other metal ions, some operations pump it to an SX/EW plant to recover the copper values (Cumming 1973).

The quantity of mine water generated at mines varies from site to site. The chemistry of mine water is dependent on the geochemistry of the ore body and the surrounding area. Water exposed to sulfur-bearing minerals in an oxidizing environment, such as an open pit or underground workings, may become acidified. This potential is greatly dependent on site-specific factors.

At underground mines, the quantity of water entering the mine depends on local hydrogeologic conditions. At some facilities, little or no water is encountered. At others, ground water may continually drain into the mine workings. Underground water inflows are often allowed to drain to low areas of the mine where sumps and pumps collect and pump the water from the mine. At some facilities, however, the inflow of water is so great that the capacities of the underground holding and pump mechanisms are exceeded, which leads to mine

flooding. In such situations, a ground water-dewatering program is implemented, or the mine is abandoned (Cumming 1973).

Ground water-dewatering programs at both surface and underground mines involve draining the surrounding aquifer using a series of interceptor wells drilled around the mine. The water table is thus lowered around the vicinity of the mine, thereby reducing the flow of water into the mine. After cessation of mine operations, water diversion schemes are generally abandoned, and the mine is allowed to fill with water (Mining Engineering 1988). A more detailed discussion of several surface and underground mine dewatering systems is presented in the *SME Mining Engineering Handbook* (1973), A. Cumming (Chairman of Editorial Board), Society of Mining Engineers, AIME, New York, New York.

Of the mines studied, information pertaining to surface- and mine-water drainage indicated that they typically handled water using diversion ditches, collection and pump back/recycling systems, and/or holding ponds. Data on mine-water management were available for the following mines: Sierrita, Bagdad, Inspiration, Morenci, Bingham Canyon, and Pinto Valley. Sierrita, Bagdad, and Inspiration utilize systems of berms, ditches, and reservoirs to control surface-water runoff and runoff. Pinto Valley has installed a diversion trench system lined with riprap to channel overflow caused by a 100-year storm event. The trench system directs overflow from its closed dump leach site to the tailings pond for evaporation. Bingham Canyon's mine-water drainage canals are constructed of epoxy-lined concrete. Morenci installed a sump and pump-back system in the bottom of the pit to capture fugitive mine drainage. The collected drainage is pumped to the leach plant circuit for copper recovery.

While specific information was not found, it is believed that many other operations have mine-water collection/pump-back systems to provide for recovery of dissolved copper, allow for makeup water for facility processes, and ensure compliance with State and Federal regulatory requirements.

SX/EW Sludge

Sludge is the semisolid gelatinous materials (i.e., soft mud, slime, slush, or mire) that can accumulate in SX/EW tanks. These sludges are colloids of suspended material (usually less than 5 angstroms in size) that cannot be easily settled or filtered.

The solvent extraction process specifically generates a "sludge," or, as it is known in the copper industry, "crud" or "gunk." This sludge consists of a solid stabilized emulsion of organic and aqueous solutions from solvent extraction. It is located at the organic/aqueous interface in the settlers and is periodically removed from the system, and centrifuged or otherwise treated to remove the organics. The aqueous solutions and the solids are disposed of and the organics are returned to the solvent extraction circuit for reuse. Depending on the characteristics of the ore body, SX/EW sludges may contain base or precious metals in quantities sufficient for recovery.

Spent Electrolyte

Spent electrolyte is generated during electrowinning activities. Historically, electrolyte went through a stripping step and was subsequently discharged to a tailings pond. Today, due to economics, this effluent is recycled to reduce capital costs associated with the electrolytic acids used in these operations.

Over time, electrolyte in the electrowinning cells becomes laden with soluble impurities and copper. When this occurs, the solution is removed and replaced with pure electrolyte (to maintain the efficiency of the solution and prevent coprecipitation of the impurities at the cathode). Purification of the spent electrolyte is done by electrowinning in liberator cells. Liberator cells are similar to normal electrolytic cells, but they have lead anodes in place of copper anodes. The electrolyte is cascaded through the liberator cells, and an electric current is applied. Copper in the solution is deposited on copper starting sheets. As the copper in the solution is depleted, the quality of the copper deposit is degraded. Liberator cathodes containing impurities (such as antimony) are returned to the smelter to be melted and cast into anodes. Purified electrolyte is recycled to the electrolytic cells. Any bleed electrolyte usually is neutralized with mill tailings and disposed of in a tailings pond (U.S. EPA 1984a).

Spent Leaching Solution

Barren solution (raffinate) is an acidic aqueous solution that has been stripped of copper but still has some carryover of the organic extraction/diluent used in the solvent extraction operation. The raffinate generated at hydrometallurgical plants is typically stored in ponds and recycled to the dump leaching operation. As a result, it does not become a waste until after the closure of the mine. Following mine closure, spent leaching solutions must be disposed of. No information was obtained on the quantity of raffinate generated or recycled at copper mine facilities (U.S. EPA 1984a).

Other Wastes and Materials

In addition to the wastes and materials described previously, extraction and beneficiation operations generate other wastes and materials typical of industrial operations, such as spent solvents, refuse, and used oil.

1.5.2 Waste and Materials Management

Wastes and materials that are generated as a result of extraction and beneficiation of copper ore are managed (treated, stored, or disposed of) in discrete units. For the purposes of this report, waste units are divided into three groups: (1) waste rock piles or dumps; (2) tailings ponds; and (3) spent ore piles once the leaching operation ceases in the case of heap leach operations. These units may be exposed to the environment, presenting the potential for contaminant transport. In addition, mine structures such as pits and underground workings are described in this section as they may expose constituents to the environment and increase the potential for transport.

1.5.2.1 RCRA Units

Waste Rock Piles

Waste rock removed from the mine is stored or disposed of in piles onsite. These piles may also be referred to as mine dumps or waste rock dumps. Often, these units are constructed without liners. Dumps may generate acid drainage if sulfide minerals, oxygen, and moisture are present in sufficient concentrations, and if adequate neutralization potential or other controls in the dump itself are not present.

Tailings Impoundments

Tailings impoundments are surface disposal units for tailings generated during flotation. The following discussion focuses on tailings impoundment design. Slurried tailings may be transported from the mill to the tailings pond by gravity flow and/or pumping through open conduits or pipes. Tailings slurries (both wet and thickened) are highly viscous and abrasive. This causes wear during operation of the tailings transport system. Pipe wear is a significant problem that may be mitigated by the use of rubber-lined steel or HDPE. In addition, the transport system can become plugged with settling solids if the minimum flow velocity is not maintained or if provisions are not made for pipe drainage during mill shutdowns. In most cases, water from the tailings impoundment is recycled to the mill for reuse. The general guidelines detailed below are applicable to the construction and operation of tailings impoundments.

There are three methods of construction for tailings impoundments: upstream, downstream, and centerline.

Figure 1-17

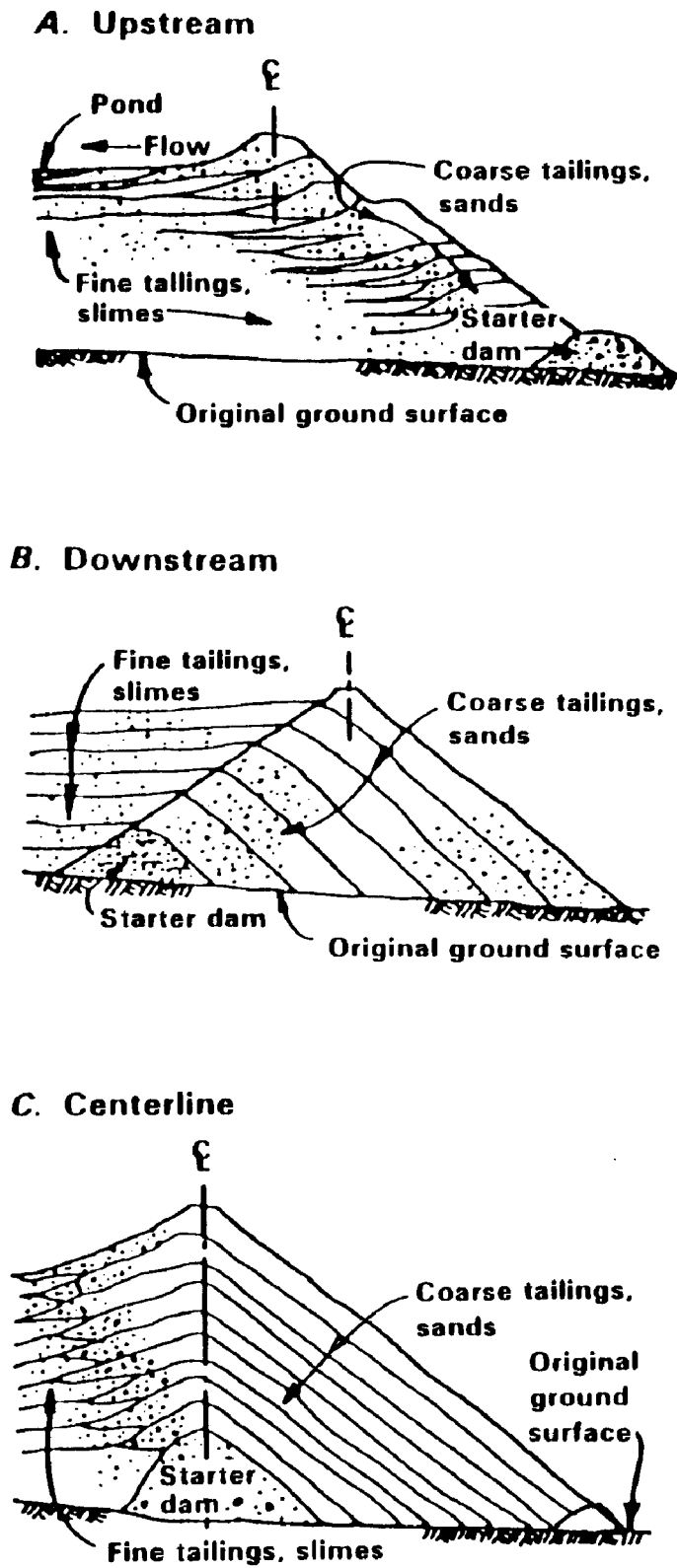


Figure 1-17. Upstream, Downstream and Centerline Methods of Construction

(Source: U.S. DOI, Bureau of Mines, 1984)

includes diagrammatic representations of these three construction methods. The choice of construction method is dependent on local topography, the availability of construction materials, and the nature of the tailings. Less common methods of tailings disposal include underground mine backfilling and in-pit backfilling (U.S. DOI, Bureau of Mines 1984. For more information, refer to U.S. EPA 1994, *Design and Evaluation of Tailings Dams.*)

Upstream tailings impoundments are most commonly constructed in the copper mining industry. In this method, the embankment is erected by depositing successive layers of coarse material on top of

the previous dike along the inside of its embankments (see Figure 1-17a). Thus, the centerline of the berm progresses upstream toward the center of the dam, while the outer slope remains stable (U.S. DOI, Bureau of Mines 1984).

In the downstream method, tailings are deposited along the outside of the dike so that the centerline progresses downstream, or away from the center of the pond (see Figure 1-17b). In the centerline method of berm erection, coarse material is deposited on top of the embankment so that the centerline of the dike does not move (see Figure 1-17c). Another modification of this method is to deposit material on both sides of the berms equalizing growth in both directions (U.S. DOI, Bureau of Mines 1984).

Placement of tailings impoundments may be influenced by a number of factors, including location and elevation relative to the mill and the hydrogeology of the area. When an embankment is to be built from tailings material, a starter or toe dam is often required to contain the tailings during the initial stage of deposition. The starter dam may be constructed of pervious or impervious material. If impervious material is used, a filter blanket can be installed, extending under the dam from the toe as far as necessary to drain the interior of the starter dam (Pfleider 1973).

Underdrains may also be installed under the toe dam. The purpose of the underdrain system is to lower the water level at the face of the toe dam and to prevent seepage where the tailings and the crest of the toe dam meet. Underdrains may be constructed with perforated asphalt-dipped pipe (in some instances, a layer of gravel or porous soil may provide sufficient drainage). The pipes are installed with the perforations face down on a suitable bed of gravel in a trench. The pipes are then covered with a layer of washed gravel, and the rest of the trench is filled with washed sand. The depth of the trench and the thickness of the gravel layers should be tailored to suit the existing conditions (Pfleider 1973).

Decanting is accomplished after the tailings have been discharged into the tailings pond. Two methods are available for decanting pond water: decant towers and pumping (usually from floating barges). Decant towers are vertical, concrete risers with intake ports that rise from the bottom of the impoundment to the surface. The tower is connected to a concrete conduit extending from the bottom of the decant tower to beyond the dam toe. In the pumping method, floating barges move to various parts of the pond and collect liquid material. The collected liquid normally is recycled to the mill, either directly or after it has been decanted in a separate decant pond.

Spent Ore Piles

Spent ore from heap and dump leaching may contain residual amounts of lixiviant and associated copper and other metal complexes. The spent ore itself typically contains unleached metals and other minerals characteristic of the ore body. Leach piles are reported to range in size from 20 feet to over 100 feet in height and may cover hundreds of acres and contain millions of tons of leached ore. When active leaching ends, the spent ore becomes a waste.

Side slope and valley dump leaches are located based on topography and design factors. Additional consideration is given to base preparation and geologic factors that may affect unit operation. These factors include the presence of limestone, porous materials (such as sandstone rocks), and geologic faults. Such factors can act to undermine the effective operation of the leaching process. Modern strip or radial leach piles are constructed using methods similar to those used to construct heap leach piles (Thompson, et al. 1984).

Most copper leaching operations are not typically constructed with synthetic liners (i.e., they are dump leach units, rather than heap leach units). However, at some mine sites, such as the Tyrone mine, new dump leaches are being designed with liners and other controls. For example, these dumps, constructed on a devegetated surface, are lined with compacted natural base materials, impermeable bedrock, or clay with drainage and have lined PLS collection systems. All surfaces and natural materials were tested and have permeabilities that range between 10^{-7} and 10^{-9} . Leach operations at the Sierrita, Chino, Morenci, and Pinto Valley mines are located on unspecified bedrock, while the Inspiration mine's dump leaches are situated on granite. According to the mine operators, bedrock is considered impermeable, or of very low permeability. The base of one of the Inspiration mine's newer dump leaches was prepared by devegetation, followed by soil cementation and coating with dilute tar.

In heap leaching operations, the use of specially constructed pads has been practiced to some extent by the copper industry. For example, heap leaching is currently performed at Magma's San Manuel facility. According to the Arizona Department of Environmental Quality (ADEQ), lined pads covering hundreds of acres and containing millions of tons of ore have been a proven technique in the gold mining industry on a scale comparative to the largest copper dump leach operation (Arizona BADCT 1990).

1.5.2.2 Non-RCRA Units

Mine Pits and Underground Workings

Mine pits may or may not be non-RCRA units during the operative life of a mine, depending upon whether or not RCRA wastes are placed in the pits. This is a complicated issue, not lending itself to generalities. Specific questions should be addressed to the nearest EPA Regional office.

Pits and underground workings may be allowed to fill with water when a mine closes or stops operation, since there is no longer a need for dewatering. This accumulated water may acidify through contact with sulfide minerals in an oxidizing environment resulting in acid generation. The acid, in turn, may mobilize metals in the remaining rock. In some cases pits and underground workings are backfilled with waste rock or tailings. The potential for contaminant release is dependent on site-specific factors.

Abandoned underground mines and mine shafts may be unprotected, and the mine may, with time, subside, though this is mostly a problem with historical mines. Deficiencies in mine shaft protection may be caused by the use of unsuitable materials, such as inadequate shaft cappings, or by unexpected occurrences that break capping seals, such as water surges in flooded mines (U.S. DOI, Bureau of Mines 1983a).

Solution Ponds (PLS and Raffinate Ponds)

During the operative life of a mine, solution ponds may or may not be non-RCRA waste management units, depending upon whether RCRA wastes are in the ponds. However, leach solution ponds become non-RCRA units upon mine closure, if they are left or reclaimed in place. (As in mine pits, this is a complicated issue; specific questions should be addressed to the nearest EPA Regional office.) These units may include pregnant solution ponds (where the copper-laden solution is collected), barren solution ponds (where lixiviant solution is held before being dispensed), surge ponds (to manage leachate during high precipitation events), make-up water holding ponds, and associated pipes or trenches. These units may be lined, depending on the quality of the solution contained and the permeability of the underlying formation. Any residual materials become wastes at closure.

PLS and raffinate ponds generally measure several hectares in size and, where the topography permits, are built into natural drainage basins. At most older copper leaching operations, the collection ponds and trenches through which the solutions flow were unlined. In addition, these areas received little or no surface preparation before leaching operations were initiated (U.S. EPA 1989e).

At newer leaching operations, liners have been installed in the collection ponds, and diversion channels have been installed to reduce seepage from the site and to increase the amount of solution recovery. This is particularly true of raffinate ponds that have been constructed within the last 10 years in conjunction with solvent extraction plants. Several facilities have also lined the pregnant liquid collection trenches and ponds. Generally, the trenches have been lined with concrete or a synthetic liner such as polyethylene. The collection ponds are typically lined with gunite, clay, or synthetics (U.S. EPA 1989e).

The San Manuel mine's PLS ponds have an unspecified type of liner. The Tyrone mine's PLS ponds are lined with compacted clay, HDPE, and gunite. The Morenci mine's PLS ponds are lined with 40-mil HDPE, with the Morenci Central Plant feed pond having a double liner and a leak detection and leachate collection system. The upper layer is a HDPE liner, and the lower layer is gunite with a leachate collection system located between the two liners. The PLS ponds at the Sierrita and Ray mines are located on bedrock with no leak detection systems or ground water monitoring systems. Most of the PLS ponds at the Inspiration mine are unlined on a bedrock base with concrete or concrete covering clay core dams. Bingham Canyon mine's PLS ponds are also clay-lined. Pinto Valley mine's PLS ponds are unlined and have rock shell and clay core dams that are keyed and grouted into bedrock. Recently, Cyprus replaced the Bagdad mine's old principal PLS hold pond with a new 100-mil HDPE-lined pond and collection system. In several of these cases, State or Federal regulations required that the PLS sumps be located at the base of heap and that the dump leaches have synthetic liners.

Little information was found for the raffinate ponds of the mines studied. However, raffinate ponds have been constructed in a manner similar to pregnant solution ponds. For example, Morenci's Central raffinate pond is constructed with a 40-mil HDPE liner over a gunite base forming a double liner with leak-detection

and leachate-collection systems. Sierrita's raffinate ponds have clay liners over bedrock. Inspiration stores excess raffinate, mine water drainage, and process water in several unlined inactive pits. No data were found on Inspiration's raffinate ponds. It appears that some mines, including Bingham Canyon, pump their raffinate directly to their dump leaches, thus eliminating the need for a raffinate pond.

1.6 ENVIRONMENTAL EFFECTS

Mine pits and underground workings; waste rock piles; tailings and other ponds; spent leach piles are of particular concern in the copper industry, because these are the areas in which toxic contaminants are most commonly found. Not all of these are waste management units, but they have the potential to present harm to the environment and thus, are discussed here. Contaminants associated with these areas may include heavy metals and, from some, acid drainage. These contaminants may degrade ground water, surface water, soil, and air quality during mine operation and after mine closure. A discussion of potential environmental effects associated with copper mining is presented in the following sections, with specific examples included, as appropriate. Actual release incidents occurring at copper mine sites are described in the Damage Case Section of this report.

This chapter does not purport to be a comprehensive examination of damage that may occur or that actually occurred at mining operations. Rather, it is a brief overview of some of the potential problems that can occur under certain conditions. The extent and magnitude of contamination depends on highly variable site-specific factors that require a flexible approach to mitigation. EPA is aware that many of the potential problems can be, and generally are, substantially mitigated or avoided by proper engineering practices, environmental controls, and regulatory requirements.

1.6.1 Potential Sources of Contamination

1.6.1.1 Mine Dewatering

Surface and underground mines may be dewatered to allow extraction of ore. This can be accomplished in two ways: pumping from ground water-interceptor wells to lower the water table and pumping directly from the mine workings. Dewatering can create a hydrologic cone of depression around the mine area and can prevent contamination from reaching the surrounding aquifer. After a mine is abandoned, pumping is generally stopped and the pit or workings fill completely or partially with water. Over time, this may lead to uncontrolled releases of mine water. Mine water can be pH neutral; however, in some cases, it is acidic and contaminated with metals, as well as suspended and dissolved solids.

1.6.1.2 Releases from Active Leach Units

Although a large proportion of the PLS generated at dump leaches is typically collected and recirculated some contaminated leachate may flow or percolate through and contaminate surrounding soils and underlying aquifers. As noted previously, the ore being leached is not considered a waste until leaching ends.

Releases of PLS occur from active leach operations (including dump and heap units, PLS and raffinate ponds, other solution collection ponds, and transport systems). Releases may occur due to infiltration beneath the unit; collection system overflow at the base of operations during snowmelt or large storm events; or failures in piles. Liners may weather, degrade, or puncture, thus losing their effectiveness in preventing releases to ground water and surface water (U.S. EPA 1989e).

Recently, more leach ponds have been constructed with liner and leak detection systems or have been sited in areas which naturally retard releases to ground water. Furthermore, ground water-monitoring systems are being installed with increasing frequency. For example, ground water-monitoring systems are now being required at some copper mines under the Arizona Aquifer Protection Permit program. In New Mexico (since 1976), permits are required for all facilities that the State determines may discharge to ground water.

As noted in Chapter 3 of this report, sulfuric acid is typically used as the lixiviant in the copper industry. The copper concentration in PLS generally ranges from 1.0 to 2.5 grams per liter (g/l) and typically has a pH of approximately 2.0. Quantification of actual fate, transport, and availability to potential receptors is not clear, due to the site-specific nature of these impacts. Similar releases in different settings can have very different environmental impacts.

1.6.1.3 Releases from Leach Units During and After Closure

There remains some potential for releases from dump and heap leach piles during and after closure. After the operation has been closed, shut down, or abandoned, runoff and leachate from the spent ore will continue to be generated. Runoff may contain constituents associated with the ore, such as heavy metals and TSS, and may be highly acidic. Site-specific factors, such as type of ore, precipitation and evaporation rates, soil alkalinity, and bedrock liners under leach units will affect the potential for releases.

Waste leach piles typically have large surface areas and contain highly permeable waste material. These factors act to increase the exposure of waste material to infiltrating liquids. When pyrite and sulfide minerals are exposed to air and water, sulfuric acid may be produced. Sulfuric acid may leach metals, yielding an iron-rich, acidic solution that contains high metals concentrations. If this solution infiltrates the underlying ground surface, it could reach the water table and potentially contaminate ground water.

Operators may continue to collect drainage from inactive dump piles. Information on Management practices for any drainage collected from inactive piles was not obtained for this report. However, the design capacity of collection systems is often based on containment of a specific storm event (e.g., the 10-year or 25-year maximum storm event).

1.6.1.4 Releases from Tailings Impoundments

Mill tailings may be particularly susceptible to leaching due to increased surface area exposure of sulfide/oxide metallic minerals not extracted during the milling operation. Surface-water discharges and seepage from tailings ponds and dams can have elevated concentrations of metals leached from the tailings.

Although the tailings may be neutralized with lime during the discharge or prior to disposal, residual chemical reagents can also remain in the tailings water. Flotation reagents, however, typically are used at very dilute concentrations to promote specific surface chemical reactions, and process wastewater is generally

recycled, rather than discharged. In addition, many of the organic collectors and frothers are relatively unstable and would rapidly volatilize or decompose if accidentally discharged into the environment.

Studies conducted by EPA in 1985 found that contaminants from waste storage impoundments (including tailings impoundment) are being released to underlying aquifers at most copper facilities. However, these releases may be caused by the use of outdated waste disposal practices (U.S. EPA 1985d). Many copper mines now are subject to permits that require the use of controls intended to protect ground water and surface-water quality. Such controls include, but are not limited to, liners, drainage collection systems, runoff/runoff controls, ground water-interceptor wells, and ground water-monitoring systems.

Many mines have modified their operations to reduce the quantities of waste/wastewaters generated and have improved waste management practices to limit the potential for environmental releases. For example, at the Inspiration Mine, water and waste circuits historically have been managed to maximize the efficient production of copper through leaching and to minimize the water and wastewater disposal costs, while meeting the needs of the smelter and mine. Since 1986, the mine has altered the water and wastewater circuits to reduce the volume of "process wastewater" by isolating the beneficiation circuit from watershed runoff, increasing reuse, and maximizing evaporation (U.S. EPA 1987). In addition, at other facilities, liners and ground water monitoring are more frequently used, and better facility-siting procedures are practiced.

1.6.1.5 Acid Drainage

Sulfide copper ores, such as chalcopyrite and bornite, typically contain sulfides of copper, lead, antimony, arsenic, and silver. During the mining of ore, the effects of the weathering may be increased due to the exposure of additional surface area and an increased oxidation rate. When the mineralized material is exposed to water, the oxidization of the sulfide minerals may lead to the formation of sulfuric acid (Doyle and Mirza 1990).

The generation of acids may then act to increase the dissolution, mobilization, and transportation of heavy and toxic metals noted above. Except for iron, all of these are toxic to humans and to aquatic life and are known to accumulate in the environment and concentrate in the food chain (Wills 1981).

Acid drainage refers to drainage that occurs as a result of the natural oxidation of sulfide minerals contained in rock that is exposed to air and water. This phenomenon is often referred to as acid mine drainage (AMD) or acid rock drainage (ARD); however, it is not necessarily confined to extraction activities and can occur wherever sulfide-bearing rock is exposed to air and water. Acid drainage can occur naturally without disturbance of the rock. Not all operations that expose sulfide-bearing rock will result in acid drainage. Acid drainage may not occur if the sulfide minerals are nonreactive or if the rock (such as limestone) contains sufficient natural potential to neutralize the acid (Berkeley Study 1985). Acid generation at mine dumps, ore piles, pits, and underground workings is dependent on the type of sulfide minerals in the ore and the surrounding rock, the climatic conditions, the hydrogeology of the area, and the availability of oxygen.

Water percolating through mine workings or tailings and waste rock piles may leach sulfides from the ore and surrounding rock and result in the formation of sulfuric acid. This acid solution may be discharged to ground or surface water, depending on the hydrology of the site. The acid generation potential, as well as the potential for release of other constituents, is increased after the rock is exposed to the atmosphere (i.e., an oxidizing environment). The rate of acid generation is also influenced by the presence or absence of bacteria. Bacteria, especially *Thiobacillus ferrooxidans*, are able to oxidize sulfur-bearing minerals. The effect of bacteria is pH-dependent; in some cases, lowering of pH over time produces a favorable environment for specific bacteria (leading to accelerated acid generation) once the pH reaches the appropriate level (Berkeley Study 1985).

In rock dumps, overburden piles, and other mine material piles that typically are unsaturated, acid drainage may start to form immediately. In contrast, because tailings piles may become dewatered over time, oxidation may lead to acid generation beginning long after the tailings have been deposited. In addition, the acid generation potential, as well as the potential for release of other constituents, is higher for tailings than for the in-place ore body because the tailings are finely ground or crushed, thus presenting greater particle surface area for oxidation to occur (Berkeley Study 1985). However, the moisture retention characteristics of tailings may act to inhibit an oxidizing environment.

The oxidation of sulfides may result in heavy metals and sulfosalts being solubilized (these include, but are not limited to, silver, cadmium, cobalt, copper, mercury, manganese, molybdenum, nickel, lead, zinc, arsenic, antimony, and selenium). Some metals will immediately form relatively insoluble oxysalts; others (notably cadmium, copper, and zinc) may accumulate in acid solutions (Berkeley Study 1985). In addition, heavy metals also may be found in any uncontrolled releases from leach circuits (see previous section on acid drainage).

Acid drainage has several characteristics (low pH, contaminants, and latency) that contribute to the severity of its effects. When pyrite is exposed to air and water by mining activity, it oxidizes, releasing acid which (in turn) can leach toxic metals from other minerals associated with the pyrite. The Berkeley study of problem mines in California notes that acidic drainage contains dissolved toxic metals (Berkeley Study 1985).

The latency of AMD is unique among the environmental hazards associated with mining wastes. When tailings are ponded, partial saturation and continual addition of basic material generally prevent acid release during the active life of the mine. After closure, however, acid formation may start and gradually migrate down through the tailings area, sometimes only reaching the ground water years or decades later (Berkeley Study 1985).

Both the acids and dissolved metals contained in AMD may be detrimental to aquatic life. Most sites generating large amounts of AMD also experience permanent elimination of, or damage to, aquatic life. This is typically confined to roughly 10 miles downstream from the point of discharge, although there are often more widespread fish kills during periods of high runoff. As the water moves downstream, the pH of the

AMD may be neutralized and the concentration of dissolved metals is reduced through dilution, adsorption, precipitation, and complexation (Berkeley Study 1985).

In ground water, AMD is diluted, attenuated by neutralization, and, possibly, chemically reduced as it moves from the site. The distance over which this occurs will vary with the reactivity of the aquifer. If ground water is used as a source of drinking water or for other purposes within this distance, the presence of AMD could pose risks to public health and the environment (Berkeley Study 1985). In many cases, particularly in the arid southwest (where many of the copper mines are located), the soils are alkaline and have ample capacity to neutralize acidic solutions and precipitate dissolved metals.

1.6.1.6 Beneficiation Reagents

In solvent extraction, the organic extractants are dissolved in kerosene or another nonreactive diluent. The extraction and stripping operations constitute a closed loop, with continual recycling of the organic extracts. All of the organic chemicals used in solvent extraction have low aqueous solubilities, and many circuits have a filter or similar operation to remove physically entrained organic chemicals from the raffinate. Consequently, loss of extractant is low, and there is little likelihood of significant discharge to the environment (Berkeley Study 1985).

1.6.2 Factors Affecting the Potential for Contamination

The potential for and impacts of environmental releases from wastes associated with copper mining activities are a function of many site-specific factors, including climate, geology, hydrogeology, access to and quality of local surface water, and distance to environmental receptors. Of particular note, many copper mines are located in scarcely populated, semiarid regions, where contaminant mobility is at least partially limited by minimal annual precipitation. However, heavy storm events can occur in these areas, which can increase the potential for releases to surface or ground water.

1.6.3 Affected Media

1.6.3.1 Ground Water/Surface Water

As described previously, mine workings (after mine closure), waste rock dumps, leaching operations, and seepage from tailings impoundments may be sources of ground water contamination. Contaminated ground water may recharge surface-water bodies (streams, ponds, and wetlands), impairing surface-water quality and providing an exposure route for contaminants. This may be especially important in alpine valleys, which usually have shallow alluvial aquifers. Withdrawal of contaminated ground water for use (i.e., drinking, agriculture, etc.) may be an exposure route for contaminants. Seasonal saturation due to snowmelt may also play a role in the transport of contaminants to ground water. It should be noted that, for those states with ground water protection programs, ground water quality is protected by permits that can require controls or demonstrations and verification that operations will have either minimal or no impacts on ground water.

Mine structures, waste rock dumps, and tailings impoundments may be constructed in areas that require the relocation of a surface-water drainage. Tailings impoundments are often constructed by damming valleys or other low-lying areas and dumping or slurring tailings to these units. These units are normally designed to prevent discharges to ground water and surface water. During infrequent high magnitude storm events, tailing dams may fail, releasing tailings to the local drainage system. Similar high-sediment loads can be generated from waste rock dumps.

1.6.3.2 Soil

Three types of environmental impacts are commonly associated with soils: erosion, sedimentation, and contamination. Erosion and sedimentation may be caused by land disturbances and removal of vegetation related to mining activities. Soil contamination may result from runoff from pits, mine workings, and tailings impoundments, as well as overburden, waste rock, mine development rock, ore, and sub-ore piles. In addition, deposition of wind-blown particulates from piles may also be a source of soil contamination. Contaminated soil may further act as a pathway for contaminant transport to ground and surface water and, in some instances, as a source of air pollutants due to re-entrainment and/or subsequent deposition of particulates.

Erosion related to mining may increase the loading of sediments into receiving streams. Sedimentation may result in elevated mortality rates among salmonoid embryos and fry because of a reduction in the permeability of spawning gravels (which prevents oxygen replenishment) and the blockage of interchange between subsurface and surface water. Indirect effects of increased turbidity and sedimentation include a reduction of photosynthesis and interference with respiratory activity (specifically, of gilled organisms). Gill irritation also exposes fish to infection by fungi and bacteria (Berkeley Study 1985).

Precipitation, adsorption, and settling of particulates reduce metal concentrations in receiving waters, but greatly increase concentrations in sediments. Sediments immediately downstream from mine discharges often contain high concentrations of heavy metals. Resuspension and mobilization of sedimented heavy metals can contribute to downstream metal loadings.

Soils may be contaminated by substances found in seepage or runoff from waste materials. Specifically, tailings may result in heavy metal, radionuclide, or other toxic constituent contamination of soils. Other sources of soils contamination include spills of fuels, flotation reagents, and cleaning solutions, as well as spills of other chemicals often used or stored at the mine site.

1.6.3.3 Air

The primary sources of air contamination at mine sites are fugitive dust emissions from: (1) mine pits and underground workings; (2) overburden, waste rock, mine development rock, ore, and sub-ore piles; (3) dried tailings; and (4) haul roads. During the active life of the mine, water may be applied to piles to control dust and prevent entrainment. After mine closure, revegetation or other stabilizing methods may be used for dust control. In addition to direct human exposure through inhalation, air may provide additional exposure routes

through deposition on surrounding soils and/or in local surface water. The potential contaminants are heavy metals, radionuclides, radon, and other toxics.

1.6.4 Damage Cases

Damages resulting from waste management from mining copper and associated minerals have been documented. Under the Comprehensive Environmental Response and Liability Act (CERCLA) (Superfund) and the Clean Water Act (CWA), EPA has documented contamination to ground water, surface water, air, and soil media.

1.6.4.1 National Priorities List

EPA has reviewed the copper mining sites on the NPL. Four sites on the Superfund NPL have problems related to copper extraction and beneficiation: the Celtor Chemical Works site in Humboldt County, California; the Torch Lake site in Houghton County, Michigan; and the Silver Bow Creek and Miltown Reservoir sites, both associated with the Clark Fork Superfund sites in southwestern Montana. Appendix 1-C provides general site descriptions and summaries of the environmental effects associated with these sites.

1.6.4.2 304(l) Sites

Section 304(l) of the Water Quality Act of 1987 requires States to identify bodies of water not meeting applicable water-quality criteria, to identify point source dischargers to these bodies of water, and to develop and require implementation of Individual Control Strategies for those point source dischargers that contribute significantly to exceedance of the water-quality criteria. Anaconda Minerals, Ferri Haggerty Mine, and Kennecott Utah Copper are sites identified under 304(l) as point source dischargers of contaminants related to copper mining activities. A summary of each is provided in Appendix 1-D.

1.7 CURRENT REGULATORY AND STATUTORY FRAMEWORK

Copper mining activities must meet the requirements of both Federal and State environmental regulations. Statutes administered by EPA, such as the CWA [33 United States Code (USC) Section 1251 et seq.] and the Clean Air Act (CAA) (42 USC Section 7401 et seq.), apply to mining sites regardless of their location. The extent to which other Federal regulations apply depend on whether a mining operation is located on federally owned land. Federal regulations exist for operations on lands managed by the Bureau of Land Management (BLM), the Forest Service (FS), the Fish and Wildlife Service (FWS), and the National Park Service (NPS). In addition, the Army Corps of Engineers has promulgated rules for construction and mining activities that have a potential impact on wetlands and navigable waters. Finally, operations must comply with a variety of State requirements, some of which may be more stringent than Federal requirements.

Federal air-quality regulations do not specifically address copper mining, but they do regulate sources of certain types of air pollution. Federal-water quality regulations, on the other hand, include effluent discharge standards for specific types of copper operations. Federal land management agencies have regulations that, in some cases, target particular types of extraction or beneficiation methods (e.g., placer mining turbidity issues). BLM has a policy for management of mining operations using cyanide and other leaching techniques. Similarly, State regulations do not usually target specific minerals, but regulate nonfuel mining in general.

This section summarizes the existing Federal regulations that may apply to copper mining operations. It also provides an overview of the operational permitting, water-quality, air-quality, waste management, reclamation, and wetlands protection regulations in the largest copper-producing State, Arizona.

1.7.1 Environmental Protection Agency Regulations

1.7.1.1 Resource Conservation and Recovery Act

The Solid Waste Disposal Act (SWDA) was first passed on October 20, 1965 (P.L. 89-272). In 1976, the Resource Conservation and Recovery Act (RCRA) comprehensively reenacted and amended the original act (P.L. 94-580, October 21, 1976). The statute was amended again on October 21, 1980, by the Solid Waste Disposal Act Amendments (P.L. 96-482). The next major amendments to the SWDA were the Hazardous and Solid Waste Amendments, enacted on November 8, 1984 (P.L. 98-616). The statute is now collectively referred to as "RCRA" and is intended to protect human health and the environment from problems associated with the management of solid and hazardous wastes. In 1978, EPA's proposed hazardous waste program identified a category of "special wastes," including mining wastes, that are generated in very large volumes. Under the RCRA Subtitle C hazardous waste program, special management standards were proposed for these wastes.

In 1980, prior to the promulgation of final hazardous waste regulations applicable to mining wastes, RCRA was amended to include what is known as the Bevill Amendment, Section 3001(b)(3)(A). The Bevill

Amendment provided a conditional exclusion from the RCRA Subtitle C hazardous waste requirements for wastes from the extraction, beneficiation, and processing of ores and minerals. The exemption was conditioned on EPA's preparation of a report to Congress on the wastes and a subsequent regulatory determination that regulation under Subtitle C was appropriate.

EPA met its statutory obligation with regard to extraction and beneficiation wastes with the 1985 *Report to Congress: Wastes From the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale* and a subsequent regulatory determination (51 FR 24496; July 6, 1986). In the regulatory determination, EPA decided that extraction and beneficiation wastes (including copper mining, milling, and leaching wastes) should not be regulated as hazardous wastes but should be regulated under a RCRA Subtitle D program specific to mining wastes.

Although copper processing is beyond the scope of this profile, EPA's regulatory activities related to processing wastes were reviewed for the purpose of gathering information. Through a series of rulemakings in 1989 and 1990, EPA also identified 20 mineral-processing wastes that qualified for the Bevill exemption; the exemption was removed from all other mineral-processing wastes, and as a result, these wastes must be managed as hazardous wastes if they are listed as such or if they exhibit one or more characteristics of a hazardous waste. Three of the 20 exempt wastes were from the primary processing of copper ores: slag, calcium sulfate wastewater treatment plant sludge, and slag tailings.

EPA studied these wastes and in 1990 submitted the *Report to Congress on Special Wastes from Mineral Processing*. In the subsequent regulatory determination (56 FR 27300; June 13, 1991), EPA determined that regulation of these 20 mineral-processing wastes (including the copper-processing wastes) as hazardous wastes under RCRA Subtitle C was not warranted because they exhibit negligible or no hazardous characteristics, pose low risk, and/or are not amenable to the requirements of RCRA Subtitle C.

As discussed above, wastes from the extraction and beneficiation of minerals are generally excluded from RCRA Subtitle C requirements by the Bevill Amendment and EPA's subsequent regulatory determination. EPA interprets this exclusion to encompass only those wastes uniquely related to extraction and beneficiation of ores and minerals; the exclusion does not apply to wastes that may be generated at an extraction or beneficiation facility but are not uniquely related to these operations. For example, waste solvents that are listed as a hazardous waste under 40 CFR 241.31 (Hazardous Wastes from Nonspecific Sources) and are generated at an extraction or beneficiation facility by cleaning metal parts are considered listed hazardous wastes since such parts cleaning is not uniquely related to extraction or beneficiation. These wastes must be managed as any other hazardous waste, subject to the requirements in 40 CFR Parts 260 through 271, or to State requirements if the State is authorized to implement the RCRA Subtitle C program, including those for manifesting and disposal in a permitted facility.

1.7.1.2 Clean Water Act

Under Section 402 of the CWA (33 USC Section 1342), all point source discharges to waters of the United States must be regulated by permit under the National Pollutant Discharge Elimination System (NPDES), with the exception of some storm water discharges covered by the 1987 amendments to the CWA. A point source is defined as any discrete conveyance, natural or man-made, including pipes, ditches, and channels. NPDES permits are issued by EPA or delegated States.

Effluent limits imposed on an NPDES permittee are either technology-based or water-quality-based. The national technology-based effluent guideline limitations have been established for discharges from most active copper mines and mills under the Ore Mining and Dressing Point Source Category (40 CFR Part 440, Subpart J). These regulations govern discharges from all types of copper extraction and beneficiation techniques.

Discharges from regulated operations must meet Best Available Technology/Best Practicable Technology/Best Available Demonstrated Technology (BAT/BPT/BADT) standards for cadmium, copper, lead, mercury, zinc, Total Suspended Solids (TSS), and pH. The specific effluent limitation guidelines for these pollutants are summarized in Table 1-7.

Table 1-7. Effluent Limitation Guidelines for Copper Mines and Mills (40 CFR Part 440)

Pollutant	BPT		BAT		NSPS	
	Daily Maximum	30-Day Average	Daily Maximum	30-Day Average	Daily Maximum	30-Day Average
Mine Drainage (see 40 CFR 440.132 for definition) [40 CFR 440.102(a), 440.103(a), 440.104(a)]						
Cadmium	N/A		0.10	0.05	0.10	0.05
Copper	0.30	0.15	0.30	0.15	0.30	0.15
Lead	0.6	0.3	0.6	0.3	0.6	0.3
Mercury	0.002	0.001	0.002	0.001	0.002	0.001
Zinc	1.5	0.75	1.5	0.75	1.5	0.75
TSS	30	20	N/A		30	20
pH	6.0 - 9.0		N/A		6.0 - 9.0	
Discharges from mills that employ froth flotation processes alone or in conjunction with other processes to beneficiate copper ores [40 CFR 440.102(b), 440.103(b), 440.104(b)]						
Cadmium	0.10	0.05	0.10	0.05	No discharge is allowed except the volume equal to the net precipitation excess (see below) or when contaminants in recycled water interfere with recovery. In such cases, any discharge is subject to mine drainage limits.	
Copper	0.30	0.15	0.30	0.15		
Lead	0.6	0.3	0.6	0.3		
Mercury	0.002	0.001	0.002	0.001		
Zinc	1.0	0.5	1.0	0.5		
TSS	30	20	N/A			
pH	6.0 - 9.0		N/A			
Process Wastewater from mine areas and mill processes and areas that use dump, heap, <i>in situ</i>, or vat leach processes to extract copper from ore or ore waste material [40 CFR 440.102(c), 440.103(c), 440.104(c)]:						
No discharge is allowed except the volume equal to net precipitation excess (i.e., precipitation on the treatment facility and surface runoff to the treatment facility minus evaporation). In such cases, the discharge is subject to mine drainage limits.						
Combined waste streams (e.g., mine drainage and froth flotation discharge):						
The quantity and concentration of pollutants are calculated as if the waste streams were discharged separately.						
Storm exemption:						
Regardless of the applicable limitation, if a facility is designed to contain the flow from the 10-year/24-hour storm event plus normal process wastewater, then discharges resulting from precipitation are allowed to take place, even if they do not meet the limitations or if they otherwise violate 40 CFR Part 440, provided that the facility takes reasonable steps to maintain treatment, minimizes the amount of overflow, and notifies EPA/State under "bypass" and "upset" provisions (see 40 CFR 440.131 for the exact conditions under which discharges are allowed).						

(Source: 40 CFR Part 440)

For discharges addressed by these guidelines, permit writers can establish additional technology-based limitations at a specific facility based on Best Professional Judgment (BPJ). For discharges not addressed by these guidelines, technology-based effluent limits are based solely on BPJ.

The CWA requires each State to develop water-quality standards to protect the designated uses of all receiving waters in the State. Permit writers must determine whether technology-based effluent limitations (i.e., BAT/BPT/BADT) are adequate to ensure that applicable water-quality standards are met. Where technology-based limits are not sufficiently stringent, water-quality-based effluent limitations must be developed. As a result, an NPDES permit may include technology-based effluent limitations for some pollutants and water-quality-based effluent limitations for others.

Contaminated storm water runoff from some mining operations has been documented as causing water quality degradation. In the past, point source storm water discharges have received limited emphasis under the NPDES program. However, EPA recently promulgated regulations that specifically address point source discharges of storm water from industrial facilities, including active and inactive/abandoned mine sites (55 FR 47990; November 16, 1990). These regulations require NPDES permits for all discharges of contaminated storm water. EPA has developed general permits that can authorize storm water discharges from mining facilities. EPA Regions and authorized States also may develop general permits or require individual storm water permits.

Some discharges from mine sites do not meet the traditional definition of a point source discharge. Specifically, diffuse runoff from tailings piles, overburden, waste rock piles, ore and sub-ore piles, and other mine areas often is not controlled through a discrete conveyance. As a result, this type of discharge frequently has been considered a nonpoint source discharge. Under Section 319 of the CWA, states are required to prepare nonpoint source assessment reports and to develop programs to address nonpoint sources on a watershed-by-watershed basis. Each state must report to EPA annually on program implementation and resulting water-quality improvements.

1.7.1.3 Clean Air Act

Under the CAA, Section 109 (42 USC Section 7409) established National primary and secondary air-quality standards for six criteria pollutants. These are known as the National Ambient Air Quality Standards (NAAQS). NAAQS set maximum acceptable concentration limits for specific airborne pollutants, including lead, nitrogen oxides, sulfur dioxide, carbon monoxide, ozone, and suspended particulate matter of less than 10 microns in diameter. To attain the air-quality goals set by CAA, States and local authorities were given the responsibility of bringing their regions into compliance with NAAQS (see CAA Section 110, 42 USC Section 7410). In addition, States were granted the authority to promulgate more stringent ambient-air-quality standards. Although fugitive dust control is not an explicit requirement of the CAA, most States require fugitive dust suppression measures as part of their State Implementation Plans (SIPs) to achieve NAAQS for particulate matter. Of the major mining States, only Alaska has no specific requirement to control fugitive dust.

Mining operations located in areas where NAAQS for one or more criteria pollutants are being exceeded ("nonattainment" areas) may be required to apply "reasonably available control technology" to limit the release of airborne pollutants from industrial and land-disturbing activities. Major new and modified sources constructed in areas where the NAAQS are not exceeded must undergo preconstruction review and apply "best available control technology." Such sources constructed in nonattainment areas are subject to the more stringent "lowest achievable emission rate" and may be required to obtain emissions offsets.

New Source Performance Standards (NSPS), authorized by Section 111 of the CAA, have been promulgated for metallic mineral-processing plants and can be found in 40 CFR Part 60, Subpart LL. Processing plants are defined as "any combination of equipment that produces metallic mineral concentrates from ore; metallic mineral processing commences with the mining of the ore." However, all underground processing facilities are exempt from NSPS. Also, NSPS particulate emission standards apply to stack emissions, but not to fugitive emissions. NSPS require operations to contain stack-emitted particulate matter in excess of 0.005 grams per dry standard cubic meter (dscm). In addition, stack emissions must not exhibit greater than 7 percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device. However, on or after 60 days following the achievement of the maximum production rate (but no later than 180 days after initial startup), operations must limit all fugitive emissions created during operation to 10 percent opacity.

State ambient air standards promulgated to meet or exceed Federal NAAQS are generally maintained through permit programs that limit the release of airborne pollutants from industrial and land-disturbing activities. Fugitive dust emissions from mining activities are often regulated through these permit programs, typically by requiring dust suppression management activities (e.g., water sprays).

Several other pollutants are regulated under the CAA by the National Emission Standards for Hazardous Air Pollutants (NESHAP). NESHAP provisions address health concerns that were considered too localized to be included under the scope of the NAAQS. The 1990 amendments to the CAA, however, require new emission limits for many airborne toxicants, including cyanide. These standards will be applied to specific industrial categories over the coming years. It should also be noted that the scope and stringency of NAAQS were increased under the 1990 CAA amendments.

Under the 1990 amendments to the CAA, Congress required EPA to establish technology-based standards for a variety of hazardous air pollutants, including cyanide compounds. In November 1993, EPA published a list of source categories and a schedule for setting standards for the selected sources. Furthermore, if a source emits more than 10 tons per year of a single hazardous air pollutant or more than 25 tons per year of a combination of hazardous air pollutants, the source is considered a "major source." Major sources are required to utilize the maximum available control technology (i.e., BAT) to control the release of the pollutants (CAA Section 112).

1.7.2 Department of the Interior

1.7.2.1 Bureau of Land Management

Copper mining operations on Federal lands generally are conducted on mining claims located pursuant to the General Mining Laws (the number of copper operations actually located on Federal lands was not determined). Under the 1872 Mining Law, a person has a statutory right to go upon the open (unappropriated and unreserved) public lands of the United States for the purpose of prospecting for, exploring, developing, and extracting minerals. Once a person has made a valuable mineral discovery and has properly located the claim pursuant to the mining laws, the person has broad possessory rights to develop the minerals upon which the claim was based.

Because of the broad nature of the claimant's possessory rights, the Federal agencies having management responsibilities over the lands upon which the claim is located cannot, in most cases, restrict mining operations entirely. Nonetheless, the surface managing agency can subject the mining operations to reasonable regulation to prevent "unnecessary and undue degradation" of Federal lands and resources. BLM's authority to regulate mining claim operations under this "unnecessary and undue degradation" standard derives from the Federal Land Policy and Management Act of 1976 (FLPMA), the statute which sets out BLM's general land management and planning authority.

BLM's general surface management regulations governing mining claim operations, which include copper mining operations, are found in 43 CFR Part 3809. These regulations cover general design, operating and reclamation standards, monitoring requirements, bonding requirements, environmental review requirements, and remedies for noncompliance. They establish three general use categories for mining operations, each eliciting different levels of oversight by BLM. These categories are:

(1) casual use operations (i.e., those that normally result in only negligible disturbances of Federal lands and resources and that require no prior notice to or approval from BLM), (2) notice-level operations (i.e., those that involve disturbances of 5 acres or less for which the operator must notify BLM prior to commencing surface disturbing activities), and (3) plan-level operations (i.e., those that involve disturbances of greater than 5 acres, and operations in some specified areas, for which the operator must obtain BLM approval of a plan of operations prior to commencing activity).

All operations, including casual use and operations under either a notice or a plan of operations, must be conducted to prevent unnecessary or undue degradation of the Federal lands. All operations must also be reclaimed and must comply with all applicable State and Federal laws, including air- and water-quality standards such as those established under the CAA and the CWA, and standards for the disposal of solid waste established under RCRA.

All mining operations are subject to monitoring by BLM to ensure that they do not cause unnecessary or undue degradation, and that all operators are responsible for fully reclaiming the area of their claim. In early 1992, BLM promulgated its *Solid Minerals Reclamation Handbook*, which is intended to ensure uniform reclamation standards on Federal and Indian lands (U.S. DOI, BLM 1992). Short-term goals are to stabilize disturbed areas; long-term reclamation goals are to restore (by shaping, stabilizing, revegetating, or otherwise treating) disturbed areas to provide a "self-sustaining, safe, and stable condition that provides a productive use of the land which conforms to the approved land-use plan for the area" (U.S. DOI, BLM 1992). The guidelines cover reclamation of exploration, development, and mining of all solid minerals, including copper. They require operators to develop, in consultation with regulatory agencies, reclamation plans that will serve as "binding agreements." These should be submitted with the plan of operations, notice, exploration plan, or mining plan and should include the requirements and mitigation measures recommended in Environmental Assessments (EAs) or Environmental Impact Statements (EISs).

By an internal Instruction Memorandum (IM) issued in 1990 (U.S. DOI, BLM 1990a), BLM established uniform standards for surface management of mining operations that use cyanide and other chemical leaching methods for mineral extraction on public lands. (Directed primarily at gold heap leaching operations, the policy also applies to "operations that use other leaching techniques for extractive purposes" and that use "potentially toxic or lethal concentrations in solution as the leachate medium." It was not determined if BLM applies the policy to copper-leaching operations that use sulfuric acid as the leachate medium.) This IM directs BLM Area and District offices to inspect all such operations at least four times a year. All facilities employing cyanide or other leaching techniques must be fenced and must ensure protection of the public, wildlife (including migratory birds), and livestock. Other requirements include the following:

- Facilities must be designed to contain the maximum operating water balance in addition to the water from a 100-year, 24-hour storm event. Containment ponds must be included in all containment systems.
- Leakage detection and recovery systems must be designed for heap and solution containment structures. Monitoring of ground and surface water through closure and final reclamation is required.
- Cyanide solution and heaps must be neutralized or detoxified.

BLM policy for bonding was established by a 1990 IM (U.S. DOI, BLM 1991). Under this IM, BLM does not require bonds for most casual use or notice-level operations. All plan-level operations, regardless of operation type, are required to post a bond. Bond amounts are set at the discretion of BLM (up to \$2,000 per acre, except as noted below), depending on the nature of the operation, the record of compliance, and whether it is covered by a satisfactory State bond. A 100-percent reclamation bond is required from all operators who have established records of noncompliance. Additionally, the IM requires the posting of a 100-percent reclamation bond for all operations that use cyanide or other leachates. The 100-percent bonding requirement applies only to portions of the operation that use cyanide or other leachates (i.e., leach heaps, pads, or dumps). (It was not determined if BLM applies this 100-percent bonding requirement to copper leaching operations.)

Mining claims located in BLM wilderness study areas are generally subject to stricter regulation than other mining claims. The regulations covering mining in wilderness study areas are found in 43 CFR Part 3802. The IM discussed above for cyanide management applies to relevant operations in wilderness study areas in addition to the 43 CFR Part 3809 regulations.

BLM has the authority to issue leases for copper on certain acquired (as opposed to public domain) lands. Although this is rarely done, such leases would be covered by the general regulations applicable to hardrock leasing found in 43 CFR Part 3500.

1.7.2.2 National Park Service and Fish and Wildlife Service

Generally, location of new mining claims is prohibited in most areas managed by NPS and FWS (both of which are under the DOI). Regulations in 36 CFR Part 9 govern activities on land managed by NPS under patented and unpatented mining claims already in existence prior to the time the lands were included within units of NPS. The regulations in 50 CFR Part 29 govern mining activities under mineral rights on lands managed by FWS that vested prior to the acquisition of the land by the United States. It was not determined whether any copper operations are located on lands administered by NPS or FWS.

1.7.3 Department of Agriculture

1.7.3.1 Forest Service

Although BLM has general management authority for the mineral resources on FS lands, BLM regulations governing activities under mining claims do not apply to units of FS. Instead, surface uses associated with operations under mining claims on FS lands are governed by regulations in 36 CFR Part 228, Subpart A. FS regulations generally mandate that operations under mining claims be conducted to minimize adverse environmental impacts on FS surface resources.

FS regulations are similar to BLM regulations and provide for FS consultation with appropriate agencies of the DOI in reviewing technical aspects of proposed plans of operation. However, FS regulations differ in that the general use categories do not specify acreage, as opposed to BLM's regulations, where the use category is based on the acreage disturbed. FS regulations require that persons proposing to initiate any operations that might disturb surface resources must file a notice of intent to operate with the district ranger with jurisdiction over the area to be affected. If the district ranger determines that the operations will likely cause a significant disturbance of surface resources, the operator must submit a proposed plan of operations. Neither a notice of intent to operate nor a proposed plan of operations are required for the locating or marking of mining claims; mineral prospecting or sampling that will not cause significant surface disturbance; operations that do not involve the use of mechanized equipment or the cutting of trees; or uses that will be confined to existing roads.

A proposed plan of operations must include a thorough description of the proposed site, the nature of the proposed operations, and measures for meeting environmental protection requirements. Operations must comply with applicable environmental laws and must, where feasible, minimize adverse environmental effects on FS resources. FS conducts environmental assessments of proposed plans of operations and, if necessary, prepares EISs pursuant to the National Environmental Policy Act.

The regulations specify standards for reclamation and provide that the district ranger may require a reclamation bond to cover the cost of reclamation. Where State bonding regulations exist, FS has established memoranda of understanding with the States to prevent double bonding. In these cases, the bond amount must meet the more stringent standard, whether it is that of the State or FS. Regulations specific to mining operations on FS Wilderness Areas are found in 36 CFR Part 293.

1.7.4 Army Corps of Engineers

Under Section 404 of CWA, the U.S. Army Corps of Engineers regulates activities with the potential to physically restructure wetlands or "navigable waters." In 1986, the Corps and EPA entered into an agreement (updated in 1990) on the definition of "fill material" for Section 404 permitting. The agreement provided that jurisdiction of some mining discharges would be determined on a case-by-case basis. Since then, the Corps has been responsible only for dredge and fill activities accessory to mining operations. These activities can include construction of sediment ponds and roads and placement of waste materials into "waters of the U.S." (which can include ephemeral drainages). Mining operations subject to Section 404 are generally regulated through Nationwide general permits issued by the Corps.

1.7.5 State Programs

1.7.5.1 Arizona

Arizona's optimal system presented in the Best Available Demonstrated Control Technology (BADCT) Draft guidance is described below for each type of mining unit. It is important to note that, besides the optimal technologies, the Arizona BADCT Draft guidance also presents several other less-protective options for each technology described. In addition, the BADCT Draft guidance presents alternative systems that may be considered as optimal under the specific conditions described for each scenario. These alternative systems may be substituted if justified by site-specific conditions. Finally, optimal BADCT recommendations only represent guidelines, and the specific design for each site is to be based on:

- Site suitability
- Extent to which site characteristics can function to control discharges
- Discharge control performance of other design elements
- Chemical characteristics of the discharge.

Arizona Optimal Waste Dump Disposal Technology

As previously stated, only "mining overburden returned to the excavation site, including any common material which has been excavated and removed from the excavation site and has not been subjected to any chemical or leaching agent or process of any kind" is exempt from BADCT requirements (Arizona Revised Statutes 49-250.B.5). However, no specific BADCT recommendations are stipulated for waste rock dumps in the Arizona BADCT Draft guidance.

Arizona Optimal Leach Dump Disposal Technology

The key minimal BADCT components in copper leaching operations are those design elements that address natural subgrade bases and surface-water run-off controls. The optimal technologies for these design elements are similar to those applicable to tailings ponds and heap leach units.

Arizona Optimal *In Situ* Disposal Technology

Control of the leach solution is the primary consideration. Ground water modelling and pilot-scale testing; controlled recovery of PLS by overpumping; proper grouting of abandoned exploration, injection, and recovery wells; and aquifer restoration are the key BADCT design components for *in situ* leaching operation design.

Arizona Optimal Tailings Disposal Technology

The key elements of BADCT for tailings disposal address depositional practices, tailing dam and impoundment design and construction, reuse of tailings water, and surface-water control. The specific design of tailings impoundment must accommodate a variety of factors, including the topography of the site, the availability and cost of materials, and the required storage capacity of the impoundment. Size is generally the main factor in the design of the tailing pond.

The treatment and deposition of tailings can effectively reduce contaminant levels in leachate, tailings permeability, and hydraulic head within tailings piles. Arizona's BADCT Draft guidance dictates that tailings should be thickened prior to deposition to remove the maximum amount of water practical for reuse in the mineral processing operation (i.e., using as little water as necessary to transport the tailings to the impoundment yet enough water to minimize pipeline wear). Thickened tailings may require treatment to neutralize pH or reduce contaminant levels. They should be deposited upstream from the tailings dam in a manner that achieves maximum size separation. Size separation will allow pervious, coarse material to be deposited close to the dam, while finer silt and clay-sized material is deposited further upstream.

Arizona's BADCT Draft guidance suggests recycling water from tailings ponds, after fine sediments have settled out, to reduce seepage. Several recommended methods are available to collect this water such as decant towers, bilge pumps, siphon systems, and drainage ditch systems. Removal of the water from the tailings impoundment can lessen the hydraulic head within the tailings pile and can help prevent the infiltration of leachate below the pile. The relative effectiveness of each is dependent on a number of site-specific factors; the main factor is the configuration of the impoundment itself. Proper maintenance is required for any of these systems to operate effectively.

Leachate collection systems at the base of tailings impoundments are recommended to collect leachate for reuse or treatment and disposal; this will reduce the potential for infiltration. Dams should be constructed to prevent failure and/or surface discharges since such discharges may adversely affect surface and ground water. Dams should be constructed in a stable area with a substrata able to bear the weight of the dam system. The types of materials used to construct the dam should prevent seepage through the dam when compacted. The height of the dam must be sufficient to maintain enough freeboard to allow for the retention of tailings water and runoff. Dam areas also should be protected from erosion and revegetated during the lifetime of the facility. This also should be done after closure, where practicable. Finally, the dam design should be integrated with the design of the leachate collection system.

In the copper industry, there is no single system which is best for all conditions. However, all acceptable systems must be able to retain waste material under the most intense storm event (100-year flood) expected during the life of the facility.

Site preparation, such as vegetation clearing and rough grading the surface, provides an added benefit in seepage reduction. The BADCT recommendation for copper tailings pond construction incorporates the use of the fines fraction of the tailings (slimes), as part of the liner system to seal the floor of the impoundment.

The effectiveness of using slimes as a liner is dependent on the particle-size distribution of the tailings solids. Laboratory or pilot-scale tests can verify whether or not the tailings slimes will perform well as a low-permeability liner for the impoundment.

Arizona Optimal Heap Leach Disposal Technology

The minimal BADCT requirements for heap leach operations are single liners of natural or synthetic material, on prepared subgrade with surface-water controls. The topography of the leach site generally determines the pad configuration. In some steep terrain, construction or installation of a liner may be technically infeasible and may not be necessary if site characteristics achieve performance similar to a liner system. In relatively flat areas, pads can be designed to drain to a single solution collection ditch outside the heap.

The degree to which subgrade preparation is necessary is dependent on the liner type and thickness, the physical characteristics of any overliner (drainage blanket), and characteristics of the ore to be leached. The extent of compaction is dependent on several factors: soil type; ability of the soil to function as an impermeable liner; and chemical attenuation. Installation of synthetic liners requires a smooth, stiff subgrade to avoid punctures and tears of the liner. Geotextiles installed beneath the liner may also be used to protect liner integrity.

Many heap leach operations utilize synthetic liners to maximize leach solution recovery. The appropriate liner type and thickness should be determined to maximize liner integrity based on consideration of the loading weight of the heap, the puncture properties of the subgrade and the overliner, and the resistance to chemical degradation by the leaching solution.

In addition to these recommendations, an overliner of porous sand or geonet/geotextile material is also recommended for heap leach designs to protect liner integrity. Drainage pipes may also be necessary to reduce head on the liner and promote collection of PLS.

Arizona Optimal Vat Leach Disposal Technology

Although the Arizona BADCT Draft guidance does not specifically address "vat leaching," it does designate vat leaching operations as facilities that may impact ground water. As such, they are required to follow BADCT for pollution prevention. Other facilities associated with vat leaching operations (such as chemical storage, processing areas, and pipelines) are also addressed in sections of the BADCT Draft guidance.

Arizona Optimal Leach Circuit Surface Impoundments

The technologies presented here are generally appropriate for new facilities. However, it may be feasible at some existing sites to employ some of these controls (depending on the amount of discharge reduction that could be achieved). The same design parameters apply to the construction of all types of leach circuit

impoundments (including the pregnant, barren, and makeup water impoundments). Therefore, the BADCT Draft guidance document described below is applicable to all of these units.

Surface impoundments should be designed and constructed with double liners and leak detection systems installed between the liners, unless site conditions provide for equally effective alternatives. Such alternatives might include siting on impervious bedrock or application of other technologies (i.e., grouting). Liners may be constructed of two synthetic liners or with a primary synthetic liner and a natural secondary liner. The specific types of liner material (i.e., synthetic or natural) and thicknesses should be based on site-specific conditions and chemical and physical characteristics of the materials to be contained in the impoundment.

All new ponds should be designed with leak detection and collection systems. For double-lined ponds, these systems generally consist of a pervious layer between the liners, with any type of seepage being collected and recovered. The specific design of each system will depend on the site topography. Other types of systems may rely on preparation of the subgrade and surface-water controls similar to those described above.

Leach circuit auxiliary units, which are used for industrial chemical storage, waste discharge, waste storage and disposal, or wastewater treatment, should be designed according to Arizona's BADCT Draft guidance. Specifically, acid solutions used in the electrolytic process should be stored and handled in a manner consistent with the chemical storage BADCT considerations. Plastic pipes or pipes coated with other inert materials should be used in all leach circuit pumping. A single liner (synthetic or natural) may be used for solution drainage ditches.

Usually, the SX/EW units are combined into one leach circuit. In some cases, where the mine uses a cementation-type leach circuit, it may have an independent electrowinning circuit. The same BADCT design recommendations described above for the leach circuit impoundment apply to all electrowinning processing facilities with separate surface impoundments. Additionally, all ancillary equipment (i.e., plumbing and drainage ditches) must meet the requirements described above.

Arizona Optimal Mine Water Handling Technology

The operator should ensure that mine-water collection points or holding ponds have sufficient holding capacity for storm events. In areas where the quantity of mine water generated exceeds the need for process water, it may be discharged in an acceptable manner. The decision on whether to discharge should be based on types and concentrations of pollutants compared to State and Federal CWA standards.

Mine sites should be designed with offsite and onsite runoff controls to prevent discharges caused by runoff from precipitation. Surface-water containment areas (such as holding ponds) are required to be capable of handling a 100-year, 24-hour storm event; and drainage ditch diversions systems capable of controlling the 100-year, 24-hour storm event. Surface-water drainage systems should be designed separately from the process-water systems (such as tailings impoundments). At many mines, the tailings pond may also act as a surface-water holding pond during storm events. The use of a tailings pond for storm water control must be

carefully planned to prevent increasing the potential for overtopping, erosion, berm washout, or seepage. This method of surface-water control may be advantageous as a source of makeup water for mines located in dry climates where water supplies are scarce.

Surface-water runoff should be rerouted by drainage diversion systems whenever possible to avoid unnecessary flooding of process areas/units. The design of runoff control systems should be sufficient to handle the maximum amount of runoff generated by a 100-year, 24-hour storm event (as necessary to protect the specific watershed). However, at the same time, a facility's need to "harvest" additional water also should be considered.

1.8 REFERENCES

- American Conference of Governmental Industrial Hygienists. 1989. *Threshold Limit Values and Biological Exposure Indices for 1988-1989*. Cincinnati, Ohio. Second Printing.
- American Mining Congress Journal. 1991 (February). "Phelps Dodge Discovers Arizona Copper Deposit." p. 16.
- Anaconda Minerals Corporation. 1987 (September). *Mill Creek RI/FS, Final Remedial Investigation Report, Mill Creek, Montana, Anaconda Smelter Superfund Site, First Operable Unit*. Document prepared for U.S. Environmental Protection Agency.
- Arizona BADCT Guidance Document for the Mining Category, Draft Guidance Document. 1990. Arizona Revised Statute 49-243 B.1., For Permitted Facilities Utilizing BADCT.
- Armburst, J., 1988a (December). "Blasting and Dewatering a Drop Art at Morenci Open Pit." *Mining Engineering*. p. 1107.
- ASARCO. 1991 (February 4). *Ray Unit Tailing Impoundment Alternative Analysis*. Appendix 11.19. Submitted to EPA Water Management Division Region IX Wetlands Program.
- Bagdad Copper Corporation. Undated. *Liquid Ion Exchange and Electrowinning Plant*. Bagdad, Arizona.
- Banghart, R.W. 1988 (April 14). *Winning Copper With Sulfuric Acid - Ray Arizona*. Staff ASARCO Ray Unit, The Sulfur Institute. Washington, DC.
- Beard, R.R. 1990 (October). *The Primary Copper Industry of Arizona in 1989*. State of Arizona Department of Mines and Mineral Resources, Special Report No. 16.
- "Berkeley Study". 1985 (June 13). *Mining Waste Study Final Report*. Prepared by the University of California at Berkeley, July 1, 1988.
- Betchel Civil and Minerals, Inc. 1981 (July). Chase Creek Drainage Study Phase II, Engineering Feasibility Report (Draft). Prepared for Phelps Dodge Corporation, Morenci Branch.
- Biswas, A.K., and W.G. Davenport. 1976. *Extractive Metallurgy of Copper*. Pergamon International Library, International Series on Materials Science and Technology, Vol. 20, Chapter 2.
- Builder Architect/Contractor Engineer. 1981 (April). *Phelps Dodge Corporation: One Hundred Years of Progress*.
- Business Wire Inc, Business Editors. 1989 (August 3). "Phelps Dodge Corporation Announces \$112 Million Project."
- Crozier, F.D. 1979 (February). "Flotation Reagent Practice in Primary and By-product Moly Recovery." *Mining Magazine*. p. 1.
- Cumming, A.B. (Chairman of Editorial Board). 1973. *SME Mining Engineering Handbook*. Society of Mining Engineers, AIME. New York, New York.

- Cyprus Miami Mining Corporation. 1989 (October 26). *Investigation of Acid Water Contamination along Miami Wash and Pinal Creek, Gila County, Arizona*. Prepared by Hydro Geo Chem, Inc. Claypool, Arizona.
- Deming, D. 1991. Correspondence from Dalea Beming, Magma Copper Company, to ADEQ, Office of Water Quality, Re: Groundwater Quality Protection Permit No. G-0058-11; April 29, 1991.
- Doyle, F.M. and A.H. Mirza. 1990. "Understanding the Mechanisms and Kinetics of Acid and Heavy Metals Release from Pyritic Wastes." In *Proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes*, Berkeley, California, May 30 - June 1, 1990, Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado.
- Ellingson, D. 1987 (September). *Dam Will Protect River From Acid*. ENR, p. 24.
- Engineering and Mining Journal*. 1991 (March). "Phelps Dodge Corp. Has Announced the Discovery of a Substantial Open-pittable Copper Mineralization." p. 71.
- Engineering and Mining Journal*. 1990 (January). "Technology Turns Southwest Waste into Ore." Vol. 191, pp. 41-44.
- Engineering and Mining Journal*. 1988 (September). "The Ray Unit Today: Big Reserves, High Yield, & Still Growing." pp. 42-47.
- Engineering and Mining Journal*. 1982 (June). "Morenci Mine: Planners Evaluate Long-term Ore and Waste Haulage Options." pp. 86-87.
- Engineering and Mining Journal*. 1980 (June). "Kennecott New SX Plant on Stream." p. 35+.
- Engineering and Mining Journal*. 1971a (August). "New Tailings Pretreatment Facilities Produce 110 Tons Per Day Of Concentrate At Kennecott Operation." p. 26.
- Engineering and Mining Journal*. 1971b (April). "Chemical Treatment of Waste Tailings Puts an End to Dust Storms." pp. 104-105.
- Epler, B., 1989a (August). "PD Announces \$112 Million Expansion at Morenci." *Southwestern Pay Dirt*. p. 9A.
- Epler, B., 1987b (February). "Phelps Dodge Gets Ground Water Permit for Morenci SX-EW." *Southwestern Pay Dirt*. p. 10A.
- Epler, B., 1986a (September). "Phelps Dodge and EPA Settle Chase Creek Pollution Suit." *Southwestern Pay Dirt*. p. 6A.
- Epler B. 1985 (April). "Magma to Develop Open-Pit Mine, SX/EW Plant at San Manuel." *New Mexico Pay Dirt*.
- GCM Services Inc. 1989 (June). *Site History of Smelter Hill - Anaconda Smelter NPL Site*. Document developed for ARCO Coal Company.

- Graybeal, F.T., and W.C. Larson, 1989. "In Situ Copper Mining at the Santa Cruz Deposit, Casa Grande, AZ." In: Mining Technology, Economics and Policy 1989. 1989 American Mining Congress Mining Convention. ISSN 0748-1993.
- Griffin, A.H., W.E. Martin, and J.C. Wade. 1981 (February). "Water Use and Water Conservation by the Copper Mining Industry." *Water Resources Bulletin*, Vol. 17, No. 1. pp. 57-61.
- Intermountain Pay Dirt*. 1985 (July). "Kennecott Preparing for Test User of RMD's Silicate Ore Plant." Karen Walenga. pp. 16A.
- Intermountain Pay Dirt*. 1982 (March). "Ray Has Been Consistent Producer from Underground, Open Pit." pp. 7+.
- Jordan, C.L. 1984 (December 27). "Phelps Doge Shuts Down Morenci Smelter." *American Metal Market*, Vol. 92, p. 1(2).
- Koop, S.W. Undated. *Pinto Valley Leaching SX/EW: Pinto Valley Copper Corp.*, Presentation to the Hydrometallurgy Division of Arizona American Institute of Mining Engineers Spring Meeting Miami, Arizona.
- Kordosky, G.A. and J.P. Dorlac. 1986. *Capital and Operation Cost for the Unit Processes of Solvent Extraction and Electrowinning as Applied to Copper Recovery*. Henkel Corporation Tucson Arizona, Society of Mining Engineers Fall Meeting Presentation at St Louis, Missouri September 7-10, 1986.
- Kordosky, G.A. and J.M. Sierakoski. Undated. *Practical Aspects of Copper Solvent Extraction: Reagent Selection, Circuit Design and Operation*. Henkel Corporation Tucson, Arizona.
- Langton, J.M. 1973. *Ore Genesis in the Morenci-Metcalf*. In SME preprint 72147, AIME Annual Meeting, San Francisco, California. February 1972. p. 247-257.
- Life Systems, Inc.* 1989 (December 20). "Endangerment Assessment for the Anaconda Smelter Site, Final Draft for the Flue Dust Operable Unit."
- Magma Copper Company. 1992. Description of Mining and SX/EW Operation, Section V of Magma Copper Company's response to request for information following EPA's mine site visit in May 1992.
- Maletzke, J.D. 1989 (July 28). Technical Memorandum Number 1. Memorandum to Lori Ransome.
- Mining and Minerals*. 1986 (August/September). "Phelps-Dodge Fired for Environmental Violations." p. 23.
- Mining and Minerals*. 1985 (June/July). "EPA Charges Phelps-Dodge with Clean Water Act Violations at Morenci." p. 14.
- Mining Engineering*. 1988 (November). "BP Minerals Completes \$400 Million Modernization At Bingham Canyon." pp. 1017-1020.
- Mining Magazine*. 1975 (April). "Pinto Valley - Another Major Copper Porphyry Open-Pit For Arizona." Vol. 133 No. 5. pp. 344-351.

- McWaters, T. 1990 (September). "Developing Magma's Tailings Leach Operation." *Mining Engineering*. pp. 1075-1080.
- Moolick, R.T. and Durek, J.J. 1966. *The Morenci District -- Geology of the Porphyry Copper Deposits, Southwestern North America*. S. R. Titley and C. L. Hicks, ed., University of Arizona Press.
- National Priorities List, Supplementary Lists and Supporting Materials*. 1990 (February).
- Niemi, L. 1980 (August). "Cyprus Bagdad: Successful Expansion Creates "State-Of-The-Art" Copper-Molybdenum Producer In Northwest Arizona." *Engineering and Mining Journal*. pp. 56-63.
- Pflieder, E.P. 1973. "Planning and Design for Mining Conservation Section." In *SME Mineral Processing Handbook*. Society of Mining Engineers, AIME, New York.
- PR Newswire SF2. 1987 (May 11). "U.S. EPA Commends Pinto Valley Copper Co. for Successfully Restoring the Environmental Integrity of Pinto Creek following a Discharge of Tailings."
- PR Newswire SF3B. 1985. "EPA Files Suit against Phelps Dodge Corporation."
- Press F., and R. Siever. 1978. *Earth*, 2nd Ed., W.H. Freeman and Company, San Francisco.
- Ransome, L. (Donahue). 1990 (February). Technical Memorandum Number 7. Memorandum to Project Files.
- Reed and Associates. 1985 (November 11). *Proposal for Groundwater Discharge Permit Application Duval Corporation, Sierrita Mine, Pima County, Arizona*.
- Robertson, A.M. 1987. *Alternative Acid Mine Drainage Abatement Measures*. Steffen, Robertson, and Kirsten (BC) Inc. Vancouver, BC, Canada.
- Ross, Benjamin. 1986 (April 4). *Review of Ground-Water Permit Application for Morenci Solvent Extraction Plant and Dump Leaching*. Prepared from Eastern Arizona Environmental Coalition by Disposal Safety Incorporated.
- Ross, Benjamin. 1985 (December 6). *Ground-Water Contamination in the Clifton-Morenci Area*. Prepared for Occupational Health Legal Right Foundation by Disposal Safety Incorporated.
- Salt Lake Tribune*. 1988 (June 4). "BP Minerals is Resolving Bingham Canyon Water Problems." Salt Lake City, Utah. pp. 4A, 5A.
- Skillings' Mining Review*. 1988 (February 27). "Tyrone-Morenci-Chino; Mayor Recommendations Implemented in 1984." p. 6.
- Skillings' Mining Review*. 1975 (June). "Phelps Dodge Corp., Metcalf Porphyry Type Deposit." p. 13-17.
- Southwestern Pay Dirt*. 1991 (July). "Phelps Dodge Relocates Highway at Morenci Mine." p. 4A.
- Southwestern Pay Dirt*. 1989b (August). "In-pit Crushing and Conveying to Reduce Costs." p. 6A.

Southwestern Pay Dirt. 1987a (February). "Modifying Ray SX/EX to Treat Sulphide Leach: Manager Reports Smooth Transition Says Operations Will Remain the Same." pp. 4A+.

Southwestern Pay Dirt. 1986c (January). "Phelps Dodge Announces \$90 Million SX-EW Plant at Morenci." p. 5A.

State of Arizona. 1987 (January). *Groundwater Quality Protection Permit*. Issued to Phelps Dodge Morenci, Inc., Arizona Revised Statutes 36-1851, A.C.R.R. Title 9, Chapter 20, Article 2. Phoenix, Arizona.

State of Arizona, Department of Environmental Quality. Undated. Unpublished data regarding Arizona Water Quality Management Processes. Phoenix, Arizona.

State of Arizona, Department of Mines and Mineral Resources. 1991. *Directory of Active Mines in Arizona; 1991*. Phoenix, Arizona.

State of Arizona, Permitting Section. 1990. *Personal Communications Between Various Staff Persons and U.S. EPA, Office of Solid Waste*. Phoenix, Arizona.

State of Michigan, Michigan Department of Natural Resources, Surface Water Quality Division. 1990. *Fish Growth Anomalies in Torch and Portage Lakes 1974-1988 Houghton County, Michigan*. MI/DNR/SWQ-90/029.

State of New Mexico, New Mexico Environmental Improvement Division. 1986. Internal Memorandum and Letters.

State of Utah, Utah Department of Health, Division of Environmental Health, Bureau of Solid and Hazardous Waste, Technical Service Section. 1987 (January 12). *Screening Site Inspection Reassessment*. Preliminary Assessment Report Bingham Creek Channel, EPA ID# UTD980959324. Anaconda Tailings EPA ID# UTD98095931.

State of Utah, Utah Department of Health, Division of Environmental Health, Bureau of Water Pollution Control. Undated. *Kennecott Copper Corporation Utah Pollutant Discharge Elimination System Permit Number UT0000051*. Salt Lake City, Utah.

Stout, K.S. 1980. *Mining Methods and Equipment*. Montana College of Mineral Science and Technology, Butte, Montana. Colorado School of Mines Library.

Taggart, A.F. 1945. *Handbook of Mineral Dressing, Ores and Industrial Minerals*. John Wiley and Sons, Inc., New York, New York.

The Northern Miner. 1991 (January 7). "Phelps Excited by Morenci Extension." p. 3.

Thompson, W.E., R.L. Hoye, and J.S. Greber. 1984. "Evaluation of Management Practices for Mine Solid Waste, Storage, Disposal, and Treatment, Conference Proceedings." In *Proceedings of the Seventh National Ground Water Contamination*, Las Vegas, NV, September 26 - 28, 1984, Source National Water Well Association, Worthington, Ohio.

U.S. Congress, Office of Technology Assessment. 1988 (September). *Copper: Technology and Competitiveness*. OTA-E-367. U.S. Government Printing Office. Washington DC.

- U.S. Department of the Interior, Bureau of Land Management. 1992. *Solid Minerals Reclamation Handbook*. BLM Manual Handbook H-3042-1. Published in Washington, D.C.
- U.S. Department of the Interior, Bureau of Land Management. (October 4) 1991. Instructional Memorandum No. 90-582; Change 1; Modification of the Bonding Policy for Plans of Operations Authorized by 43 CFR 3809.
- U.S. Department of the Interior, Bureau of Land Management. (August 6) 1990. Instructional Memorandum No. 90-566; Cyanide Management Policy for Activities Authorized Under 43 CFR 3802/3809.
- U.S. Department of the Interior, Bureau of Mines. 1992. *Copper 1990 Annual Report* (by Janice Jolly).
- U.S. Department of the Interior, Bureau of Mines. 1993a. *Mineral Commodity Summaries 1993*. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1990a. *Mineral Commodity Summaries 1990*. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1993b. *1991 Copper Annual Report* (by Janice Jolly). Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1989. *Minerals Yearbook - 1989*. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1987a. "Froth Flotation in the United States, 1985" (by Edelstein, D.). Information Circular. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1985. "Mineral Facts and Problems 1985 Edition" (by Jolly, J.L.). Bulletin 675. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1984 (November). "Copper, Lead, Zinc, Gold, and Silver Waste Disposal Activities and Practices in the United States" (by Coppa, L.V.). Open File Report, OFR 4-84. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1977. "Design Guide for Metal and Nonmetal Tailings Disposal" (by Soderberg R.L. and R.A. Busch). Information Circular 8755. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1965a. *Copper: A Materials Survey*. (by A.D. McMahon). IC 8225. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. 1965b. *Design Guide for Metals and Nonmetal Tailings Disposal*. Washington, DC.
- U.S. Department of the Interior, Bureau of Mines. Unpublished. *Copper Mine Address and Current Status All Mines Operating 1984-1987 and Status of Domestic Copper Mines, Leaching, and SX Operations*. Washington, DC.
- U.S. Department of the Interior, Geological Survey. 1973. "Copper". In *United States Mineral Resources*. Geological Survey Professional Paper 820, by F.S. Simons and W.C. Prinz. Reston, Virginia.

- U.S. Department of Labor, Mine Safety and Health Administration, Safety and Health Technology Center. Unpublished. *Technical Support Database Document September/October 1990 Metal Mines Address Listings*. Denver, Colorado.
- U.S. EPA, Office of Solid Waste. 1994 (August). *Design and Evaluation of Tailings Dams*.
- U.S. EPA. 1990a (July). *Report to Congress on Special Wastes from Mineral Processing*. EPA/530-SW-90-070C. Washington, DC.
- U.S. EPA, Office of Solid Waste. 1990b (June 14). Telecopy from R. Rimelman, SAIC, to Steve Hoffman and V. Housman, U.S. EPA, Office of Solid Waste, regarding mining operations listed under Section 304(l) of the Clean Water Act. Prepared for U.S. EPA by Science Applications International Corporation under EPA Contract No. 68-C8-0066.
- U.S. EPA. 1990c (May). *Final Draft: State Regulatory Programs Mining Waste State Regulatory Summaries*. Prepared by CDM Federal Programs Corporation. Washington, DC.
- U.S. EPA, Mining Waste Staff. 1990d (March). Personal Contact with U.S. EPA Region 9 and the Arizona State Department of Environmental Quality, Surface Water and Compliance Monitoring Sections.
- U.S. EPA. 1990e. *Final Remedial Investigation Report Operable Unit 1: Torch Lake*. Prepared by Donahue and Associates, Inc. under U.S. EPA Contract No. 68-W8-0093.
- U.S. EPA. 1990f. *Site Assessment for Torch Lake, Houghton, County, Michigan*. Prepared by the Weston-Major Programs Technical Assistance Team. under U.S. EPA Contract No. 68-01-7367. Washington, DC.
- U.S. EPA. 1989a (September 29). *Superfund Site Close-out Report, Celtor Chemical Works, Hoopa Valley Indian Reservation, Humboldt County, California*. Washington, DC.
- U.S. EPA, Region IX. 1989b (June 27). *Phelps Dodge Corporation, Morenci, Screening Site Inspection Reassessment*. Temporary Highway 666, Morenci, Arizona 85540. EPA ID# AZD039055413. Prepared for U.S. EPA by Ecology and Environment, Inc. (Campbell, L. and T. Beer).
- U.S. EPA. 1989c (June 2). *State Regulations of Solid Wastes from the Extraction, Beneficiation, and Processing of Non-fuel Ores and Minerals*. Prepared by CDM Federal Programs Corporation. Washington, DC.
- U.S. EPA, Region IX. 1989d (Spring). *CERCLA Site Inspection Report at Cyprus Sierrita Corporation*. Pima County, Arizona, AZD035940410. Tucson, Arizona. Prepared for U.S. EPA by Errol L. Montgomery and Associates, Inc.
- U.S. EPA. 1989e. *Final Report: Copper Dump Leaching and Management Practices that Minimize the Potential for Environmental Releases*. Prepared by PEI Associates, Inc. (Hearn, R. and Hoye, R.) under U.S. EPA Contract No. 68-02-3995.
- U.S. EPA. 1988a (August 31). *Final Draft Summaries: Selected States Mining Regulatory Programs with Supporting Interview Notes*. Prepared by CDM Federal Programs Corporation. Washington, DC.

- U.S. EPA, Region IX. 1988b (March 28). *CERCLA Site Inspection Report at Cyprus Sierrita Corp. Pima County Arizona*. (AZD035940410). Prepared by Ecology and Environment, Inc. (Robertson C.A.). San Francisco, California.
- U.S. EPA, Region IX. 1988c (March 28). *CERCLA Site Inspection Report of the ASARCO, Inc. Mission Unit Mine*. PAN number FAZ0068SAA; Site EPA ID number: 8ZT000623678; Inspection ID number: C(87)C247; TDD Number F9-8701-021. Prepared by Robertson, C.A. and M.V. Anderson.
- U.S. EPA. 1988d (January 6). *Superfund Record of Decision: Anaconda Smelter/Mill Creek, Montana*. Washington, DC.
- U.S. EPA, Region IX, Water Management Division. 1987 (April). *NPDES Sampling Documentation and Results Report* (by G.V. Arthur). Washington, DC.
- U.S. EPA, Office of Research and Development and Office of Solid Waste. 1986 (November). *Site Specific Data Summary Forms - Facilities Involved in the Extraction and Beneficiation of Ores and Minerals*. Prepared for U.S. EPA by PEI Associates, Inc.
- U.S. EPA. 1985a (December). *Report to Congress - Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale*. EPA 530-SW-85-033. Washington, DC.
- U.S. EPA, Office of Emergency and Remedial Response. 1985b (September 30). *Superfund Record of Decision, Celtor Chemical Works, California, (Second Remedial Action)*. EPA ROD R09-85/009. Washington, DC.
- U.S. EPA. 1985c (March). *Draft Remedial Investigation Report, Celtor Chemical Works Site, Hoopa, California*. Washington, DC.
- U.S. EPA. 1985d (February 8). *Summary of Environmental Incidences from the Disposal of Mining Waste*. Prepared by Science Applications Services for U.S. EPA under Contract No. 68-017053. Washington, DC.
- U.S. EPA. 1984a (December). *Overview of Solid Waste Generation, Management, and Chemical Characteristics*. Prepared for U.S. EPA under Contract Nos. 68-03-3197, PN 3617-3 by PEI Associates, Inc.
- U.S. EPA. 1984b (March 5). *Summary of Damage Sites from the Disposal of Mining Waste Vols. 1 and 2*. Prepared by SCS Engineers for U.S. EPA under Contract No.68-023179. Washington, DC.
- U.S. EPA, Office of Emergency and Remedial Response. 1983a (October). *Superfund Record of Decision, Celtor Chemical Works Site, California*. EPA ROD R09-83/001. Washington, DC.
- U.S. EPA, Office of Solid Waste. 1983b (March). *Lining of Waste Impoundment and Disposal Facilities*. NTIS - PB 86-192796, SW-870. Washington, DC.
- U.S. EPA, Office of Solid Waste. 1991 (June 21). *Mining Sites on the National Priorities List. Final Draft. NPL Site Summary Reports Volumes I-V*. NTIS - PB 92-124767, PB 92-124775, PB 92-124783, PB 92-124791, PB 92-124809.

- U.S. EPA. 1976 (December). *Water Pollution Caused by Inactive Ore and Mineral Mines - A National Assessment*. Prepared for U.S. EPA by Martin, H.W. and W.R. Mills.
- U.S. EPA, Region IX. Undated. *Aquifer Restoration Under the Federal Clean Water Act* (by Arthur, G.V. and S. Tolle).
- U.S. Geological Survey. 1973. *Mineral Resources of the U.S.* Prof. Paper 820.
- Vancas, M.F. 1987 (February 27). *Development of the San Manuel Oxide Ore Reserves - Present and Future*. American Institute of Mining Engineers, Society of Mining Engineers Littleton, Colorado Annual Meeting. Number 87-82.
- Walenga, K., 1986b (September). "Plant to Yield 100 Million PPY of 30-Cent Copper." *Southwestern Pay Dirt*. p. 4A.
- Weiss, N.L. 1985. *SME Mineral Processing Handbook*. Editor-in-Chief, Vols. 1 and 2, Society of Mining Engineers of AIME, Seeley W. Mudd Memorial Fund of AIME, New York, New York.
- Wills, B.A. 1981. *Mineral Processing Technology, An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery (in SI/Metric Units)*. Second Edition. Pergamon Press. 163 pp.
- Woodward-Clyde Consultants. 1990. *Ground Water Quality Investigation, Upper Mangas Valley, Tyrone Mine*.
- Zipf, P. 1986 (August 28). "Phelps Dodge Settles with Justice on Arizona Water Pollution." In *American Metal Market*. Vol. 94, p. 1(2).

APPENDIX 1-A
SUMMARY OF COMMENTS AND EPA RESPONSES

Comments on the Draft Industry Profile and EPA Responses

A draft of the *Industry Profile: Copper* was provided for review and comment to the following organizations: U.S. Department of the Interior (DOI) Bureau of Mines, the Western Governors' Association, the Interstate Mining Compact Commission, the American Mining Congress (AMC), and environmental organizations for their review and comment. A large number of comments were submitted to the U.S. Environmental Protection Agency (EPA) by the following 10 reviewers: U.S. DOI Bureau of Mines and Bureau of Land Management; Arizona Department of Environmental Quality (ADEQ); State of New Mexico Energy, Minerals, and Natural Resources; State of Utah Department of Natural Resources, Division of Oil, Gas, and Mining; ASARCO Incorporated; Cyprus Minerals Company; Kennecott Corporation; Magma Copper Company; and Phelps Dodge Corporation. The comments included technical and editorial changes, as well as comments on the scope of the profile and how it relates to authorities provided under the Resource Conservation and Recovery Act (RCRA) Subtitle D.

Because several general concerns were raised by a number of commenters, EPA has grouped the comments into two categories. The first includes five general concerns that were raised by all commenters. These are addressed in the first section below. The second category of comments includes technical comments on this profile, which were raised by specific reviewers, rather than the group as a whole. These are addressed in the second section below. All other comments, including minor technical and marginal notes, have been incorporated into the revised profile; EPA believes these comments have served to improve the document's accuracy and clarity. EPA would like to thank all the agencies, companies, and individuals for their time and effort spent reviewing and preparing comments on the profile.

General Issues Pertaining to All Profiles

1. Comment: Several commenters objected to the use of hypothetical phrases like "may cause" or "may occur." Their use was characterized as misleading and inappropriate in describing environmental impacts in an industry profile of this type.

Response: EPA believes that the descriptions of conditions and impacts that may occur regarding potential effects is appropriate in many cases, since the intent of the relevant sections of the profiles is to describe potential impacts that may occur as a result of extracting and beneficiating ores and minerals. As noted in the responses to related comments below, EPA has extensively revised the sections of the profiles addressing environmental effects. They are now more focused and direct; they describe, in general terms, a number of specific types of impacts that can occur under particular conditions or in particular environments.

2. Comment: A related issue raised by commenters was that EPA did not balance the profiles by describing environmental protection practices currently followed by the mining industry. Instead, the commenters were critical that EPA selected the worst sites to describe, which represent only a small number of mines.

Response: EPA believes the profile (and related site reports) represents current environmental management practices as described in the current literature. EPA discusses current waste management practices in specific site visit reports, which are part of the Copper Technical Report.

3. Comment: Reviewers were concerned that the sites described in the discussion of environmental effects were under some other regulatory authority [e.g., the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)].

Response: As noted above, the relevant sections of the profiles have been revised extensively. However, EPA believes that, with proper qualification, sites under other regulatory authorities, including CERCLA, are relevant to any examination of actual or potential environmental effects.

4. Comment: Commenters were concerned that the profiles considered materials other than those considered "wastes" under RCRA.

Response: EPA believes it is proper to consider in the profile both wastes and materials that have the potential to pose risks to human health and the environment.

5. Comment: Many commenters recommended that the mitigating measures used to control potential environmental impacts be discussed.

Response: As noted above, EPA has revised the relevant sections of the profiles, including the addition of language that emphasizes the site-specific nature of potential environmental impacts. The regulatory section of the Profile discusses permit requirements, which often establish specific mitigation requirements.

Technical Issues Specific to the Copper Profile

A large number of technical comments were received on the Preliminary Draft of the Profile. These comments addressed both minor and major technical issues. With the following exceptions, all technical comments have been incorporated into the revised Draft Profile.

6. Comment: The details of the flowsheet in Section 1.4 are out of date.

Response: Information for the Profile was assembled from publicly available information. A generic copper flowsheet showing extraction and beneficiation was not located for this draft.

7. Comment: Expand discussion of State regulations by including more information and expanding the number of States covered.

Response: As noted in the text, EPA has described regulations in the Nation's largest copper-producing State. The description of Arizona regulations has been revised to reflect Arizona DEQ comments.

8. Comment: In the section on the Ray mine (Appendix B), it was requested that the discussion pertaining to settlement cracks in tailings disposal ponds be deleted.

Response: The company did not explain their rationale for this request. Consequently the brief discussion regarding the tailings dam remains in the current text.

APPENDIX 1-B

**CASE STUDIES OF PUBLISHED INFORMATION ON
MINE WASTE MANAGEMENT PRACTICES AT COPPER MINES**

1. Kennecott Utah Copper; Bingham Canyon Mine; Salt Lake County, Utah
2. ASARCO Inc.; Ray Complex; Pinal County, Arizona
3. Cyprus Sierrita Corporation; Sierrita Mine; Pima County, Arizona
4. Cyprus Bagdad Copper Company; Bagdad Mine; Yavapai County, Arizona
5. Magma Copper Company, Pinto Valley Mining Division
6. Cyprus Miami Mining Corporation, Cyprus Miami Mine and Smelter, Gila County, Arizona
7. ASARCO Inc.; Mission Mine; Pima County, Arizona

This appendix presents information concerning the waste management practices employed by the copper mining industry. Specifically, site descriptions are presented for seven of the top-producing copper mine sites (as now listed in Table 1-1) in the United States. Three others are the subject of site visit reports in subsequent chapters of this document. These ten copper mines produced over 90 percent of all domestic copper in 1992.

DATA SOURCES

Copper mining companies, the Arizona Department of Environmental Quality (ADEQ), the U.S. Department of Interior (DOI) Bureau of Mines, the U.S. Bureau of Land Management, and published materials provided the information presented in the site descriptions. The scope of this appendix includes extraction and beneficiation operations; for information on processing operations, see the U.S. Environmental Protection Agency's (EPA's) 1990 *Report to Congress*.

EPA directly contacted two mining companies to obtain information about the current waste management practices at five mining facilities, these include: the Cyprus Mining Company (Sierrita, Bagdad, and Cyprus Miami mines), and the American Smelting and Refining Corporation (ASARCO) (Mission mine). Each company provided varying levels of detail on its mines, due to time constraints on data collection activities. Some material for this appendix originated from U.S. DOI, Bureau of Mines, which collected data on mine sites for a technical report entitled *Methodology to Measure the Economic Impact of Mining and Mineral Processing Waste Regulations* (U.S. DOI, Bureau of Mines 1990a). The Cyprus Mining Company gave permission to U.S. Bureau of Mines to release data to EPA for use in this report.

Computer literature searches for this project were conducted. The purpose of these searches encompassed determining what information is publicly available on waste treatment/management technologies associated with copper extraction and beneficiation operations. The results of these literature searches, coupled with follow-up information gathering, provided much of the information for the site descriptions.

DISCUSSION OF THE MINE WASTE MANAGEMENT PRACTICES AT NINE COPPER MINE SITES

1. Kennecott Utah Copper; Bingham Canyon Mine; Salt Lake County, Utah

The Kennecott Utah Copper Corporation's Bingham Canyon mine is located near Salt Lake City (see Figure 1-18

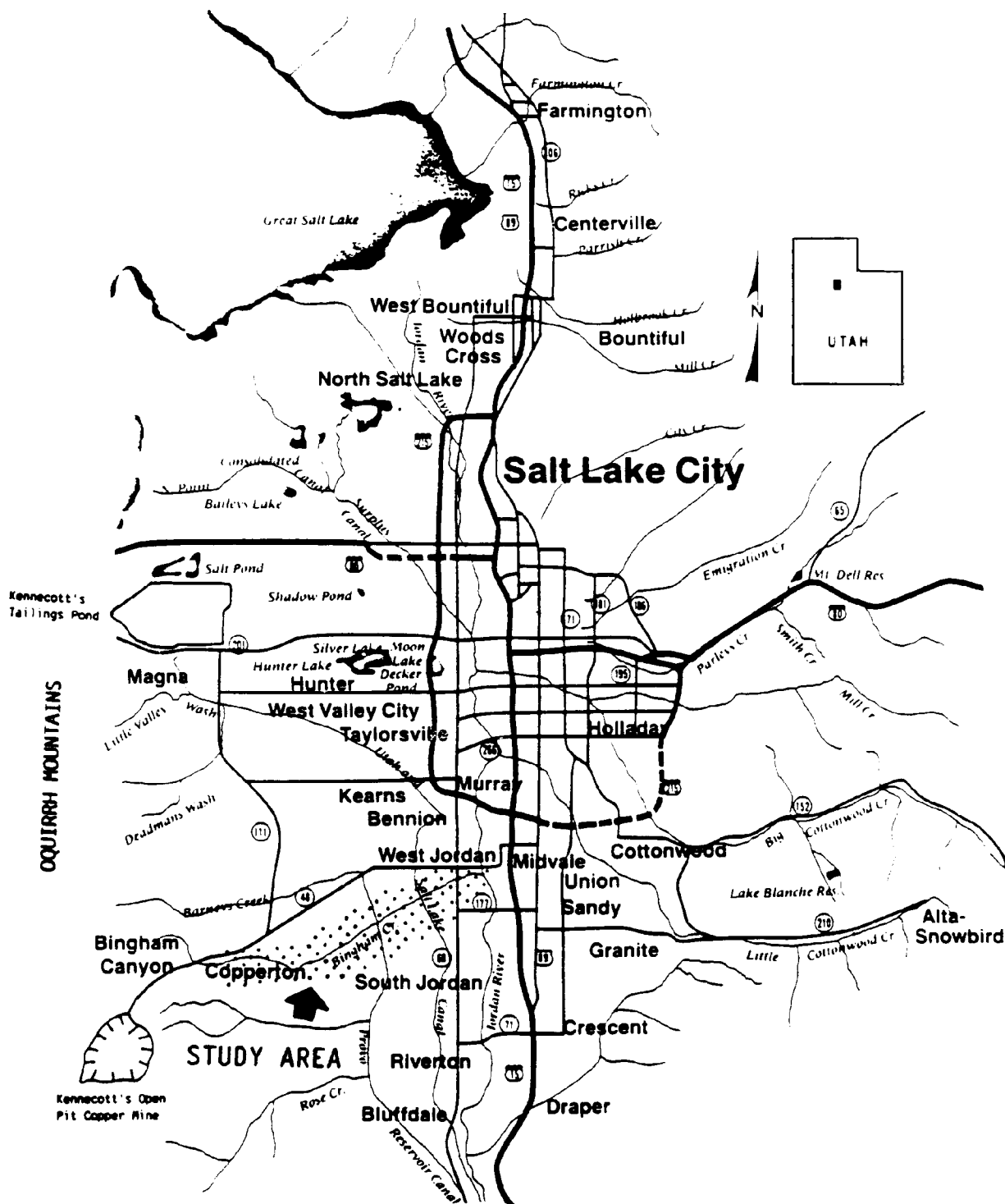


Figure 1-18. Location of Bingham Canyon Mine

(Source: State of Utah 1987)

US EPA ARCHIVE DOCUMENT

) in the Oquirrh Mountains in northern central Utah. Land use in the immediate vicinity of the mine is predominantly rural. The town of Magna (population 8,600) is located 15 miles north of the site. Salt Lake City, a major metropolitan area, is located 20 miles northeast of the site (U.S. EPA 1989e).

This is a fully integrated facility comprised of extraction, beneficiation, and processing operations. The extraction operations consist of an open-pit copper mine, dump leach systems, and a precipitation plant. The beneficiation facility includes an in-pit crusher and two concentrators. The metal byproducts of copper mining at Bingham Canyon are molybdenum, gold, silver, uranium, selenium, platinum, and palladium (U.S. DOI, Bureau of Mines 1965a; State of Utah, undated; U.S. EPA 1989e; Kennecott 1992).

The Bingham Canyon ore body is monzonite porphyry intruded into sedimentary rocks, which have been severely altered. The predominant mineralization is disseminated sulfide ore of chalcopyrite and

pyrite. The deposit is zoned with the most intense mineralization near the two main intrusive stocks (U.S. DOI, Bureau of Mines 1965a).

Sulfide mineralization is associated with the Bingham stock, a complex granite and granite porphyry body that intrudes quartzite and metasilicate country rock. The copper ore body is exposed over a lateral area of approximately 0.66 of a square mile and through a vertical depth of approximately 1,500 feet. In the primary, intrusive ore zone, chalcopyrite is the principal copper mineral, although bornite is common in ore from the central portion of the ore body. The central portion of the ore body is also characterized by a relatively low pyrite content and a relatively high molybdenite content. Surrounding the intrusive granite and granite porphyry is a halo that is several hundred feet wide and is composed of ore-grade sulfide mineralization in fractured quartzitic country rock. This zone was secondarily enriched with chalcopyrite, which is the principal copper mineral in the quartzite ores. This halo also is characterized by a very high pyrite content, which is several times higher than the average pyrite content of the rest of the ore body (U.S. EPA 1986, 1989e).

Extraction

The open-pit mine is about 2.5 miles in diameter and 0.5 mile deep. Since the Bingham Canyon Mine began operation in 1906, over 5 billion tons of material have been excavated. The mine produces about 300,000 short tons (st) of copper, 300,000 ounces (oz) of gold, 2.3 million oz of silver, and 12 million pounds (lbs) of molybdenite annually. In 1988, the mine produced approximately 107,000 short tons per day (stpd) of ore. The mine utilizes conveyor belt systems in addition to a standard rail system for ore haulage (U.S. EPA 1986; Salt Lake Tribune 1988).

About 3 billion tons of mineral waste rock have accumulated in waste dumps at the Bingham Canyon Mine since open-pit operations began in 1906. All mine waste is hauled from the pit to waste dumps via truck. Mine wastes are segregated according to their metal content in the rock and sent to different dumps. The material is dumped over the edge of a hillside to form sideslope dumps. Most of the dumps are contained within steep, narrow canyons. In some drainages/canyons, the dumps are up to 1,000 feet thick and will increase in thickness as mining continues and the dumps are extended beyond the confines of the drainages (Kennecott 1992).

Beneficiation

Approximately 125,000 tons of material between 0.0 percent copper and 0.325 percent copper are extracted at the mine daily. Approximately one-third to one-half of this material is between 0.15 percent copper and 0.325 percent copper and is amenable to leaching. This material is placed on terraced dumps and leached to recover copper. This tonnage will tend to decrease with time (Kennecott 1992).

Dump leaching and cementation operations at the Bingham Canyon Mine were initiated in 1923. The leach dumps (east and west) currently occupy approximately 2,110 acres (3.3 square miles) and contain an estimated 1.5 billion tons of material. The active leach dumps (east and west) occupy approximately 800 acres (1.3 square miles) and contain an estimated 700 million tons of material. Both the east and west side dumps are being leached (Kennecott 1992).

Approximately one-third of the total area of the east and west side dumps is leached at one time. A typical leach cycle involves 30 to 60 days of leaching and 60 to 120 days of resting (Kennecott 1992). To minimize the buildup of iron precipitates on the surface of the dumps, the top 4 to 5 feet of material is ripped by a bulldozer after each rest cycle. After about two cycles, the top layer is scraped off and pushed over the edge of the dump (U.S. EPA 1989e).

The low-grade ore is leached with a dilute solution of *in situ*-generated sulfuric acid (sulfuric acid is not added for leaching). The lixiviant has been applied by using either infiltration ponds, trickle leach, or rainbird sprinkler methods. The pregnant leach solution (PLS) is collected at the base of the dumps in clay-lined ponds. The PLS, which has fairly high concentrations of dissolved copper, is transported to the precipitation plant via concrete ditches and pipeline. Any excess PLS flows to a double-lined pond with a leak detection system, where it is held for treatment to remove the copper. After the copper has been recovered from the PLS, the barren solution from the cones flows to a sump in the central pump station; from there, it is pumped back to the top of the terraced leach dump piles and recirculated. The pH of this solution ranges from 2.5 to 3.0 (U.S. EPA 1989e; Kennecott 1992).

Each of the PLS ponds have unlined overflow ponds to collect any overflow from the PLS ponds due to a rainfall event or equipment malfunction. The PLS ponds were created by constructing concrete cutoff walls across natural drainages; the walls are keyed into bedrock to prevent subsurface losses. From the ponds, the PLS is conveyed via a main collection canal, which is constructed of epoxy-lined concrete, to the precipitate plant (U.S. EPA 1989e).

Kennecott's east collection system is "state-of-the-art." In addition to the main collection canal, a second, emergency overflow canal (constructed of epoxy-lined concrete) collects excess storm water runoff and conveys it to a 500-million-gallon overflow reservoir. This large reservoir is partially lined with clay (i.e., the face of the dam and the bottom of the pond extending away from the dam for several feet are lined). The reservoir is being upgraded to include a plastic liner (Kennecott 1992). This excess storm water is used within the concentrating process. Site personnel have stated that this collection system does not contribute to existing ground water-contamination problems at the site (U.S. EPA 1989e).

Kennecott has two concentrator plants, the Copperton Concentrator and the North Concentrator, with a combined design throughput of 142,000 tons per day (tpd). The Copperton plant, commissioned in 1988 and expanded in 1991, utilizes four conventional semi-autogenous (SAG) mill/ball mill circuits (102,000 to 150,000 tpd) for size reduction with the slurried product feeding a rougher/scavenger froth flotation circuit. Here, copper-, gold-, silver-, and molybdenum-bearing minerals are concentrated. This concentrate is then subjected to subsequent cleaning steps to remove gangue. In addition, the concentrate is further treated in the molybdenite froth flotation circuit where copper, gold, and silver minerals are chemically depressed, recovering a molybdenite concentrate as froth. The copper/gold/silver "tailing" from this step is then thickened and pumped via a 6-inch slurry pipeline to a filter plant, which is adjacent to the smelter some 18 miles away. The molybdenite concentrate is subjected to four further flotation cleaner steps, dried, and then packaged onsite for sale.

The North concentrator utilizes conventional primary, secondary, and tertiary crushing, then a 4-line rod mill/ball mill circuit (30,000 tpd). This portion of the plant, known as the Bonneville plant, was constructed in 1967. Slurry from the mill is gravity fed 1.8 miles to a froth flotation circuit, constructed in 1984 at the Magna plant. This circuit, although smaller, is identical to the flotation circuit at Copperton. No molybdenite recovery circuit is in use at Magna, but plans call for installation in 1992 (Kennecott 1992). Table 1-8 details the major beneficiation equipment at each plant. Table 1-9 shows reagent type and usage in the flotation process. Reagent type and consumption are the same at both plants.

Table 1-8. Beneficiation Equipment by Plant

Equipment	Copperton	North
Primary Crusher	60/109 Gyratory at mine	54/74 Gyratory
Secondary Crusher	--	2 7-foot standard cones
Tertiary Crusher	--	3 7-foot shorthreads
SAG Mills/Rod Mills	3 34-foot 12,000 HP (SAG) 1 36-foot 16,000 HP (SAG)	4 12- x17-foot 1,250 HP (ROD)
Ball Mills	6 18- x 28-foot 5,500 HP 2 20- x 30-foot 7,500 HP	4 12- x17-foot 1,250 HP 8 12- x 15-foot 1,250 HP
Mechanical Flotation Cells	54 3,000 (ft ³) 16 1,000 ft ³ 14 500 ft ³	20 1,500 ft ³ 14 500 ft ³
Column Flotation Cells	22	--
Thickeners	3 400-foot' tailings 1 200-foot conc. 2 180-foot conc. 1 200-foot clarifier	2 75-foot conc.

(Source: Kennecott 1992)

Table 1-9. Reagent Consumption in Flotation Process

Reagent	Lbs/Ton-Ore Copper Circuit	Lbs/Ton-Conc. Molybdenite Circuit
Lime	1.2	2.0
Collector	0.024	--
Sodium Cyanide	0.003	--
Frother (Alcohol)	0.048	--
Fuel Oil	0.026	0.28
Sodium Hydrosulfide	--	6.8
Sodium Silicate	--	0.65
Flocculent	0.02	--

(Source: Kennecott 1992)

The Arthur and Magna concentrators recover 90 percent of the ore values in the concentrates. Very fine particles interfere in the flotation process and reduce recovery. By installing two new tailings pretreatment plants (one at each concentrator), Kennecott has been able to recover some lost copper-molybdenum concentrates. The new plants receive mill tailings from the concentrators by pipeline. Four clusters of nine cyclones are used to separate the fine slimes (material less than 200 mesh in size) from the coarser tailings. The cyclone overflow (slimes) is routed to the tailings pond (see the discussion below), while the underflow is diluted with water to 45 percent solids and recycled to rougher flotation units. Rougher concentrate is then pumped to a regrind circuit consisting of closed-circuit ball mills with cyclone hydraulic separators. The product from this process is subjected to three stages of cleaner flotation, which recovers the copper concentrates (Engineering and Mining Journal 1971a).

Tailings Disposal

Tailings from the North Concentrator are gravity fed to a single point discharge into the 5,300-acre tailings pond. Tailings from the Copperton Concentrator are gravity fed through a 13-mile long pipeline to a peripheral discharge system and a point discharge on the same tailings impoundment. Approximately 70 percent of the Copperton tailings are distributed through the peripheral system with the balance through the point discharge. Additional inflows to the tailings impoundment are tailings from the Smelter slag concentrator, effluent from the wastewater treatment plant, and ash sluice from the power plant. Water is recovered for recycle from the pond using siphons. Excessive storm water can be discharged at two permitted discharge points. The water flows through the C-7 ditch to the Great Salt Lake under the conditions of a Utah Pollutant Discharge Elimination System (UPDES) permit (Kennecott 1992).

As in normal practice, the tailings impoundment perimeter is constructed of tailings. An upstream dike construction method is used. The overall slope of the dike rises at 5 to 1. The pond level increases at 6.5 feet per year (Kennecott 1992).

Dust is controlled through operating practice, road dust control, and revegetation. The perimeter tailings discharge system is used to keep the interior surface wetted. Magnesium chloride is used for dust control on roads. Surfaces exposed due to dike raising activities are prepared and seeded with a variety of grasses and seedling trees (Kennecott 1992).

Table 1-10

Table 1-10. Summary Data Sheet for the Kennecott Copper Company - Bingham Canyon Mine Tailings Pond Analysis

Substance (Total)	Concentration By Sites/Date						Water-quality Standards (in µg/l)
	Arthur Tailings 3/13-3/19/78 (in µg/l)	Magna Tailings 3/20-2/26/78 (in µg/l)	Tailings Pond 3/20-3/26/78 (in µg/l)	Treatment Plant Influent 3/20-3/26/78 (in µg/l)	Treatment Plant Effluent 3/20-3/26/78 (in µg/l)		
Antimony	<500	<500	100	<100	<100	100-50	
Arsenic	5,000	5,000	100	400	30	50	
Beryllium	150	80	<5	<5	<5	1	
Cadmium	<25	<25	<5	<5	<5	5	
Chromium	12,000	6,900	20	80	30	100	
Copper	100,000	95,000	260	8,000	60	1,300	
Lead	3,000	2,500	<20	400	<20		
Mercury	2.0	1.0	0.8		0.7	2	
Nickel	9,900	5,700	20	<20	70	100	
Selenium	100	200	10	50	10	50	
Silver	<100	<100	<20	<20	<20	50	
Thallium	<200	<200	<100	<100	<100	1-2	
Zinc	5,800	3,600	<20	500	30	5,000	
Cyanide	1.24	0.10	0.60	<0.02	0.08	.2	
Phenol	0.75	0.325	0.200	0.006	0.025	---	

(Source: U.S. EPA 1986)

presents the results of chemical constituent analyses of tailings generated at the Bingham Canyon site (U.S. EPA 1986). Tailings composition varies as a function of ore composition (Kennecott 1992). These analyses were performed on the influent tailings stream containing 30 percent solids (Kennecott 1992). The results of the treatment plant and recycled tailings water sampling show significant improvement (U.S. EPA 1986).

Dried tailings can be a potential source of wind-blown dust. To address this problem, Kennecott has developed a soil-stabilization program for the tailings pond. In addition, Kennecott has tested many chemical additives to reduce dust blow. A chemical emulsion called Coherex, manufactured by Witco Chemical Corporation, has been effectively used at Kennecott for dust control. Coherex contains petroleum oils and resins mixed with water; it is sprayed onto the dry periphery of the tailings pond by trucks or sprinkler systems. Coherex imparts a permanent cohesiveness to the tailings by coating dust particles and forming an adhesive membrane over adjacent particles (Engineering and Mining Journal 1971b; U.S. EPA 1986).

In 1988, Kennecott upgraded the peripheral tailings distribution system so that up to 30,000 gallons per minute (gpm) of tailings are continuously distributed around the inside of the impoundment's dike. This has resulted in the ability to keep at least 95 percent of the tailings impoundment surface wet. The system is part of the Utah PM₁₀ State Implementation Plan (Kennecott 1992).

Kennecott has a program to revegetate the faces of the tailings pond dam. A variety of grasses and trees (mainly Russian Olive) have been planted with some success. Kennecott has been cooperating with U.S. DOI, Bureau of Mines, United States Soil Conservation Service, and the Utah State University in developing, maintaining, and analyzing vegetation test plots on the tailings. Some areas of the tailings pond dam are supporting a thicker vegetative cover than the surrounding native soil. However, some slopes, notably the south-facing slopes, are more difficult to revegetate due to the intensity of the sun (State of Utah, undated).

Leach Circuit

For many years, Kennecott has operated a precipitation plant which employs a cementation process to extract copper from aqueous solutions. The precipitate plant contains 12 cones and operates on a continuous basis. Annual precipitate production in 1985 was 6,000 tons (Kennecott 1992).

At Kennecott's precipitation plant, the pregnant solution flows through a cone precipitator filled with iron shavings that works similar to a cyclone (U.S. Congress, Office of Technology Assessment 1988).

The precipitation system consists of a cylindrical wooden tank (measuring 6 to 7 meters high and 4 to 6 meters in diameter) in which a 4-meter-long stainless-steel cone is fixed (apex down). The upper third of the cone is constructed of stainless steel screen. The PLS is swirled into the cone via openings in two rings attached to the inside of the cone (the openings are one-third and one-half the way up the cone's side). The PLS swirls upwards through the shredded iron scrap, causing the copper to precipitate (Biwas and Davenport 1976; U.S. EPA 1989e).

The swirling action washes the copper from the iron surfaces, and the particles become suspended in the solution. The copper particles are carried upwards to near the top of the cone, where, as the velocity decreases due to increased cone width, they sink through the screened section into a collection area at the bottom of the tank. Kennecott's cone system is a high-capacity unit, which can handle up to 10 cubic meters (m³) of solution per minute. Furthermore, the system is flexible, and two or more cones can be placed in series to maximize copper recoveries and/or handle solutions with high copper concentrations. Finally, an additional advantage of this system is that it has a low iron consumption rate (Biwas and Davenport 1976).

Process Wastewater Management

Makeup water for the concentrators is obtained from deep wells, Utah Lake (through a canal), surface drainage, springs, Bingham pit mine water, and mine dump runoff. The water supply is supplemented from two wells, located in the valley about three miles east of the mine. The depth to ground water at these wells is 300 to 400 feet (State of Utah, undated; U.S. EPA 1986; Kennecott 1992).

At the Copperton concentrator, makeup water is commingled with recycled tailings water in the ore feed slurry. Lime is added to a pH of 12. After beneficiation, the tailings slurry (approximately 51,000 gpm) is piped to the tailings pond. Additional wastewater flows to the tailings pond include approximately 15,000 gpm of process water from the Magna concentrator, 1,500 gpm of process water from the slag tailings concentrator, 2,500 gpm from the smelter and refinery wastewater treatment plant, and 1,000 gpm of ash sluice wastewater. Before it is discharged to the tailings pond, the process wastewater from the smelter and refinery is treated with lime and ferric chloride (State of Utah, undated; Kennecott 1992).

Runoff

The mine pit and leach and waste dumps border two surface-water drainages (Bingham Canyon and Butterfield Canyon). Surface runoff from these drainages flows east toward the Jordan River, which feeds the Great Salt Lake (Kennecott 1992).

Of particular note are ground water and surface-water impacts associated with contamination in Bingham Creek. Bingham Creek is a small ephemeral stream which flows east and south of the town of Copperton. Bingham Creek originates in the Oquirrh Mountains in Bingham Canyon and has historically flowed towards the northeast into the Jordan River. Bingham Creek and its floodplain have drained a large, mineralized area for millions of years. The creek was also used for many years by non-Kennecott mining companies for mine waste disposal. Some of the first mining activity in the Salt Lake area included placer mining of Bingham Creek gravels followed by underground mining of lead/silver ores throughout Bingham Canyon. Kennecott has mined only copper ores; their involvement dates from 1936. Various mining companies used the creek to some extent for mine drainage, tailings disposal, leachate collection, and run-off control. Bingham Creek channel currently does not carry any flowing water (State of Utah 1987; Salt Lake Tribune 1988; Kennecott 1992).

During 1983 and other particularly wet years, Kennecott diverted excess snow melt runoff into a series of evaporation ponds located a few miles south of Bingham Creek. Some runoff water may have seeped into the ground and into the aquifer in the South Jordan area (State of Utah undated; Kennecott 1992).

To eliminate the need for using the lower portion of Bingham Creek for excess storm water and snowmelt runoff, Kennecott has installed a series of dams in the drainages above the mine area to capture runoff water before it crosses the mine and disturbed land areas. This clean water is then piped to the copper company's Copperton concentrator for makeup water supply. An 11-mile canal now extends completely around the mine drainage area. This canal was constructed to collect potentially contaminated runoff and any leach liquor that escaped the leaching system and divert it to a Kennecott reservoir. This reservoir is currently being lined (State of Utah, undated; Kennecott 1992).

2. ASARCO Inc.; Ray Complex; Pinal County, Arizona

The ASARCO Ray Complex is located about 80 miles southeast of Phoenix in the Mineral Creek mining district. The mine lies in the Mineral Creek Valley approximately 5 miles north of the Gila River.

From 1911 to 1955, the mine was an underground block-caving operation. In 1955, the current open-pit mining operation started. Forty-three million tons of overburden were excavated during the initial development of the pit (U.S. DOI, Bureau of Mines 1965a). The site consists of the open-pit mine, heap and dump leaches, a 30,000-tpd concentrator and a 40,000-tpy SX/EW plant. Sulfide ore is also transported to a 30,000-tpd concentrator at Hayden. An active 625,000-tpy smelter and a 1,600-tpd acid plant are also located at Hayden.

The Ray Mine and associated dump leaching operations are constructed on both sides of Mineral Creek Valley, in a surface-water-flow channel restricted by bedrock. Mineral Creek is diverted around the mine through a 3.25-mile, concrete lined tunnel. The Ray mine is underlain by bedrock (primarily Precambrian pinal schist, Apache group sediment, diabase, and porphyry formations). The pits and surrounding bedrock are relatively dry (from a hydrogeologic perspective); no alluvial aquifers exist. Bedrock yields small, but sustained, ground water flow. Water is present at depth in isolated fracture zones, but none of the bedrock formations are capable of supplying significant or sustained yield (U.S. EPA 1989e).

The ore body is quartz porphyry diabase intrusive and approximately 40 percent Precambrian schist. The schist and porphyry ores are mineralized principally with supergene chalcocite, although the predominant mineral in the diabase is chalcopyrite. Copper oxide silicates of chrysocolla, cuprite, malachite, tenorite, and native copper comprise about 20 percent of the ore (U.S. DOI, Bureau of Mines 1965a). The mineralogy at the Ray mine site is quite complex and contains zones of sulfide, oxide, and native copper. The ore body has undergone extensive faulting, oxidation, and erosion, producing the two major forms of supergene copper mineralization. Early mining focused on the higher grade chalcocite, while the lower-grade chalcopyrite is being mined today. The oxide copper zones are characterized by high-grade chrysocolla (Engineering and Mining Journal 1988; U.S. EPA 1989e).

Extraction

Mining

Mining is being conducted in the Sonora, Sharkey, Calumet, and Pearl Handle mining areas. There are six active, low-grade copper sulfide ore dumps (Nos. 1 through 5 and No. 7 waste dumps) and one active copper silicate ore heap leach (see description of heap leaching below). Figure 1-19

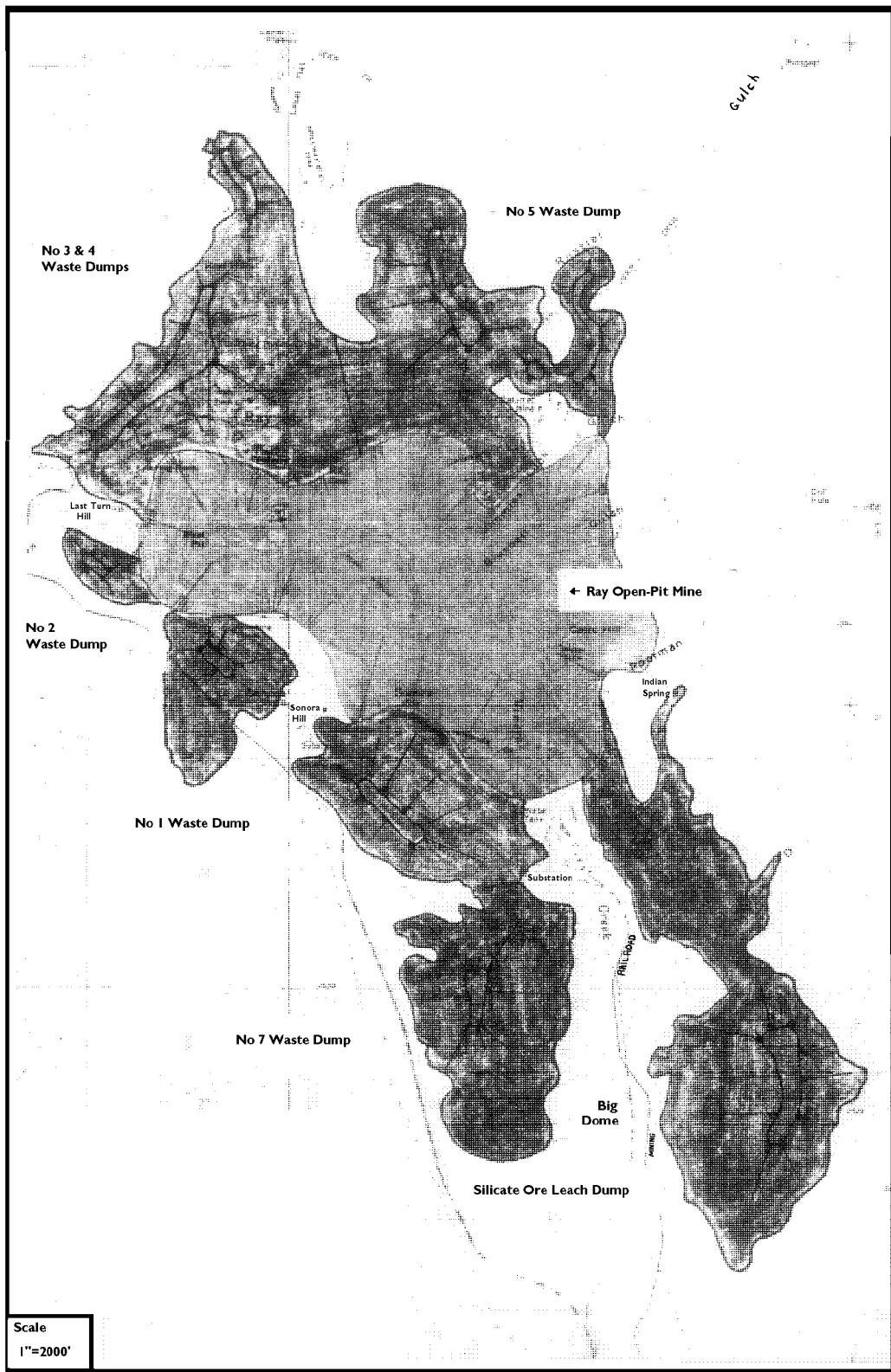


Figure 1-19. Existing Ray Mine Site Disturbed Areas

(Source: ASARCO 1990)

shows the locations of the Ray open pit and each of the dumps (U.S. EPA 1989e; ASARCO 1991).

Extraction operations are conducted at the Ray pit using electric shovels supplemented by front-end loaders. The total materials production rate is 220,000 tpd. Each day, 60,000 tons of sulfide ore undergo primary crushing to minus 8 inches at the mine site and 30,000 tpd shipped by rail to the Hayden concentrator. About 13,000 tpd silicate ore are crushed and sent to heap leaches. The rest of the material generated is low-grade ore (which is hauled to dump leaches) and waste rock (which is sent to waste dumps). The stripping ratio is 2.5 to 1 (waste to ore).

Mine planning is predicated on the sulfide operation. As a result, silicate ore is stockpiled when in excess and is fed from the stockpile to the primary crushers to maintain heap placement.

Mine overburden is separated into barren and copper-bearing portions. Only barren material is placed on those dump sites on the northeast side of the mine to prevent pollution of Mineral Creek from dump drainage (U.S. EPA 1989e).

Dump Leaching

Onsite leaching of copper has become an integral part of the Ray mine operation. Twenty-five percent of the mine's production originates from leaching operations. For many years, the sulfide dumps were leached to recover cement copper, which was precipitated in cones or launders loaded with shredded iron. The cement copper was then shipped to the Ray smelter for further refining. With the advent of SX/EW technology, operation of the cementation precipitation unit operation was suspended (Engineering and Mining Journal 1988).

The sulfide leach dumps surround the southwest side of the mine workings (see Figure 1-19). Approximately 1,100 acres are available for the low-grade copper sulfide ore leaching processes (only 10 to 15 percent of which is being flushed with water at any one time). The remaining area is at rest under oxidizing conditions. The dump leach piles are located directly on the existing topography. According to ASARCO, there was no special surface preparation prior to the initial deposition of dump material since the bedrock is nearly an impervious conglomerate.

Mine-run ore is hauled to the leach piles by truck and spread with bulldozers. After each lift is completed, the surface of the pile is ripped to a depth of approximately 5 feet. The leach solution is usually applied to a pile in 30- to 60-day on-off cycles. The solution that is applied to the dumps has a pH of approximately 2.0. It is delivered to the dumps at 8,700 gpm and applied through a series of impulse sprinklers. The pregnant liquor is collected behind concrete storage dams, keyed to bedrock but unlined, and is reapplied to the dumps until the copper concentration is sufficient for SX/EW recovery. It was originally pumped to either the north or south precipitation plants. The pregnant solution influent to the precipitation plants generally contained approximately 0.42 g/l of acid and had a pH of 2.8. The tail water from the precipitation plants was redistributed onto the leach surfaces. Since 1987, pregnant solution from dump leaches is directed to the SX/EW plant at the site (U.S. EPA 1989e; Beard 1990).

Stope Leaching

Another source of precipitate copper at the Ray mine was from historic *in situ* stope leaching of the caved areas in the underground mine during Kennecott's ownership of the mine. Stopes, once used to access and mine the copper ore, are now used to improve leaching recovery. Acidic mine water was recovered from block-caved sections of closed underground mining operations. The ore chutes or draws were originally sealed off as soon as the oxidized capping or the broken protore began to appear in the ore drawn from the chutes. As a result, a large quantity of low-grade, oxidized copper-bearing broken rock remained in the mine. This ore was subjected to the slow natural leaching process by downward percolating meteoric waters that produced copper-rich leachate or Acid Mine Drainage (AMD). As of 1982, copper leachate or AMD was pumped out of the mine and sent to the cementation unit. The cementation precipitates, containing about 80 percent copper, were then being dried and shipped to the Chino Branch smelter at Hurley, New Mexico (Intermountain Pay Dirt 1982).

The quantity of copper produced from *in situ* leaching cementation operations increased from 3,600 tons in 1954 to 17,700 tons in 1957. Additional pumps were installed in 1959 to expand stope leaching capacity

into additional caved areas (U.S. DOI, Bureau of Mines 1965a). Stope leaching operations, however, are no longer in operation at the Ray Complex.

Beneficiation

Milling

At the concentrator, secondary crushing further reduces the sulfide ore to minus 0.5 inch. Then, the material is conveyed to fine ore bins, which feed 130 to 280 tons per hour (tph) of ore to each of seven grinding sections. The ore is combined with water to form a slurry that is concentrated in a sulfide flotation circuit. The reagents used at the concentrator in the primary flotation circuit are Raconite (sodium butyl xanthate) for the collector, and MIBS (shell 10) for the frother. The average pH in the flotation circuit is 11.5 (Crozier 1979). Previously stockpiled copper smelter slag is currently being reclaimed and fed to the mill in small quantities (Beard 1990).

In 1989, a \$12-million expansion project was completed to maintain production capacity as the pit deepened and the hardness of the ore increased. In addition, a \$254-million expansion was completed at the Ray mine site in early 1992. A 60,000-tpd relocatable in-pit crusher and conveyor system was installed, and a 30,000-tpd concentrator was built at the mine site (ASARCO 1992).

Silicate Ore Vat Leaching Operations

Because oxide copper in the silicate ore could not be recovered by conventional sulfide recovery methods, the Silicate Ore Leaching Process Plant (SOLP) plant was built in 1965 to process the oxide ore. The plant processed 10,000 tpd of copper silicate ore. It was designed to produce 24,000 tpy of copper. The SOLP consisted of a vat leaching system containing a crushing facility; 14 vats (100 x 110 x 20 feet, each holding about 10,000 st of ore); a conveyor system to fill them with crushed ore, and a gantry crane with bucket to unload the leached material. The SOLP plant was designed to use sulfuric acid lixiviant. A 750-tpd acid plant was also built as part of the \$35-million project. A 14-day cycle consisting of 10 days for leaching, 1 day for unloading, 2 days for washing, and 1 day for reloading was used in the SOLP. The PLS solution was sent from the SOLP to an electrowinning circuit. During leaching, aluminum salts, iron, and other contaminants detrimental to electrowinning were dissolved, along with the copper. These impurities significantly reduced cathode quality (Engineering and Mining Journal 1980; Intermountain Pay Dirt 1982; Intermountain Pay Dirt 1985).

In 1976, an agitation leaching facility was constructed to work in conjunction with the vat system. This facility increased the amount of ore that could be handled from 10,000 to 14,000 stpd. The facility produced 30-45 stpd of copper precipitate per year that required smelting and electrowinning (Engineering and Mining Journal 1980).

Also in 1976, the silicate leach plant was expanded by an additional 40 percent. No new vats were added; the increased capacity instead came from separate processing of the fine material and from modifications in other areas. The ore was processed by a three-stage crushing circuit and then was split into two sizes by 1/2-inch diameter screens. The fines were subjected to leaching and the coarse fraction was treated in the 14-day, vat-leaching cycle. The SOLP system was closed in 1982 and was subsequently replaced in 1985 by the heap leaching operation (Intermountain Pay Dirt 1982; Engineering and Mining Journal 1988).

Heap Leaching

A copper silicate ore heap leaching operation is currently used to recover copper from copper silicate mineralized ores. The silicate heap leach dump is located southeast of the mine workings (see Figure 1-19). The silicate ore grade averages about 1.10 percent total copper, of which 0.77 percent is readily soluble. Mine-run ore is delivered by haulage trucks to the primary crusher (which reduces the ore to minus 8-inch size). The crushed ore is then conveyed to a secondary/tertiary crushing facility (which reduces the ore to minus 3/4-inch size). This finely crushed product is then conveyed to a fine-ore building, which has a capacity of approximately 35,000 tons. The crushed ore is fed from fine-ore storage onto a series of conveyors which move the ore to a truck hopper area adjacent to the copper leaching area. On the conveyor, the ore is prewet with concentrated sulfuric acid at 93 percent and at a rate of 60 pounds per ton (lbs/t). Trucks then load and transport the ore to the heap site. Each lift on a pad is 8 feet and ore is added at a rate of 13,000 stpd to a volume of 40,000 tons. Prior to building each new 8-foot lift, the existing lift is ripped. After placement on the pads, the ore is sprinkled with sulfuric acid solution (recycled raffinate) containing from 18 to 19 g/l H₂SO₄, at a flow rate of 7,000 gpm using a Drisco pipe network and sprinklers. Each lift is leached for 33 days. The leachate is collected in a PLS collection basin and sent to the SX/EW plant. The PLS, which contain less than 2.0 g/l of free acid and 4.5 g/l of copper, are collected in unlined ponds and pumped to the SX/EW plant. After the leaching cycle is completed, new materials are added to the pads (ASARCO 1992).

Leach Circuit SX/EW Plant

In 1980, ASARCO started up a new copper SX plant at the SOLP. The SX plant was designed with a maximum capacity of 108 stpd. In 1980, SX plant production was almost 90 stpd. The SX plant has two parallel trains of mixer-settlers for extraction and stripping, along with other tanks and vessels associated the system. There are a total of 29 stainless steel, 3 carbon steel, and 14 reinforced concrete tanks. Stainless steel is also used in 80 percent of the piping and in all of the pumps, mixers, centrifuge, and tank liners (Engineering and Mining Journal 1980; Intermountain Pay Dirt 1985).

In 1987, ASARCO modified the SX plant to use the full 40,000-tpy capacity of the SX/EW system. A portion of the increased output, 7,500 tons, came from processing of PLS from sulfide dump leaching. The remainder of the additional output of the SX/EW plant came from increased processing of solutions from heap leaching of copper silicate ores. During the expansion, the existing SX trains were converted to accommodate the lower-grade dump leach solutions (Southwestern Pay Dirt 1987a).

Prior to the expansion, leach solutions from the sulfide dumps were processed in the precipitation plant at Ray, then sent offsite for smelting and refining. After the modifications were completed, ASARCO began sending PLS from the sulfide dumps to the SX/EW plant, and the precipitation plant was closed. Within the SX plant, sulfide ore leach solutions are processed in one train, while silicate ore leach solutions are processed separately in the other train. The 1987 modifications further made it possible to sweeten the low-grade pregnant solutions from the sulfide waste dumps. The lean electrolyte produced from the sulfide dumps is commingled with rich electrolyte from the silicate train, yielding a combined electrolyte for the tankhouse with a copper concentration of 48 to 50 g/l (Southwestern Pay Dirt 1987a; Engineering and Mining Journal 1988).

The silicate train operates at a solution flow rate of 4,000 gpm carrying 4.5 g/l of copper and includes two extraction and two stripping stages. The flow rate to the sulfide dump train is 8,000 gpm of 0.77 g/l copper, divided between two lines of vessels arranged to provide one extraction and one stripping stage. The organic extractant used is Acorga P-5397 carried in 90 percent solution of Phillips SX-7 (kerosene). The plant is

equipped with eight settlers, each having a surface area of 56 by 54 feet. Each settler has three 5,000-gallon tanks with Mixco agitators (ASARCO 1992).

Tailings

The tailings pond for the Ray concentrator is located three miles to the southeast of the Ray mine. The Hayden concentrator tailings ponds are located 18 miles southeast of the Ray mine near the town of Hayden, Arizona. Tailings are piped from the concentrator to the tailing ponds. The site is in the San Pedro Valley at the confluence of the San Pedro and Gila Rivers. The valley is bounded to the northwest by the Dripping Springs Mountains and to the southwest by the Tortilla Mountains. Tailings Ponds AB-BC and D are sited on floodplain deposits along the Gila River. The alluvial soils are predominantly granular with appreciable amounts of silt and clay. The thickness of alluvium in the valley is about 200 to 500 feet. The elevation of Tailings Pond AB-BC is 1,950 to 2,000 feet. The ground surface beneath Tailings Pond AB-BC slopes at approximately one percent from north to south. Tailings Pond D is constructed on the side of a hill at a six percent slope to the southwest (ASARCO 1991).

Tailings Pond AB-BC has been in operation since the early 1900s. Tailings disposal operations commenced in 1910 at a rate of about 4,000 tpd. The rate of deposition was increased to about 16,000 tpd in 1952; 21,000 tpd in 1960; and gradually since then to the present 30,000 tpd (ASARCO 1991).

No information was found concerning the details of the initial dam construction of Tailings Pond AB-BC. From 1910 to the 1960s tailings were discharged into the pond from a single point near the eastern end of the pond. Decanted water may have been discharged directly into the Gila River. Since the early 1950s, the dam has been raised in 10-foot lifts by bulldozers that pushed dried-out material from the beach area of the ponds to the edge and spread it out to form a crest. In the 1960s, the pond surface was divided into three pond areas by dikes to start a cycle of one pond area being filled with tailings, one area being dried out, and the other area being formed by diking. The Tailings Pond is now divided into two sections AB and BC (each divided into the three areas described above) (ASARCO 1991).

Peripheral spigotting of tailings to Pond AB-BC was started in the mid-1960s. However, the crest of the dam was still being raised with bulldozers and draglines. Seepage has occurred, and is still occurring, along the contact point between newly spigotted materials and the previously deposited tailings, primarily along the western half of Pond AB-BC. The seepage appears to originate from relatively pervious sands tailings resting upon relatively impervious silty tailings. Tailings water at the surface of the ponds percolates through the peripheral coarser materials until it reaches the much finer-grained tailings; from there it spreads and travels horizontally towards the face and seeps out at the contact between the two material types (ASARCO 1991).

A slope failure occurred near the northwest end of the dam on December 2, 1972. It was reported to have produced a gap in the crest of the dam estimated to be about 500 feet across, 30 to 50 feet deep, and 200 feet into the reservoir. A smaller failure occurred on February 3, 1973, about 1,000 feet east of the previous slope failure. It left a gap estimated to be about 500 feet wide, 20 to 40 feet deep, and 150 feet into the reservoir. After this failure, water was found seeping out of the failed portions and active channeling was observed at several points near the contact of the sandy and silty tailings. A geotechnical investigation was conducted in the failure areas that resulted in new dike construction being set approximately 200 feet inside the original dam to flatten the overall slopes and increase stability (ASARCO 1991).

The starter dike for Tailings Pond D was constructed to an elevation of 2,020 feet between November 1981 and July 1982. The starter dike is approximately 8,700 feet long, up to 48 feet high, and has an upstream slope of 2 to 1 (horizontal to vertical) and a downstream slope of 2.5 to 1. The starter dike was constructed

from alluvial soils excavated from upstream of the inside toe of the dike. The eastern 3,000 feet of the dike was constructed of more coarser grained soils than the western portion (ASARCO 1991).

After 29 weeks of tailings disposal in Pond D, a settlement crack with an associated tailings seep was observed by mine employees. The crack shape and surface evidence indicated that the upstream point of the dike had settled relative to the downstream part. It was believed that the cracks were the result of differential settlement between the coarser and finer grained dike sections upon exposure to the wetting front induced by the tailings. Varying embankment heights might also have accounted for some of the differential settlement cracking.

Tailings pond water control at both Ponds AB-BC and Pond D is accomplished using siphons. The system consists of a 30-inch (diameter) pipe mounted on buoys that extend 1,000 feet from the berm into the center of the pond. Approximately 7 million gallons per day (MGD) are recycled (Weiss 1985).

Electrowinning Plant

The electrowinning plant was built by Holmes and Narver and contains one starter sheet section comprised of 36 cells. Each cell is equipped with 40 titanium blanks to make 11-lb starter cathodes used in the commercial section. The rated capacity of the starter sheet section is 20,000 lb/day. Electrolyte flow rate through the cells is 10 gpm (Engineering and Mining Journal 1988).

The commercial section consists of 400 cells divided into four electrical and flow circuits. These cells contain 41 lead anodes and 40 copper cathodes. Electrolyte flow through these cells is 50 gpm. Each cell produces 225 to 275-lb copper cathodes at a DC cell voltage of 1.9 and a current of 9,000 to 17,000 amps. The tankhouse is capable of producing 130 stpd of cathode copper (ASARCO 1992).

Mine-water Management

The Gila River receives all drainage in the area and flows southwest to the Ashurst-Hayden diversion dam near Florence, approximately 15 miles below Kelvin, where the river is totally diverted for use as agricultural irrigation water. Mineral Creek, which was the original drainage course through the Ray mine, meets the Gila River at the town of Kelvin. To prevent contamination of Mineral Creek and the Gila River, ASARCO has constructed a large flood control and diversion dam north of the mine site which diverts the flow of Mineral Creek into a 3.4-mile tunnel that conveys the flow of Mineral Creek around the mine site (Intermountain Pay Dirt 1982; U.S. EPA 1989e).

The entire Ray mine area is underlain with bedrock. All solution recovery dams are keyed into bedrock to ensure containment of pregnant solutions. Dams and associated pipelines which lie above gradient are designed to flow into containment areas during any upset condition. Dams lying downgradient of the headwater reservoirs are equipped with primary and backup pumping capability. In the event this capability is lost or is insufficient for incoming flows, each dam is designed to overflow into the plastic lined Big Dome Reservoir, a 14-million-gallon capacity pond (U.S. EPA 1989e).

The PLS from the leach dumps is retained by a dam constructed across the downgradient side of the drainage channel. Waters which might overflow the leach dams are collected in the Big Dome Reservoir. Process water spills and runoff from process areas would also be contained in this pond. This water is either pumped back to the leach dumps or treated at the lime neutralization/precipitation facility (U.S. EPA 1989e).

All natural surface- and ground-water drainage from the area drains to diversion ditches. These have been constructed around the sulfide ore leach dumps located west of the open pit workings to minimize the amount of surface water entering the process/water system (U.S. EPA 1989e).

Both pits are confined by bedrock and extend well below the elevation of Mineral Creek (U.S. EPA 1989e).

3. Cyprus Sierrita Corporation; Sierrita Mine; Pima County, Arizona

The Sierrita Mine and related operations occupy approximately 20,000 acres on the east slope of the Sierrita Mountains south of Tucson. The complex, as shown in Figures 1-20

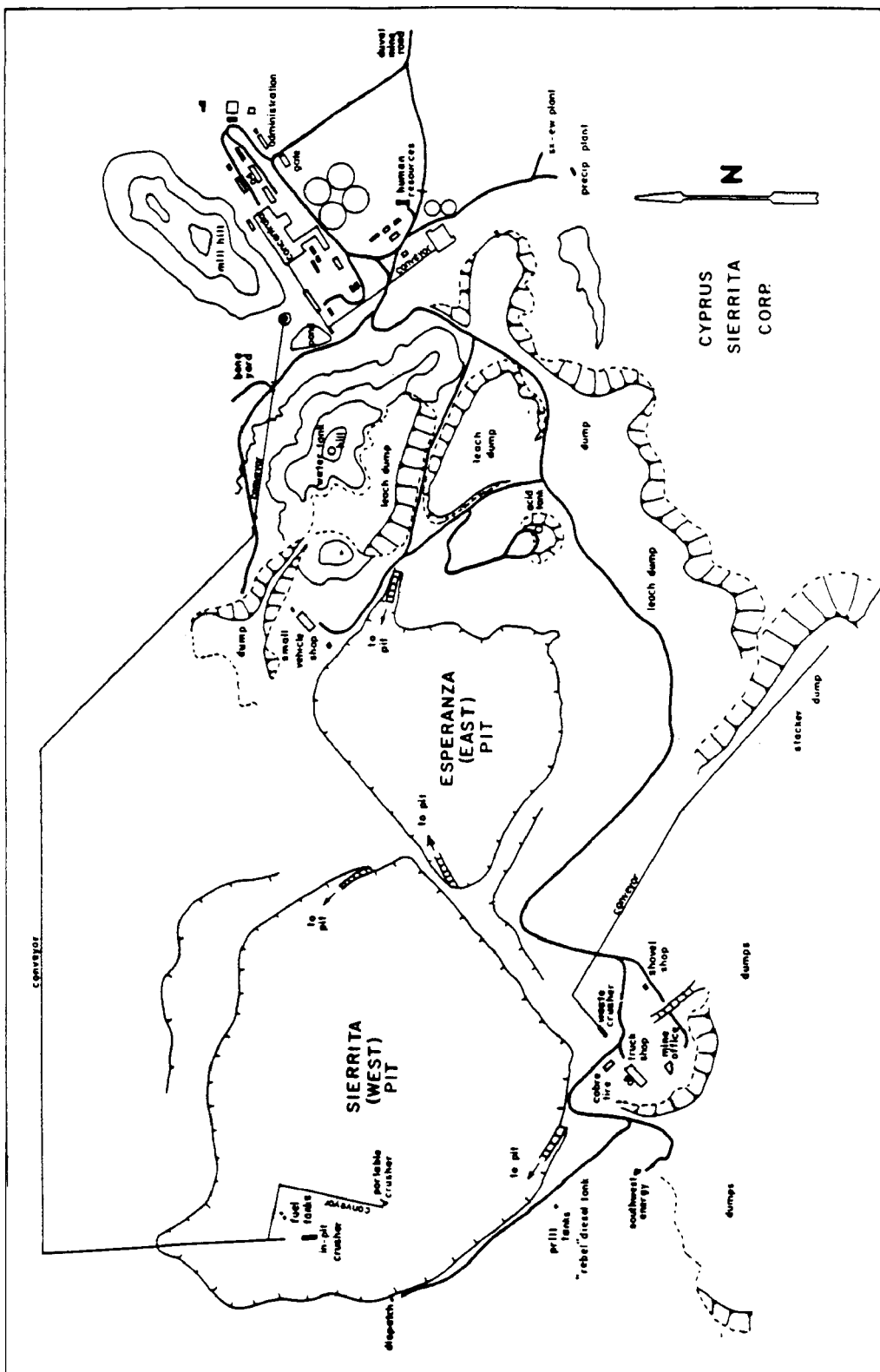


Figure 1-20. Cyprus Sierrita Process Location Map

(Source: Cyprus Sierrita Corporation 1989)

and 1-21, is located in Pima County, Arizona, about 22 miles south of the intersection of Interstates 19 and

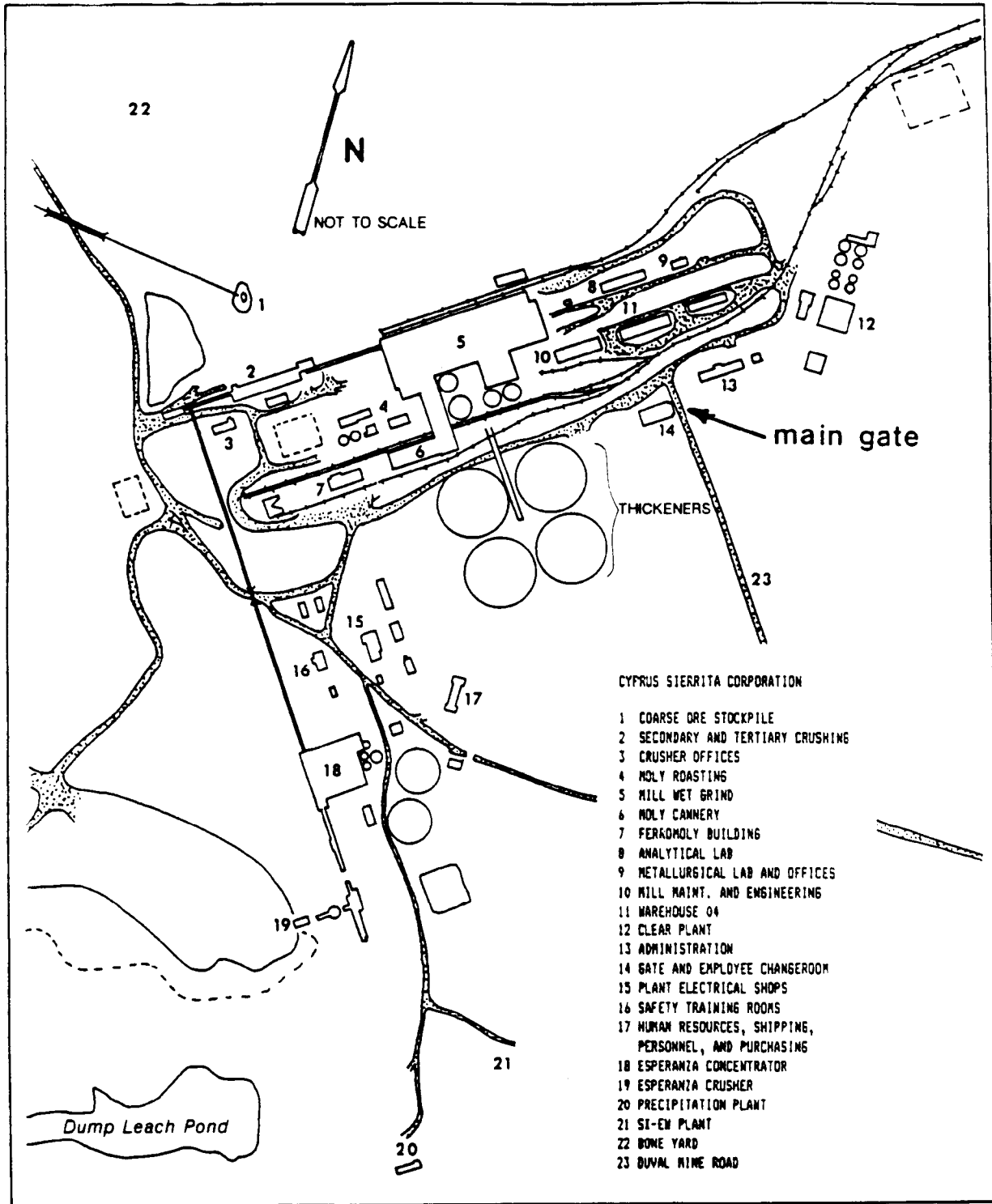


Figure 1-21. Cyprus Sierrita Facility Map

(Source: Cyprus Sierrita Corporation 1989)

10 and 7 miles west of I-19 near the town of Sahuarita, Arizona (28 to 32 miles south of Tucson). Cyprus Sierrita Corporation operates a sulfide ore concentrator, a heap leaching operation, a ferro-molybdenum plant, a rhenium plant, and an SX/EW plant in conjunction with mining operations at the Sierrita pit (U.S. DOI, Bureau of Mines 1965a; Reed and Associates 1985).

The ore body is a sulfide-enriched zone (primarily chalcopyrite) in a quartz monzonite porphyry intrusion (U.S. DOI, Bureau of Mines 1965a). Ore is mined from two adjacent open pits (Sierrita and the Esperanza pits). Ore crushing, grinding, flotation, and molybdenum roasting stages follow extraction operations. Beneficiation consists of a sulfide copper molybdenite concentrator with a 100,000-tpd capacity (U.S. EPA 1986). Copper concentrates, molybdic oxide, ferro-molybdenum, and rhenium (as ammonium perrhenate), and silver byproduct are produced at the site (U.S. EPA 1988b).

Three principal wastestreams are generated at the Sierrita mining operation. They are overflow from the dump leaching operation, tailings that result from operations at the Sierrita mill and concentrator, and septic system effluent (U.S. EPA 1989d).

Extraction

Mining

Overburden stripping operations at the Esperanza open-pit mine began in 1957, utilizing a combination of scrapers, conveyors, and dump wagons; ore extraction began in 1959. The Sierrita Mine began production in mid-1970. The two mining operations were combined in 1988 and are no longer referred to separately; they are identified together as the Sierrita Mine. The combined production rate is 60,000 to 70,000 tpd. The metals output per year is 200,000,000 lbs for copper, 20,000,000 lbs for molybdenum, and 1,000,000 oz for silver. (U.S. EPA 1988b).

Conventional drilling and blasting open-pit mining methods are used for extraction of the sulfide ores. Blast holes are drilled in groups in 50-foot-high benches by a fleet of eight rotary drills, then filled with an Ammonium Nitrate and Fuel Oil (ANFO) blasting mixture. Electric shovels and scrapers load the ore onto electric-drive dump trucks, which take it to primary crushers in the pit. The ore is transported to either the portable or stationary pit crushers and crushed to about 6 inches, then discharged onto a 3-mile-long conveyor belt system and delivered to the coarse ore stockpile. Waste rock and alluvium are transported by truck to the surface where they are crushed, then transported by conveyor to a dump (U.S. EPA 1988b).

In 1989, the stripping ratio at the Sierrita Mine was 0.77 to 1. Over 113 million tons of overburden have been excavated, and 540 million tons of waste rock and 61 million tons of dump/heap leach waste have been generated. Waste rock covers approximately 5.6 million square yards and dump/heap leach waste covers 1.3 million square yards. Waste rock and leach dump waste management units do not have liners, leachate detection systems, or ground water monitoring systems (U.S. DOI, Bureau of Mines 1965a; U.S. EPA 1986; Beard 1990; U.S. DOI, Bureau of Mines 1990a).

Approximately 3 million gallons of water per year are pumped from the Sierrita pit into a surface impoundment. This impoundment has no liner, leachate collection system, or ground water monitoring wells (Reed and Associates 1985).

Dump Leaching Operations

Cyprus Sierrita Corporation maintains a dump leaching operation for recovering copper from oxide ore. The leaching operation is comprised of the leach dumps, a series of ponds for containment of PLS and raffinate, and an SX/EW plant for copper extraction (U.S. EPA 1989d).

Dump leaching of low-grade ore began in 1964 at the Sierrita Mine site and in 1959 at the Esperanza pit (shortly after mining operations began). A sprinkler system is used to spray dilute sulfuric acid solution onto the leach dumps (no other chemicals have been used in the leach dumps). As the dilute acid solution leaches through the dump, bacteria flourish in the low-pH environment (the pH is monitored and kept above 2.3) and contribute to the release of copper. The PLS percolates through the oxide ore. According to Cyprus, the bedrock serves as a collection surface for the resultant PLS. Bedrock topography beneath the leach dumps appears to allow the PLS to discharge to the surface. Most of the PLS flows into the Amargosa wash drainage, although smaller amounts discharge to the Esperanza wash drainage. A series of ponds located along Amargosa wash and Esperanza wash (near the base of the leach dumps) have been constructed for containment of PLSs (see the discussion below) (U.S. EPA 1989d).

PLS discharged to the Amargosa wash drainage is contained by the No. 1 dam. The copper leach pregnant pond at the No. 1 dam is approximately 1 acre in size and 6 feet deep. It has the capacity to store 6 acre-feet of PLS per year. This impoundment is located on bedrock. There is no leachate collection or ground water monitoring system around this pond, although the unit has a seepage collection pond which acts as a runoff/runoff control system (U.S. DOI, Bureau of Mines 1990a). Collected PLS is pumped by pipeline to the SX/EW plant, where copper is extracted.

After organic extraction, barren solution is discharged from the SX/EW plant into the raffinate pond (a clay-lined pond underlain by bedrock). The solution is then pumped through a 20-inch line from the raffinate pond to a booster station and an intermediate tank located about halfway up the dump. To maintain the pH, additional sulfuric acid is added to the barren solution from two nearby tanks. The recharged acidic solution is then pumped onto the tops of the various leach dumps (U.S. EPA 1988b, 1989d).

Two additional ponds have been constructed in the Amargosa wash downstream of the raffinate pond. These ponds are designed to receive potential overflow from the raffinate pond. Overflow from the raffinate pond is initially contained by the dam at pond A, located about 500 feet downstream from the raffinate pond. Overflow from pond A is contained by the dam at pond B, located about 1,600 feet downstream from the pond A dam. Water or solution which accumulates in ponds A and B is pumped back to the raffinate pond for delivery to the leach dumps. Any overflow from pond B is diverted from the Amargosa wash and discharged to the Duval canal. This canal conveys the overflow from pond B and pond C to a natural drainage system south of the Esperanza tailings impoundment. This natural drainage directs runoff to the Sierrita tailings impoundment at a point near the reclamation pond. The Duval canal is constructed from fill material and is unlined (U.S. EPA 1989d).

PLS entering the Esperanza wash is contained downstream by dam No. 3-1/2 and further downstream by dam No. 4. The average pumping rate from the No. 3-1/2 dam is about 100 gpm, and the average pumping rate from the No. 4 dam is about 50 gpm. According to Cyprus, the dump leaching operation is isolated from the regional ground water aquifer, because the heap leach operation is completely contained by bedrock (Reed and Associates 1985).

In August 1988, overflow was observed at Ponds A, B, and C. Specifically, overflow from Pond B to the Duval canal was observed at a rate of about 75 gpm. This overflow may have resulted from recent summer rainfall in the area, or from mechanical problems with the pumping equipment (Berkeley Report 1985).

Cyprus Sierrita Corporation has recently expanded the storage capacity of the No. 4 dam. This expansion has increased the capacity of the No. 4 dam to meet design requirements for the 25-year flood. The increased storage capacity of No. 4 dam, together with the ability to pump fluids from the No. 4 dam to either the No. 1 dam or the Sierrita tailings thickeners, substantially reduces potential for overflow (U.S. EPA 1989d).

Beneficiation

Milling

A secondary and tertiary crusher system further crushes the ore from the coarse ore stockpile. Fine ore, about 0.75 inch in size, is transported by conveyor to the surface mill building. Water is subsequently mixed with the fine ore in each of 16 separate divisions of ball mills in the sulfide mill building. The resulting slurry circulates through a closed system which diverts the finest ore particles (pulp) to the concentrator flotation cells (U.S. EPA 1988b).

The capacity of the Sierrita concentrator is 100,000 tpd (Beard 1990). It uses various inorganic and organic compounds to aid in the extraction of copper and molybdenum. These compounds serve as frothers, flocculents, collectors, flotation modifiers, depressants, leachants, dewatering aids, and water treatment agents. Quantities of organic compounds used at the concentrator are regulated so that these compounds largely remain with the metal concentrate product and are not discarded with process water (U.S. EPA 1989d).

The following inorganic and organic chemical compounds are utilized during ore processing at the Sierrita mill and concentrator: lime, potassium amyl xanthate, allyl ester of amyl xanthate, alkyl sulfonate, Methyl Isobutyl Carbinol (MIBC), petroleum hydrocarbons, anionic polyacrylamides, phosphates, sodium hydrosulfide, sodium sulfosuccinate, and ferric chloride. Frothing, collector, and flocculent reagents are added to the slurry to facilitate the separation of the sulfide-bearing minerals in the flotation cells (U.S. EPA 1988b). The quantities of some of the reagents used at Sierrita mill are listed in Table 1-11 below:

Table 1-11. Reagent Quantities Used at the Sierrita Concentrator

Reagent Name	Quantity (pounds per ton of ore)
Potassium amyl xanthate	0.02
Allyl ester of amyl xanthate	0.0002
Petroleum hydrocarbons	0.004
MIBC	0.08

(Source: U.S. EPA 1988c)

The primary copper-molybdenum flotation circuit is a conventional roughing, cleaning, and recleaning operation in which the rejects from both the cleaning and recleaning stages are returned to the prior flotation step. In the copper and molybdenum flotation cells, low pressure air is introduced and forms a froth, causing the copper and molybdenum sulfide minerals to float to the surface for removal. The finely ground waste rock pulp that remains in the bottom of the flotation cells is the tailings (U.S. EPA 1988b).

All primary copper-molybdenum flotation reagents are added to the ball mill feed. Pulp alkalinity is maintained with 0.25 to 0.30 lbs of available lime per ton of mill water. Flotation reagents are selected not only for maximum recovery in the primary circuit, but also with consideration of their effect on the subsequent copper-molybdenum separation process (U.S. EPA 1988b).

Concurrent utilization of both automatic froth level control and mechanical froth skimmers is practiced on all flotation cells to ensure positive froth removal and to reduce operator dependency. Froth level is maintained with electrical resistance air-froth interface probes controlling air-operated darts in each transition and tail box. Mechanical froth skimmers on each flotation cell mechanize and meter froth removal from both sides of each flotation cell (U.S. EPA 1988b).

Molybdenum separation from copper and gangue minerals is conducted with a circuit using sodium hydrosulfide as the sole copper mineral depressant. The separation is accomplished through sulfidization in rougher, cleaner, and recleaner flotation; single-pass regrinding; and second recleaner flotation. The molybdenum flotation circuit floats the molybdenum sulfides while the copper sulfides remain as tailings. The copper sulfides (tailings) are then thickened, filtered, and shipped by rail offsite to a copper smelter. Water reclaimed from the thickeners (and waste from the tailings ponds) is recovered and recycled to the process. Each of the molybdenum flotation cells contains several stages of flotation for optimal extraction. Filtered final molybdenum flotation concentrate is dried and leached to reduce copper and lead levels to less than 0.15 percent and 0.05 percent, respectively. This process consists of a chloride metal salt leach at an elevated temperature. The leached concentrate is washed free of chloride salts and dried (U.S. EPA 1988b).

Dried, leached molybdenum concentrate is roasted in multiple hearth roasters to produce commercial molybdenum trioxide. The roasting and gas cleaning system includes two 23-foot hearth roasters, two lime-slurry scrubbers, and two acid/PCB scrubbers. The molybdenum trioxide product is processed and packaged for sale in various containers including drums, cans, and bags. The packaging facility also includes a hydraulic press and blending facilities for producing self-reducing molybdenum oxide briquettes (U.S. EPA 1988b).

Esperanza Tailings Disposal

The Esperanza tailings impoundment is located about 4 miles southeast of the Sierrita mill. Disposal of mine tailings from the Esperanza concentrator to the Esperanza tailings impoundment was continuous from October 1959 to December 1971 and from January 1973 to December 1978, and it was intermittent from January 1979 to December 1981, when the tailings impoundment was closed (U.S. EPA 1989d).

The inactive Esperanza tailings pond, which covers about 650 acres, was drained and solidified. The maximum height of the solidified tailings dam embankment face is about 100 feet. A tailings-capping program was initiated by Sierrita after it discontinued operation of the Esperanza tailings pond. This closure program required the placement of about 1 foot of alluvial soil over the surface of the former tailings pond to control dust emissions. The capped tailings pond surface area has been reseeded with native plants and grasses to control erosion and maintain aesthetics (U.S. EPA 1988b).

Sierrita Tailings Disposal

Cyprus Sierrita operates the Sierrita tailings impoundment, located about 4 miles southeast of the Esperanza tailings impoundment. The largest wastestream generated at the Sierrita operation is tailings slurry from the concentrator, which is discharged to the Sierrita tailings impoundment via pipeline. Disposal of mine tailings from the Sierrita concentrator in the Sierrita tailings impoundment began in March 1970 and still continues (U.S. EPA 1988b).

The tailings pond contains approximately 430 million tons of tailings (U.S. EPA 1986). The pond encompasses more than 4,000 acres, with a crest length along the dam face of about 25,000 feet. The tailings dam face is currently about 150 feet high (U.S. EPA 1988b).

The tailings slurry from the concentrator, which consists of finely ground host rock and water, is sent to four 350-foot (diameter) tailings center-drive thickeners. These thickeners, located south of the mill, serve to reduce the water content of the tailings. Fresh makeup water is added near the center well of each tailings thickener. Flocculent application is necessary to control slime levels in the thickeners. The thickener overflow water is recycled to the concentrator while thickener underflow pulp, which is from 54 to 56 percent solids, is discharged through two spigots per thickener into a common 42-inch (diameter) tailings line and transported by gravity to the tailings pond. The underflow pulp density is regulated with hydraulically operated pinch valves on each spigot. Pulp density controllers, receiving density measurements from gamma gauges located on each thickener underflow pipe line, adjust the control valve on each thickener spigot (Weiss 1985; U.S. EPA 1988b).

Tailings slurry is discharged to the Sierrita tailings impoundment through spigots installed on pipelines positioned along the tailings impoundment dam. The slope of the tailings impoundment surface permits decanted water to flow to the west, where the water collects at the reclamation pond. Decanted water is then recycled to the Sierrita mill (U.S. EPA 1989b).

The Sierrita tailings impoundment is divided into two separate discharge areas (the north area and the south area) by a central divider dike. Tailings deposition into the impoundment alternates between the two areas (allowing the tailings embankment in one section to be raised while the other section is being filled). Approximately 1 year is required to fill each discharge area to its temporary capacity (U.S. EPA 1989d).

Each tailings area is further subdivided by shorter berms constructed perpendicular to the embankment crest. The shorter berms are situated on approximately 1,000-foot centers around the periphery of the impoundment. These berms allow relatively even distribution of tailings discharged into the pond and direct the slimes and free water away from the embankment crest. By employing hydraulic classification (using hydrocyclones), the coarsest fraction of the tailings is deposited near the embankment crest. The surface of the tailings slopes away from the embankment at a grade of about 1.5 percent. As a result, the free-water pond is forced against the hillside in the back or the west side of the impoundment (Weiss 1985; U.S. EPA 1988b).

The tailings embankment is raised in lifts by construction of a new dike on top of the crest of the embankment following each period of filling. The dikes are constructed of the coarse tailings or beach sands deposited adjacent to the embankment crest. Bulldozers are used to spread the sand, and a sheep-foot roller is used for compaction. The height of the dike for each lift is about 8 feet. On completion of every third lift, or each 24-foot increase in embankment height, the dike for the next lift is constructed approximately 40 feet inside the crest of the embankment. Thus, a 40-foot wide bench is provided on the slope of the tailings embankment. The tailings discharge line is then dismantled, and the line segments are raised with a crane onto the new bench and reassembled. The overall slope of the tailings embankment is 3 to 1 (horizontal to vertical) (U.S. EPA 1989d).

The starter dam at the base of the tailings embankment is a homogeneous section constructed of onsite alluvial materials. The starter dam extends along the entire eastern side of the tailings impoundment and continues for several thousand feet along its north and south sides, with a maximum height of approximately 70 feet. The upstream slope of the starter dam was constructed at 1.5 to 1; the downstream slope at 2 to 1 (Weiss 1985; U.S. EPA 1988b).

According to Cyprus, chemical analyses of the tailings pond water show that it meets Federal primary and secondary drinking-water standards, with the exception of high TDS and sulfate levels. Because high-alkaline conditions are maintained during the flotation process at the Sierrita concentrator, the tailings slurry discharged to the Sierrita tailings impoundment has an elevated pH (U.S. EPA 1989d).

As water is decanted from the free-water pond, pumps positioned near the shore line in the back of the impoundment return the water to the mill for reuse. However, a fraction of the tailings pond water may percolate through the alluvial soils and reach the aquifer, which is currently about 400 feet below the ground surface. Results of the water balance calculation indicate that seepage from the Sierrita tailings impoundment has ranged from about 10,469 acre-feet in 1981 to about 5,085 acre-feet in 1987. The average volume of seepage from the Sierrita tailings impoundment during the period from 1979 to 1987 was about 41 percent of the total water delivered to the tailings impoundment (U.S. EPA 1989d).

Elevated sulfate and TDS levels have been detected in numerous ground water-monitoring wells (both onsite and offsite) (U.S. EPA 1988b). Specifically, the 13 monitoring wells in the vicinity of the tailings pond have shown "a slight increase in sulfate concentration." Eleven interceptor wells have been installed a few hundred feet downslope from the east and south sides of the tailings embankment surrounding the tailings pond. These wells may create a hydrologic barrier designed to prevent tailings pond water migration (Reed and Associates 1985; U.S. DOI, Bureau of Mines 1990a). Water obtained from these interceptor wells is pumped to milling operations. Sierrita currently collects and diverts potentially contaminated runoff (generated by heavy rainfall during winter storms) away from the tailings (U.S. EPA 1988b).

An instrumentation program has been undertaken to monitor the performance of the tailings embankment. Open-well piezometers installed along five profiles through the tailings embankment observe the location of the potentiometric surface within the embankment. In addition, several inclinometers have been installed to measure the magnitude and direction of horizontal movements within the embankment. Survey monuments are installed on the east face of the dam for deformation measurements, and subsidence monuments are located at the toe of the dam to measure potential subsidence resulting from interceptor well pumping (U.S. EPA 1988b).

Leach Circuit

Historically, copper cementation-type plants extracted copper from PLS. Copper was extracted by adding shredded iron to the PLS, which formed a copper and iron precipitate containing about 65 percent copper. In March 1987, the copper cementation precipitation plants were replaced by an SX/EW plant. The average daily production of the SX/EW plant is about 28,000 lbs of copper (U.S. EPA 1988b).

The PLS from the leach dumps (see the previous discussion) is gravity fed to the SX/EW plant, where the copper is extracted. The extraction process uses a phenolic oxime/kerosene mixture as an extractant. The copper is then stripped from the organic extractant with a sulfuric acid solution, forming a purified copper electrolyte that flows to the electrowinning cells in the plant. The following compounds are used in the SX/EW plant operation: sulfuric acid, kerosene, phenolic oxime, and cobalt sulfate (U.S. EPA 1989d).

The SX plant consists of 25 mixer-settler units that mix the aqueous and organic components. Both components are immiscible and are allowed to separate. The mixer-settler units are arranged in five identical, parallel rows, each utilizing three extraction units, one wash unit, and a stripping unit. Organic flow is countercurrent to the aqueous flow and flows continuously through the stripping, washing, and extraction phases. After extraction of the copper from the organic liquid, the barren aqueous solution, or raffinate, is collected in a raffinate pond and pumped back to the leach dumps at a rate of 3,300 gpm (U.S. EPA 1988b; U.S. DOI, Bureau of Mines 1990a).

The electrowinning plant contains 60 fiberglass cells, each containing 22 anode sheets and 21 cathodes. The plant has a capacity to produce 30,000 lbs of finished cathodes per day (U.S. EPA 1988b).

The SX/EW process is a closed system; there are no effluent discharges. All of the reagents and intermediate liquors are stored in covered storage tanks in accordance with applicable regulations (not specifically identified in the available references) (U.S. DOI, Bureau of Mines 1990a).

Other Wastes Associated with the Sierrita Operation

Other wastestreams disposed of at the Sierrita site include sanitary wastes, discharges from the rhenium extraction plant, and discharges of tailings from the Cyprus Twin Buttes Corporation oxide plant. These wastestreams discharge to the Sierrita tailings thickeners (U.S. EPA 1989d).

Sanitary Wastes

Sanitary wastes generated at the Sierrita operation discharge to a series of septic systems serving different parts of the facility. A total of nine septic systems are currently in use at the Sierrita operation. Estimated daily discharges to septic systems range from about 75 gallons for septic systems No. 4 and No. 9 to about 9,500 gallons for septic system No. 1 (U.S. EPA 1989d).

Septic system No. 1 serves the Sierrita mill area. Effluent discharged from septic system No. 1 is treated with potassium permanganate disinfectant prior to discharge to the Sierrita tailings impoundment to mitigate potential biological contamination. Mitigation of nitrate and phosphate discharges is accomplished through dilution in the tailings wastestream. Average daily discharge of water to the Sierrita tailings impoundment from the Sierrita mill for 1987 was more than 14 MGD; as stated above, the effluent discharge from septic system No. 1 is about 9,500 gallons per day (gpd), or about 0.07 percent of the total water delivered to the tailings impoundment (U.S. EPA 1989d).

Septic system No. 6 serves the Sierrita truck shops, change rooms, and engineering offices. It receives about 7,750 gpd. Effluent discharged from septic system No. 6 is delivered to a leach field. Seepage from the leach field is believed to migrate to bedrock and flow along the Esperanza wash channel. This seepage water may then flow into springs, which discharge to Esperanza wash upstream of the No. 4 dam. These discharges are contained in the wash by the No. 4 dam, and are pumped to the Amargosa wash drainage for processing at the SX/EW plant (U.S. EPA 1989d).

According to Cyprus, "no usable ground water underlies the septic tanks, and there is no opportunity for discharge from septic tanks to enter the regional aquifer system" (Reed and Associates 1985). Accordingly, Cyprus does not propose to submit a ground water-permit application for any of its septic tanks (U.S. EPA 1989d).

Rhenium Plant Wastes

The element rhenium occurs in minor amounts with molybdenum ore. In 1982, a rhenium plant was constructed in the vicinity of the Sierrita mill to recover rhenium oxide from the acid demister effluent generated by the molybdenum roaster. The recovery process is a closed-system, ion-exchange, evaporation-crystallization process that has a capacity to recover up to 15 lbs of rhenium per day (as ammonium perrenate). Reagents used at the rhenium plant include caustic soda, sodium hypochlorite, and ammonium thiocyanate. The design and operation of the rhenium plant requires that the ammonium thiocyanate remain with the final product or be recycled (U.S. EPA 1988b, 1989d).

During the rhenium extraction process, liquor from the rhenium plant flows to the Sierrita tailings thickeners at about 5 gpm. The pH of this solution is approximately 11 (U.S. EPA 1989d).

In conjunction with the operation of the rhenium plant, a holding pond for storage of acidified liquor to be processed by the rhenium plant is located west of the Esperanza tailings impoundment. Fluids contained in the lined rhenium pond are part of the production circuit (U.S. EPA 1989d).

Twin Buttes Oxide Plant Wastes

Cyprus Sierrita Corporation-Twin Buttes began short-term operation of the Oxide plant at the Sierrita site in March 1989. The Oxide plant is comprised of a vat leaching circuit and an SX/EW plant. Discharge of tailings from the vat leaching circuit of the plant is piped to tailings slurry pipelines at the Sierrita operation for delivery to the Sierrita tailings impoundment. Oxide tailings from the Twin Buttes operation are from about 45 to 50 percent solids and have a pH of about 2.0. Average flow rate for tailings from the Twin Buttes Oxide plant is 1,800 gpm. Because the tailings discharged from the Sierrita operation are alkaline, tailings from the Twin Buttes Oxide plant are neutralized, and any dissolved constituents should be precipitated in the Sierrita tailings impoundment (U.S. EPA 1989d).

4. Cyprus Bagdad Copper Company; Bagdad Mine; Yavapai County, Arizona

The Bagdad Mine is located in western Yavapai County, 27 miles from Hillside and 120 miles northwest of Phoenix, Arizona. Its operating capacity is 95,000 metric tpy of copper. The ore body is a chalcocite-enriched zone in quartz monzonite porphyry that outcrops from an irregular stock. In 1948, mining operations changed from block-caving to open-pit production (U.S. DOI, Bureau of Mines 1965a; Niemi 1980). The mine-strip ratio in 1991 was 0.9 to 1, with an average ore grade of 0.44 percent copper. The concentrator capacity is 75,000 tpd since completion of the expansion in 1990 (Cyprus Minerals Company 1992).

The Bagdad operation consists of an open-pit copper-molybdenum mine, a 55,000-tpd concentrator, a dump leach operation, and an SX/EW plant. A \$21-million expansion program underway was to have added a fifth grinding line to the existing mill and to have increased production capacity from 15 to 20 percent by mid-1990 (Beard 1990).

Extraction

Mining

Mining is conducted using electric shovels. Trucks are used to haul the ore to the primary crusher and dump. Bagdad uses an in-pit primary crusher and 6,400-foot-long conveyor system that transports the ore to the concentrator (Niemi 1980). The Bagdad open-pit mine generates about 20 million tons of overburden and 17 million tons of waste rock each year (for an accumulated lifetime volume of 424 million tons of waste material). The mine overburden and waste rock areas cover approximately 1,470 acres (Cyprus Minerals Company 1992).

The mine waste disposal areas do not have any type of impermeable liners or leachate collection systems. Storm water runoff from the waste disposal areas drains to the open pit where it is used as make-up process water (Cyprus Minerals Company 1992).

Leaching Operations

Sulfide ores that have a high-oxide content are placed in dumps and leached for 60 days before being sent to the concentrator (Beard 1990). Dump leach operations began in 1960. Cyprus is currently operating a number of leach dumps for sulfide ore that has a high-oxide content. The two main leach dumps are located along Copper Creek, and a third is located along Mineral Creek. Several other small dumps are located along Copper, Niagara, and Alum Creeks (see Figure 1-22)

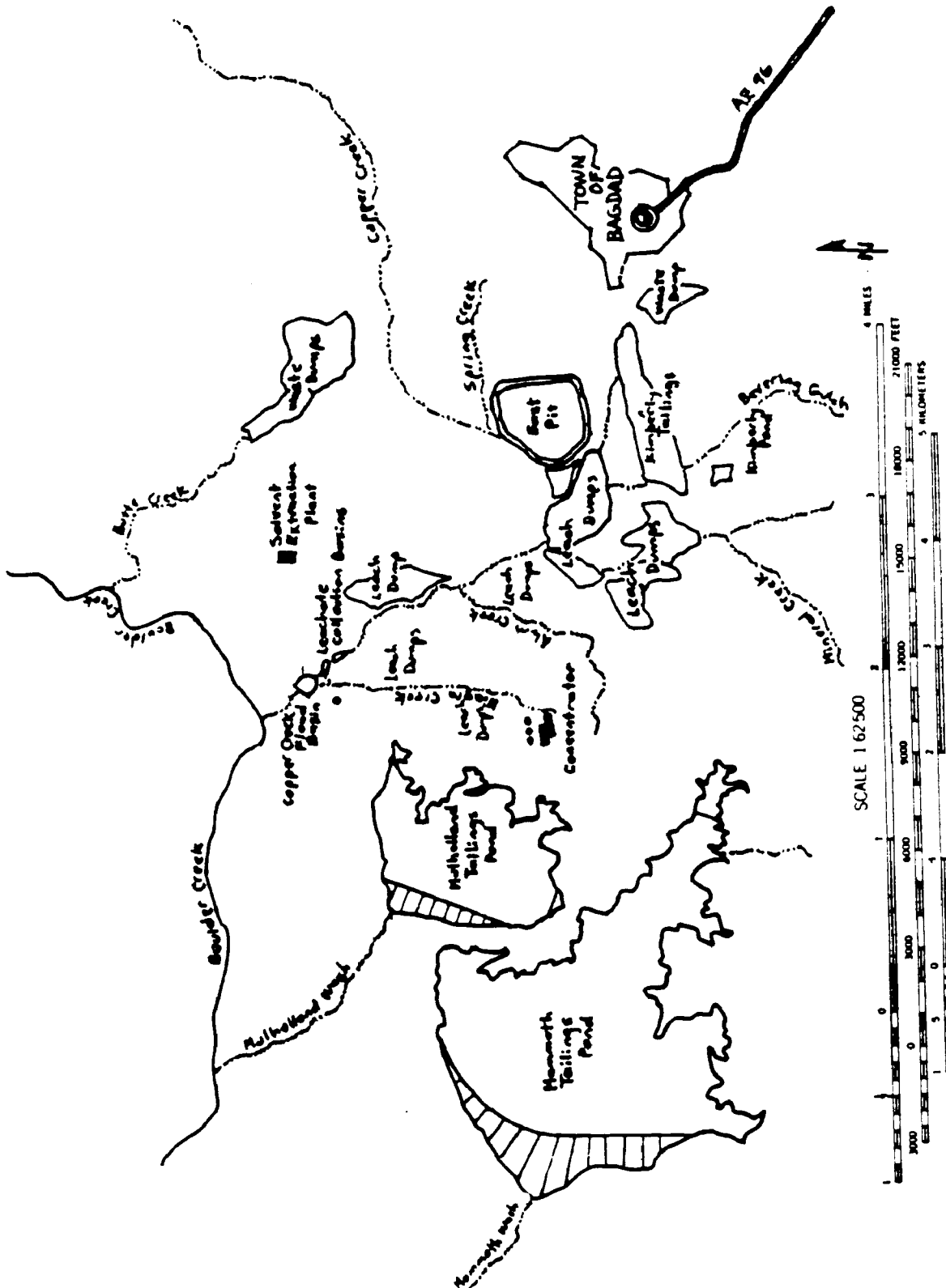


Figure 1-22. Locations of Bagdad Leach Dumps

(Source: U.S. EPA 1987)

(U.S. EPA 1987). The dumps contain over 600 million tons of oxide ore, and only 10 to 15 percent are active at any given time (U.S. EPA 1989e).

Low-grade, mine-run ore is used in the leach dumps. Ore having an oxide copper content of at least 0.07 percent, but not having sufficient copper to justify mining, is generally deposited on the leach dumps (Cyprus Minerals Company 1992). The dumps have been built directly on the existing topography, utilizing the natural drainage created by the contours of several canyons located on the property to divert and collect the PLS (U.S. EPA 1989e). "Leach dump site preparation has been minimal. Convenient, comparatively narrow, steep-walled canyons are selected. They are then subjected to critical examination for major fractures, etc." (Weiss 1985).

Haulage trucks carry the ore from the pit to a leaching area where it is dumped and spread by a bulldozer. Lift heights range from 40 to 300 feet depending on the particular topography of the land.

After a lift is completed, the surface is ripped to a depth of about 5 feet, and the solution distribution system is installed (U.S. EPA 1989e).

The rice paddy flooding method was first used at the leach dumps for solution introduction. Since that time, lixiviant is dispersed with a wiggler-type sprinkler system between 3,000 to 4,000 gpm. This reduces channeling and ensures uniform coverage. The lixiviant solution consists of dilute sulfuric acid (containing 8 g/l of sulfuric acid) having a pH of approximately 1.0. Initially, each lift is leached until the surface begins to pond due to a buildup of iron salt precipitates. After this period, the dumps are allowed to rest. The ratio between the leach period and the rest period is approximately 3 to 1.

Pregnant solution is collected at the base of each pile in a lined pond or large plastic-lined surge holding tanks. The pregnant solutions from the leach piles (except Allum Creek reservoir) are then combined in a series of ponds located in an ephemeral tributary to Copper Creek. The number, specific locations, and construction of these ponds are unclear from the available references. Pregnant solution from the Allum Creek reservoir is pumped to the top of the Copper Creek dump, through which it is allowed to percolate. The average concentration of copper in pregnant solution ranges from 1.07 to 1.89 g/l. The pregnant solution from the series of ponds is eventually metered out through Niagara dam into a trench and a collection reservoir. The dam is made of concrete and keyed into the bedrock of the surrounding hillside. In 1989, both the trench and the collection reservoir were lined with 100-mil polyethylene liner. The pregnant solution collected in the reservoir is then pumped to the SX/EW plant (Niemi 1980; Weiss 1985; U.S. EPA 1989e; Beard 1990).

The techniques used in 1989 to install the liner in the collection trench and pond were similar to those used in the lining of heap leach piles. The area chosen for the trench and pond was first excavated and rough graded. After the excavation and grading were completed, a fill subgrade material was hauled to the site and compacted in layers. After the subgrade material was in place and had been adequately compacted and finished, the liner was installed. The liner was cut and spread by hand in the trench and collection reservoir areas. The seams were then welded and tested to ensure their integrity. After the liner had been installed, a pumping system was installed to carry the pregnant liquor to the copper recovery plant (U.S. EPA 1989e).

After the copper has been recovered in the SX/EW plant, the barren solution is recycled to the leach dumps. Approximately 100 tpd of acid is added to this solution to reduce the pH. Mine water is used as makeup water. Between 500 and 800 gpm of water is produced in the mine pit. The mine water collected in the pit is used only in the mining operations (as makeup water) and is not discharged off the property (U.S. EPA 1989e). Cyprus has installed two wells as part of a ground water-monitoring system, and more are scheduled (Cyprus Minerals Company 1992).

Beneficiation

Milling

The beneficiation operation consists of a sulfide concentrator and a leach plant. Sulfide ore is transported 6,400 feet via conveyor belt to the coarse ore stockpile at the concentrator. At the concentrator, the ore is further crushed and ground by autogenous and ball mills. The concentrator flotation cells use sodium ethyl xanthate as a primary collector, Phillips Co. 400 as a secondary collector, and ore prep F-547 as frother. The pH is kept at 10.5 by applying lime. Column cells are utilized in the molybdenum flotation circuit. The primary depressant used in the molybdenum plant is sodium hydrosulfide (Cyprus Minerals Company 1992).

Tailings Disposal

There are two large tailings ponds (the Mulholland and Mammoth ponds) and a third small tailings pond (the Kimberly pond) at the Bagdad Mine (as shown in Figure 1-22) (U.S. EPA 1987). Approximately 25 million tpy of tailings are disposed of in the tailings ponds. The ponds contain about 270 million tons of tailings and cover approximately 1,200 acres. Tailings are piped by gravity to the disposal site, where they separated and dispersed by cyclones. Cyprus uses the center-line method of raised embankment berm erection. Barge-mounted pumps reclaim up to 21,000 gpm of water from the tailings impoundment (Cyprus Minerals Company 1992). The tailings ponds are not lined.

Leach Plant

Historically, a cementation plant was used at the Bagdad Mine between 1961 and 1970 (Cyprus Minerals Company 1992). Pregnant liquor was pumped from the holding tanks to precipitation cells filled with shredded scrap iron, which precipitated copper while solubilizing iron. A bleed stream was introduced to control the pH and prevent iron scaling in the pipes (Weiss 1985). As the quality of the scrap iron degraded and demand increased, undesirable insoluble materials, such as calcium and iron, required more cleaning by magnetic separators. Increased processing and cleaning costs necessitated introducing a new technology.

In 1970, Cyprus opened its SX operation. Cyprus' SX process produces 60,000 lbs of pure copper cathode per day (Cyprus Minerals Company 1992). Pregnant solution is passed through four extraction and stripping stages to recover the copper ion from the solution. The process utilizes a special reagent (LIX-64N) which has a high affinity for copper ion in a weak acid solution and a low affinity for other metal ions (Niemi 1980).

The reagent operates on hydrogen ion cycles, which, in general, proceed in the following manner. The reagent, carried in an organic medium, is intimately contacted with aqueous leach solutions in the extraction system. There, hydrogen ions are exchanged for copper ions. Sulfuric acid in the leach solution is regenerated while the copper is extracted. The organic medium containing the copper passes to the stripping system where it contacts aqueous copper sulfate in the presence of sulfuric acid; there, copper ions are exchanged for hydrogen ions. The reagent is regenerated and recycled to the extraction system. The enriched copper sulfate solution is essentially an impurity-free, concentrated electrolyte from which high-quality cathode copper is produced by electrowinning. The barren solutions are returned to the dumps after the copper has been extracted (Bagdad Copper Corp. undated).

Electrowinning

The electrowinning plant has two stages, a starter sheet and a commercial cathode production section. The starter sheet operation uses 48 stainless steel blank cathodes and 49 anodes in 6 cells. Commercial cathode production has 50 cells with 48 cathodes and 49 anodes per cell (Cyprus Minerals Company 1992).

Wastewater Management

The natural contours of the land divert the runoff from the surrounding hills around the mining and leaching operations. Precipitation falling within the mine area itself is collected in either the pregnant solution collection ponds or the mine pit. An overflow floodplain reservoir has been constructed to protect against a 100-year flood event. Runoff collected in the floodplain reservoir is pumped into the pregnant solution collection reservoir and used in the leaching circuit (U.S. EPA 1989e).

5. Magma Copper Company, Pinto Valley Mining Division

The Pinto Valley mine is an open-pit mine located adjacent to the Inspiration mine, near Globe in central Arizona. The Pinto Valley Division (PVD) consists of the Pinto Valley unit (Castle Dome and Copper Cities), the Miami unit, and the No. 2 Tailings Hydraulic Operation (Beard 1990).

The Pinto Valley ore body is fairly typical quartz monzonite porphyry-type deposits, which intrudes granite porphyry and is crosscut by diabase dikes. The ore body is bounded by major fault systems and is highly fractured. The host rock for the deposit at the Miami mine is Precambrian pinal schist, which is partially covered by the Gila Conglomerate. The principal copper mineral is chalcocite with minor amounts of chalcopyrite, bornite, covellite, malachite, azurite, chrysocolla, cuprite, and native copper. The mine produces both copper and molybdenum concentrates (Mining Magazine 1975; U.S. EPA 1989e).

Extraction

At the Pinto Valley unit, mining is accomplished with electric shovels, and trucks haul 64,500 tpd of ore to the concentrator (Magma 1992). The overall waste-to-ore ratio is 1.5 to 1. The total excavation is estimated to produce 500 million tons of waste and leach-grade material. The maximum pit size will be 6,000 feet long by 3,500 feet wide and 1,450 feet deep (Mining Magazine 1975). The Copper Cities unit consisted of an open pit operation and concentrator which were active between 1954 and 1975. All mining and milling operations ceased in late 1975. Initial open-pit mining began at the Pinto Valley site around 1972 (U.S. EPA 1989e). A dump leaching operation and a 7,000-gpm SX/EW plant are also located at the site (Magma 1992).

Solution Mining

Leaching at the Pinto Valley site consists of eleven waste dumps. The dumps currently contain approximately 297 million tons of leachable waste ore. About 28 million tons of leachable waste are being added to the dumps each year.

Active dump leaching operation began in 1981 when construction of the SX plant was completed. The operation currently covers an area of approximately 6,570 acres (470 acres of which are covered by leach dumps). Approximately 85,000 tons of copper are produced annually from the Pinto Valley operation (15 percent of which are produced from the leaching operation) (U.S. EPA 1989e).

Currently, only about 120 acres of the dumps are being leached at the Pinto Valley site. Trucks haul the material from the mine pit to the leach dump. The leach dumps at the Pinto Valley site have been constructed on existing topography with no prior subsurface preparation. After each lift is completed, the surface is ripped to a depth of approximately 3 to 4 feet using a cat ripper, and the distribution system is installed. The distribution system consists of 2-inch perforated Drisco pipe spread over the dump (U.S. EPA 1989e).

The leach solution applied to the Pinto Valley dumps contains approximately 2.25 g/l of sulfuric acid and has a pH ranging from 1.7 to 1.8. It is applied continuously until the surface of the dump begins to pond, indicating excess precipitation of iron salts. The pregnant leach liquor contains about 0.95 g/l of sulfuric acid and has a pH ranging from 2.0 to 2.1; it is collected in the drainage below the dumps. According to company personnel, the subsurface area on which the leaching operation is conducted consists of bedrock (U.S. EPA 1989e).

Copper Cities Unit

Pregnant liquor from the leach dumps at the Pinto Valley site is collected in an unlined reservoir behind Gold Gulch dam No. 1. An overflow catchment dam (Gold Gulch dam No. 2) has been constructed down the valley to retain any flows that may result from an upset condition. Both dams have a rock shell with a clay core and are key-cut grouted to bedrock. Pumps lift the solution through 1 mile of pipe to the SX/EW plant (U.S. EPA 1989e).

Miami Unit

When the dump leaching operation at the Copper Cities mine site was closed in 1982, Pinto Valley Copper Corporation constructed a system of diversion trenches to channel overflows from the leach pile collection sumps and storm water runoff onto the tailings pond for evaporation. The trench system was designed to handle flows resulting from a 100-year storm event and was lined with riprap to prevent erosion (U.S. EPA 1989e).

In situ stope leaching began on a small scale in 1942; full-scale leaching began when the underground mine was closed in 1959. The leach solution is percolated through the caved area by underground injection and surface spraying. The pregnant leach liquor is collected at the 1,000-foot haulage level and pumped to the surface (U.S. EPA 1989e).

The PLS contains 0.57 g/l of sulfuric acid and has a pH of 2.2. The raffinate from the SX plant contains 1.6 g/l of sulfuric acid and has a pH ranging from 1.7 to 1.8. The raffinate is recycled back to the caved area for distribution as part of the leach solution. The Miami mine's *in situ* stope leaching operation has a positive water balance. This indicates that the underground mine is acting as a sump, collecting water from surrounding areas and (at least in part) preventing the migrating of leachate away from the mined area (U.S. EPA 1989e).

In 1989, Pinto Valley began hydraulic reining of the No. 2 tailings dam sediments. These tails were slurred in an open launder system to a vat leaching operation that recovered copper from the tails (Beard 1990).

Hydraulic Mining

Magma has undertaken hydraulic reining of the No. 2 tailings pile, which contains approximately 38 million tons of abandoned tailings. Tailings are reclaimed in the area lying adjacent to the drainage way of the main street in the town of Miami. The hydraulically reined tailings are then reprocessed by vat leaching (McWaters 1990). Note, however, these are historical tailings and are not a result of flotation (U.S. DOI, Bureau of Mines 1992). The hydraulic mining operation uses up to four 4-inch hydraulic mining jet monitors, feeding two separate educator pump sets capable of pumping 523 gpm of water at 28 bars of pressure. The hydraulic monitors are automatically controlled. The hydraulic mining peptizes the tailings into a 32.4 percent solids slurry. Production from this operation is expected to be about 14 short tpd of copper (Magma 1992). Both the hydraulic mining and vat leaching operations take place in Miami, Arizona, approximately 65 miles from the San Manuel Mine (ADEQ 1992).

Beneficiation

Milling

Mined ore is loaded on 190-ton trucks and delivered to a primary crusher. Secondary and tertiary crushing are accomplished using separate cone crushers. Each crusher is equipped with belt conveyors and ore bins (Mining Magazine 1975).

The concentrator contains six ball mills with dedicated cyclones operating in a closed-circuit configuration. The flotation unit is a standard copper-molybdenum-sulfide-type, arranged in a two-staged circuit. The first stage is comprised of 6 rows of 14-cell rougher-scavenger trains with cyclone hydraulic separators. The second stage is comprised of two trains of four recleaner, six cleaner, and four scavenger cells with cyclones (Mining Magazine 1975). The concentrates and cathodes (from the SX/EW plant) are shipped to San Manuel, Arizona, for processing (Beard 1990).

The concentrator's milling capacity is 70,000 tpd. The addition of the 14 rougher cells in 1989 was expected to increase the copper metal recovery rate 2 percent; actual recovery rates are slightly greater than 90 percent (Magma 1992).

Tailings Disposal

Prior to 1975, tailings (from the copper-molybdenum rougher and cleaner flotation stages) were thickened in three 350-foot diameter thickeners. Thickener overflow was recycled into the mill water supply, while the thickened tailings were diverted to one of five tailings ponds. Water from the tailings disposal areas was also reclaimed for reuse in the mill (Mining Magazine 1975).

Because of the steep topography at Pinto Valley, five separate tailings ponds were built. Each starter dam formed a homogeneous embankment and was designed with a drainage blanket that was connected to a filter bed extending through the embankment for water removal. Any water that percolates through the drainage blanket is caught by a small dam downstream and is pumped back into the water system. The foundations of the dams were excavated to solid bedrock to form a strong and relatively incompressible base for the starter dams (Weiss 1985). Beginning in 1990, Pinto Valley began cycloning tailings for berm construction, replacing the previously used spigotting method.

Pinto Valley revegetated the Solitude tailings pond near Miami, Arizona, beginning in 1959. These efforts have involved spreading native soil over the top and side slopes of the 550-acre tailings pond and planting native plants. The soil was obtained from the surrounding hills to minimize haulage costs. The area surrounding the tailings pond was stripped, and vegetation and the surficial layer of dirt was excavated. A layer of this dirt (approximately 25 cm deep) was spread over the entire surface of the tailings pond. Available mining equipment was used to remove, haul, and spread the soil. The surface of the tailings pond and the area from which the dirt had been obtained were then seeded with a 10-seed mixture of native plants. The project required approximately 20 months to complete (U.S. EPA 1989e).

Vat Leaching

The remined tailings slurry is pumped to vat leaching operations (located 65 miles away in Miami, Arizona) in separate pipelines or from each educator sump. An agitated vat leach and SX is used to process the tailings. The vat leach system is capable of holding 323,000 ft² of material and is completely computerized. The process units are constructed of two Miami-type thickeners that were refurbished with HDPE linings.

The vessels, pumps, and plumbing are constructed of corrosion- and abrasion-resistant materials, such as stainless steel, polyethylene, and rubber (McWaters 1990).

The first step in the vat leaching process is to sort the remined tailings at a screening tower where 10+ mesh material is rejected. The undersize, screened material is initially piped to an agitated vessel where sulfuric acid is added to lower the pH to about 1.5; then, it is pumped to the first thickener (McWaters 1990).

Overflow from the first thickener is pumped to a second agitation vessel. There, it is washed with raffinate and sent to the second thickener. The overflow from the second thickener flows to a suction vessel, which feeds a group of water pumps that supply the hydraulic mining circuit. The circuit's underflow reports to a vessel where it is again washed with raffinate and pumped to the disposal-reclaim circuit. The leachate overflow from the No. 1 thickener is flocculated, clarified, and sent to a PLS pond, where it is mixed with leachate from another leaching circuit before flowing to the SX process (McWaters 1990).

Tailings from the vat leaching process are pumped in a 13-inch HDPE line to Copper Cities deep pit for disposal. The pipeline is located in a containment ditch. Also located in the containment ditch, adjacent to the slurry pipeline, is a 12- to 14-inch HDPE return-water pipeline. Both pipelines are continuously monitored by pressure and end flows to identify and contain leaks. The containment ditch leads to an HDPE-lined 333-square-foot containment pond (McWaters 1990).

Magma Copper Company has installed spill prevention measures at the vat leaching operations. According to Magma, its engineers over-designed the system to last longer than anticipated and installed leak detection systems (McWaters 1990). A barge with four centrifugal, elastomer-lined pumps transports the washed reprocessed tailings 4.5 miles from the process plant to an abandoned mine pit (the Copper Cities deep pit). According to Magma, this pit is geologically separated from the nearest known aquifer by the "relatively impervious" Miami fault system (McWaters 1990).

Leach Circuit SX/EW Plant

SX/EW Plant - PVD, Miami Unit

Copper is recovered from the leach solution at an SX/EW plant. The SX plant has been in operation since 1976 and is centrally located only a short distance from the heap leach pile. It originally consisted of two circuits of three extractor and two stripper cells. Each of these circuits was designed to handle 1,505 gpm of pregnant solution (McWaters 1990). The original SX/EW plant was designed and located so that it could be expanded at minimal cost, and, in 1989, it was expanded to handle 6,022 gpm. The solutions from *in situ* leaching (see below) are also fed to this plant, which has been expanded to a production capacity of 50,000 tpy of copper (Beard 1990).

Before the SX phase, pregnant solution is subjected to a flotation process to recover any entrained organic particles that may interfere in the electrowinning process. Clarity of the PLS is important because particles can form the nuclei for organic- and aqueous-phase emulsions and sludges (Beard 1990; McWaters 1990). After flotation/clarification, the PLS is fed into four asymmetrical SX circuits. The organic ion exchange reagent used to extract the copper consists of 7 percent LIX 984 by volume in a kerosene solution (Beard 1990; McWaters 1990).

In the extraction circuits, more than 90 percent of the copper is transferred in the organic phase. The loaded organic solution is then pumped through two circuits of two mixer-settler vessels in series. The copper is encouraged to transfer to the electrolyte by low pH and intimate mixing. The electrolyte is fifty times more concentrated than the original PLS. Before flowing to the electrowinning tankhouse, the electrolyte is passed

through a bedded filter to remove particulates. The depleted PLS (raffinate) is predominantly recycled to the *in situ* leaching field (McWaters 1990).

The effluent from the SX circuit is of sufficient strength to be directly pumped through electrowinning cells. The electrolyte is warmed in heat exchangers where the heat sources are steam and the heat of the electrolysis process itself. The copper is then electrowon directly onto stainless steel cathodes rather than on the standard copper starter sheets (McWaters 1990).

As of 1987, the electrowinning tankhouse plant had 60 cells. Fifty-four cells were for commercial cathode production and six were dedicated to starter sheet production. More recently, the 60 cells were converted, and the facility was expanded with 42 new cells (McWaters 1990).

Wastewater Management

Diversion ditches and collection ponds have been constructed around the entire Copper Cities leach pile to catch any runoff and leachates. Overflow catchment dams have been constructed to retain any flow from these containment areas during upset conditions. Solutions collected in the ponds and catchment areas are diverted to the inactive tailings ponds, where the liquid is evaporated (U.S. EPA 1989e).

6. Cyprus Miami Mining Corporation, Cyprus Miami Mine and Smelter, Gila County, Arizona

The site is located 6 miles west of Globe, Arizona, between the towns of Claypool and Miami. The Inspiration operations consist of open-pit copper mines (formerly called Inspiration mines); leach dumps; a 24,000-tpd concentrator that is on stand-by status; an SX/EW plant; a 450,000-tpy electric furnace smelter and associated acid plant; an electrolytic refinery; and a 135,000-tpy rod plant (Beard 1990). The operations stretch from the Lower Oxide mine to the confluence of Miami wash, Bloody Tanks wash, and Russell gulch; a distance of over 7 miles. The Inspiration operations are part of a larger mining district near the Towns of Miami and Globe that includes Pinto Valley Copper Company's Oxide mine operations and Old Ranchers Exploration Bluebird mine (U.S. EPA 1987).

The site operation, a mine for leach operation, produces 110,000 short tpy of cathode copper, copper rod, and blister copper (U.S. DOI, Bureau of Mines 1992). The operation originally consisted of a fully integrated facility with mine, mill, concentrator, leach plant, and smelter (Weiss 1985). However, the pits are now only used as holding ponds for leaching solutions; the concentrator and tailings disposal ponds have been shut down since 1986 (U.S. EPA 1987; U.S. DOI, Bureau of Mines 1990a). Only leaching of oxide ore continues today (except for processing units).

The site and the larger mining district of which it is a part are extremely complex. There are numerous interrelated units under different ownership. Many changes in ownership and operational status have occurred, resulting in numerous inconsistencies among the available references.

Extraction

Mining

The mine was an underground block-caving operation, which was converted into two open-pit mines in 1948. During the active mining period, material was mined from several pits at the Inspiration site, including upper and lower Oxide pits, Barney north pit, Red Hill pit, Live Oak pit, Bluebird pit, Thorton pit, and Joe Bush pit (U.S. EPA 1987). Of these, only the Bluebird pit is active. The Bluebird pit was acquired from Ranchers Exploration and Development Corporation in July 1984. Approximately 80,000 tpd of ore is being mined at the Bluebird pit. The Live Oak pit is being dewatered (U.S. EPA 1989e).

The ore occurs as a complex mixture of disseminated chalcocite or oxidized copper minerals in an alteration zone surrounding the monzonite porphyry intrusive (U.S. DOI, Bureau of Mines 1965a). The ore was mined at a rate of 50,000 tpd with electric shovels and hauled by truck to primary crushers and waste dumps (Beard 1990).

The mine produced approximately 11 million tpy of waste rock, totaling 391 million tons for the life of the mine. This material was placed in dumps at the edge of the pit for permanent disposal. Figure 1-23

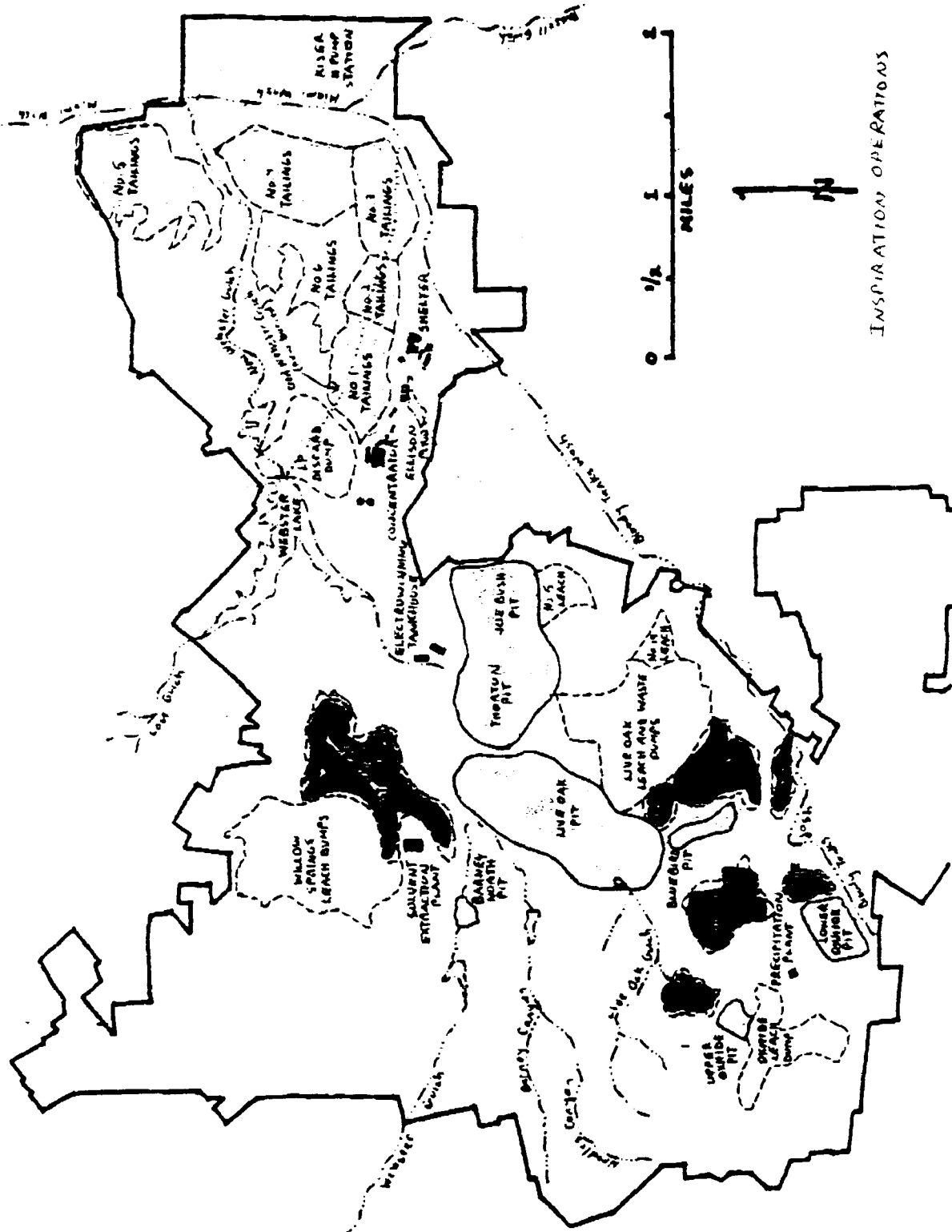


Figure 1-23. Locations of Cyprus Miami Mine and Smelter Waste Dumps

(Source: U.S. DOI, Bureau of Mines 1990)

shows the location of the waste dumps. These dumps have no impermeable liners or leachate collection systems (U.S. DOI, Bureau of Mines 1990a).

Leach Dumps

Dump leach operations were started in 1955. The mine produced approximately 23 million tpy of leach material, totaling approximately 294 million tons during the life of the mine. This leach material covers 5.4 million square yards. Inspiration mine has five leach dump areas: the Willow

Springs leach dump, the Live Oak leach and waste dumps, the Nos. 5 and 19 leach dumps, and the Oxide leach dumps (U.S. EPA 1987; U.S. DOI, Bureau of Mines 1990a). Low-grade ore was sorted according to the primary mineralogy and transported to the appropriate leach dump site. Leach dumps Nos. 5, 9, and 27 are low-grade oxide ore dumps, and leach dumps Nos. 19, 28, 33, 34, and 35 are a mixture of oxide and sulfide low-grade ore dumps (U.S. EPA 1987).

Inspiration operates two separate leach circuits: a conventional dump leaching operation and a ferric cure leaching operation. Ore containing above 0.3 percent copper as chalcocite and oxides is delivered to the ferric cure circuit, while ore containing less than the 0.3 percent copper cutoff is delivered to the conventional leaching circuit. These circuits are operated in series (i.e., the PLS recovered from the conventional operation is used as the leaching solution for the ferric cure operation) (U.S. EPA 1989e).

The majority of the leach dumps in the old Inspiration property were built on the existing topography. The underlying surface was cleared of existing vegetation and graded to channel the PLS into the collection ponds located at the toe of the pile. The underlying surface of the old Bluebird leach dumps was also cleared of vegetation and dressed, and the soil was cemented and covered with dilute tar for curing and sealing (U.S. EPA 1989e).

New lifts of leach material are built on previously leached dump piles. Prior to the placement of a new lift, the surface of the dump is ripped to a depth of approximately 6 feet. The ore is then hauled to the pad by trucks and spread with bulldozers. After the lift has been completed, the surface of the lift is ripped and the solution distribution piping is laid (U.S. EPA 1989e).

The leaching solution distribution system consists of 2-inch piping perforated with 1/8 inch holes. The leaching solution contains approximately 5 to 15 g/l of sulfuric acid and has a pH of 1.0. It is applied to each lift for a period of up to 125 days at varying flow rates. A flow rate of approximately 15,000 gpm is maintained for the entire system (U.S. EPA 1989e).

Dumps and collection ponds have been constructed on a surface which Cyprus described as a tight formation of bedrock of relatively impermeable granite. To optimize drainage of leach liquors, the pads were constructed with compacted native soil and have collection ponds at their bases. A ground water monitoring-well system has also been installed around the periphery of the leach dumps (U.S. EPA 1986, 1987, 1989e; U.S. DOI, Bureau of Mines 1990a). No information is available on the analyses of samples collected from the monitoring-well system.

A stepped leaching process is used to enrich leach solutions. Lixiviant solutions from the barren pond are applied to the surface of leach dumps Nos. 5, 9, and 27 (the oxide waste dumps) in a conventional acidic leach-type operation. After the lixiviant percolates through these leach dumps, PLSs are collected, cured by adding acid, and applied to the "ferric cure" leach dumps Nos. 19, 28, 33, 34, and 35 (mixed oxide and sulfide ores). This procedure allows the "ferric ion" solution generated in the oxide leach circuit to react with the sulfide minerals, thus enhancing oxidization. Some of the higher-grade PLS is recycled to the "ferric cure" leach dumps. The remainder of the PLSs are collected in a system of small reservoirs and routed either to a precipitation plant located 4 miles southwest of the concentrator near the Oxide mine area or to a SX plant located 2.5 miles west of the concentrator near the Willow Springs leach dump (U.S. EPA 1987).

The leaching technique used in the ferric cure operations is unique because the leach pads are carefully constructed in uniform dimensions. The leach pads are generally rectangular, measuring approximately 250 feet wide by 600 feet long. A pad is stacked to a height of approximately 30 feet. After completion of the pad, the pile is cured. The cure solution contains 200 g/l of sulfuric acid and between 2 to 3 g/l of ferric iron. Sufficient cure solution is applied to the pad in two separate applications. The pad is then allowed to cure or

rest for 15 days, after which it is rinsed with conventional leach solution for up to 120 days. It is estimated that, at the end of the leaching cycle, approximately 70 percent of the copper has been recovered (U.S. EPA 1989e). It is unclear whether the ferric cure operation is a separate heap-leach-type operation rather than a dump leach operation.

Diversion ditches have been dug around some of the dumps to divert runoff from the piles into collection ponds. In addition, diversion ditches have also been dug to divert surface runoff from outside the property away from the dumps (U.S. EPA 1989e). The leach solutions from each of the leaching circuits are collected in the ponds at the base of each dump. Most of these collection reservoirs are unlined. All of the retaining dams used to hold the pregnant solution are made of concrete with either clay or concrete cores. All of the dams have been keyed into the bedrock in the existing hillsides to prevent leakage. The pregnant solution collected in the ponds is pumped to an SX/EW plant for copper recovery. The SX/EW plant currently receives and processes approximately 4,500 gpm of pregnant liquor. The barren solution (or raffinate) produced by the SX/EW plant is then recycled into the conventional leaching circuit (U.S. EPA 1989e). Also, sulfuric acid (generated by roasting and converting of concentrates) is captured at the acid plant in the scrubber units and is added to the raffinate produced at the SX plant before it is recycled to the leach dumps (U.S. EPA 1987).

Beneficiation

Tailings Disposal

The Cyprus Miami Mine and Smelter operation's sulfide concentrator and crushing units were decommissioned in January 1986. At that time, Cyprus suspended operation of the six tailings ponds (Nos. 1 through 6). They are located east of the concentrator and on the northwest side of Bloody tanks and west of Miami wash (U.S. EPA 1987). No additional information is available on the operation of the flotation units, including the types of reagents used.

When operating, the mill used a system of sloughing tanks with thickeners to dewater the tails to between 22 and 31 percent solids. An upstream construction method was used for the tailings impoundments. They were constructed of a series of 40-foot raised embankment berms (Taggart 1945). Seventy-foot-high trestles were constructed on the inside berm around the tailings pond. The trestles supported an open-chute launder with automatic desliming cones spaced at 12-foot intervals along each trestle. These cones were used to dispense and segregate the tails at regular intervals around the periphery of the pond. The coarse sediments from the desliming cones created a series of piles at the base of the trestles which combined to form the new berm. When a new raise was completed, the old trestles were abandoned and new trestles were constructed about 80 feet behind the base of the new berm. About 50 percent of the water used in the concentrator was recovered from the tailings ponds by decant systems using pumps (Taggart 1945; U.S. EPA 1986). The tailings ponds contain a combined volume of approximately 480 million tons of tailings materials (U.S. EPA 1986; U.S. DOI, Bureau of Mines 1990a).

According to Cyprus, one of the tailings ponds is "closed" and dry. No additional information is available on the closure status of the other tailings ponds.

The tailings ponds were constructed without liners. Five ground water wells (located downgradient of the base of the tailing dam) are monitored on a quarterly basis (U.S. EPA 1986; U.S. DOI, Bureau of Mines 1990a). Additionally, a 25-well monitoring system was installed along the downgradient side of the property (U.S. DOI, Bureau of Mines 1990a). No information concerning the results of the quarterly monitoring was available.

Leach Circuit

PLS from the Oxide leach dumps, along with Mine Water Drainage (MWD) from the Live Oak pit, make up the influent to the precipitation plant. The effluent from the precipitation plant, known as "iron-laundry off-solution" is combined with MWD from the lower Oxide pit and recycled back to the Oxide leach dumps. Excess barren leach solution is stored in the upper Oxide and Bluebird pits (U.S. EPA 1987).

In the precipitation process, PLS filters through surface impoundments containing submerged scrap iron. The copper ions in the solution replace the iron ions in the scrap to form copper flakes. The iron scrap is reused until it is consumed. Periodically, the ponds are hosed down to collect copper scale, which is allowed to dry and then shipped to a smelter (U.S. EPA 1987).

In the SX process, a chelating agent is added to the pregnant solution to form an uncharged extractable complex of copper. The uncharged complex then partitions into an organic solution with a low dielectric constant. Ionic compounds, such as dissolved iron, remain with the leach liquor. Usually, kerosene is the organic solution used. Through the process of complexing the copper and partitioning the complex into a relatively small volume of kerosene, the copper is concentrated. The remaining leach solution (raffinate) contains low concentrations of copper and low pH. The loaded organic solvent, containing the extracted copper, is directed to strippers that reverse the process and redissolve the copper in relatively concentrated sulfuric acid. The copper acid solution (known as electrolyte) proceeds to the tankhouse, where the process of electrowinning removes the copper from solution. Oxidized metal in solution is reduced (gains electrons) through the application of an electric current. The positively charged lead in the electrolyte, known as the "cathode," is usually made of a thin copper starter sheet. Ions of copper migrate through the electrolyte and plate on the starter sheet. This process produces nearly pure plates of copper which are known as "cathodes." The electrolyte recycles back through the strippers and the tankhouse (U.S. EPA 1987).

Water and Wastewater Management

The mine operates an integrated water and wastewater management system that consists of three principle circuits: the industrial/fresh-water circuit, the process-water-leaching circuit, and the process-wastewater circuit. A 1987 flow diagram of water and wastewater management (including all three circuits) at the Inspiration mine site is presented in Figure 1-24

**WATER AND WASTEWATER MANAGEMENT
INSPIRATION OPERATIONS
MARCH 1987**

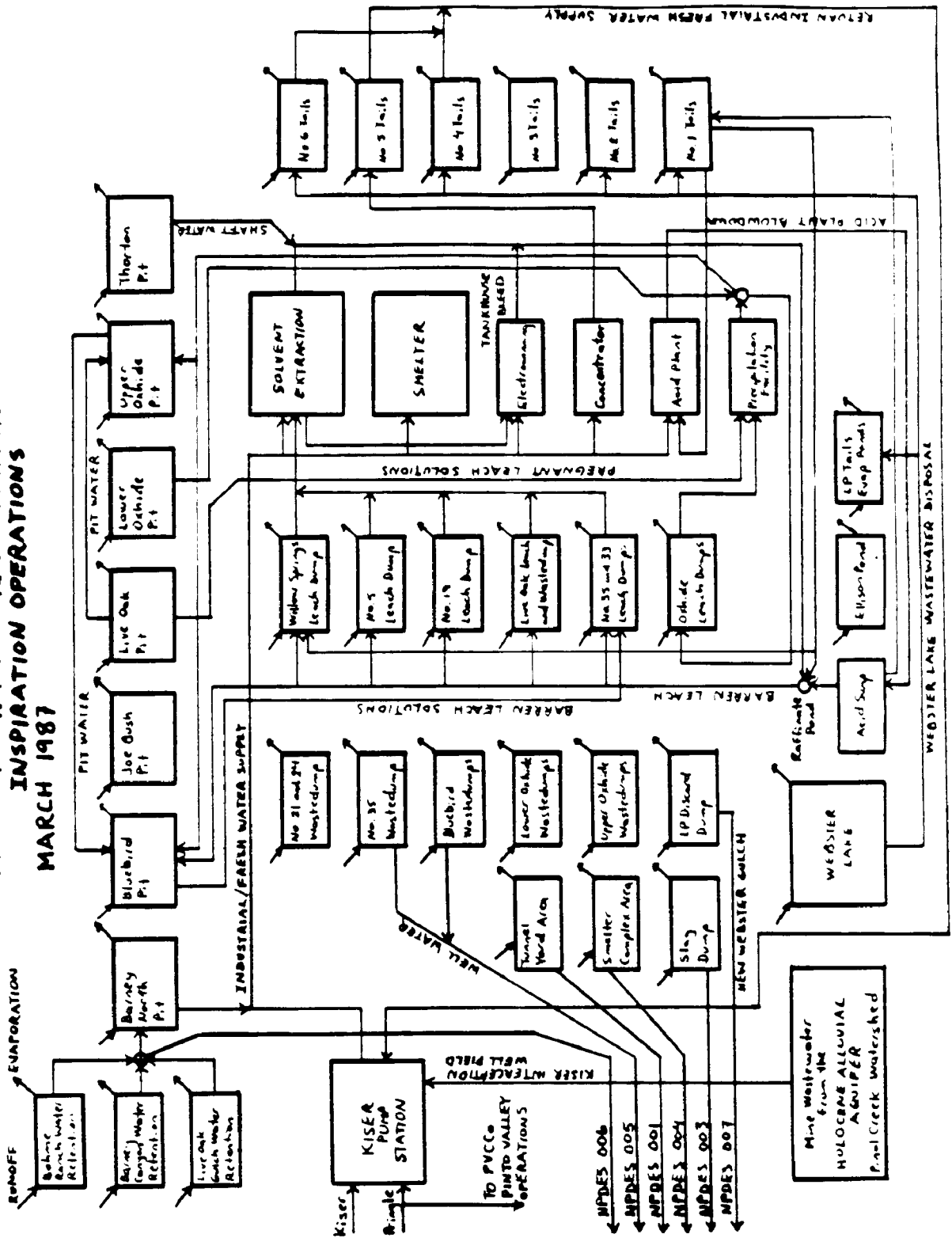


Figure 1-24. Water and Wastewater Management at Inspiration Operations

(Source: U.S. EPA 1987)

In the past, the water and waste circuits were managed to maximize the efficient production of copper and to minimize the water and wastewater disposal costs. However, the mine now has altered the water and wastewater circuits to reduce the volume of process wastewaters by isolating this circuit from watershed runoff and to decrease the generation of process wastewater by increasing reuse and evaporation (U.S. EPA 1987).

Industrial/Fresh-water Circuit

The industrial/fresh-water circuit consists of a fresh-water segment and an industrial-water segment. Both systems are recirculated through the No. 5 tailings pond and the Kiser water treatment plant and pump station. The fresh-water segment provides potable water for use as acid plant blowdown water,

power plant cooling water, steam plant compressor water, slag dryer launder water, crusher dust suppression and lubrication water, makeup water for the SX/EW plant, and domestic water for housing and shops. The industrial-water segment provides water for use as anode casting, converter, and blister copper cooling water in the smelter; wash rack water; and truck fill water for dust suppression on roads. A large flow of water from the industrial-water segment is circulated through the inactive concentrator and tailings circuit to prevent tailings slurries from silting up the internal drainage systems (U.S. EPA 1987).

The fresh-water segment of this circuit is fed from three sources. First, relatively clean water is pumped out of the Gila Conglomerate formation from the Pringle well field. The well field is located midway between the headwaters of the perennial portion of Pinal Creek and the creek's confluence with the Salt River. Second, any seepage beneath the tailings ponds is intercepted and diverted to this segment. Third, well No. 62 of the Kiser well field extracts water from both the Gila Conglomerate formation and the overlying Holocene alluvium. This well is located near Russell gulch. All water from each of the three sources enters the fresh-water circuit at the Kiser water treatment plant and pump station, located near the Miami wash/Bloody tanks wash/Russell gulch confluence (U.S. EPA 1987).

The industrial-water segment of this circuit is fed by five sources. First, overflow of excess potable water from the fresh water segment is routed into the industrial water segment. Second, water is pumped out of the Gila Conglomerate formation by production well No. 20 of the Kiser well field. This well is located between the No. 3 tailings pond and the Miami wash. Third, contaminated wastewater in the Holocene alluvium is recovered by Kiser interception wells Nos. 1 and 2. Fourth, collected wastewater from the steam plant compressor and the slag dryer launder is recycled. Fifth, storm water runoff from the undisturbed areas west of the mining operations behind three fresh water retention dams (the Bohme ranch, Barney canyon, and Live Oak gulch) is collected and recycled. These three impoundments then feed the Barney north pit. The first three sources (production well No. 20, Kiser interception wells Nos. 1 and 2, and fresh-water overflow) enter the industrial-water circuit at the Kiser water treatment plant and pump station. The wastewater from the steam plant compressor and slag dryer launder drains into a portion of the industrial-water segment known as the anode sump. The storm water runoff in the Barney north pit is used in only the truck fill and wash rack water portion of the industrial-water segment (U.S. EPA 1987).

Water circulated through the inactive concentrator and tailings water (from the anode pond, tankhouse facility shops, and a storage tank) drain into tailings pond No. 5. Internal drains convey any seepage from the No. 5 decant pond along with additional seepage from the Nos. 4 through 6 decant ponds to the industrial/fresh-water circuit at the Kiser water treatment plant and pump station (U.S. EPA 1987).

To reduce the amount of water in the industrial/fresh-water circuit, Inspiration has applied for an NPDES permit to discharge water from the storm water retention dams into Bloody tanks wash. In addition, Cyprus Miami Mining sells Pringle well-field water to Pinto Valley. It is routed away from the industrial/fresh-water circuit by diversion through the Burch pump station to Pinto Valley's operation (U.S. EPA 1987).

Process Water Leaching Circuit

The process water leaching circuit is designed to facilitate leaching of copper from the dumps and provide for evaporation of process wastewater. The process water leaching circuit relies on the continuous recirculation of leach waters through the dumps. Inspiration replaces evaporation and bedrock infiltration losses at the leach dumps with rain-fall runoff from the dumps; drainage and pit water from the Bluebird, Live Oak, lower Oxide, upper Oxide, and Thornton pits; and supplements of process wastewater drawn from the top of the No. 1 tailings pond. The process water leaching circuit consists of two segments that are defined by the method of copper recovery (the leach segment feeding the precipitation plant and the main leach segment feeding the SX plant) (U.S. EPA 1987).

Evaporation losses in the SX leach segment are replaced with mine water from the Bluebird pit and process wastewater. The Bluebird pit supplies mine water that is used to supplement the lixiviant solution used at leach dumps Nos. 28, 34, and 35. Process wastewater feeds the raffinate pond. The process wastewater is made up of acid plant blowdown drawn from the acid sumps, wastewater mixtures drawn from the top of the tailings pond No. 1, shaft water from the Thorton pit area, and electrowinning tankhouse bleed. Excess raffinate is stored in the Bluebird pit (U.S. EPA 1987).

The surface impoundments and units integrated into the leach circuit include:

- Eleven surface-water-holding reservoirs: Nos. 19, 27, 28, 33, and 35; C; Live Oak; Barney canyon; Bohme ranch; on-pond collecting; and Davis canyon
- Eleven ponds: 001 NPDES; 003 NPDES; 004 NPDES; No. 4 decant; No. 5 decant; Main sewage disposal; Ellison; aqueous feed; raffinate; acid sump; and LP discard evaporation
- One basin: Honeyman overflow basin
- Seven water-holding pits: lower Oxide; upper Oxide; Bluebird; Live Oak; Thorton; Barney north; and Honeyman overflow basin (U.S. EPA 1987).

The locations of these units are shown in Figure 1-25

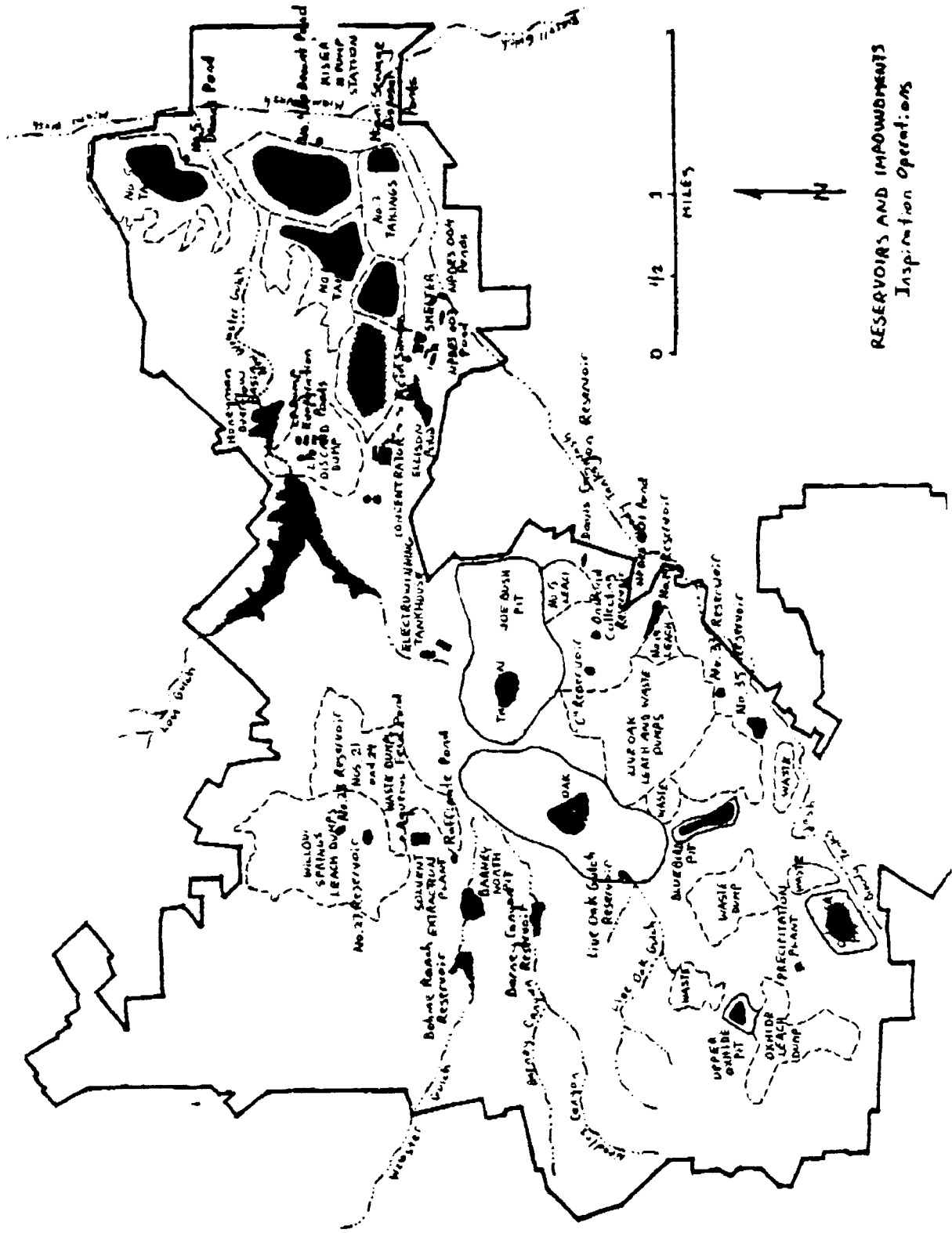


Figure 1-25. Reservoirs and Impoundments at Cyprus Miami Mine and Smelter Operations

(Source: U.S. EPA 1987)

. No information is available concerning the design of these units (including whether or not they are lined).

Process Wastewater Circuit

The process wastewater circuit handles three types of process wastewater: contaminated Webster Lake water, storm water runoff (except that from active leaching areas), and sewage from the Town of Miami (U.S. EPA 1987).

Since the formation of Webster Lake in 1941, Miami (formerly Inspiration) and Pinto Valley mines historically have used it as a storage and disposal reservoir for various process water leach solutions and process wastewaters. In the August 28, 1986, Cyprus Miami Mine and Smelter listed 15 separate current and past sources of wastewater discharge to Webster Lake. Among these sources are storm water runoff; vat leach iron-laundry off-solution; *in situ* leach off-solution; Live Oak iron-laundry off-solution; raffinate discard; Thorton shaft pumpage; black copper dump leach solution; tankhouse water treatment brine; secondary crusher dust control water; Webster east pumpage; Thorton pit water; slime pit iron-laundry off-solution; and Copper Cities leach dump solutions. The other two sources were not identified. The combined wastewater feed into Webster Lake between 1941 and 1986 from these sources was over 2,485 million gallons (U.S. EPA 1987).

To assess the impact of the mine's operation on the surrounding ground water system, Cyprus Miami conducted a comprehensive water-quality study around several active and abandoned mines in Arizona's Miami/Globe area. This study required a monitoring network composed of 113 new wells.

This network included existing water-supply wells and wells converted to hydrologic monitoring nests of shallow small-diameter wells; wells drilled adjacent to deeper existing wells; and deep wells (U.S. EPA 1989e).

As a result of the study, the practice of disposing of waste solutions into Webster Lake was discontinued. In addition, Inspiration was required to drain Webster Lake by July 28, 1986. Prior to 1986, Webster Lake held an average of 1.46 billion gallons of process wastewater (U.S. EPA 1987).

To drain the lake, withdrawn lake water was applied to the LP evaporation ponds and the Nos. 1, 2, 4, and 6 tailings ponds for evaporation. Water from Webster Lake was also mixed with the process water leaching circuit by combining it with the acid sump surges and tailings pond No. 1 water, which feeds the raffinate pond. In addition, three fresh-water-retention structures were constructed to divert surface-water runoff from the watershed of the lake (U.S. EPA 1987).

Cyprus Miami is required to control surface-water runoff from areas not under leaching by retention and evaporation or by discharge through an NPDES-permitted outfall. Inspiration's NPDES Permit No. AZ0020508 authorizes the discharge of storm water runoff from waste dumps near the tunnel yard at Outfall 001. Storm water runoff from the slag dump south of the smelter yard is discharged at Outfall 003. Storm water runoff from the smelter yard area is released at Outfall 004. Runoff from waste dumps Nos. 21 and 24 and the lower and upper Oxide waste dumps are retained and evaporated. Wastewater from the Bluebird pit dewatering wells is discharged from Outfall 005. Storm water runoff, captured in the three new fresh-water-retention facilities west of the mining operations, is discharged at Outfall 006. Finally, seepage accumulating in the New Webster Gulch is released at Outfall 007. The Town of Miami pumps municipal sewage onto the top of the No. 3 tailings pond (U.S. EPA 1987).

7. ASARCO Inc.; Mission Mine; Pima County, Arizona

ASARCO's Mission Mine is located approximately 15 miles south-southwest of Tucson. The facility occupies approximately 23 square miles (see Figure 1-26)

) (ASARCO 1992). Development of the Mission Mine began in the 1950s, with full-scale production beginning in the early 1960s. The adjacent Pima mine began operation in 1951 as an underground stoping operation and was converted to an open-pit operation in 1955. In 1982, while under different ownership, the mine was shut down (U.S. DOI, Bureau of Mines 1992). The Mission Mine expanded when it consolidated with the Pima mine in September 1985. At that time, the Pima concentrator was closed and dismantled (U.S. EPA 1988c). The Mission unit now consists of the Mission, Eisenhower, San Xavier, and Pima mines consolidated into one large open-pit mine referred to as the "Mission complex." Also included is the smaller San Xavier north pit (Beard 1990). In 1991, ASARCO completed a \$100 million expansion of the Mission complex. The complex was expanded from 90,000 st of copper to 124,000 st. Reserves at the Mission complex are estimated at 600 million st, grading 0.681 copper (Mining Engineering 1991).

Geologically, the mine is located within a faulted complex of sedimentary, volcanic, and plutonic rocks along the eastern pediment of the low-lying Sierrita Mountains. During the Laramide Orogeny, the Paleozoic and Mesozoic rocks were intruded by the northwest-trending Laramide porphyrys. The area was segmented by the San Xavier low angle-thrust fault. Subsequently, the deposit was covered by alluvial fan deposits and volcanics (U.S. DOI, Bureau of Mines 1965a; Weiss 1985; U.S. EPA 1986, 1988c).

The ore body was mineralized by hydrothermal fluids resulting from the emplacement of a Laramide-age quartz monzonite porphyry. The copper porphyry sulfide ore occurs primarily in sedimentary rocks, dominated by carbonates. The principal sulfide mineral is chalcopyrite. Other minerals include pyrite, chalcocite, covellite, minor bornite, galena, sphalerite, pyrrhotite, and minor molybdenite. Silver content in the sulfide concentrate is approximately 0.11 oz/st. Other copper oxide minerals include malachite and azurite, which are copper carbonates (U.S. DOI, Bureau of Mines 1965a; Weiss 1985; U.S. EPA 1986, 1988c).

Extraction

The pit is relatively deep for an open-pit mine and has a high strip ratio of 2.5 to 3.0 at a cut-off grade of 0.30 percent copper (Weiss 1985).

Ore is extracted using conventional open-pit mining methods by drilling groups of blast holes 50 feet deep, then filling them with an ANFO blasting mixture. Electric shovels and scrapers load the blasted, fractured ore and/or waste rock into 170- and 200-ton electric drive dump trucks, which deliver the ore to three primary crushers. The waste rock and alluvium are subsequently transported to various dumps (Weiss 1985).

The Mission Complex produces approximately 150,000 tpd of mine waste rock, which is removed from the pit and placed in dumps for potential future leaching. Mine dumps are generally of a side-slope type. The mine waste dumps cover approximately 3,175 acres. Because mining has been completed in some areas of the pit, backfilling with waste rock is also practiced (Weiss 1985).

Vat Leaching

In the San Xavier north and south properties, the upper zone of the sulfide ore body is oxidized; its principal mineral is silicate chrysocolla. The oxide ore vat leach plant operated from 1972 through 1979, when the oxide ore reserves were depleted (U.S. EPA 1988c). After crushing, the ore was delivered to one of nine large concrete leach vats, where it was mixed with sulfuric acid. Copper was leached out of the ore into the sulfuric acid solution, forming a copper-rich pregnant solution. The pregnant solution was processed by cementation-precipitation methods in ponds filled with scrap iron. Copper precipitate (containing some iron) was recovered by spraying water over the scrap iron on a vibrating screen. The precipitate was then recovered in a sump and delivered to an offsite smelter, where the copper was processed. Scrap iron was reused until consumed. The iron-rich barren solution was sent to an evaporation pond located on the North Dump. This evaporation pond is presently closed and covered by waste rock (U.S. EPA 1986, 1988c).

Beneficiation

Mission Mill

The sulfide plant began operation in 1961 with four rod-and-ball mills (U.S. EPA 1988c). The sulfide ore currently undergoes secondary and tertiary stage crushing to about 0.75-inch in diameter, and it is then stockpiled. At the mill, water is mixed with the ore to form a slurry, which is ground by six rod-and-ball mills and two single-stage ball mills. The slurry is classified and the fines (about 0.008 inches in diameter) are diverted to the concentrator flotation cells (U.S. EPA 1988c; ASARCO 1992).

The concentrator is a double-circuit, sulfide copper-molybdenite system. In the primary flotation cells, low-pressure air is introduced, forming a froth and causing the copper and molybdenum-sulfide minerals to float to the surface as froth or sulfide rougher concentrate. Frothing and collector reagents are added to the slurry to facilitate the separation of the sulfide-bearing minerals in the flotation cells (Table 1-12). The finely ground waste material that remains in the bottom of the flotation cells (tails) is sent to the tailings ponds. The sulfide concentrate is reground and floated two more times in the cleaner-recleaner flotation cells. Remaining tails are also sent to the tailings ponds. Before the molybdenum plant closed, the sulfide concentrate was further processed to recover molybdenite. Additional reagents were added to float the molybdenum sulfides. The molybdenite flotation cells included a rougher section and seven cleaner-recleaner sections (U.S. EPA 1988c).

Table 1-12. Reagents and Ore Used at Mission Mine

Reagents	Usage (in pounds per ton of ore)
Lime	2.0
Pine oil	0.01
Potassium amyl xanthate	0.007
Dithiophosphate	0.006
MIBC	0.05

(Source: U.S. EPA 1988c)

Prior to 1988, the concentrator's capacity was about 28,000 tpd (ASARCO 1992). During 1988, the concentrator's capacity was increased to 40,000 tpd. This was accomplished by lengthening the 10.5-foot (diameter) ball mills from 15 to 18 feet and installing 2 new ball mills (salvaged from a Sacaton, Arizona, mill); adding additional rougher flotation capacity in 1991; and installing six 8-by-52-foot column flotation cells for cleaners (Beard 1990; ASARCO 1992).

Mission Tailings Disposal

Waste tails from the concentration processes are thickened to approximately 50 percent solids in the four thickening units and transported by gravity in a slurry line to three tailings ponds. Water reclaimed from the thickeners and tailings ponds is recycled as process water for the sulfide plant (U.S. EPA 1986, 1988c).

The three tailings ponds are located on San Xavier Indian Reservation land. The combined area of these ponds is 1,500 acres, and the total accumulated volume of tailings disposed of is approximately 250 million tons (U.S. EPA 1988c).

The tailings impoundments were constructed with compacted alluvial starter dams. Berms are constructed with a dragline. Sixty- to 80-foot center decant towers are used for water recovery. The tailings impoundments do not have liners and are underlain by native soil comprised of sand and gravel. The tailings areas were prelined before deposition (ASARCO 1992). In 1991, 208 gallons of water per ton of ore was required. One third of this was lost to seepage, which percolates through the alluvium and reaches ground water (about 250 feet below the surface). Ground water may have elevated sulfate and TDS levels (U.S. EPA 1988c). The remainder was lost to evaporation and containment in the dam (ASARCO 1992).

A U.S. DOI, Bureau of Mines, study found that the overall permeability of the tailing ponds was 2×10^{-6} cm/sec (U.S. EPA 1988c). In addition, Mission pit mine water, which is produced at about 200 gpm, is pumped to mill reclaim tanks. No other information was available on the generation and management of mine water. Runoff from surrounding areas is diverted around the tailing impoundments (U.S. EPA 1988c).

According to the Inspection Report, ASARCO Inc.'s Mission Mine had ground water near its tailings pond sampled. Previous analyses by the Pima Association of Governments for inorganics documented a release to the environment, although the Target Compound List was not analyzed. The Pima Association of Governments documented elevated levels of sulfates and TDS immediately downgradient from the tailings ponds. However, elevated levels of TDS or sulfates above enforceable EPA secondary drinking-water standards were not present in the nearest domestic water well located 1 mile downgradient from ASARCO's tailings impoundments. Tailings impoundments were moistened to control dust emission (U.S. EPA 1987).

FIT concluded that no additional sampling was required under CERCLA, as prior sample data and investigations indicated that there were no hazardous substances present in the ground water and no potential public health threat (U.S. EPA 1987).

South Mill Tailings Disposal

When the Pima concentrator was active, tailings were disposed of in upper and lower tailings ponds. When one of the ponds was full, the tails were routed to other ponds to allow the berms to be raised and dried while the other pond was filling. Spigotting was used to deliver nonsegregated tailings to the ponds; this supplied the sediment for the next level of dam construction to be built utilizing the upstream method (Weiss 1985). Periodically, coarse materials were raked back onto the berm by shovels or a drag line to form 15-foot dikes (Weiss 1985; U.S. EPA 1986).

About 75 percent of the water in the Pima tailings pond was recycled to a reservoir and subsequently returned to the process (U.S. EPA 1986). The reservoir was constructed with an 8-inch reinforced concrete bottom with 6-inch gunite walls. The reservoir was divided in half by a spillway which allowed settling in the feed compartment prior to overflow to the discharge side of the reservoir pond. The water level was kept constant by a probe, which regulated the inflow of fresh water. Sludges, which occasionally accumulated in the feed compartment, were pumped out to the tailings pond by a system of three stationary pumps (Weiss 1985).

The Pima tailings ponds are now completely capped with alluvial material to prevent blowing dust; they are well-stabilized with vegetative material (Weiss 1985).

APPENDIX 1-C

NPL SITE SUMMARIES RELATED TO COPPER MINING ACTIVITIES

1. Silver Bow Creek - Part of the Clark Fork Superfund Sites
2. Milltown Reservoir - Part of the Clark Fork Superfund Sites
3. Celtor Chemical Works, Humboldt County, California
4. Torch Lake, Houghton County, Michigan

1. Silver Bow Creek - Part of the Clark Fork Superfund Sites

Site Overview

The Silver Bow Creek site is one of four separate but contiguous Superfund Sites located near the City of Butte, along the course of the Clark Fork River in southwestern Montana. The four sites, known collectively as the Clark Fork Superfund Sites, are the Anaconda Smelter site, the Milltown Reservoir site, the Montana Pole site, and the Silver Bow Creek/Butte Area site. All four sites have the potential to contaminate Silver Bow Creek and/or the Clark Fork River. Also, Milltown Reservoir has the potential to contaminate the sole-source aquifer below Missoula. The Superfund effort in the Clark Fork Basin encompasses the largest geographic area of all Superfund assignments in the United States. Except for the Montana Pole site, contamination at the sites is primarily mining wastes and heavy metal-laden soils and water. The Montana Pole site, which lies adjacent to the Silver Bow/Butte Area site, is contaminated with wood-treating wastes, unrelated to mining activity (U.S. EPA 1991).

The Silver Bow Creek/Butte Area Superfund Site is the largest and most complex of the four sites. Silver Bow Creek has historically received discharge from mining, smelting, wood treating, and other industrial sources for over 110 years. The Silver Bow Creek/Butte Area site includes the Cities of Butte and Walkerville (population 38,000), the Berkeley Pit (a nonoperating open-pit copper mine); numerous underground mine works (operated by New Butte Mining, Inc.); the Continental Pit (operated by Montana Resources); Silver Bow Creek; Warm Springs Ponds (mine tailings); and Rocker Timber Framing and Treating Plant. The approximate size of the Silver Bow Creek/Butte Area site is 450 acres. The Silver Bow Creek site was added to the NPL in September 1983. Originally, the site encompassed the Silver Bow Creek floodplain from Butte (downstream) to Warm Springs Ponds. Remedial Investigations were initiated in this area in 1985. In November 1985, the site boundaries were expanded to include Butte (U.S. EPA 1991).

Operating History

In the years following the discovery of gold (in 1864), the Butte area became an internationally recognized mining center with over 300 combined copper and silver mines and 8 smelters in operation by 1884. The Butte area has been mined almost continuously for 110 years. Most of the ore mined in Butte was shipped 26 miles west to the smelting complex in Anaconda, Montana (a separate Superfund Site); however, ore was also smelted in any of eight smelters in the Butte area. Smelting continued in the Butte area until the Washoe Smelter became operational in Anaconda in 1902. By the 1950s, the Anaconda Company (purchased by Atlantic Richfield Company in 1979) had consolidated all mining activity in the area (U.S. EPA 1991).

Copper, silver, gold, zinc, lead, manganese, and molybdenum have been mined by both underground (vein) mines and open-pit mines in the Butte area. Major underground mining activity took place from the late 1880s through 1960. Over 3,500 miles of underground workings exist in the area; some of the vein mines reached over 5,000 feet in depth. The Berkeley Pit, an open-pit mine, operated from 1955 to 1982. It is estimated that over 3,500 miles of underground mine workings are interconnected with the Berkeley Pit. The pit is over 1 mile deep and 1.5 miles wide at the rim. Mining companies installed a pumping system to dewater the underground mines and the Berkeley Pit during active mining. In the 1950s, bulkheads were installed underground to inhibit the flow of water between mines and the pits and create two underground flow systems, the east camp (includes the Berkeley Pit) and the west camp. These bulkheads were installed to improve the efficiency of pumping operations (U.S. EPA).

In 1964, a mill was constructed in Butte to concentrate the copper sulphide ore from the Butte mines. High-grade ore was processed through the mill and smelter, while lower-grade ores were leached with acid water from the mines in large leach dumps located near the tailings disposal area. The mill tailings were impounded

behind a 2-mile-long dam northeast of the mining operation (Yankee Doodle Tailings Pond). Prior to 1911, when pollution control measures were first initiated, all mining, milling, and smelting wastes were discharged directly to Silver Bow Creek (U.S. EPA 1991).

The first pollution control measures consisted of ponds created by dams built to trap and settle the mining wastes (sediments, tailings, and sludges). In 1911, a 20-foot high dam was erected on Silver Bow Creek, creating Warm Springs Pond 1. Another dam, 18 feet high, was erected on the creek in 1916, creating Warm Springs Pond 2. (This dam was extended to a height of 23 feet.) A third dam, 28-feet high (built between 1954 and 1959), was primarily for sediment control. This dam was eventually raised to 33 feet. In 1967, Pond 3 was converted to treat mill losses, precipitation plant spent solution from Butte operations, and overflow from the Opportunity Ponds. Treatment consisted of adding a lime/water suspension to raise the Ph of the surface water in Silver Bow Creek and precipitate heavy metals in Pond 3. The three ponds are currently used to physically, chemically, and biologically treat Silver Bow Creek surface water through sedimentation and chemical and biological precipitation of heavy metals (U.S. EPA 1991).

Mining activity in the Butte area continued until 1982, when the Berkeley Pit was closed. At this time, the pumps dewatering the mine were shut down and the underground mines began to flood. As the water levels reached the bottom of the Berkeley pit, it began to fill. In 1986, mining activity resumed, although on a smaller scale. The Continental Pit, operated by Montana Resources, produces approximately 50,000 tons per day of copper/molybdenum ore; New Butte Mining, through its underground operation, produces approximately 500 to 1,000 tons per day of silver, lead, and zinc ore. Montana Resources operates an onsite mill to concentrate its ore, discharging the tailings to the Yankee Doodle Tailings Pond area; New Butte Mining ore is shipped offsite for milling and smelting (U.S. EPA 1991).

Environmental Damages and Risks

The wastes generated by mining, milling, and smelting activities are sources of contamination for soils, surface water, and ground water. Contamination is occurring through blowing dust, contaminated runoff and contaminants leaching through the soil into the ground water. Investigations into the environmental problems associated with mining activity in the Upper Clark Fork area were conducted first by the Potentially Responsible Party (PRP) (Anaconda Minerals Company) from 1966 to 1982. EPA initiated the Remedial Investigation/Feasibility Study process in 1983. An Initial Remedial Investigation for the Silver Bow Creek site prior to inclusion of the Butte area was completed in 1987 (U.S. EPA 1991).

EPA established priorities to ensure the most serious problems were dealt with first (i.e., areas involving potential human health risks were given a higher priority than environmental risks). The four Operable Units at the Silver Bow Creek/Butte Area Superfund Site which are considered high priorities are: (1) Warm Springs Ponds; (2) Rocker Timber Plant; (3) Butte Mine Flooding; and (4) Butte Priority Soils. The Streamside Tailings Operable Unit is considered an intermediate priority (U.S. EPA 1991).

Ground water infiltration into underground mines and the Berkeley Pit could potentially contaminant the shallow ground water aquifer and surface water if the water in Berkeley Pit rises beyond 5,410 feet. As of February 27, 1990, the water level was 4,975 feet, and has not, therefore, reached the critical level. The contaminants of concern are arsenic, cadmium, lead, copper, zinc, iron, manganese, and sulfates (U.S. EPA 1991). Wells for domestic-water consumption are located in the vicinity of the Silver Bow Creek site and draw water from the shallow aquifer.

Surface water in Silver Bow Creek was sampled to determine levels of heavy metals and the results were reported in the 1987 Remedial Investigation. For the protection of aquatic life, the concentrations of total recoverable arsenic, cadmium, copper, lead, and zinc in surface water should not exceed specific criteria.

When these heavy metals were measured, concentrations did exceed the standards for protection of aquatic life in Silver Bow Creek (U.S. EPA 1991).

The West Camp/Travona underground mine-flooding discharges could contaminate Silver Bow Creek through direct discharge of ground water into Missoula Gulch, which joins Silver Bow Creek. When pumps for the West Camp mines were shut off in 1965, ground water began to flood basements in the residential areas south of the mine shafts. An intercept well was drilled in 1965. From 1965 to 1969, water flowed from this well into Missoula Gulch, and then, into Silver Bow Creek (U.S. EPA 1991).

Agricultural soils and crops were also affected by the mine wastes from the Silver Bow Creek site. Circumstantial evidence exists that approximately 5,400 acres of land have been contaminated by heavy metals to varying degrees, by using Silver Bow Creek or the Upper Clark Fork River water for irrigation (U.S. EPA 1991).

Fish and water fowl were also studied during the 1987 Phase I Remedial Investigation. There is evidence that fish, particularly Rainbow Trout, are receptors of heavy metals within the study area. However, it was found that arsenic concentrations in fish tissue were below U.S. Department of Agriculture (USDA) food standards (U.S. EPA 1991).

2. Milltown Reservoir - Part of the Clark Fork Superfund Sites

Operating History

The Milltown Reservoir Superfund Site is located in Milltown Valley, 5 miles east of Missoula, Montana. The Milltown dam was built in 1906 and 1907 below the confluence of the Clark Fork and Blackfoot Rivers to provide hydroelectric power. The Towns of Milltown and Bonner are the main population centers in the study area. The Milltown Reservoir Site is one of four Superfund Sites in the Clark Fork River Basin. The three other sites, located upstream of Milltown Reservoir along the Clark Fork River, are the Anaconda Smelter site, the Silver Bow Creek/Butte Area site, and the Montana Pole site.

Although mining, milling, and processing activities were never conducted at this site, the reservoir has accumulated large volumes of river-borne sediments from upstream mining areas of Anaconda and Butte. Sedimentation from mining-related activities has been determined to be the source of both surface- and ground water contamination in the area. Mining operations in the Clark River Basin began with the 1864 gold discovery in Butte. Mining wastes from these areas were discharged directly into tributaries of the Clark Fork River. These wastes, containing arsenic, cadmium, copper, iron, lead, and zinc, were added to the normal sediment load (U.S. EPA 1991).

The Milltown Reservoir is subject to considerable sediment accumulation from both the Clark Fork River and Blackfoot River watersheds. The Clark Fork and Blackfoot Rivers drain approximately 3,710 square miles and 2,290 square miles, respectively. In 1984, Woessner, et al., estimated that the reservoir contains 120 million cubic feet of sediment. Assuming a density of 1.8 grams per cubic centimeter (g/cc), this translates into approximately 6.5 million tons of sediment (U.S. EPA 1991).

Environmental Damages and Risks

Concern arose at the site in May 1981, when arsenic was found in four community supply wells at concentrations ranging from 0.54 to 0.90 mg/l. In August 1981, residents were advised not use water from these wells for potable purposes. In 1983, EPA and MDHES initiated a Remedial Investigation to determine the environmental characteristics and the type and extent of contamination in the Milltown area. Testing

conducted during this investigation indicated that contamination appeared to be hydraulically confined to the uppermost aquifer in the present area (U.S. EPA 1991).

In 1983, vegetables from two gardens in Milltown were analyzed for arsenic. Tests by MDHES laboratory showed spinach to have an arsenic level of 2.66 ppm, lettuce had a level of 1.41 ppm, and two rhubarb plants had arsenic levels of 1.1 and 0.2 ppm, respectively. Levels of arsenic and copper in two plant species growing in the Milltown Reservoir were studied and were compared with levels of arsenic and copper in the same species located in the Blackfoot River (representative of background concentrations). The study found that arsenic and copper levels for both species were greater in the Reservoir samples, with the greatest levels occurring in the east section of the Reservoir (in the roots of the plants) (U.S. EPA 1991).

The Milltown Reservoir was placed on the NPL in 1983. The Remedial Investigation/Feasibility Study began in 1983 for the Water Supply Operable Unit. In 1984, an interim ROD described the two selected actions: abandonment of the existing ground water supply and replacement and relocation of water supply and transmission facilities. The actions were funded and completed in 1985. In 1985, a supplemental ROD described two additional measures: replacement of household water-supply equipment (as needed to reduce contamination) and on going sampling at residences (U.S. EPA 1991).

Additional studies were completed to determine if releases of hazardous substances, pollutants, or contaminants have occurred, or have the potential to occur, downstream from the Reservoir. ARCO had started working on the Remedial Investigation/Feasibility Study for the Milltown Reservoir/Sediments Operable Unit in 1990. The main objectives of the Feasibility Study include clean-up or control of the following: contaminated ground water; submerged contaminated reservoir sediments; and contaminated soils and exposed sediments (U.S. EPA 1991).

In addition, EPA will conduct an Endangerment Assessment to evaluate any present or future risks that the sediments pose for human health and the environment. Work groups are currently evaluating Risk Assessment work plans to assess the effects of contamination on public health, fisheries, and wetlands, and continued releases from the Reservoir (U.S. EPA 1991).

3. Celtor Chemical Works, Humboldt County, California

Operating History

The Celtor Chemical Works site covers 2.5 acres and is located in Humboldt County, California, in the Klamath mountain range. The site is located at the north end of the Hoopa Indian Reservation, several hundred feet from the Trinity River. There are approximately 900 residents within 3 miles of the site. Local residents use the area for agriculture, fishing, and grazing their domestic animals.

The Celtor Chemical Works mill began operation in 1958. Sulfide ores were mined at the Copper Bluff mine and shipped to the mill. Copper, zinc, and other precious metals were extracted at the Celtor mill. Tailings were then either stockpiled or (presumably) flushed down a gully to the Trinity River.

After the facility ceased operation in the early 1960s, an abandoned tailings pile washed into the Trinity River during a heavy flood in 1964. The State of California Department of Health Services also noted that other tailings may have caused acidic surface-water runoff in the area and high heavy metals concentrations in area soils (U.S. EPA 1991).

Environmental Damages and Risks

The site was proposed for industries on NPL on December 30, 1983, and the final Remedial Investigation found that the Celtor Chemical Works site poses a significant threat to human health and the environment due to elevated levels (in excess of CAM TTLCs, DWSs, and AWQCFALs) of arsenic, cadmium, copper, lead, and zinc in soil and surface-water samples.

Direct contact with contaminated water, especially through ingestion of more than 2 liters per day, could cause human health problems. Ingestion of contaminated soils is also thought to be a potential human health hazard. Contamination may be responsible for the defoliation of lands adjacent to the site due to runoff. The State of California issued citations to the Celtor Chemical Works due to fishkills that were most likely caused by runoff from the tailings located at the site. As a result of activities at the Celtor Mill, the area is no longer suitable for agriculture, and the nearby Trinity River can be used only for limited recreational fishing (U.S. EPA 1991).

4. Torch Lake, Houghton County, Michigan

Operating History

Torch Lake is located on the Keweenaw Peninsula of Upper Michigan. The surface area of Torch lake is 2,717 acres; it has a mean depth of 56 feet and a maximum depth of 115 feet. The area of the Torch Lake watershed is 77 square miles. Two small communities with populations of approximately 1,000 each (Linden and Hubbell) are located on the west side of Torch Lake.

For more than 100 years, Torch Lake was the center of Michigan's copper mining, smelting, and milling activities. Mining began in the 1860s in an elemental copper belt extending from the northern tip of Keweenaw Peninsula 100 miles to the southwest. Over 10.5 billion pounds of copper were beneficiated in the Torch Lake area, and an estimated 200 million tons of tailings were pumped into Torch Lake and surrounding properties between 1868 and 1968. The tailings reduced the lake's volume by 20 percent. Mining activities in the Torch Lake area peaked in the early 1900s (U.S. EPA 1991).

Beginning in 1916, technological innovations allowed for the recovery of copper from tailings previously discarded in Torch Lake. The submerged tailings were collected, screened, recrushed, and gravity-separated at one of three reclamation plants. These plants included Calumet and Hecla (opened in 1916), Tamarack (1925), and Quincy (1943). In the 1970s, copper recovery plants began operating in the Torch Lake area. The only discharge to Torch Lake from the copper recovery plants was noncontact cooling water. By 1986, only one small copper recovery plant was still operating.

Environmental Damages and Risks

By the 1970s, there was concern over the environmental health of Torch Lake because of the century of mining waste deposition into it. Copper ore tailings are present in and around Torch Lake and other areas of the Keweenaw Peninsula. The sources of contamination include tailings and associated debris and flotation chemical drums in the tailings, drums in Torch Lake, and industrial chemicals.

Torch Lake was listed on NPL in June 1988. In 1983, the Michigan Department of Public Health (MDPH) issued a fish consumption advisory on all sauger and walleye caught in Torch Lake. In a study of heavy metal concentrations in Torch Lake sediments and mining wastes, it was concluded that the water in Torch Lake is not directly contaminated with heavy metals, although the tailings are directly contaminated with arsenic, chromium, copper, lead, tin, and zinc. Furthermore, heavy metals may be entrained in wind currents, but they do not represent a serious human-health risk.

Over 96 percent of the copper input is from surface runoff, 3 percent is from precipitation, and 1 percent is from ground water inflow. Copper loss occurs by outflow into Portage Lake. The budget indicates an annual net loss of dissolved copper. However, copper concentrations have been relatively stable for the past 14 years. Therefore, precipitation, complexation, dissolution, absorption, and diffusion control dissolved copper concentrations.

In a 1988 health assessment for Torch Lake, the Agency for Toxic Substances and Disease Registry (ATSDR) concluded that the site is a potential public health concern because of possible exposure to unknown etiological agents that may create adverse health effects over time. Although Torch Lake is currently contaminated with mine tailings, there are no known health effects linked to this contamination (U.S. EPA 1991).

APPENDIX 1-D

304(l) SITE SUMMARIES RELATED TO COPPER MINING ACTIVITIES

1. Anaconda Minerals
2. Ferri Haggerty Mine
3. Kennecott-Utah Copper Division

1. Anaconda Minerals

The Anaconda Minerals Company operates a treatment system, including settling ponds, to collect nonpoint source runoff from tailings previously generated by an inactive copper smelter near Butte, Montana. One settling pond discharges to Silver Bow Creek. The discharge from this pond contains high concentrations of copper, zinc, and arsenic exceeding applicable water-quality standards. Additional discharges of contaminated runoff from the Anaconda site have occurred during precipitation events, when the volume of runoff exceeds the capacity of the treatment system. When capacity is exceeded, runoff is discharged directly into Silver Bow Creek (U.S. EPA 1990b).

Downstream of the Anaconda site, numerous other nonpoint source dischargers also contribute high metal loads. The contamination from the Anaconda site and the nonpoint discharges from other mine sites have caused extensive degradation of Silver Bow Creek and have led to its classification as an NPL site (U.S. EPA 1990b).

2. Ferri Haggerty Mine

The Ferri Haggerty Mine, an active copper mine, discharges mine water into surrounding water bodies. The discharges from the mine have caused exceedances of applicable water-quality standards for copper. Discharges from the site have been found to be toxic to aquatic life. To control the levels of copper in the discharge, the owner/operator has developed a three-step plan to ensure compliance. The plan includes passive ion exchange, flow management within the mine workings, and wetlands treatment (U.S. EPA 1990b).

3. Kennecott-Utah Copper Division

Kennecott-Utah Copper Division operates a copper mine near the Great Salt Lake. The facility discharges contaminated runoff from the tailings area to a ditch (known as C-7). In turn, the C-7 ditch discharges into the Great Salt Lake. The discharges have been shown to be toxic to aquatic life. According to the facility, this is primarily due to arsenic. Kennecott has spent over \$10 million to reduce arsenic levels in its discharges.

**APPENDIX 1-E
ACRONYM LIST**

ACRONYM LIST

AAC	Arizona Administrative Code
AEQA	Arizona Environmental Quality Act
AMD	Acid Mine Drainage
amps/m	amps per meter
ANFO	Ammonium Nitrate and Fuel Oil
AOC	Area of Concern
APP	Aquifer Protection Permit
ARCO	Atlantic Richfield Corporation
ATSDR	Agency for Toxic Substances and Disease Registry
AWQCFAL	Ambient Water Quality Criteria for Freshwater Aquatic Life
AZMMR	Arizona Department of Mines and Mineral Resources
BADCT	Best Available Demonstrated Control Technology
BMP	Best Management Practices
CAM	California Assessment Method
CDC	Centers for Disease Control
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
cm	centimeter
CMP	Corrugated Metal Pipe
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DWS	Drinking Water Standards
EP	Extraction Procedure
FIT	Field Investigation Team
ft/sec	feet per second
g/l	grams per liter
gpm	gallons per minute
gpm/ft ²	gallons per minute per square foot
GPR	Ground Penetrating Radar
HDPE	High-Density Polyethylene
ICS	Individual Control Strategy
IJC	International Joint Commission
in/ft	inches per foot
IPCC	In-pit Crusher and Conveyer
km ³	kilograms per cubic meter
l/m ²	liters per square meter
lbs	pounds
LC ₅₀	Lethal Concentration (50% mortality)
LD ₅₀	Lethal Dose (50% mortality)
m ³	cubic meter
MCL	Maximum Contaminant Level
MDNR	Michigan Department of Natural Resources
MDPH	Michigan Department of Public Health
mg/kg	milligrams per kilogram
mg/l	milligrams per liter
MGD	Million Gallons Per Day

ACRONYM LIST (Continued)

MIBC	methyl isobutyl carbinol
ml	milliliter
mm	millimeter
mph	miles per hour
MSHA	Mine Safety and Health Administration
MTU	Michigan Technical University
MWD	Mine Water Drainage
MWHP	Mine Water Holding Ponds
NIPDWS	National Interim Primary Drinking Water Standards
NOD	Notice of Disposal
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPSP	Nonpoint Source Discharge Permit
PCB	Polychlorinated Biphenyl
PD	Phelps Dodge Corporation
PDWS	Primary Drinking Water Standards
PLS	Pregnant Leach Solution
ppm	parts per million
PVC	Polyvinyl Chloride
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
RI	Remedial Investigation
ROD	Record of Decision
RPM	Remedial Project Manager
SAIC	Science Applications International Corporation
SIC	Standard Industrial Classification
SMCL	Secondary Maximum Contaminant Level
SME	Society of Mining Engineers
STEL	Short Term Exposure Limit
SX/EW	Solvent Extraction/Electrowinning
TAT	Technical Assistance Team
TCE	Trichloroethylene (Trichloroethene)
TCLP	Toxicity Characteristic Leachate Procedure
TDS	Total Dissolved Solids
tpd	tons per day
tph	tons per hour
tpy	tons per year
TSP	Total Suspended Particulates
TTLC	Total Threshold Limit Concentration
TWA	Time Weighted Average
USBM	U.S. Bureau of Mines
USC	United States Code
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
	micrograms per kilogram
	micrograms per liter
	micrograms per cubic meter
	micrometer