THE COPPER INDUSTRY AND WATER IN ARIZONA

by

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ABSTRACT

Two of Arizona's most important natural resources are copper and water. Copper has been vital to the development of the state's economy. Currently the copper industry accounts for more than five billion dollars in direct and indirect economic benefits in Arizona. The copper deposits are, however, located in areas with little or no surface water resources. The lack of adequate surface water supplies has resulted in the exploitation of the ground water resources. Many areas of the state are experiencing ground water overdrafts.

The copper industry's water withdrawals while insignificant at the state level, accounting for less than 3 percent of the state total, are often very important to the local water resources. The copper industry's water requirements are expected to increase over the next 10 to 20 years. To prevent further depletion of the state's ground water resources, conservation measures must be adopted.

There are a number of conservation methods available to reduce the copper industry's new water requirements. These methods can be instituted by various management strategies at the state and local levels. The strategies include development of a comprehensive state water plan, land use regulations, and taxing schemes.

CHAPTER I

INTRODUCTION

Arizona is a state with many natural resources. Perhaps the two most important resources are copper and water. Copper has been very important in Arizona's economic development and is still a major source of revenue in the state. Water has always been a precious resource in the arid southwest where supplies are often scarce.

The mining and processing of copper ore requires substantial quantities of water. Unfortunately most of the copper deposits in Arizona are located in areas with little or no surface water. As a result development of copper deposits has necessitated the development of ground water resources. Many areas of Arizona are experiencing severe ground water overdrafts. The copper industry is contributing to this overdraft situation.

This chapter provides the background information on the copper industry in Arizona and the water resources of the state. The economic importance of copper to Arizona and the impact of the copper industry on the state's water resources are discussed. The objective of this study is delineated and the approach is outlined.

The Copper Industry in Arizona

Production and Growth

Arizona has been the nation's leading copper producer for over 65 years. Although copper was of little importance in the early days of the Arizona Territory the subsequent exhaustion of major gold and silver deposits brought attention to the "red metal." The first major copper mining company, the Detroit Copper Company, was founded in 1875 at Morenci (Peplow, 1958). The growth of electrical technology at the turn of the century increased the demand for copper, thus, increasing exploration and development of Arizona's copper resources. Arizona surpassed Montana in 1910 to become the nation's largest copper producer. In 1973 Arizona's 27 copper mines produced 927,271 tons of copper from 181,311,945 tons of ore at a value of 1,103,453,000 dollars (Phillips, 1975). This represented 54 percent of the U.S. production and 12 percent of the world copper production. The growth of the copper industry has been continual, as shown in Figure 1, with some set backs due to economic fluctuations and labor problems.

While total output has continued to grow, the quality of the ore being mined has decreased. In the period around 1912 most ores mined contained 2 to 5 percent recoverable copper, however, today most ores are 0.5 percent recoverable copper. Increased production from these lower grade ores is possible because of technical innovation in the copper industry. The adaptability and growth of the copper industry have kept it in the forefront of the state's economy.

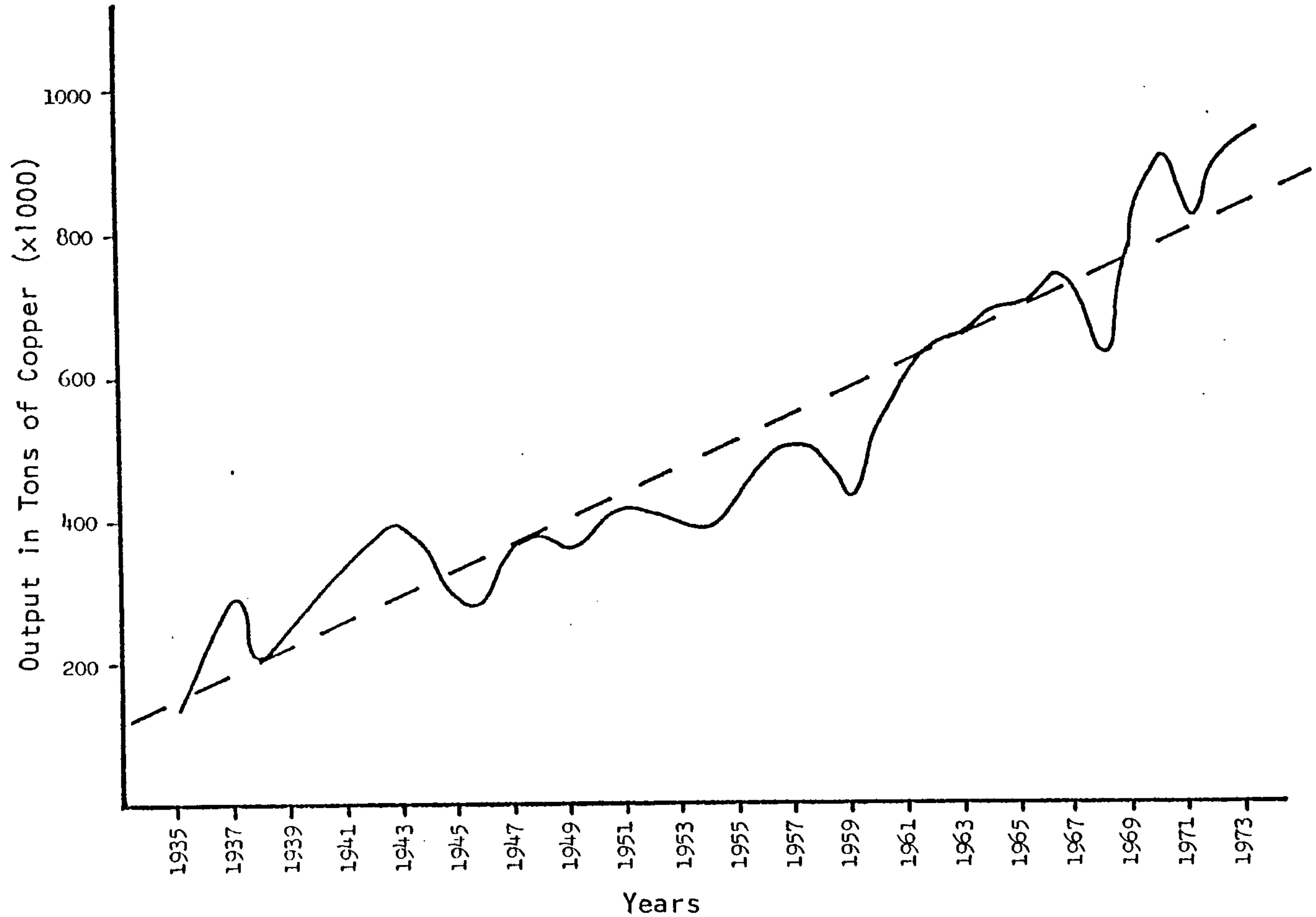

Figure 1. Arizona Copper Output 1935 to 1973. -- Source: Arizona Department of Mineral Resources

The Importance of Copper in Arizona

The copper industry has been important to the development of Arizona since it was a territory. Many communities and transportation networks were established in response to the development of copper deposits in isolated areas (Peplow, 1958). The expanding copper industry also attracted many supporting businesses. The copper industry was for many years the major source of income in the state. Today it is second only to manufacturing as a major income source (see Table 1). The impact of the copper industry on Arizona's economy is very important to the state's well being.

The copper industry is an important part of Arizona's economy contributing substantially to the rapid growth experienced in the state. In 1974 the industry was important in stabilizing the economy in the face of declines in construction and manufacturing (Leaming, 1975). Tables 2 and 3 show how the 1974 copper revenues were distributed through the economy.

The total direct and indirect personal income generated by the copper industry amounted to nearly 1.4 billion dollars or 13 percent of the state's total personal income. This means that 1 of every 8 dollars of Arizona's personal income is generated by copper production. The total income to Arizona business amounted directly and indirectly to 3.3 billion dollars. Government revenues generated by the copper industry totaled 410 million dollars in direct and indirect payments to state and local governments. This accounts for 25 percent of Arizona's tax revenues. Table 4 shows the direct taxes paid in 1974 by the copper producers.

Table 1. Major Sources of Income in Arizona.

Source of Income	1971	1972
Manufacturing (value added)	1,384,600	1,630,000
Mining	981,000	1,091,000
Tourism	600,000	650,000
Livestock	415,005	479,986
Crops	303,089	342,253

Source: Moore, 1973

Table 2. Combined Impact of the Copper Industry on the Arizona Economy, 1974.

Type and Source of Impact		Amount
DIRECT IMPACT		
Personal Income	$	352,400,000
Business Income		403,391,400
Government Income[a]		100,483,000
Total Direct Impact:	$	856,274,400
INDIRECT IMPACT[b]		
Personal Income	$	1,028,433,000
Business Income		2,965,893,500
Government Income		309,697,900
Total Indirect Impact:	$	4,304,024,400
TOTAL ECONOMIC IMPACT		
Personal Income	$	1,380,833,000
Business Income		3,369,284,900
Government Income		410,180,900
Total Impact:	$	5,160,298,800

[a] State and local governments only.

[b] Caused by the recirculation within Arizona of the copper industry's direct contributions to personal, business, and government income.

Source: Leaming, 1975

Table 3. Distribution of Copper Industry Income to the Arizona Economy, 1974.

VALUE OF OUTPUT		$1,193,809,000
PERSONAL INCOME		$ 352,400,000
Wages and Salaries	$330,600,000	
Dividends to Arizona Stockholders	6,200,000	
Pensions to Arizona Residents	15,600,000	
BUSINESS INCOME		$ 403,491,300
Construction	$ 75,662,900	
Manufacturing	50,423,900	
Transportation	22,367,900	
Public Utilities	78,490,000	
Wholesale Trade	159,139,700	
All Other Businesses	17,406,900	
GOVERNMENT REVENUES		$ 100,483,000
State of Arizona	$ 35,976,200	
Schools and Colleges	41,258,600	
Other Local Governments	23,248,200	
LEAKAGES		$ 337,434,700
Federal Taxes	$ 73,637,700	
Out-of-State Costs	269,500,800	
Dividends to Investors[a]	48,351,100	
Retained for Reinvestment	54,054,900[b]	

[a]Does not include dividends paid to Arizona residents.

[b]Indicates net investment inflow to Arizona.

Source: Leaming, 1975

Table 4. State and Local Taxes Paid by the Arizona Copper Industry, 1974.

Type of Tax	Amount Paid
Property Taxes	$ 38,960,000
Severance Taxes	
Privilege Sales Tax	12,104,700
Education Excise Tax	6,052,300
Special Education Excise Tax	8,517,000
Corporate Income Tax	9,729,000
Payroll Taxes	
Unemployment Compensation	1,716,000
Workmen's Compensation	5,901,000
Miscellaneous Taxes[a]	11,445,000
Land Rents and Royalties	6,058,000
TOTAL:	$ 100,483,000

[a]Includes sales taxes paid on Arizona purchases as well as motor vehicle licenses and fees

Source: Leaming, 1975

The total direct impact amounted to $856,374,300 or 71 percent of total copper revenues in 1974 (Leaming, 1975). The total direct and indirect impacts amounted to almost $5.2 billion or 4.3 times the total revenues (Leaming, 1975). Clearly the copper mines are a major part of the Arizona economy. The impact in some local areas is more important then to the state as a whole. Tucson, for example, relies heavily on nearby mines for employment and revenues (Leaming, 1975).

Arizona's copper resources have been very important to the development of the state. The economic contributions of copper exploitation are expected to continue growing. One of the problems with copper development is the need for large quantities of water. The availability of water resources will be dealt with in the following section.

Arizona's Water Resources

Climate

Many people envision Arizona as a state of vast desert wastelands, filled with sand and cactus. Despite this image Arizona has many different climatic areas. This variation in climate is due, in part, to the wide range in elevation from 137 feet to 12,600 feet above sea level (Sellers and Hill, 1974). The state can be divided into six climatic regions as shown in Figure 2.

Roughly half of the state receives less than 10 inches of precipitation annually (Figure 2). The southwest climatic region which contains the largest population center, vast farmlands, and

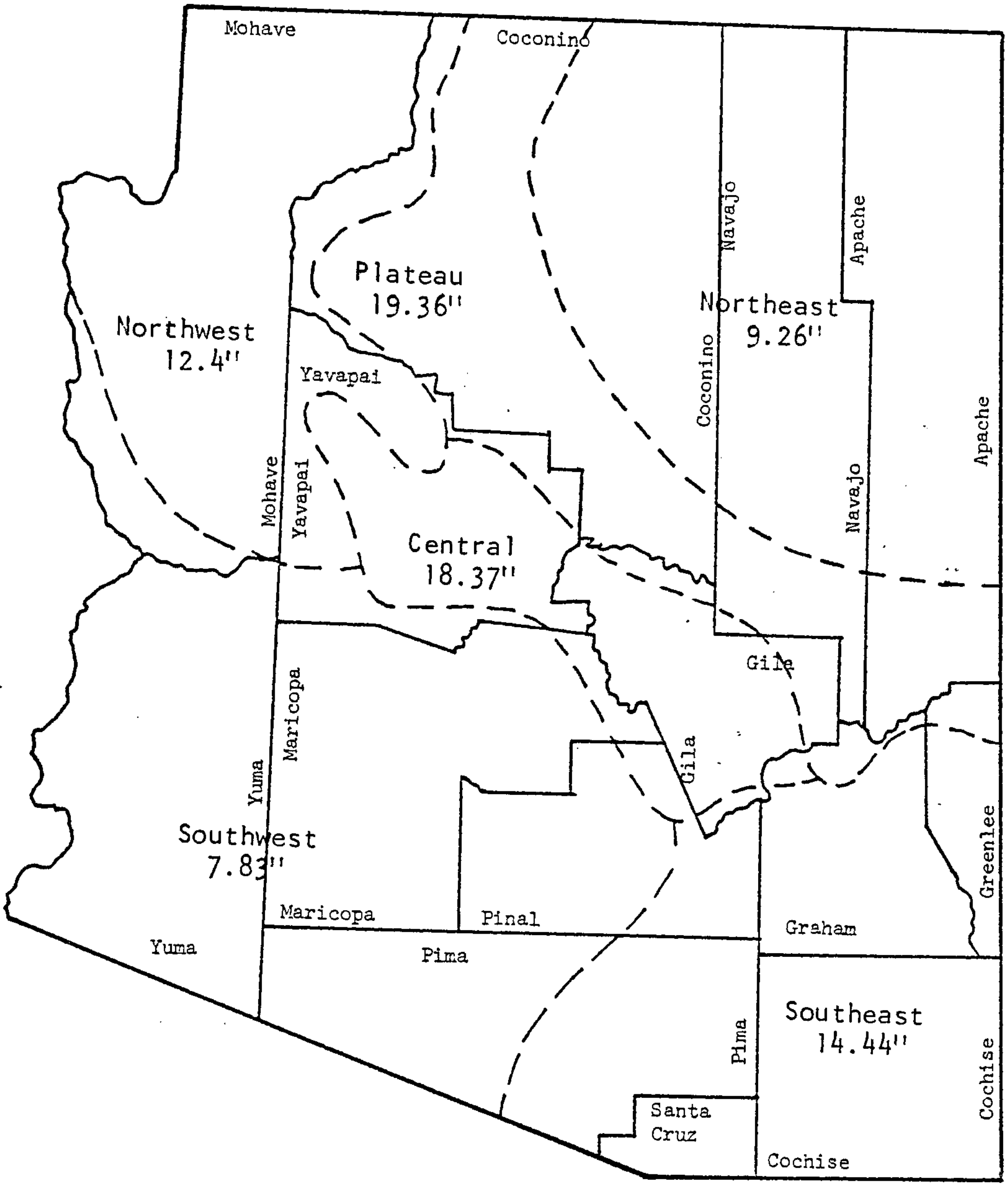

Figure 2. Climatic Regions and Average Annual Rainfall. -- Source: Sellers and Hill, 1974

highest evaporation rate also receives the least amount of rainfall. The major urban areas of Phoenix and Tucson receive a mean annual precipitation of 7.26 inches and 10.69 inches, respectively (Arizona Water Commission, 1975). These relatively small amounts of precipitation are further reduced by the high evaporation potential throughout the state. Actual lake evaporation generally ranges from 55 to 75 inches annually (Sellers and Hill, 1974). Extremes of 80 to 90 inches per year occur in the southwestern region. Evaporation potential greatly exceeds precipitation throughout the state. It has been estimated that as much as 95 percent of the precipitation is lost to evaporation (Arizona Water Commission, 1975).

This hot dry climate of south-central Arizona has in recent years become a strong attraction. The rapid population growth which has occurred since 1940 in the Tucson and Phoenix areas is to some extent related to the climate. People enjoy the hot summers and warm dry winters. In two studies conducted in the Tucson area it was found that 30 to 50 percent of those moving into the area did so for reasons of climate (Pima Association of Governments, 1975). This is ironic in that for many years it was the climate (i.e., lack of rain) which kept all but the foolhearty away. However, the development of the ground water resources has made the dry climate a major attraction. This rapid growth is putting stress on the ground water resources. Many areas are experiencing serious ground water overdrafts. It is important to understand the location and reasons for these overdrafts.

Water Resources Inventory

When Arizona's water resources are discussed the state is normally divided into three basic regions. These are the Basin and Range Province, the Plateau Uplands Province, and the Central Highlands Province as depicted in Figure 3. Each of these provinces has characteristic topography and water resources.

The Central Highlands Province which contains 15 percent of Arizona's land area is a region of rugged mountain terrain. Because of the steep, narrow valleys there are many ideal dam sites. The province corresponds to the central and plateau climatic regions (Figure 2) and receives 18 to 20 inches precipitation annually. This rainfall is sufficient to maintain streamflow and ground water recharge.

Surface water from the Central Highlands accounts for 50 percent of the surface water originating in the state. The Salt and Verde Rivers are the two major systems in the province. A system of dams and reservoirs along the Salt River provides water for agricultural, industrial, and domestic uses in the Phoenix area.

Ground water in the Central Highlands Province has not been developed to any great extent because of the abundance of surface water (Arizona Water Commission, 1975). The occurrence of ground water is dependent on local geologic structure which is highly variable in the mountain terrain. The Central Highlands Province has had no ground water development by the copper industry.

The Plateau Uplands Province contains 40 percent of the state's land area. The province ranges in elevation from 4,000 to 12,000 feet

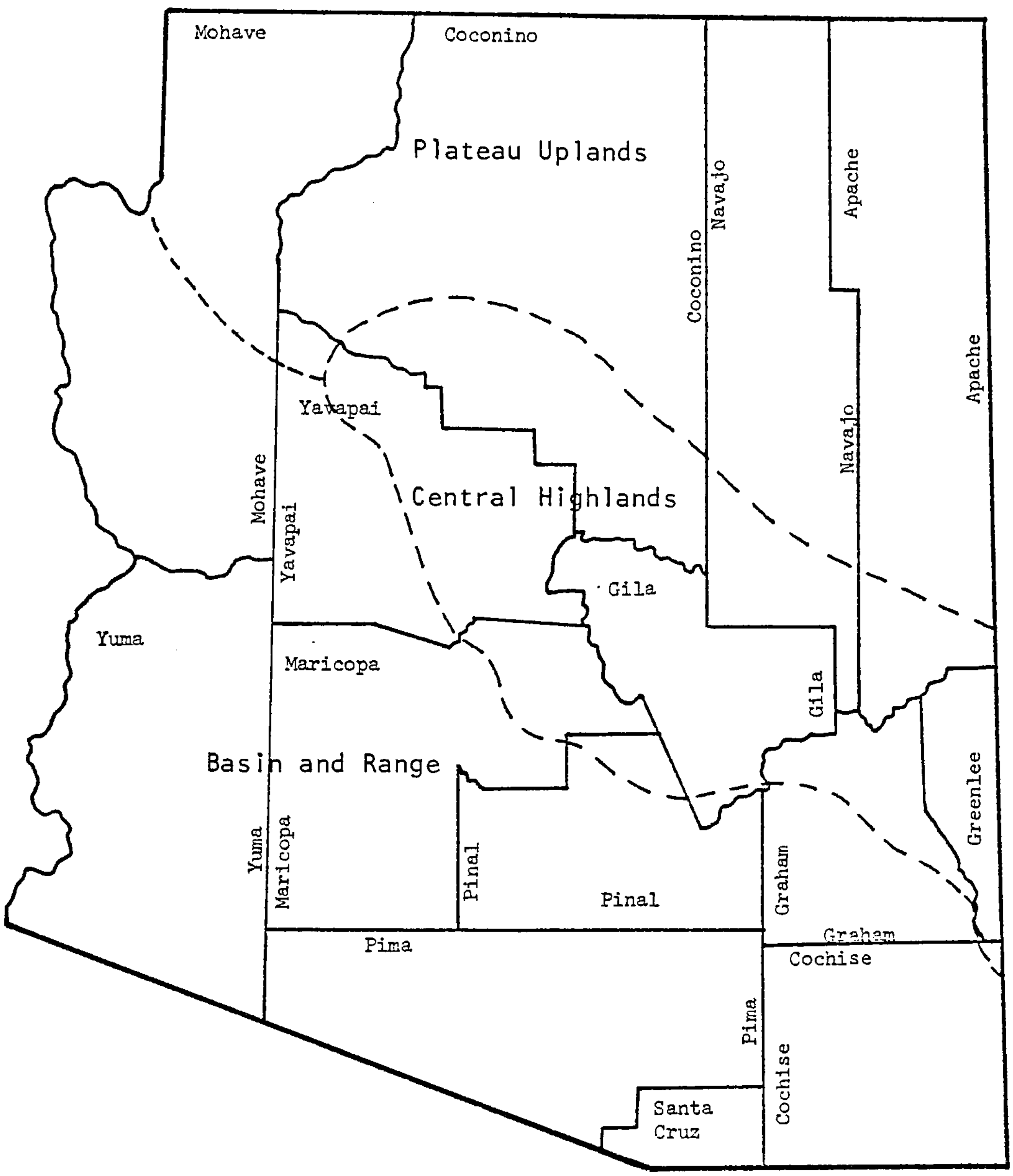

Figure 3. Arizona Water Provinces. -- Source: Arizona Water Commission, 1975

with many extreme surface conditions including plateau, mountain, and canyon (Arizona Water Commission, 1975). Situated across three climatic regions (Figure 2) the rainfall in the province varies widely from 6 to 30 inches annually. The high precipitation in some areas would be expected to sustain surface flow, however, the highly porous rocks of the province tend to reduce such flows. Streams which are perennial in the highlands lose their water to evaporation and seepage, causing intermittant flow at their lower reaches. The major surface flow in the Plateau Uplands Province is the Little Colorado and its tributaries. Many other streams flow in response to seasonal storms thus providing a variable water supply.

Ground water in the Plateau Upland is virtually nonexistent in the northwestern and Grand Canyon areas (Arizona Water Commission, 1975). In other areas water may be withdrawn from the alluvium along stream channels. The storage in these channels is very small. The eastern half of the province has extensive sandstone aquifers with high storage but very low yields. The Plateau Upland has had little water development in response to copper production.

The remaining and most critical area is the Basin and Range Province. This province comprises 45 percent of the state land area, however, it contains 85 percent of the state's population, 95 percent of the cultivated land, and all major copper production (Kelso, 1973).

The Basin and Range Province receives about 10 inches of precipitation annually ranging from 3 to 30 inches (Sellers and Hill, 1974). The terrain of the province is characterized by high mountain ranges separated by broad alluvial filled basins (Arizona Water Commission, 1975).

Surface water in the province is very limited with few perennial streams. The Basin and Range Province is best characterized by dry washes which flow only in response to storm precipitation. This limited supply of surface water has caused development of the ground water resources.

Ground water occurs under similar geologic conditions throughout the province. The broad basins contain alluvium to depths of several thousand feet providing large ground water storage. These alluvial basins often have very high yields from depths ranging from 10 to 500 feet below the surface (Arizona Water Commission, 1975). Unfortunately the recharge in the province is relatively small. The typical summer storm and resultant flash floods provides very little recharge. Although exact amounts of recharge are unknown indications are that only a small fraction of surface runoff reaches the ground water reservoir (Kelso, 1973). In many of the basins withdrawal far exceed recharge.

The increasing dependence on ground water supplies in response to the growth in the Basin and Range area has created a condition of declining water tables in many parts of the Province. The copper mines in the Basin and Range counties (Table 5) have developed extensive well fields which contribute to the overall depletion.

Looking at the state as a whole we find that surface water accounts for approximately 40 percent of the water used in Arizona (Arizona Water Commission, 1975). Ground water makes up the remaining

Table 5. Major Copper Producers

Mine	Company	County
Pima	Pima Mining Company	Pima
Twin Buttes	Anamax Company	Pima
Sierrita	Duval Corporation	Pima
Esperanza	Duval Corporation	Pima
New Cornelia	Phelps Dodge	Pima
Mission	American Smelting and Refining Corporation	Pima
Silver Bell	American Smelting and Refining Corporation	Pima
San Xavier	American Smelting and Refining Corporation	Pima
San Manuel	Magma Copper Company	Pinal
Ray	Kennecott Copper Company	Pinal
Inspiration	Inspiration Consolidated	Gila
Copper Cities	Cities Service Company	Gila
Morenci	Phelps Dodge Corporation	Greenlee
Mineral Park	Duval Corporation	Mohave
Bagdad	Bagdad Copper Corporation	Yavapai

Source: Moore, 1973; Phillips, 1975

60 percent of the water used in the state. When the Central Arizona Project is completed additional surface water will be available for use. With its completion Arizona will be able to use its full allocation of 2.8 million acre-feet of Colorado River water (McBride, 1972). Currently, however, the total diversions and withdrawals in Arizona amount to 8.3 million acre-feet (Arizona Water Commission, 1975). Fifty-eight percent of this or 4.8 million acre-feet is depleted while 42 percent or 3.5 million acre-feet is recharged or returned to surface flows. Table 6 compares the dependable supply with the depletions for each county. Dependable supply is considered to be the annual amount of water which can be used over a long period of time without lowering the ground water tables. Notice that the counties with bad depletion/supply ratios are all in the Basin and Range Province. They are also the copper mining counties (Table 5). The worst county, Pima County, uses 4.7 times its dependable supply. This results in serious ground water overdrafts and declining water levels. The role of the copper industry's withdrawals must be evaluated.

Major Water Users

Table 7 lists by county the major water users and their depletions. Copper production appears to be insignificant at the state level accounting for less than 3 percent of the total depletion. However, at the county level the impact of the copper industry's water withdrawals are more important. In Pima County the copper industries depletion is approximately 15 percent of the total depletion. At the

Table 6. Estimated Annual Dependable Supplies, Depletions and Overdrafts by County Normalized 1970 Conditions (in 1,000 Acre-Feet)

County	Dependable Supply	Depletion	Ground Water Overdraft	Ratio: Depletion vs. Supply
Maricopa	971	1,873	902	1.9
Pima	72	339	267	4.7
Apache	17	17	0	1.0
Coconino	14	14	0	1.0
Navajo	44	44	0	1.0
Yavapai	22	34	12	1.5
Mohave	67	72	5	1.1
Yuma	1086	970	79	0.9
Gila	19	19	0	1.0
Pinal	254	874	620	3.4
Cochise	85	353	268	4.2
Graham	132	159	27	;.2
Greenlee	33	33	0	1.0
Santa Cruz	5	13	8	2.6
State Total	2821	4814	2188	

Source: Arizona Water Commission, 1975

Table 7. Estimated Annual Water Depletion by County Normalized 1970 Conditions (in 1,000 Acre-Feet)

County	Irrigated Agriculture	Municipal & Industrial	Mineral Industry	Miscellaneous	Total
Maricopa	1681	183	1	8	1873
Pima	211	69	53	6	339
Apache	14	2	1	0	17
Coconino	9	5	0	0	14
Navajo	26	15	0	3	44
Yavapai	24	5	5	0	34
Mohave	23	7	4	38	72
Yuma	954	13	0	3	970
Gila	2	3	14	0	19
Pinal	830	12	31	1	874
Cochise	335	9	8	1	353
Graham	157	2	0	0	159
Greenlee	17	2	14	0	33
Santa Cruz	11	2	0	0	13
State Total	4294	329	131	60	4814

Source: Arizona Water Commission, 1975

local level the depletions are even more important. The highly concentrated pumping of the mining operations can have a great local impact.

Although the copper mines are small state wide water users being overshadowed by the large withdrawals of agriculture, they have a significant impact on the local water resources. Their exact impact must be evaluated to assess any attempt at ground water conservation.

Objective of Study

The intent of this investigation is to explore the alternative management strategies designed to reduce the ground water withdrawals of the copper mining industries. The strategies are to be developed and evaluated with respect to the copper industry's impact on Arizona's water resources and economy. In pursuing this objective the intent is to estimate the new water requirements of the copper industry, make projections of future requirements, discuss areas of possible conservation, evaluate current ground water policy and strategies, and propose policies and strategies.

Contents

Chapter 2 is divided into three sections. The first section physically describes the copper mining processes and operations. This section is based on information provided by the United States Bureau of Mines, Arizona Bureau of Mines, and the Arizona Mining Association. The second section contains estimates of the copper industry's water requirements. These estimates are based on information provided by the copper mining companies and is supported by estimates by the Arizona

Water Commission and Marum and Marum, Incorporated. The final section presents possible water conservation measures adoptable by the copper industries. These measures are the results of investigations by the U.S. Bureau of Mines and from personal interviews with mining personnel.

Chapter three contains two basic sections. The first section evaluates the current policy and strategies of Arizona in regard to ground water management. The second section suggests a new policy and the strategies to achieve that policy.

Chapter four is the summary and general discussion.

CHAPTER II

WATER IN THE COPPER INDUSTRY

Water is an important production factor in Arizona's copper industry. It is used in all of the production processes from mining to the final refining. Each step in the production process employs water in varying manners and quantities. In this chapter the average copper operation will be described showing the importance of water to each process. The actual new water requirements for copper production will be estimated. The impacts of these withdrawals on the state and local water resources will be evaluated. Finally, estimates of the copper industry's future requirements will be made and possible conservation measures discussed.

The Copper Production Process

Although the methods of production vary from company to company the basic processes are similar throughout the copper industry. A typical operation would consist of a mine (open pit or underground), ore preparation (i.e., ore crushing and sizing), floatation concentration, leaching, and smelting. Each of these processes require water in varying amounts. It is important to understand these processes before attempting to institute conservation programs.

The Mining Operation

The extraction of ore is accomplished by two methods in Arizona: open pit mining and underground mining. The open pit method is the most widely used method in the state. In 1972, 79 percent of Arizona's copper production came from open pit operations (Moore, 1973).

The open pit method is, as it sounds, simply digging a large pit down to the ore deposit. It often requires removal of large amounts of overburden to reach the ore body. Once the pit is developed the ore and waste material are loosened by drilling and blasting. The large rotary drilling rigs use water to remove the material from the 9 inch bore holes.

After the material is loosened it is loaded by large shovels into trucks ranging in capacity from 50 to 200 tons. The trucks transport the ore and waste material by haulage roads out of the pit. The ore is taken to the crushers and the waste material is placed in large dumps. The haulage roads as well as other areas of the pit are watered frequently for dust control. Small amounts of water are also used to clean the pit equipment.

There are three basic methods of underground mining: room-and-pillar; cut-and-fill; and block caving (Bennett, 1973). These methods although differing technically use water in the same manner; as a dust control medium and in some drilling processes. Less water is used in the underground operation than the open pit due to the lower evaporation rate.

Although the mining process uses relatively small amounts of water it is important to note that all water used in the process is lost to evaporation or seepage (Gilkey, 1963; Appendix A). All requirements are filled by new water pumpage as no recycling is practiced in the mining process.

Ore Preparation

After the ore is removed from the mine it is taken to the primary crusher which reduces the large chunks of ore into a more manageable size. The ore passes through various types of crushers until it is ground into a fine powder. The main use of water in this operation is for dust control and crusher bearing coolant. Relatively little water is used in this process.

Floatation Concentration

The floatation concentrator takes the finely ground ore and concentrates the copper minerals. Copper occurs as two basic mineral groups; copper sulfides and copper oxides. The most abundant are copper sulfides. The concentration process is adaptable to both types of ore, however, it is most commonly used to process copper sulfides.

Floatation concentration is the most widely used method of recovering copper compounds from the ore. In 1972, 86.3 percent of the copper produced in Arizona was processed by concentration (Moore, 1973). The floatation operation starts by mixing the powdered ore with water to form a slurry. This mixture is fed into a floatation cell with the appropriate reagents (see Figure 4). Compressed air is pumped through the slurry causing a foaming action. The reagents cause the copper

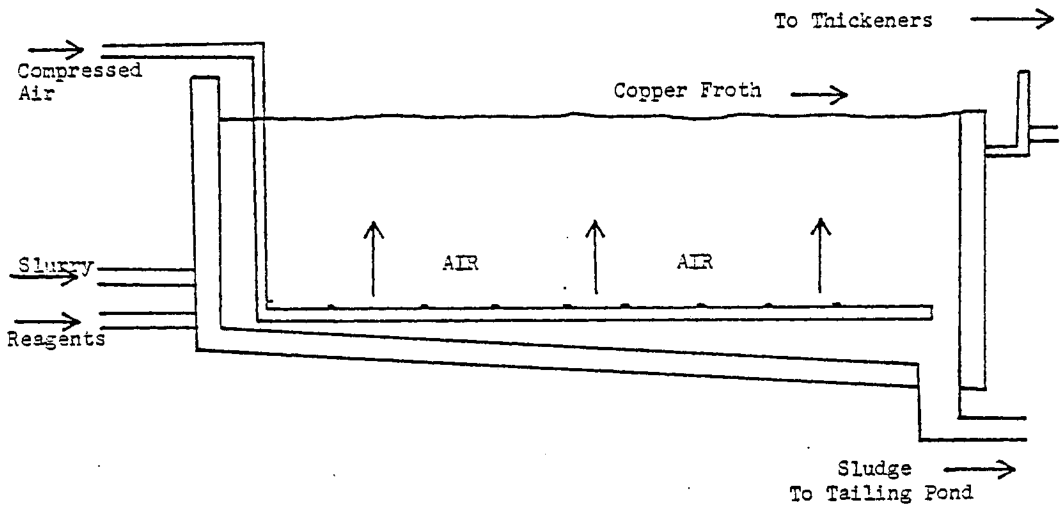

Figure 4. Floatation Concentration Cell

compounds to collect on the surfaces of the many bubbles. The foam containing the copper compound is skimmed off the top and the waste sludge is drained off the bottom. The copper rich foam moves to the thickeners and dryers where excess water is removed until the concentrated copper mineral become a cake of damp powder containing 20 to 30 percent copper (Bennett, 1973). The waste sludge is piped to the tailing ponds or tanks where the sludge settles out and the water can be recirculated.

Water intake in the concentrators is very high, however, recycling rates are also high. Water is lost from the operation by evaporation from the floatation cell, tailing ponds, and the thickeners. Some water is also lost by incorporation into the "cake" product which is sent to the smelters and by seepage from the tailing ponds.

Leaching

Leaching is an operation which uses an acid solution to remove copper compounds from ore. Although applicable to both sulfide and oxide copper compounds it is most frequently used with the oxides. There are four basic types of leaching operations: dump, heap, vat, and inplace.

Dump leaching refers to the leaching of the waste dumps made in the open pit operation. These dumps usually contain waste material mixed with extremely low grade ores. The dump leaching operation is used to obtain both sulfide and oxide coppers (Sheffer, 1968). The dumps, once established, are saturated with a sulphuric acid solution. The method of solution application varies among operations.

There are three basic methods of applying solution to the dump area: spraying, flooding, and vertical pipe delivery. Spraying the acid solution onto the dump is the most common method of application. The solution is pumped to the dump area and applied by irrigation type spraying nozzles. The solution saturates the surface and percolates through the material removing the copper compounds. In the flooding method the solution is allowed to build up in prepared ditches and ponds on the dump surface. The acid solution infiltrates into the material removing the copper. The vertical pipe method uses perforated delivery pipes placed vertically into the leach dump (see Figure 5). The acid solution is pumped to the leach area and dispersed by the vertical pipes below the surface reducing evaporative water losses.

Regardless of the method of delivery the acid solution performs the same task of removing the copper compounds. The solution leaches through the low grade ore mixture removing the copper it contacts. The "pregnant" solution (i.e., solution containing copper compounds) is collected at the bottom and pumped to the processing plant. There are two basic methods of processing the pregnant solution: precipitation with iron, and solvent extraction (Sheffer, 1968). In the precipitation process the pregnant solution is circulated through tanks of shredded scrap iron causing the copper to precipitate. The precipitated sludge called cement copper contains about 60 percent pure copper (Bennett, 1973). The cement copper is passed on to be smelted. The barren solution is checked for proper acidity and is recirculated to the leach dump.

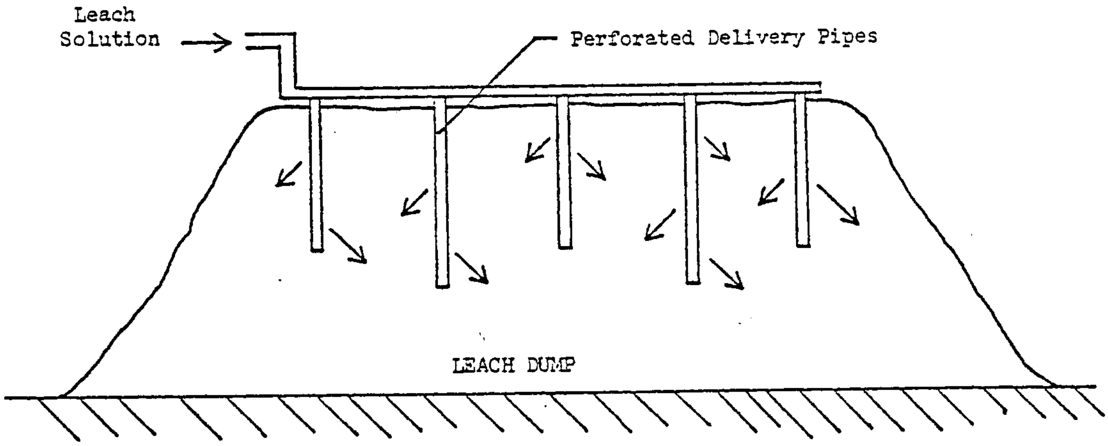

Figure 5. Vertical Pipe Delivery System

The solvent extraction method uses a liquid ion exchange process to remove the copper from the solution. The copper is then refined by electrolytic deposition which yields almost pure copper. The advantage of this method is that it eliminates the smelting process.

The heap leaching process is very similar to dump leaching. In the heap leaching operation the heap or dump contains only ore material and is deposited on a prepared surface. The prepared surface enables more efficient recovery of the pregnant solution. Heap leaching is only used to leach copper oxide ores. Water is utilized in the same manner in heap leaching as with dump leaching. The pregnant solution is processed by the same methods.

Vat leaching is used to extract copper from oxide or oxide-sulfide mixed ores. This process is usually used with high grade ores of 0.5 percent acid soluble copper content. The vat leaching operation requires ore preparation as does the concentration process. The powdered ore is placed in large vats and is saturated with the acid solution. Solution recovery from the vats is very high. The pregnant solution is processed the same as dump and heap solutions.

In place or in situ leaching is applicable to both sulfide and oxide ores. The ore body is drilled and blasted to cause fracturing. The solution is introduced at the surface and leaches through the fractured area. The pregnant solution is removed from the bottom by drilling wells through the material. The pregnant solution is processed as usual.

The leaching operations require large quantities of water to saturate the piles of ore and dissolve the copper compounds. Much of this water is recycled after processing. However, water is lost to evaporation by the spraying and flooding methods of solution application. Evaporation also occurs in the precipitation and ion exchange process. Some water is also lost to seepage in the dump and in situ methods. The vat leaching method is under more controlled conditions and tends to lose less water.

Smelting and Refining

The smelting operation takes the concentrator "cake" and the leaching cement copper which ranges from 20 to 60 percent copper and processes it in two furnaces. The reverberatory and converter furnaces remove most of the impurities leaving a product called blister copper which is about 99 percent copper. The blister copper is further refined in an electrolytic refinery. An anode of blister copper is placed in an electrolytic solution. The copper is deposited on the cathode. The refined copper cathodes are 99.99 percent pure copper (Arizona Mining Association, 1975).

Water in the smelting operation is used mainly as a coolant for the large furnaces. In electrolytic refining, water is used to make up the electrolyte.

Trends in Operational Changes

The copper industry has proven to be very innovative over its long years in Arizona. Many times the end of the industry has been predicted due to lessening grades of ore (Peplow, 1958). Constant changes in technology have enabled the copper industry to survive (if not thrive). Some changes seem to be underway now. One observable trend has been a shift toward more leaching and less concentration. As shown in Table 8 leaching accounted for 6.1 percent of Arizona copper production in 1962, however, in 1972 it accounted for 12.9 percent (Gilkey, 1963; Moore, 1973). The shift has resulted from a number of factors. The decrease in ore yields has made it uneconomical to process some ores by concentration. Leaching operations, in most cases, require less capital investment and lower operating costs then a floatation concentrator (Bennett, 1973).

The trend toward increased leaching can be expected to continue, if not increase, over the next 20 to 30 years. A recent study in Nevada (Nevada Bureau of Mines, 1973), has predicted that by the year 2000 most new copper production will be in situ leaching operations. The study continued that by 2020 all copper production will be from in situ and vat leaching operations. Similar trends may be expected in Arizona.

Summary

The processing of copper ore into copper is complex. It is highly capital intensive requiring much machinery and manpower. Copper production also requires large amounts of water. This can be a problem in the arid areas of Arizona. Most operations, however, pump adequate amounts from the ground water resources. The water loss from these operations is largely a result of evaporation and seepage. In trying

Table 8. Trends in Copper Production Methods 1960 to 1972 (in Tons of Copper)

Method of Production	1960[1]		1972[2]	
	Ton of Production	Percent of Production	Tons of Production	Percent of Production
Concentration	500,500	92.9	783,918	86.3
Leaching	33,000	6.1	117,862	12.9
Miscellaneous	5,100	1.0	6,832	0.7
TOTAL	538,605	100.0	908,612	100.0

[1]Source: Gilkey, 1963

[2]Source: Moore, 1973

to conserve the ground water resources it is beneficial to know how much water is lost in each process. Thus, enabling formation of conservation measures which are effective but not harmful to the industry.

Water in Copper Production

The Arizona Water Commission has made estimates of the depletions made by the state's major water users. Table 7 shows the estimates for normalized 1970 conditions. The mineral industry's depletion is 131,000 acre-feet or 2.7 percent of the total state depletion. In Pima County the depletion is 53,000 acre-feet or 15.6 percent of the county's total depletion. These estimates while valuable for viewing the overall water situation are too broad to be of value in strategy evaluation.

The copper industry represents about 90 percent of the mineral industry's total depletion. The withdrawals made by the copper industry are often very concentrated and have a high local impact. The depletions from the various production processes vary widely. It is important to know the new water requirements of each of these processes to formulate conservation strategies which will be effective.

Water Requirements

The processes described in the previous section are the basic operations used throughout the industry. However, each operation varies slightly from mine to mine. A floatation concentrator at one mining operation may have significantly different water and reagent requirement than a similar concentrator elsewhere. The estimates presented in this section represent industry averages taken from the data supplied by different companies throughout the state. The calculation of the averages and the data questionnaire are shown in Appendix A.

The operations which are the largest water users are the floatation concentration and leaching operations. Table 9 shows the total water requirements and new water requirements of the concentration and leaching operations for 1960 and 1974. The less water intensive mining and smelting operations are also contained in Table 9. These operations have all undergone increases in total water intake. Part of the increases for these operations can be explained by the decrease in ore yields since 1960. In 1960, the ore average 1.75 percent recoverable copper and 0.53 percent in 1974. This means that in 1960 it took 133 tons of ore to produce 1 ton of copper while in 1974 it took 188 tons of ore. This 41 percent increase in the volume of ore which must be processed also increases the water requirements per ton of copper. However, all of the increase cannot be attributed to changes in ore yield.

The water requirements for the mining operation have increased considerably. About half of the increase is due to yield changes which means more ore must be mined. The increase has also resulted from more intensive use of water in the open pit operation. An increased concern for working and environmental safety has resulted in more water being used for dust control and equipment cleaning in the mining process. Unfortunately, all the water used in the mining process is lost to evaporation with no recycling.

Table 9. Water Requirements for Arizona Copper Production (1960 and 1974)

Production Processes	1960[1] gal/ton of copper	1960[1] % Recycled	1974[2] gal/ton of copper	1974[2] % Recycled
Mining				
New Intake	2,200		3,600	
Total Intake	2,200	0	3,600	0
Concentration				
New Intake	28,000		26,000	
Total Intake	107,000	74	126,000	79
Leaching				
New Intake	51,000		34,000	
Total Intake	60,000	15	219,000	85
Smelting				
New Intake	1,500		4,500	
Total Intake			4,500	0

[1] Source: Gilkey, 1963

[2] Source: Arizona Copper Mines (confidential)

The floatation concentration process has remained fairly constant in water intake. The total intake has increased 20 percent, however, the recycling rate has also increased. The result is a net reduction in the new water intake. These changes have resulted from technological innovations in the process itself.

The leaching operations have undergone significant technical changes since 1960. The total intake has increased three-fold. However, the recycling rate has increased from 15 to 85 percent. The result being a reduction in new water intake by one-third.

The smelting operation has tripled its new water intake. The major cause is technical changes in the process rather than ore quality changes.

The information contained in Table 9 points out the relative water intensity of the various production processes. It does not, however, indicate the complete requirements for a production method or the total requirements for copper production. Table 10 contains the new water requirements for the mining-concentration-smelting method (M-C-S), the mining-leaching-smelting method (M-L-S), and the total copper industry requirements for 1960 and 1974.

The M-C-S method as shown in Table 10 has increased by 2,700 gallons per ton since 1960. This method is used to produce about 86 percent of the copper in the state (Moore, 1973). The increase in water intake in the M-C-S method has been a result of increased intake in the mining and smelting processes.

Table 10. New Water Requirements for Copper Production 1960 and 1974 (in Gal/Ton of Copper)

	1960[1]	1974[2]
Mining-Concentration-Smelting	31,400	34,100
Mining-Leaching-Smelting	54,900	42,000
Total New Water[3]	42,885	45,852

[1]Source: Gilkey, 1963

[2]Source: Arizona Copper Mines (confidential)

[3]Includes all domestic and miscellaneous uses (support facilities, water supplied to homes)

The M-L-S method has actually decreased its new water intake by 12,000 gallons despite the increases in the mining and smelting processes. The M-L-S method and similar leaching operation are growing in importance and are currently responsible for about 13 percent of the state's copper production (Moore, 1973).

A weighted average of the M-C-S and M-L-S methods indicates that the direct production operations currently require an average of 35,137 gallons of new water per ton of copper produced. However, the total new water requirements for copper production includes water for domestic uses, power generation, ground care and many miscellaneous uses. As shown in Table 10 the total new water requirement is 45,800 gallons per ton of copper produced. The total requirement is helpful in determining the impact on the water resources in a particular region. The amount of copper produced (in tons) in an area can be multiplied by the total requirement per ton to get the total water withdrawal by copper production in the region.

Impact on Arizona's Water Resources

The copper industry's water needs are met for the most part by ground water pumpage. Approximately 85 percent of the water used in copper production is ground water while the remainder is from surface water diversions. Most mining operations have extensive well fields developed in the proximity of the mines. The major impact of copper mining on Arizona's water resources is the depletion of the ground water resources by the concentrated pumping. At the state level the copper industry's pumpage may seem insignificant, however, the real impact is on the local resources. Table 11 contains the copper industry withdrawals in the copper producing counties. In most cases the withdrawals are highly concentrated in a mining district and not dispersed throughout the county.

In Pima County, the largest copper producing county, all the water for copper production comes from ground water pumpage. The 52,000 ac-ft withdrawal (Table 11) is a significant portion (15%) of the county's total depletion. The Tucson Basin contains 7 of the 8 major copper mines in the county. These mines located near Sahaurita, 25 miles south of Tucson, withdraw approximately 44,600 ac-ft annually (calculated from industry data). This amounts to 20 percent of the total basin withdrawal (Davidson, 1973). The location of the mines near Tucson puts them in direct competition with agricultural and urban water users. The City of Tucson and FICO, a large agricultural cooperative, are interested in the water in the Sahaurita area. The amount of water withdrawn for copper production is important in terms of the decreased supply for FICO and Tucson. The high demand for water in the Tucson Basin has lead to declining water tables and increased legal conflicts. Currently, there are several pending suits concerning the adjudication of water rights. Projections of increased future withdrawals by the mines, agriculture and Tucson indicate increased conflict and ground water declines in the basin (Kelso, 1973).

Other counties have similar problems due to the high local withdrawals of the mining operations. Some mines, however, because of

Table 11. Total Water Depletion by Copper Production in 1973

County	Copper Production[1]	Depletion[2]	
	tons	million gallons	acre-feet
Pima	371,200.0	17,020.3	52,209.4
Pinal	236,174	10,829.1	33,218.0
Gila	94,569.8	4,336.2	13,301.3
Yavapai	19,151.5	878.1	2,693.7
Greenlee	119,534.5	5,480	16,812.6
Cochise	42,015.3	1,926.5	5,909.5
Mohave	23,676	1,085.6	3,330.0
State Total[3]	927,271	41,556	130,420

[1]Source: Arizona Department of Mineral Resources (Phillips, 1975)

[2]Source: Calculated from data provided by Copper Industries (confidential)

[3]State total includes small producers not included in county data

their isolation from other users, have no immediate impact other than their contribution to the general depletion of the state's ground water resources.

Another impact on the water resources which is not very well understood is the potential pollution of ground water by mine tailing pond seepage. Metalic salts which form in the leaching process infiltrate from the tailing ponds. Because of the slow movement of the infiltrated water toward the water table the exact impact is unknown (Pima Association of Governments, 1975; Marum and Marum, Inc., 1973). Some research is being conducted in the Sahuarita area to determine the effect of tailing pond seepage.

Clearly, the most evident and potentially critical problem is where mining interfaces with other users to cause serious overdraft situations. It is, therefore, important to understand the water requirements of current and potential copper production and to plan for ways of meeting or altering those requirements.

Trends in Copper Mining Water Requirements

The total withdrawals made by the copper mines has increased substantially since 1960. It is likely that their water needs will continue to increase. In 1960, the total withdrawal was 70,900 ac-ft (Gilkey, 1963) compared with 130,000 ac-ft in 1973 (Table 11). This increase was due to increases in total copper output, changes in ore quality and changes in the production technology. Further changes in these categories can be expected in the future.

Conservative estimates show that ore reserves of grades similar to current production will last 20 years with probable new reserves supplying ore for an additional 20 years at the current production level (Arizona Bureau of Mines, 1969). Some mines have independently placed their own production life at 50 years or more. Clearly, in terms of management considerations, copper mining will be active in the state for some time.

The copper output is expected to increase over the next 10 to 20 years. By using a straight line projection of the output data in Figure 1, it can be seen from Figure 6 that output could reach 1,300,000 tons of copper by 2000. That is a 40 percent increase over 1973 output. Assuming technology remains fairly constant the water requirements would increase a corresponding 40 percent by 2000. Table 12 contains the projected water withdrawals for the state, Pima County, and the Tucson Basin. Similar projection for the Tucson Basin were made by Marum and Marum, Incorporated. These projections are contained in Table 13. The projections, although highly speculative, provide an insight into the possible future demands of copper mining on the water resources. Certainly we can expect production to increase over the next 20 years. However, technology will not remain constant. Trends in technology and process emphasis will also affect the water requirements.

The trend toward more leaching which was described in an earlier section could cause an increase in water requirements due to the higher intake of the leaching process. If the trend continues as it has since 1960 it will account for 25 percent of the copper production by 2000.

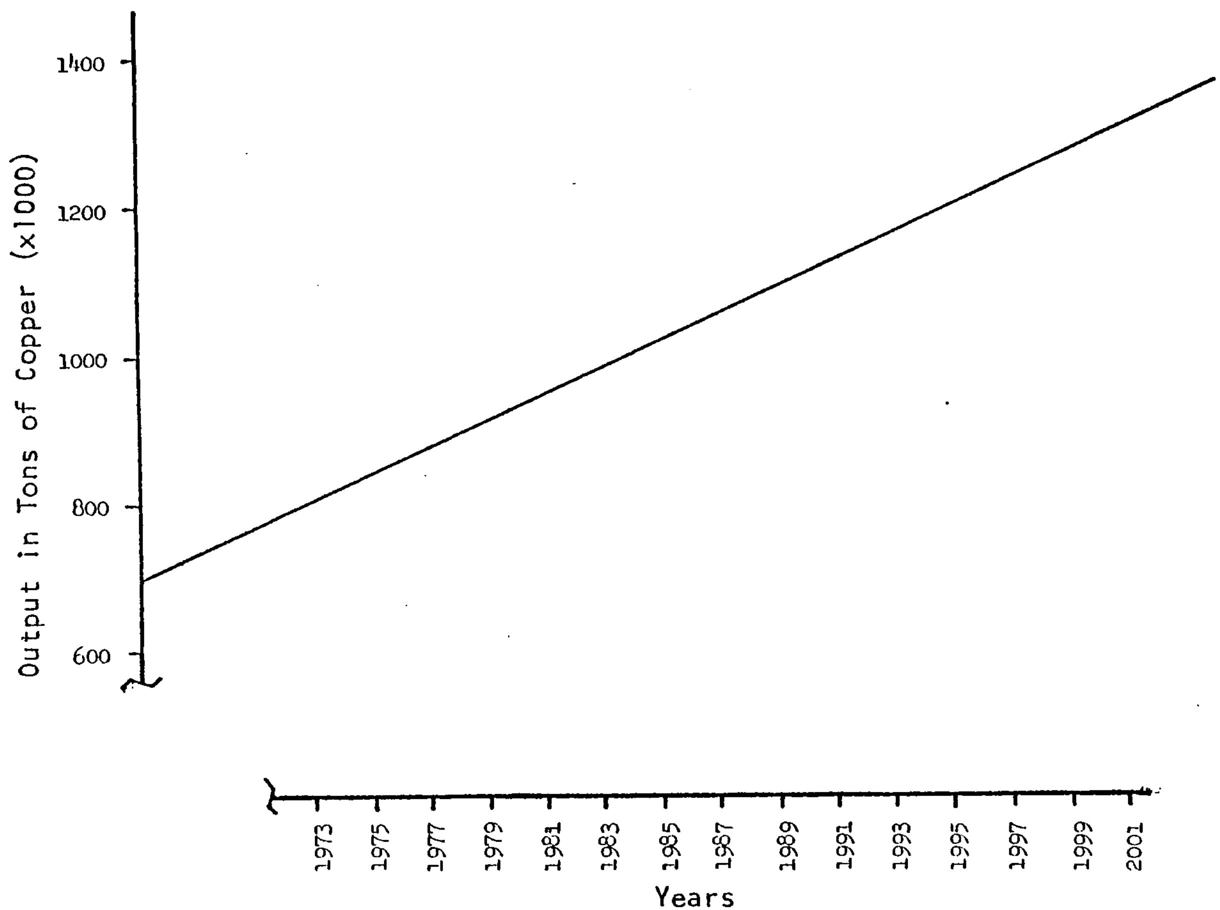

Figure 6. Projected Arizona Copper Output

Table 12. Projected Water Requirements

Area	Copper Production (tons)		Withdrawals (ac-ft)	
	1973	2000	1973	2000
Pima County	371,200	490,000	52,209	73,000
Tucson Basin	317,406	444,000	44,600	62,000
State Total	927,271	1,300,000	130,000	168,000

Table 13. Tucson Basin Projected Water Requirements

1970	2000	2020
44,000 ac-ft	58,000 ac-ft	58,000 ac-ft

Source: Marum and Marum, Inc., 1973

This would amount to a 3,500 ac-ft/yr increase at current production levels or 5,000 ac-ft/yr at projected production levels. It is expected the leaching will grow much faster and may account for as much as 60 percent of the production in the year 2000.

The possible reduction in ore yields would also mean increased water requirements. Significant yield changes are, however, not expected in the foreseeable future (Joralemon, 1973). Some newly discovered deposits in the Tucson Basin are of a higher grade than those under current production. The general trend will be continued production at current grades of ore.

Although the quantities are highly uncertain, the water requirements of the copper industry can be expected to increase over the next 20 years. If we have an increase of 40 percent as shown in Table 12, the impact on the state level will still be minimal, however, at the county and local levels serious conflicts may occur. In the Tucson Basin where current withdrawals far exceed recharge, an increase in mining withdrawals of 40 percent would cause serious water problems. Conservation measures which could be instituted now might help avoid such a problem.

Possible Water Conservation in the Copper Industry

The copper industry has a great deal invested in the future production capabilities of their operations. In the face of declining water tables and increasing conflict over water rights it is certainly to the advantage of the mines to secure a dependable water supply and to conserve the water resources by reducing their requirements. This section contains possible methods of developing a dependable supply and reducing the requirements of the copper industry. Some of the conservation measures are simple and easy to institute, involving changes in procedure and water substitutions. These methods require minimal capital investment and may be accomplished in the short run. Other methods involve large capital outlays and substantial process changes over the long run. This section is divided into short run and long run conservation measures.

Short Run Conservation Measures

The short run conservation measures are those that can be instituted with minimal technical change and capital investment. Water substitution is a prime conservation tactic. Substitution for dust control in the mining process is an obvious application. Large quantities of ground water are applied to the haulage roads and various pit areas. The use of chemical dust suppressants could greatly reduce the water requirements for dust control. Some compounds may be added directly to the water and act to reduce evaporation. The effect is to require fewer applications then with water alone. Oil-like substances can be used in place of water. Sewerage effluent could also be substituted for well water as a dust control medium. The use of the effluent from nearby communities would not only reduce the new water requirement but provide a beneficial use for the effluent.

Equipment cleaning is another area of possible conservation in the mining operation. If all vehicles were washed in a catchment area the water could be recycled for dust control or other operations with minimal quality requirements.

Conservation of domestic water could also greatly help. The water required for grounds upkeep could be reduced by watering at night, substituting sewage effluent, or eventually changing to natural desert vegetation. Domestic requirements could also be reduced by installing water saving shower heads in the change rooms. Shower heads which use half as much water may mean an annual savings of 500 to 1500 ac-ft (Gilkey, 1963).

The leaching operation is another area which has potential for conservation. The use of the vertical pipe acid delivery system (Figure 5) for all dump, heap, and in situ operations would cut down significantly on the evaporative losses incurred in the spraying and ponding systems. Additional leach water could be saved by covering the tailing ponds. Possible coverings range from styrofoam pads to mononuclear films. These coverings could substantially reduce evaporations.

Long Run Conservation Measures

The long run measures involve substantial time, capital, and technical change to be instituted. Most of these measures involve process changes and ground water substitutions.

The leaching operation, as we pointed out in the first two sections of this chapter, is growing in production importance and can be expected to continue on that trend. The increase in leaching will result in an increase in water withdrawal unless construction measures are taken.

The use of the vertical pipe delivery system as discussed above would help prevent loss to evaporation. Another area of loss is seepage from the bottom of the leach dump. The leach solution which infiltrates through the material is collected at the bottom. Some of the solution is lost to seepage. This loss could be prevented by preparation of the leach bed prior to deposition of the material. Figure 7 is a diagram of leach bed preparation that has been successfully used to prevent seepage. The bed is formed by compacting clay, applying an asphalt layer, and compacting a top layer of fine material (Sheffer, 1968). This method can also be used to prevent seepage from the tailing ponds (see Figure 8). Seepage from the ponds is a two-fold problem of ground water pollution and water loss. The preparation shown in Figure 8 could alleviate both problems. The use of a leaching operation which employed a vertical pipe delivery system, tailing pond evaporation suppressant, and leach bed preparation should have significantly lower water requirements than current leaching or concentration processes. If all new production could be developed by this leaching process it would greatly reduce the future requirements.

The greatest potential for ground water conservation and the development of a dependable supply for the industry comes from sewage effluent substitution. The water quality requirements for the leaching operation are in the range of secondarily treated sewage effluent (confidential Industry Data). One mining operation currently operates a leach process which is completely dependent on effluent and pit drainage for its water supply (Industry Data). The impact of this substitution is very significant in the face of declining water tables and increased

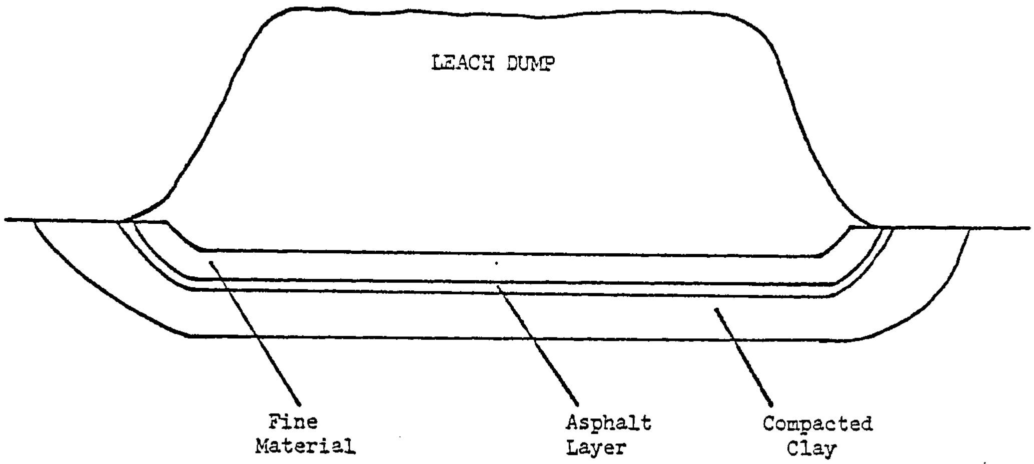

Figure 7. Leach Dump Bed Preparation

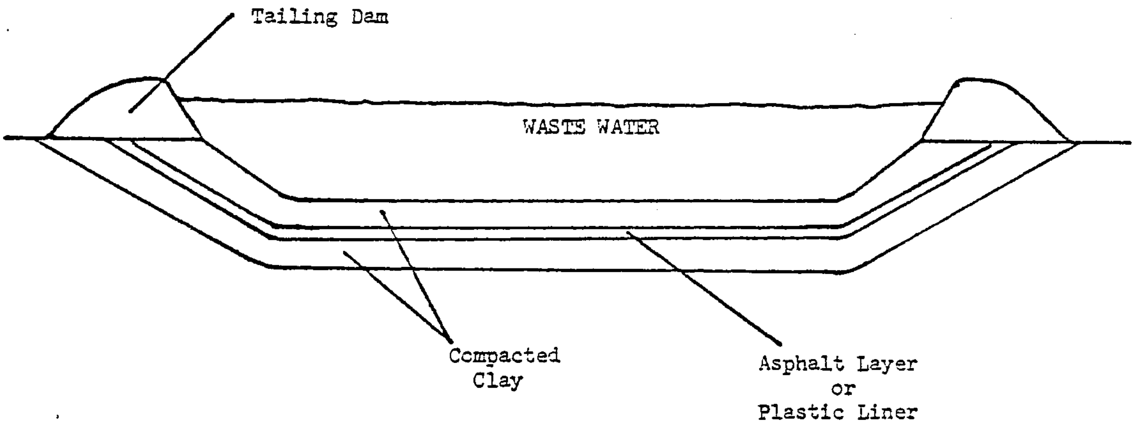

Figure 8. Tailing Pond Bed Preparation

leaching. The substitution of effluent for new water in the leaching operation would greatly reduce the copper industries ground water withdrawals. This conservation method is particularly effective in mining areas where urban centers are nearby such as the Tucson Basin. The effluent of a major city like Tucson would provide a very stable and dependable water supply for the mining operations.

Sewage effluent can also be used for the floatation concentration process. A preliminary investigation has shown that direct substitution of secondarily treated effluent from Tucson's treatment plant reduces the recovery of copper and bi-product molybdenum in the floatation process (Table 14). It was found, however, that by changing the reagents and treating the effluent with activated charcoal filters the recovery rate was increased substantially (Fisher, 1976).

The substitution of sewerage effluent for leaching and concentrating could provide a substantial savings in new water withdrawals. Table 15 shows the potential savings at the state, county, and basin levels. The Tucson Basin is the area most applicable to effluent substitution. Tucson currently discharges 38,000 ac-ft annually with a potential for 143,000 ac-ft by 2000 (Marum and Marum, Inc., 1973). This supply would be more than enough for the mines south of Tucson. The drawback to this substitution is the capital investment required for the transport of effluent from Tucson to the mining area.

Summary

There are many means by which the copper mines could reduce their new water requirements. Those described here are only a few.

Table 14. Recovery Rates

Water	Percent Recovery	
	Copper	Molybdenum
Standard	89.9	72.0
Sewage	87.5	56.7

Source: Fisher, 1976

Table 15. Water Savings by Effluent Substitution

Area	Acre-feet			
	Mining*	Leaching	Concentrate	Total
Pima Co.	2,049	800	28,994	31,843
Tucson Basin	1,752	800	24,703	27,255
State Total	5,119	10,500	65,743	81,562

*Assuming 50% substitution

The use of chemical dust suppressants and domestic conservation measures would help to conserve water. The most important measures would be the substitution of sewerage effluent in the mining, concentration, and leach processes (Table 15). This is a potential savings to the state of nearly 82,000 ac-ft annually. However, due to the isolation of some mining operations the acquisition of effluent is impractical. The Tucson Basin is ideal for such a substitution. The savings to the basin could be as much as 27,000 ac-ft at 1973 production rates. Combined with other strategies the savings could be higher. Clearly the potential for reduction in the copper industry withdrawals exists. The right policy and strategies must be designed to achieve this reduction.

CHAPTER III

GROUND WATER MANAGEMENT STRATEGIES

The water problem in Arizona is basically one of continual ground water overdraft. Many parts of the state depend almost entirely on the ground water resources. The overdraft in some counties is becoming critical. The worst is Pima County which withdraws nearly 5 times its dependable supply (Table 6). Legal conflicts between users are becoming more common. If Arizona wishes to maintain the growing economy it has enjoyed for so long, the water situation must be stabilized. This can be accomplished through two basic approaches: increase supply or decrease demand. To achieve either or both of these goals management strategies must be adopted. These strategies must be evaluated in terms of their effectiveness on the water situation and their impact on the users. Copper mining, the third largest water user, is very important to Arizona's economy. Strategies designed to reduce the copper industry's water withdrawal must also be evaluated in terms of the economic impact. The impact of management strategies on the copper industry is therefore an important consideration in the strategy formation process.

This chpater will describe and discuss the proposed and possible alternative management strategies. The strategies will be evaluated in terms of their effectiveness, political feasibility, and impact on the copper industry.

Current and Proposed Water Management Strategies

It is important to understand what is meant by management strategy. A strategy is a specific means to achieve a policy goal. There may be an array of possible strategies for any given policy. For Arizona's water problem there is an array of possible policies ranging from non-intervention (a do-nothing-policy) to a policy of complete ground water regulation. Each policy may have several feasible strategies. The policy of ground water regulation may be achieved through a strategy of state ownership and allocation of the resource or a strategy of pump licensing and rate regulation. A set of possible strategies can be delineated with the adoption of a concise policy statement. Unfortunately, Arizona does not have a clear overall water policy making the approach to water management strategies very difficult (Mann, 1963).

This section contains an approximation of Arizona's water policy and the stragegies employed. The continued depletion of the state's water supply has caused pressure for policy changes. New management strategies are being proposed by both houses of the state legislature. The direction of these proposals will also be discussed in this section.

Current State Water Policy

The ground water policy of Arizona has been largely one of non-intervention. The appropriation doctrine was applied to all surface waters and water in a definite underground channel (Chalmers, 1974). The percolating ground waters belong to the owners of the land. Since it is extremely difficult to prove that water is flowing in an underground channel all ground water is considered property of the land owner. The use of ground water is limited only by statutes requiring filing of a notice of intent to drill and by the doctrine of reasonable use (Clark, 1974). As ground water withdrawals increased in the 1930's and 1940's many areas experienced severe water table declines. The Arizona legislature, with pressure from the federal government, passed the Ground Water Act of 1948 which established critical ground water areas (Chalmers, 1974). The bill was very weak with many loopholes and provided little management power. Other bills since then have also been ineffective. The ground water policy of non-intervention has survivied all the attempts at reform.

The decision makers have perceived a ground water problem in Arizona for some time. Due to strong special interests and an attitude of individual freedom to pump water, no management action has been taken. The decision makers, maintaining the non-intervention policy, have approached the problem by attempting to increase the supply via the Central Arizona Project (CAP). Another strategy has been the educational approach. The state, through the Arizona Water Commission, has released reports and studies which point out the need for water conservation. These two approaches (the CAP and education) seem to be the main two strategies of the state's non-intervention-but-aware-of-the-problem strategy.

Importation of water to the central counties is a solution to the immediate water problem in those areas. The Central Arizona Project will bring water from the Colorado River to the central counties including Pima County. The use of CAP water will decrease the dependence on ground water withdrawals and reduce the overdrafting. However, the CAP has been used to encourage growth and continued urban expansion with no emphasis on conservation (Tucson City Staff, 1975). This means that ground water withdrawals will again increase and further importations will be needed. An importation strategy, such as the CAP which is not associated with a conservation strategy, only postpones dealing with the real water problem.

The CAP was first proposed in the 1940's but suffered many political setbacks in Congress (Chalmers, 1974). Many congressmen from other states do not like paying for water so Arizonans can continue wasting it. Although construction is underway on various phases of the project further delays are expected. These delays may force Arizona into forming a ground water code (Chalmers, 1974).

The CAP strategy could have some impact on the copper industry withdrawals. The average cost of water developed by the copper mines is approximately 40 dollars per ac-ft (Industry Data). The cost of CAP water is estimated at 134.50 dollars per ac-ft (Tucson City Staff, 1974). There is little incentive to contract CAP water when the mining operation can supply their own water cheaper. In the Tucson Basin, however, there are several operations which may find the CAP water more appealing. One operation, involved in suits over its withdrawals, may opt for a dependable CAP supply. Another operation reports its water costs at 390 dollars per ac-ft. Obviously, CAP water is cheaper. If the mines in the Tucson area can be encouraged to use CAP water the savings to the basin would be some 44,000 ac-ft at 1973 production rates. If the mines do contract for CAP water it could mean a definite savings to the ground water resources and a dependable supply for the mines.

While the CAP strategy is only a short term solution providing breathing room it is a feasible substitution for copper mining ground water withdrawals. The CAP although not politically certain, is under construction and should be continued. It seems to be a good approach if used in conjunction with other strategies. However, by itself it is only a time delay.

It is difficult to appraise the effectiveness of the educational strategy. Making the people aware of the water problem should help in overall conservation. However, in some cases it develops an attitude of pump-it-while-you-can. Some users, aware of the problem and of the impending regulation, want to make their profits while they can.

The educational strategy is completely feasible politically (Maloney and Slovonsky, 1971). It is difficult to criticize the generation and distribution of pertinent information.

The education strategy has little impact on the copper industry. The copper mines feel they are doing an excellent job by recycling large amounts of water in the concentration and leaching operations. They tend to point at agriculture as the source of the water problem. The value of the educational strategy may be to show the mines that legislation is pending and therefore they should begin conservation on their own.

The most important impact of a non-intervention policy will come from the legal conflicts which arise. As the ground water continues to be depleted, competition for the resource will increase causing legal confrontations. Several court cases are pending now in the Tucson area. The decisions from these cases may force the state into new policy. The non-intervention policy leads by default, to judicial intervention which will force new policy considerations. Unfortunately, the courts do not have water resource expertise. The decisions they make may not be the most efficient in terms of the resources. It is certainly better for the decision maker to formulate new policy to alleviate the conflict situation than to be forced into a new policy by the judiciary.

The policy of non-intervention concerning Arizona's ground water resources is supported by two main strategies; the strategy of increasing supply by importing surface water and by information distribution. These strategies, however, do little to ultimately alter the long term depletion of the state's ground water supplies. Although the state has continually refused to get involved in any form of ground water management, there is an increase awareness of the potential severity of the overdraft situation. This awareness is leading, eventually, to new policy goals.

Policy Direction and Proposed Strategies

There has been an increasing effort by some legislators, special interests, local officials, and concerned citizens for the state to adopt a ground water management policy. People are recognizing that Arizona must take a more active role in managing its water resources (Arizona Daily Star, 1974). A number of House and Senate bills have been proposed which would do just that. County and local governments are considering policies which would alter demand patterns. These proposals reflect the direction new policies will take.

There have been many ground water law reform bills proposed since the 1940's. Most of these bills have met with stiff opposition from special interest groups including the copper industry (Mann, 1963). Often the opposition stems from a general mistrust of change rather than any clear cut determinant to the group. The copper mines in conjunction with the cattlemen and cotton growers have formed an effective lobbying group called the Arizona Tax Research Association (Mann, 1963). Pressure from this and other lobby groups has been very effective in preventing ground water law reform. The copper industry was extremely powerful in the early state legislature. It was often said that bills had to pass the copper mining interests before they could get to the House and Senate (Reichley, 1964). Such overt influence has been waning in recent years. The influence exercised today by the copper industry stems from its economic importance to the state. A bill that would hurt the copper mines could hurt Arizona. This reasoning has been drastically overplayed. The status of the mines is also dependent on the condition of the state. A stable water situation is a benefit to all parties.

Four recent ground water reform bills including three Senate bills (SB 1376, SB 1378, and SB 1389) and one House bill (HB 2394) serve to show the types of strategies being considered by some to support a state policy of ground water management. Senate bill 1389, introduced March 1975, was aimed at ground water management through regulation of drilling and operation of wells in declared critical and closed ground water basins. The strategy is to declare areas either critical or closed then regulate well drilling and operation through the state land department. This approach does not deal directly with water management but could be effective.

The strategy of SB 1389 could be effective if the evaluation of each well permit is complete and objective. It does not, however, have any effect on existing wells.

Unfortunately, the political feasibility of SB 1389 proved to be very poor. Opposition rose over the definition of critical and closed areas. A critical area was defined as any basin where withdrawal exceeds recharge. A closed basin is where the present supply is not adequate to last 100 years at current withdrawal rates. These in combination include much of the Basin and Range Province.

This bill would have little impact on the copper industry. Most mines have developed extensive well fields which can supply their needs for some time.

Senate bills 1378 and 1376, introduced in February 1975, have similar strategies for approaching ground water management. SB 1376 establishes county water conservation districts while SB 1378 provides for multi-county districts. In both bills the districts act as tax-levying public improvement offices designed to promote maximum utilization of all water resources in the district. The district office will levy a tax on all water withdrawals in the county not to exceed 10 dollars per ac-ft.

This strategy seems to be a very effective approach. The formation of district offices responsive to the area's needs is an approach which has met with success in other states (Radosevich and Sutton, 1972). The taxation of all water withdrawal implies complete and accurate monitoring of all ground water withdrawals providing precise information for water surveys. The addition of a tax to the cost of water may also act to reduce demand.

Such a tax has virtually no political feasibility among the legislators. Agricultural groups oppose it strongly because they feel it unequitably puts a bruden on irrigators.

The only effect on the copper mines would be the disclosure of exactly how much they pump. The addition of 10 dollars per ac-ft would have little impact due to the small production cost of water. Any short run impact from the tax could be offset by a very small increase in the copper market. Table 16 shows the costs of water as a percent of the price of copper in 1973. A ten dollar increase in the price of water could be offset by one cent/lb increase in copper prices. It could have some effect on those operations with higher than average water costs and requirements.

House bill 2394, introduced in February 1975, declares all water property of the state, establishes a state hydrologist, and institutes a water user tax. By making all water public property ground water will also come under the appropriation doctrine. The state hydrologist will act as a state water administrator. The user tax ranging from 50 cents to 1 dollar per million gallons would be levied on all water users.

Table 16. Water as a Production Cost

Water Cost $/ac-ft	Cost of water as a % of price of copper	% with the addition of $10.00/ac-ft tax
30	0.36%	0.48%
40	0.48%	0.60%
80	0.96%	1.08%
200	2.39%	2.51%
300	3.59%	3.71%

The establishment of a state water administrator and the application of the appropriation doctrine to ground water are two excellent approaches to comprehensive water management. Through this strategy a market for ground water could develop since water rights would be independent of the land. The proposed user tax, however, would do little more than raise revenues for the hydrologists office. A tax of one dollar per million gallons is less than 33 cents per ac-ft and would not provide a deterent to use.

This bill would provide a radical change in policy and as such is politically infeasible. Much of the opposition is generated simply because the declaration of ground water as public property sounds too radical. The resist-all-change groups rally to defeat this type of proposal.

HB 2394 would have little impact on the copper industry. The copper mines would be able to pay for the water it needed in a market situation. Because of the relatively small water requirement associated with high product value the copper industry would be able to buy water rights at a higher price than other users (Arizona Water Commission, 1975).

There have also been proposals made at county and local levels. Tucson has proposed providing sewage effluent to the mining operations in the area. It has also been a policy of urban governments to retire farm land from cultivation and pump the water for municipal needs.

These approaches can be very effective in the local areas. The use of effluent is a strategy which has much support. The drawback seems to be over who will pay the construction costs. These strategies are negotiable and therefore politically feasible.

Summary

The policy of non-intervention which has prevailed in Arizona for many years must soon give way to some form of ground water management policy. The continued overdraft has brought about strategy proposals which although politically infeasible would help the ground water problem. Proponents of ground water law reform must form stronger coalition and dispel the fear of the resist-any-change groups.

Feasible Strategies

The pressure for change in Arizona's ground water policy is increasing rapidly. A trend toward a policy of active water resource management can be observed from the proposed bills discussed above. The problem with these proposals has been their political infeasibility. Legislators from non basin and range counties and special interest areas are not interested in water law reform and tend to maintain the status quo (Mann, 1963; Chalmers, 1974). The proponents of reform have been using the "shot gun" technique for introducing ground water measures. The supporters introduce many variations of ground water law measures hoping that one will be accepted. The response has been a tendency to automatically reject the bills without proper consideration.

There are a number of methods to alter this situation. This section contains two possible approaches to promote ground water management; the direct and indirect approaches. The first method or direct approach entails the development of one indepth comprehensive water bill. The other method is the indirect approach relying on land management, taxation and other miscellaneous measures.

The Direct Approach

The constant deluge of ground water bills has made many legislators insensitive to the water issue. The "shot gun" approach, employed by reform advocates, relies on the introduction of many similar bills to the House and Senate. The legislators, confronted with numerous water bills, consider them as a group and do not weight the merits of the individual bills. The tendency is to reject any and all legislative measures which hint of ground water law. Six separate water bills were defeated in one day by a Senate committee (Arizona Daily Star, 1976).

The reform supporters are, in effect, fishing for a management strategy that will be acceptable. This fishing expedition has, thus far, not been successful. Perhaps a better course of action may be reduction of the number of bills proposed. This would require the development of a comprehensive water management package.

The development of one water management strategy package would provide a focus for the reform supporters. With a specific goal and specific strategy in mind the water reform legislators may have an easier time finding support for their bill(s). A clear cut position backed by sound information is much easier to support than a general call for water reform. Currently the Arizona Water Commission is conducting a three phase water study which includes consideration of alternative management strategies. A water management bill backed by the findings of the Arizona Water Commission would be more feasible than any bill current.

A comprehensive management package could be introduced as one major piece of legislation or as a number of consecutive bills. In the latter approach each section of the management package could be introduced, discussed, compromised, and finally passed before the next step. The subsequent sections of the package can be altered to reflect the opposition to the first sections.

Support for passage of the management package may be increased by attaching more popular issues to the legislation. The CAP is a good example. The means by which CAP water is to be distributed and paid for are still in legal limbo (Egbert, 1972). A bill which included a clear plan for CAP allocation and payment could gain the valuable support of CAP advocates.

Strategies which are known to draw opposition must be changed to insure acceptance. One such strategy is the use of water user fees and withdrawal taxes. The development of an equitable tax system for ground water management could be a very effective tool and under the right format, politically acceptable. A system which rewards efficient users and penalizes wasteful users as suggested by Maddock and Haimes (1975) may find political support.

The direct approach as described above is a suggested course of action for the ground water reform proponents. If affirmative action is to be expected from the state legislature their approach to the problem must be changed. A single comprehensive plan should be developed and supported uniformly instead of shot gunning numerous strategies.

The Indirect Approach

The indirect approach is most applicable to the county and local governments. The major impact of water users such as the copper mines is felt most strongly at the local level. Inaction at the state level perpetuates the problems confronting the county decision makers. Many of these decision makers are looking at possible strategies to alleviate the water problems in their area. Local strategies must be considered in lieu of a comprehensive state water plan. The most feasible approach to these local water problems is often an indirect approach. This approach entails using land use regulations, taxing schemes, and other miscellaneous regulations to alter the water withdrawals without dealing directly with ground water law.

Land use regulations could provide a very effective indirect water management tool particularly for the copper industry withdrawals. A county land use regulation could require that all new tailing ponds and leach dumps brought into production must meet certain construction standards. The standards could include seepage proof bed preparation (Figure 7 and 8), vertical pipe acid delivery (Figure 5) in the leaching operation, and some type of tailing pond covering. Such regulations would indeed conserve water. The feasibility would also be high do to the duality of the reguations: that of reducing evaporative losses and preventing possible ground water pollution by seepage.

Another method of the indirect approach is to use various taxing schemes. The county may decide to give tax breaks to those companies actively researching methods to reduce their new water intake. Such a taxing scheme could be very effective. A reduction in a mining company's property tax could provide an incentive for development of less water intensive processes. The county could also place a tax on all operations still using spraying and flooding leach acid delivery systems after a deadline. This would provide incentive for mining operations to slowly change to more efficient delivery systems. Taxing schemes if used properly could be a very effective tool for the county governments.

Another option for the local governments may be the use of government bonds to help finance a system for sewage effluent exchange. This strategy is specifically applicable to the Tucson Basin. The City of Tucson and Pima County could negotiate with the copper mines to help pay for the transport system needed for an effluent exchange. Similar negotiation and cooperation over CAP water could greatly aid the local water situation. An expenditure to build an effluent transport system or entice CAP water contraction could save significant amounts of water in the Tucson Basin (Table 15; Tucson City Staff, 1974).

The county and local governments have a number of indirect management options available to them that would provide relief to their water problems while waiting and pressuring for state action. These methods include land use planning, taxation, and government projects. This approach could be very effective, however, more information should be generated before decisions are made.

Summary

Arizona's ground water policy of non-intefvention has lead to a situation of serious overdraft in many parts of the state. Advocates of ground water law reform have introduced numerous bills to the state House and Senate. These bills have not gained much support. New approaches are indicated. A comprehensive water plan must be developed at the state level. County and local governments may choose to develop indirect water management methods to alleviate their particular water problems.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

Arizona's Copper and Water Resources

Copper and water are two of Arizona's most important natural resources. The development of the state's vast copper deposits has been an important part of Arizona's economic development. The copper industry has played a major role in forming the state's economy (Peplow, 1958; Leaming, 1975). Currently the copper industry accounts for more than $5 billion of direct and indirect economic benefits (see Table 3). It is second only to manufacturing as a major source of income (see Table 1). Unfortunately, most of the copper mines are located in the most arid regions of the state. The water needed for copper production must be obtained from the ground water resources. These resources, however, are being depleted in many areas of the state.

The lack of adequate surface water supplies has lead to the wholesale development of the state's ground water resources. The growth and development experienced in Arizona has been dependent on the availability of vast quantities of ground water. However, this rapid development has caused an overdraft situation, in which more water is withdrawn then is recharged. The depletion of the ground water resources is often most critical where the three major water users (mining, agriculture, and urban-industrial) are in direct competition for the resources. The Tucson Basin is such an area. The withdrawals made by the copper industry, although small at the state level, are very important to the local water resources as in the Tucson Basin. The copper industry while contributing to the ground water overdraft situation is very important to the state's economy. Any attempt at ground water conservation or regulation must include a consideration of impact on the ground water users. It is, therefore, important to know precisely how much water is required per unit of copper production.

The Copper Industry's Impact on Arizona's Water Resources

Water is an important production factor in Arizona's copper industry. It is used in varying quantities in all of the production processes. The new water requirements for floatation concentration and leaching, the two main production methods, are 34,100 gallons per ton of copper and 42,000 gallons per ton of copper, respectively. The total new water requirement including all production processes and miscellaneous uses averages 45,800 gallons per ton of copper produced. At 1973 production levels this amounts to an annual state withdrawal of 130,000 ac-ft or less than 3 percent of the total state depletion. A small amount when considered with their large economic contribution. However, at the local level, the copper industry's impact on the water resources is more significant. The annual withdrawal in the Tucson Basin amounts to 44,600 ac-ft or 20 percent of the total basin withdrawal. The copper industry although a small water user on the state level is extremely important to the local water resource situation.

The total withdrawals made by the copper industry has increased substantially in the last 15 years. It is likely that the requirements will continue to increase. Conservative estimates give the Arizona copper industry a 50 year life expectancy. Substantial growth is expected over the next 10 to 20 years. Any increases in output will lead to increased water withdrawals. A trend toward increased copper production by the leaching process is also expected to increase requirements. Such increases could be very harmful to the already critical water problem in many of the mining areas. Major increases in mining withdrawals in the Tucson Basin could cause difficulties for the other users in the basin.

These increases in requirements can be met either by increasing the total withdrawal, and thus increasing the overdraft, or by instituting conservation measures in the copper production process. Since Arizona does not have an infinite water supply the best approach is to conserve its water resources. The copper industry has several areas where conservation measures can be introduced to significantly lower the new water requirements.

The conservation measures which have the greatest potential water savings include methods of evaporative loss reduction and water substitutions. A number of methods are available to reduce evaporative losses. The usage of evaporation suppressants and coverings on tailing ponds in the leaching operation could provide significant savings. The greatest potential savings would come from the substitution of sewage effluent for ground water. In areas with adequate effluent supplies, as in the Tucson Basin, ground water withdrawals can be cut in half by effluent substitution. The possible savings by using these measures in combination is substantial. Clearly the copper industry's water requirements can be reduced if conservation can be adopted. Currently, however, there is little incentive for the industry to adopt these measures themselves. The state, county and local governments must develop strategies which will promote conservation in the copper industry as well as with the other users.

Management Strategies

The water problem in Arizona is largely one of continual ground water overdraft. The overdraft situation is becoming critical in many areas of the state. In view of the predictions of increased withdrawals by the copper industry and other major users the state must begin to manage its ground water resources. The water situation must be stabilized if economic growth is to continue. The policy of non-intervention which has prevailed since Arizona was a territory must be changed. There have been many bills in the state legislature which have attempted to change the policy, however, they have not received a broad base of political support. If active water conservation is to be initiated water management strategies must be developed at the state, county, and local levels. Two suggested approaches are to develop a comprehensive state water plan and to promote conservation indirectly by land use regulations and taxation at the county and local levels.

The development of a comprehensive state water plan would require considerable research and planning. The time required for research and development of the plan could also be used to integrate a broad base of support for the necessary legislation. Since the Arizona Water Commission is currently engaged in such research the strategies and their support should be developed as soon as possible.

The indirect approach at the county and local level can provide some relief to the local water problems. Land use regulations and taxing schemes which provide incentive for the use of sewage effluent or other conservation measures would greatly alter the water problem in areas like the Tucson Basin. Clearly strategies are available to both the state and local governments to promote active water resource conservation.

Conclusions

The copper industry is the third largest water user in the state. Although insignificant at the state level the withdrawals made by the copper mines are important to the local water resources. The Tucson Basin is an area where the mining withdrawals are most heavily felt. There are conservation tactics which could reduce the copper industry's new water requirements and curb future requirement increase. These tactics may best be instituted by the indirect approach at the county and local levels. Since the impact of the withdrawals are felt most sharply at the local levels (e.g., the Tucson Basin), conservation attempts should gain support more readily at that level. In the case of the Tucson Basin, Pima County and the City of Tucson would be expected to be more responsive than the state institutions.

The county and local governments have available to them a number of indirect management strategies by which the conservation tactics may be instituted. The package of strategies which seems most feasible includes land use regulation, taxation, and bond issues. These strategies in combination could provide a strong conservation incentive.

A land use regulation, perhaps in the form of a building code, could greatly reduce seepage and evaporative losses. Such a regulation could set construction standards for new and redesigned tailing ponds and leaching dumps. The standards could require seepage proof bed preparation, vertical pipe delivery systems, and tailing pond coverings. The land use regulations could be supported under the promotion of the general public welfare and pollution control.

A taxing scheme although not effective for marginal cost pricing of mining water, may be used to provide minimal conservation incentives. A copper producer which is pursuing water conservation could receive a tax break on their property tax or severance taxes. A copper producer which has not undertaken certain conservation measures by a certain date may be levied additional property taxes.

Through the use of a bond issue the City of Tucson could pay part of the costs of a sewage effluent exchange program with the mines in the Tucson Basin. The city, supplying effluent to the mines, would receive in return well water that was previously used in the mining operation. Such financial support could also be used to encourage the mines to contract CAP water. Either approach would result in additional well water being available to the city.

These strategies, in combination, could provide incentive for copper mining water conservation. The savings to the Tucson Basin could be 30,000 ac-ft at 1973 production levels and as much as 60,000 ac-ft at projected production levels.

APPENDIX A

INDUSTRY DATA

The data for the 1974 water requirements was gathered through correspondence with the major copper mining companies in the state. Letters, accompanied with a questionnaire, were sent requesting pertinent water information. The companies were assured that their information would be used to calculate an average requirement for the copper industry as a whole and individual data would be kept confidential. Ten letters and questionnaires were sent to the largest copper producers. Responses were received from six companies. These companies represented 67 percent of the total 1973 copper output.

The average requirements were calculated by weighing the individual company requirements with their percentage of the 1973 output. The copper industry water requirements for 1973 as contained in this paper are a weighted average of the requirements of six mining companies responsible for 67 percent of the copper output.

Requested Information

TYPE OF PROCESS [the processes which are carried on in the production of copper by your company, including leaching, concentrating, and smelting and percentage of production from the process, e.g., dump leaching 10%, concentrating 90%]

____

____

WATER REQUIREMENT [the water required in each process for each ton of ore processed]

____

____

PERCENTAGE OF RECYCLED WATER [recycling rate for each process]

____

____

ESTIMATE OF TOTAL WATER CONSUMPTION [the total amount of new water required to produce one tone of copper, including all water consumed in production processes and miscellaneous uses (dust control and domestic uses)]

____

WATER QUALITY REQUIREMENTS [the water quality limitation for each process]

____

ESTIMATED COST OF WATER ______________________________

SOURCES OF WATER [for example, 50% surface water and 50% ground water]

____

____

TOTAL WAGES PAID [1974] ______________________________

TAXES PAID [in 1974 to all levels of Arizona government]

____

ESTIMATED INCOME GENERATED IN ARIZONA [the addition to the state's income by your company's copper mining operation]

____

____

SELECTED BIBLIOGRAPHY

Arizona Bureau of Mines, 1969. Mineral and Water Resources of Arizona. Bulletin No. 180, University of Arizona, Tucson, Arizona. 638 p.

Arizona Daily Star, 1974. "Groundwater, Going, Going, ...". February 17.

Arizona Daily Star, 1976. "Senate Panel Quickly Kills Water Reform." May 4.

Arizona Department of Mineral Resources, 1941. Production Possibilities of the Marginal Copper Mines in Arizona. State of Arizona, Phoenix, Arizona. 123 p.

Arizona Mining Association, 1975. This is Copper Country. Phoenix, Arizona.

Arizona State Legislature, 1975. Bills introduced: SB 1376, SB 1378, SM 1389, and HB 2394. Phoenix, Arizona.

Arizona Water Commission, 1975. Inventory of Resource of Resources and Uses. State of Arizona, Phoenix, Arizona. 224 p.

Bennett, Harold J., 1973. An Economic Appraisal of the Supply of Copper from Primary Domestic Sources. U.S. Bureau of Mines, Washington, D.C. 85 p.

Bottage, R. G., 1974. Comparative Porphyry Copper Mining and Processing Costs -- Alaska and Arizona. U.S. Bureau of Mines, Washington, D.C. 117 p.

Brown, Geoffrey, 1969. The World of Copper. Oxford University Press. London. 61 p.

Chalmers, John R., 1974. Southwestern Groundwater Law. University of Arizona, Tucson, Arizona.

Charles River Associates, Inc., 1969. Economic Analysis of the Copper Industry. Charles River Associates, Inc., Cambridge, Mass. 337 p.

Clark, Robert E., 1974. "Arizona Ground Water Law: The Need for Legislation." Arizona Law Review. Vol. 16, No. 4, pp. 799-819.

Dale, Vernon B., 1962. Mining, Milling, and Smelting Methods, San Manuel Copper Corporation. U.S. Bureau of Mines Information Circular 8104. Washington, D.C. 145 p.

Davidson, Edward, 1973. Geohydrology, Water Resources, Tucson Basin, Arizona. U.S. Geological Survey, Washington, D.C.

Davis, Robert K. and Steve H. Hanke, 1973. "Potential for Marginal Cost Pricing in Water Resource Management," Water Resources Research. Vol. 9, No. 4, August. pp. 808-825.

Egbert, James P. F., 1972. "Arizona Water Resource Management Problems Created by the Central Arizona Project." Arizona Law Review. Vol. 14, No. 1, pp. 157-180.

Fisher, W. W., 1976. "Utilization of Clear-Water Sewage Effluent in Mineral Processing." Ongoing project for Office of Water Resources Research No. A-046-ARIZ. pp. 43-48.

Gilkey, M. M., 1963. Water Requirements and Uses in Arizona Mineral Industries. U.S. Bureau of Mines Information Circular 8162. Washington, D.C. 97 p.

Joralemon, Ira B., 1973. Copper. Howell-North Books, Berkeley. 407 p.

Kelso, Maurice M., 1973. Water Supplies and Economic Growth in an Arid Environment. University of Arizona, Tucson, Arizona. 327 p.

Leaming, George F., 1975. The Copper Industry's Impact on the Arizona Economy 1974. Arizona Economic Information Center. Marana, Arizona. 41 p.

Maddock III, T. and Y. Y. Haimes, 1975. "A Tax System for Groundwater Management." Water Resources Research. Vol. 11, No. 1, pp. 7-14.

Maloney, John C. and Lynn Slovonsky, 1971. "The Pollution Issue: A Survey of Editorical Judgements." Roos, Leslie L. (ed.). The Politics of Ecosuicide. Holt, Rinehart, and Winston, Inc. United States. pp. 64-78.

Mann, Dean E., 1963. The Politics of Water in Arizona. University of Arizona Press. Tucson, Arizona. 317 p.

Marum and Marum, Inc., 1973. A Regional Plan for Water, Sewerage, and Solid Waste Management. Pima Association of Governments. Tucson, Arizona.

McBride, L., 1972. "Comment -- Arizona's Coming Dilemma: Water Supply and Population Growth." Ecology Law Quarterly. Vol. 2, No. 2, pp. 357-384.

Moore, Lyman, 1973. The Mineral Industry of Arizona. U.S. Bureau of Mines. Washington, D.C.

Nevada Bureau of Mines, 1973. Water for Nevada, Part Four: Forecasts for the Future -- Mining. University of Nevada, Reno, Nevada.

Peplow, Edward H., Jr., 1958. History of Arizona. Lewis Historical Publishing Company. New York, New York.

Pima Association of Governments, 1975. The Comprehensive Plan. Pima Association of Government. Tucson, Arizona.

Phillips, Kenneth A., 1975. The Copper Industry. Arizona Department of Mineral Resources. Phoenix, Arizona. 35 p.

Phoenix Gazette, 1975. "Suit Seeks to Block CAP Dam." June 11.

Radosevich, G. E. and W. M. Sutton, 1972. "Legal Problems and Solutions to Surface-Groundwater Management." 48th Annual Meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science.

Reichley, James, 1964. States in Crisis. University of North Carolina Press. Chapel Hill, N.C. 264 pp.

Sellers, William D. and Richard H. Hill, 1974. Arizona Climate. University of Arizona, Tucson, Arizona. 616 p.

Sheffer, Herman W., 1968. Copper Leaching Practices in the Western United States. U.S. Bureau of Mines, Washington, D.C. 57 p.

Smith, G. E. P., 1936. Groundwater Law in Arizona and Neighboring States. University of Arizona. Tucson, Arizona.

Straayer, John A., 1970. "Public Problems and Non-Decision Making -- A Study of the Tucson Water System." Natural Resources Journal. Vol. 14, No. 3. pp. 545-556.

Sutulov, Alexander, 1967. Copper Production in Russia. University of Concepcion. Chile. 220 p.

Tuck, Frank J., 1963. History of Mining in Arizona. Arizona Department of Mineral Resources. Phoenix, Arizona. 47 p.

Tucson City Staff, 1974. The Central Arizona Project. City of Tucson. Tucson, Arizona. 133 p.